Test Beam Facilities for HEP Detectors

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HEPAP Meeting

December 5-6, 2024

Outline

- Applications for test beam facilities for HEP detectors
- General requirements
- Overview of worldwide facilities
  - N.B.: Fermilab's FTBF covered in separate talk
- Future needs

Snowmass White Paper: "Test Beam and Irradiation Facilities"
https://arxiv.org/abs/2203.09944

Applications for test beam facilities

- Allow HEP community to test the performance of their detectors (sensors, electronics, materials) under realistic conditions. Need to qualify new technologies!

- Crucial especially for collider and neutrino detector technologies
  - HL-LHC upgrade, desired features: (O)MHz proton beam with MIP energies and high-quality tracking telescopes
  - Neutrino community: R&D for DUNE, Hyper-K and hadron production measurements with target materials; test beams are also used to measure response of detectors to particles of interest, providing data for detector calibration (→physics)
- Synergies with EIC and satellite experiments

General requirements

- There is interest in beam energies from MeV to hundreds of in all particle species

  ➔Test beam facilities should be versatile, offering as much variety in beam shape, intensity and particle composition as possible

- Neutrino detectors:
  - Experiments are generally interested in charged particles and neutrons with momenta ranging from 100 MeV to a few GeV
  - Accelerator-based neutrino experiments also benefit from hadron production experiments that provide data necessary for neutrino flux calculations and measurement of nuclear processes
    - benefit from medium to long-term installations
- In all cases there should be robust instrumentation to finely control and characterize the beam

Current facilities (from Snowmass white paper)

Facility	# of Beams	Particles	Energy Range	Availability
CERN/PS	2	e,h,μ(sec.)	0.5-10 GeV/c	9 mos/yr
CERN/SPS	4	p(prim.); e,h,μ(sec.); e,h(tert.); Pb(prim); other ion species	20-400 GeV/c proton equivalent	9 mos/yr
CERN/CLEAR	1	e^-	50-250 MeV/c	8-9 mos/yr
DAFNE Frascati	1	e^+/e^-(prim. and sec.); photons	25-750 MeV/c	25-35 wks/yr
DESY (Hamburg, GE)	3	e^+/e^-(sec.); e^-(prim., planned)	1-6 GeV/c; 6.3 GeV/c	11 mos/yr
ELPH (Sendai, JP)	2	photons (tagged); e^+,e^- (conversion)	0.7-1.2 GeV/c; 0.1-1 GeV/c	2 mos/yr
ELSA (Bonn, GE)	1	e^-	1.2-3.2 GeV/c	$\sim$ 30 days/yr
FTBF (Fermilab, US)	2	p (prim.); e,h,μ (sec.); h (ter.)	120 GeV/c; 1-66 GeV/c; 200-500 MeV/c	8 mos/yr
IHEP (Beijing, CN)	2	e (prim.); e,p,π (sec.)	1.1-2.5 GeV/c; 0.1-1.2 GeV/c	3 mos/yr
IHEP (Protvino, RU)	5	p,C-12 (prim.); p,K,π,μ,e (sec.)	70 (6-300) GeV/c; 1-45 GeV/c	2 mos/yr
MAMI (Mainz, GE)	3	e^-,photons	$<$ 1.6 GeV/c	$\sim$ 30 days/yr
NSRL (Brookhaven, US)	1	p, heavy ions	0-1 GeV/n	10 mos/yr
piEI,ppiMI,etc. (PSI, CH)	2-4	π,μ,e,p	50-450 MeV/c	6-8 mos/yr
PIF (PSI, CH)	1	p	5-230 MeV/c	11 mos/yr
RCNP (Osaka, JP)	7	p,heavy ions,n,μ^+	24-400 MeV/c	7-8 mos/yr
SLAC (Stanford, US)	0	e (prim.); e (sec.)	2.5-15 GeV/c; 1-14 GeV/c	currently no beam
SPRING-8 (Compton Facility, JP)	2	photons (tagged), e^+,e^- (conv.)	0.4-2.9 GeV/c	>60 days/yr

Table 1: Overview of existing test beam facilities

Most relevant facilities for US community

Facility	# of Beams	Particles	Energy Range	Availability
CERN/PS	2	e,h,μ(sec.)	0.5-10 GeV/c	9 mos/yr
CERN/SPS	4	p(prim.); e,h,μ(sec.); e,h(tert.); Pb(prim); other ion species	20-400 GeV/c proton equivalent	9 mos/yr
CERN/CLEAR	1	e^-	50-250 MeV/c	8-9 mos/yr
DESY (Hamburg, GE)	3	e^+/e^-(sec.); e^-(prim., planned)	1-6 GeV/c; 6.3 GeV/c	11 mos/yr
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NSRL (Brookhaven, US)	1	p, heavy ions	0-1 GeV/n	10 mos/yr
SLAC (Stanford, US)	0	e (prim.); e (sec.)	2.5-15 GeV/c; 1-14 GeV/c	currently no beam
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

NASA is main customer

Fermilab

Key facilities for current collider experiment developments

- FNAL/FTBF:
  - 2 beamlines
  - 120 GeV p (pri.), 1-66 GeV e/h/μ (sec.), 200-500 MeV h (ter.)
  - availability ~8 mo/yr

shutdown 1/2027-7/2030
construction for LBNF/PIPII

- CERN/SPS:
  - 4 beamlines
  - 20-400 GeV p(pri.), e/h/μ (sec.), e/h (ter.) and ions
  - availability ~9 mo/yr

shutdown 9/2026-7/2029
construction for HL-LHC upgrade

- DESY/DESY II:
  - 3 beamlines
  - 1-6 GeV e^+/e^-
  - availability ~11 mo/yr

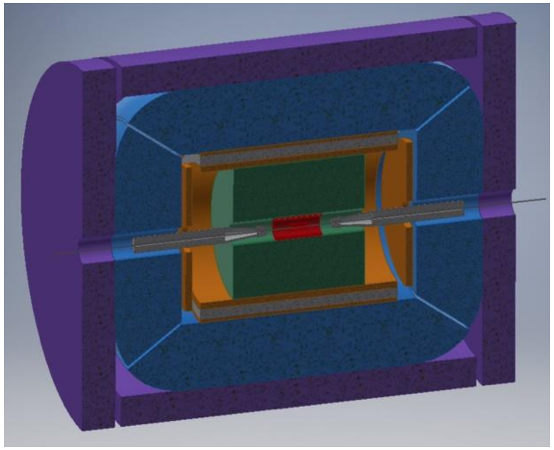
shutdown 2030-2032
construction for PETRA IV/DESY IV

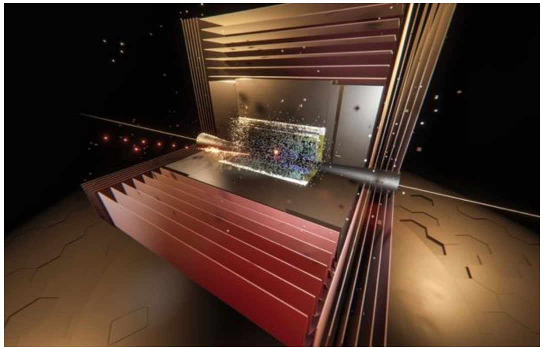
New and planned facilities

- LESA at SLAC:
  - parasitically use LCLS II SRF Linac, extract dark current with kicker
  - delivers low current 4-8 GeV CW e- beam, 25 ns beam pulses
  - together with LDMX
  - expect first test beam experiments in Spring'25
- FNAL:
  - taskforce working on plans for test facilities at PIP II (see Evan's talk)
- DESY:
  - planning upgraded test beam facility at PETRA IV (not yet approved)

Future needs

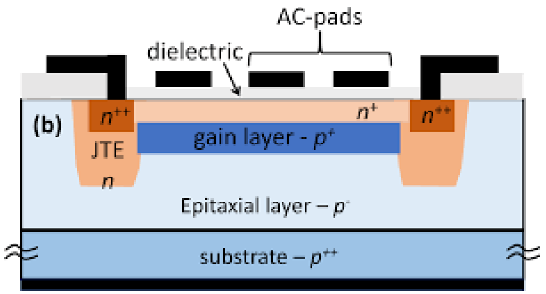
- A broad array of test beam capabilities are required to develop the next generation of detectors for tracking, calorimetry, and particle identification
- Beams of different particle species at a wide range of energies are critical to test the response and performance of different detector technologies, where well-calibrated instrumentation such as trigger hodoscopes, tracking telescopes, and Cherenkov detectors is often required to analyze and understand the performance of the device under test
- Developing **O(1ps)-timing detectors** requires test beams with high repetition rate and extremely short pulses
- Developing **rad-hard detectors** would benefit from colocation of test beam and irradiation facilities for ease of handling/storage and faster turnaround times





Future needs: precision timing detectors

- Future collider detectors will require 1-5 ps time resolution
- Testing the timing precision of these detectors is challenging because it requires some external time reference of comparable or better precision. A beam with very short pulses and an adaptable repetition rate, where the accelerator RF provides an extremely precise time reference, would be highly advantageous.



- The critical capabilities required are
  1. pulses of ps length or less
  2. the availability of a clean time reference from the accelerator
  3. the ability to set the repetition rate low enough to disambiguate the effects of different beam pulses. At the same time, the ability to deliver a high (and controlled) repetition rate is valuable for testing detectors' responses to the high event rates expected in many next-generation experiments.

Summary

- Test beam facilities are a crucial tool in the development of new technologies for HEP experiments
- Versatility in particle content, energy, time structure is a must
- As a worldwide community we need to make sure that sufficient beam time is available at all times
- The test beam landscape is volatile. If I forgot any existing beams or plans for new facilities, let's discuss!