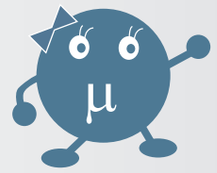
物理学会２０１６年春季大会



MuSEUM 実験のための磁気シールド、**RF** 系及びガスシステムの開発

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

東京大学、理研

田中香津生

RIKEN's Programs for Junior Scientists

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Muonium Spectroscopy Experiment Using Microwave

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19aAH-9 **19aAF-11** **19aAH-8**

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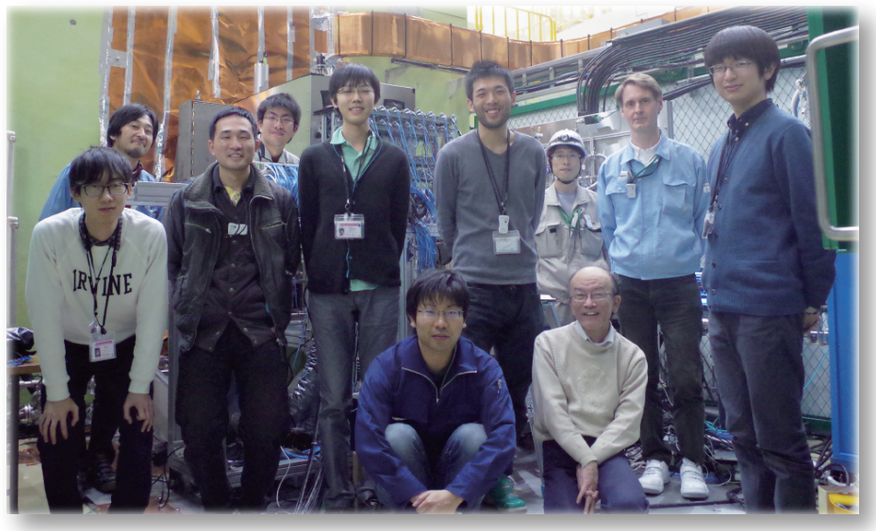
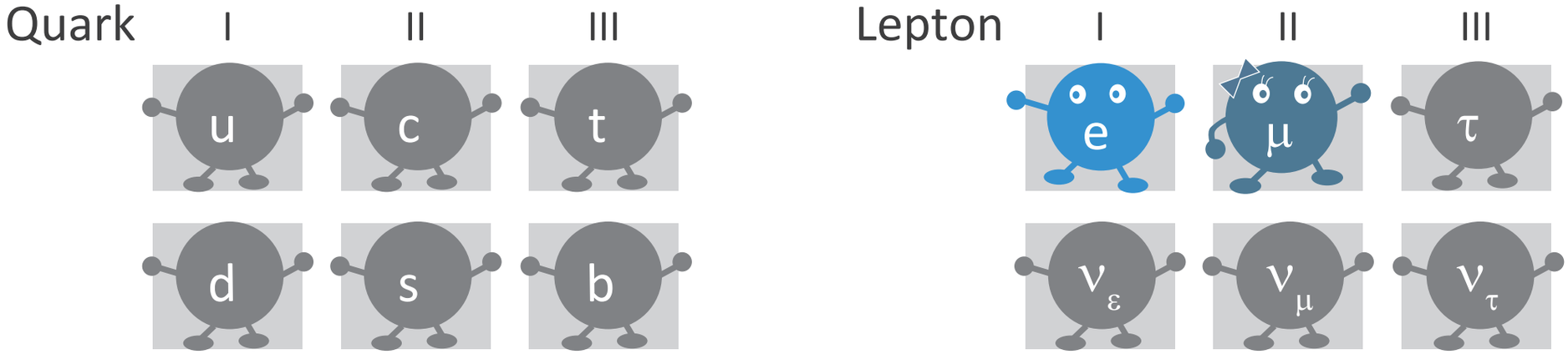
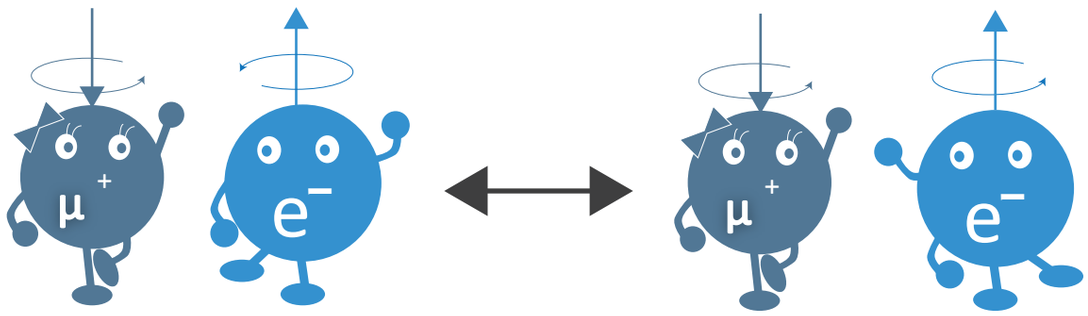


HYPERFINE SPLITTING OF MUONIUM

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.

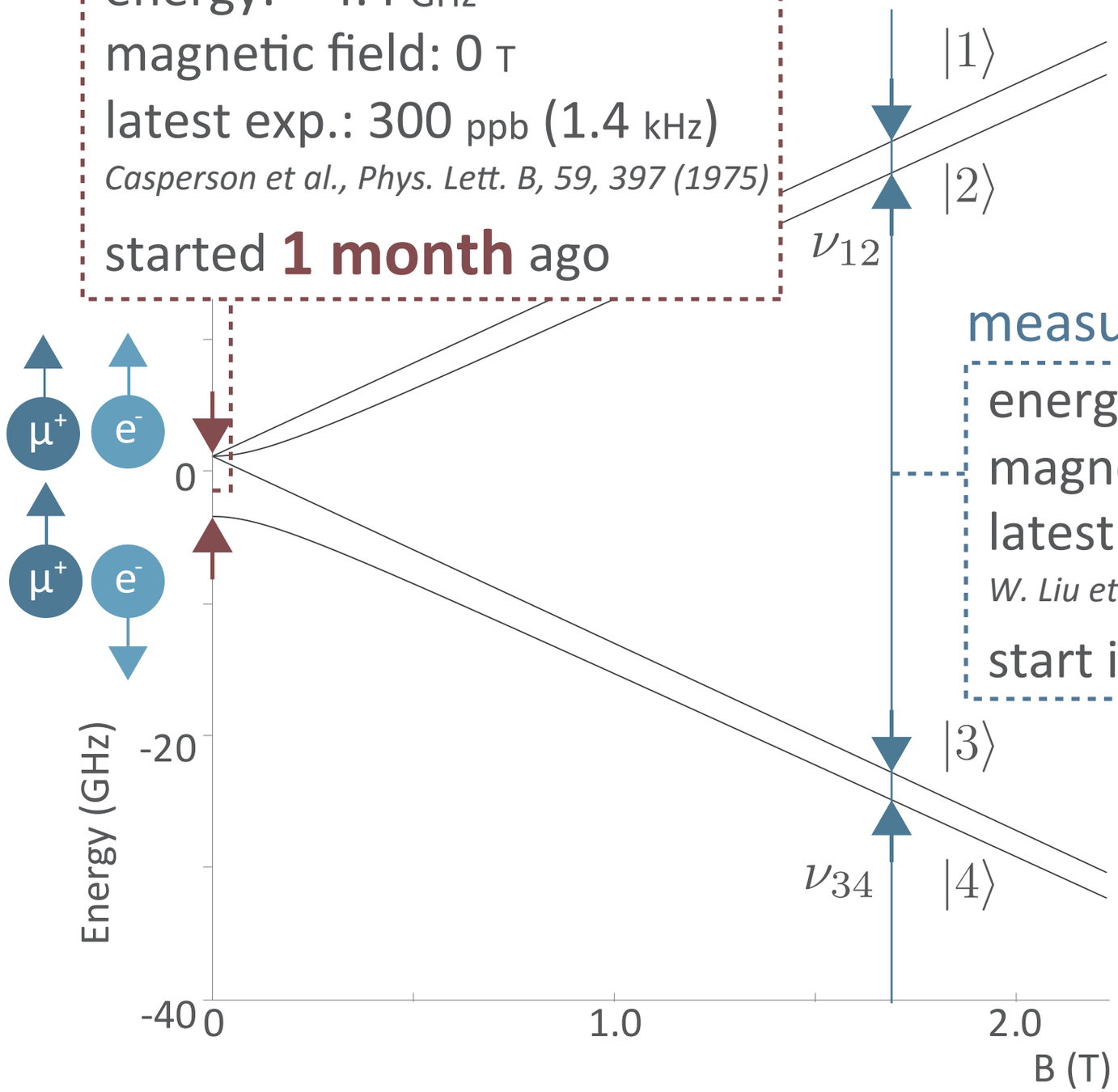
HYPERFINE SPLITTING OF MUONIUM

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

high field experiment

measurement of ν_{12} and ν_{34} .

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

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

$\leftrightarrow$

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

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

determine fundamental values

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

g-2 experiment

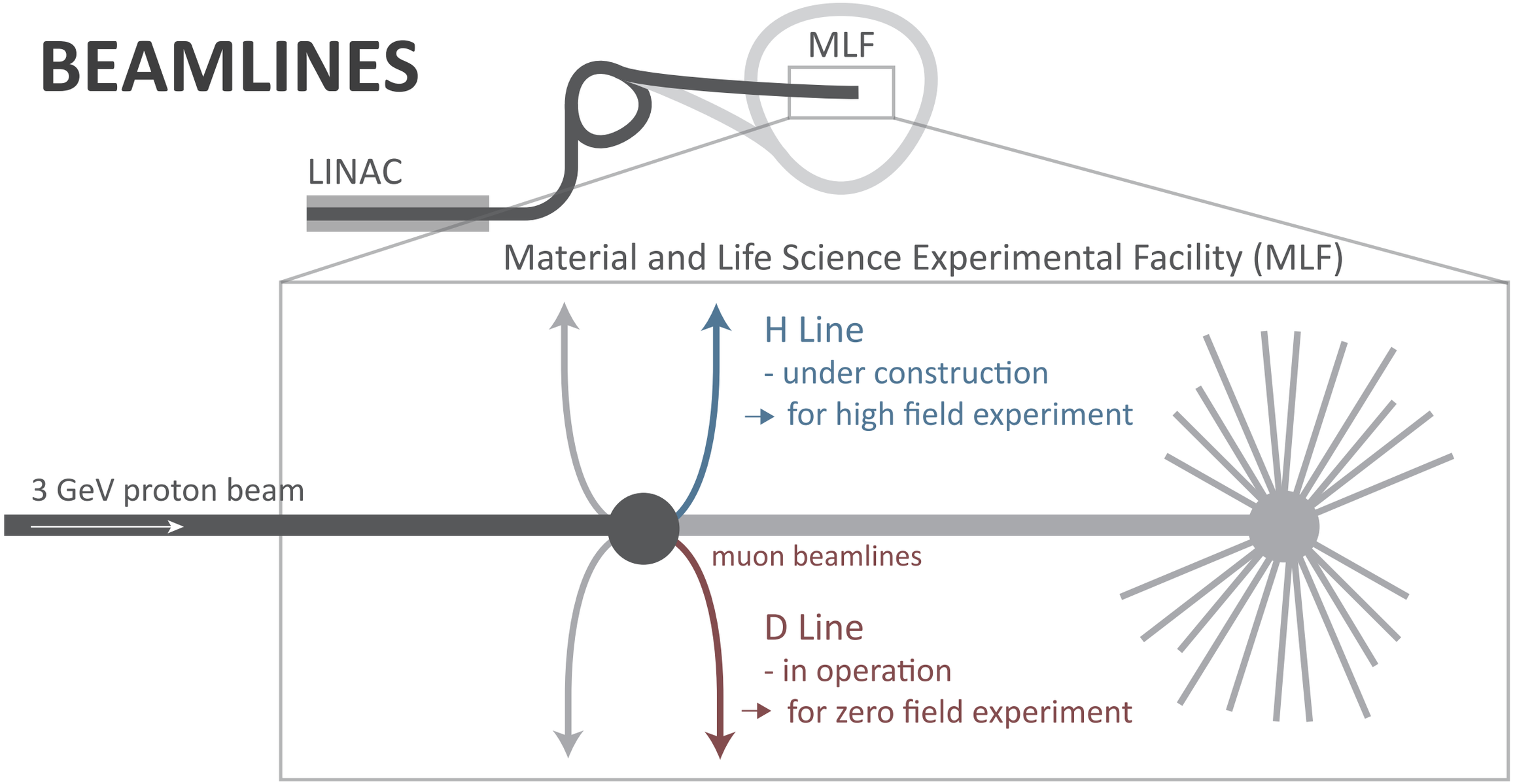
from g-2 exp.: 560 ppb(BNL) → ~100 ppb(J-PARC)

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

from MuHFS exp.
170 ppb(LAMPF)

I-37 Tsutomu Mibe

BEAMLINES



beamline in LAMPF (DC beam)

$$\frac{1 \times 10^7\ \mu^+/s}{\text{beam intensity}} \times \underbrace{\frac{3.9}{3\,9 + 9\,9}}_{\text{chopping ratio}}$$

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

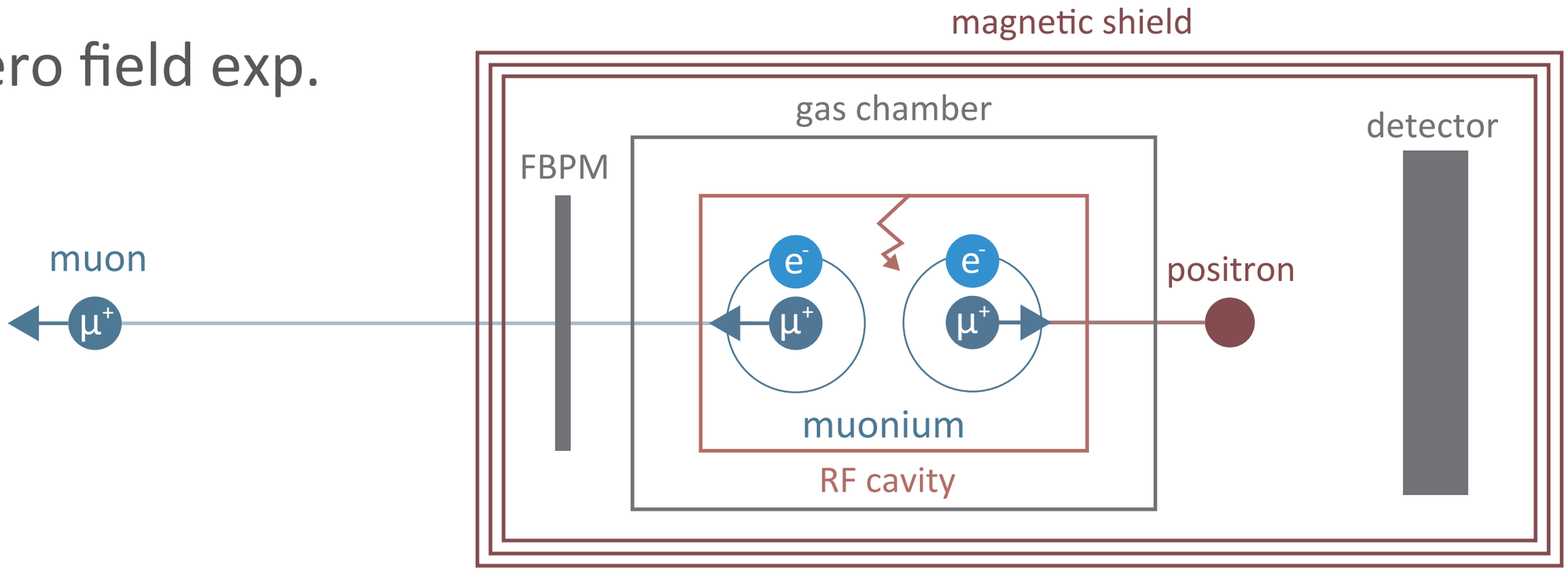
H Line (pulsed beam)

$$\frac{1 \times 10^8\ \mu^+/s}{\text{beam intensity}} \times \underbrace{1}_{\text{pulsed beam}}$$

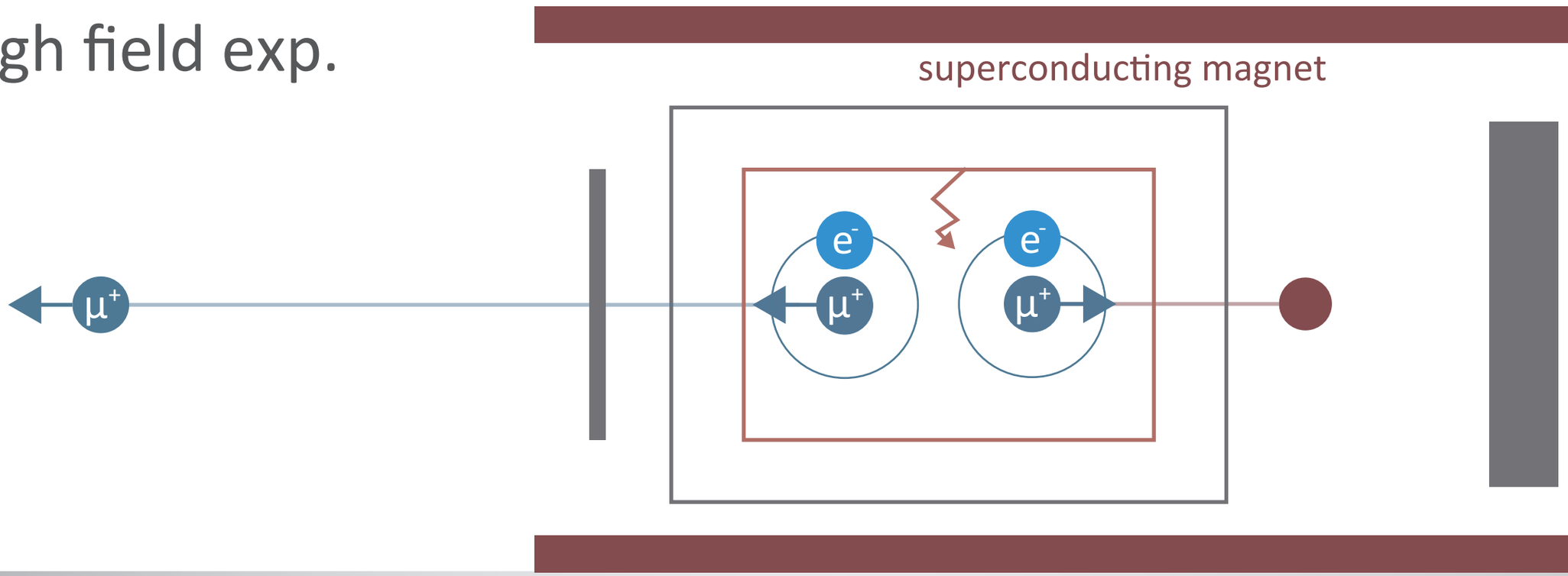
$$\approx 1 \times 10^8\ \mu^+/s$$

EXPERIMENTAL PROCEDURE

zero field exp.

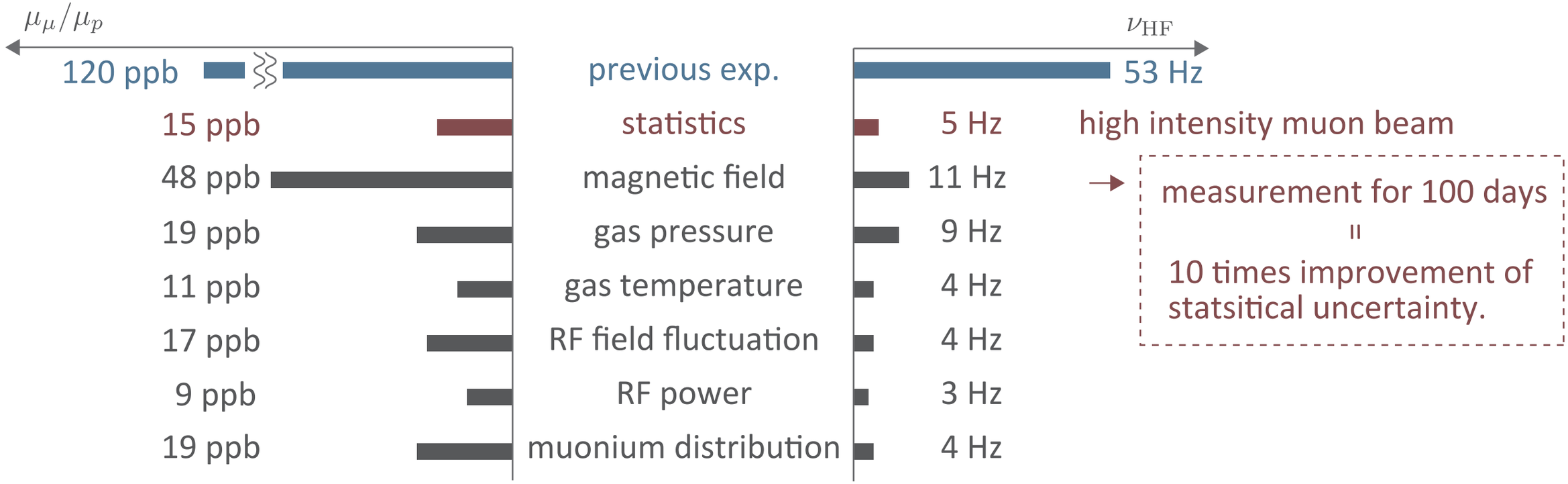


high field exp.



ESTIMATION OF UNCERTAINTIES

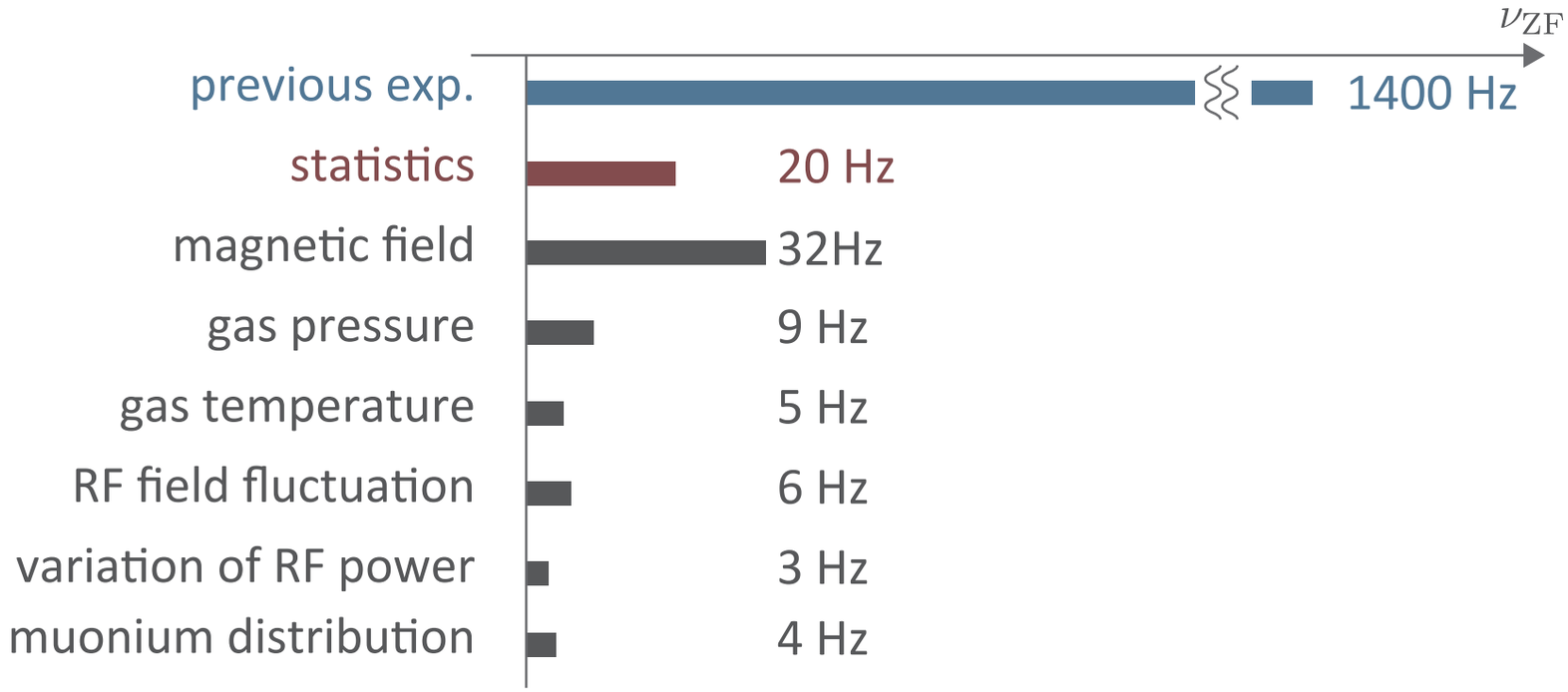
high field experiment



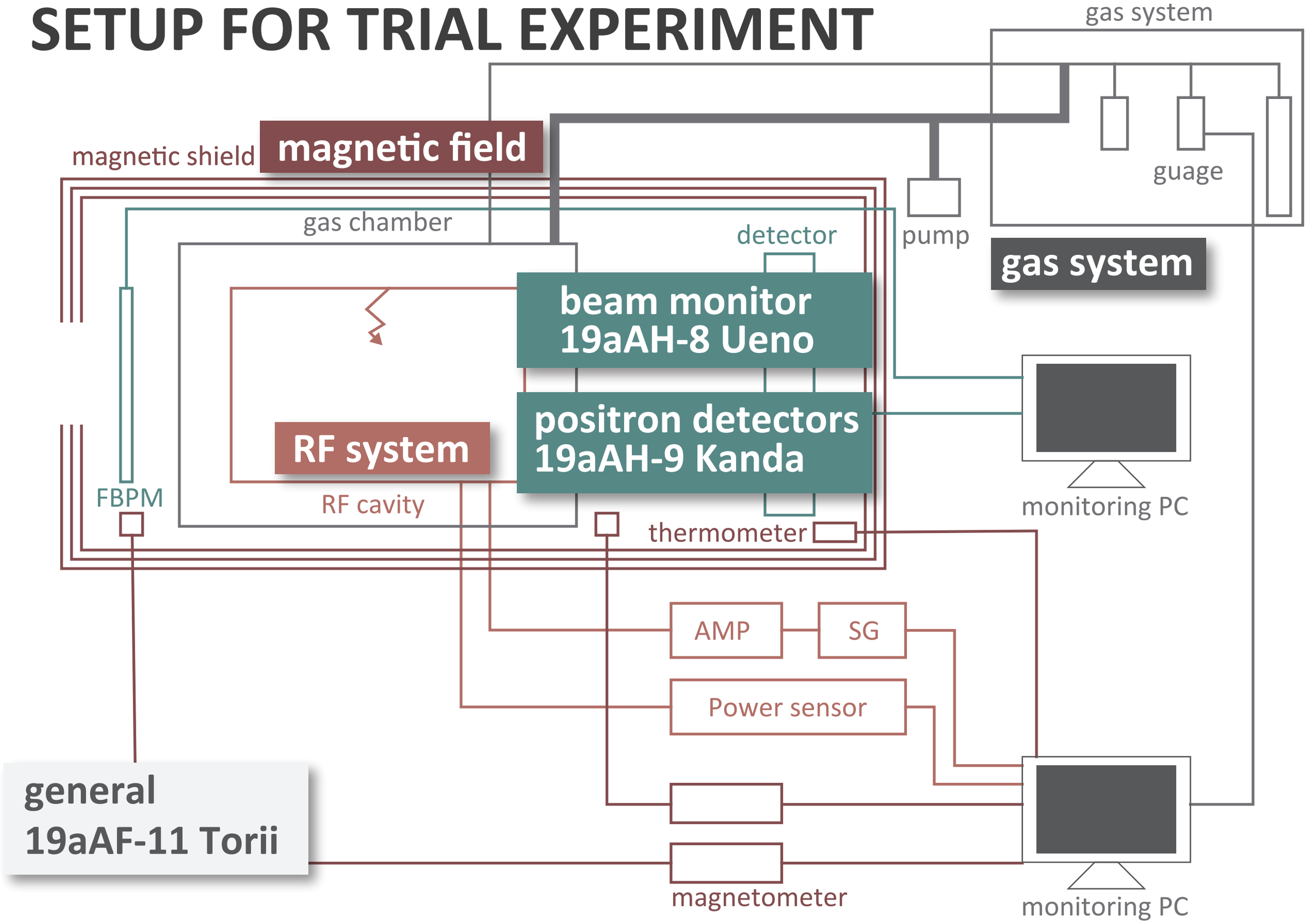
high intensity muon beam

→ measurement for 100 days
=
10 times improvement of statsitical uncertainty.

zero field experiment



SETUP FOR TRIAL EXPERIMENT



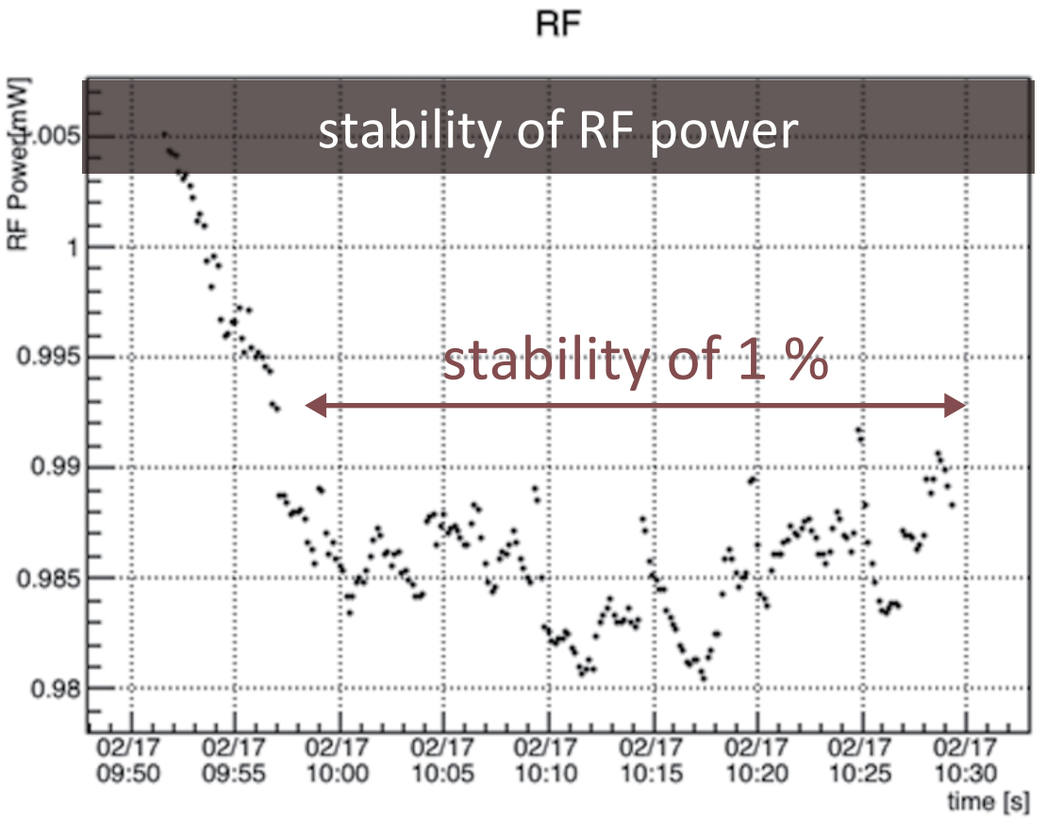
SETUP (RF SYSTEM)

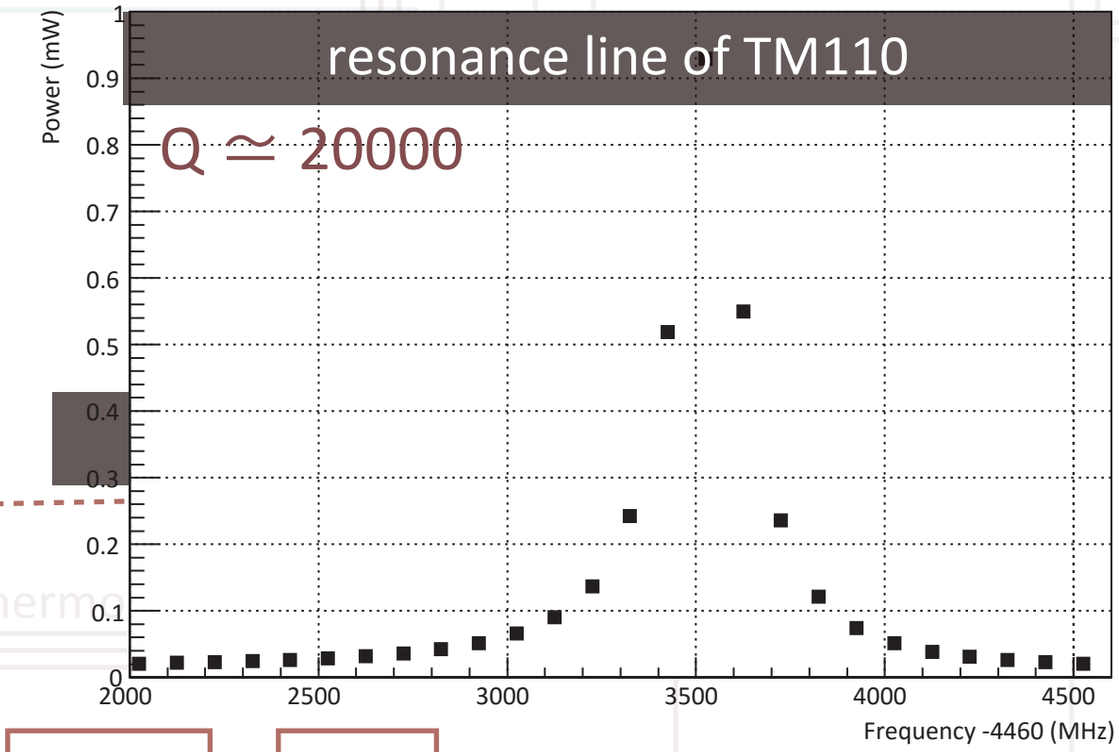
resonance mode: TM110 (Q-factor =2×10^4)

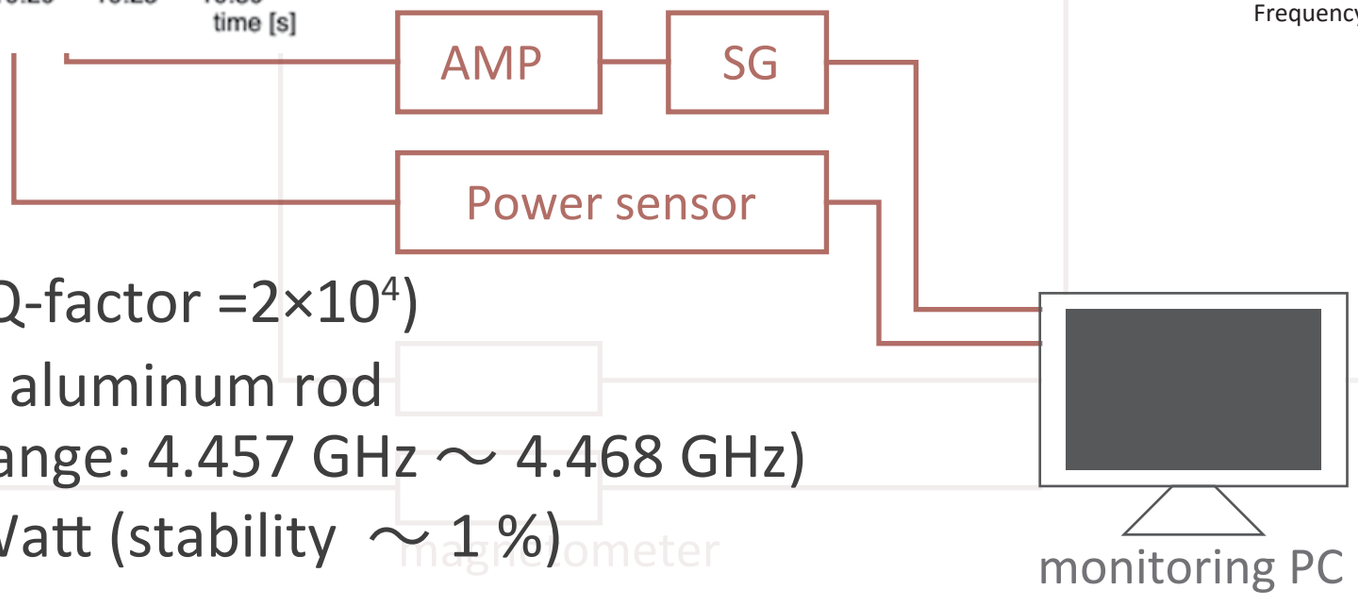
frequency: tuned by aluminum rod
(tuning range: 4.457 GHz ～ 4.468 GHz)

RF power: several Watt (stability ～1 %)

SETUP (RF SYSTEM)







resonance mode: TM110 (Q-factor =2×10^4)

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

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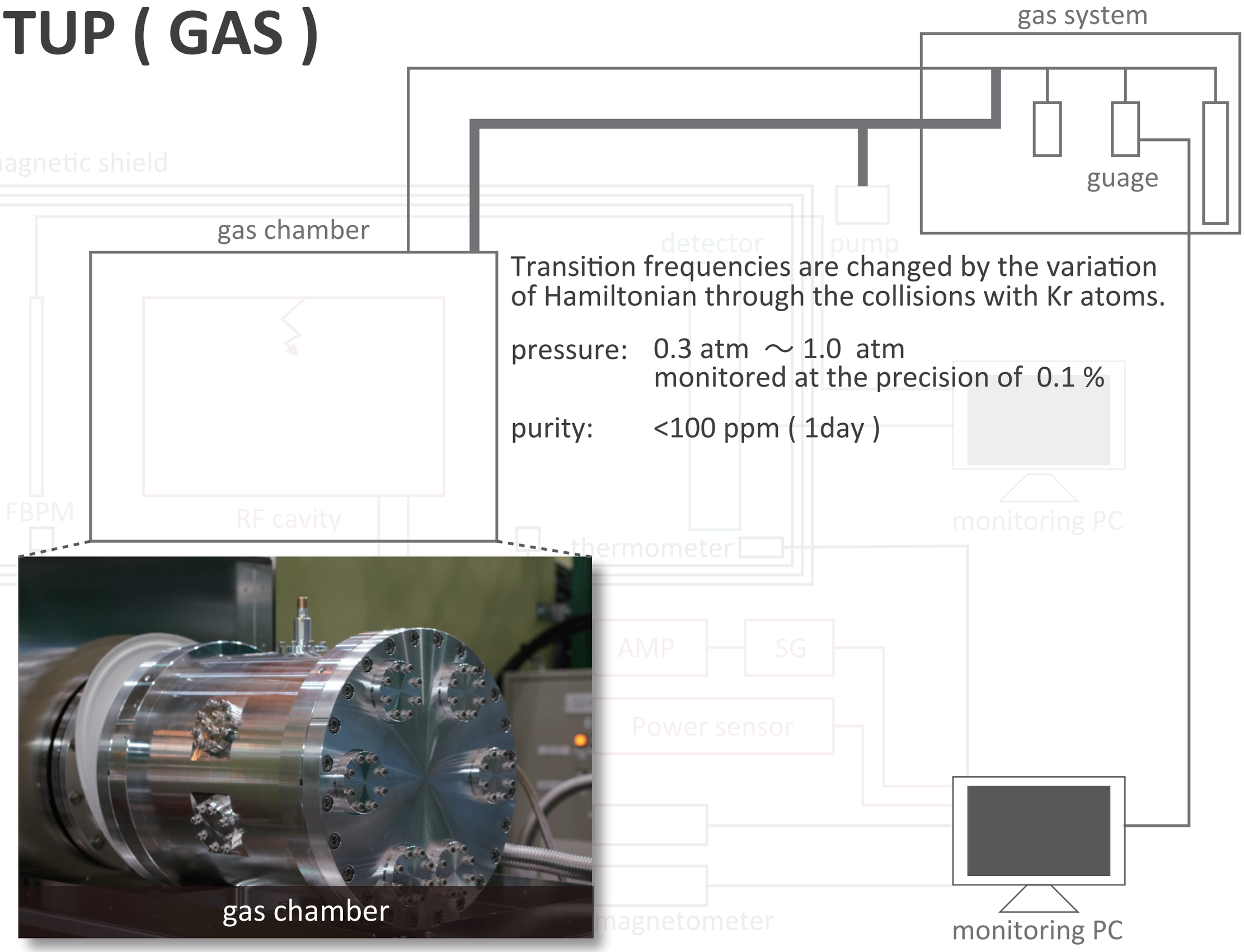
SETUP (GAS)



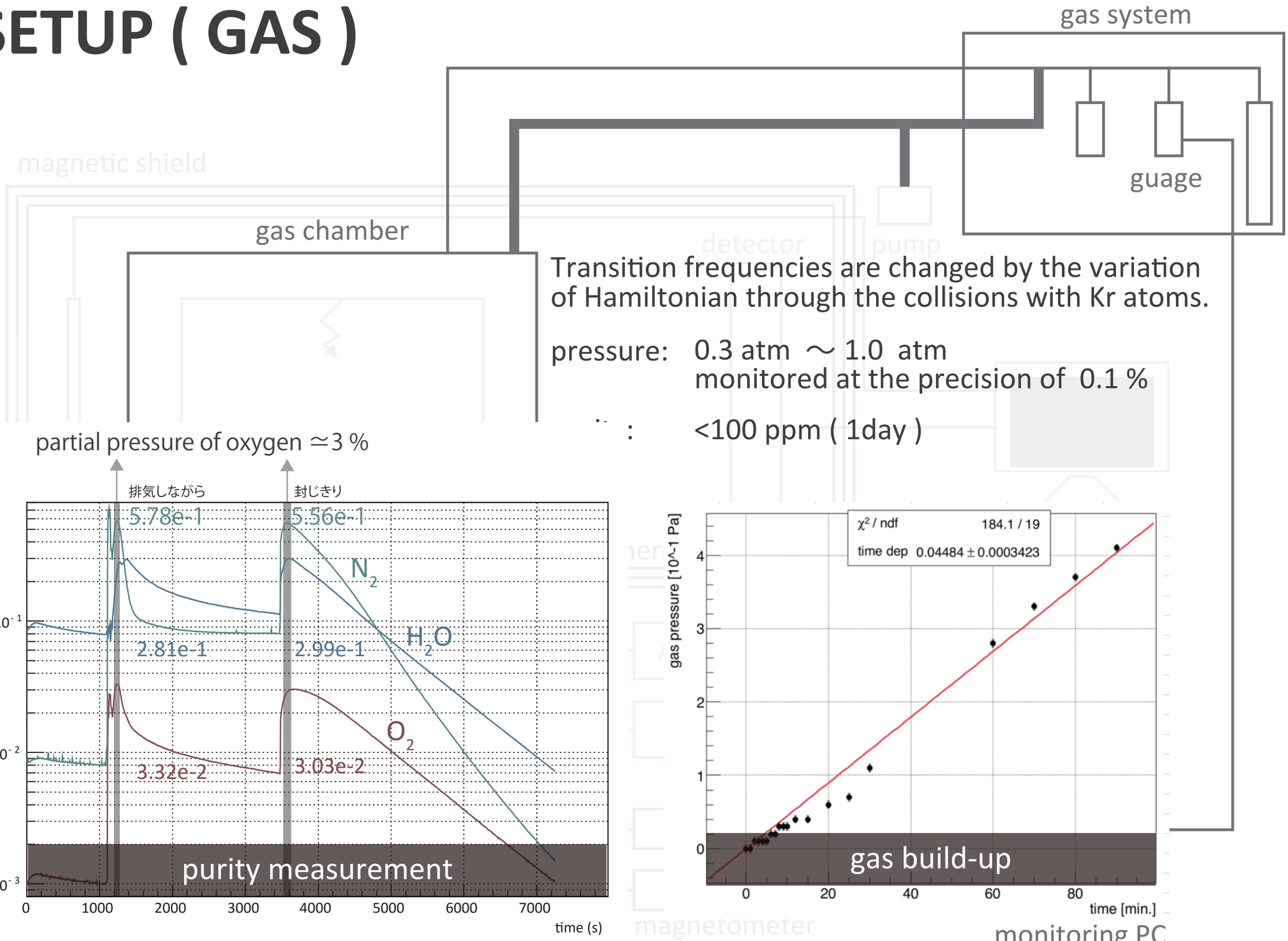
Transition frequencies are changed by the variation of Hamiltonian through the collisions with Kr atoms.

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

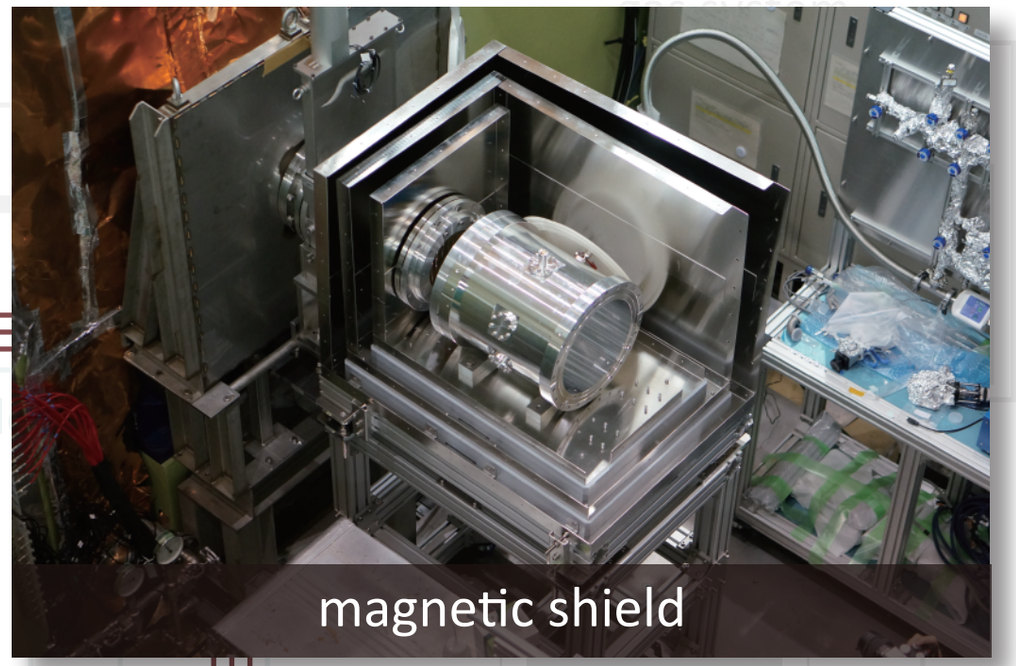
purity: <100 ppm (1day)

gas chamber

SETUP (GAS)


gas system
guage
magnetic shield
gas chamber
detector
pump
partial pressure of oxygen ≃3 %
排気しながら
封じきり
5.78e-1
5.56e-1
N2
H2O
2.81e-1
2.99e-1
O2
3.32e-2
3.03e-2
purity measurement
pressure (Pa)
time (s)
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 %
: <100 ppm (1day)
χ2 / ndf 184.1 / 19
time dep 0.04484 ± 0.0003423
gas pressure [10^-1 Pa]
time [min.]
gas build-up
magnetometer
monitoring PC

SETUP (MAGNETIC FIELD)


magnetic shield

magnetic shield

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

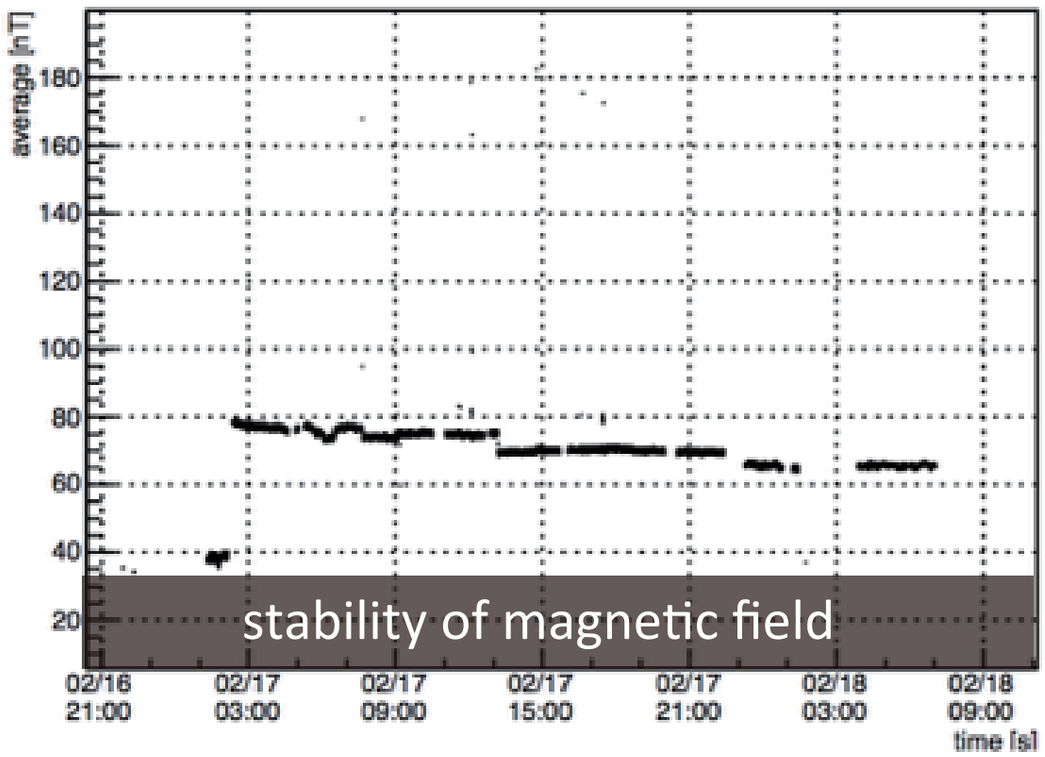
magnetometer
three-axis fluxgate magnetometers
precision: 10 nT

SETUP (MAGNETIC FIELD)

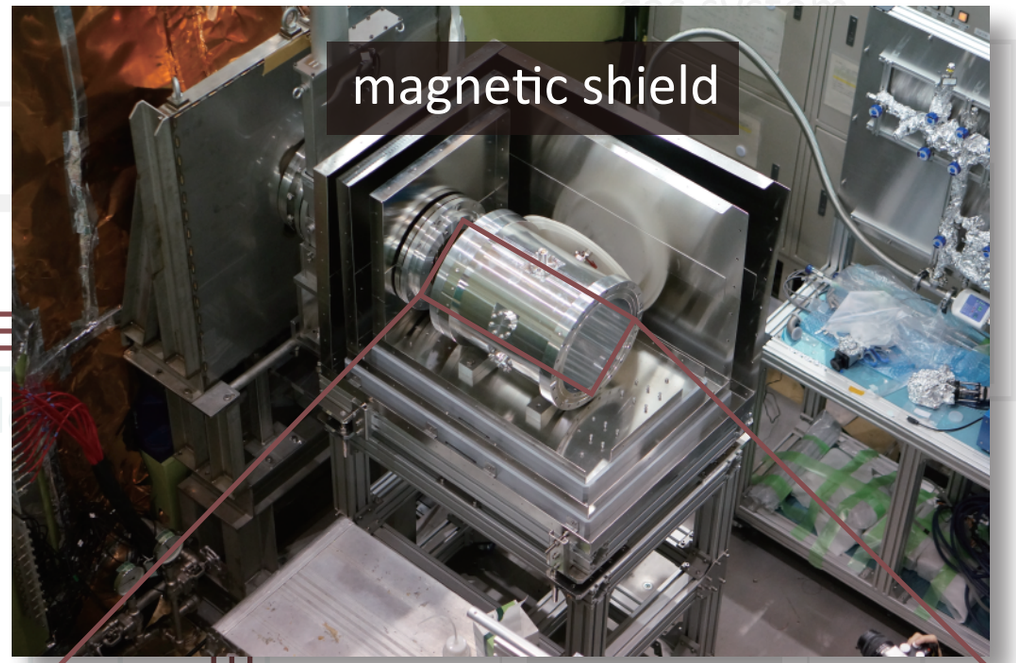
magnetic shield

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

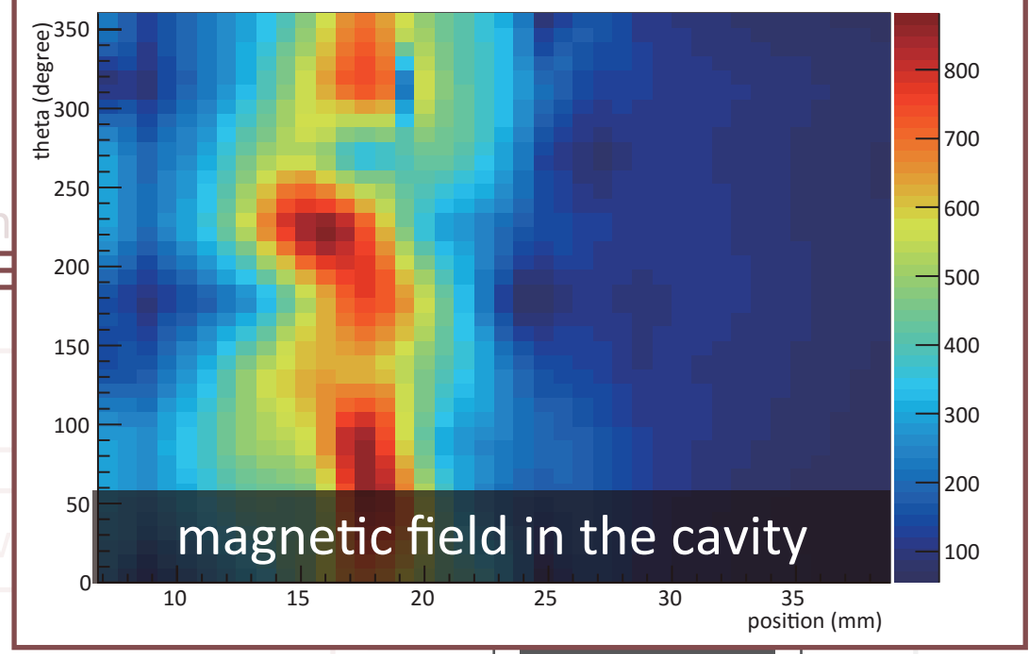
magnetometer



stability of magnetic field



magnetic shield



magnetic field in the cavity

magnetometer

monitoring PC

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.
- ▶ statistics (only 30 hours of beamtime is available)
- ▶ e+ prompt and duct streaming

schedule of Feb. 2016 experiment.

magnetic field scan(24 hours)
↓
baking for gas chamber(12 hours)
↓
beamtime(**30 hours**)
> 200 kW operation in D2@J-PARC

coincidence hit (RF off)