Performance of the H4-VLE Beam and Instrumentation

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The H4-VLE Beam

- Particle production chain:
  - 400 GeV/c protons from SPS on prim. target
  - 80 GeV/c mix. hadrons on sec. target
  - 0.3 – 7 GeV/c VLE beam to NP-04
- VLE beam is composed of pions, protons, kaons, electrons, muons.
- Rate and composition depend on target material and VLE momentum:
  - Optimized choice for balancing particle rate vs. pion-positron-ratio:
    - Tungsten for $p \leq 3$ GeV/c
    - Copper for $p > 3$ GeV/c
    - (Lead for pure electron beams)
Instrumentation:

Beam Line Design

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Beam Optics Optimization

- Beam optics calculation and tracking to simulate charged particle trajectories
- Two different optimization goals achieved:
  - Maximizing particle transmission
  - Minimizing beam spot size at detector entrance
- First runs operated with maximized transmission to NP-04
Monte-Carlo Simulations

• Full Monte-Carlo models implemented in Geant4 (via G4beamline) and FLUKA
  • Incl. particle production, transmission and decays
• Calculation of beam rate and composition for different momentum and target combinations
Measured Trigger Rates

- Very good agreement between expected and measured trigger rates
- The data has been normalized to 1 Mio. events on the secondary target

- Similar detector modules for trigger and beam profiles.
- Beam prof. efficiency (at least 1 hit) >95.5% for all monitors
- Assumed similar efficiency of 95% for the two trigger modules
Beam Line Instrumentation

• Goals of the beam line instrumentation:
  • Trigger of experiment
  • Transverse profiles for beam tuning
  • Particle identification on event-by-event basis:
    • Momentum measurement
    • Time-of-Flight measurement
    • Tagging by Cherenkov light

• Installed detectors in H4-VLE:
  • Newly developed scintillating fiber detectors:
    • 8 beam profile monitors (XBPF)
    • 3 triggering modules (XBTF)
    • 2 threshold Cherenkov counters using different pressures and/or gases
Beam Line Instrumentation

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Momentum: 3 GeV/c
No light in both Cherenkov detectors
Beam Composition Measurement

- Recorded data samples for 1, 2, 3 and 6 GeV/c analyzed
- Expected momentum vs. TOF diagram reproduced
- Beam composition for each VLE momentum can be determined by combination of TOF measurement and Cherenkov tagging
Beam Composition (Data and MC)

- Default target: W for 1-3 GeV/c, Cu for 4-7 GeV/c (measured data for 2 GeV/c was taken with Cu target)

**Positrons**

- FLUKA sim with default target for 2 GeV/c

**Pions/Muons (+Positrons >4 GeV/c)**

- FLUKA with default target for 2 GeV/c
Beam Composition (Data and MC)

- Default target: W for 1-3 GeV/c, Cu for 4-7 GeV/c (measured data for 2 GeV/c was taken with Cu target)

Protons

Kaons

FLUKA sim with default target for 2 GeV/c
• ROOT EventTree Builder to store information for each recorded trigger has been developed
• Gradually including more information based on analysis results
  • Implementation of ParticleID algorithms into EventTree structure currently on-going
• Production of EventTree for all “GoodRuns” planned
• EventTrees will be available on /eos/experiment/neutplatform/…

• GoodParticle nTuples of G4beamline simulations also available on /eos/…
  • Recently added simulation results for 1 GeV/c with a statistics of 500 Mio. secondary hadrons (≈75k-100k triggered VLE events)
  • More simulation runs on request!
Summary

• H4-VLE beam line successfully designed and built. Commissioning and operation starting in August 2018, leading to very successful data-taking of NP-04 experiment.

• The beam line instrumentation (fiber profile monitors, Cherenkov detectors and trigger planes) shows a within specification performance. No particular issues were observed, while particle identification, momentum and coordinates of particles were recorded and saved both at CERN and FNAL databases and are available for offline analysis. Time of flight also worked as expected.

• The measured beam line performance (particle production, beam optics/transmission and trigger rates/beam composition) is in excellent agreement with both FLUKA/G4beamline sim., within $\approx 20\%$.

• Simulated G4beamline nTuples available on /eos/experiment/neutplatform/…

• EventTree production for all “GoodRuns” has been requested and is being developed, will be available on eos soon.
Questions?

And many thanks to all people involved, especially P. Carriere, S. Girod, V. De Jesus, E. Harrouch, A. Rahmoun and many many others.
Backup Slides
The CERN North Area

• SPS proton beam (400 GeV/c) slowly extracted and directed to North Area Targets (T2, T4, T6, T10)

• Production of secondary and tertiary beams
  • electrons, muons, hadrons
  • momentum range: \(\sim 10 \text{ GeV/c} \rightarrow 400 \text{ GeV/c}\)

• Low momentum limit mainly defined by:
  • Particle production flux
  • Hardware limitations of magnets

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Extended by new “very low energy” branches in 2018
Beam Optics Optimization

- Beam Optics Calculation and Tracking of the beam optics using MADX / MADX-PTC
  (*Methodical Accelerator Design – Polymorphic Tracking Code*)
- Evaluation and optimization using the linear R-Matrix parameters

### H4–VLE High Transmission Optics, Horizontal Plane

![Graph showing beam optics in the horizontal plane with Q17, Q18, Q19, B18C12, Q20, B19, Q21Q22, and B20 indicated.](image)

### H4–VLE High Transmission Optics, Vertical Plane

![Graph showing beam optics in the vertical plane with Q17, Q18, Q19, B18C12, Q20, B19, Q21Q22, and B20 indicated.](image)
Commissioning of the 2 lines

• Commissioning of H2-VLE and H4-VLE in 2018

• First beam taken in H4-VLE end of September 2018 and H2-VLE in November 2018

Two XBPF to measure transverse position after spectrometer magnet

Table with copper and tungsten targets

Scintillator to measure incoming secondaries
Overview of PID

- Particle Identification based on:
  - Time-of-flight between XBTF687 and XBTF706
  - Cherenkov Signal in Cherenkov1 (C1, 713) and/or Cherenkov2 (C2, 716)
  - TDC Timestamps of Cherenkov Signals and Hits in the four XBTF sections matched to a particle trigger in defined time window.
- Optimum case:
  - One possible TOF combination and one or no timestamp matched to each particle trigger
Results for 1 GeV/c

- Calibration of TOF depending on channel AA, AB, BA, BB:
  - Between 65.5-66.5ns subtracted from each channel

![Graph showing TOF (ns) vs Events for different particles](image)

- Positrons
- Protons
- Pion/Muon

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Results for 2 GeV/c

- C1 is not used, C2 sees light only for positrons.
Results for 3 GeV/c

- C1 (high pressure) sees light for positrons, pions and muons
- C2 (low pressure) sees light only for positrons
Results for 6 GeV/c

- C1 (high pressure) sees light for pions, muons, positrons and kaons
- C2 (low pressure) sees light for pions, muons and positrons