Possible Synergies with upcoming Physics Proposals at CERN

Workshop on Muon Collider Testing Opportunities

Johannes Bernhard (BE-EA)

24.03.2021

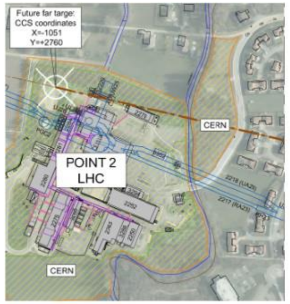
Content

- Synergies with proposed and existing facilities
- Beam-induced background
- Magnetic collimation
- Service measurements and benchmarking
- LHC forward experiments
- Crystal collimation
- Non-conventional muon sources
- Far-fetched ideas

- Not covered today: Detector R&D

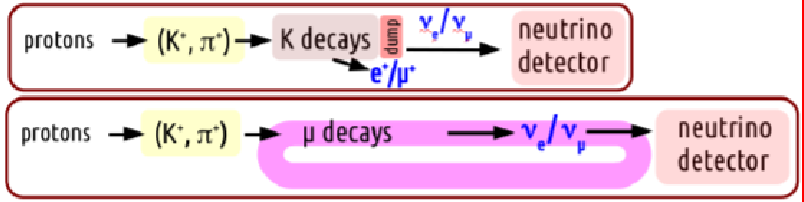
nuSTORM

- **nuSTORM** is a proposed facility within the Physics Beyond Colliders framework (CERN-PBC-REPORT-2019-003)
- Originally planned as a short baseline neutrino project based on a low-energy muon decay ring, synergies with the muon collider study have been identified, for instance as a possible demonstrator for cooling, targetry and as a test facility for R&D activities for muon collider components.
- In addition, combination with the **ENUBET** proposal for tagged neutrino-beams seems interesting as well as the high intensity on the primary beam dump (4e13 protons / extraction) that might be useful for further experiments.
- See the following talk by Chris Rogers and Anna Holin for more details.



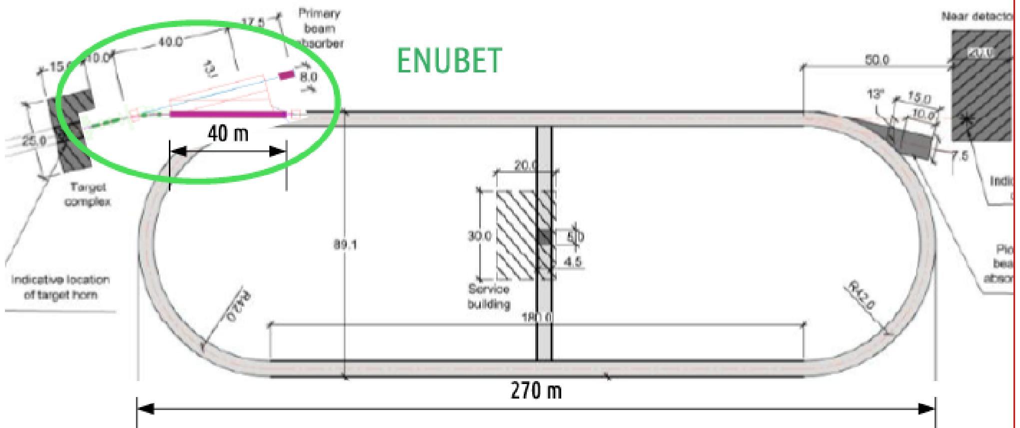
ENUBET and nuSTORM

nuSTORM & ENUBET



	Decay region	Hadron dump	Proton extraction	Target, sec. transfer line, p-dump	Neutrino detector
ENUBET	~40 m. Instrumented.	Yes. Dumps muons in addition preventing a (small) ν_e pollution to K_{e3} - ν_e	Slow, 400 GeV (flexible)	Yes, similar	~100 m (some flexibility)
nuSTORM	Replaced by straight section of the ring (180 m).	No. Muons are kept: the most interesting flux parents.	Fast, 100 GeV	Yes, similar	> 300 m from target (ring straight section)

- Different concepts, budget, geometry.
- Main synergy: target facility, 1^{st} stage of meson focusing, proton dump.



A. Longhin Neutrino 2020 20

F. Terranova, PBC Annual Meeting, March 2021

Comparison of needs

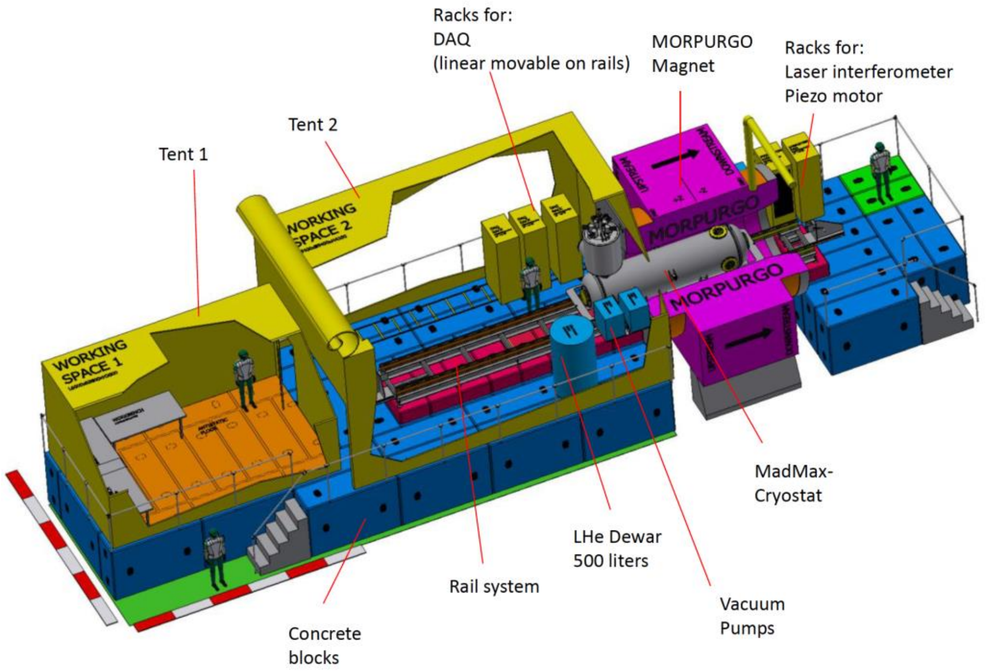
Table 1: Key parameters of the SPS beam required to serve nuSTORM.

Momentum	100 GeV/c	100-400 GeV/c
Beam Intensity per cycle	4◊ 10^{13}	4 x 10^{13} (@400 GeV)
Cycle length	3.6 s	2-5 s
Nominal proton beam power	156 kW	164 kW
Maximum proton beam power	240 kW	
Protons on target (PoT)/year	4◊ 10^{19}	4 10^{19} pot/y
Total PoT in ~~5~~ year's data taking	2◊ 10^{20}	~9 10^{19} pot
Nominal / short cycle time	6/3.6 s	2 s (slow) (*)
Max. normalised horizontal emittance (1 ‡)	8 mm.mrad	600 mm mrad
Max. normalised vertical emittance (1 ‡)	5 mm.mrad	
Number of extractions per cycle	2	**1 (slow)** 10 (horn)
Interval between extractions	50 ms	**- (slow)** 100 ms (h)
Duration per extraction	10.5 μs	**2-4s (slow)** 2-5 ms (h)
Number of bunches per extraction	2100	~~X~~
Bunch length (4 ‡)	2 ns	~~X~~
Bunch spacing	5 ns	~~X~~
Momentum spread (dp/p)	2◊ 10^{-4}	~~X~~

(*) For horn option 2-10 ms in 2s flat top at 10 Hz + many s (20s ?) of inactivity

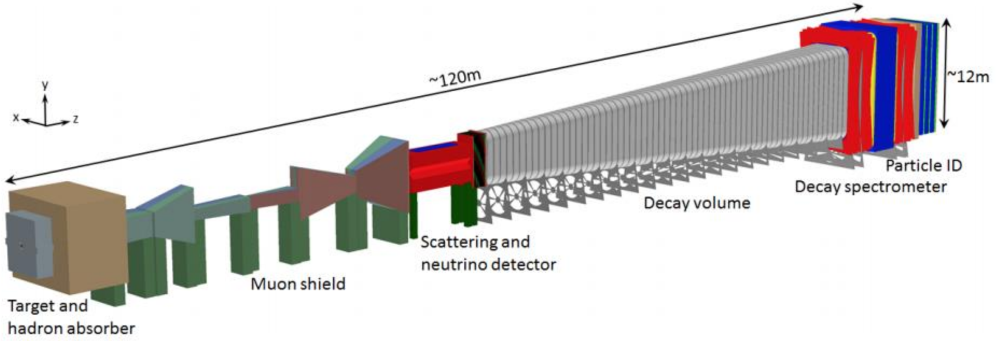
MADMAX

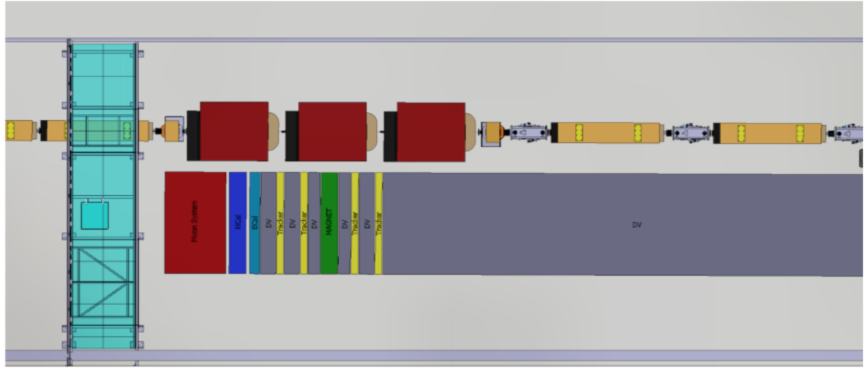
- **MADMAX**/P-366 is a proposed test of a dielectric haloscope for dark-matter axion detection in the Morpurgo magnet in the H8 beam line outside in the YETS periods.
- The experiment makes use of RF-cavity like equipment and will be operated in the 1.6T dipole field of the magnet with all necessary infrastructure available on request, including liquid helium for the superconducting magnet.
- This could be in principle envisaged for testing RF cavities in magnetic fields as possibly required for the cooling section (thanks to S. Gilardoni for pointing this out, see e.g. here).



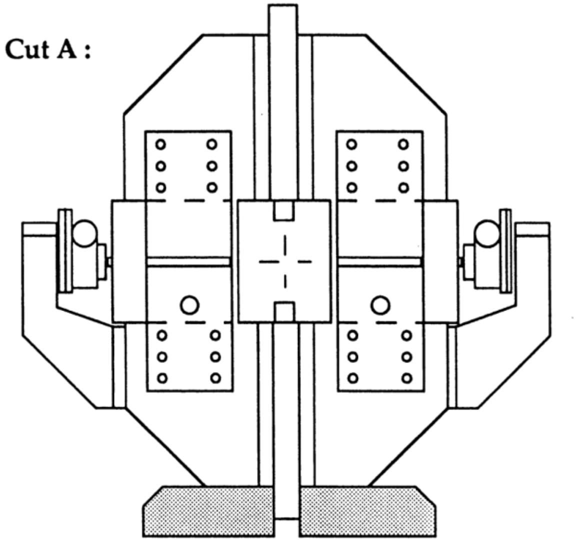
Beam-induced backgrounds

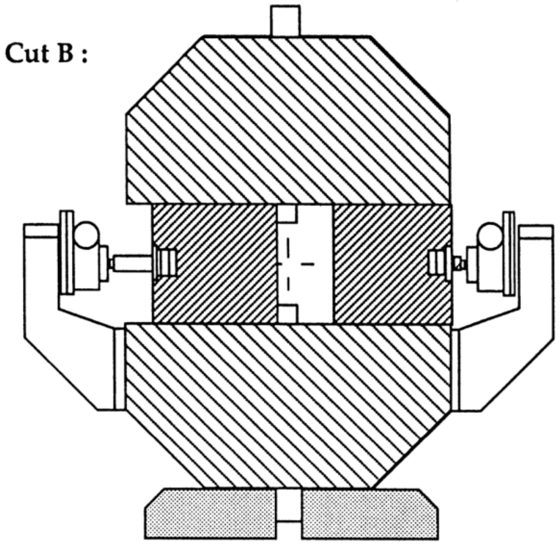
- Several fixed-target experiments require a control of beam-induced background (mostly muons) to a level that seemed to be unrealistic before, e.g. **NA62** and **NA64** both requiring understanding of their sources of background to a level below 10^{-11}.
- Dedicated studies have been performed with the help of several simulation codes for these experiments, such as Fluka, Geant4, G4beamline and BDSIM. The experiments and involved CERN groups would be happy to share their experience.
- In addition, active mitigation of these backgrounds is more and more important:
  - Magnetic collimation in the M2 and K12 beamlines for **COMPASS** and **NA62**.
  - Muon shields for proposed beam dump experiments, e.g. **SHiP** and **SHADOWS**.

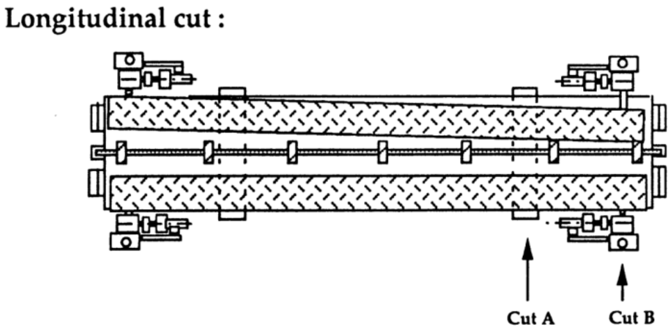




Excursion: Magnetic Collimation (1/2)

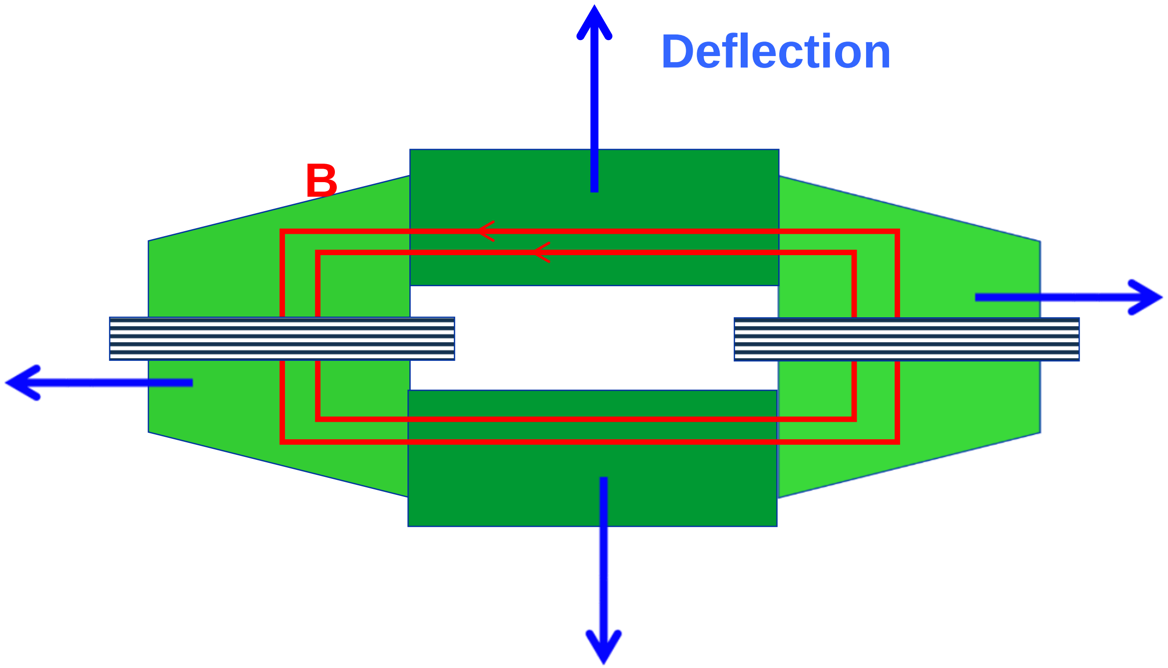






- Adjustable magnetic collimators (“scrapers”): Toroidal magnets with adjustable gaps, 5 m length.
- Field in iron of about 1.5 T (saturated at 100 A).
- Negligible quadrupolar field component in the centre.

Excursion: Magnetic Collimation (2/2)



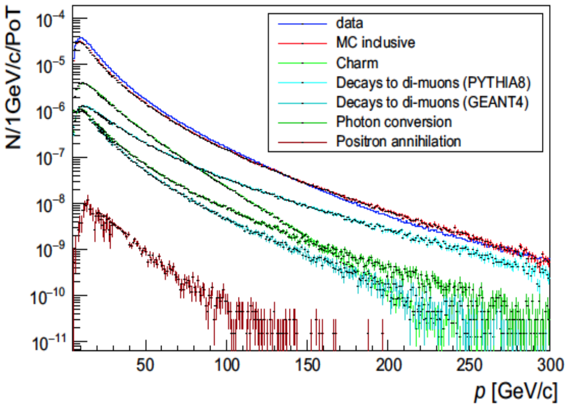
- Fixed magnetic collimators: Toroidal magnets with fixed gaps.
- Field in iron of about 1.5 T (saturated at 100 A).
- Length between 3.2 m to 8 m, minimising scattering in the yoke (proportional to √L) with respect to the magnetic deflection (proportional to L).

Muon Shields: SHiP

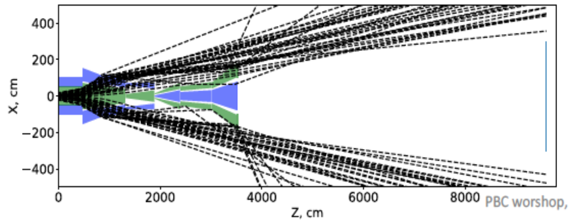
Brief reminder of the muon shield basics

Wide range of the muon momentum spectrum produced in the dump (good agreement with data both in shape and in integral)

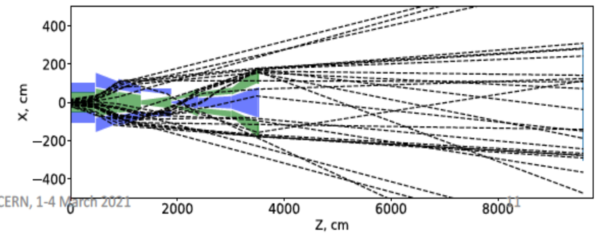
1st part of the shield deflects muons
2nd half (with reversed polarity) deflects "low momenta" muons returned to the detector acceptance by reversed polarity field of the 1st half
→ **Fraction of penetrating muons crucially depends on the amount of muons undergoing catastrophic energy losses and re-scattering in the muon shield material**



Deflected muons

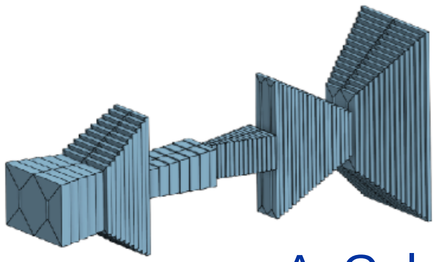


Penetrating muons



PBC worshop, CERN, 1-4 March 2021

Recap of the baseline technology



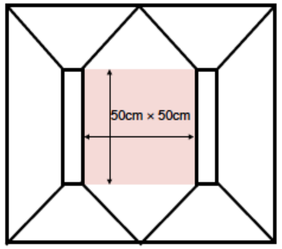
~30m long construction made of CRGO steel sheets 0.3mm thick
>1kT weight
Maximum cross section 6.6×3.8 m^2
Module(production unit) 50mm depth
Block(installation unit) 50cm depth

A. Golutvin, PBC Annual Meeting, March 2021

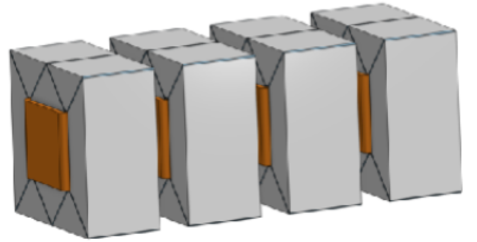
R&D challenges

- ✓ Assembling modules and blocks with maximum possible stacking factor (>98%)
- ✓ Demonstrate good quality and fast (and cheap) welding (minimize distortions of magnetic field)

Produce a representative technological prototype:



Field 1.8T
Nominal field area: 50×50 cm^2
Length ~2m
→ 4 blocks interspersed with electronic detectors to trace muon trajectories inside the shield



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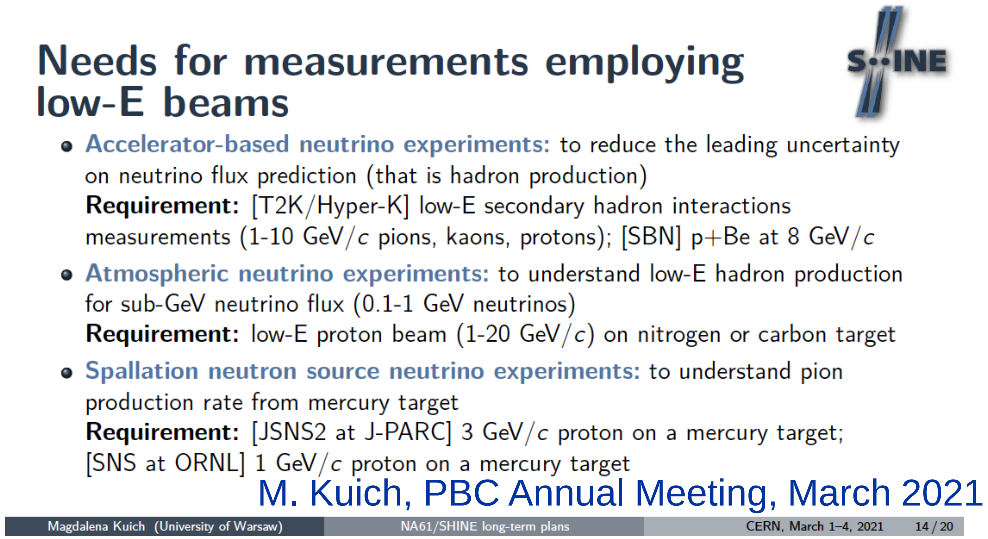
- Tests beams planned in the North Area to measure field maps inside of the material with the help of muons.

Service measurements and benchmarking

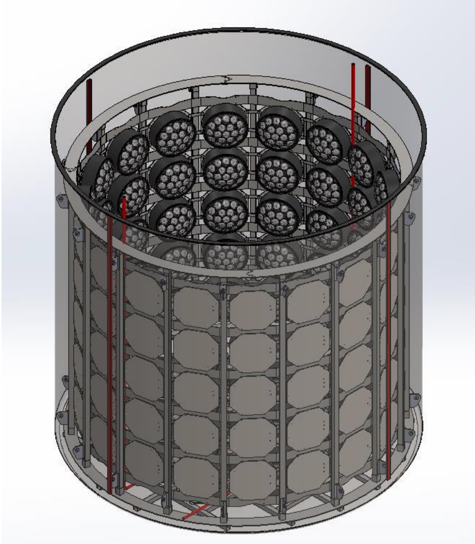
- Besides their main objective for dense matter QCD physics, the **NA61 experiment** specialises in measurement of hadron production for neutrino physics at low energies, where existing data is sparse, but high statistics and high-quality data are needed.
- Several requests for neutrino detector tests came up in the last years, also mostly focused on low energies. With the **H2 and H4 low energy beams** in the North Area and the newly renovated beams of the **East Area**, these experiments can also contribute to hadron production studies.



Needs for measurements employing low-E beams

- **Accelerator-based neutrino experiments:** to reduce the leading uncertainty on neutrino flux prediction (that is hadron production)
  Requirement: [T2K/Hyper-K] low-E secondary hadron interactions measurements (1-10 GeV/c pions, kaons, protons); [SBN] p+Be at 8 GeV/c
- **Atmospheric neutrino experiments:** to understand low-E hadron production for sub-GeV neutrino flux (0.1-1 GeV neutrinos)
  Requirement: low-E proton beam (1-20 GeV/c) on nitrogen or carbon target
- **Spallation neutron source neutrino experiments:** to understand pion production rate from mercury target
  Requirement: [JSNS2 at J-PARC] 3 GeV/c proton on a mercury target; [SNS at ORNL] 1 GeV/c proton on a mercury target

M. Kuich, PBC Annual Meeting, March 2021

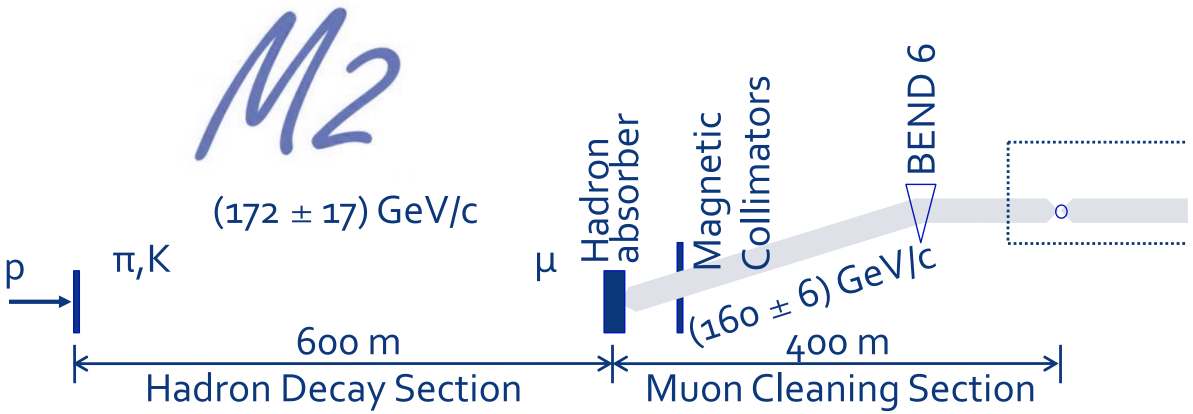


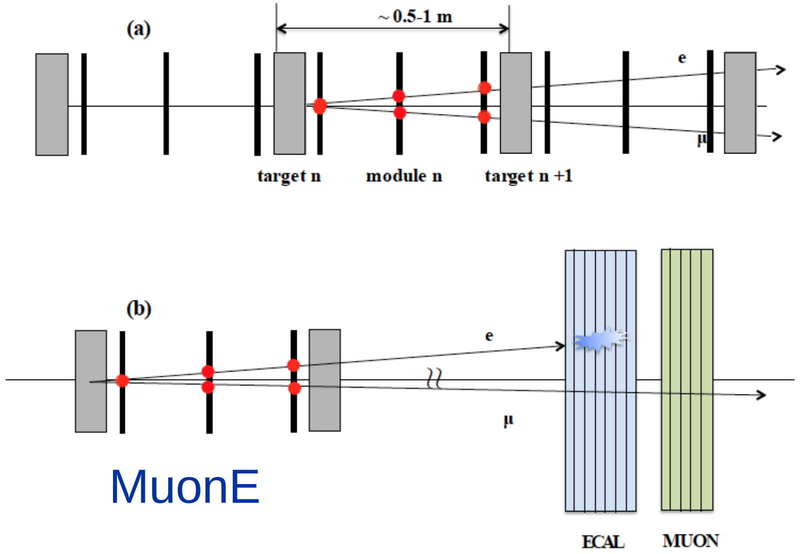
WCTE, CERN-SPSC-2019-042

ARIADNE, https://arxiv.org/abs/1910.03406

Service measurements and benchmarking

- The **M2 beam** in the North Area is a high energy muon beam at 100 GeV – 200 GeV and with relatively high intensities (few 10^8 μ / extraction). In principle, it can be used to check collimation etc. at higher energies.
- The **MuonE** collaboration plans to measure the hadronic vacuum polarisation to a very precise level with the help of the M2 beam and deploying 40 thin Beryllium targets. For them, precise knowledge of multiple scattering (including tails) is key to the experiment. There might be possibilities for collaboration on these aspects.





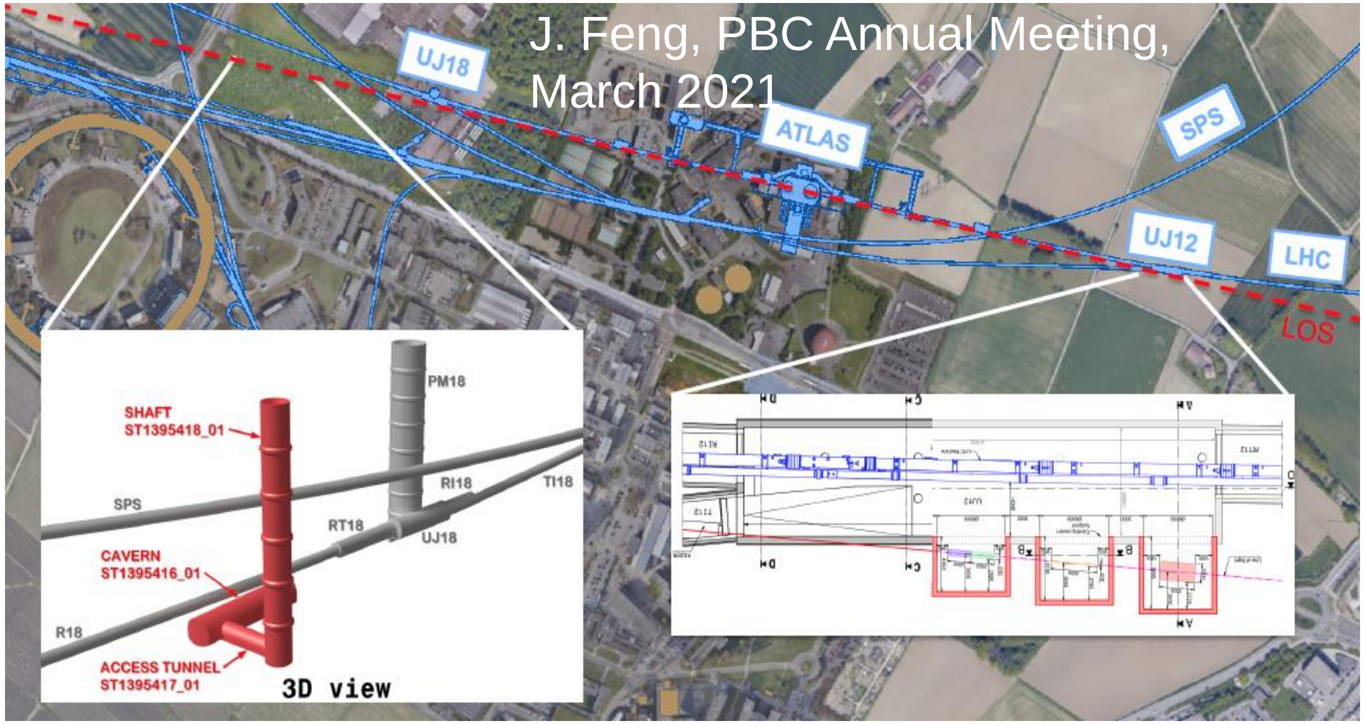
MuonE

LHC forward experiments

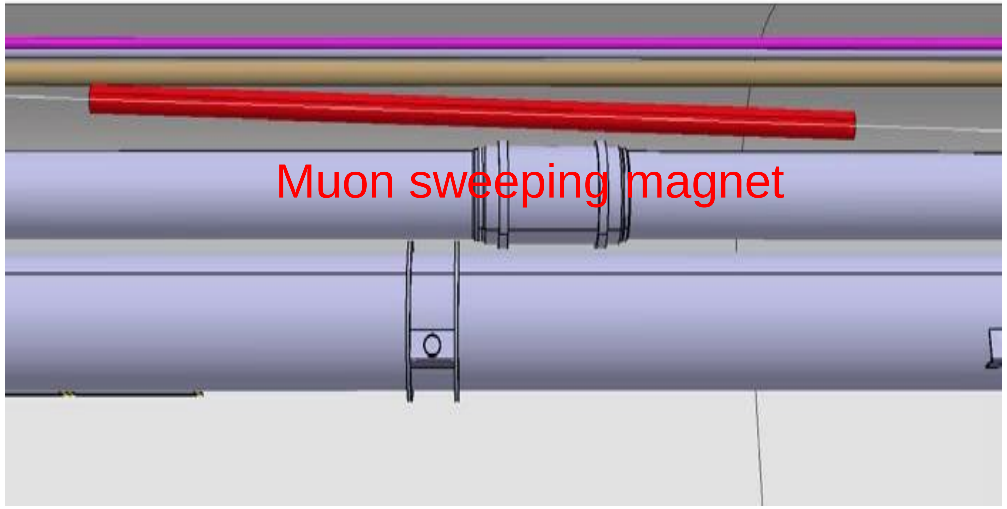
- The **TOTEM collaboration** measures the elastic cross section at the highest energies with high precision. In principle, the experiment could be upgraded with muon detectors and have access to very forward muons.
- Several new detectors either have been planned or have been already set on the forward direction with respect to the LHC interaction points (e.g. **FASER**, **SND**). These detectors are usually shielded by about 100 m of rock in between the IP and the detector, but still have access to high energy muons.

LHC forward experiments

- The idea of an **Forward Physics Facility** has been brought up at the last PBC workshop. The proposal includes a muon sweeping magnet, which could be used for direct access to highest energy muons without having rock in between (CE works necessary however).

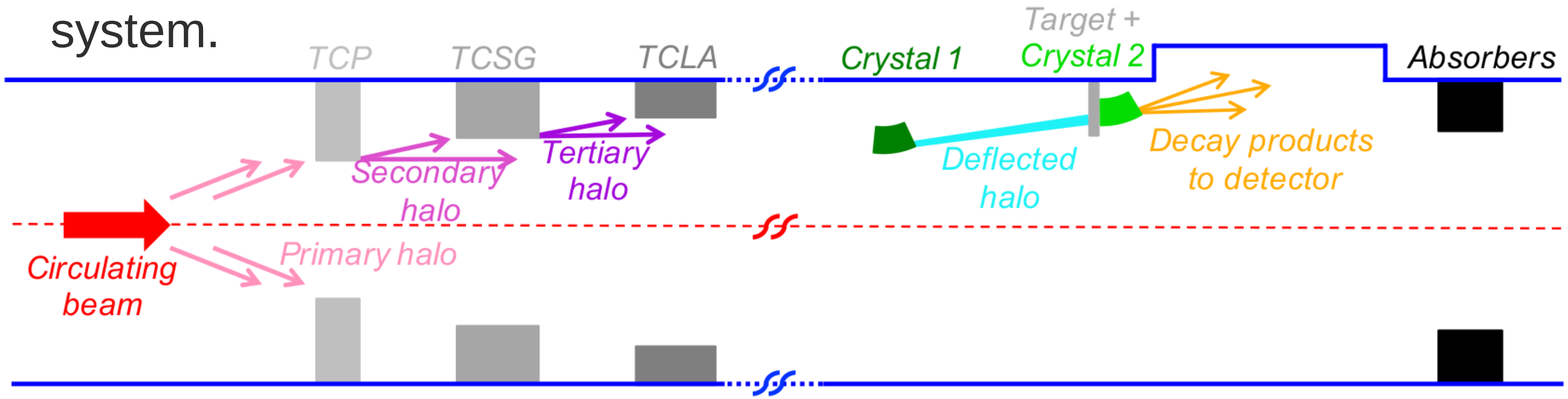


Forward Physics Facility - Kickoff Meeting: https://indico.cern.ch/event/955956/



Crystal collimation

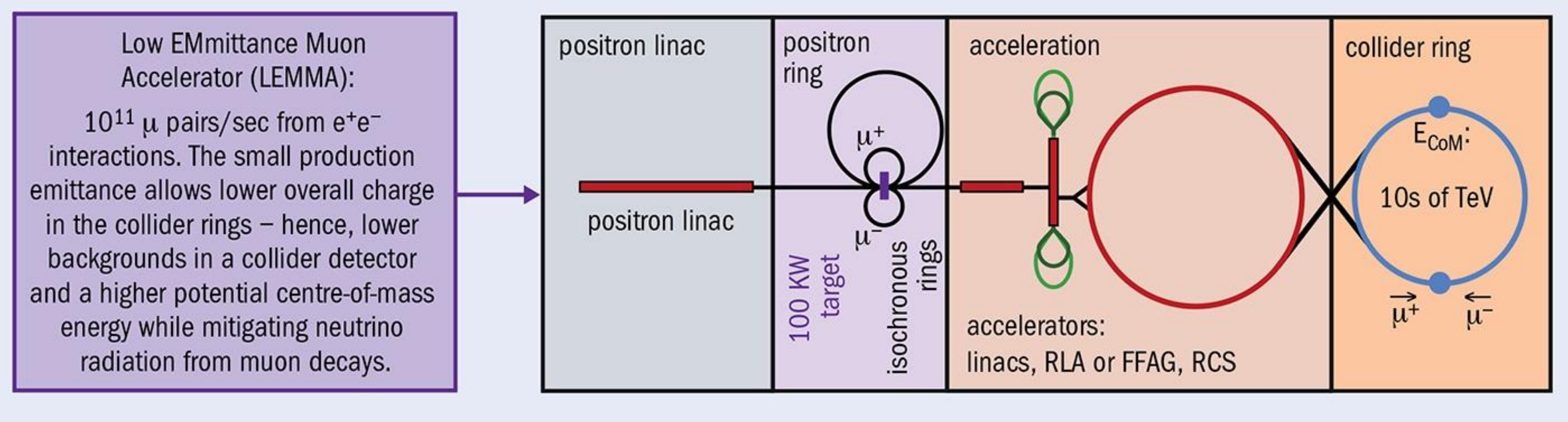
- The **UA9 experiment** studies deflection of charged particles in crystals since many years, both in the accelerators as well as in the H8 beam.
- Crystals offer very high fields within relatively small dimensions and thus could be potentially interesting for collimation of beams (mostly for positive beams, still potentially also for negative ones).
- Some applications have been already studied for the **LHC fixed target** proposals, making use of the deflected proton halo to feed gaseous and solid targets.
- Crystal collimation is now also part of the LHC upgrade baseline for the collimation system.



M. Ferro-Luzzi, PBC Annual Meeting, March 2021

Non-conventional muon sources: LEMMA

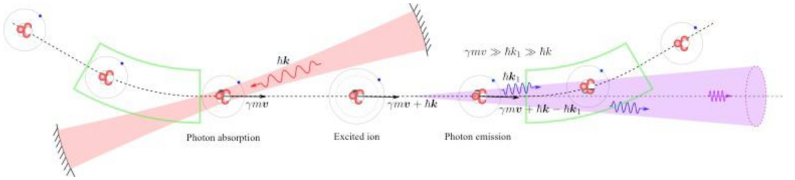
- **LEMMA** is an approach to provide a low-emittance source for muon colliders by exploiting production of muons from $e^+e^- \rightarrow \mu^+\mu^-$ at the production threshold with a 45 GeV/c positron beam on a thin target (Nucl. Instrum. Meth. A 807 (2016))
- See talk by M. Zanetti for details.

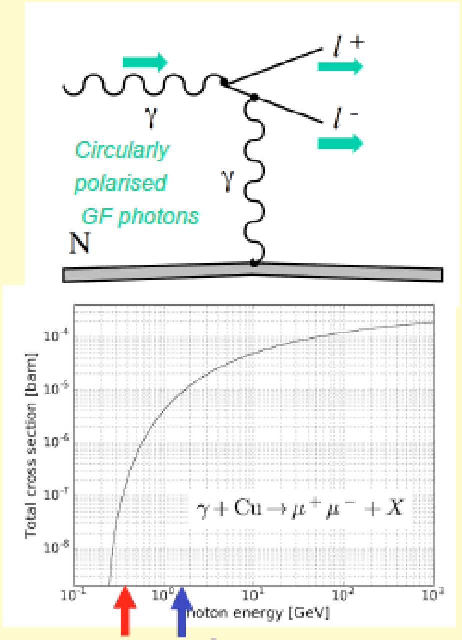


Non-conventional muon sources: Gamma Factory

- Proposal to use a beam of partially stripped ions as a light source.

Two ways of producing polarised muons by photons

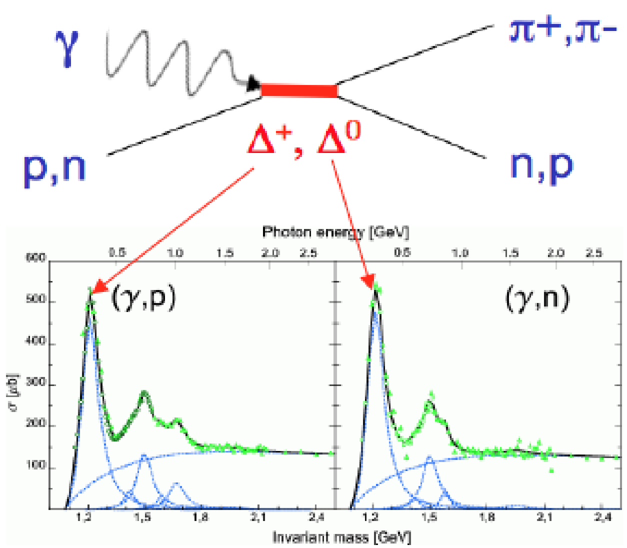


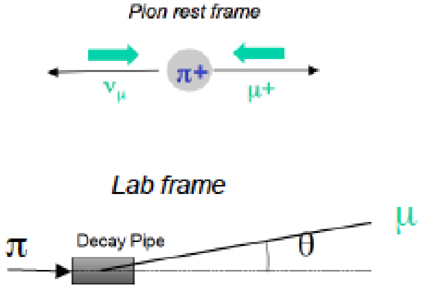


GF@LHC GF@HE-LHC

~ 10^{10} μ/s source for GF@LHC
(Mass threshold effect)

New concept





Polarisation $= P(\theta)$

Requires quasi-monochromatic pion beam …and θ–dependent packing of muons into successive RF buckets to minimise the polarisation smearing!

High intensity source: 2×10^{13} (10^{14}) μ^+ and μ^- per second for the 2X0 graphite (deuterium) target and 1 MW, 300 MeV photon beam!

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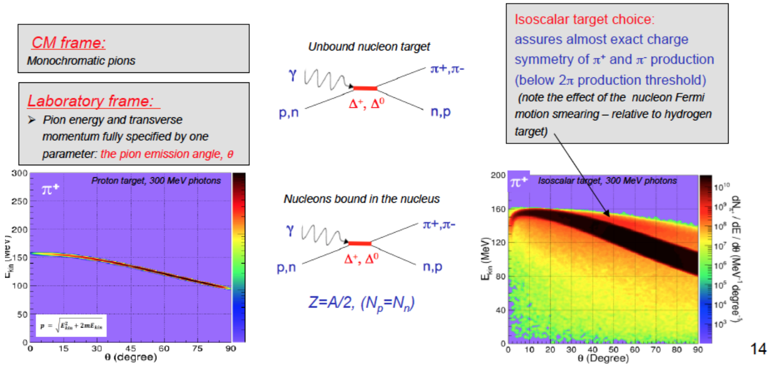
Quasi-monochromatic pion source:
De-randomising pion spectra and restoring their charge symmetry



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M. W. Krasni, PBC Annual Meeting, March 2021

Far-fetched ideas

- Investigate **Plasma Wakefield Acceleration** in collaboration with **AWAKE**? However what about positive muons? Some further ideas seem to be also discussed.
- The **NA61 experiment** possibly is interested to deploy **Gabor Lenses** in the H2 beamline. Is that possibly interesting?

Conclusion

- The landscape of experiments, facilities and beams at CERN offers a wide range of possible synergies with the R&D program for a future muon collider.
- The ideas presented today are just an example of this, and with the plenty new ideas coming from Physics Beyond Colliders and other initiatives, there will be surely many more in the upcoming years.
- As much as there are possible synergies for the muon collider R&D, there are also at the same time opportunities for using new R&D facilities also for experiments, e.g. for tagged neutrino beams and dark matter searches. If this is well aligned with the European Strategy for Particle Physics, there is a strong argument for both facility and experiment.

Thank you very much for your attention!

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