PROCEEDINGS OF SCIENCE

Development of tracking software and detector design studies for the proposed FASER-2 experiment at the LHC

Olivier Salin[a,*] and Alan Barr[a] on behalf of the FASER-2 collaboration

[a] *Department of Physics, University of Oxford, Keble Road, OX13RH, Oxford*

E-mail: olivier.salin@ens-paris-saclay.fr, alan.barr@physics.ox.ac.uk

FASER-2 is a potential upgrade to the FASER experiment, and could be hosted in the proposed Forward Physics Facility (FPF) 620m to the west of the ATLAS interaction point, in the far-forward region of the LHC collisions. The experiment would have sensitivity for long-lived particles (LLPs) produced by rare meson decays that could be potential candidates for light dark matter. The proposed upgrade involves a significantly enlarged volume compared to FASER, resulting in an increase in reach for various BSM signals of several orders of magnitude and allows sensitivity to models that were previously out of reach, such as Dark Higgs and Heavy Neutral Leptons. This poster will present the development of a tracking software for the FASER-2 experiment using the A Common Tracking Software (ACTS) toolkit to aid in accurate mass and pointing reconstruction of charged particles. The developed tracking software will be used to compare various FASER-2 layouts and tracker technologies, thereby contributing to the design studies of the FASER-2 experiment.

The Eleventh Annual Conference on Large Hadron Collider Physics (LHCP2023)
22-26 May 2023
Belgrade, Serbia

*Speaker

PoS(LHCP2023)241

1. Introduction

Since the discovery of the Higgs boson [1], much research has focused on searching for physics beyond the Standard Model to explain phenomena such as the nature of dark matter. Large detectors at the LHC are well instrumented at large angles relative to the beamline but have a blind spot for particles produced approximetely parallel to the beamline, making the previously unexplored far-forward direction an attractive option for new physics searches. Experiments in this far-forward direction may detect long-lived particles (LLP) [2] characteristic of very weakly interacting particles produced by rare meson decay that are possible candidate for light dark matter. As proof of principle the FASER [3], ForwArd Search ExpeRiment, detector has been proposed and installed to study collisions at 480 m from the ATLAS interaction point and has been taking data during Run-3 of the LHC.

The Forward Physics Facility (FPF) [4] [5] is a proposal to construct a dedicated 65 m long cavern facility to house a suite of far-forward experiments during the High-Luminosity LHC era approximately 620 m west of the ATLAS Interaction Point. The location of the FPF provides a low background environment thanks to the shield of concrete and rock which is crucial for weakly interacting particles and rare processes to be observed. The FPF is expected to host existing upgraded detectors such as FASER-2, FASERnu2, and Advanced SND, as well as new experiments such as FORMOSA, which seeks to identify millicharged particles and related signals, and FLArE, a noble liquid TPC that might detect neutrinos and look for light dark matter produced by the LHC.

FASER-2 [5] is a new experiment proposed for the FPF with a significantly enlarged volume compared to FASER, which increases the angular acceptance of long lived products from neutral pions and B-meson and improves sensitivity for larger LLP masses that results in an improvement in the reach by a factor of four orders of magnitude. LLPs are predicted to be produced by rare decays of heavy mesons, and their charged decay products would be efficiently detected by the magnetic spectrometer and tracker that is FASER-2. The proposed dark photon and dark Higgs models serve as benchmarks for LLPs in FASER-2 detector design studies.

Particle physics experiments often rely on tracking software that can depend strongly on the specific design of the detector but share common features on some algorithms. This is why A Common Tracking Software (ACTS) [6] was developed as an experiment-independent toolkit in modern C++ and Python for charged particle track reconstruction in high-energy physics experiments. The ACTS project offers high-level track reconstruction modules that can be utilized in any tracking detector. Several experiments, such as the ATLAS, ALICE experiment or LDMX [7], are implementing ACTS.

The aim of this study is to develop a reliable tracking software for FASER-2 using the ACTS toolkit to facilitate accurate mass and pointing reconstruction of the detector. This tracking software will then be utilised to compare possible FASER-2 layouts and tracker technologies to contribute to the design studies of FASER-2.

2. FASER-2 geometry

The expected design of FASER-2 is depicted in Fig.[1] using a Geant4 [8] simulation, created using the python library pyg4ometry [9]. Studies are on-going to optimise this baseline design of the detector.

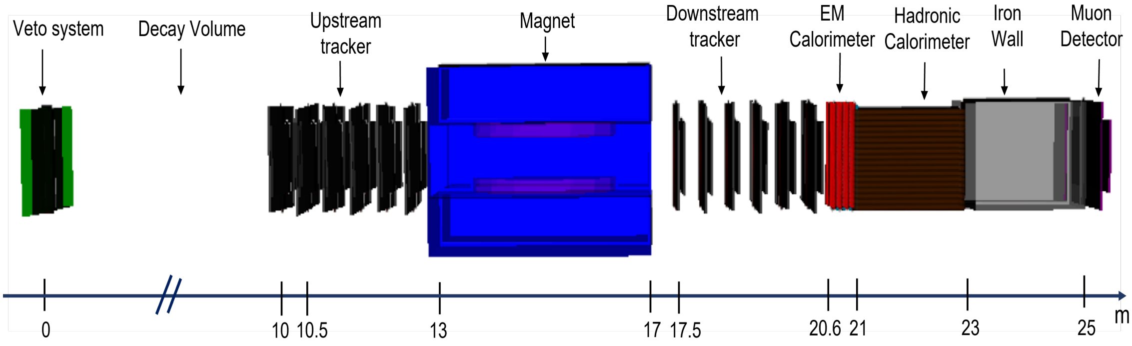

Figure 1: FASER-2 detector Geant4 simulationr. From left to right, it comprises a veto system, a large cuboid decay volume, followed by a spectrometer composed of a large 1T magnet [10] with 6 tracking stations based on LHCb's SciFi detector [11] each upstream and dowstream, electromagentic and hadronic dual-readout calorimeters [12], an iron wall, and a muon detector for particle identification and precise muon reconstruction.

3. Track reconstruction performance

FASER-2 tracking software was implemented using the toolkit ACTS. The evaluation of the track reconstruction performance is a crutial aspect of the tracking software development.

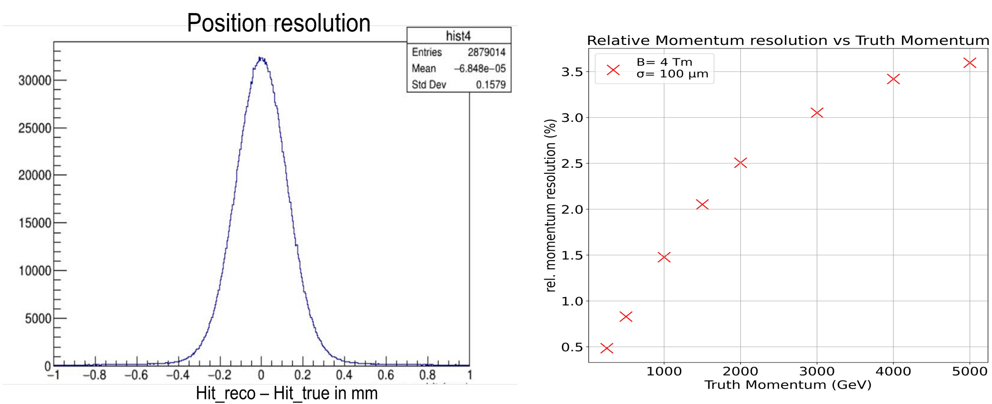

Figure 2: Simulation of 50 000 muons using ACTS toolkit to evaluate track reconstruction performance with the nominal FASER-2 geometry described in 1 . Left: Position resolution of each hits in the simulated trackers after the effect of the detector resolution modeled by a gaussian of σ = 100 um. Right: Plot of the momentum resolution $\sigma(\frac{p_{\text{reco}}-p_{\text{truth}}}{p_{\text{truth}}})$ of muons from 200 MeV to 5 TeV simulated using particle gun

4. FASER-2 detector design

FASER-2 track reconstruction software was then used to explore an optimisation of the design with more cost-efffective technologies while keeping great performances (impact of the trackers resolution for example). The study of the effect of the misalignment of the tracking station has a major impact on the tracking performance that needs to be quantified in simulation. The mechanical precision of the tracker placement is estimated to be around 250 μm.

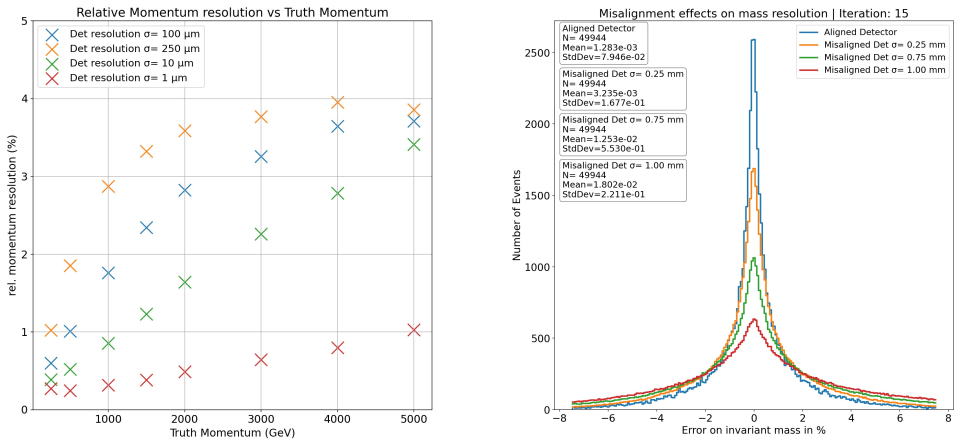

Figure 3: Simulation in FORESEE [13] of Long-Lived Particle decays with benchmarkmodel Dark Higgs $\rightarrow \mu^{+}\mu^{-}$ (without background) reconstructed using ACTS toolkit with the nominal FASER-2 geometry described in 1 . *Left*: Plot of momentum resolution to compare the track reconstruction performance of FASER-2 trackers with detector resolution from 1 μm to 100 μm. *Right*: Invariant mass plot with aligned detector and toy randomly misaligned detector for different values of misalignment (0.25 mm, 0.75 mm, 1.0 mm) averaged by 15 iterations to lessen the impact of randomness. The results from the plot shows that with a 250 μm as expected by mechanical precision the performance is not significantly impacted.

5. Conclusion and perspective

Our study of the evaluation of the track reconstruction demonstrated very good performance and showed the great potential of FASER-2 for precise mass and vertex reconstruction. Additionally, we were able assess and compare the performance of various FASER-2 layouts for the search of Long-Lived Particle. Theses insights have influenced our FASER-2 detector design studies, leading to potential modifications to the tracker and magnet design that could significantly reduce the cost of the detector without compromising performance. Even though substantial progress has been made, there is room for further improvement and refinement of the FASER-2 tracking software.

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