N-15 Muon Lifetime

PHYS 4410 - Experiment

David Thuman

Goal of Experiment

To experimental measure the lifetime of a muon

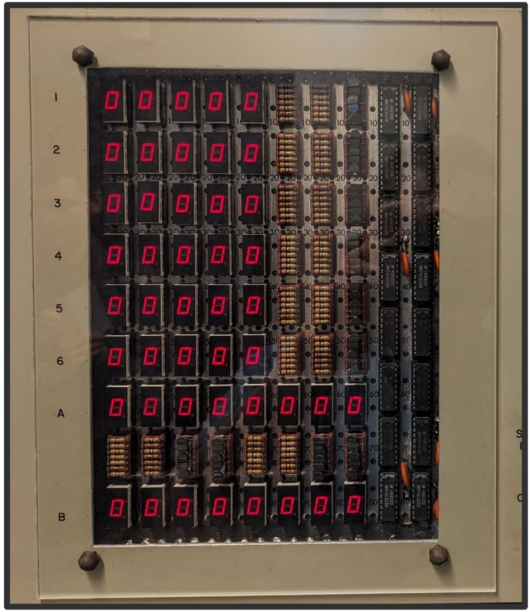
- Techniques of particle detection
- Calibration of equipment
- Statistical analysis of data

Registering Muon Pulses

Scintillator

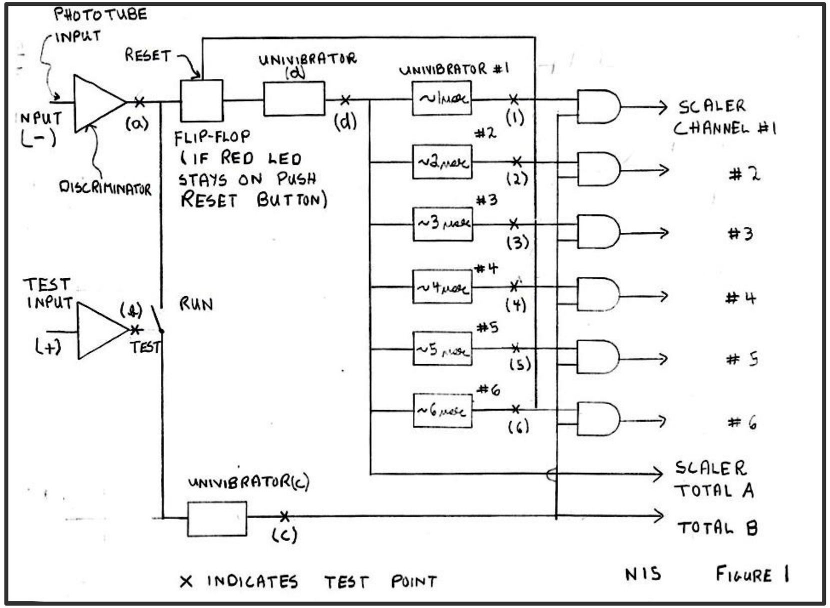
Photomultiplier Tube (PMT)

Counter and Counter Circuit



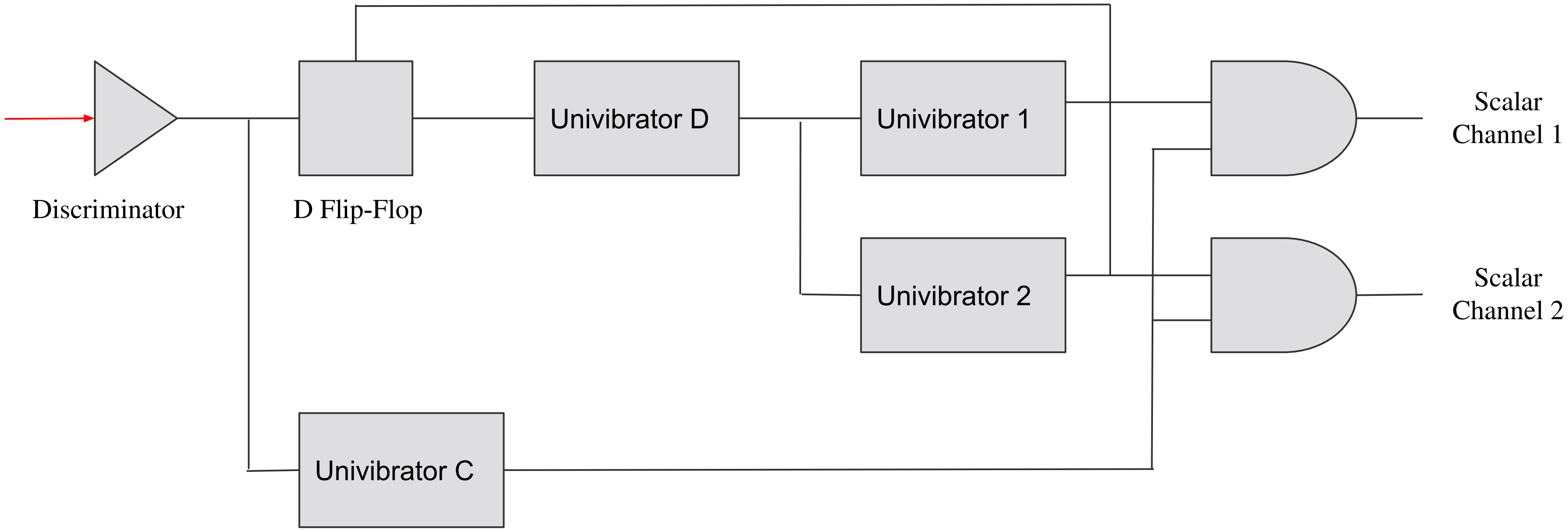
Left Figure:
Counter display

Right Figure:
Counter Block diagram



Counting the Muons

Univibrator	Time Delay	Pulse Width
D	Faction of μsecond	unknown
C	< D	unknown
1	unknown	~ 1 μsecond
2	unknown	~ 2 μsecond



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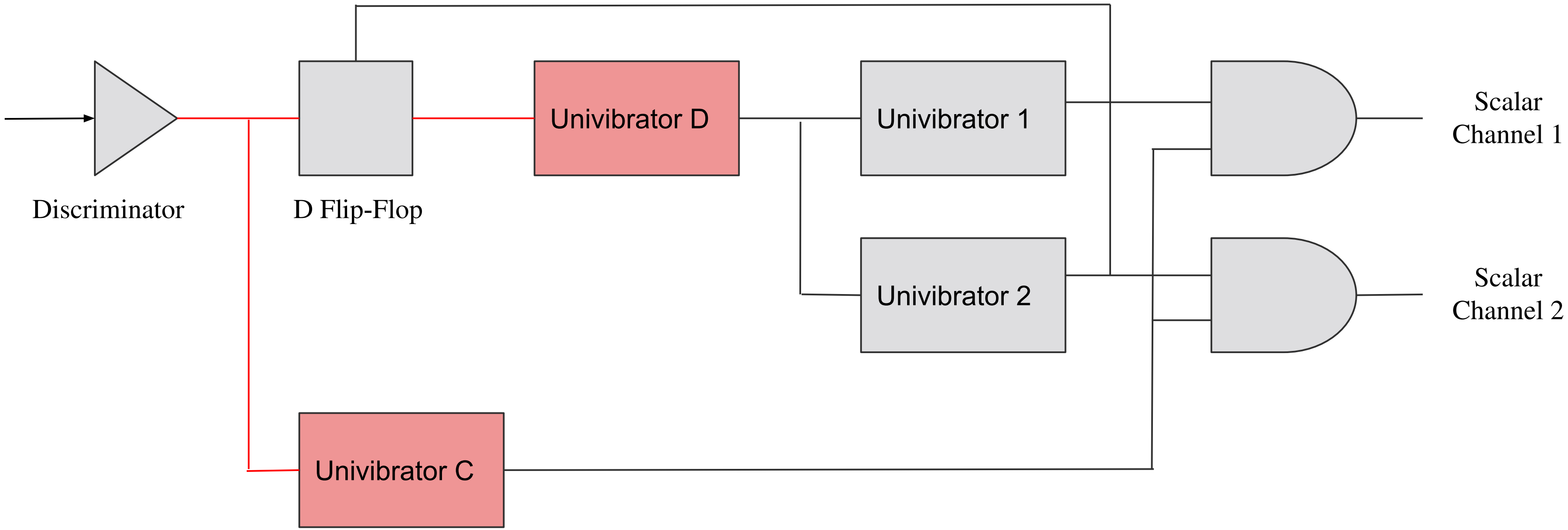

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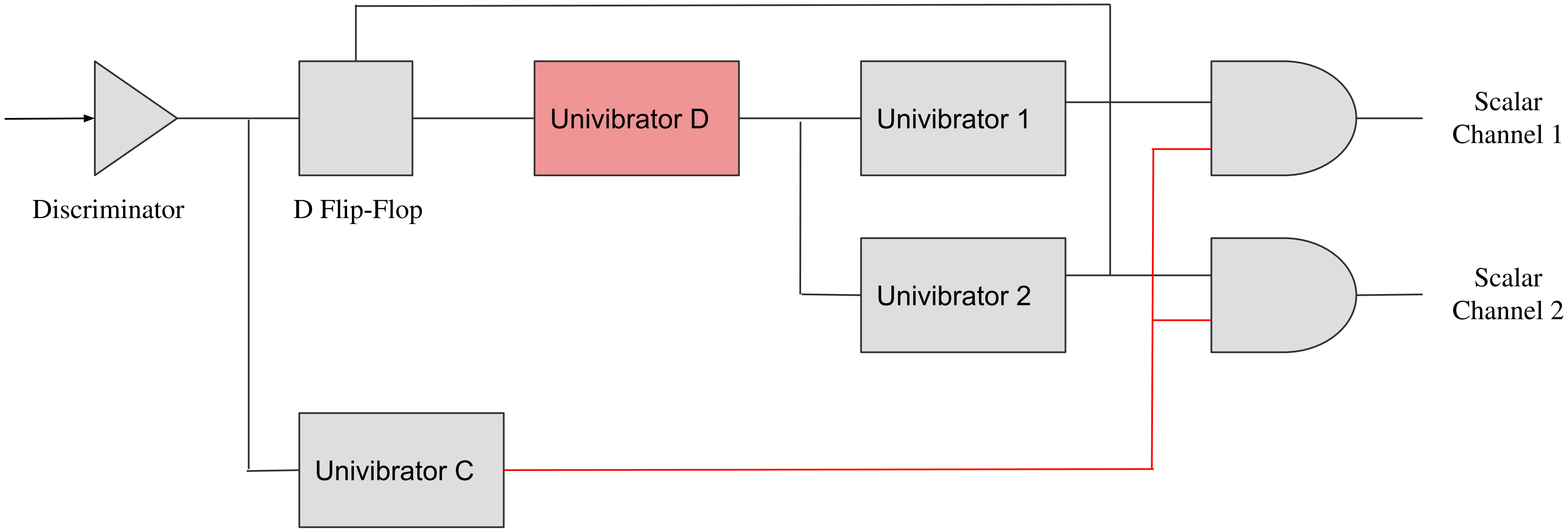

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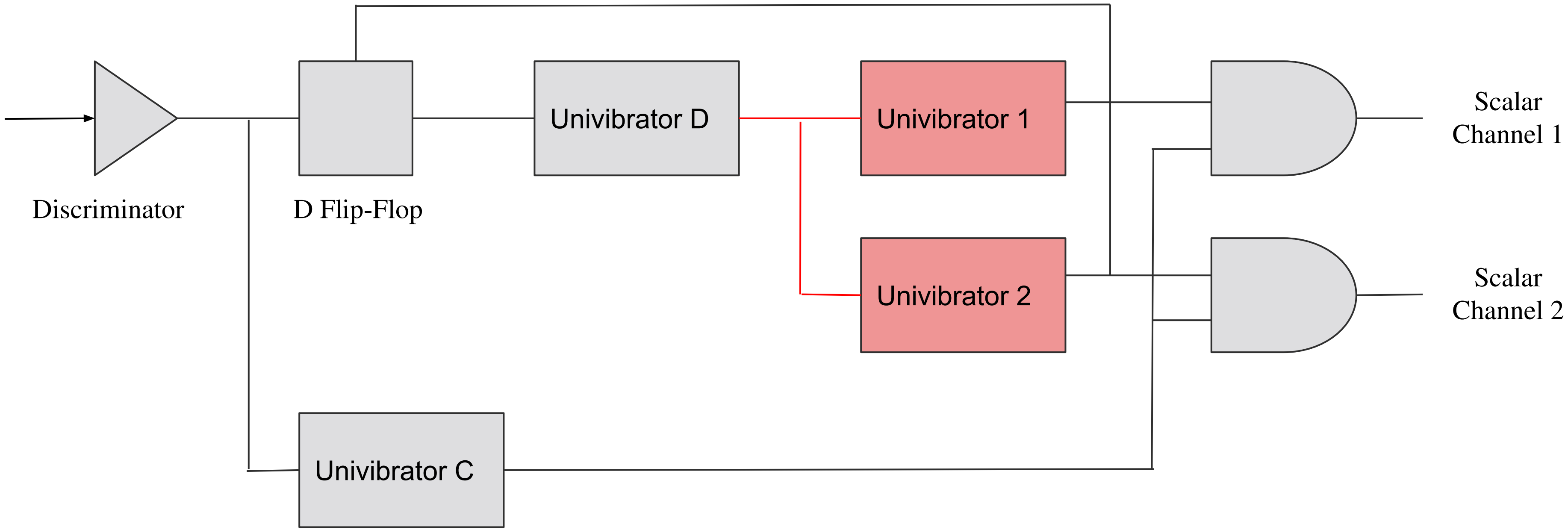

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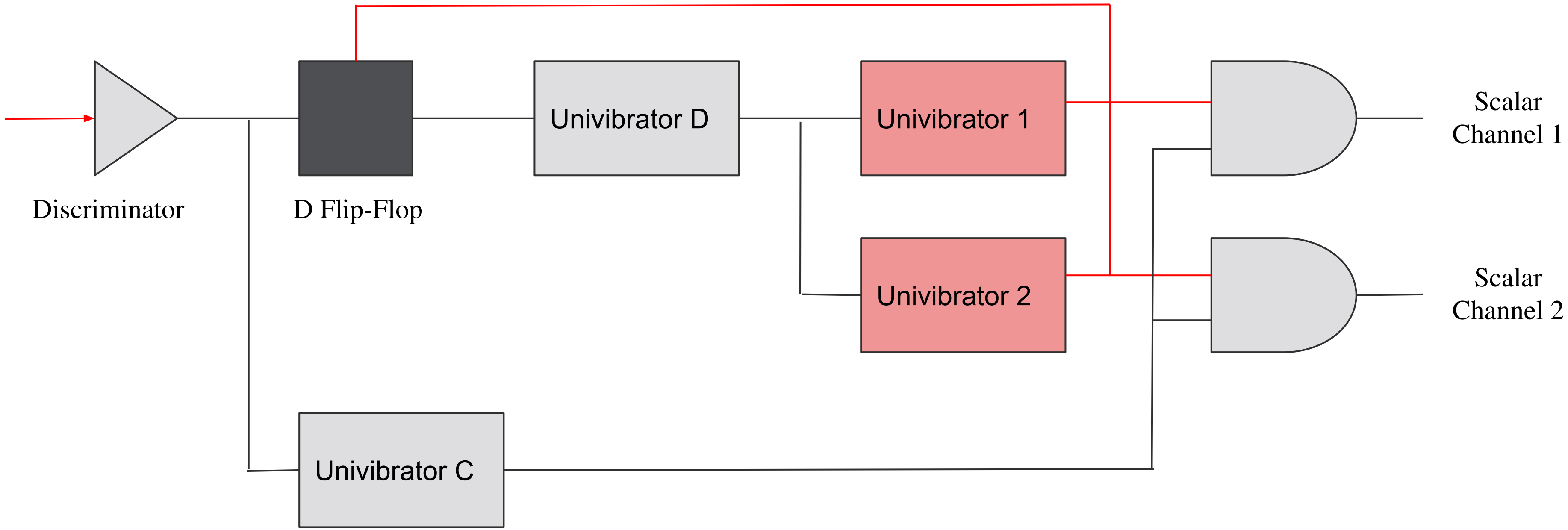

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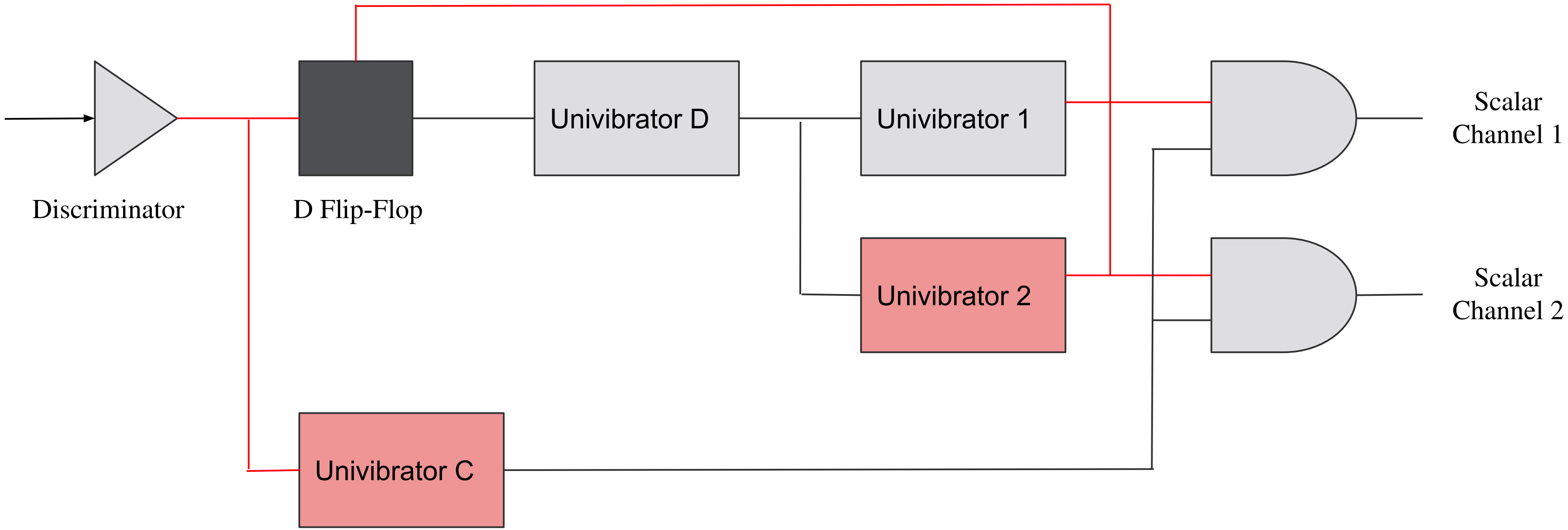

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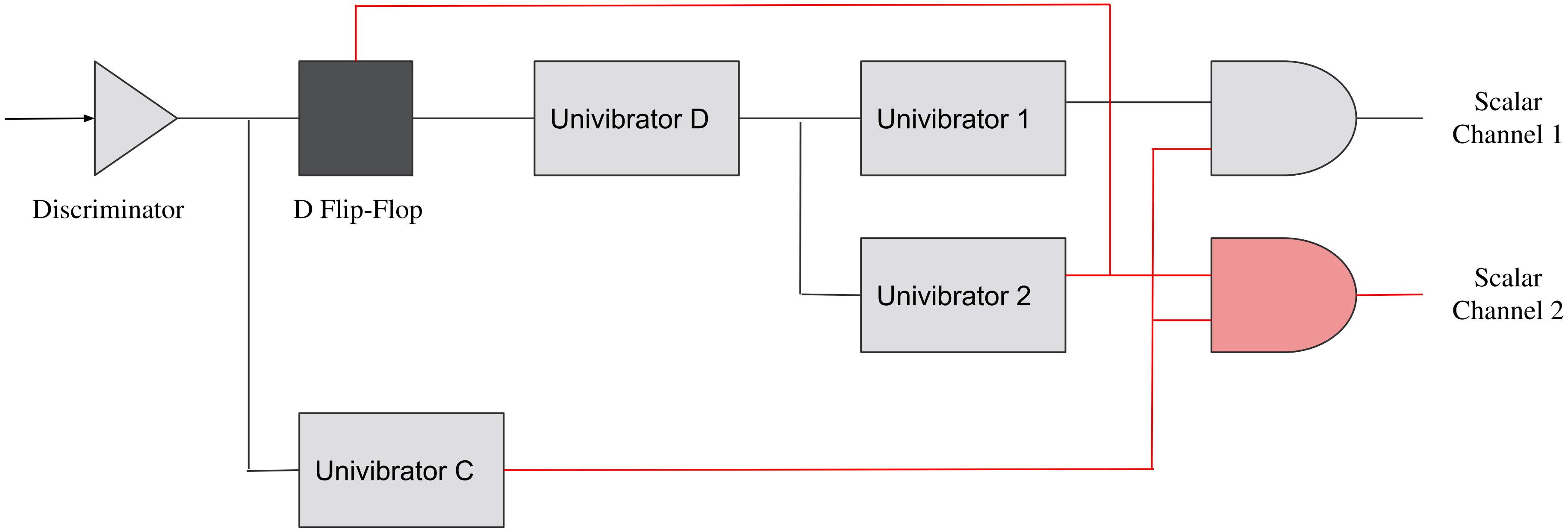

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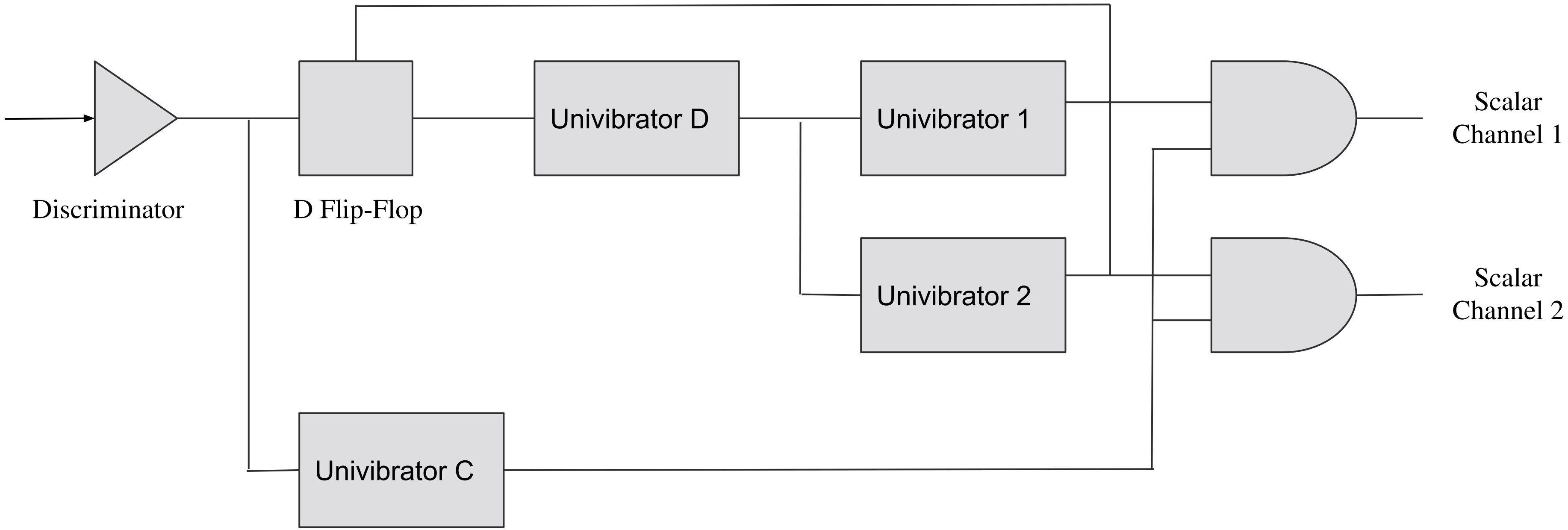


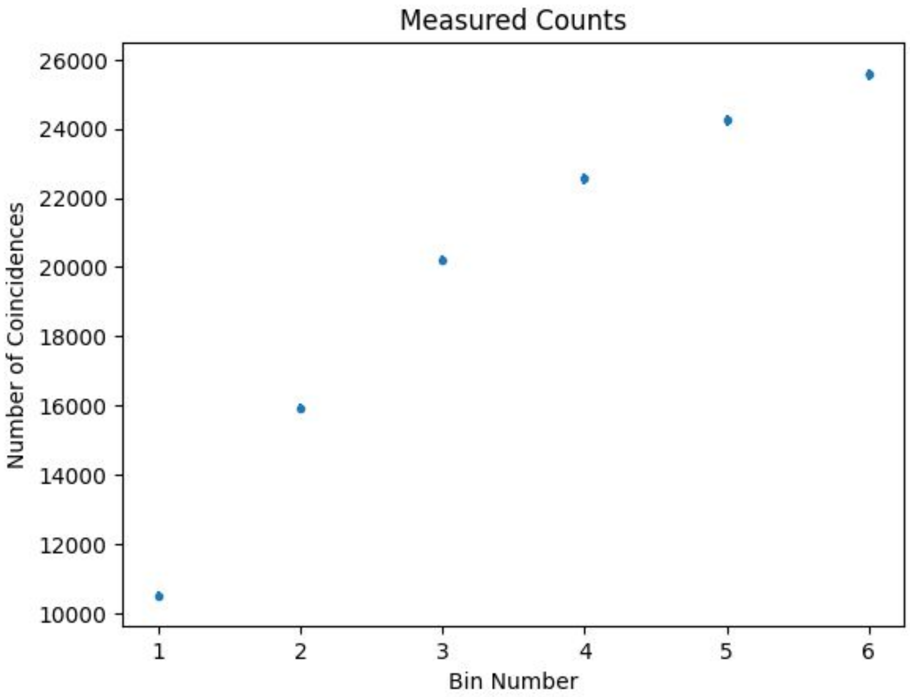
Calculating Bin Width

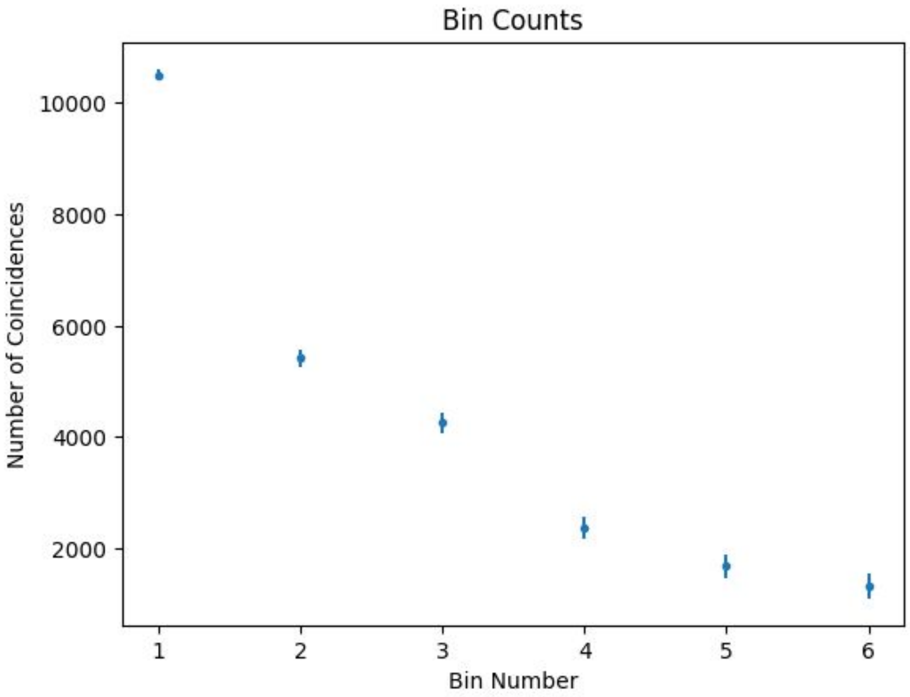
$$\text{Bin Width (i)} = \frac{\text{Bin Count (i)}}{\text{Scalar A} * \text{Repetition Rate}}$$

Item	**Value**
Repetition Rate (Hz)	$100.9 \pm 0.2 \times 10^3$
Bin 1	695 ± 26
Bin 2	512 ± 44
Bin 3	569 ± 55
Bin 4	541 ± 64
Bin 5	548 ± 72
Bin 6	637 ± 80
Scalar A	6755 ± 82
Scalar B	102987859 ± 10148

Bin	**Width (seconds)**
1	$1.02 \pm 0.041 \times 10^{-6}$
2	$0.75 \pm 0.069 \times 10^{-6}$
3	$0.83 \pm 0.89 \times 10^{-6}$
4	$0.8 \pm 0.11 \times 10^{-6}$
5	$0.8 \pm 0.12 \times 10^{-6}$
6	$0.9 \pm 0.14 \times 10^{-6}$

Fitting Observed Data





Function to Fit Data

$$f(i;\lambda,N) = \frac{\int_{t_i}^{t_{i+1}} Ne^{-\lambda t}}{\int_{t_1}^{t_7} e^{-\lambda t}}$$

Item	Value
Bin 1	10507 ±103
Bin 2	5420 ±163
Bin 3	4261 ±190
Bin 4	2368 ±206
Bin 5	1682 ±216
Bin 6	1326 ±223

i is the Bin number

t_i is the start time of Bin i

t_{i+1} is the end time of Bin i (or the start time of Bin $i+1$

N is the total number of observations

λ is the inverse muon decay rate

Uncertainty Analysis - Least Squares

Least Squares Optimizer

for $\delta t_i = 0$

$$S(\alpha) \equiv \sum_{i=1}^{p} \left[\frac{y_i - f(t_i)}{\sigma_i} \right]^2$$

Least Squares Optimizer

for $\delta t_i \neq 0$

$$S(\alpha) = \sum_{i=1}^{p} \left[\frac{y_i - f(t_i)}{\delta_i} \right]^2$$

$$\delta_i^2 \equiv \left[\frac{\partial f}{\partial t} \right]^2 [\delta t_i]^2 + [\delta y_i]^2$$

Negative Muon Capture

However, the apparatus captures both negative and positive muons

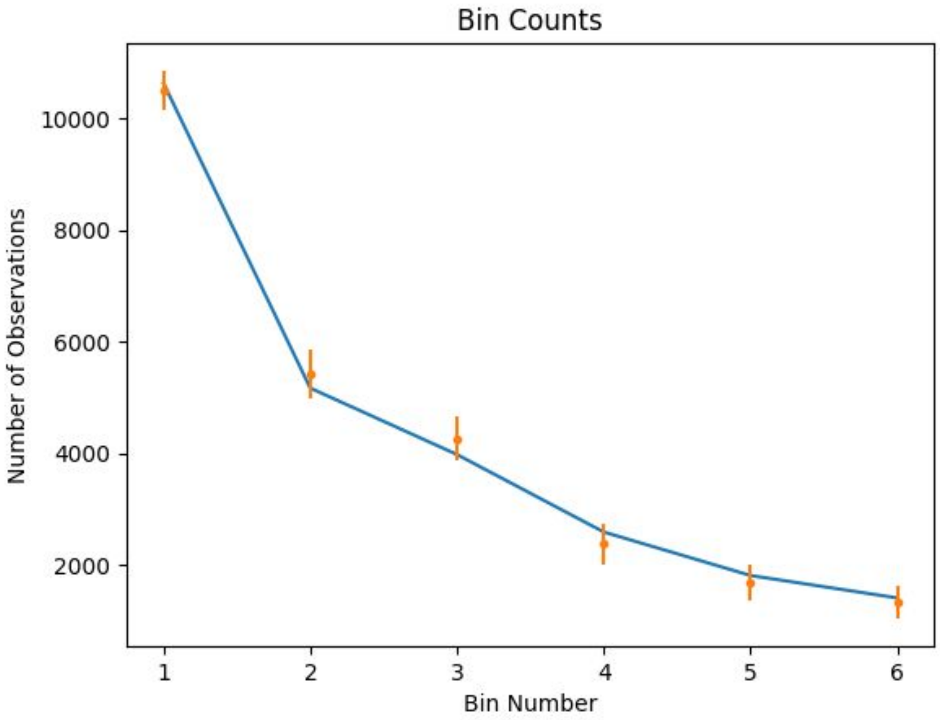
Negative muons have a slightly shorter decay time

Using

- Ratio of positive to negative muons: r = 1.18 ± 0.12
- Capture rate in carbon: $\Lambda_{\text{caputre}} = 3.76 \pm 0.04 * 10^4$ Hz

$$\lambda_{vacuum} = \lambda_{measured} - \frac{\Lambda_{capture}}{1+r}$$

Results



Uncertainty Corrected Least Squares

$2.15 \pm 0.062 * 10^{-6}$ seconds

Negation Muon Correction

$2.23 \pm 0.068 * 10^{-6}$ seconds

Accepted Value

$2.19703 \pm 0.00004 * 10^{-6}$ seconds