Cooling Demonstrator Target Study

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Aims

Short term

- Study the pion yield from a 14 GeV proton beam (PS) and compare with alternative options (26 GeV PS and 100 GeV SPS)
  - Start from an existing target and capture design
  - Look at pion yield in the momentum range of interest for the demonstrator

Medium-long term

- Optimise the target and capture system
  - Target material, geometry
  - Horn vs Solenoid comparison

Demonstrator facility siting options at CERN

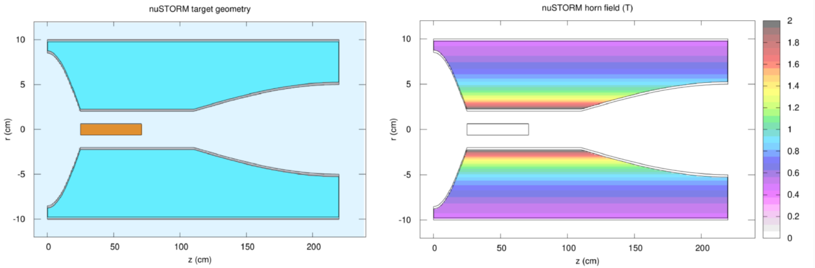
Study motivated by the different siting options

- Intersection Storage Rings (ISR) complex
  - In the TT7 extraction line
  - Proton beam from the PS
  - At surface level, radiation concerns motivate a lower proton beam energy, 14 GeV (10 kW beam power)
- TT10
  - Proton beam from the PS (26 GeV)
  - Underground, beam power up to 80 kW
- nuSTORM facility
  - Proton beam from the SPS (100 GeV)

Baseline Target and Capture System

From the Fermilab nuSTORM optimization study (A. Liu, A. Bross, D. Neuffer, *Optimization of the magnetic horn for the nuSTORM non-conventional neutrino beam using the genetic algorithm*, NIM A, **794**, p. 200-205, 2015)

- Target: Inconel, cylindrical, $L = 46\ \mathrm{cm}$ (3 interaction lengths), $r = 0.63\ \mathrm{cm}$
- Capture: Horn, optimised to deliver 5 GeV pions (!) from a 120 GeV proton beam impinging on the target



FLUKA simulation

- Simulated 10^6 POT for three proton beam energies (14, 26 and 100 GeV, all with $\sigma_{x,y} = 2.67$ mm)
- Horn current scaled linearly as $I(p_\pi) = \frac{219}{5} p_\pi = 8.76\ \mathrm{kA}$ (very weak focusing, to be addressed)
- Particle position and momentum recorded at:
  - target surface
  - the downstream end of the horn, within the 10 cm outer conductor radius

π^+ Yield Inconel target

Table: Number of pions in the 270 - 330 MeV/c range

E_0 [GeV]	14	26	100	100 (220 kA)
At target	99367	148286	345974	346132
Yield at target [/POT]	0.10	0.15	0.35	0.35
At horn end	478	877	2809	40057
Within 2 mm rad DA	105	134	385	1375
Yield [10^{-4}/POT]	1.05	1.34	3.85	13.75
Yield [10^{-6}/POT/GeV]	7.50	5.15	3.85	13.75

Number of pions produced at target scale with the proton beam energy.
The capture efficiency can be improved by scaling up the horn current (see last column) and/or redesigning of the horn/capture system.
Pion yield per proton energy largest at 14 GeV.

At target (Inconel): π^+ Transverse Momentum Distributions (270-330 MeV/c momentum range)

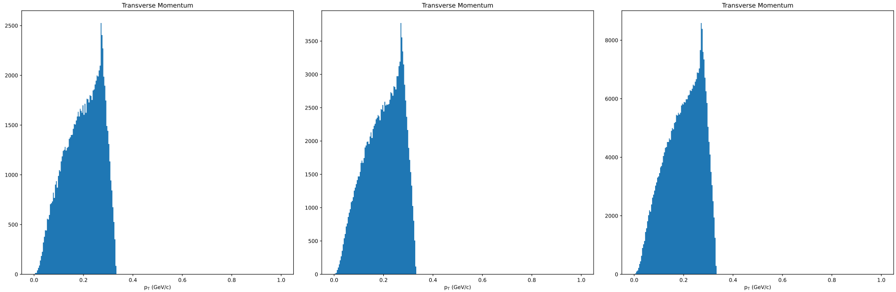


Figure: (left) 14 GeV, (middle) 26 GeV, (right) 100 GeV proton beam energy

At target (Inconel): π^+ Angle Distributions (270-330 MeV/c momentum range)

Angle: $\theta = arctan(p_T/p_z)$

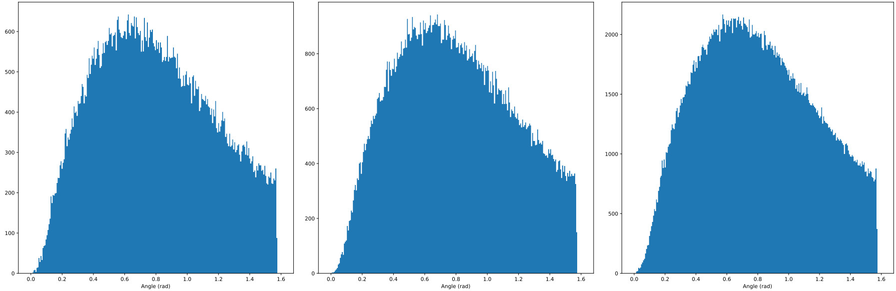


Figure: (left) 14 GeV, (middle) 26 GeV, (right) 100 GeV proton beam energy

At target (Inconel): π^+ Longitudinal Position Distributions (z) (270-330 MeV/c momentum range)

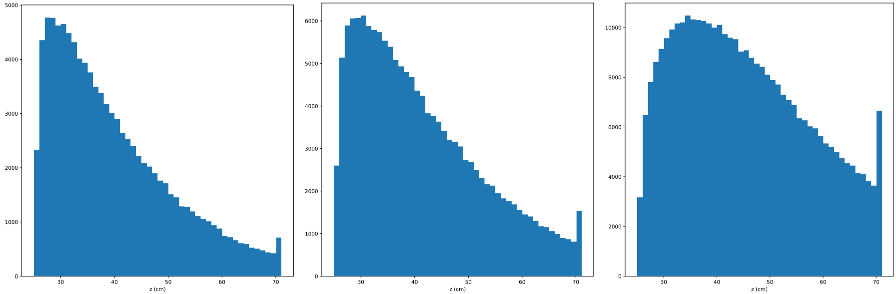


Figure: (left) 14 GeV, (middle) 26 GeV, (right) 100 GeV proton beam energy

At lower proton beam energies, more pions are emitted towards the upstream end of the target. Might inform capture system design.

π^+ Yield Graphite target

Choice of material motivated by the extensive knowledge on graphite targets.

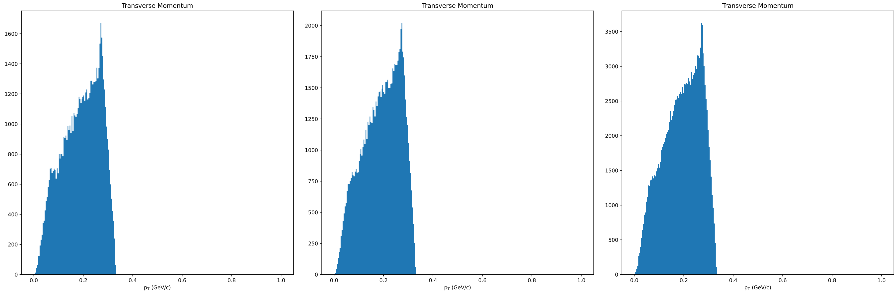
- Target: Graphite, cylindrical, $L = 80$ cm (1.78 interaction lengths), $r = 0.63$ cm
- Capture: Horn, I = 220 kA

Table: Number of pions in the 270 - 330 MeV/c range

E_0 [GeV]	14	26	100
At target	70766	88665	156150
Yield at target [/POT]	0.071	0.089	0.156
At horn end	7905	10518	20715
Within 2 mm rad DA	280	427	753
Yield [10^{-4}/POT]	2.80	4.27	7.53
Yield [10^{-6}/POT/GeV]	20.00	16.42	7.53

Pion yield per proton energy largest at 14 GeV.

At target (Graphite): π^+ Transverse Momentum Distributions (270-330 MeV/c momentum range)



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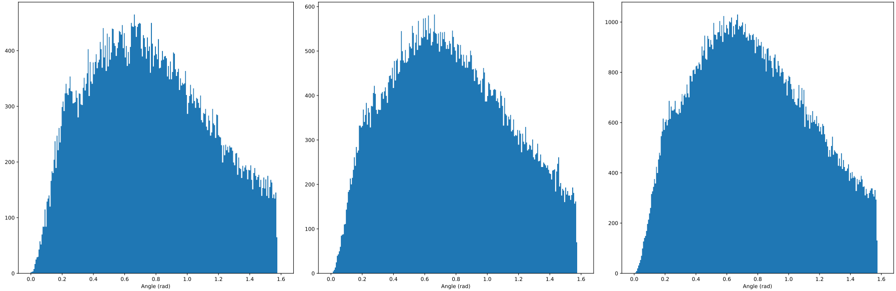

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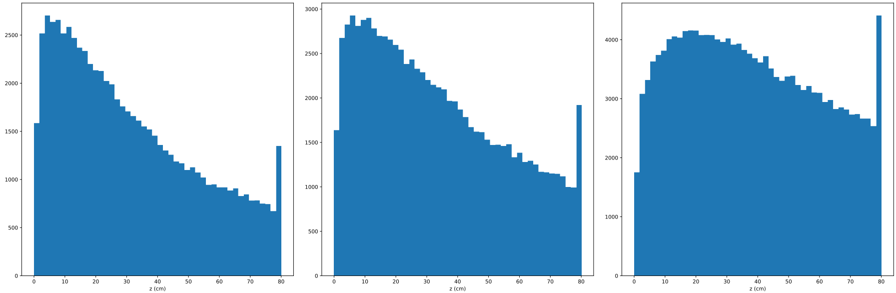

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At lower proton beam energies, more pions are emitted towards the upstream end of the target. Might inform capture system design.

Next Steps

- Target: material and geometry optimisation study
- Capture system: Design and optimise
  - Challenging due to high angles of the outgoing pions
  - Study horn vs solenoid. Assess performance and feasibility (cost, physical constraints - narrow tunnel, short space available for capture and decay)

Thank you!

Back-up

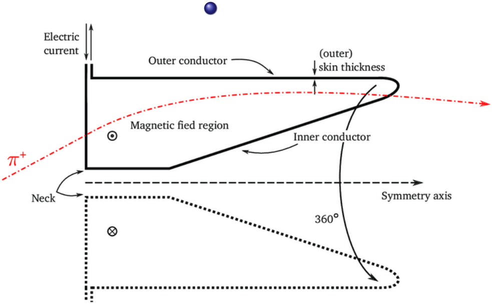
Magnetic Horn - Working Principle

Toroidal magnetic field generated between the inner and outer conductors

$B_z = B_r = 0$

$B_\phi = \frac{\mu_0 I}{2\pi r}$

Induces a radial kick to charged particles passing through the field region



Parabolic Inner Conductor Profile

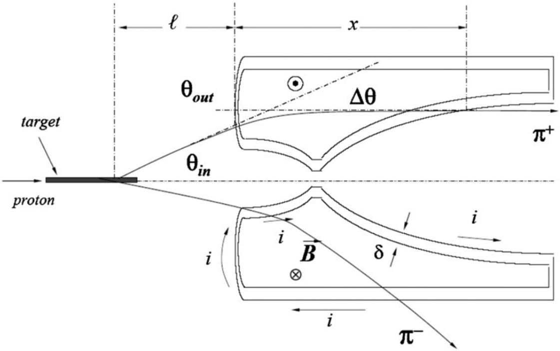
$$\Delta\theta = \frac{B_\phi z}{p}$$

$$\Delta\theta = \frac{\mu_0 I}{2\pi r}\frac{z}{p}$$

Let $z = ar^2$. Then

$$\Delta\theta = \frac{\mu_0 ar}{2\pi}\frac{I}{p}$$

For a particular momentum - current choice, the kick is proportional to the radius at which the particle enters the horn



Conical Inner Conductor Profile

$$\Delta\theta = \frac{B_\phi z}{p}$$

Can set the angular kick to equal the average/most likely angle of the incoming particle distribution

$$\Delta\theta = \frac{\mu_0 I}{2\pi r}\frac{z}{p} = \langle p_T \rangle / p$$

$$z = \frac{2\pi r}{\mu_0 I}\langle p_T \rangle$$