Status of the PBC Conventional Beams Working Group Studies

03-March 2021

A. Gerbershagen on behalf of Conventional Beams Working Group

PBC Conventional Beams WG - Projects

PBC Conventional Beams WG – EHN1

NA61 – Shielding Upgrade

N. Charitonidis
S. Girod

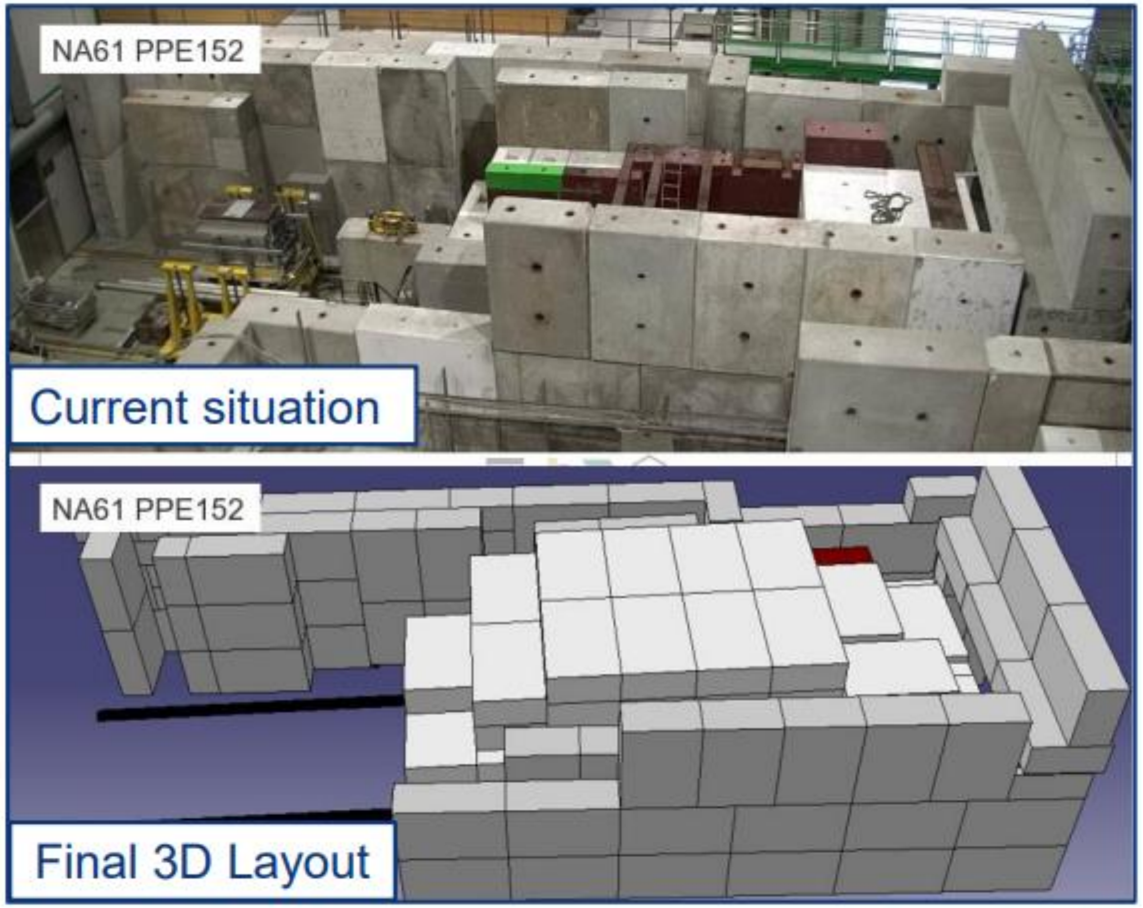
Running heavy ion experiment

Approved by Research Board

Worksite news:

- Towards higher intensities
- 10^6 Pb ions per spill
- Shielding is completed
- Roof will be installed
  for the ion runs

⇒ Will be ready for data taking

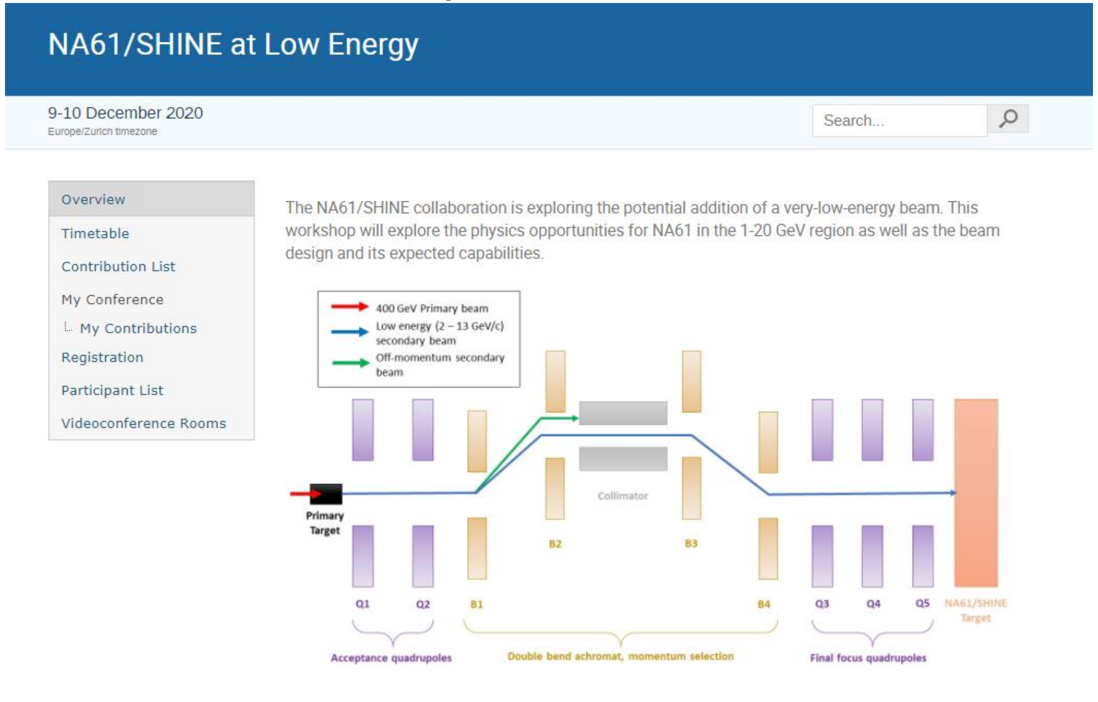


On behalf of S. Girod

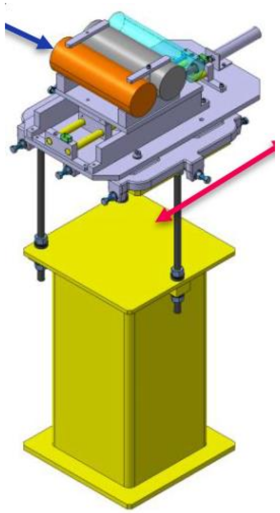
NA61++ New Low Energy Beam

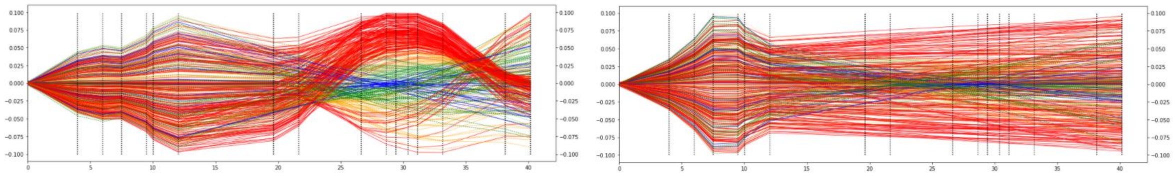
C. Mussolini
N. Charitonidis

A new, tertiary branch just upstream of the existing facility has been requested by NA61 in order to open new possibilities for important cross-section measurements. World-wide interest was expressed in a dedicated workshop in Dec ‘20.



- Set of three target heads, since there is a trade-off between high yield and particle composition for the different energies (1-13 GeV)
- First beam optics proposed
- Future goals:
  - Increase beamline acceptance
  - Investigate options for particle identification
  - Perform background studies



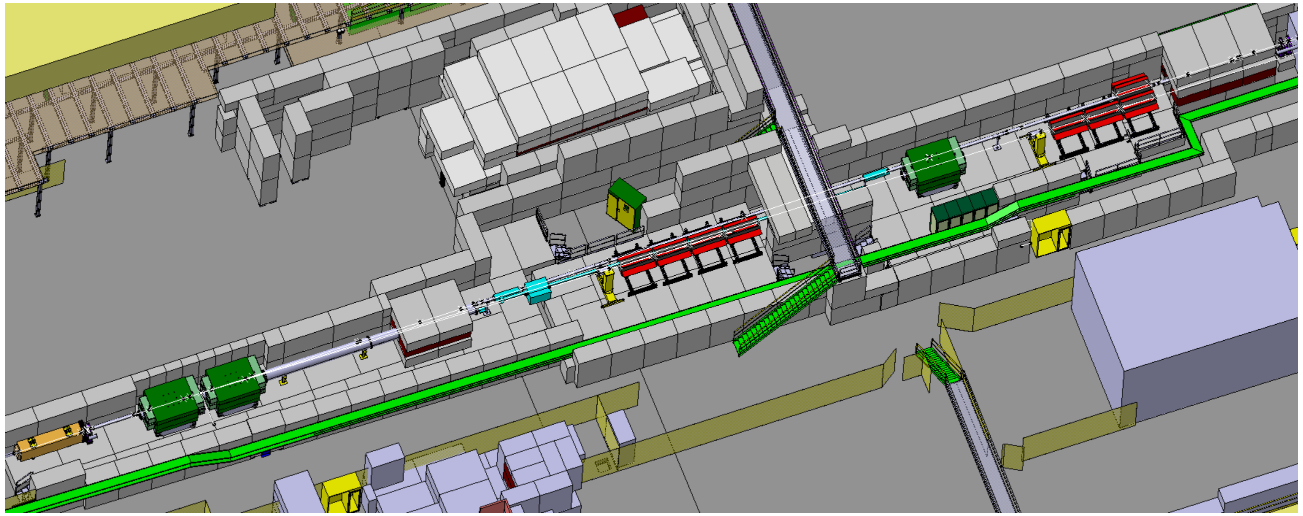


https://indico.cern.ch/event/973899/

NA64e – Towards Higher Intensities

N. Charitonidis
S. Gninenko
V. Poliakov
P. Crivelli

- Continuing the quest of Dark Matter – necessity of ~$4x10^{13}$ e.o.t for the next 4-5 y.
- Dedicated studies have been launched for the possibilities of increased intensity @ H4. Possible target intensity increase or reconfiguration of the line.
- Ideas for enabling true muonium experiments with positrons around 45 GeV/c also being studied.

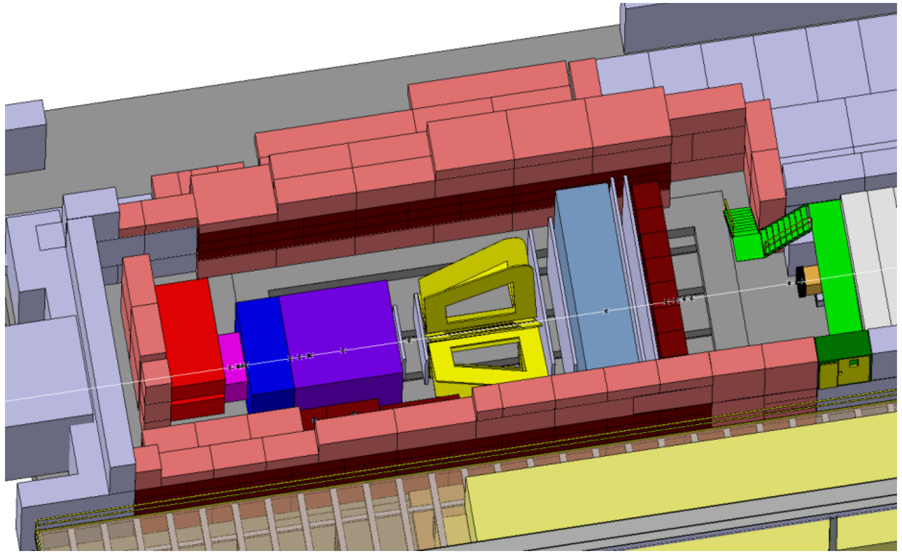


New dedicated zone PPE144 is under construction.

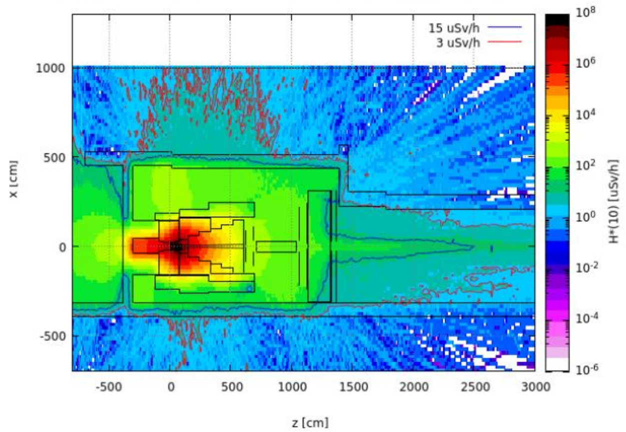
NA60+ in EHN1 Zone 138

Ch. Ahdida
H. Vincke
A. Gerbershagen
S. Girod

- New ion experiment for study of dimuons and open charm
- Regular technical meetings are being held
- Integration studies ongoing
  - Experiment can fit into the zone after modifications
    - Reduction of detector transverse size to ~6.2 m
    - Adaptation of zone's entrance bridge, shielding walls and the location of gas and power racks
- Radiation Protection studies ongoing
  - Intensity request reduced by factor 4: 10^7 Pb ions per spill and ≤160 AGeV/c seem feasible, however:
    - Additional iron shielding of 1.6 m around absorber is required
    - High residual dose at the target (e.g. 30 μSv/h after 1 month cool-down), so access only with RP



H*(10) (1e7 Pb/spill, 160A GeV, 40 s, 2 spills), y [-50;50], shield 9



PBC Conventional Beams WG – EHN2

D. Banerjee
J. Bernhard
A. Gerbershagen
F. Metzger
S. Schuh-Erhard

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 intensity 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_{μ}-2).
    - Requires high intensity 160 GeV/c, low divergence muon beam.
    - Full setup ~ 40 m long.
  - Successor to the **COMPASS** experiment - A QCD Facility (**AMBER**)
    - Currently occupies the EHN2 hall with a 55 m long setup, filling the hall due to large transverse dimensions.
    - Requires conventional muon and hadron beams in the 1st and 2nd phase including a new RF separated option in the 2nd phase (under study).

Tentative Beam Times up to LS3

D. Banerjee
J. Bernhard

Experiment	Year	Activity	Duration (Pending SPSC recommendation)	Beam
COMPASS (CERN-SPSC-2017-034/SPSC-P-340-ADD-1)	2021 mid - 2022	Transversity run (approved)	150 days	μ
AMBER (CERN-SPSC-2019-022/SPSC-P-360)	2021	Proton Radius Test Run (approved)	20 days	μ
	2022-2023	Proton Radius	310 days	μ
	2022-2023	$\bar{p}$ production measurement (approved)	40 days	p
	2024+	Drell-Yan: pion PDFs and Charmonium production mechanism (approved)	≲ 2 years	p, K^+, π^+ $\bar{p}$, K^-, π^-
NA64μ (CERN-SPSC-2019-002/SPSC-P-359)	2021 end	Test Run (approved)	14 - 20 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	Test Run (approved)	20 days	μ
	2022 end	Run 1	30 days	μ
	2023 +	Physics Run	~ 3 years	μ

Tentative Beam Times up to LS3

D. Banerjee
J. Bernhard

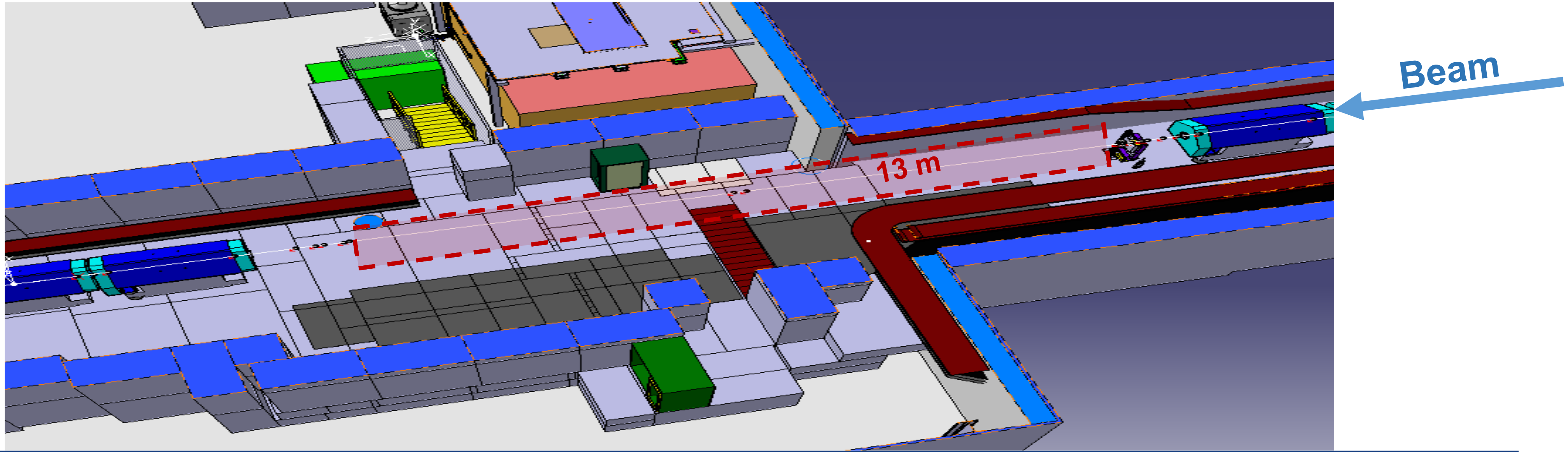
Experiment	Year	Activity	Duration (Pending SPSC recommendation)	Beam
COMPASS (CERN-SPSC-2017-034/SPSC-P-340-ADD-1)	2021 mid - 2022	Transversity run (approved)	150 days	μ
AMBER (CERN-SPSC-2019-022/SPSC-P-360)	2021	Proton Radius Test Run (approved)	20 days	
	2022-2023	Proton Radius		
	2022-202[illegible]			p, K^+, π^+ $\bar{p}$, K^-, π^-
		(approved)	14 - 20 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	Test Run (approved)	20 days	μ
	2022 end	Run 1	30 days	μ
	2023 +	Physics Run	~ 3 years	μ

Delays due to COVID → 2021 runs - NA64μ not before September; MuOnE not before 25 October; AMBER IKAR TPC ready.
SPSC with its EHN2 subcommittee will propose the running schedule up to LS3

2021 Test Runs

D. Banerjee
J. Bernhard

- **NA64μ** requires ~ 13 m space for their minimal setup and a focused 160 GeV/c muon beam.
- **MuOnE** requires ~ 7 m space with a parallel 160 GeV/c muon beam for two target stations and an ECAL.
- **AMBER** proton radius requires 9 m space for their TPC, trackers and vacuum tubes with a focussed 160 GeV/c muon beam.
- The 13 m space available upstream of the current COMPASS setup where the CEDARs are located is deemed feasible for all three test runs in 2021.



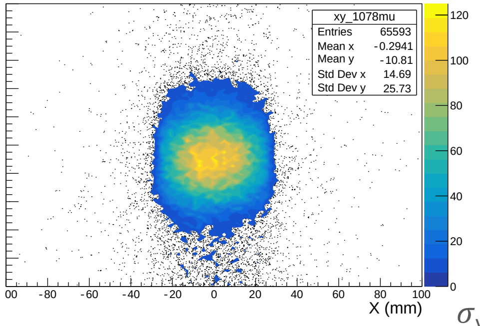
2021 Test Runs - Two Optics options

D. Banerjee
J. Bernhard

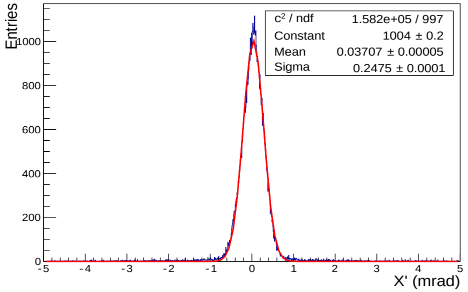
Parallel beam (MuOne)

σ_x = 13 mm

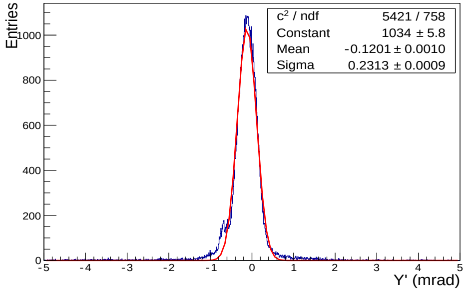
σ_y = 22 mm



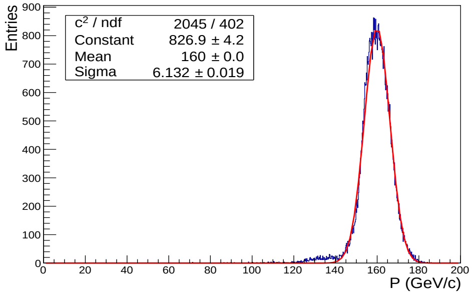
$\sigma_{x'}$ = 0.23 mrad



$\sigma_{y'}$ = 0.24 mrad



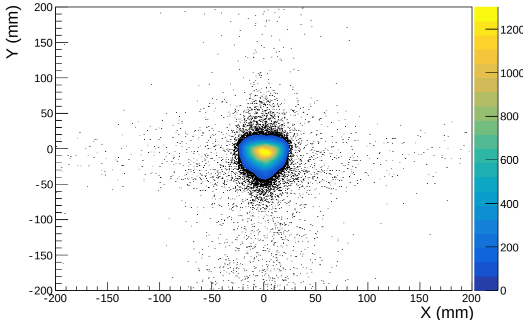
σ_p = 6 GeV/c



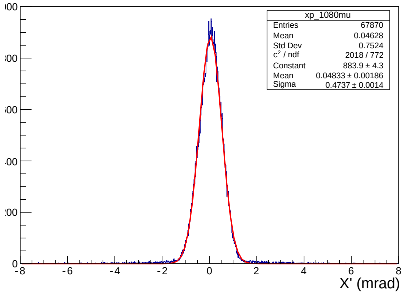
Focussed beam (AMBER, NA64μ)

σ_x = 9.99 mm

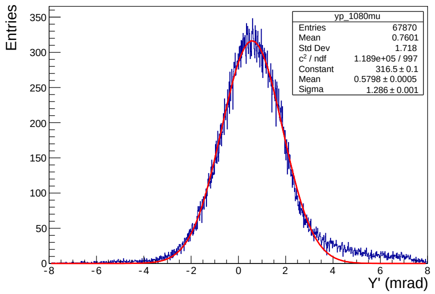
σ_y = 11.8 mm



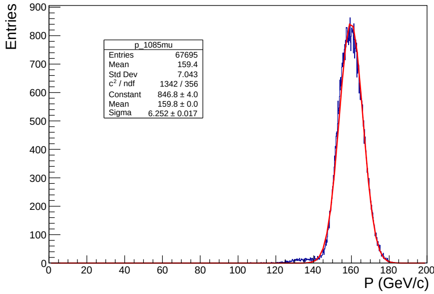
$\sigma_{x'}$ = 0.47 mrad



$\sigma_{y'}$ = 1.3 mrad



σ_p = 6 GeV/c



2021 Test Runs - User Requirements

D. Banerjee
J. Bernhard
S. Girod

Experiment	Needs / Technical Solution	Status
NA64μ	Installation of a **MBPL magnet** on rails, water manifold modification for new magnet installation, power cables, interlock and cooling of MBPH.065101 to be extended via terminal box for the new magnet (cables available in 867 storage), installation of experiment in beamline.	Manifold modification verified with EN-CV, included in the planning. Magnet availability, installation and powering scheme confirmed with TE-MSC. **Integration drawings OK for 2021. Installation to be planned.**
AMBER	**Hydrogen infrastructure** → existing barrack B-888/R413 to be used as recirculation area, Compass ATEX rack to be reused; vacuum / helium pipes and windows.	Hydrogen connection from storage to TPC gas area checked by BE-EA, gas infrastructure being finalized. User requirements for vacuum pipes received. **Integration drawings OK for 2021.**
MuonE	High precision alignment (EN-SMM), a **"tent" to be used for thermal housing** / temperature stability for the experimental area, cooling of the rack room (new separation added to B-888/1-014 will serve as the rack room).	Preliminary discussion done with EN-CV. Details of the "tent" and setup confirmed with the user. Solutions being identified with EN-CV. **Integration drawings OK for 2021.**
General Infrastructure	Installation of **rails for CEDAR removal / Magnet installation**, Gas infrastructure; DAQ fibers – Procurement ongoing; Racks and space (B-888/R-007), Electrical outlets + grounding panel; Existing meeting (B-888/1-008) refurbishment for control room.	Rail design ongoing; gas infrastructure verified with the proponents – installation being planned; Ticket created for EN-EL works; **General planning & resource checking ongoing – ECR in preparation**

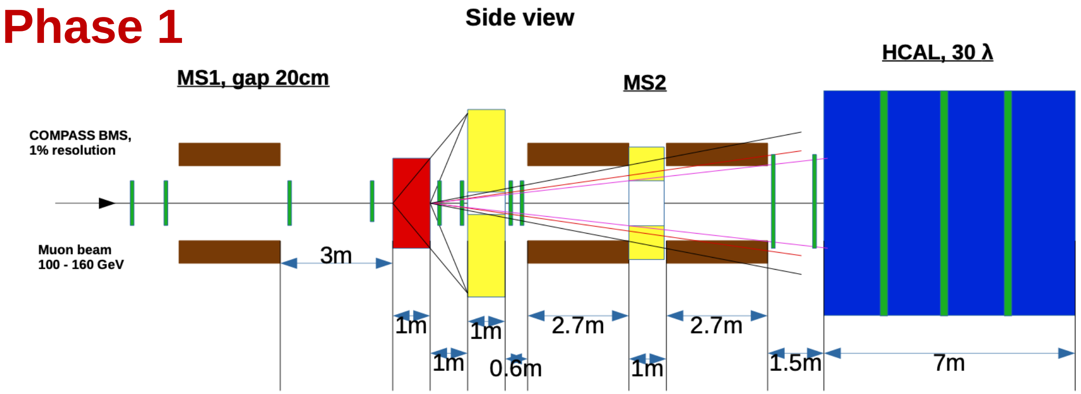
Ready for the runs in 2021

2022 and beyond

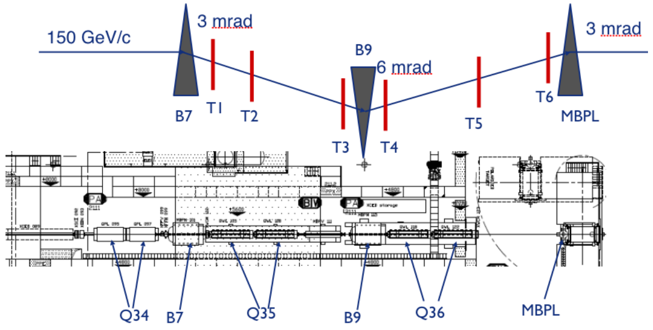
D. Banerjee
J. Bernhard

- NA64μ
  - For Phase 1 the space required is ~ 25 m.
  - Upstream location compatible with Phase 1 request - requires minor modifications to the beamline.
  - For Phase 2 proposal to install in COMPASS SM2 magnet and use magnetic chicane + additional MBPL magnet near current COMPASS target location as additional magnetic spectrometer
  - Optics ready, integration study continues awaiting input for more details on the experimental detectors.

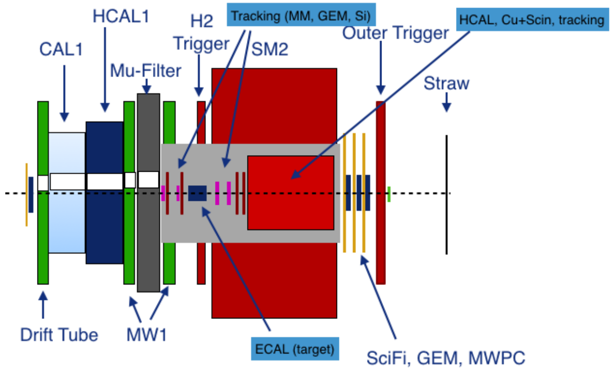
Phase 1



Phase 2



PPE211

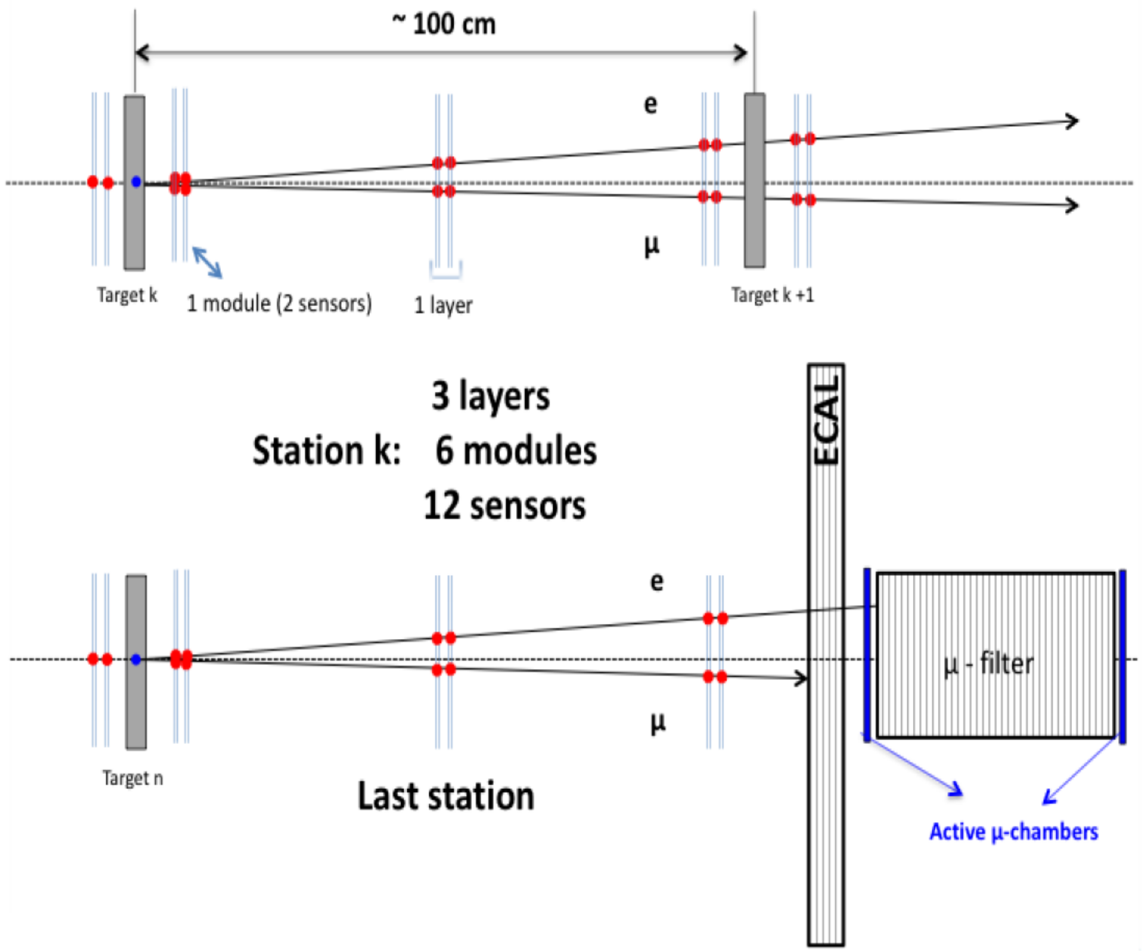


PPE221

2022 and beyond

D. Banerjee
J. Bernhard

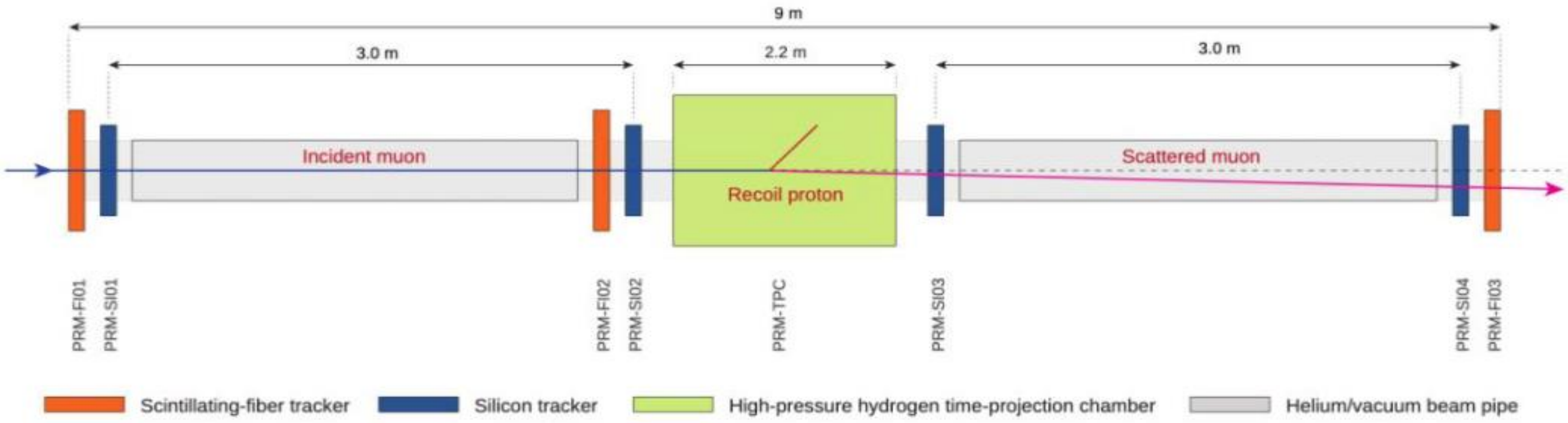
- MuOnE
  - Following the pilot run results beam request in 2022 will include run with full setup.
  - For full setup, downstream beam line elements to be removed to accommodate the requested > 40 m space for 40 target stations.
  - Integration studies including studies for cooling, thermal housing for full setup, online survey and vacuum requirements continue.



AMBER - 2022 and beyond

D. Banerjee
J. Bernhard

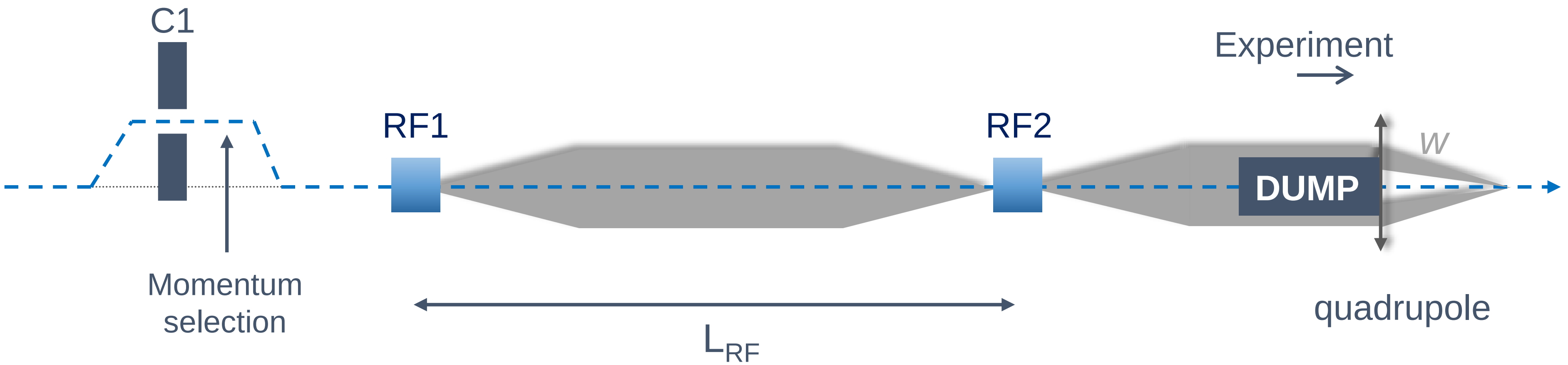
- AMBER
  - For the 2022 Proton Radius run, the setup will be installed at the current COMPASS target location in the zone PPE221.
  - Required optics is very similar to the currently operated muon beam.
  - Requested beam files for different energies exist for experiment simulations.
  - Integration studies to be done as more details become available.
  - Safety infrastructure being studied, for Drell Yan: additional shielding, new user zone splitting.
  - ECR is currently being drafted



The RF-separated beams

E. Montbarbon
J. Bernhard
L. Gatignon
F. Metzger
S. Schuh-Erhard

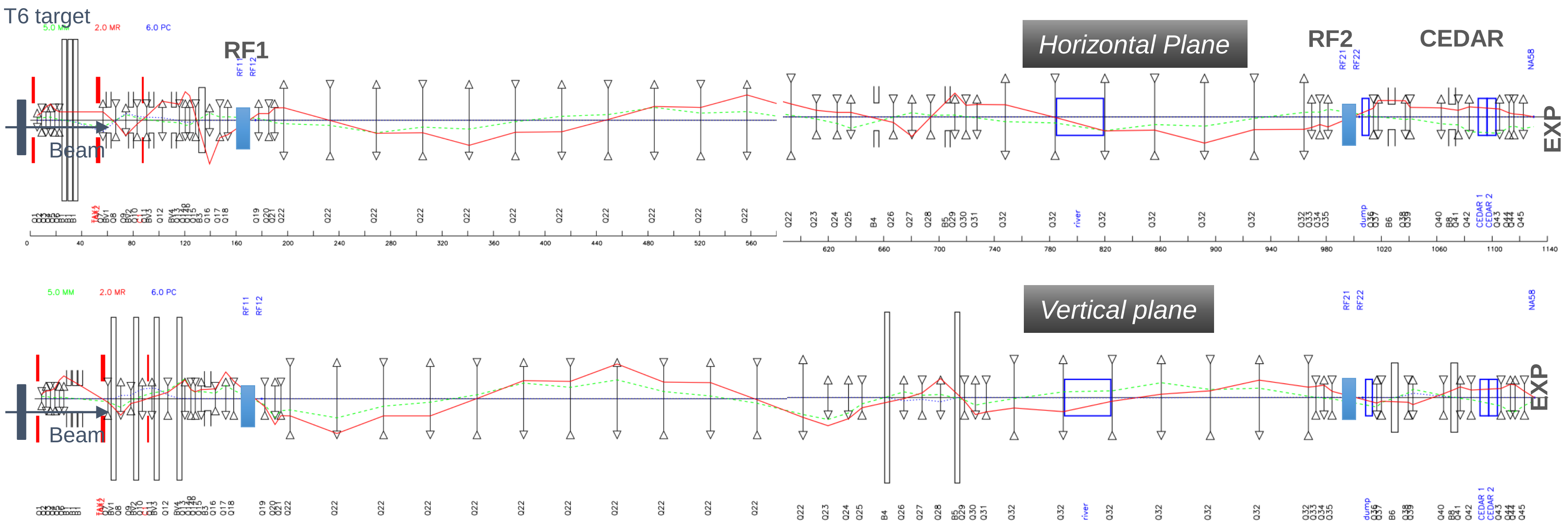
- Particle species discrimination: same momentum but different velocities
  - For M2: Interest in K^- and antiproton beams
- Time-dependent transverse kick by RF cavities in dipole mode
- RF1 kick compensated or amplified by RF2 depending on velocity, i.e. particle species
- Studies to evaluate the feasibility for physics have started.
  - 3.9 GHz cavities are one de facto standard these days
- Studies for M2 beam line in parallel to K12 beam line
- Workshop is being organized (summer-autumn 2021)



The RF-separated beam optics in M2

E. Montbarbon
J. Bernhard
F. Metzger
S. Schuh-Erhard

- First optics up to the COMPASS target position done
  - Aim for momentum resolution better than 1%
  - Beam spot size in the two RF cavities optimized and distance between the cavities maximized
  - Implementation of two RF-defectors
  - Space made available for a 5 m long dump (to dump unwanted particles)
  - Beam as parallel as possible at CEDAR location



PBC Conventional Beams WG – ECN3

PBC Projects in ECN3

- **NA62-BD** – Beam Dump mode of NA62 for dark matter search

- **KLEVER** - K_L -> $\pi^0\ \nu\ \bar{\nu}$ branching ratio
  - To operate with 2 x 10^{13} ppp on T10

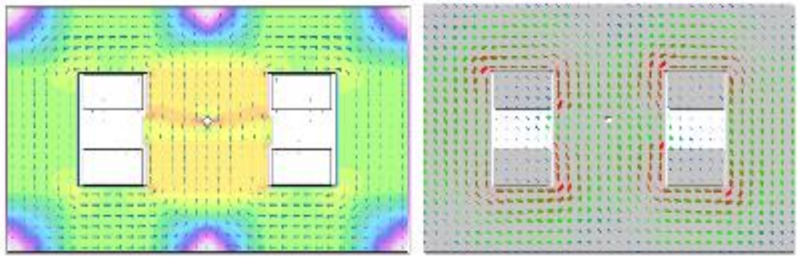
- **NA62 4xI** – Upgrade of NA62, measuring K^+ -> $\pi^+\ \nu\ \bar{\nu}$ branching ratio
  - To operate with 1.2 x 10^{13} ppp on T10

- **SHADOWS** - Search for feebly-interacting particles.
  - Off-axis experiment (possible to operate in parallel to NA62-BD)

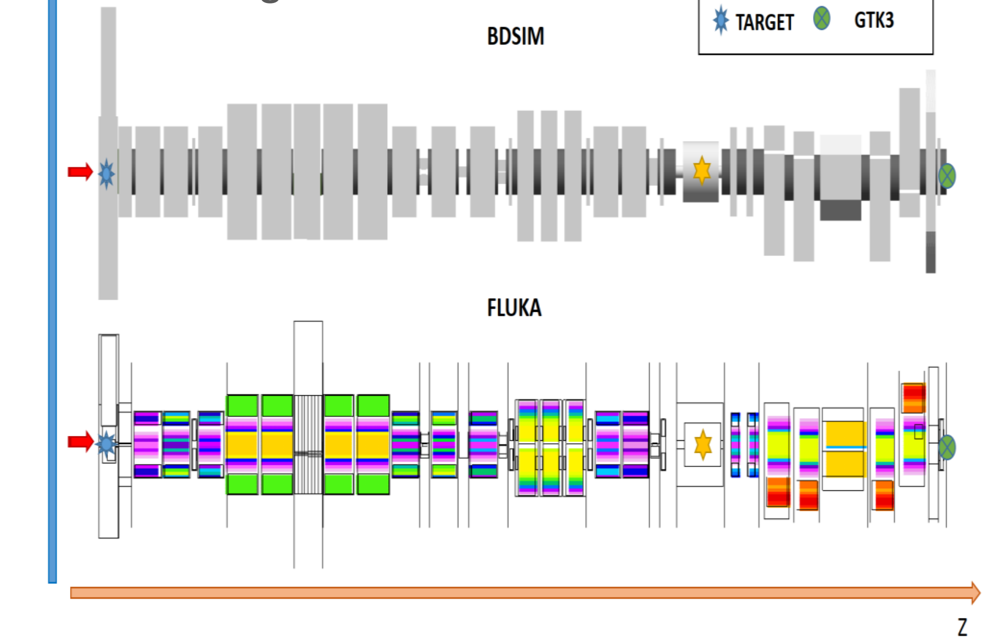
G.L. D'Alessandro
J. Bernhard
L Gatignon
A. Gerbershagen
M. van Dijk

K12 Simulations for NA62

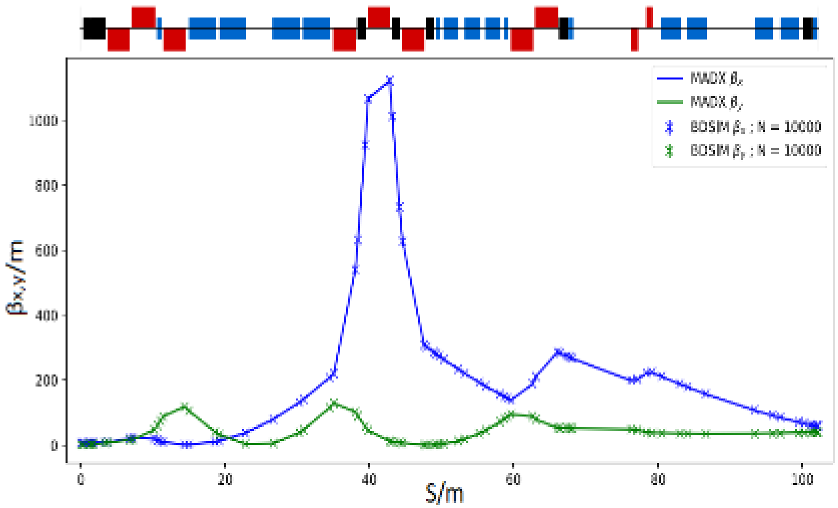
- Work in synergy for standard and beam dump mode
- Built high-detailed models for all magnets and components.
- To be used for studies of background reduction



Implemented field maps from Opera 2D



Optics comparison, BDSIM-MADX

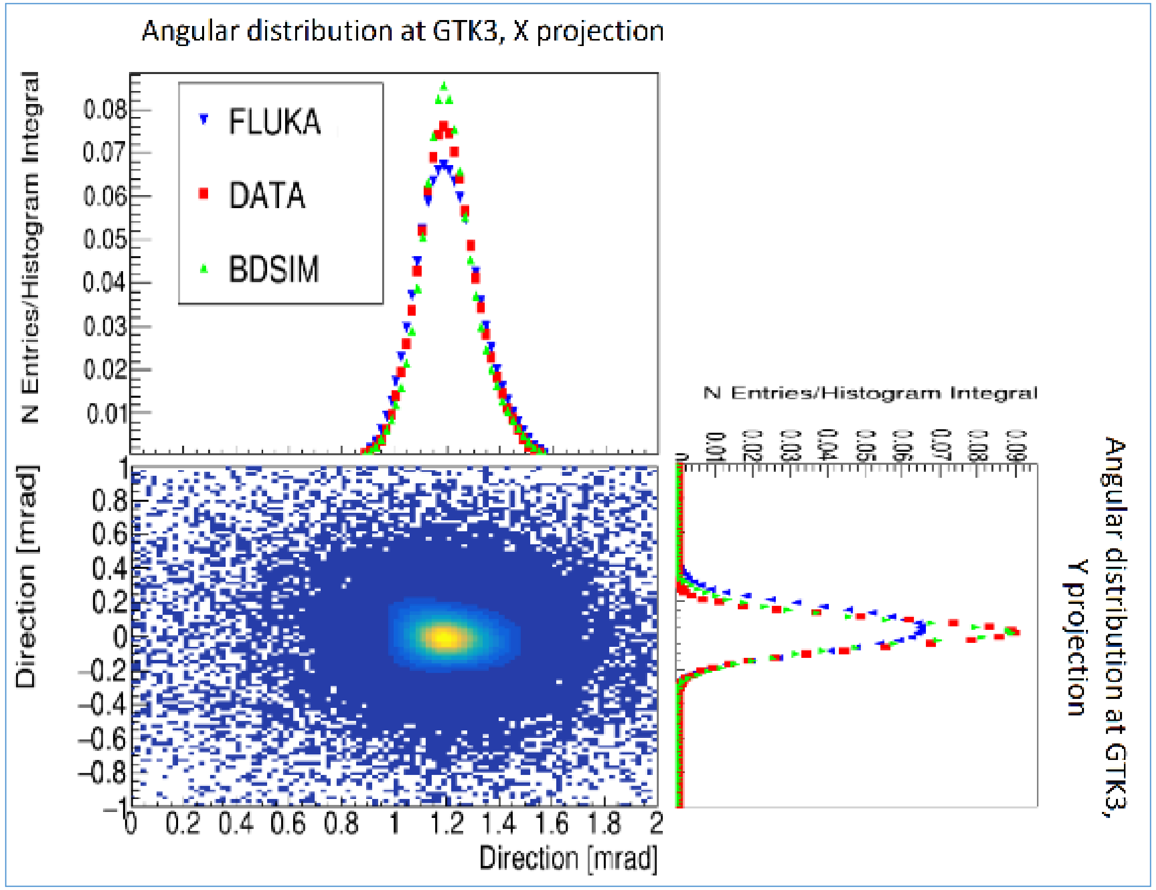


Beta function in x and y->Proportional to beam size in function of s (trajectory of ref. particle)

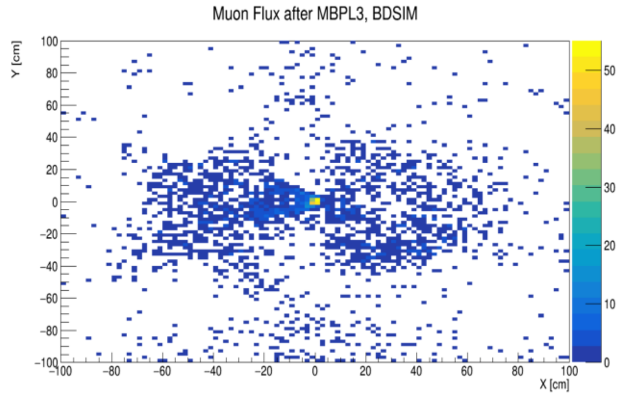
Beam Spot and Background at NA62

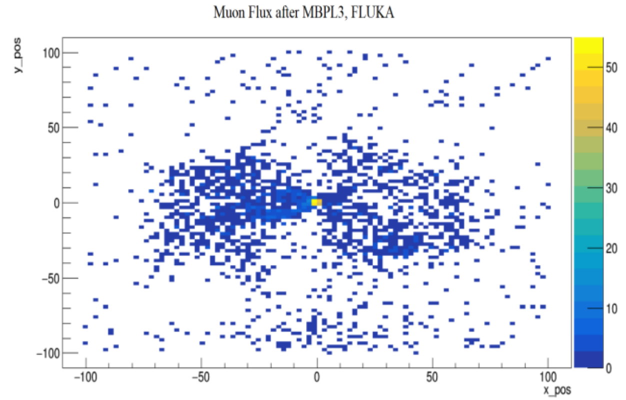
G.L. D'Alessandro
J. Bernhard
L Gatignon
A. Gerbershagen

Beam spot at GTK3



Muon flux after final sweeping dipole



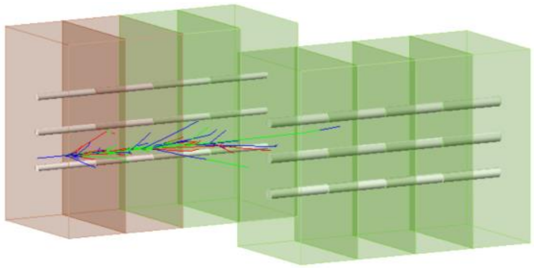


NA62-High Intensity and NA62-BD

F. Stummer
G.L. D'Alessandro
J. Bernhard
A. Gerbershagen

NA62-BD:

- New model with modified B-field configuration and with the T10 target removed.
- Future studies will involve background calculations and RP examination.
- TAX studies for higher beam intensities



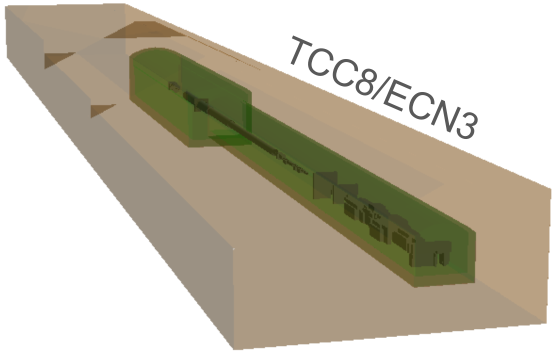
NA62-High-Intensity:

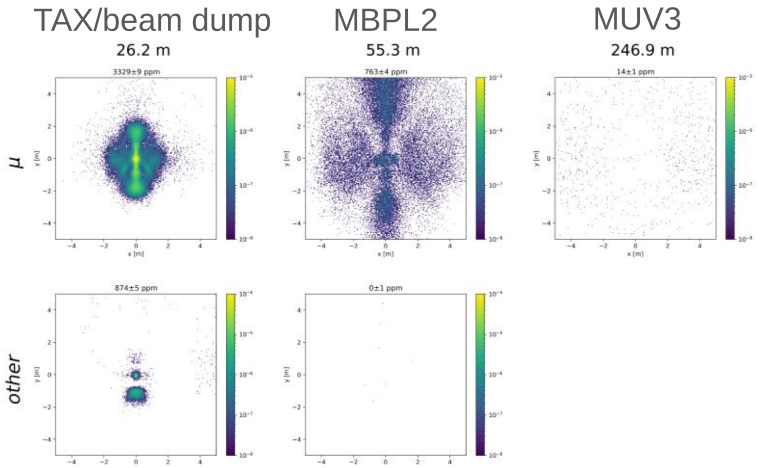
- Identical beam line configuration to standard operation NA62
- Run with higher intensity
  -> More protons on target
  -> More events can be observed
  -> Study TAX and target upgrades
- Currently studying the beam interaction with residual gas to estimate the number of background events
- Future
  -> Use model for radiation studies in FLUKA.

F. Stummer
G.L. D’Alessandro
J. Bernhard
A. Gerbershagen

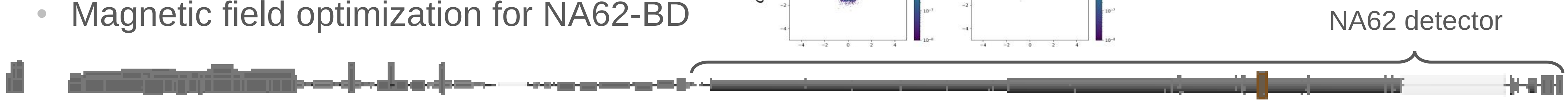
Studies for NA62-BD

- BDSIM model extended by
  - TCC8 tunnel and ECN3 cavern (enabling radiation studies)
  - NA62 detector geometry (impact of detector material included)
- Beam dump mode successfully implemented
- Study for the impact of the model improvements finished
  - Evaluation for NA62 (nominal) mode
  - Evaluation for NA62-BD mode
- Outlook for the near future:
  - Benchmarking the model to experimental data provided by the NA62 collaboration
  - Magnetic field optimization for NA62-BD





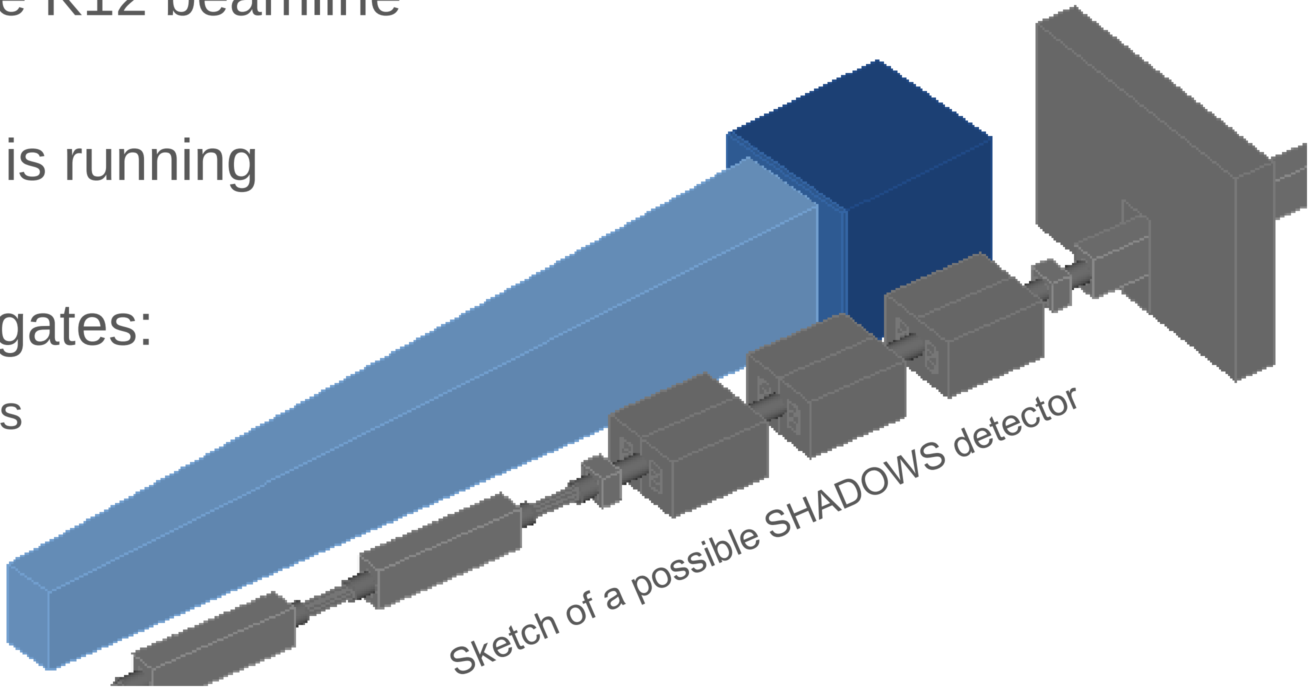
x-y-fluxes show: Only relevant background for NA62-BD will be muons



SHADOWS

F. Stummer
G.L. D'Alessandro
J. Bernhard
L. Gatignon
A. Gerbershagen

- SHADOWS aims at installing an off-axis detector for the search of feebly interacting particles
- The experiment will be presented by Gaia Lanfranchi
- Possible placement alongside the K12 beamline close to the beam dump
- It can take data whenever NA62 is running in beam dump mode
- Conventional Beams WG investigates:
  - BDSIM model building and simulations
  - Muon background studies
  - Impact on NA62 and NA62-BD

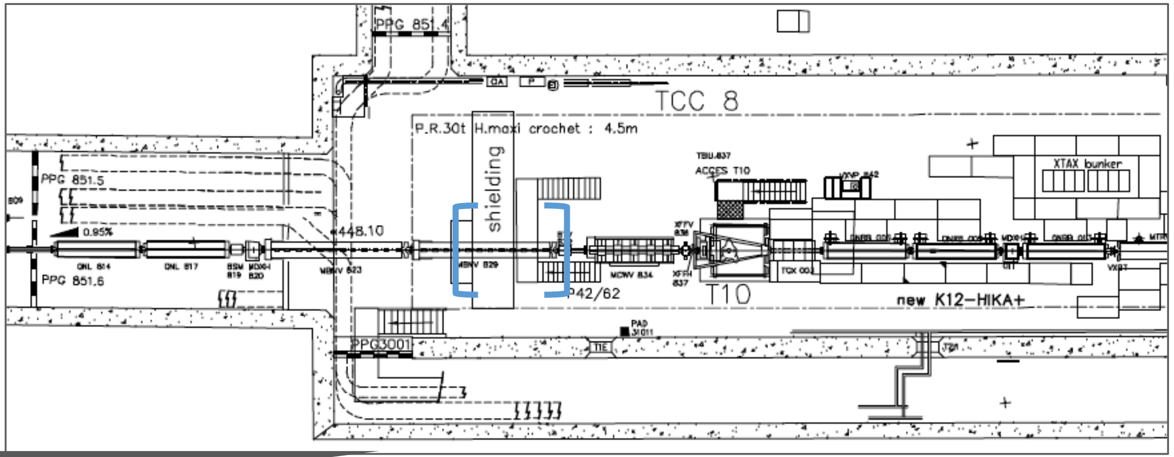


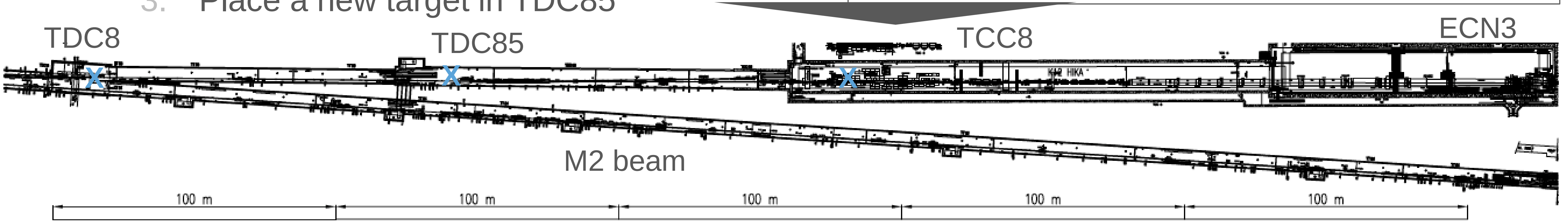
Sketch of a possible SHADOWS detector

C. Ahdida
G.L. D'Alessandro
J. Bernhard
M. van Dijk
H. Vincke

Target location possibilities for KLEVER

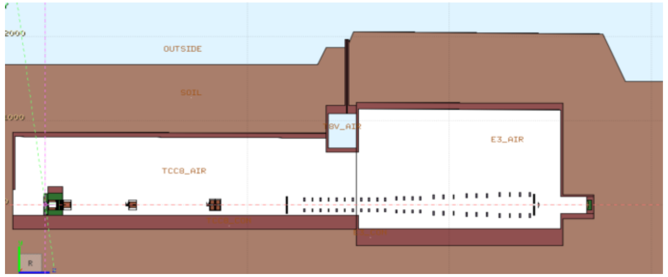
- $\Lambda \rightarrow \pi^0 + n$ decay background can be mitigated by prolonging the distance between target and detector
- Three different configurations are being investigated at the moment
  1. Keep the T10 target at its current location and either use a larger production angle or extend the ECN3 hall
  2. Place a new target in TDC8
  3. Place a new target in TDC85





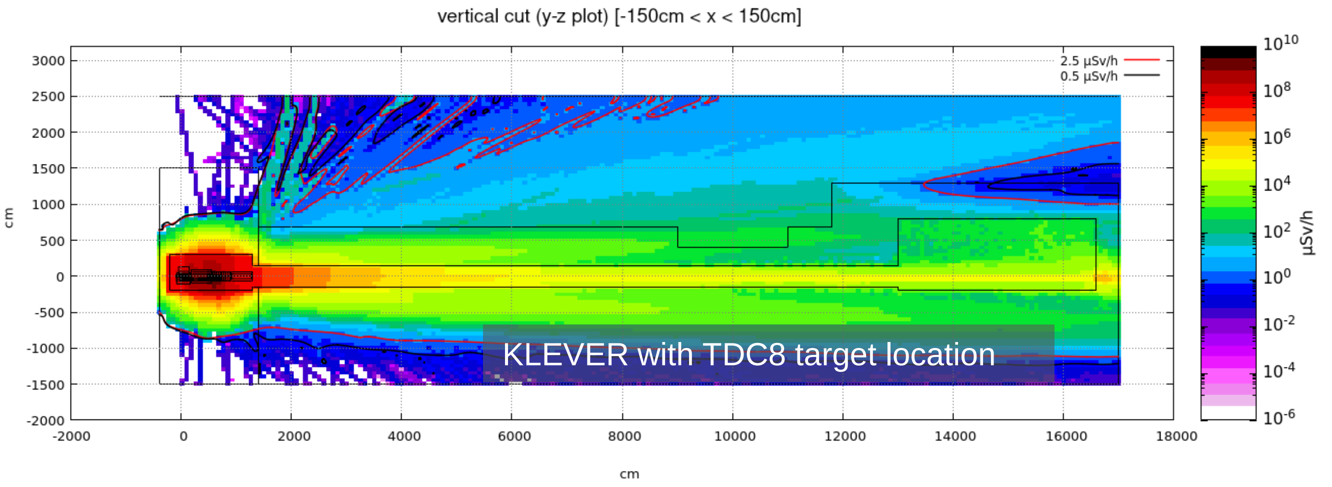
K12 FLUKA Model for KLEVER

C. Ahdida
G.L. D'Alessandro
J. Bernhard
M. van Dijk
H. Vincke



- RP-studies -> model used as input
- Model can be easily adapted to new configuration

- Results of RP studies for new target locations:
  - Muon rate is difficult to mitigate
  - E.g. for T10 target in TDC8 would require
    - Around target station: 7.5 m concrete
    - Around beam line: up to 10 m soil



=> Prolongation of ECN3 to be studied next

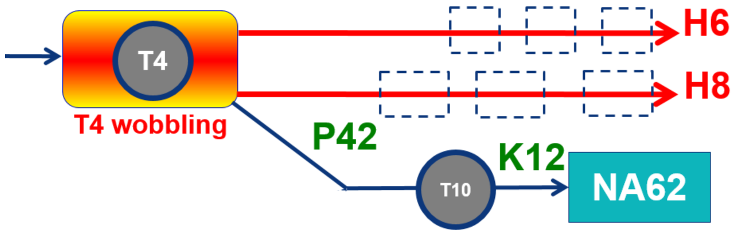
T4 Target By-Pass

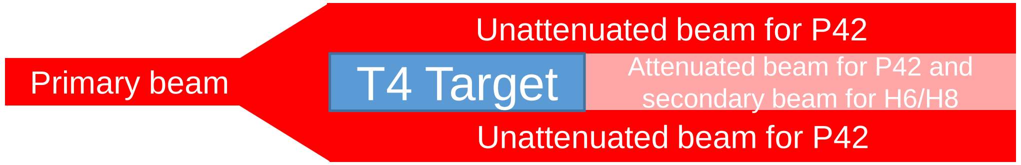
G.L. D'Alessandro
L. Gatignon
A. Gerbershagen
F. M. Velotti

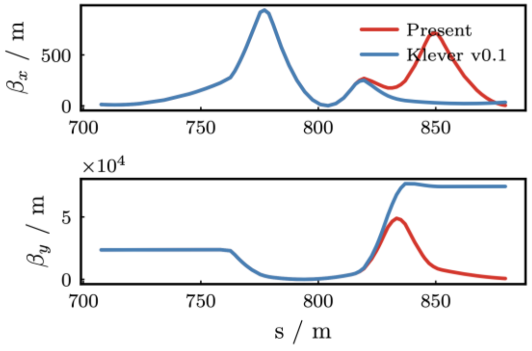
- T4 target
  - Is used to generate the secondary beam for H6 and H8
  - Attenuates the primary beam towards NA62/KLEVER
  - Is a thin Be plate, 2 mm in vertical extent with adjustable length (40-500 mm)
- Increase the vertical beam size, so that only 10 % of the beam intercepts the target

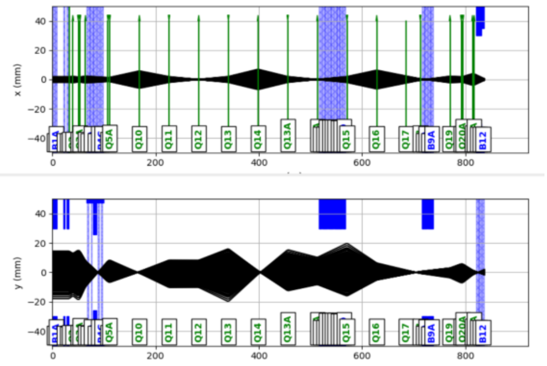
  ⇒Reduce unnecessary absorption in T4 target for T10 intensity increase

  ⇒Use a longer target head for better electron beams in H6 and H8





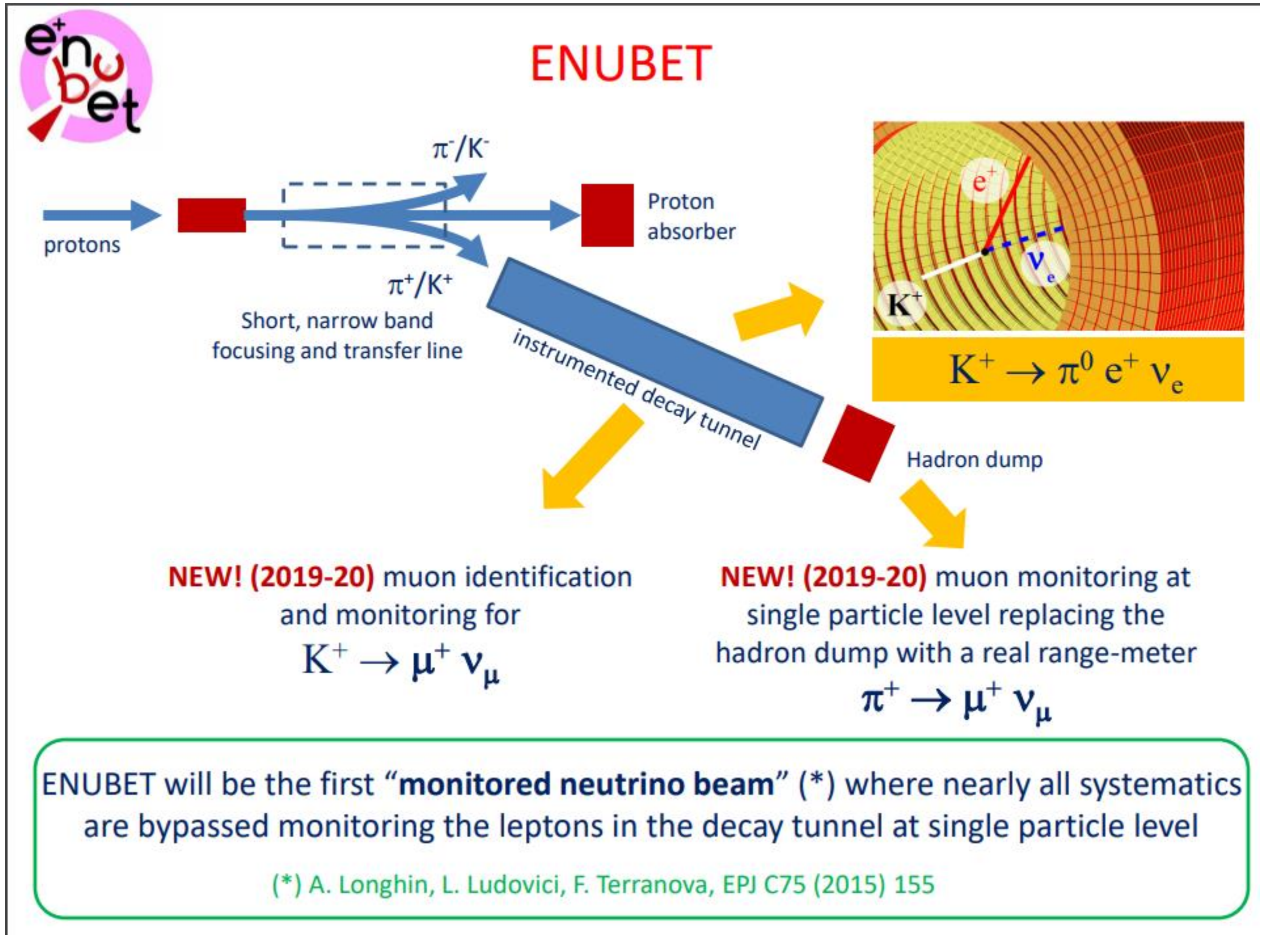




PBC Conventional Beams WG - Projects

ENUBET

E. G. Parozzi
N. Charitonidis



Work ongoing on a broad-momentum beam line (4-8.5 GeV/c), target optimization, collimation and background studies. Currently a generic design, which is location independent.

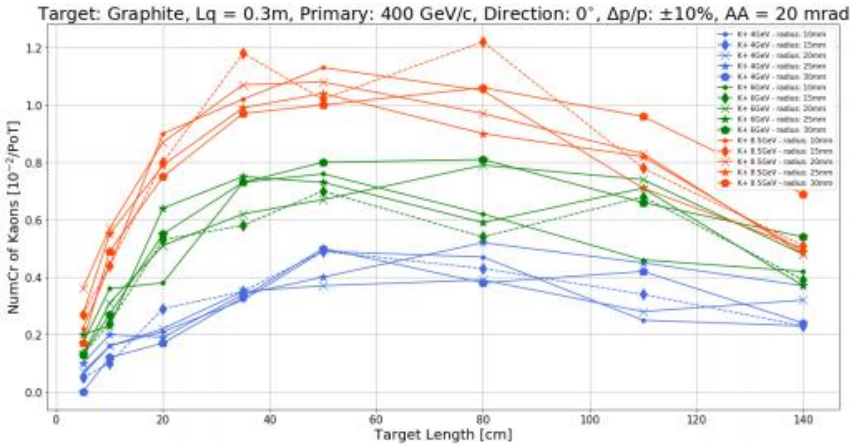
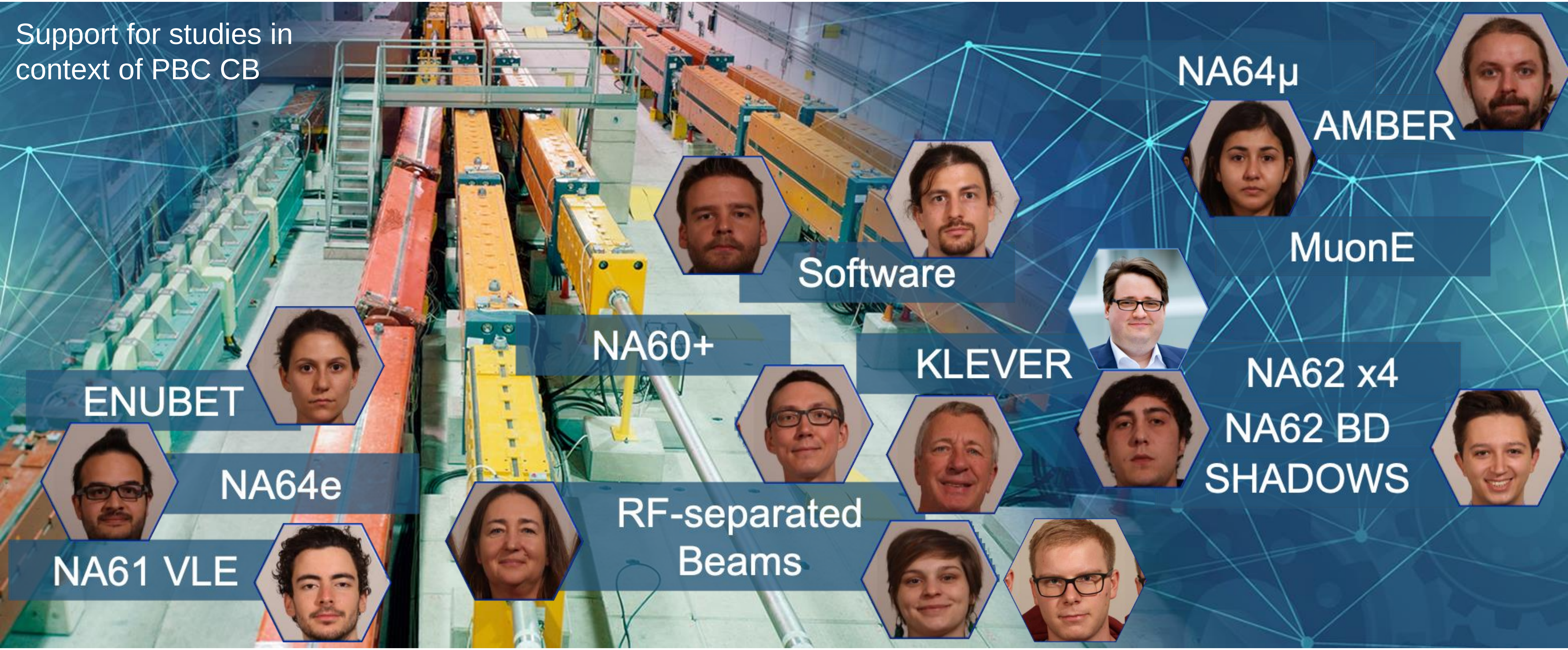


Figure 4. Kaon yields as a function of the graphite target length. The primary beam simulated is a 400 GeV/c proton beam. The figure of merit for this study is the number of kaons of given energy with 10% momentum bite that enters an ideal beamline with ±20 mrad angular acceptance (AA) in both planes, placed 30 cm after the target (Lq). The error bars are not plotted to ease the reading; statistical errors are negligible (1%), while the Monte-Carlo systematics amounts to ~20%.

Appl. Sci. **2021**, *11*(4), 1644

PBC CB Study Team of BE-EA-LE



Thank you for your attention!