FASER

ForwArd Search ExpeRiment at the LHC

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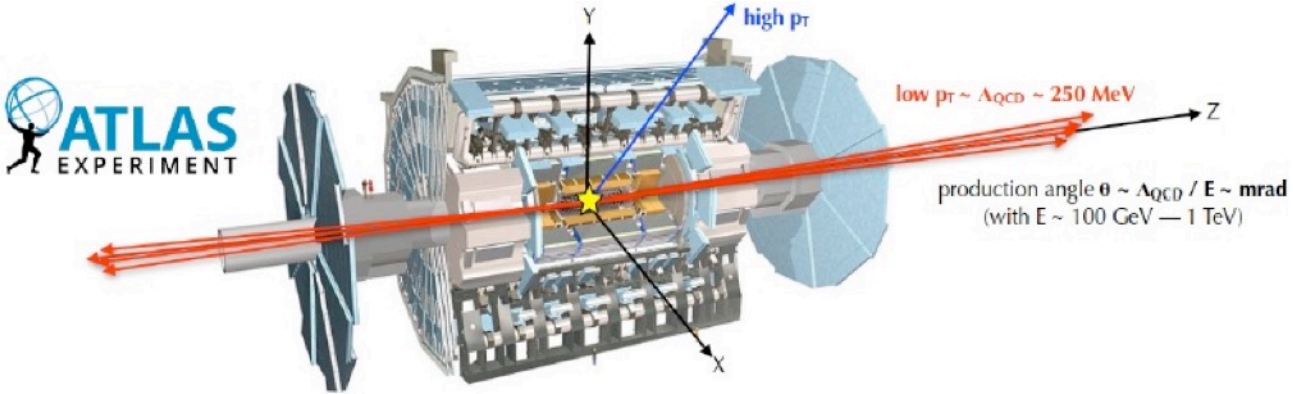
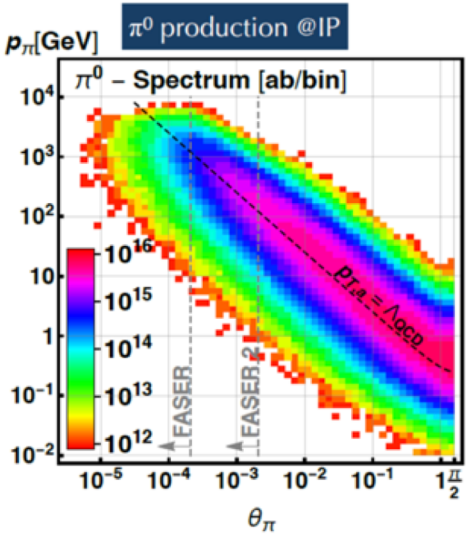
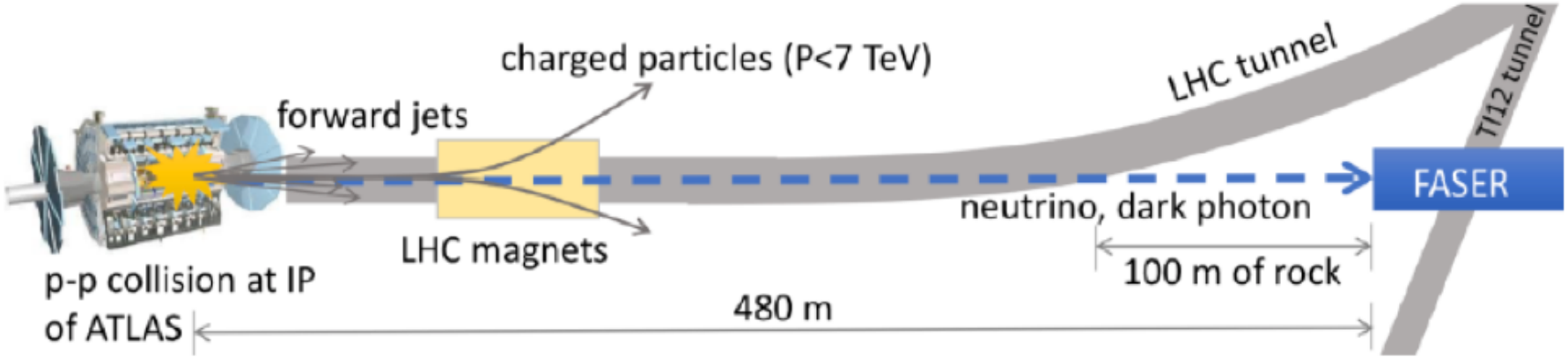
Motivation

- ATLAS/CMS searches for heavy, strongly interacting new particles (high p_T, promptly decay)
- What if new particles are light and weakly interacting?
- LHC will produce ~2.3×10^{17} π ,~2.5×10^{16} η,~1.1×10^{15} D,~7.1×10^{13} B in Run-3, most of which along beam collision axis
- Try a complementary search in forward direction





ForwArd Search ExpeRiment



- A new small experiment to search for new long-lived particles(LLP) produced in Interaction Point 1 (IP1/ATLAS) at the LHC from Run-3
- First concept in 2017 (Feng, Galon, Kling, Trojanowski), approved by CERN in March 2019 (limited budget ~ 2M$)
- Detector design, construction and testing are progressing well in the Long Shutdown 2

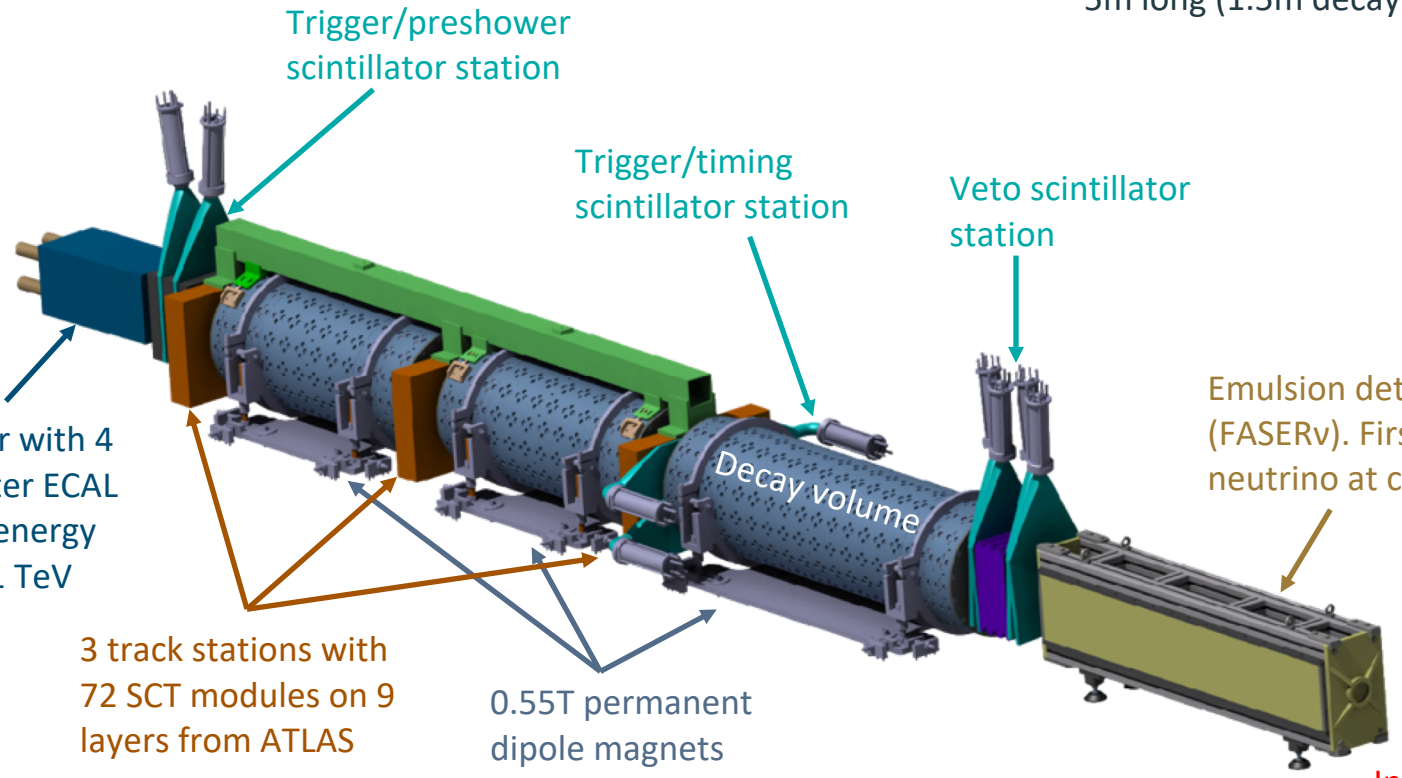
FASER Collaboration

65 collaborators, 18 institutions, 8 countries

https://faser.web.cern.ch/home

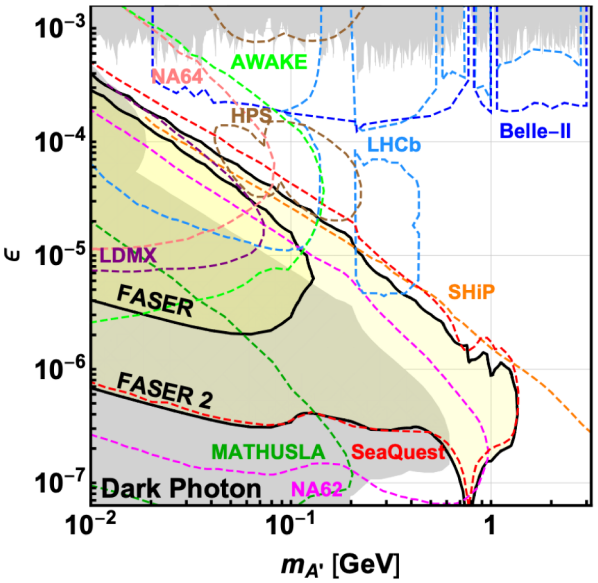
FASER detector

20 cm aperture (η>9.1)
5m long (1.5m decay volume)

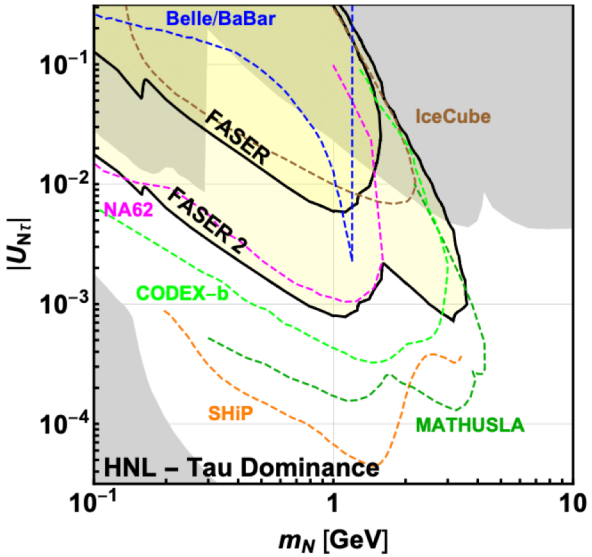


Physics potential

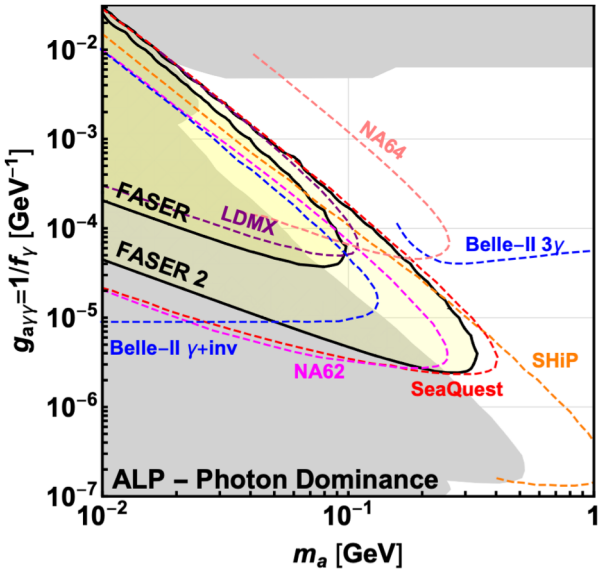
Dark photons (A’)



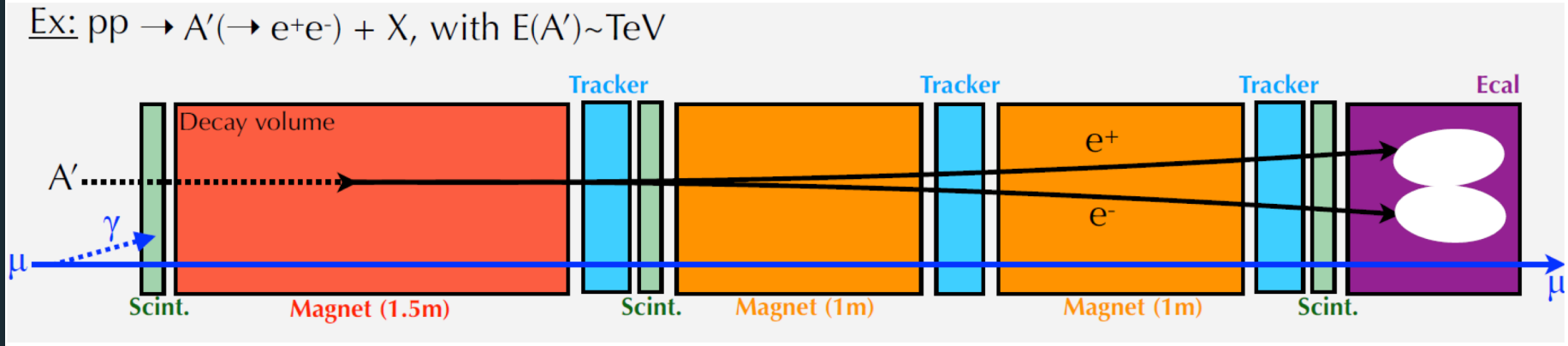
Heavy Neutral Leptons (HNLs)



Axion-like particles (ALPs)



Dark Photon Signal and Backgrounds

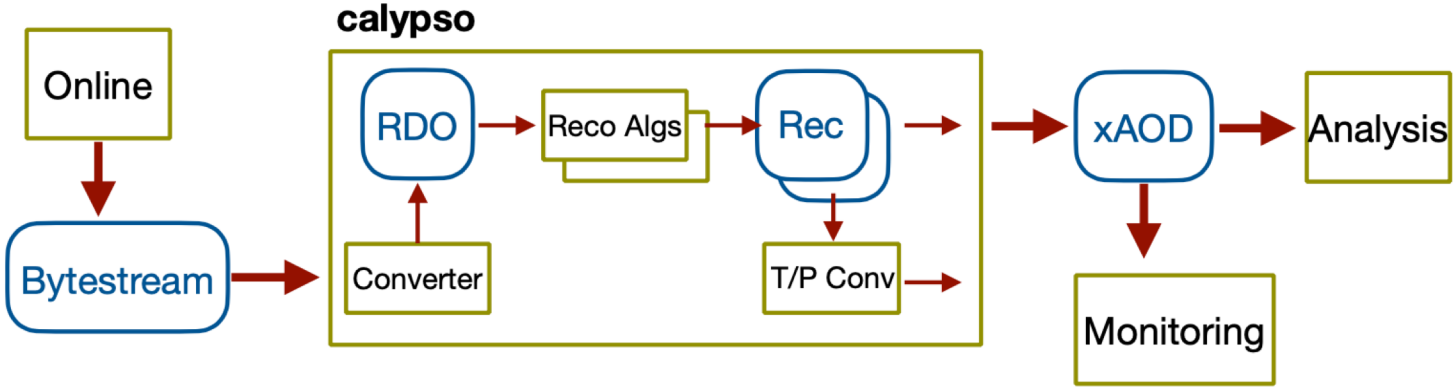


- Signal is two oppositely-charged tracks originating in decay volume, pointing back to IP1 and depositing nearly all their measured momentum as electromagnetic energy in the Ecal

- FLUKA simulations and in-situ measurements used to assess expected backgrounds
  - ✓ IP1 collisions (neutrino, muon)
  - ✓ off-orbit protons hitting beam pipe aperture close to FASER
  - ✓ beam-gas interactions

Offline software

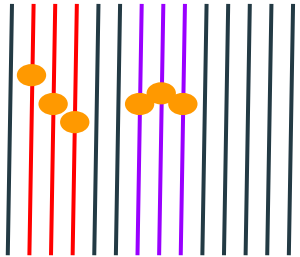
- Adapt open source ATLAS Athena (→ “Calypso”) framework for offline: https://gitlab.cern.ch/faser/calypso

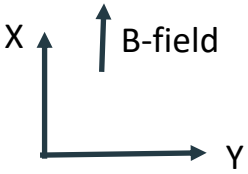


- Bytestream - files written by online, array of bytes
- RDOs - Raw Data Objects, start of reconstruction
- Calypso data is transient, must ‘persistify’ it (i.e write it to a file)
- xAOD - Analysis Object Data - output file (root-readable data format)

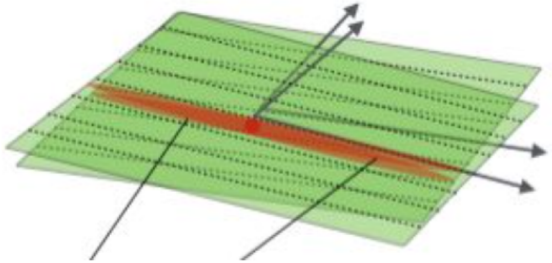
Offline track reconstruction

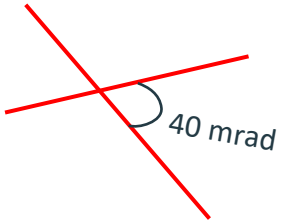
Group adjacent hit strips as clusters



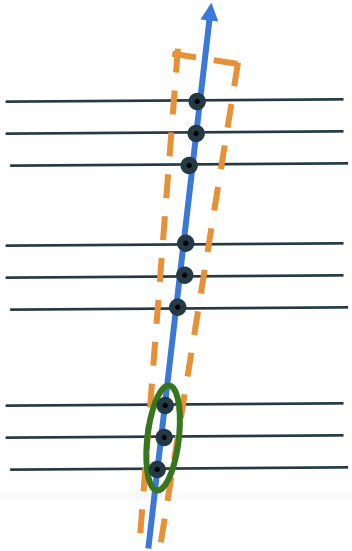


Combine the clusters on front and back sensor of one SCT modules to form space points

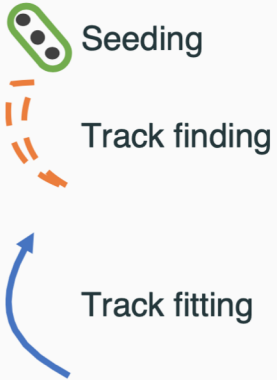




Pattern recognition and ambiguity solving



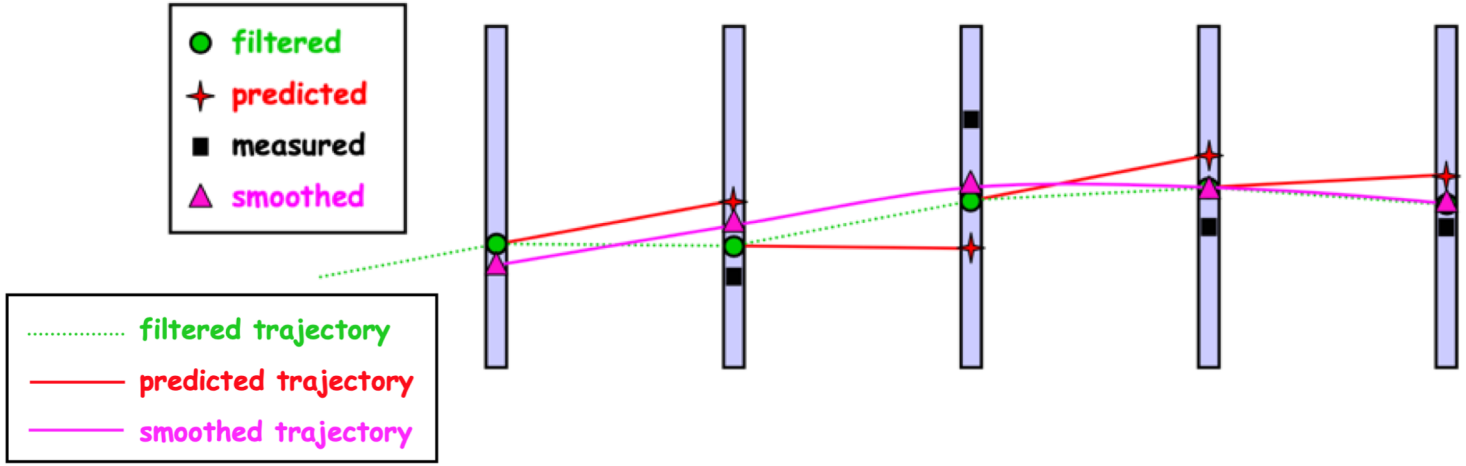
Track fitting with selected space points



A Common Tracking Software (ACTS)

- Based on the ATLAS tracking software
- Provide a toolbox with experiment-independent components
- Minimal dependencies (e.g. no required ROOT dependency)
- Allow building (possibly) experiment-specific applications like seeding, track finding, vertex finding
- Primary goal: ATLAS run 3 and beyond

Kalman filter

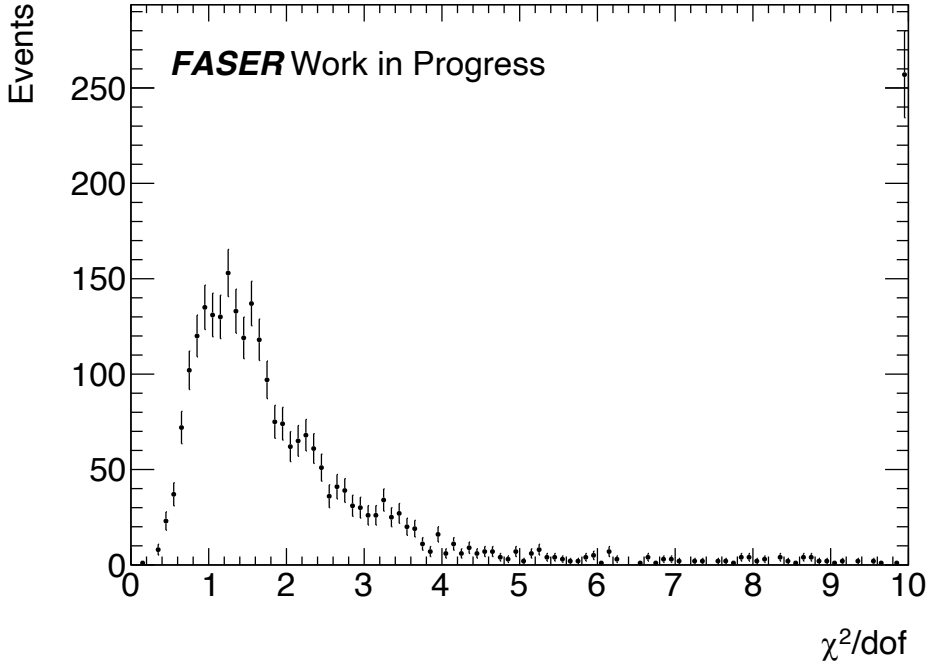


- The filtering is a weighted average of the measurements y_n and prediction y_p

$$y_f = \frac{\frac{1}{\sigma_p^2} y_p + \frac{1}{\sigma_n^2} y_n}{\frac{1}{\sigma_p^2} + \frac{1}{\sigma_n^2}}$$

- Iterative
- The computation time increases only linearly with the number of measurements
- The estimated track parameters closely follows the real path of the particle

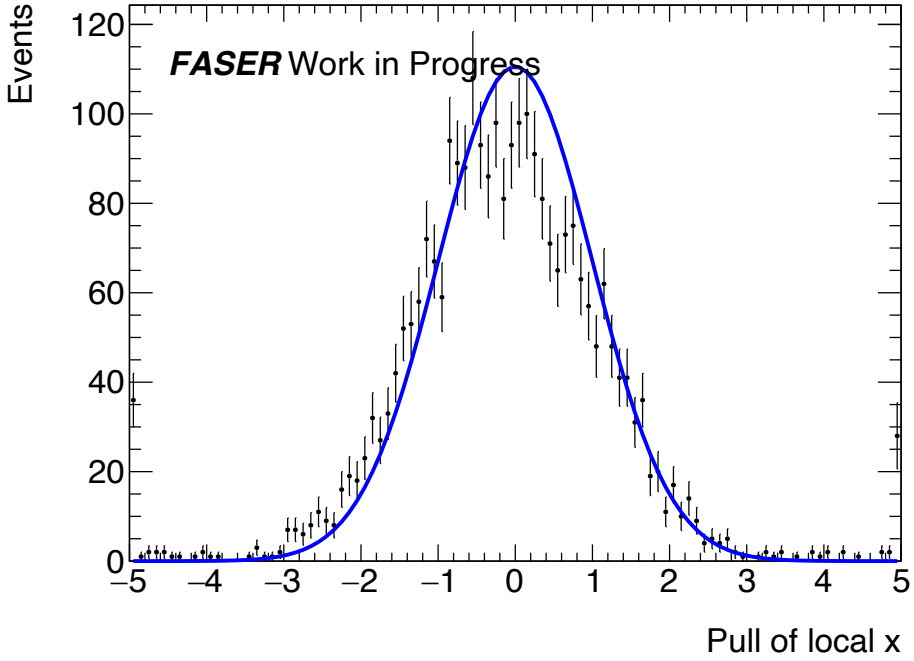
Fitting performance



- Shoot 100 GeV μ^+ from IP1
- Full Geant4 simulation -> digitization -> clusters making -> space points formation -> kalman fitter

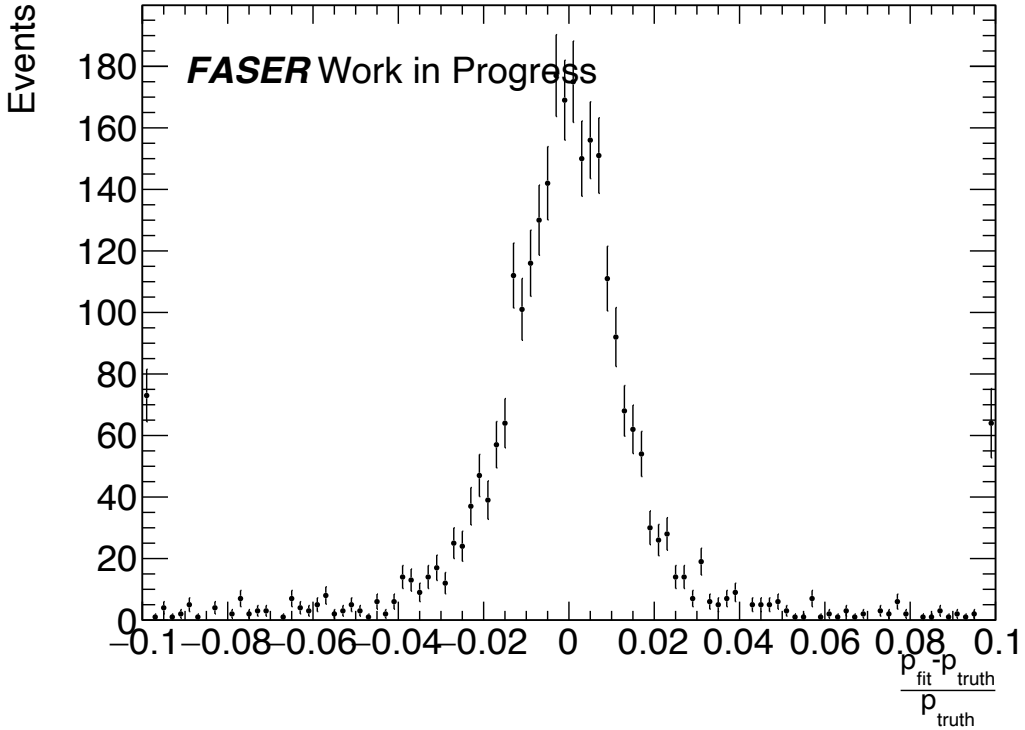
Fitting performance

Perpendicular to strips on side 0 sensor



- Pull distribution of local x on the first layer
- Bule curve is standard gaussian distribution as reference

Fitting performance



- The relative momentum resolution is ~1% level

Summary

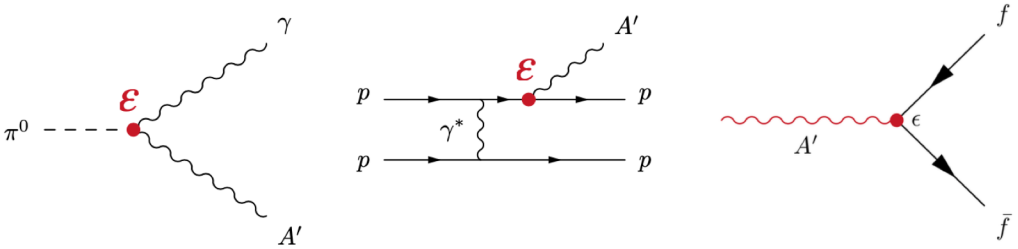
- FASER is a new experiment at the LHC to search new long-lived particles, which complements the current physics program
- FASER is on track for LS2 installation, and plan to take data from Run-3
- The first version of offline software based on Athena is done, and getting maturer

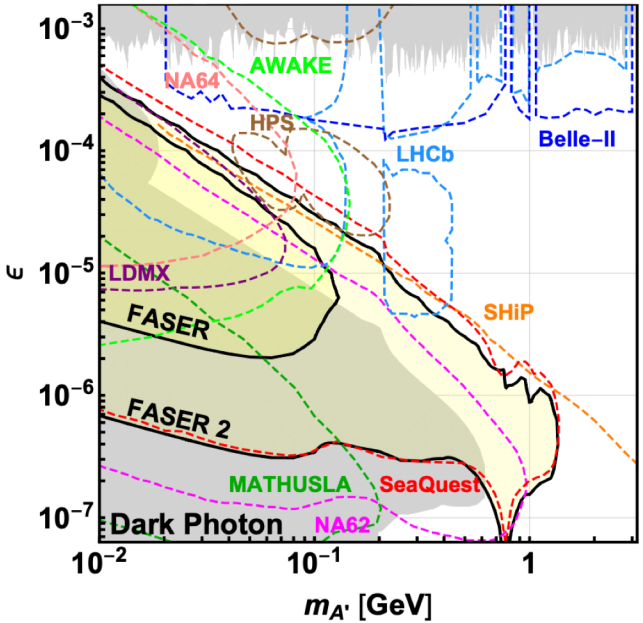
Backup

Dark photon(A')

- Light, weakly coupled mediator to a dark sector with DM particle
- Dark photons (A') similar to SM photon but massive, $m_{A'}$, and couplings to SM particles suppressed by ε.
- Decays to pair of charged particles
- Expect $N_{A'} \sim 100$ (for $m_{A'} = 100$ MeV) signal events even with large suppression ($\varepsilon^2 = 10^{-10}$)

The LHC can be a dark photon factory!

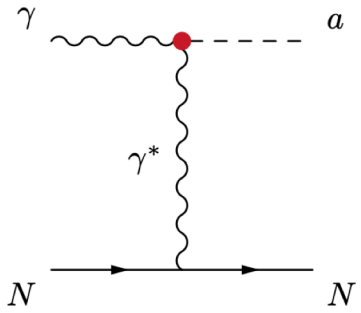




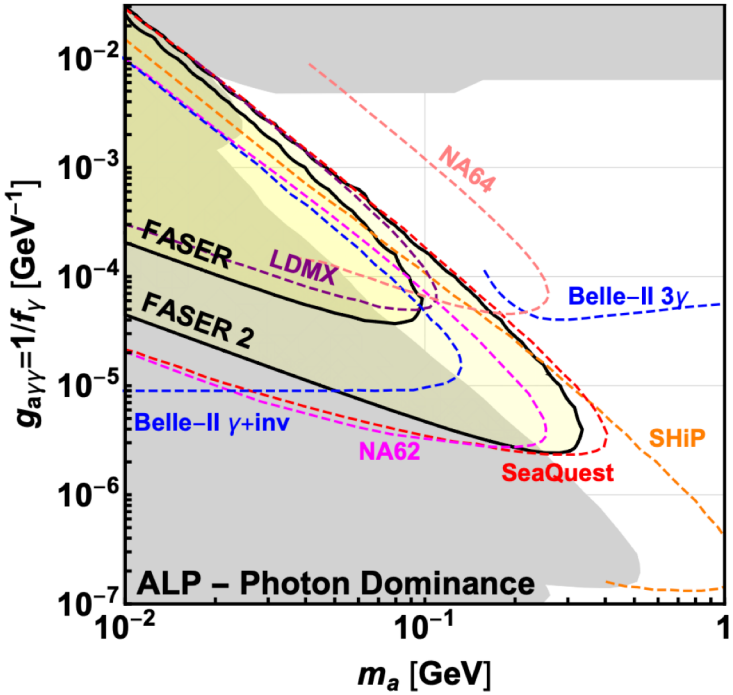
Axion-like particles (ALPs)

- **ALPs** can be produced in the LHC
  - Production at LHC neutral beam absorbers (TAN) through the Primakoff process $\gamma N \rightarrow aN$
  - ALP travels ~ 350 m and decays to $\gamma\gamma$ in FASER
- Striking signature of no charged tracks and > TeV deposited energy in EM calorimeter

"Beam dump" experiment at the LHC!



$a \rightarrow \gamma\gamma$

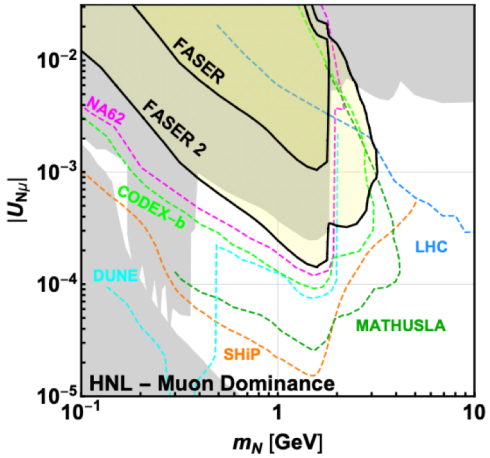


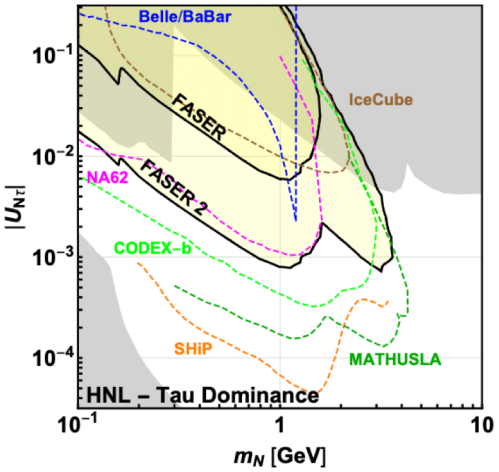
Heavy Neutral Leptons (HNLs)

- Model where HNL couples to one SM lepton doublet.
  - Parameters: mass m_N, mixing $U_{N\alpha}$ where α=e, μ, τ
- HNL production mainly occurs through heavy meson and τ decays

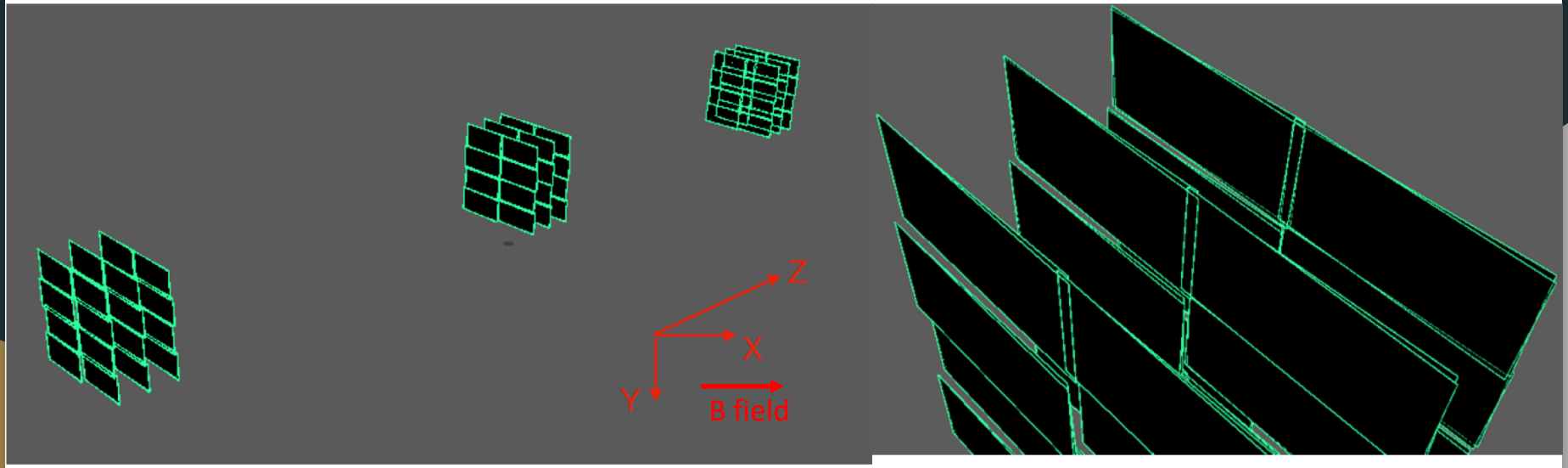
  $B^+ \to lN, B \to DlN, D_s \to lN, D \to KlN$
- Several decay modes e.g. $N \to \pi^{\pm} l^{\mp}, ll\nu, \pi^+\pi^-\nu$
- Existing limits on HNL coupling to τ are not very well constrained

FASER sensitive to large unconstrained region for ν_τ mixing



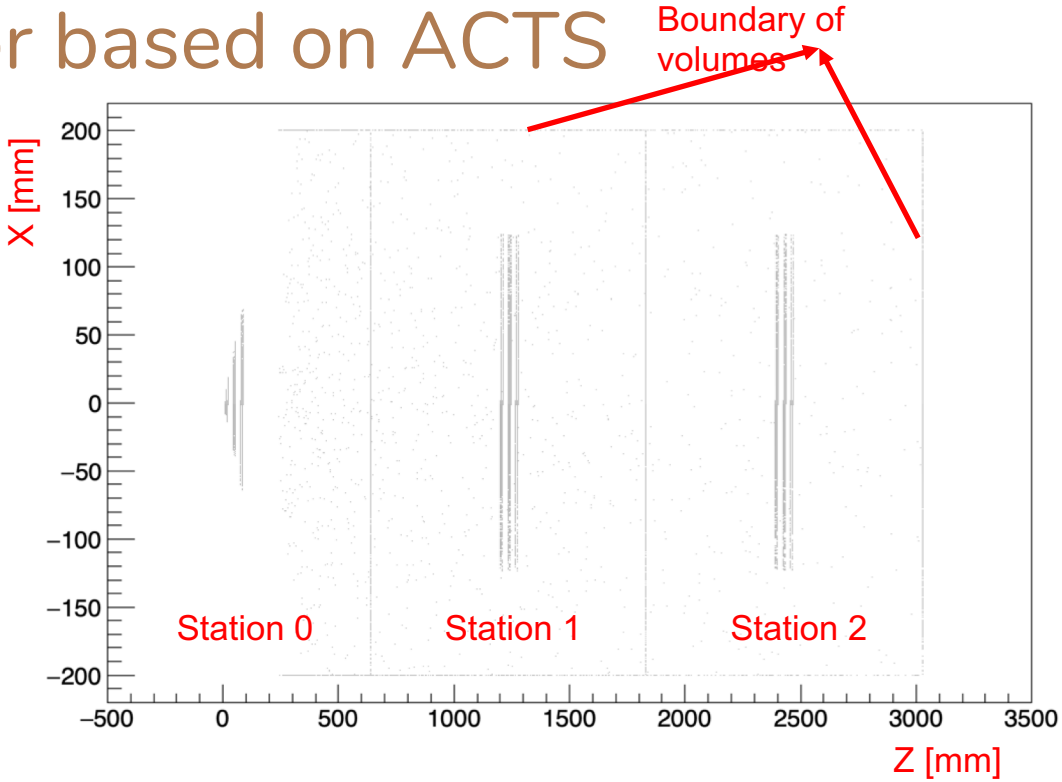


Tracking geometry with ACTS



- Build the TrackingGeometry with ACTS CuboidVolumeBuilder
- One cuboid volume for one station
- Retrieve SCT elements from DetectorStore and construct ACTS surfaces
- Keep two-sided sensor and staggering structure of each layer

Extrapolator based on ACTS

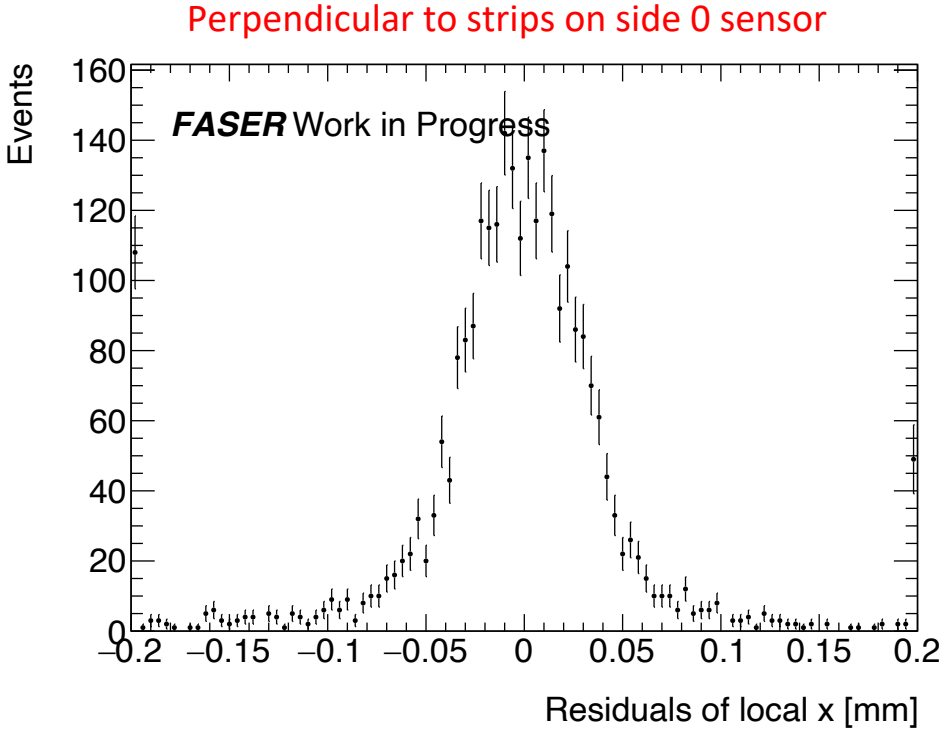


- Based on ACTS propagator
- Shoot particles from (0,0,0) and extrapolate the particles step by step
- Read the realistic FASER magnetic field from condition directly

The definition of 5 track parameters

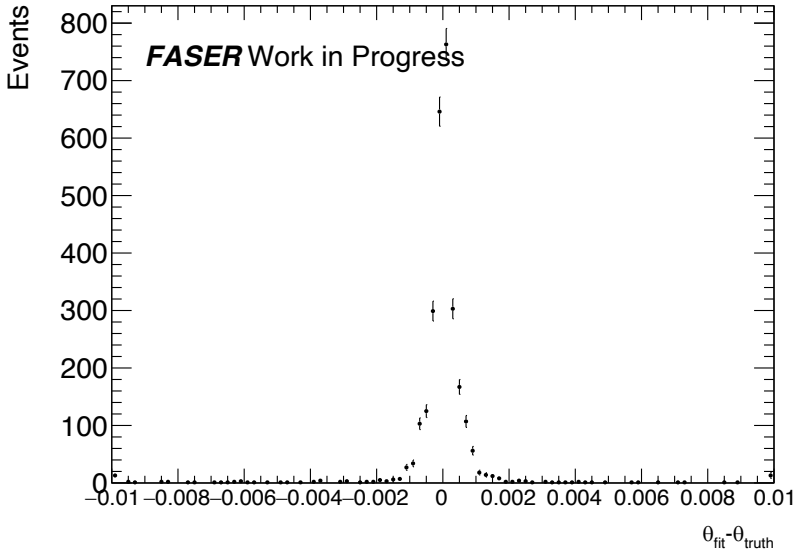
- Local x and local y are the local position on the side 0 sensor of the SCT module where the track pass through the 1st layer
- $\boldsymbol{\theta}$ is the polar angle of the momentum in global coordinate system at the 1st layer
- $\boldsymbol{\varphi}$ is the azimuthal angle of the momentum in global coordinate system at the 1st layer
- q/p is charge over momentum at the 1st layer

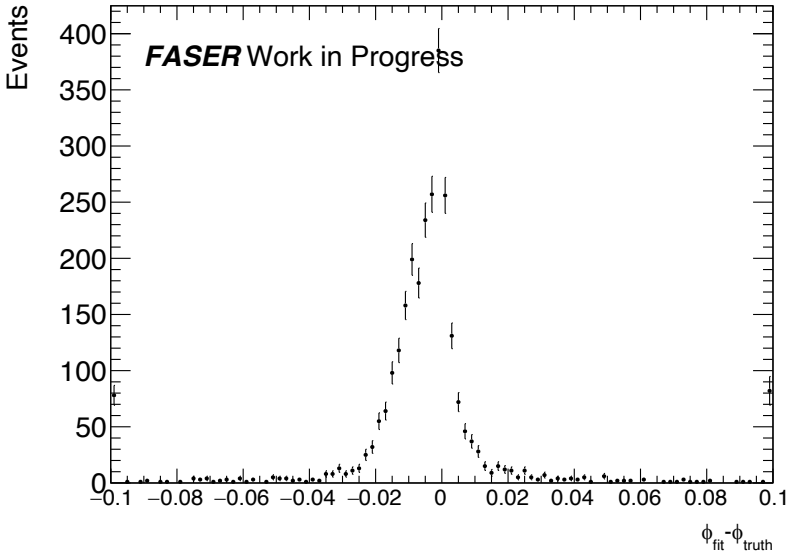
Fitting performance



- Residuals of local x on the first layer

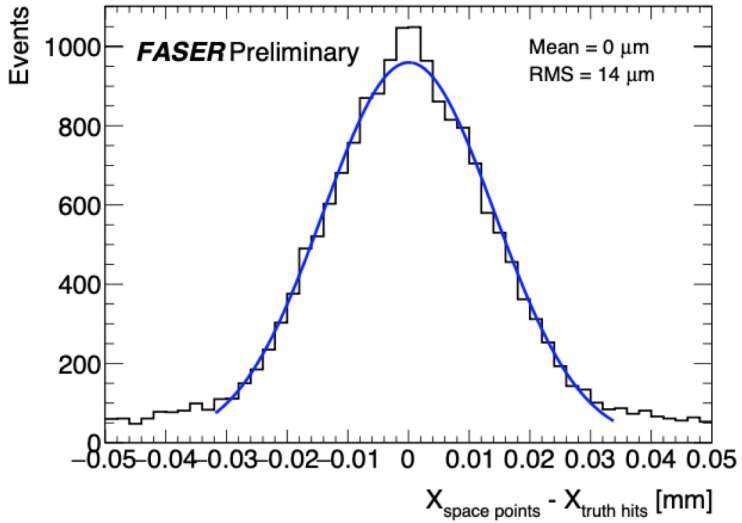
Fitting performance





- The fitted and truth track parameters are all on the first layer

Residual distribution in technical proposal



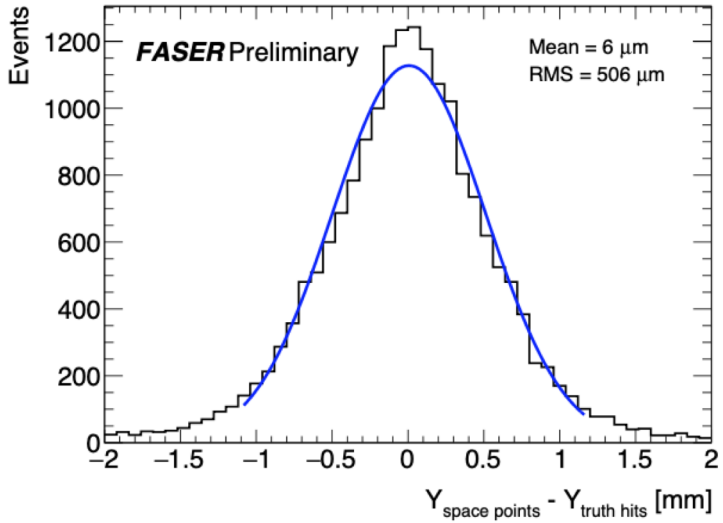


FIG. 55. Spatial resolution of reconstructed space-points in the magnetic bending direction (left) and along the strip direction (right), with respect to Monte Carlo truth, for the first detector plane.

Momentum resolution in technical proposal

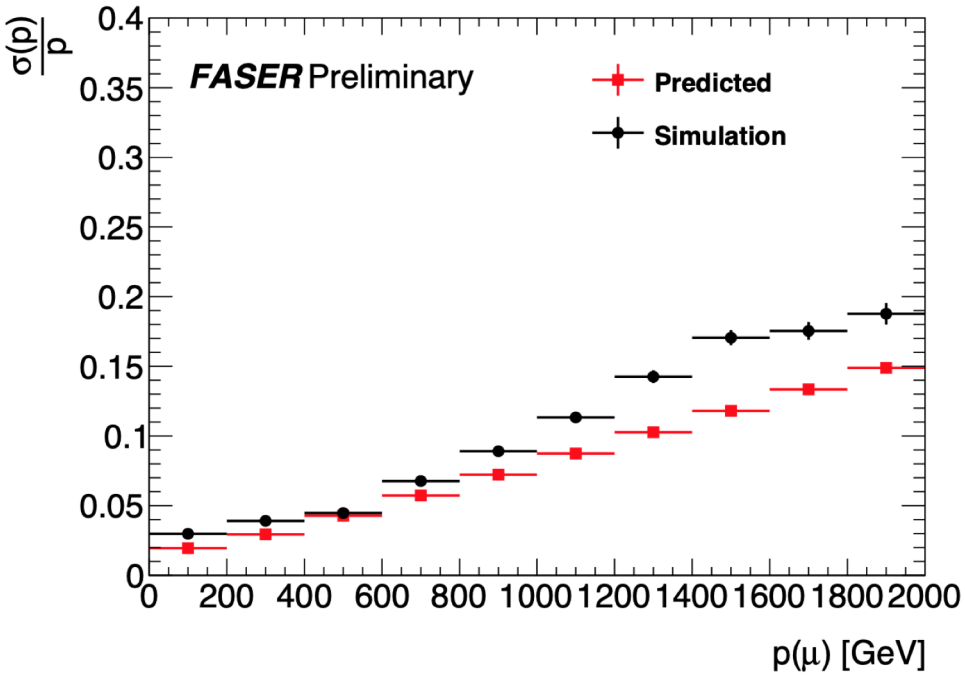


FIG. 56. Fractional momentum resolution (σ_p/p) for reconstructed muon tracks as a function of momentum, compared to the predicted resolution from Karimaki [39].