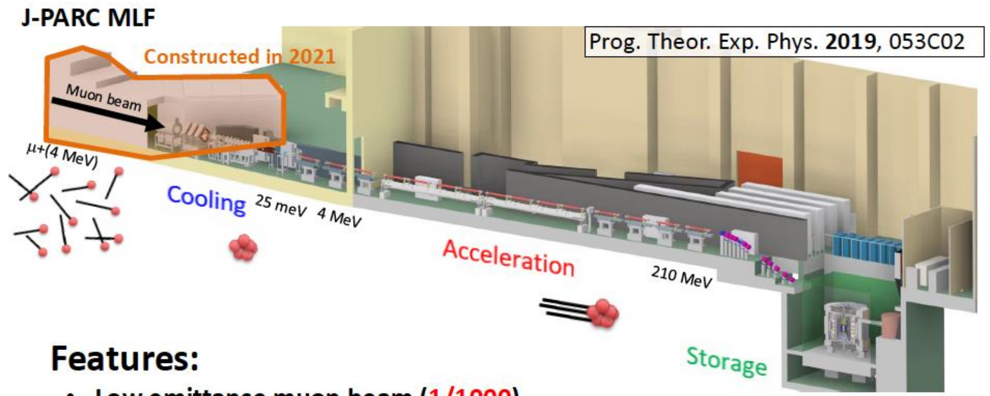
Ongoing work/discussions with J-PARC

Graziano Venanzoni

10/3/2025

All started with Mibe visit in Liverpool in October 2024

J-PARC muon *g*-2/EDM experiment **18**



Features:

- Low emittance muon beam (1/1000)
- No strong focusing (1/1000) & good injection eff. (x10)
- Compact storage ring (1/20)

The only experiment to check FNAL/BNL *g*-2 results

Excellent sensitivity to **muon EDM** about **100 times** better than the previous limit (sensitivity : 1.5 E-21 ecm)

Visit of Tsutomu Mibe to Liverpool

G. Venanzoni – 7/10/24

An interesting observation…possibility to reach O(100ppb) by increasing the momentum to 450-600 MeV

Expected uncertainties

	Estimation
Total number of muons in the storage magnet	5.2×10^{12}
Total number of positrons	0.57×10^{12}
Effective analyzing power	0.42
Statistical uncertainty on ω_a [ppb]	450
Statistical uncertainty on ω_p [ppb]	100
Uuncertainties on a_μ [ppb]	460 (stat.) < 70 (syst.)
Uncertainties on EDM [10^{-21} $e{\cdot}$cm]	1.4 (stat.) 0.36 (syst.)

Prog. Theor. Exp. Phys. **2019**, 053C02 (2019)

Topics for discussion

- **muon g-2**
  - J-PARC muon g-2/EDM
    - silicon strip tracker (mechanical design of structure, assembly)
    - timing layer
    - timing calibration
    - options for higher energy (300 MeV/c → 600 MeV/c?), higher polarization (>50%?)
  - MUonE
    - precision alignment monitor, silicon strip tracker
- **muon EDM@PSI & J-PARC**
  - Injection
  - detector alignment
  - track reconstruction
- **Misc.**
  - KEK/J-PARC summer student program for undergraduate students
  - MPP2024, Shinji Ogawa (KEK, the leader of detector mechanics and assembly) will come to Liverpool in November.

$$\frac{\delta\omega_a}{\omega_a} = \frac{1}{\omega_a \gamma \tau P}\sqrt{\frac{2}{NA^2}}$$

$$\omega_a = a\frac{qB}{m}$$

If p (=300 MeV) → 2 p (=600 MeV):
- B → 2 B → ωa → 2 ωa
- γ → 1.9 γ

→ A factor 3.8 statistical gain:
450 ppb → **119 ppb** (=450/3.8)

If Polarization (50%) → 2 P (=100%):
- additional factor 2:
- 119 ppb –> **60 ppb** (=230/2)

- TOT: possible factor 7.6 stat gain

GV – Muon meeting 7/10/2024

https://indico.ph.liv.ac.uk/event/1764/contributions/8713/attachments/3957/5595/visita_mibe.pdf

Soon confirmed by Mibe

Towards higher precision measurements of muon g-2 and EDM at J-PARC

Tsutomu Mibe (KEK)

December 18, 2024

1 Introduction

The J-PARC muon $g-2$/EDM experiment [1] aims to measure the $g-2$ and EDM of muon with precision of 450 ppb, 1.5×10^{-21} e·cm, respectively. The FNAL $g-2$ experiment has already obtained results with 200 ppb level and the final precision will be around 100 ppb level. An experiment at PSI plans to reach the EDM sensitivity in the order of 10^{-23} e·cm with the novel spin frozen method to enhance the EDM sensitivity. It is desired to have higher precision for both $g-2$ as well as EDM beyond the current precision.

The statistical precision of the anomalous spin precession angular frequency ω_a is determined as

$$\frac{\Delta\omega_a}{\omega_a} = \frac{1}{\omega_a\gamma\tau P}\sqrt{\frac{2}{NA^2}} \quad (1)$$

where key parameters are given int Table 1.

In the past, We considered options to improve the degree of spin polarization of muon [2] and intensity of muon beam [3]. On top of these options, new possibilities were proposed to increase beam energy and magnetic field as a result of discussion with Prof. G. Venanzoni and his colleagues during my visit to University of Liverpool in October, 2024. Figure 1 shows expected improvement of $g-2$ precision as a function of the beam momentum. Here we assumed the magnetic field is scaled up linearly with higher momentum. For example, two times higher momentum (p = 600 MeV/c, B = 6 T), precision becomes 120 ppb which is comparable to the Fermilab final precision. With the improvement of polarization to 90 %, the precision goes down beyond the Fermilab to 70 ppb. After my visit to Liverpool, I had a follow-up discussion on these possibilities with the core members in the collaboration.

This document briefly summarizes these possibilities and potential challenges. Note that all discussion described below are private considerations.

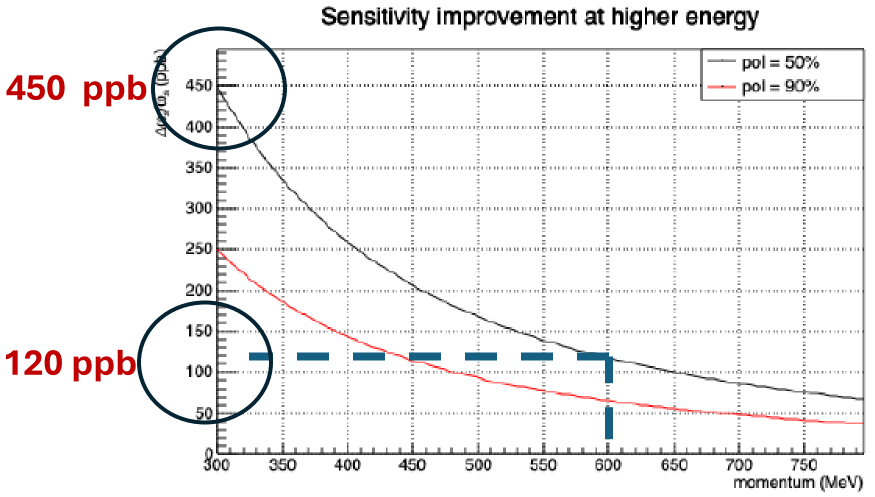


Figure 1: Expected improvement in sensitivity as a function of beam momentum. Based on private communication with G. Venanzoni

Work on three pillars and ongoing UK-JPARC collaboration with monthly meetings

- (Higher) Laser muon polarization (50% → ?)
- Higher magnetic field (3 → 6 T)
- High RF cavity (17 → O(30) MeV/m)

Jparc- Liverpool Monthly meetings

March 2025

05 Mar J-PARC g-2: UK-Japan Coordination Meeting

February 2025

05 Feb J-PARC g-2: UK-Japan Coordination Meeting

December 2024

18 Dec J-PARC g-2: UK-Japan Coordination Meeting

https://indico.ph.liv.ac.uk/category/12/

Laser muon polarization

- Ongoing work of Jonathan and Italian laser expert colleagues (A. Fioretti, C. Ferrari, C. Gabbanini) + JPARC colleagues
- Jonathan at JPARC these days
- Learning curve phase
- Challenging to achieve higher (> 50%) polarization
- EPSRC-JST funding application

Work in progress…

Higher magnetic field (3 → 6 T)

- Few companies contacted
- Reply from ASG

(www.asgsuperconductors.com)

-

> 40years experience on on SC and MRI magnets with close collaboration with research institutes and laboratories (CERN, Fermilab, etc…)

R. Marabotto (ASG)

https://indico.ph.liv.ac.uk/event/1890/sessions/1322/attachments/4229/5966/ASG%20Superconductors%2005%2003%202025.pdf

Higher magnetic field feasibility study (R. Marabotto, ASG)

R. Marabotto

Phase 1

FEASIBILITY STUDY FOR HIGH FIELD MAGNET

ASG SUPERCONDUCTORS

Pase 1:

Simlulation tool set-up & preliminary evaluations on feasibility:

3 T Magnet technical allignement: fine – tuning of the optimization tool & cross-check with existing design

High Field Magnet preliminary design and feasibility focused on:

- Field uniformity specs
- Shielding strategy
- Identification of possible showstopper on: performance / manufacturability / cost

Intermediate Review: Decision Go /non Go Phase 2

www.asgsuperconductors.com

Phase 2

FEASIBILITY STUDY FOR HIGH FIELD MAGNET

ASG SUPERCONDUCTORS

Phase 2:

Feasibility study & Conceptual design, drill down on :

- Cryogenics
- Quench protection
- Mechanical instabilities
- Manufacturing & Components tollerances

Cost evaluation

Deliverable: Conceptual Design Report

Timeline:

Phase 1 ~ 2.5 Months

Phase 2 ~ 3.5 Months

www.asgsuperconductors.com

https://indico.ph.liv.ac.uk/event/1890/sessions/1322/attachments/4229/5966/ASG%20Superconductors%2005%2003%202025.pdf

- 6 months study
- O(70kE) cost

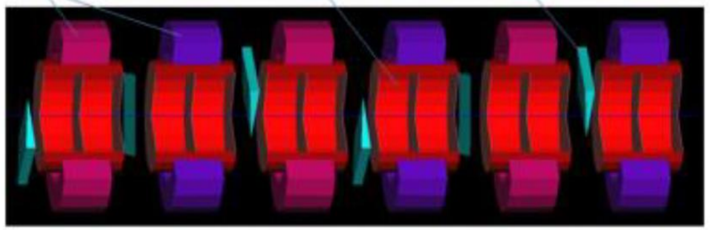
High gradient RF cavities (17 → O(30) MeV/m)

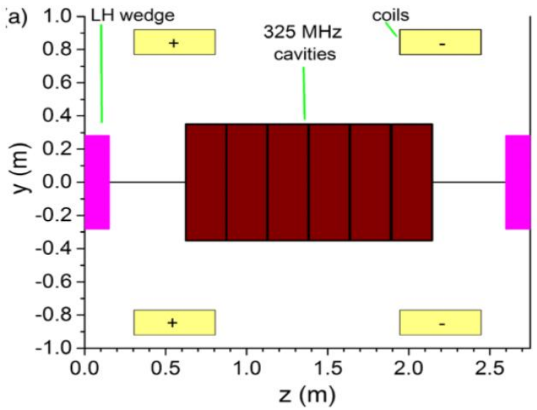
- In principle doable (Tsutomu suggests not to use SC cavities)

RF system for muon capture and cooling

Summarized from:
David Neuffer
Chris Rogers

Region	Length [m]	N of cavities	Frequencies [MHz]	Gradient [MV/m]	Magnetic field [T]	Peak RF power [MW/cav.]
Buncher	21	54	490 - 366	**0 - 15**		1.3
Rotator	24	64	366 – 326	**20**		2.4
Initial Cooler	126	360	325	**25**	**2**	**3.7**
Cooler 1	400	1605	325, 650	**22, 30**	**2-3, 4-6**	
Bunch merge	130	26	108 - 1950	**~ 10**		
Cooler 2	420	1746	325, 650	**22, 30**	**2-5, 8-13**	
Final Cooling	140	96	325 - 20			
Total	**~1300**	**3951**				**=> ~12GW**





It is a very large and complex RF system with high peak power

High gradient RF cavities: expertise at Liverpool/Daresbury (Cockcroft Institute)

“Professor Welsch’s QUASAR Group at the Cockcroft Institute has extensive expertise in beam diagnostics, accelerator design and optimization, and advanced RF technology, making them well-positioned to contribute to the design of high-gradient cavities for a higher-precision g-2 experiment in Japan. Given the need to increase the muon momentum beyond 300 MeV, achieving higher acceleration gradients, beyond the current 17 MeV/m, will be an important challenge, and the QUASAR Group’s capabilities in high-gradient RF structures, beam dynamics simulations, and experimental validation makes them well-placed to contribute. They routinely collaborate with other RF specialists within the Cockcroft Institute (including engineers specialized in normal-conducting high-power RF cavities). If funding is secured, the QUASAR Group could therefore contribute through simulation studies, diagnostics development, design and testing of novel cavity designs to support this ambitious goal.”

From Carsten Welsch

Outlook

- 6-12 months time to decide on the higher energy option
- As first step a feasibility study of the magnet with time and costs (→ proposal from ASG)
- In parallel: higher gradient E field RF and laser muon polarization
- Remind on possible sensitivity:
  - 450 MeV with 50% (75%) polarization → 200 (135) ppb statistical error
  - 600 MeV with 50% (75%) polarization → ~120 (80) ppb statistical error
- **Competitive** with Fermilab g-2 experiment (!)
- Physics/infrastructure constraints can be showstoppers (!)
- Look for funds/grants, collaboration
- Possible one PhD student from October

Next meetings:

- 19/3/2025: JPARC g-2 CB meeting. Presentation of Liverpool proposal to join g-2@JPARC experiment
- 24/3-25/3: Meeting in Shangai (discussion focused on current/new collaborations on g-2, MUonE, and possible other experiments)
- 7/4/25: (Monthly) Meeting Liverpool – JPARC
- 25/6-27/6: JPARC g-2 Collaboration meeting. Plan to attend it in person

If you are interested to join this activity please let me know...

Shangai workshop

Monday, 24 March

09:00 → 09:10	**Opening Remarks**	10m	Tsung-Dao Lee library/Fourth ...
09:10 → 12:10	**Muon g-2 and EDM Experiments** Convener: Tsutomu Mibe (IPNS/KEK)		Tsung-Dao Lee library/Fourth ...
09:10	**J-PARC g-2/EDM Experiment Overview** Speaker: Tamaki Yoshioka (Kyushu University)	30m	
09:40	**End-to-End Simulation** Speaker: Masato Kimura (KEK)	1h	
10:40	**Coffee Break**	30m	
11:10	**AI-Enhanced Magnetic field measurements** Speaker: Bingzhi Li (Zhejiang Lab / Shanghai Jiao Tong University)	30m	
11:40	**Higher Energy, Stronger B-field** Speaker: Tsutomu Mibe (IPNS/KEK)	30m	
12:10 → 14:00	**Lunch**	1h 50m	Tsung-Dao Lee library/Fourth ...
14:00 → 16:40	**MUonE Experiment and Synergies** Convener: Graziano Venanzoni (University of Liverpool)		Tsung-Dao Lee library/Fourth ...
14:00	**MUonE Status and 2025 Run** Speaker: Riccardo Pilato (University of Liverpool)	40m	
14:40	**In-person Discussion**	1h	
15:40	**Discussion Including Remote Participants**	1h	
16:40 → 17:10	**Coffee Break**	30m	Tsung-Dao Lee library/Fourth ...

Remote sessions: **Monday 24/3**:

- 7:40am UK time (8:40am CET): MUonE
- 9:20am UK time (10:20am CET): g-2

Tuesday 25/3: 9:00 am UK time (10 am CET): MUonE longer plans

Monday, 24 March

16:40 → 17:10	**Coffee Break**	30m	Tsung-Dao Lee library/Fourth ...
17:10 → 18:10	**Muon g-2 and EDM Experiments** Convener: Tsutomu Mibe (IPNS/KEK)		Tsung-Dao Lee library/Fourth ...
17:10	**Polarization**	10m	
17:20	**Discussion Including Remote Participants**	50m	
18:10 → 20:10	**Workshop Banquet**	2h	

Tuesday, 25 March

09:00 → 11:30	**Muon Physics Programs in China** Convener: Prof. Liang Li (Shanghai Jiao Tong University)		Tsung-Dao Lee library/Fourth ...
09:00	**A Pulsed Muon Source Based on a High-Repetition-Rate Electron Accelerator (SHINE)** Speaker: Prof. Kim Siang Khaw (TDLI/SJTU)	30m	
09:30	**Conceptual Design Report of Muonium-to-Antimuonium Conversion Experiment (MACE)** Speaker: Gui-Hao Lu (Sun Yat-Sen University (Zhongshan University))	30m	
10:00	**Design and Prospect of Muon Station for Science, Technology, and Industry (MELODY)** Speaker: Yu Bao (IHEP, China)	30m	
10:30	**Coffee Break**	30m	
11:00	**The Feasibility Study of the GeV-Energy Muon Source Based on HIAF (High Intensity Heavy Ion Accelerator) Complex**	30m	
11:30 → 12:30	**Discussion on Collaborations with MUonE and/or J-PARC g-2/EDM** Conveners: Graziano Venanzoni (University of Liverpool), Tsutomu Mibe (IPNS/KEK)		Tsung-Dao Lee library/Fourth ...
12:30 → 13:30	**Lunch Break**	1h	Tsung-Dao Lee library/Fourth ...
13:30 → 16:30	**Visit to SHINE**	3h	SHIN
16:30 → 17:00	**Coffee Break**	30m	Tsung-Dao Lee library/Fourth
17:00 → 18:00	**MUonE Experiment and Synergies: Remote Discussion on Longer-term Collaboration** Convener: Themis Bowcock (University of Liverpool)		Tsung-Dao Lee library/Fourth ...