Status and plans of the NA64 experiment at the M2 beam line (NA64$_{\mu}$)

Laura Molina Bueno on behalf of NA64 collaboration

138th meeting of the SPSC
11th June 2020

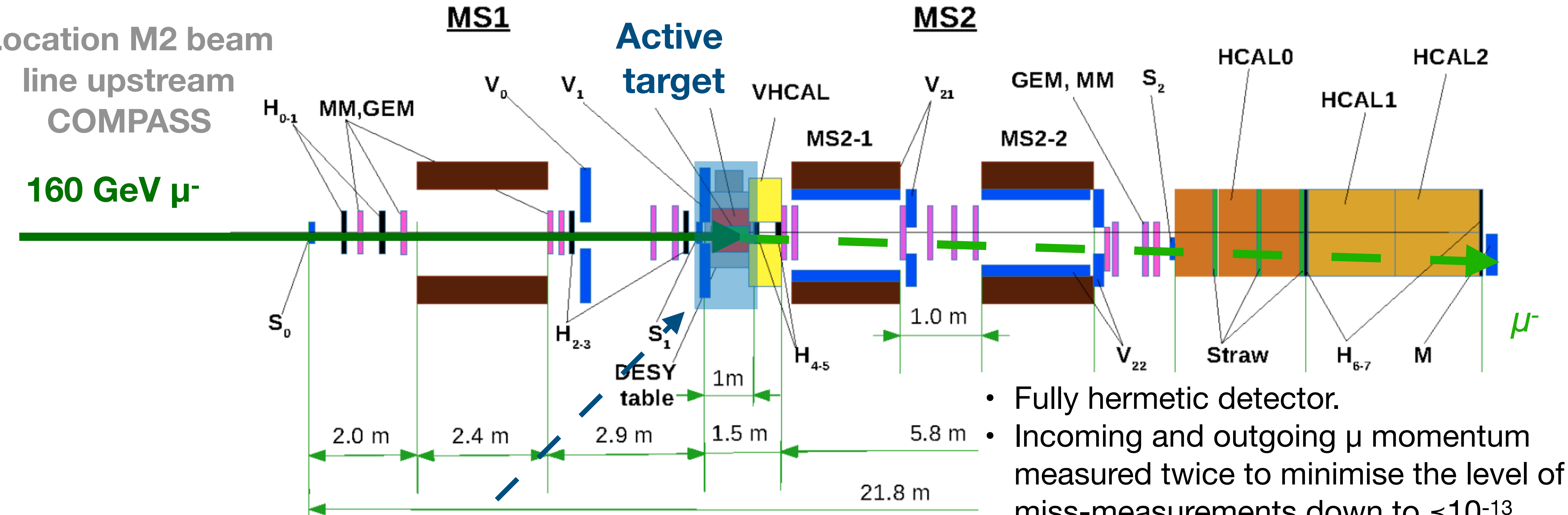
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

IPA

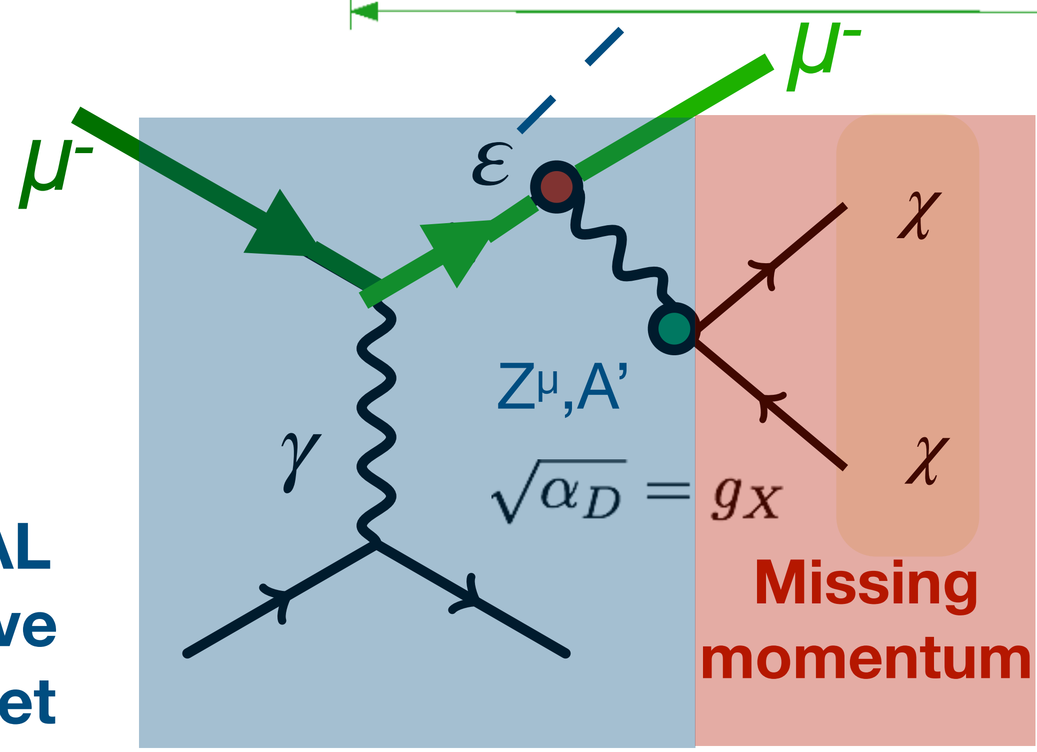
NA64μ proposal

Exploring dark sector physics weakly coupled to muons

Location M2 beam line upstream COMPASS



- Fully hermetic detector.
- Incoming and outgoing μ momentum measured twice to minimise the level of its miss-measurements down to ≲10^{-13} .

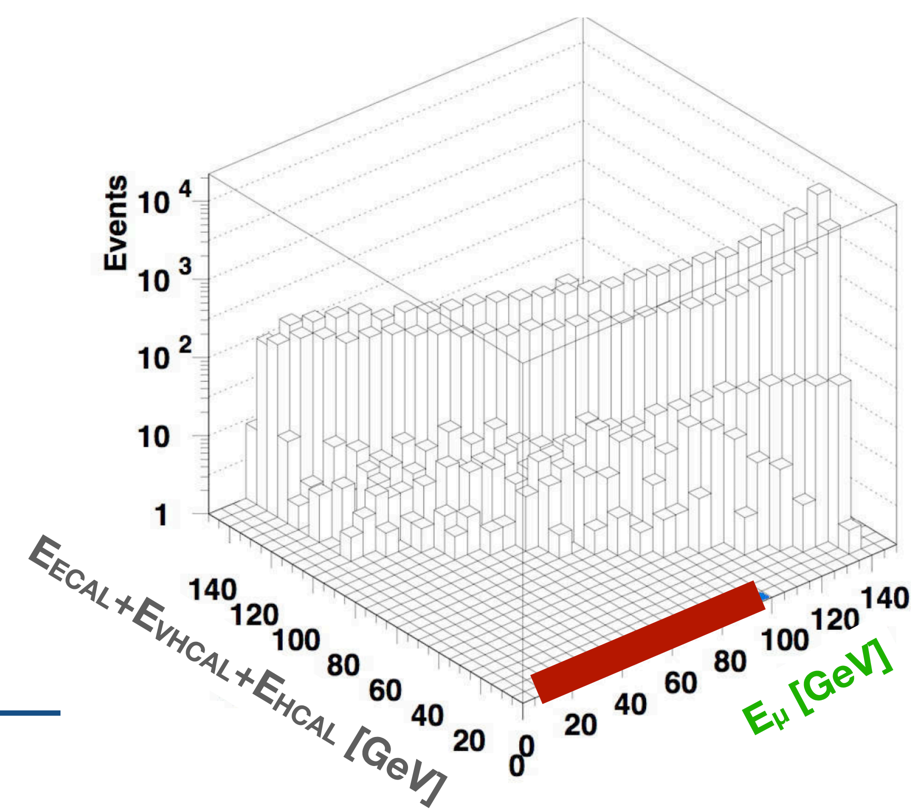


ECAL active target

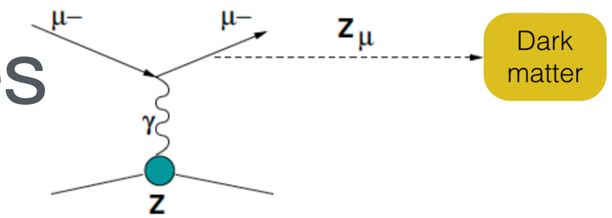
Zμ,A' decaying to DM particles

Signature

- Missing momentum (Deflected μ- energy <80 GeV).
- No energy on ECAL, VHCAL and HCAL (meaning compatible with a MIP energy).

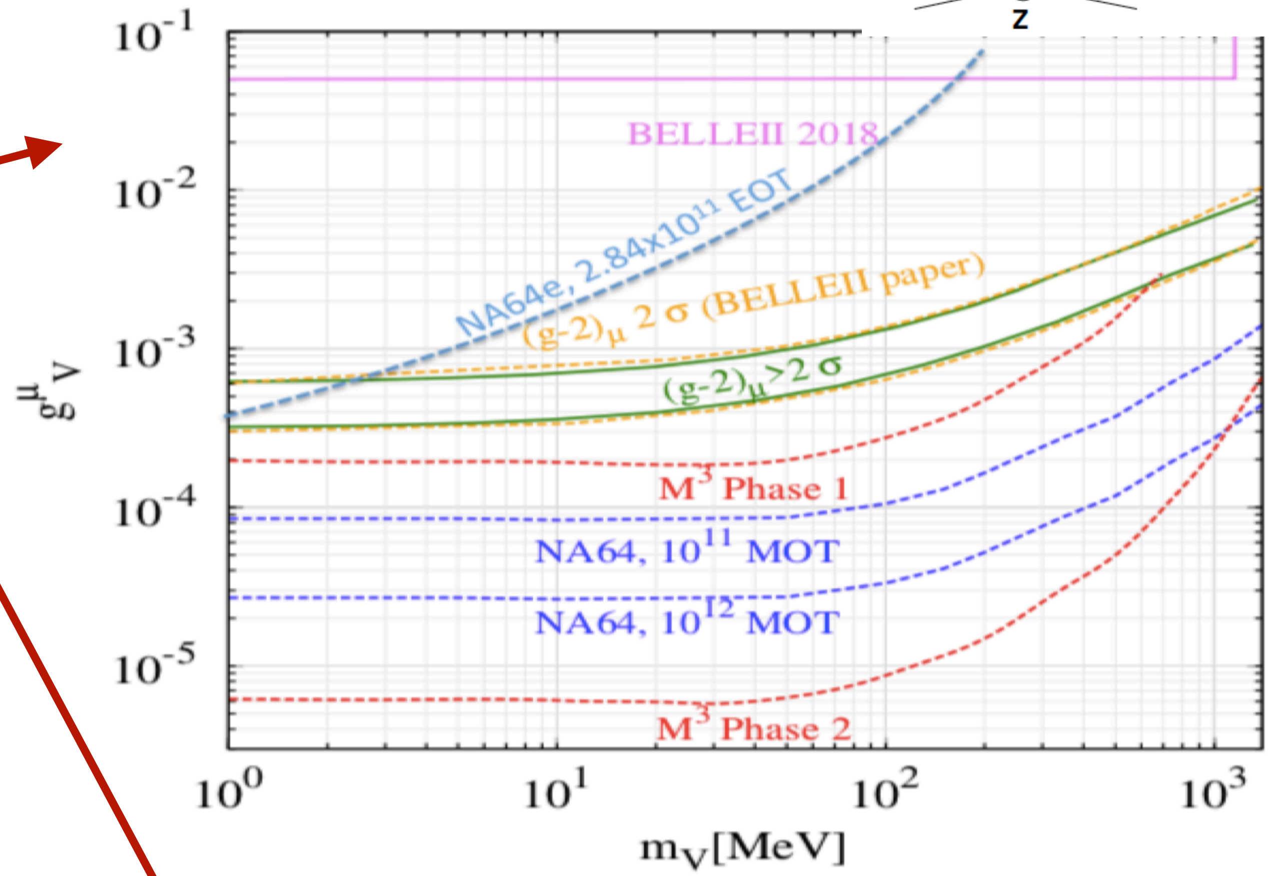


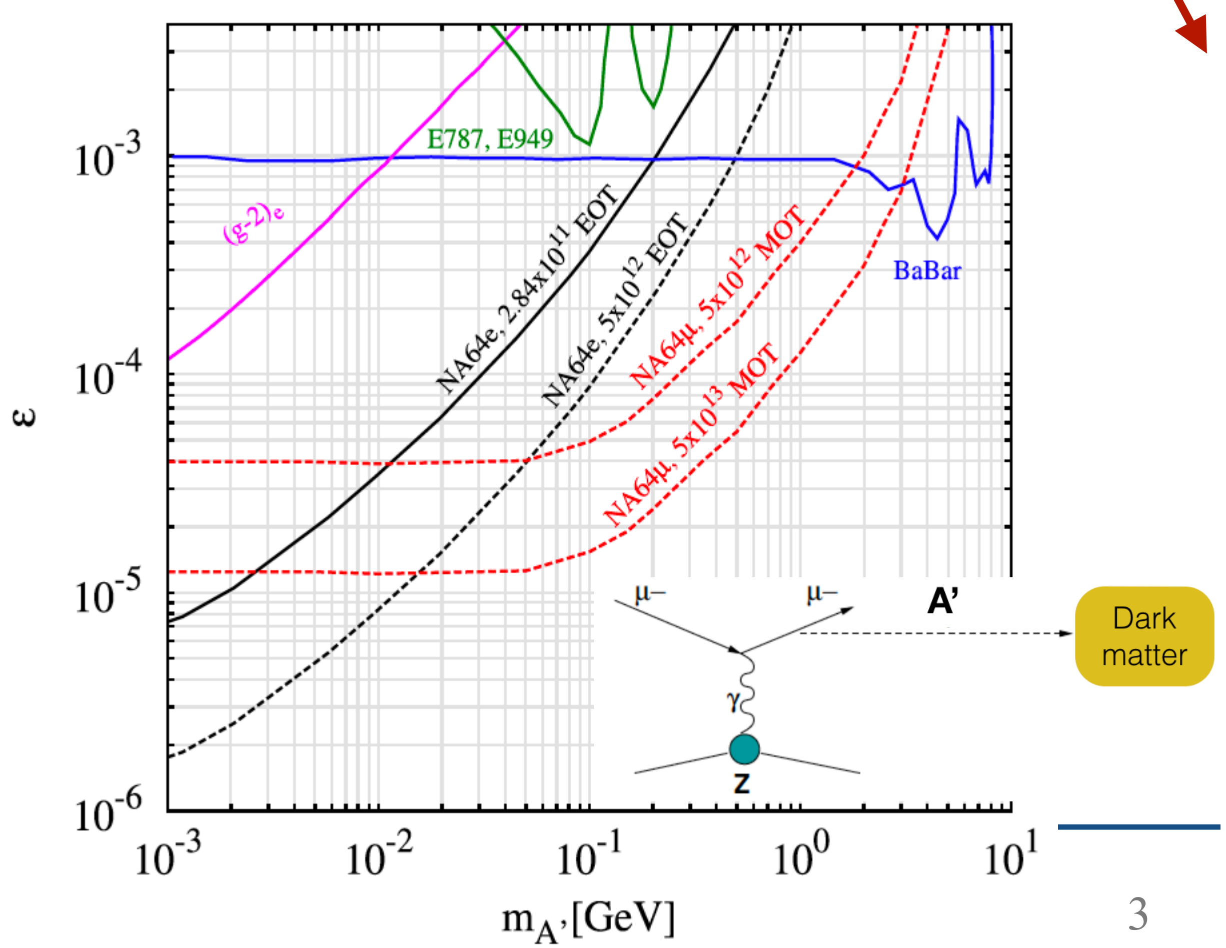
NA64μ Physics goals: projected sensitivities

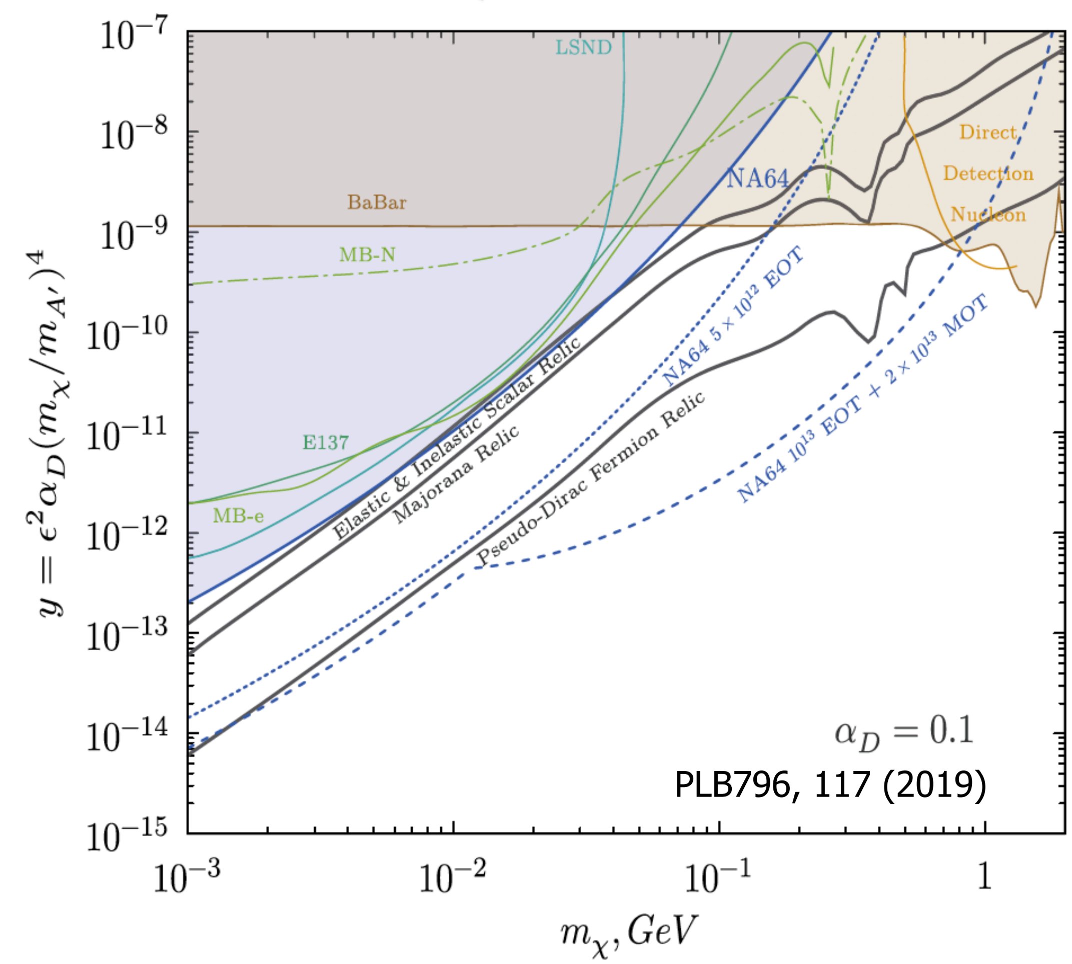


Main physics goals:

1. **Light Z' coupled to the muon**, as a remaining explanation of the $(g\text{-}2)_\mu$ (the muon anomaly).
2. **Light Dark Matter** interacting with the Standard Matter via dark photon A' in the A' mass region ≥ 0.1 GeV (complementary search to NA64e).
3. **Scalar**, **ALPs** coupled to the muon, **millicharged** particles, ...
4. **Lepton Flavour Violation in μZ -> τZ conversion** in flight.

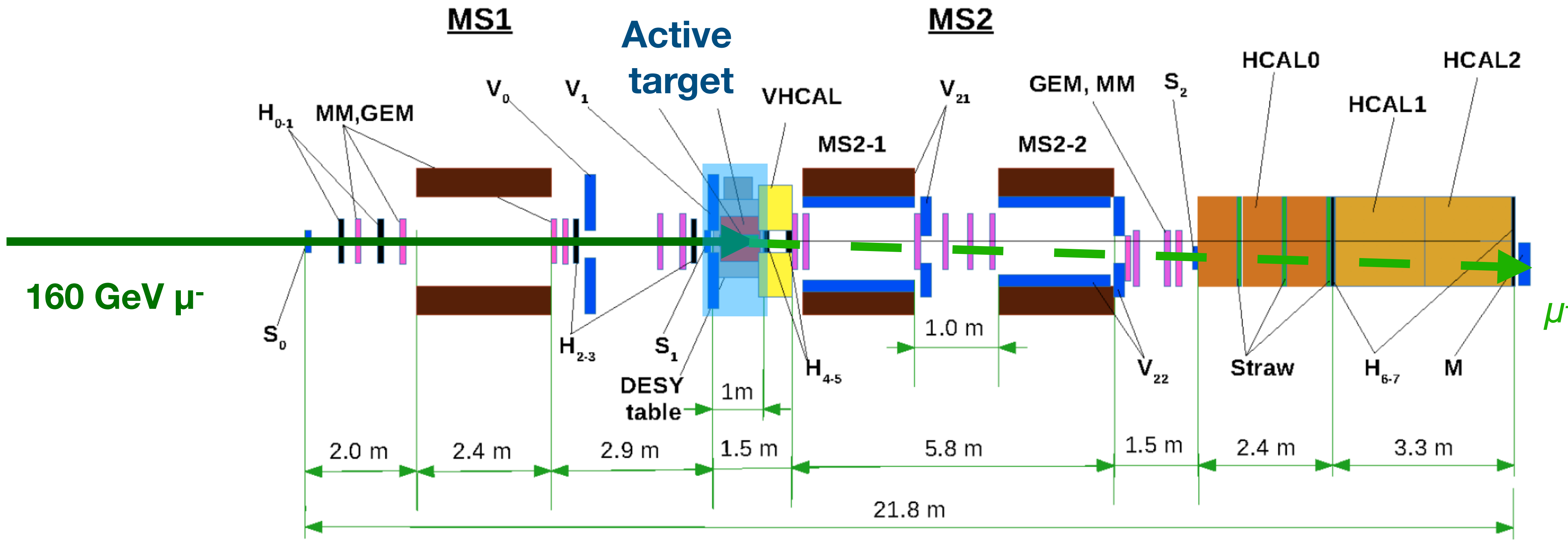






NA64μ proposal

Exploring dark sector physics weakly coupled to muons



Expected timeline

LS2			LS3	
2020	2021	2022	2023	2024
	Pilot run	Expected first physics runs to *probe Z' as $(g\text{-}2)_\mu$ explanation*		Phase 2: *cover high A' masses*

Focus of this talk: Preparation and status of the pilot run

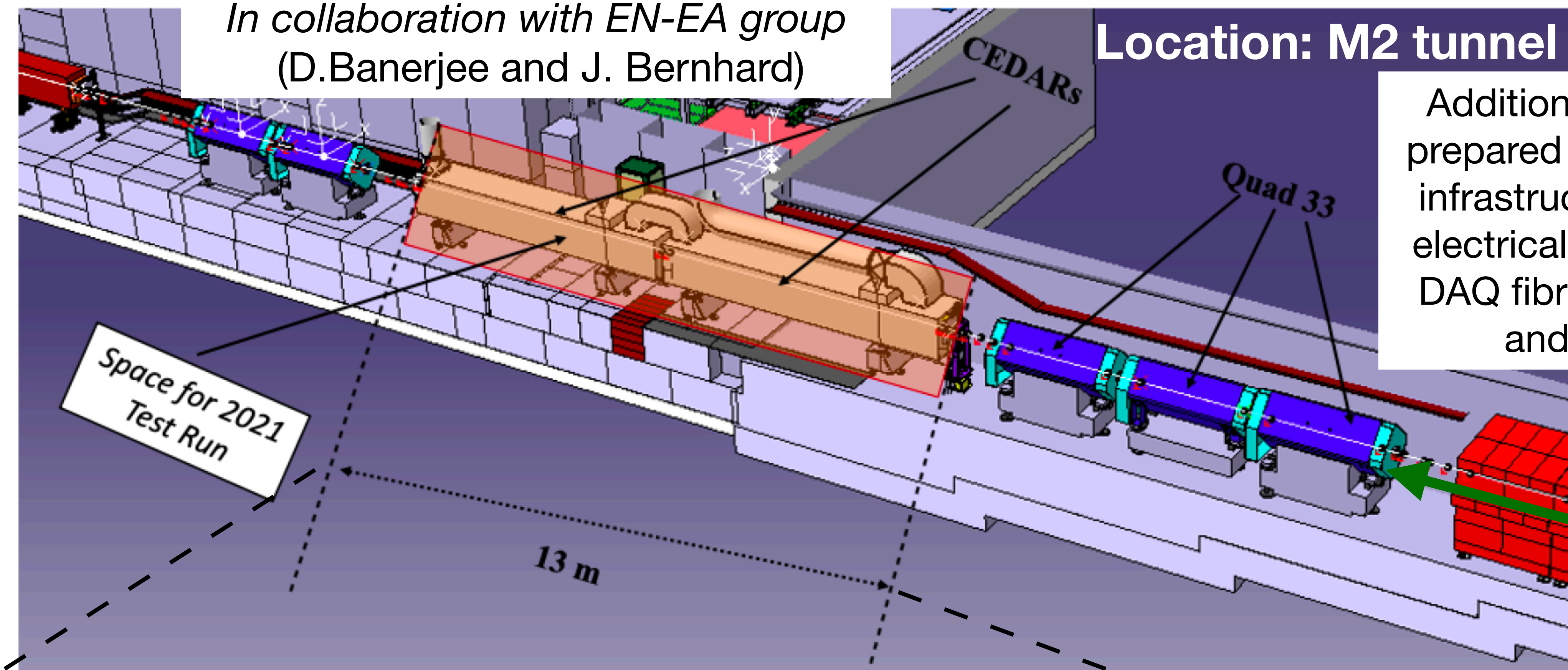
Experimental setup for the NA64μ pilot run

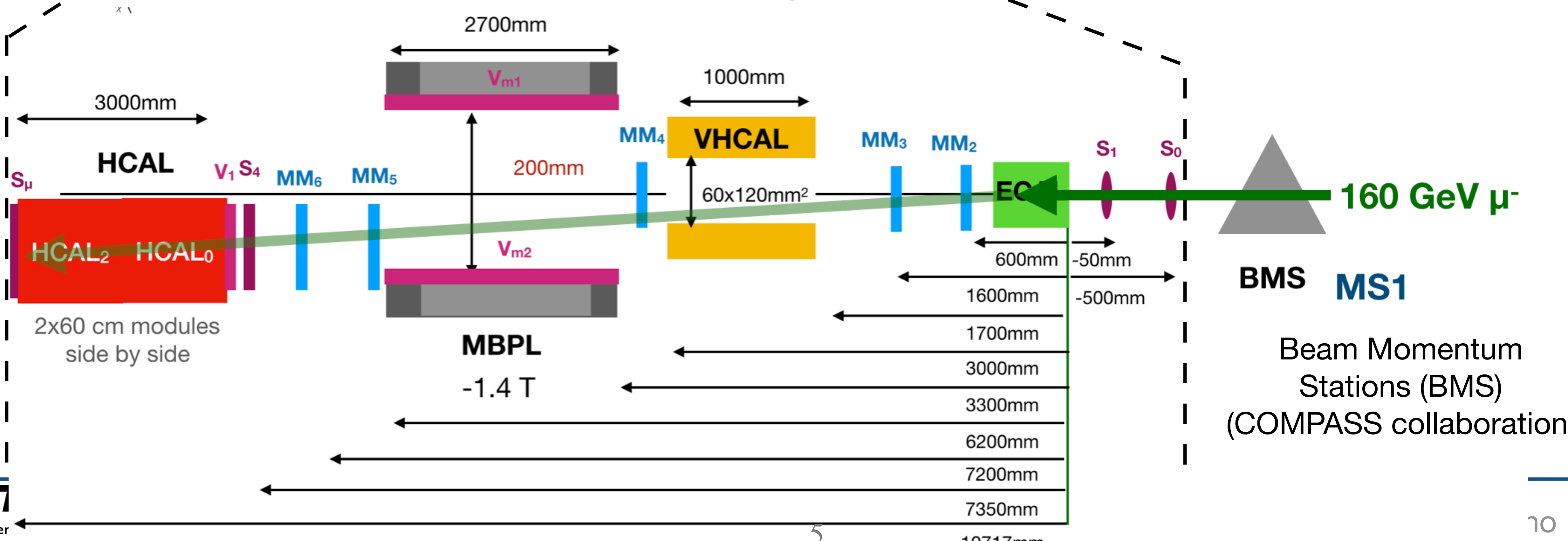
GOAL: **Feasibility of the technique to search for a Z' boson in the MeV-GeV range**

In collaboration with EN-EA group
(D.Banerjee and J. Bernhard)

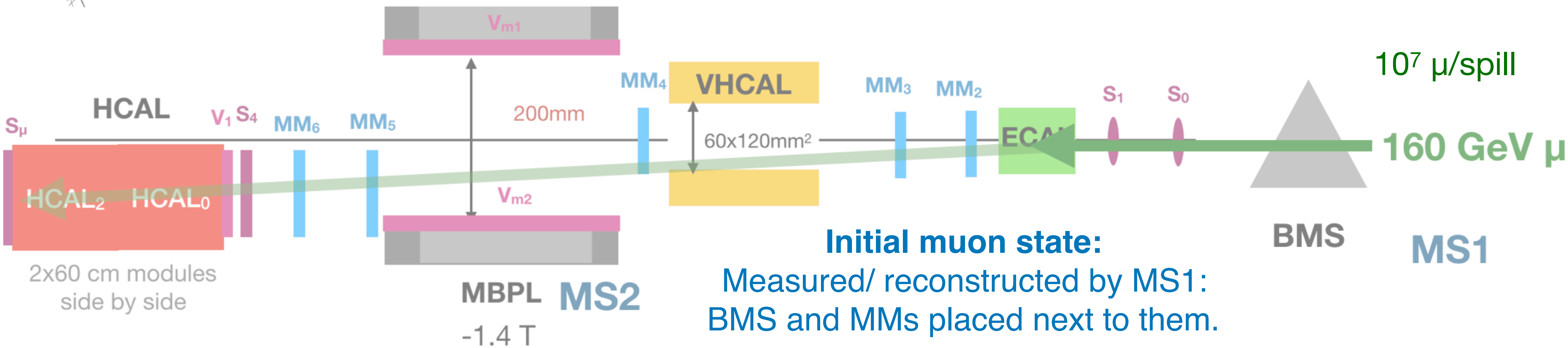
Location: M2 tunnel

Additional space would be prepared for commonly used infrastructures such as gas, electrical outlets, grounding, DAQ fibres, space for racks and control room.





Experimental setup for the NA64μ pilot run



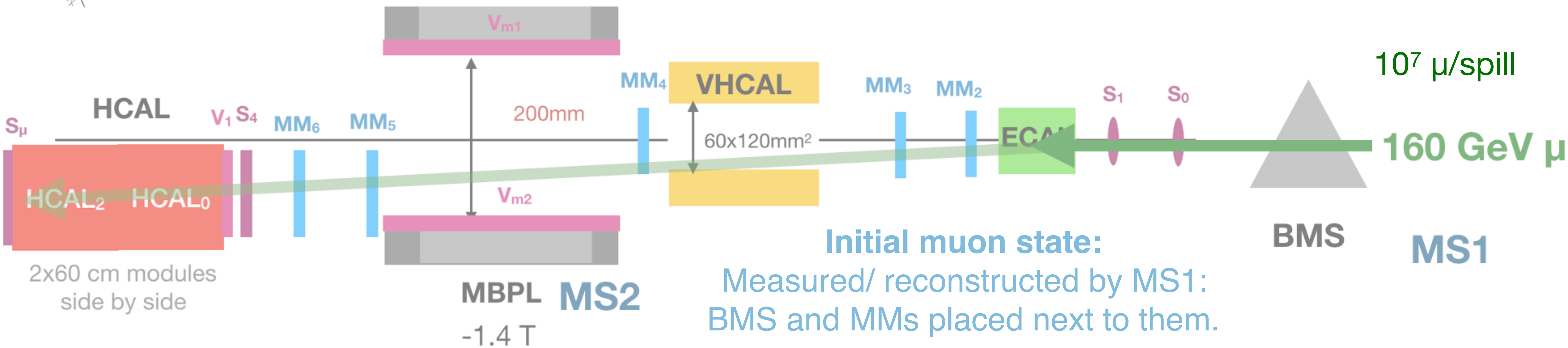
Initial muon state:
Measured/ reconstructed by MS1: BMS and MMs placed next to them.

Final muon state:
Measured/ reconstructed by a magnet spectrometer (MS2) which consists of a single MBPL magnet and micromegas detectors.

Signature

- Missing momentum (momentum loss of the out-coming muon larger than 80 GeV)
- No energy on the ECAL, HCAL, VHCAL (compatible with MIP energy)

Experimental setup for the NA64μ pilot run



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Detector parts from NA64e

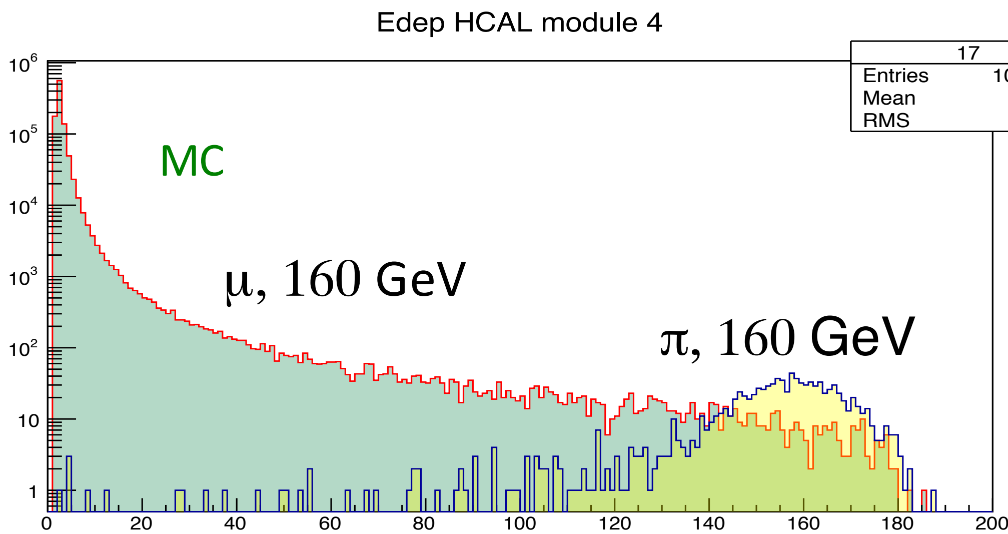
- ECAL as target
- 8x8 cm² Micromegas for tracking before MBPL.
- GEMs for tracking
- 4 HCAL modules placed side by side (120 cm width)
- Upgraded NA64e DAQ system (50kHz)
- New Veto hadron calorimeter (production ongoing) More details on Paolo's talk

New detectors

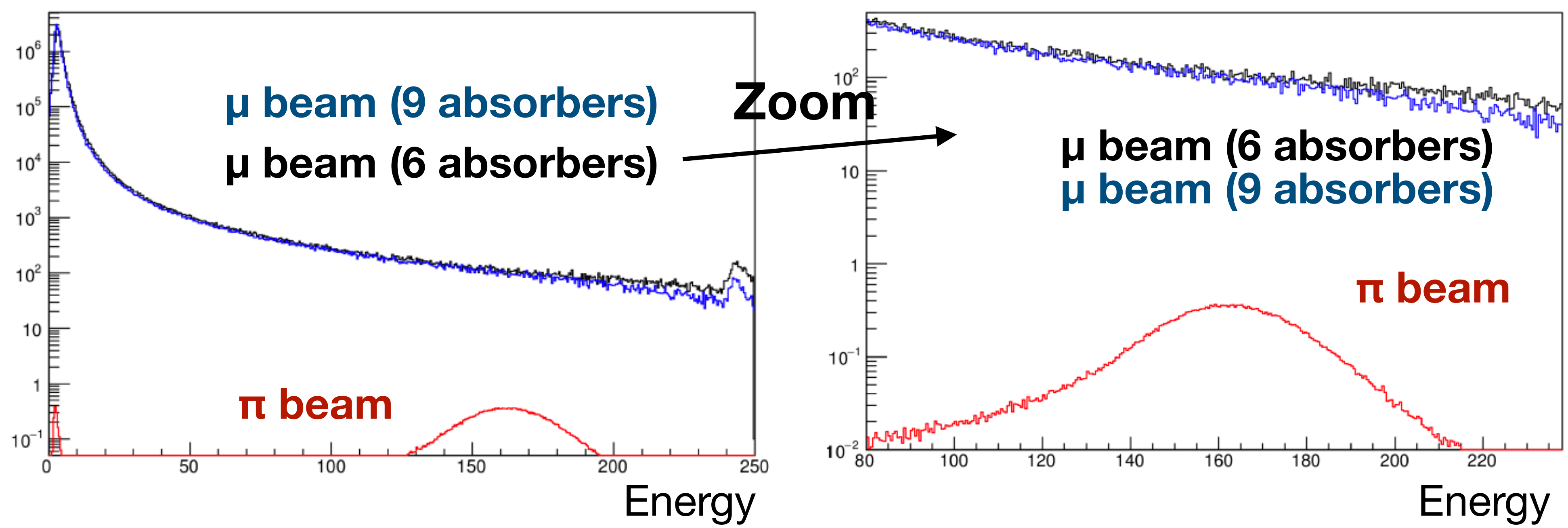
- **25x8 cm² Micromegas for tracking after MBPL** (design ongoing).
- Large area straw detectors 120x60 cm² (production ongoing, will be ready by the end of the year)
- **MBPL magnet with 20 cm gap:** availability confirmed by the EN-EA-LE with TE-MSC. The powering scheme and cooling are foreseen by TE-MSC and TE-EPC.
- **Scintillators counters trigger system** based on the deflection of the scattered muon after the magnet to run at 10^7μ/spill:

$$S_0 \times S_1 \times S_4(\text{shifted}) \times \overline{V_1} \times \overline{V_{m1}} \times \overline{V_{m2}} \times S_\mu$$

K,π contamination in the M2 beam line



- Measurements performed by S.Donskov and V.Poliakov in COMPASS beam in 2017.
- Empty LiH Target
- HCAL calibration 160 GeV π
- Comparison between:
  - μ beam: **6** and **9 absorbers** (10^6 μ/spill)
  - Pure hadron beam (π) (10^4 π/spill)



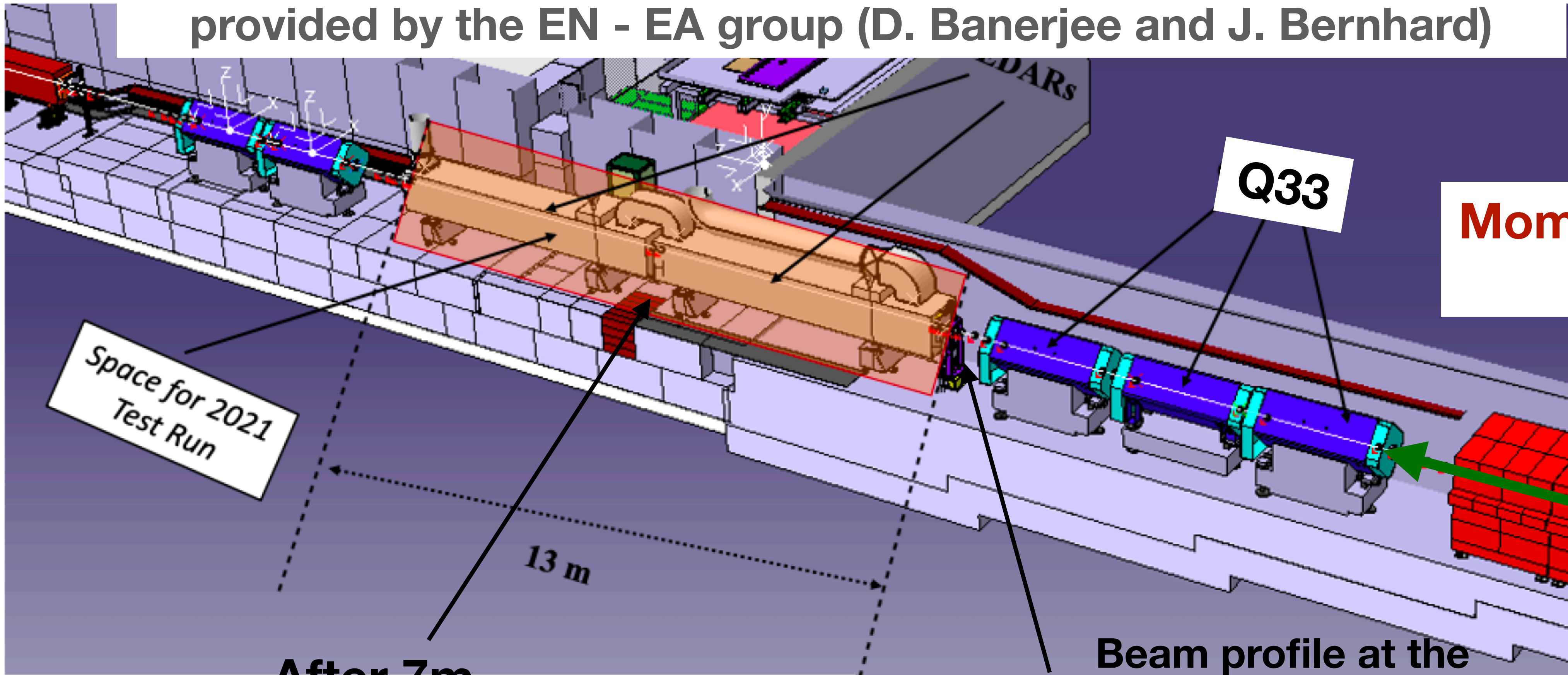
Generalized Maximum Likelihood Method was used to find the pion contamination in the beam:

$\mu(6 \text{ abs.}) = \mu(9 \text{ abs.}) + \pi$ π,K /μ = $(9.7 \pm 1.4) \times 10^{-5}$ Preliminary result

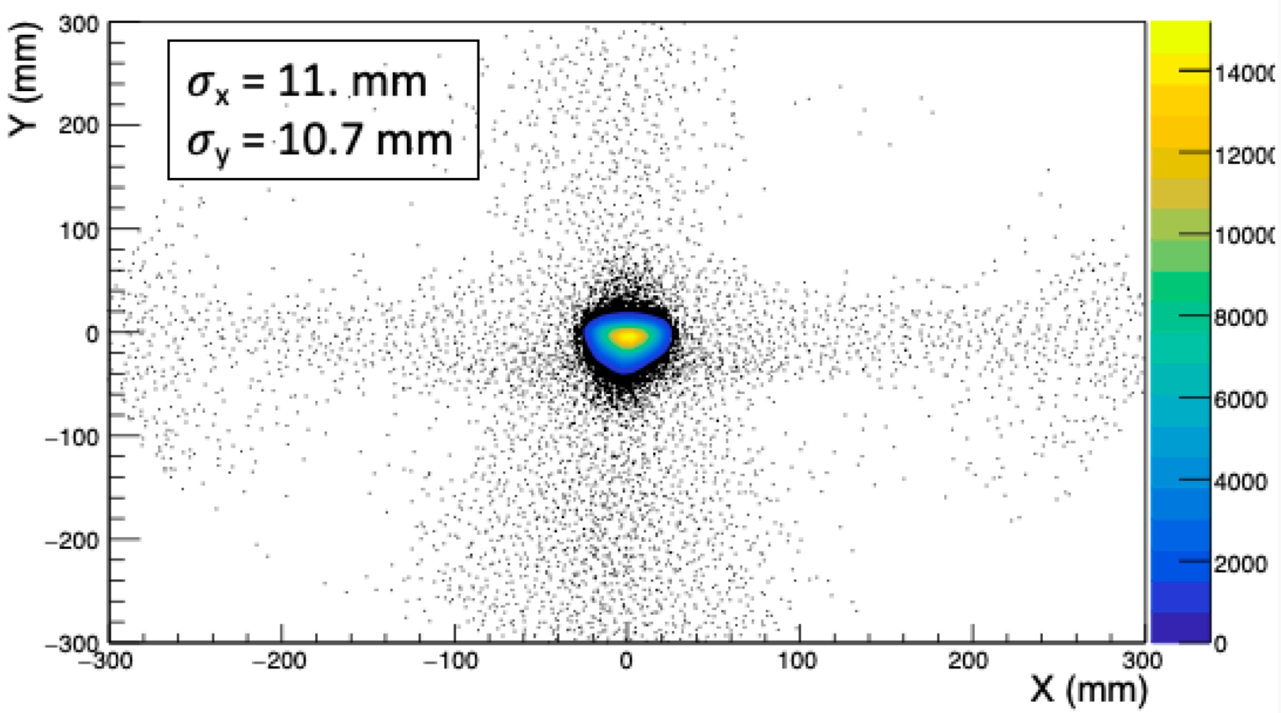
We would like to repeat this measurement at the real NA64μ location. The hadron contamination in the beam is a key quantity for our measurement background estimation.

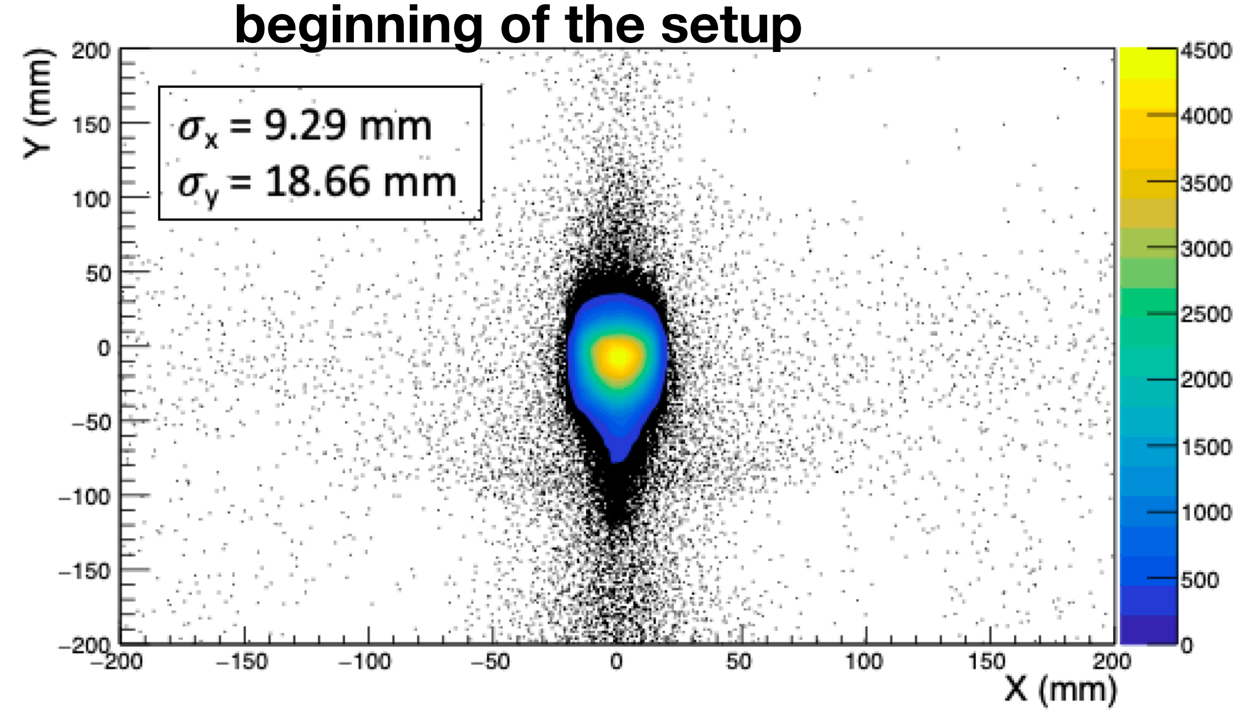
Simulations: μ beam

Input μ beam and halo profiles from the M2 beam line simulations
provided by the EN - EA group (D. Banerjee and J. Bernhard)



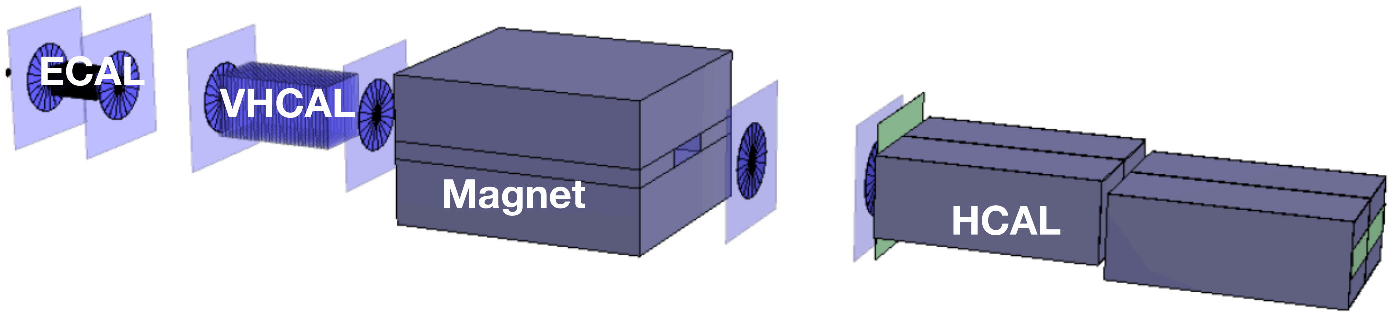
Momentum spread
$\sigma_p/p = 4\%$





Simulations: **pilot run setup**

Full simulation and reconstruction package developed in GEANT4.



Mass [MeV]	$S_0+S_1+S_\mu$ + $S_4(X_{S4}[mm]<-50$	HCAL	VHCAL	Reco. Momentum
100	**37%**	**30%**	**29%**	**22%**
Primary μ beam	**0.2%**	**0.1%**	**0.1%**	**0.07%**

Cuts:

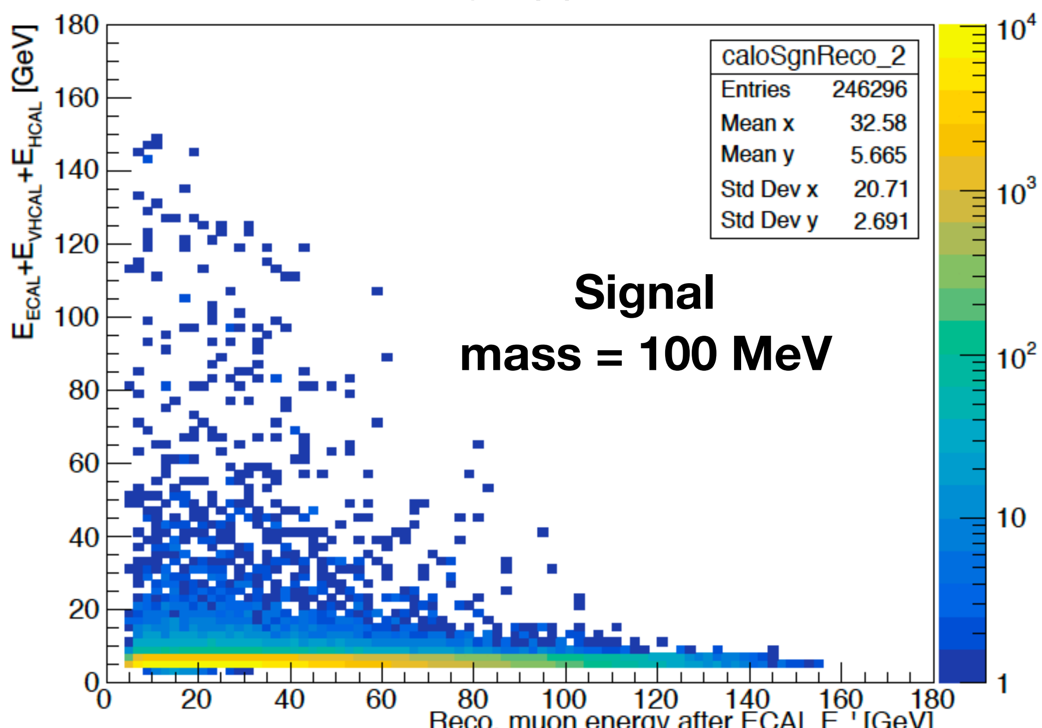
-Signal compatible with a MIP in HCAL and VHCAL.

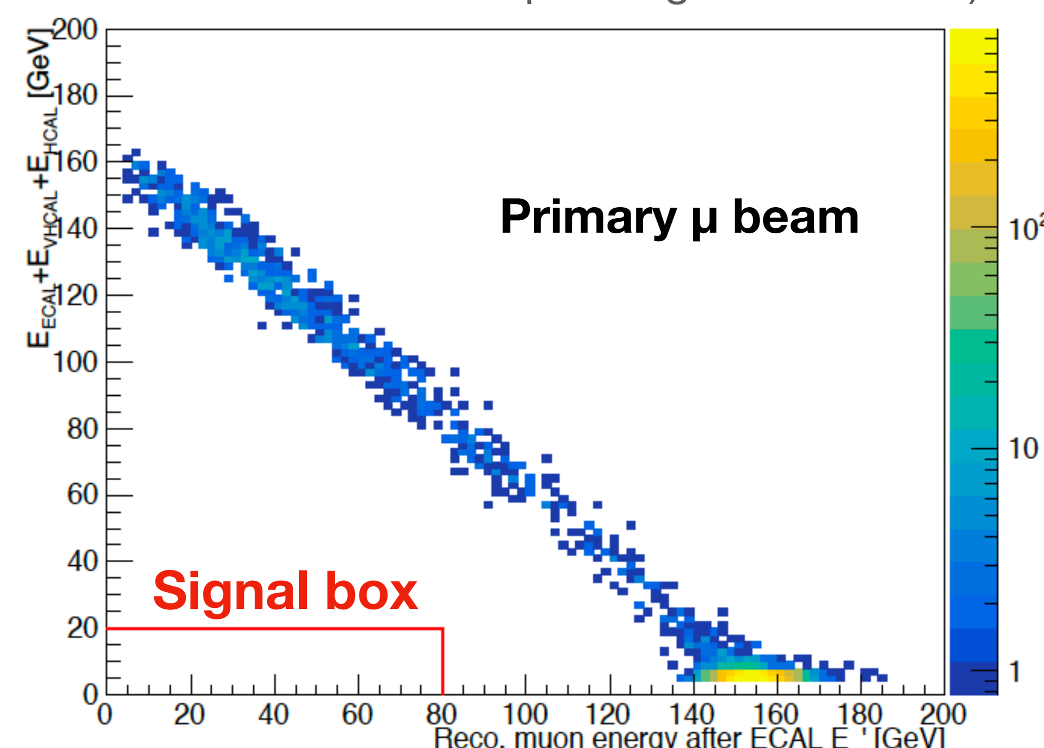
-Momentum reconstruction quality cuts:

$$\tilde{\chi}^2 = \sum_{i=1}^{4} \frac{(p_{\perp,\,i}^{\mathrm{reco}} - \overline{p}_{\perp}^{\mathrm{reco}})^2}{\overline{p}_{\perp}^{\mathrm{reco}}}$$

MM:number of hits per Micromega ≤1

2×10^7 muons simulated (e-,γ,μ-nuclear interactions cross-sections biased corresponding to 10^9 muons)





Plans for 2021

During the two weeks of data taking foreseen for the pilot run we expect:

1. **Commissioning of the beam:** It is expected before the test run where all the beam parameters such as beam spot size, divergence and halo rate will be optimised. The results will be also used to validate the beam simulations with data.

2. **Installation, commissioning, initial alignment and calibration of the detector.** It is planned to collect a sample of events to study the detector alignment and response, and to validate its simulations with data.

3. **Trigger rate** study for different detectors and beam configurations.

4. **Hadron contamination in the beam:** crucial step to understand the level of background in our measurement.

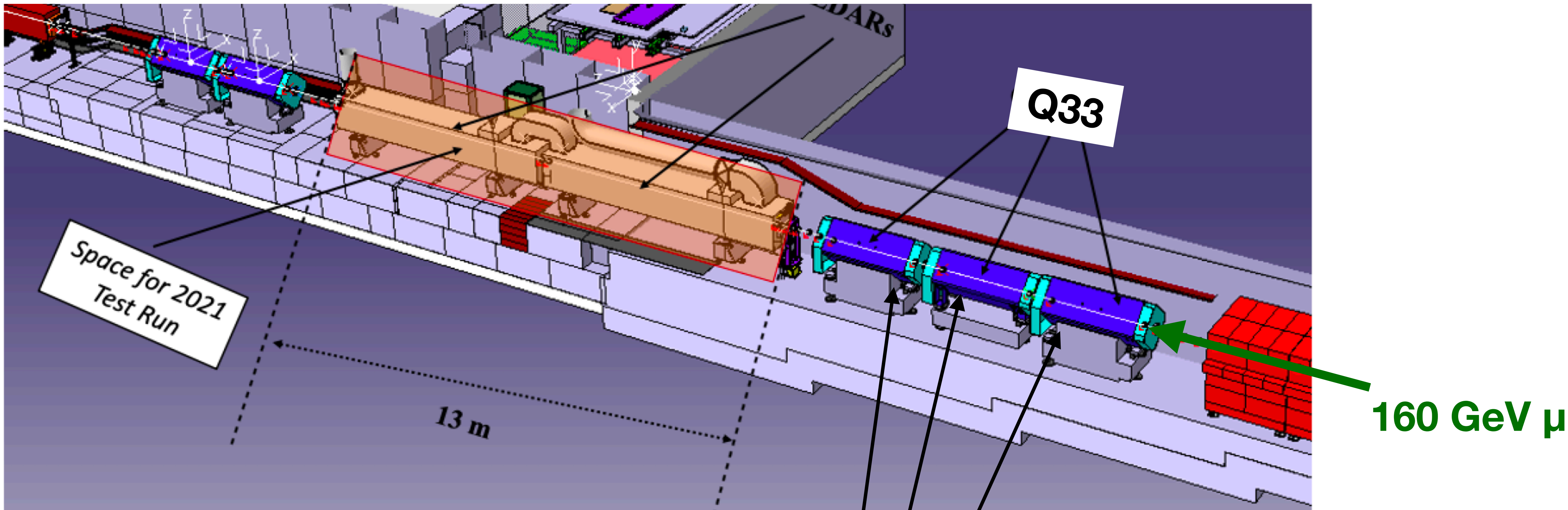
5. Collect a large sample of events to study the detector hermeticity and validate the beam simulations with data.

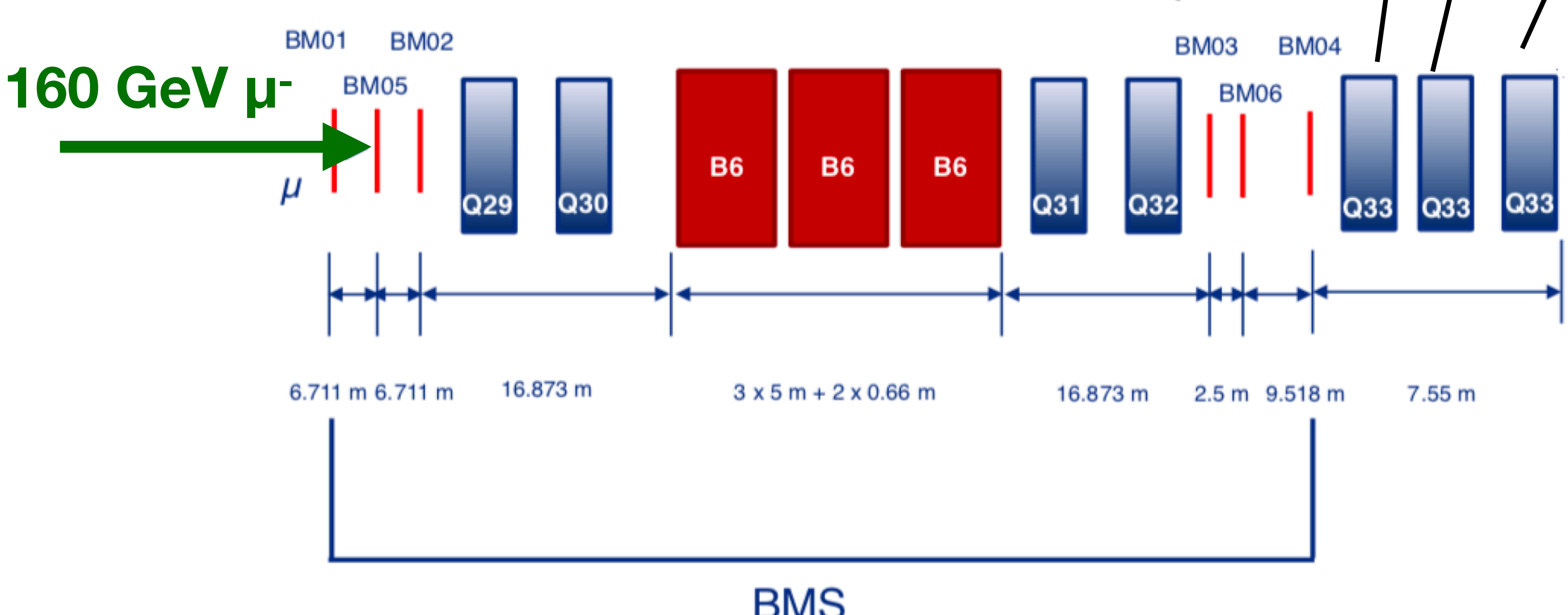
The analysis of the beam and the obtained results would play an essential role to understand the detector and the next steps.

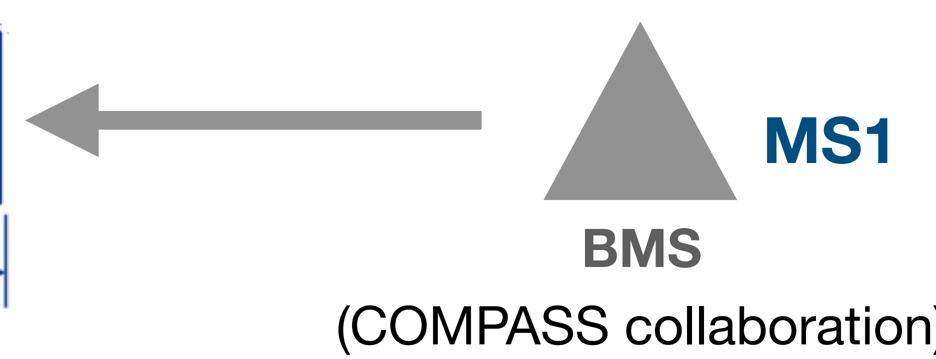
Back-up

Initial momentum definition

Beam Momentum Stations + complementary/alternative measurement from 8x8 cm² Micromegas detectors placed next to them (NA64e like)







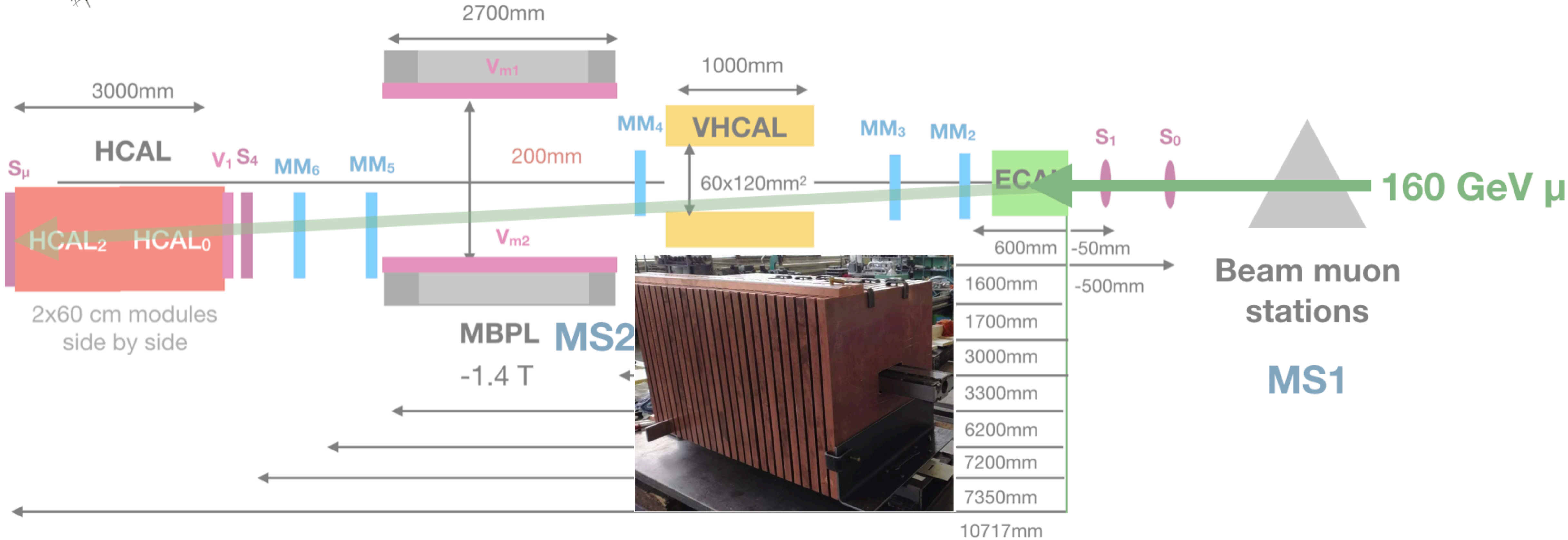
4 scintillator hodoscopes stations

BM01-04 σ =1.4 mm

2 scintillating fibers stations

BM05 (σ =0.72 mm) and BM06(σ =0.36 mm)

Status of new detectors



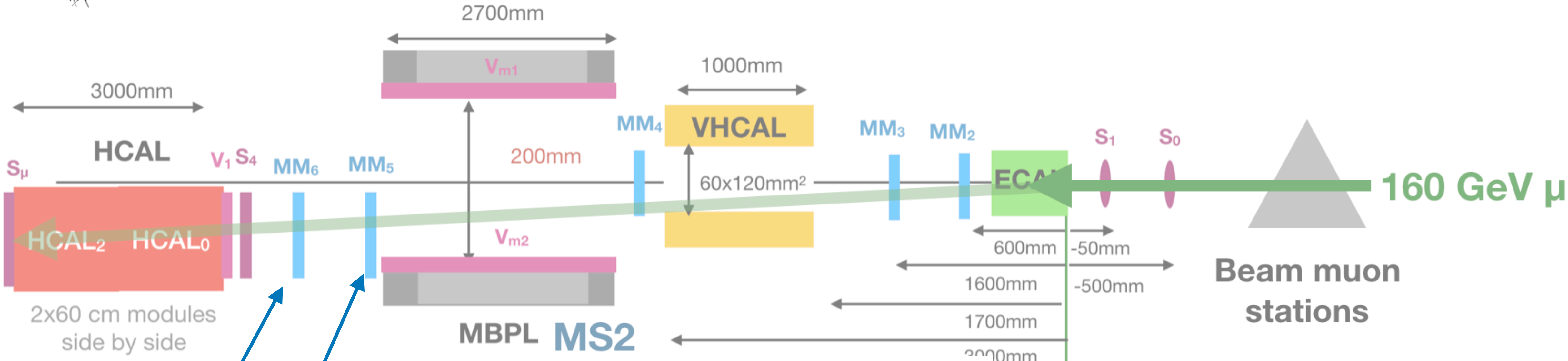
Already in production and detector fully assembled by the end of the year

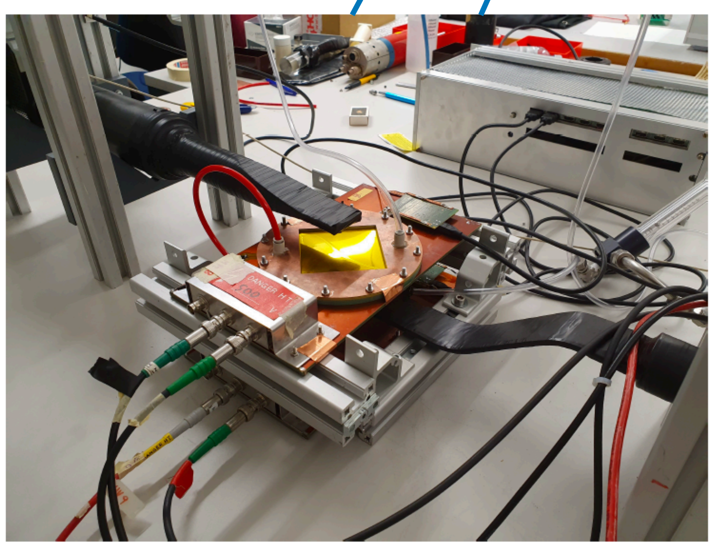
New detectors

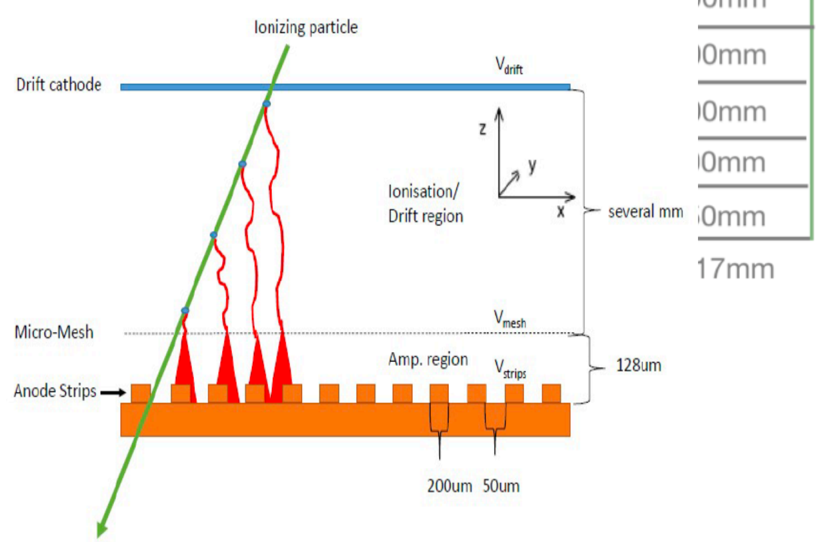
- Number of layers 30: each 25 mm copper + 2 mm scintillator
- Read out through 1 mm diameter WLS fiber, 12 fibers per scintillator
- Light yield: 15 photoelectrons per MIP

- **Veto hadron calorimeter same as NA64e.**
- 25x8 cm^2 Micromegas for tracking after MBPL.
- Large area straw detectors 120x60 cm^2
- MBPL magnet with 20 cm gap
- Trigger system based on scintillators to run at 10^7μ/spill.

Status of new detectors







- Design ongoing
- Similar to the ones needed for the new NA64e visible setup
- Larger length only along the bending axis to keep the number of channels under control and maximise signal efficiency.

New detectors

- Veto hadron calorimeter same as NA64e.
- **25x8 cm² Micromegas for tracking after MBPL.**
- Large area straw detectors 120x60 cm²
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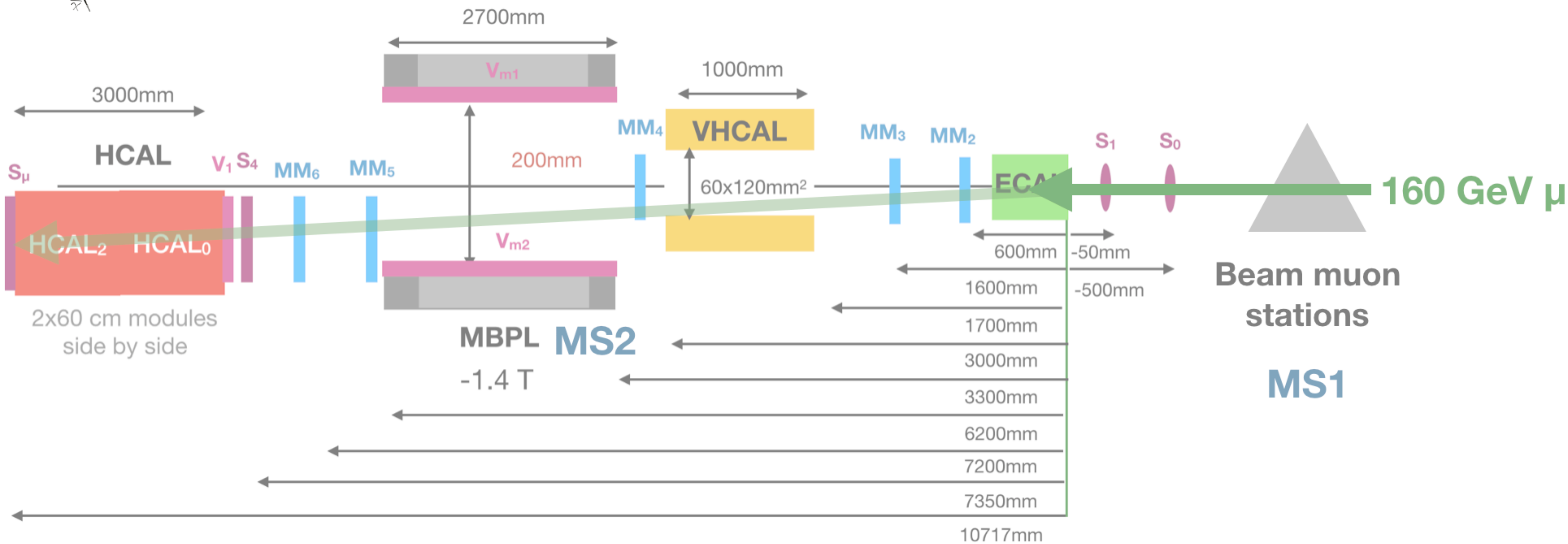
Status of new detectors



New detectors

Seven new 6 mm double layer Straw Tube chambers with the size of 120x60 cm^2 have been developed for the test run with the muon beam. The chambers are currently in production:

- 10 out of 14 planes are ready.
- 3 out of 7 chambers are inserted into the frames.
- 1 chamber is already equipped by anode wires.
- 2 chambers are sealed.

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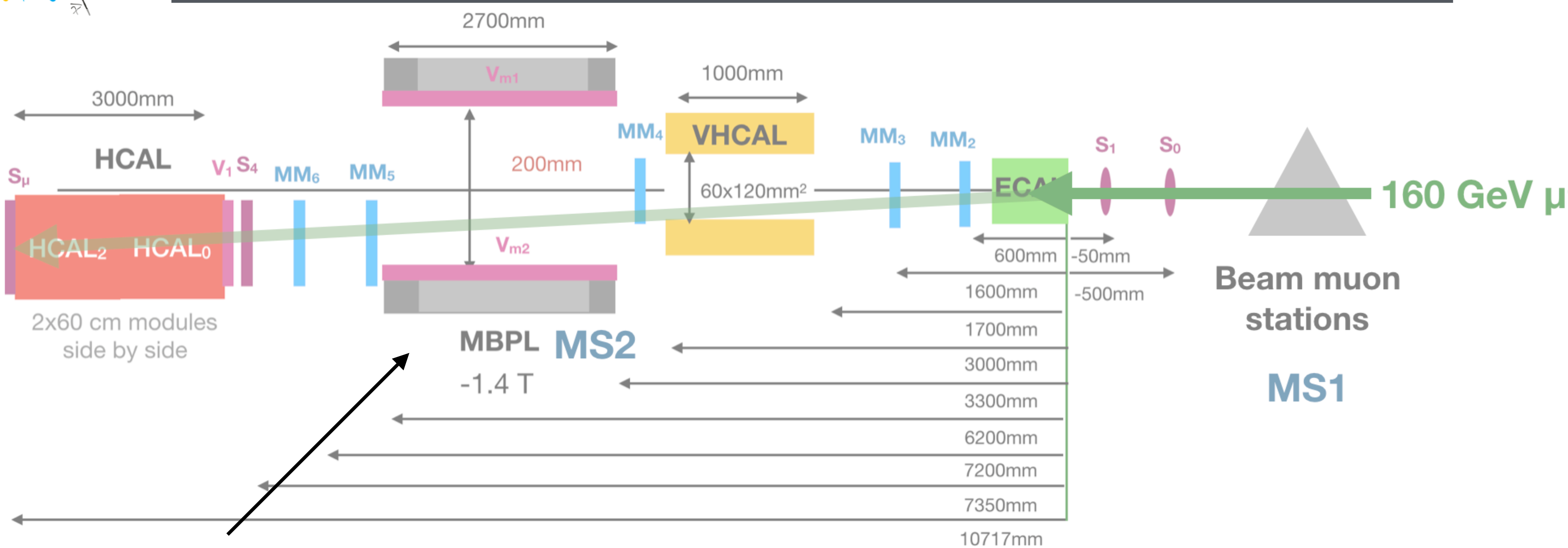

- Availability of the MBPL magnet has been confirmed by the EN-EA-LE with TE-MSC.
- The powering scheme and cooling are foreseen by TE-MSC and TE-EPC.
- The location is not accessible by a overhead crane, so a rail system is planned to be installed in the zone during LS2 (reducing also the installation times for other equipment)
- It will be placed on three mechanical jacks with an XY adjustable table to aid the alignment of the magnet

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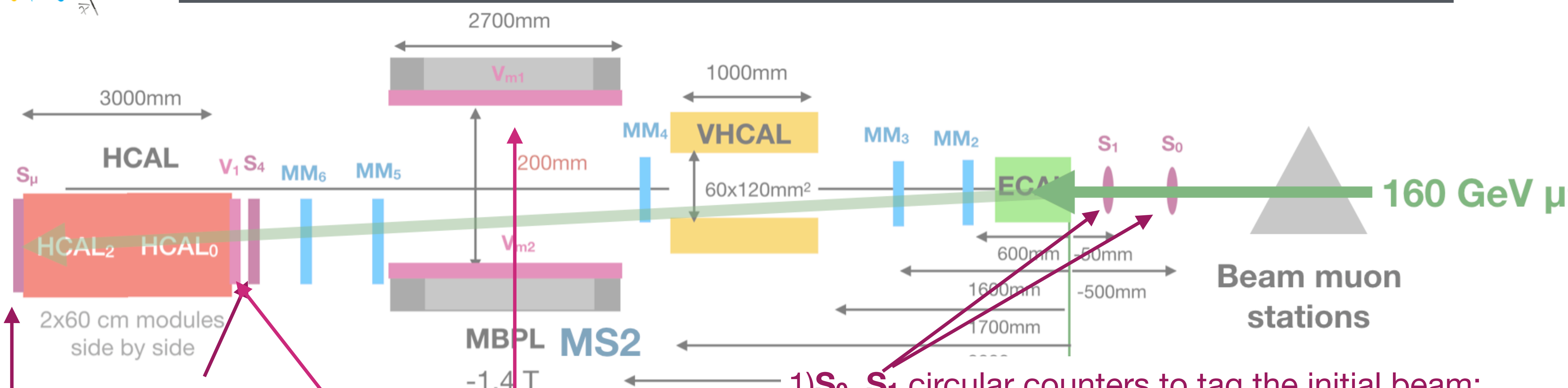

1)**S_0, S_1** circular counters to tag the initial beam: ~70% efficiency depending on the size (2.5-3cm radius (under study), 3mm thick). Similar design as the ones used in NA64e
-Once triggered, no lost of muons in the last muon counter.

2)**S_4:** rectangular X shifted counter (100 cm width) to maximise the signal efficiency.

3)**S_μ:**Rectangular counter at the end of the setup (120 cm width) to tag the muon candidates.

4)No signal on Veto V_1 (circular counter, radius under study) and on veto magnet sytem (counters V_{m1}, V_{m2}).

-Veto magnet system:

- 2cm thick rectangular counters.
- Scintillator strips with two light guides from both sides and connected to PMTs.
- Light yield: 200-300 photoelectrons per MIP.

New detectors

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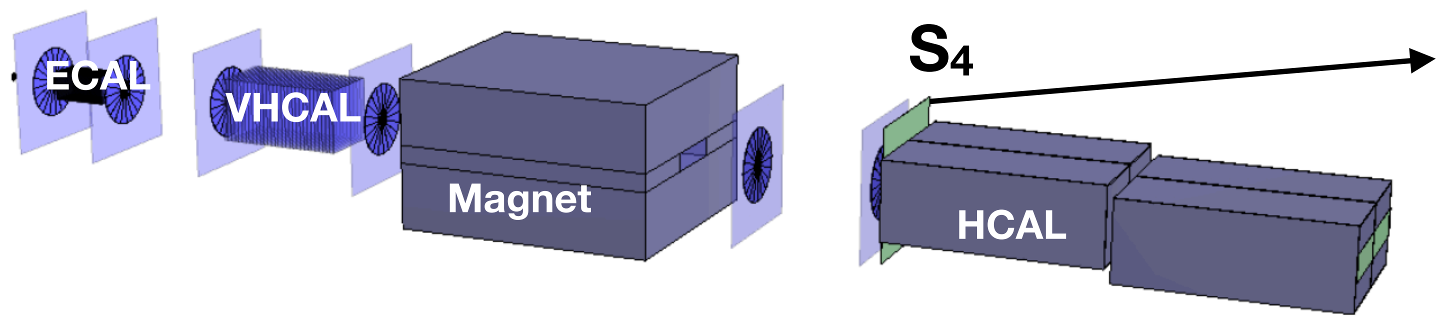
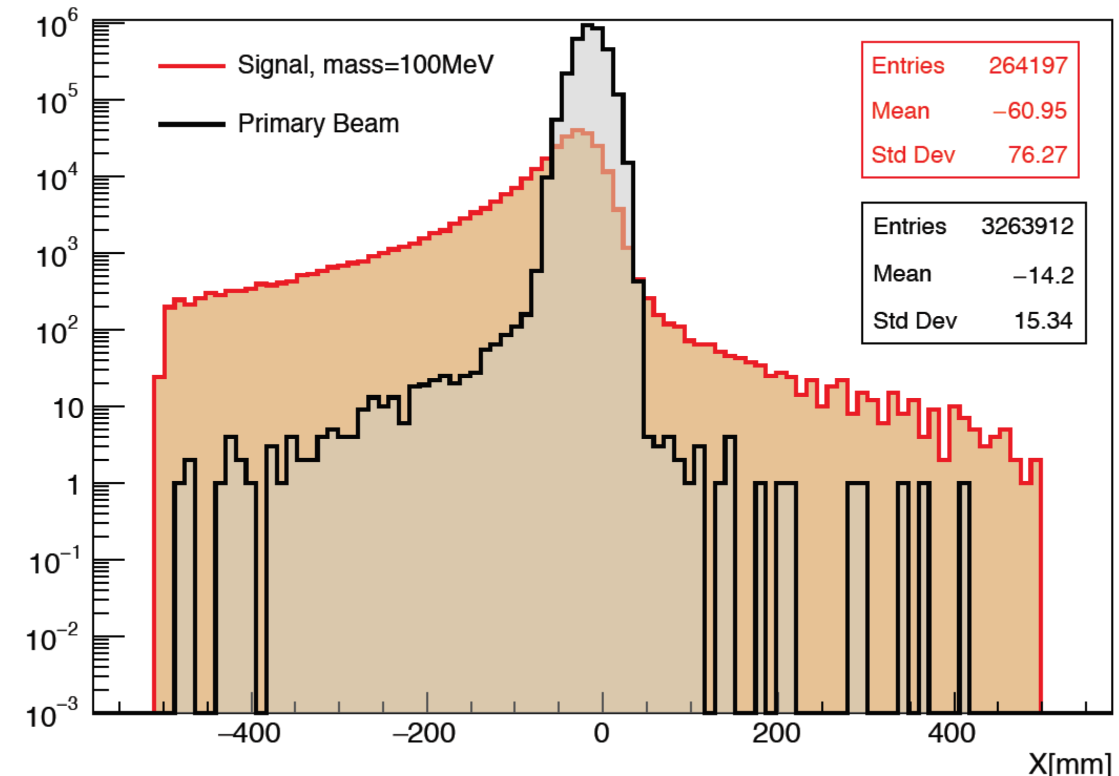
Simulations: **pilot run setup**

Full simulation and reconstruction package developed in GEANT4.





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