# Summary of $\mu$SR Beam Studies at M13

TWIST Collaboration Meeting

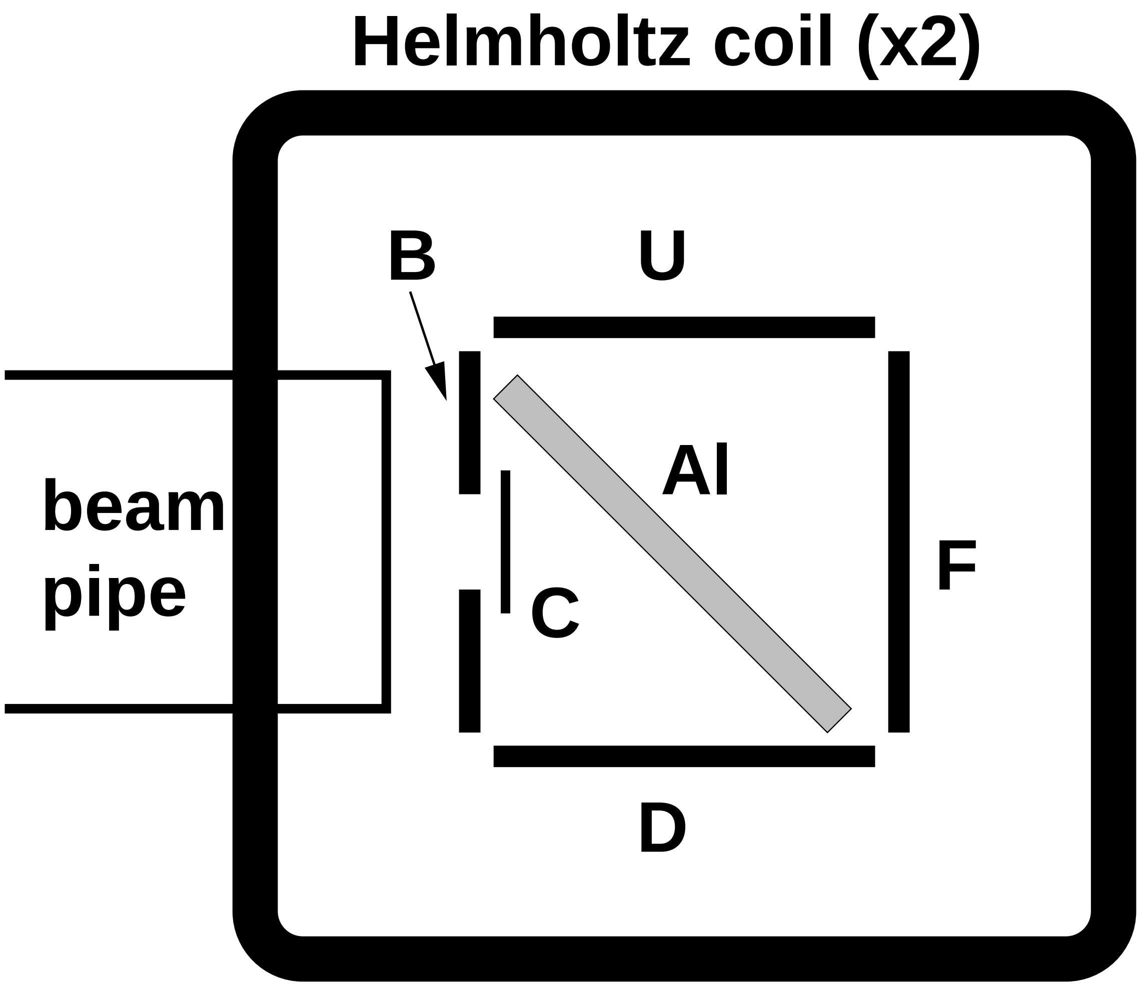
26 January, 2001

Robert MacDonald
University of Alberta
rpm1@ualberta.ca

- Momentum scans (calibration of channel momentum and momentum bite)
- Structure of beam w.r.t. RF time of flight
- Calculation of relative particle rates
- $\mu$SR theory
- Muon decay curves and $\mu$SR fits
- Explanation of "mystery" muons
- Summary and conclusion

These slides will be available on the web.

## $\mu$SR Apparatus




- B, U, F, D are thick (about 1 cm) scintillators.
- C is a thin (about 0.1 mm) scintillator.
- Al is aluminum.

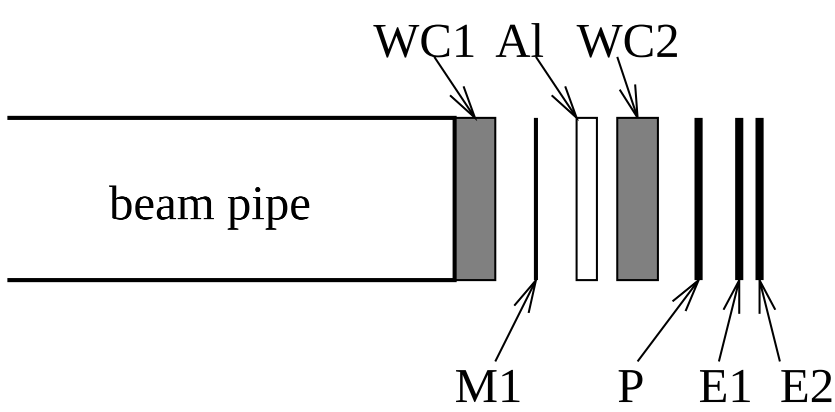
# Momentum Scans

| **Beryllium target** | | |
|---|---|---|
| B1 Field at Edge (Gauss) | $879.6 \pm 0.4$ | |
| Momentum bite | 2.1% | |
| **Graphite target** | **1st scan** | **2nd scan** |
| B1 Field at Edge (Gauss) | $878.7 \pm 0.4$ | $878.1 \pm 0.4$ |
| Momentum bite | 1.6% | 1.7% |

- Scan with the beryllium T1 target took place Oct. 30, 2000.
- Scans with graphite T1 target took place Nov. 13 and Nov. 20, 2000.
- Scans performed using muon and positron scalers normalized to T1ION scaler (ie. normalized to proton current).
- B1 field measured by NMR probe.
  - Uncertainty represents coarseness of B1 power supply control.
- Momentum bite = width of edge (10%–90% levels).

$$B \propto p \quad \Rightarrow \quad \frac{dB}{B} = \frac{dp}{p}$$

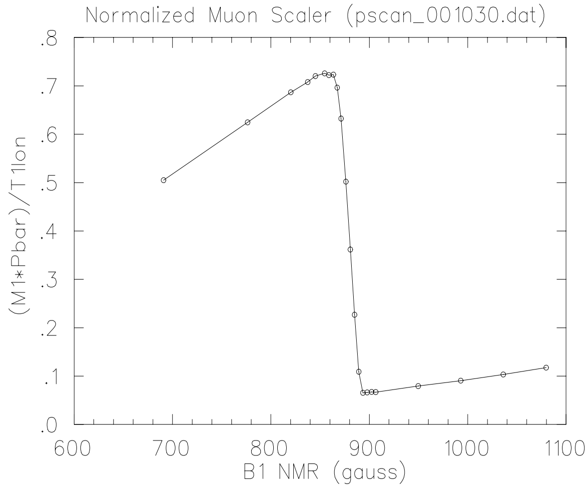
  - Good agreement with Jaap Doornbos's prediction:
    F1 Horizontal Slit @ 2.5 cm $\Rightarrow \frac{dp}{p} = 2\%$.



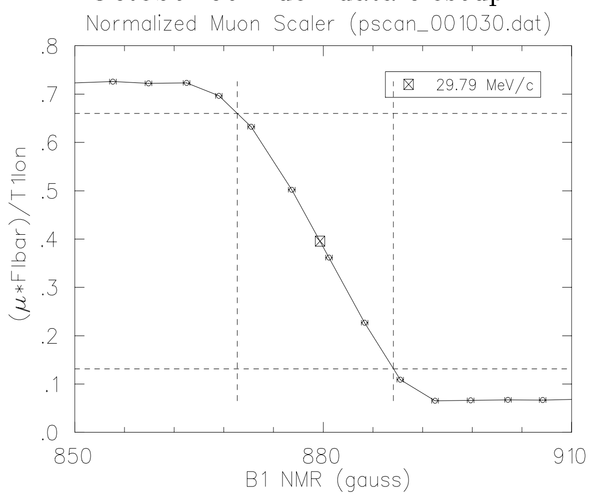

Schematic of apparatus. M1, P, E1, E2 are scintillators. WC1, WC2 are wire chambers.
Al is aluminum sheets.
(Not to scale.)

# Momentum Scans—Beryllium Target

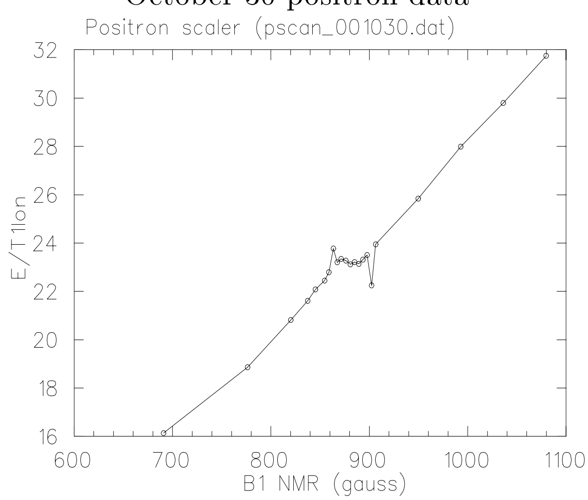
October 30 muon data




October 30 muon data closeup

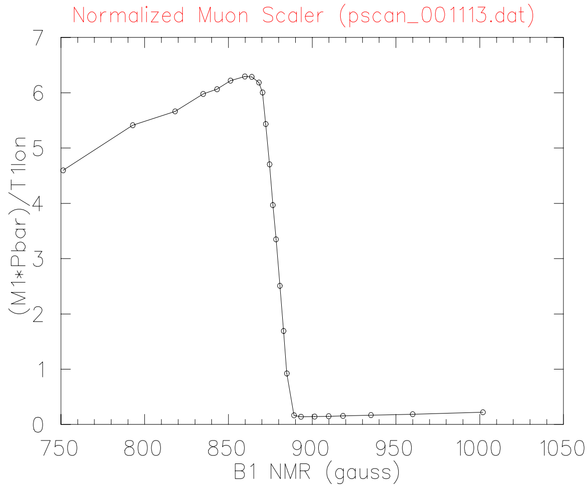



October 30 positron data

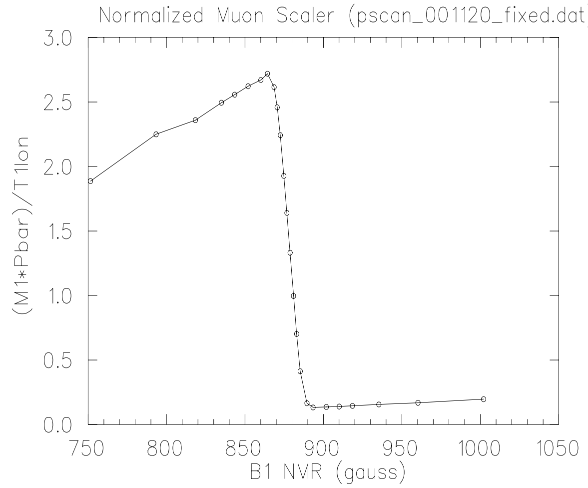


# Momentum Scans—Graphite Target

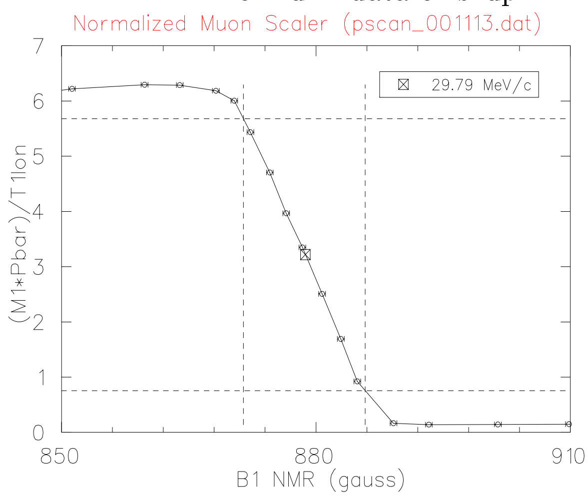
November 13 muon data



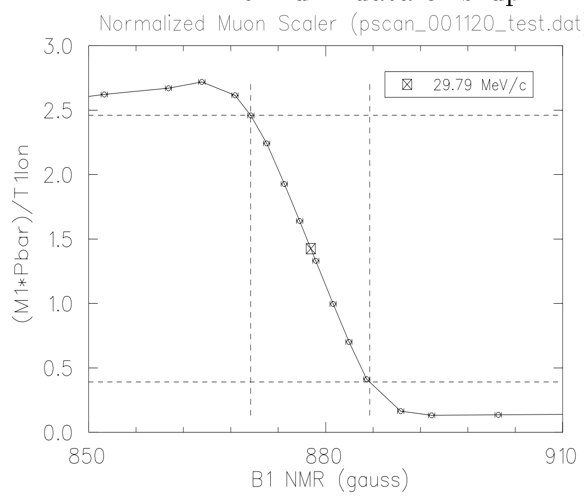

November 20 muon data



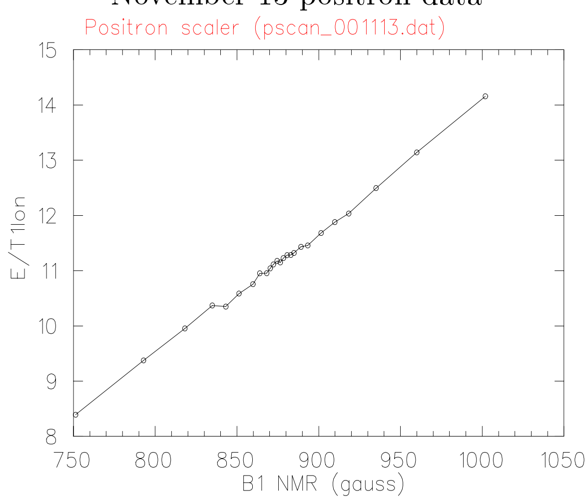

November 13 muon data closeup



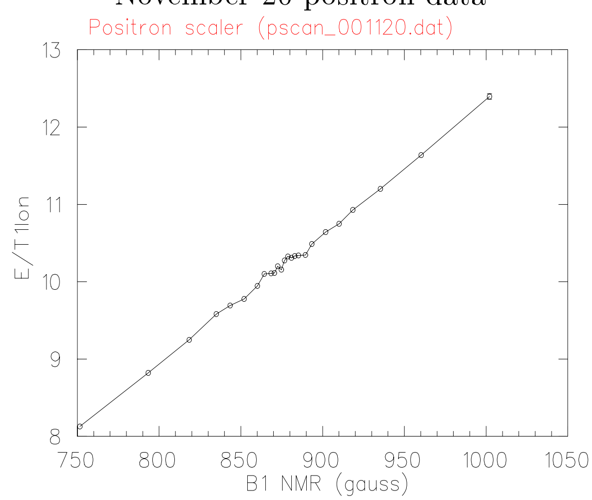

November 20 muon data closeup




November 13 positron data




November 20 positron data



# Summary of $\mu$SR Study Results

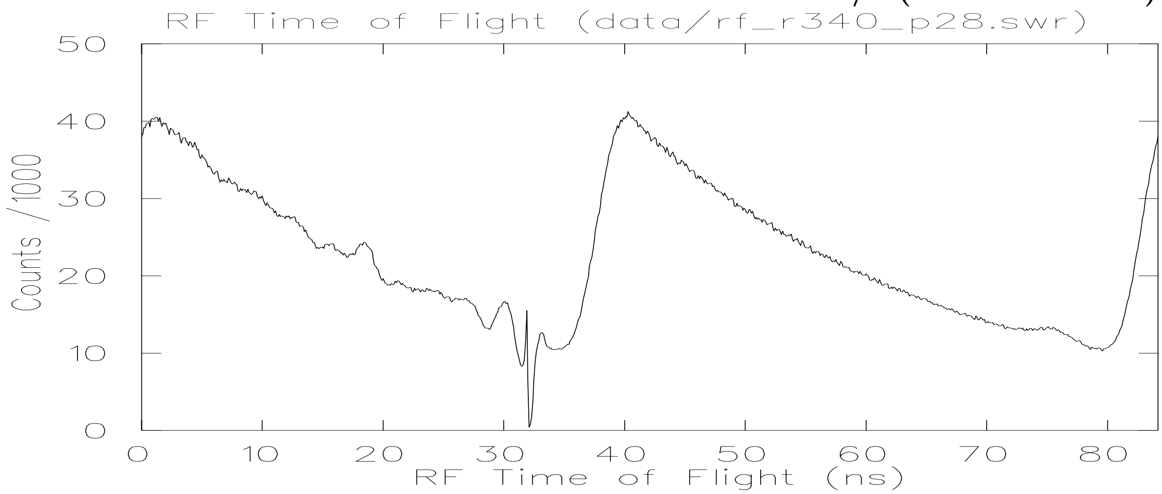
**All data is for the Beryllium target.**

| **Particle Type** | **Relative Rate** | **Relative Polarization** |
|---|---|---|
| Surface muons* | 1.00 | $1.000 \pm 0.008$** |
| "Mystery" muons*** | 0.00227 | $0.9 \pm 0.3$ |
| Cloud muons | 0.089 | $-0.299 \pm 0.006$ |
| Pions | 0.018 | |
| Positrons | 5.2 | |

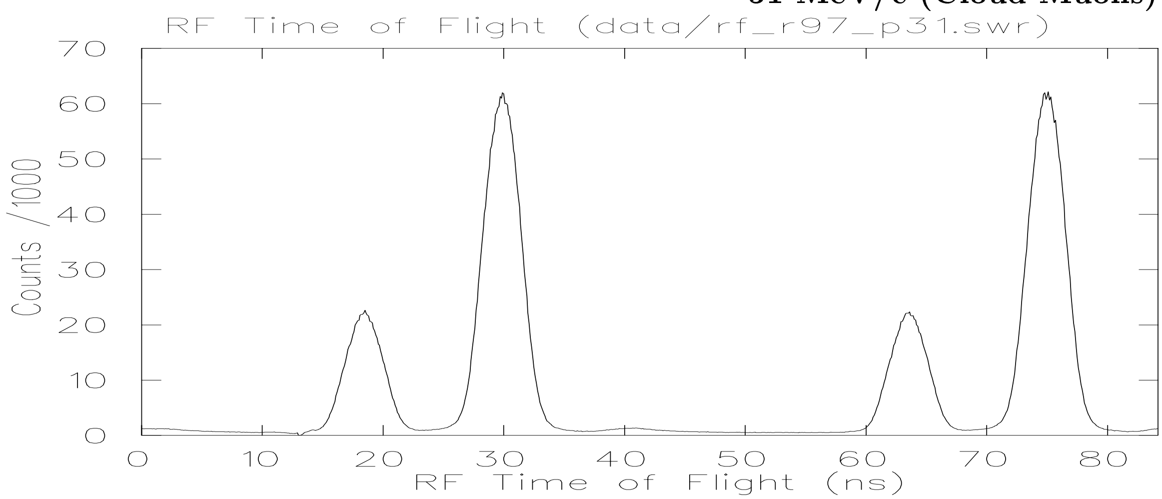
* Rates and Polarizations are relative to surface muon measurements.
** This uncertainty represents the uncertainty in $\mu_s$ asymmetry.
*** These are believed to be surface muons.

# RF Time-of-Flight

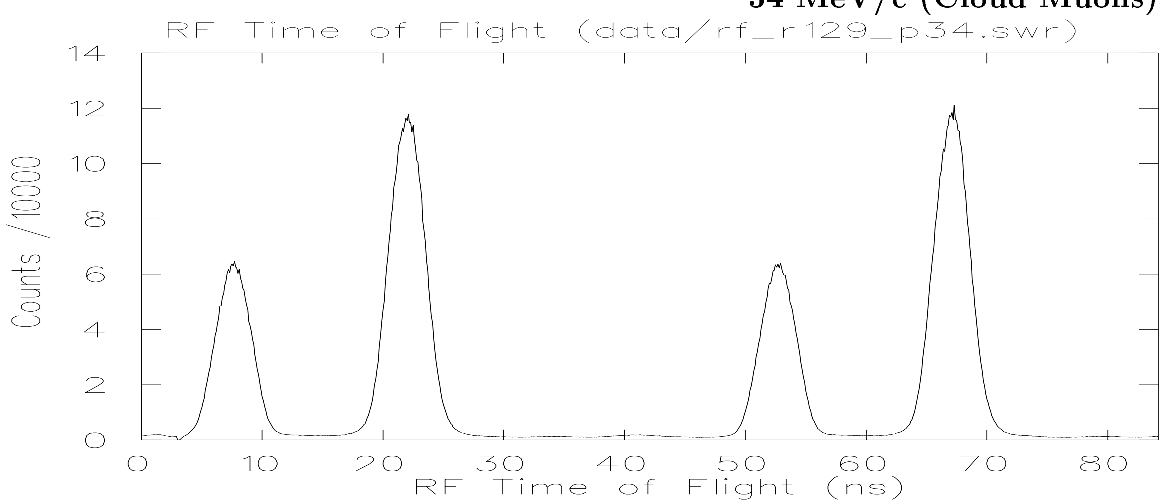
**28 MeV/c (Surface Muons)**




**31 MeV/c (Cloud Muons)**

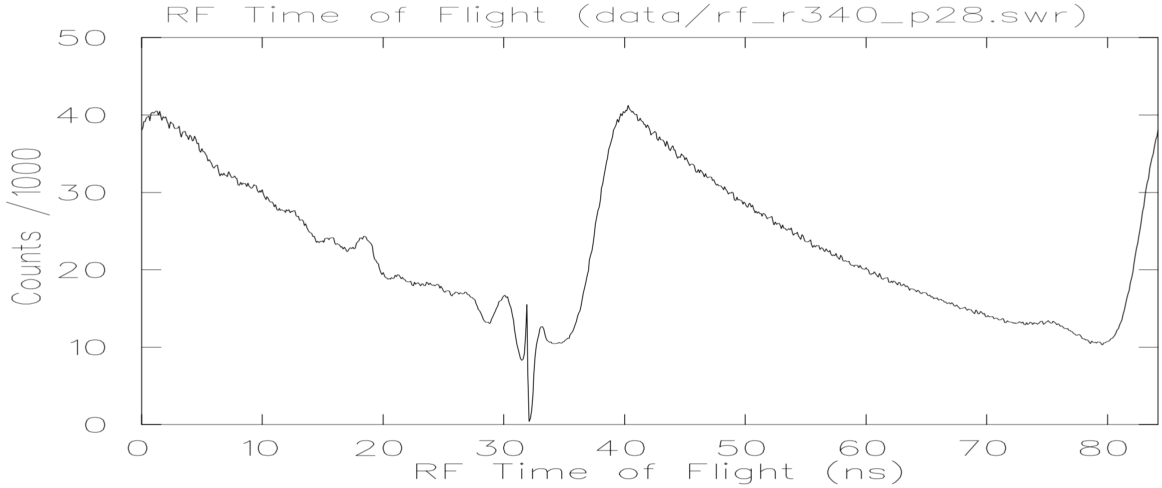



**34 MeV/c (Cloud Muons)**

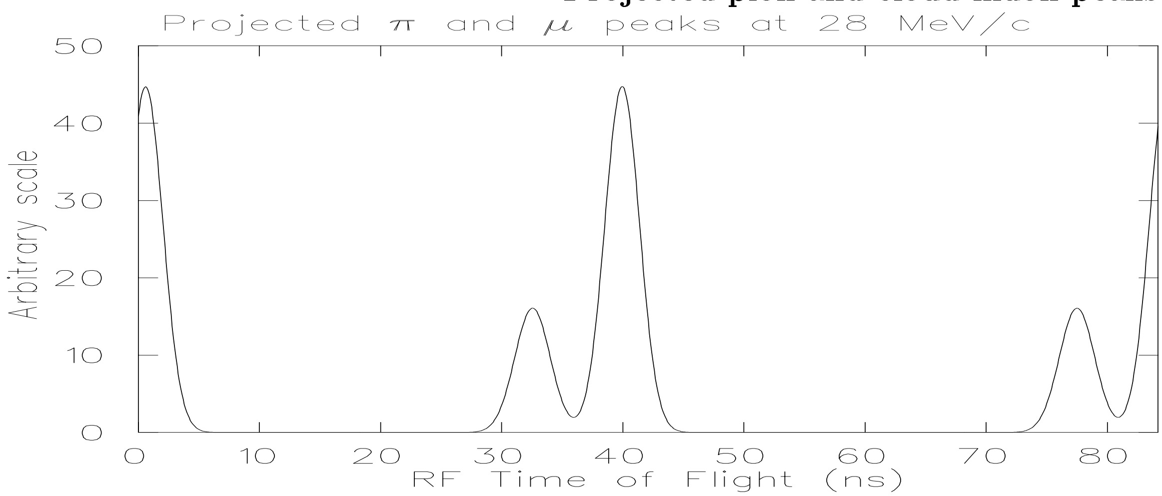


# Peak Positions at 28 MeV/c

**Actual TOF data**



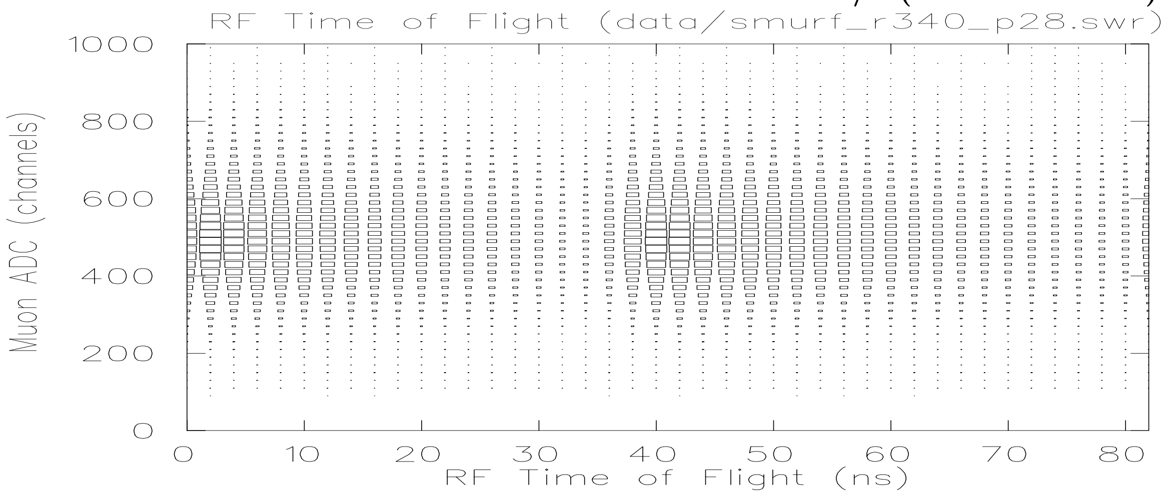

**Projected pion and cloud muon peaks**



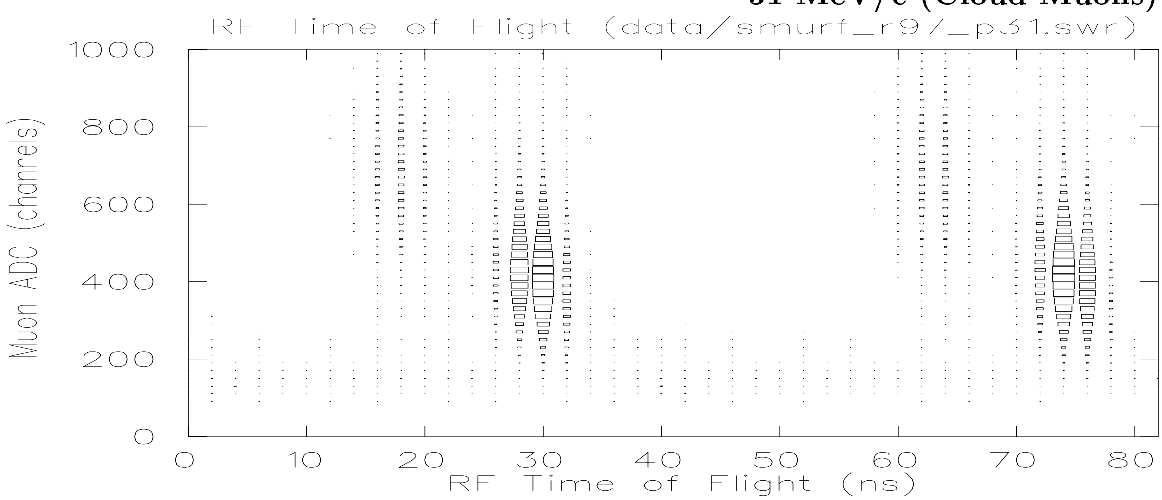

(No vertical scale corrections were made for the projected peaks.)

# Muon ADC vs. RF TOF

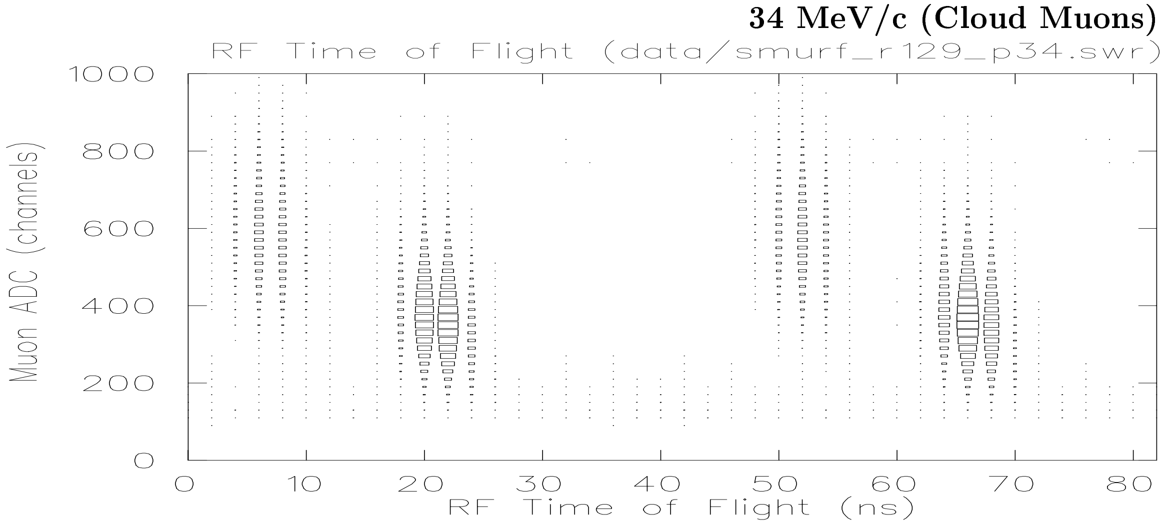
**28 MeV/c (Surface Muons)**




**31 MeV/c (Cloud Muons)**




**34 MeV/c (Cloud Muons)**



# The Calculation of Rates

Relative particle rates:

| $\mu_s$ | $\mu_M$ | $\mu_c$ | $\pi$ | $e$ |
|---|---|---|---|---|
| 1.0 | 0.0023 | 0.089 | 0.018 | 5.2 |

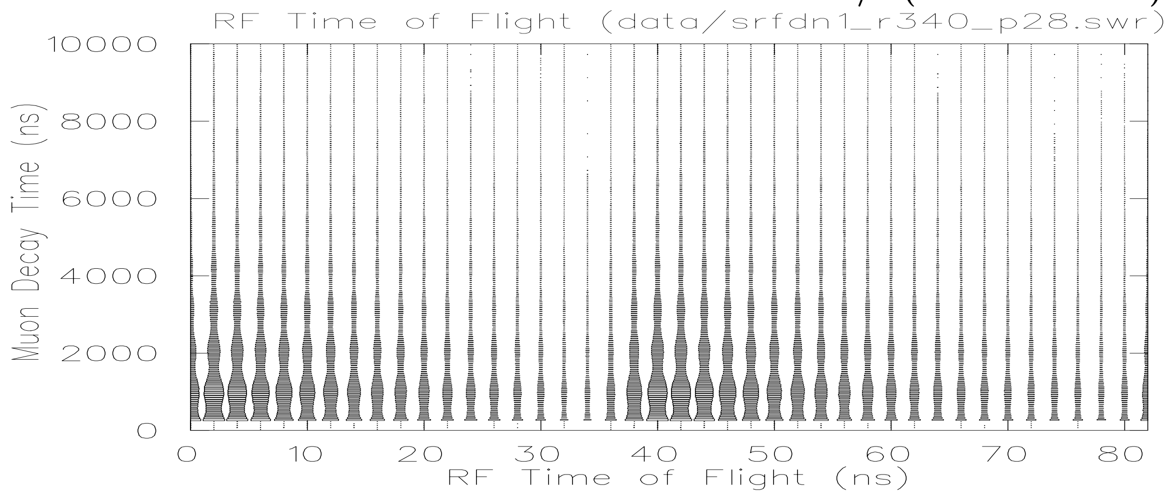
- All rates were normalized by dividing by "T1Ion" scaler (proportional to proton beam current).
- The positron rate was determined from a scaler on the F (positron) scintillator.
  - It is thick enough to be sensitive to positrons.
  - It is downstream of the aluminum target (few if any muons or pions penetrate the aluminum).
- The cloud muon and pion rates were determined from a scaler on the C (muon) scintillator.
  - Rates were calculated at 31 MeV/c, and assumed to be independend of momentum. (Approximately true.)
  - Relative rates ($e^+ : \mu_c^+ : \pi^+$) determined by RF TOF curve. ($e^+$ background was subtracted from peaks.)
  - These proportions were then applied to the C scaler rate to obtain cloud muon and pion rates.
- The surface muon rate was determined from a scaler on the C (muon) scintillator.
  - Background ($e^+, \mu_c^+, \pi^+$) rates assumed independent of momentum.
  - At 28 MeV/c, C scaler counts $\mu_s + \mu_c + \pi$.
    * Compare to pion and cloud muon rates at 31 MeV/c.
    * Let $R = C(31MeV/c)/C(28MeV/c)$. Then

$$R = \frac{\mu_c}{\mu_s + \mu_c + \pi}$$

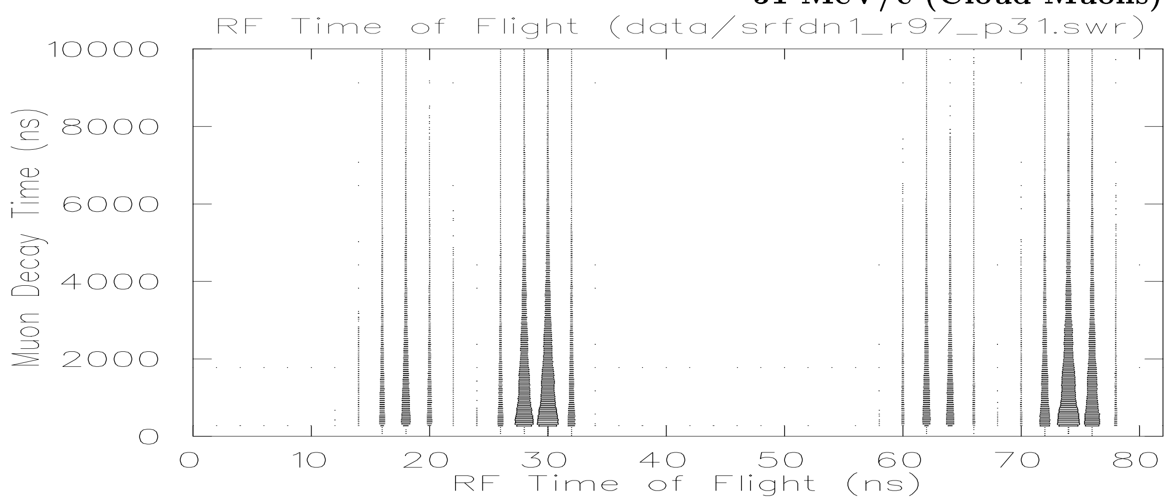
    * Use known $\pi/\mu_c$ ratio to find $\mu_c/\mu_s$ ratio.
- The "mystery" muon rate was determined by summing the "background" region (off of pion and muon peaks) of the RF TOF curve at 31 MeV/c, and the equivalent region at 28 MeV/c, with an ADC cut in place to remove positron counts.

# Correlations between Muon Decay Times and RF TOF

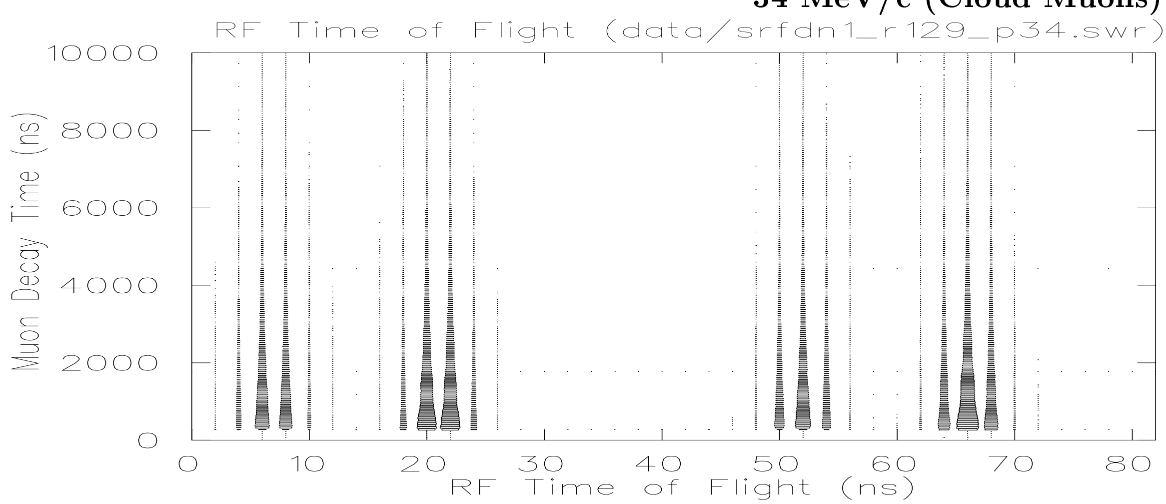
**28 MeV/c (Surface Muons)**




**31 MeV/c (Cloud Muons)**




**34 MeV/c (Cloud Muons)**



# $\mu$SR Theory

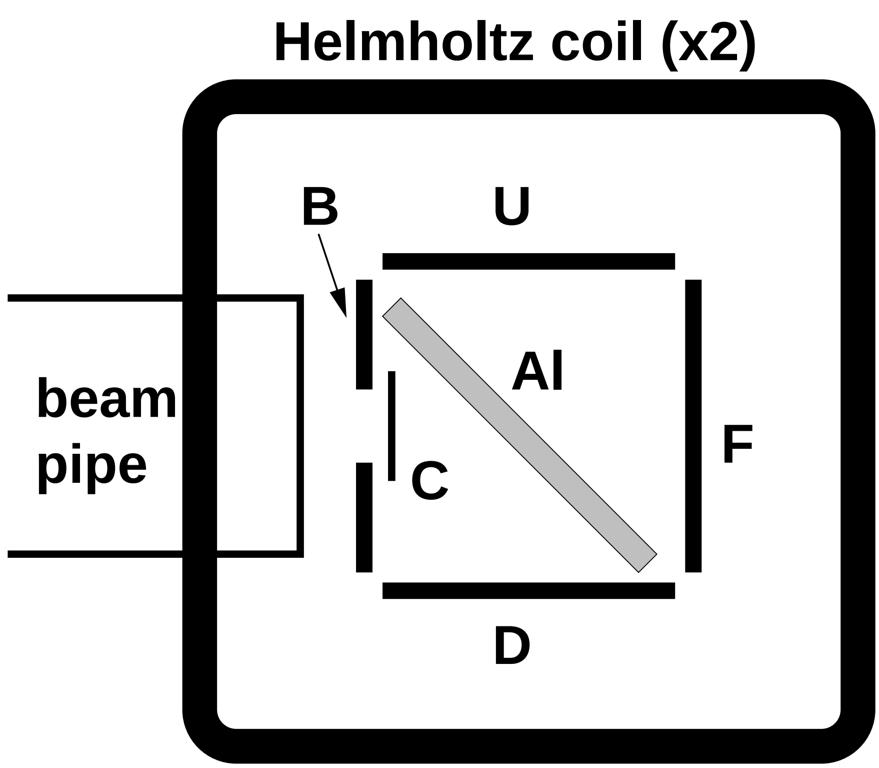
- Muons precess in a magnetic field.
- Muon decay is anisotropic.
- Muon decay time histogram is exponential, with oscillations:

$$N = N_0 e^{-t/\tau}(1 + \alpha \cos(2\pi f t + \phi)) + B$$

where $N$ = counts, $t$ = decay time $N_0$ = normalization, $\tau$ = lifetime, $\alpha$ = asymmetry, $f$ = precession frequency, $\phi$ = precession phase, $B$ = constant background.

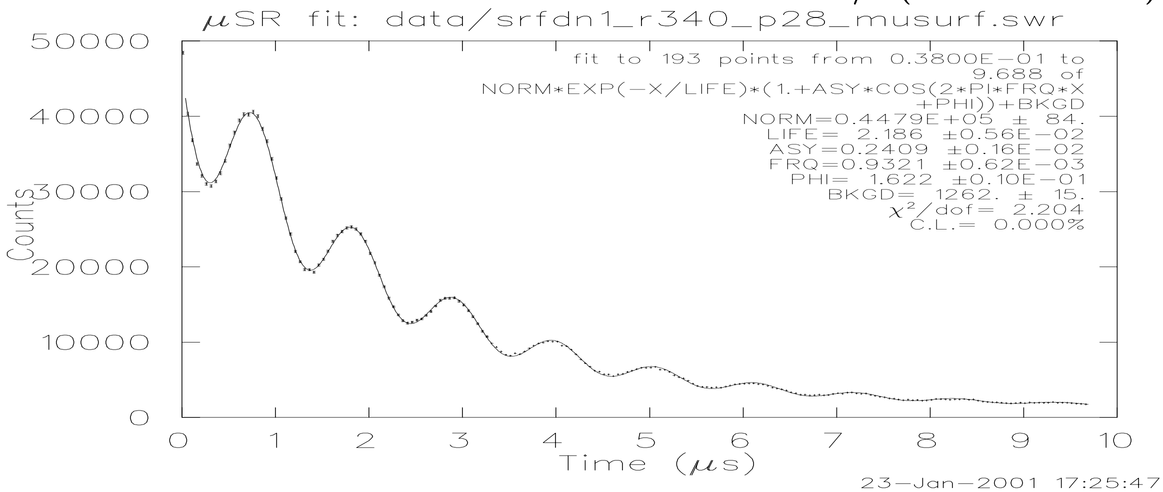
- Frequency $f$ is proportional to magnetic field.
- **Asymmetry $\alpha$ is proportional to muon polarization.**

- Muon scintillator (C) triggers TDC start.
- Decay scintillator (U or D) triggers TDC stop.

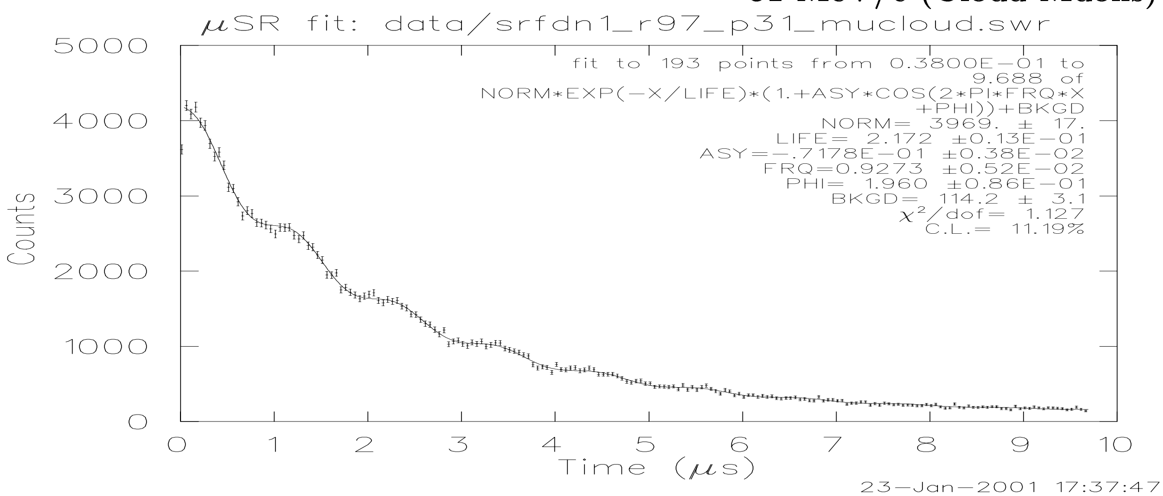


# Muon Decay Curves

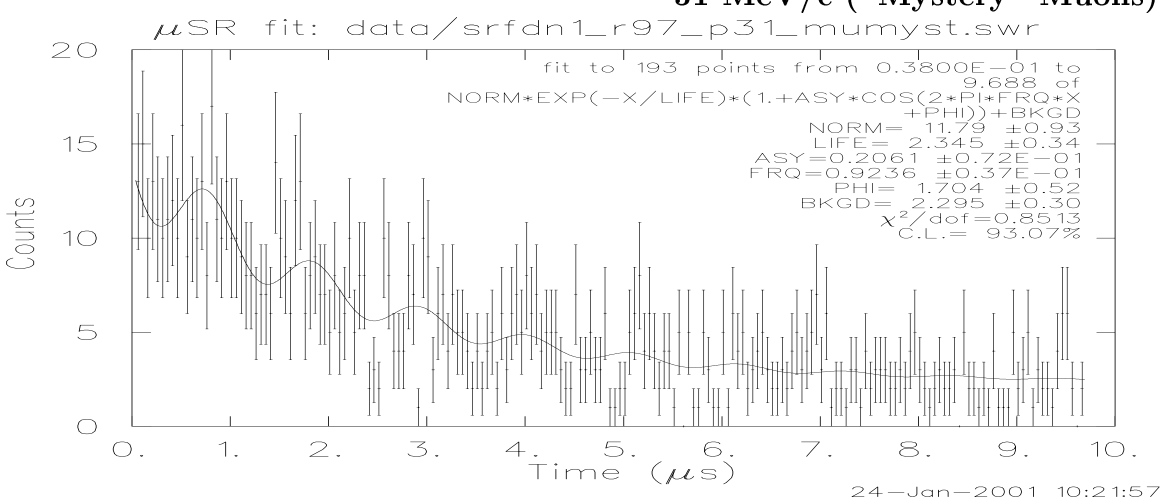
**28 MeV/c (Surface Muons)**




**31 MeV/c (Cloud Muons)**



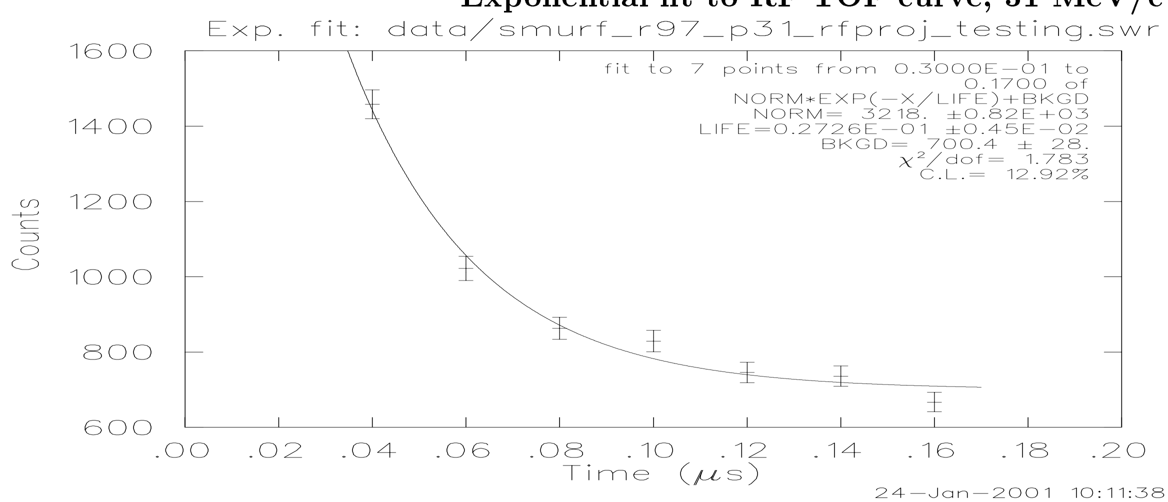

**31 MeV/c ("Mystery" Muons)**



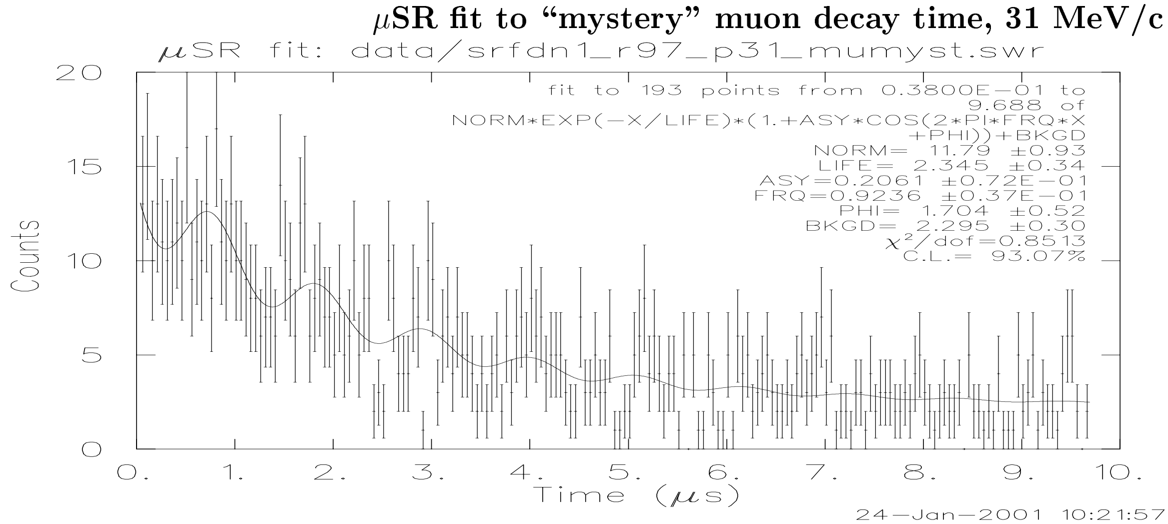
# Explanation of "Mystery" Muons

- "Mystery" muons: muons at 31 MeV/c which do not fall in the cloud muons' RF TOF peak.
- Believed to be **surface muons**.
  - Asymmetry of mystery muons matches that of surface muons.
    - Surface muons: $\alpha = 0.241 \pm 0.002$
    - Mystery muons: $\alpha = 0.21 \pm 0.07$
  - RF TOF distribution follows pion decay curve
    - Pion lifetime: 26 ns
    - RF TOF lifetime: $27 \pm 5$ ns

**Exponential fit to RF TOF curve, 31 MeV/c**




**$\mu$SR fit to "mystery" muon decay time, 31 MeV/c**



# Summary and Conclusion

**All data is for the Beryllium target.**

| **Particle Type** | **Relative Rate** | **Relative Polarization** |
|---|---|---|
| Surface muons | 1.00 | $1.000 \pm 0.008$ |
| “Mystery” muons | 0.00227 | $0.9 \pm 0.3$ |
| Cloud muons | 0.089 | $-0.299 \pm 0.006$ |
| Pions | 0.018 | |
| Positrons | 5.2 | |

- Channel momentum and momentum bite can be determined by measuring muon rate vs. B1 field.
- Momentum bite is roughly consistent with prediction.
- Pions and cloud muons can be selected against by a cut on RF Time of Flight.
- Positrons can be selected against by a cut on the muon ADC.
- “Mystery” muons do not contaminate the surface muon signal (since they *are* surface muons).