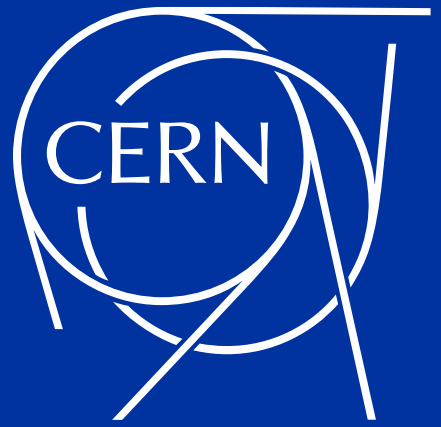




# Protons in Europe : Possible synergies with the Muon Collider

**N. Charitonidis** [CERN, BE-EA]
**Acknowledgements :** G. Arduini ,J. Bernhard, M. Brugger, M. Calviani, R. Losito, D. Reggiani, C. Rogers ,D. Schulte and others

**23.06.2023**

# Outline

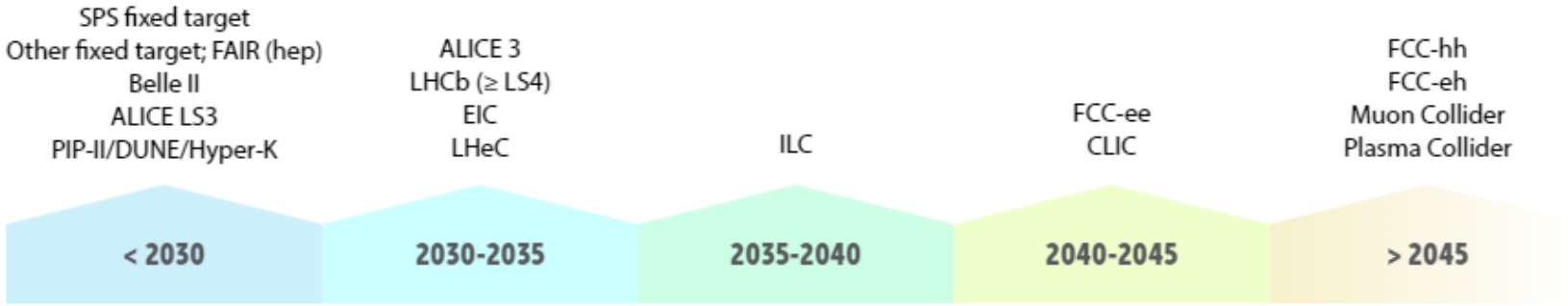
- **Introduction – Scope of the presentation**
- **Existing proton (or proton-driven) facilities in Europe**
  - Focusing on already proposed or ideas for synergies with the Muon Collider Community
- **Outlook on future proposals**
  - Keeping the door open for collaborations and possible knowledge sharing

- **Not covered :**
  - Medical facilities, LHC experiments, FCC, ions beams and Light Sources (SLS, SwissFEL ...)
  - Any facility with proton momenta < 0.5 GeV/c (GSI UNILAC, Legnaro, GANIL ..)
  - Any facility that by mistake have been overlooked ?

# Introduction

- **Today many proton facilities available in Europe, both for physics and for test-beams**

- **In the foreseeable future: the ESPP outlined an indicative timeline for future collider and larger accelerator facilities, many of them proton-driven**





- **Sharing concepts, techniques, materials and knowledge→ "Synergies"**
  **→ Focus on exactly this aspect for the Muon Collider Collaboration**

**European Strategy for Particle Physics - Accelerator R&D Roadmap**

# Two types of beam structures

- **“Slowly” extracted beams**
  - Debunched beams with spill lengths > ~ ms
  - Useful to characterize and benchmark detectors with primary or secondary beams

- **“Fastly” extracted beams**
  - Bunched beams with bunch lengths < ~ms
  - Useful for experiments that need high instantaneous intensities and for understanding material thresholds

# Existing Proton-driven Facilities

# Proton facilities in Europe – CERN PS (1)

- **T08 – East Area Irradiation Facilities**
  - Proton beam **24 GeV/c**– **debunched** – spill length **~400 ms**, intensity ~**5x10$^{11}$ pps**
  - **Primary beam (IRRAD) and Secondary Field (CHARM) available**
  - Flexible to accommodate new experimental collaborations for tests

- **T09/10 – East Area Secondary lines**
  - Mixed hadron or electron beams **0.1 – 12 GeV/c, debunched** – spill length **~400 ms** intensities **~10$^{6}$ pps**

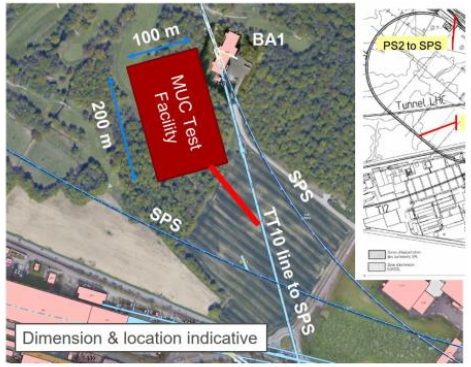
- **n-TOF – Neutron Time-of-Flight facility**
  - Proton beam **20 GeV/c** - 4σ bunch length : **28** or **40 ns**, intensity ~**8x10$^{12}$ ppb**
  - An experiment can be installed in TT2A line before the target and use the proton beam.
  - Possibilities for a demonstrator in TT7 and TT10 under consideration (R. Franqueira, R. Losito, M. Calviani et al)

- **ISOLDE - Radioactive Ion beam facility**
  - Proton beam **1.4 GeV/c** from PS Booster, bunch length **230 ns,** intensity **8x10$^{12}$ ppb**
  - **Dedicated facility for nuclear, fixed target, condensed matter & biophysics**

# A possible MUC demonstrator facility at CERN ?

## TT10 line option (recap)

- First ideas proposed by Marco C. in the 1st Community meeting. **TT10 line option seen as most attractive** (Roberto L. presentation).
  - O(80kW) should be easily feasible by going sufficiently underground.
  - 4 MW does not appear to be a showstopper in this layout, but detailed studies will have to be performed.
  - Future upgrades towards a collider and HP-SPL should be compatible with this layout.
  - **Experience** with other facilities available




**Courtesy: R. Ximenez, M. Calviani**

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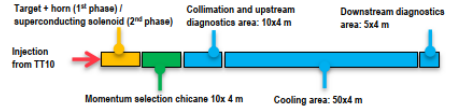
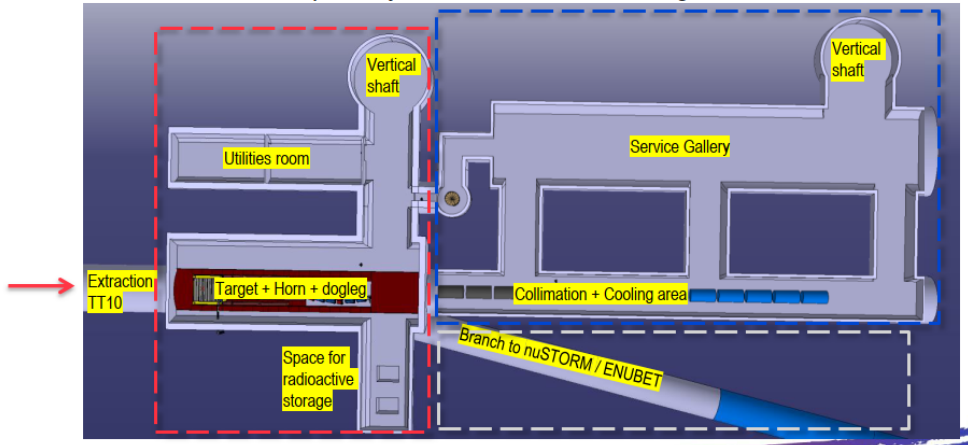
**See talk of D. Schulte → This workshop**

## Conceptual layout




**MUC Demonstrator** VERY Conceptual layout → To be taken with a "grain of salt"

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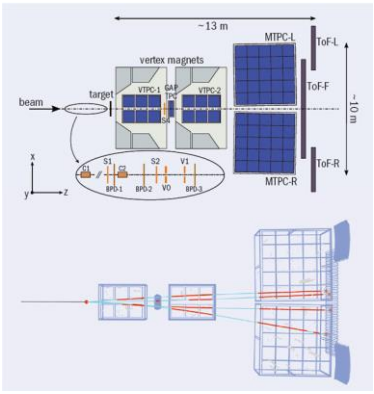
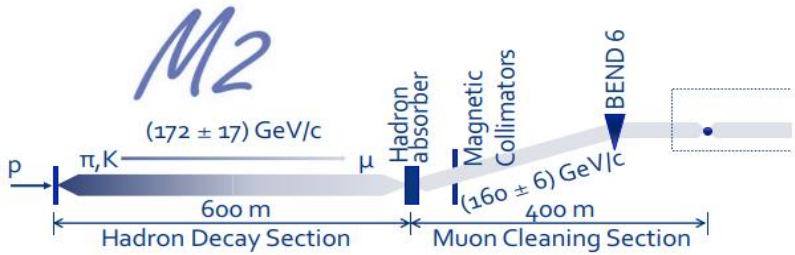
# Proton facilities in Europe – CERN SPS (2)

- **H2/H4/H6/H8 : North Area Secondary beams**
  - Proton beam **400 GeV/c**– **debunched** – spill length **~4.8 s**, intensity **1x10$^2$~1x10$^7$ pps and** momentum spread **up to 2%**
  - Flexible to accommodate new experimental collaborations for tests
  - **Hadron production or other service measurements** possible with the NA61 collaboration TPC




- **M2: Muon beam**
  - Unique high energy muon beam in the world, **debunched** – spill length **~4.8 s** intensities **~10$^8$ mps** between **100 – 200 GeV/c**
  - **For the moment dedicated to AMBER experiment**
  - **However: Strong possibility for synergies on magnetic collimation, muon shields, simulation codes, ...**





Adjustable Magnetic collimator


Fixed Magnetic Collimator

# Proton facilities in Europe – CERN (3)

- **HiRadMat test facility**
  - Proton beam **440 GeV/c** - 4σ bunch length : ~**1** ns, intensity ~**5x10$^{9}$ 2.3x10$^{11}$ ppb, up to 288 bunches in total (6x10$^{13}$ ppp)**
  - An experimental area available for tests with the LHC-type high-brightness beams → **Useful for MMW targetry studies or accelerator components (like vacuum windows)**
  - **Transnational access support for experimental teams to perform their experiment via EURO-LABS**
  - **Possibilities of scaling the HiRadMat beam to similar parameters as the muon collider proton or even muon beam, in order to study single pulse effects ?**
  - **Possibilities for extracting lower momentum beams to HiRadMat with the same time structure being currently studied.**

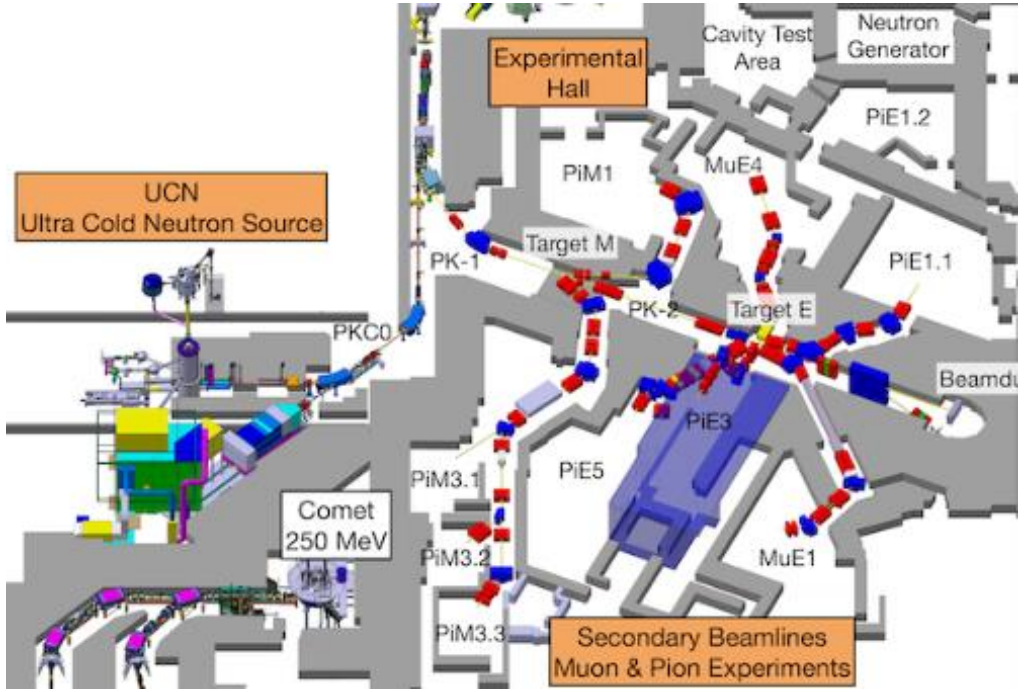
HiRadMat
High-Radiation to Materials


Example:
33 bunches of p+ @ 1x10$^{11}$ppb @440 GeV/c @0.25 mm → 0.90 kJ/cm$^{3}$ @ 1um $Si_3N_4$

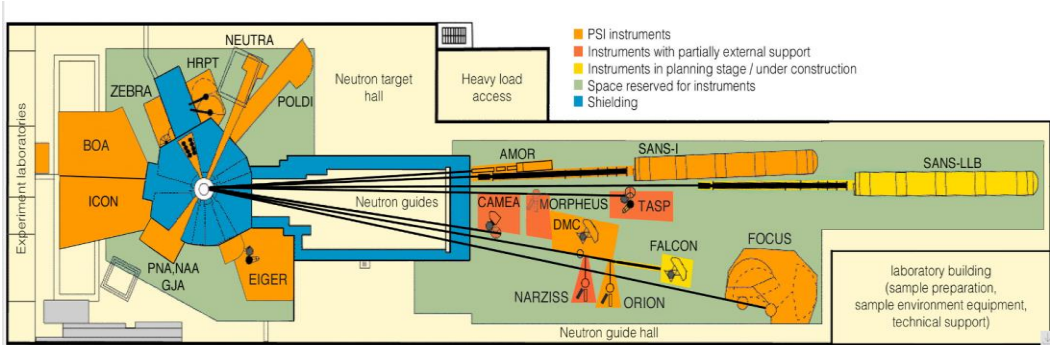
4x10$^{12}$ mu+ @32 MeV/c @ 0.6mm → 0.89 kJ/cm3 @ 1um $Si_3N_4$
Calculations: J. Ferreira Somosa

# Proton facilities in Europe – PSI

- **PSI Secondary beam lines**
  - **Secondary muons**, pions protons electrons & ultra-cold neutrons
  - Momenta up to **0.5 GeV/c** with maximum fluxes **up to 2x10$^9$ p/s/mA and** momentum spread up to **8%.**
  - **Various properties quite dependent on the specific beamline**
  - **Could be useful for components testing**
    - **More information for the muon beams available here**
    - **Future project HIMB will provide muon beams up to 10$^{10}$ muons/s**



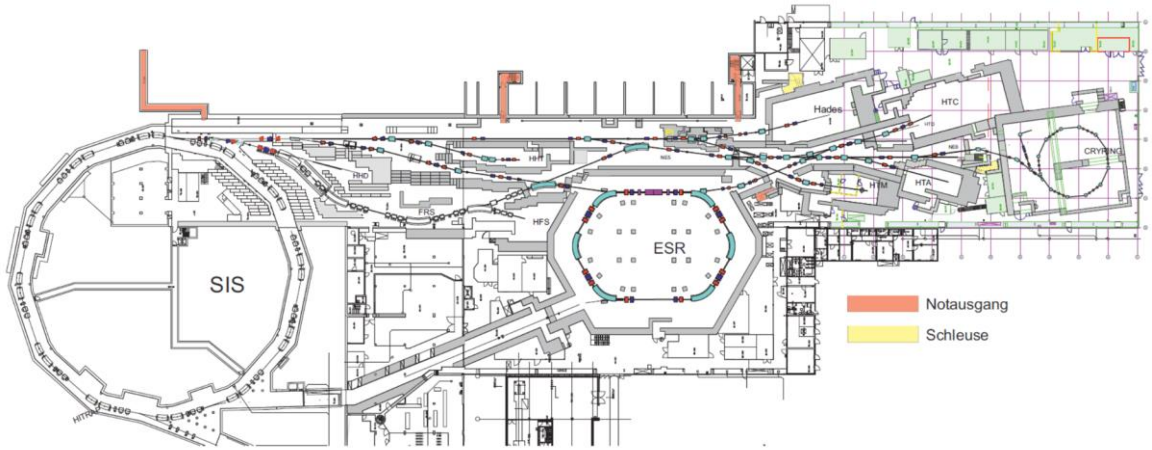

- **SINQ : Neutron Scattering in the SSNS**
  - A unique continuous neutron source providing a flux of 10$^{14}$ n/cm$^2$/s (starting from 590 MeV protons) with a max. power of ~1 MW
  - **Cold and utra-cold neutrons** can be **useful for material research**
  - **Very broad** spectrum of research with dedicated instruments available – **Possible synergies need to be looked at in detail**



# Proton Facilities in Europe – GSI

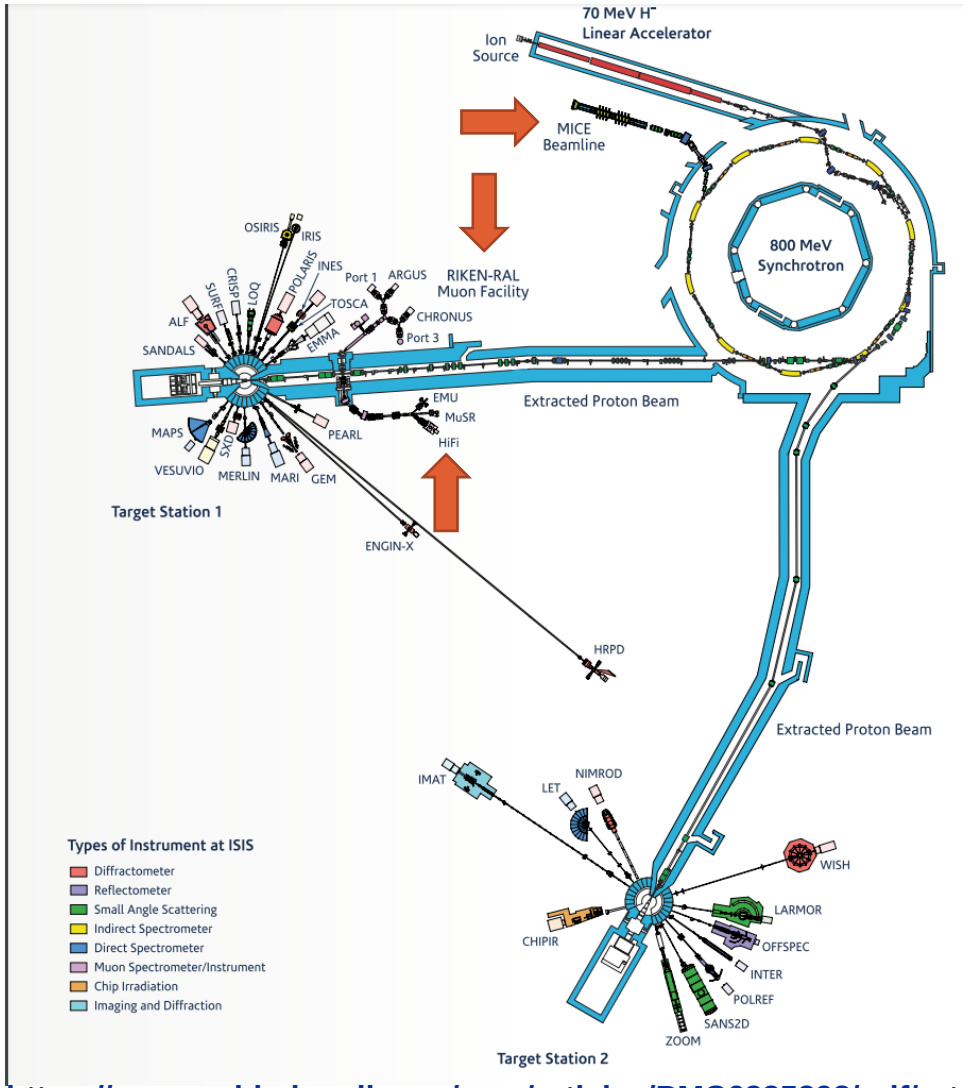
- **SIS18 Synchrotron & HEST beam lines**

  - Primary protons @ **4.5 GeV/c, up to $10^{11}$ p/spill,** with possibilities for both slow (**200 ns – 8ms)** and fast **(1us)** extraction.
  - In the **HEST beam lines**, secondary pion beams **also available up to 2 GeV/c and intensities up to $10^{11}$ p/spill**
  - **Possibilities for tests of components ?**




# Proton Facilities in Europe - STFC

- **ISIS : Muon and Neutron source**
  - Protons (stripped H-) accelerated up to **0.8 GeV/c, 2.5x10$^{13}$ ppb,** with **70ns** bunch length towards the muon and neutron targets.
  - **Focusing on Muons :**
    - **See talk of R. Steward → this workshop !**
    - EC muon facility : **28 MeV/c momentum**, +-2% momentum spread, up to **1x10$^{6}$ muons / s.**
    - RIKEN/RAL muon facility : **Adjustable muon momentum between 17 MeV/c and 120 MeV/c,** with intensities up to **O(10$^{6}$) muons/s.**
    - **MICE beamline: Dedicated for MICE experiment @ 140, 200 and 240 MeV/c → Now dismantled**
    - **A wide variety of experiments and instruments available. Synergies for components tests ?**




https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6335298/pdf/rsta20180064.pdf

# Future Proton-driven Facilities

# Future Proton Facilities – CERN HI ECN3

- **The CERN ECN3 cavern is a unique place for high-energy, high-intensity beam experiments.**
  - Today hosting the NA62 experiment
- **Within the Physics Beyond Colliders initiative and the ECN3-HI TF, three proposals are being considered for post-LS3 (2029) operation :**
  - **HIKE** : A proposed expansion of the current NA62 experiment for studying rare decays of charged kaons and (later) neutral kaons ;
  - **SHADOWS** : A new experiment that would look for visible feebly-interacting particle (FIP) decays off-axis and could run in parallel to HIKE ;
  - **BDF/SHiP** : A proposal that would allow a full investigation of hidden sectors in the GeV mass range.
- **All experiments would require unprecedented intensity extracted towards the CERN North Area (4x10$^{13}$ protons / slowly extracted spill – O(10$^{19}$) protons per year)**
  - **Possible synergies with the MUC would need to be looked at more in detail (e.g targetry tests ? )**

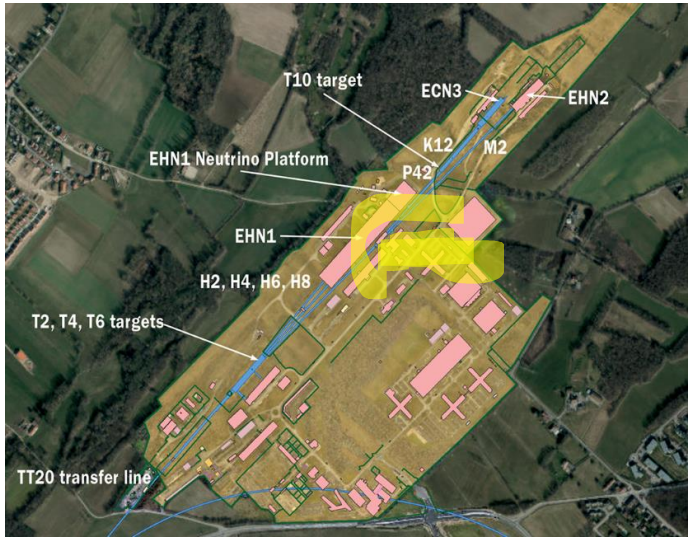




Figure 1: Overview of the locations considered for the implementation of the BDF.

**https://cds.cern.ch/record/2802785/files/2204.03549.pdf**

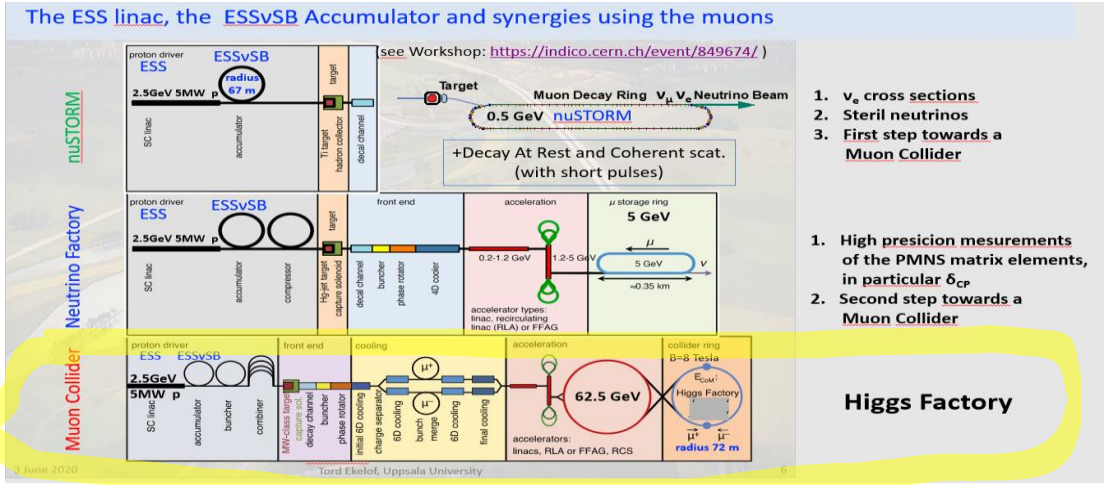
# Future Proton Facilities – ESS (& ESSnuSB)

- **European Spallation Source will be a multi-disciplinary research facility based on a powerful neutron source**

  - Proton-driven by a linac accelerating protons **up to 2 GeV, 14Hz** repetition frequency**, 62.5 mA** pulse current **and 2.86ms** pulse length

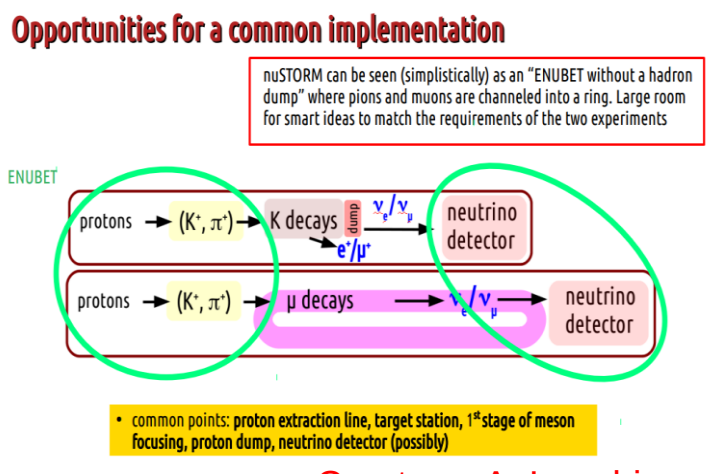
  - **ESSnuSB** project proposes to add to the ESS a ‘super beam’ neutrino facility where ~$10^{20}$ muons / year will be produced as “by-product” – modifying the proposed ESS accumulator ring.

  - Various ideas for target synergies and even the idea of an Initial Cooling Experiment in ESS have been also proposed.



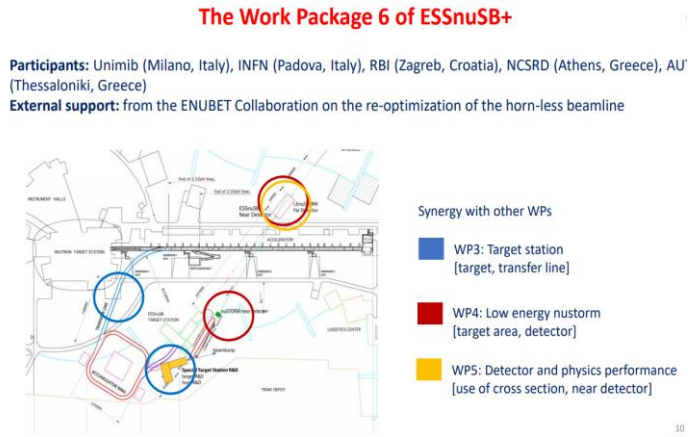
# ENUBET & NuSTORM

- **ENUBET: A mature collaboration, supported by an ERC grant with the purpose to develop a monitored neutrino beam**
  - Monitoring of the large angle positrons & muons towards measurements of $\nu_\mu$ and $\nu_e$ cross-sections
  - Beamline design advanced, a conceptual feasibility analysis will start at CERN in the framework of **Physics Beyond Colliders investigating also synergies with the ProtoDUNE collaboration**
  - **Strong synergies with the MUC, especially in the case of the CERN-based demonstrator, both on targets & civil engineering**




Courtesy: A. Longhin

- **NuSTORM: A proposed facility to deliver a definitive neutrino-nucleus scattering program using νμ & νe**
  - **See talk of K. Long → This workshop !**
  - Proposing a unique storage ring of mu+ between 1 GeV/c and 6 GeV/c and neutrinos between 300 MeV/c up to 5.5 GeV/c. Can be a muon source ?
  - Strong synergy with **ESSnuSB** using possibly the **NuSTORM detector for the lower momenta ?**
  - **Muon Collider demonstrator at CERN** → Both NuSTORM and ENUBET could branch off ???

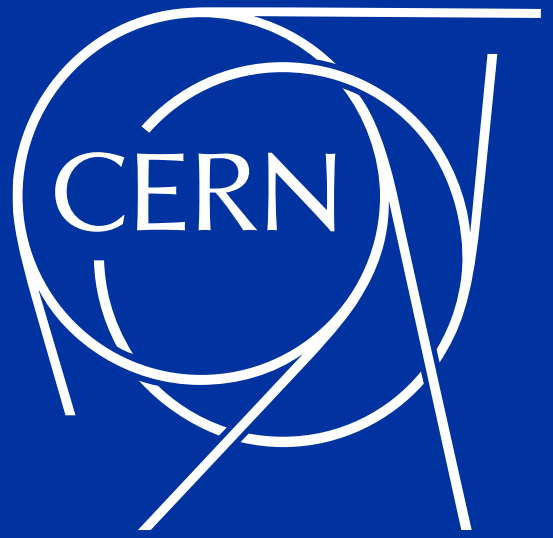



Courtesy: F. Terranova

# Summary

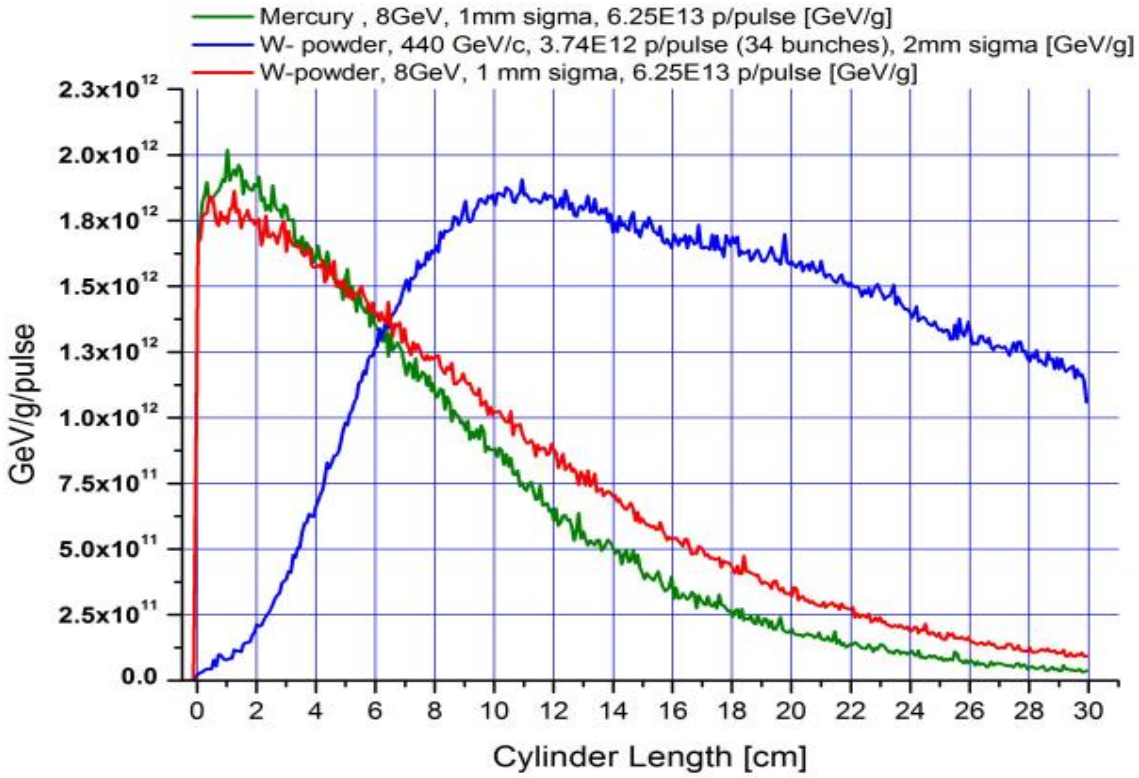
- **There are many existing proton facilities in Europe than synergies can be investigated with the muon collider collaboration.**
  - Accelerator-driven facilities that could serve for a proof-of-principle demonstration or to test detectors / components or contribute to the MUC R&D effort

- **The possible synergies “landscape” has yet to be fully explored – also many new ideas will be coming from Physics Beyond Colliders or other inititatives in the upcoming years**


CERN

# An example emulating a multi-MW beam @ HiRadMat

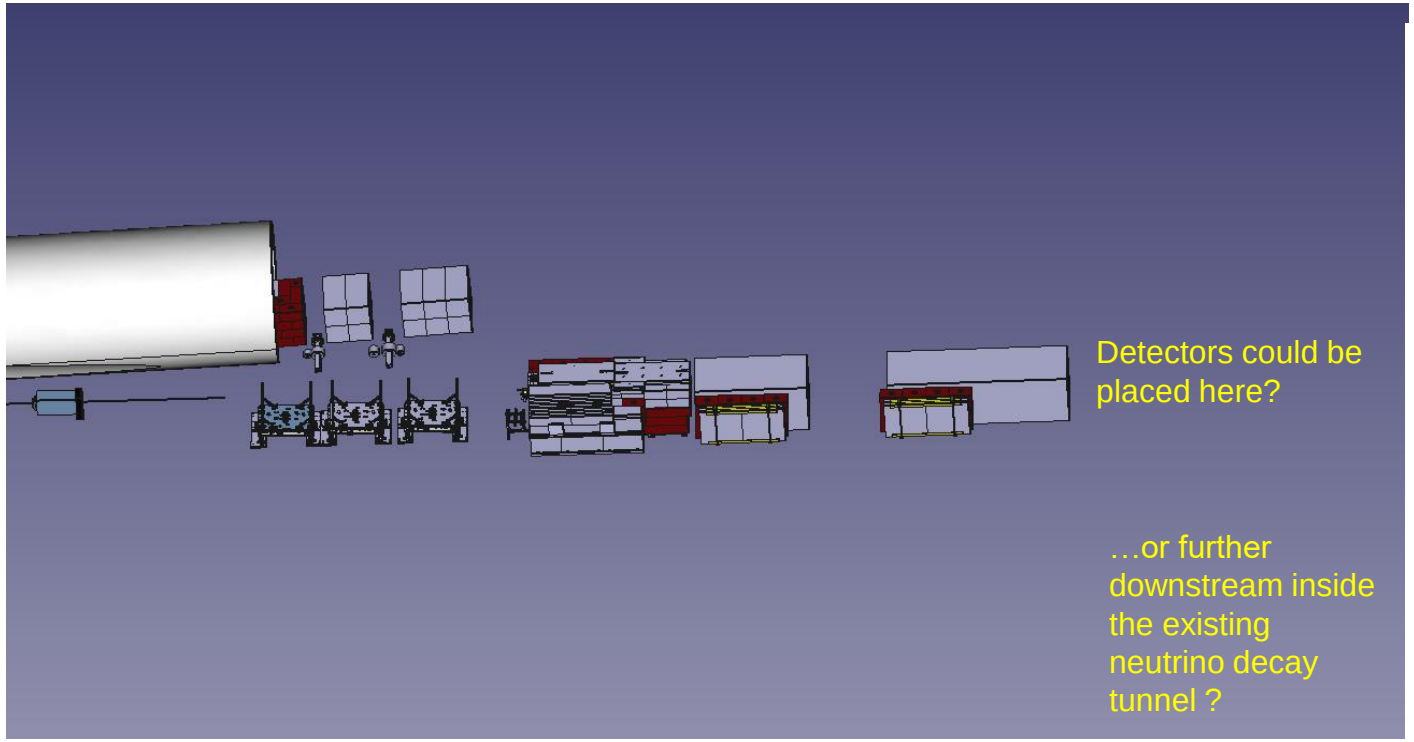
- **Assumption :**
  - **4MW beam e.g :** 50 Hz, 6.25E13 p/pulse, 8 GeV/c, 1 mm sigma @ 30 cm **Mercury**
  - **Compared with :** 34 HiRadMat bunches, 3.74E12 p/pulse, 2 mm sigma @ 30 cm **Tungsten Powder**

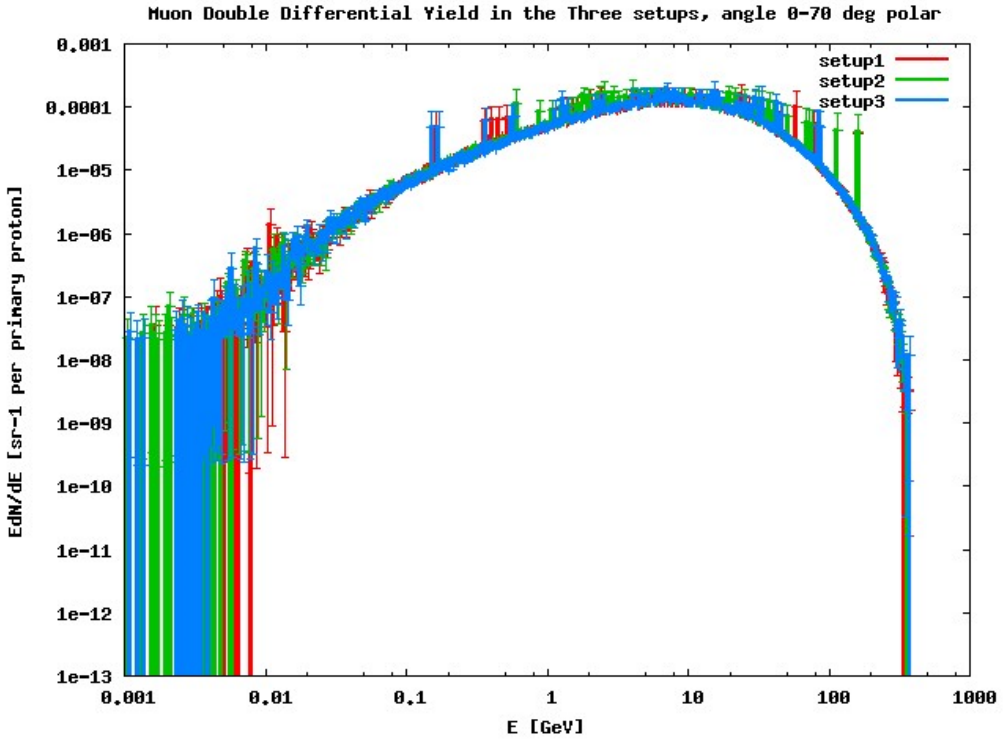



The HiRadMat beam parameters can be ‘tuned’ in order to emulate the same maximum energy density as expected in proposed multi-MW beams, as the one required in a future Muon Collider.

# Tests at HiRadMat ?

- **Test detectors or components with very high energy muons ?**




A high muon yield behind the dump could be used ?

**Space and muons available for a demonstrator setup – e.g for placing/trying high-field fast-ramping dipoles ?**

# PSI secondary beams

PAUL SCHERRER INSTITUT PSI

## Overview of Secondary Beam Lines Features

| | PiM1 | PiE5 | PiE1 | PiE3 | PiM3 | MuE4 | MuE1 |
|---|---|---|---|---|---|---|---|
| Target | M | E | E | E | M | E | E |
| Particle Type | e/μ/π/p | μ/π | π/μ/p | μ (surface) | μ (surface) | μ (surface) | μ (cloud) |
| Momentum Range | 10-500 MeV/c | 10-120 MeV/c | 10-500 MeV/c | 10-40 MeV/c | 10-40 MeV/c | 10-40 MeV/c | 60-120 MeV/c |
| Typical Momentum | 15-350 MeV/c | 28-85 MeV/c | PP: 10-50 MeV/c<br>μSR: 28 MeV/c<br>Irrad: 300 MeV/c | 28 MeV/c | 28 MeV/c | 28 MeV/c | 60-120 MeV/c |
| Max Rate [$s^{-1}mA^{-1}$] | π+: $2x10^8$ | π+: ~$10^9$<br>μ+: $2x10^8$ | π+: ~$10^9$ | $3x10^7$ | $3x10^6$ | $4x10^8$ | $6x10^7$ |
| Typical Use | Particle Physics Test Experiments Detector/Material Irradiation | Particle Physics Experiments | μSR Dolly Facility<br>Particle Physics Experiment, Detector Irrad. | μSR HAL 9500 (High Field) Facility | μSR GPS and LTF Facilities | μSR LEM Facility | μSR GPD Facility |

Courtesy: D. Reggiani