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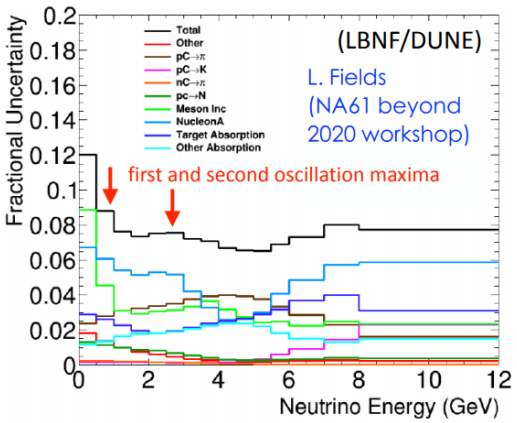
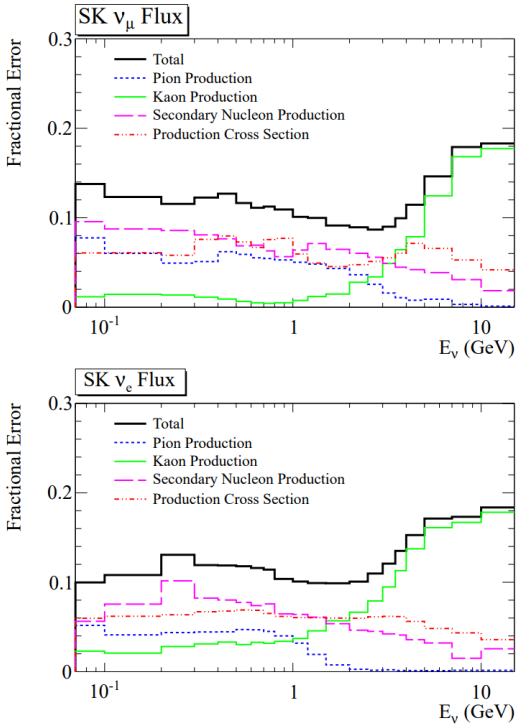
Designing a Novel Low-Energy Beamline for NA61/SHINE

Need for a Low-Energy Beamline

As there is a lack of particle production data in the 1 – 13 GeV/c momentum range, results obtained by NA61/SHINE using this beamline could prove to be of great use in reducing the systematic uncertainties of many experiments such as [1]:

- T2K
- DUNE
- Hyper-K
- JSNS2
- COHERENT





[1] "NA61/SHINE at Low Energy" workshop, December 2020

Plot on left from: L. Fields, Overview and hadron production for LBNF/DUNE, "NA61 beyond 2020" workshop, July 2017

Plots on right from: T2K Collaboration, K. Abe et al., "T2K neutrino flux prediction", in "Phys. Rev. D", vol. 87, p. 012001 (2013)

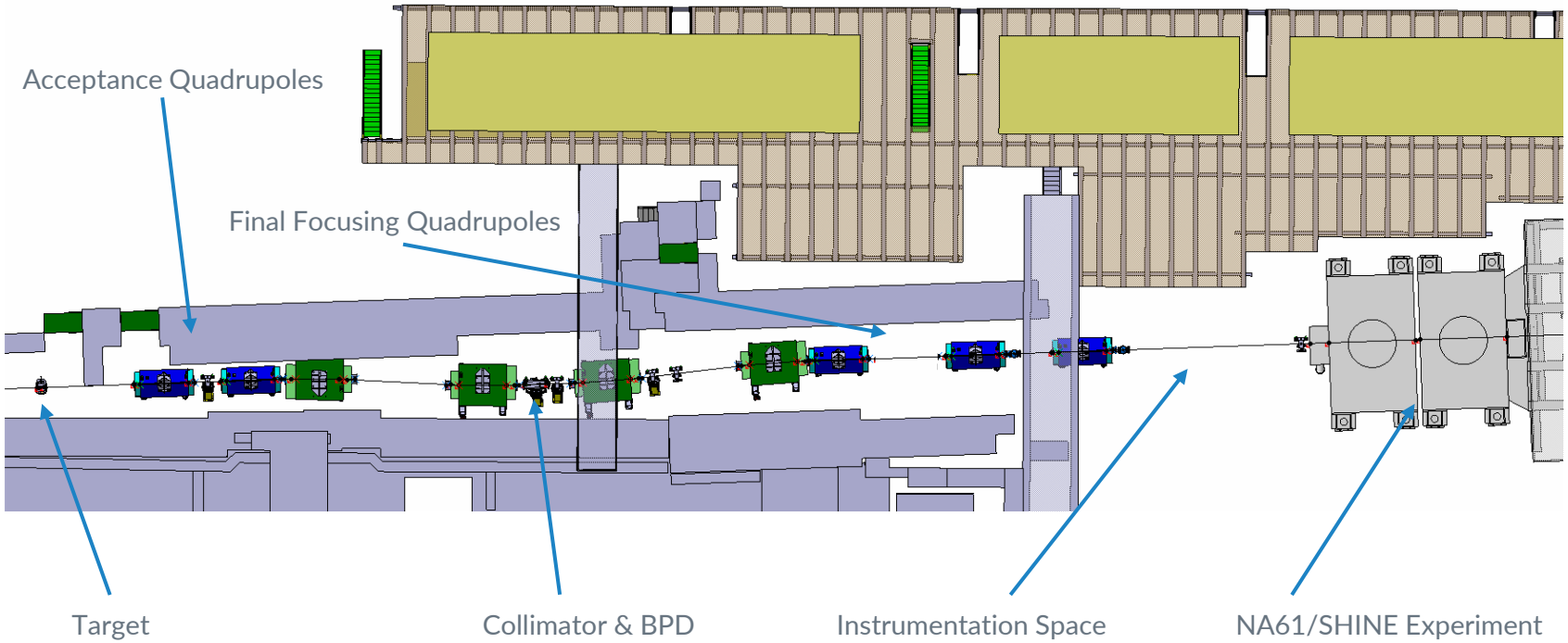
Need for a Low-Energy Beamline

CERN's North Area beam facilities offer a unique place for test-beams and fixed target experiments, however low-energy particles are extremely challenging:

- SHINE's H2 beamline is designed for momenta greater than 300 GeV/c
- Limitations on the magnets, the power supplies, and the acceptance
- Length is a limiting factor as beamline is too long for low energy particles and many of the pions and kaons decay before they reach the experiments (H2 length to NA61 is 600 m)

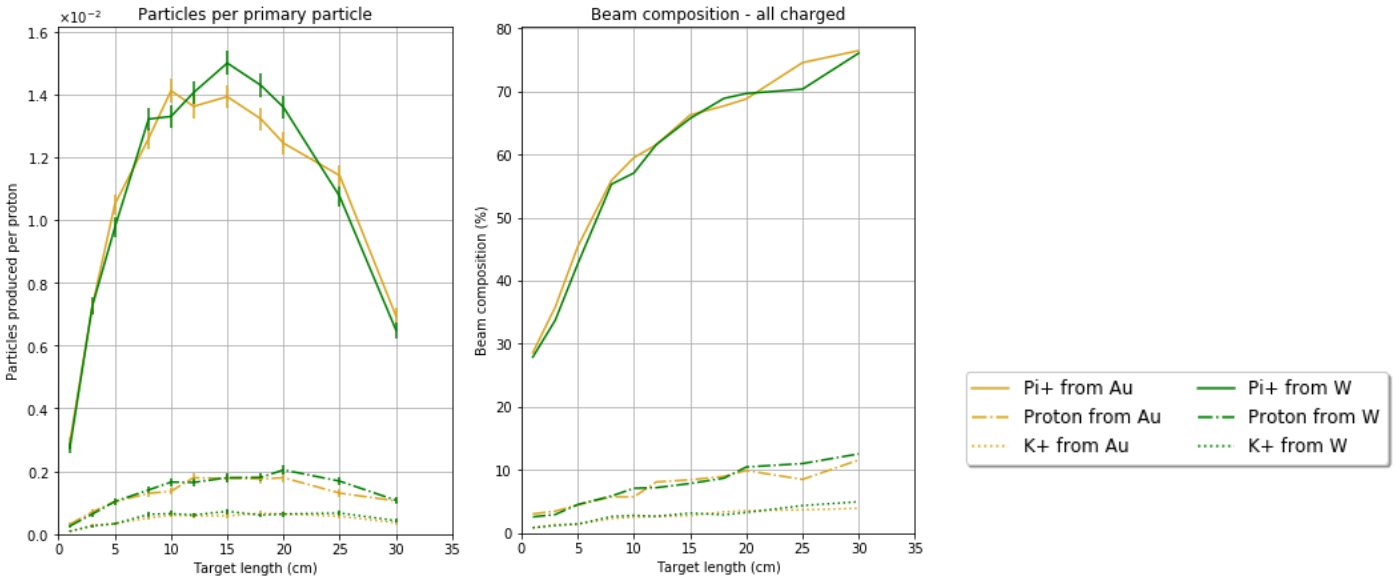
For these reasons, a new design has been studied, tailor-made for lower energy particles

The new secondary beamline proposal



Here we can see how the beamline will fit in the North Area

Optimisation: target studies



- Simulated many different targets geometries and materials, both high and low-Z
- Found that there was a trade-off between rate and beam purity
- There is no target which is optimal for the whole energy range for each particle

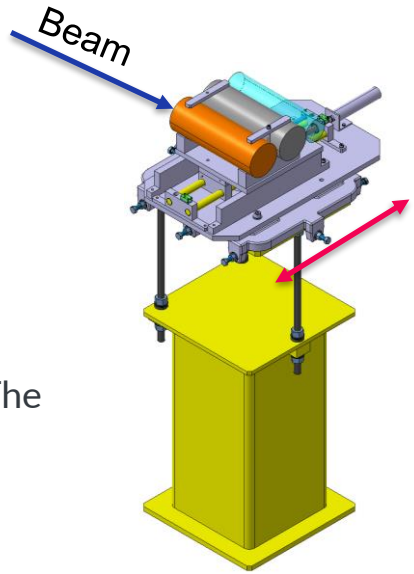
Optimisation: target studies

A multi target station is envisaged for the new beam line

Our study of the targets has found three possible targets for the production of secondary hadrons. These were:

- For **high yields** : 20 cm W target with a 400 GeV primary
- For **balanced** : 30 cm W target with a 400 GeV primary
- For **high hadron compositions** : 15 cm W target with a 70 GeV primary

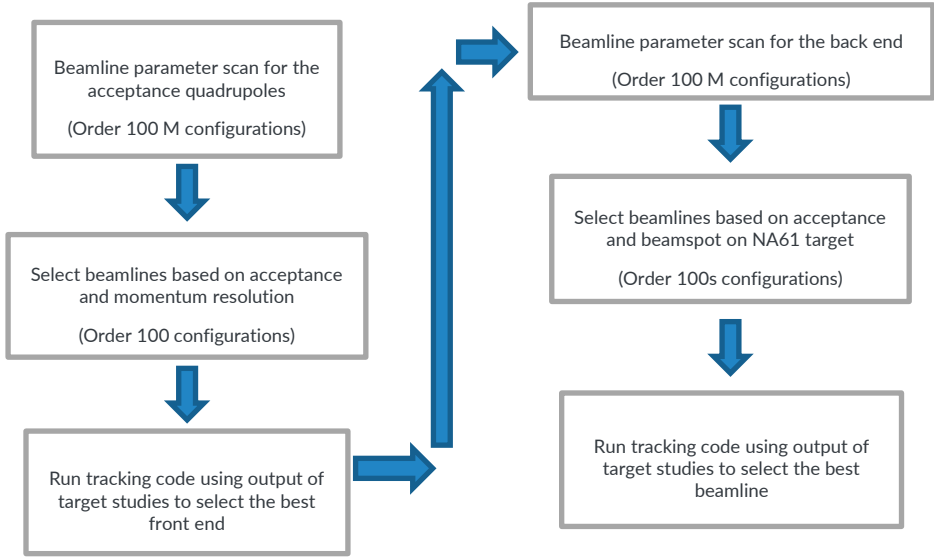
They all provided different types of beams, focusing on different properties. The implementation would be trivial, remote exchange of target very easy



Beamline optimisation

The beamline must:

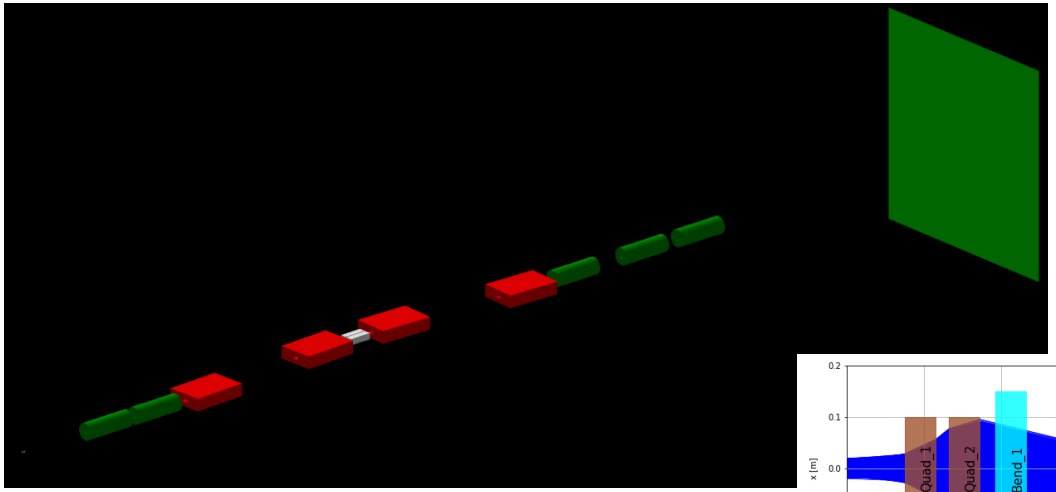
- Have a large acceptance, for a sufficient rate
- Be short, to minimise particle decays
- Have a good momentum resolution
- Have a small spot size at the NA61 target
- Not be too contaminated by backgrounds



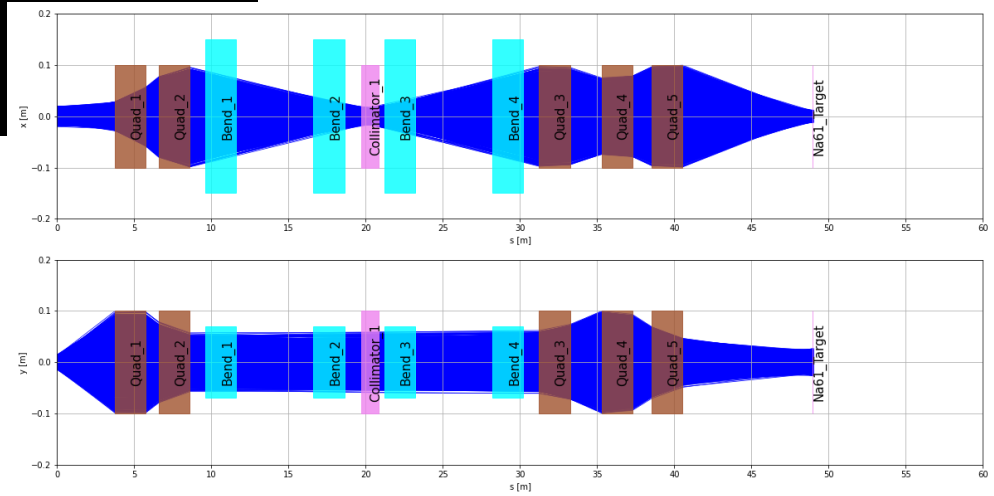
A full parameter scan

- Our approach to design this beamline has been to scan the parameter space and generate millions of beamline configurations, their acceptance and spot size at the end of the line.
- Using this information it is then possible to select the beamline that best matches the experiment's requirements, as every solution should be there

Optimisation: the beamline optics



The optics have been designed with a wholly new optimisation scheme, custom made to meet the demands of NA61/SHINE



Focused on optimising the:

- Acceptance of the beamline
- Momentum resolution
- Small beamspot at the end of the line

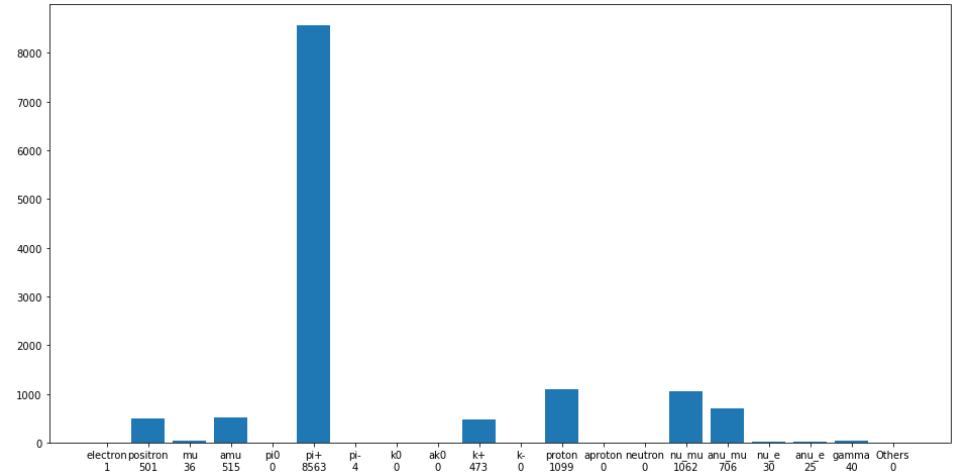
Particle rates

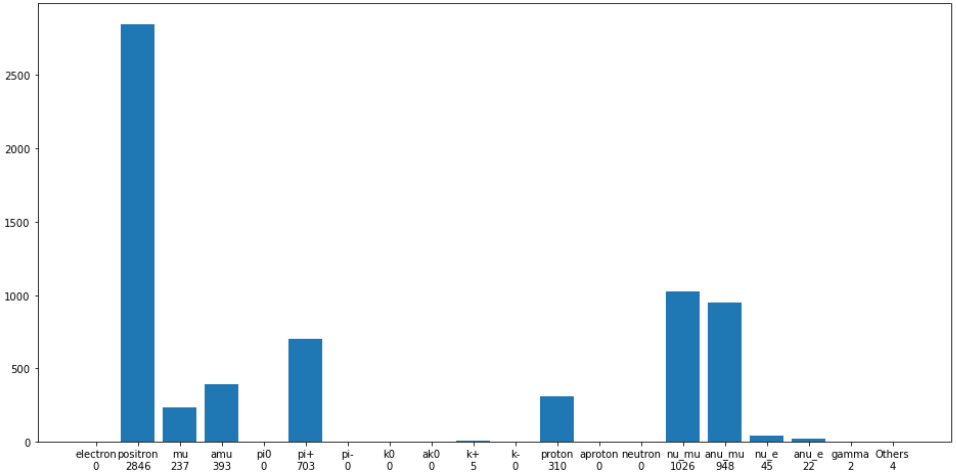
These rates are for 1E6 400 GeV/c primary protons extracted from the SPS. We can expect around 3000 such spills per day

The top plot shows the particle rates at 13 GeV/c, bottom is at 2 GeV/c

Overall, we can expect around 2.5E7 pions per day at 13 GeV/c and 2.1E6 at 2 GeV/c

A normal run is expected to be a few weeks per year





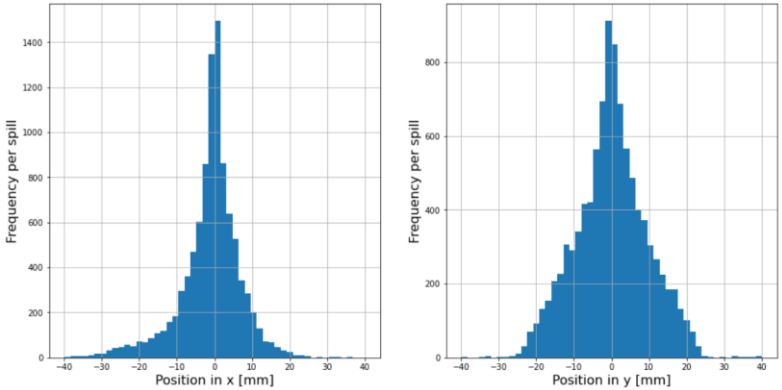
Spotsize and momentum resolution

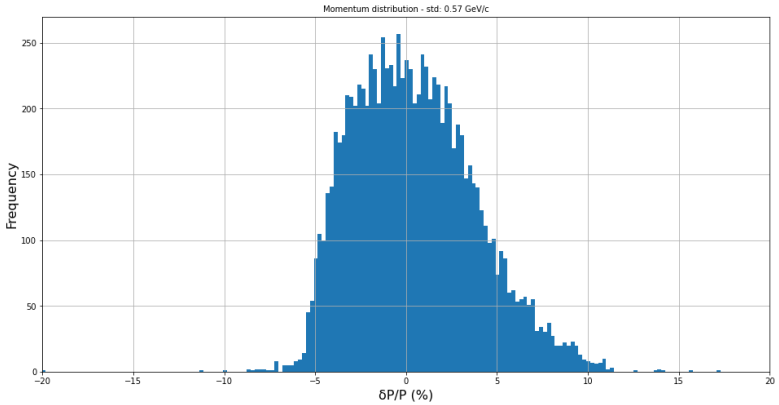
It is important to keep the size of the beam at the NA61/SHINE target as small as possible to maximise the number of interactions and have a good momentum resolution

The beamline can achieve at 13 GeV/c

- Std – x = 9.7 mm
- Std – y = 12.1 mm
- 4% momentum resolution – can go down to 1% (1 sigma)

Similar results can be obtained at other energies



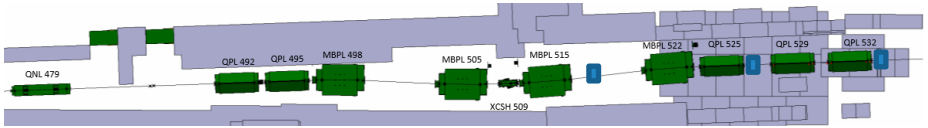


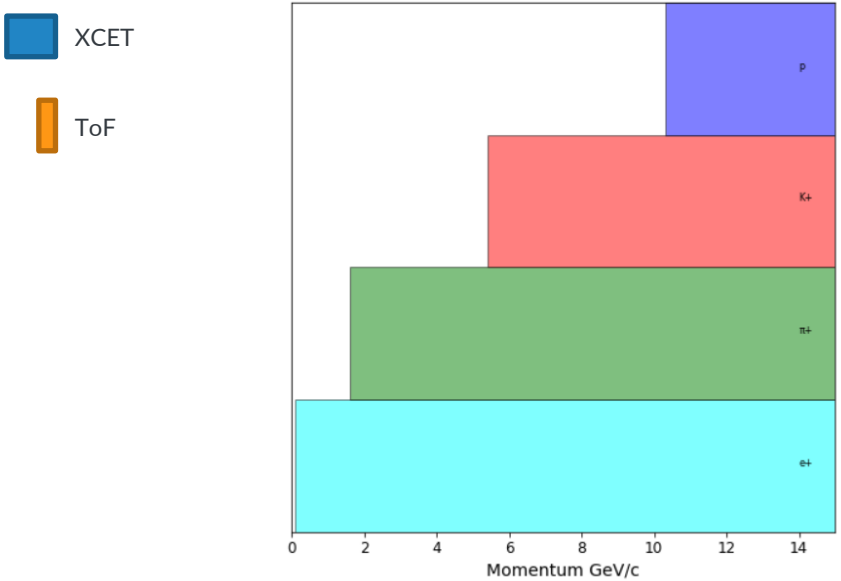
Instrumentation proposal

Above 5 GeV/c:

Use 3 XCET (starting at 15 bar CO2) to identify electrons, pions and kaons

With scintillator for total number of particles, all species can be identified





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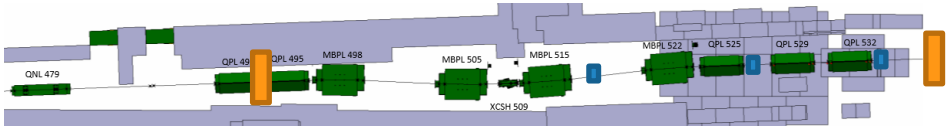
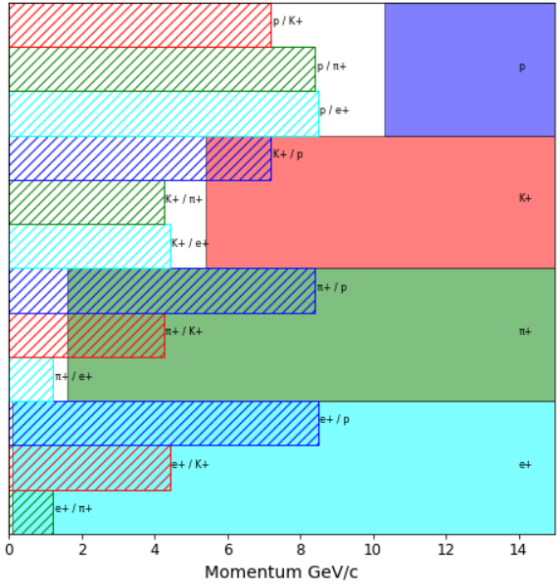
- Use ToF (40 meters apart) to identify the protons
- Use XCET 1 to identify electrons (7 bar He)
- After 3 GeV/c use XCET 2 (at 7 bar CO2) to identify pions. At lower energies ToF will suffice starting



XCET

ToF



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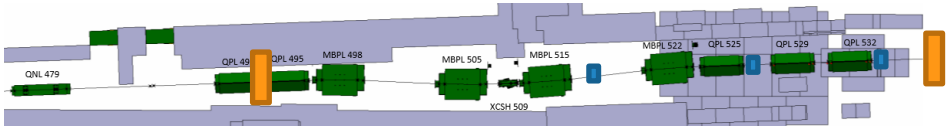
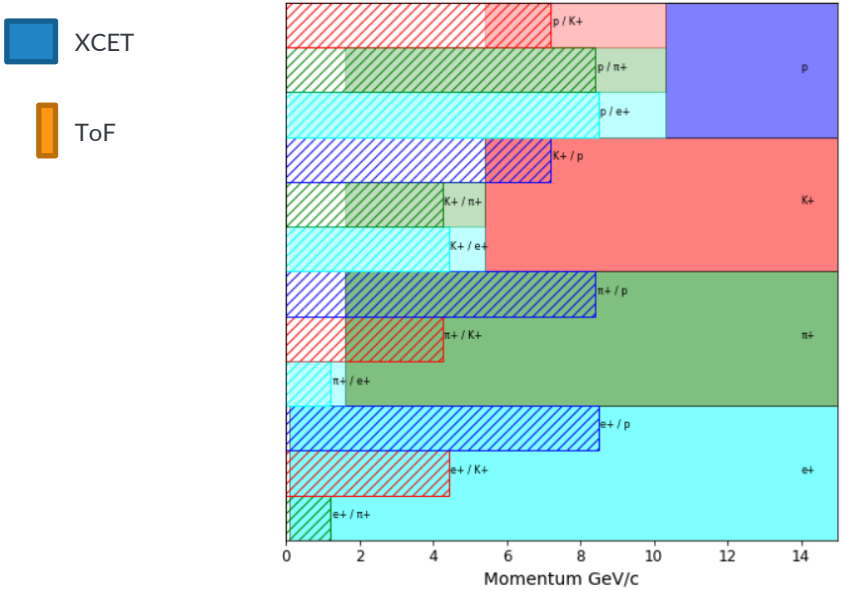
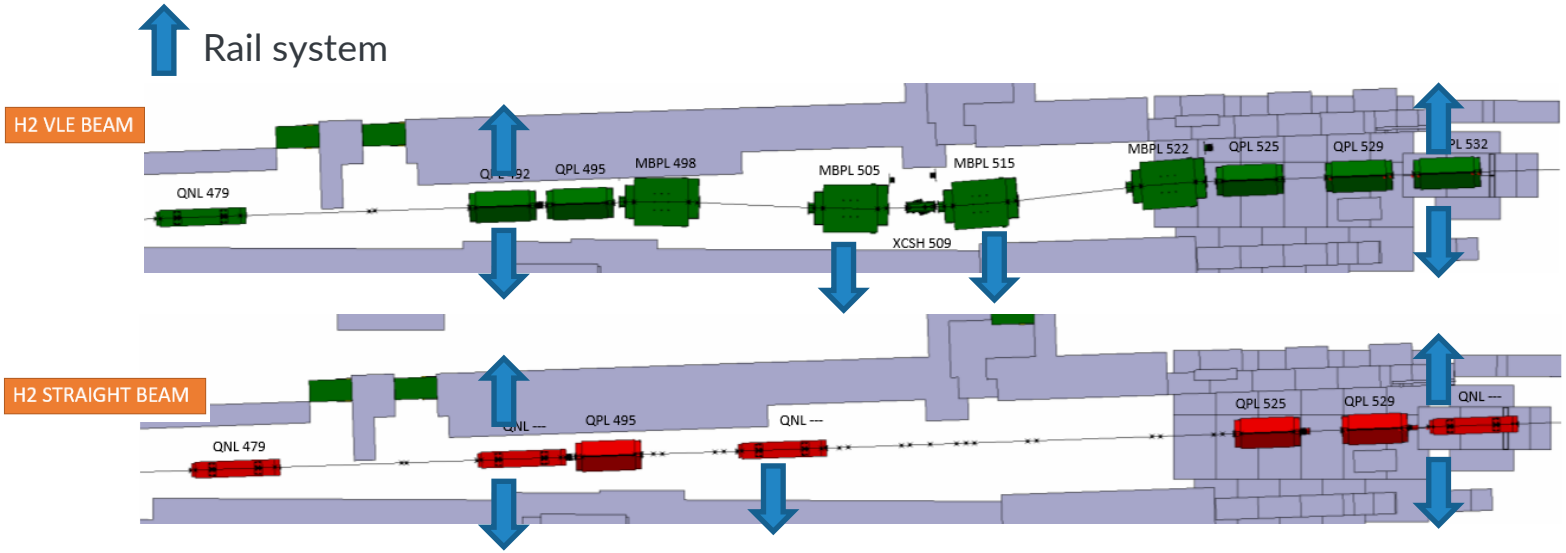




Installation in the North Area

To minimise the switch time between the low-energy and the standard H2 beamline a system using rails is currently being envisioned

Some modifications to the shielding are envisioned but the North Area's flexibility allows this to happen easily



Where does the project stand

Started working on this beamline in 2020 and since then we have

- Completed the design of the beamline
- Finalising the selection on the instrumentation
- Have brought this to CERN's SPSC in October 2021 and addressed the follow up in June 2022
- Aiming for this beamline to be installed in YETS 2023
- Are now preparing the Engineering Change Request for this beamline, the final step before changes are implemented in the experimental areas

> "The SPSC recognizes the scientific value of the improvements that the low energy beam line could bring to the knowledge of the neutrino cross sections and recommends that the corresponding technical feasibility be studied in detail."

Conclusion

A new low-energy beamline has been proposed and is in an advanced stage of development:

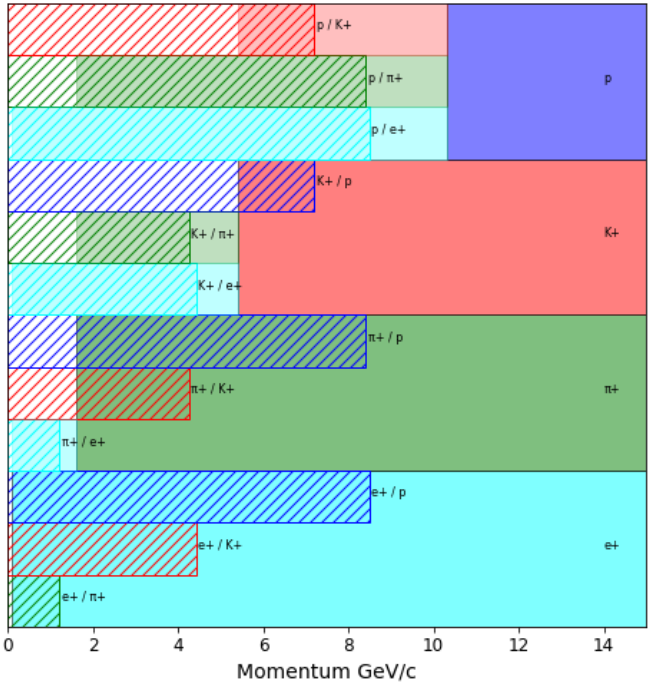
- Optimisation of targets and beamline optics completed
- Meeting all requirements set out by NA61/SHINE
- Studied the implementation of the beamline with the technicians and developed a system to implement the beamline
- Minimising the impact on the existing experiments
- Developed a scheme for the instrumentation to enable particle-by-particle identification
- Have the support of the SPSC and will move to attempt to build the beamline in 2023

Thank you for your attention

Any questions?

Additional slides

General information on instrumentation

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Hatched regions are showing ToF discrimination,
boxes where particles can be seen with Threshold Cherenkov Counter

Parameters Threshold Cherenkov Counter:
Gas: N2
Max pressure: 15.0 bar
A constant: 50.0 cm^-1
Length: 200.0 cm
Minimum number of photoelectrons: 5

Parameters Time of Flight:
Length: 40 m
Resolution: 200.0 ps
```

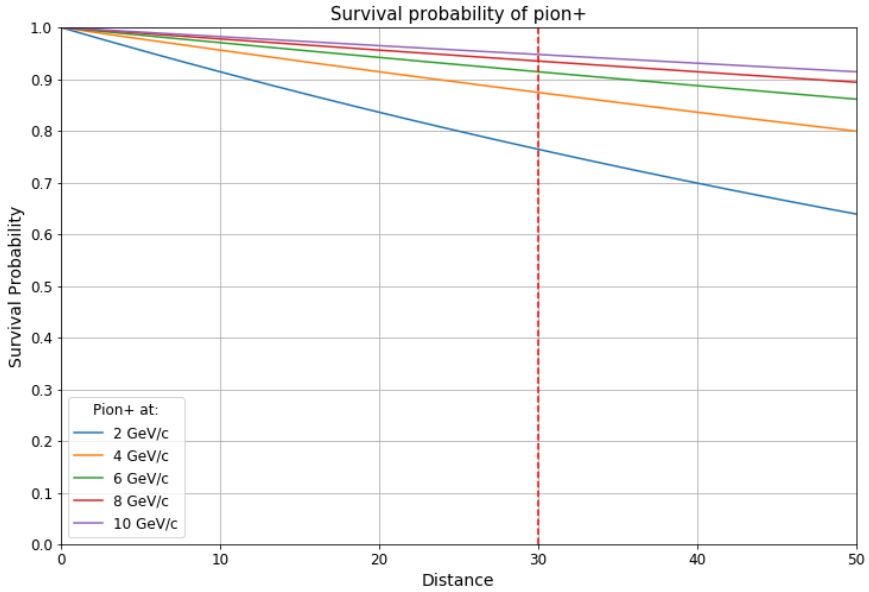
Library of targets and Analysis

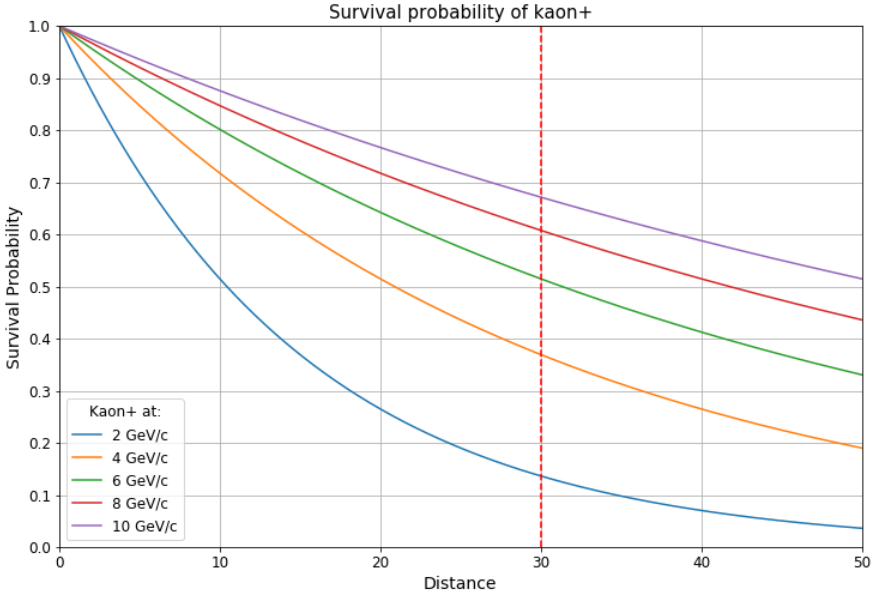
Primary protons with momenta of 40, 70,150, 240, 400 GeV/c impinging on:

- **Beryllium, Carbon, Graphite** and **Inconel** cylindrical targets (low Z)
  - With a length of 5, 10, 20, 35, 50, 80, 110, 140 cm
  - A radius of 10, 15, 20, 25, 30 mm
- **Tungsten, Gold** and **Copper** cylindrical targets (high Z)
  - With a length of 1, 3, 5, 8, 10, 12, 15, 18, 20, 25, 30 cm
  - A radius of 10, 15, 20, 25, 30 mm

All simulations with 100 000 primary protons each. In the analysis we have assumed a ±10% momentum acceptance (Δp/p) and a ±20 mrad angular acceptance ($\arctan(\frac{p_x}{p_z})$) for the low energy beam line. All plots shown in the body of the presentation also take into consideration particle decay, assuming a length of 30 m

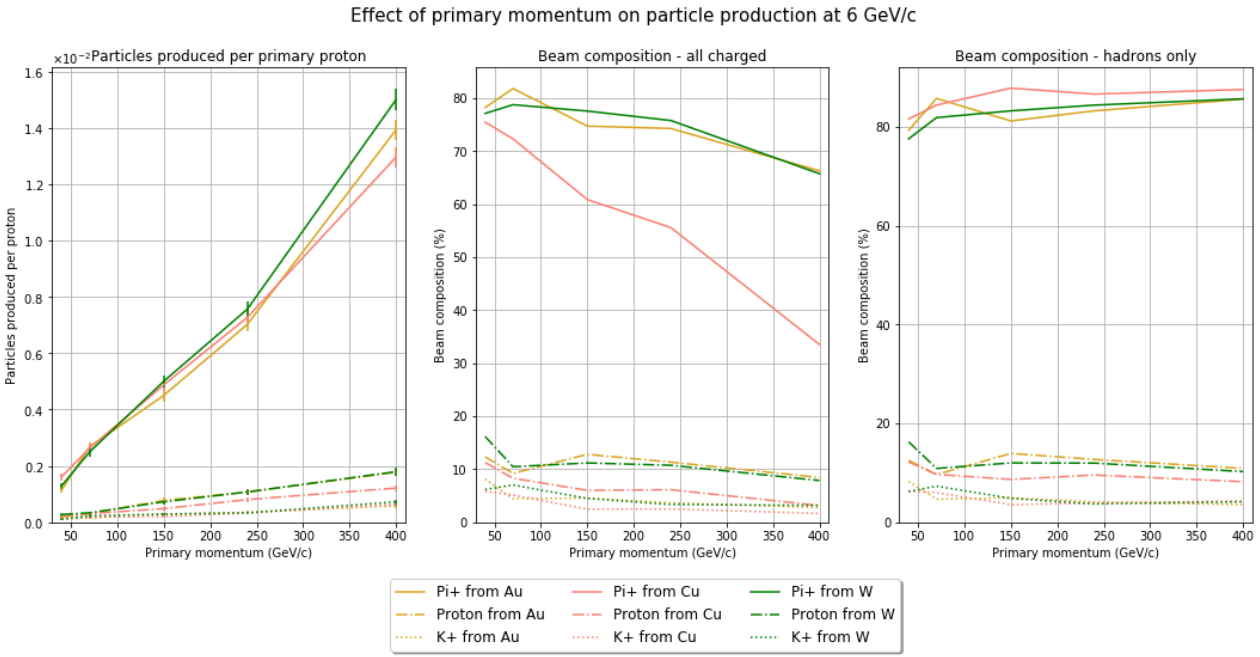
Expected survival in beamline





- With a 30 meter beamline we expect a survival of above 75% for pions at all energies
- For Kaons, we expect a survival of 13.6% @ 2 GeV/c, 36.9% @ 4 GeV/c, 51.4% @ 6 GeV/c

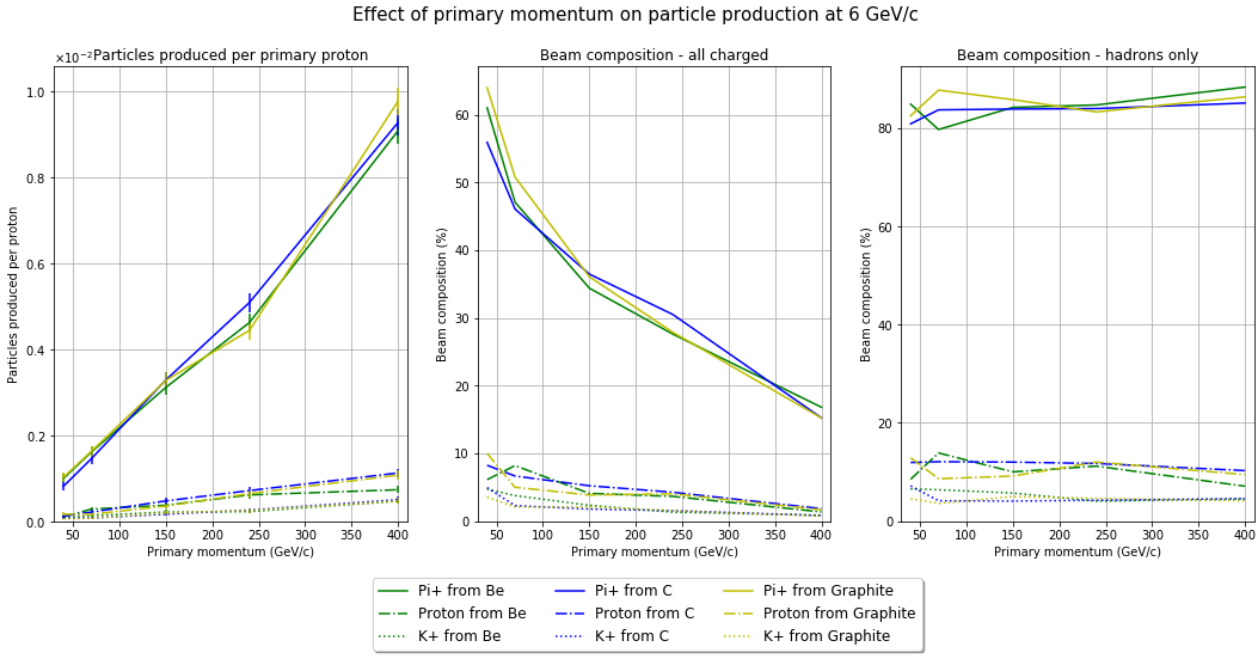
Effects of primary momentum (High Z)



Primary momentum

- Considering **a realistic** beam on 15 cm long targets
- Trade off between high particle yields and beam composition
- Electron suppression may be necessary

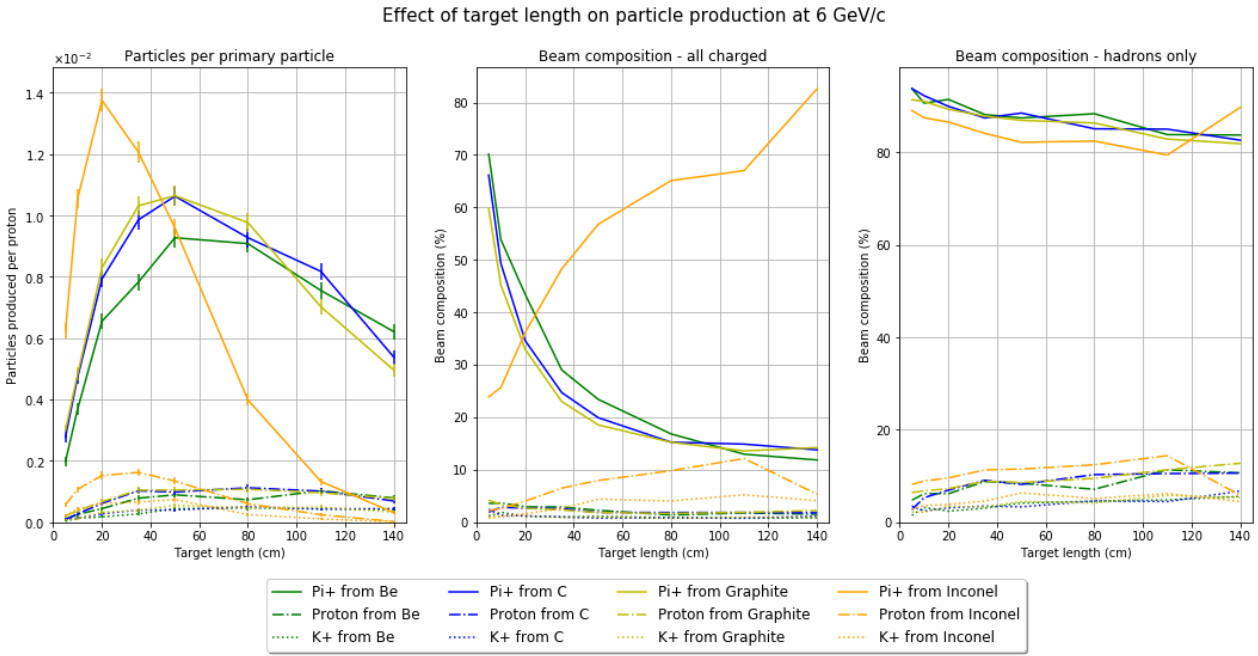
Effects of primary momentum (Low Z)



Primary momentum

- Considering **a realistic** beam on 80 cm long targets
- Trade off between high particle yields and beam composition
- Electron suppression may be necessary

Effects of length (Low Z)



Target Length

- Considering **a realistic** beam at 400 GeV/c
- Trade off between high particle yields and beam composition
- Electron suppression may be necessary