Impressions of the M2 beam line

Review of the M2 beam at CERN

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EA

Physics Beyond Colliders

Agenda

- The “Physics Beyond Colliders” Initiative
- Secondary Beams at CERN
- The M2 Beam
- Specialties with Muons Beams
- The EHN2 Experimental Area
- 2018 Test Beams in EHN2
- Summary and Outlook

http://pbc.web.cern.ch/

Physics Beyond Colliders – Introduction

- Extrapolary study aiming at exploiting the full scientific potential of CERN's accelerator complex and its scientific infrastructure through projects complementary to the LHC, HL-LHC and other possible future colliders
- Projects targeting fundamental physics questions that are similar in spirit to those addressed by high-energy colliders, but that require different types of beams and experiments
- Initiated by CERN director-general and coordinated by J. Jaeckel, M. Lamont and C. Vallee (chair)
- Kick-off workshop (September 2016) identified a number of areas of interest
- Working groups set-up to pursue studies in these areas
- PBC study remains open to further ideas for new projects

Physics Beyond Colliders – Physics

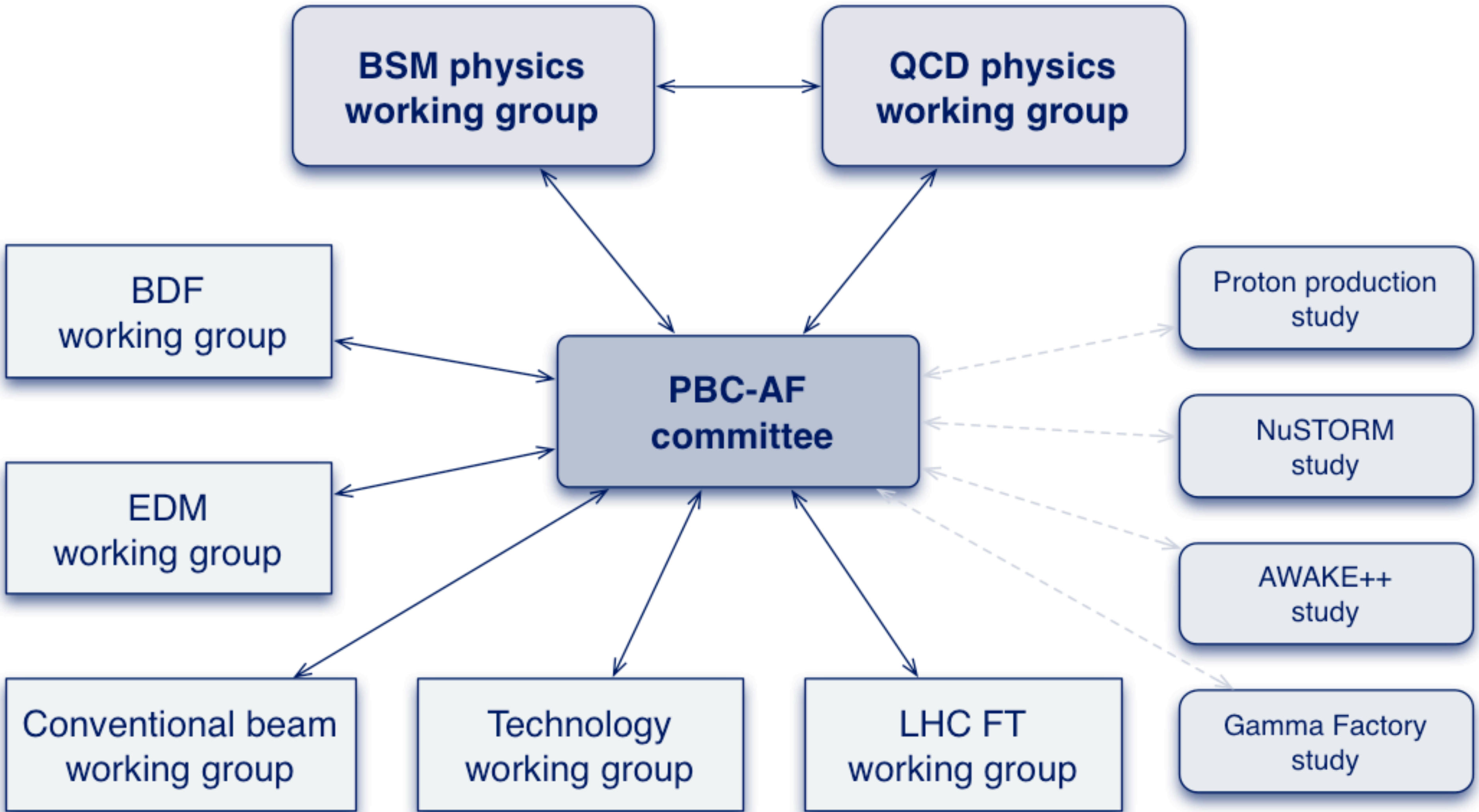
Physics Groups

- **BSM subgroup:** SHIP; NA64++; NA62++; KLEVER; IAXO; LSW; EDM; REDTOP
- **QCD subgroup:** COMPASS++; ***μ-on-e***; LHC FT (gas target + crystal extraction); DIRAC++; NA60++; NA61++

Deliverables:

- Evaluation of the physics case in the worldwide context
- Possible further detector optimization
- For new projects: investigation of the uniqueness of the CERN accelerator complex for their realization

Accelerator Working Group



Physics Beyond Colliders – Introduction

- ***Conventional beams subgroup***: Evaluation of NA62 beam dump, COMPASS RF separated beam, NA61++ beam, KLEVER beam + possible siting of NA64++, ***μ-on-e***, NA60++, and DIRAC++ beams
- **BDF subgroup**: Completion of technical feasibility studies of a Bump Dump Facility as input to the SHiP conceptual design study (CDS)
- **EDM subgroup**: Feasibility study including preliminary costing
- **LHC Fixed Target subgroup**: Collection of various initiatives (UA9, LHC collimation team, AFTER collaboration) with the aim of a conceptual design report
- **Technology subgroup**: Evaluation of possible technological contributions of CERN to non-accelerator projects possibly hosted elsewhere

Conventional Beams – Strategy

- Large number of fixed target proposals
- Pre-proposal studies for working groups to ensure progress with their evaluation
- Focus first on projects with
  - Possible short and medium time-scale implementation
  - Limited resources
  - Most advanced and competitive (based on the available input and first feasibility analysis regarding the FT implementation)
- Additional studies based on the information provided by the collaborations and the following criteria:
  - Analysis of the physics WG
  - Sufficient details known that are required for an implementation study
  - Initial study can be performed within the timescale of the European Strategy update

Conventional Beams – Projects

Under consideration at present:

- NA62: Proposal to operate in beam-dump mode (HNL, axions)
- NA64++: High intensity electron, muon and hadron beams for dark sector searches (A')
- K_LEVER: High intensity K_L beam (high flux, pencil beam, new target) for rare decays, in particular $K_L \rightarrow \pi\nu\nu$
- COMPASS++: RF separated beams for hadron structure and spectroscopy; proton radius measurement with muon beam
- ***μ-on-e: 150 GeV muon beams for high precision measurement of hadron vacuum polarisation for g-2 of the muon***
- DIRAC++: DIRAC@SPS for high statistics of mesonic atoms
- NA60++: Heavy ion beams for di-muon physics and open-charm
- NA61++: Higher intensity ion beam for open-charm studies

Conventional Beams – Structure

CONVENTIONAL BEAMS WORKING GROUP

Conveners: L.Gatignon, M.Brugger

Members: Experiments, H.Wilkens, G.Lanfranchi, T.Spadaro, EA physicists, HSE, RP, EL, CV, RF, STI

CBWG-ECN3

Convener: L. Gatignon

- K_LEVER
- NA62 Dump
- NA60
- DIRAC

CBWG-EHN2

Convener: J. Bernhard

- COMPASS (μ, RF-separated and low energy pbar beams)
- μ-on-e
- NA64-μ
- CEDAR project

CBWG-EHN1

Convener: N. Charitonidis

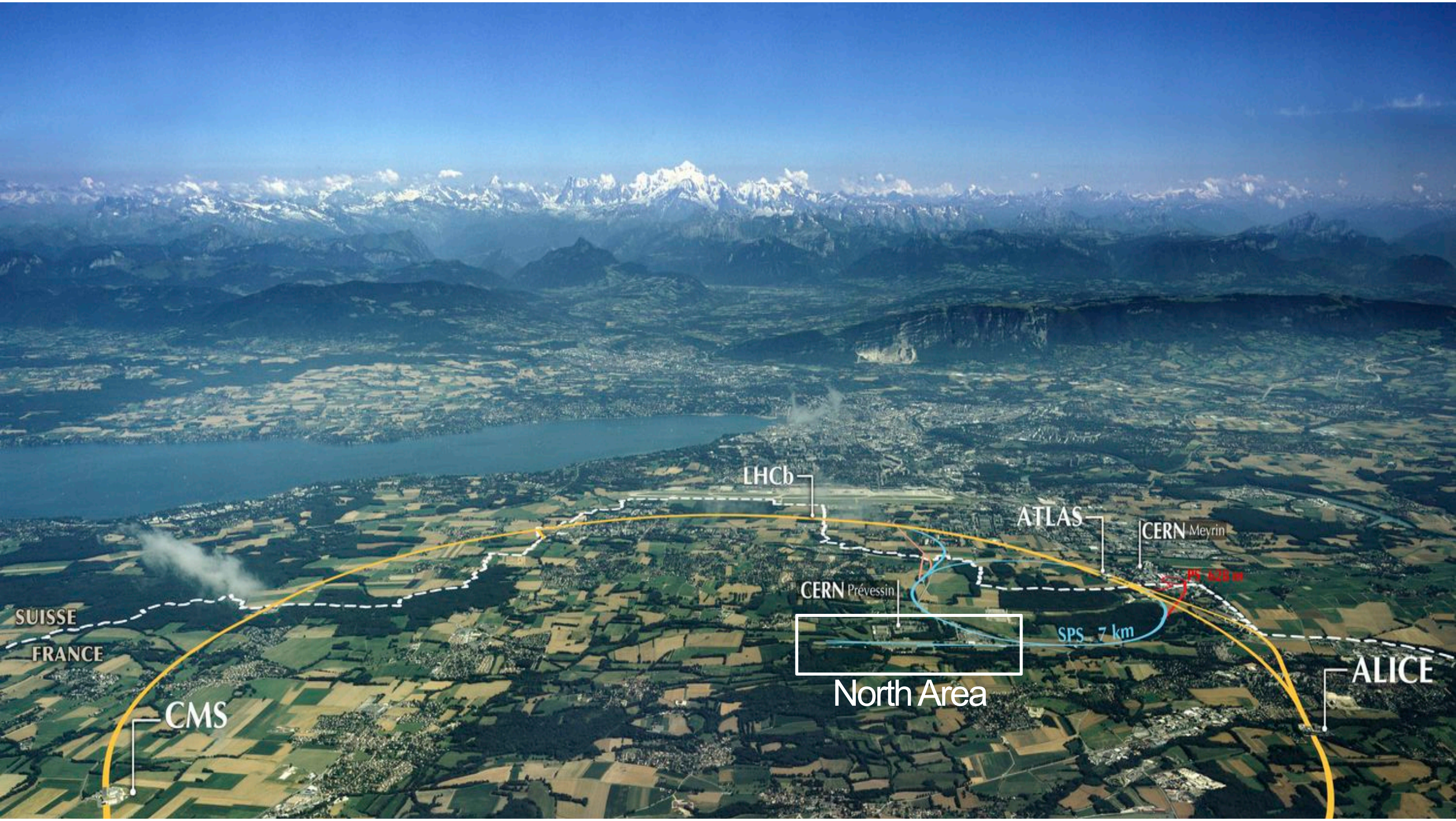
- NA61
- NA64 hadrons

Main deliverable: Conceptual Design Report by end of 2018

EHN2 Working Group

- Work Breakdown Structure (top level)
  - WP1: Muon beams post 2020
  - WP2: Hadron and Electron beams post 2020
  - WP3: RF-separated beams
  - WP4: Beam Particle Identification (dedicated meetings and WP leader S.Mathot/EN-MME)
- User presentations for technical details and plans completed
- Track progress by continuous reporting, about one WG meeting per month
- Next step: Finalise user requirements document
- One project associate (full-time) and one fellow (part-time) for studies

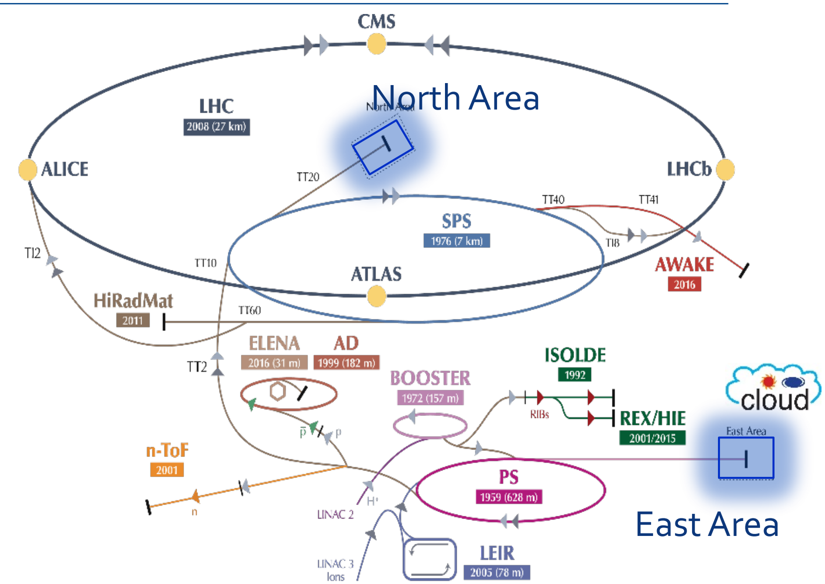
Secondary Beams at CERN

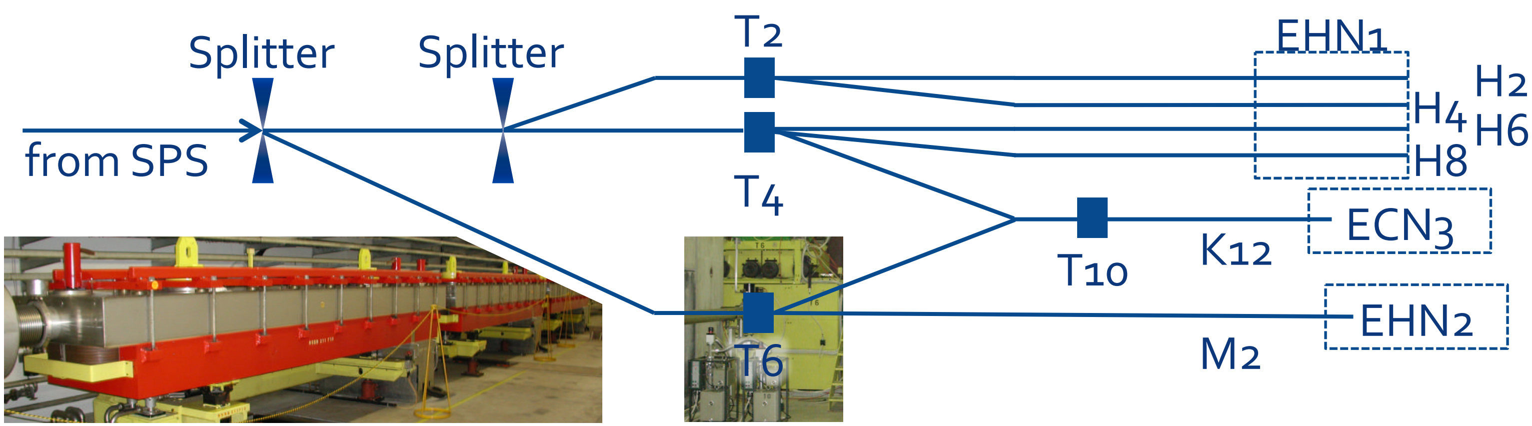


Secondary Beams at CERN

High intensity secondary beams in a wide range of momenta with largely selectable particle species

- East Area / PS (24 GeV/c primary protons and ions for irradiation and 0.5 – 15 GeV/c secondary beams)
- North Area / SPS (400 GeV/c primary protons and up to 380 GeV/c secondary and ion beams)





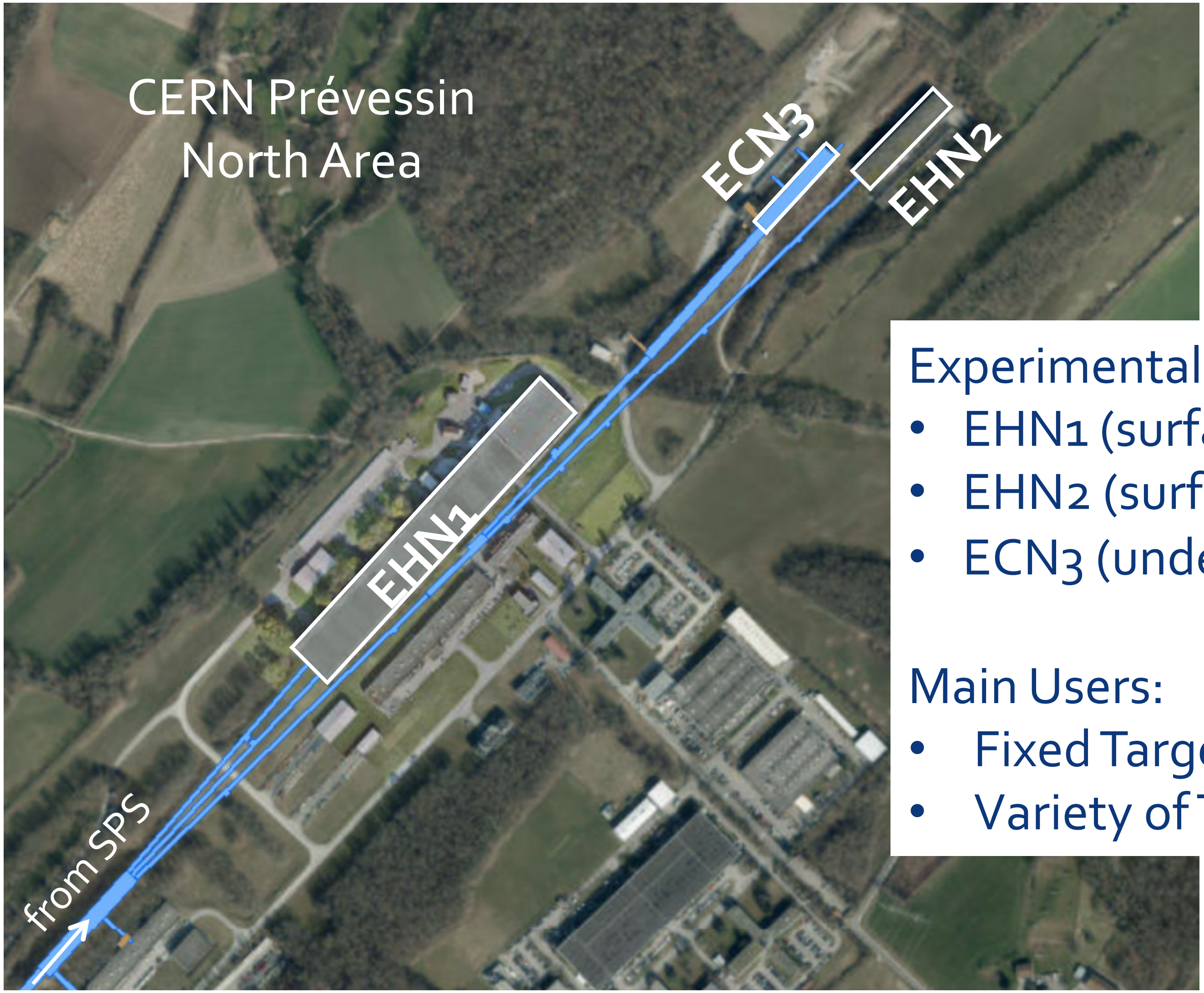
NA61 SHINE

NA63

NA62

COMPASS

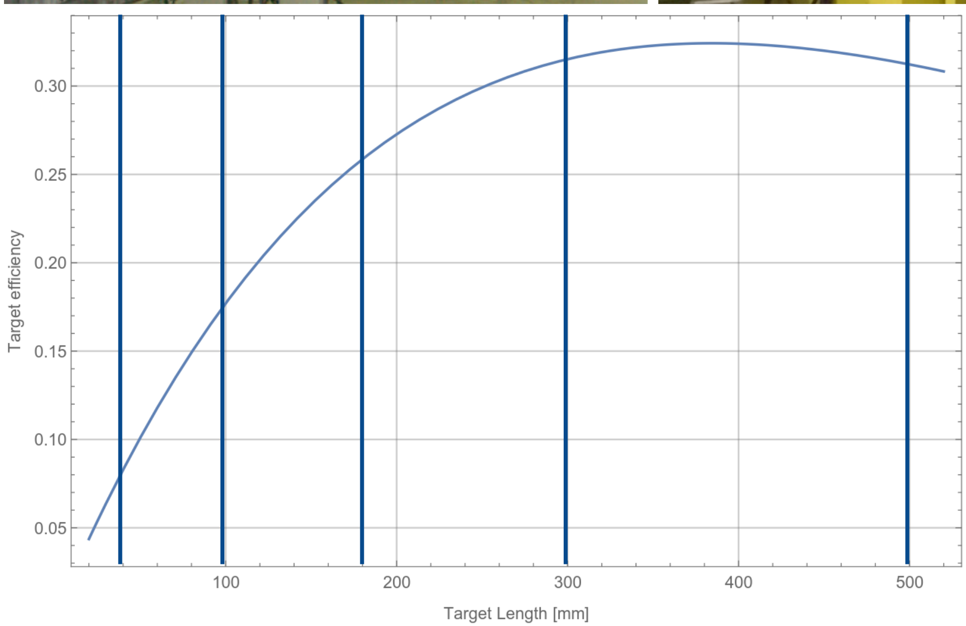
Secondary Beams at CERN



Experimental Areas:
- EHN1 (surface building)
- EHN2 (surface building)
- ECN3 (underground cavern)

Main Users:
- Fixed Target Experiments
- Variety of Test Beam Users

Production Targets



Position	Material	Length (mm)	Height (mm)	Width (mm)
0	*Air/OUT*	-	-	-
1	Be	500	2	160
2	Be	300	2	160
3	Be	180	2	160
4	Be	100	2	160
5	Be	40	2	160
		5x plates, 40 mm inter-plate distance		

Secondary Particle Production

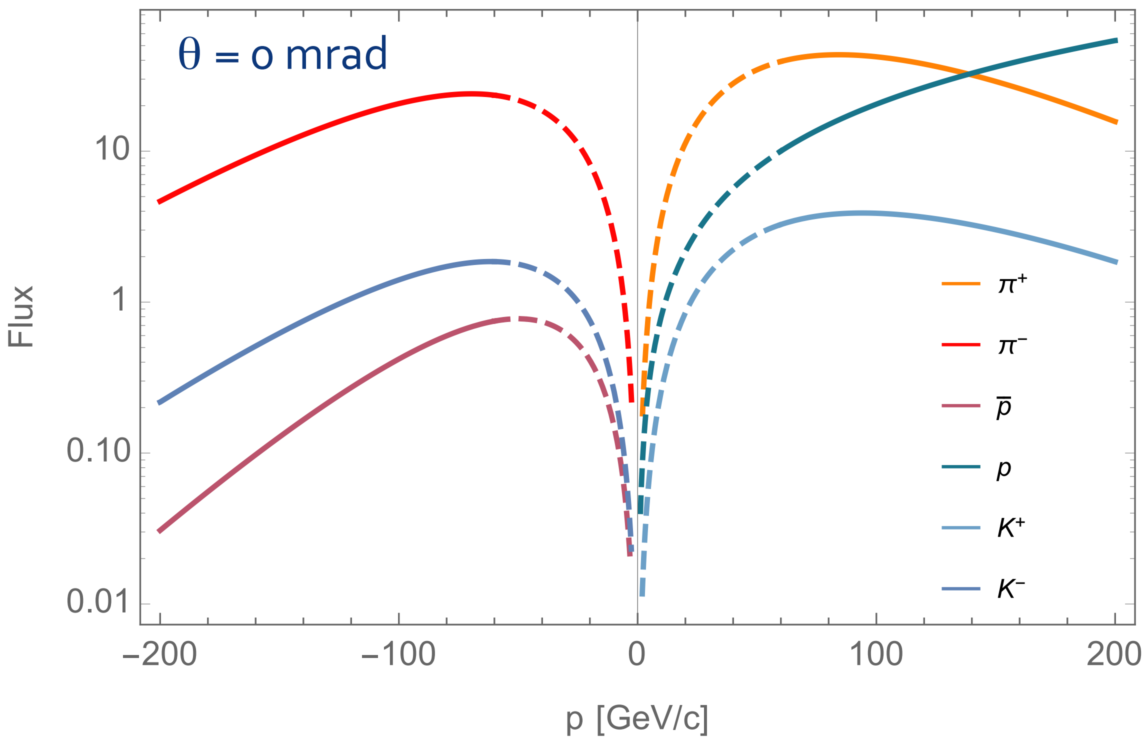
Atherton parameterisation (CERN 80-07):

$$\frac{d^2N}{dpd\Omega} = A\left[\frac{B}{p_0}\, e^{-Bp/p_0}\right]\left[\frac{2Cp^2}{2\pi}\, e^{-C(p\theta)^2}\right]$$

$$\frac{d^2N}{dpd\Omega} = A\left[\frac{(B+1)}{p_0}\left(\frac{p}{p_0}\right)^B\right]\left[\frac{2Cp^2}{2\pi}\, e^{-C(p\theta)^2}\right]$$

with primary momentum p_o and production angle θ

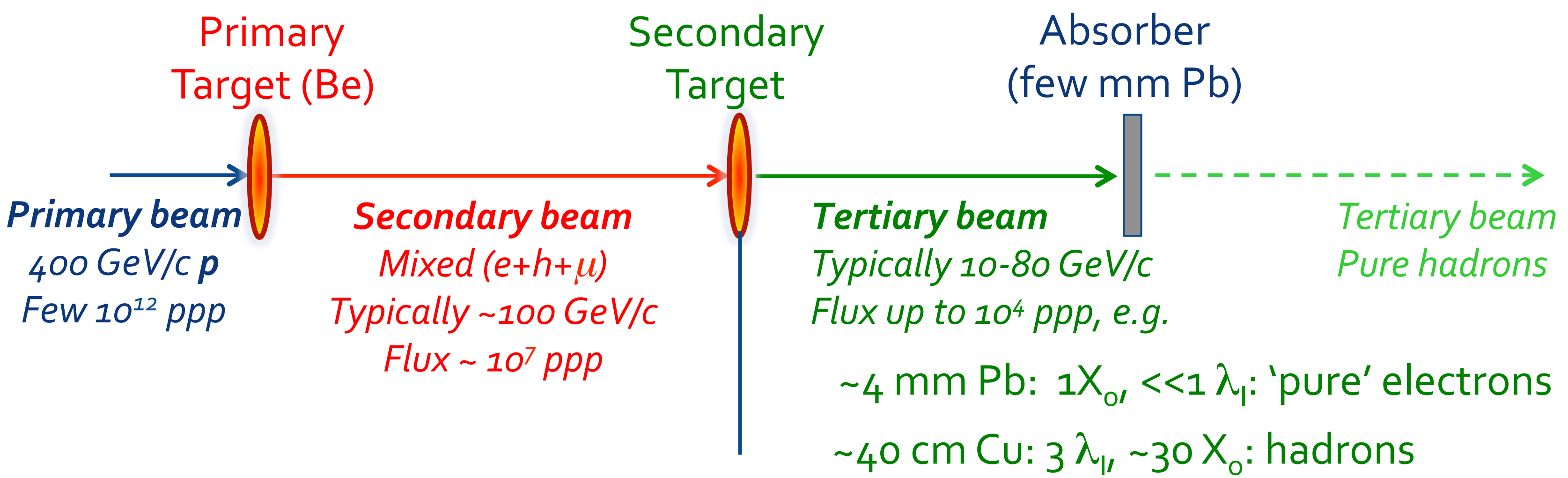
Flux per solid angle [steradian], per interacting proton, and per dp [GeV/c]



	A	B	C
p	0.8	-0.6	3.5

	A	B	C
π^+	1.2	9.5	5.0
π^-	0.8	11.5	5.0
K^+	0.16	8.5	3.0
K^-	0.10	13.0	3.5
$\bar{p}$	0.06	16.0	3.0

Secondary Particle Production



Nota bene: Flux given for a typical EHN1 beam line, e.g. H8

The M2 Beam

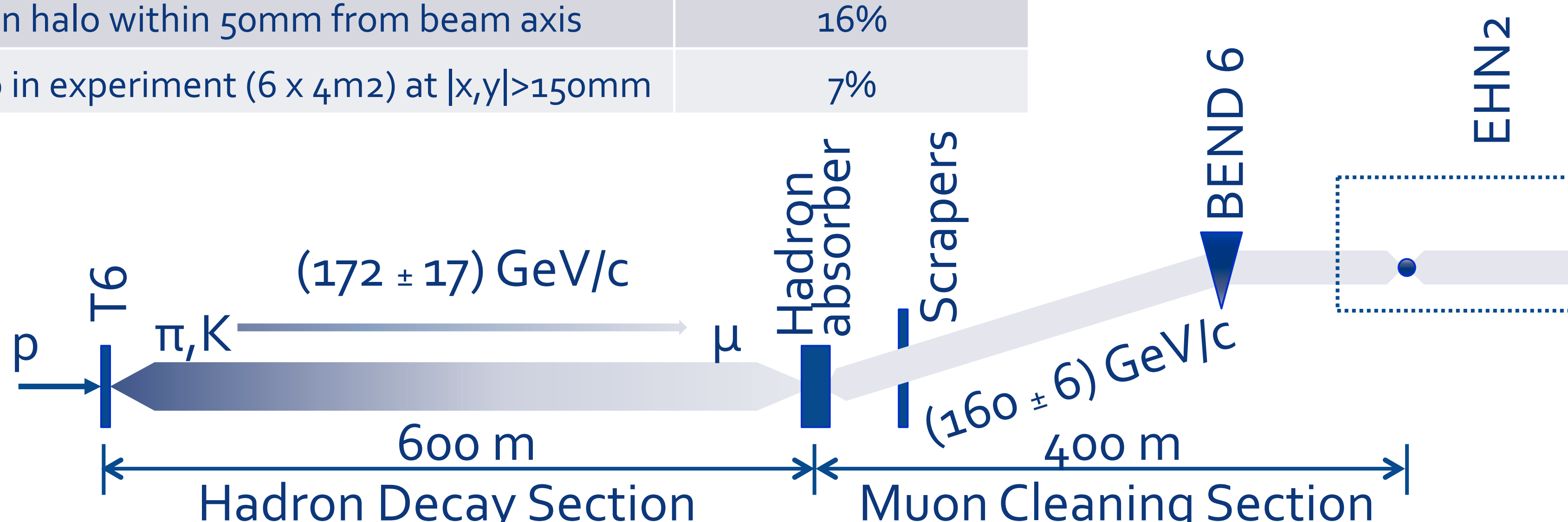
Three main operation modes:

- High-energy, high-intensity muon beam. Normally for muon momenta up to 200 GeV/c. Higher momenta up to 280 GeV/c are possible, but the flux drops very rapidly with beam momentum.
- High-intensity secondary hadron beam for momenta up to 280 GeV/c with radiation protection constraints.
- Low-energy, low-intensity (and low-quality) in-situ electron calibration beam.

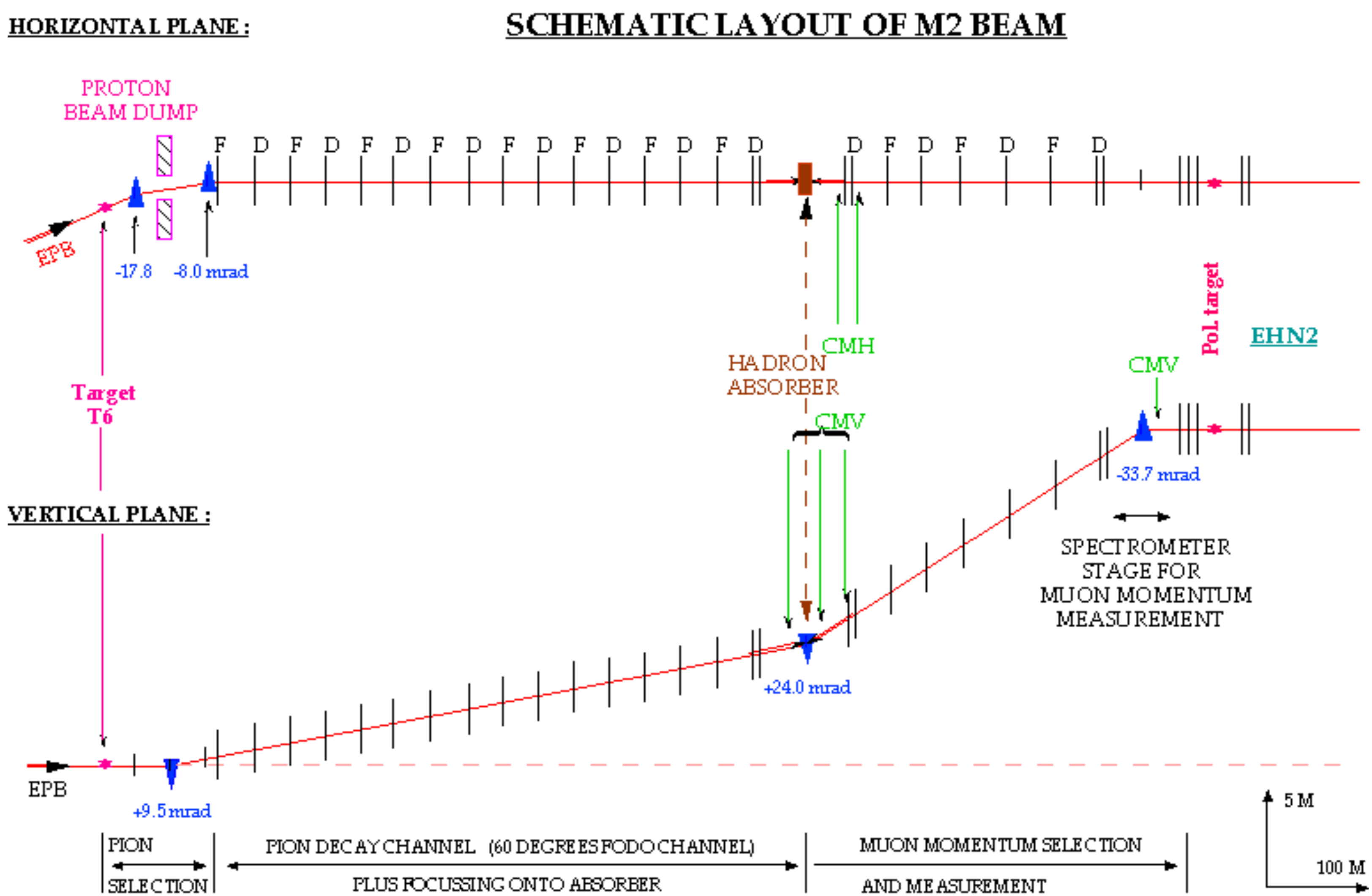
Beam Mode	Momentum (GeV/c)	Max. Flux (ppp / 4.8s)	Typical $\Delta p/p$ (%)	Typical RMS spot at target	Polarisation	Absorber (9.9 m Be)
Muons	+208/190 +172/160	~10^8 2.5 10^8	3%	8 x 8 mm	80%	IN
Hadrons	+190 -190 Max. 280	10^8 (RP) 4 10^8 (with dedicated dump)	-	5 x 5 mm	-	OUT
Electrons	-10 to -40	< 2 10^4	-	> 10 x 10 mm	-	OUT

The M2 Beam – Parameters and Principle

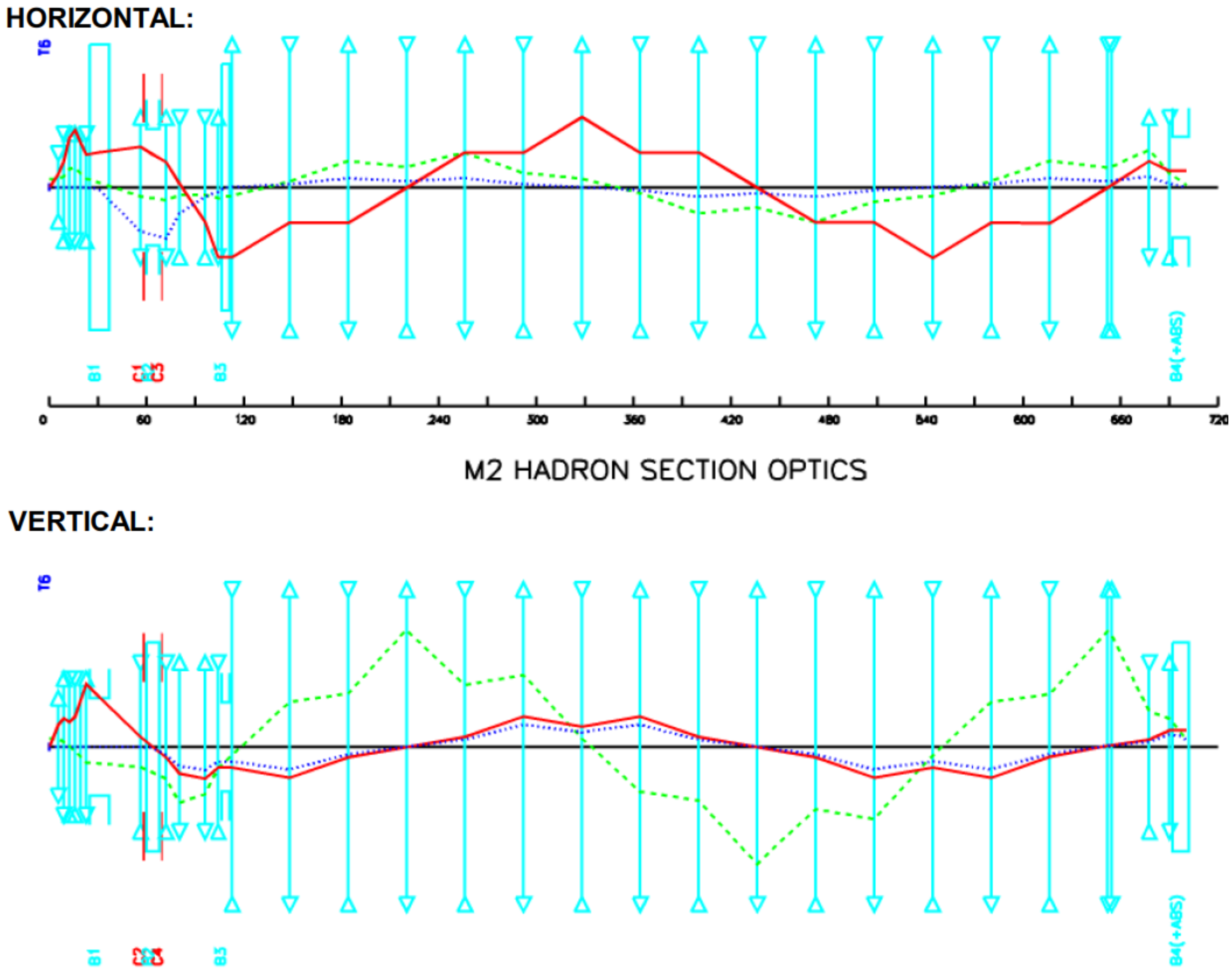
Beam Parameters for COMPASS	Measured
Beam momentum p_μ/p_π	160 / 172 GeV/c
Proton flux on T6 per SPS cycle	$1.5\ 10^{13}$
Muon flux at COMPASS per SPS cycle	$2.5\ 10^{8}$
Beam polarisation	-80% ± 4%
Spot size at COMPASS target (σ_x x σ_y)	8mm x 8mm
Divergence at COMPASS target (σ_{dx} x σ_{dy})	0.4mrad x 0.8mrad
Muon halo within 50mm from beam axis	16%
Halo in experiment (6 x 4m2) at |x,y|>150mm	7%



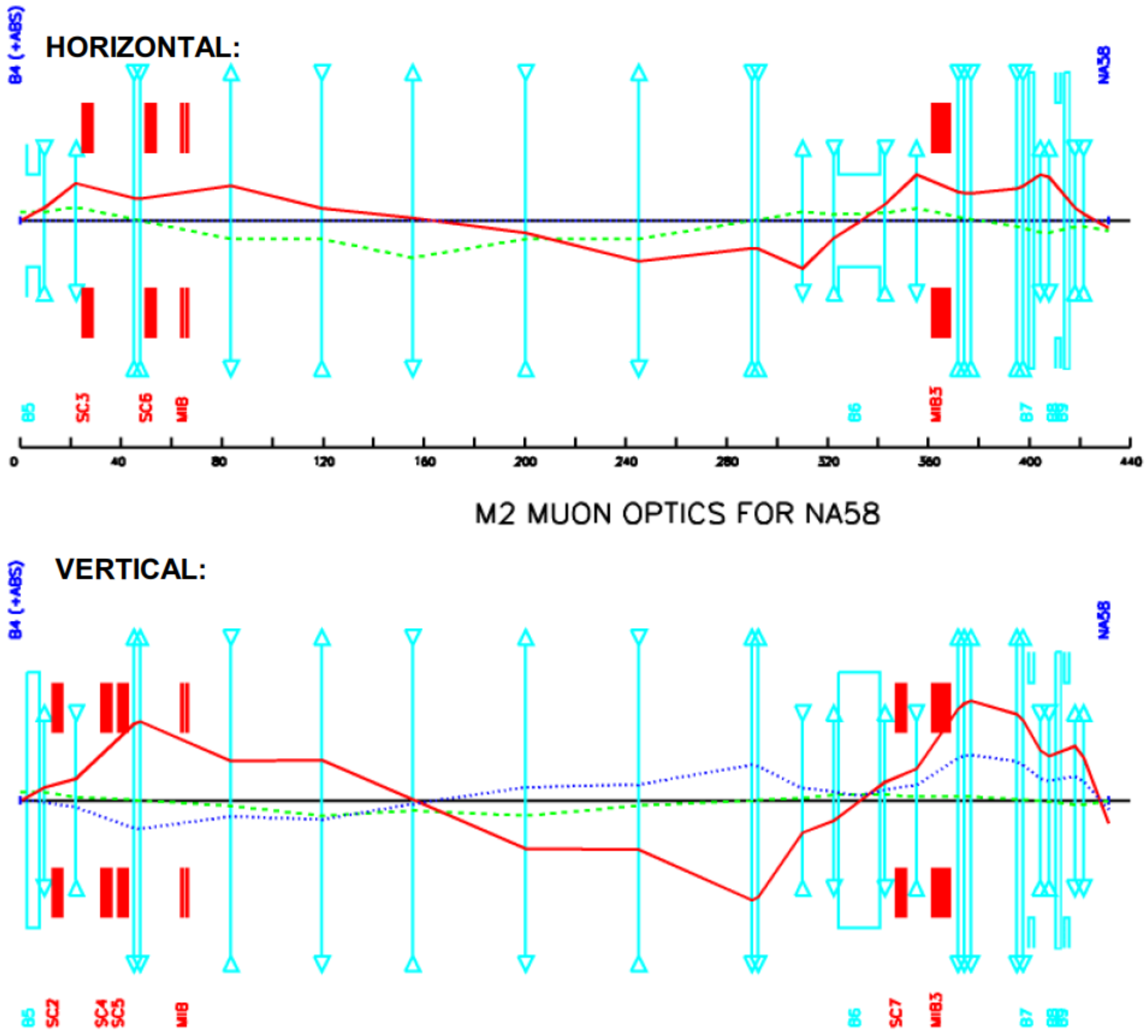
Layout


HORIZONTAL PLANE :
SCHEMATIC LAYOUT OF M2 BEAM
PROTON
BEAM DUMP
F D F D F D F D F D F D F D F D
D F D F D F D
EPB
-17.8
-8.0 mrad
Target
T6
HADRON
ABSORBER
CMH
CMV
Pol. target
EHN2
CMV
-33.7 mrad
SPECTROMETER
STAGE FOR
MUON MOMENTUM
MEASUREMENT
VERTICAL PLANE :
+24.0 mrad
EPB
+9.5 mrad
5 M
100 M
PION
SELECTION
PION DECAY CHANNEL (60 DEGREES FODO CHANNEL)
PLUS FOCUSSING ONTO ABSORBER
MUON MOMENTUM SELECTION
AND MEASUREMENT

Optics – Hadron Section

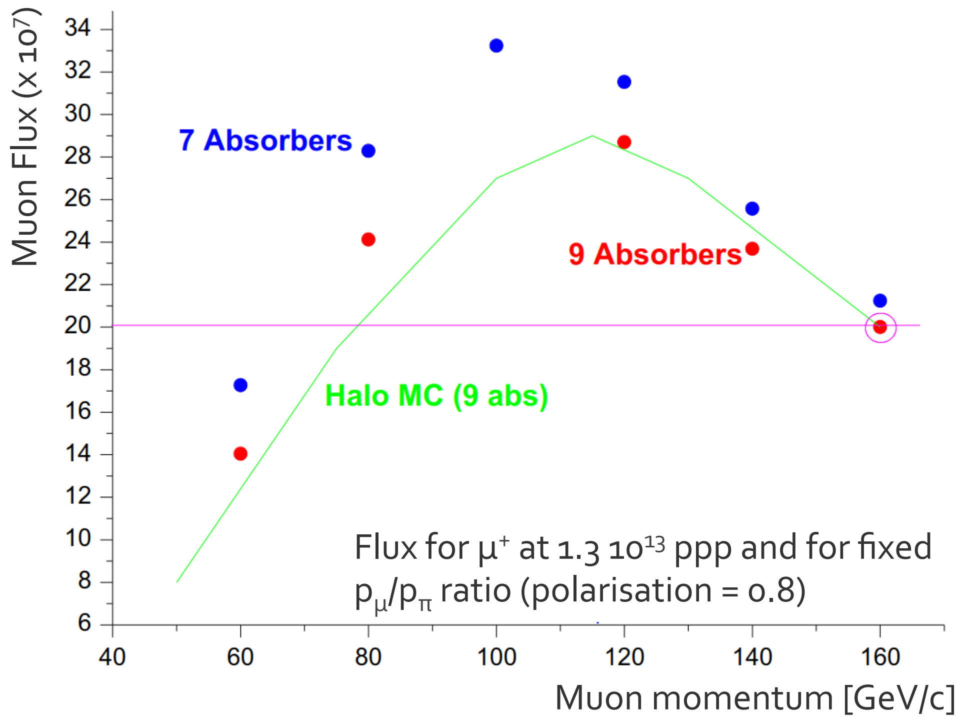


Optics – Muon Section



<u>Nota bene:</u>
Focussing on target non-trivial as the beam is not produced from a point-like source and has a relatively large Δp/p

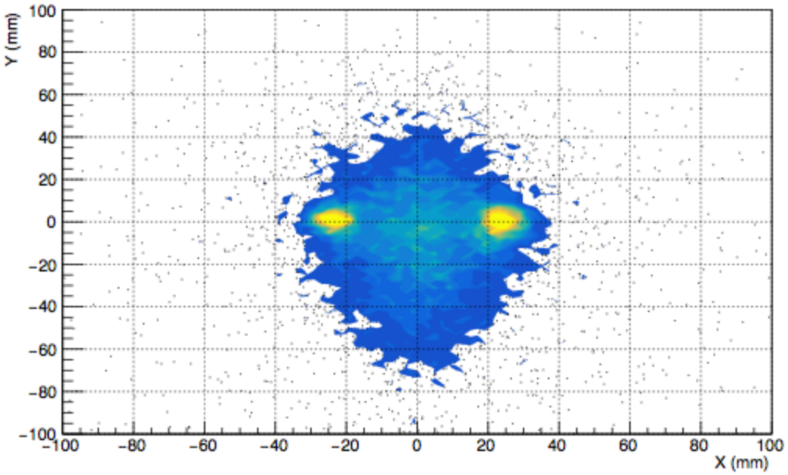
Flux

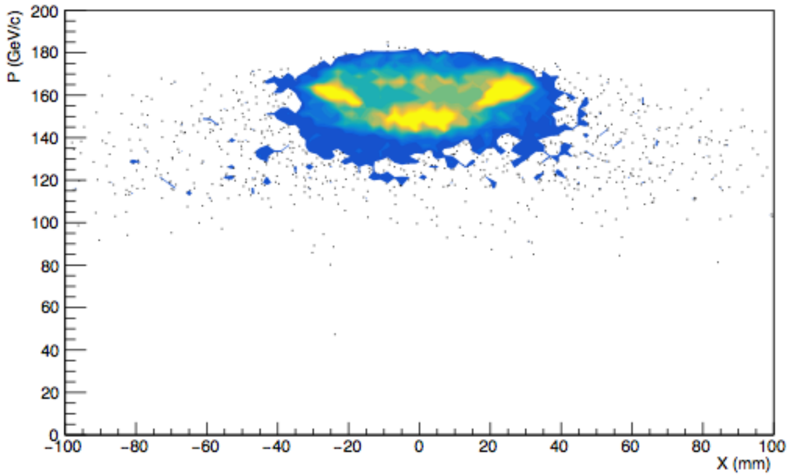


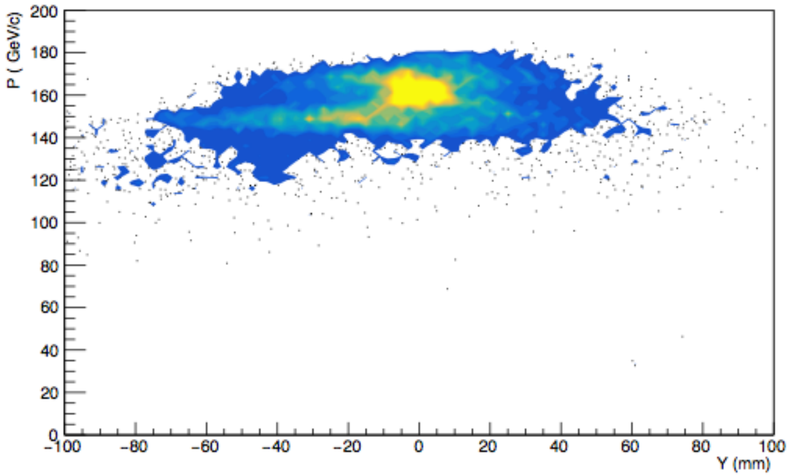
- Factor typically factor 2.7 smaller for μ^- at same momentum
- In principle limited at lower momenta by radiation protection considerations
- Test measurement could be envisaged this year to find RP limit in current set-up (to be agreed with COMPASS and RP)

Muon Halo

- Halo Distribution at COMPASS







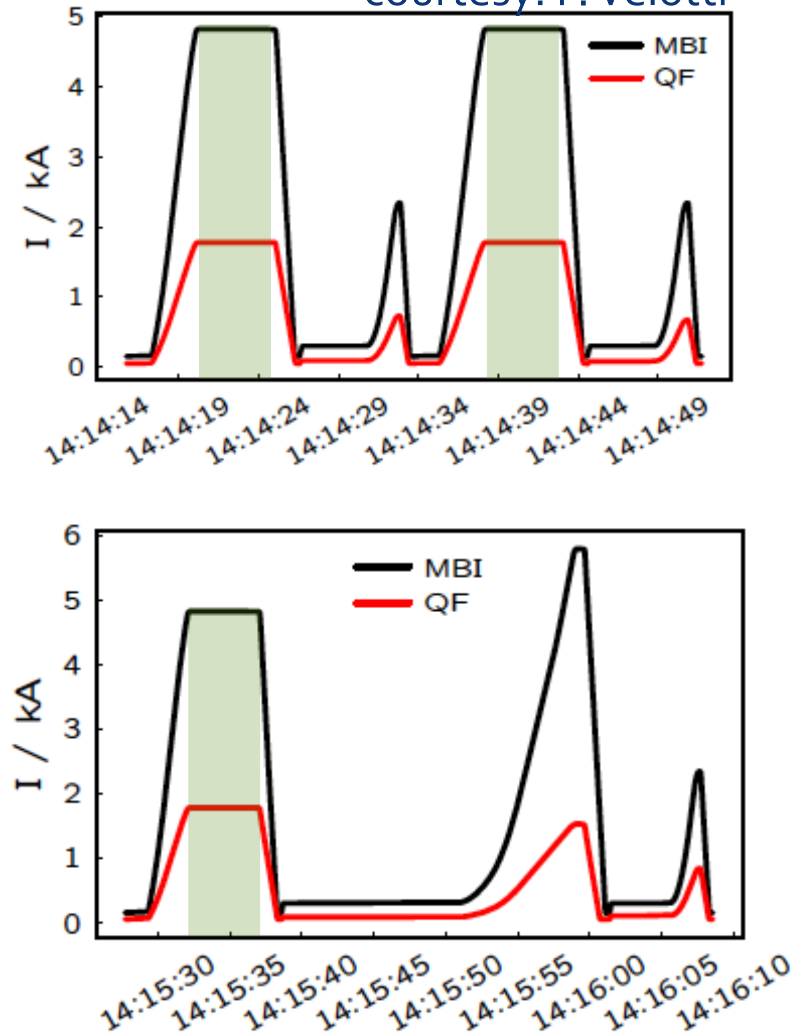
Muon Halo within 15 cm of beam axis = 17%

Muon Halo in Experiment (within 3.2 x 2.5 m^2) at |x,y| > 15 cm = 6 %

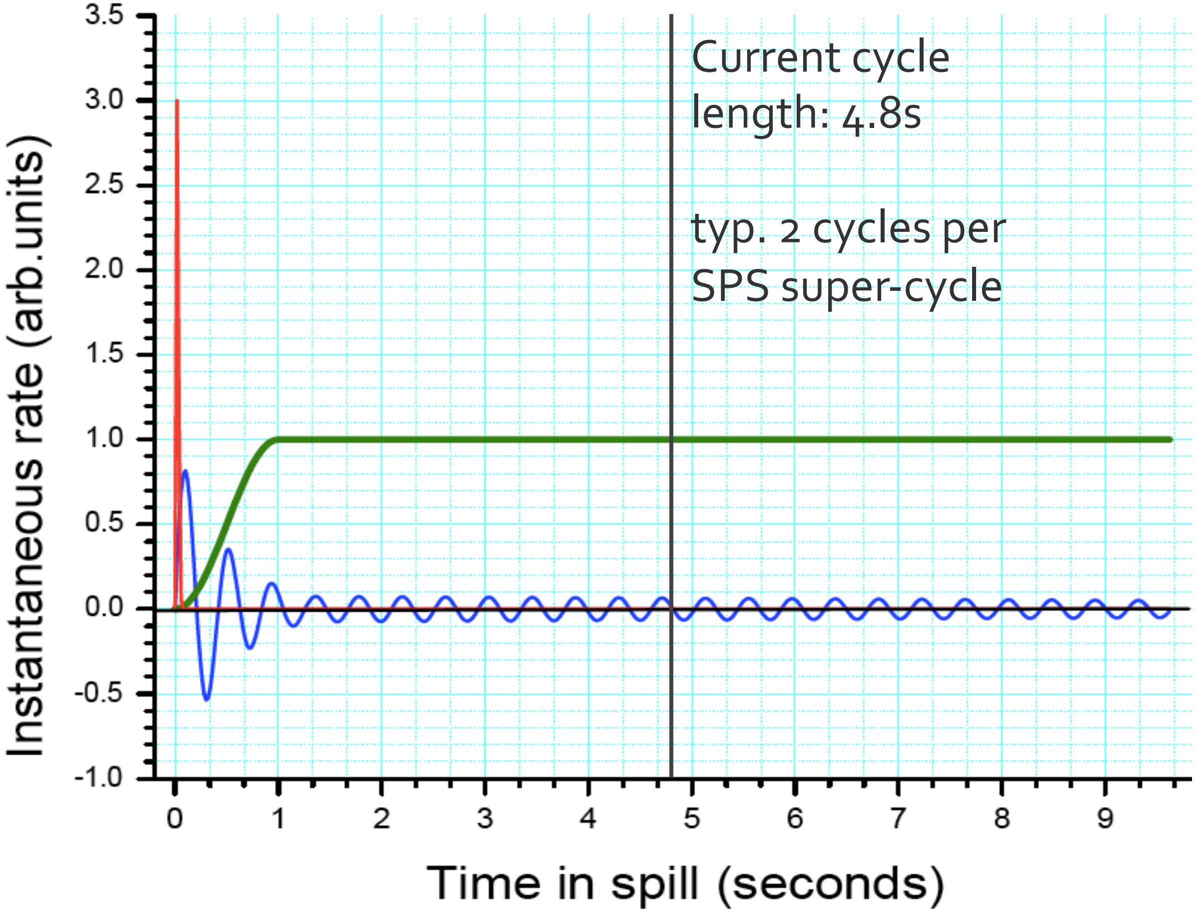
Time structure

- SPS is a cycled machine
- Different cycles ("spills") can have different destinations, such as the LHC for filling and the slow-extracted beam to the North Area for fixed target physics
- The composition of different cycles is called super-cycle (SC)
- Depending on the user requirements, the SC composition changes up to a few times per day
- The availability of beam for a destination is called duty cycle

courtesy: F. Velotti



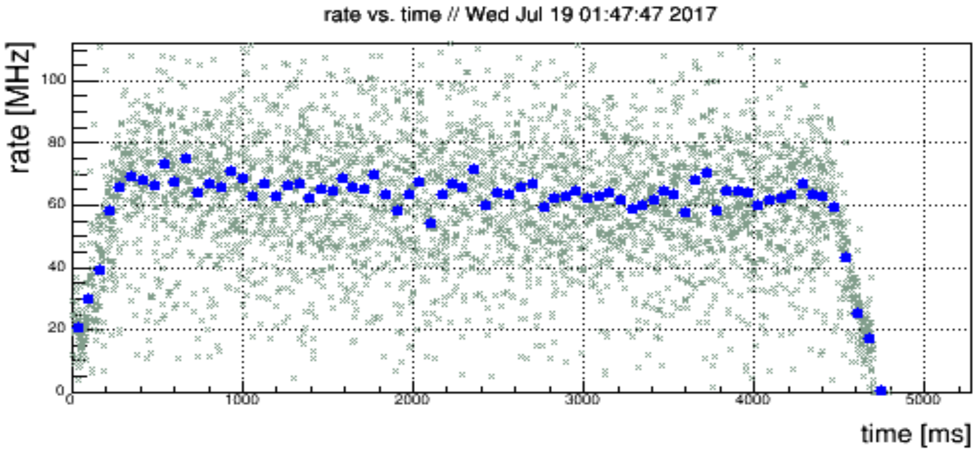
Time structure

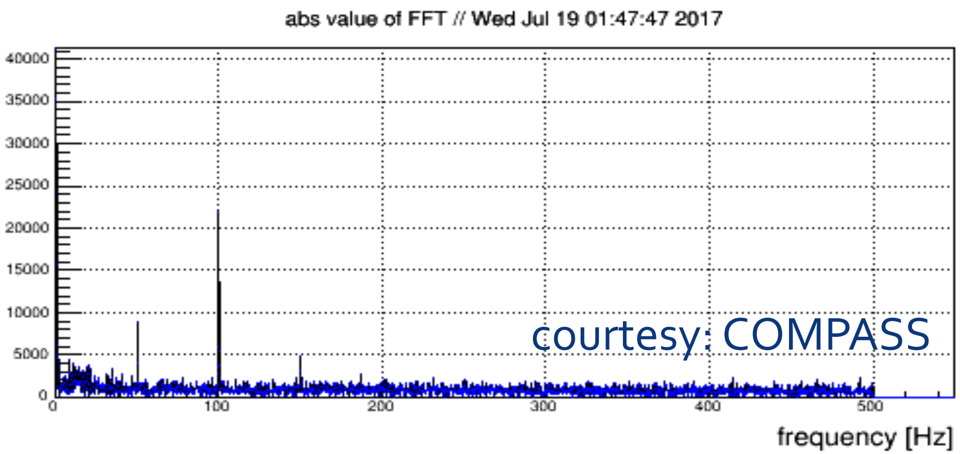


- The high frequency time structure (RF, f_{rev}) is still very present in the first 500 to 1000 milliseconds. Also: Low frequencies (e.g. 50Hz) from power converters.
- High-intensity spikes may occur at the beginning of the spill, in particular if the intensity is ramped up (too) quickly. A magnet glitch (e.g. QF) can produce a spike at any time.
- The slow ramping up is thus favored by the experiments, but together with the remnant structure it leads to a reduced effective spill.

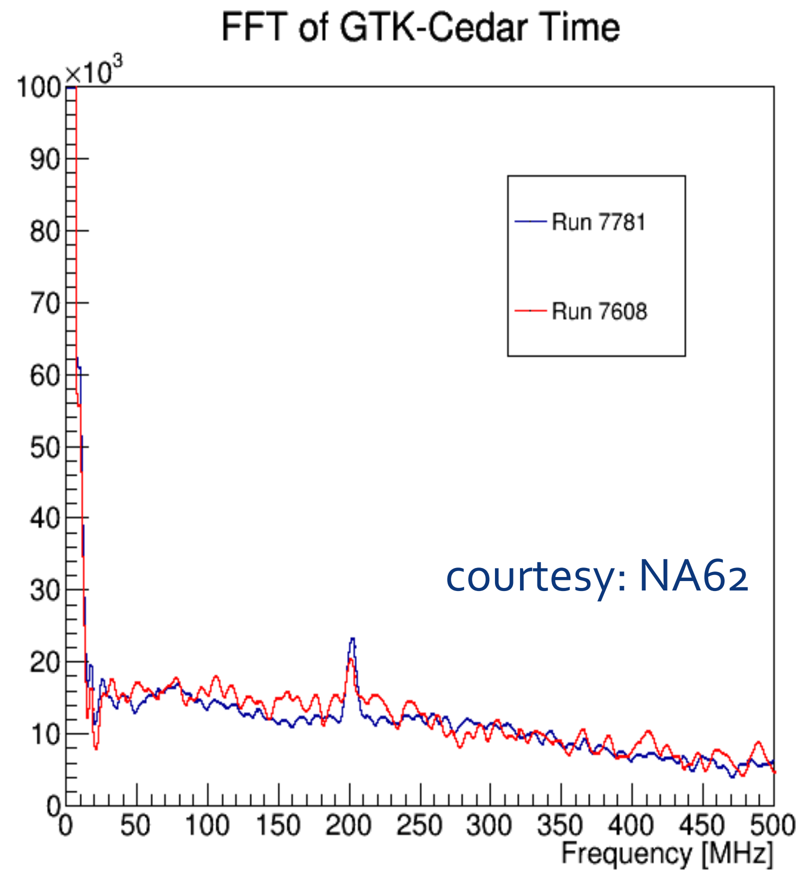
Time structure – Examples

Low frequencies



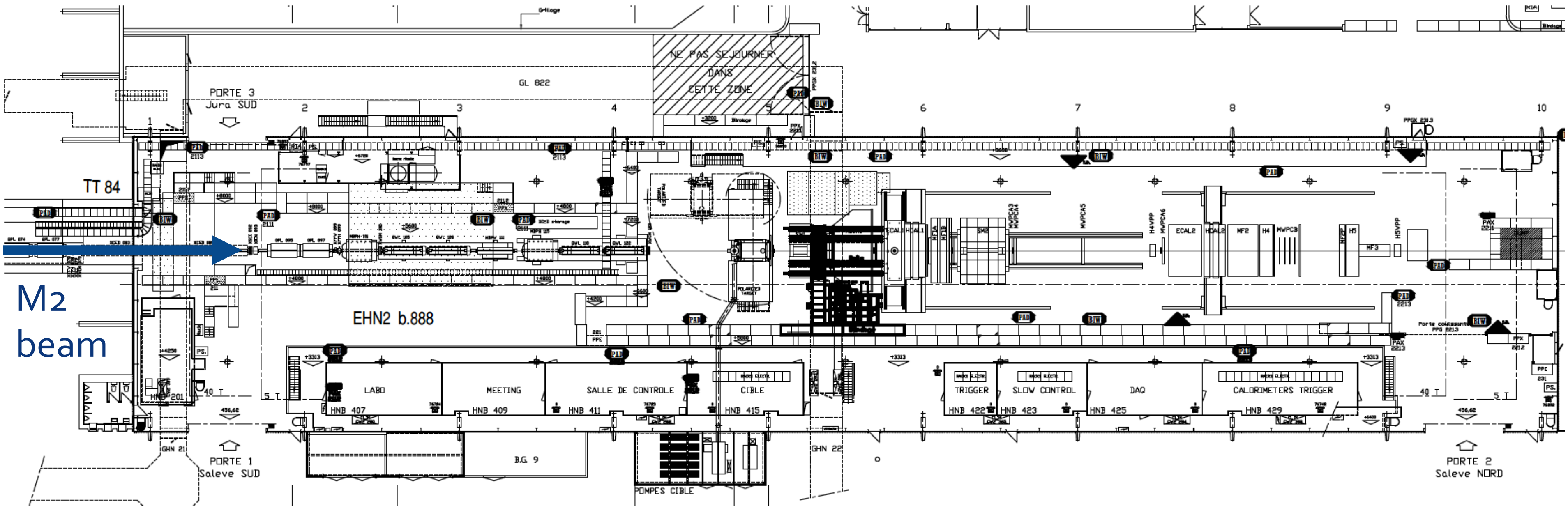


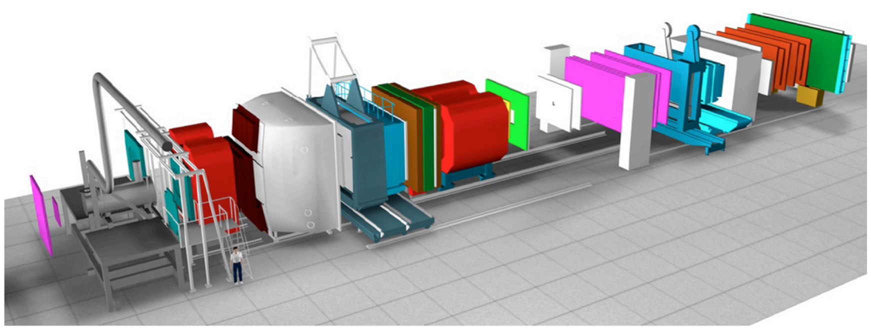
High frequencies



For more details, see presentation at slow extraction workshop: https://indico.cern.ch/event/639766/contributions/2750913/

The EHN2 Experimental Area

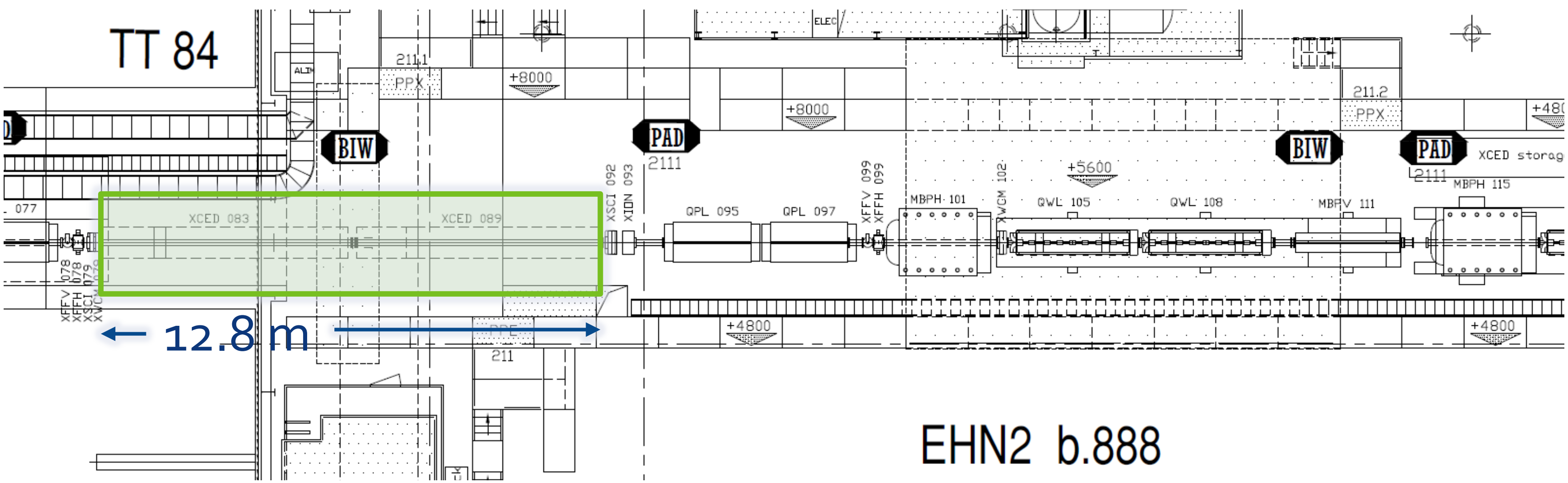




- Large surface experimental area
- Houses currently the COMPASS experiment

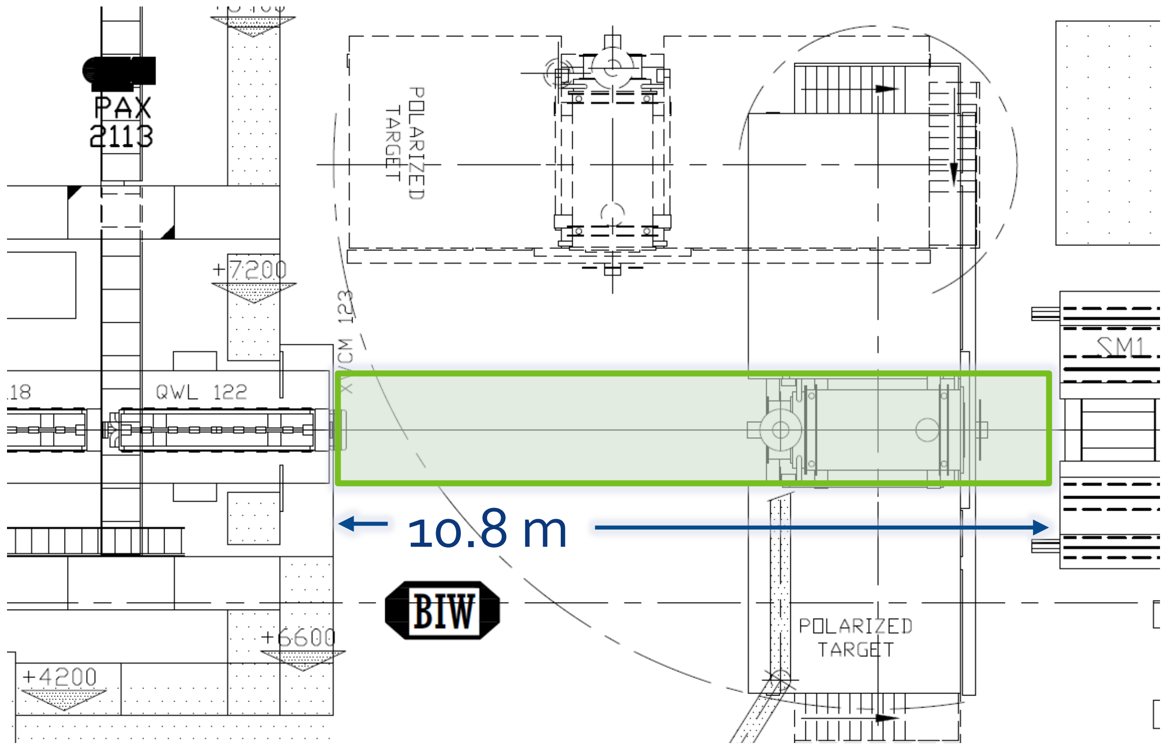
Locations for μONe tests in EHN2

- Three options to be studied for location of μ-on-e scattering proposal set-ups that would be compatible with current COMPASS running
  - Option 1
    - Pro: rather easy to install, no interference with COMPASS as long as CEDARs are not used
    - Con: limited space, not compatible with COMPASS running at the same time



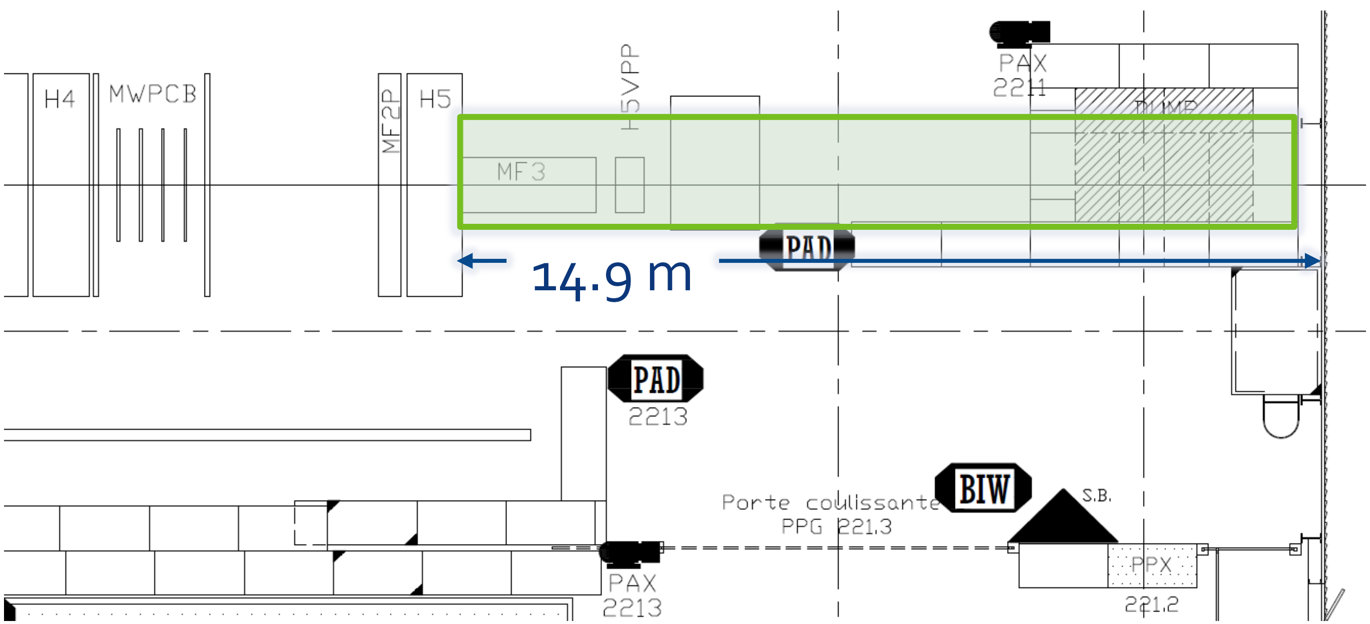
Locations for μONe tests in EHN2

- Option 2
  - Pro: might be compatible with COMPASS running at the same time (PT in garage position, small angle spectrometer available with SM2, muon ID, calorimetry)
  - Con: limited space



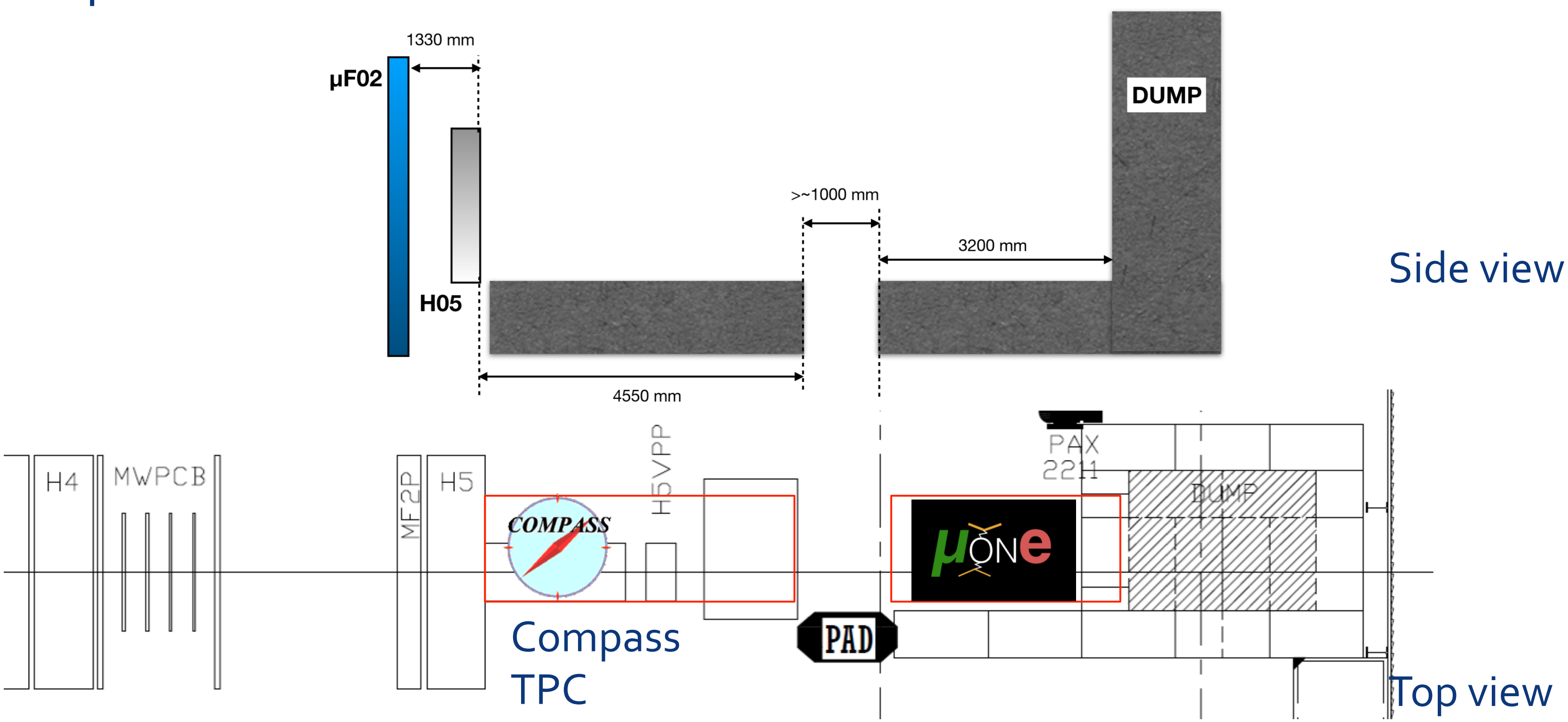
Locations for μONE tests in EHN2

- Option 3
  - Pro: compatible with COMPASS running at the same time
  - Con: Limited space, energy loss of muons in COMPASS



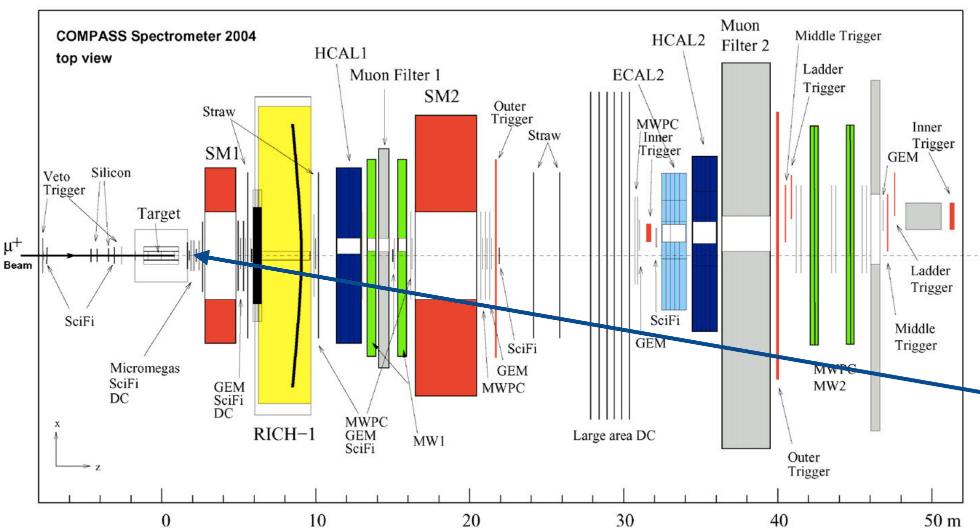
2018 Test Beams

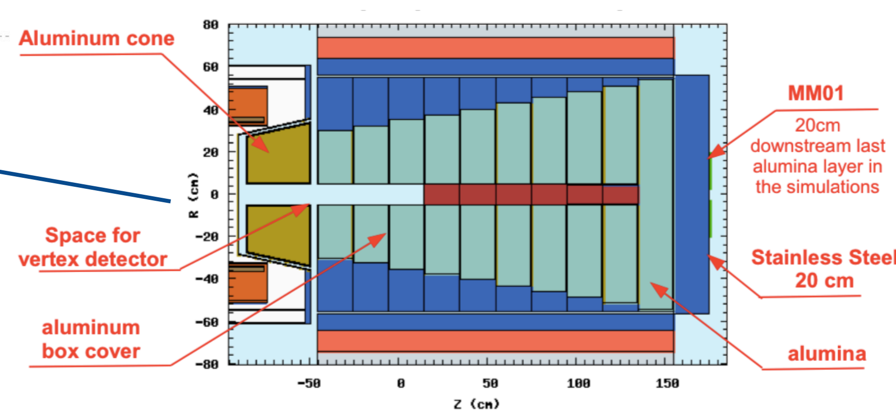
- µ-on-e: Measure µ-e scattering on 2 target modules with Silicon instrumentation + 1 EM calorimeter. Total length 3m.
- Compass TPC: Measure µ-p scattering in high pressure TPC + Silicon telescope



2018 Test Beams

- Studies initialised due to parasitic nature of 2018 tests
- COMPASS has a physics program that uses the 190 GeV/c hadron beam mode with a dedicated hadron absorber
- Goal: Extrapolate muon beam through COMPASS set-up and assert widening of beam due to multiple scattering with HALO

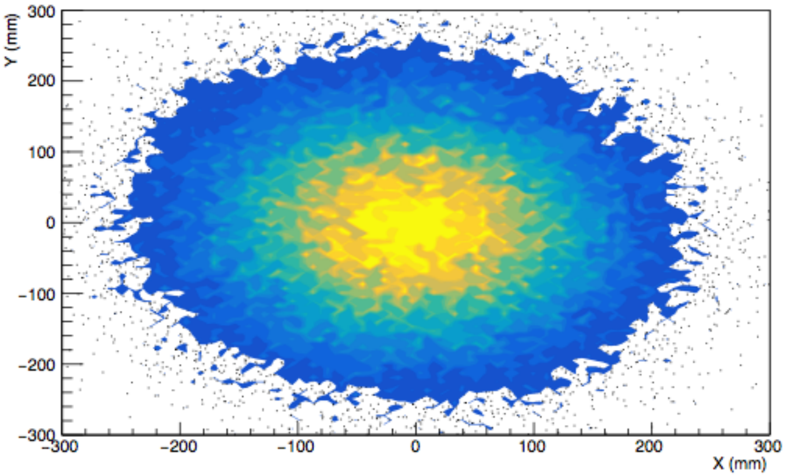




2018 Test Beams

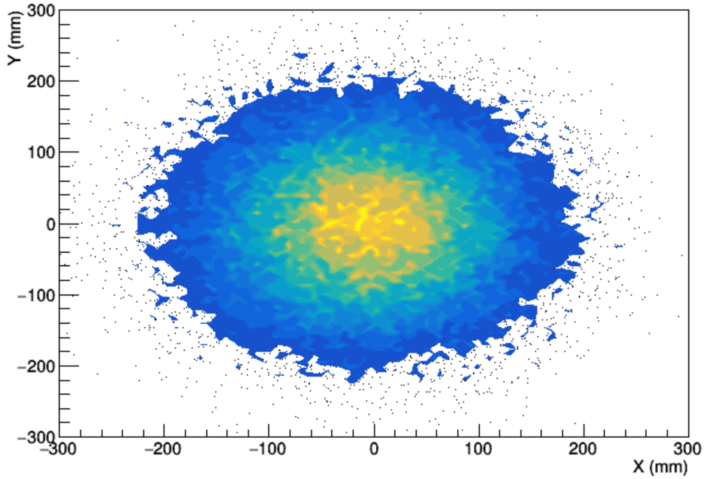
- Beam distribution at test location

160 GeV/c



$\sigma_x \times \sigma_y$ = 93 mm x 100 mm

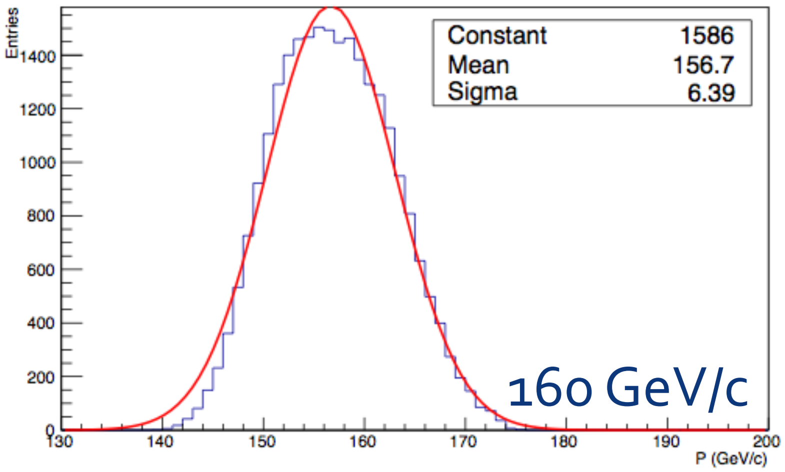
190 GeV/c

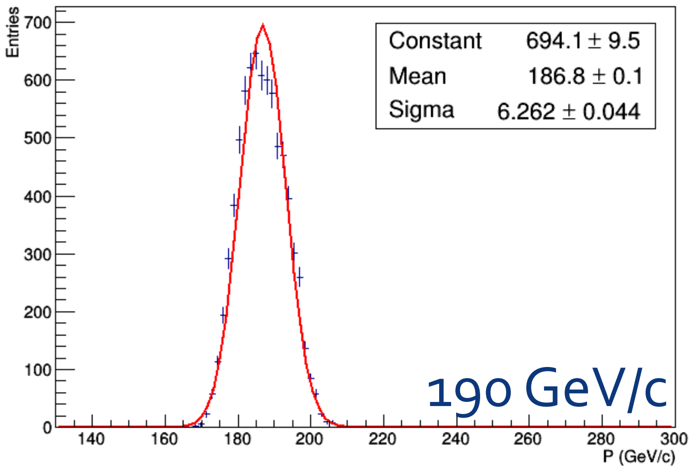


$\sigma_x \times \sigma_y$ = 81 mm x 84 mm

2018 Test Beams

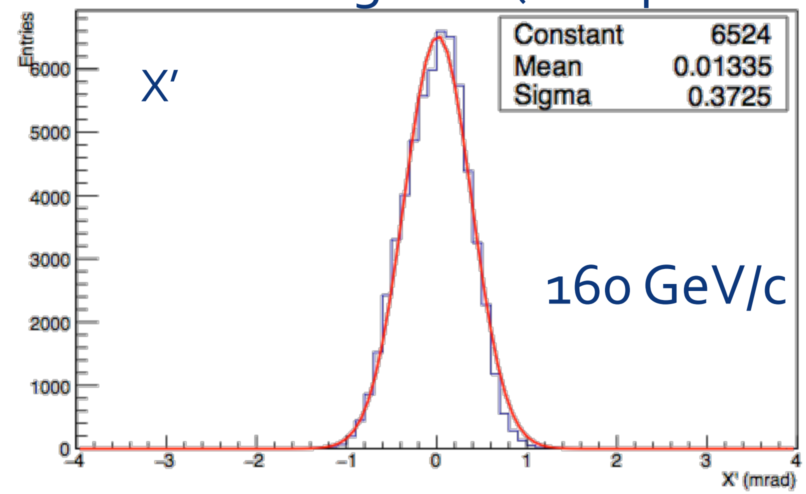
- Beam momentum after passing hadron absorber

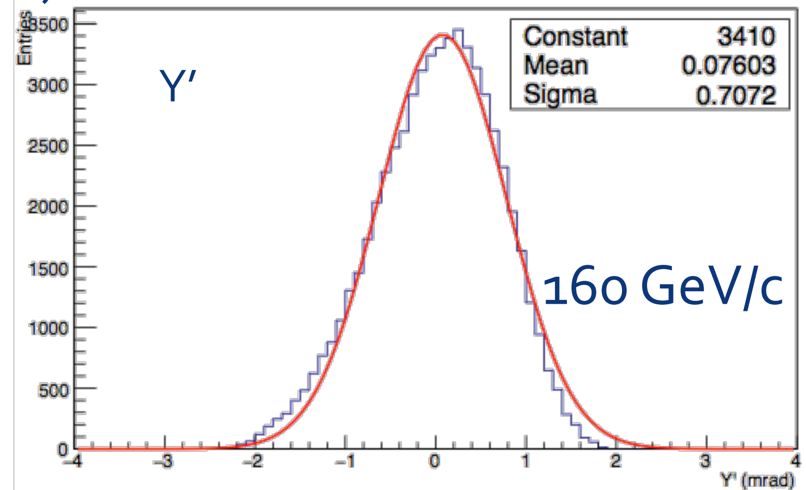


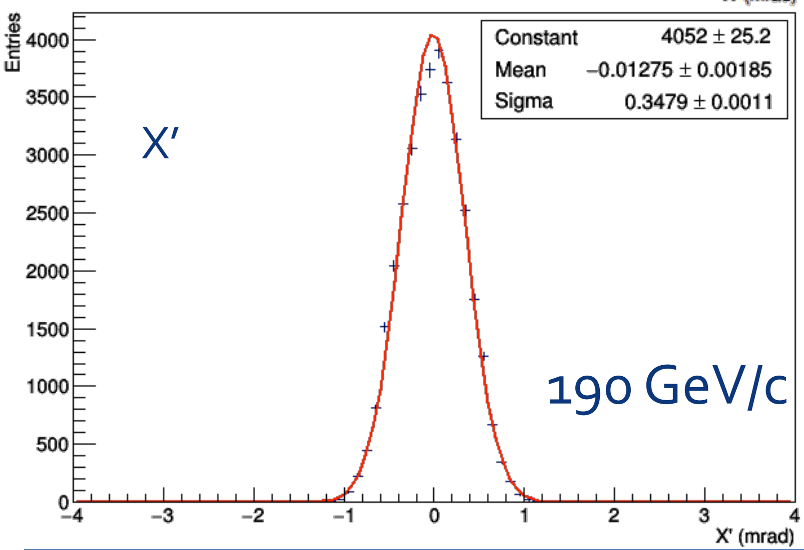


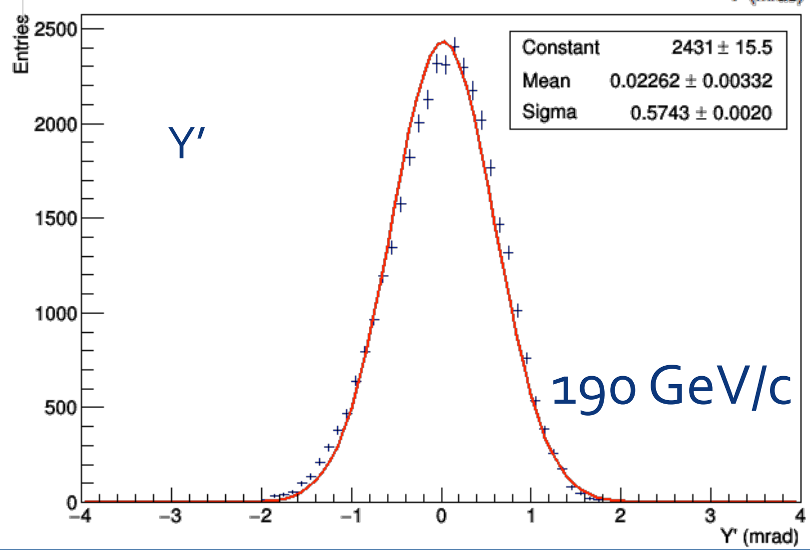
2018 Test Beams

- Beam divergence (Compass Target)



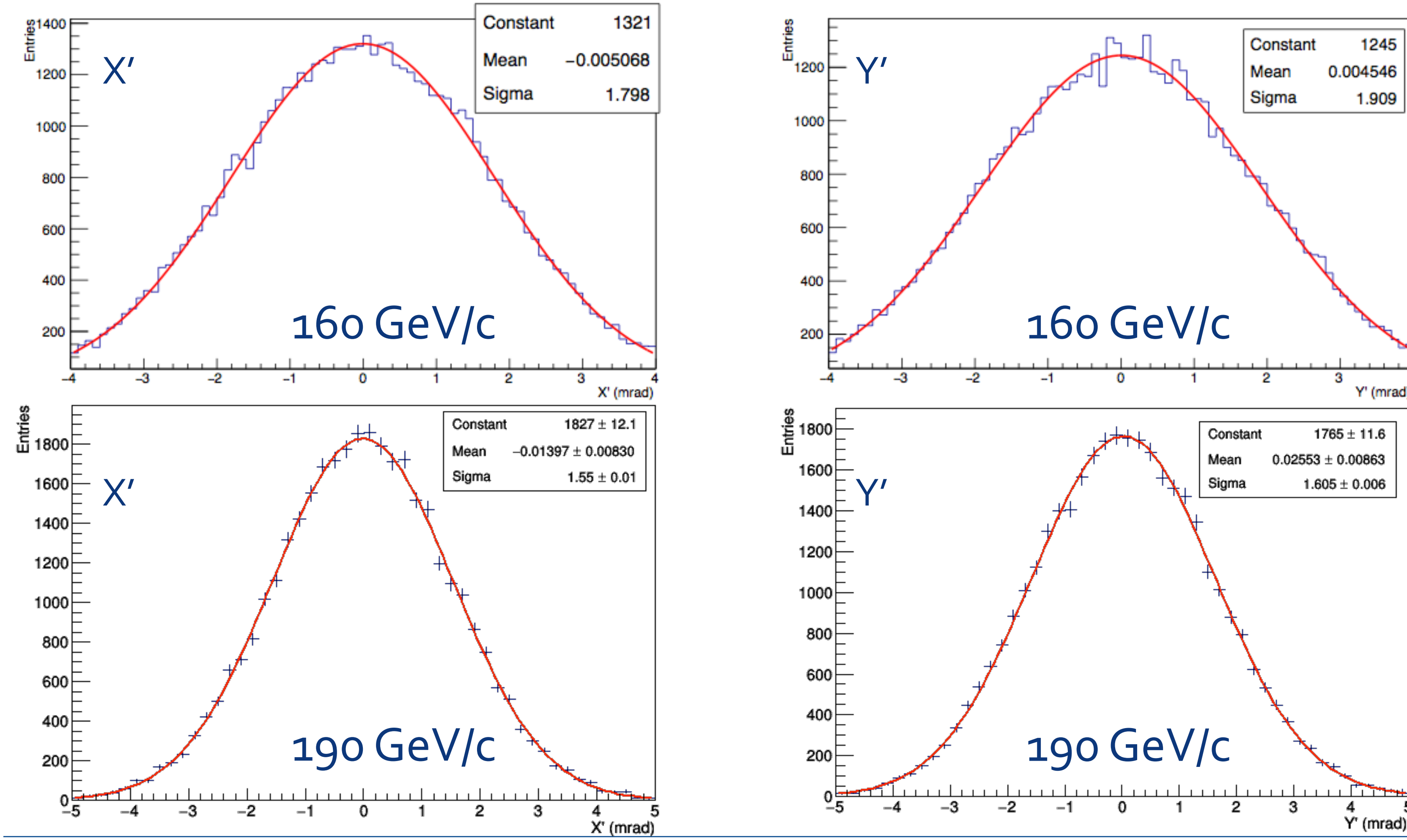






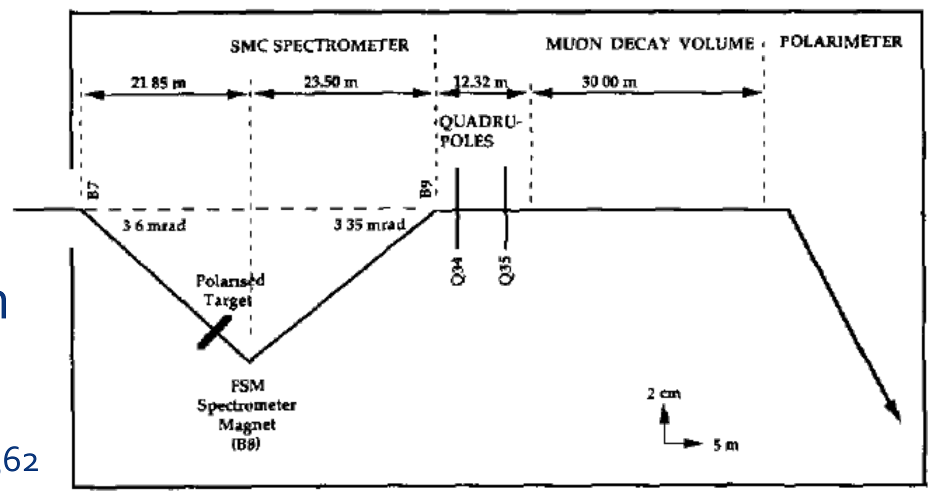
2018 Test Beams

- Beam divergence (after passing absorber)



Future Options for μONe in EHN2

- Historically, EHN2 has already housed more than on muon beam experiment / set-up (e.g. NA2 + NA4, SMC + polarimeter)
- Challenge: Will we be able to run μ-on-e together with another experiment (COMPASS, NA64)?
- Main questions
  - Are the physics requirements compatible enough (e.g. beam momentum)?
  - Are the required intensities comparable?
  - Is there enough space?
- Need to study this from scratch

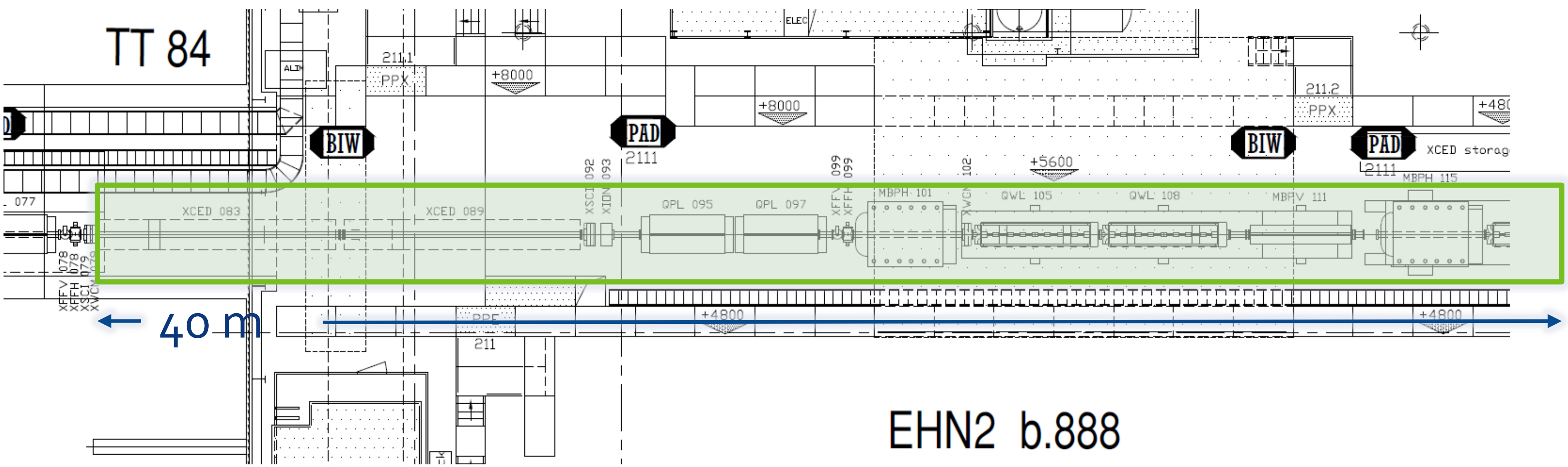


Experimental hall (not on scale)

L. Gatignon, N. Doble et.al., NIM A 343 (1994) 351-362

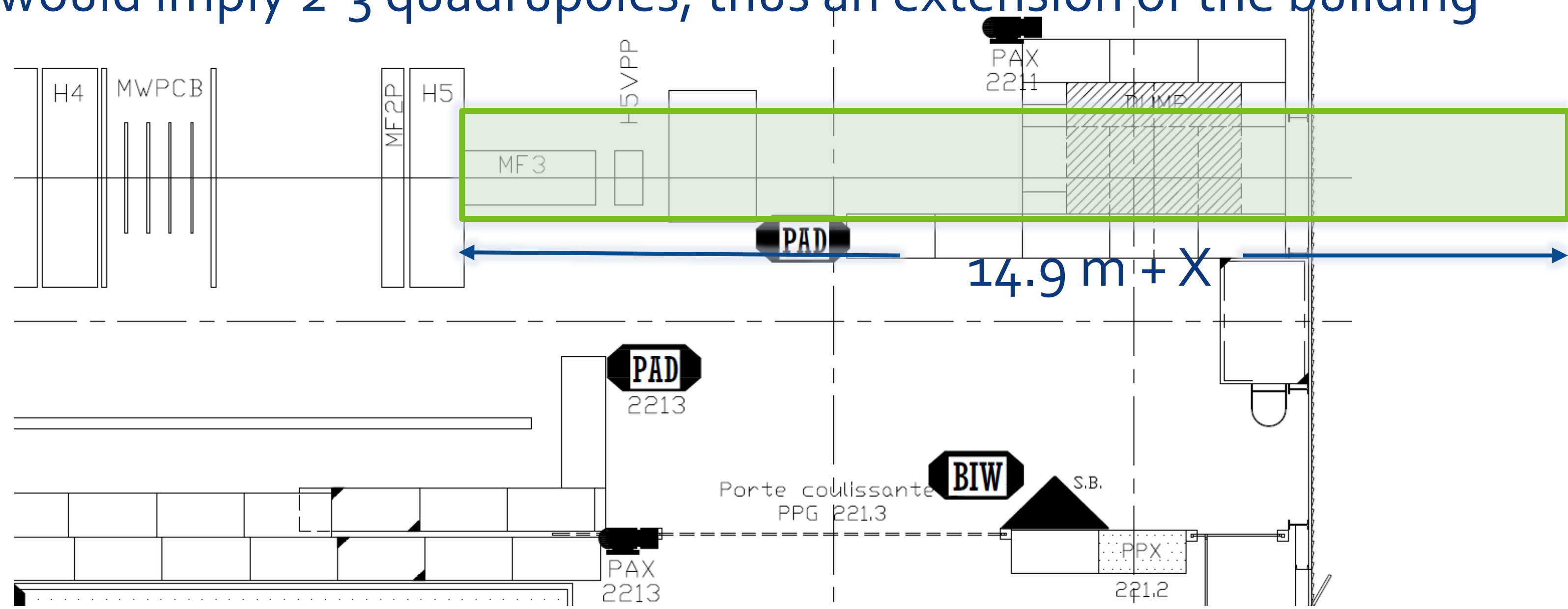
Future Options for μONe in EHN2

- Entrance Area of EHN2
  - Pro: no interference with COMPASS spectrometer, enough space for full set-up
  - Con: needs many weeks change-over time, not compatible with COMPASS running in the same year



Future Options for μONe in EHN2

- Downstream Area of EHN2
  - Pro: compatible with COMPASS running at the same time (able to use full COMPASS set-up)
  - Con: safety aspects (lock ABS in, no hadron beams), limited space, energy loss of muons in COMPASS could imply to re-measure momentum (i.e. another spectrometer magnet), re-/de-focusing of muons would imply 2-3 quadrupoles, thus an extension of the building



Summary and Outlook

- The M2 beam at CERN continues to serve as the highest energy muon beam with highest intensities in its 40th year
- M2 seems to be well suited for μ-on-e, compatibility with other experiments and integration of the full set-up is currently being studied within the conventional beams working group of Physics Beyond Colliders
- More personnel available for studies since 12/17, more from March
- Successful 2017 test beam in H8 to be complemented by tests in M2
- Optics studies for 2018 tests are being finalised
- Proposal: Check RP limit for μ flux with tests early this year

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Thank you!