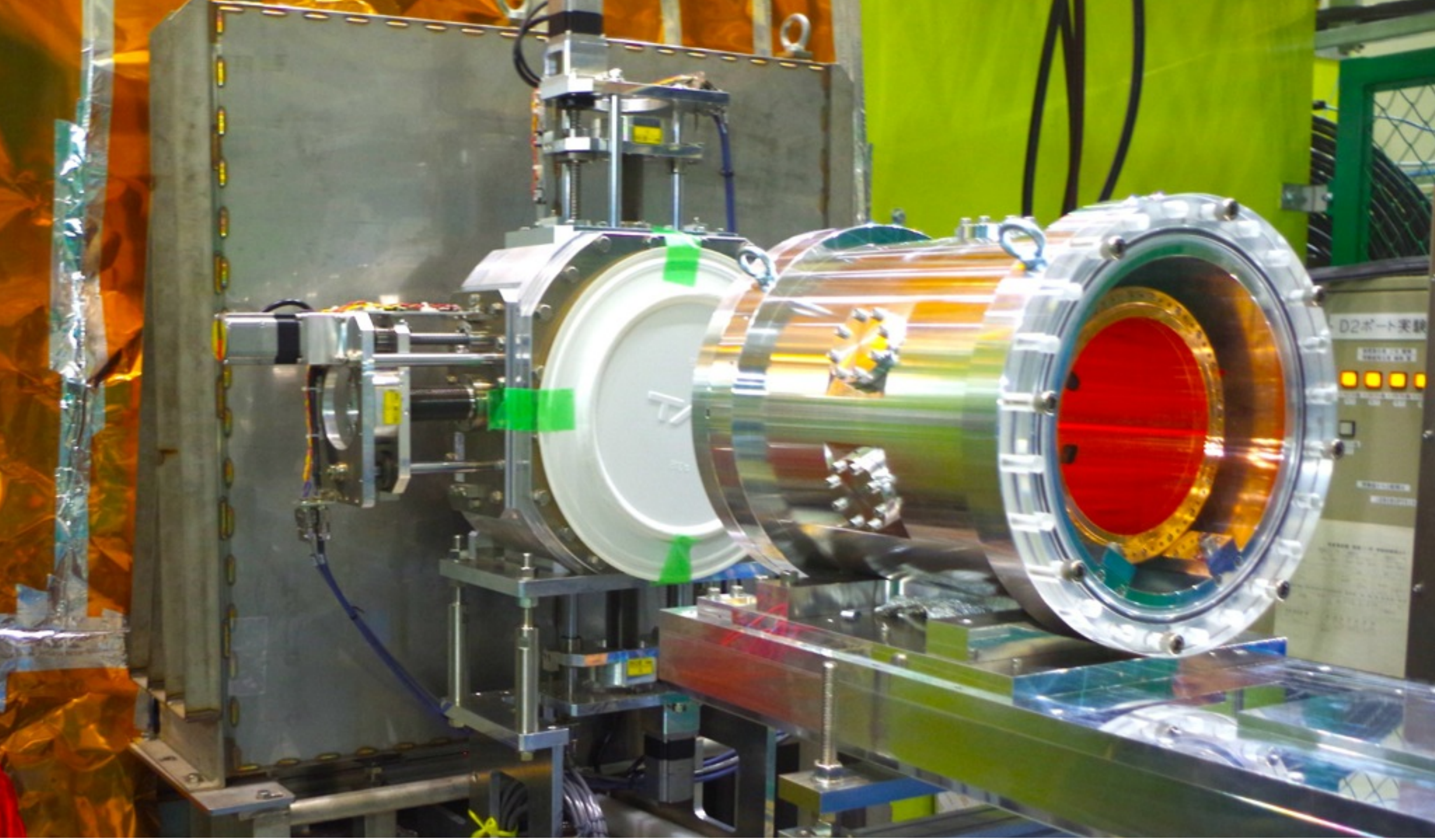

MuSEUM and Its Systematic Uncertainty

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University of Tokyo
Matsuda Lab. M1

Today's Menu

1. MuSEUM (motivation, set up, uncertainties)

2. Muon beam profile monitor(BPM) and beam test

MuSEUM

J-PARC

RIKEN

ICU

UMASS

What Is MuSEUM Experiment?

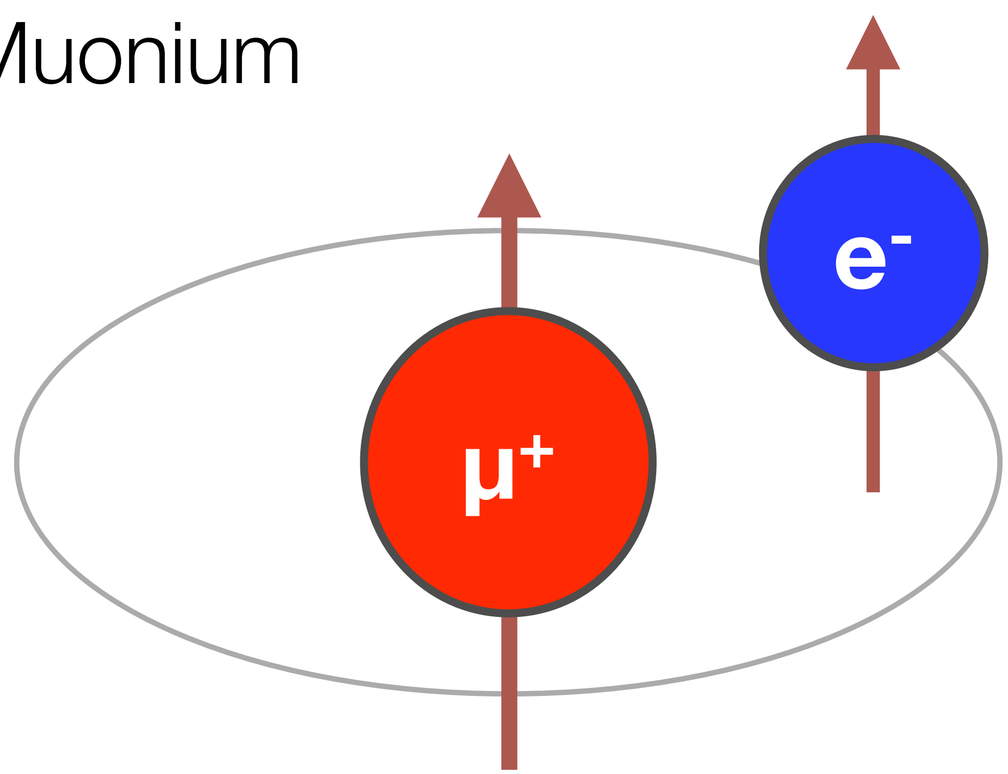
- **Mu**onium **S**pectroscopy **E**xperiment **U**sing **M**icrowave

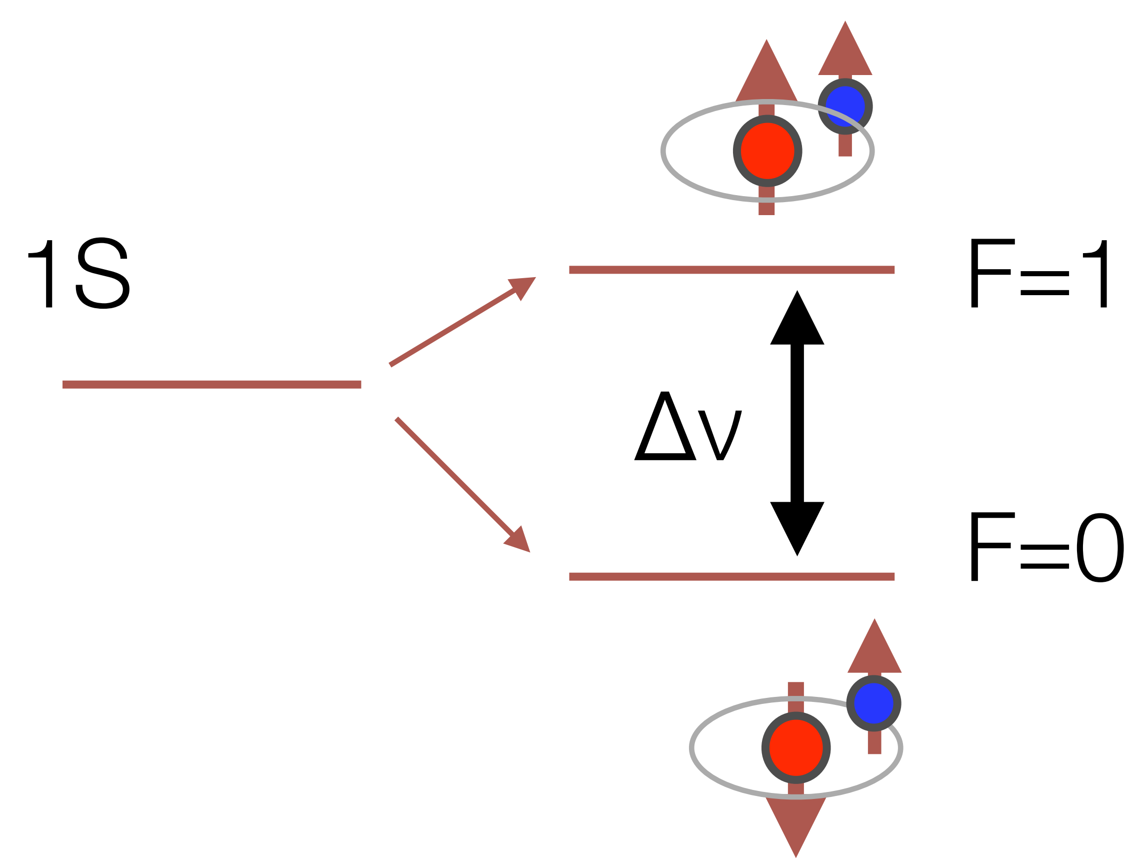
- Precise measurement of <u>**muonium hyperfine structure**</u> (MuHFS) @J-PARC

$$\Delta\nu(\text{exp}) = 4\,463\,302\,776(51)\ \text{Hz} \quad (11\ \text{ppb})$$

Liu, et al. PRL82 771(1999)

Muonium





"There is a reason physicists are so successful with what they do, and that is they study the hydrogen atom and the helium ion and then they stop."

– R. P. Feynman

Why Muonium Hyperfine Structure

- Indeed! **Hydrogen(-like) atom spectroscopy** played an essential role in understanding physics (e.g.) Bohr Model, Lamb shift, bound QED… etc.

- **The finite-size of proton,** however, prevents physicists from testing quantum electrodynamics (QED).

- **Muonium** = positive muon (μ^+) + electron (e^-) → **purely leptonic (two 'point like' particles)**

Why Muonium Hyperfine Structure

Stringent Test of Bound-State QED

Muonium → Two point-like particles
no proton structure effect

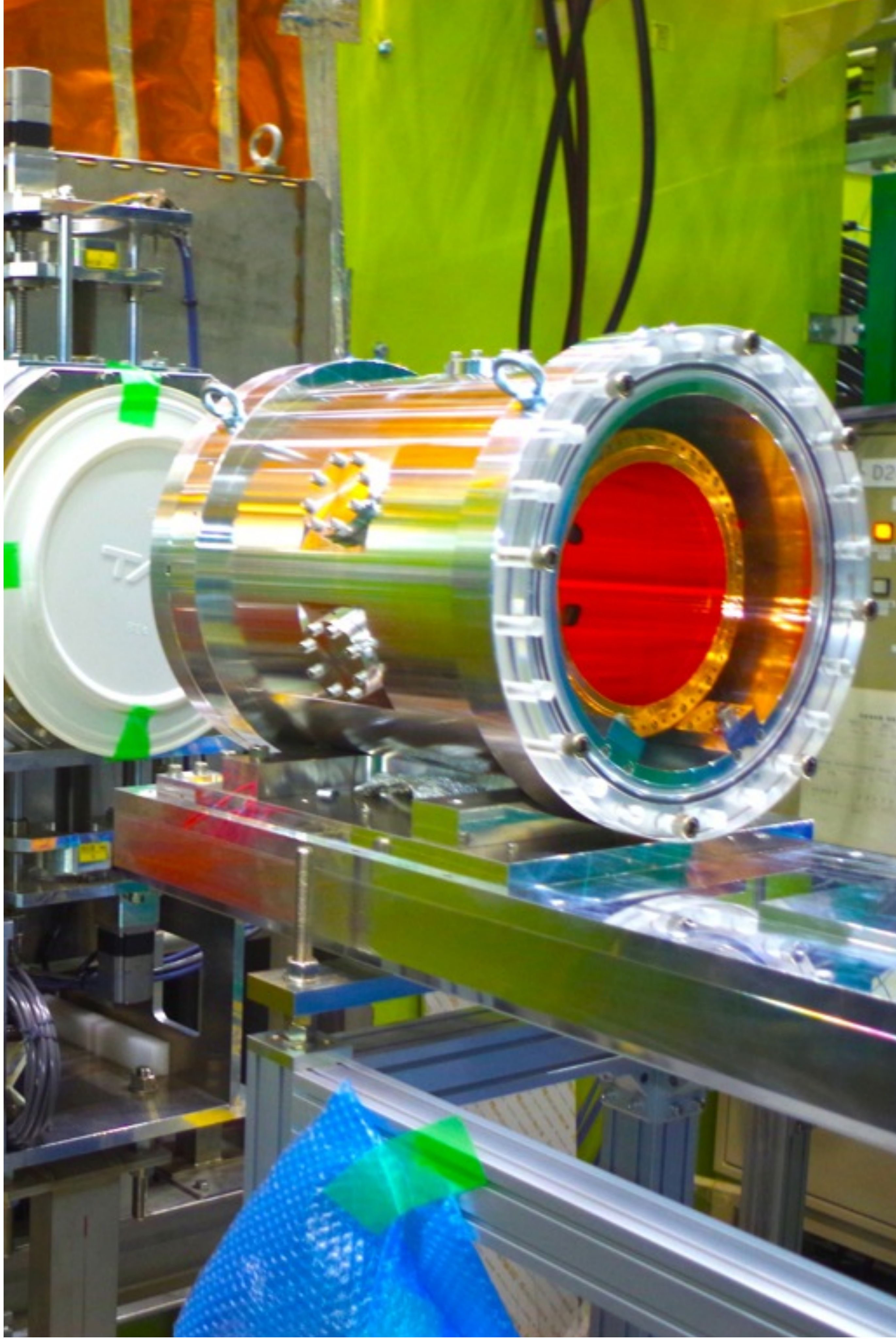
Determination of Muon Mass

An external parameter for muon g-2 experiment

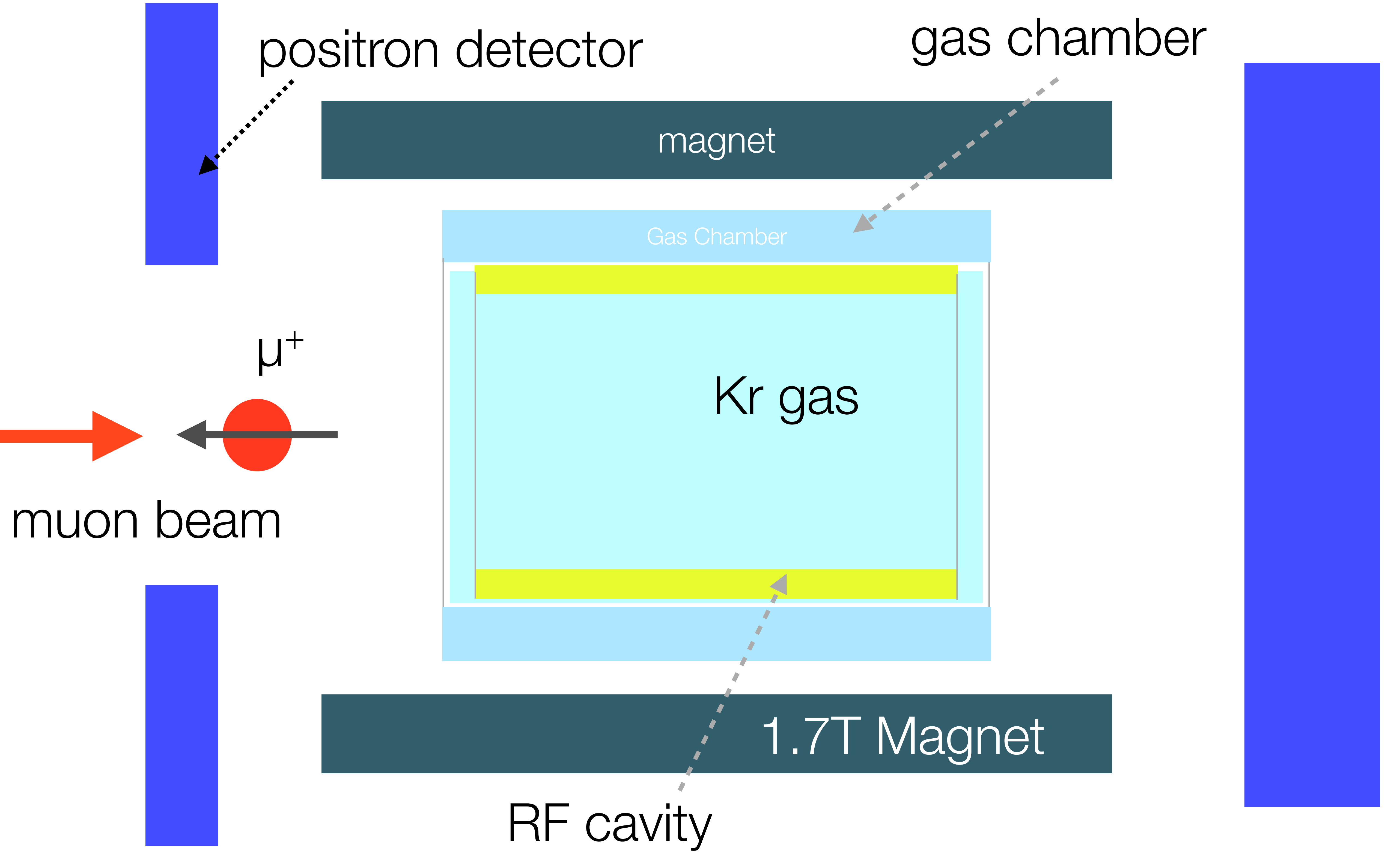
@J-PARC(E34) or Fermilab

Contribution to new physics search

Experimental Set Up



How To Measure?



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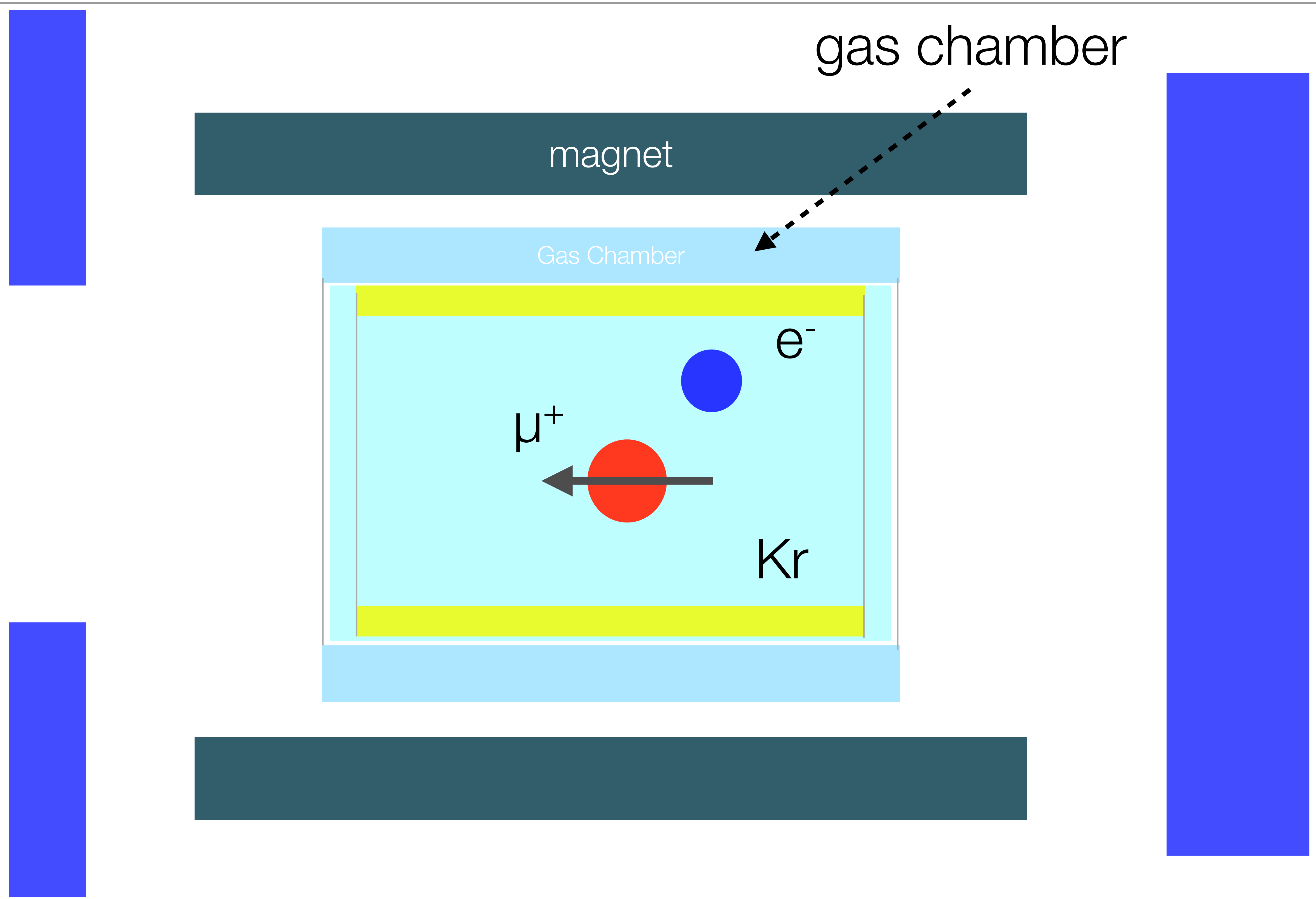

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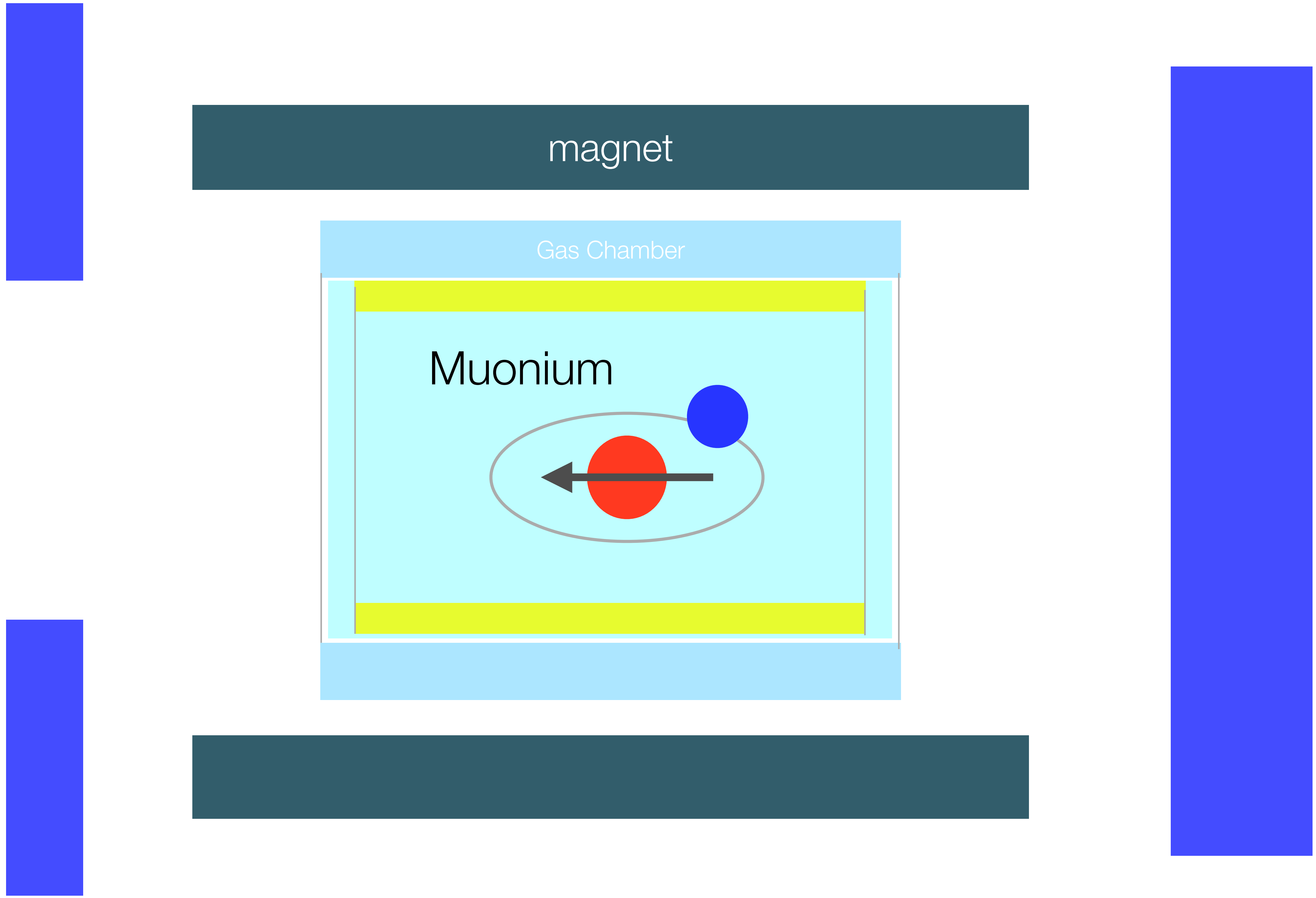

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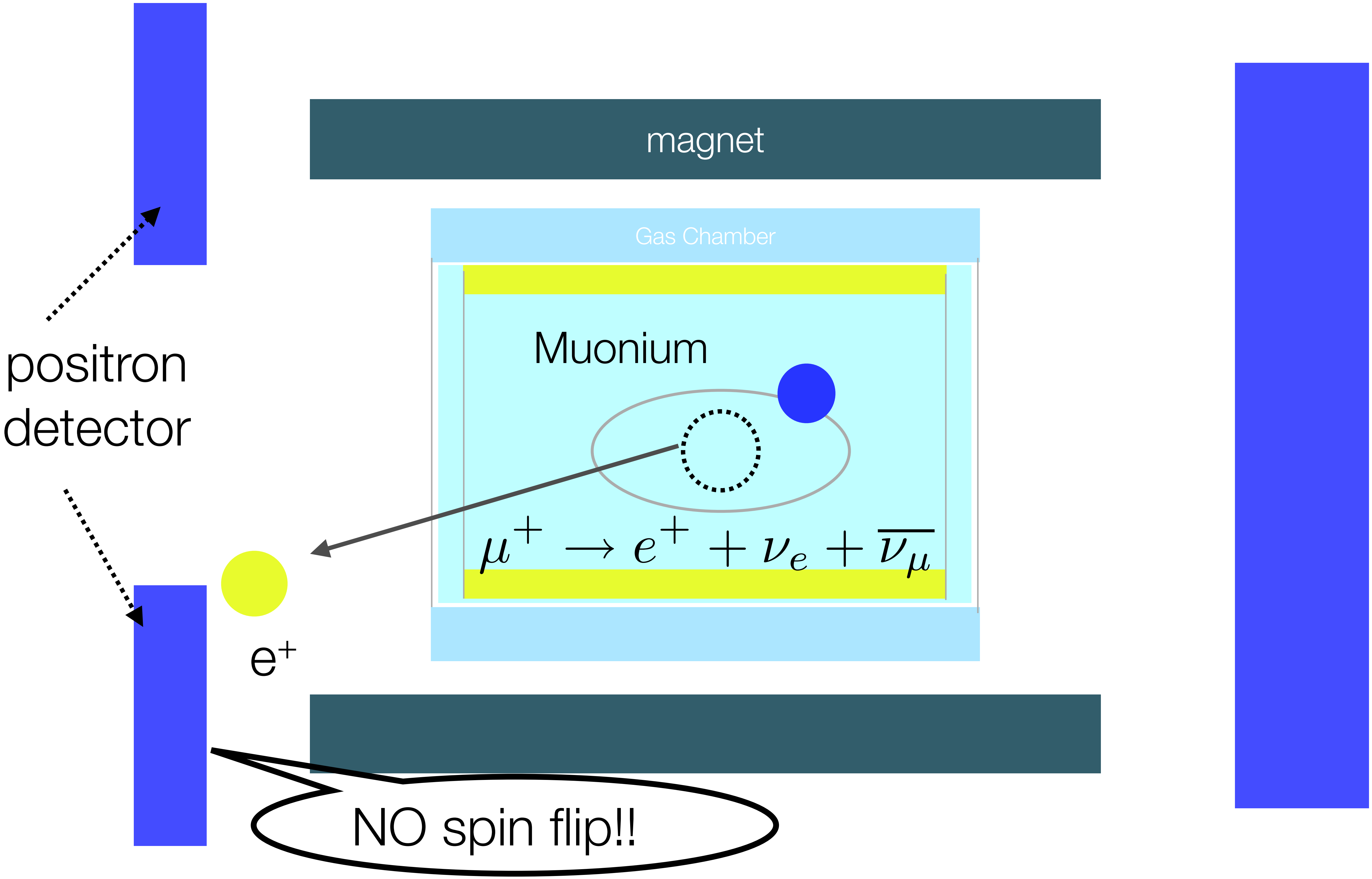

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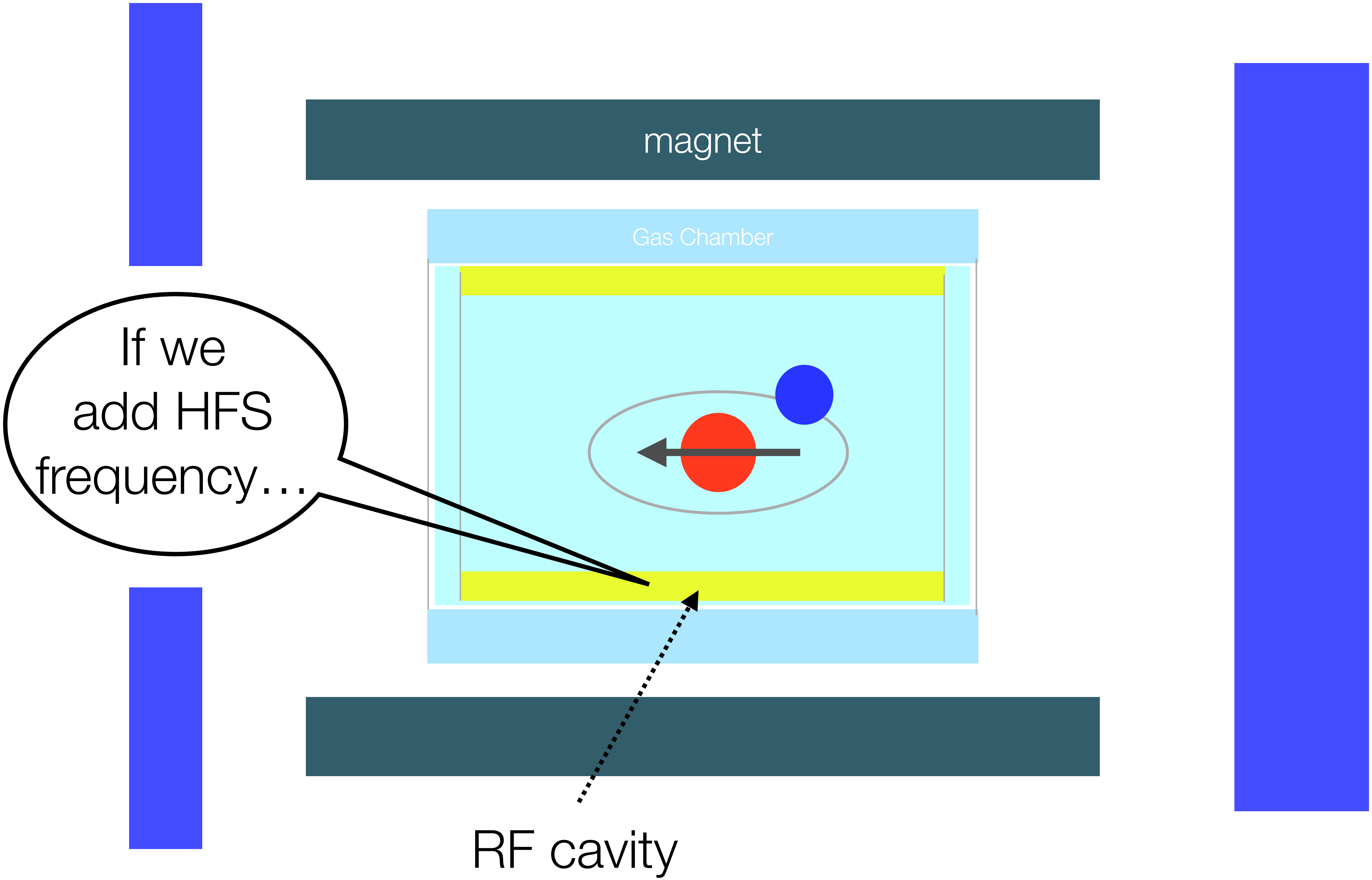

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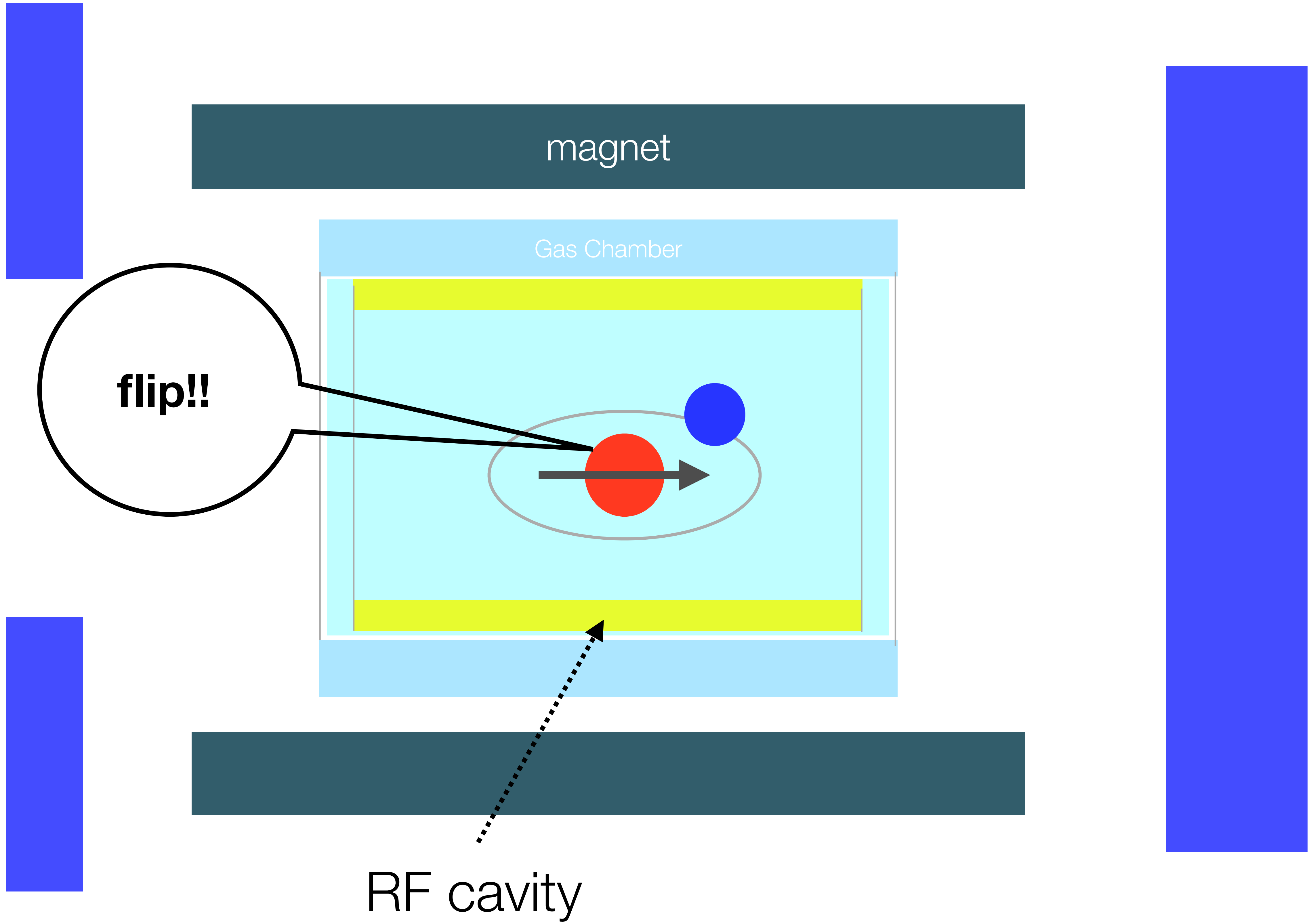
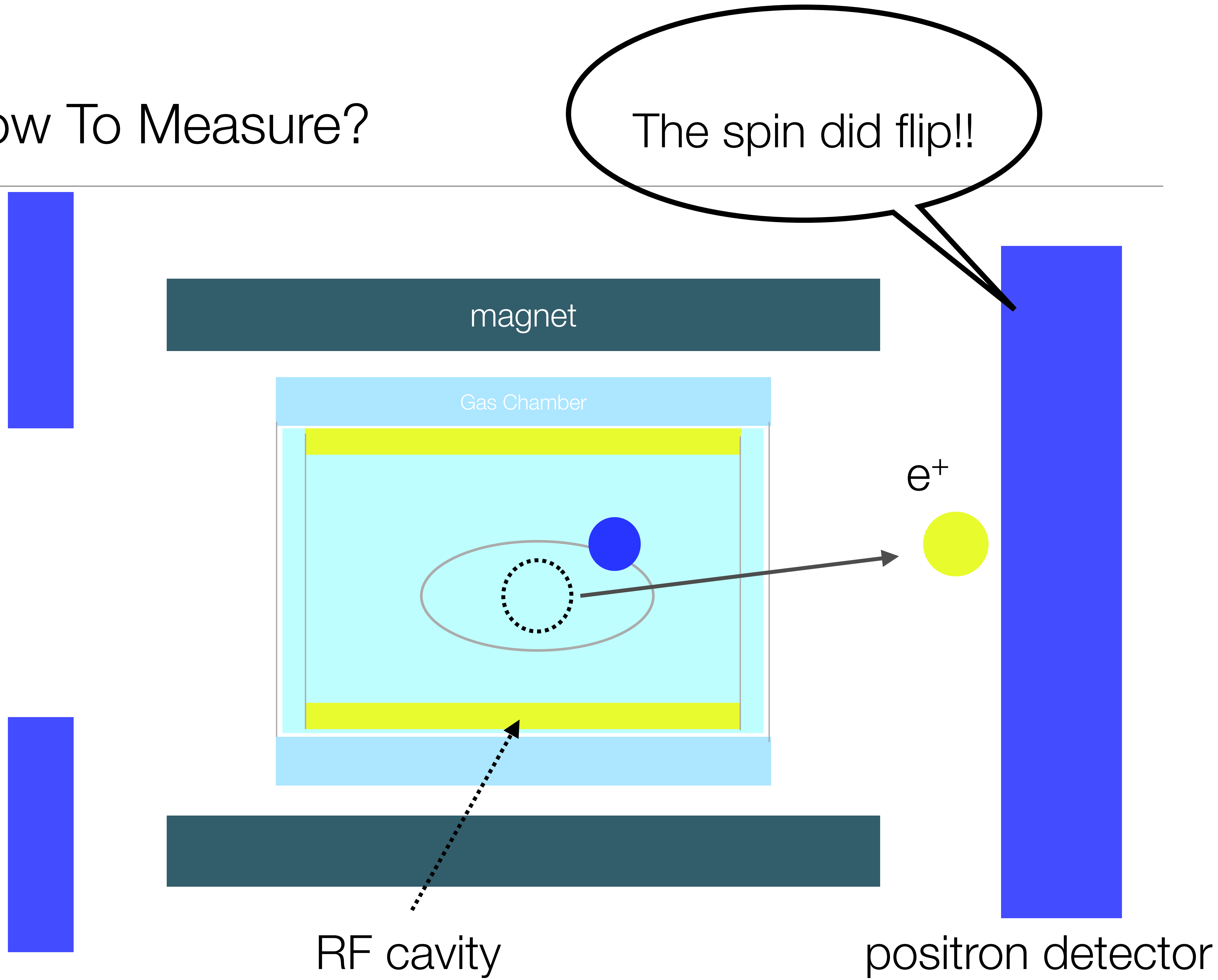
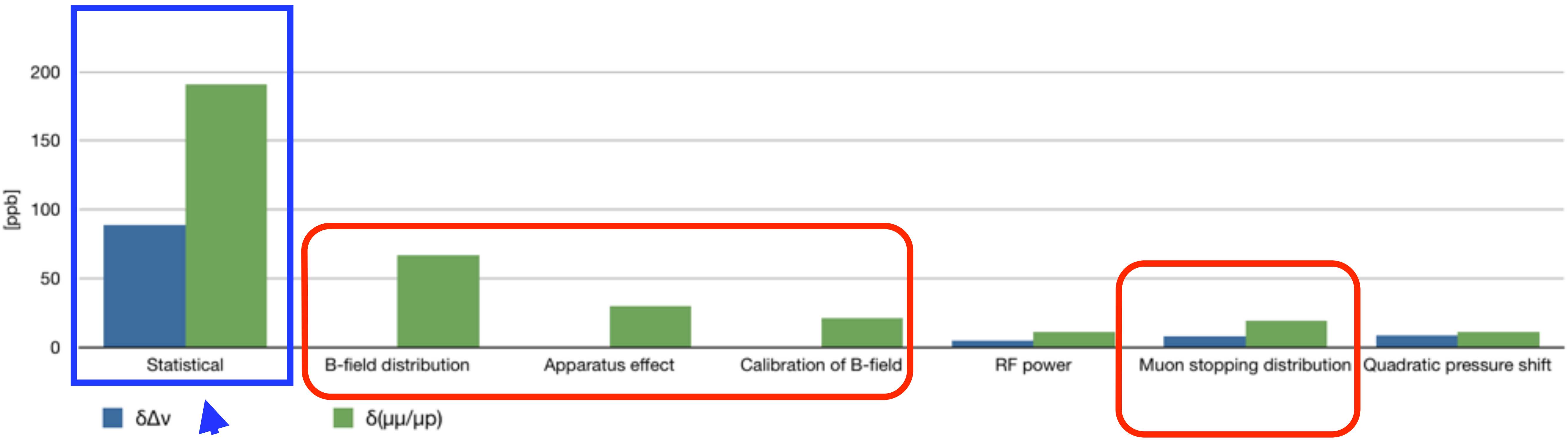


How To Measure?



Uncertainties

Previous experiment
@Los Alamos Meson Physics Facility(LAMPF)



magnetic field

muon stopping distribution

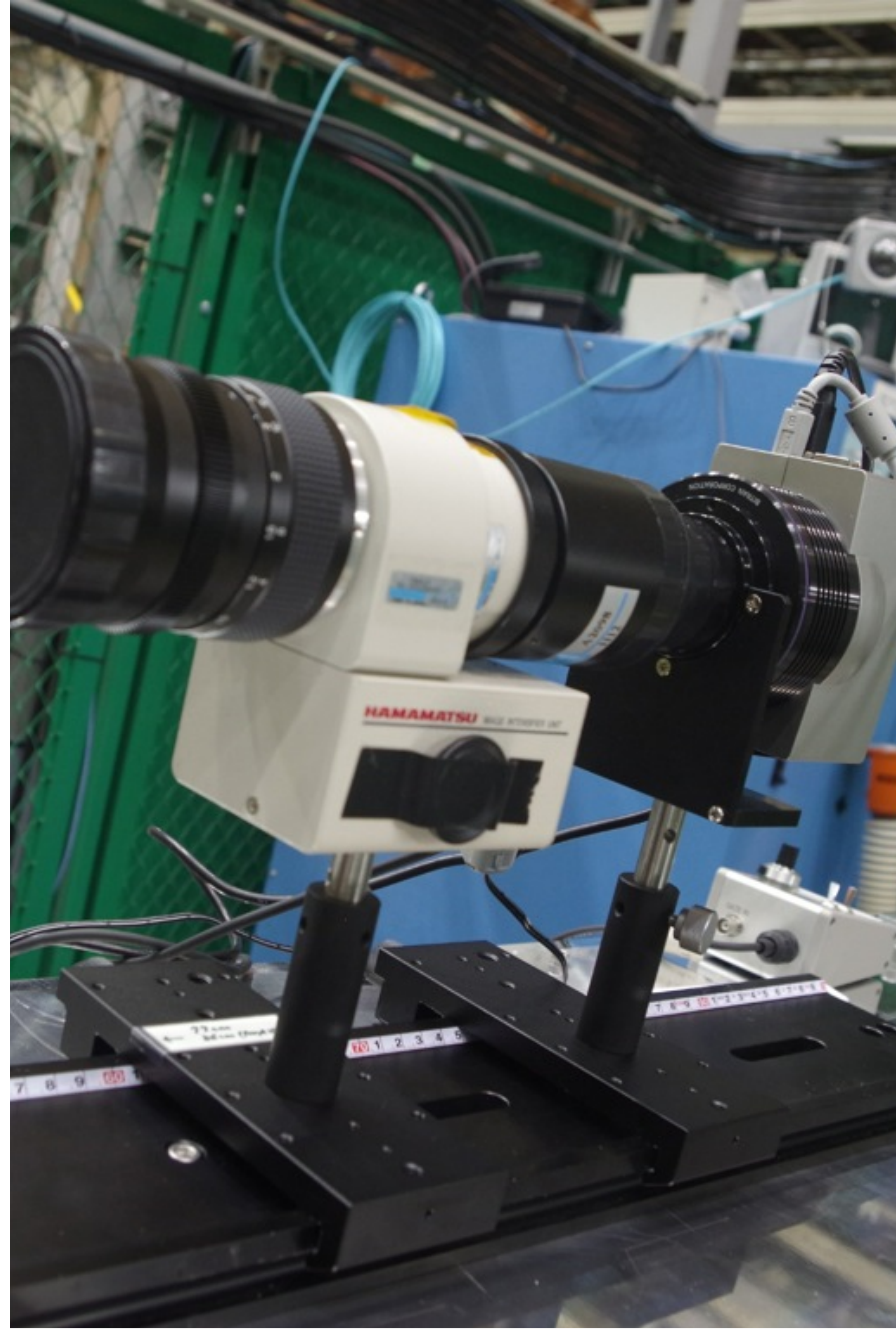
statistical
to be suppressed

Liu, *et al*. PRL82, 711(1999)

Muon Beam Profile Monitor (BPM)

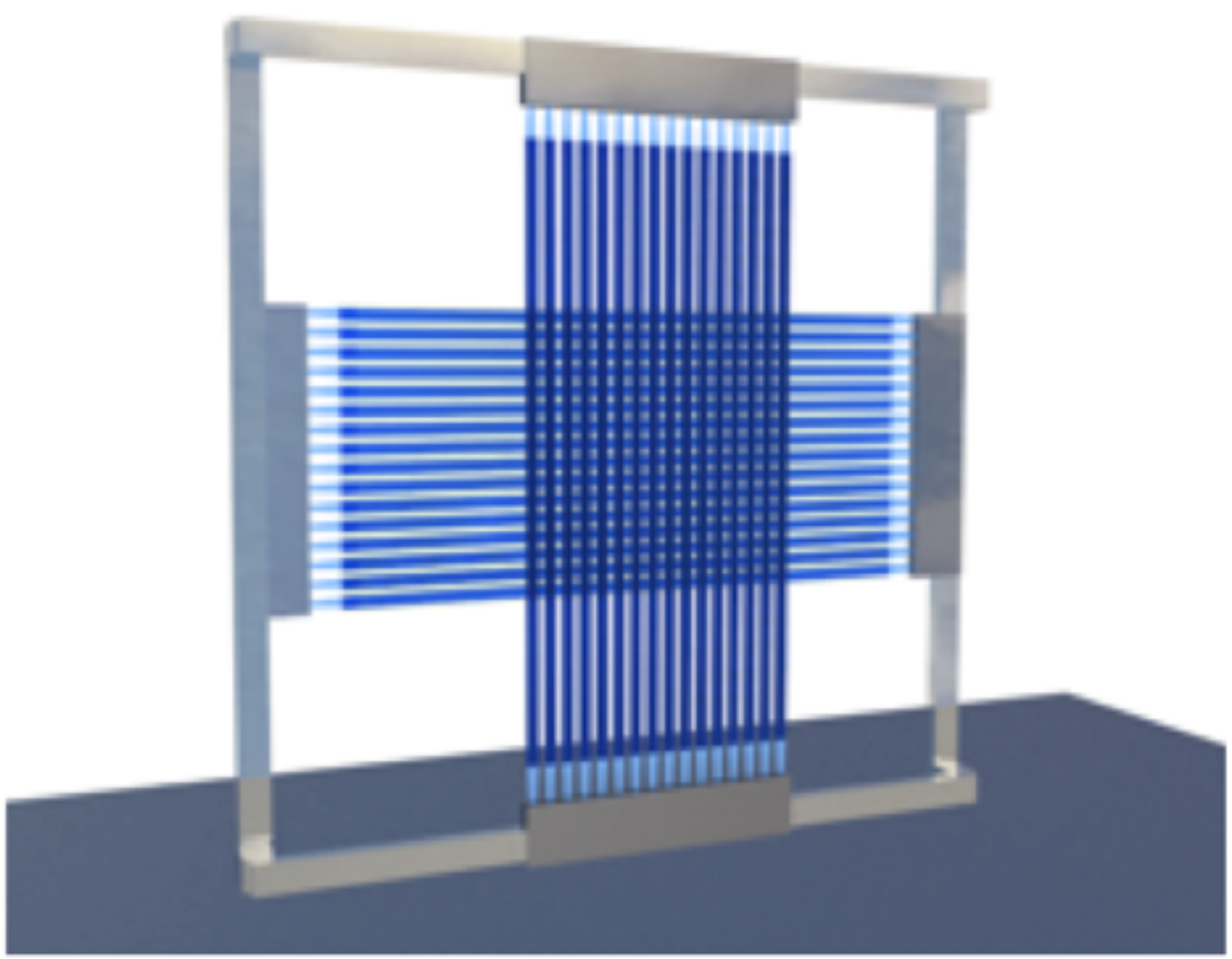
On-Line Beam Profile Monitor

Off-Line Beam Profile Monitor
(Main Topic of today)



On-line Beam Profile Monitor

- Designed and developed by S. Kanda (U. Tokyo)
- Composite of very **thin** (~100μm) **scintillation fibers**

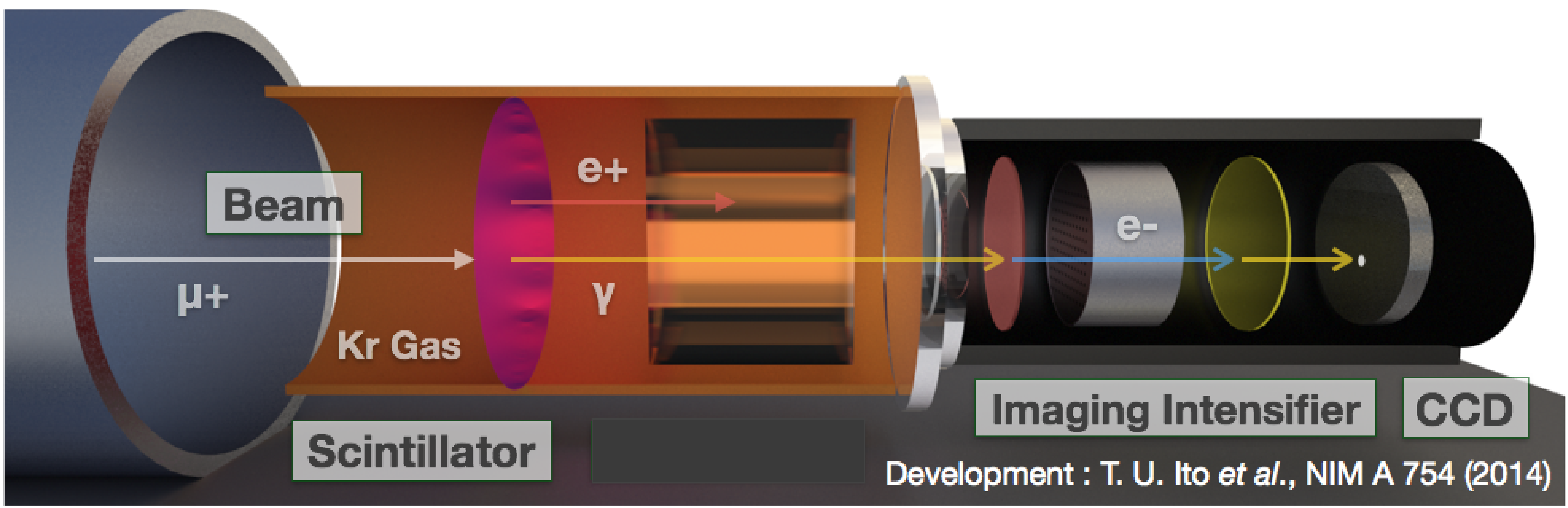


- Fiber hodoscope for beam stability monitoring
- Pulse by pulse measurement of profile and intensity

S. Kanda. J-PARC symp.

Off-line 3D Beam Profile Monitor

- design and development by T. U. Ito, JAEA
- Composite of **Scintillator**, Gated Image Intensifier (IIF) and **CCD camera**
- Determination of muon stopping distribution



S. Kanda. J-PARC symp.

Beam Test @J-PARC

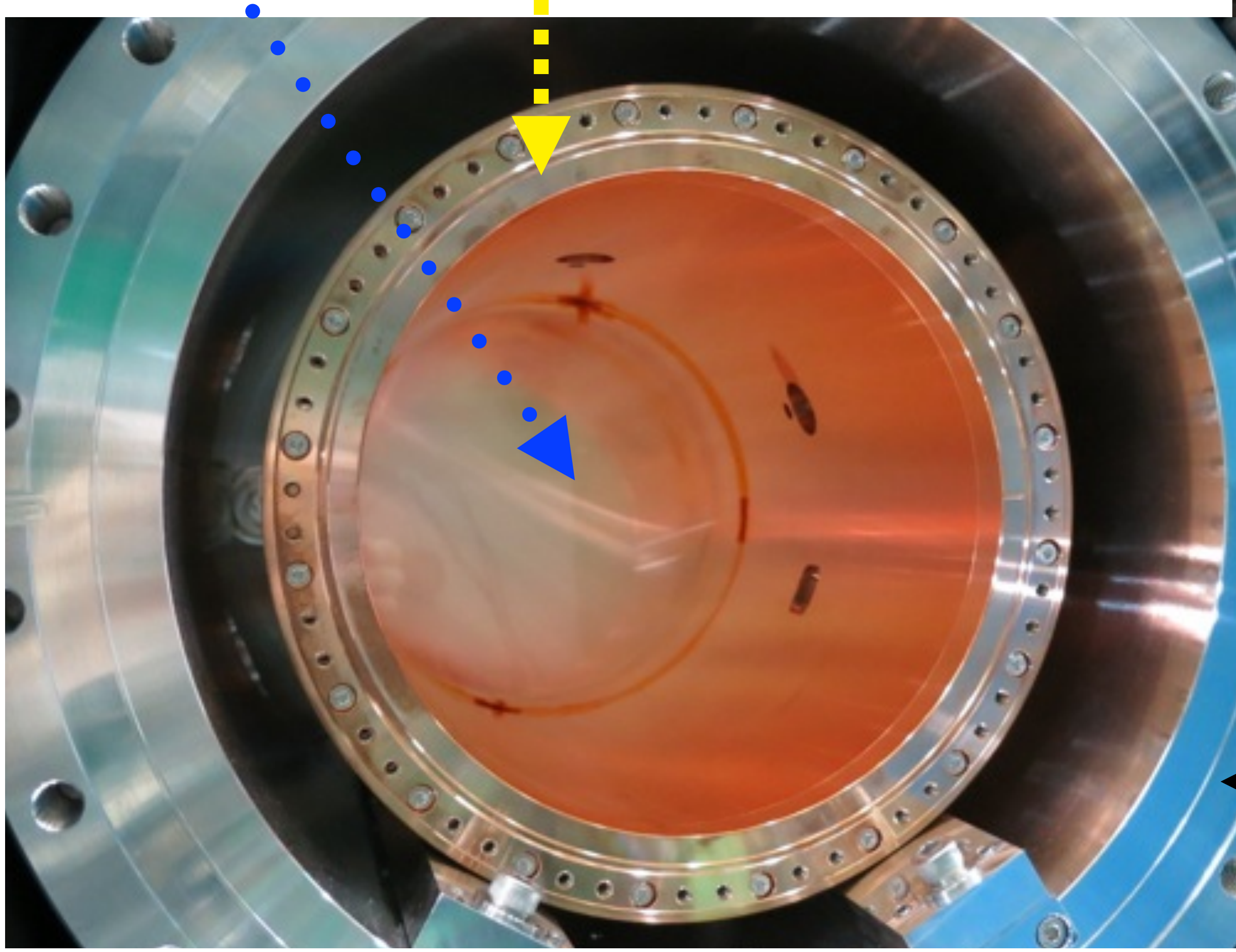
- Aim
  - Establish the operation of beam profile monitor
  - Evaluate the performance of the monitor

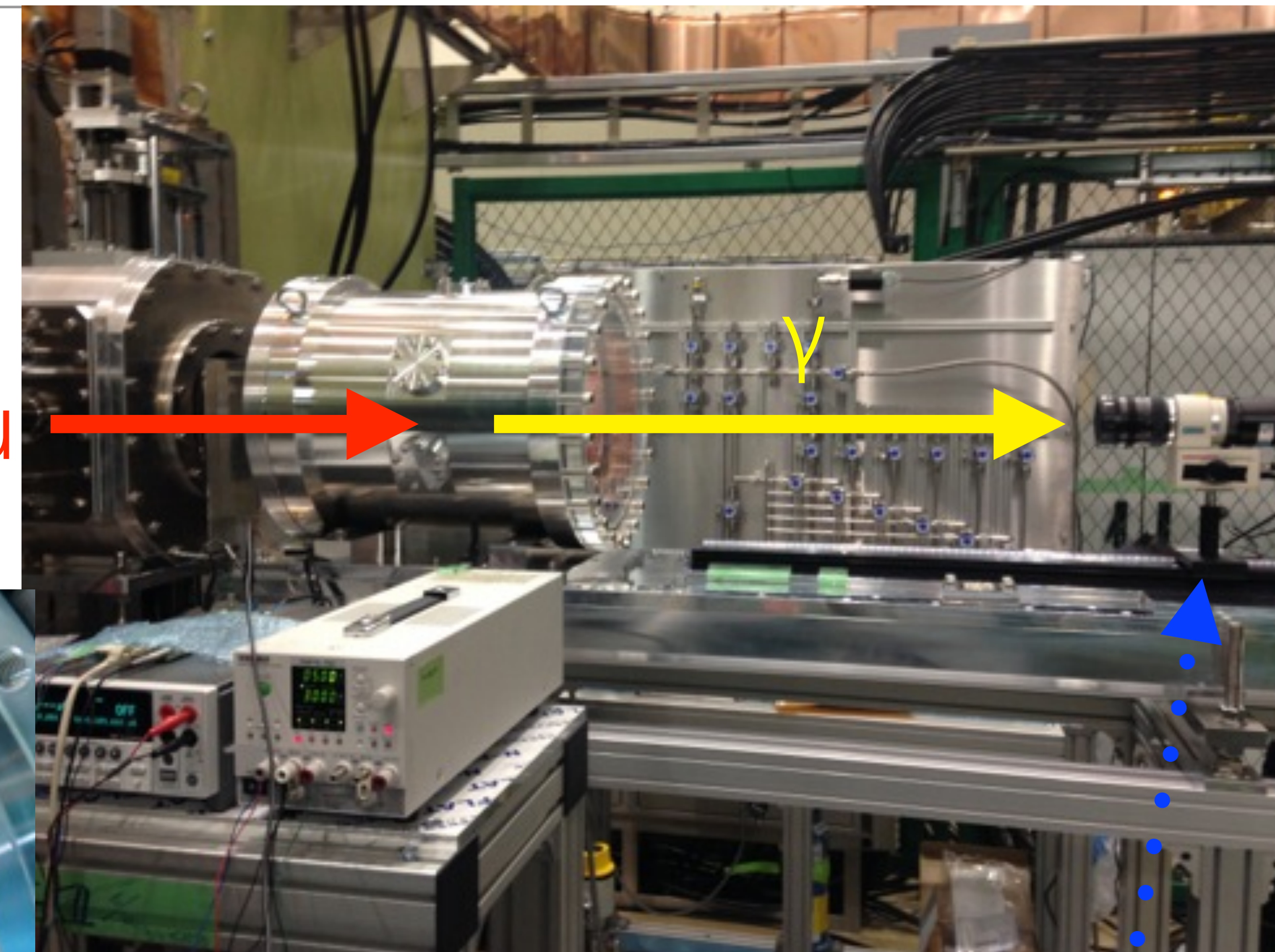
Photo credit, H. A. Torii

Beam test

RF
cavity

Scintillator



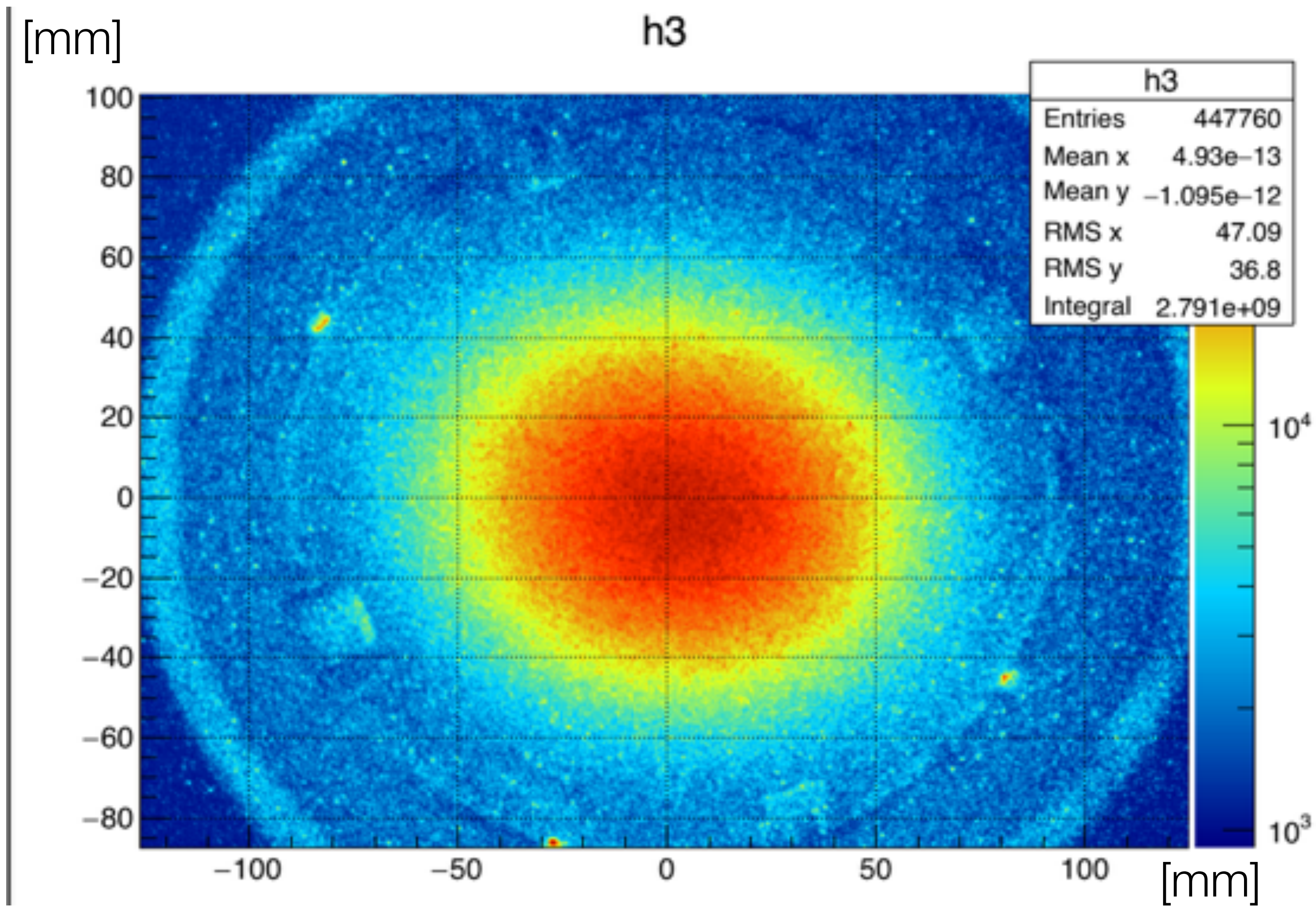


CCD
camera

gas
chamber

Reconstruction of 3D Distribution

- Acquired image



- Calibration for beam intensity is done

Future Prospects

Reconstruct the muon distribution

Operational test under magnetic field

Improvement of scintillation sector

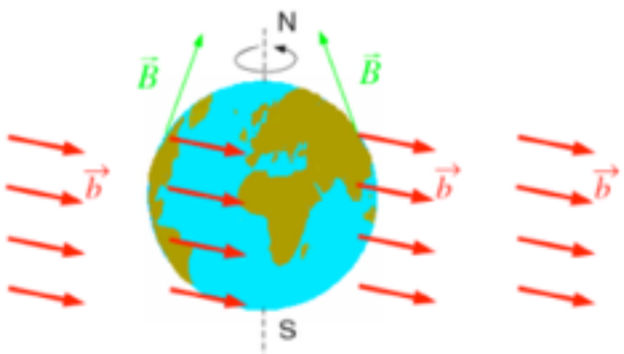
Summary

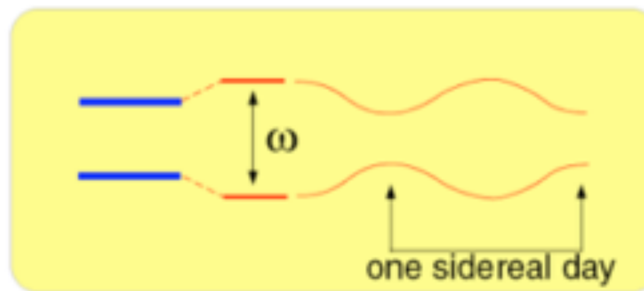
- Aim of MuSEUM: determination of the values of muonium HFS
- Demonstration of beam profile monitor has been done
- Data analysis is ongoing
- Further study for muon stopping distribution and improvements follows

JPS @WASEDA, 21st MARCH, 2015 A.M.(DF room)

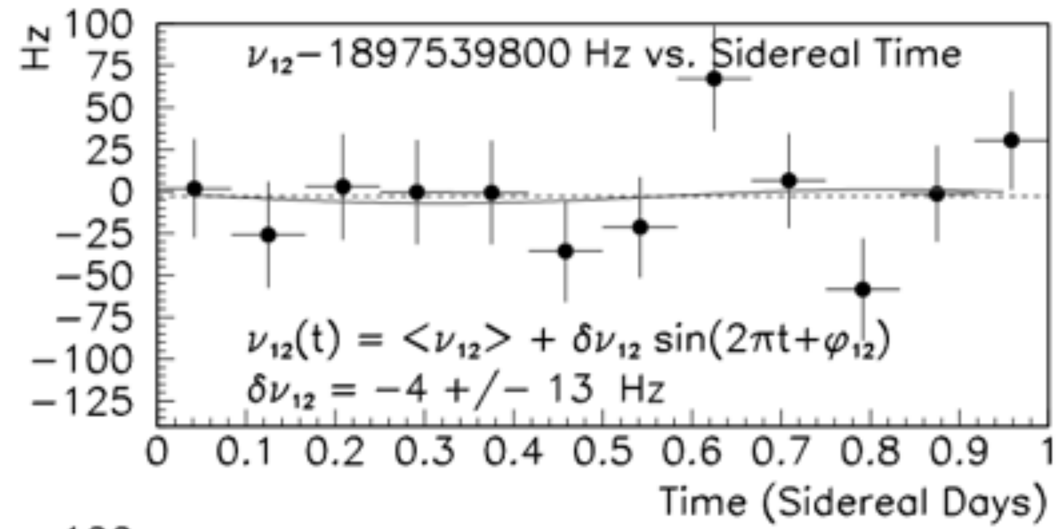
THANK YOU FOR YOUR ATTENTION!!

CPT and Lorentz invariance





R. Bluhm. “Testing Lorentz and CPT Symmetry”, http://users.ictp.it/~smr1951/Programme_files/08-Bluhm.pdf (2008), Jan 25, 2015.



V. W. Hughes, *et al*. PRL87, 11(2001)

- Hyperfine transition frequency can exhibit sidereal time oscillation as the earth rotates

- The bound of Lorentz violation parameter for muon sector (obtained from the previous Mu HFS)

$$\sqrt{(\tilde{b}_X^{\mu})^2 + (\tilde{b}_Y^{\mu})^2} \leq 2 \times 10^{-23}\ \mathrm{GeV}.$$

Muon mass

- LAMPF experiment (last MuHFS experiment) decided m_μ (120 ppb)
- CODATA m_μ →30 ppb
- CODATA = LAMPF+other theoretical calculations

muonium HFS VS positronium HFS

- μ_μ/μ_p → contribution to g-2 experiment on μ+
- positronium HFS →strong recoil effect, annihilation effect
- positronium HFS uncertainty ~ppm A. Ishida, Ph.D. Thesis, (2014)

  while muonium HFS uncertainty ~10 ppb
- positronium HFS ~200GHz muonium 4GHz

μ_μ/μ_p ratio

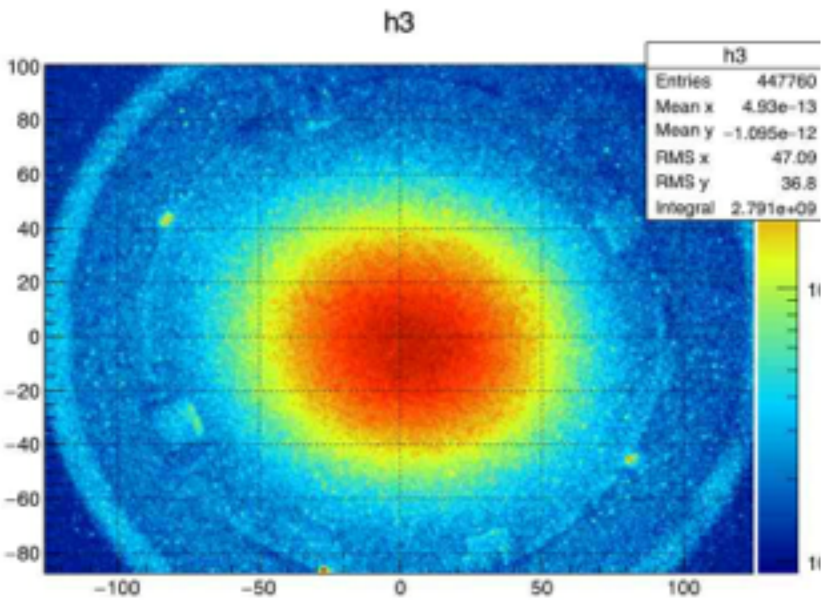
- With these assumption, we can determine the muon-proton magnetic moment ratio
  - QED is correct
  - No SUSY
  - α and R_∞ is well determined (i.e. they are external parameters)

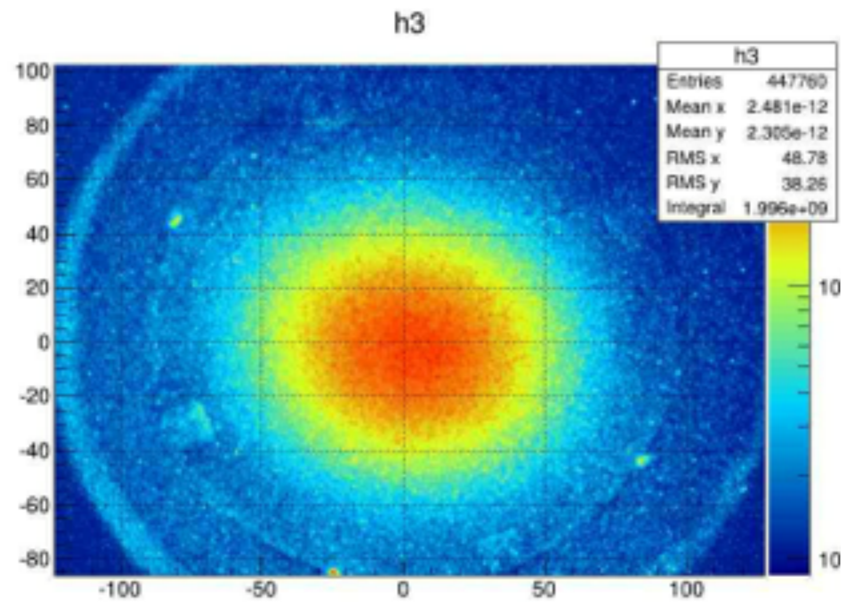
1s-2s VS HFS

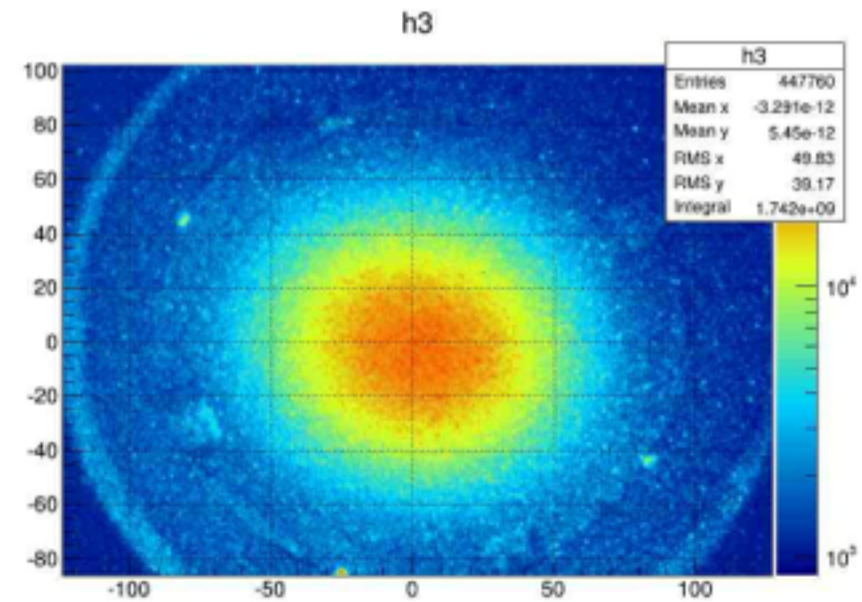
- The energy scale of hyperfine splitting is much smaller than that of 1s-2s transition

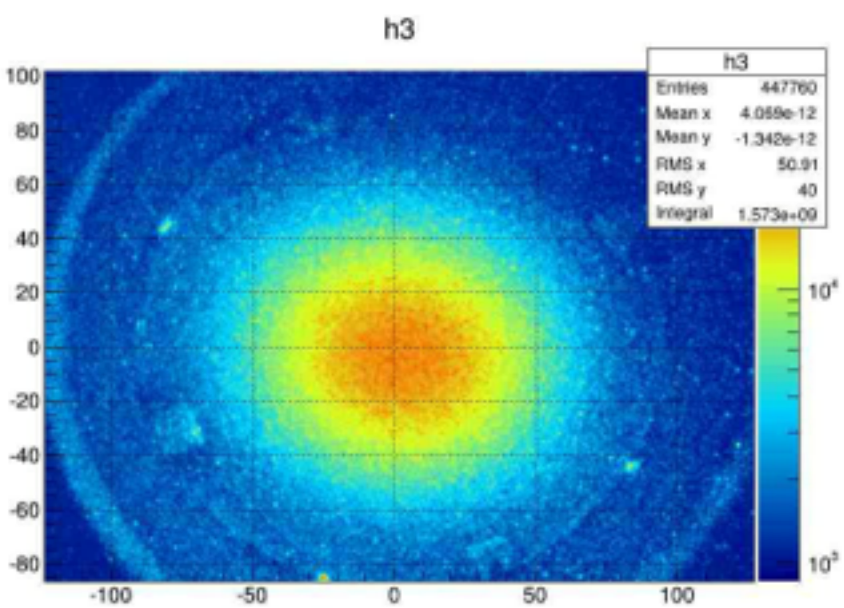
- →better absolute energy resolution (i.e. better sensitivity to CPT and Lorentz violation)

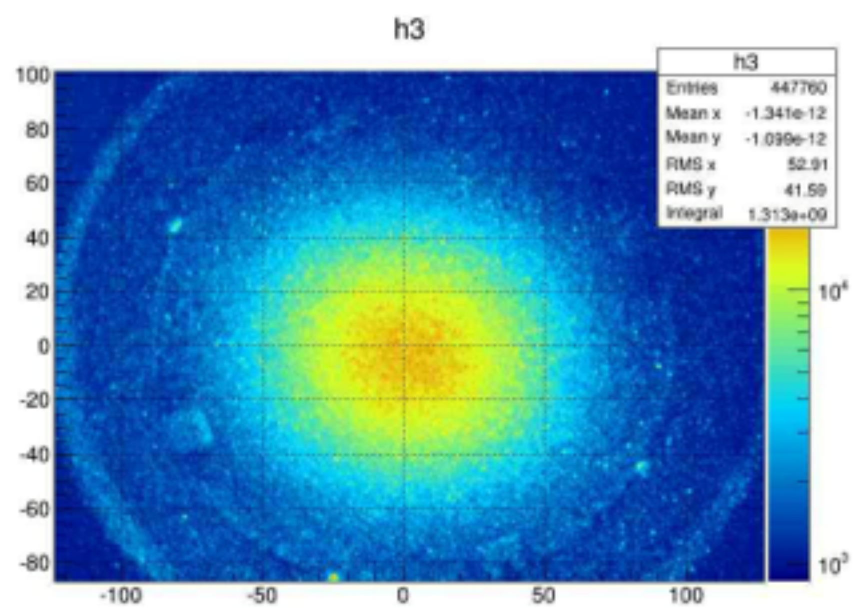
Beam test - Validation-Gas Pressure











0.1 0.3 0.5
0.7 1.0 [atm]

Magnetic Field

- LAMPF experiment: the muon-stopping area excessed the area where magnetic field was precisely measured→Large uncertainty related to magnetic field

- MuSUEM suppress these uncertainties from both sides - magnetic field and muon stopping distribution

- Best effort has been (will be) done to reduce magnetic-field uncertainty

- To suppress the uncertainty from muon stopping distribution, <u>Muon beam profile monitor is essential</u>

Why Muonium Hyperfine Structure

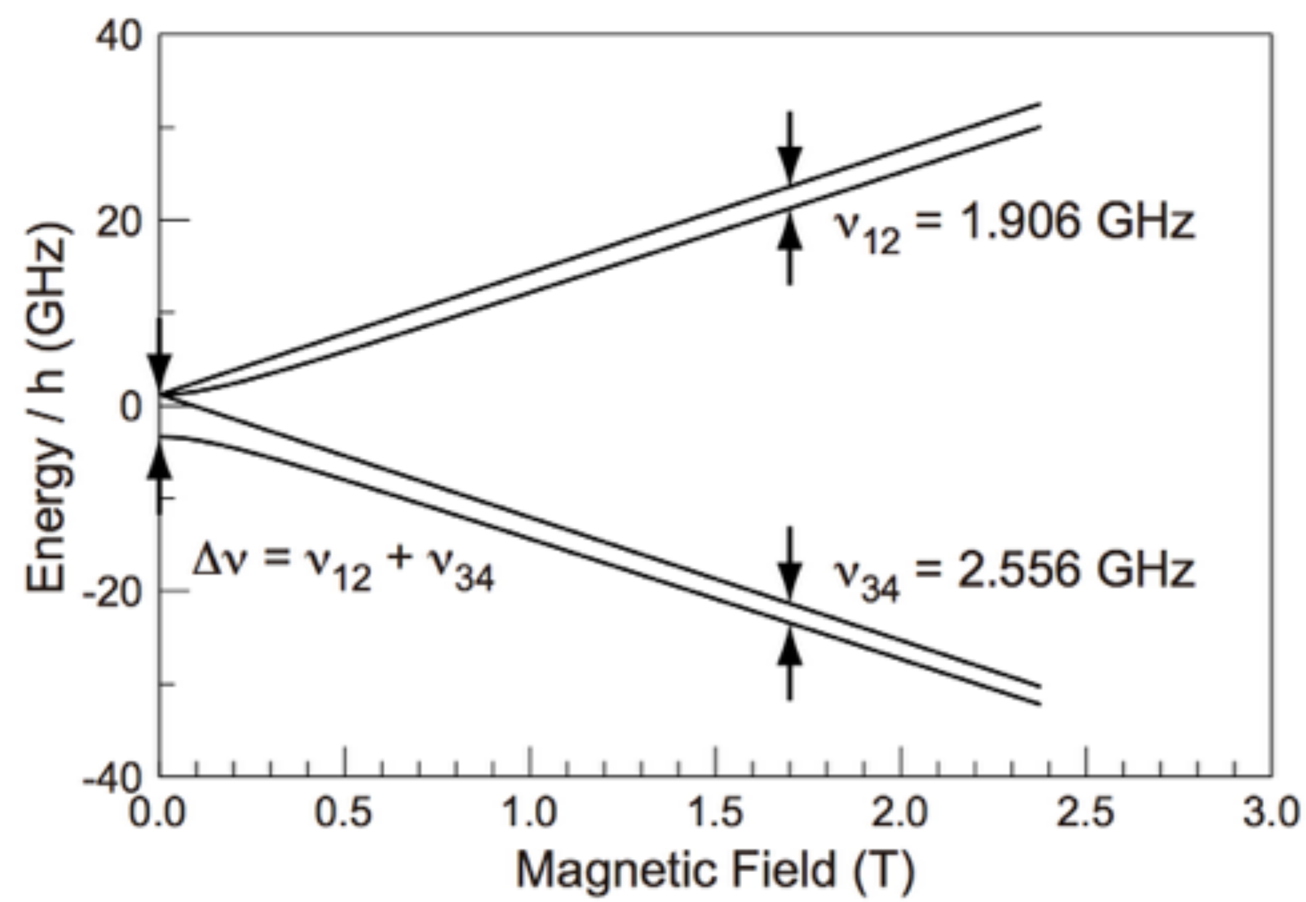
- Muonium HFS is a good probe for **bound QED theory**
- the experiment also determines **muon mass** →better input parameter for new muon g-2 experiment at J-PARC and Fermilab

$$\nu_{12} + \nu_{34} = \Delta\nu$$

$$\nu_{12} - \nu_{34} \propto m_\mu / m_p$$

- Test of CPT and Lorentz invariance

R. Bluhm, *et al*. PRL84, 1098(2000)



P. Strasser, *et al.* Proceedings for NUFACT 2014, to be published in the Proceedings of Science.

Statistic

- Last muonium HFS measurement was at LAMPF (Los Alamos Meson Physics Facility), USA
- The muonium HFS value by the LAMPF experiment is deteriorated by insufficient statistic
- H-Line is a new high-intensity muon pulse beam facility@ J-PARC
- The statistic acquired by H-line in four days is equal to the whole statistic of LAMPF experiment
- Reduction of systematic uncertainty is important