Investigation of new Muonium emitters at room temperature

Joint Annual meeting of ÖPG and SPS
Innsbruck 2021

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Muonium in fundamental physics
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Spectroscopy

$\mu^+ \text{ cooling}$

$\mu^+ \text{ cooling}$

$M - \bar{M} \text{ oscillations}$

A) Cryogenic developments

B) room temperature studies

this talk
Investigated target materials

Laser-ablated Aerogel
  - based on SiO$_2$
  - ablated with holes

Zeolite
  known Positronium (e$^+$e$^-$) emitter

Semi-conducting Carbon nanotube samples (CNT)

Courtesy of S. Kamal & G. Marshall TRIUMF
Overview over Measurements

A
Measurement with scintillator bars

B
Measurement with MicroMegas detectors
Measurement principle with scintillator bars

\[ \mu^+ \]

\[ t = 0 \]

Entrance detector

20 mm

Counts vs. time

Expected M signal

\[ \mu^+ \]

\[ e^+ \]

Scintillator bars

Target

\[ \mu^+ \]

\[ t = 0 \]
Measurement principle with scintillator bars

Expected M signal

Counts

t [ns]

0 2000 4000 6000 8000

Counts

0 20 40 60 80 100 120 140 160

data bg estimate

t [ns]

Large exponential background from $\mu^+$ decays!

$\mu^+$

t = 0

entrance detector

20 mm

scintillator bars

$e^+$

$\mu^+$

target
Measurement principle with scintillator bars

Muon entrance detector at \( t = 0 \) followed by 8 kV target.

Scintillator bars densely packed with 20 mm spacing. Positron coincidences significantly suppressed by a factor of over 50.

Data with \( e^- \) coincidence shows reduced background compared to expected signals.
Comparison of samples

- Aerogels emit thermal Muonium, Zeolite slightly faster
- Zeolite emits M with slightly lower yield than Aerogel
- Emission characteristics of CNT are very different, much faster arrival
Overview over Measurements

A

Measurement with scintillator bars

B

Measurement with MicroMegas detectors
Working principle of MicroMegas detectors

One of the used detectors provided by the NA64 experiment
Setup with MicroMegas detectors

- Vacuum cell
- MM 1
- MM 2
- Entrance detector
- Aerogel target
- μ^+
- μ^+
- e^+
- e^+
- 20 mm
Results of the Micromegas measurement

- Muonium cloud visible in projected hit map
- Excess hits between peaks not explainable by resolution of peaks or background hits

Snapshot for $t = 1000 - 2000$ ns
Fit emission models to data - absolute yield estimation

Data fits well to thermal emission model with $T = 300$ K

Find absolute yield of Aerogel sample from best fit:

$$\xi_{\text{Aerogel}} = 7.23 \pm 0.77 \% \quad \text{at } p_\mu \sim 12.5 \text{ MeV/c}$$
Summary

• Development of setups for studying Muonium emitters at room temperature
  - Scintillator bars: efficient background reduction with atomic electron, relative yields, comparison of dynamics
  - MicroMegas: detailed study about emission characteristics, absolute yield estimation

• new Muonium emitters: Zeolites and semi-conductor CNT
Thank you for your attention!
Additional slides
Background suppression and efficiency of atomic electron detection

- Estimate background suppression using PVC target (no M emission)
  \[ \Rightarrow \text{background suppressed with factor < 0.02} \]

- Efficiency of \( e^- \) detection
  - Overall efficiency estimated from data: \( \sim 35 \% \)
  - Efficiency for detection of \( e^- \) with \( \sim 8 \text{ keV} \)

\[ \varepsilon_{PMT} = 80.0 \pm 5.8_{(\text{stat})} \pm 8.5_{(\text{sys})} \% \]

(from comparison with simulations of \( e^- \) acceleration)
Background measurement with PVC
Production of Muonium in vacuum

- implant $\mu^+$ beam into target surface
- stopped $\mu^+$ recombine with free electron
- Muonium atom diffuses through sample
- Fraction of $M$ atoms is emitted into vacuum

Characteristics of emission:
- Fraction of emitted $M$ - vacuum yield
- Kinetic energy of emitted $M$
- Angular distribution (accordance with Lambert cos law?)
Aerogel targets

Courtesy of S. Kamal & G. Marshall TRIUMF

Type I

Type II
relative yield $0.76 \pm 0.14$
Zeolite targets

Zeolite 1:
Alkaline-treated MFI ZSM-5 Z40 (HZ40-AT2)

Zeolite 2:
Alkaline-treated CBV712-B

Alkaline treatment removes silica from the framework, leaving voids up to 10 nm

Courtesy of L. Gerchow, P.L. Begona, P. Crivelli ETHZ
Working principle of MicroMegas detectors

One of the used detectors provided by the NA64 experiment
Setup with MicroMegas detectors

- Combined trigger entrance - top scintillator
  choose time window 1000-2000 ns
- allow only tracks with $\theta \leq 10^\circ$
- extrapolate tracks to central plane
Comparison of various emission models and data

\[
\chi^2 / n_F = 44.1 / 29
\]

$\cos \Theta$ fit on $[-12, 4]$:
Comparison of projected 2D hit maps

Measurement

Monte Carlo

Thermal emission at 300 K, Lambert cos emission distribution
Resolution of MicroMegas measurement

![Graph showing FWHM vs. angle cut with data points for experimental and simulated entrance and target angles.](image-url)