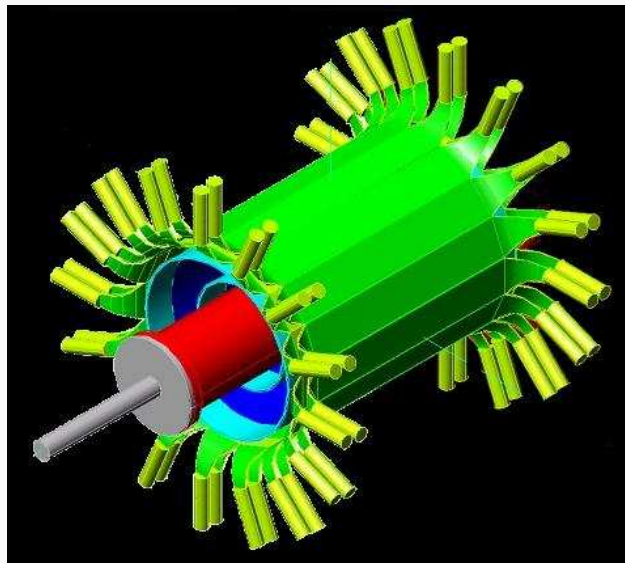


Precision Measurement of the Singlet Muon Capture Rate on the Proton at PSI

MuCap Experiment

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and Paul Scherrer Institute (Switzerland)



On behalf of the MuCap Collaboration

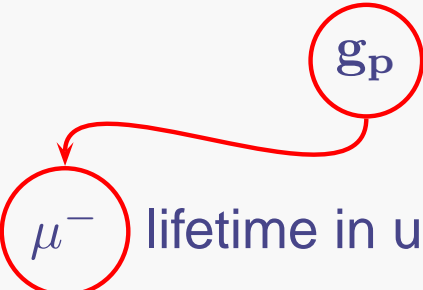
Outline

- ✓ Motivation
- ✓ Experimental Principle
- ✓ Detector
- ✓ First Results
- ✓ Future

Scientific Questions

What is the weak-nucleon charged current?

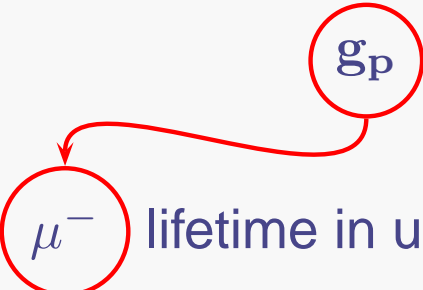
Precision μ^- lifetime in ultra-pure hydrogen gas g_p

A diagram consisting of two red circles. The top circle contains the symbol g_p . The bottom circle contains the symbol μ^- . A red curved arrow originates from the bottom of the g_p circle and points to the top of the μ^- circle.

Scientific Questions

What is the weak-nucleon charged current?

Precision μ^- lifetime in ultra-pure hydrogen gas g_p

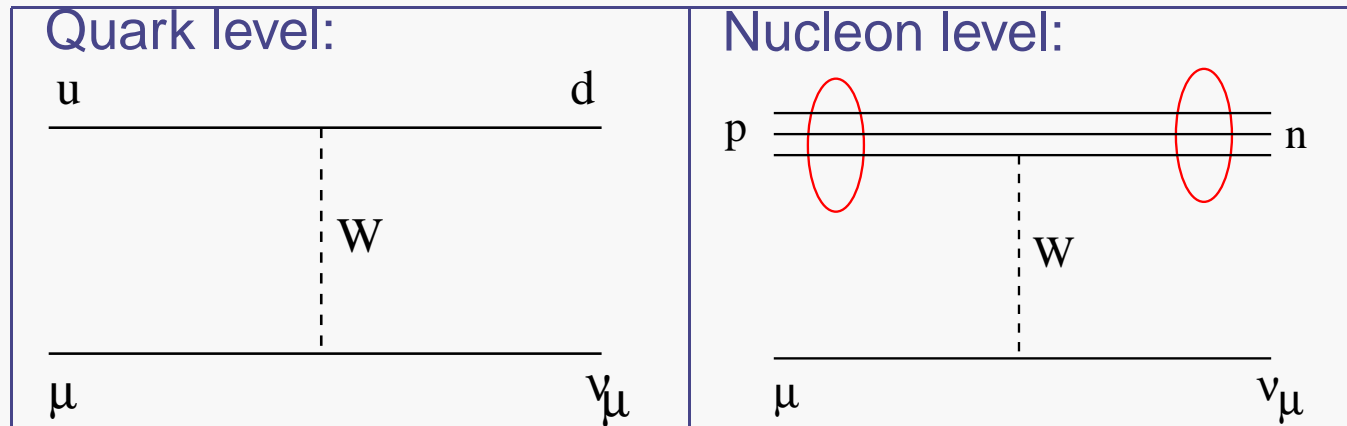
A diagram consisting of two red circles. The top circle contains the symbol g_p . The bottom circle contains the symbol μ^- . A red arrow originates from the bottom of the g_p circle and points to the top of the μ^- circle.

1% measurement of the singlet muon capture rate Λ_s in protium ...



... leading to a 7% determination of g_p .

Weak probe of strong-interaction physics



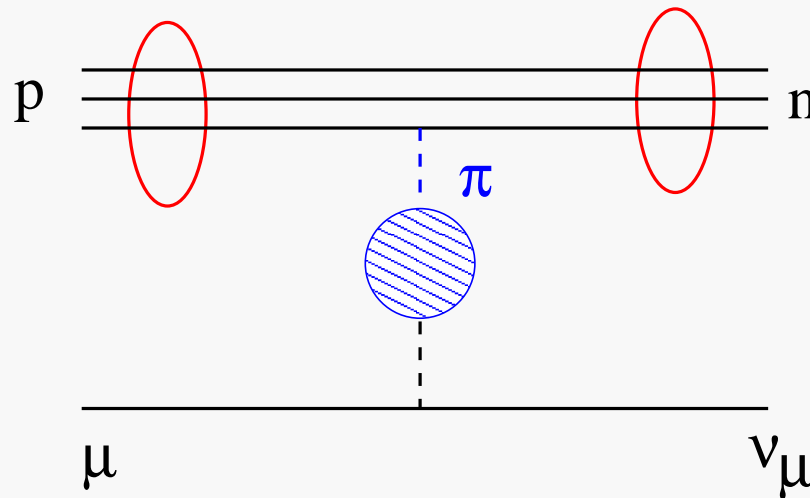
- ✓ At quark level, current is just $V - A$: $\gamma_\mu(1 - \gamma_5)$.
- ✓ “Induced form factors” result from QCD binding of nucleon:

$$J_\alpha = g_V(q^2)\gamma_\alpha + i\frac{g_M(q^2)}{2m_N}\sigma_{\alpha\beta}q^\beta - g_A(q^2)\gamma_\alpha\gamma_5 - g_P(q^2)\frac{q_\alpha}{m_\mu}\gamma_5$$

+ second class currents

- ✓ $g_V = 0.9755(5)$ $g_A = 1.245(3)$ $g_M = 3.5821(25)$ $g_P = 8.4 \pm \sim 20\%$
- ✓ g_P is by far the least well known of these form factors.

Theoretical predictions for g_P



- ✓ Partially conserved axial current (PCAC):

$$g_P(q^2) = \frac{2m_\mu m_N}{m_\pi^2 q^2} g_A(0) = 8.7 \text{ at } q = p_n - p_p \rightarrow q^2 = -0.88m_\mu^2$$

- ✓ Heavy baryon chiral perturbation theory (χPT):

$$g_P(q^2) = \frac{2m_\mu g_{\pi NN} F_\pi}{m_\pi^2 - q^2} - \frac{1}{3} g_A(0) m_\mu m_N r_A^2 = 8.26 \pm 0.23 (\pm 3\%)$$

- ✓ Two rather different methods seem to agree well.
- ✓ χPT is a low-energy expression of a fundamental symmetry of QCD, so it is important to check it.

Experimental methods

✓ Ordinary muon capture (OMC)

$$\mu^- + p \rightarrow \nu_\mu + n \quad \text{Branching Ratio : } \sim 10^{-3}$$

- ◇ Neutron counting (7 experiments)
- ◇ Lifetime difference method (Saclay: Bardin et al.)

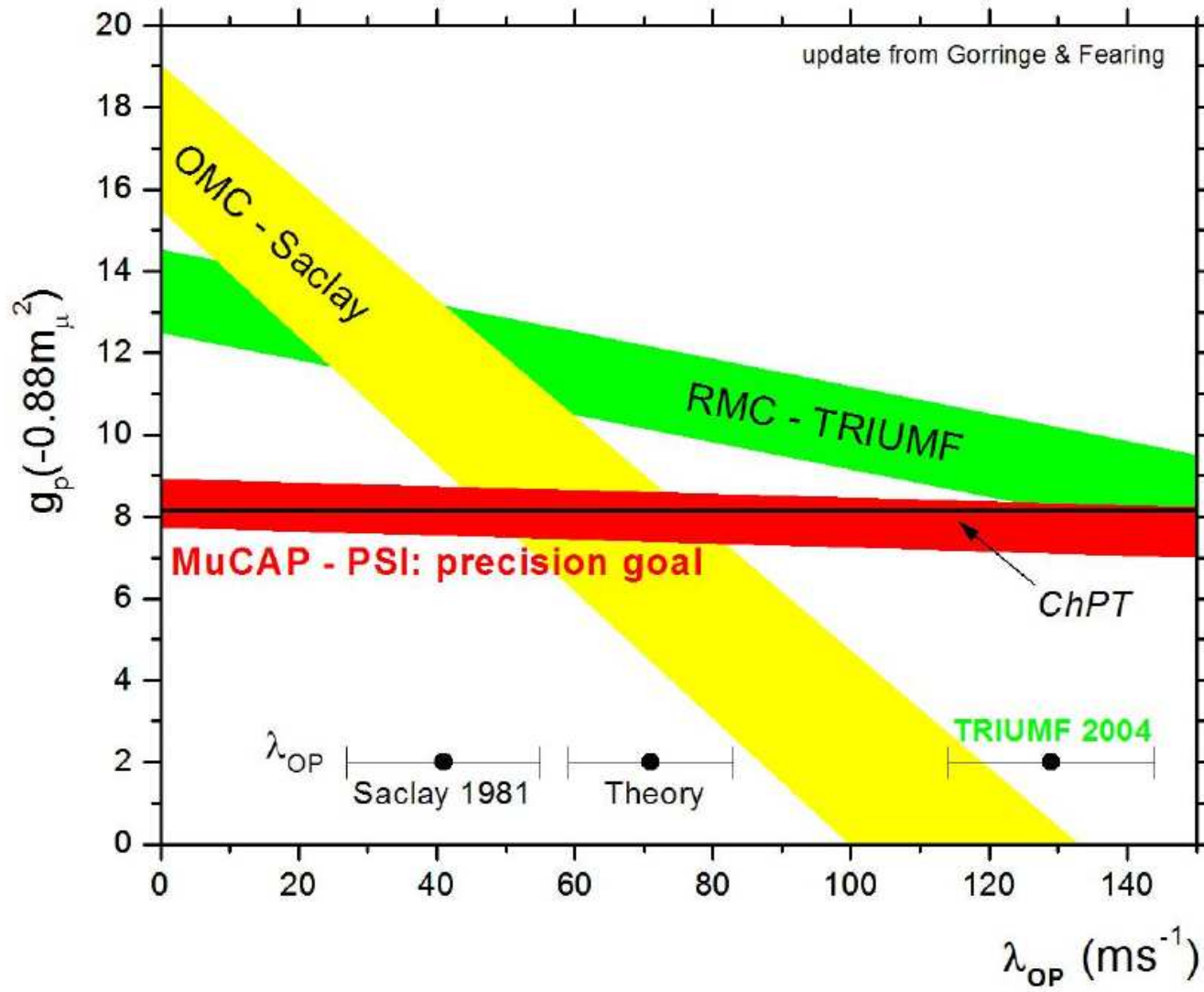
✓ Radiative muon capture (RMC)

$$\mu^- + p \rightarrow \nu_\mu + n + \gamma \quad \text{Branching Ratio : } \sim 10^{-8}$$

- ◇ Count photons > 60 MeV
- ◇ q^2 closer to pion pole: enhances sensitivity to g_p

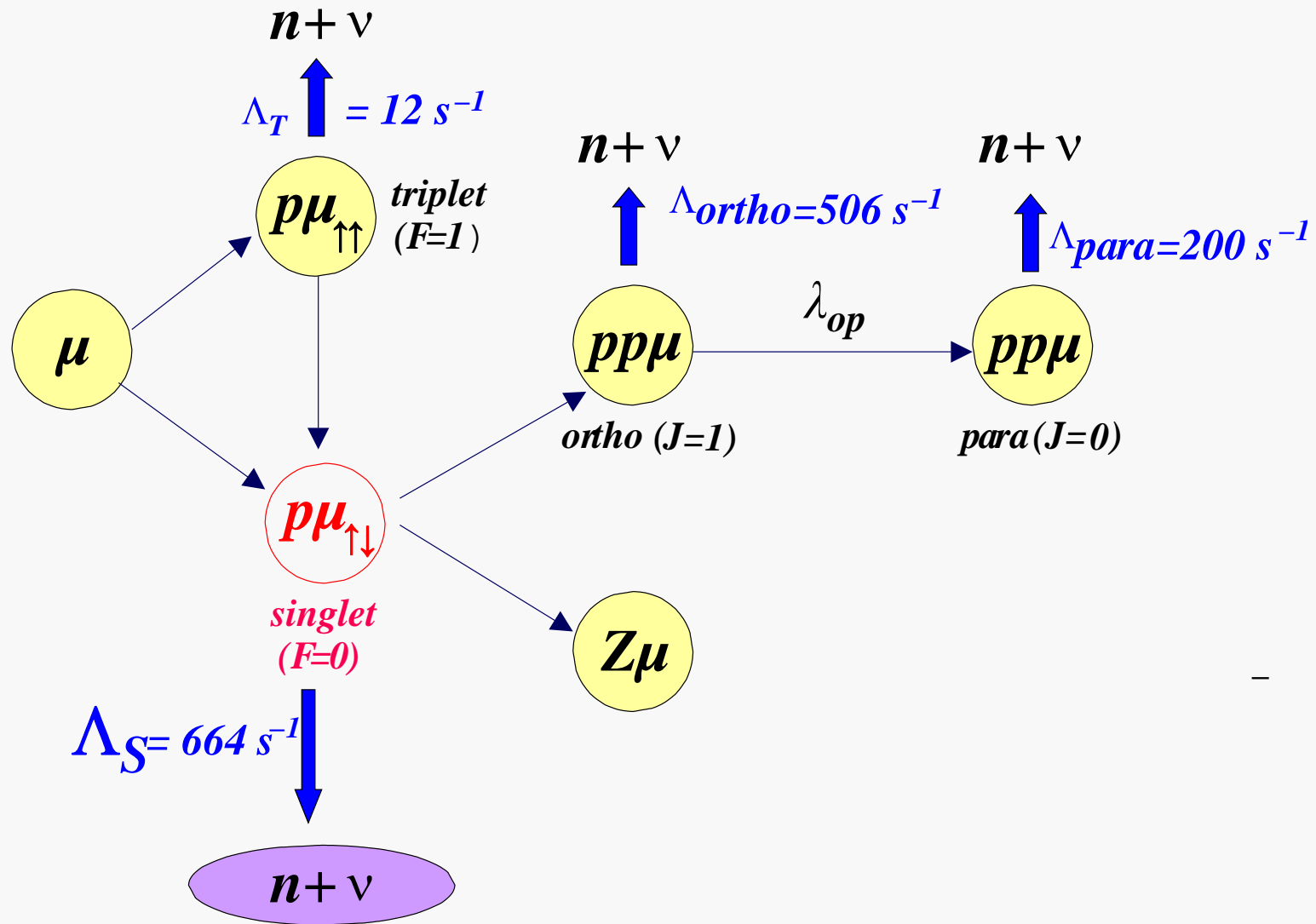
✓ Others: capture in nuclei, ...

Experimental puzzle



Cannot simultaneously reconcile experiment and theory for g_p and λ_{op} !

What is λ_{op} ?



How is MuCap a better experiment?

- ✓ Molecular effects
 - ◇ Reduce density: gas instead of liquid target.
- ✓ High- Z impurities capture
 - ◇ Minimize impurity (~ 0.01 ppm): Pd filter, Zeolite trap, circulation.
- ✓ Transfer to deuterium
 - ◇ Ultra pure protium (< 0.5 ppm)
- ✓ Muons stop in walls
 - ◇ Track every muon to its final position.
 - ◇ Require fiducial volume.
- ✓ Usual lifetime experiment concerns
 - ◇ overlapping pulses,
 - ◇ μ -e correlations, etc.
- ✓ Statistics
 - ◇ Make a 10 ppm lifetime measurement for both μ^- and μ^+ (i.e., collect 10^{10} of each)

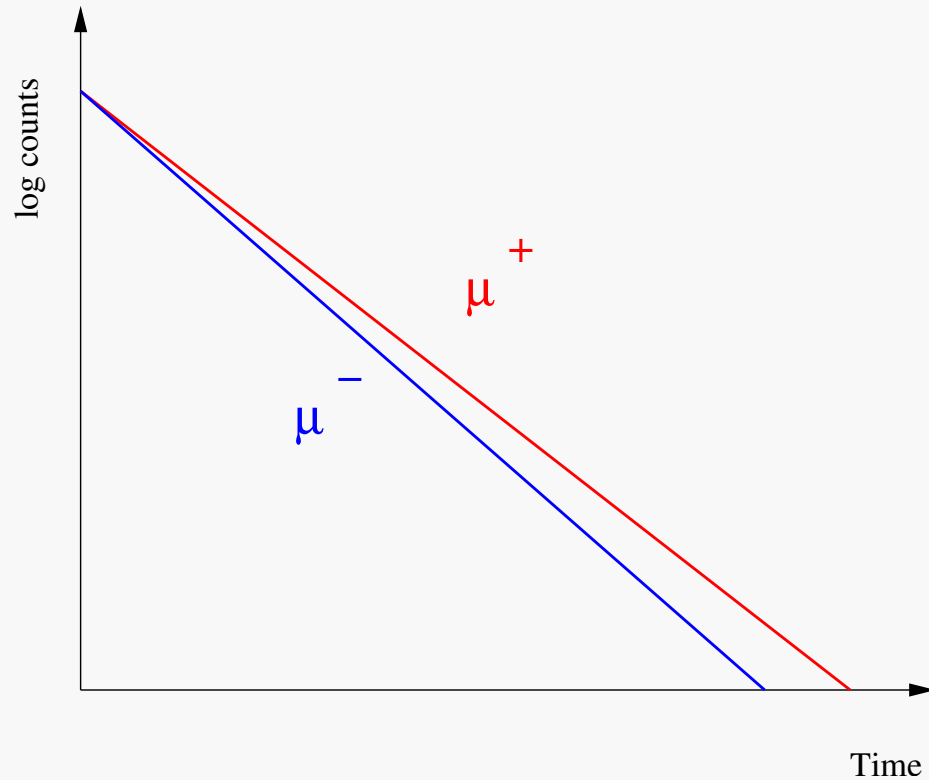
Principle: Comparison of Lifetimes

$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

$$\tau = 2.19703 \mu\text{s}$$

$$\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu \quad \text{BR:99.85\%}$$

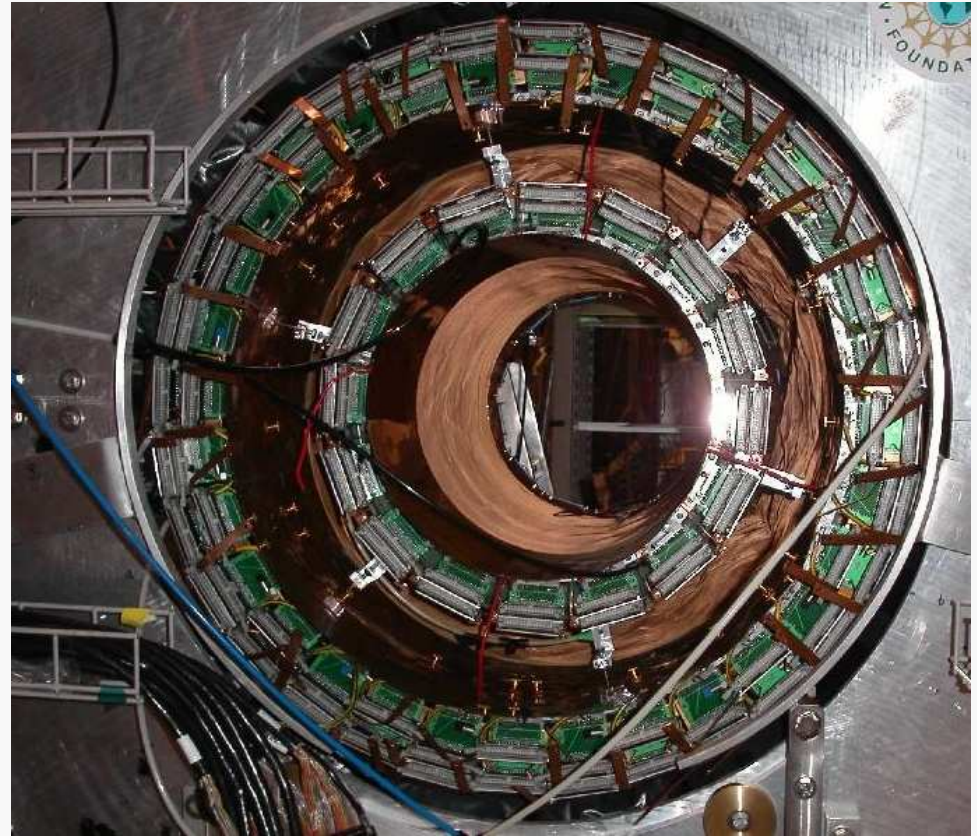
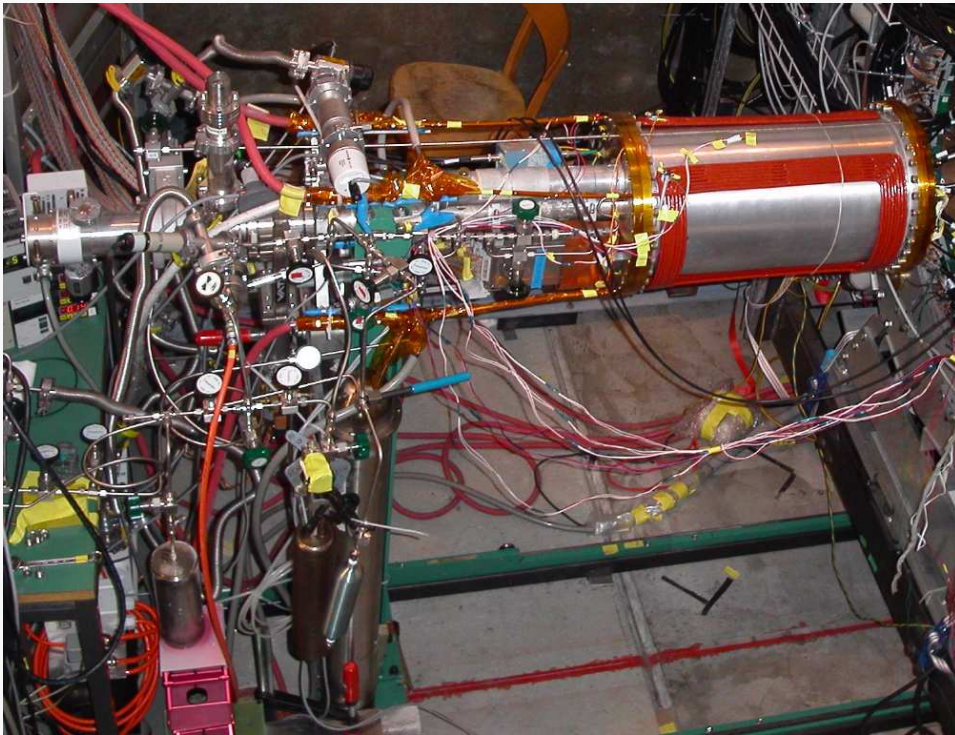
$$p\mu^- \rightarrow n + \nu_\mu \quad \text{BR:0.15\%}$$



$$\Lambda_S = \frac{1}{\tau_{\mu^-}} - \frac{1}{\tau_{\mu^+}}$$

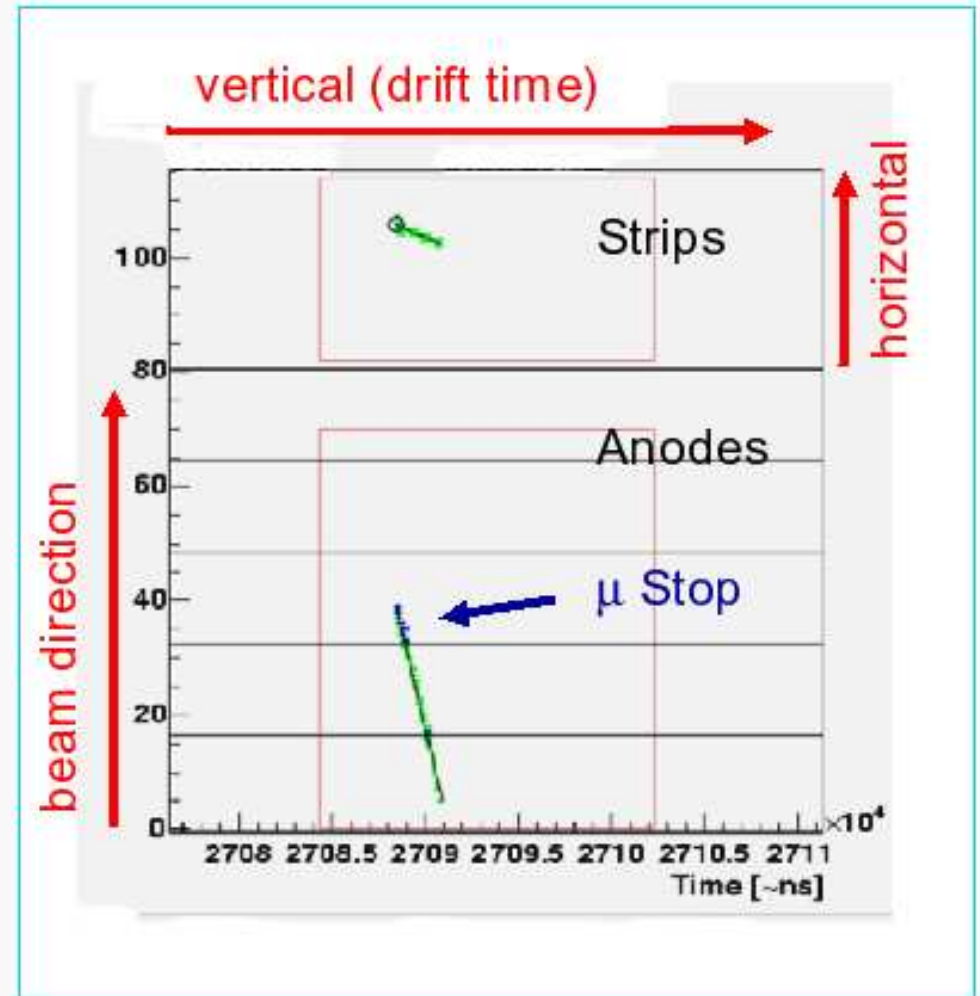
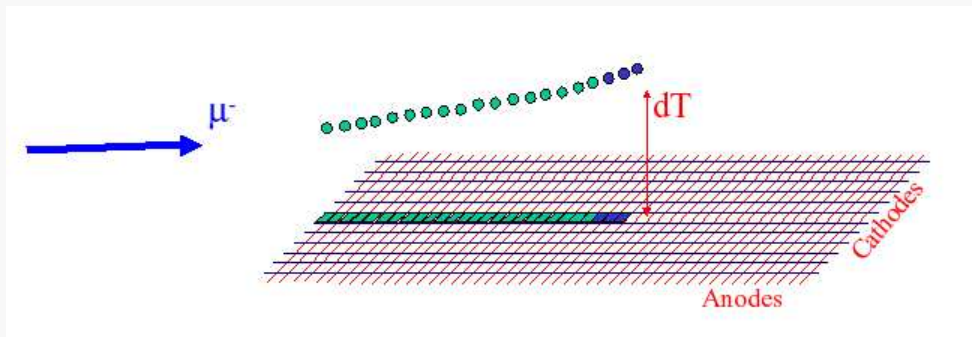
required precision: $\frac{\Delta\tau_{\mu^\pm}}{\tau_{\mu^\pm}} = 10^{-5}$

MuCap

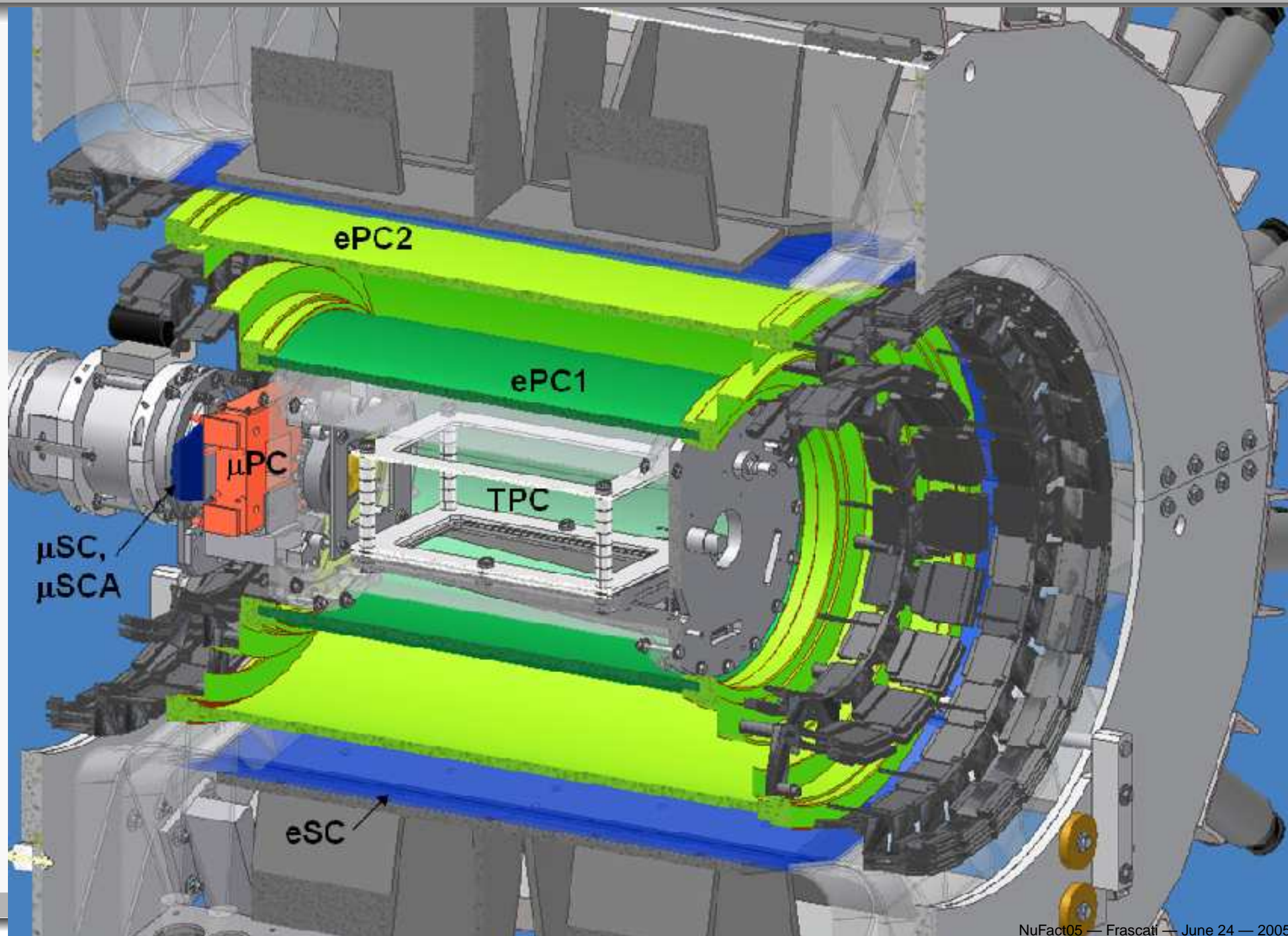


Experimental goal:
measure τ_{μ^-} and τ_{μ^+} to 10^{-5}

TPC: Active stopping target: 10 bar Protium

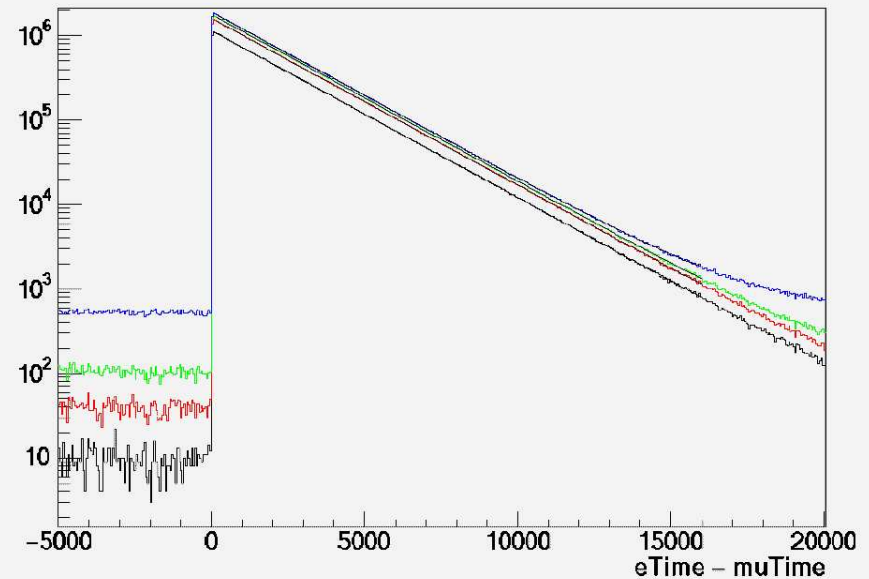
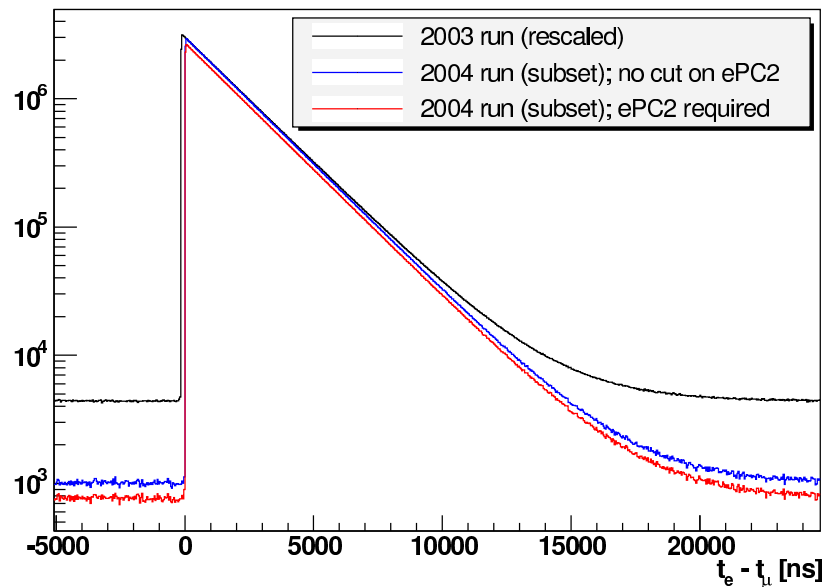


MuCap Detectors

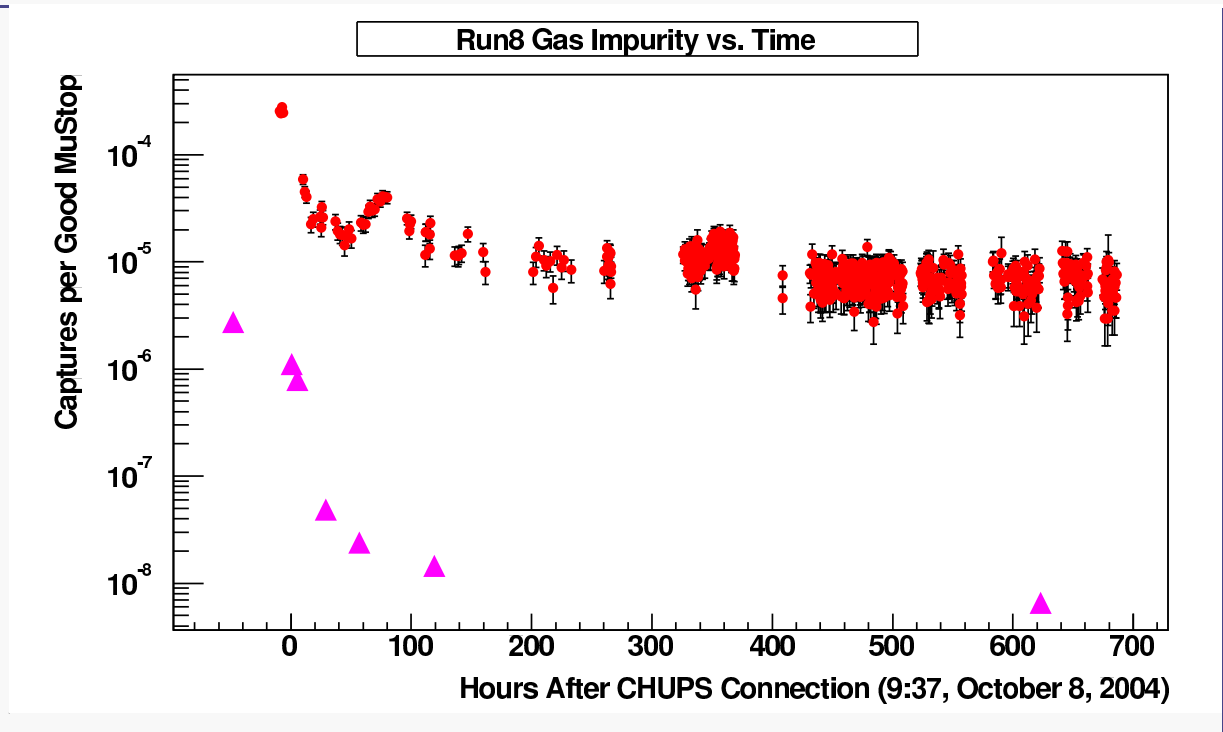
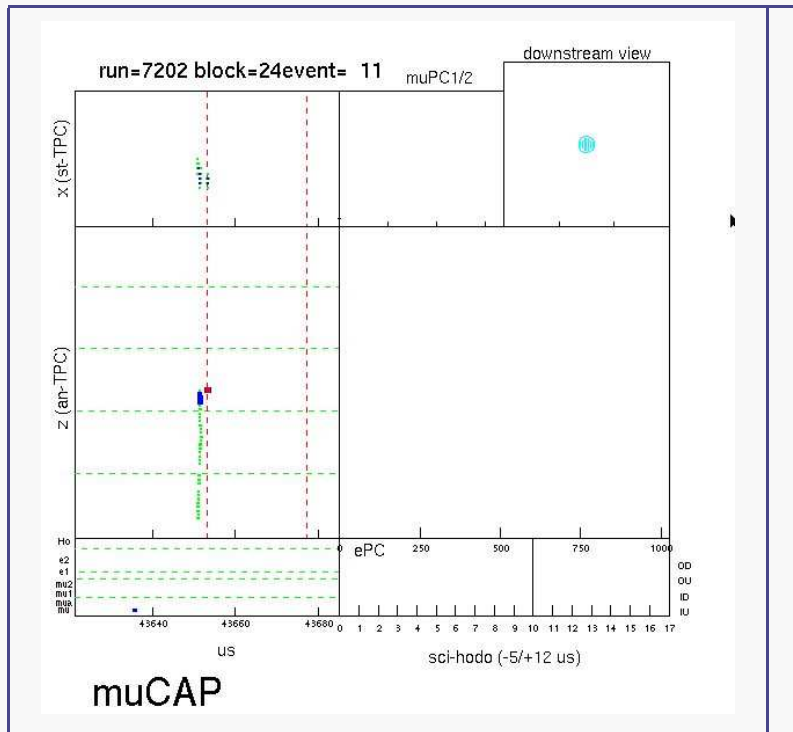


MuCap Fall 2004 Achievements

- ✓ full experiment ran stably for several weeks
- ✓ collected 2.5×10^9 statistics $\Rightarrow \Lambda_S = 2 - 3\%$

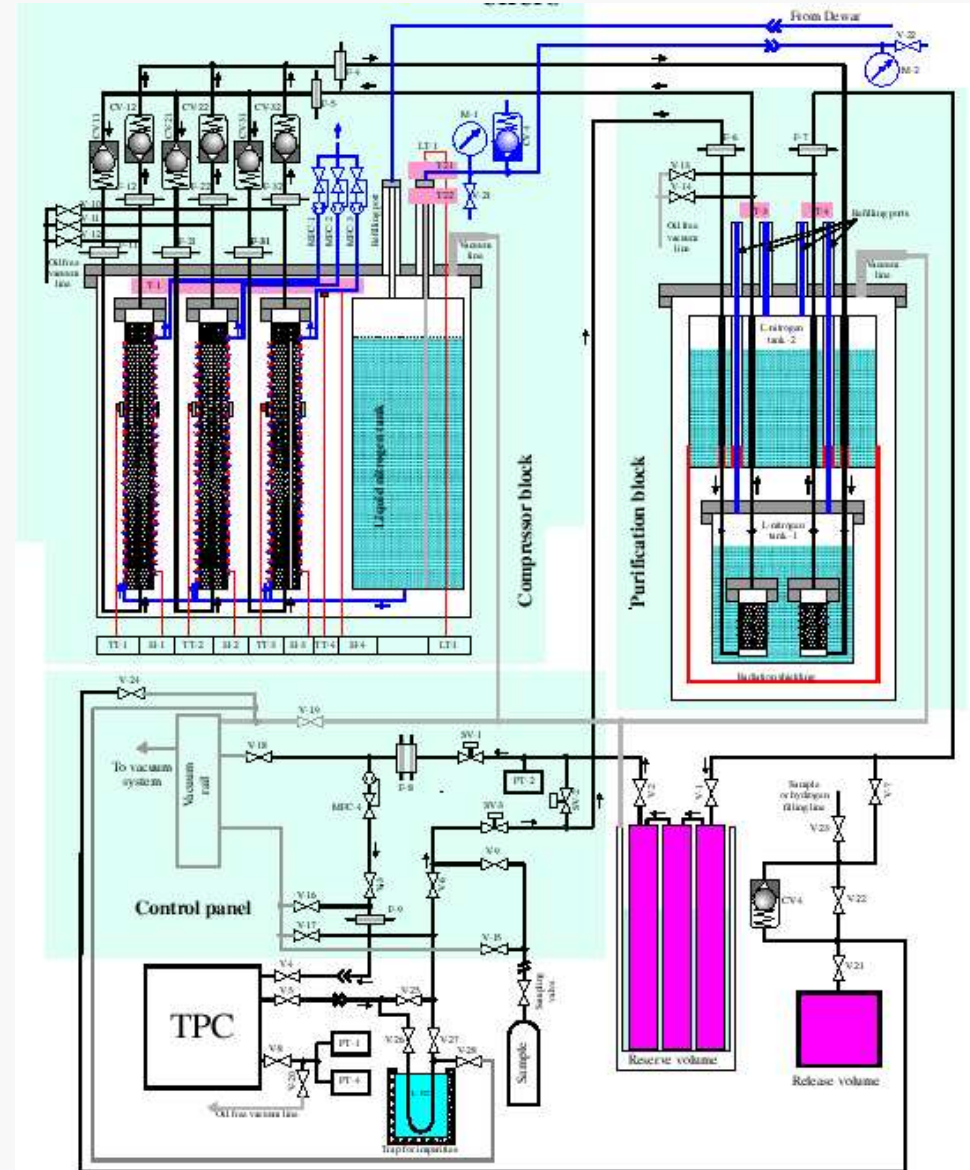
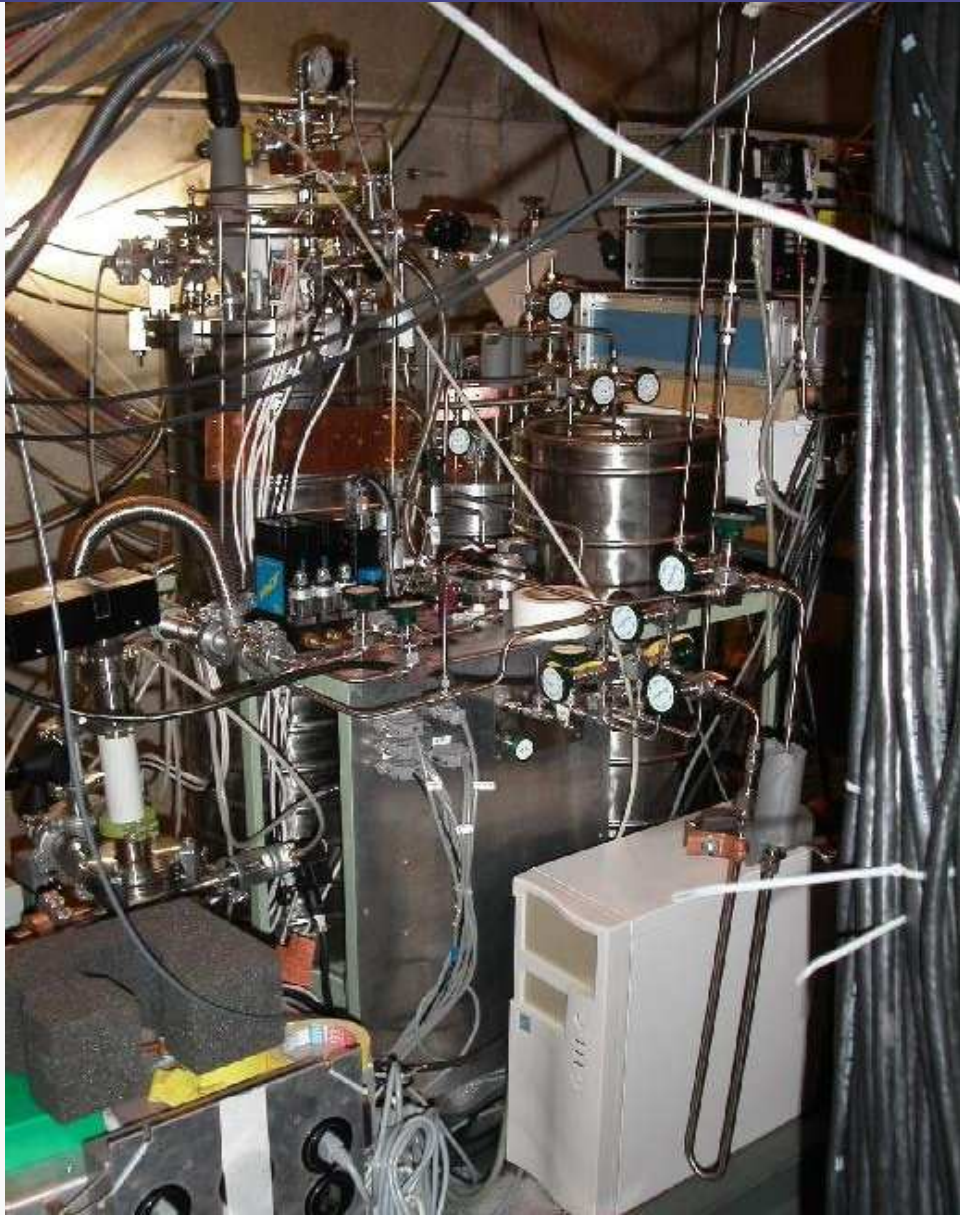


High- Z impurity monitoring



- ✓ Purity at 70 ppb established.
- ✓ 1–2 ppm Deuterium.

Continuous High-Z Cleaning



MuCap Future plans

✓ 2005:

- ◇ Improve gas circulation system: 70 ppb \rightarrow 10 ppb
- ◇ TPC sensitive to Alvarez muons: Increase voltage
- ◇ Collect about 8×10^9 stops
- ◇ Test kicker mode: toward higher statistics

✓ 2006:

- ◇ Final production run to collect full proposed 10^{10} statistics (μ^+ and μ^-): Λ_s to 1%, g_P to $\sim 7\%$.

✓ beyond:

- ◇ “Muon-on-request” mode with MuLan kicker to collect higher statistics: Λ_s to 0.3%, g_P to $\sim 3\%$.
- ◇ Measure muon capture rate in deuterium (MUD):
 - \rightarrow Test of two-body currents
 - \rightarrow Determine $L_{1,A}$; calibrate neutrino experiments and the Standard Solar Model

Collaborations

	MuLan	MuCap
University of California, Berkeley (USA)	✓	✓
Boston University (USA)	✓	✓
University of Illinois at Urbana-Champaign (USA)	✓	✓
James Madison University (USA)	✓	
Technische Universität München (Germany)		✓
University of Kentucky (USA)	✓	✓
Université Catholique de Louvain (Belgium)		✓
Petersburg Nuclear Physics Institute (Russia)		✓
Paul Scherrer Institute (Switzerland)	✓	✓