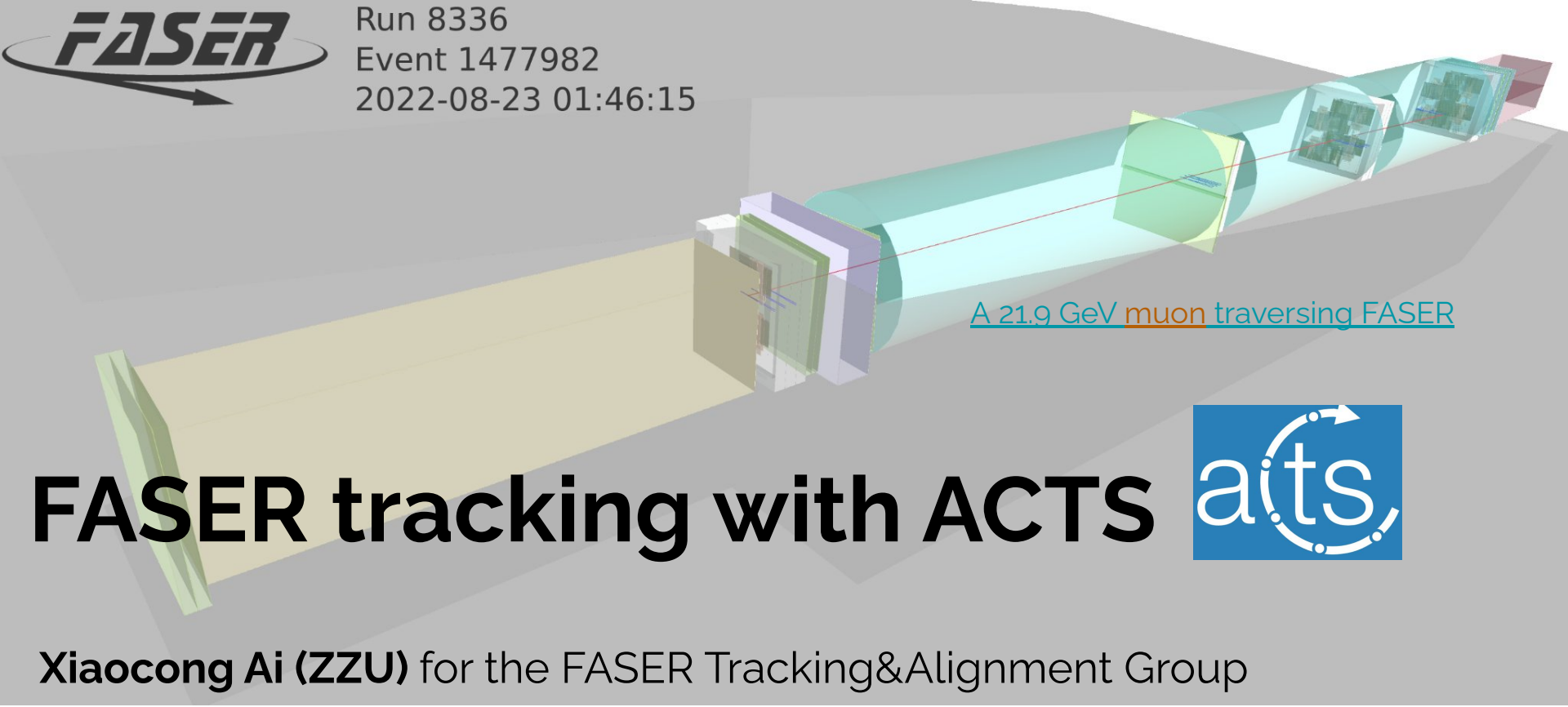


A 21.9 GeV muon traversing FASER

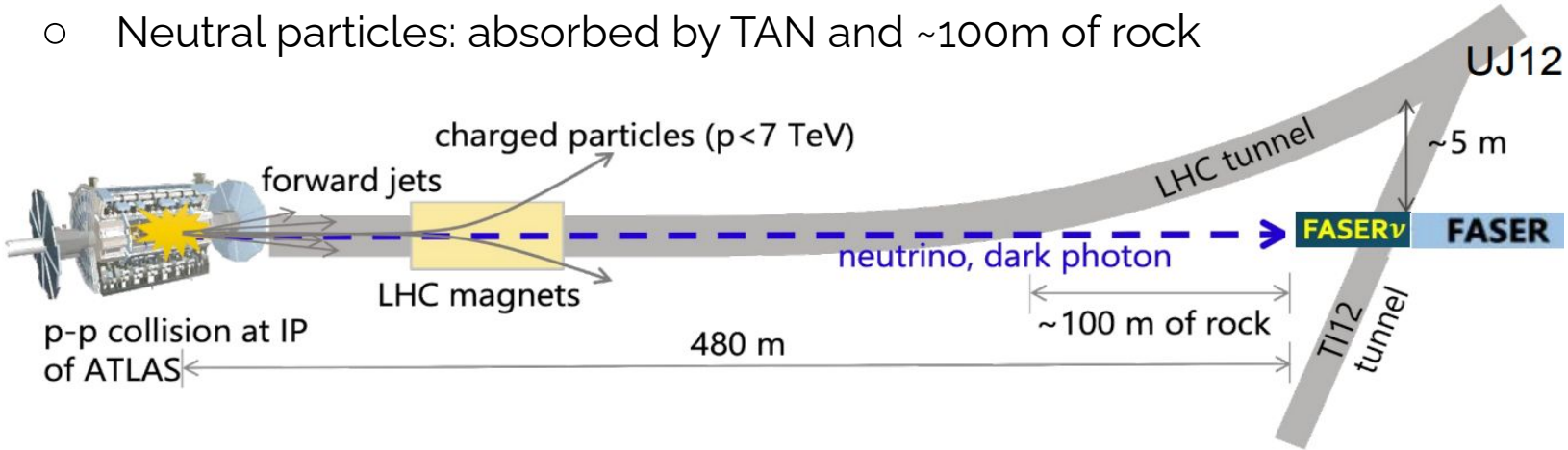
FASER tracking with ACTS

Xiaocong Ai (ZZU) for the FASER Tracking&Alignment Group

ACTS Developers Workshop 2024, Nov 18, 2024

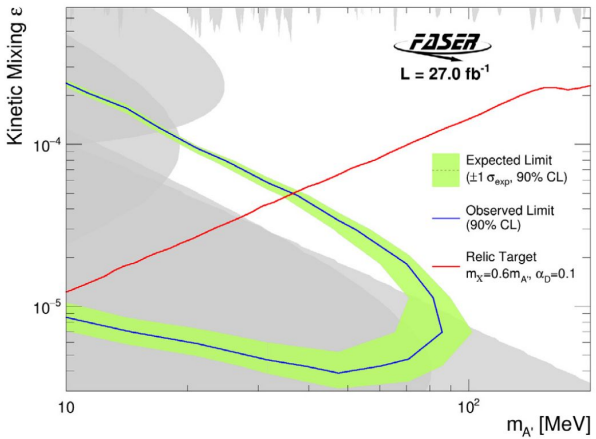
FASER experiment

- ForwArd Search ExpeRiment (FASER) is designed to search for **Long-Lived Particles (**LLPs) and **neutrinos** produced in pp collisions at the ATLAS IP
  - Placed along the beam collision axis, **480 m** downstream from the ATLAS interaction point
- Clean backgrounds
  - Charged particles: bent by LHC magnets
  - Neutral particles: absorbed by TAN and ~100m of rock

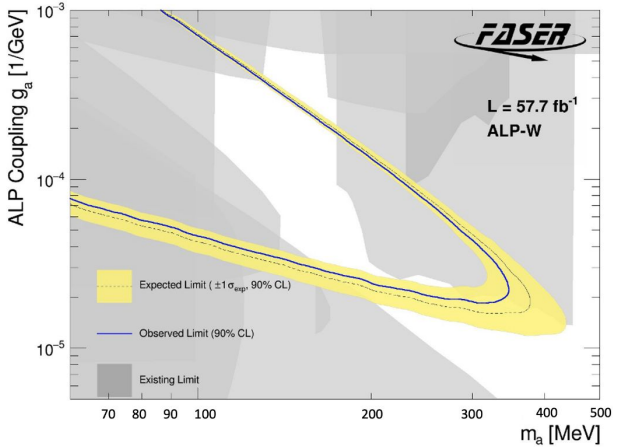


FASER physics goals

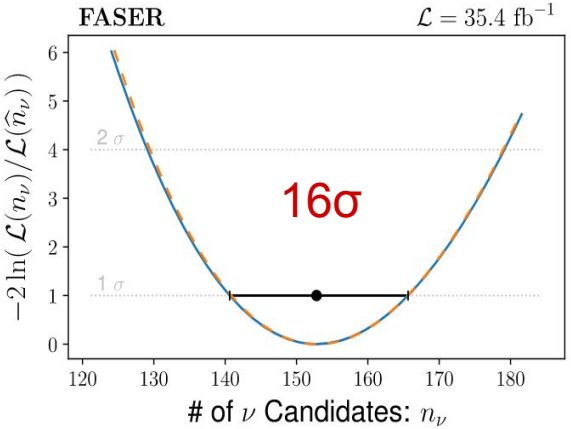
- **LLPs search:** dark photon (mainly from ~TeV forward π^0, $\pi^0 \rightarrow A' \gamma$) , Axion-like particles (ALPs) from e.g. high energy photons colliding with the TA(X)N, CP-odd scalars mainly from heavy quark decay b → sA …
- **Direct collider neutrinos search**: ν_e, ν_μ, ν_τ from hadron decays



Search for dark photons at FASER, PLB 848 (2024) 138378



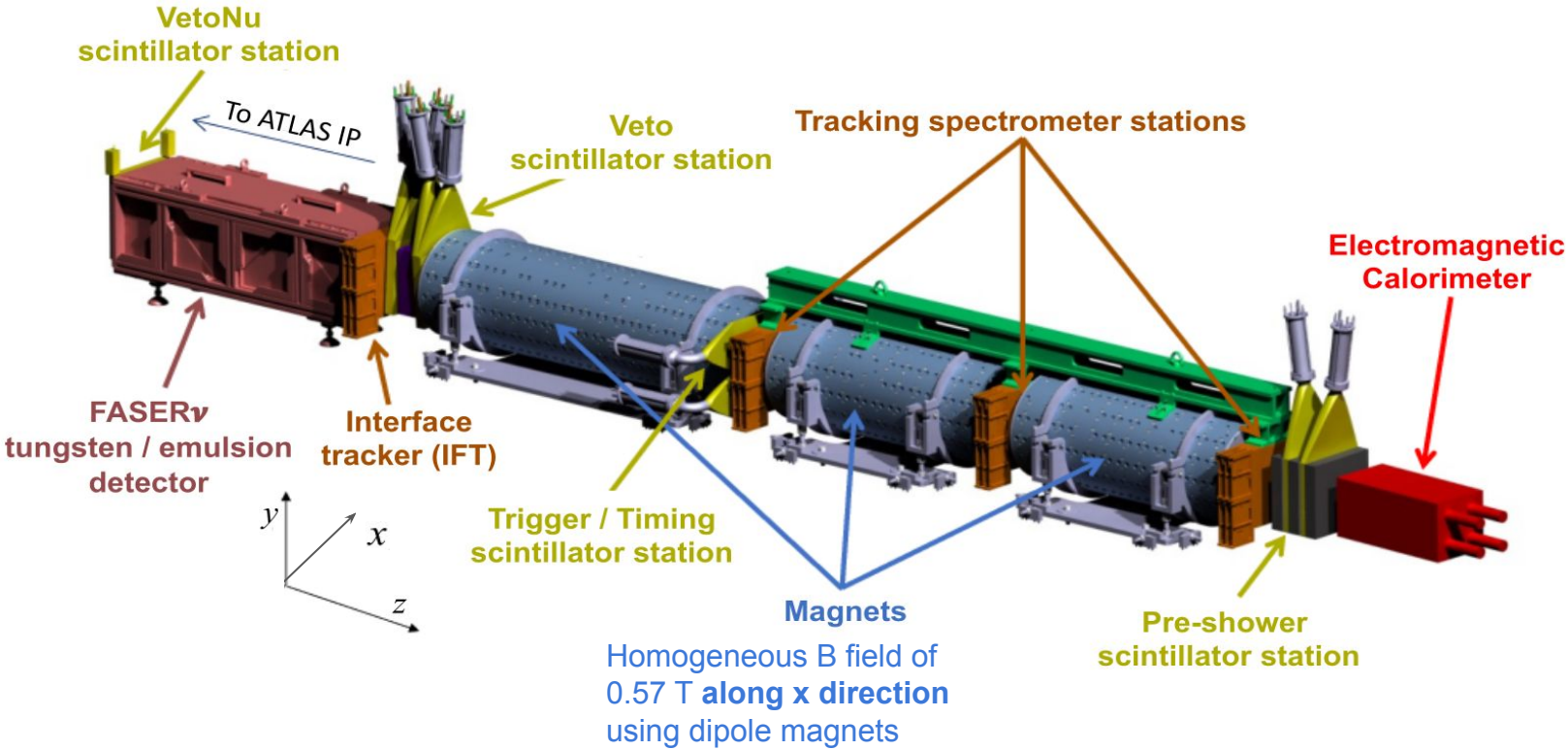
Search for ALP at FASER arXiv: 2410.10363



First direct observation of collider ν_μ neutrino PRL 131, 031801 (2023)

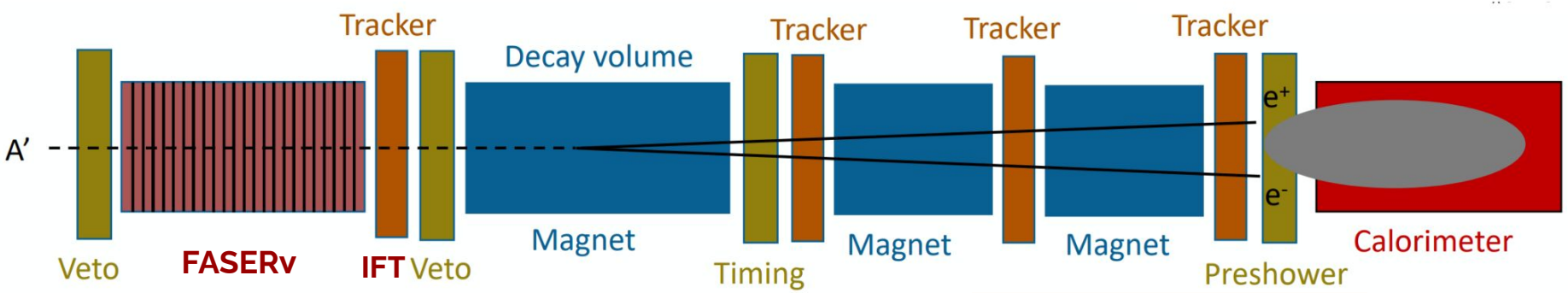
FASER detector

- For detection of charged tracks, photons and neutrinos

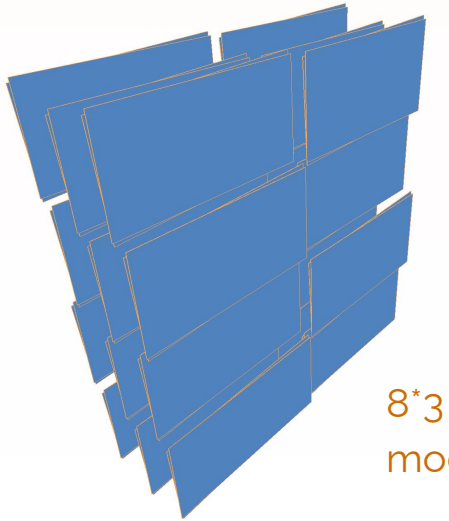


FASER tracking system

Sketch from Brian Petersen



- Including 4 tracker stations
- Each tracking station is made of 3 layers of double-sided silicon micro-strip detectors
  - coverage 24cm x 24cm
- Each layer has 8 SCT modules (same as ATLAS SCT modules)
  - 80 μm strip pitch, 40 mrad stereo angle



8*3 = 24 modules/station

ACTS tracking geometry

- Each side of a module is described using ACTS plane surface
- Each station is placed in a cubic volume
  - 3 ACTS layers for each station
- Material is mapped to (inner) approach surface of each layer

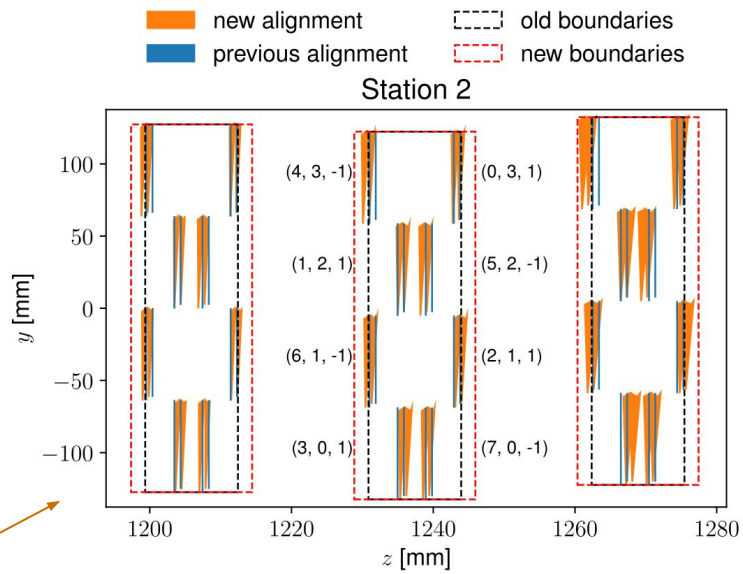
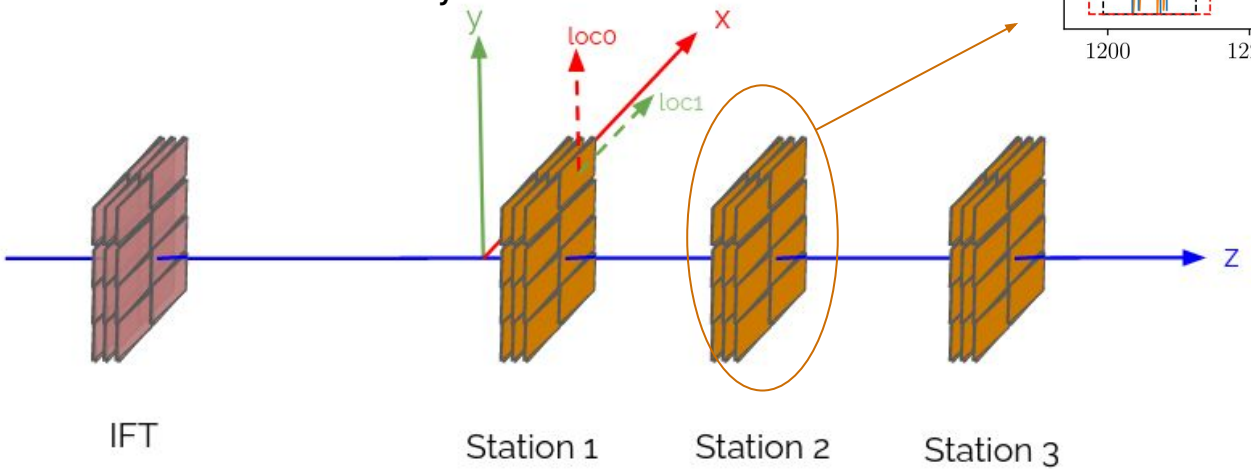


Figure from Tobias Böckh



The charged tracks to detect

- Single high-momentum (e.g. >30 GeV) lepton resulting from neutrino interaction with tungsten (e.g. $\nu_\mu + N \rightarrow \mu + X$)
- Two highly collimated (e.g. r<95mm) charged tracks (e.g. >20 GeV) from dark photon (e.g. $A' \rightarrow e^+e^-$)
- Also three tracks in final state (e.g. μ with dark scalar to dimu)

Figure from PRL 131, 031801 (2023)

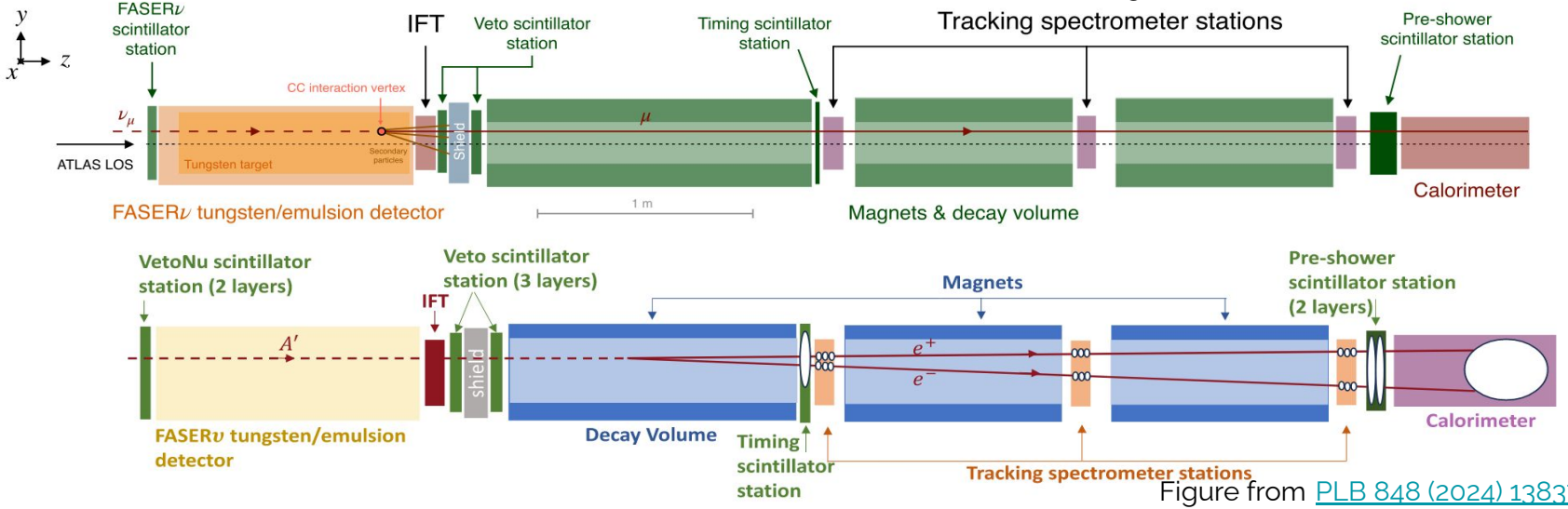
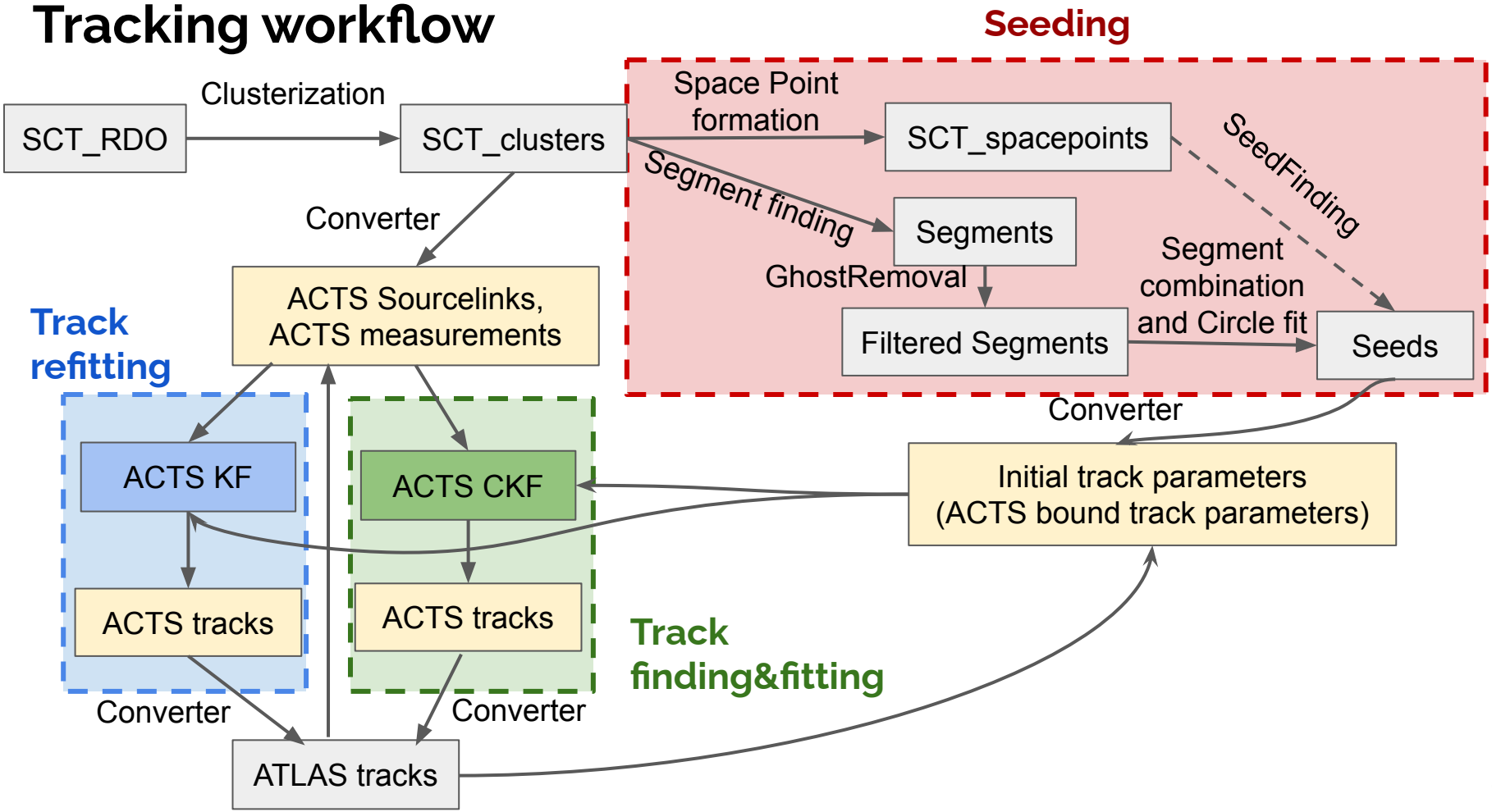


Figure from PLB 848 (2024) 138378

Tracking strategy

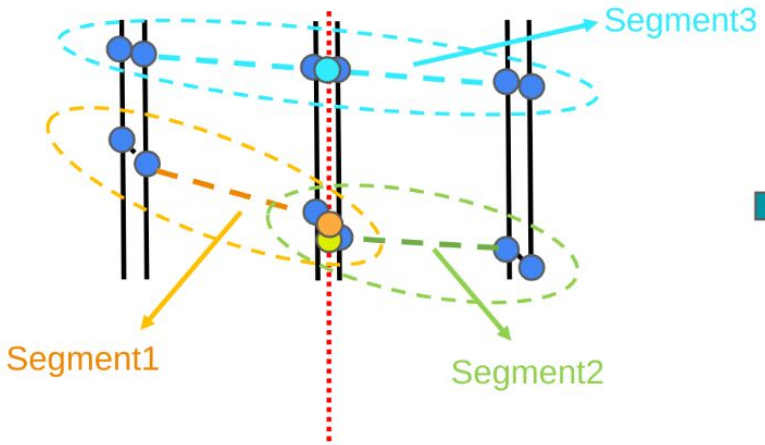
- FASER adopted ACTS for tracking at a very early stage.
  - ACTS is well integrated into FASER offline software Calypso (based on Athena)
- ACTS Combinatorial Kalman Filter (CKF) is used for simultaneous track finding and track fitting.
- ACTS Kalman Filter (KF) is used for track refitting.
- Dedicated seeding strategy is used at FASER with a telescope-like geometry.

Tracking workflow

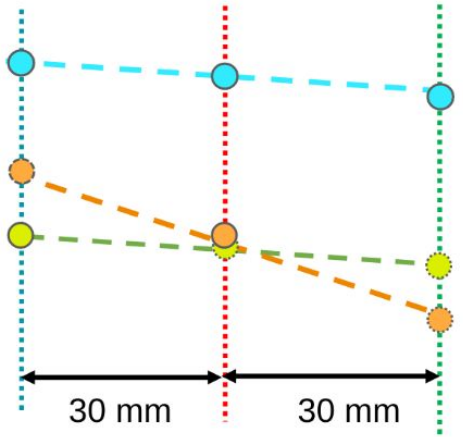


Seeding – segment finding

- Segment finding: linear χ^2 fits of cluster in a single station
  - A segment can have at least 4 and most 36 clusters (possibility of >=2 clusters from one layer)



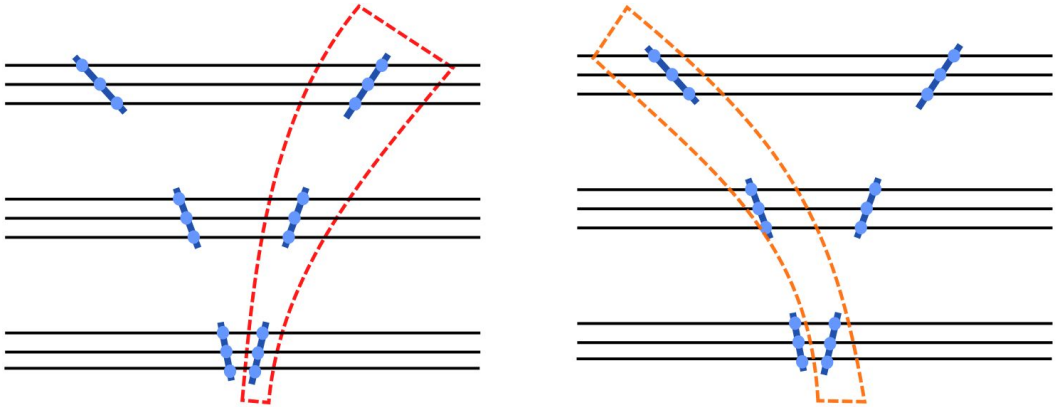
Each segment is linear-extrapolated to the station center zCenter



The segment is further linear-extrapolated to zCenter - 30 and zCenter + 30

Seeding – segment combination and fit

- The segments are combined to form seeds
  - In the order of 4-segment seed → 3 segment seed → 2 segment seed …
- Linear fit in x-z plane and circle fit in y-z plane
- Seeds are sorted by number of clusters and χ^2
- Start with best seed, remove any other seed with more than 6 shared clusters or fewer than 10 clusters



Sketch from Tobias Böckh

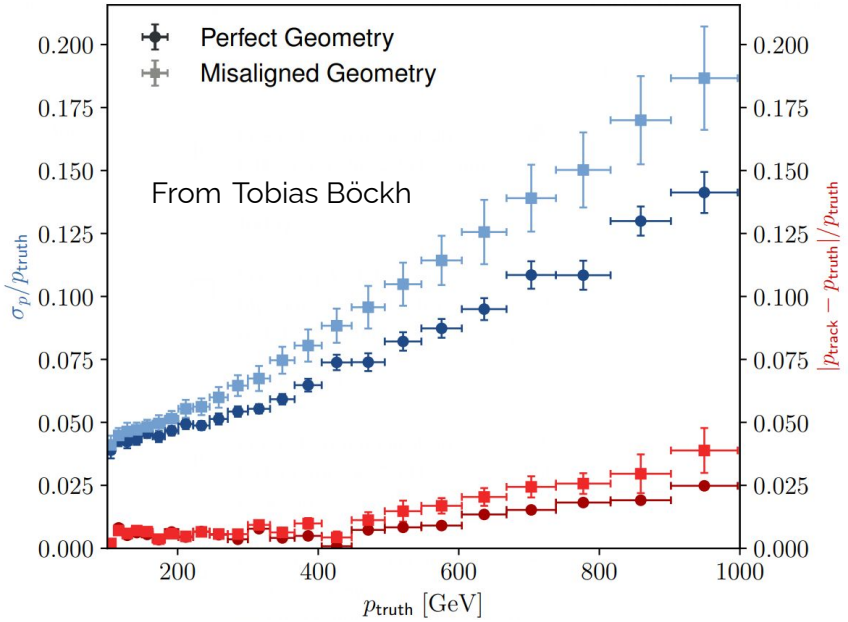
A seed have 1/2/3/4 segments from different stations

CKF for track following

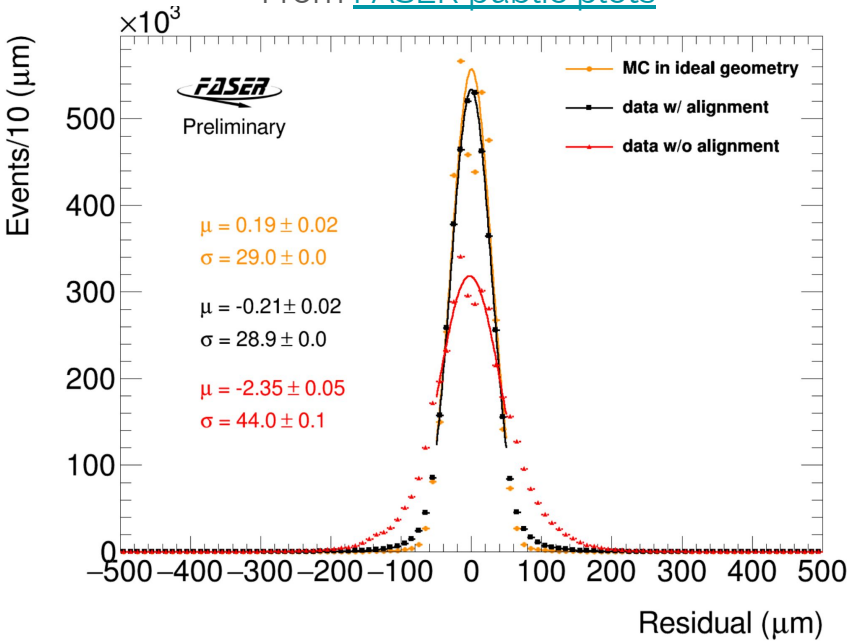
- Four tracking modes
  - Forward tracking without or with station 0
  - Backward tracking without or with station 0
- The track parameters from circle fit is derived at the target position and transformed into ACTS track parameters
  - Forward tracking, targetZ = zMinMCluster - 10 mm
  - Backward tracking, targetZ = 2470 mm
- CKF cuts:
  - nBranchesMax = 10, chi2Max = 25, propagation maxSteps = 1000

Tracking resolution

- In the case of perfect alignment of the FASER tracking detectors:
  - A momentum resolution of ~3.9% at 100 GeV, ~5.5% at 300 GeV, and ∼14.1% at 950 GeV is expected.
  - Hit resolution is around 29 μm

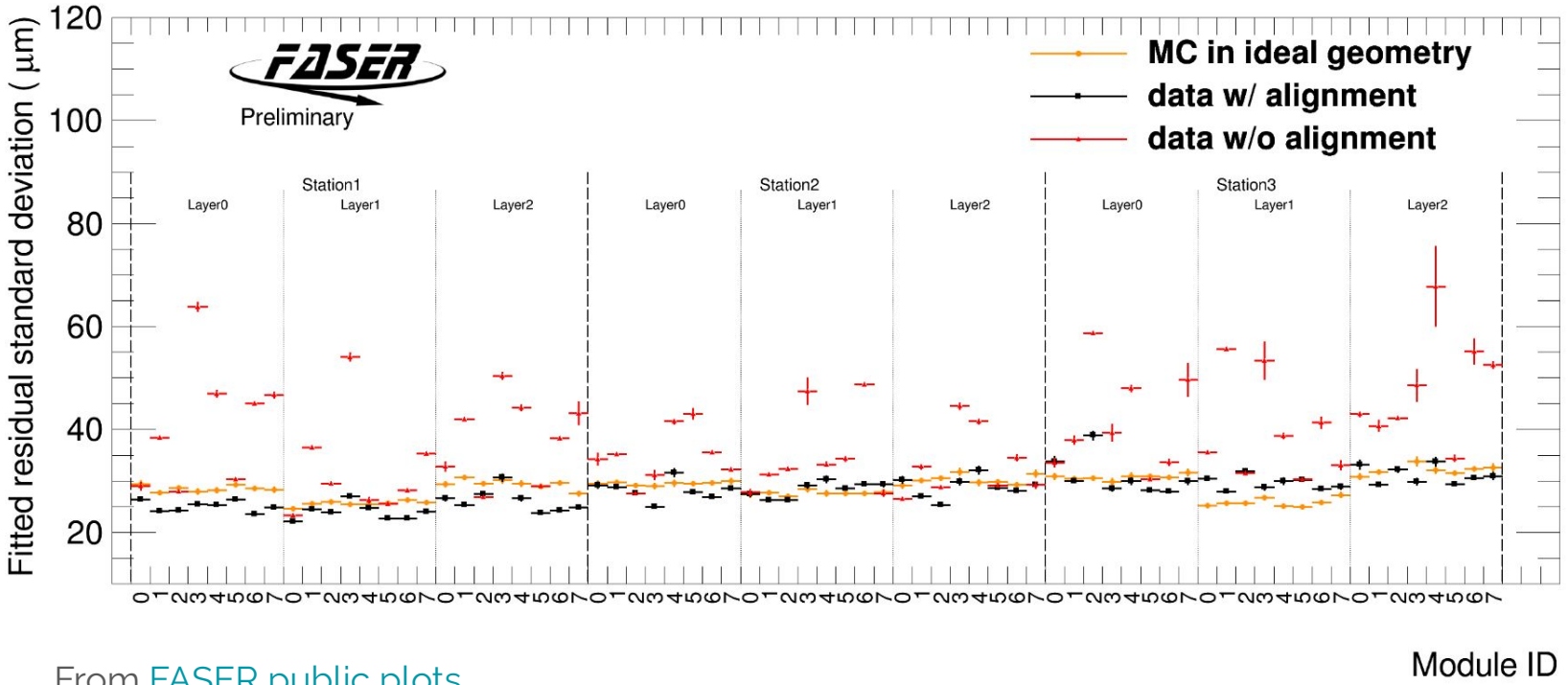


From FASER public plots



Hit resolution versus station/layer/module

- The hit residual ranges around 25-35 μm with station/layer/module



From [FASER public plots]

Two-track tracking efficiency

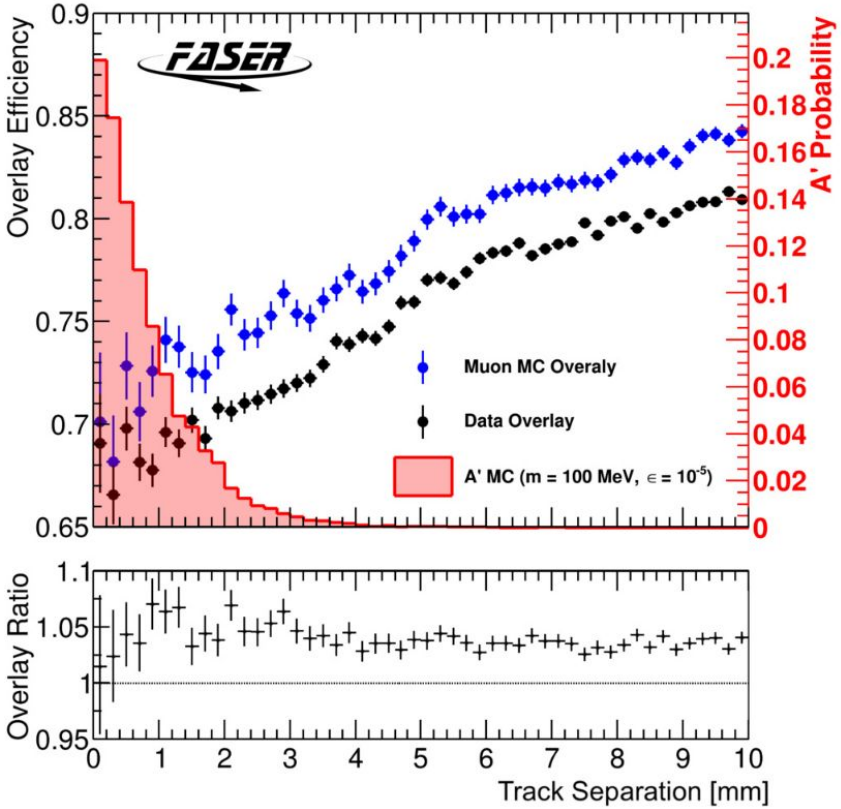


Figure from [PLB 848 (2024) 138378]

- Efficiency defined as $N_{nTrack==2}/N_{nTrack>=1}$
  - Events with more than 2 tracks are NOT counted in the numerator
  - Average > 90% efficiency if including third track events in the numerator
- Needs to understand and remove the artificial third track

Summary and outlook

- FASER is designed to search for LLPs and neutrinos
  - Has a telescope-like tracking system to detect high-momentum tracks (mostly one or two tracks per event)
  - Telescope-style seeding algorithm is developed and working well
- **ACTS (C)KF** (version 14.1.0) have been **well used for tracking at FASER producing rich physics results** (direct collider neutrino observation, dark photon search …)
- Recently, ACTS has been updated to version 32.0.2 along with alma9 migration of FASER offline software
  - Performance has been validated and room of improvement is under investigation (e.g. customized KF smoother to avoid the smoothing parameters issue of overlapping states…)

backup

– two fiducial reconstructed tracks of good quality;

  * a good quality track has a track fit χ^2/(number of degrees of freedom) $<$ 25, at least 12 hits on track, and a momentum > 20 GeV

  * a fiducial track has an extrapolated position of < 9.5 cm radius at all scintillators and tracking stations