Mighty Tracker: Pixel to Fibre track finding algorithm

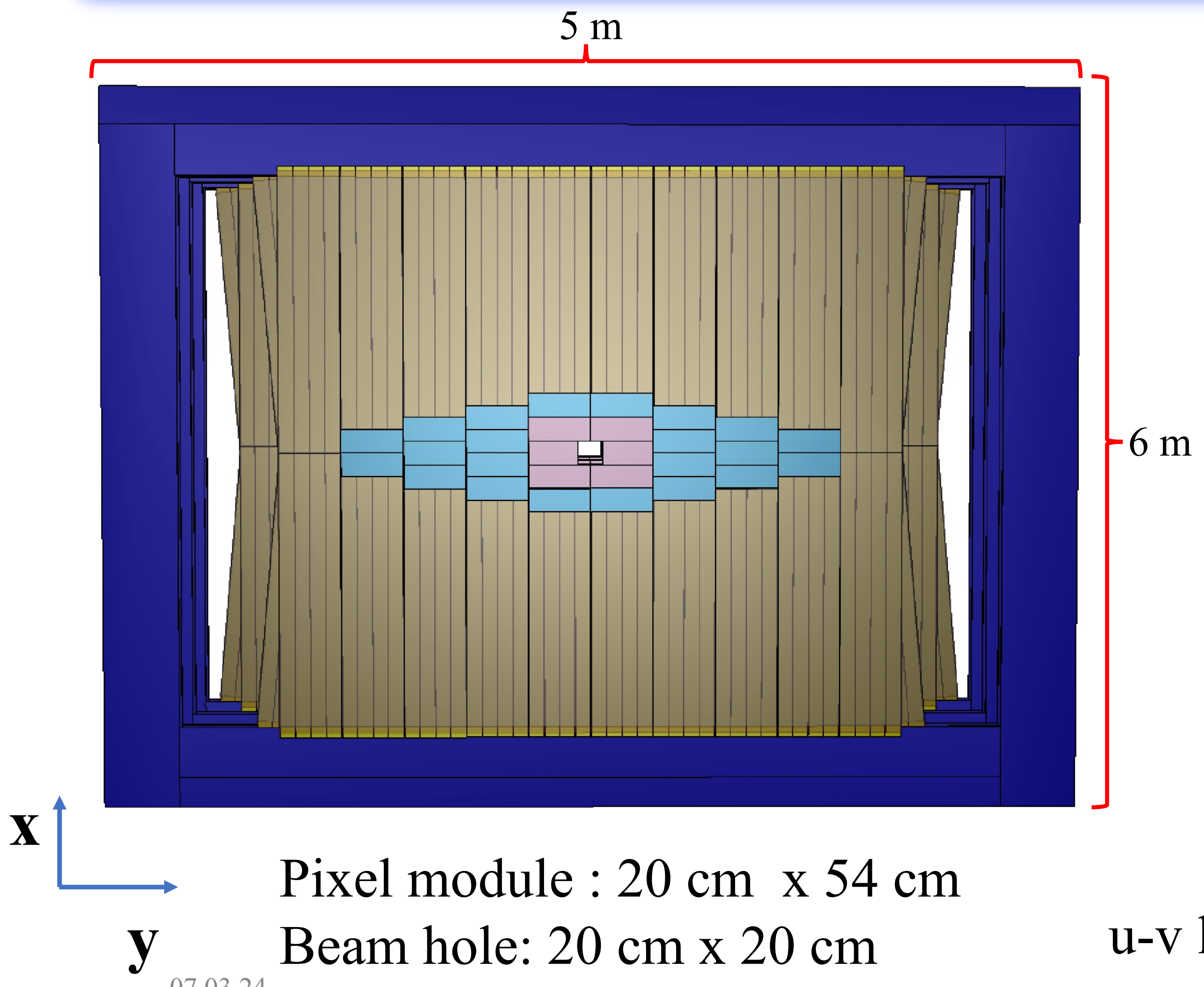
Abhijit Mathad and Renato Quagliani

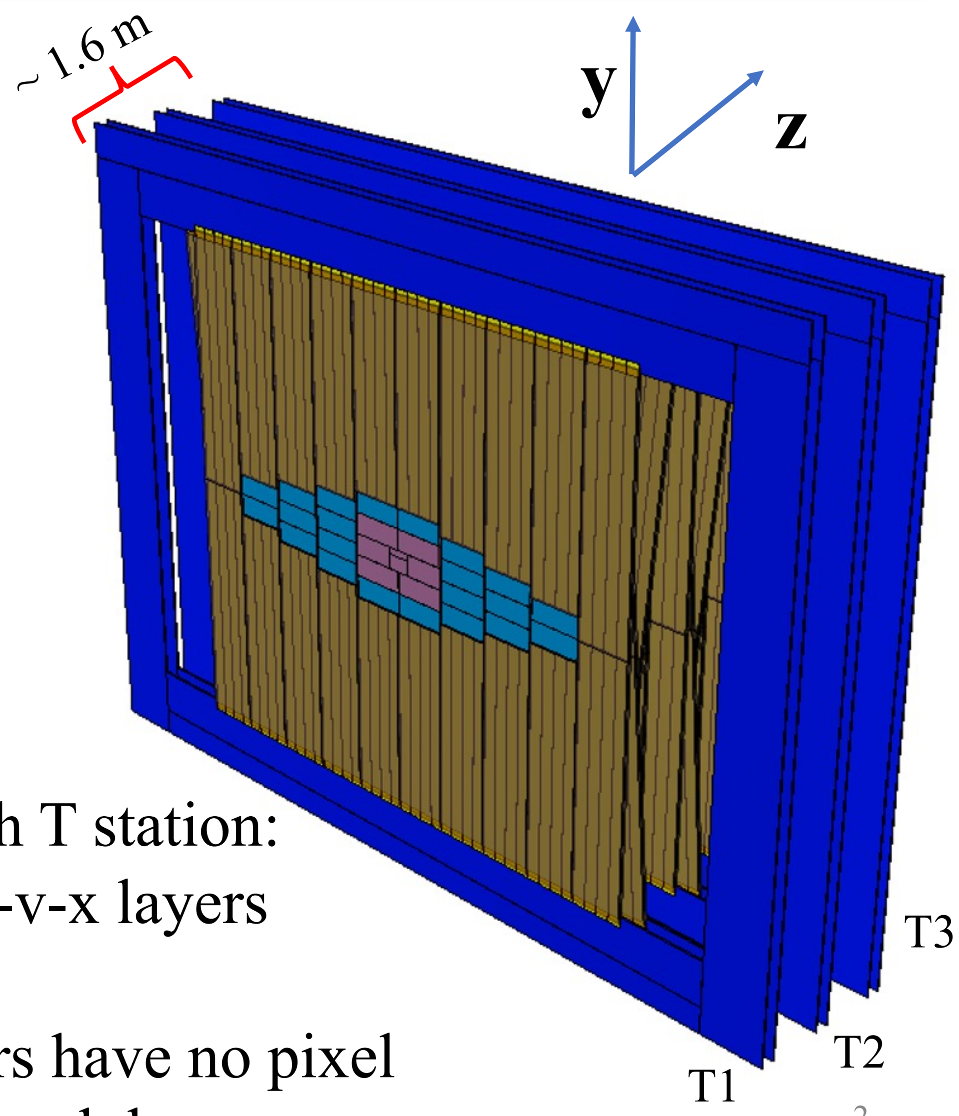
LHCb Upgrade II Tracking workshop

14 November 2023

Credit: ChatGPT

Mighty Tracker (MT)





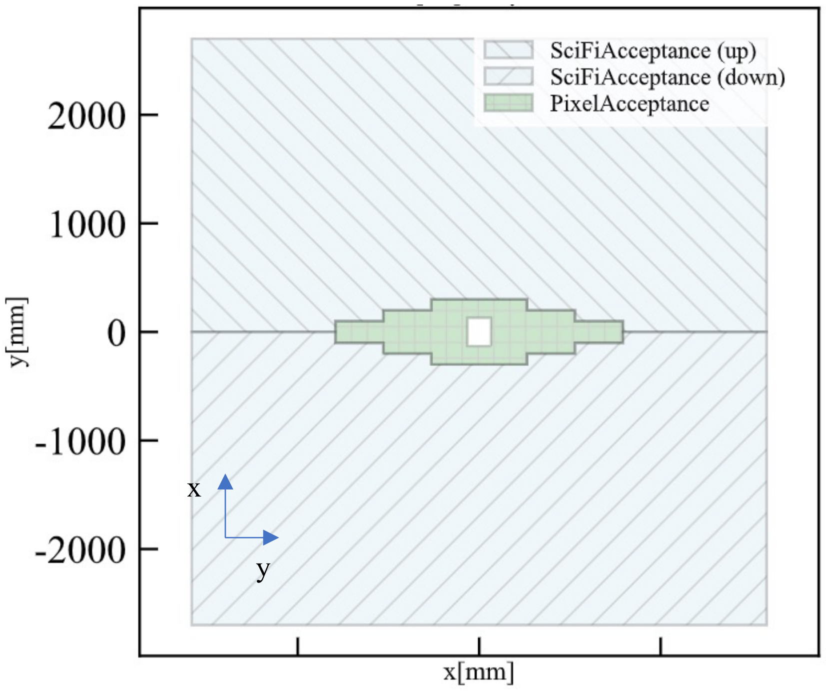
Each T station:
x-u-v-x layers

Pixel module : 20 cm x 54 cm
Beam hole: 20 cm x 20 cm

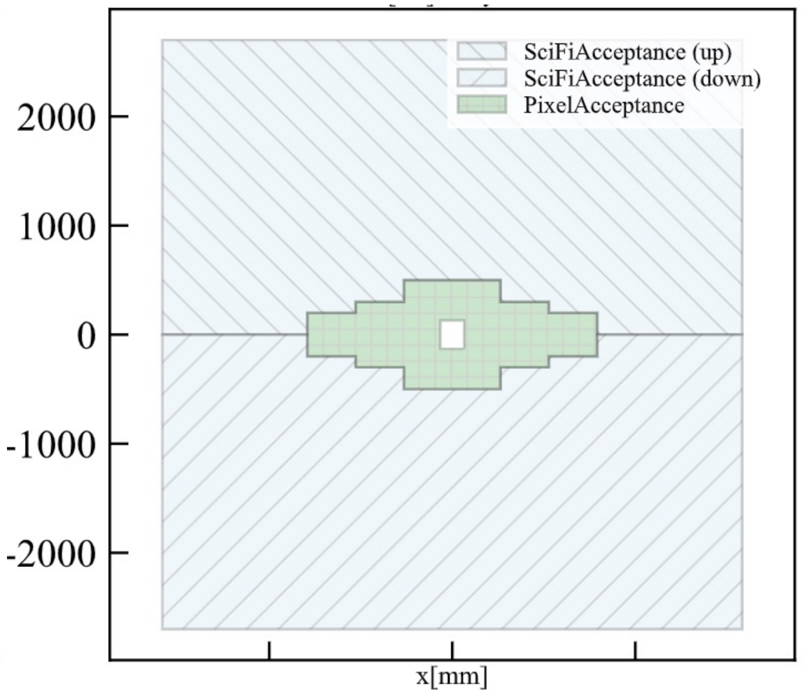
u-v layers have no pixel modules

Descoping scenarios of MT

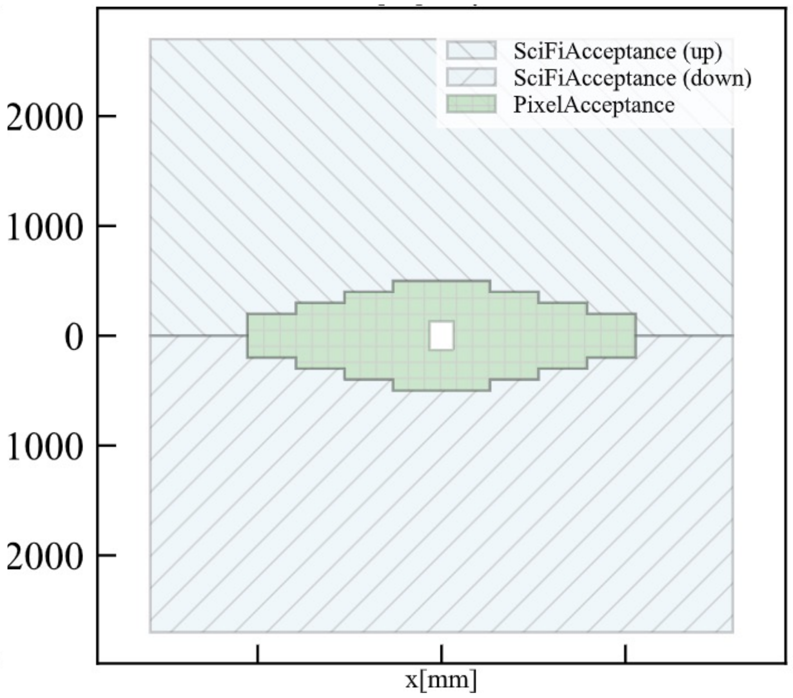
Frugal geomtry
with $L_{inst} = 1 \times 10^{34}\ cm^{-2}s^{-1}$



Modest geomtry
with $L_{inst} = 1.3 \times 10^{34}\ cm^{-2}s^{-1}$



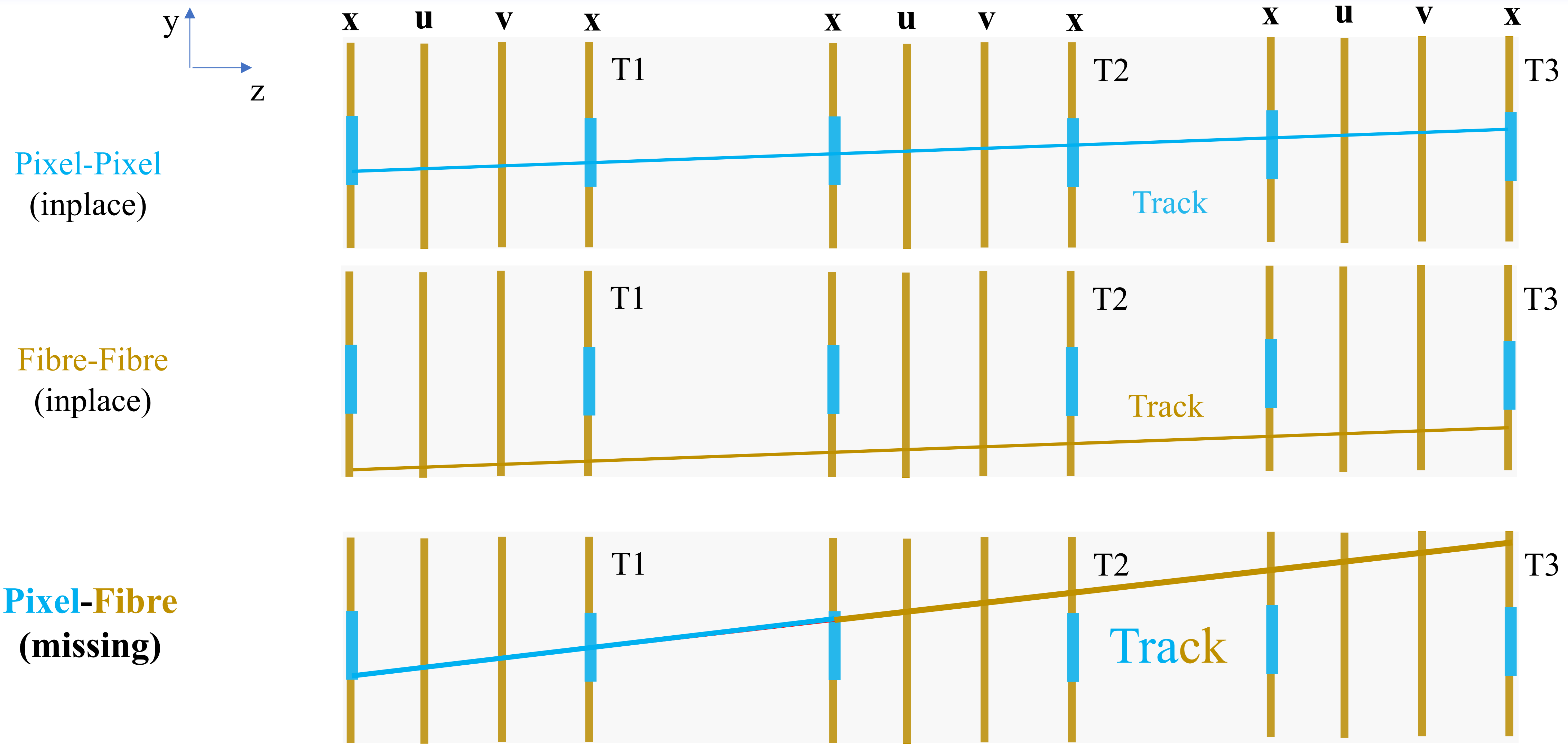
FTDR geomtry
with $L_{inst} = 1.5 \times 10^{34}\ cm^{-2}s^{-1}$



→ Increasing pixel area

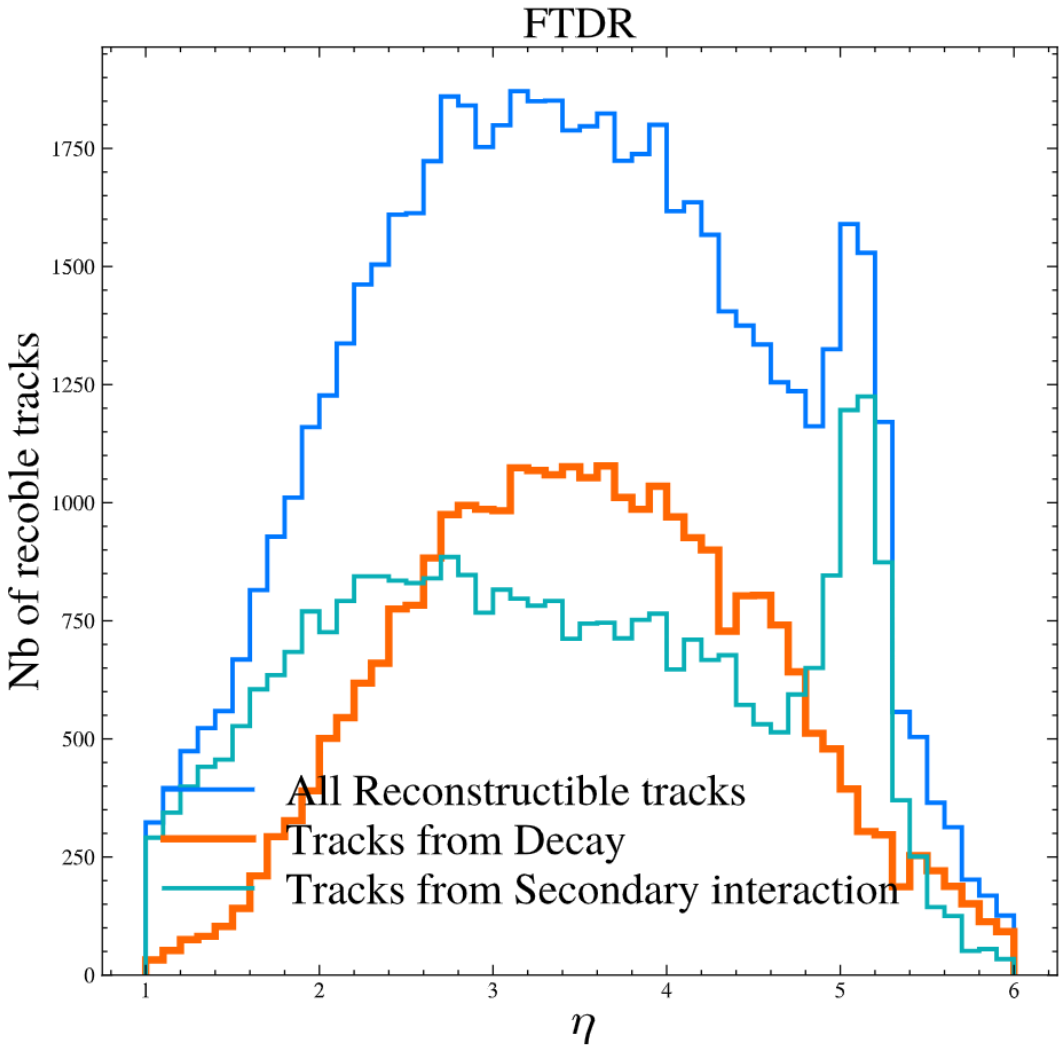
*A hole of 260 mm wide is choosen in all the studies presented here.

Flavours of MT tracks



What is the gain in track efficiency and effect on ghost rate for long and downstream tracks?

Tracks in the MT

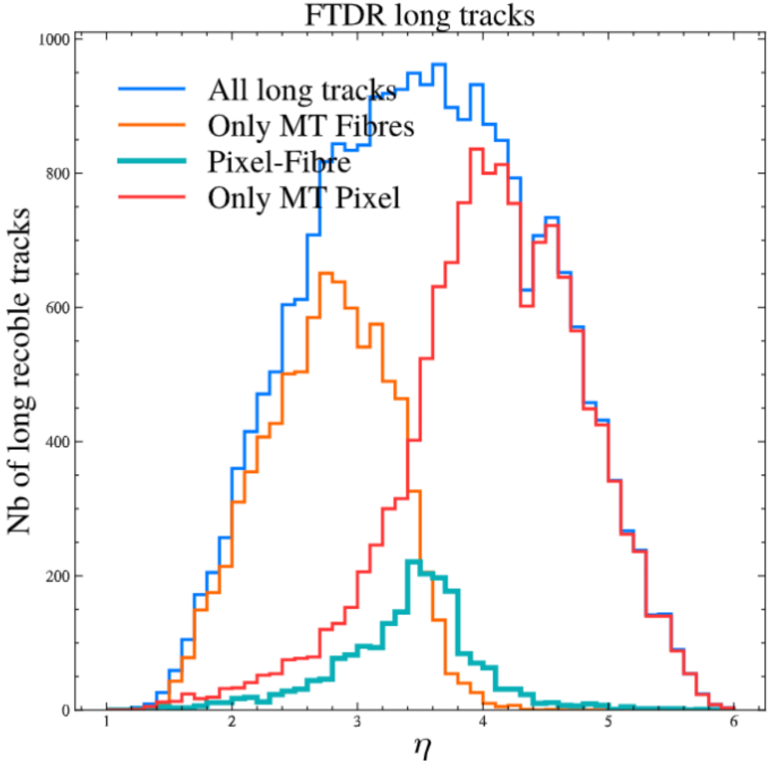


Large fraction of tracks from secondary interactions.

What is the fraction of Pix-Pix, Fib-Fib and Pix-Fib tracks?

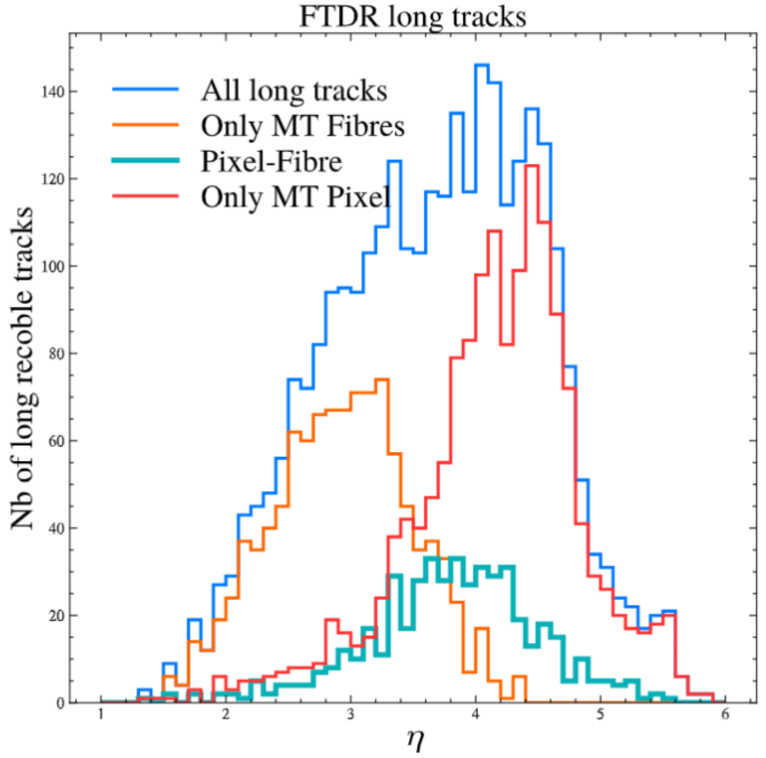
Fraction of MT Pixel-Fibre (Long tracks)

Tracks from decay or primaries



	% (Fibre Only)	% (Pixel Only)	% (Pixel-Fiber)
Frugal	38.4 %	53.0 %	8.6 %
Modest	23.1 %	69.2 %	7.6 %
FTDR	20.1 %	74.3 %	5.6 %

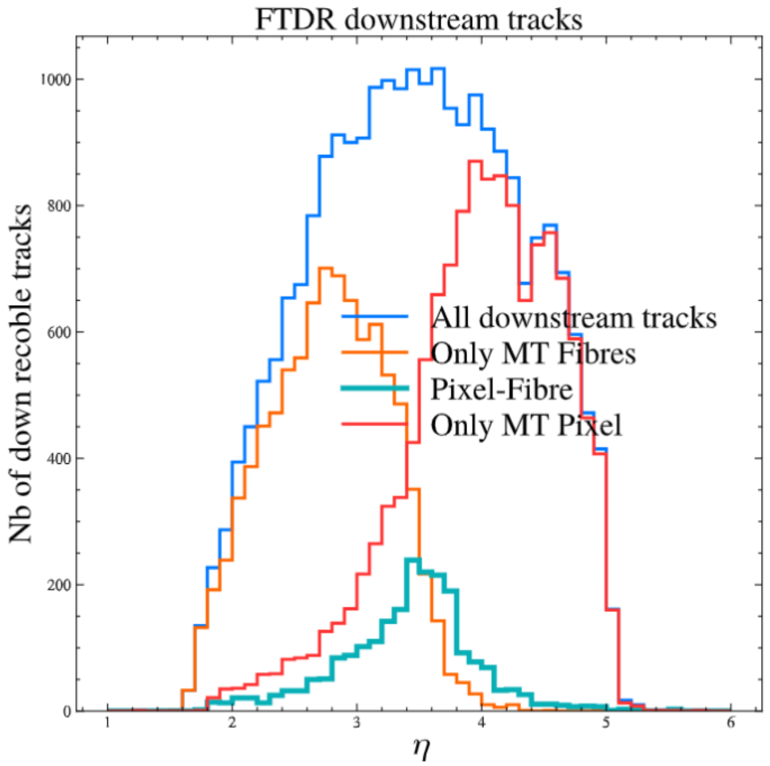
Tracks from secondaries



	% (Fibre Only)	% (Pixel Only)	% (Pixel-Fiber)
Frugal	40.1 %	46.5 %	13.3 %
Modest	24.1 %	65.1 %	10.8 %
FTDR	17.6 %	73.8 %	8.6 %

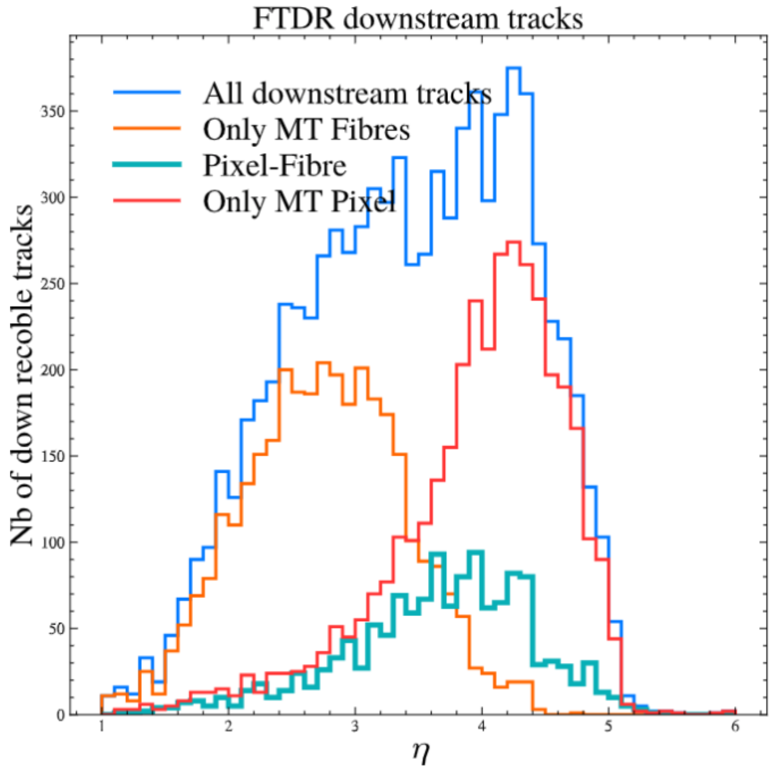
Fraction of MT Pixel-Fibre (Downstream tracks)

Tracks from decay or primaries



	% (Fibre Only)	% (Pixel Only)	% (Pixel-Fiber)
Frugal	41.3 %	49.6 %	9.0 %
Modest	25.1 %	66.7 %	8.2 %
FTDR	21.9 %	72.0 %	6.1 %

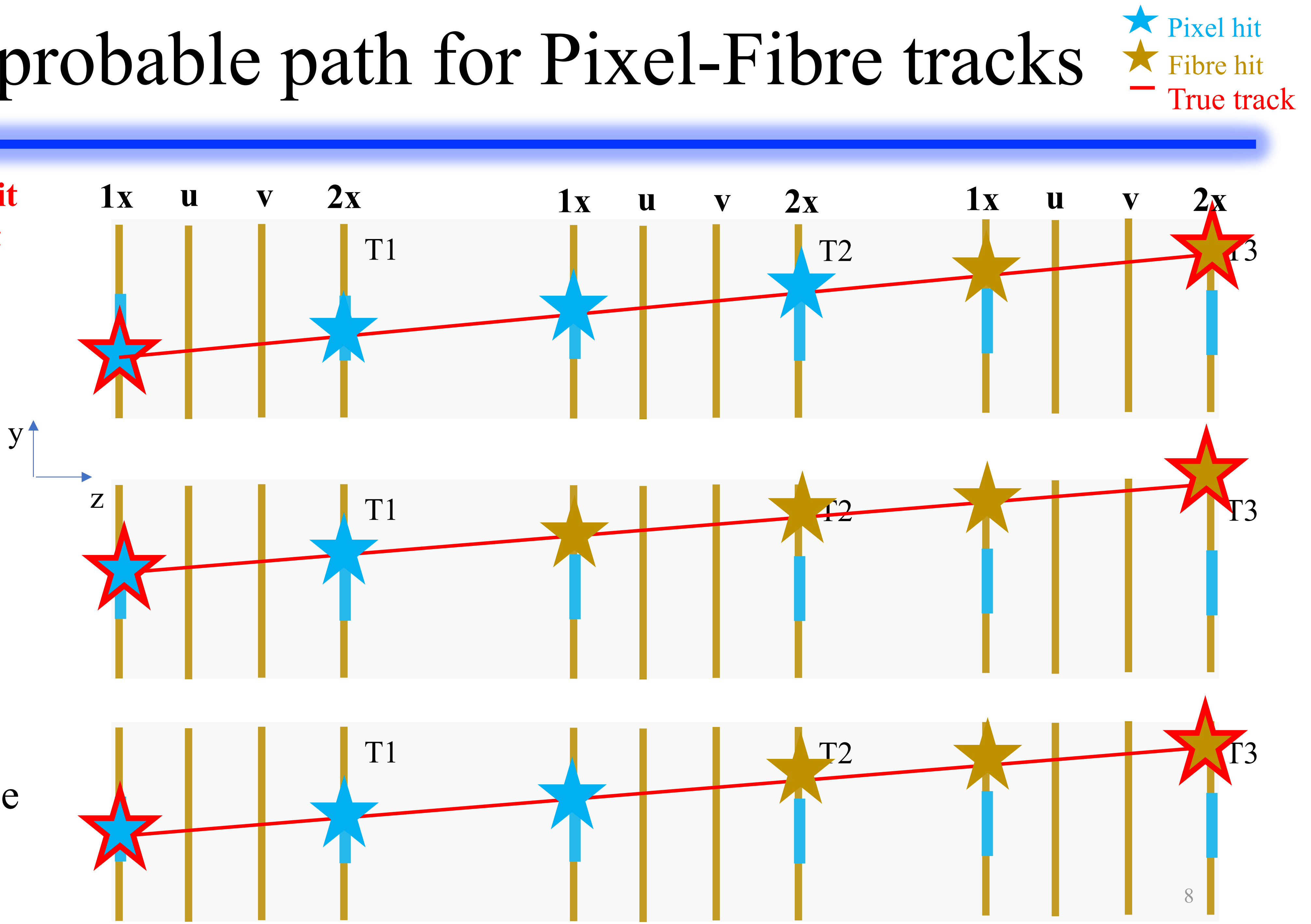
Tracks from secondaries



	% (Fibre Only)	% (Pixel Only)	% (Pixel-Fiber)
Frugal	42.6 %	42.8 %	14.6 %
Modest	24.8 %	63.1 %	12.1 %
FTDR	17.4 %	73.1 %	9.5 %

Most probable path for Pixel-Fibre tracks

Given T1_1x pixel hit and T3_2x fibre hit



Most probable path (40%)

Most probable path (40%)

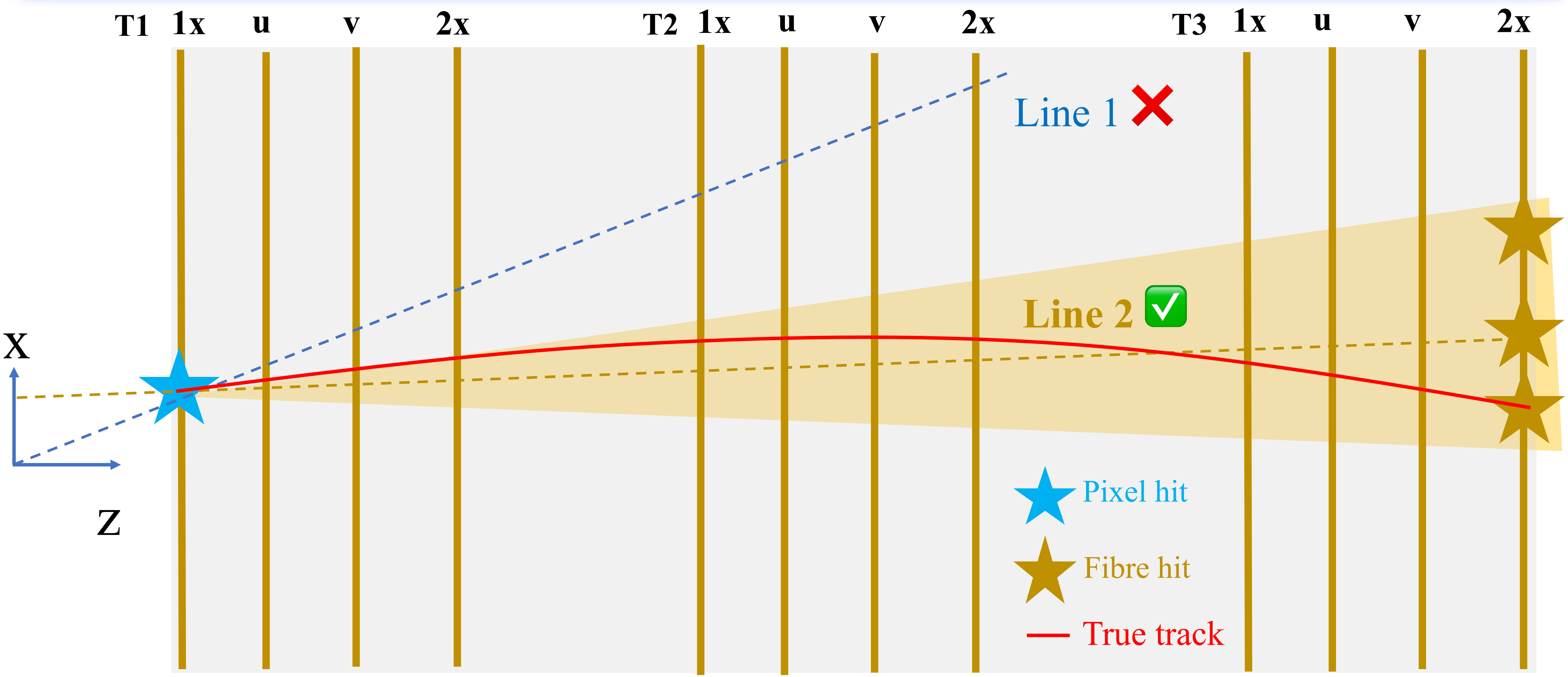
2nd most probable path (17%)

Details of the algorithm

Setup and configurations

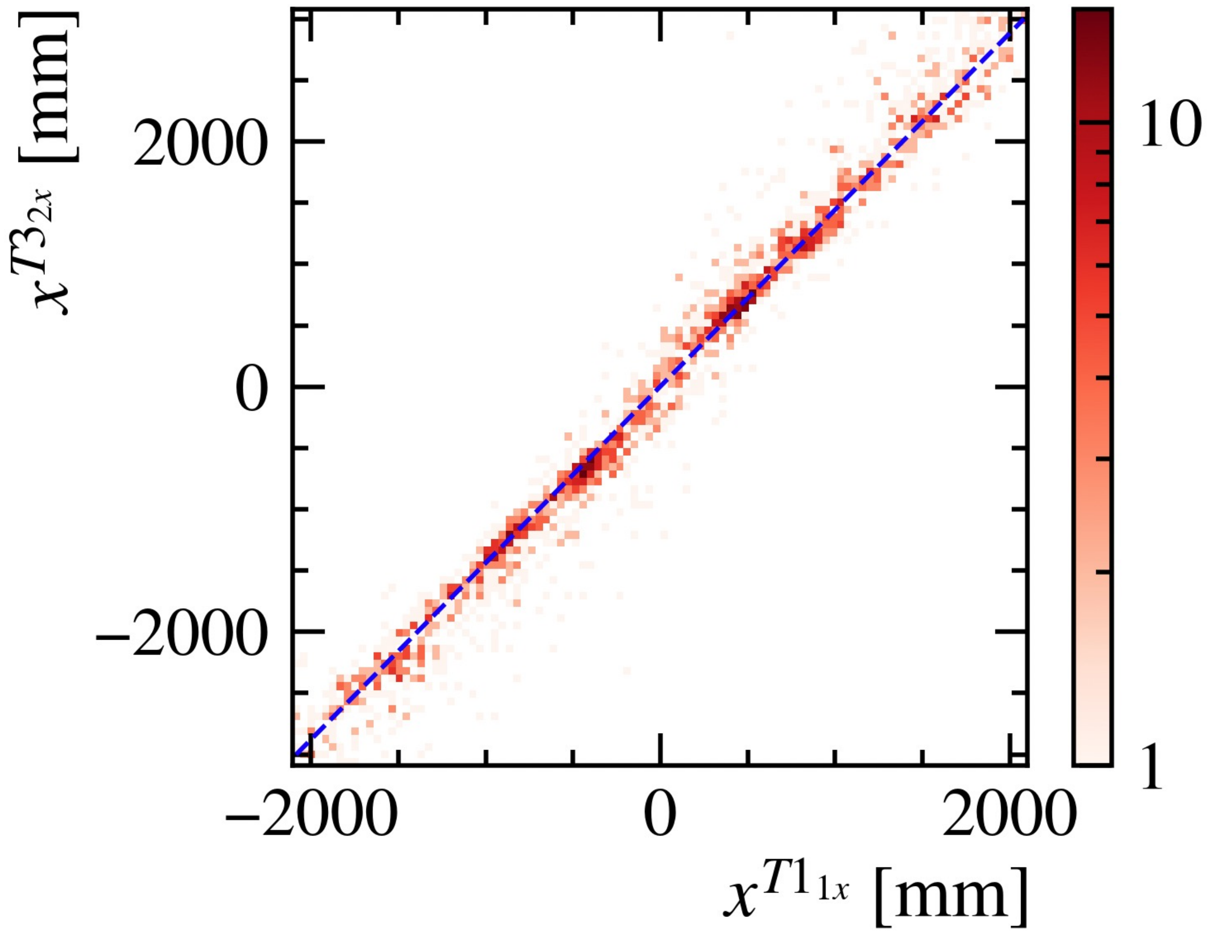
- For this study use 3 samples:
  - $B^0 \to J/\psi\phi$ (low and high lumi options)
  - Minibias (mid lumi option).
- Developments are done inside the pyreco package (MR).
- Here the MCHits are smeared according to resolution:
  - Pixel hits with x pitch and y pitch size: 52 x 150 micros.
  - Fiber hits with x pitch size of 250 microns.
  - Pixel hit efficiency is 96% and Fiber hit efficiency is 98%.

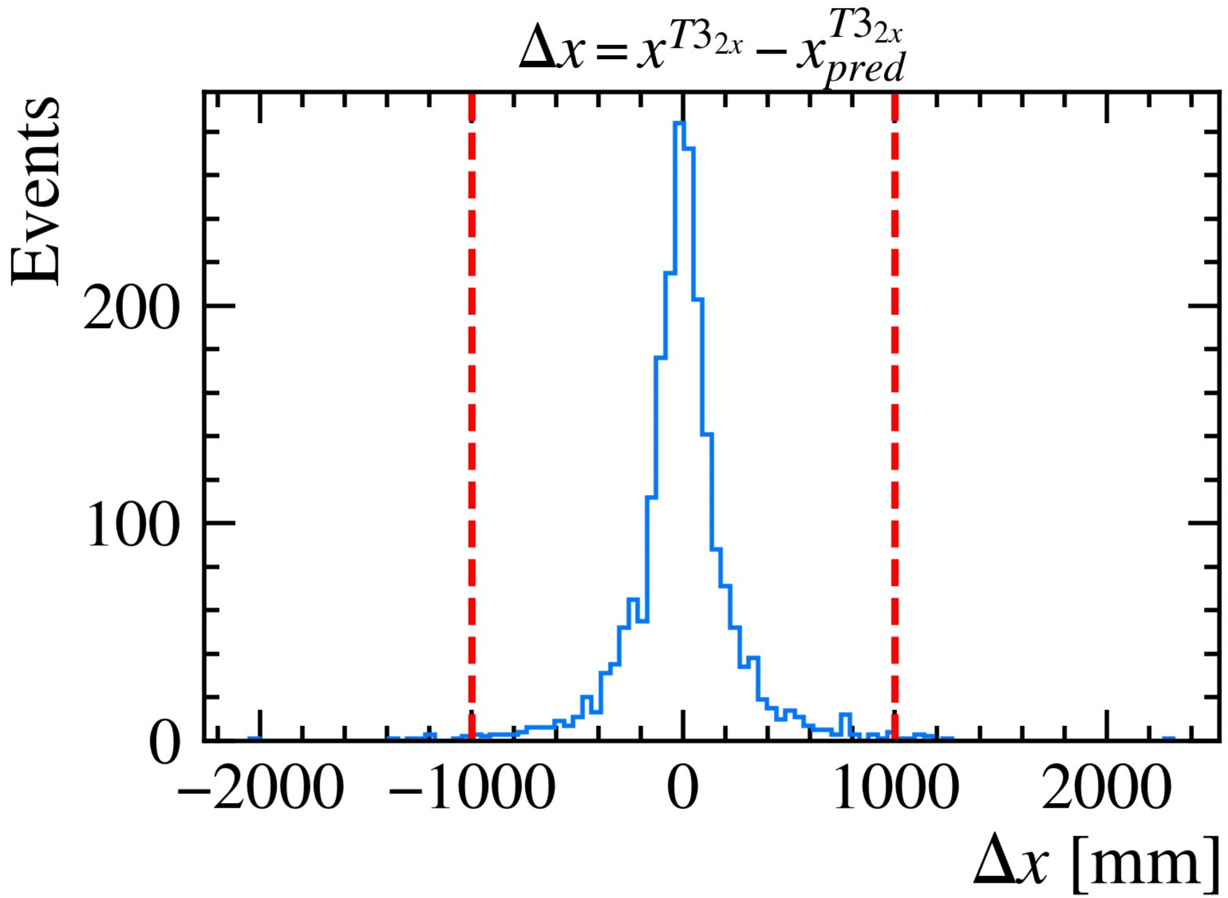
Step 1 (Two hit combo): Collect T3_2x fibre hits



Two hit-combo (far in z and in distinct stations) to minimise effect of hit inefficiency.

Two hit combination window: Truth info

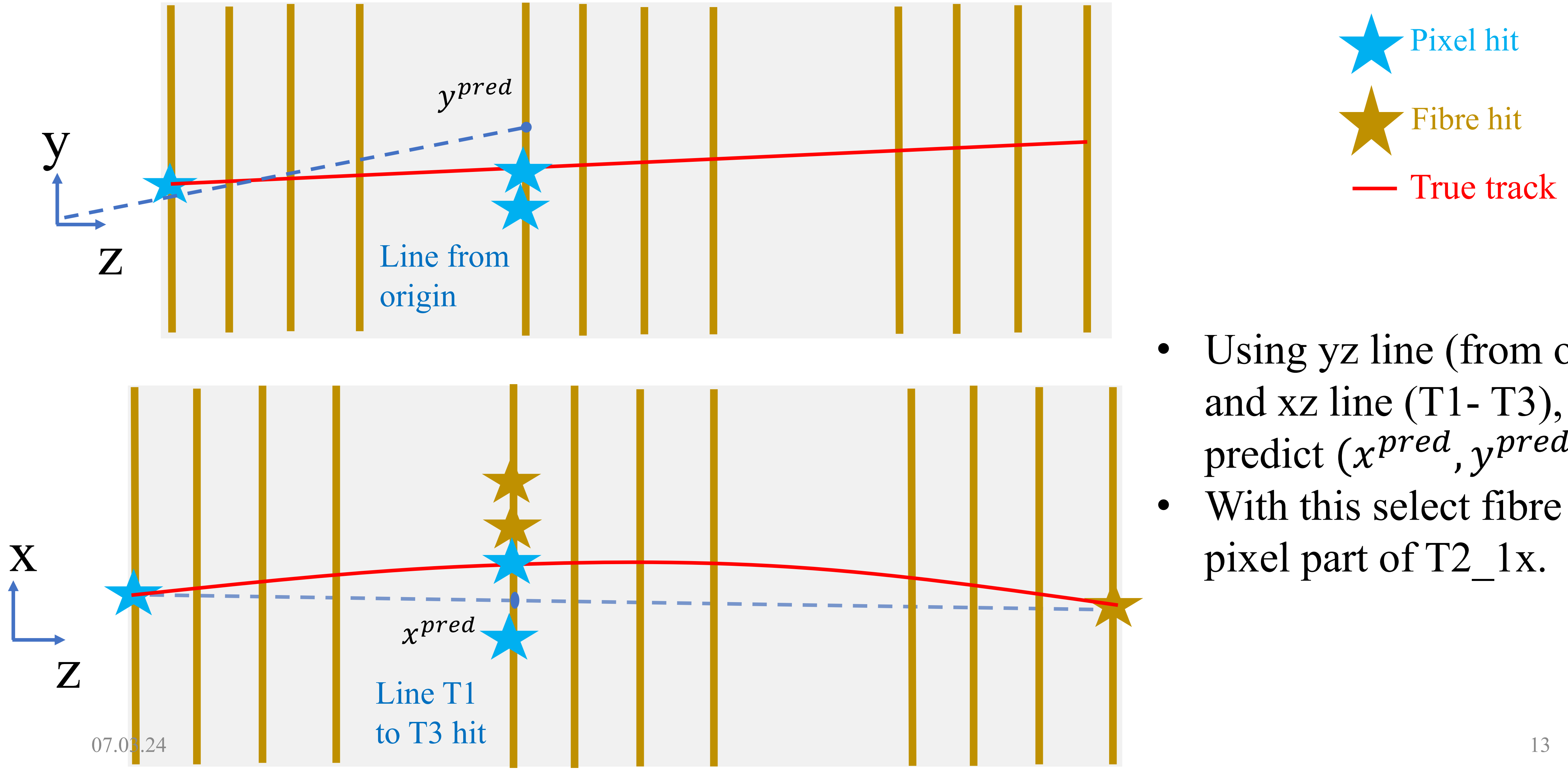




Model it with a straight line

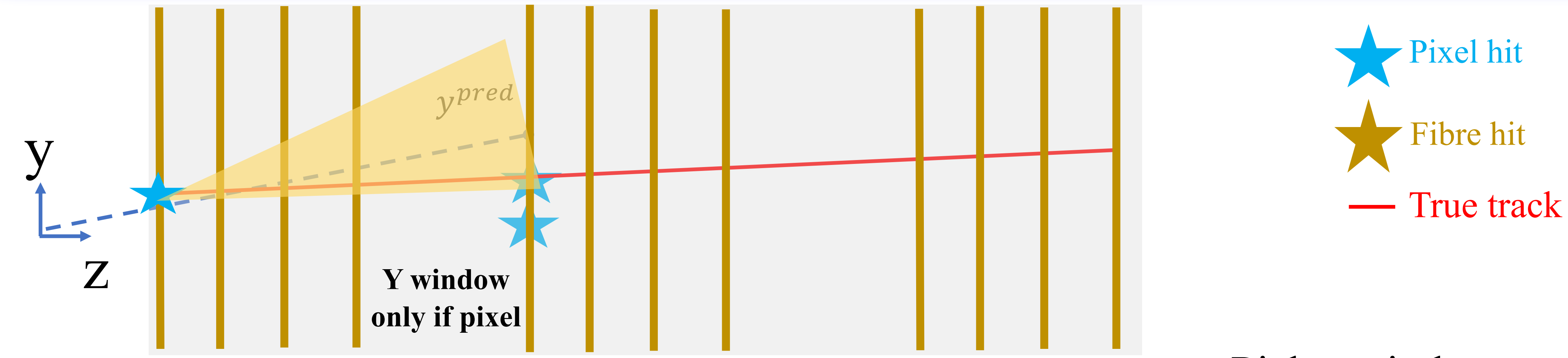
Pick a window with high eff.

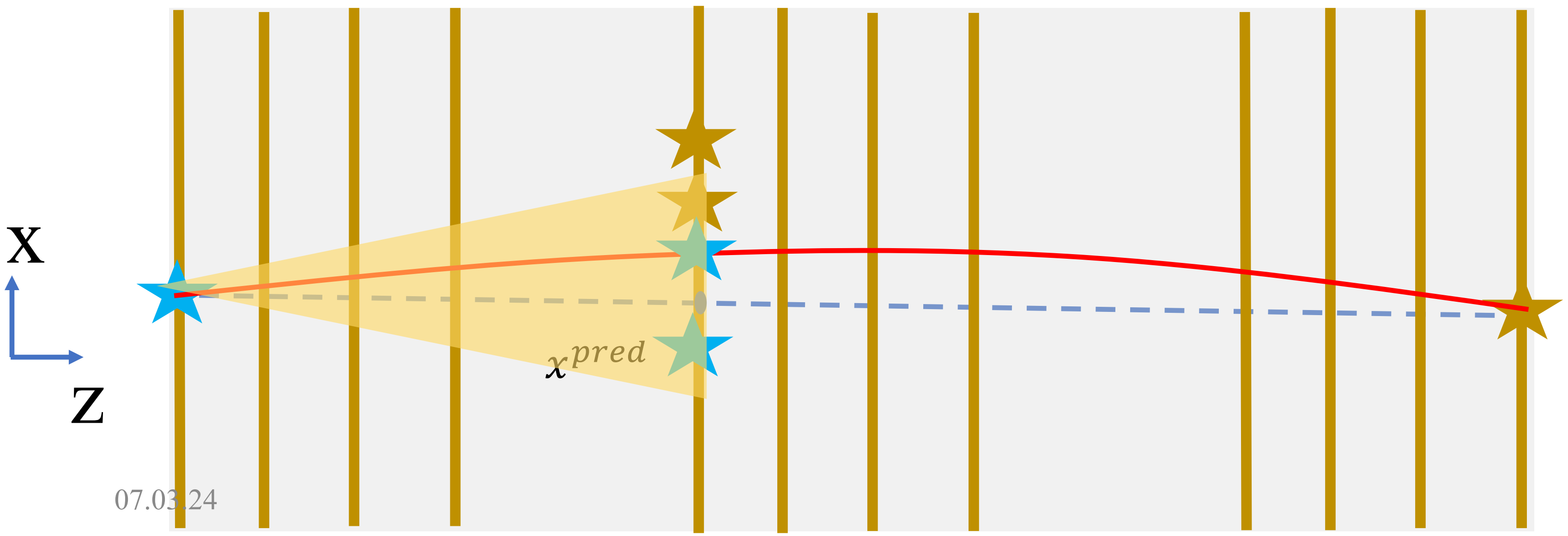
Step 2: Pixel or fibre part of T2_1x?



- Using yz line (from origin) and xz line (T1- T3), predict (x^{pred}, y^{pred}).
- With this select fibre or pixel part of T2_1x.

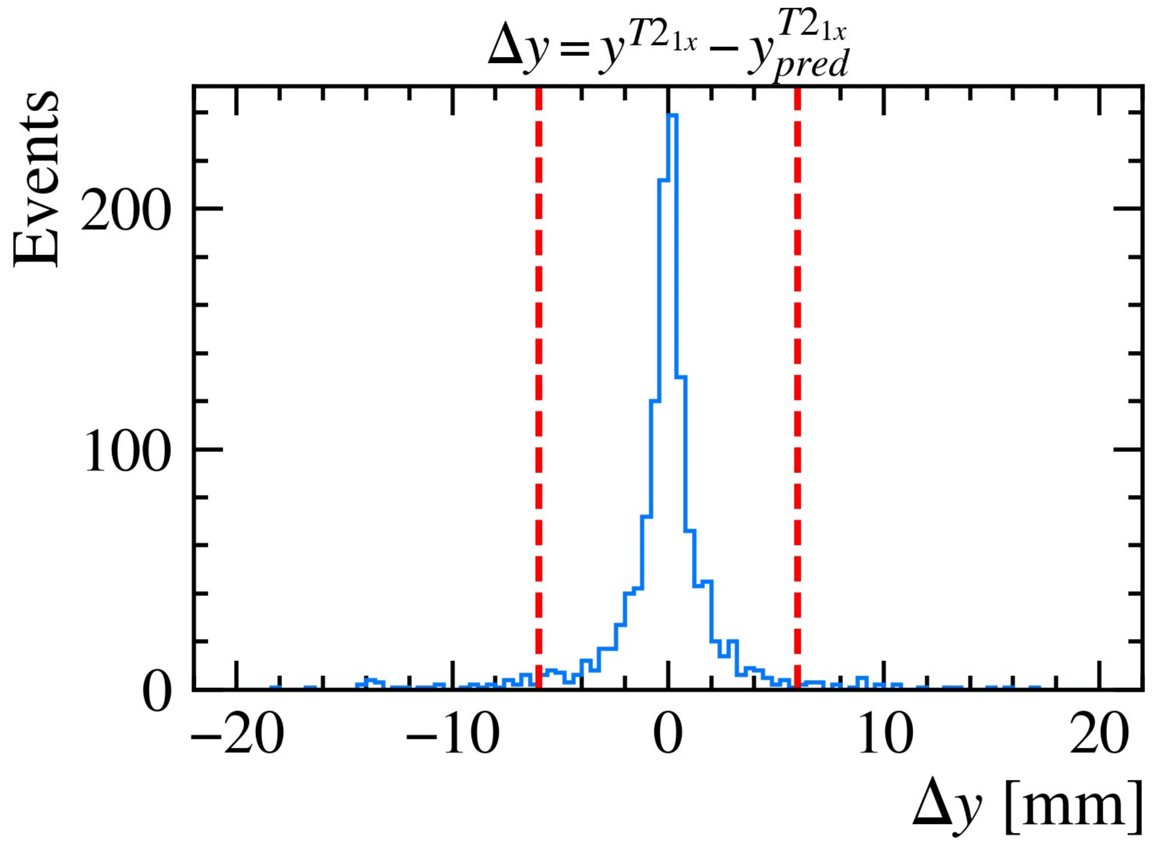
Step 3: Collect T2_1x pixel or fibre hits

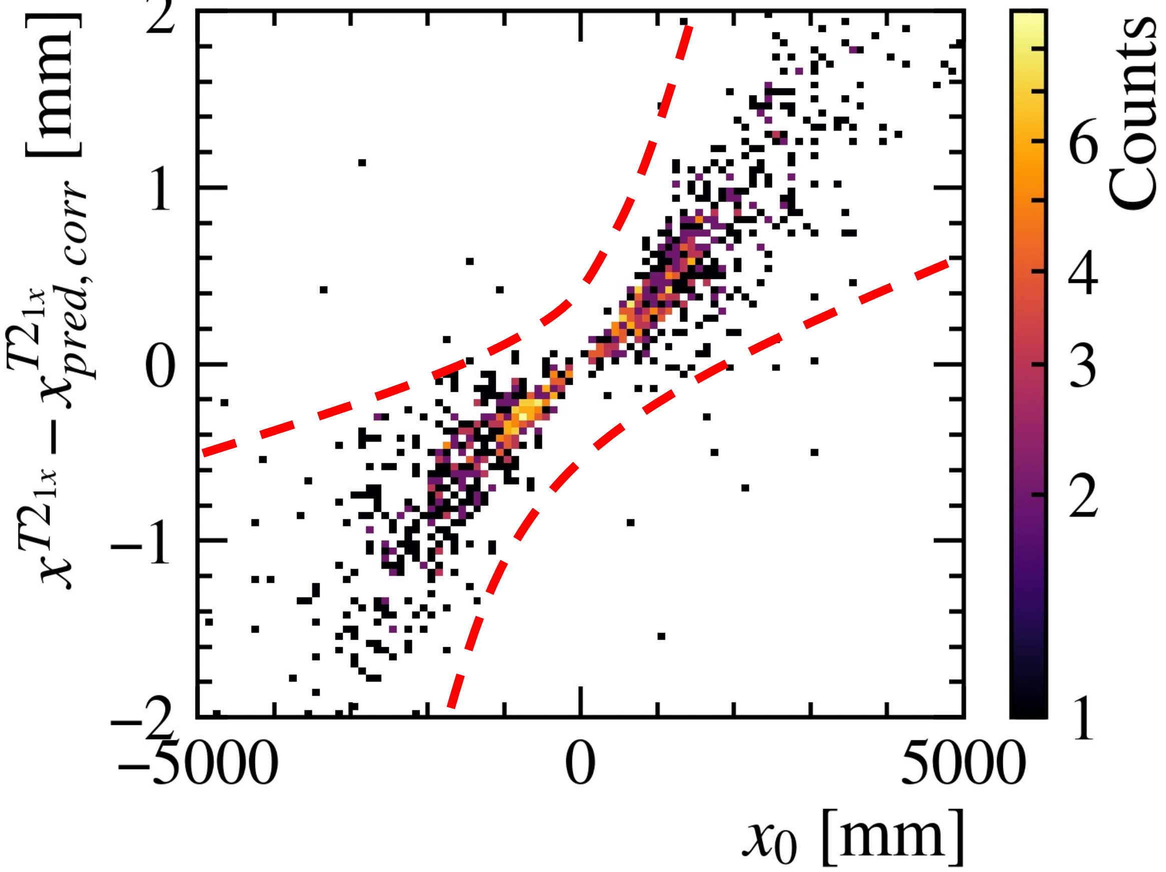




Pick a window around predicted values, correcting for “assumption of infinite momentum track (xz line)” and collect hits in T2_1x.

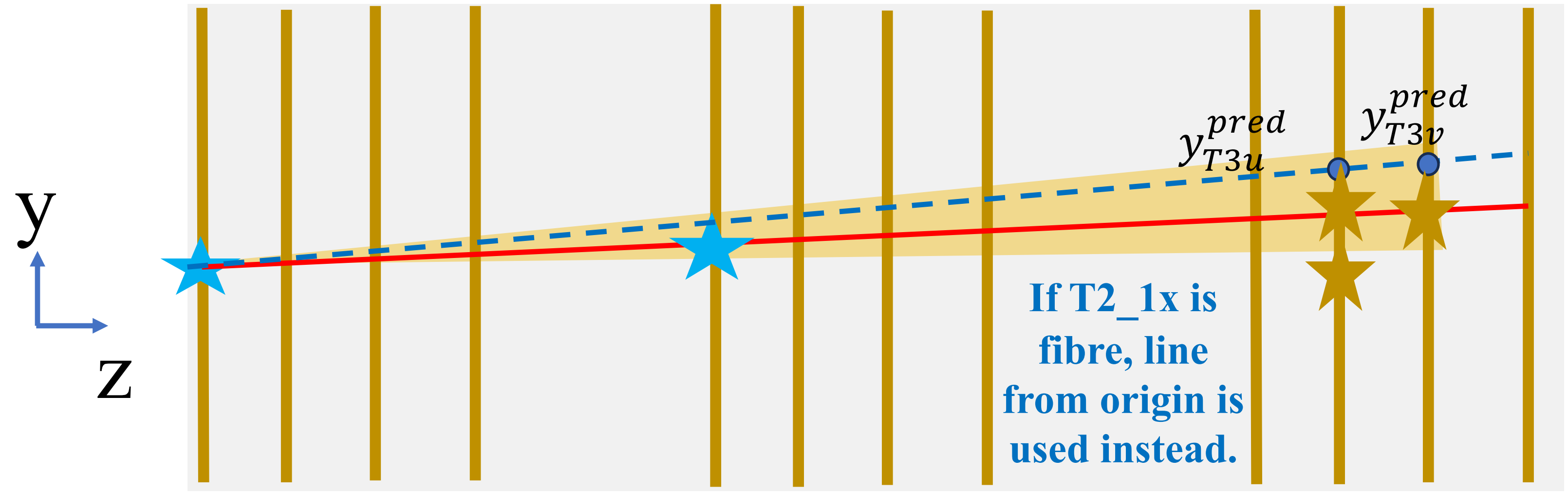
Three hit combination window: Truth info

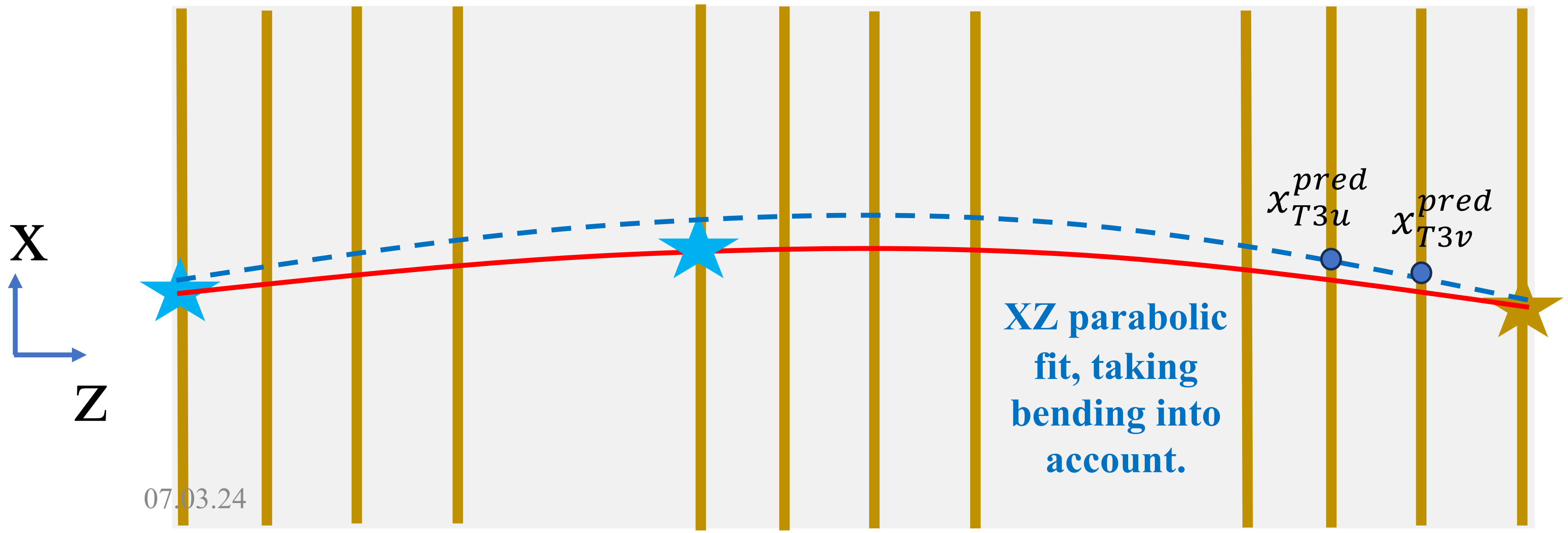




Windows in Δy and Δx^{corr} as function of x intercept, x_0
(in other works track momentum) is defined.

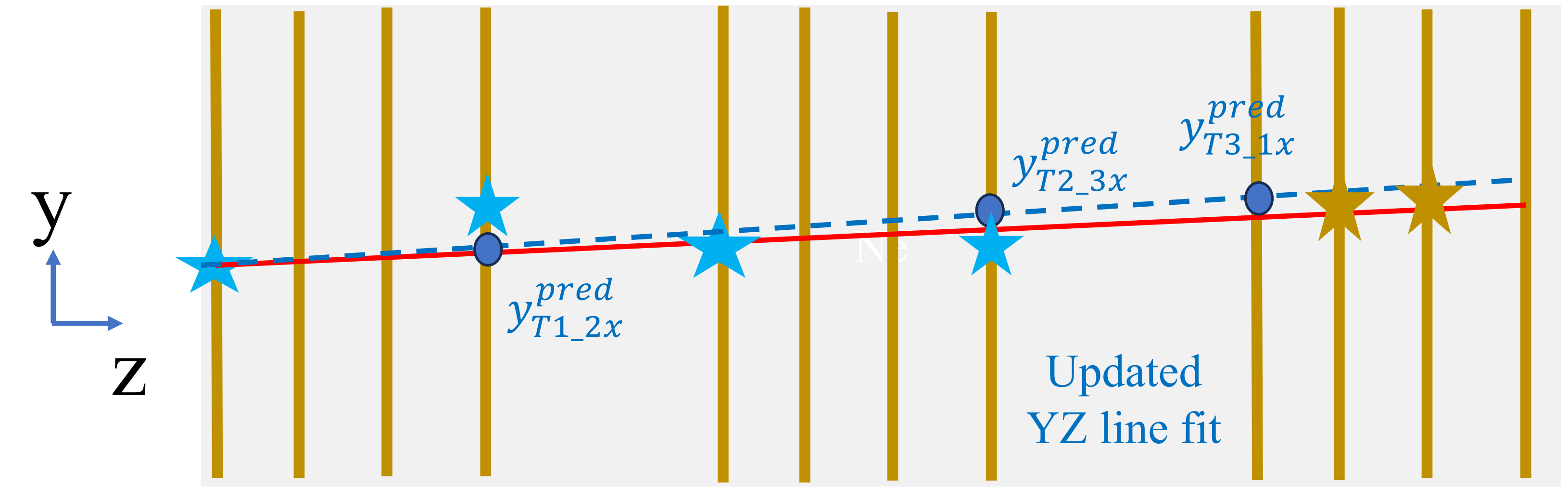
Step 4: Collect hits in T3 u/v layers

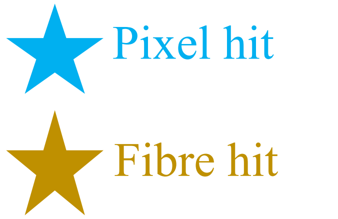


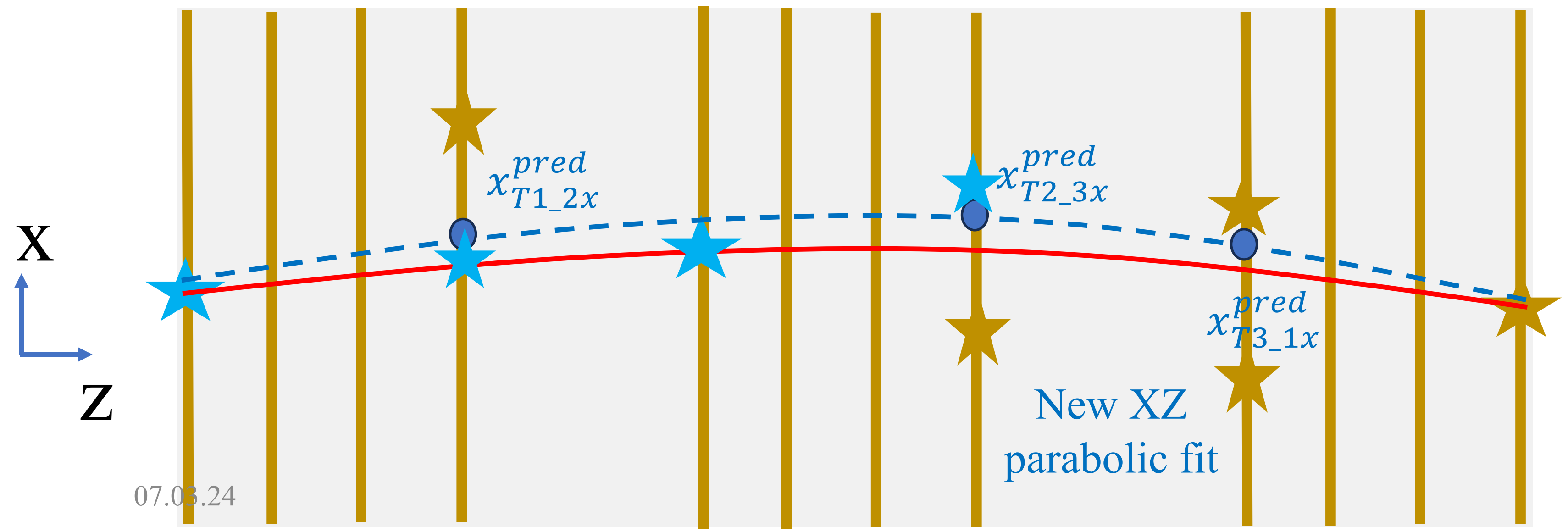


- Using updated yz line + xz parabola, get (x,y) prediction at T3 u/v.
- The x prediction + u/v hits give y information
- Open window in y to collect T3 u/v hits.
- Window size: 1 mm if T2 pixel or 5 mm for T2 fibre.

Step 5: Pixel or fibre part of other x layers?

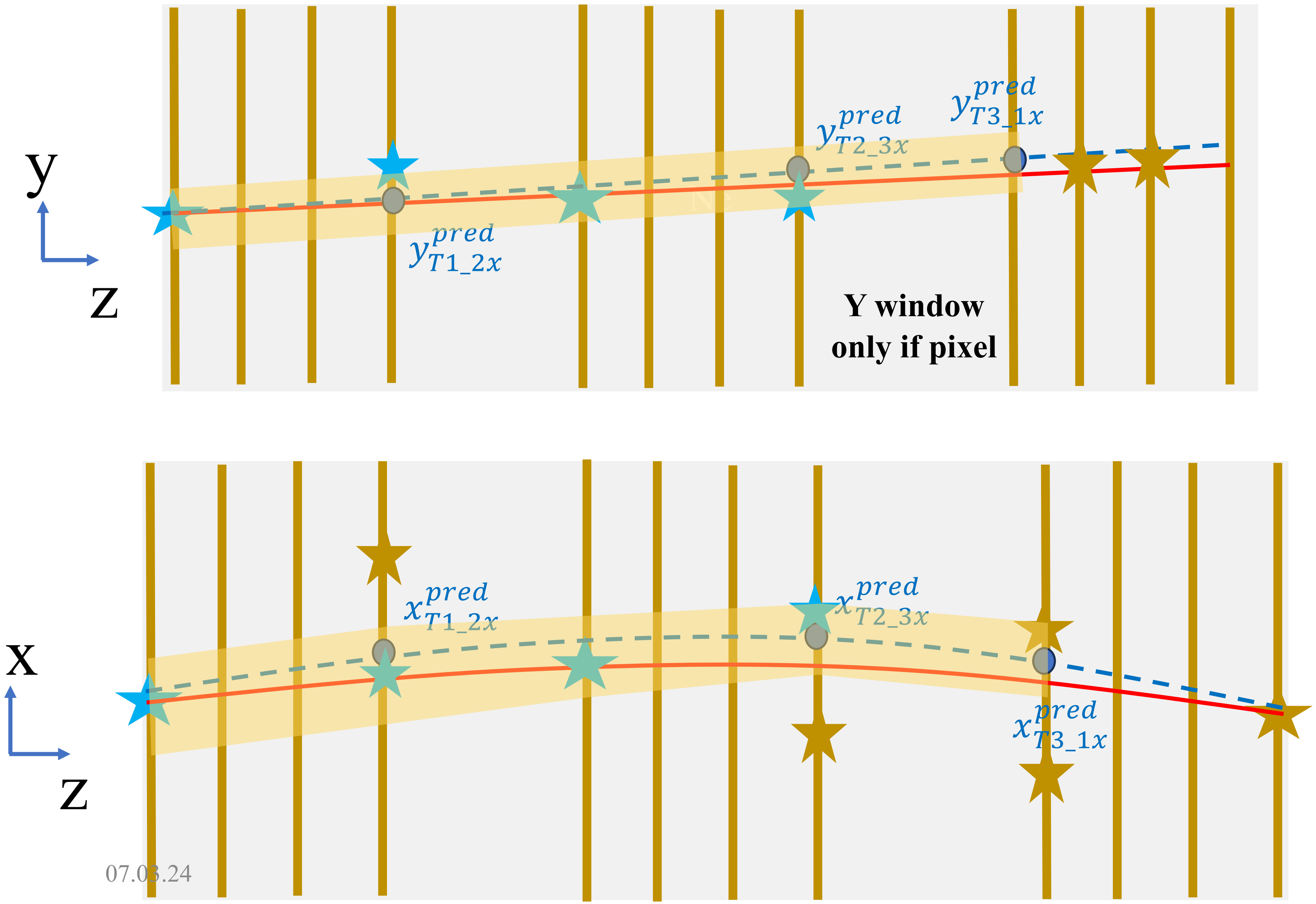


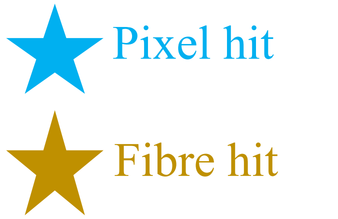




- With updated yz line + old parabola, predict x,y at other x layers.
- With this pick either pixel or fibre part.

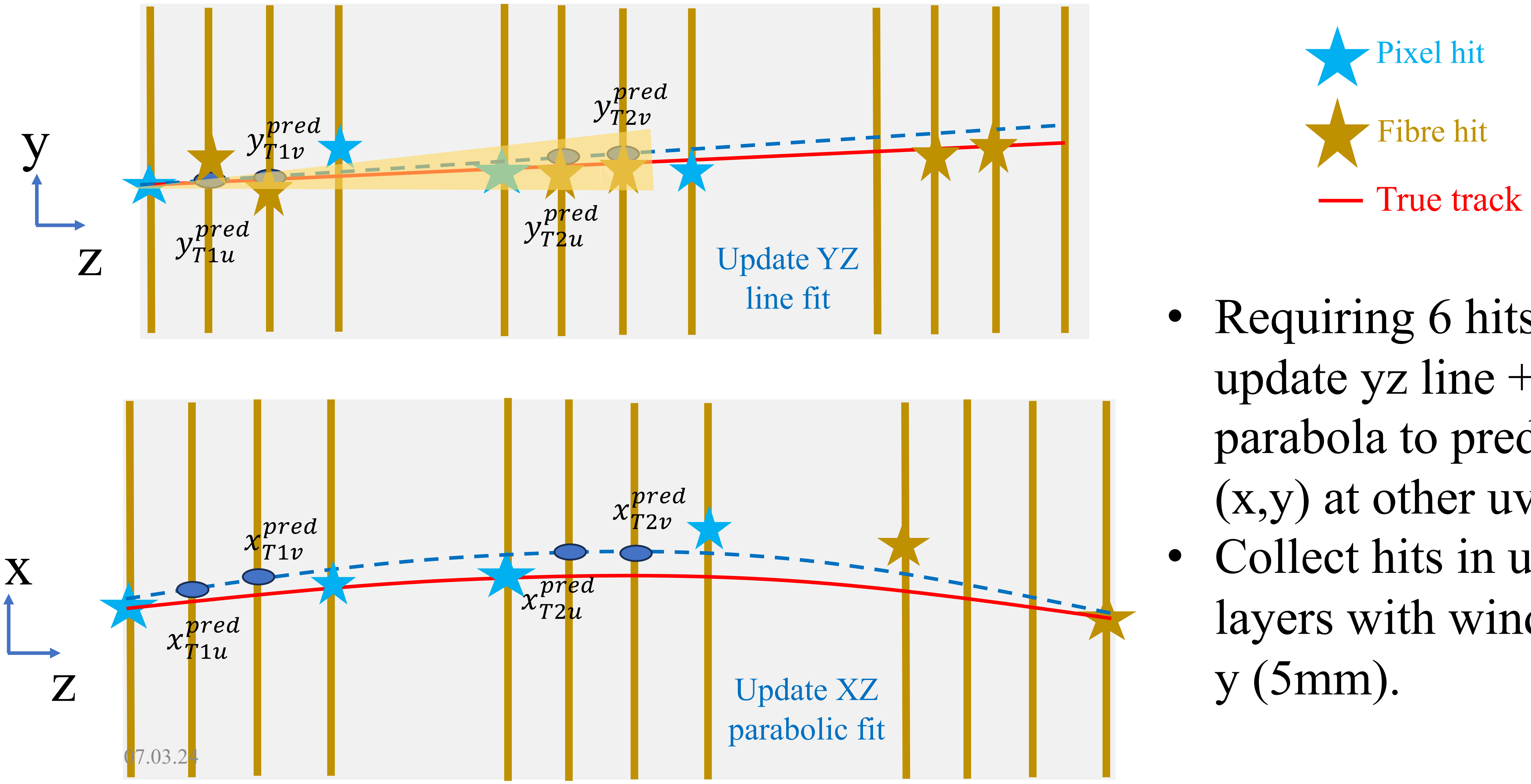
Step 6: Collect pixel or fibre hits in all other x layers





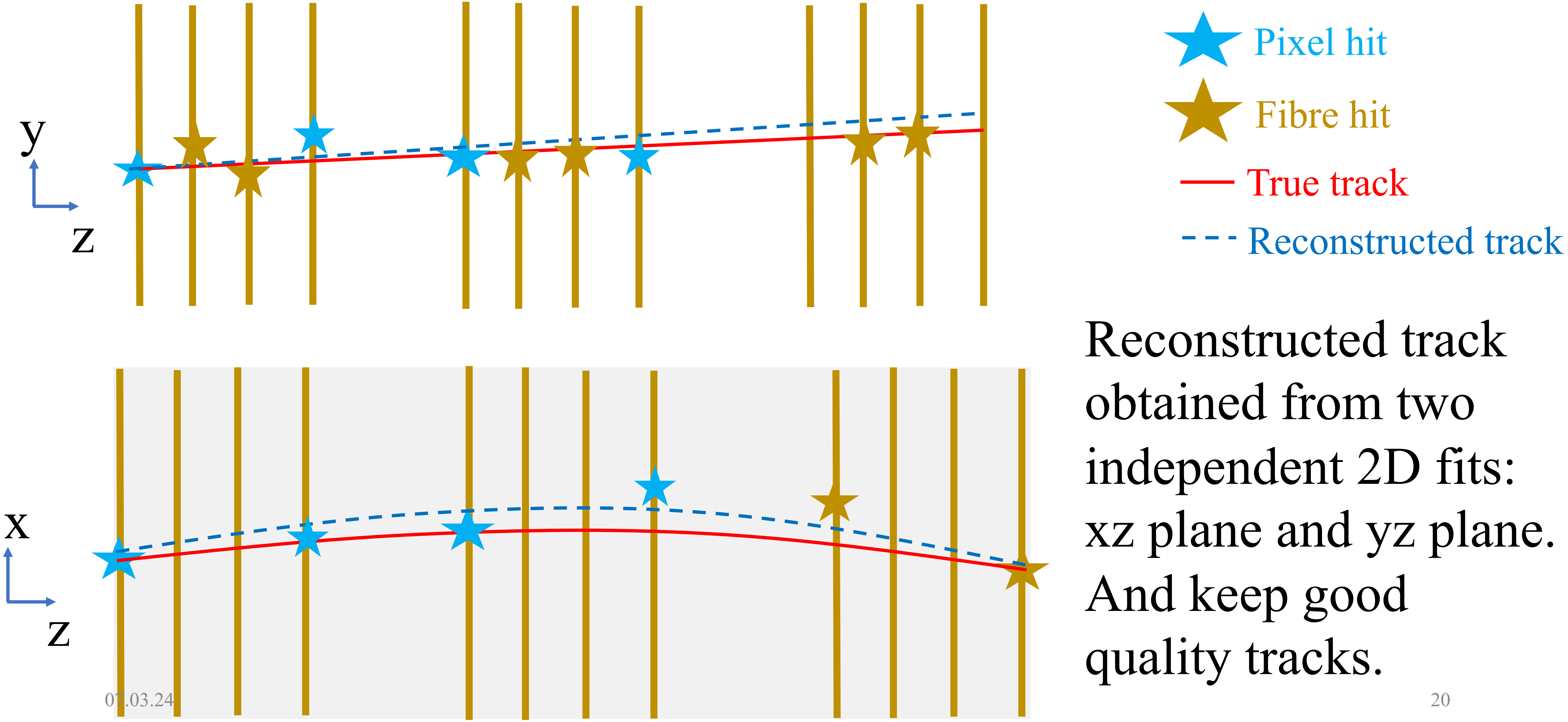
- Define windows in x and y to collect hits in x layers.
- Window size: x is 1 mm and y is 10 mm.

Step 7: Collect hits in other uv layers



- Requiring 6 hits, we update yz line + parabola to predict (x,y) at other uv layers.
- Collect hits in uv layers with window in y (5mm).

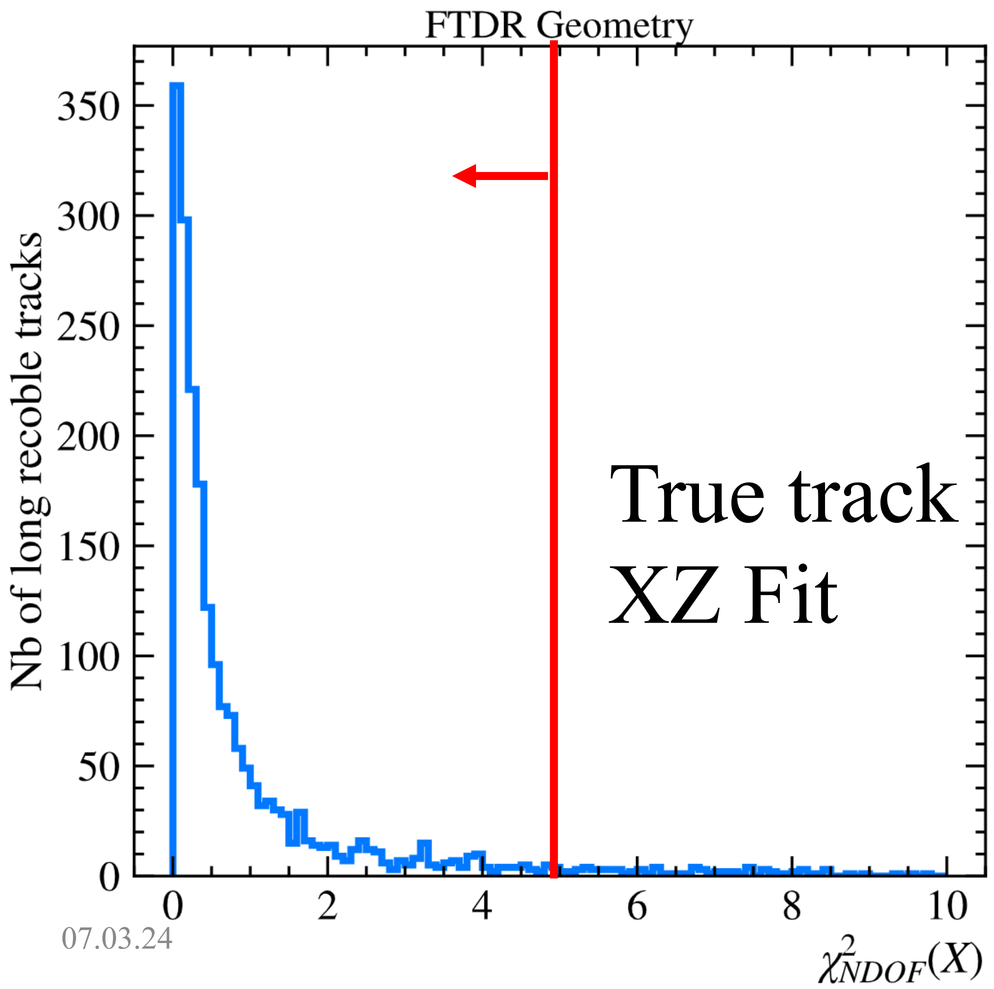
Step 8: Build the MT track with track quality cuts

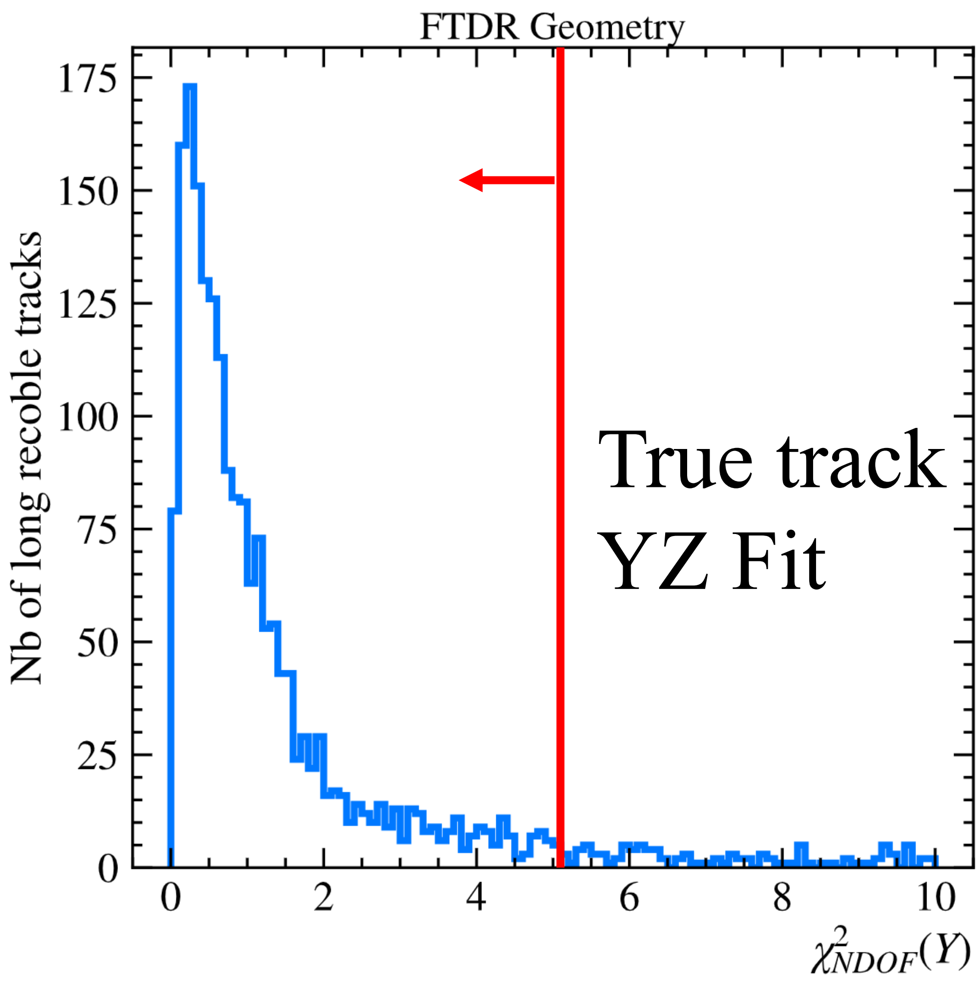


Reconstructed track obtained from two independent 2D fits: xz plane and yz plane. And keep good quality tracks.

What is the good track quality requirement?

Fit the true tracks like the reconstructed tracks to decide on **cut**.





Increasing tracking efficiency and clone killing

- Ambiguity in selecting T2_1x or T2_2x in 3 hit combination. To increase efficiency, we execute both scenarios, each time excluding the hits that have already been used.
- Ambiguity also exists in selecting layers in T1 and T3. Here we build tracks for all four scenarios: (T1_1x-T3_2x), (T1_2x-T3_2x), etc.
- At the end we run clone killing: Out of two tracks that are close and have more than 30% (pixel) or 20% (fibre) hit overlap, only one is kept based on nhits or min track χ^2.
- Additionally to decrease the clone rate, we remove all the hits used in building Pixel-Pixel tracks in MT.

Performance

Frugal: Before and after Pixel-Fiber tracking

Before

settings_Frugal_6Layers_L1p0e34.json

Category	Nb Reco/Nb Recoble	Efficiency	Clones
HasMT(all)	46547 / 86391	53.88 %	53(0.11 %)
HasMT(pix-pix)	19557 / 31102	62.88 %	26(0.13 %)
HasMT(fib-fib)	26782 / 42244	63.40 %	27(0.10 %)
HasMT(pix-fib)	208 / 13059	1.59 %	0(0.00 %)
Long(all)	30174 / 37305	80.88 %	22(0.07 %)
Longeta[2,5]	27702 / 34099	81.24 %	22(0.08 %)
Longeta[2,5],p>5GeV	18213 / 21424	85.01 %	15(0.08 %)
(!e)Longeta[2,5]	26078 / 31694	82.28 %	21(0.08 %)
(!e)Longeta[2,5],p>5GeV	17291 / 20193	85.63 %	14(0.08 %)
(!e)Long(Pix-Pix)	12138 / 12710	95.50 %	13(0.11 %)
(!e)Long(Pix-Pix),eta[2,5]	10489 / 10955	95.75 %	13(0.12 %)
(!e)Long(Pix-Pix),eta[2,5],p>5GeV	9716 / 10013	97.03 %	13(0.13 %)
(!e)Long(Fib-Fib)	16212 / 19151	84.65 %	8(0.05 %)
(!e)Long(Fib-Fib),eta[2,5]	15506 / 17965	86.31 %	8(0.05 %)
(!e)Long(Fib-Fib),eta[2,5],p>5GeV	7525 / 8314	90.51 %	1(0.01 %)
(!e)Long(Pix-Fib)	84 / 2863	2.93 %	0(0.00 %)
(!e)Long(Pix-Fib),eta[2,5]	83 / 2774	2.99 %	0(0.00 %)
(!e)Long(Pix-Fib),eta[2,5],p>5GeV	50 / 1866	2.68 %	0(0.00 %)
#Events	#RecoedTracks	#FakeTracks	GhostRate
100	58023	11328	19.52 %

After

settings_Frugal_6Layers_L1p0e34.json

Category	Nb Reco/Nb Recoble	Efficiency	Clones
HasMT(all)	49123 / 86391	56.86 %	792(1.61 %)
HasMT(pix-pix)	19573 / 31102	62.93 %	26(0.13 %)
HasMT(fib-fib)	25772 / 42244	61.01 %	140(0.54 %)
HasMT(pix-fib)	3778 / 13059	28.93 %	626(16.02 %)
Long(all)	31560 / 37305	84.60 %	428(1.35 %)
Longeta[2,5]	29079 / 34099	85.28 %	416(1.43 %)
Longeta[2,5],p>3GeV	25416 / 28858	88.07 %	366(1.44 %)
Longeta[2,5],p>5GeV	19208 / 21424	89.66 %	244(1.27 %)
Long_decay	28373 / 33260	85.31 %	380(1.34 %)
Long_decayeta[2,5]	26082 / 30325	86.01 %	368(1.41 %)
Long_decayeta[2,5],p>3GeV	22957 / 25886	88.69 %	318(1.38 %)
Long_decayeta[2,5],p>5GeV	17570 / 19502	90.09 %	212(1.20 %)
(!e)Longeta[2,5]	27232 / 31694	85.92 %	368(1.35 %)
(!e)Longeta[2,5],p>5GeV	18185 / 20193	90.06 %	212(1.16 %)
(!e)Long(Pix-Pix)	12144 / 12710	95.55 %	13(0.11 %)
(!e)Long(Pix-Pix),eta[2,5]	10495 / 10955	95.80 %	13(0.12 %)
(!e)Long(Pix-Pix),eta[2,5],p>5GeV	9720 / 10013	97.07 %	13(0.13 %)
(!e)Long(Fib-Fib)	15518 / 19151	81.03 %	57(0.37 %)
(!e)Long(Fib-Fib),eta[2,5]	14838 / 17965	82.59 %	57(0.38 %)
(!e)Long(Fib-Fib),eta[2,5],p>5GeV	7145 / 8314	85.94 %	38(0.53 %)
(!e)Long(Pix-Fib)	1922 / 2863	67.13 %	298(15.06 %)
(!e)Long(Pix-Fib),eta[2,5]	1899 / 2774	68.46 %	298(15.24 %)
(!e)Long(Pix-Fib),eta[2,5],p>5GeV	1320 / 1866	70.74 %	161(11.89 %)
#Events	#RecoedTracks	#FakeTracks	GhostRate
100	60503	11076	18.31 %

Pix-Fib is 67% efficient with 15% clone rate
5% boost in Long track eff.
Ghost rate reduction by 1.2%

NB: The windows for hit selection have not been fully tuned!

Modest: Before and after Pixel-Fiber tracking

Before

settings_Modest_6Layers_L1p3e34.json

Category	Nb Reco/Nb Recoble	Efficiency	Clones
HasMT(all)	54517 / 105473	51.69 %	55(0.10 %)
HasMT(pix-pix)	30379 / 50568	60.08 %	24(0.08 %)
HasMT(fib-fib)	23892 / 38216	62.52 %	31(0.13 %)
HasMT(pix-fib)	246 / 16723	1.47 %	0(0.00 %)
Long(all)	36027 / 44953	80.14 %	21(0.06 %)
Longeta[2,5]	33069 / 41131	80.40 %	21(0.06 %)
Longeta[2,5],p>5GeV	22684 / 26000	87.25 %	0(0.00 %)
(!e)Longeta[2,5]	31199 / 38299	81.46 %	20(0.06 %)
(!e)Longeta[2,5],p>5GeV	21550 / 24547	87.79 %	0(0.00 %)
(!e)Long(Pix-Pix)	19643 / 20817	94.36 %	6(0.03 %)
(!e)Long(Pix-Pix),eta[2,5]	17594 / 18561	94.79 %	6(0.03 %)
(!e)Long(Pix-Pix),eta[2,5],p>5GeV	15954 / 16425	97.13 %	0(0.00 %)
(!e)Long(Fib-Fib)	14265 / 17146	83.20 %	14(0.10 %)
(!e)Long(Fib-Fib),eta[2,5]	13507 / 15940	84.74 %	14(0.10 %)
(!e)Long(Fib-Fib),eta[2,5],p>5GeV	5540 / 6086	91.03 %	0(0.00 %)
(!e)Long(Pix-Fib)	98 / 3922	2.50 %	0(0.00 %)
(!e)Long(Pix-Fib),eta[2,5]	98 / 3798	2.58 %	0(0.00 %)
(!e)Long(Pix-Fib),eta[2,5],p>5GeV	56 / 2036	2.75 %	0(0.00 %)
#Events	#RecoedTracks	#FakeTracks	GhostRate
100	62716	8030	12.80 %

After

settings_Modest_6Layers_L1p3e34.json

Category	Nb Reco/Nb Recoble	Efficiency	Clones
HasMT(all)	57544 / 105473	54.56 %	987(1.71 %)
HasMT(pix-pix)	30396 / 50568	60.11 %	24(0.08 %)
HasMT(fib-fib)	22747 / 38216	59.52 %	216(0.95 %)
HasMT(pix-fib)	4401 / 16723	26.32 %	747(16.35 %)
Long(all)	37824 / 44953	84.14 %	536(1.41 %)
Longeta[2,5]	34843 / 41131	84.71 %	527(1.51 %)
Longeta[2,5],p>3GeV	30975 / 34798	89.01 %	439(1.41 %)
Longeta[2,5],p>5GeV	23888 / 26000	91.88 %	242(1.01 %)
Long_decay	34088 / 40088	85.03 %	349(1.02 %)
Long_decayeta[2,5]	31334 / 36590	85.64 %	346(1.10 %)
Long_decayeta[2,5],p>3GeV	28036 / 31230	89.77 %	300(1.07 %)
Long_decayeta[2,5],p>5GeV	21886 / 23693	92.37 %	182(0.83 %)
(!e)Longeta[2,5]	32716 / 38299	85.42 %	376(1.15 %)
(!e)Longeta[2,5],p>5GeV	22662 / 24547	92.32 %	204(0.90 %)
(!e)Long(Pix-Pix)	19646 / 20817	94.37 %	6(0.03 %)
(!e)Long(Pix-Pix),eta[2,5]	17597 / 18561	94.81 %	6(0.03 %)
(!e)Long(Pix-Pix),eta[2,5],p>5GeV	15956 / 16425	97.14 %	0(0.00 %)
(!e)Long(Fib-Fib)	13583 / 17146	79.22 %	93(0.68 %)
(!e)Long(Fib-Fib),eta[2,5]	12853 / 15940	80.63 %	93(0.72 %)
(!e)Long(Fib-Fib),eta[2,5],p>5GeV	5347 / 6086	87.86 %	70(1.31 %)
(!e)Long(Pix-Fib)	2292 / 3922	58.44 %	279(11.85 %)
(!e)Long(Pix-Fib),eta[2,5]	2266 / 3798	59.66 %	277(11.90 %)
(!e)Long(Pix-Fib),eta[2,5],p>5GeV	1359 / 2036	66.75 %	134(9.64 %)
#Events	#RecoedTracks	#FakeTracks	GhostRate
100	66560	8652	13.00 %

Pix-Fib is ~60% efficient with 12% clone rate.
4% boost in long track eff.
Ghost rate reduction by 1.2%

NB: The windows for hit selection have not been fully tuned!

FTDR: Before and after Pixel-Fiber tracking

Before

settings_FTDR_6Layers_L1p5e34.json

Category	Nb Reco/Nb Recoble	Efficiency	Clones
HasMT(all)	65133 / 128306	50.76 %	72(0.11 %)
HasMT(pix-pix)	40868 / 70822	57.71 %	54(0.13 %)
HasMT(fib-fib)	23986 / 39238	61.13 %	18(0.08 %)
HasMT(pix-fib)	279 / 18297	1.52 %	0(0.00 %)
Long(all)	43342 / 54008	80.25 %	25(0.06 %)
Longeta[2,5]	39833 / 49379	80.67 %	25(0.06 %)
Longeta[2,5],p>5GeV	27615 / 30935	89.27 %	12(0.04 %)
(!e)Longeta[2,5]	37623 / 45962	81.86 %	17(0.05 %)
(!e)Longeta[2,5],p>5GeV	26265 / 29210	89.92 %	4(0.02 %)
(!e)Long(Pix-Pix)	25873 / 27800	93.07 %	8(0.03 %)
(!e)Long(Pix-Pix),eta[2,5]	23428 / 25020	93.64 %	8(0.03 %)
(!e)Long(Pix-Pix),eta[2,5],p>5GeV	20454 / 21029	97.27 %	0(0.00 %)
(!e)Long(Fib-Fib)	14958 / 18161	82.36 %	9(0.06 %)
(!e)Long(Fib-Fib),eta[2,5]	14084 / 16694	84.37 %	9(0.06 %)
(!e)Long(Fib-Fib),eta[2,5],p>5GeV	5770 / 6349	90.88 %	4(0.07 %)
(!e)Long(Pix-Fib)	115 / 4371	2.63 %	0(0.00 %)
(!e)Long(Pix-Fib),eta[2,5]	111 / 4248	2.61 %	0(0.00 %)
(!e)Long(Pix-Fib),eta[2,5],p>5GeV	41 / 1832	2.24 %	0(0.00 %)
#Events	#RecoedTracks	#FakeTracks	GhostRate
100	72889	7595	10.42 %

After

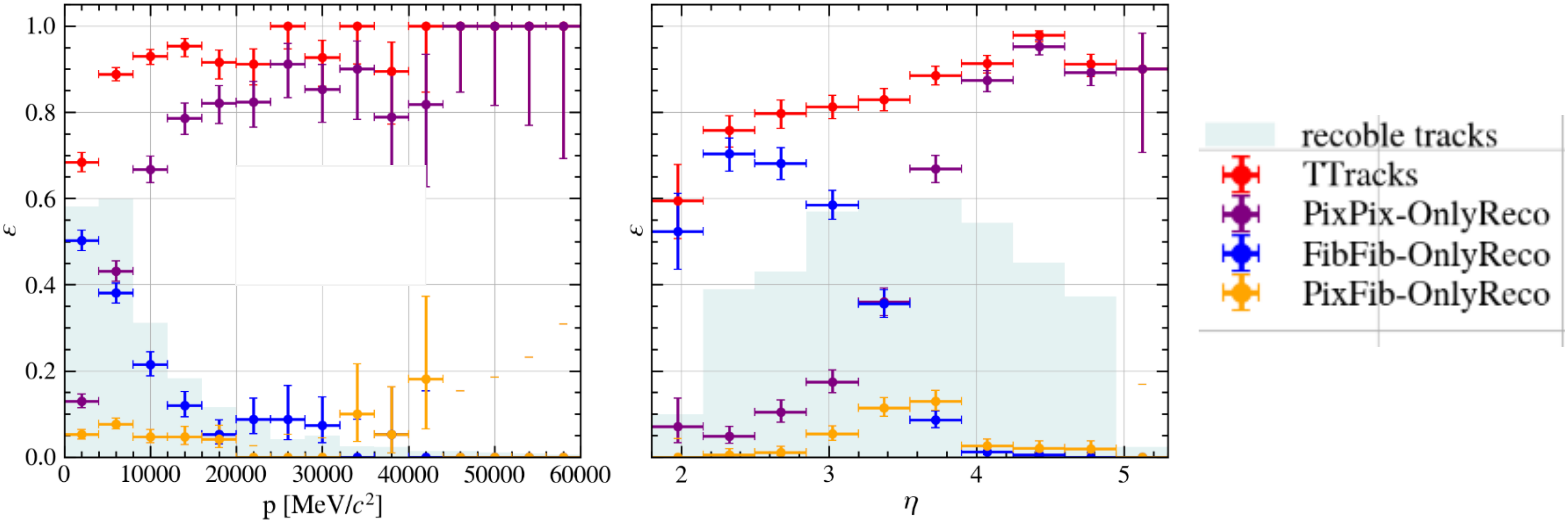
settings_FTDR_6Layers_L1p5e34.json

Category	Nb Reco/Nb Recoble	Efficiency	Clones
HasMT(all)	68144 / 128306	53.11 %	828(1.21 %)
HasMT(pix-pix)	40879 / 70822	57.72 %	54(0.13 %)
HasMT(fib-fib)	23010 / 39238	58.64 %	115(0.50 %)
HasMT(pix-fib)	4255 / 18297	23.26 %	659(15.01 %)
Long(all)	45233 / 54008	83.75 %	322(0.71 %)
Longeta[2,5]	41724 / 49379	84.50 %	316(0.76 %)
Longeta[2,5],p>3GeV	37196 / 41517	89.59 %	243(0.65 %)
Longeta[2,5],p>5GeV	28687 / 30935	92.73 %	123(0.43 %)
Long_decay	40660 / 47985	84.73 %	233(0.57 %)
Long_decayeta[2,5]	37411 / 43749	85.51 %	227(0.61 %)
Long_decayeta[2,5],p>3GeV	33612 / 37187	90.39 %	170(0.51 %)
Long_decayeta[2,5],p>5GeV	26235 / 28139	93.23 %	84(0.32 %)
(!e)Longeta[2,5]	39222 / 45962	85.34 %	235(0.60 %)
(!e)Longeta[2,5],p>5GeV	27232 / 29210	93.23 %	84(0.31 %)
(!e)Long(Pix-Pix)	25877 / 27800	93.08 %	8(0.03 %)
(!e)Long(Pix-Pix),eta[2,5]	23432 / 25020	93.65 %	8(0.03 %)
(!e)Long(Pix-Pix),eta[2,5],p>5GeV	20455 / 21029	97.27 %	0(0.00 %)
(!e)Long(Fib-Fib)	14348 / 18161	79.00 %	58(0.40 %)
(!e)Long(Fib-Fib),eta[2,5]	13507 / 16694	80.91 %	58(0.43 %)
(!e)Long(Fib-Fib),eta[2,5],p>5GeV	5574 / 6349	87.79 %	22(0.39 %)
(!e)Long(Pix-Fib)	2306 / 4371	52.76 %	169(7.22 %)
(!e)Long(Pix-Fib),eta[2,5]	2283 / 4248	53.74 %	169(7.29 %)
(!e)Long(Pix-Fib),eta[2,5],p>5GeV	1203 / 1832	65.67 %	62(5.09 %)
#Events	#RecoedTracks	#FakeTracks	GhostRate
100	76936	8468	11.01 %

Pix-Fib is 53% efficient with 7% clone rate.
~4% boost in long track eff.
Ghost rate increases by 0.6%

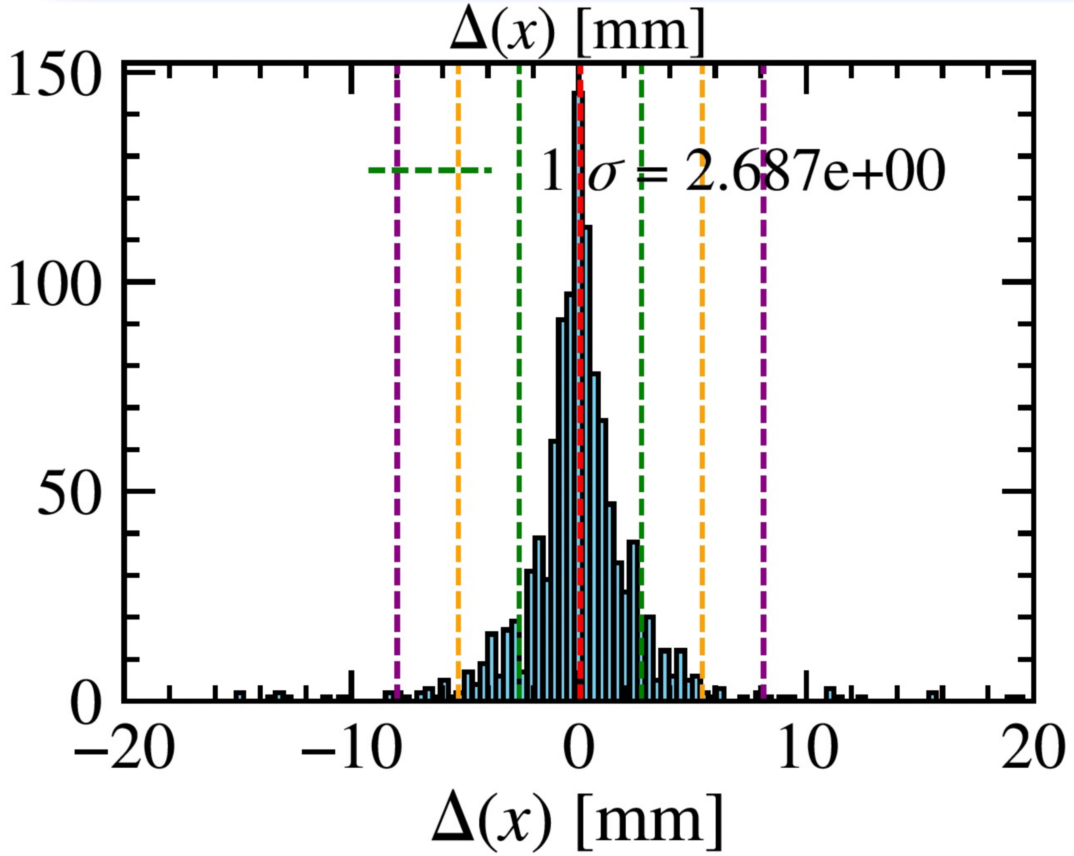
NB: The windows for hit selection have not been fully tuned!

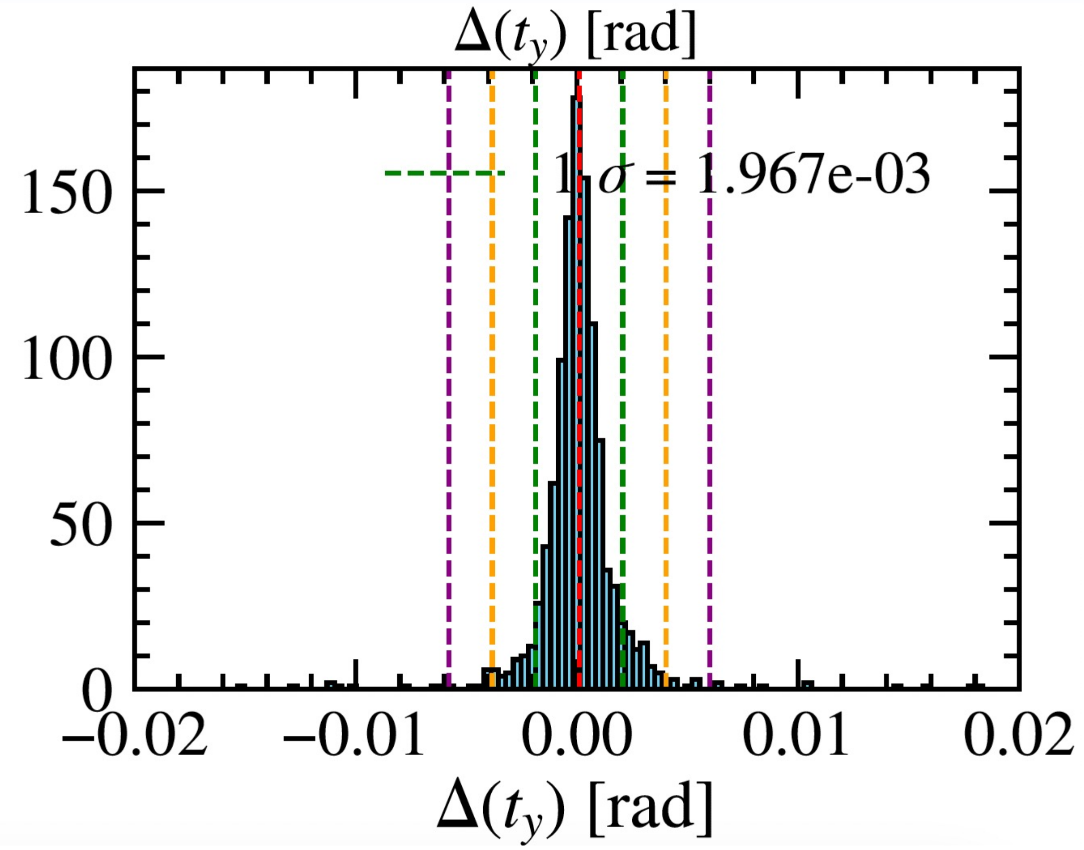
In which kinematic range do we have gains?



Gain comes in the low momentum and mid pseudo-rapidity region.

Extrapolation of state to VELO





Hits in Pixel-Fibres matched, fitted and extrapolated back to VELO exit. Then the track state parameters are compared with the truth values.

Extrapolation works well given VELO exit and MT entry are ~7 m apart.

Conclusions

Take home message

- We have a **first protype** of MT Pixel-Fiber track finding in pyreco package.
- This **completes** the standalone MT track reconstruction.
- For free comes the **modest boost** in long/downstream track efficiency.

Next steps

- Ghost rate needs to be reduced with further tuning of windows.
- Port the prototype to the LHCb software for long track reconstruction.
- For TDR timescale, explore other innovative ideas for MT tracking e.g. GNNs (similar efforts ongoing for VELO).