ACTS in FASER (ForwArd Search ExpeRiment)

Ke Li on behalf of FASER collaboration
09/26/2022

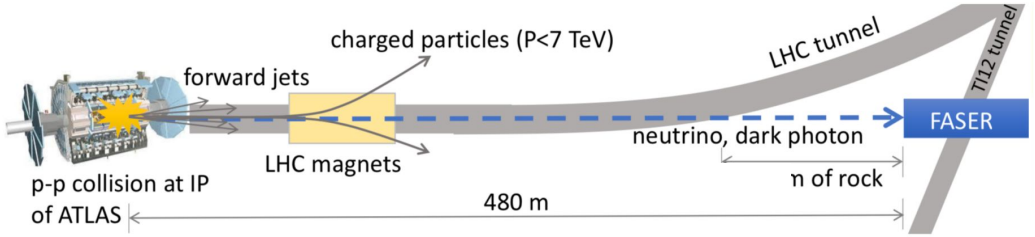
ACTS workshop

UNIVERSITY of WASHINGTON

FASER is supported by:
Heising-Simons foundation and Simons Foundation.

Introduction

- **FASER is designed to search for long lived particle (LLP) produced in pp collision in ATLAS IP:**
  - pp -> SM light mesons -> LLP
  - The light mesons are predominantly produced very collimated with the beam direction
  - Detectors are placed at ~480m from P1 on the beam collision axis with transverse radius of 10cm
  - 100m rock to shield most of the background, good sensitivity for discover



FASER detector

3 Tracker stations:

- Each has 3 layer of 8 silicon strip modules
- Measure track trajectory
- More details in NIMA166825(2022)

Scintillator

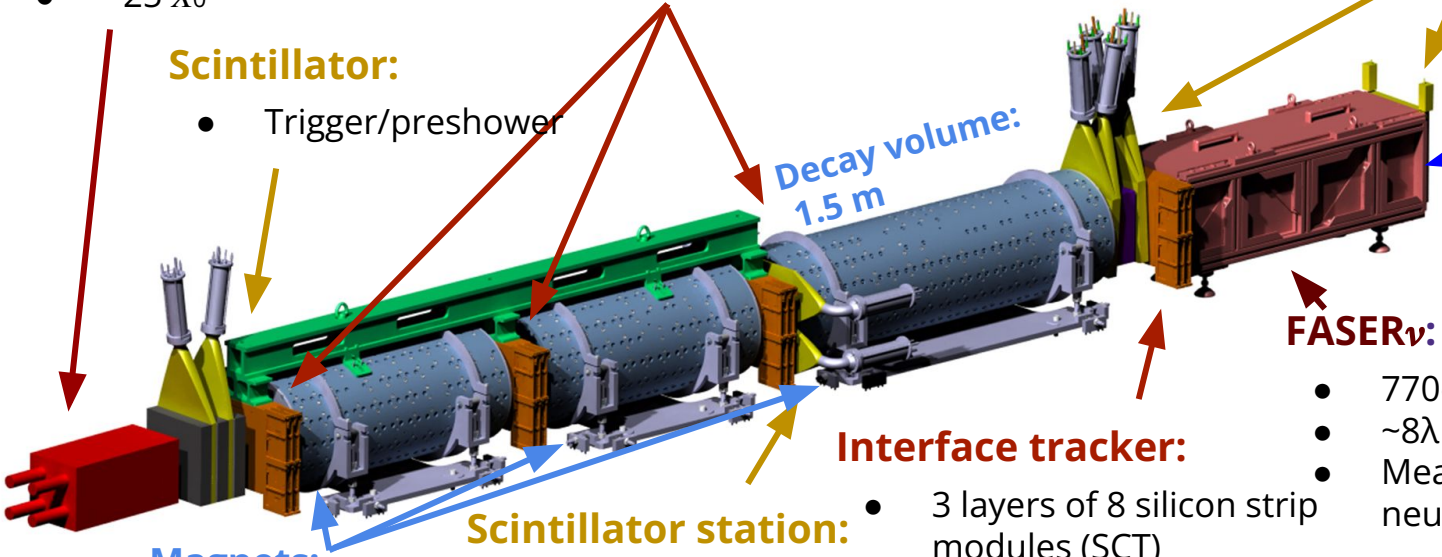
- Veto charged particles

EM Calorimeter:

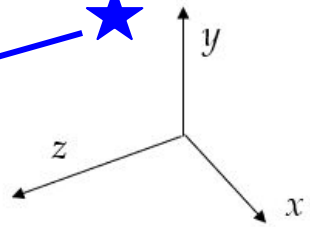
- 66 scintillator + lead planes
- ~25 X_0

Scintillator:

- Trigger/preshower



ATLAS IP



FASERν:

- 770emulsion + tungsten plate
- ~8λ
- Measure track trajectory, neutrino flavor

Interface tracker:

- 3 layers of 8 silicon strip modules (SCT)

Scintillator station:

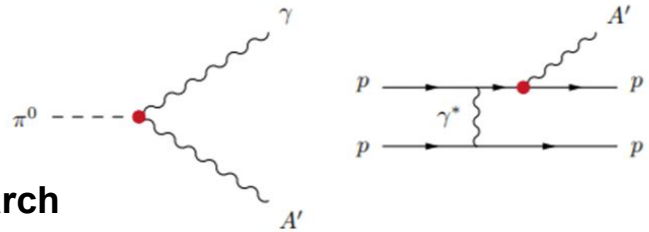
- Triggger/timing
- More details in INST16,P12028 (2021)

Magnets:

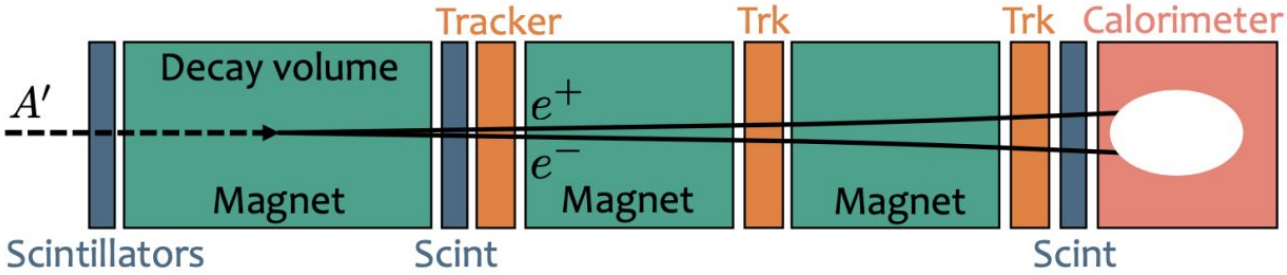
0.55 T

Benchmark signal – dark photon

- Two high energy oppositely charged tracks originating froma common vertex in the decay volume, and with a combined momentum pointing back to the IP
- No hit in the veto scintillator
- EM shower in the calorimeter

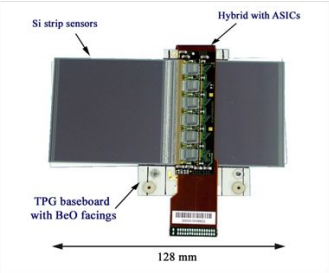


Charged track reconstruction is the key for the search

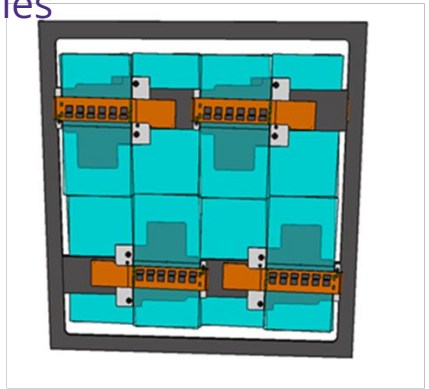


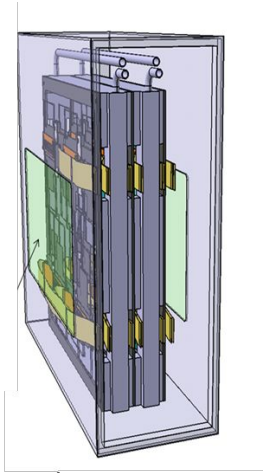
Tracker

- Made by 4 tracking stations (including interface station)
  - Each containing a 3 layer (24cm x 24cm) of double-sided silicon micro-strip detectors
  - Each layer has 8 SCT modules
    - same SCT modules with ATLAS
    - 80μm strip pitch, 40mrad stereo angle
  - 12 layers => 96 SCT modules



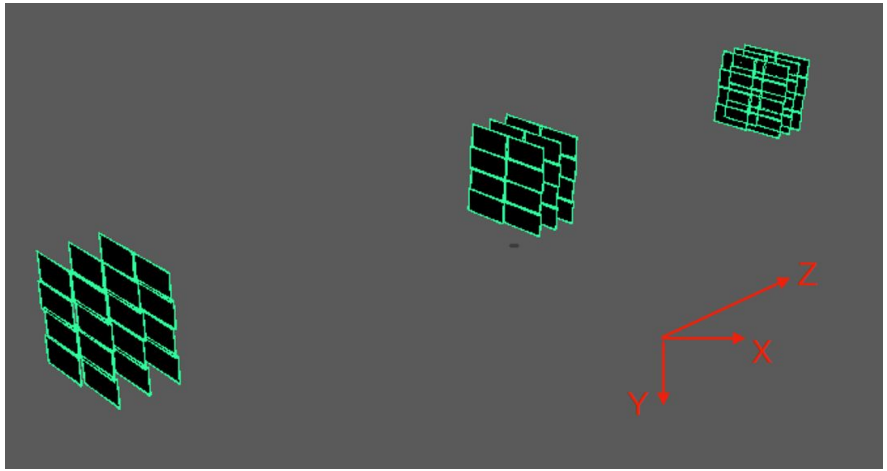
SCT module


Tracking layer


Tracking station

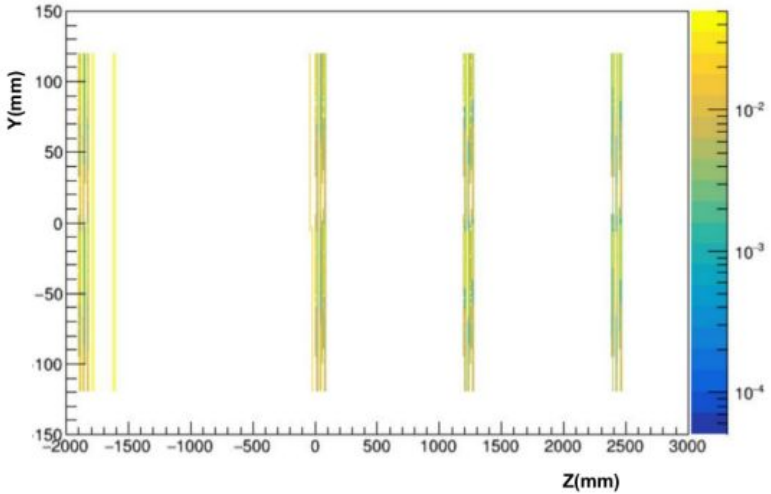
Tracking geometry wtih ACTS

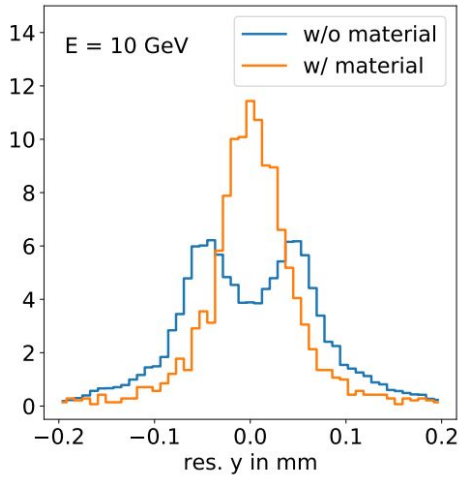
- One cuboid volume for whole detector
  - One sub-volume for each tracker and veto/trigger stations
  - Each module has two plane surfaces and has shift on Z with nearby modules in the same layer
  - One material cylinder surface for magnets

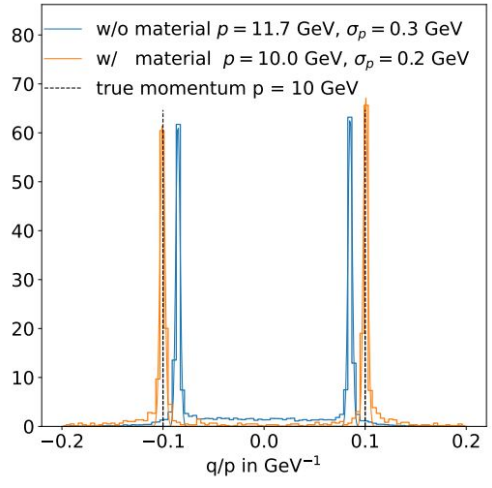


Material mapping

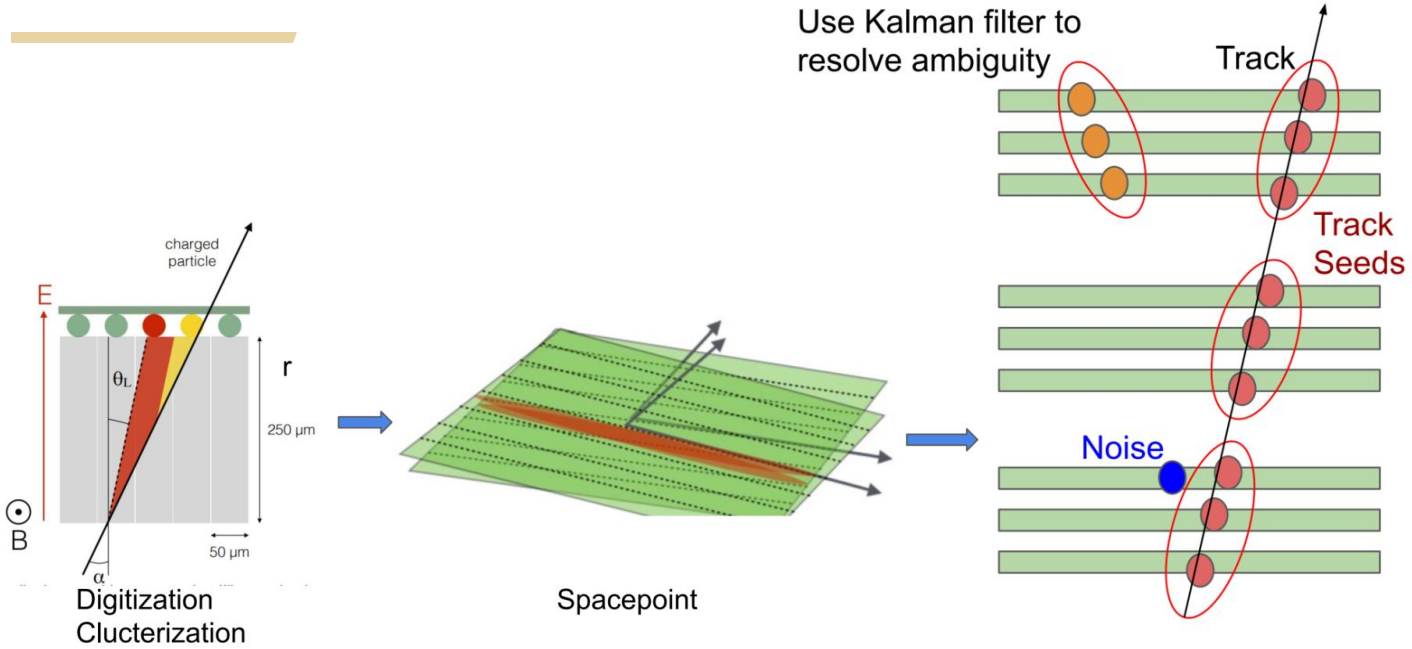
- Shoot geantino particles through whole detector and record the interactions with material
- Map the material to the simplified tracking geometry, i.e. surface, to consider the interactions with material correctly







Track reconstruction



Same with ATLAS (Athena)

- **Same EDM**
- **Similar algorithm**

Acts

- **(Combinatorial) Kalman Filter**

Track seeding

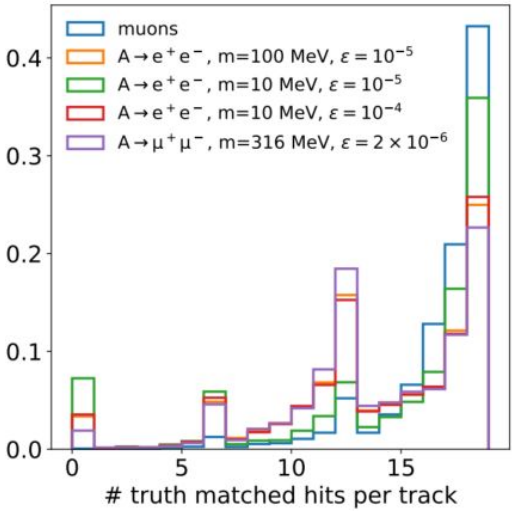
- Start with track segments in each stations
  - 3 layers of SCT modules
    - Each layer is expected to have 2 clusters
  - Linear chi2 fit (no magnet field in stations)
  - Allows for missing hits (can create track segment from only 4 clusters)
- Combine 3 or 4 track segments to build a track candidate

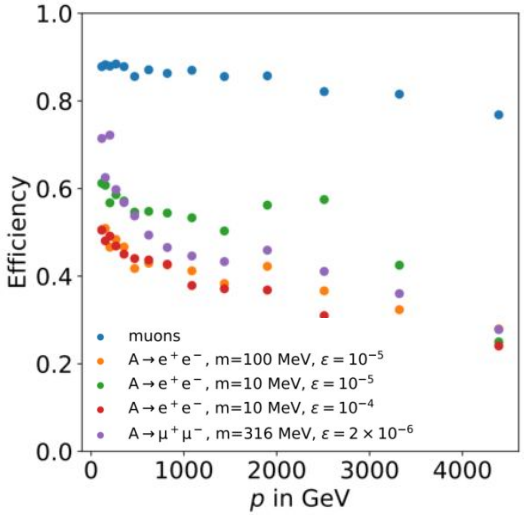
	Efficiency in % $\epsilon = \frac{\#\text{ segments with all hits matched to the same particle}}{\#\text{ events}\cdot 6}$	Purity in % $p = \frac{\#\text{ segments with all hits matched to the same particle}}{\#\text{ segments}}$
all segments	93.4	3.5
segment selection	90.0	46.9
remove ghosts	89.6	83.6

W.I.P.
More study are on going

Track finding

- Track finding = find the correct clusters to build a track candidate
- Combine 3 or 4 track segments from different stations
  - Each combination will goes to track fitting
- Efficiency = truth-matched tracks / all truth tracks



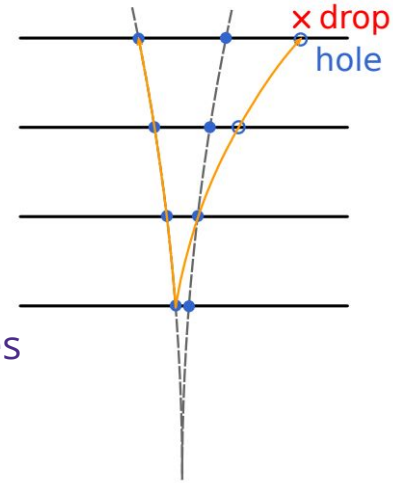


Truth-matched track:

- Momentum is close to truth momentum
- At least 4 Truth-matched clusters per station

W.I.P.
More study are on going

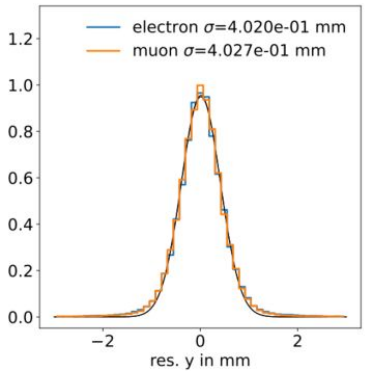
Track reconstruction with ACTS

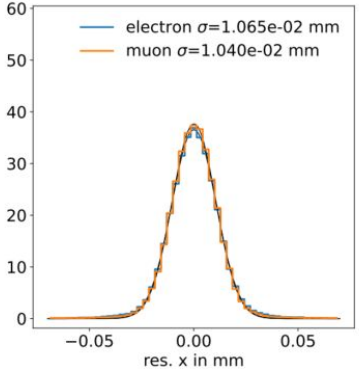


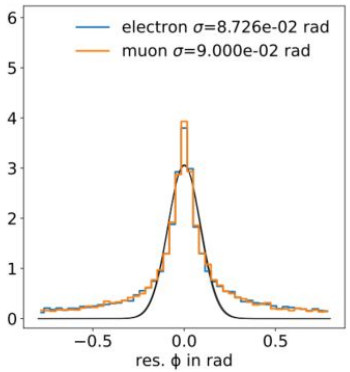
- Three approaches
  - ACTS Kalman Filter (KF)
    - Loop over all the track candidates
  - ACTS Combinatorial Kalman Filter (CKF)
    - Tracking finding + fitting
    - Loop over the initial parameters from all track candidates
    - Solve the ambiguity while propagating
  - Chi2Fitter
    - Loop over all the track candidates
    - Use ACTS to propagate the track parameters to other layers
    - Use TMinuit to minimize $\chi^2 = \sum_i \frac{\left(x_{\mathrm{meas_i}} - x_{\mathrm{pred_i}}\right)^2}{\sigma_x^2} + \frac{\left(y_{\mathrm{meas_i}} - y_{\mathrm{pred_i}}\right)^2}{\sigma_y^2}$
  - Cross check with each other

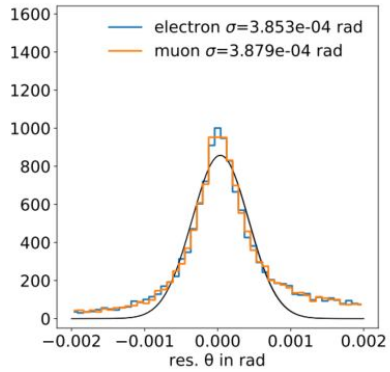
Track parameters from CKF

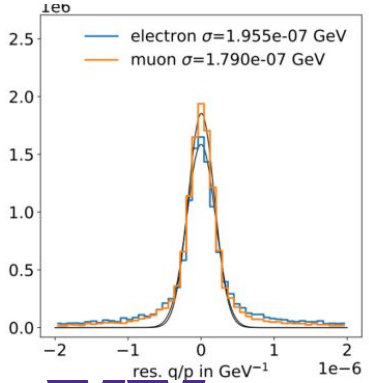
- Tested with single particle MC simulation
- Track parameter is defined at a fixed plane surface
- Resolution for track x/y is ~400/10 μm
  - For single measurement (space point), resolution is 816/16 μm







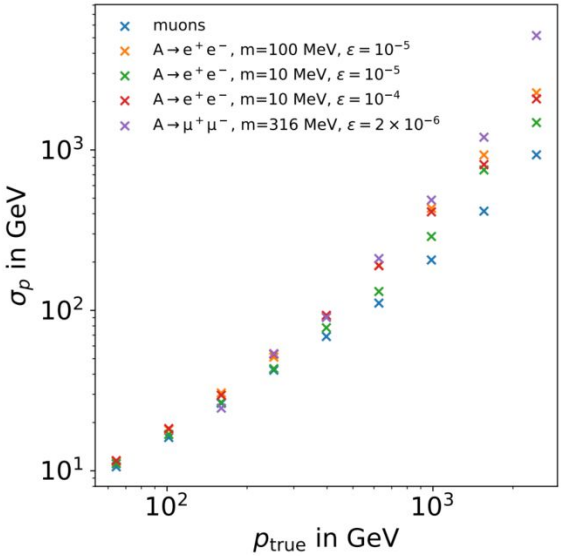


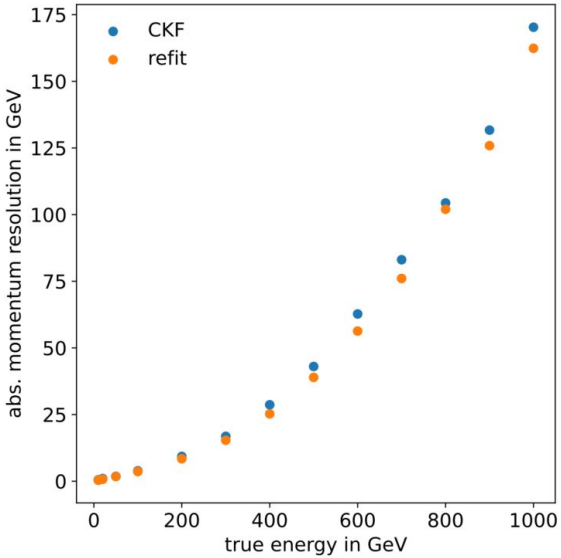


Track parameters: truth - reco

Combinatorial Kalman Filter

- The momentum resolution is tested with a series of MC simulations
- Around 10% resolution at 100 GeV, and 17% at 1 TeV
- CKF input: a large covariance for initial parameter and all measurements
  - Refit with the previous results as input can improve the precision

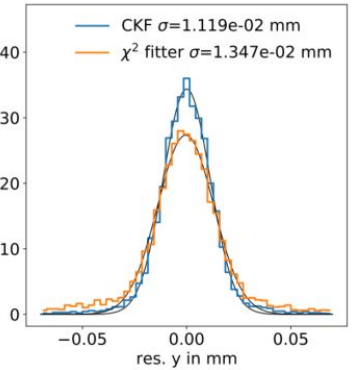


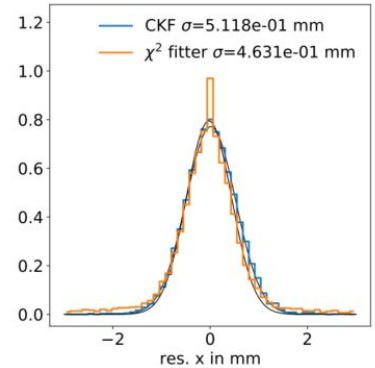


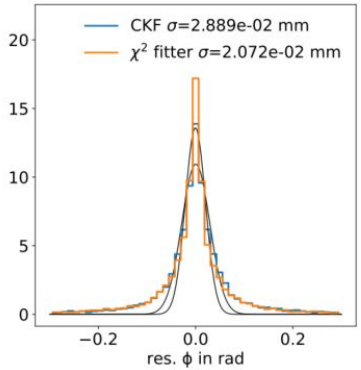
W.I.P.
More study are on going

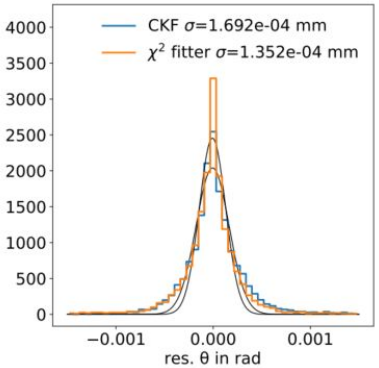
CKF and Chi2Fitter

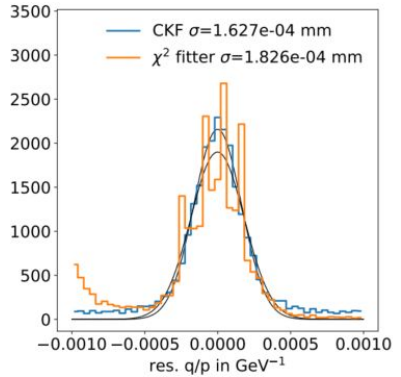
- Tested with single particle MC simulation
- In general similar track parameters for two approaches
  - Both are using ACTS propagator
  - Differences are strategy to find and fit track
  - CKF can do finding + fitting







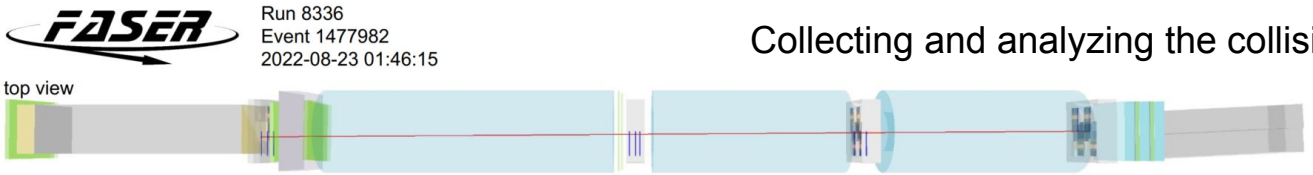




Track parameters: truth - reco

Summary and discussions

- ACTS-based track reconstruction is implemented for FASER
  - Performance is studied with MC simulations
  - CKF is the baseline approach
    - Consist performance to other approach, i.e. Chi2Fitter
    - Refit with previous results as input give better precision
- Discussions:
  - CKF could fail due to inaccurate initial parameter or covariance, any better solution
  - No common vertex for FASER, any better position to shoot geantino particle for material mapping
  - Status of ACTS alignment

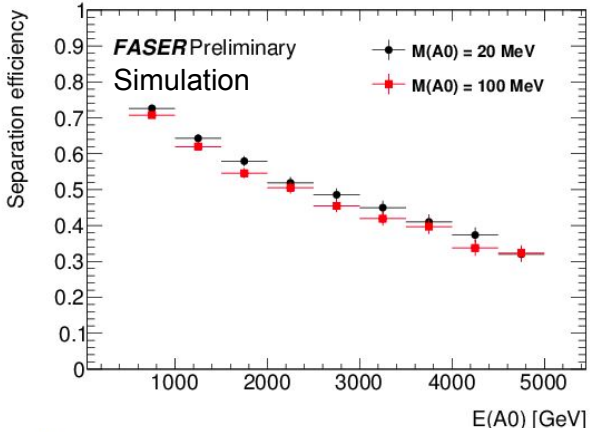


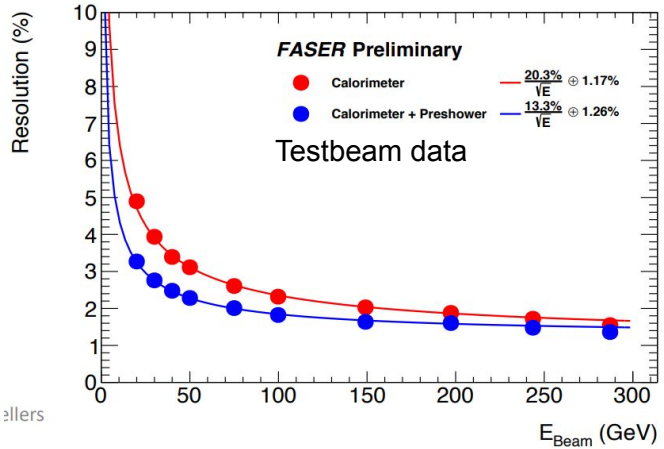
Collecting and analyzing the collision data now.

back-up

Key features for BSM search

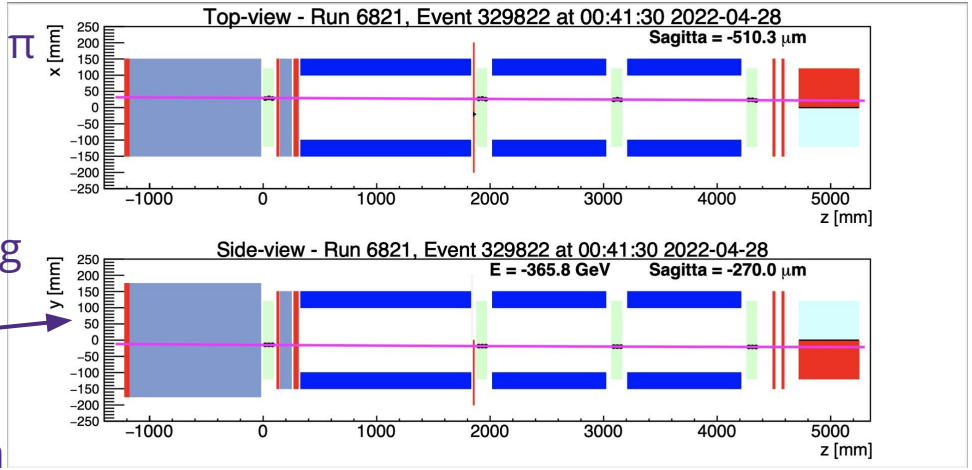
- Trigger rate O(500-1200 Hz) - dominated by muons
- Muon flux is 1 Hz/cm^2 for L=2×10^{34} cm^{-2}s^{-1}
  - Confirmed by in situ measurements in 2018.
- Tracking detector strip pitch 80 μm with 40 mrad stereo angle
  - ~ 20 μm resolution in precision coordinate
  - ~ 550 μm in the other coordinate
- Good separation for two collimated tracks
- EM shower energy resolution: ~1% for TeV deposits





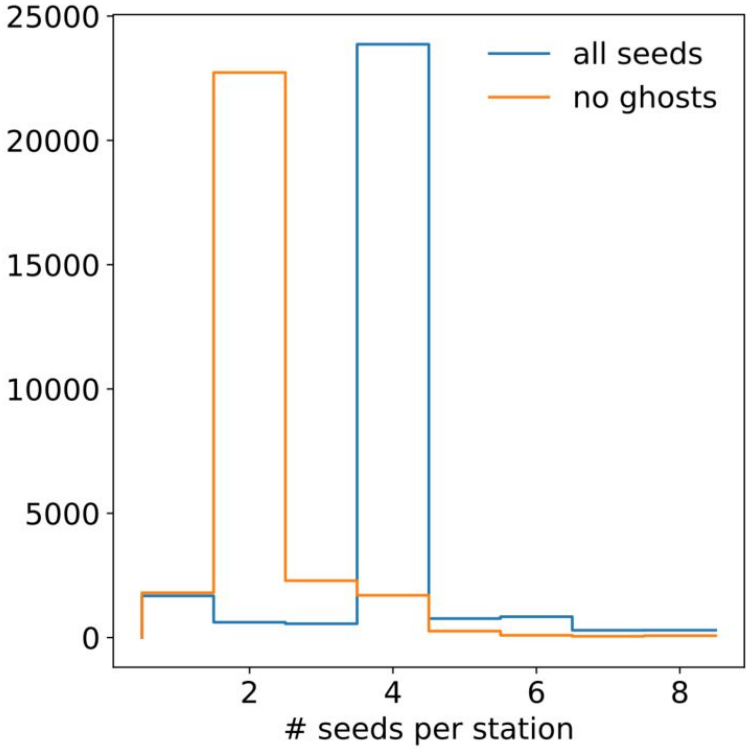
Commissioning

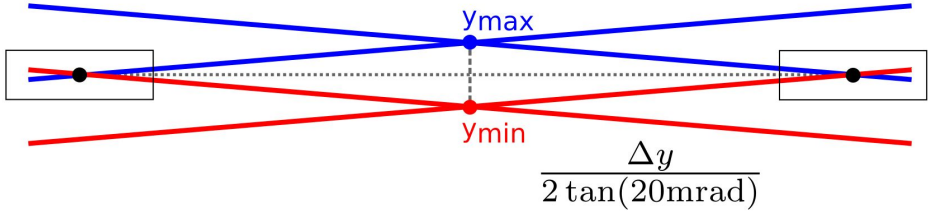
- FASER's construction is complete, detector installed in tunnel in March 2021
- Have collected data from LHC pilot beam, test beam, and cosmics
- SPS test beam (summer 2021) with over 150 million events of e, μ, and π particles in subset of detector for performance studies
- Data is being analyzed for characterization and commissioning of the detector
- In last 3 week data from LHC beam commissioning
- Simulation and data reconstruction are on-going
  - Both are already well developed



D. Fellers, slides
Lake Louise Winter Institute 2022

Number of seeds per station





Tracking with IFT

Interface tracker

3 tracker stations