Muons for HEP

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Workshop on Laser Driven GeV Muon Sources
March 20, 2025

Muon beams are very important tools for the present and future of experimentation in HEP, for at least three different reasons

- Fundamental Physics Studies (SM precision test, BSM searches)
- Muon or electron-muon colliders
- Test beams for detector’s characterization

These are very different topics that require completely different beam characteristics and consequently very different machine set-ups

Muon beams for Fundamental Physics

Muons are ideal probes for new physics searches since their SM properties are very well known and under theoretical control

Experiments include:

- Precise measurements of muon anomaly
- Ultra rare or forbidden decays measurements
- Studies on «exotic states», such as muonium or muonic atoms
- Scattering experiments for the study of the proton radius

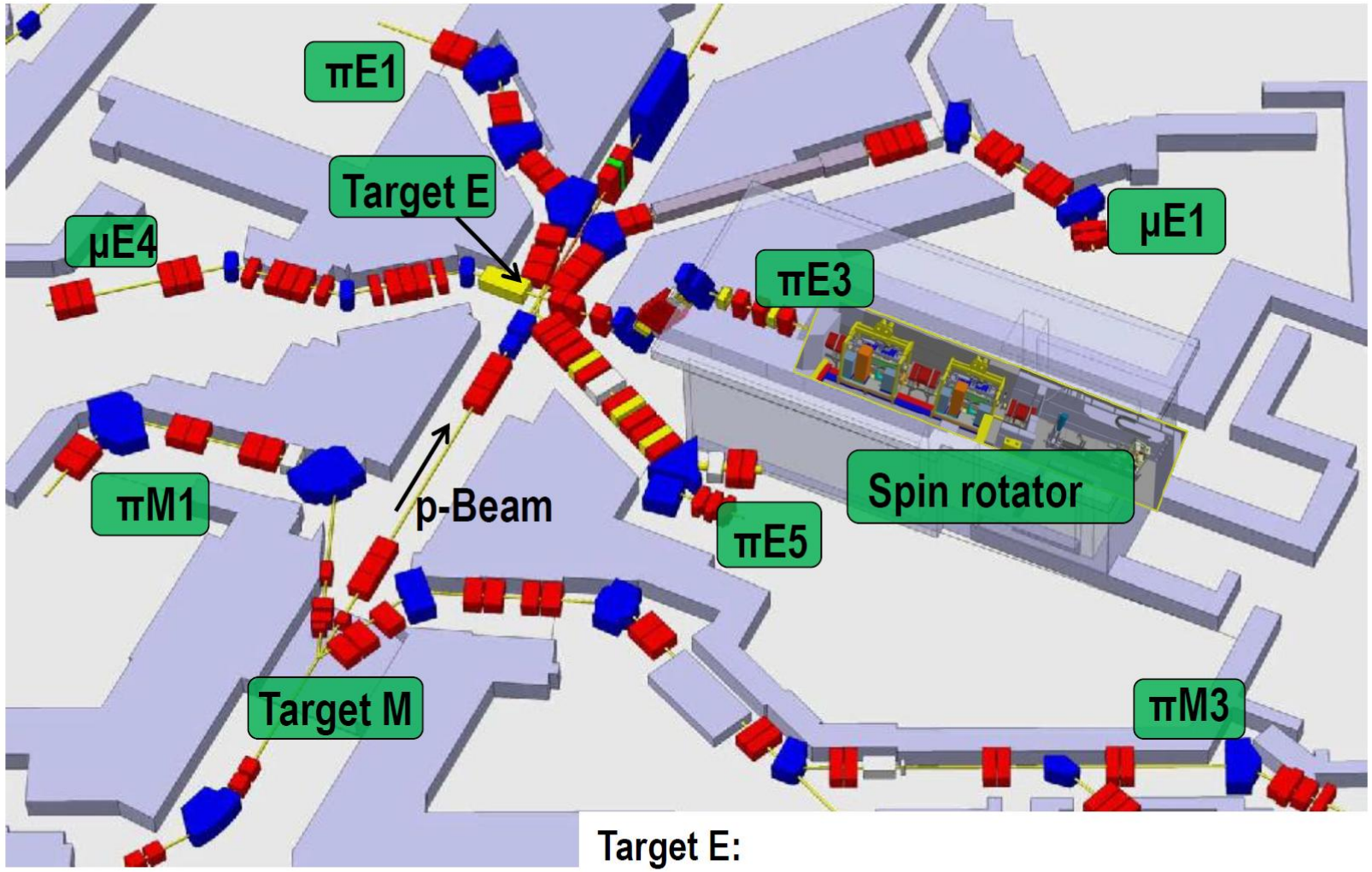
Beam requirements strongly vary among various experiments

- In general **fluxes** must be high or even very high for rare decay experiments (*BR*s down to $O(10^{-12})$)
- **Energy spectrum**: lower momenta better to minimize decay volume, but less collimation of decay products; for exotics in general the lower the better
- **Momentum resolution**: very precise (per mil level) for scattering experiments, less demanding for others

There are (at least) three major running facilities which provide muon beams for fundamental physcis

- **PSI**, Villigen Switzerland: Rare muon decays (MEG), Muon scattering (MUCOL)
- **FERMILAB**, Batavia USA, Muon Magnetic Anomaly, Rare Muon decays (MU2e)
- **JPARC**, Tsukuba Japan

μ/π Secondary Beam Lines



Taken from D. Kiselev, 24.03.21

Target M:
πM1: 100-500 MeV/c Pions
πM3: 28 MeV/c Surface Muons

Target E:
πE1: 10 - 500 MeV/c High Intensity Pions und Muons
μE1: Polarized Muon Beam
πE3: 28MeV/c Surface polarized Muons
μE4: 30 - 100 MeV/c High Intensity Polarized Muons
πE5: 10 - 120 MeV/c High Intensity Muons

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Overview of Secondary Beam Lines

	PiM1	PiE5	PiE1	PiE3	PiM3	MuE4	MuE1
Target	M	E	E	E	M	E	E
Particle Type	π/e/μ/p	μ/π	π/μ/p	μ, π	μ	μ	μ (cloud)
Momentum Range	10-500 MeV/c (max 300 MeV/c for positive particles)	20-120 MeV/c	10-500 MeV/c ustream ASK 10-120 MeV/c downstream ASK	μ:10-40 MeV/c π: 50 – 250 MeV/c	10-40 MeV/c	10-40 MeV/c	60-120 MeV/c
Typical Momentum	15-300 MeV/c	28-85 MeV/c	PP: 10-50 MeV/c μSR: 28 MeV/c Irrad: 300 MeV/c	28 MeV/c	28 MeV/c	28 MeV/c	60-125 MeV/c
Max Rate [mA^{-1} s^{-1}]	@ 350 MeV/c $\pi^{+/-}$:$2x10^8$	@120MeV/c π^+:$2x10^{10}$ μ^+:$5x10^8$	@ 300 MeV/c π^+:$4x10^9$	μ^+:$3x10^7$ π^+ :$2x10^9$ @ 170 MeV/c	μ^+:$3x10^6$	μ^+:$4x10^8$	@ 300 MeV/c μ^-:$6x10^7$
Typical Use	Particle Physics Test Experiments, Detector/Material Irradiation	Particle Physics Experiments	μSR Dolly Particle Physics Experiment, Detector Irrad.	μSR HAL 9500 (High Field)	μSR GPS and LTF	μSR LEM Facility	μSR GPD Facility

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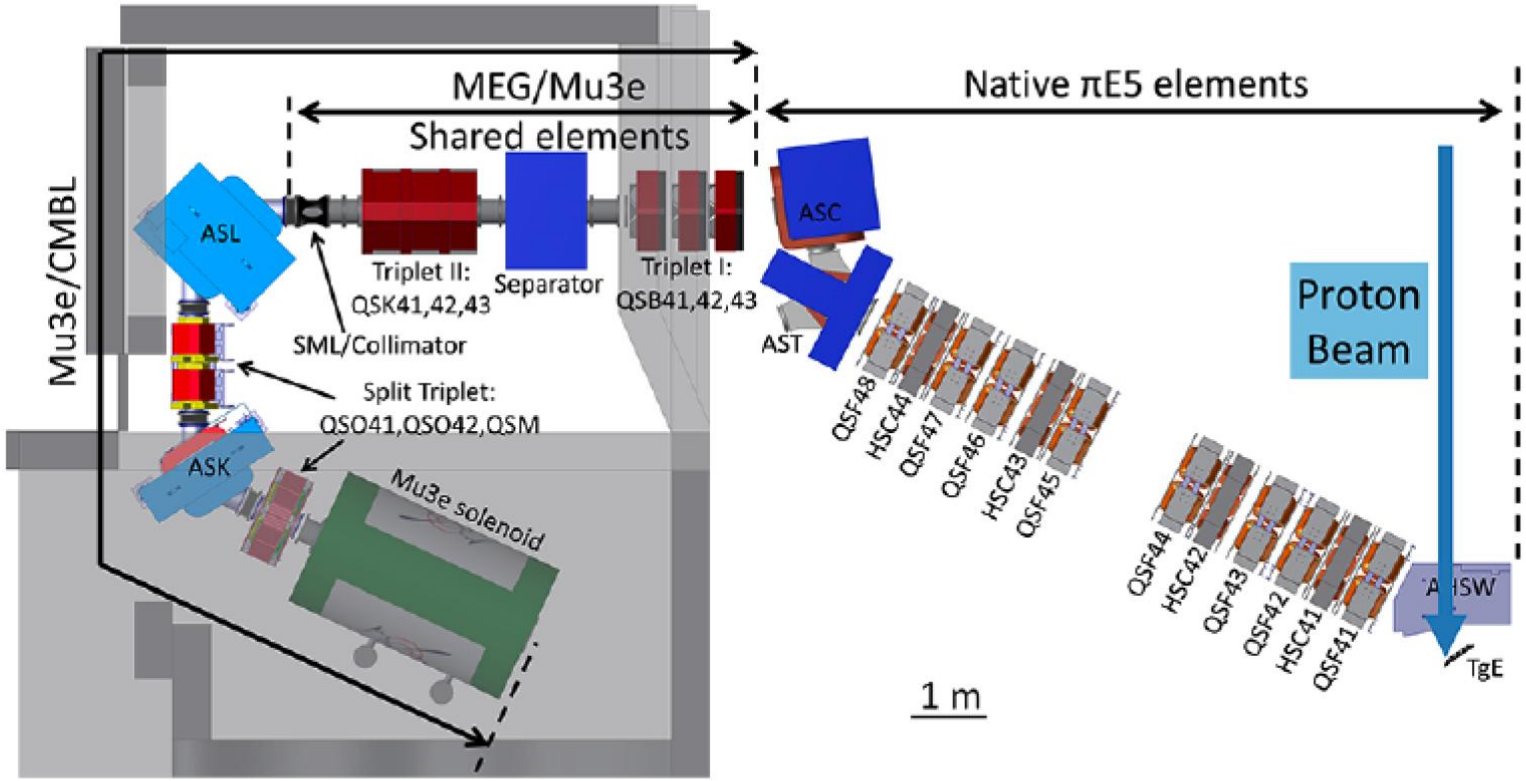
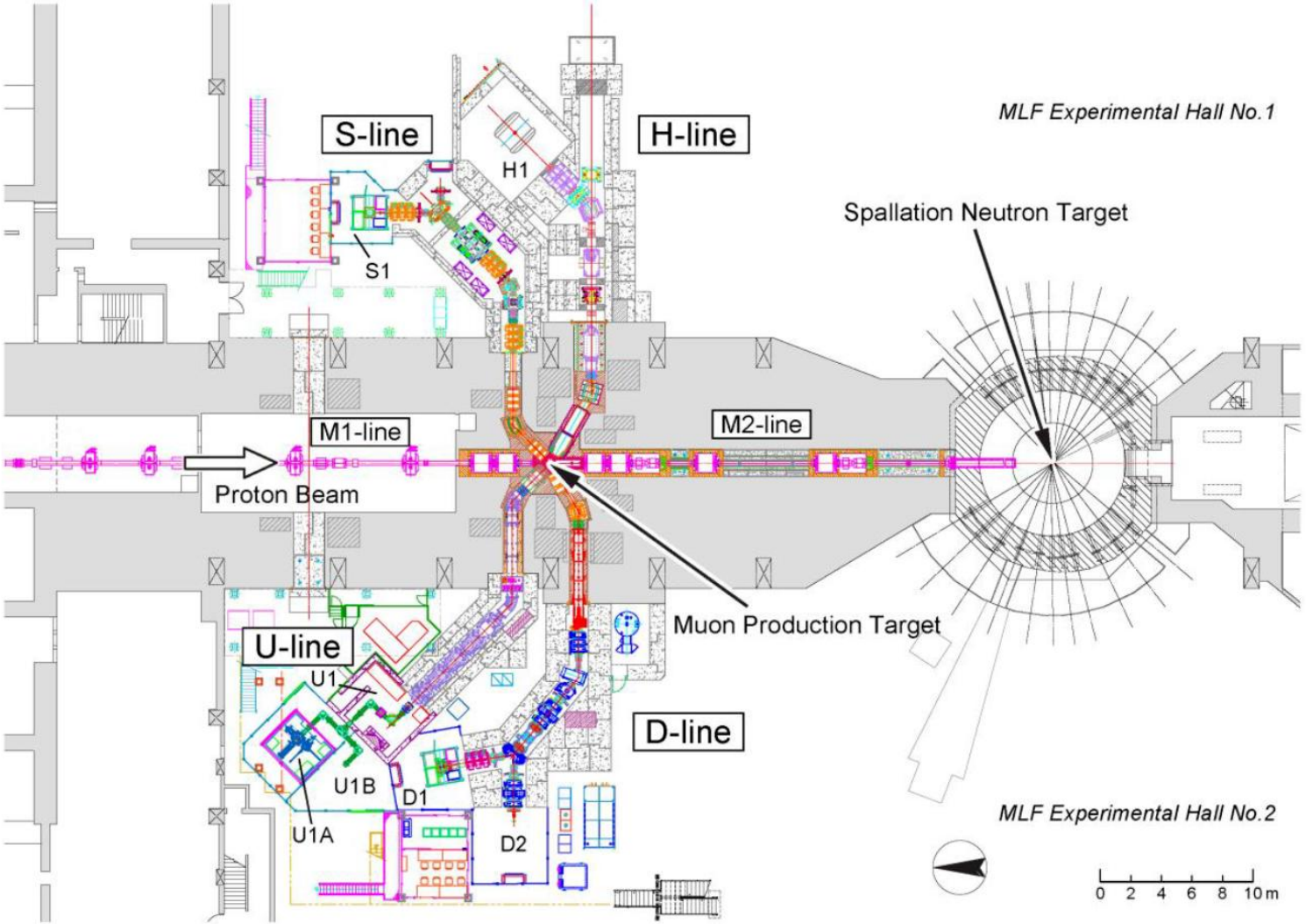
Particle physics: (**CHRISP facility**)

μSR (Muon Spin Rotation), SμS (Swiss Muon Source)

Mu3e beamline



JPARC Muon Facility



S line

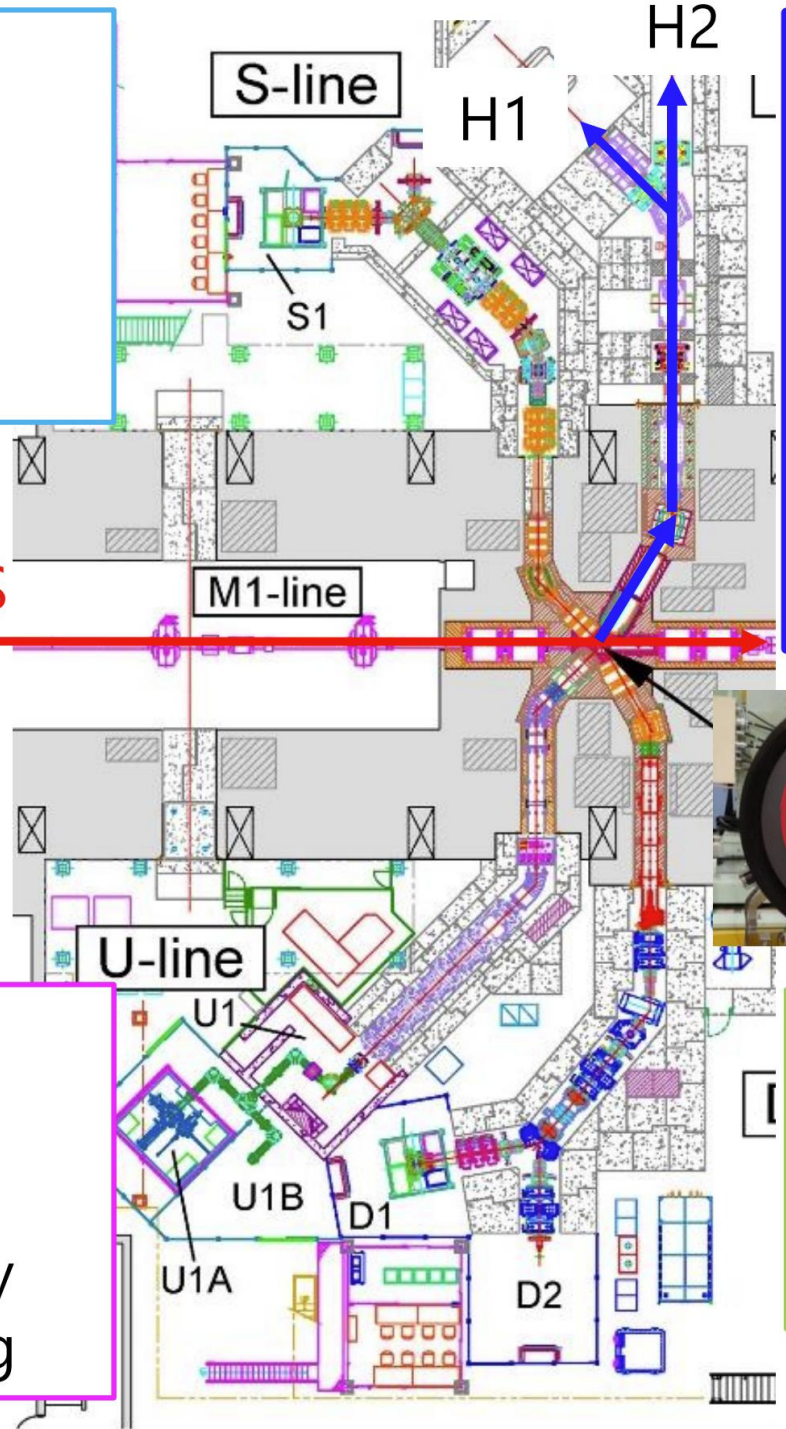
- surface μ^+
- S1 for μSR
- **S2 for Mu 1S-2S**
- S3/S4 are planned

H line

- surface μ^+ (10^8 μ^+/s), cloud μ^+/μ^- (up to 120MeV/c)
- for high intensity & long beamtime experiments
- **H1 for Mu HFS & $\mu^-N \rightarrow e^-N$**
- **H2 for g-2/EDM & TμM, under construction**

3GeV proton from RCS

2e15 /s @1MW



Muon target
(graphite, ^{t}20mm)
Rotating target

U line

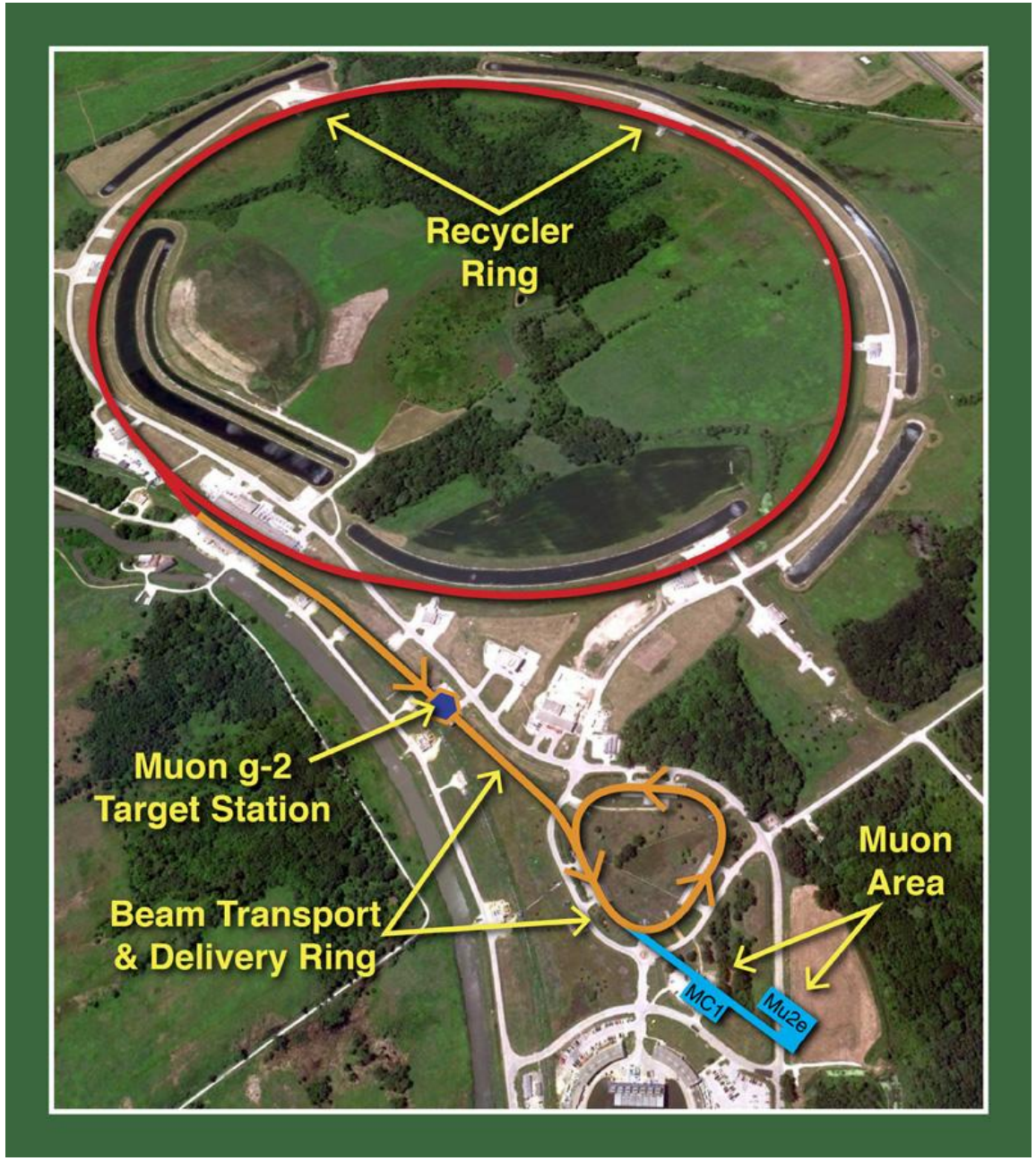
- ultra slow μ^+
- U1A for nm-μSR
- U1B for μ microscopy
- under commissioning

D line

- decay μ^+/μ^-, surface μ^+
- D1 area for μSR
- D2 for various sciences

FERMILAB

This aerial image shows the beamlines used for both the **Muon g-2** and **Mu2e** experiments. The Recycler Ring sends protons into the Muon g-2 target station to produce muons, which go through the Delivery Ring to the experiment in the MC-1 building. For the Mu2e experiment, the Recycler Ring will send protons into the Delivery Ring; from there the protons head to the Mu2e target station in the Mu2e building



Muon Collider Studies

In the course of the last few years a strong interest has risen in the HEP community for the possibility of building a multi-TeV muon collider

Studies submitted to the 2020 update of the ESPP showed that such a machine would be extremely promising both as a precision and as a discovery machine

Note also that at KEK (Japan) a proposal for a electron-muon collider (μ-Tristan) has also been put forward

Muon Collider Studies

There are many technical issues that need to be solved before a real machine of this type can be really put in operation, some of which can be studied in smaller scale facilities

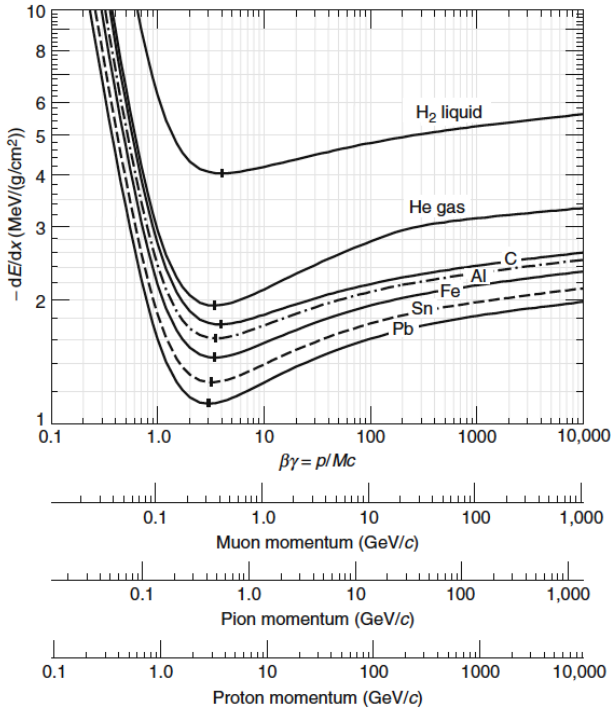
For instance developing methods for minimizing the emittance of the beams is a critical issue. What can be done with a laser source?

Also, i believe, it could be interesting to understand whether a non conventional muon source can be more cost and space effective wrt the tradional ones (this is pure speculation on my side, though)

Muon Beams for Detectors Test

Effective muon beams are strongly required for detector's test and characterization

Muons of momenta larger than a few hundreths MeV are minimum ionizing particles, thus excellent «standard candles» for calorimeters response and a perfect test tool for tracking devices



Examples of beam requirement for gaseous detector R&D

- **Gain calibration :** Penetrating particles, low beam contamination, limited energy spread, rate of the order of few kHz/cm^2
- **Space resolution :** Penetrating particles, low beam contamination, limited energy spread, rate of the order of few kHz/cm^2, limited angular divergence
- **Time resolution :** Penetrating particles, low beam contamination,limited energy spread, rate of the order of few kHz/cm^2, limited angular divergence

Beam Line	Particle type	Maximum beam momentum	Maximum intensity/ spill	Spill length [s]	Δp/ pmax	Acc.	Beam height	Beam physicist	Deputy	Operational Support
H8	Protons Electrons Hadrons Positrons Muons Ions	Primary proton beam: 400 GeV/c Secondary beam: 360 GeV/c	Hadrons: 10^6 Electrons: 10^4 Ions: 10^5	4.8	±1.5 %	2.5 µSr	2860 mm	Maarten Van Dijk	Johannes Bernhard	Anna Baratto Roldan

https://be-dep-ea.web.cern.ch/experimental-areas/north-area/ehn1

A conference devoted to a discussion on muon based experiment will be held in Venice on May 26-30. Abstract submission extended to March 31st

https://agenda.infn.it/event/42349/