Tertiary beamline design and simulation

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WCTE Workshop
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Outline

- Beamlines for WCTE
- Hardware
- Beam simulation ➔ particle rates and backgrounds

Motivation

- **WCTE requires electron, muon, pion, and proton beams between 0.2 GeV/c and 1.2 GeV/c**
- Muon and pion beams not compatible → short beam for pions vs. long beam for muons
- **SOLUTION: use secondary beams for muons and electrons and build a tertiary beam for pions and protons**
    - **Tertiary beam is a part of the experiment**

Beamline areas at CERN

North area

- Primary beam from SPS
- Secondary beam ~10 - 160 GeV/c
- Large experimental area
- Neutrino platform is there
- Building tertiary beam is not efficient (400 GeV/c → ~100 GeV/c → < 1.2 GeV/c)

East area

- Primary beam from PS
- Secondary beam: 0.4 - 15 GeV/c
- Tertiary beam is more efficient (24 GeV/c → 12 GeV/c → < 1.2 GeV/c)

East area is a better choice!

East area

- Primary beam from PS (24 GeV/c)
- Secondary beams 0.4 - 15 GeV/c
- Max. intensity: ~$5{\cdot}10^6$ particles per 0.4s extraction, max. 3 times per 40s PS supercycle
- **T9 and T10 beamlines**

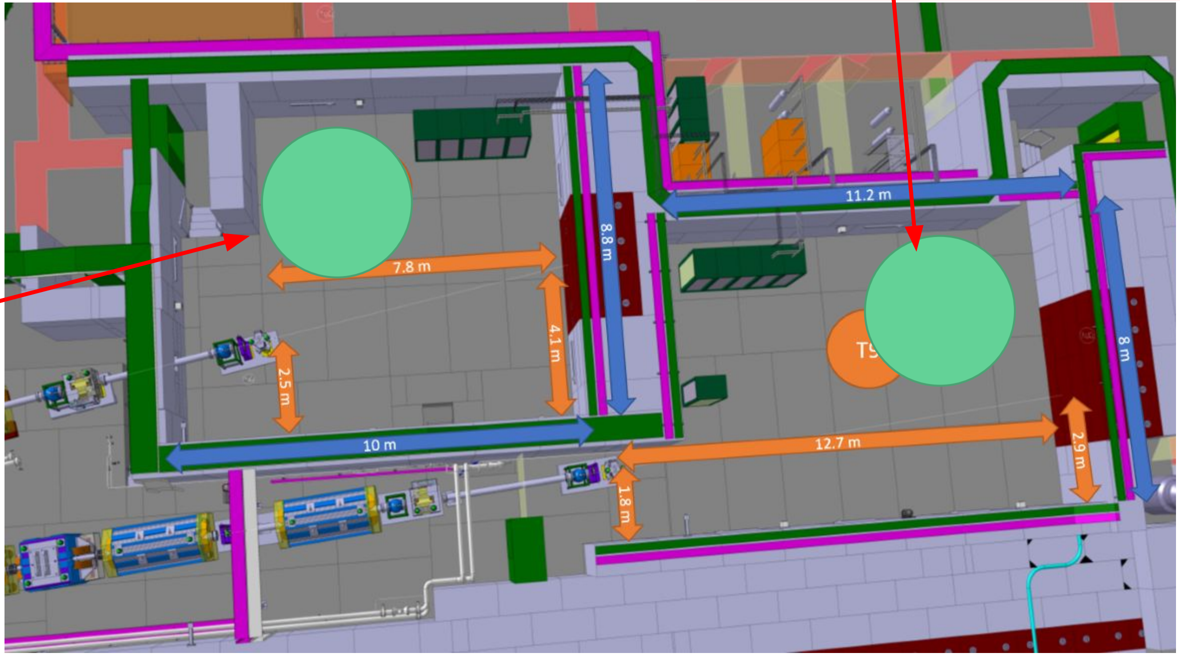
T9 or T10 beamline?

- For the tertiary pion beam, tank must be placed away from the surviving secondary beam

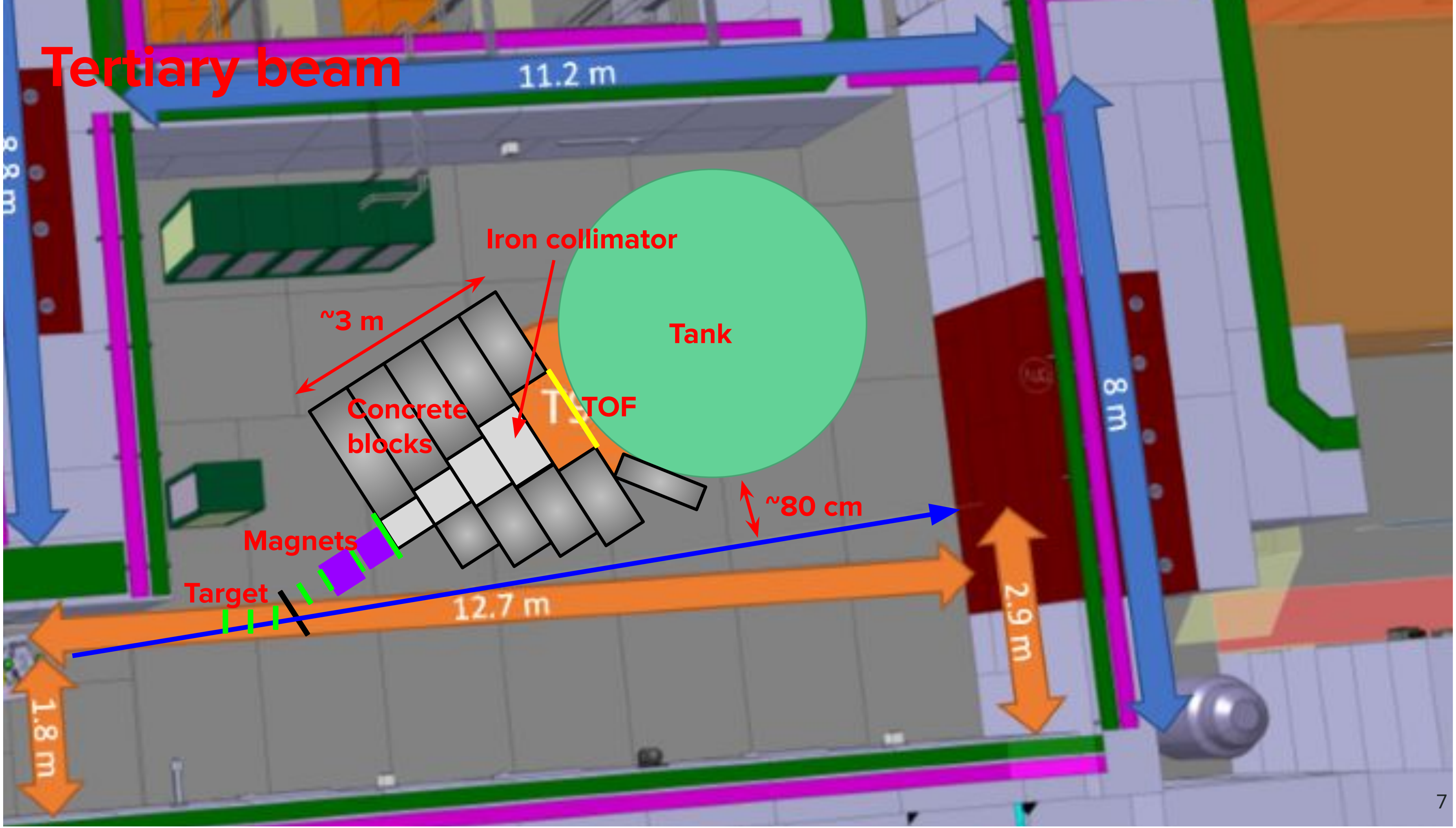
T9 has much better layout for WCTE

Only place in T10 which is able to accomodate the water tank

- Not enough space for the spectrometer and shielding
- Tertiary pion production angle must be very large



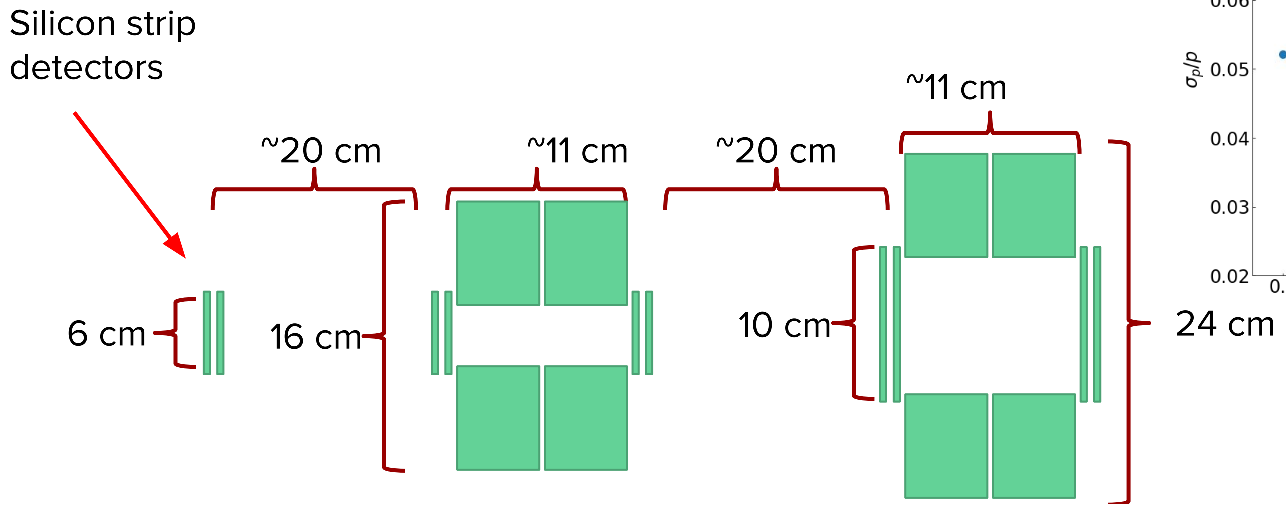
Tertiary beam

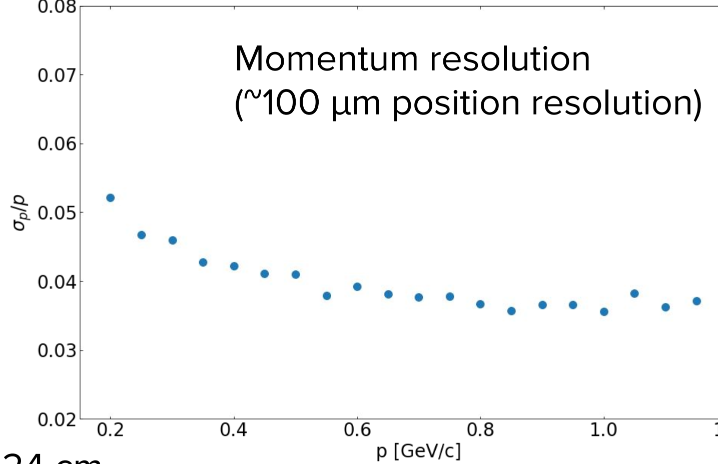


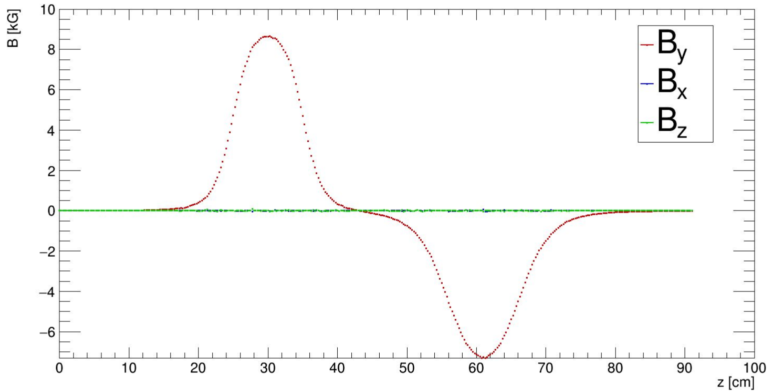
Tertiary beamline

- The beamline is a part of the experiment ➔ needs to be simple and cheap
- Target + spectrometer + collimator and shielding
- The design uses two dipole magnets (momentum measurement and compensation)
- Compact spectrometer (~60 cm long) + TOF
- Large beam spot (tens of cm in diameter)
- No momentum selection

Spectrometer design

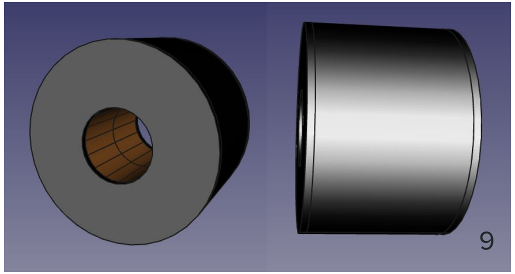






Exact silicon strip configuration still not determined

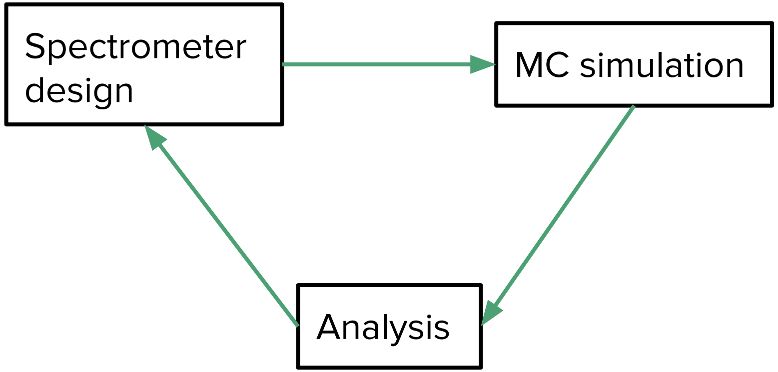
N52 Halbach arrays



Spectrometer hardware

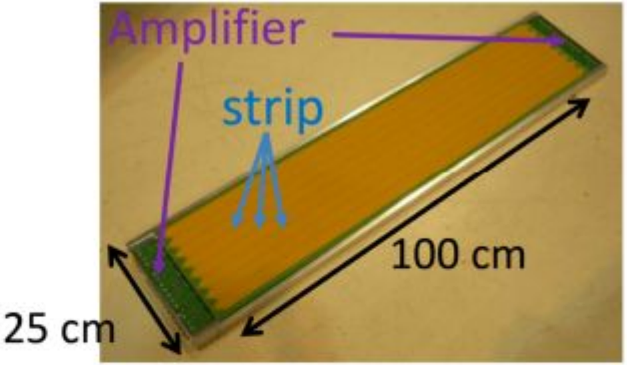
- 2 cm thick tungsten target
- Scintillators for the secondary beam triggers
- Tracking layers → silicon strips
- Tertiary particle ID → RPCs
- **Two permanent Halbach array magnets**

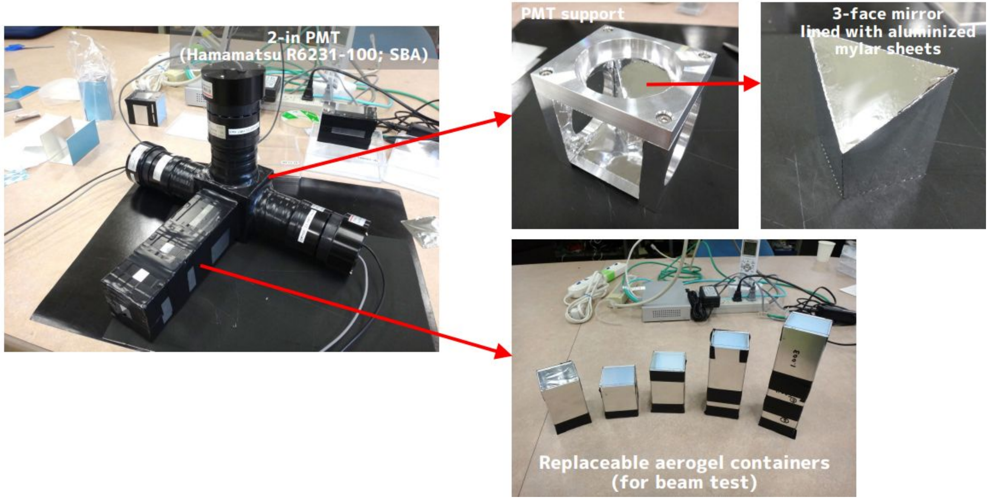
See the next talk, by Pradeep Sarin!



Particle ID

- Time-of-flight measurement with RPCs (timing resolution ~100 ps)
- Aerogel Threshold Cherenkov detector for pion/electron separation > 0.4 GeV/c





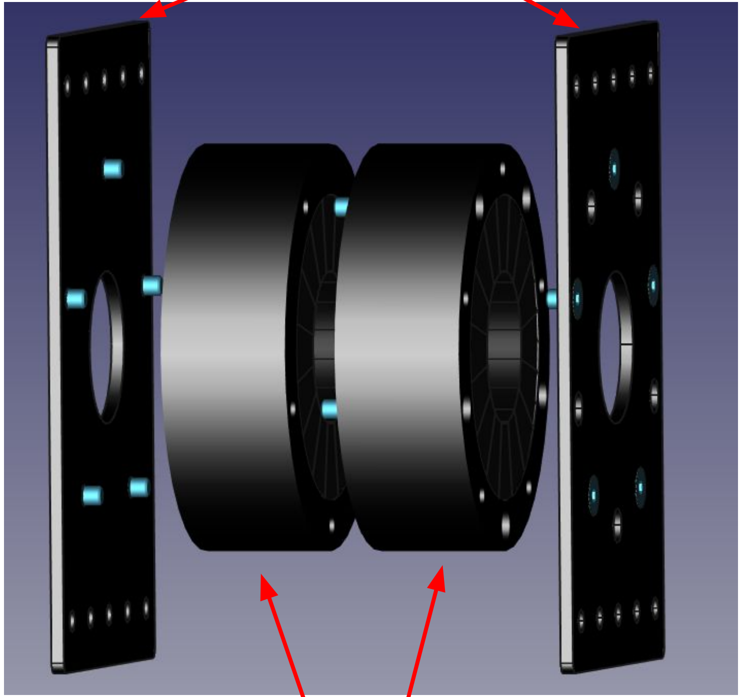
Magnet design

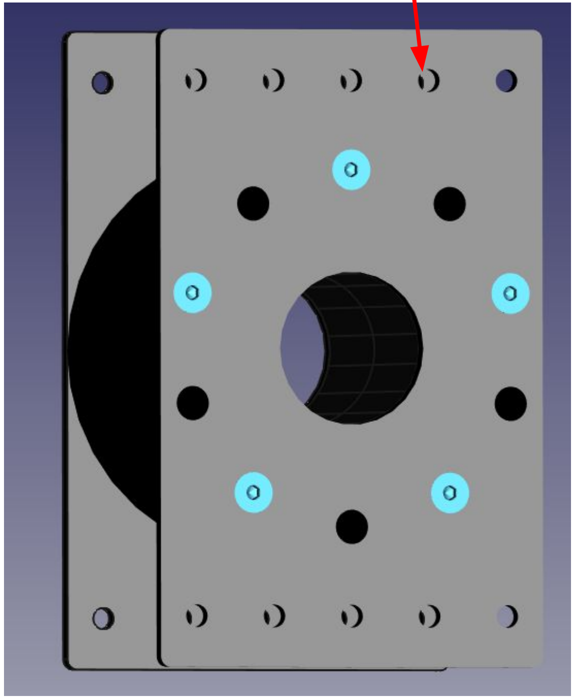
- Halbach array ➜ small rare-earth segments are stacked together to achieve desired field configuration
- N52 neodymium segments (1.44 T internal field) ➜ dipole fields up to 2 T in the magnet bore
- Magnet size, bore diameter and bending power are determined from the MC simulation and from manufacturer limitations
- Compensation magnet needs to be bigger ➜ beam is wider

Magnet design

Holes for M8 bolts → works with 4040 aluminium extrusions

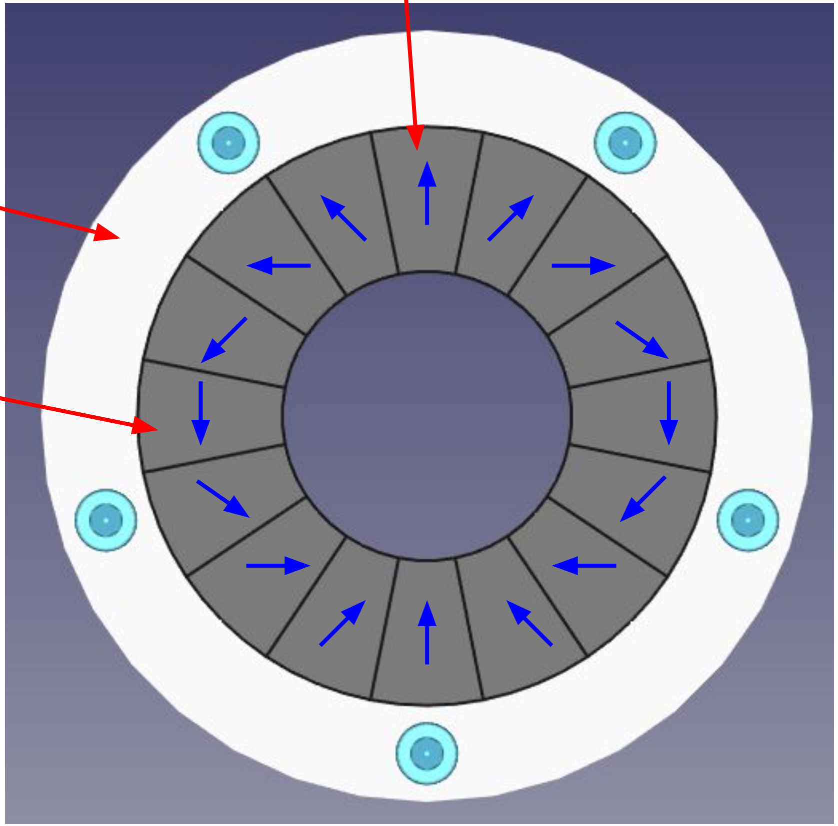
0.5 cm thick 304 stainless steel endplates





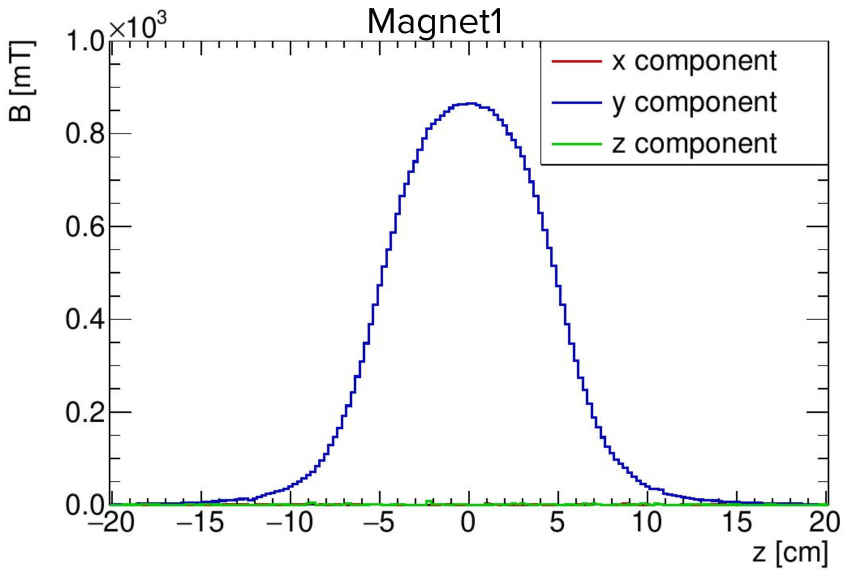
2x 5 cm long Halbach cylinders

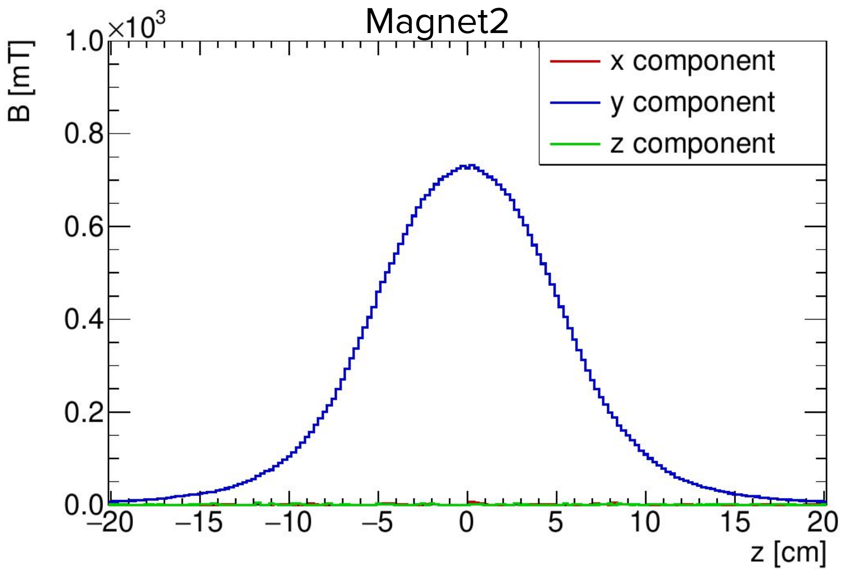
Magnet design



	Magnet 1	Magnet 2
ID [cm]	6	10
OD [cm]	16	24

Field maps (x = y = 0 cm)

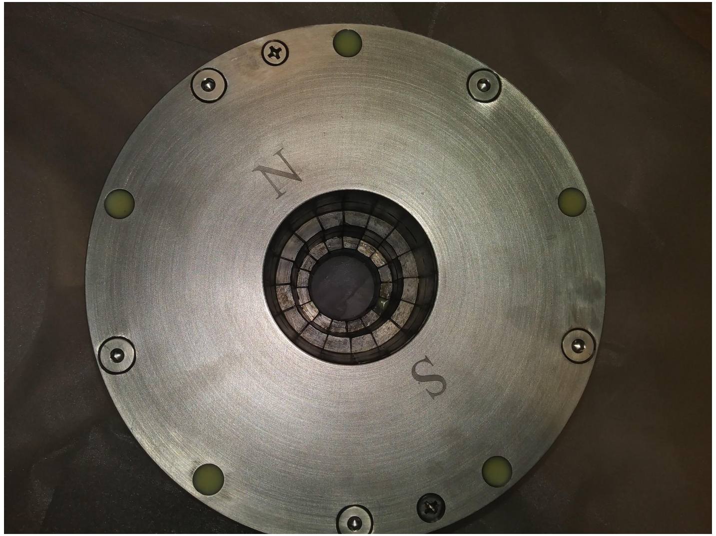




- Simulation done in Comsol 5.4
- Bending power of magnet 1 is 0.075 Tm ➔ ~5% momentum resolution achievable with silicon strips with 80 µm pitch and $X/X_0 = 0.003$ per detector

Magnet design

- In contact with company from China
- We have already purchased similar magnet from the same company for EMPHATIC experiment
- 10 kUSD for bigger and more complicated design



MC simulation

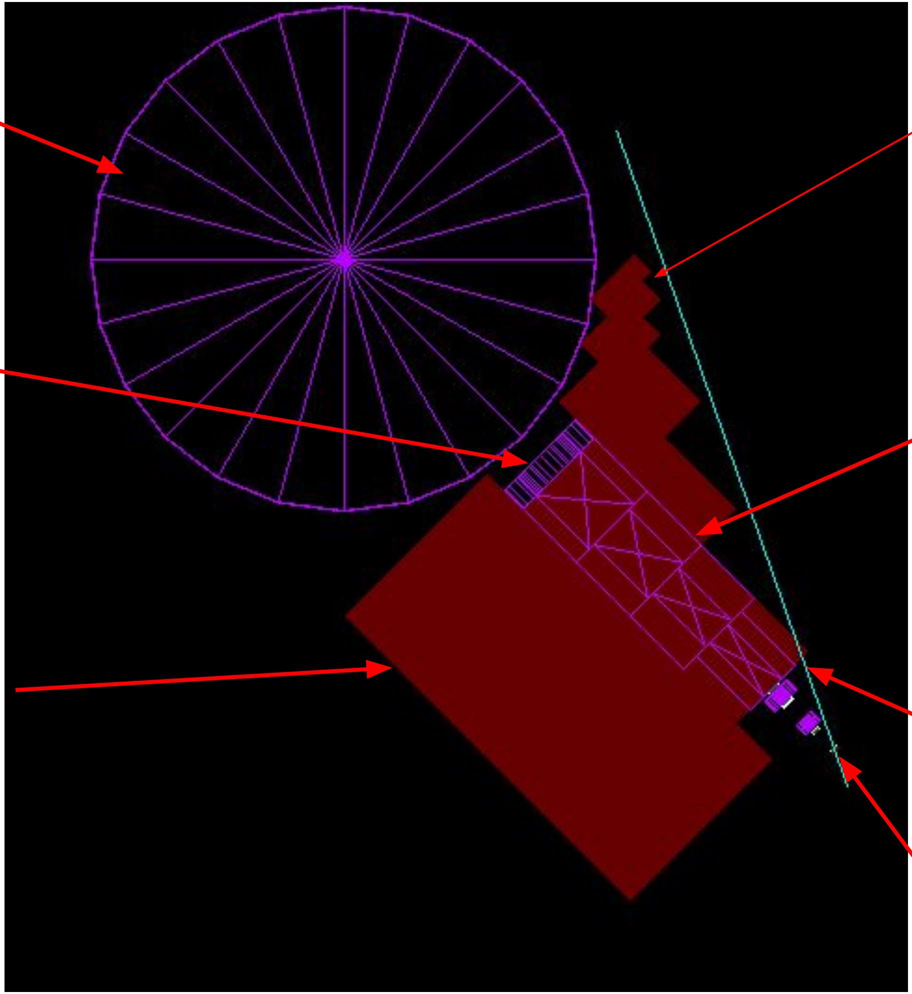
- 12 GeV/c protons
- 2 cm tungsten target
- GEANT4.10.06 FTFP_BERT
- 450 mrad tilt between the beam direction and the spectrometer
- **Surviving secondary beam does not hit the water tank**

Target length, material, beam momentum, production angle, magnet bending power have been optimized!

Water tank

The last collimator piece has r = 25 cm circular bore

Standard block size → multiple of 80 cm.



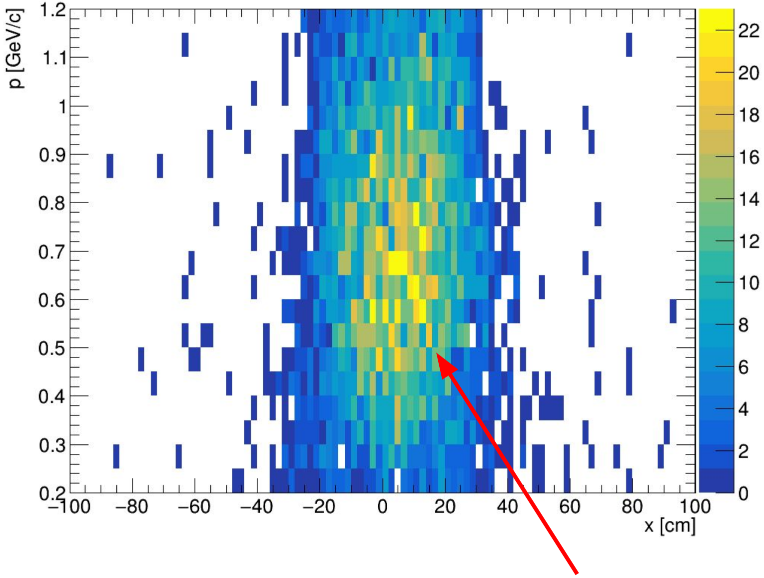
Non-standard block size

Square iron collimator with outer dimensions 80x80 cm2

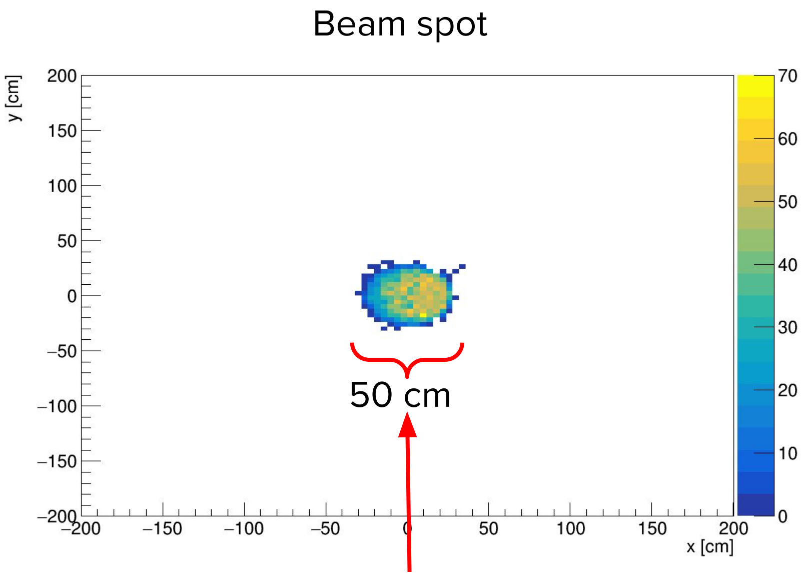
First collimator segment is a bit smaller to avoid surviving secondary beam

Target

Beam spot size



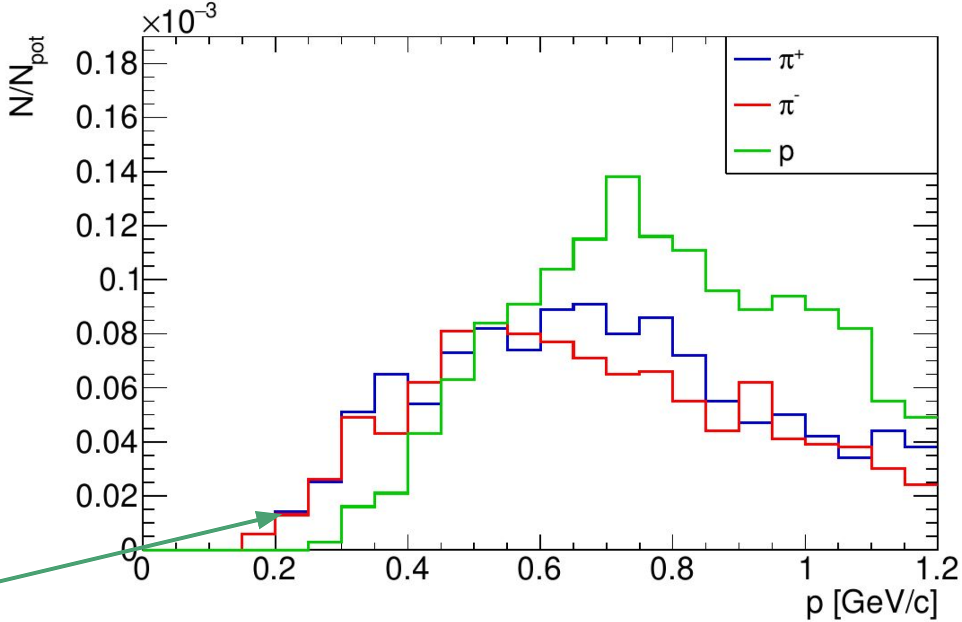
Weak dependence on momentum ➔ compensation works well



Limited by the beam window size

Particle rate

- Selection:
  - Single charged particle with all clusters in the tracking layers
  - Hits the tank



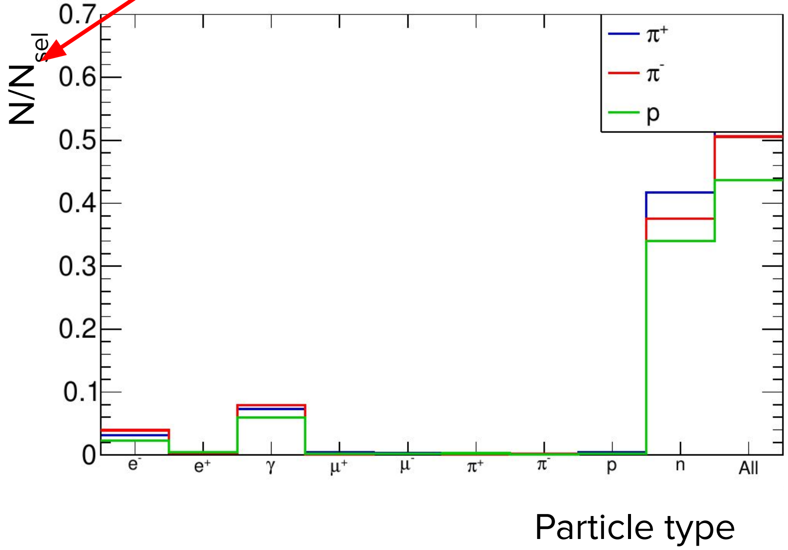
Max. intensity: 10^6 particles per 0.4s extraction, max. 3 times per 40s PS supercycle → >90000 π+ per day of data-taking for 0.20 - 0.25 GeV/c region

Backgrounds

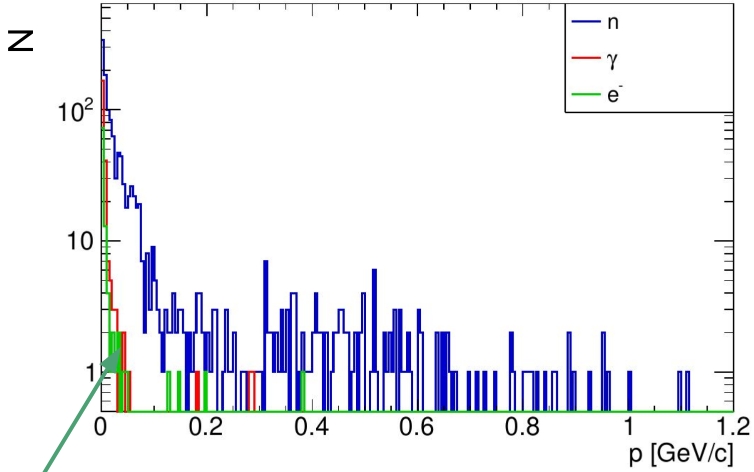
1. Neutral and charged particles created in the target, magnet, collimator and shielding alongside selected particle
2. Muons (pion decays before hitting the tank)
3. Interactions in the tank structure (beam window) ➔ negligible ➔ <<1% interaction length

Background (type 1)

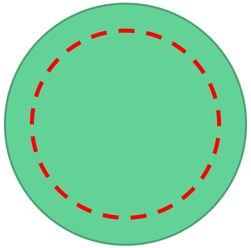
Number of background particles per selected particle



>60% of selected particles have 0 background particles
➡ some have multiple

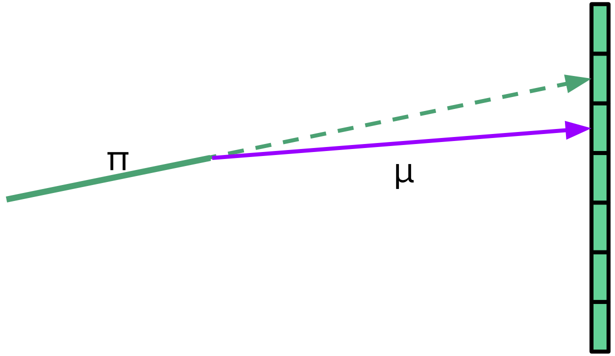


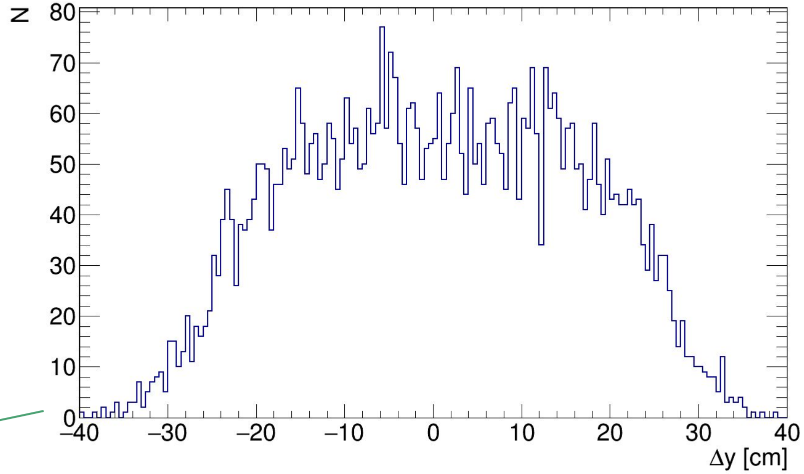
We can remove most of the low momentum backgrounds by using fiducial volume cut



Background (type 2)

- Particle ID is done by tof (RPCs)
    - 25x25 cm^2
- Segmented TOF detector is needed to identify pion decays ➔ kinks in the pion trajectory
- Exact background muon rate not yet determined ➔ depends on the number of channels





Difference between predicted pion position and muon position at 350 cm

Conclusions

- WCTE will use low momentum tertiary beamline as a part of the experiment
- **Simple, cheap and unique design**
- The beamline uses simple design with 60 cm long spectrometer
- > 90000 pions per day of data-taking per 50 MeV/c
- ~0.7 of background particles per selected tertiary beam particle
    - ~5% of background particles above 200 MeV/c ➔ mostly neutrons
- Design approved by CERN radiation safety