LEAP2016

Measurement of muonium hyperfine structure at J-PARC

Introduction:	What is muonium HFS?
Procedure:	experimental procedure of muonium HFS exp.
Apparatus:	RF system, gas system,magnetic field,detectors
Measurement:	first trial of the measurement

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Muonium Spectroscopy Experiment Using Microwave

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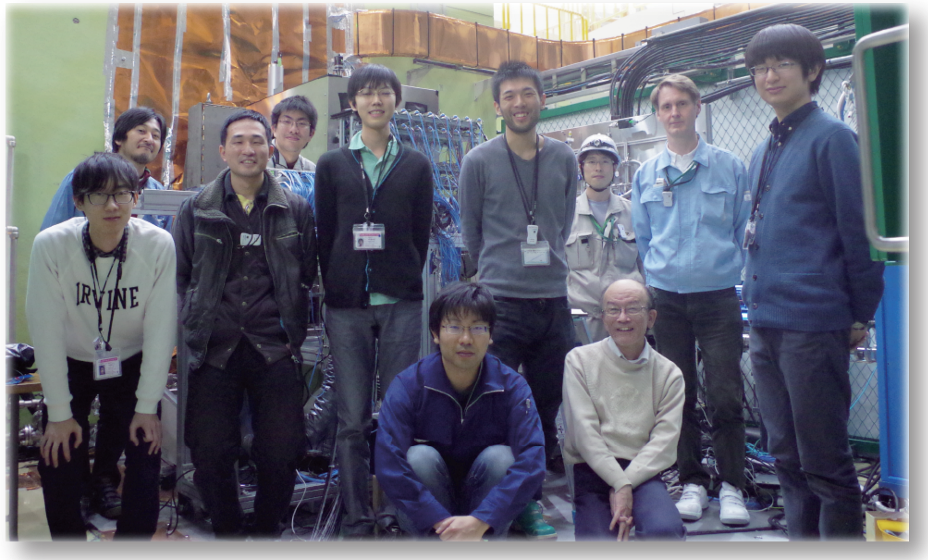
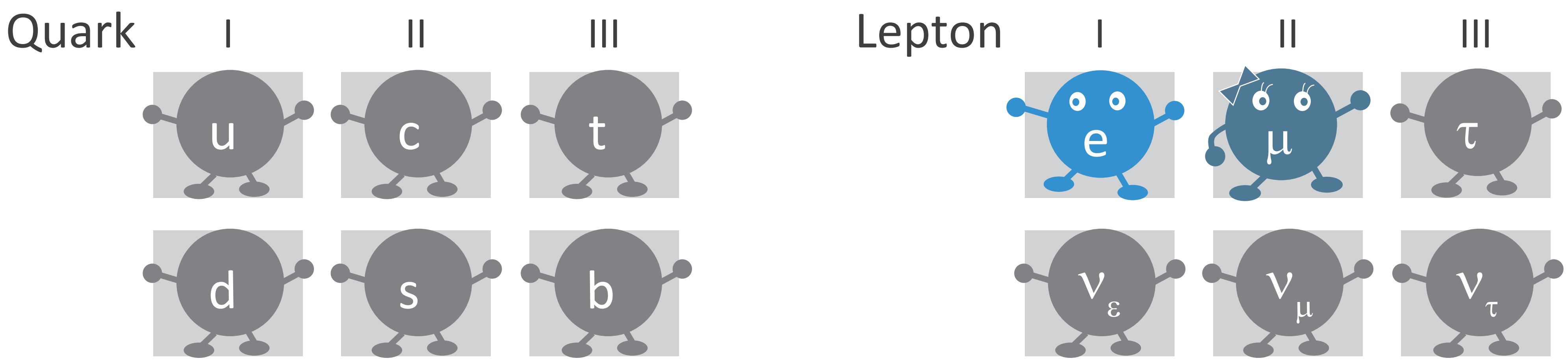
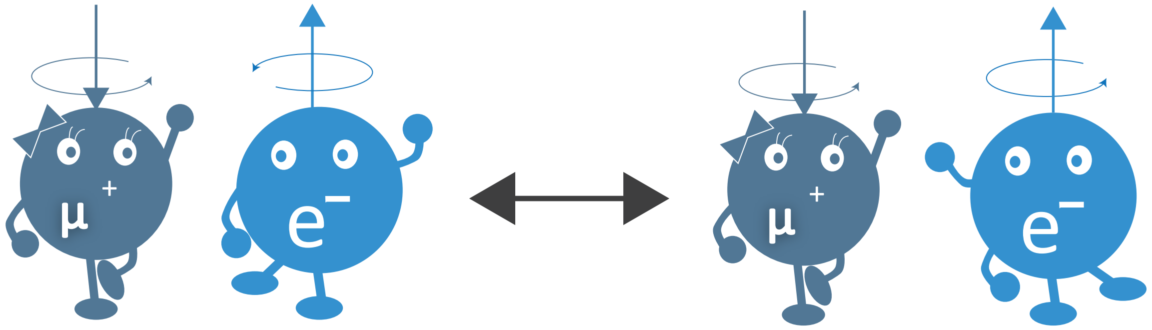


HYPERFINE SPLITTING OF MUONIUM

Muon is an elementary particle belonging to second generation of the family of Leptons



Muonium is a hydrogen-like bound state of a muon and an electron.
We aim to measure its hyperfine splitting at the precision of 9 digits.



$$\Delta\nu_{\mathrm{Mu}}^{\mathrm{ex}} = 4.463302765(53)\ \mathrm{GHz}\ (12\ \mathrm{ppb})$$

W. Liu et al., PRL, 82, 711 (1999)

↓

at the level of a ppb precision.

HYPERFINE SPLITTING OF MUONIUM

measurement in zero field

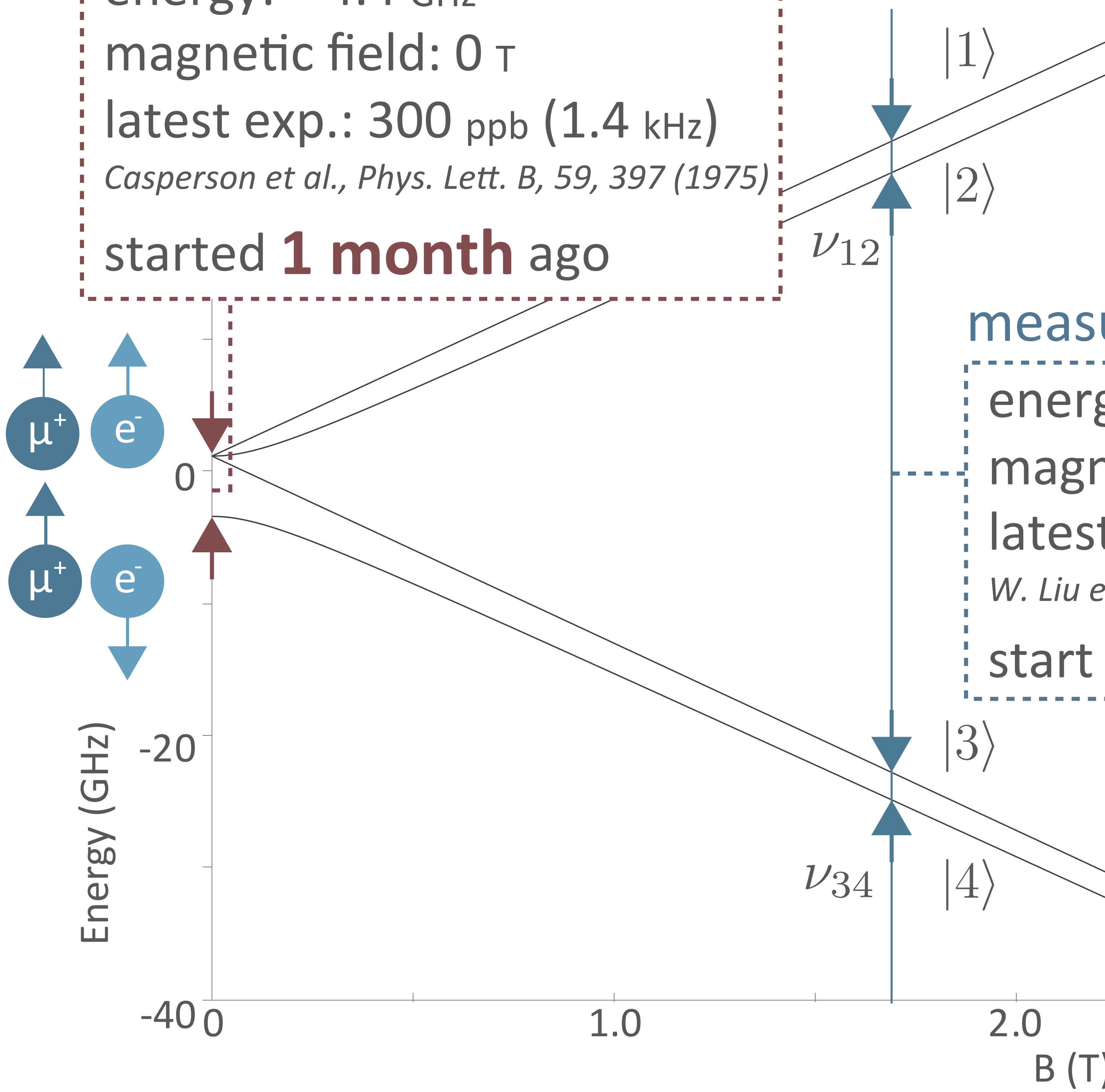
energy: ~4.4 GHz
magnetic field: 0 T
latest exp.: 300 ppb (1.4 kHz)
Casperson et al., Phys. Lett. B, 59, 397 (1975)

started **1 month** ago

measurement in high field

energy: ~1.9 GHz & ~2.6 GHz
magnetic field: ~1.7 T
latest exp.: 12 ppb (53 Hz)
W. Liu et al., PRL, 82, 711 (1999)

start in 2017



MOTIVATION

zero field experiment

directly measurement of muonium HFS in zero field.

testing bound QED theory

$$\nu_{HFS}(\text{exp.}) = 4\ 463.302\ 765(53)\ \text{MHz}\quad [12\ \text{ppb}]$$

↔

$$\nu_{HFS}(\text{theory.}) = 4\ 463.302\ 891(272)\ \text{MHz}\quad [63\ \text{ppb}]$$

high field experiment

measurement of ν_{12} and ν_{34} .

$$\Delta\nu_{\mathrm{M}}^{\mathrm{ex}} = \nu_{12} + \nu_{34}$$

$$\frac{\mu_\mu}{\mu_\mathrm{p}} = \frac{\Delta\nu_{\mathrm{Mu}}^2 - \nu^2\left(f_\mathrm{p} + 2s_\mathrm{e} f_\mathrm{p} \nu_{f_\mathrm{p}}\right)}{4s_\mathrm{e} f_\mathrm{p}^2 - 2f_\mathrm{p}\nu(f_\mathrm{p})}\left(\frac{g_\mu(\mathrm{Mu})}{g_\mu}\right)^{-1}$$

determine fundamental values

$$\mu_\mu/\mu_p = 3.18334524(37)$$
$$m_\mu/m_\mathrm{e} = 206.768276(24)$$

g-2 experiment

from g-2 exp.: 560 ppb(BNL) → ~100 ppb(J-PARC)

$$g - 2 = \frac{R}{\mu_\mu/\mu_p - R}$$

from MuHFS exp. 170 ppb(LAMPF)

I-37 Tsutomu Mibe

MOTIVATION

■ proton radius puzzle

- introduced in I-13 J. D. Tasson
- zemach radius can be obtained by comarpsion of hyperfine splitting of muonium and hydrogen

S. J. Brodsky, C. E. Carlson, J. R. Hiller, and D. S. Hwang. Erratum: Constraints on Proton Structure from Precision Atomic-Physics Measurements. Physical Review Letters, 94:169902, Apr 2005.

■ testing CPT and Lorentz invariance

- introduced in I-11 R. Pohl
- measurement of sidereal variation

V. W. Hughes, M. G. Perdekamp, D. Kawall, W. Liu, K. Jungmann, and G. z. Put-litz. Test of CPT and Lorentz Invariance from Muonium Spectroscopy. Physical Review Letters, 87:111804, Aug 2001.

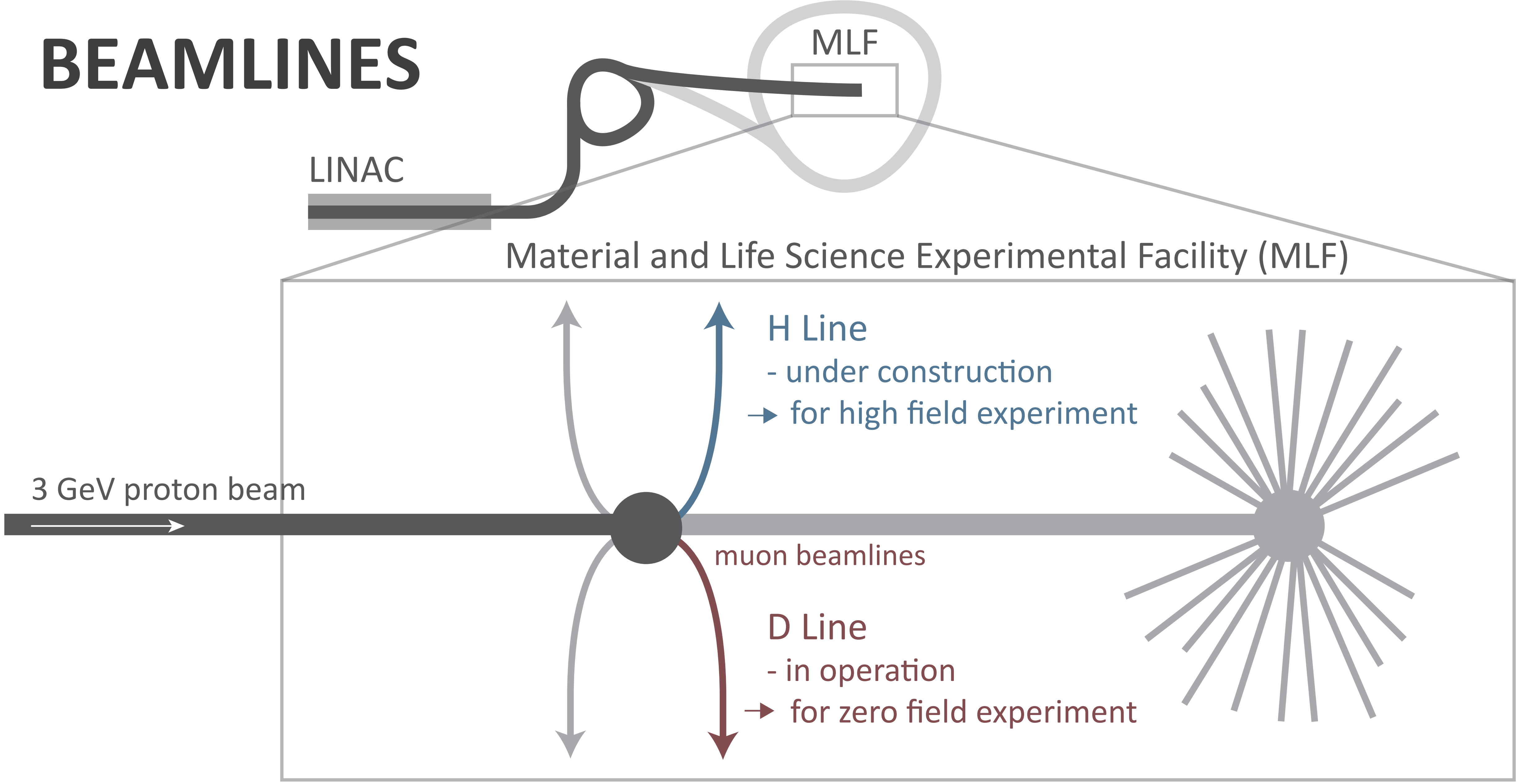
■ new light particle search

S. G. Karshenboim. Constraints on a long-range spin-dependent interaction from precision atomic physics. Physical Review D, 82:113013, Dec 2010.

S. G. Karshenboim and V. V. Flambaum. Constraint on axionlike particles from atomic physics. Physical Review A, 84:064502, Dec 2011.

S. G. Karshenboim, D. McKeen, and M. Pospelov. Constraints on muon-speci�c dark forces. Physical Review D, 90:073004, Oct 2014.

BEAMLINES



beamline in LAMPF (DC beam)

$$1 \times 10^7 \ \mu^+/s \times \frac{3.9}{3\,9 + 9\,9}$$

beam intensity — chopping ratio

$$\approx 2.8 \times 10^6 \ \mu^+/s$$

→

H Line (pulsed beam)

$$1 \times 10^8 \ \mu^+/s \times 1$$

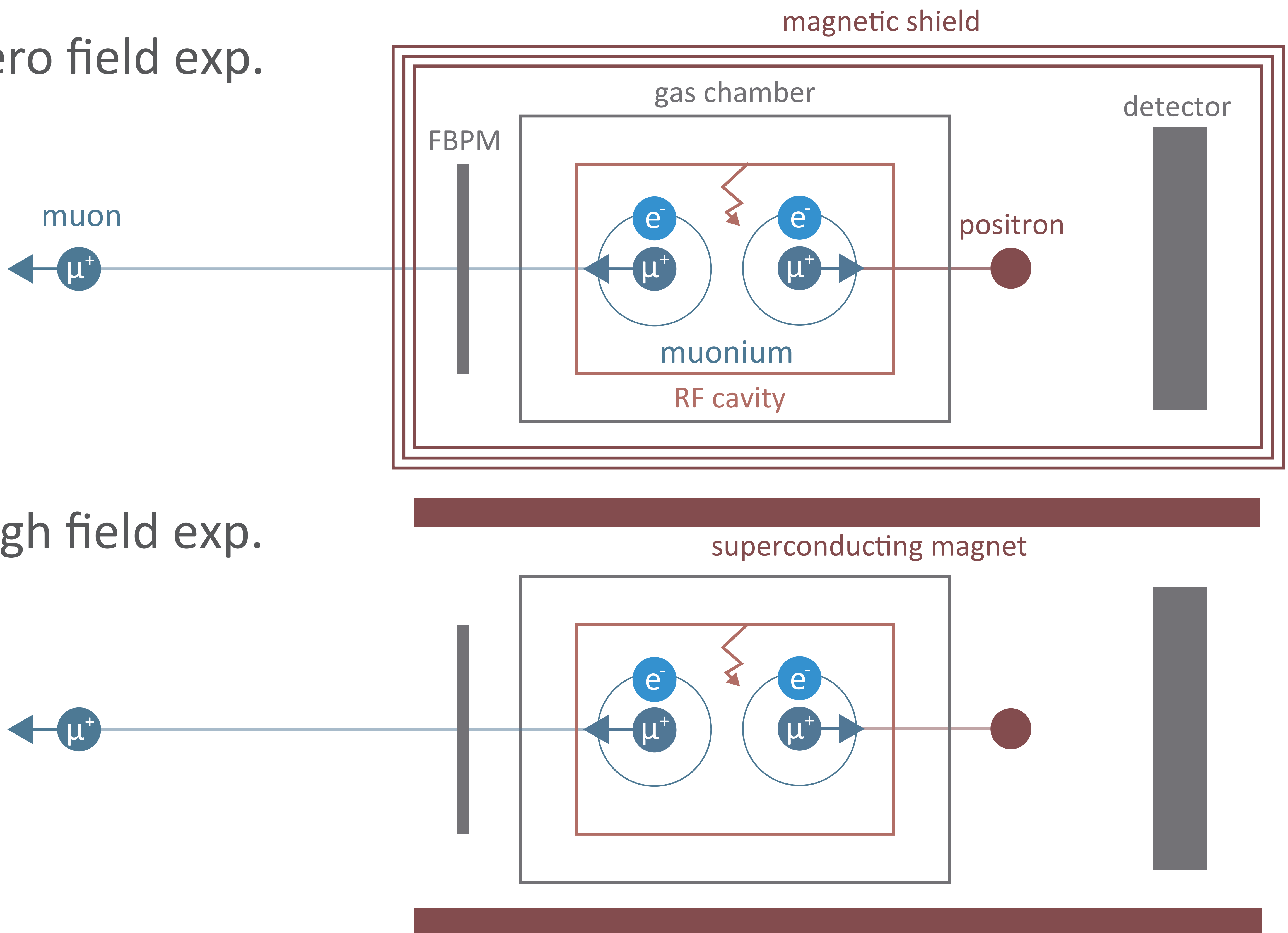
beam intensity — pulsed beam

$$\approx 1 \times 10^8 \ \mu^+/s$$

EXPERIMENTAL PROCEDURE

zero field exp.

high field exp.



ESTIMATION OF UNCERTAINTIES

high field experiment

μ_μ/μ_p		ν_{HF}
120 ppb	previous exp.	53 Hz
15 ppb	statistics	5 Hz
48 ppb	magnetic field	11 Hz
19 ppb	gas pressure	9 Hz
11 ppb	gas temperature	4 Hz
17 ppb	RF field fluctuation	4 Hz
9 ppb	RF power	3 Hz
19 ppb	muonium distribution	4 Hz

high intensity muon beam

→ measurement for 100 days

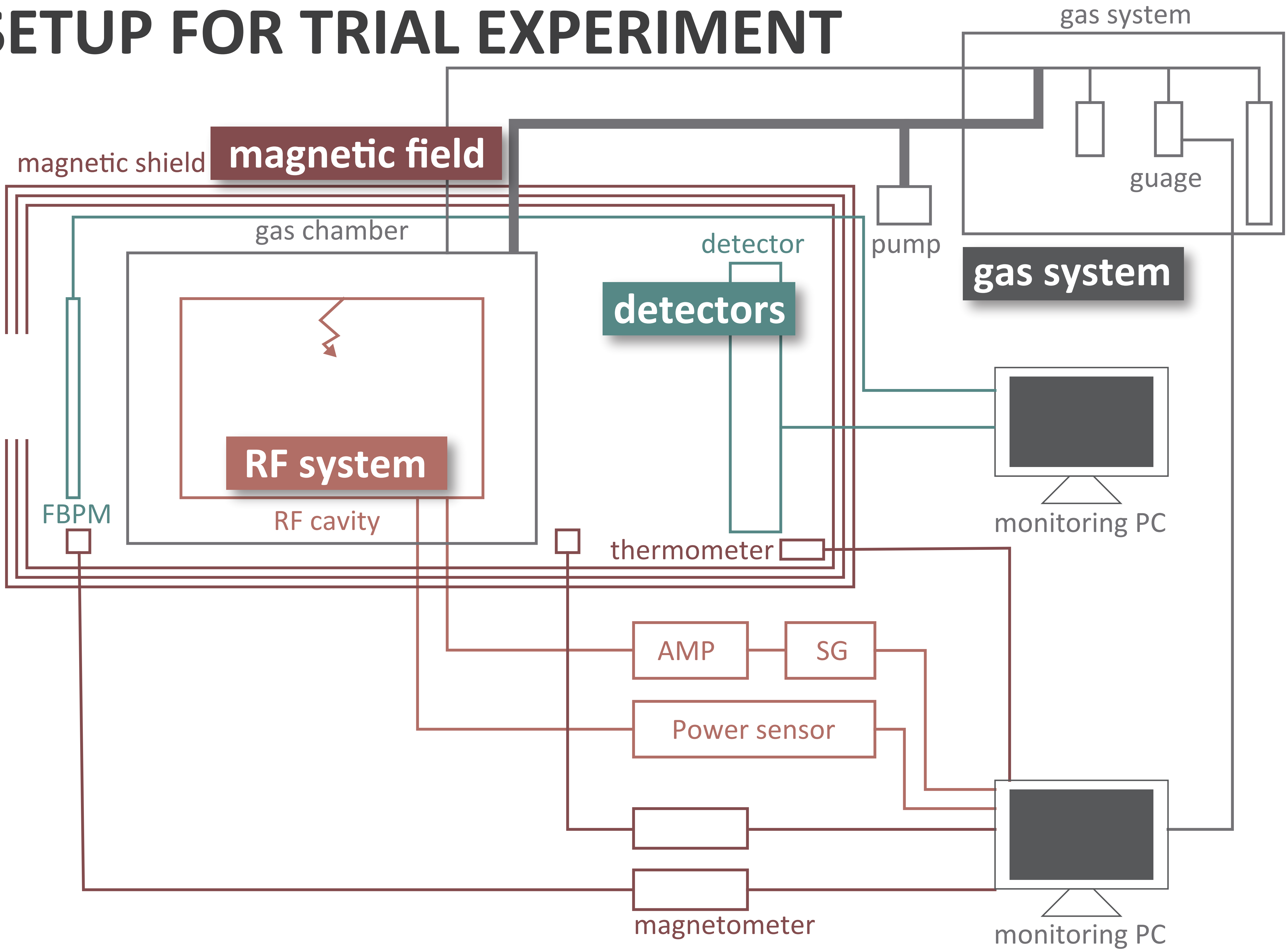
=

10 times improvement of statsitical uncertainty.

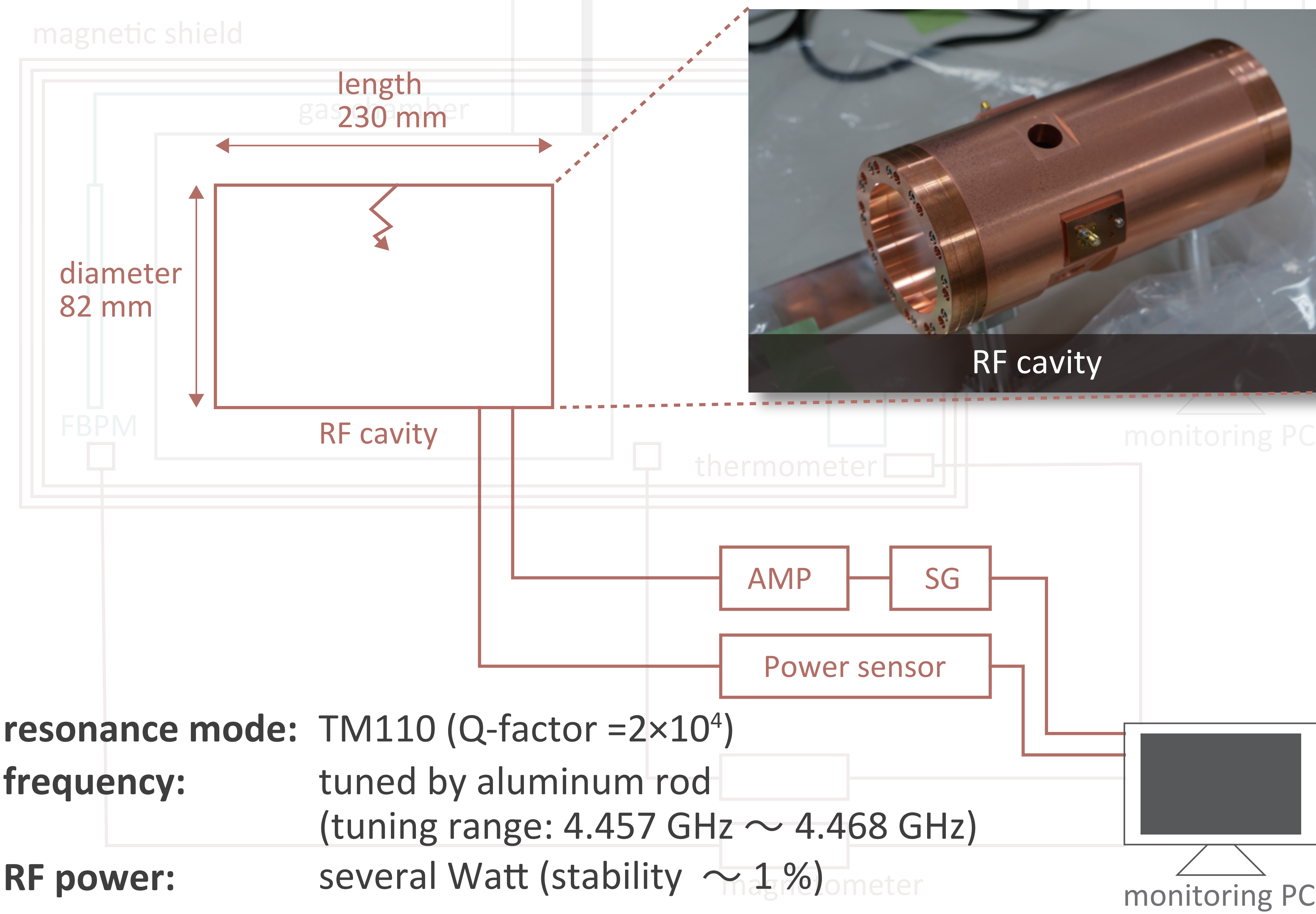
zero field experiment

	ν_{ZF}
previous exp.	1400 Hz
statistics	20 Hz
magnetic field	32Hz
gas pressure	9 Hz
gas temperature	5 Hz
RF field fluctuation	6 Hz
variation of RF power	3 Hz
muonium distribution	4 Hz

SETUP FOR TRIAL EXPERIMENT



SETUP (RF SYSTEM)

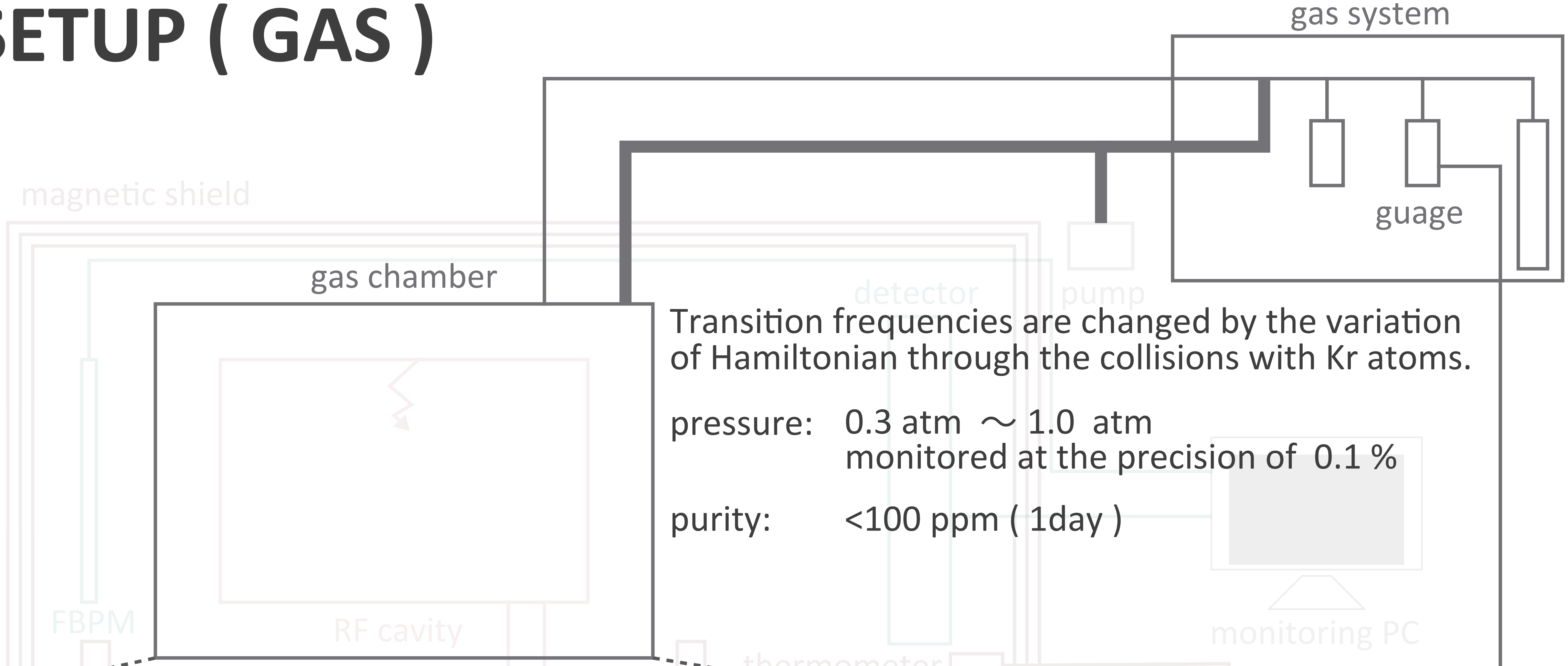


resonance mode: TM110 (Q-factor $=2\times10^4$)

frequency: tuned by aluminum rod (tuning range: 4.457 GHz ～ 4.468 GHz)

RF power: several Watt (stability ～1 %)

SETUP (GAS)



Transition frequencies are changed by the variation of Hamiltonian through the collisions with Kr atoms.

pressure: 0.3 atm ～ 1.0 atm
monitored at the precision of 0.1 %

purity: <100 ppm (1day)

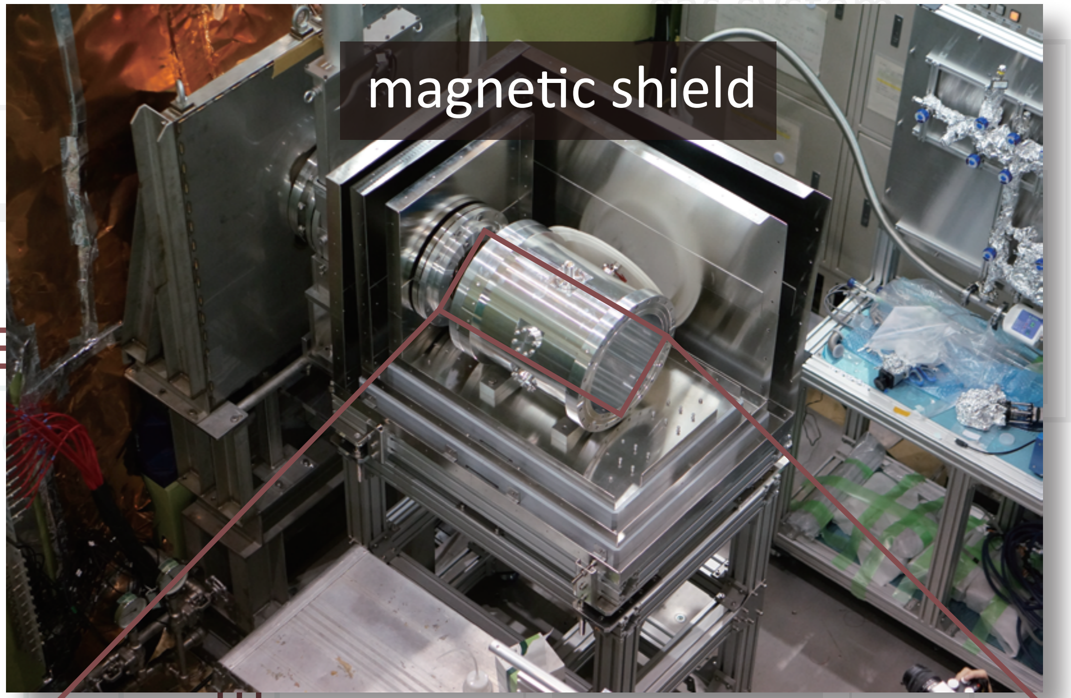

gas chamber

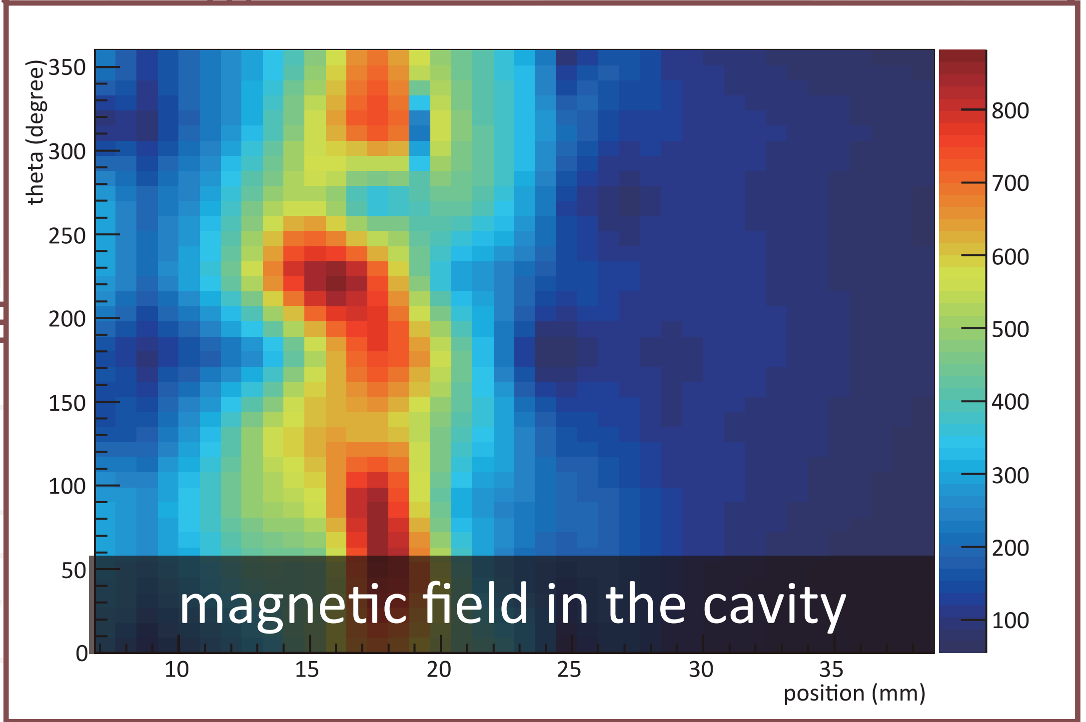
SETUP (MAGNETIC FIELD)

magnetic shield

magnetic shield
3 layers of permalloy plates (1.5 mmt)
magnetic field in the shield (~ 100 nT)

magnetometer
three-axis fluxgate magnetometers
precision: 10 nT

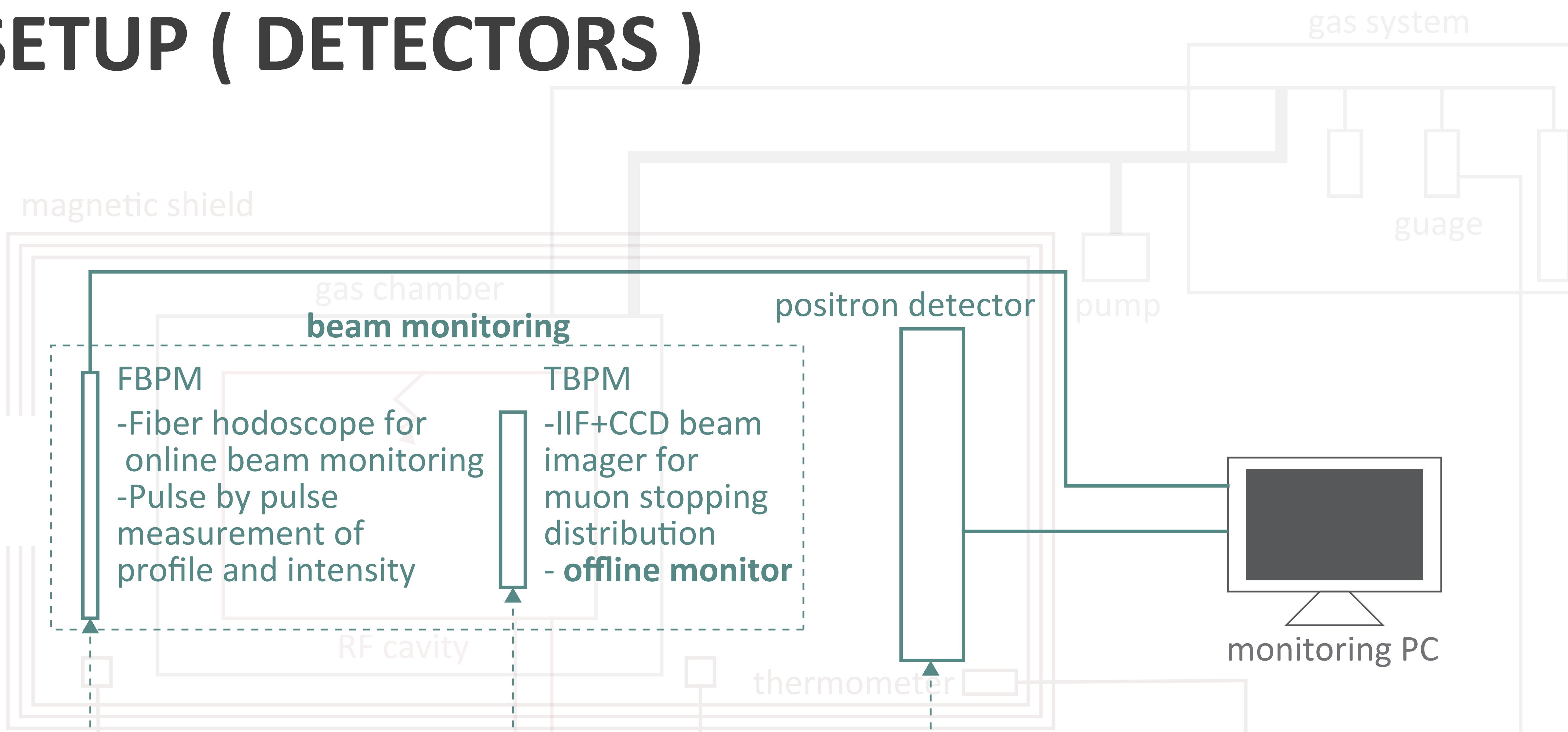


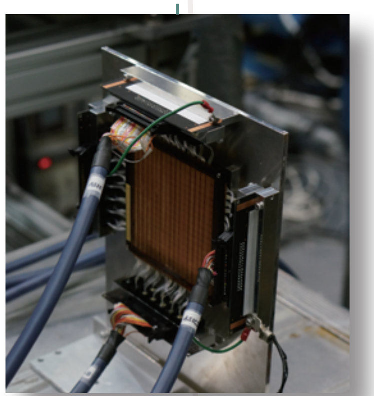


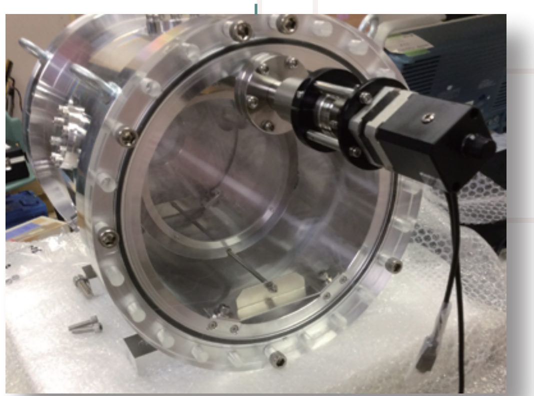
magnetometer

monitoring PC

SETUP (DETECTORS)







positron detector
- Spectrometer for HFS measurement
- Segmented scintillator+SiPM
- rate: 3% loss at 3MHz.

P-12 Yasuhiro Ueno @ poster session

P-11 S.Kanda @ poster session

TRIAL EXPERIMENT IN ZERO FIELD

- Trial experiment is held in Feb 2016.
- under analyzing.

All systems are worked.
- stability of the gas pressure and its purity are enough for the exp.
- Q-factor of the cavity and the stability of the RF power satisfy requirements.

No significant sign of the resonance.
- only 30 hours of beamtime is available
- insufficient for beam tuning, detector adjustment, measurement of muon stop dist and resonance test....

schedule of Feb. 2016 experiment.

magnetic field scan(24 hours)

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baking for gas chamber(12 hours)

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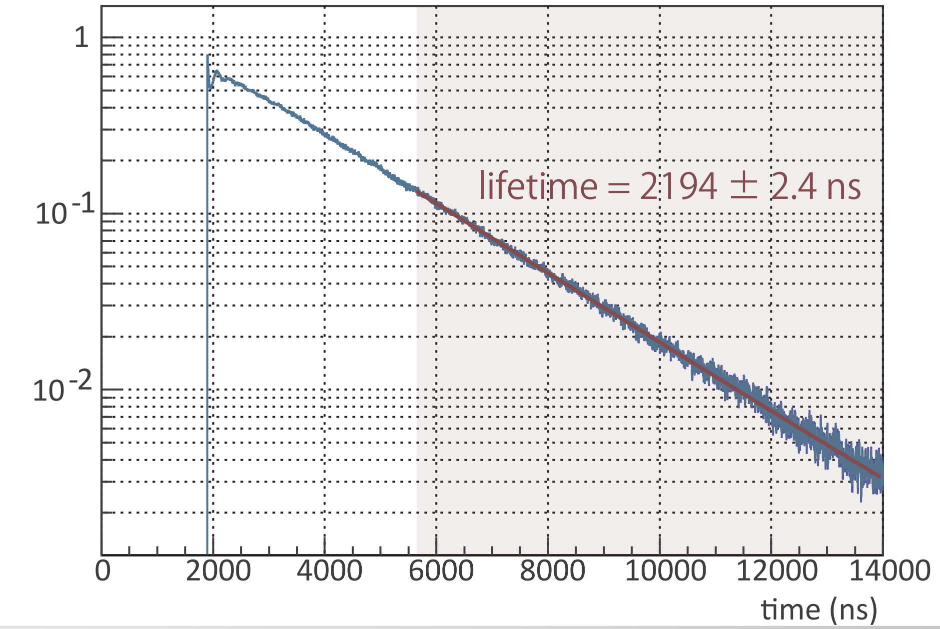
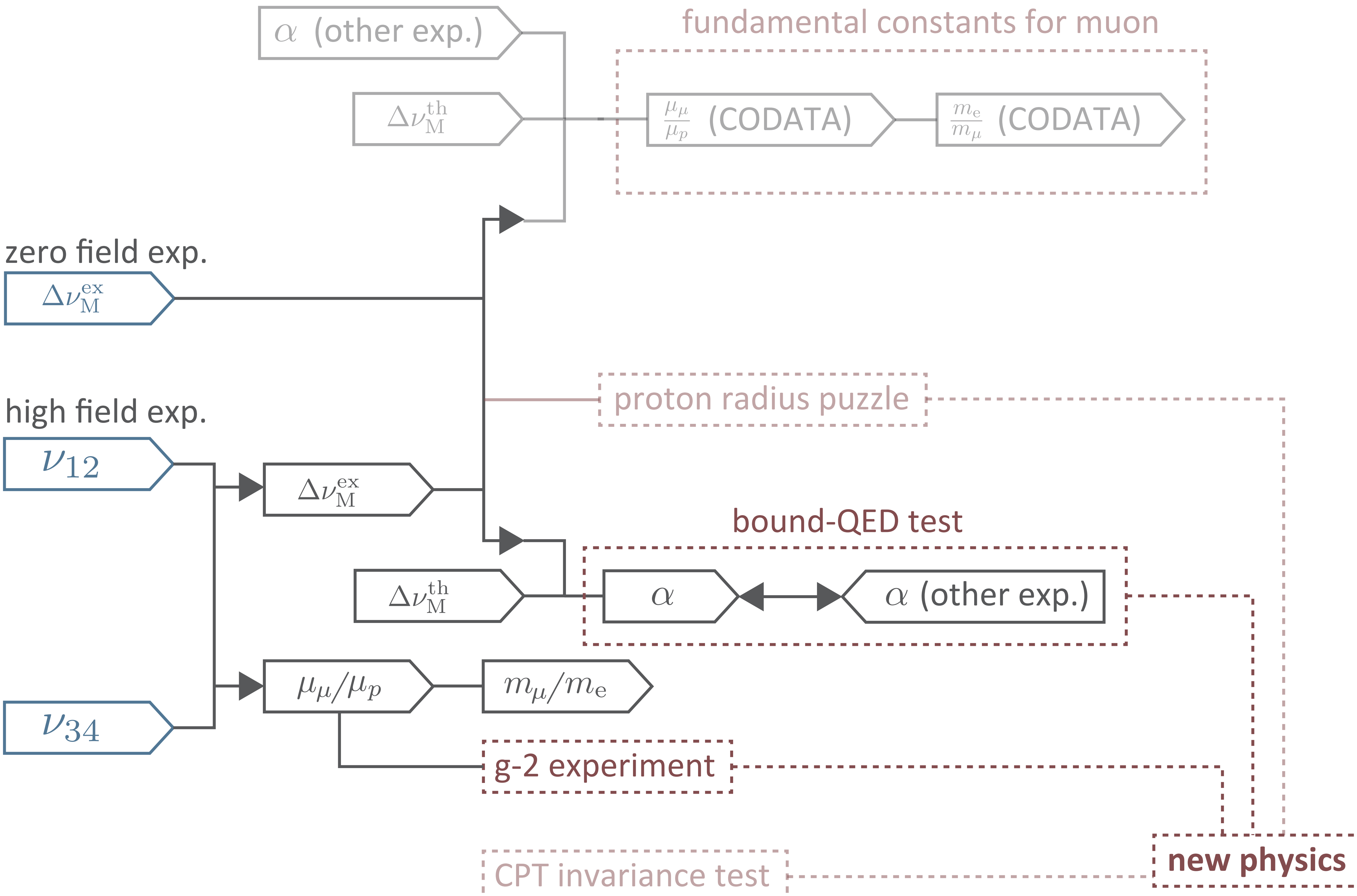
beamtime(**30 hours**)
> 200 kW operation in D2@J-PARC

coincidence hit (RF off)



SUMMARY

- We plan to start measurement of MuHFS in zero field and high field.
- First trial measurement of MuHFS in zero field is performed in last month.
- All systems (RF, gas, magnetic field, detectors) are worked.
- We have not obtained resonance line shape yet mainly because of statistics.
- We plan to be ensured several days of beamtime which is sufficient to improve latest experiment of zero field experiment at the beginning of next fiscal year.



α (other exp.)
fundamental constants for muon
$\Delta\nu_{\mathrm{M}}^{\mathrm{th}}$
$\frac{\mu_\mu}{\mu_p}$ (CODATA)
$\frac{m_e}{m_\mu}$ (CODATA)
zero field exp.
$\Delta\nu_{\mathrm{M}}^{\mathrm{ex}}$
proton radius puzzle
high field exp.
ν_{12}
$\Delta\nu_{\mathrm{M}}^{\mathrm{ex}}$
bound-QED test
$\Delta\nu_{\mathrm{M}}^{\mathrm{th}}$
α
α (other exp.)
ν_{34}
μ_μ/μ_p
m_μ/m_e
g-2 experiment
new physics
CPT invariance test