LIV.INNO

FASER

UNIVERSITY OF LIVERPOOL

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Studying the tracking performance for dark photons with the FASER detector

Sinead Eley

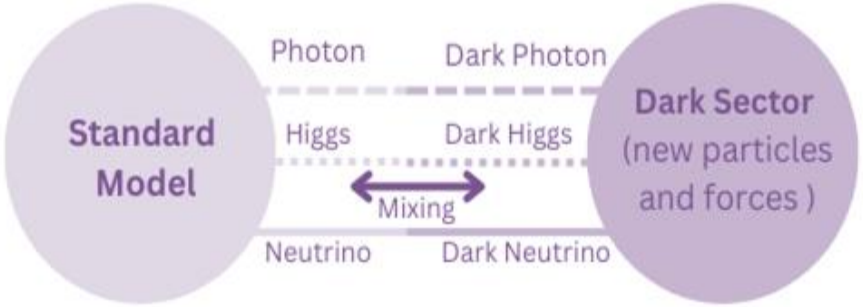
Supervisors: Dr. C. Gwilliam & Prof. M. D'Onofrio

1st Year Presentation

CERN

Hidden Sectors

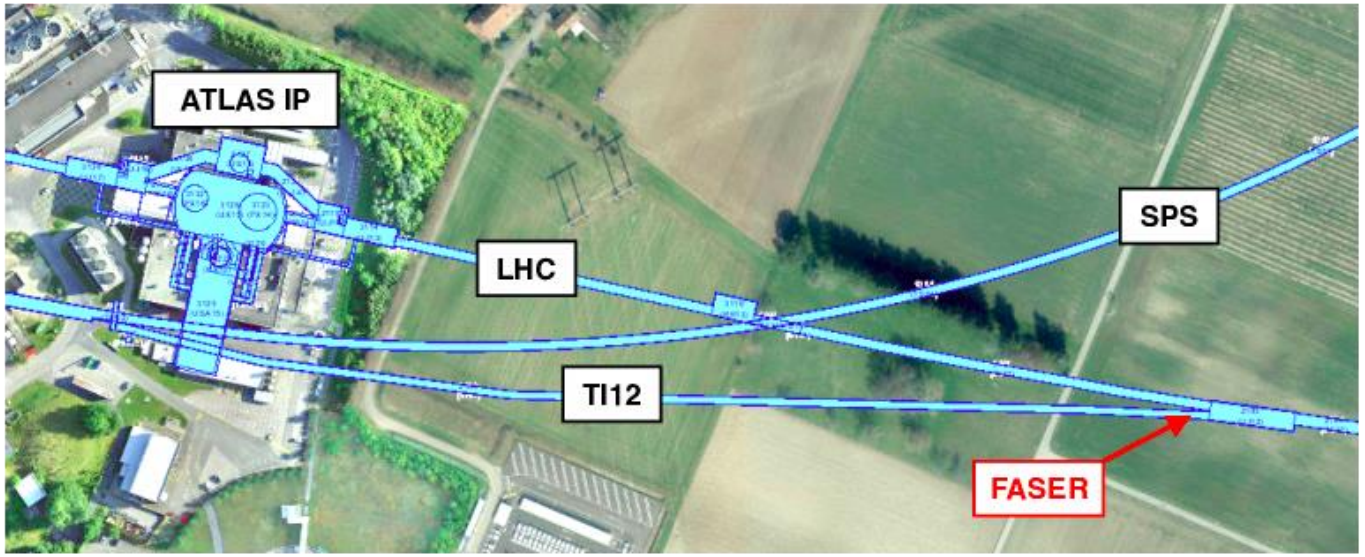
- SM can't explain everything
  - Matter-Antimatter asymmetry
  - Gravity
  - Dark Matter
- Motivation for theories beyond the standard model (BSM)
- Cosmological evidence of dark matter
  - Could be part of a hidden sector known as dark sector
- 4 benchmark approaches which utilise 4 renormalizable 'portals'
  - Each can be defined by the mass of the mediator (m) and their coupling to the SM (ϵ)

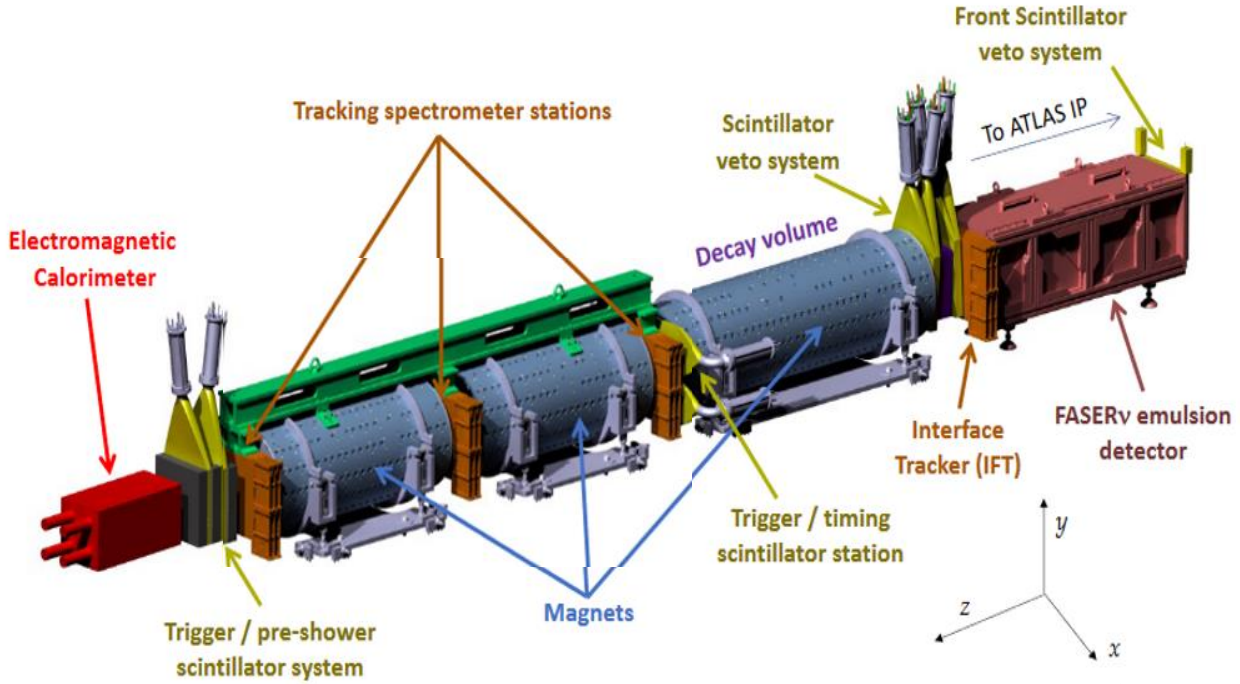


Portal	Mediator
Scalar	Dark Higgs
Vector	Dark Photon
Neutrino	Heavy Neutral Lepton (HNL)
Pseudoscalar	Axion-Like Particle (ALP)

FASER

- Forward Search Experiment
- Located in Far Forward Region @ LHC
  - 480m from ATLAS interaction point
    - where weakly-interacting long-lived particles (LLPs) are produced
  - Specifically searching for dark sectors and studying neutrinos
- Started taking data at start of LHC Run 3 (2022)
  - Will continue to take data for remainder of Run 3 and Run 4
    - Collecting ~ 250 fb^{-1} of data during Run 3





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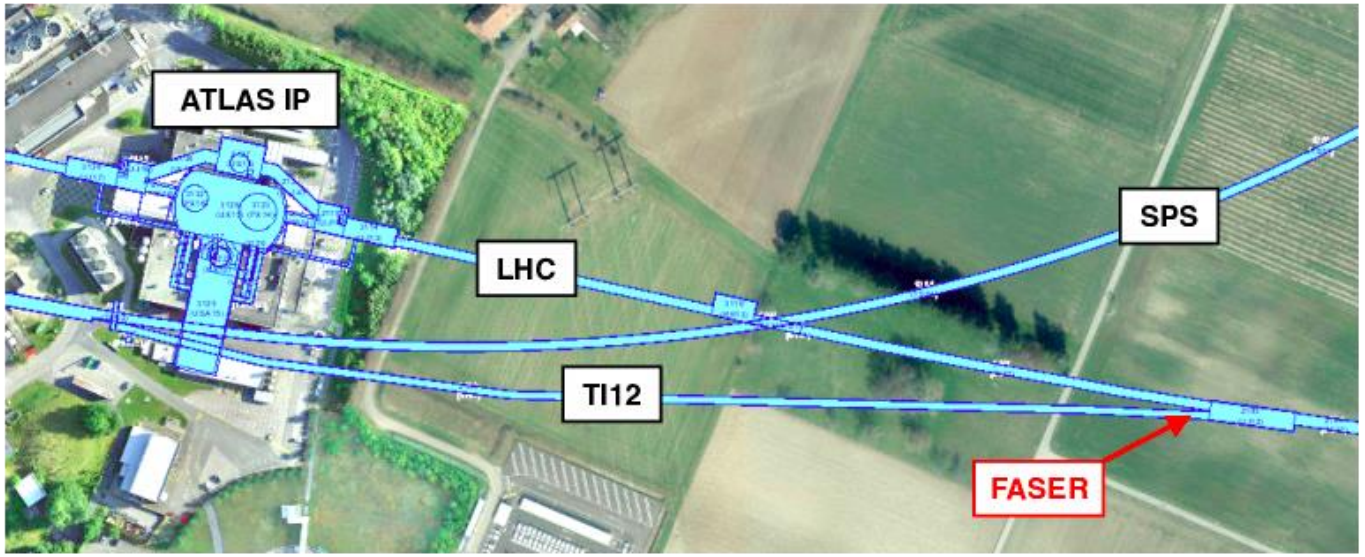
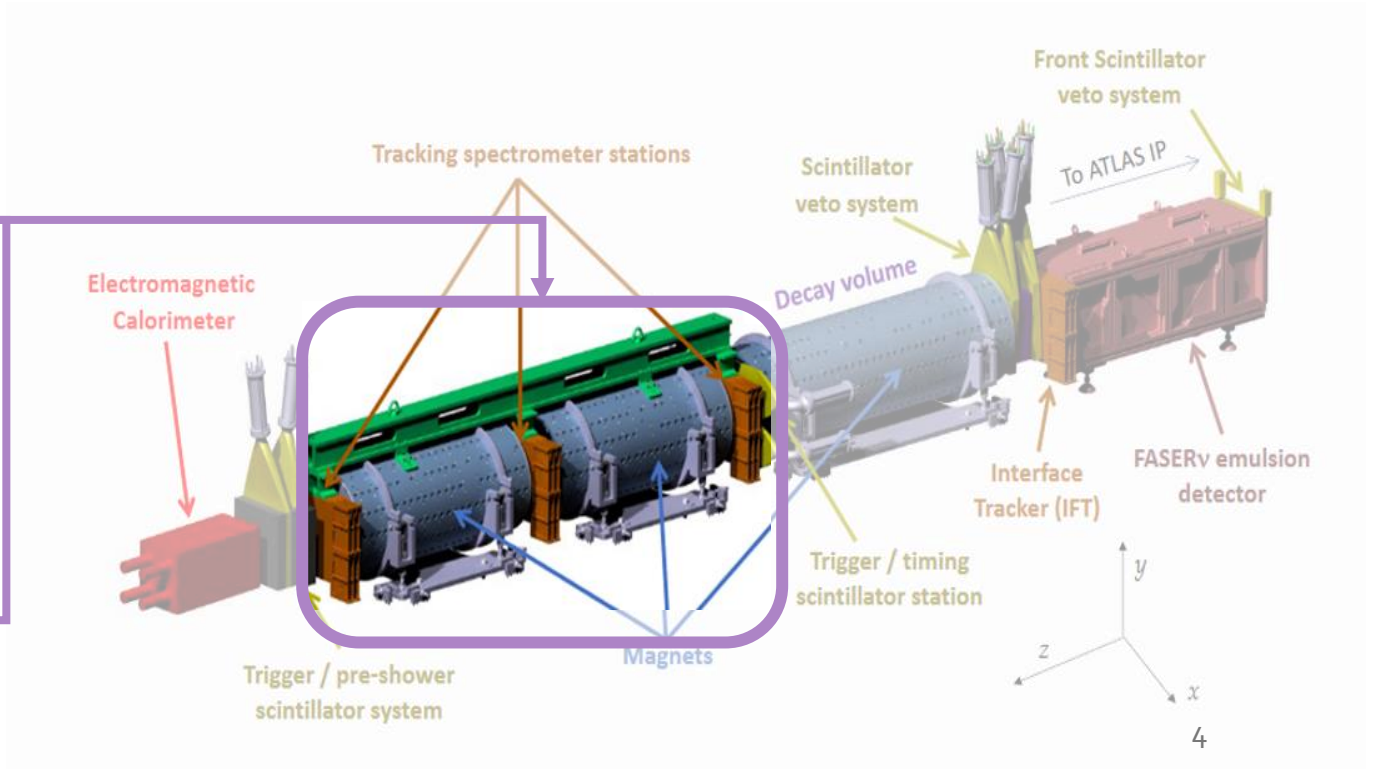


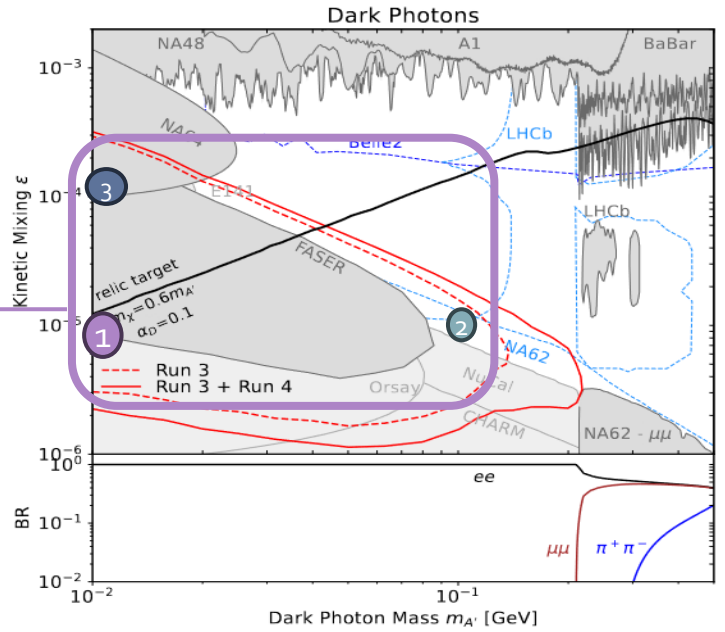
Tracking spectrometer

- 3 tracking stations
  - Within a magnetic field of 0.55T
  - 3 layers of double-sided silicon strip modules in each
    - Uses ATLAS SCT modules
    - Maximum of 18 hits in tracking spectrometer



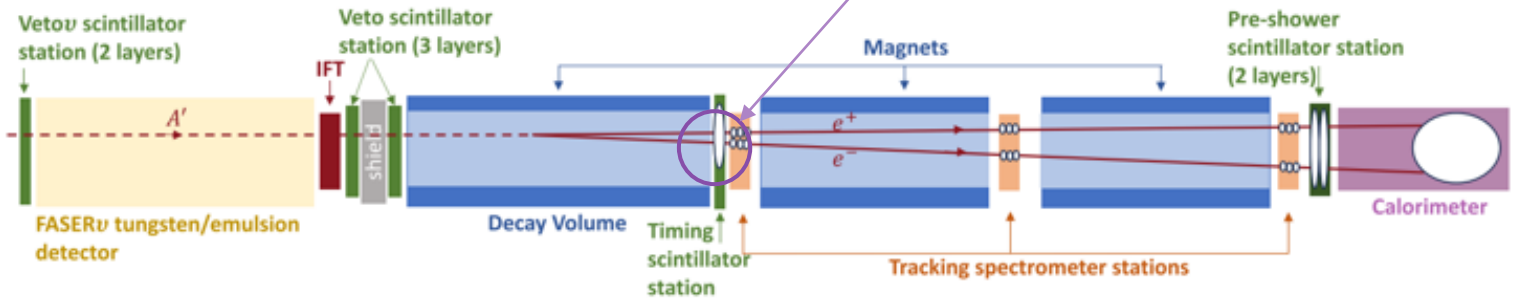
Dark Photons @ FASER

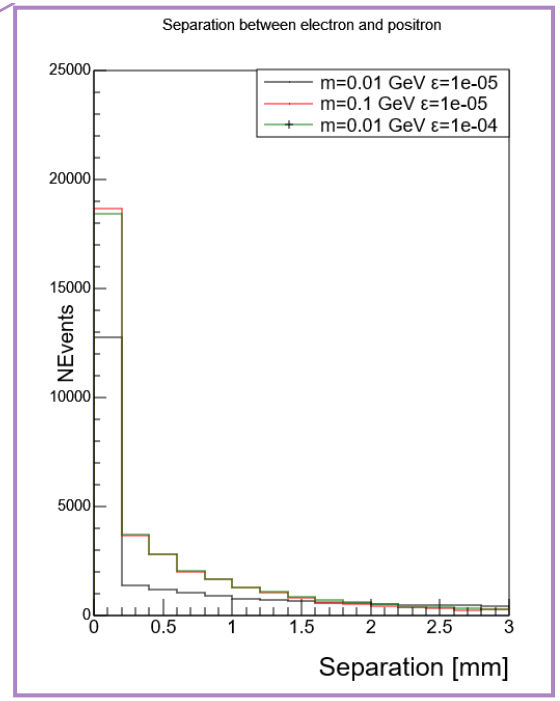
- 3 MC simulated dark photon samples used with 20k events
- LLPs produced at IP1 and decay within FASER to e+ e- pair
  - Distance travelled by dark photon : $c\tau = \frac{(12\,\pi)}{\epsilon^2\, e^2\, m_{A'}}$
- Separated by magnetic field
- Tracks detected in tracking spectrometer
- Energy deposited in calorimeter



Problem!

Particles can be very close by

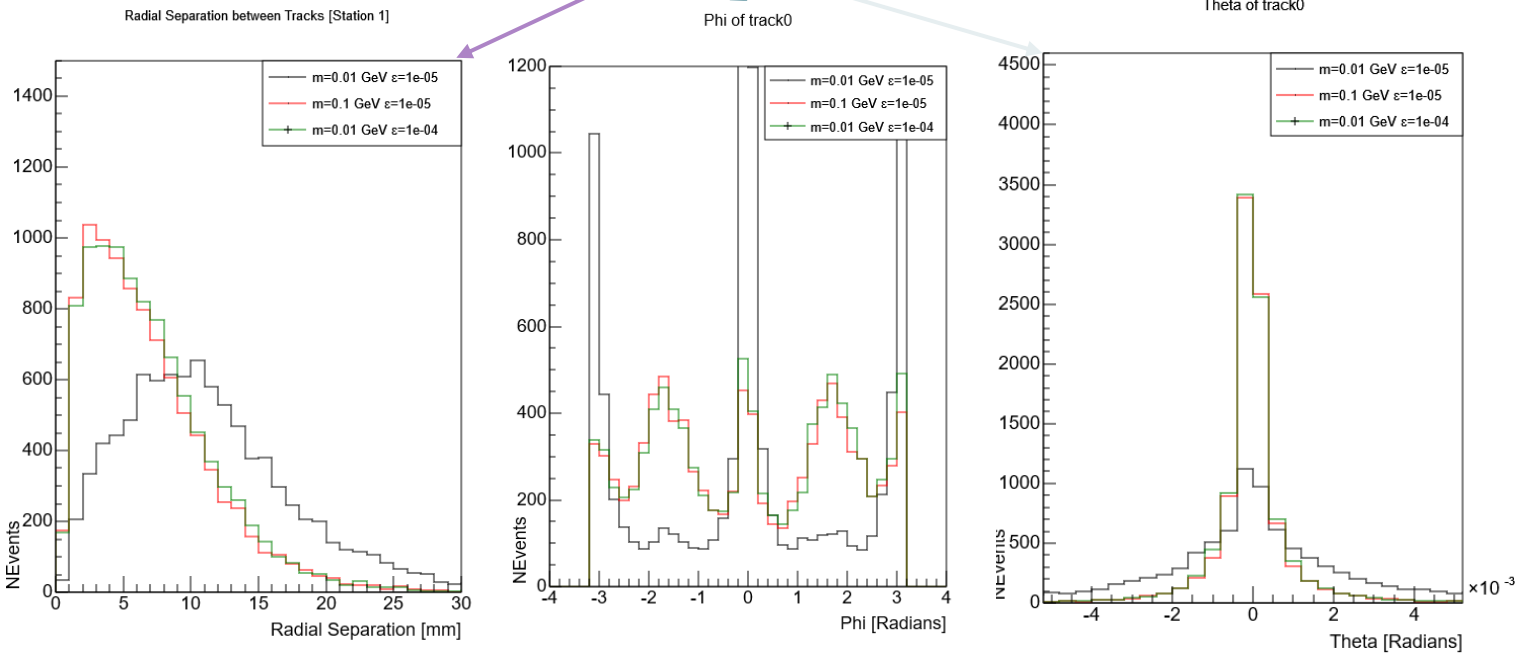


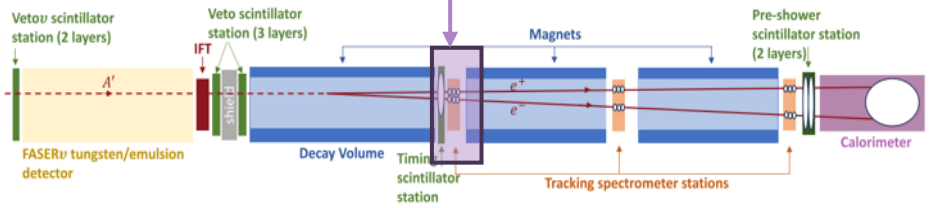


Tracking @ FASER

Current Default : Tracking starting at station 1 [*Forward* Tracking]

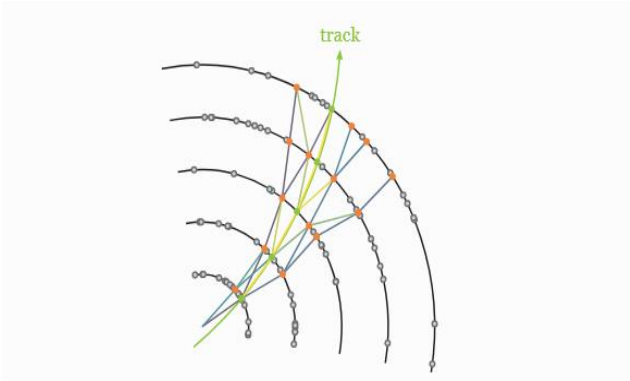
- Tracking at FASER uses a combinatorial Kalman Filter (CKF)
- Utilizes track parameters: $\vec{x} = \left(l_0, l_1, \phi, \theta, \frac{q}{p}\right)^T$





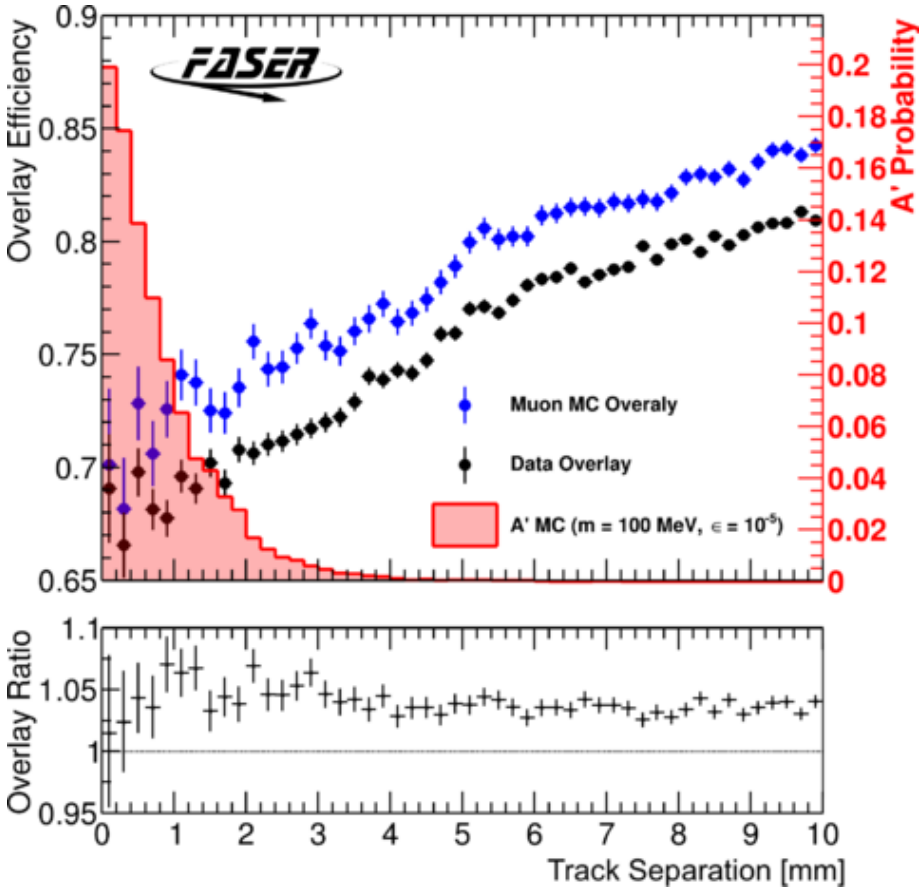
Steps of a CKF

1. Starts from initial track seed
2. Considers the branching of the fit at each sensitive surface it encounters
3. Measurements selected based on compatibility with current state by using residuals
4. Quality selection criteria applied to identify and remove bad candidates
5. Implements a scoring function that use properties of track parameters
6. Higher score means there is a larger probability that is associated with track of the particle



Alternative Tracking Method : Backtracking

- Starting from tracking station 3 (end of tracker) instead of at front
  - Should be able to reconstruct tracks that are closer together
  - Aims to increase efficiency at low track separation
  - Can be compared to efficiency of forward tracking



[1] FASER Collaboration 2023

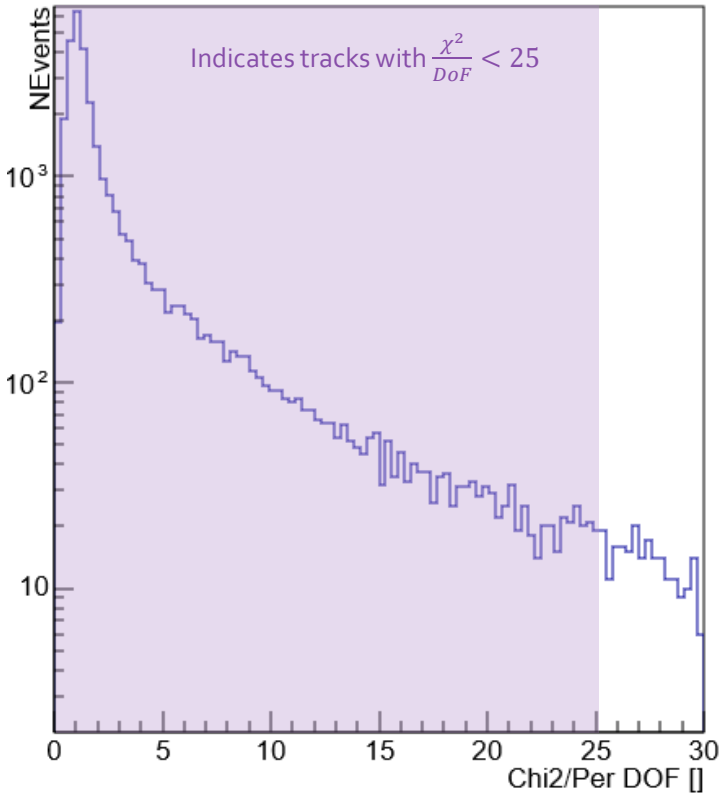
[1] FASER Collaboration, H. e. a. Abreu, "Search for dark photons with the FASER detector at the LHC," Phys. Lett. B 848 (2024) 138378, arXiv:2308.05587 [hep-ex].

Dataset

Good Tracks
a good quality track has a track fit χ2 /(number of degrees of freedom) < 25 , at least 12 hits on track, and a momentum > 20 GeV

- In this study:
  - Each sample has 20k events produced
  - All tracks required to be 'Good Tracks'
  - Two tracks with the highest z momentum are selected

χ^2 Per Degree of Freedom [Before selections]
Sample with m=0.01 GeV and $\epsilon = 10^{-5}$



Total number of events passing each cut for >=1 Good tracks and ==2 Good Tracks

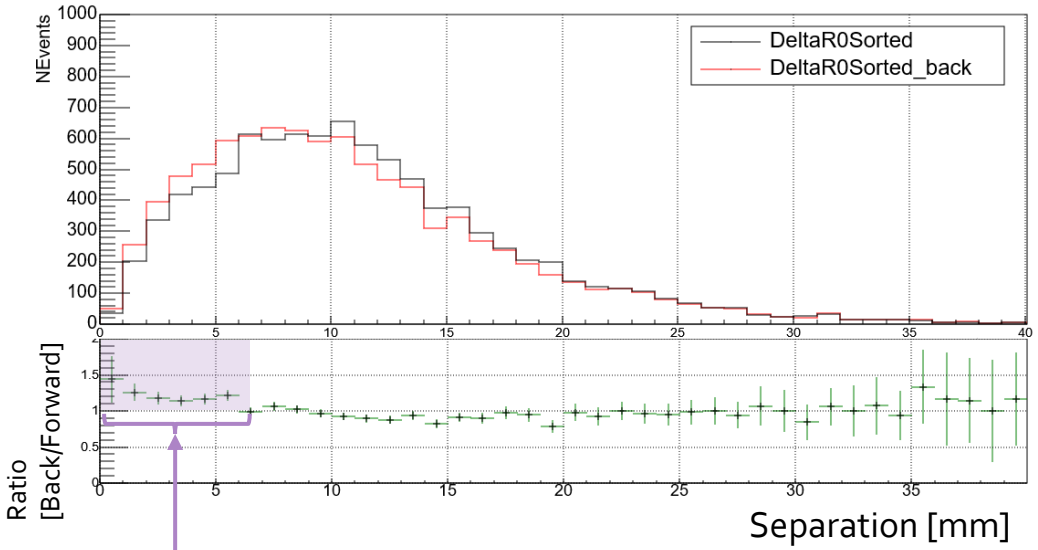
Tracking Direction	Mass	Coupling	Total Events	Events with >=1 Trk	Events with ==2 trk
Forward	0.01	10^-5	20000	17023	9178
	0.1	10^-5	20000	18661	12148
	0.01	10^-4	20000	18589	12428
Backward	0.01	10^-5	20000	17055	9091
	0.1	10^-5	20000	18476	11320
	0.01	10^-4	20000	18672	11513

Worst case will be for low mass and low coupling
- longer lived therefore separation is smaller

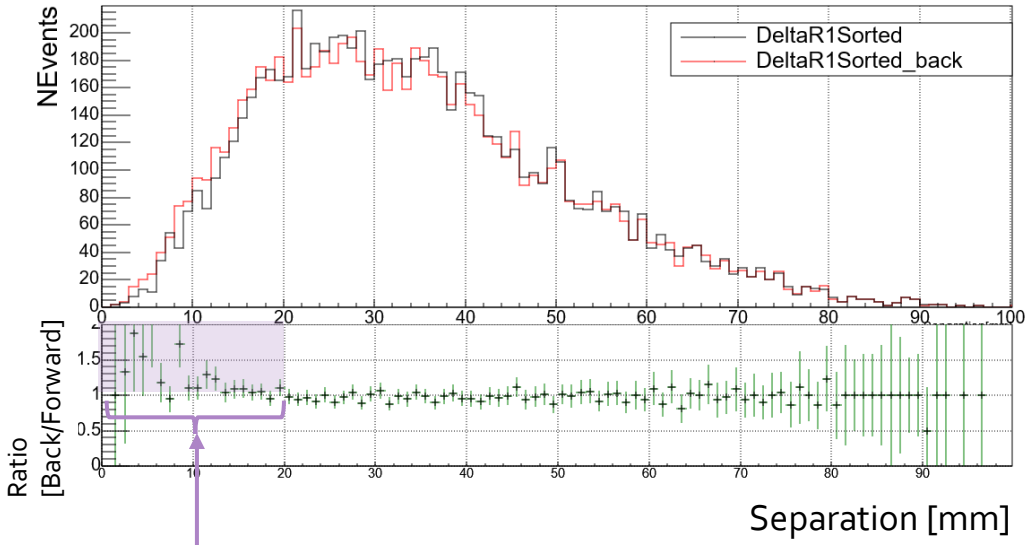
Effect on Track Reconstruction at Low Separation

- Requiring events to have only 2 tracks
- Backtracking reconstructs more tracks than forward tracking at separations of less than 10mm
- Ratio (Number of events [Backwards Tracking]/Number of Events [Forwards Tracking]) is consistently over 1
  - Backwards tracking picks up more events than forwards tracking
    - below ~ 7mm upstream [tracking station 1]
    - Below ~20mm downstream [tracking station 3]

Separation Between Track 0 and Track 1 at Station 1[Upstream]
Sample with m=0.01 GeV $\epsilon = 10^{-5}$

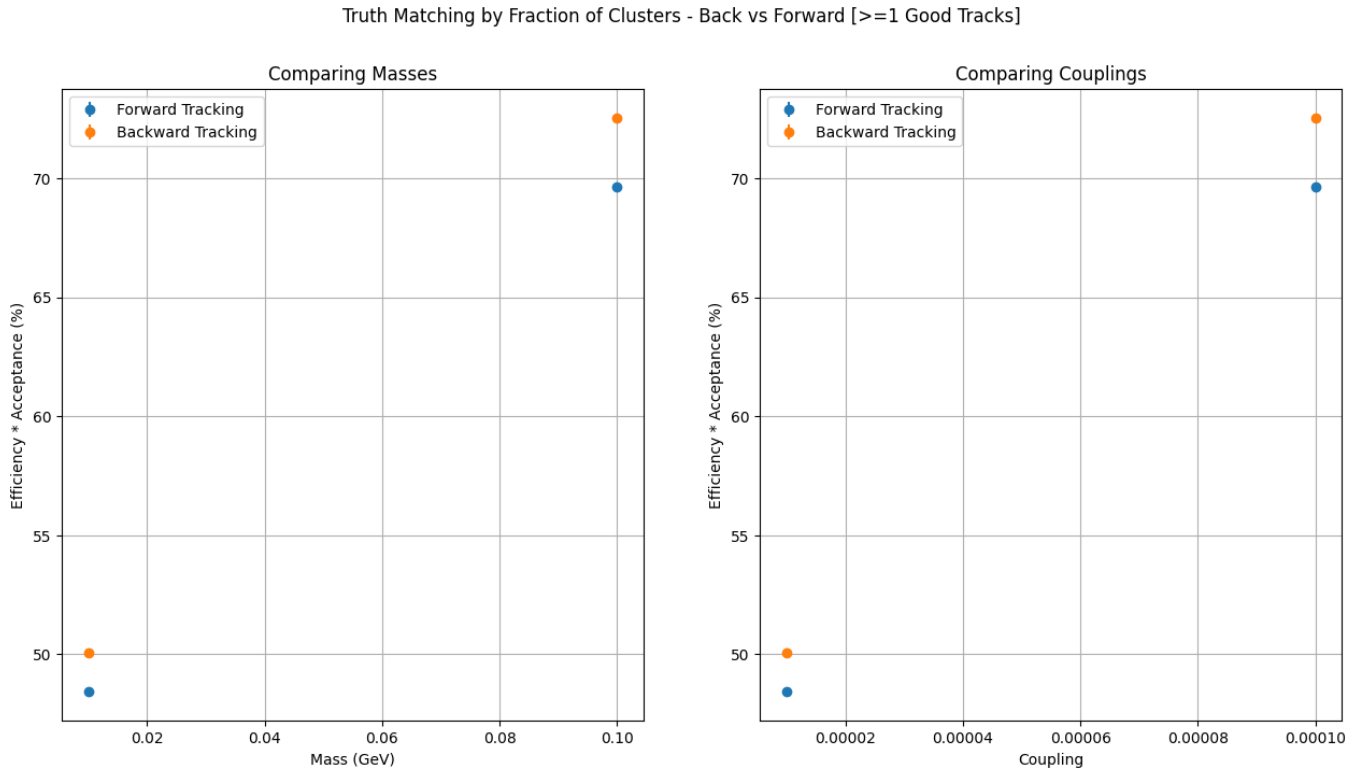


Separation Between Track 0 and Track 1 at Station 3 [Downstream]
Sample with m=0.01 GeV $\epsilon = 10^{-5}$



Truth Matching

- To fully quantify the overall efficiency and acceptance
  - Need to quantify the fraction of events that are effectively matched to the truth
- Done using 3 methods:
  - Matching by minimum radius between each track and the truth particle
  - Matching by fraction of clusters for each truth particle and associated to the track
  - Matching by charge of track



Efficiency x Acceptance (E*A)

>=1 Good Track:

$$Efficiency \times Acceptance_{\geq 1} = \frac{Number\ of\ Events\ (Matched\ to\ both\ e+\ \&\ e-\ AND \geq 1\ GoodTracks)}{20000(Total)}$$

==2 Good Tracks:

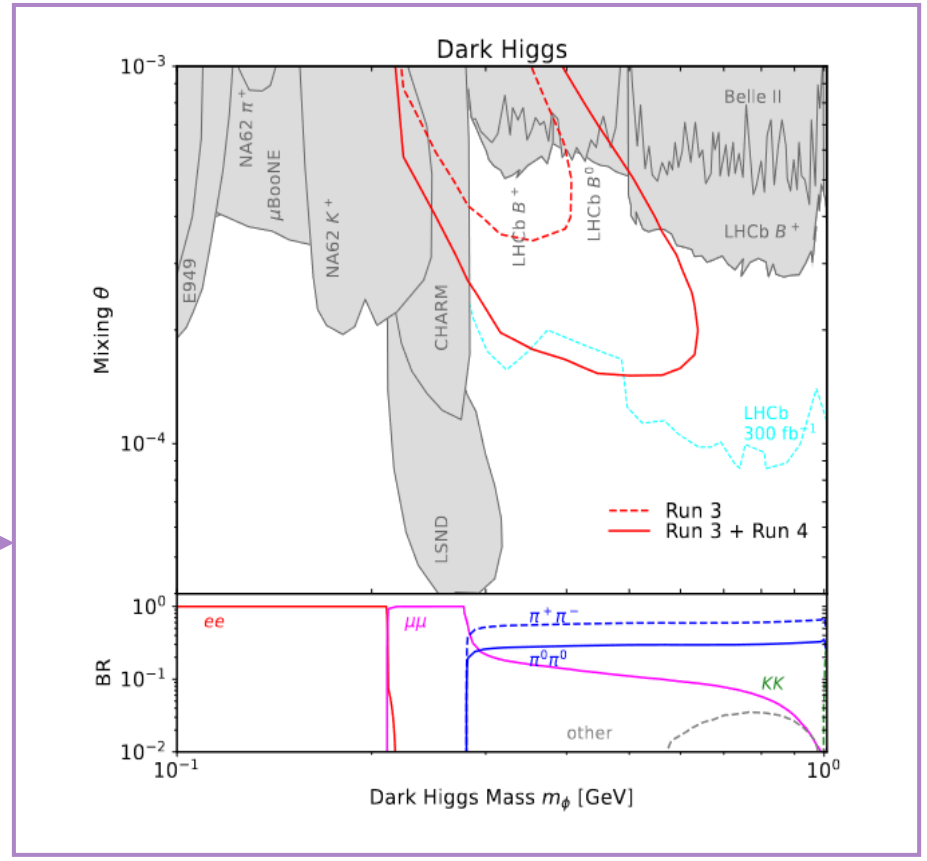
$$Efficiency \times Acceptance_{=2} = \frac{Number\ of\ Events\ (Matched\ to\ both\ e+\ \&\ e-\ AND == 2\ GoodTracks)}{20000(Total)}$$

Efficiency * Acceptance for sample with m=0.01 GeV and $\epsilon = 10^{-5}$

Matching By	Tracking Direction	E*A (>=1 Good Tracks) (%)	E*A (==2 Good Tracks) (%)
Fraction of Clusters	Forward	48	45
	Backward	50	44
Charge of Track	Forward	46	43
	Backward	48	43

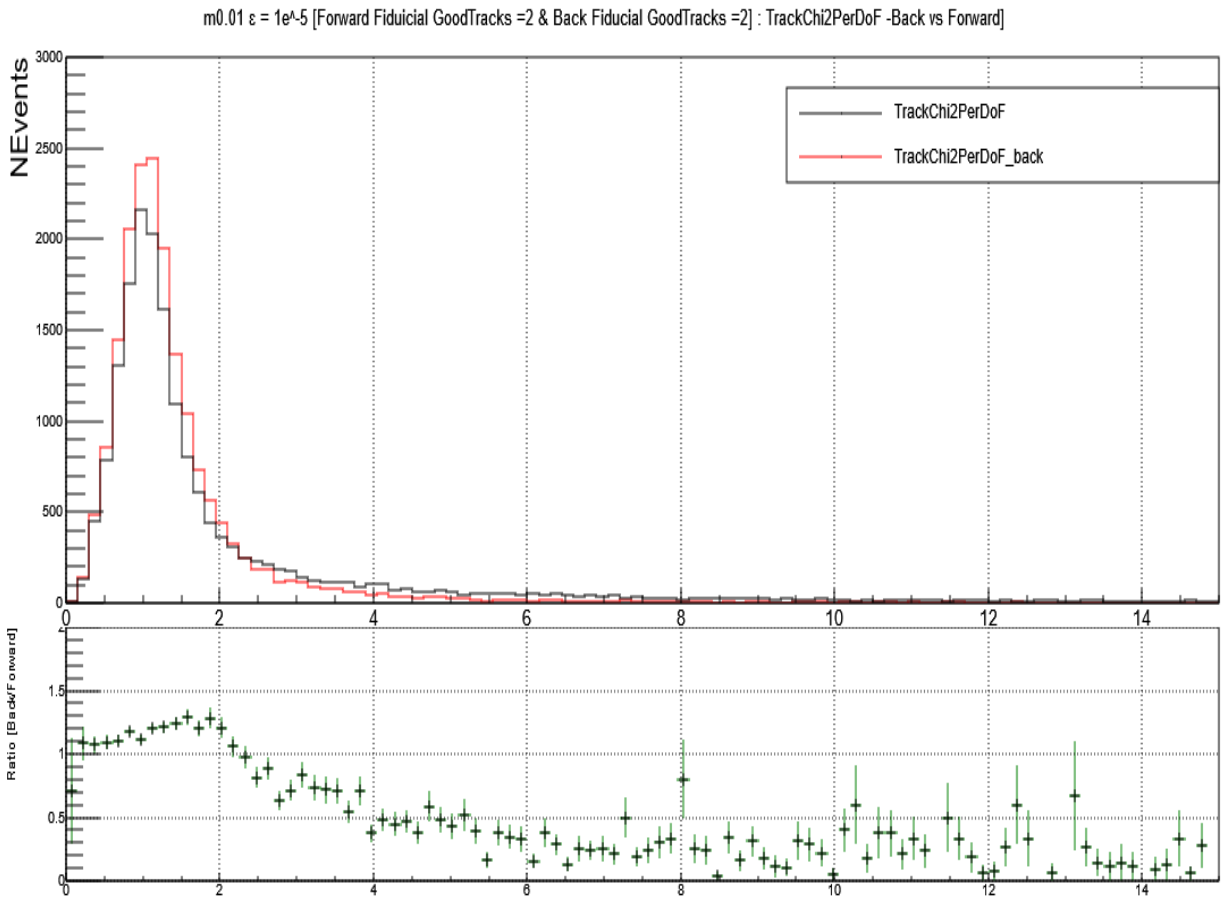
Conclusion and Future Work

- Preliminary results of backwards tracking are promising
  - Backwards tracking picks up more events than forwards tracking at lower separations
- Finalising the studies of the benefits of backwards tracking
- Implement in the dark photon analysis workflow
- Ideal scenario would be to combine forwards and backwards tracking
  - Currently been explored in the collaboration
- Use the results to improve the tracking for the search for the **Dark Higgs**
  - Will form the analysis for my thesis



Back Up

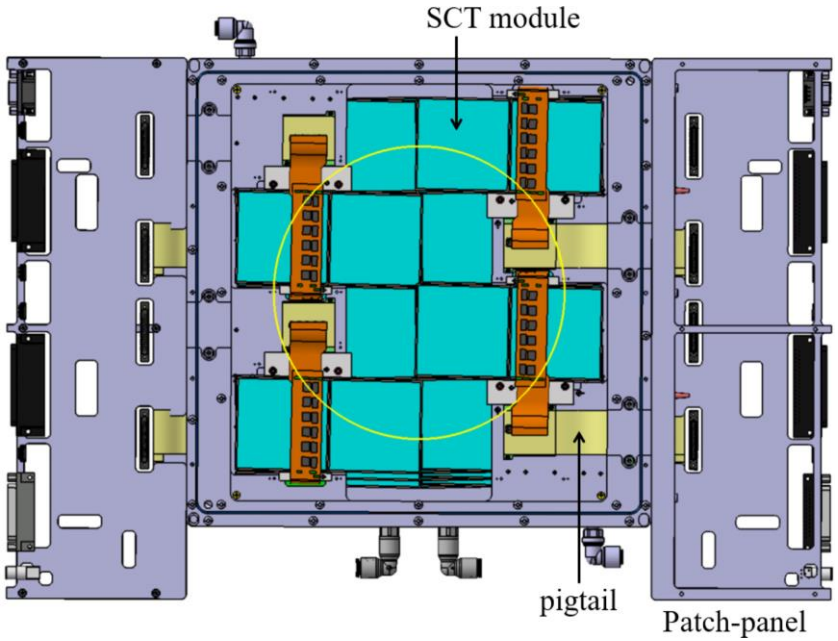
- χ^2 per degree of freedom has higher peak at 1 for backwards tracking than forwards tracking
  - Fit of tracks is better in backwards tracking is better by this metric

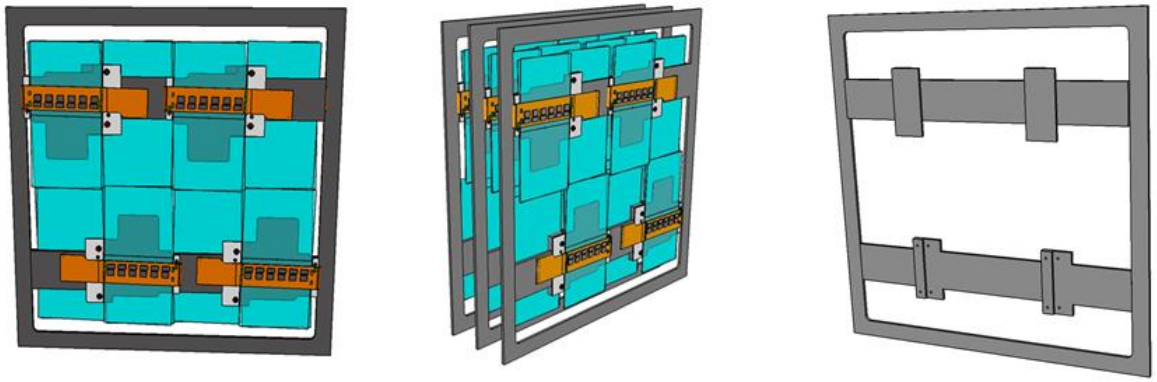


χ^2/DoF for Forwards Tracking vs Backwards Tracking

FASER Tracker

- Utilises silicon strip detectors
  - Back to back at a stereo angle of 40mrad
  - Spatial resolution of 17μm in precision coordinate
  - ~580 μm in non-precision coordinate
- Magnetic field applied in y
  - Charged particles separated in x





Truth Matching Efficiencies

Forwards Tracking

Matching By	Mass (GeV)	Coupling	E*A (>=1Good Tracks) (%)	E*A (==2 Good Tracks) (%)
Fraction of Clusters	0.01	10^{-5}	48.405	45.235
	0.1	10^{-5}	69.64	57.05
	0.01	10^{-4}	71.255	58.845
Charge of Track	0.01	10^{-5}	46.71	43.73
	0.1	10^{-5}	57.37	46.345
	0.01	10^{-4}	59.5	48.705

Backwards Tracking

Matching By	Mass (GeV)	Coupling	E*A (>=1 Good Tracks) (%)	E*A (==2 Good Tracks) (%)
Fraction of Clusters	0.01	10^{-5}	50.07	44.41
	0.1	10^{-5}	72.545	51.795
	0.01	10^{-4}	74.33	53.36
Charge of Track	0.01	10^{-5}	48.51	43.04
	0.1	10^{-5}	64.07	45.44
	0.01	10^{-4}	66.21	47.45