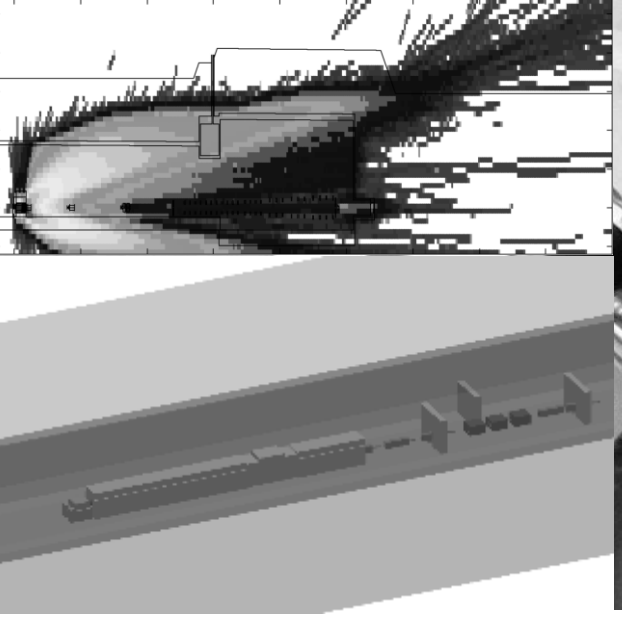
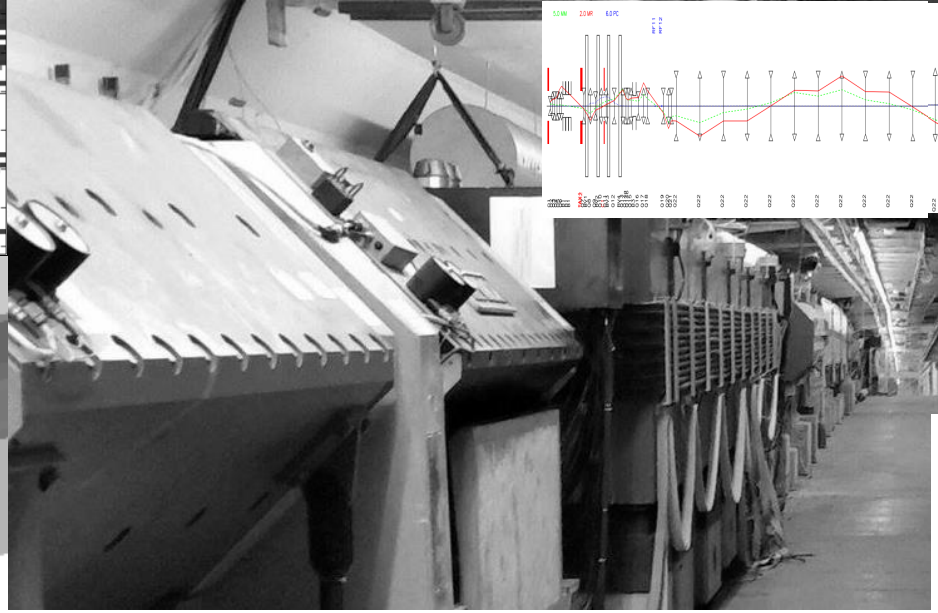
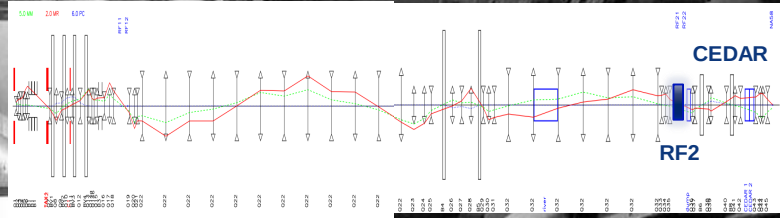
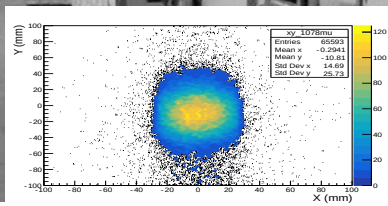








PBC Conventional Beams Working Group

Physics Beyond Colliders Working Group Meeting, CERN

D. Banerjee, M. van Dijk on behalf of the CBWG

6 November 2019

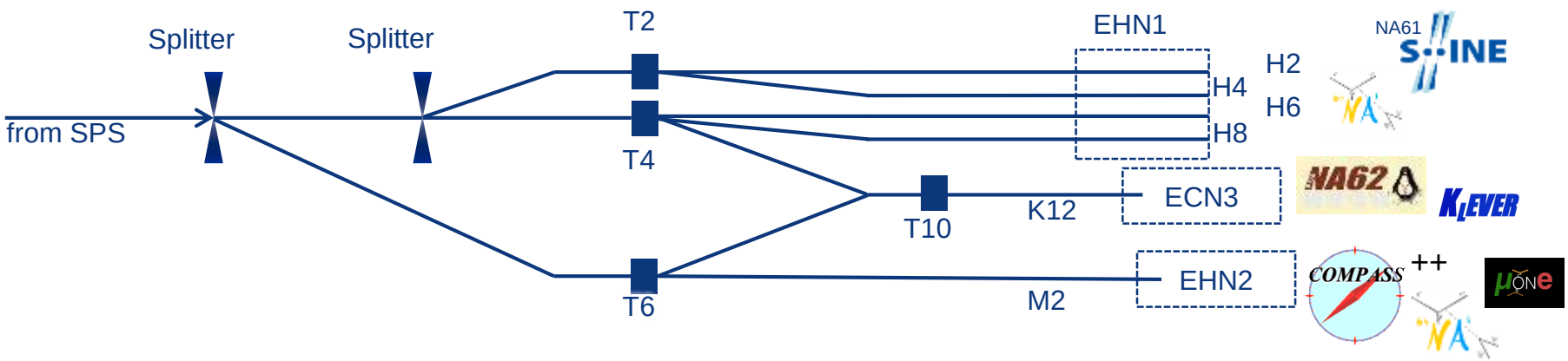
CERN | EN ENGINEERING DEPARTMENT | EA | Physics Beyond Colliders

Introduction

- CBWG report for ESPP is complete and is aimed to probably be released as Yellow Report
- Projects have been grouped by “short term” and “long term”
  - Short term projects (up to LS3) passed to SPSC, will progress towards implementation

    NA61++, NA62-BD, COMPASS/AMBER Phase 1 (R_p, Drell Yan, $\bar{p}$), MuOnE, NA64-e, NA64μ (Phase 1)
  - Long term projects

    KLEVER, NA64μ (Phase 2), COMPASS/AMBER (RF-separated beams), NA60++, DIRAC++, REDTOP




T10 target
ECN3
EHN2
K12
M2
EHN1 Neutrino Platform
P42
EHN1
H2, H4, H6, H8
T2, T4, T6 targets
TT20 transfer line

D.Banerjee
J.Bernhard
E. Montbarbon

PBC Proposals for the EHN2 Beamline

- Several projects for the ENH2 beamline in the CERN North Area have been proposed:
  - NA64μ - Muon Program for dark sector physics
    - Requires medium to high intensity 100 GeV/c – 160 GeV/c muon beam.
    - Setup ~ 15 - 20 m long and about 120 cm x 60 cm transversely (Phase 1).
  - MuOnE - aiming to investigate the hadronic contribution to the vacuum polarisation in context of $(g\text{-}2)_\mu$.
    - Requires high intensity 150 GeV/c, low divergence muon beam.
    - Setup ~ 40 m long and about 50 cm x 50 cm transversely .
  - Successor to the COMPASS experiment - A QCD Facility (AMBER)
    - Currently occupies the EHN2 hall with a 55 m long setup.
    - Requires conventional muon and hadron beams in the 1st and 2nd phase including a new RF separated option in the 2nd phase (under study).

D.Banerjee
J.Bernhard

Requested Beamtimes up to LS3

Experiment	Year	Activity	Duration	Beam
COMPASS/AMBER (CERN-SPSC-2019-022/SPSC-P-360)	2021 spring	Proton Radius	20 days	μ
	2022	Proton radius $\bar{p}$ production test	160 days 10 days	μ p
	2023	$\bar{p}$ production measurement Proton Radius	30 days 150 days	p μ
	2024, 2024+	Drell-Yan: pion PDFs and Charmonium production mechanism	$\lesssim$ 2 years	p, K^+,π^+ $\bar{p}$, K^-,π^-
NA64μ (CERN-SPSC-2019-002/SPSC-P-359)	2021 spring	Test Run	14 days	μ
	2022 spring	Pilot Run	30 days	μ
	2023 end	Phase 1	40 days	μ
	2024 beg.	Phase 1	40 days	μ
MuonE (CERN-SPSC-2019-026/SPSC-I-252)	2021 end	Pilot Run	20 days	μ
	2022 end	Run 1	30 days	μ
	2023 +	Physics Run	~ 3 years	μ

D.Banerjee
J.Bernhard

Requested Beamtimes up to LS3

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COMPASS/AMBER (CERN-SPSC-2019-022/SPSC-P-360)	2021 spring	Proton Radius	20 days	μ
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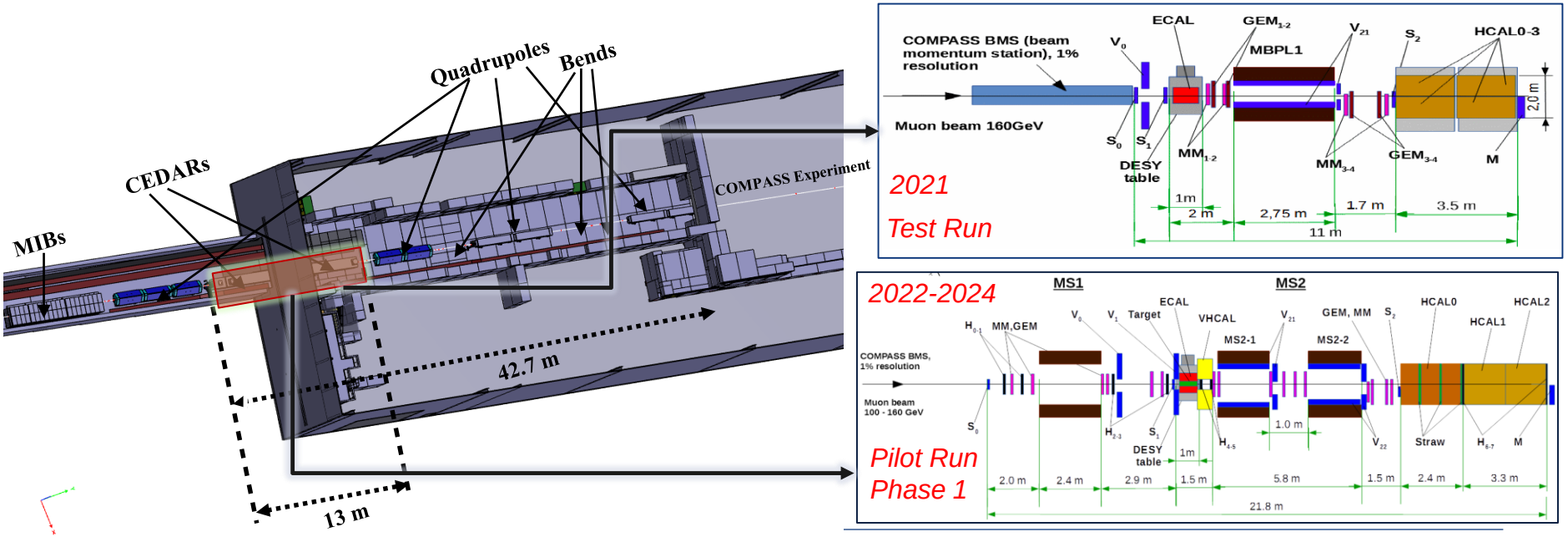
	2023	$\bar{p}$ production measurement Proton Radius	30 days 150 days	p μ
	2024, 2024+	Drell-Yan: pion Drell-Yan	[illegible]	[illegible]
NA64μ	[illegible]	[illegible]	14 days	μ
	[illegible]	[illegible] run	30 days	μ
	2023 end	Phase 1	40 days	μ
	2024 beg.	Phase 1	40 days	μ
MuonE (CERN-SPSC-2019-026/SPSC-I-252)	2021 end	Pilot Run	20 days	μ
	2022 end	Run 1	30 days	μ
	2023 +	Physics Run	~ 3 years	μ

EHN2 subcommittee of SPSC will propose the running schedule up to LS3

D.Banerjee
J.Bernhard

EHN2: NA64-μ Phase 1

- Proposal submitted to SPSC.
- Upstream location compatible with user requirements.
- Use of a 20 cm aperture MBPL magnet for the Test Run feasible that can stay during the COMPASS beamtime to limit change-over time with no effect to the beam downstream, availability still to be checked.
- For the Pilot run / Phase 1 minor changes to the beamline required.
- Cost and time estimations for cabling and infrastructure changes done that can be completed during the 2021-2022 YETS.



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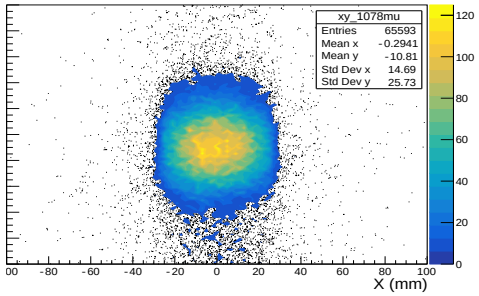
EHN2: NA64μ - Phase 1

- Optics calculations updated and two options exist

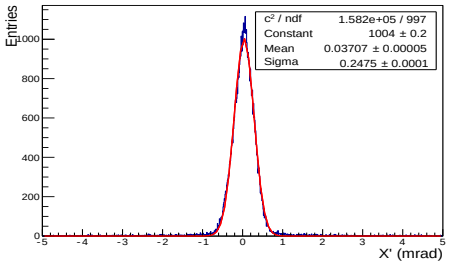
Parallel beam

σ_x = 13 mm

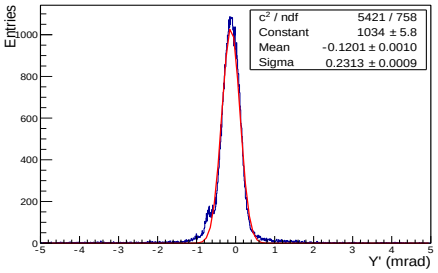
σ_y = 22 mm

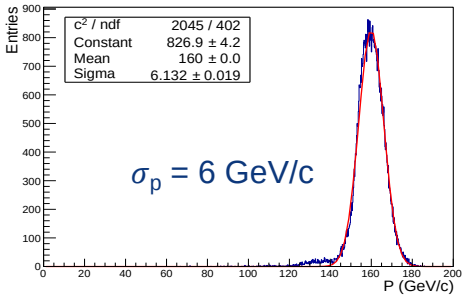


$\sigma_{x'}$ = 0.23 mrad



$\sigma_{y'}$ = 0.24 mrad

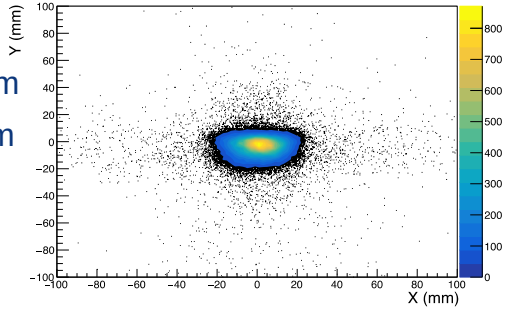




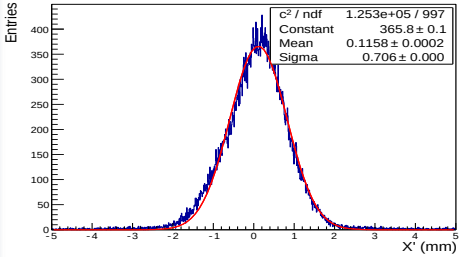
Focussed beam (MBPL position)

σ_x = 9.3 mm

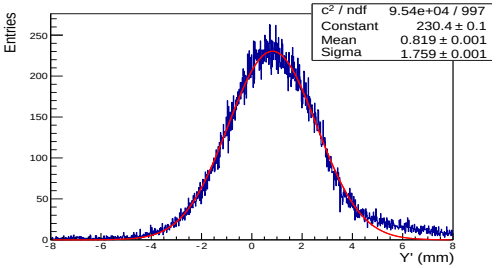
σ_y = 5.8 mm

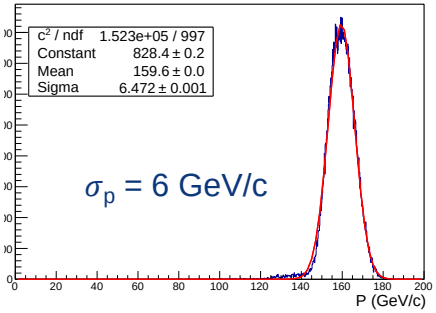


$\sigma_{x'}$ = 0.7 mrad



$\sigma_{y'}$ = 1.7 mrad

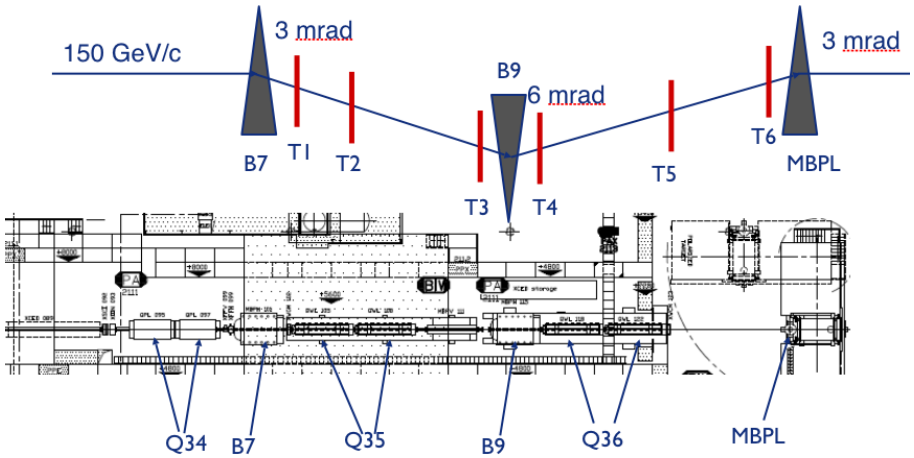




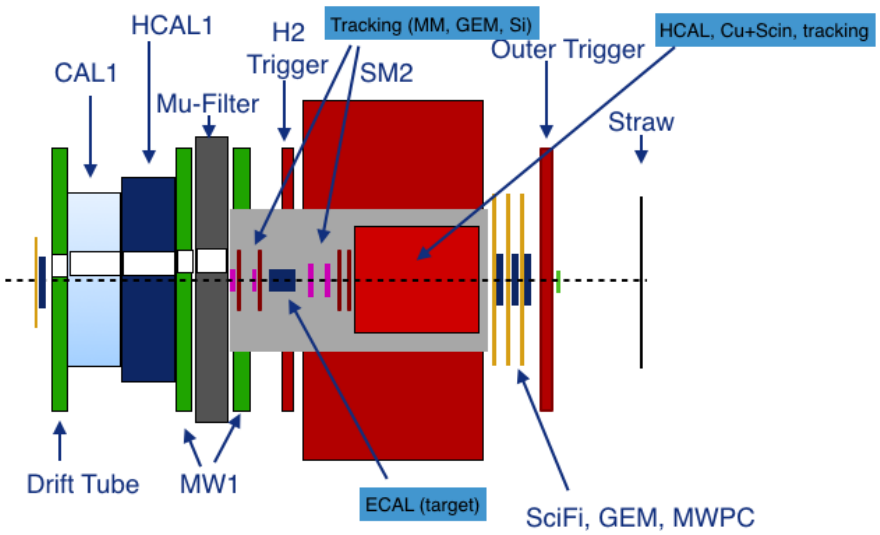
D.Banerjee
J.Bernhard

EHN2: NA64μ - Phase 2

- Phase 2 (After LS3)
  - Proposal to install inside SM2 spectrometer magnet.
  - Optics ready, integration study continues awaiting input for more details on the experimental detectors.
  - Proposal to use magnetic chicane + additional MBPL magnet near current Compass target location as additional magnetic spectrometer.



PPE211

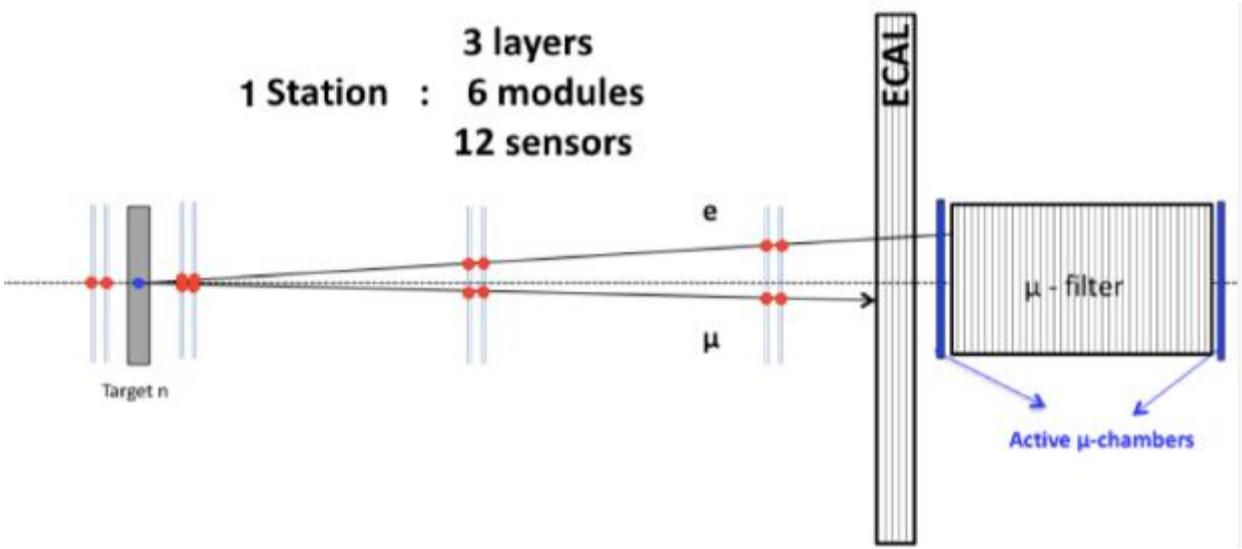


PPE221

D.Banerjee
J.Bernhard

EHN2: MuonE – Pilot Run

- LOI Submitted.
- Request for pilot run end of 2021 with 2 target stations, 1 m long each, ECAL and μ-ID.
  - Upstream location compatible with user requirements without change to the beamline.
  - Same location as for the requested NA64μ Phase 1 installation.
  - Optimised parallel beam optics presented before fits well with the beam parameter request.



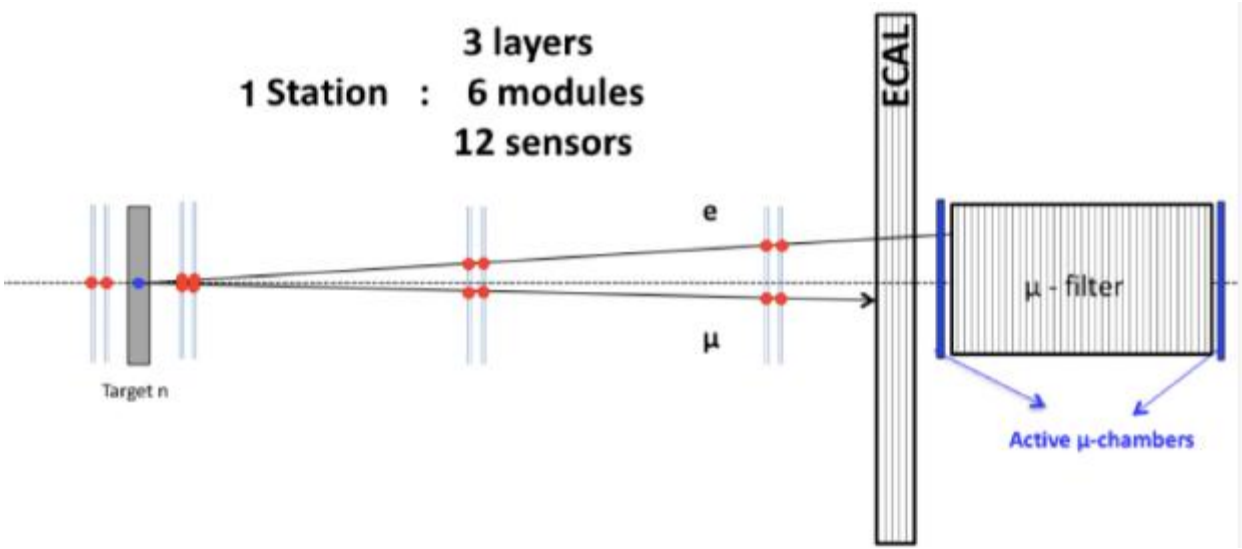
D.Banerjee
J.Bernhard

EHN2: MuonE – Pilot Run

- Infrastructure and Services requirements identified that includes:
  - Water cooling for tracker electronics.
  - Thermal housing for temperature stability.
  - Survey for stations alignment.
  - Support in case universal alignment platforms are used.
- Studies to be launched to check if the CEDAR cooling infrastructure can be used for the test run stage (not adequate for the 40 m setup).
- Support from the EN-SMM for survey needs much appreciated.
- Preliminary costing available for gas, DAQ needs and control room.

EN-CV

EN-SMM



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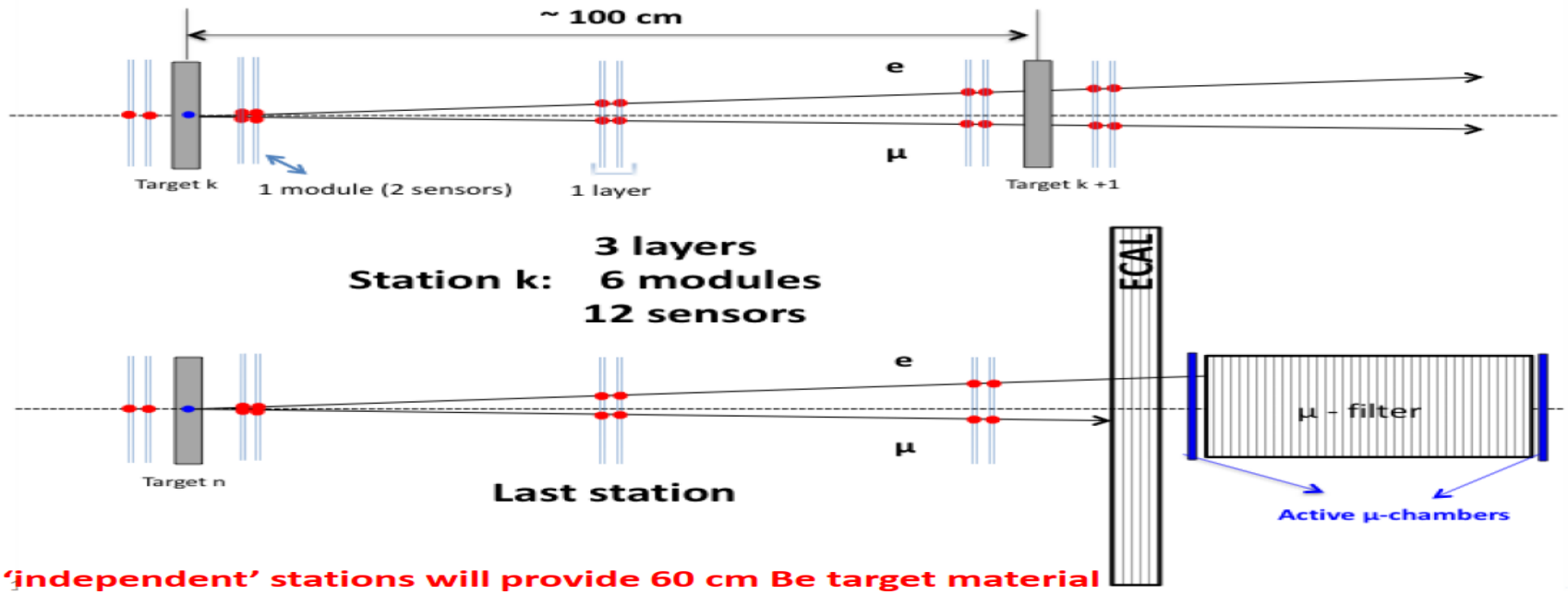
EHN2: MuonE – Run 1

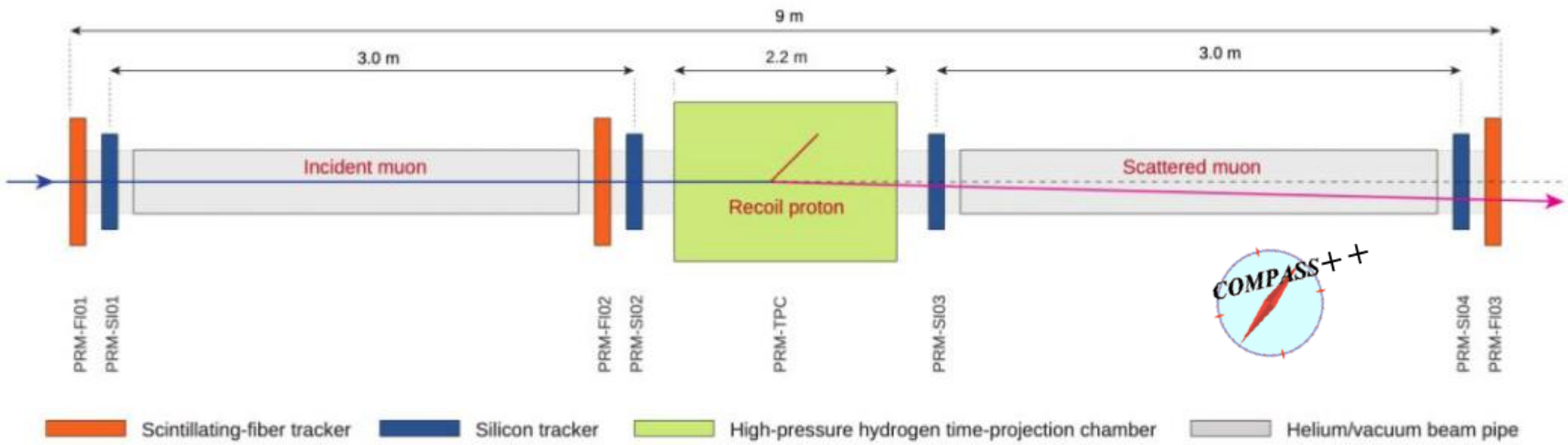
- Following the pilot run results beam request in 2022 will include run with full setup.
- For full setup, downstream beamline elements to be removed to accommodate the requested 40 m space for 40 target stations.
- Installation on modular support under study to reduce change-over time.
- Integration studies including studies for cooling, thermal housing for full setup, online survey and vacuum requirements continue.



D.Banerjee
J.Bernhard

EHN2: COMPASS++/QCD facility (AMBER)

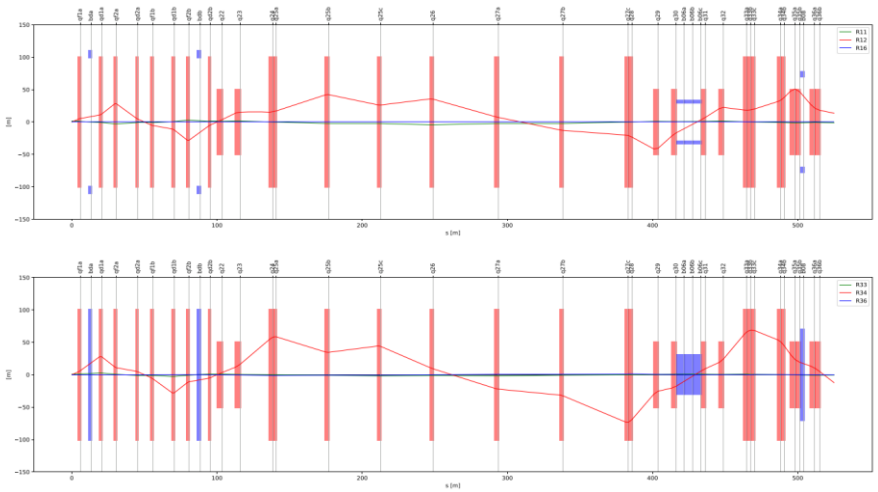
- For the requested 2021 proton radius test run available upstream space is compatible with the user requirements.
- Several optics configurations studied (focussed & parallel) and are suitable for the experiment needs.
- For the 2022 Proton Radius run required optics is very similar to the currently operated muon beam.
- Requested beam files for different energies exist for experiment simulations.
- Only minor integration studies to be done when more details become available.
- Safety infrastructure to be studied.

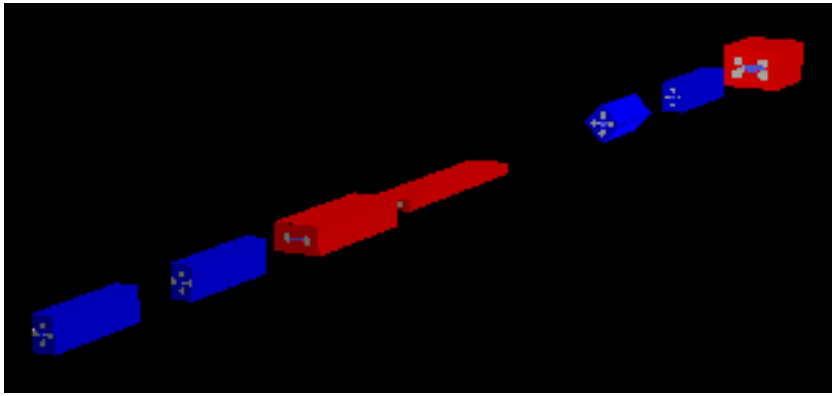


D. Banerjee
M. Van Dijk
E. Montbarbon
J. Bernhard

EHN2: COMPASS++/QCD facility (AMBER)

- For the high intensity hadron beams shielding studies completed using FLUKA models and validated with RP for the 2018 configuration.
- For runs beyond 2024, even more detailed Geant4/FLUKA models of the beamline being prepared for more detailed studies including studies for degradation of divergence at the CEDARs in case of differential absorption for high energy hadron beams.



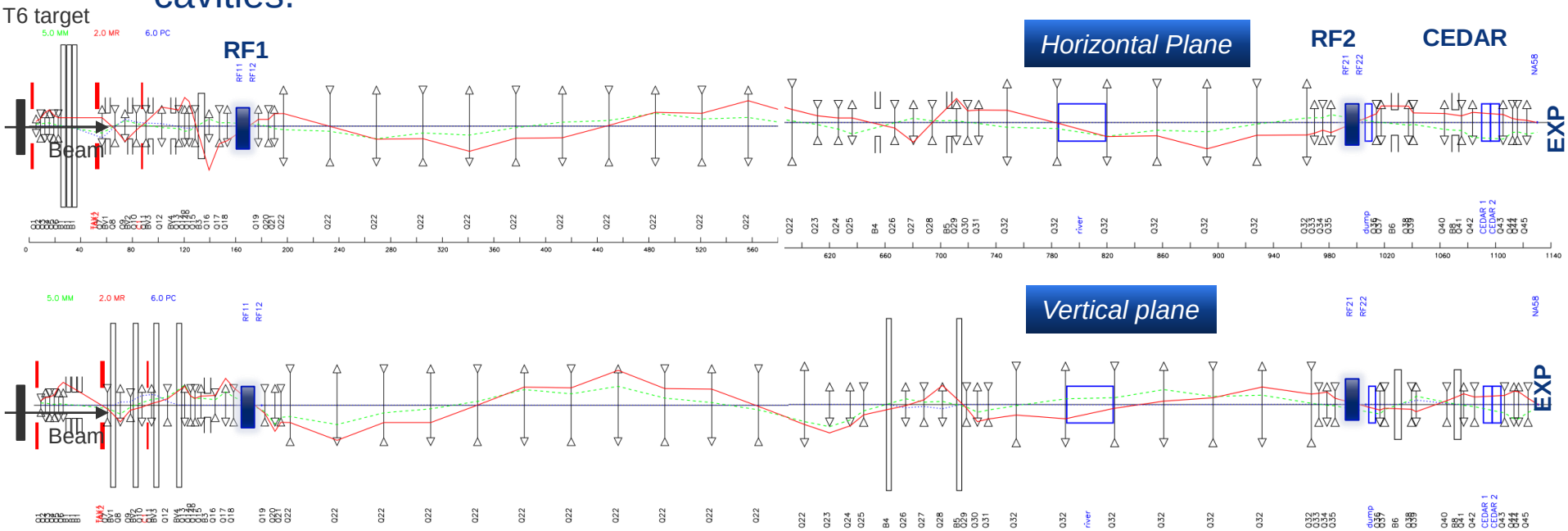


- Required optics similar to the current optics configuration for the hadron beam.
- These studies have also profited from migration to state-of-the-art software (Transport → MADX; HALO → Geant4/FLUKA models of beamlines).

E.Montbarbon
J.Bernhard

EHN2: COMPASS++/QCD facility (AMBER)

- RF-separated beams: First optics until the COMPASS Target position done with momentum resolution < 1% dp/p compared to the current 10% acceptance.
  - Beam spot in the cavities optimised and the distance between the cavities maximized for first iteration.
  - Studies to be done to evaluate the feasibility for physics with a compromise between the highest achievable momentum, frequency and acceptance of the cavities.

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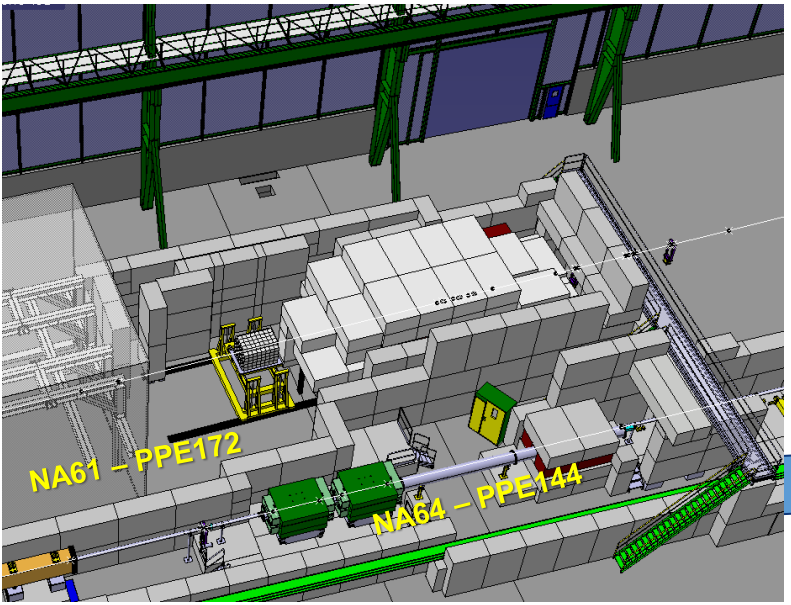
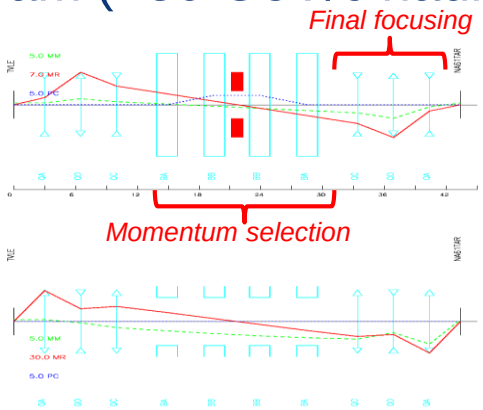
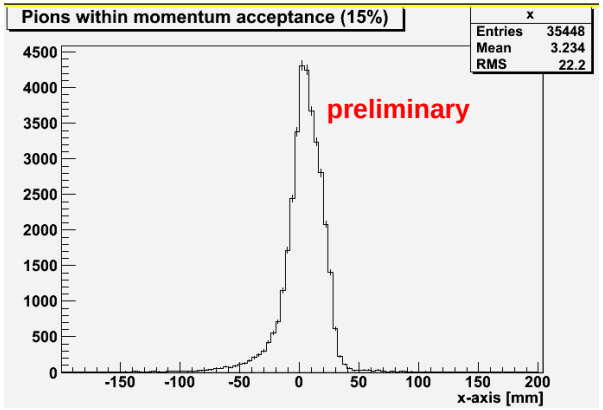
T2, T4, T6 targets
TT20 transfer line

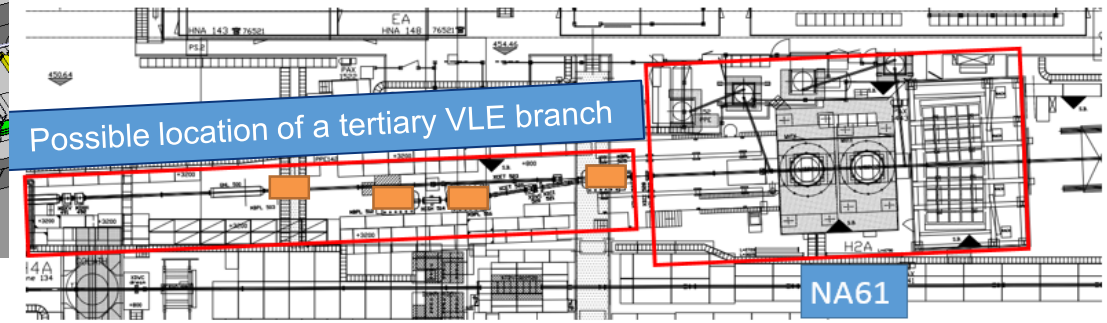
EHN1: PBC Improvements for NA61++

- Shielding upgrade in PSD Zone – will allow higher ion intensities (10^6 ions/spill)
  - Design agreed between EN/EA, SMB and HSE/RP
  - Installation pending funding approval
- Studies on a low energy beam (<30 GeV/c hadrons / protons) ongoing







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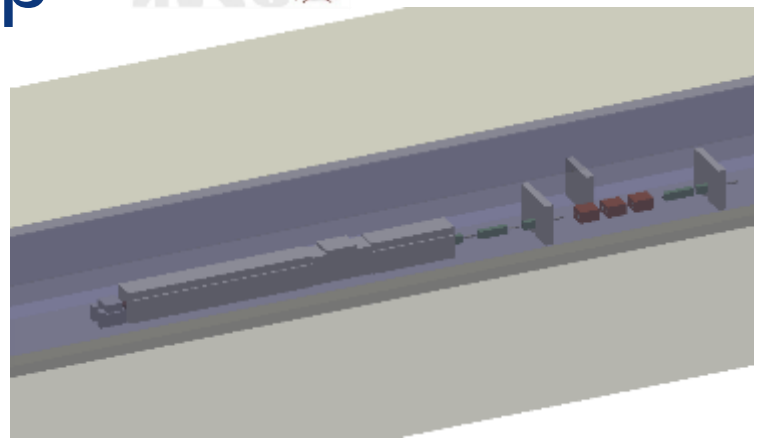
ECN3: NA62

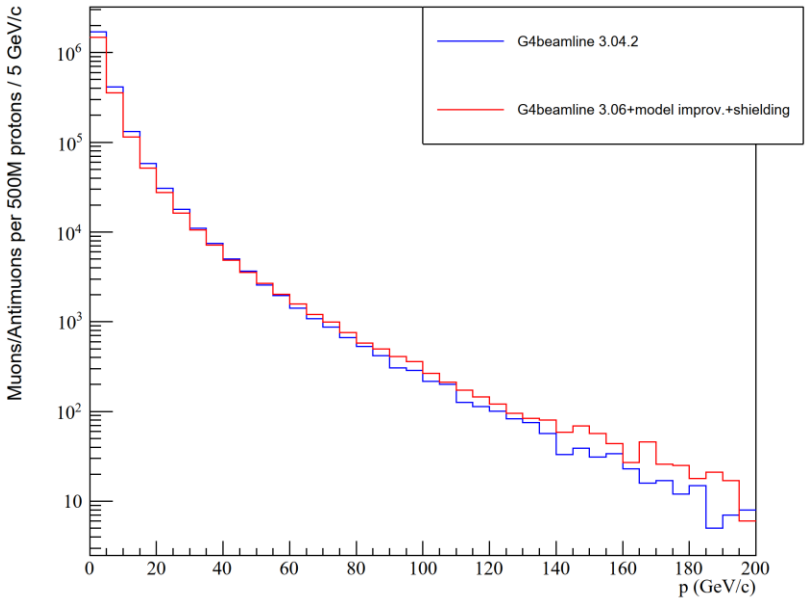
- G4beamline model of NA62 Beam Dump adjusted for use in NA62
- Upgrade of G4Beamline improves agreement with estimates from KTAG
  - G4beamline 3.04 → G4beamline 3.06
  - Geant 4.10.03 → Geant 4.10.05 (current release: 4.10.05 patch-01)

	NA62 TDR (102m)	KTAG estimate (~70m)	G4beamline 3.04 (69.2m)	G4beamline 3.06 (69.2m)
π^+	525 MHz		586 MHz	464 MHz
K^+	45 MHz		52.2 MHz	51.6 MHz
p	173 MHz		322 MHz	153 MHz
π^+/K^+	11.7	9.2	11.2	8.99
π^+/p	3.03	3.0	1.82	3.02
p/K^+	3.84	3.1	6.17	2.97

ECN3: NA62 beam-dump



- Final changes to G4beamline simulation
  - Updated G4beamline version
  - Upstream shielding added
- Muon spectrum post-TAX checked
  - Decrease at low momentum
  - Minor increase at high momentum
- Handover point implemented between beam simulation and NA62 MC (Geant4)
  - To be followed up with improvements under consideration



C. Ahdida + RP
M. van Dijk

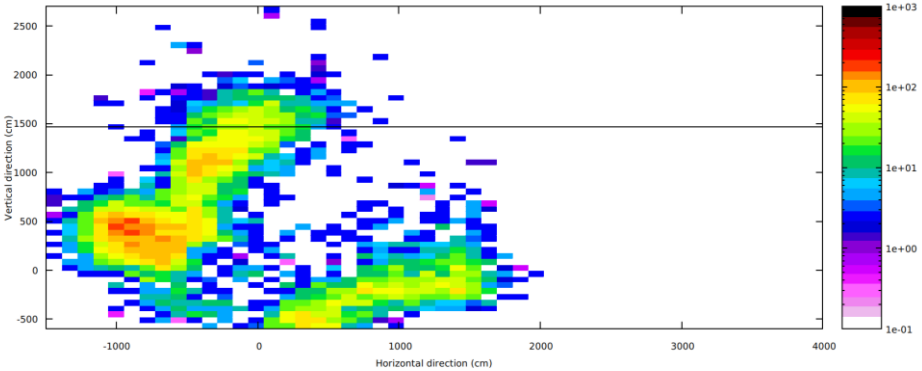
ECN3: KLEVER

- First iteration of dose rate studies for KLEVER complete
  - Neutrons do not give high rates above target (0.07 μSv/h) and at road (0.2 μSv/h)
  - Significant neutron dose in access building to TCC8 (~20 μSv/h) – airlock
  - High muon flux emanating from target area is also potentially problematic

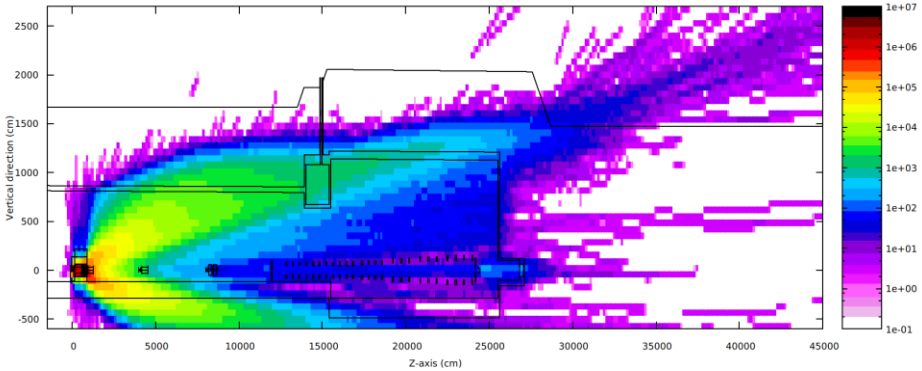
    Resulting dose rate has been assessed, significant dose rate at end of earthen barrier (~70 μSv/h) – to be addressed

    Potential solutions include changes to muon sweeping and adding shielding in target region. Will be investigated

Muons only, projection at z=300m

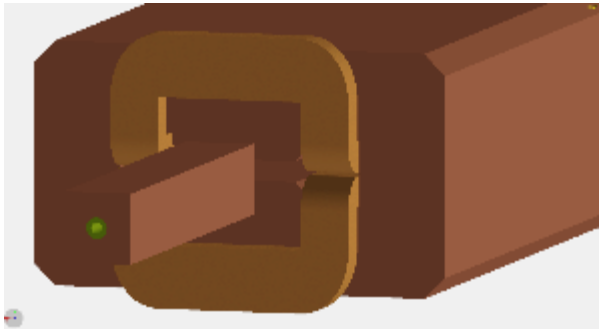


Muons only, projection at x=0m

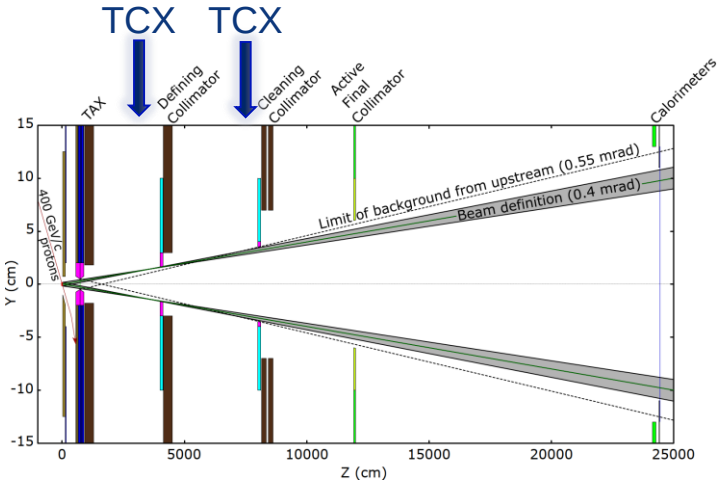


M. van Dijk

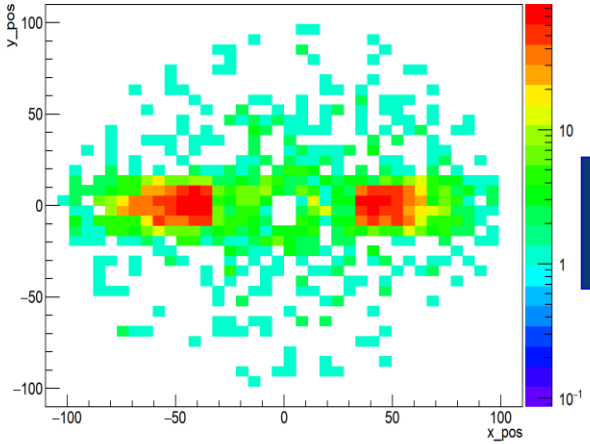
ECN3: KLEVER



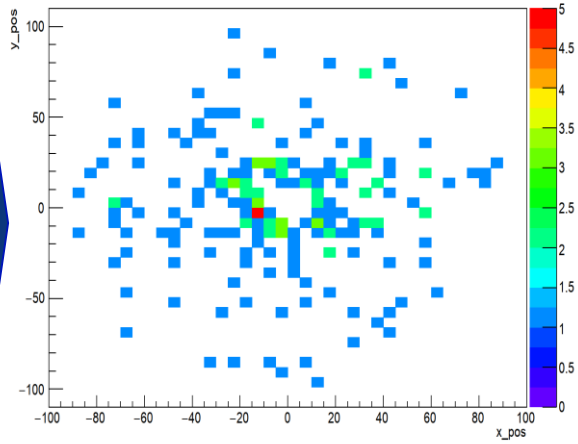
- Rates found in Active Final Collimator are high (AFC, lead / scintillator shashlik detector)
- NA48 type collimator (XCLD) outer dimensions not sufficiently large
  - Particles propagate around cleaning collimator through gaps in magnet
  - Add fixed collimators (TCX) in front of defining and cleaning collimators
  - Pattern (from magnet apertures) completely disappears



Particles at AFC (no TCX)



Particles at AFC (with 2xTCX)

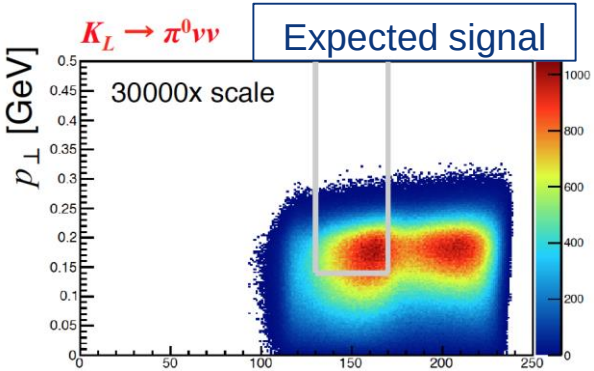


M. van Dijk
A. Lechner

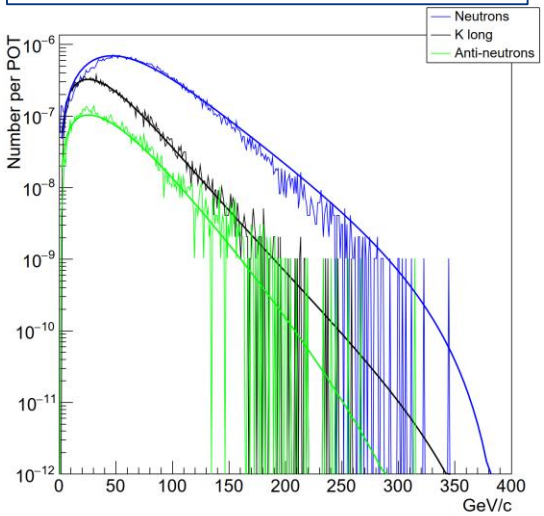
ECN3: KLEVER

- Background from beam-gas simulated assuming NA62 gas composition
- Used major beam components passing active final collimator (AFC)
- Adapted beam-gas interaction routine in FLUKA to generate events (courtesy A. Lechner)
- Found background of ~16.7 signal-like events over KLEVER lifetime at 10^{-6} mbar (NA62)
- Linear with pressure, 10^{-7} mbar could be goal

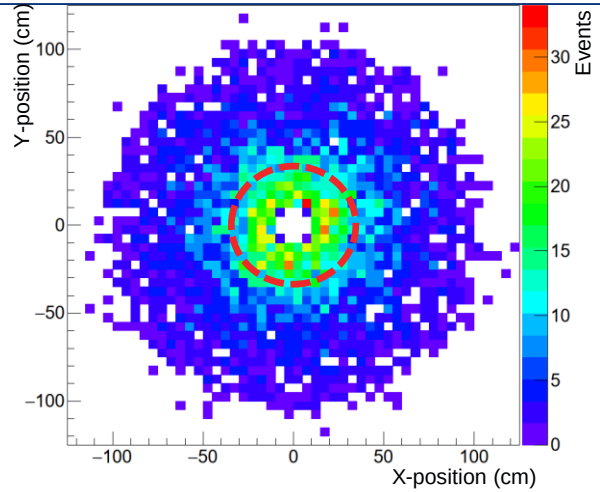
Expected signal



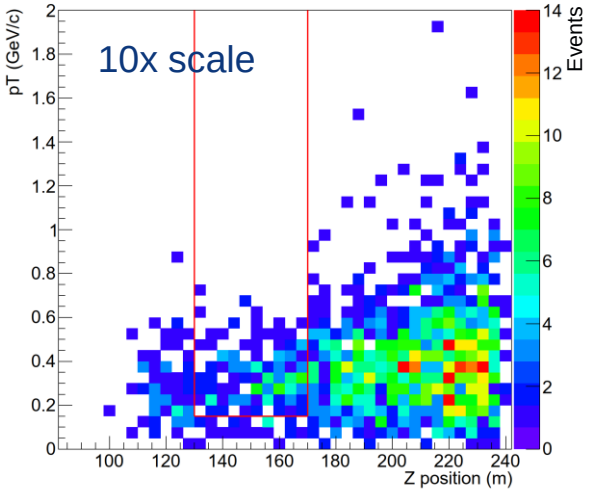
Simulated beam components



Illumination of final calorimeter for signal-like events (only 2γ detected)



Signal-like events from beam-gas



Summary and Outlook

- The CBWG studies give good indications of the feasibility and implications of the beams and infrastructure modifications associated with the proposed experiments.
- In a next step for EHN2 more detailed studies will focus on longer term projects like the feasibility for physics of the RF-separated beam and implementation of NA64-μ Phase 2 and studies for the Drell-Yan programme of COMPASS++/AMBER.
- A shielding upgrade for NA61 has been prepared, pending funding approval. A low energy beam option is currently under study.
- An initial radiation study for the KLEVER project is complete, with the path forward clear. Background from upstream has been suppressed, and the impact of beam gas quantified.
- An upgrade to G4beamline improved the performance of the NA62 Beam Dump simulation.
- Synergies with ongoing deployment of state-of-the-art software in EA-LE also facilitate future studies for both PBC and non-PBC projects.

Documentation

- Full report:
  CERN-PBC-REPORT-2018-002
- Executive Summary:
  CERN-PBC-Notes-2018-005
- Technical notes:
  CERN-PBC-Notes-2018-002
  CERN-PBC-Notes-2018-004
- ICAP'18 proceedings
  Single-Muon Rate Reduction for Beam Dump Operation of the K12 Beam Line at CERN
- IPAC'2019 Proceedings
  The "Physics Beyond Colliders" Project for the CERN M2 Beam
  THE K12 Beamline for the KLEVER Experiment
- 29th International Symposium on Lepton Photon Interactions at High Energies
  Search for Dark Sector Physics at the NA64 Experiment in the context of the Physics Beyond Colliders Project
- MENU 2019
  Studies for New Experiments at the CERN M2 Beamline within "Physics Beyond Colliders": AMBER/COMPASS++, NA64mu, MuonE
- In preparation: ECAART 2019

CERN-PBC-REPORT-2018-002 17 December 2018

Physics Beyond Colliders

PBC CONVENTIONAL BEAMS

Report from the Conventional Beams Working Group to the Physics beyond Collider Study and to the European Strategy for Particle Physics

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on behalf of the Conventional Beams working group

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Thank you!

Acknowledgements

We have profited from and are grateful for important input from technical experts, in particular C.Ahdida, P.Avigni, M.Battistin, M.Calviani, S.Cholak, A.Ciccotelli, S.Esposito, Y.Gaillard, S.Girod, D.Jaillet, V.de Jesus, J.Lehtinen, S.Pagan, Ph.Schwarz, N.Solieri and H.Vincke. The studies reported in this report have been performed in close collaboration with the representatives of the proposals submitted to the group, in particular A.Aduszkiewicz, V.Andrieux, P.Crivelli, O.Denisov, B.Dobrich, S.Gninenko, E.Goudzovski, G.Lanfranchi, G.Mallot, C.Matteuzzi, M.Moulson, L.Nemenov, S.Pulawski, E.Scomparin, T.Spadaro. Finally, we acknowledge the excellent collaboration with and support from the PBC management and the chairs of the physics working groups. This research project has been supported by a Marie Skłodowska-Curie COFUND project of the European Commission's Horizon 2020 Programme under contract number 665779 COFUND.

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Backup slides

ECN3: NA62 beam-dump

- Dump configuration optimized relative to nominal BD configuration
  - Scenario 1: use TAX as dump, B1A / B2 off, B1B@-0.3T, B1C@-1.82T
  - Scenario 2: use TAX as dump, B1A / B2 off, B1B@-1.82T, B1C@-1.82T
  - Scenario 3: replace first B3 magnet with 3.2m copper dump, retune remaining line
  - Scenario 4: like scenario 3, but replace downstream QNL with additional MBPL

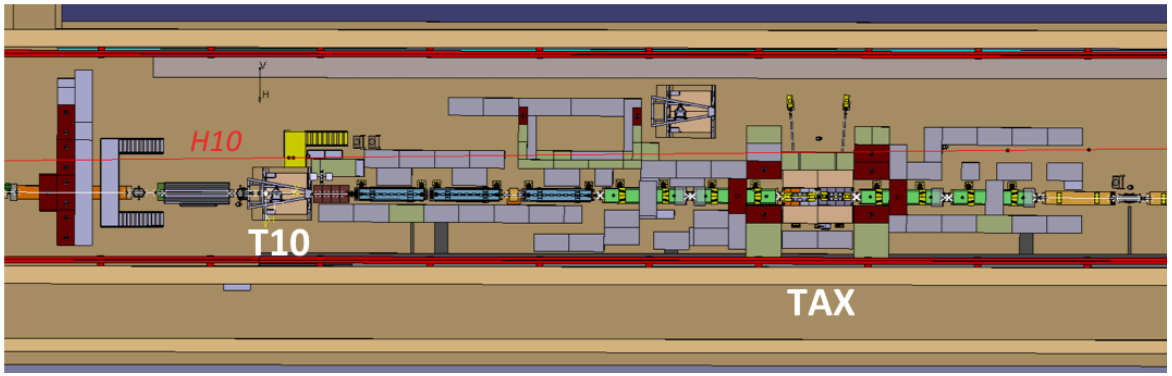
μ in MUV3	p>0 GeV/c	p>5 GeV/c	p>10 GeV/c	p>15 GeV/c	p>20 GeV/c
Nominal	100%	100%	100%	100%	100%
Scenario 1	26%	22%	21%	21%	21%
Scenario 2	295%	88%	9%	3%	3%
Scenario 3	333%	319%	335%	350%	365%
Scenario 4	611%	98%	22%	20%	20%

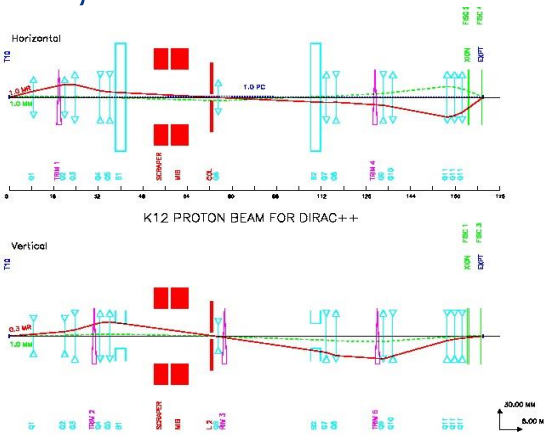
- Scenario 1 minimizes overall muon rates, scenario 2 minimizes high-momentum
- No improvement observed with dump placed downstream

L. Gatignon

NA60++ / DIRAC++

- If K12 beam line and NA62 are dismantled, cohabitation of both experiments in principle possible.
  - Requires re-establishing the end of P41 and H10 beam lines for NA60++ (beam optics existing and available).
  - New optics for proton delivery beam line to DIRAC++ calculated.
  - Reactivation of H10 has severe impact on front-end shielding and place for detector maintenance.
  - Front-end shielding considered vital for radiation protection above and behind ECN3 cavern (limits available space for π decays into μ).
  - DIRAC++ operation might require ECN3 ventilation, to be studied.





L. Gatignon

REDTOP

- REDTOP is an experiment for very rare eta decays, originally proposed for FERMILAB. Discussions with several machine experts have taken place concerning implementation at CERN. They request 10^{18} pot per year and hence a duty cycle of 80% or more.
- In **LEIR** the beam energy is too low and many machine aspects would need serious studies and investment. In particular LEIR is not a shielded machine.
- The upgraded **PSB** energy after LS2 would match perfectly, but here the implementation would also be difficult and penalising for the other users.
- At the **PS** slow extraction into a heavily shielded facility (like the IRRAD+CHARM bunker in the East Hall) has been looked at. No showstopper has been identified. Again many studies would be required and the impact on the rest of the PS physics program would be very significant. Reduced flux requirements could ease the situation.
- For the moment this study is put on hold and any further study should be done in a more machine oriented working group.