Measuring the π^+ lifetime at TRIUMF
Feasibility Studies Status

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PIONEER collaboration meeting
Seattle, Oct. 18, 2023

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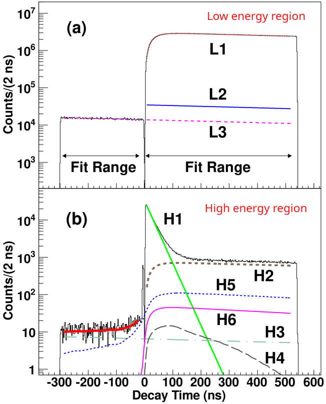
Pion Lifetime and $R_{e/\mu}$ Error Budget

Impact on PIENU syst. uncertainty: $\delta R = \pm 0.57 \times 10^{-8}$ ($\delta R/R = 0.005\%$)

[R. Mischke]



[PIENU, Phys. Rev. Lett. **115** (2015) 071601]

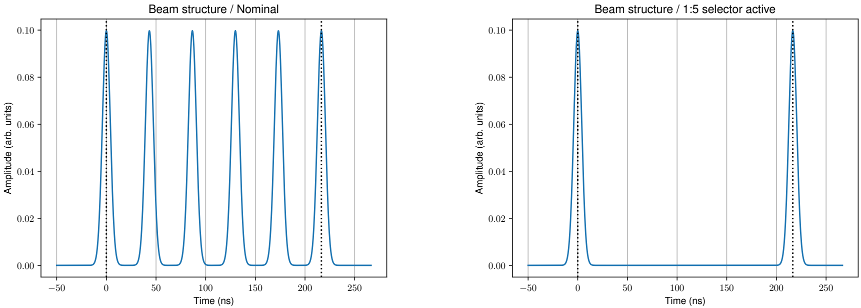
	PIENU 2015	PIONEER Estimate
Error Source	%	%
Statistics	0.19	0.007
Tail Correction	0.12	<0.01
t_0 Correction	0.05	<0.01
Muon DIF	0.05	0.005
Parameter Fitting	0.05	<0.01
Selection Cuts	0.04	<0.01
Acceptance Correction	0.03	0.003
Total Uncertainty	**0.24**	$\leq$ **0.01**

[arXiv:2203.01981]

Pion lifetime is a fixed parameter in the fit, uncertainties propagated to $R_{e/\mu}$

(TRIUMF Cyclotron – 5:1 Selector)

TRIUMF's cyclotron driving freq. is 23 MHz (one bunch every $\approx$ 43.3 ns)

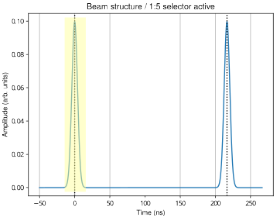


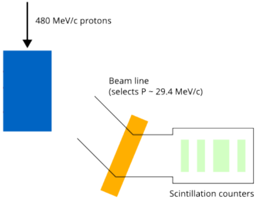
When enabled, the "5:1 selector" suppress 4/5 bunches, bringing the repetition period to $\approx$ 215 ns

Pion Lifetime – Experimental Technique

Measure the rate of **surface-muons** emitted from a **target** as a function of the cyclotron's RF cycles (bunched beam!)

Select a narrow momentum range near the surface-muon peak ($P = 29.4$ MeV/c) and suppresses protons, pions and positrons





Today's presentation focuses on feasibility studies. Preliminary sensitivity studies presented at TRIUMF's PP-EEC DocDB #159-v1

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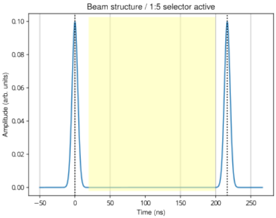
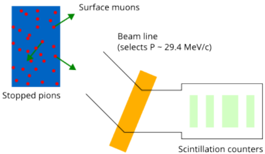
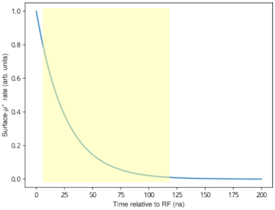






Today's talk presentation on feasibility studies. Preliminary sensitivity studies presented at TRIUMF's PP-EEC [DocDB #159-v1]

Pion Lifetime – State of the Art

The PDG 2022 average is $\tau_\pi = 26.033 \pm 0.005$ ns ($\delta\tau/\tau = 0.02\%$)

$\pi^\pm$ MEAN LIFE

Measurements with an error $> 0.02 \times 10^{-8}$ s have been omitted.

VALUE (10^{-8} s)	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
2.6033 $\pm$0.0005 OUR AVERAGE	Error includes scale factor of 1.2.				
2.60361$\pm$0.00052	[1] KOPTEV	95	SPEC	+	Surface μ^+'s
2.60231$\pm$0.00050$\pm$0.00084	NUMAO	95	SPEC	+	Surface μ^+'s
2.609 $\pm$0.008	DUNAITSEV	73	CNTR	+	
2.602 $\pm$0.004	AYRES	71	CNTR	$\pm$	
2.604 $\pm$0.005	NORDBERG	67	CNTR	+	
2.602 $\pm$0.004	ECKHAUSE	65	CNTR	+	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
2.640 $\pm$0.008	[2] KINSEY	66	CNTR	+	

[1] KOPTEV 95 combines the statistical and systematic errors; the statistical error dominates.
[2] Systematic errors in the calibration of this experiment are discussed by NORDBERG 67.

TABLE I. Systematic uncertainties.

Sources	Uncertainties (ns)
Beam leakage,[a] slow π[a]	0.0083
Prompt positron background	0.0002
Flat positron background	0.0003
Pion background	0.0002
Extra muons	0.0001
Other pion sources	0.0001
Diffusion	0.0003
Total uncertainty	0.0084

[a] Included in the fit.

TRIUMF experiment: M. C. Fujiwara, T. Numao, A. J. Macdonald, G. M. Marshall, A. Olin, Phys. Rev. D **52** (1995) 4855

→ "Beam leakages" contribute significantly to the final error

Pion Lifetime – PP-EEC

Project submitted to TRIUMF Particle Physics Experiments Evaluation Committee in April 2023 [DocDB #159-v1]

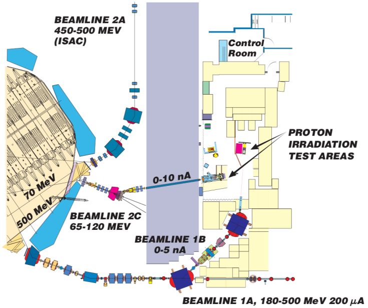
> *[...] The EEC therefore endorses this LOI with high priority to carry out beam studies in support of a full proposal [...]*

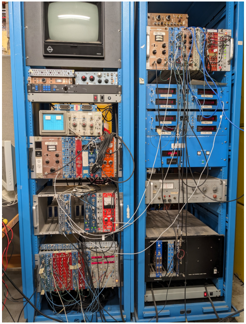
We have to answer two questions:

- Can beam leakages be significantly reduced compared to the previous measurement?
- Is the momentum bite of beamline M20 (μSR) small enough?

5:1 Selector & Beam Leakages

The 5:1 selector had not been used since (many) years. Measure beam leakages with 480 MeV protons†





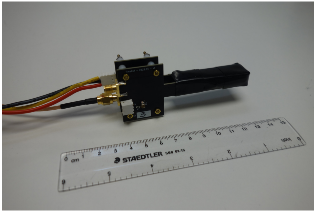
Two beam development shifts partially dedicated to the selector. Setup put together in beamline 1B with scintillation counters & NIM logic.

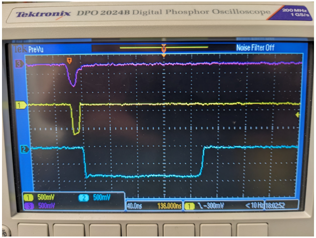
†Beamline 1A and 2C can run concurrently. We plan to have online monitoring for beam leakages.

5:1 Selector & Beam Leakages

First measurement (two counters) dominated by random coincidences
→ Third counter added for the second run.

We don't have access (yet) to the 5:1 selector 4.6 MHz driving signal
→ Non-ideal NIM logic.



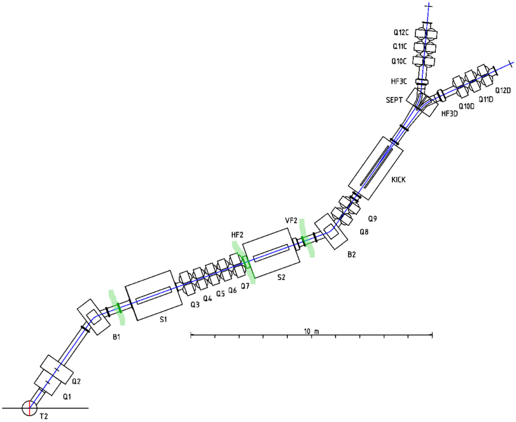


Short gate	1.2×10^6
Long gate	0

Results are encouraging, beam line instrumentation has been substantially improved since 1993. Work in progress! Camille (PIF & NIF), Chloé, Claire, Colin, Doug, Emma

M20 beamline (μSR)

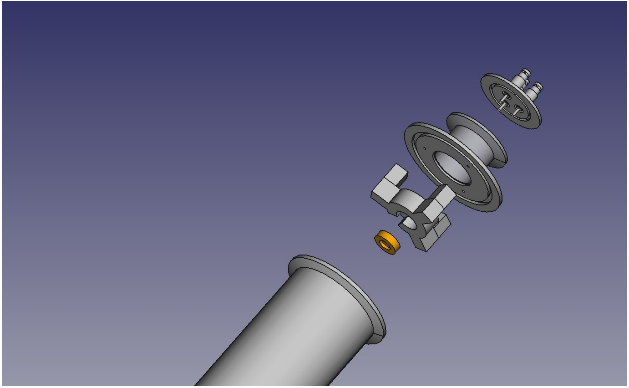
5×11 mm FWHM beam spot, 550k μ^+/s (open slits), 2 DC separators, three PETE windows.



The momentum bite is not precisely known (depends on slits positions). A detailed G4Beamline sim has been developed by TRIUMF's CMMS group.

Planned M20 Beamline Studies

Three shifts (24h) allocated to us on Nov 27. We plan to measure the momentum bite as a function of the slits positions. This will be used to validate the G4beamline sim.



The detector active area is 13.8 mm diam (fully depleted, thickness $\approx$ 1 mm). Mechanical integration well advanced.

Outlook

Reducing the pion lifetime uncertainty is important to fully profit from PIONEER potential.

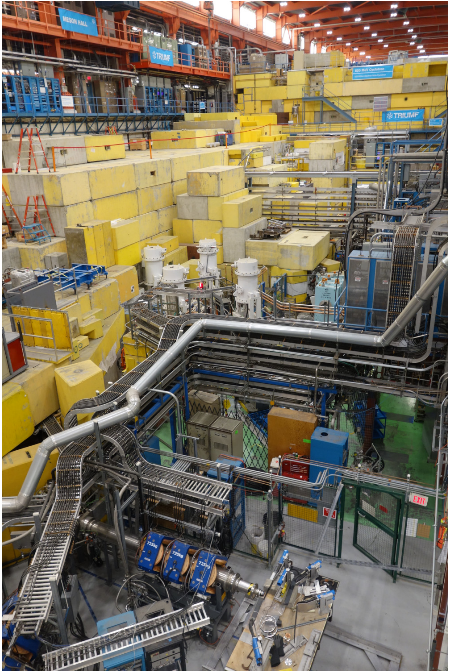
Improved beam instrumentation & online monitoring provide more handles to control the beam leakages.

Many more questions have to be tackled before doing a measurement, among others:

- Find the optimal detector layout,
- Revisit the sensitivity studies,
- Design the DAQ system.

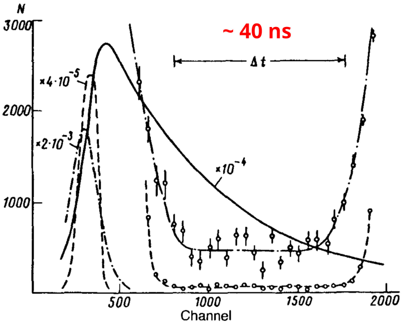
Can we use the device developed to study M20 properties in πE5?

The prospects for an improved pion lifetime measurement at TRIUMF look very encouraging.


MESON HALL
TRIUMF
520 MeV Cyclotron
TRIUMF
725kg
725kg
725kg
EXIT

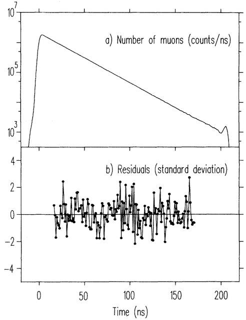
Previous Measurements

Two "recent" experiments (1995): Koptev et al. and Numao et al., both used momentum-analyzed surface-muons. ‡



Koptev et al., statistics limited.

$\tau_{\pi}^{+} = 26.0361 \pm 0.0052$

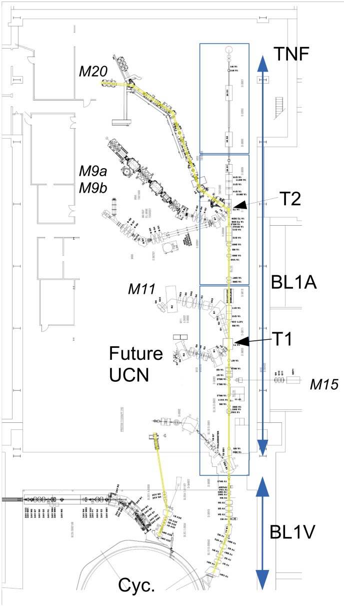


Numao et al., **150 ns** examination window, systematics limited.

$\tau_{\pi}^{+} = 26.0231 \pm 0.0050 \pm 0.0084$

‡ Older experiments examined the $\pi^+ \to \mu^+$ or $\pi^+ \to \mu^+ \to e^+$ (stopped pions) sequence, or the $\pi^\pm$ attenuation along a decay volume, see PDG for details.

TRIUM Beamline 1A



Impact of τ_π on the PIONEER Error Budget

Base principle, count $\pi \to e$ and $\pi \to \mu \to e$ events, τ_π enters in the ratio:

$$R_{e/\mu} = \frac{\lambda_\mu}{\boldsymbol{\lambda_\pi} - \lambda_\mu} \frac{\boldsymbol{N_{\pi e}}}{De^{\lambda_\mu t_s} - \boldsymbol{N_{\pi\mu e}}} \left(1 - e^{-(\boldsymbol{\lambda_\pi} - \lambda_\mu)t_s}\right)$$

[E. Di Capua et al, Phys. Rev. **133** (1967) B1333]