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Capabilities of a future Low-Energy Beamline for NA61/SHINE

Introduction

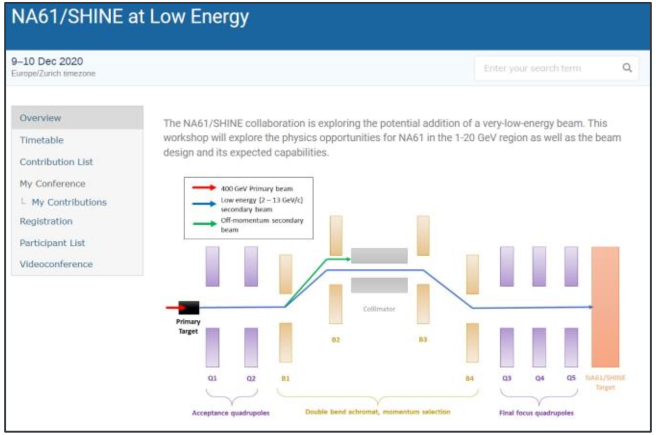
Over the past three years there has been a push to design a new low-energy beamline to enable measurements of hadrons in the 1-13 GeV/c momentum range

In this talk:

- Why is this beamline necessary
- Discussion of the performance of this beamline
- Instrumentation equipping the beamline
- Status of implementation of the beamline

Will not discuss:

- Physics case for beamline **(Yoshikazu's talk)**
- How the beamline was designed



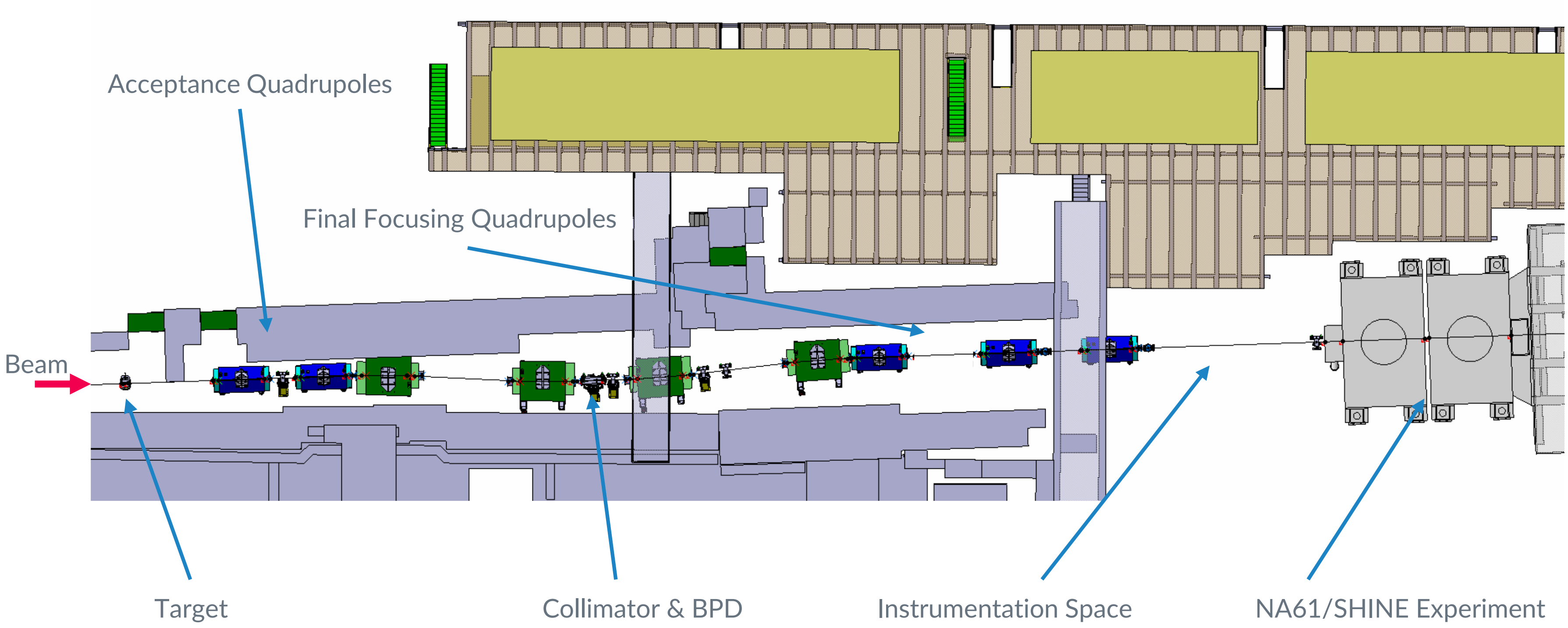
Need for a Low-Energy Beamline

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

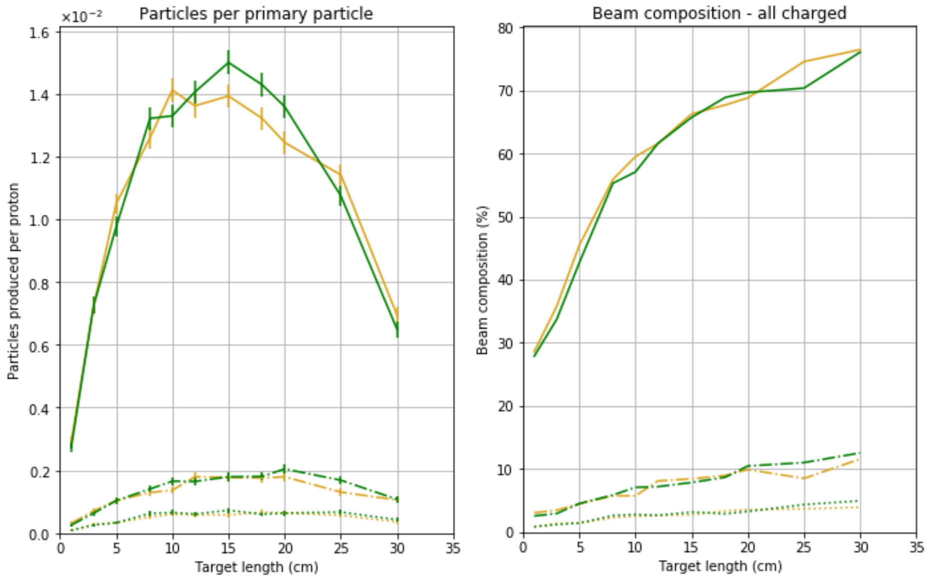
- The H2 beamline was originally designed for momenta greater than 300 GeV/c
- Limitations on the magnets, the power supplies, and the acceptance
- Length is a limiting factor as beamline is too long for low energy particles and many of the pions and kaons decay before they reach the experiments (H2 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



Target optimisation



Attempting to maximise the number of pions, protons and kaons while minimising number of positrons

- 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

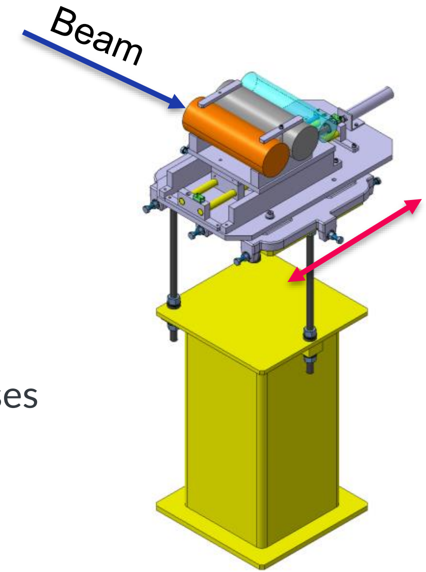
Selection of targets

Since the targets behaved so differently three different targets have been chosen.

- 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

These can be placed on a target switching station which can be operated remotely and switched as desired

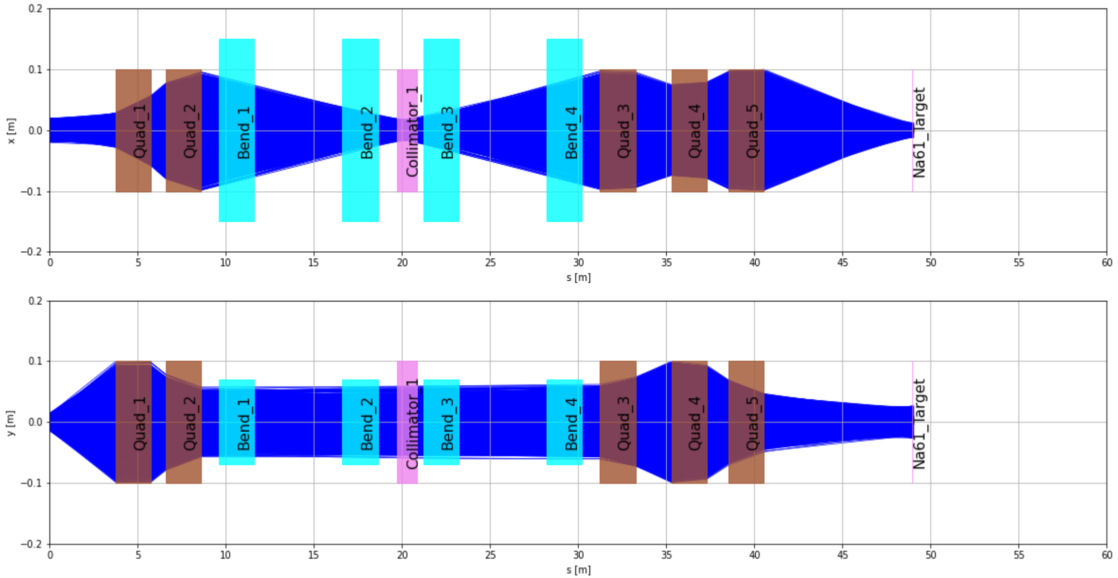
Possible to optimise for **other** ideal parameters e.g. one target which maximises rate of low-energy protons



The beamline's optics

Optics are comprised of:

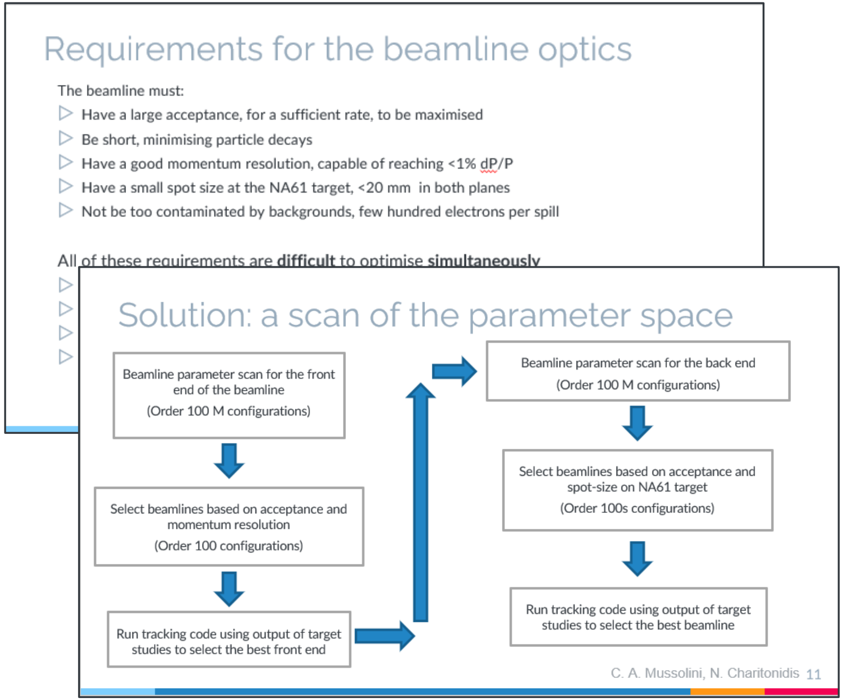
- A front end doublet to maximise the acceptance of secondary particles
- 4-Bend achromat to remove off momentum particles
- A triplet to focus the beam onto the NA61/SHINE target



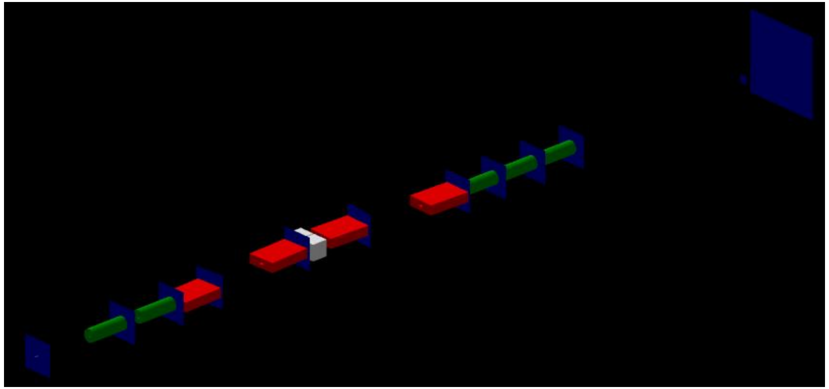
The beamline's optics

The optimisation was a challenging process trying to simultaneously meet many different design requirements

- More here: [NA61/SHINE Collaboration Meeting May 2022]



Extensive simulations of the beamline have been performed in G4Beamline



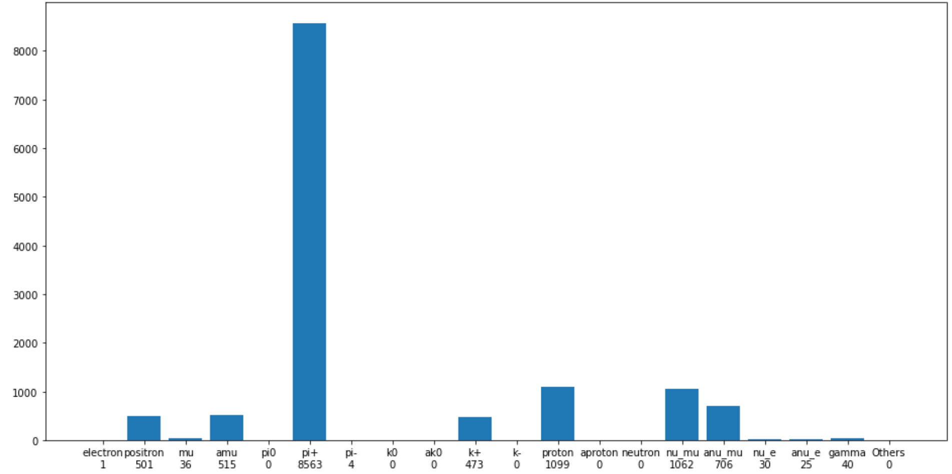
Particle rates

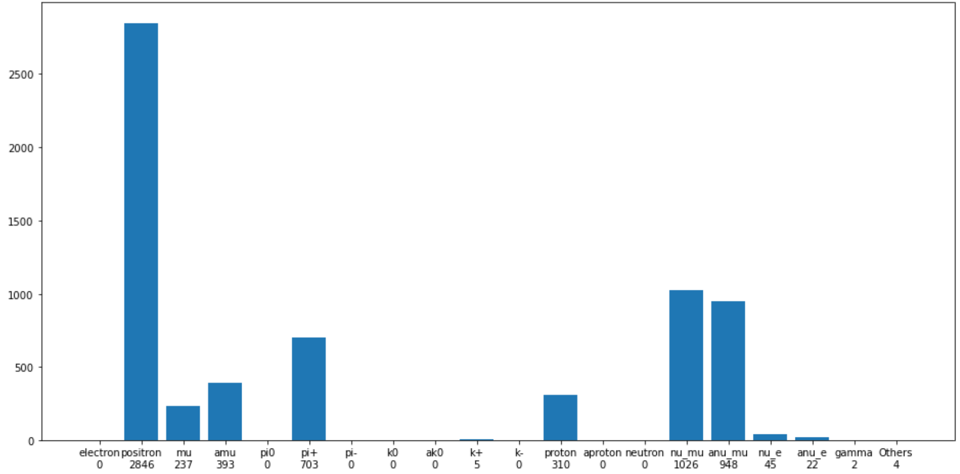
With 1E6 400 GeV/c primary protons extracted from the SPS, expecting around 3000 such spills per day

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

Muons will **not** be a significant background, only 0.0077 per 50 us detection window of NA61/SHINE

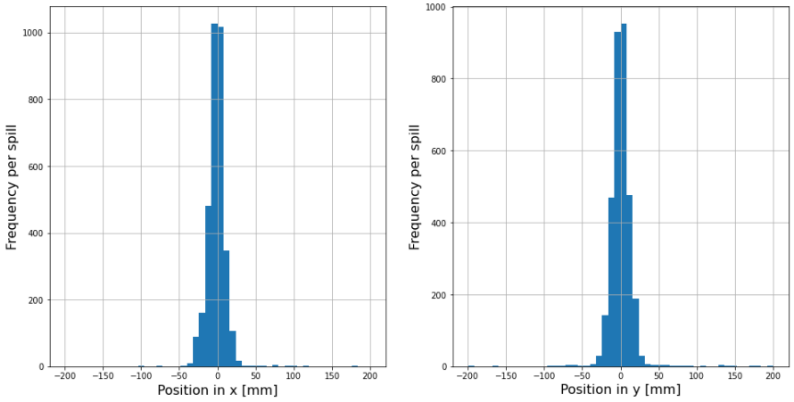




Beam-spot and momentum resolution

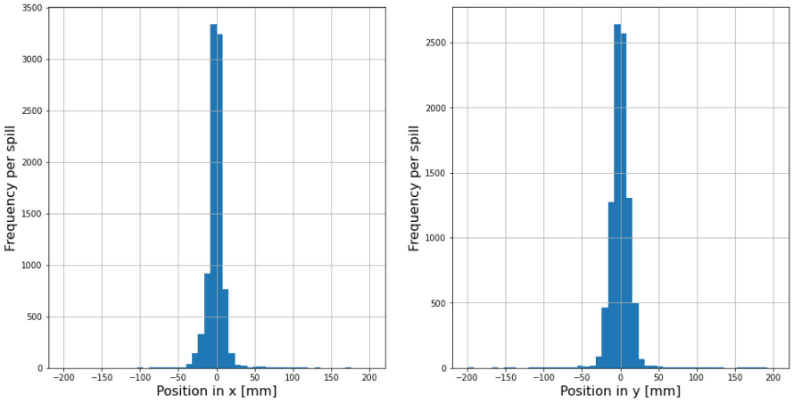
Aim: obtain beam-spot smaller than 20 mm in both planes, reach 1% momentum resolution, full particle tagging

2 GeV/c



Standard deviation in x = 12.03
Standard deviation in y = 16.18

13 GeV/c



Standard deviation in x = 16.89
Standard deviation in y = 18.53

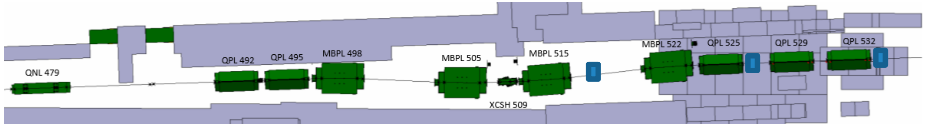
By modifying the instrumentation used we can maintain the beam-spot of the beam below 20 mm as desired

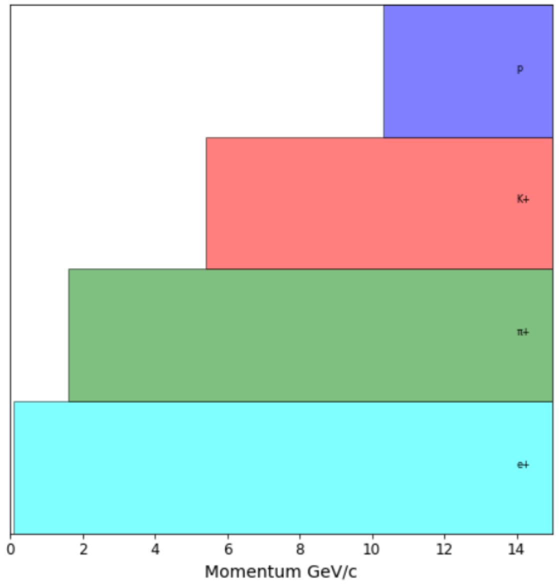
Instrumentation proposal

Above 5 GeV/c:

Use 3 XCET (starting at 15 bar CO_2) to identify electrons, pions and kaons

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





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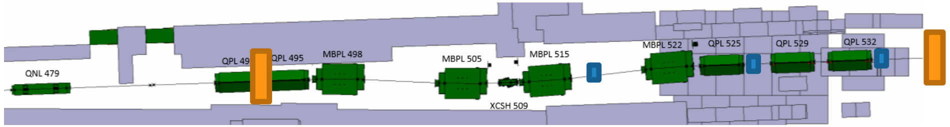
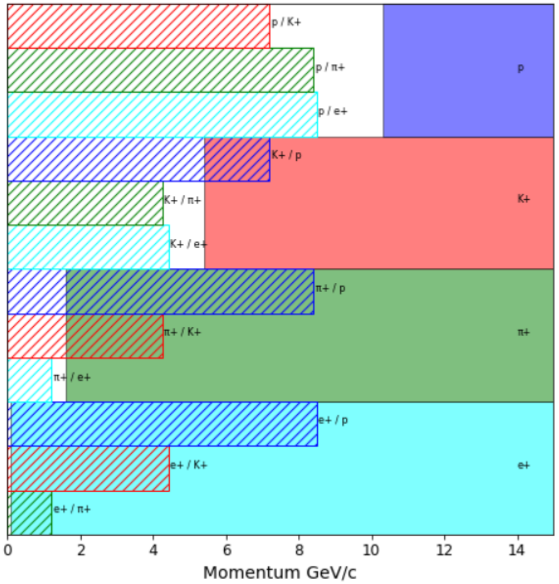
Below 5 GeV/c:

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





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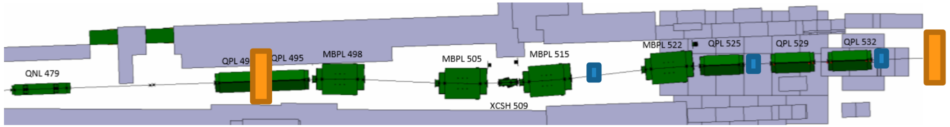
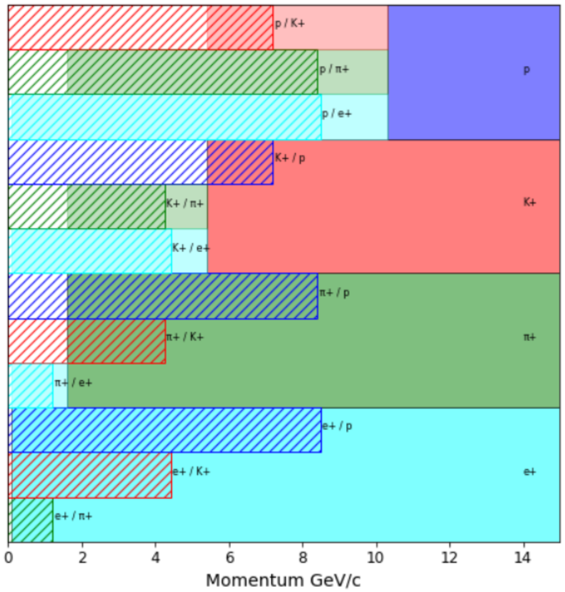
Modifying the pressures and windows we can maintain a low enough material budget



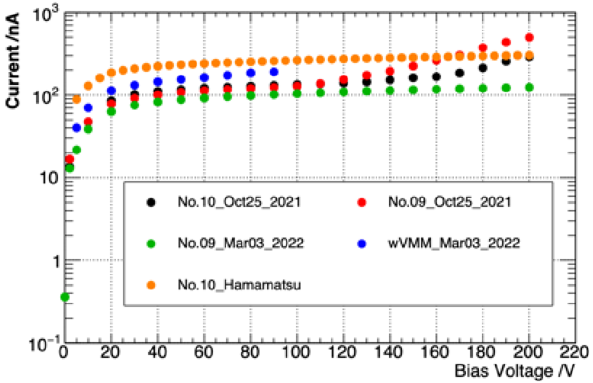


Si Strip BPD Studies

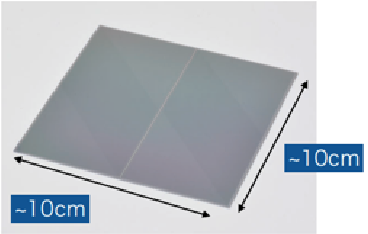
Credit to Hino-san for the slides

- For beam profile monitor development, "Hamamatsu SSD" + "SRS system" is being investigated.
- So far
  - SSD I-V property measurement
  - Electronic/DAQ test w/ Am alpha source -> the preamp gain (12 mV/fC) of VMM was inadequate for MIP particle detection.
  - APV (65 mV/fC) is under testing instead.

I-V Property

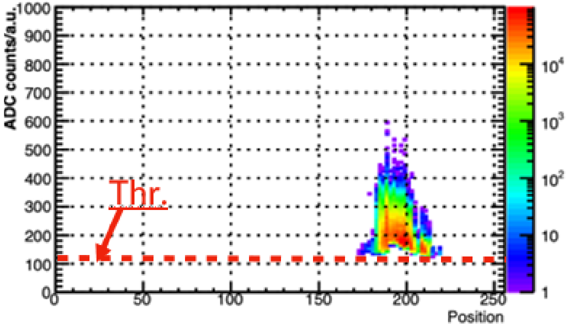


Si strip detector(Hamamatsu S13804)

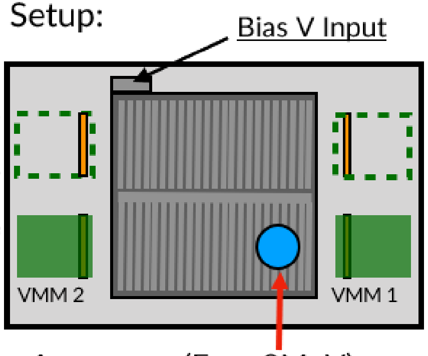


0.19mm pitch x 512ch x 2

Si BPD + VMM + Am source Test



Setup:



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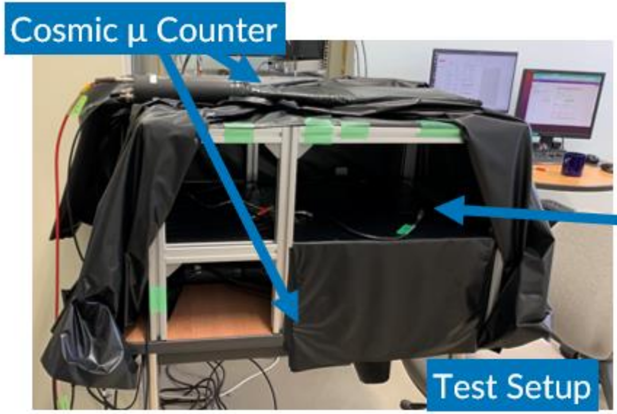
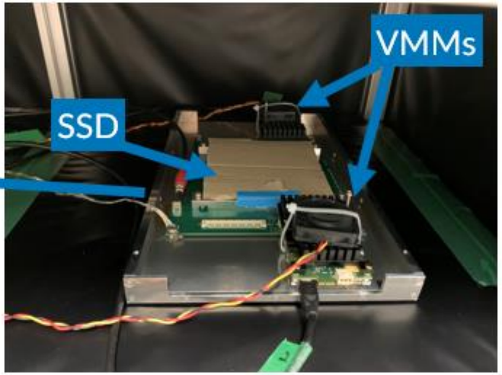
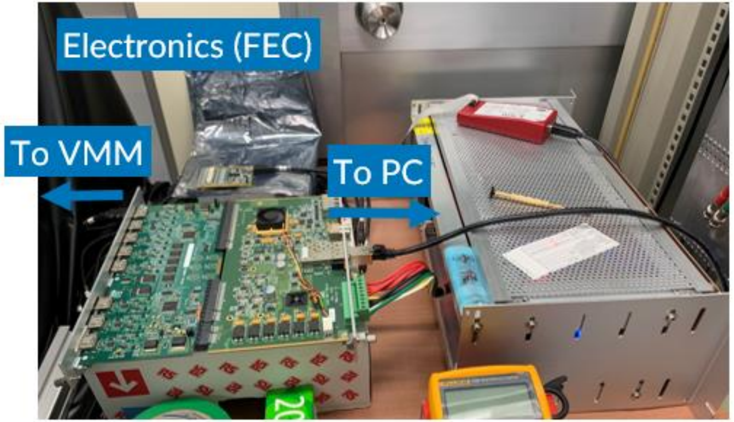


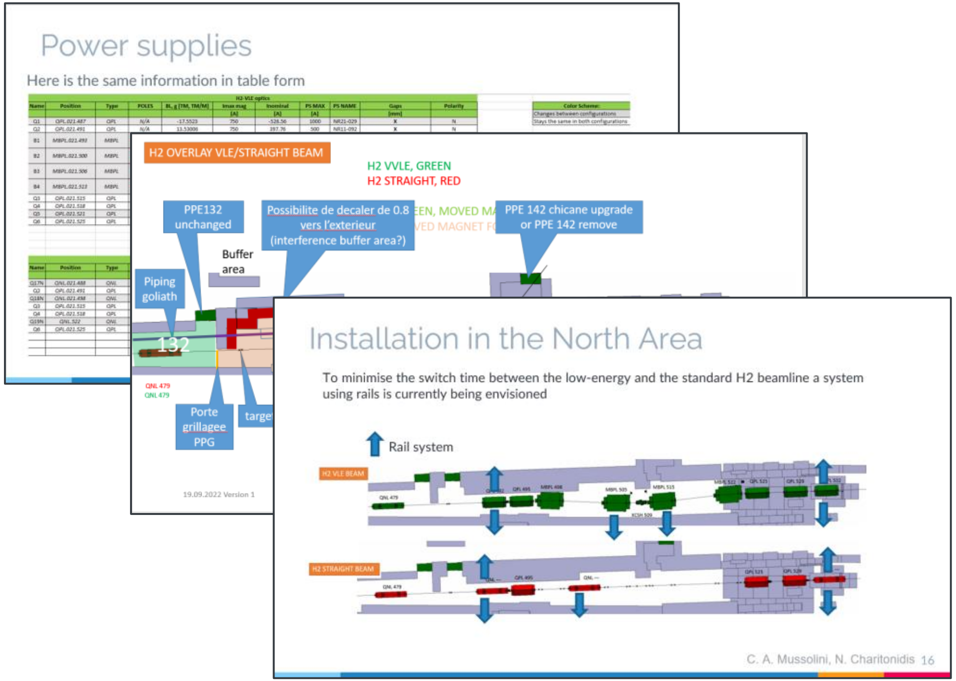




Beamline's implementation in NA

Significant work has gone into implementation studies for the beamline in the NA:

- 400 GeV/c capabilities maintained
- Power supplies availability
- Shielding modifications
- Installation challenges
- Magnet refurbishment
- Budget estimate, approx. 1 Mchf

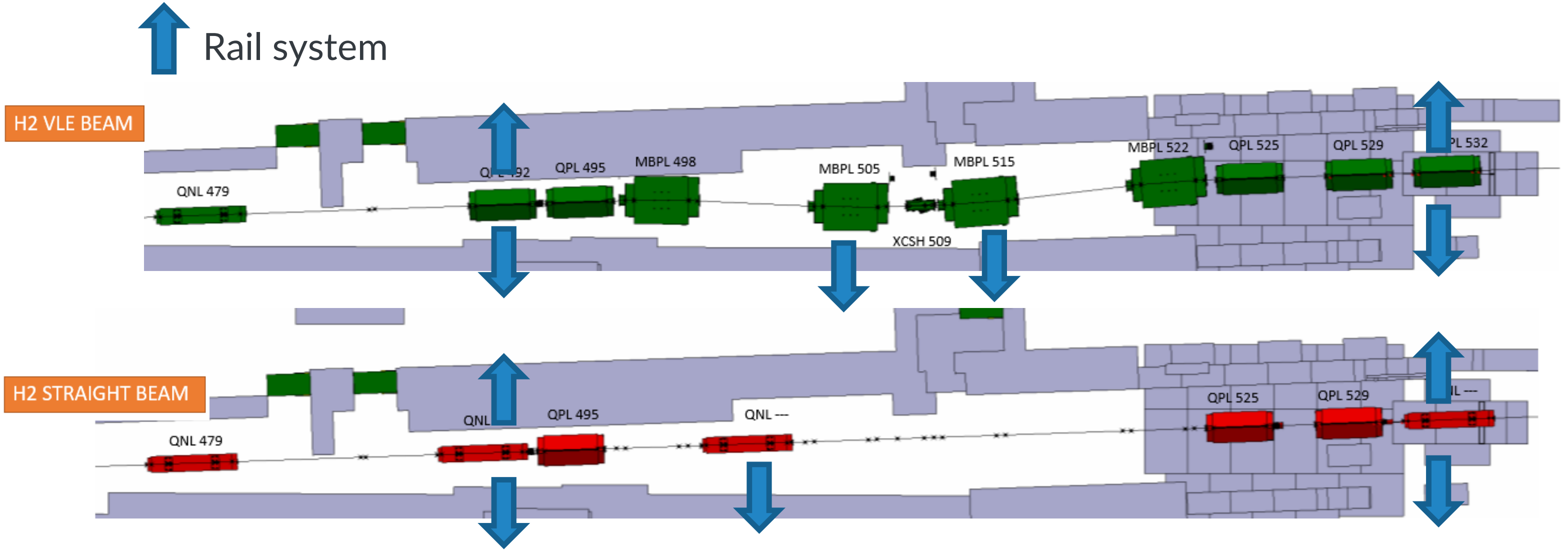


No show stoppers have been found

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 this is not challenging in North Area. Some NA61/SHINE instrumentation may need to be moved downstream



Project's timeline

Idea developed in 2017, 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
- Engineering Change Request for this beamline is being circulated, required for installation in the experimental areas and to begin securing CERN funds
- Ideally, the aim to have the beamline installed during YETS 2023, pending full approval from relevant CERN bodies

> "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:

- Will enable the delivery of low energy hadrons with momenta in the 2-13 GeV/c range
- Meeting all requirements set out by NA61/SHINE
- Optimisation of targets and beamline optics completed
- Studied the implementation of the beamline with the technicians and found no show stoppers
- 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 secure funding to build the beamline in 2023

Thank you for your attention

Any questions?

Additional slides

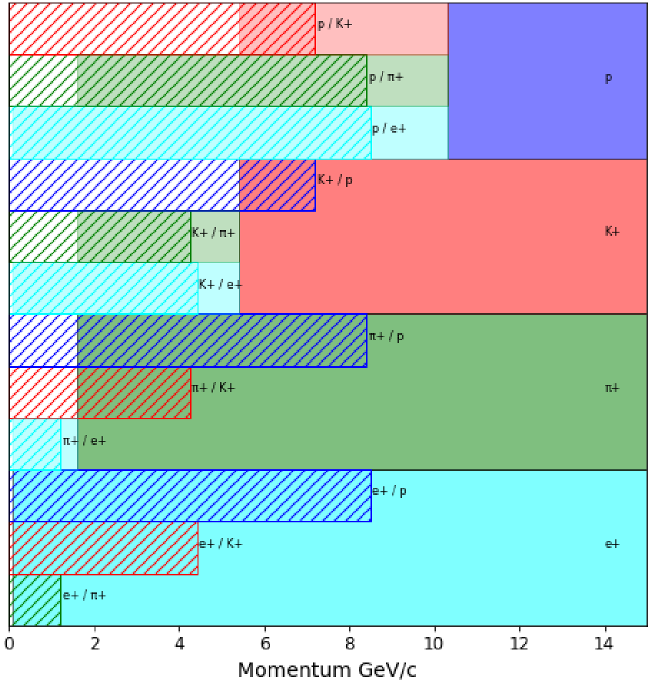
Library of targets and Analysis

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

General information on instrumentation

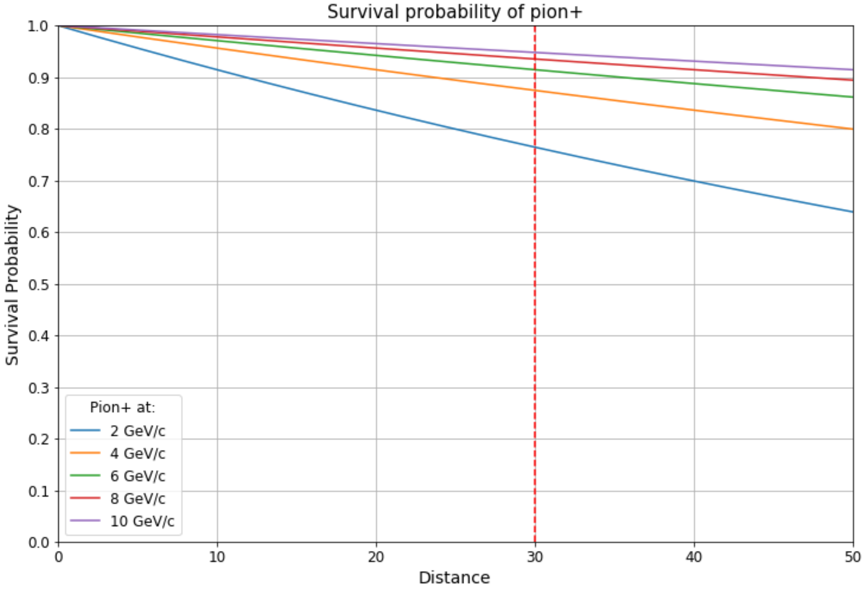


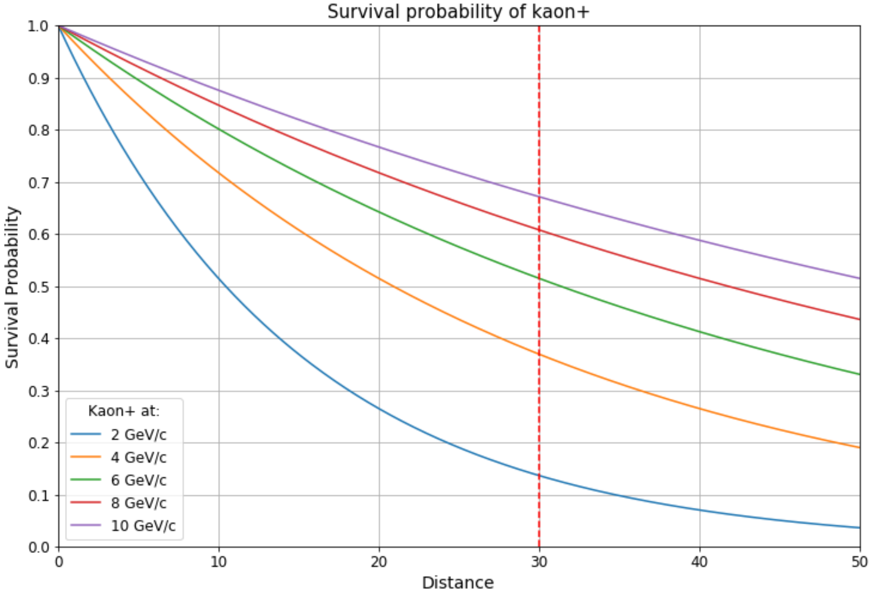

```
Hatched regions are showing ToF discrimination,
boxes where particles can be seen with Threshold Cherenkov Counter

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
```

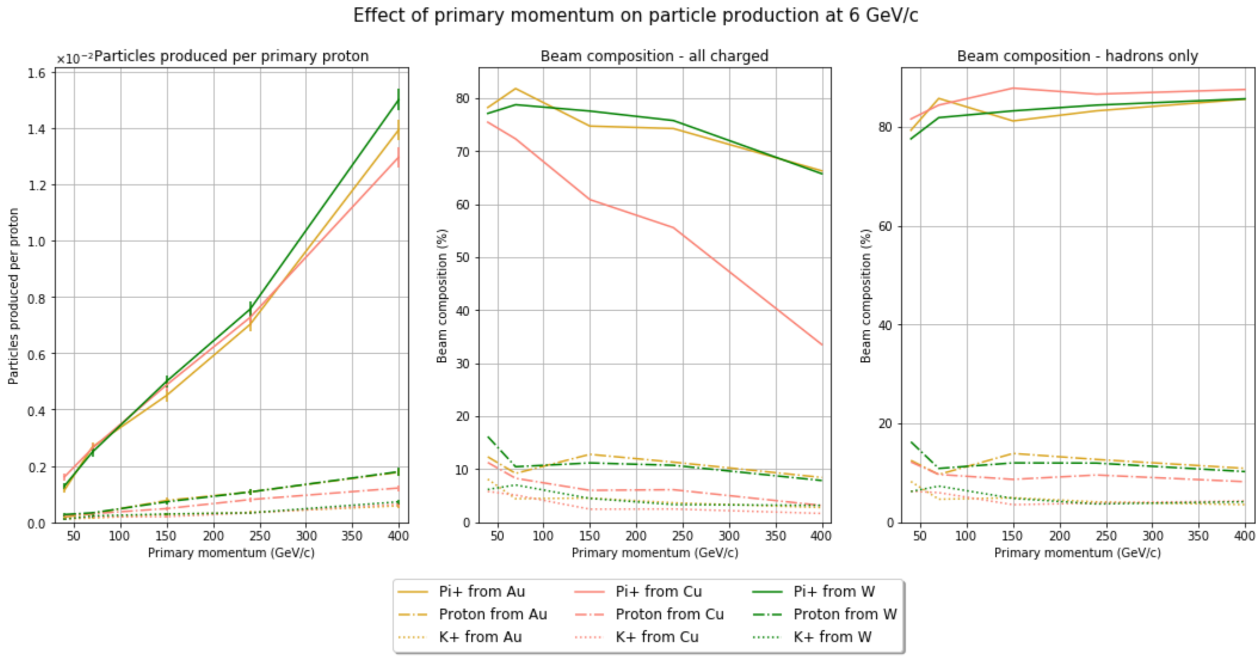
Expected survival in beamline





- 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

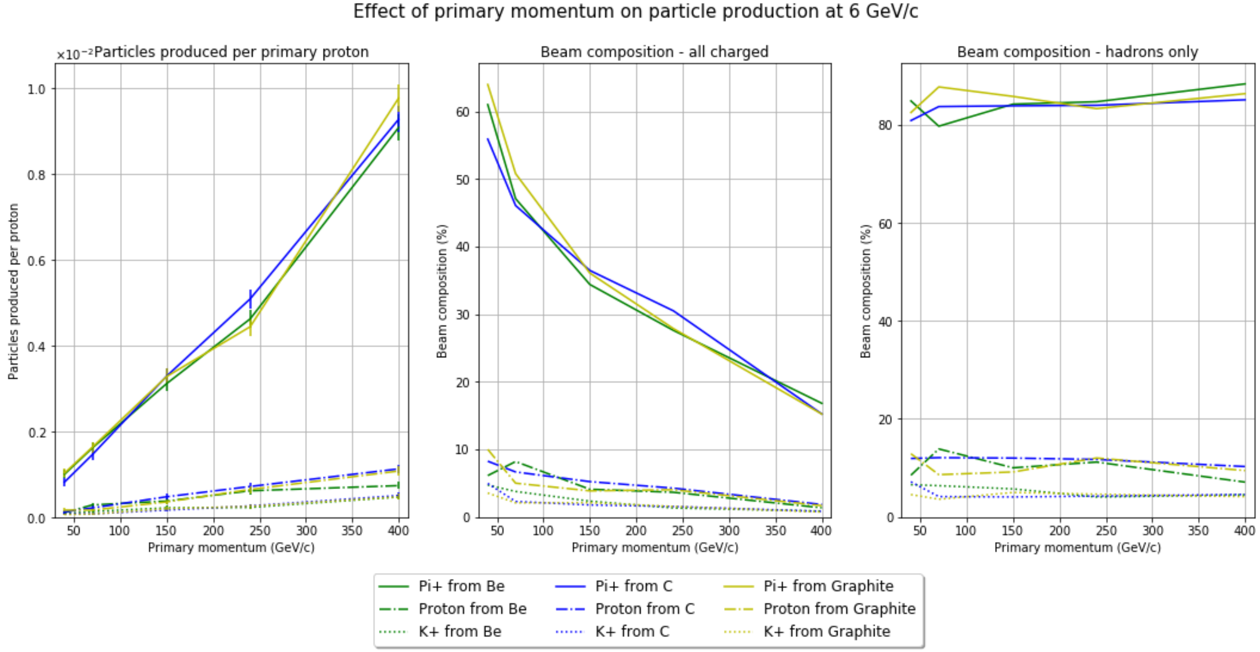
Effects of primary momentum (High Z)



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

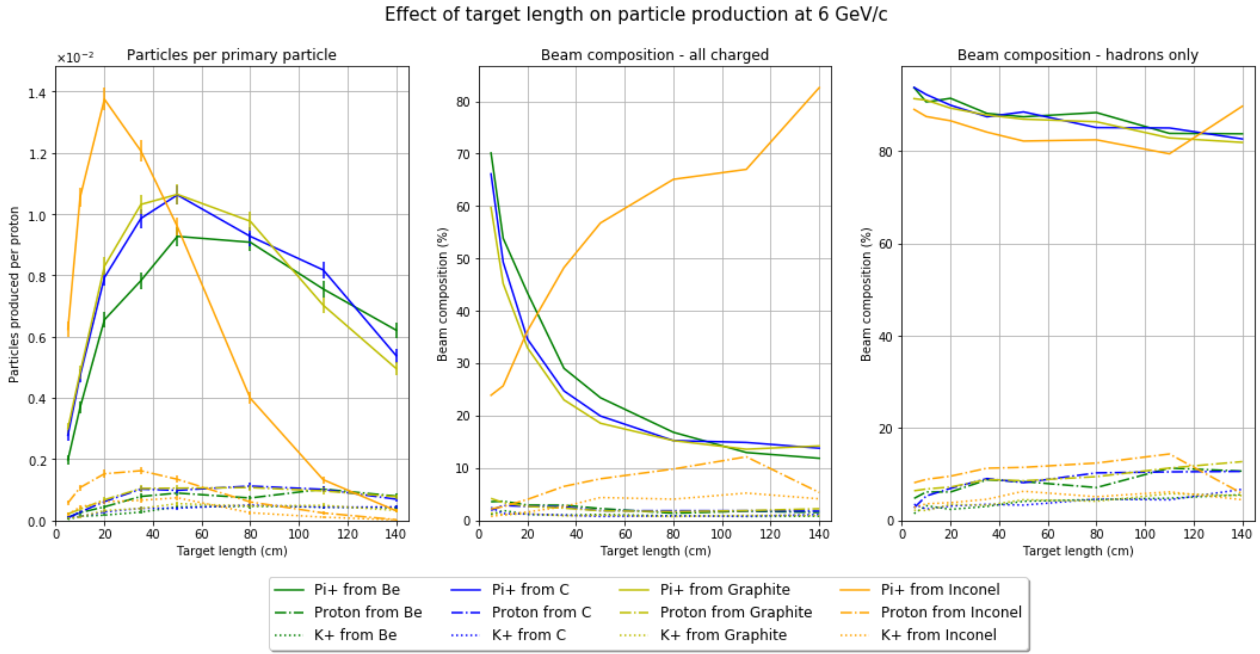
Effects of primary momentum (Low Z)



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

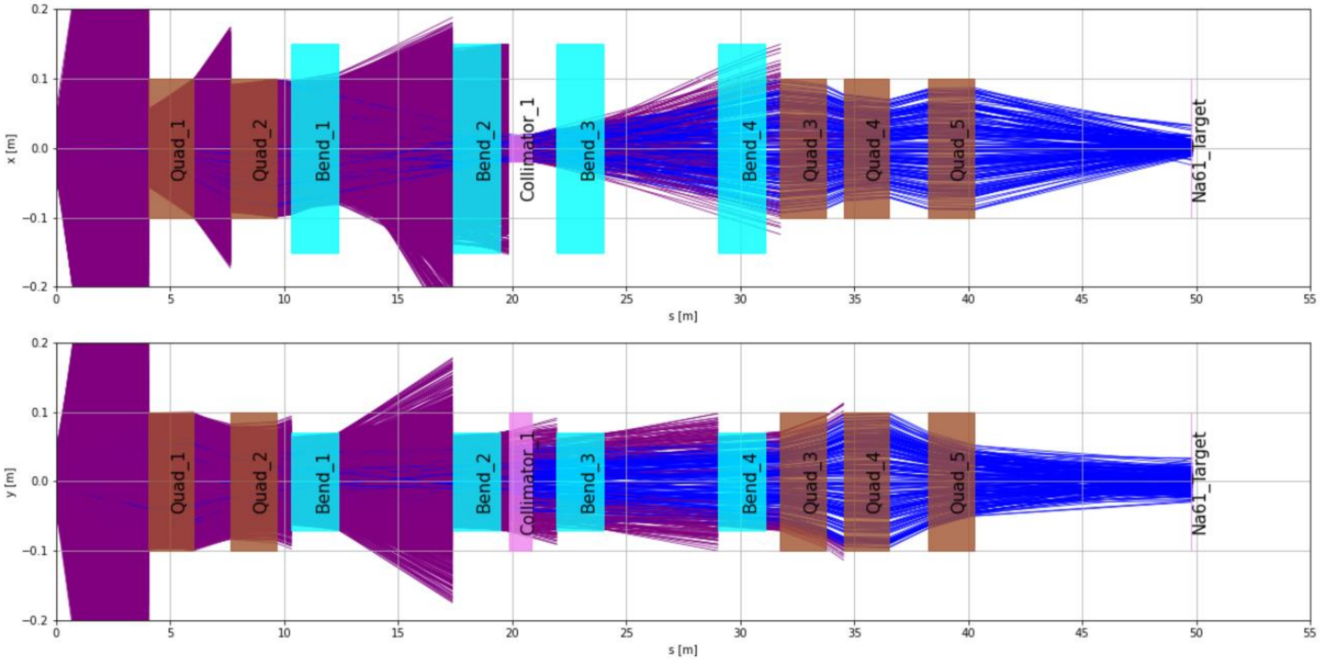
Effects of length (Low Z)



Target Length

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

Beamline design



Tracks which do not reach the end of the line are shown in purple. The back end does not significantly affect the overall acceptance, so back end and front end can be designed separately

XCET Resolution

To detect single particles we need to pick a pressure where we have no uncertainty over what is scintillating.

CO2 (left) works everywhere except for separating pions and electrons, but this can be solved by using He in one of the XCET