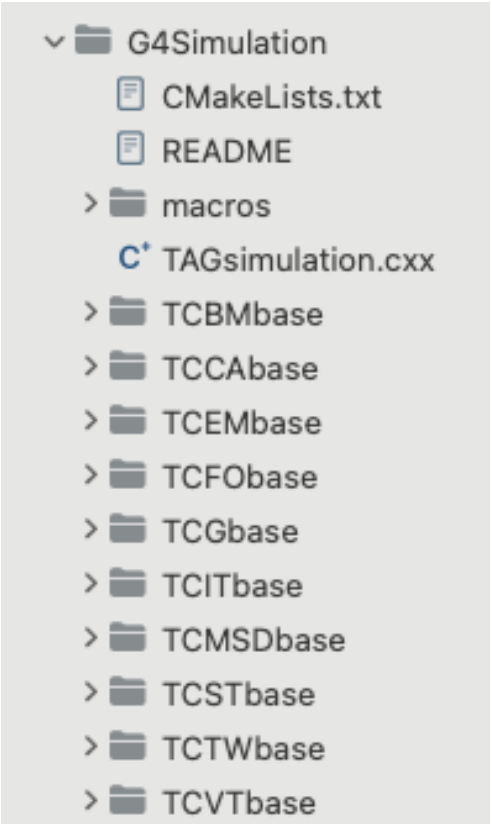
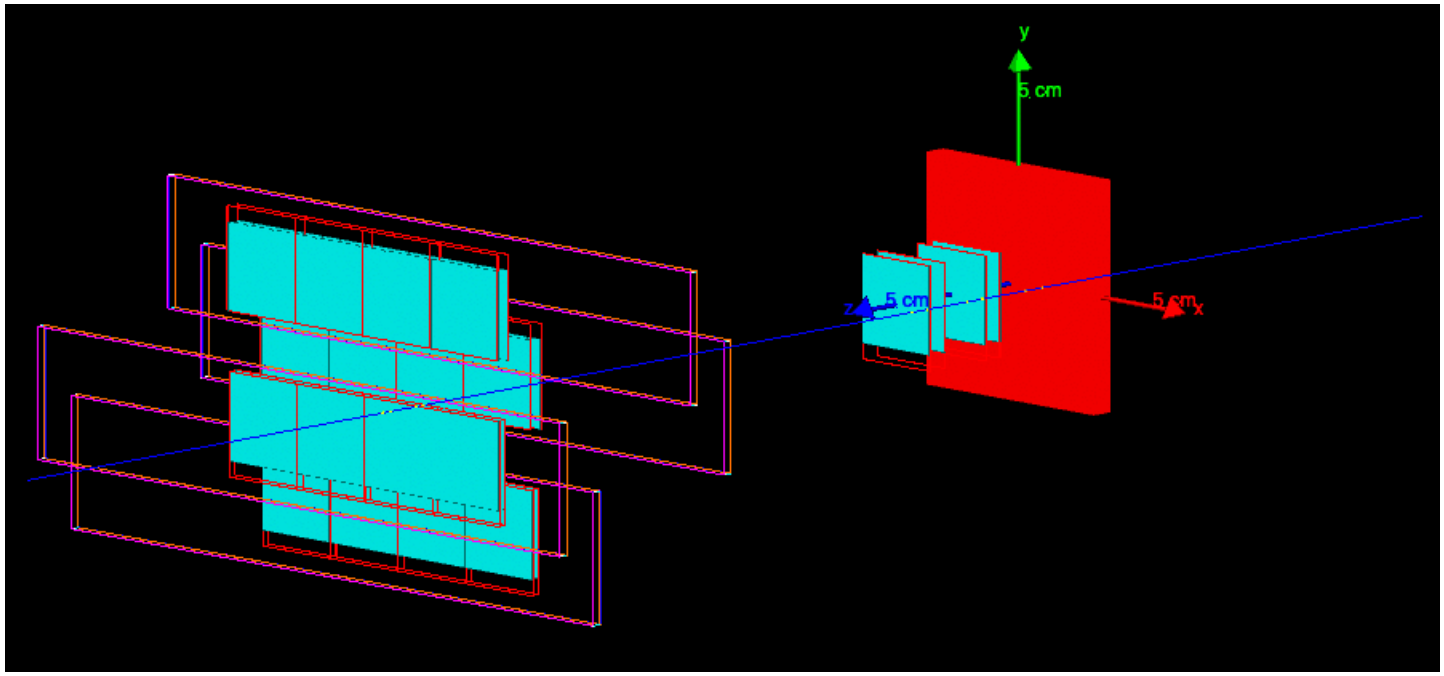
Interaction Region (IR) Alignment

Geant4

- G4Simulation:



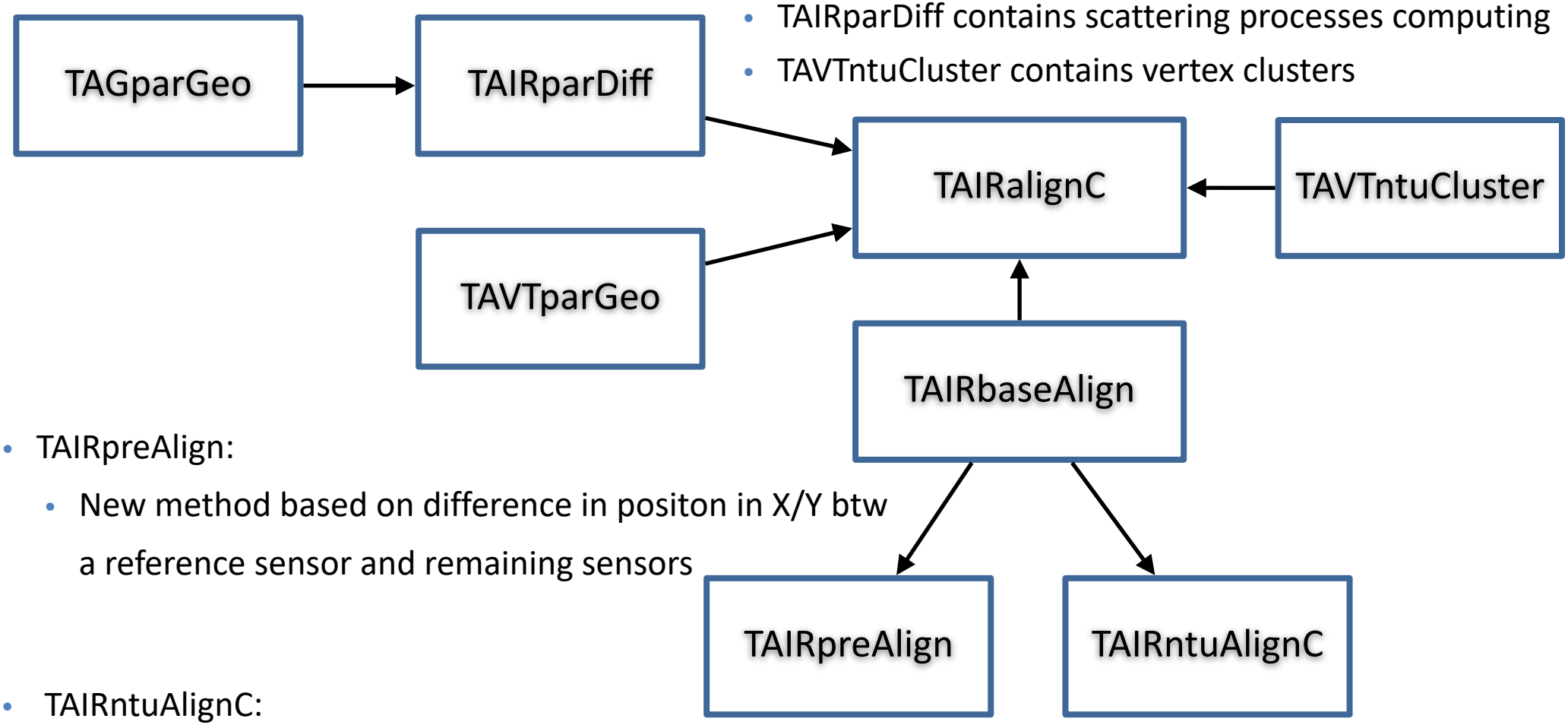


- Revive Geant4 interface in shoe (add cut on EM processes, by default)
- Still some issues for BM and CAL, no box with passive material
- Region numbering issue

VTX alignment (i)

- TAGparGeo contains information of beam and target
- TAIRparDiff contains scattering processes computing
- TAVTntuCluster contains vertex clusters

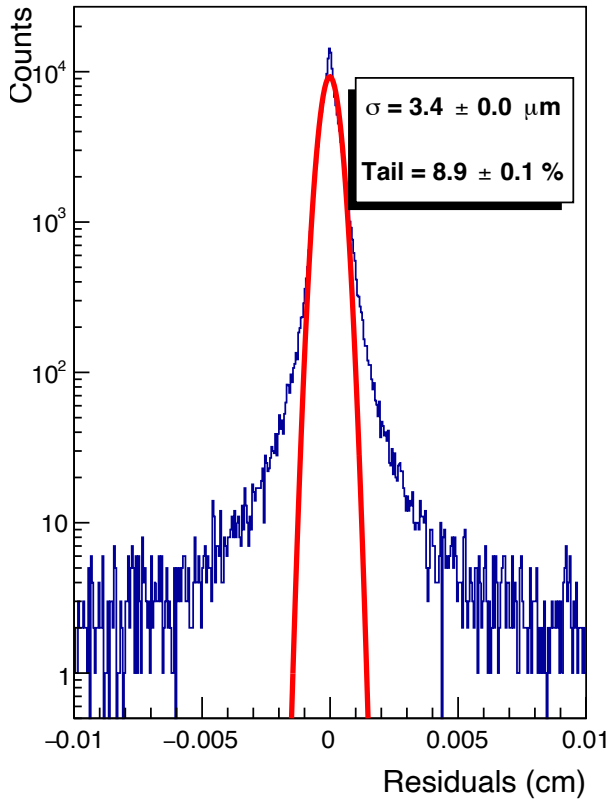
❑ TAIRbase:

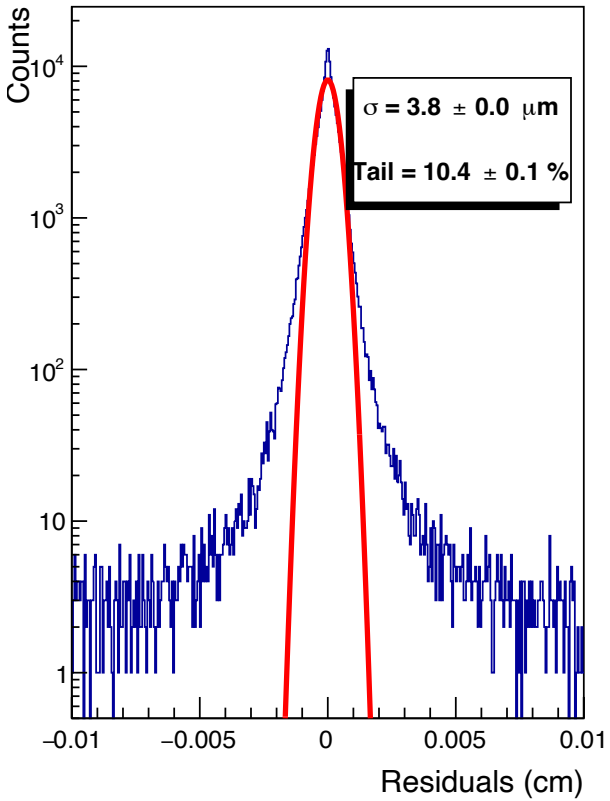


- TAIRpreAlign:
  - New method based on difference in positon in X/Y btw a reference sensor and remaining sensors
- TAIRntuAlignC:
  - Standard method published in C.-A. Reidel, Ch. Finck et al, N.I.M. A 931 (2019) (Compute from cluster positions)

VTX alignment (ii)

- CNAO2023 with TAIRntuAlignC:
  - Taken a fragmentation run (6144), cut on cluster size (> 15)

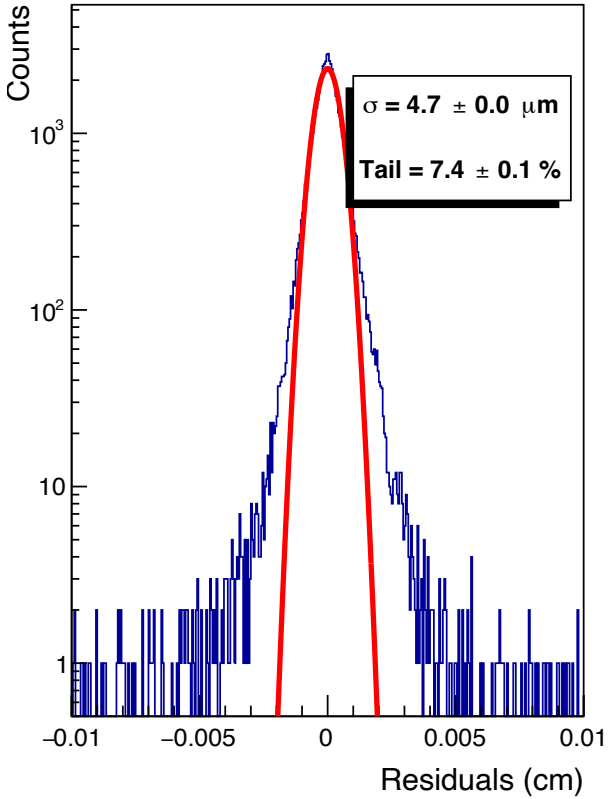


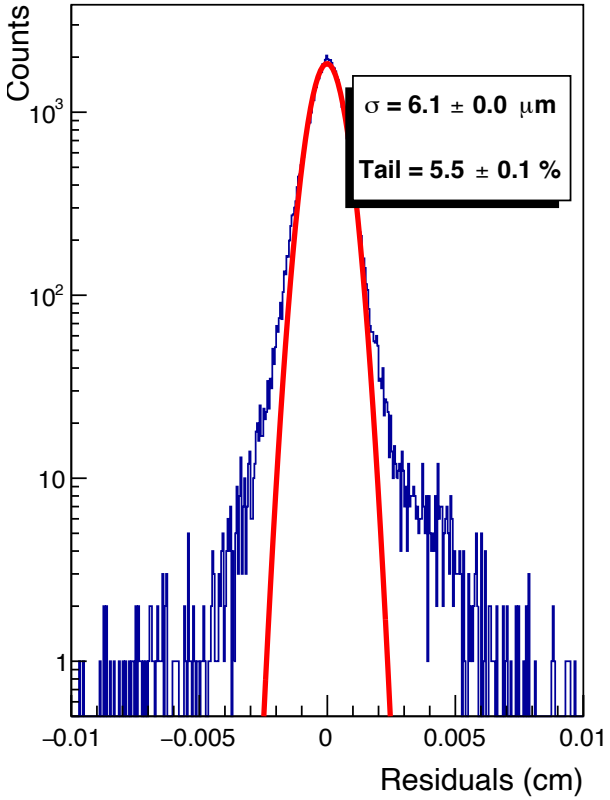


➡ Successfully aligned

VTX alignment (iii)

- CNAO2024 with TAIRpreAlign:
  - Taken a fragmentation run (6960), cut on cluster size (> 15)



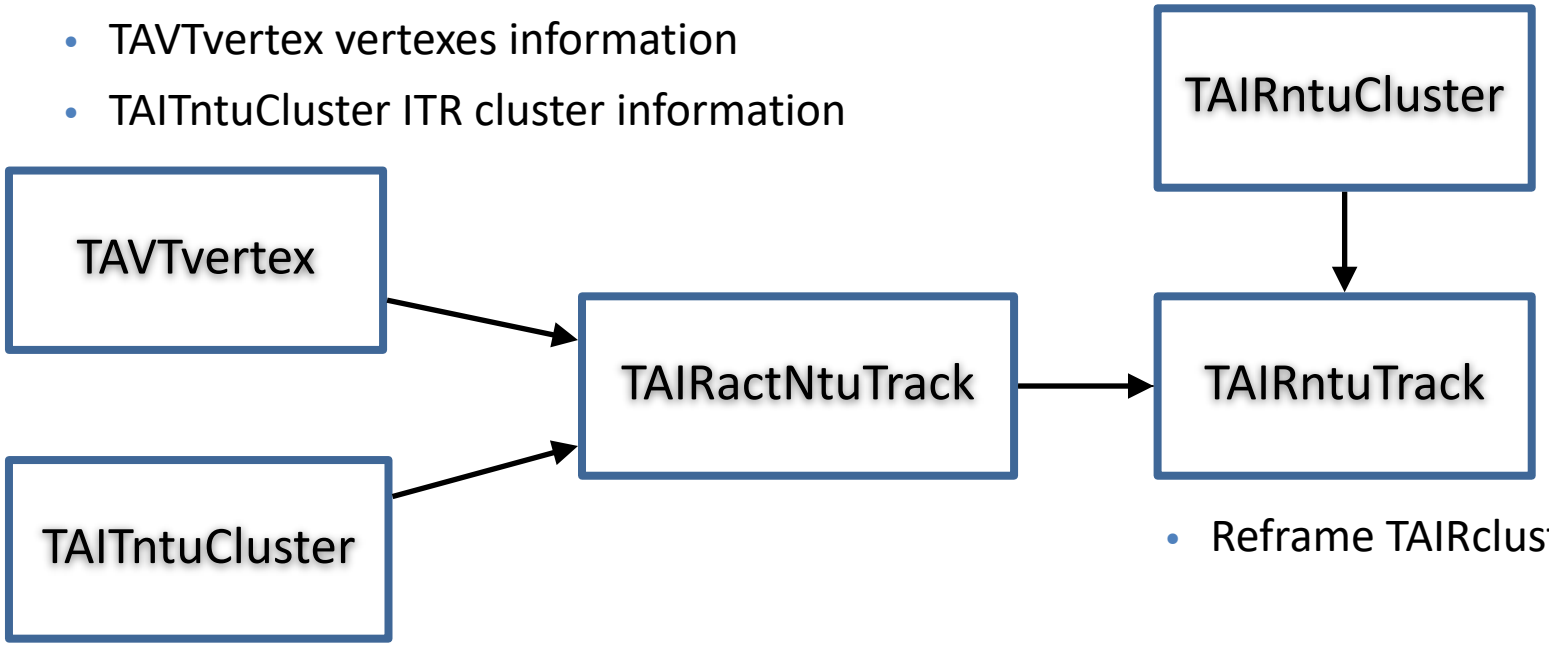


➡ Successfully aligned

IR Tracking (i)

❑ TAIRactNtuTrack: combining VT tracks with IT clusters (no magnetic field):

- TAVTvertex vertexes information
- TAITntuCluster ITR cluster information



- Reframe TAIRcluster/TAIRtrack classes

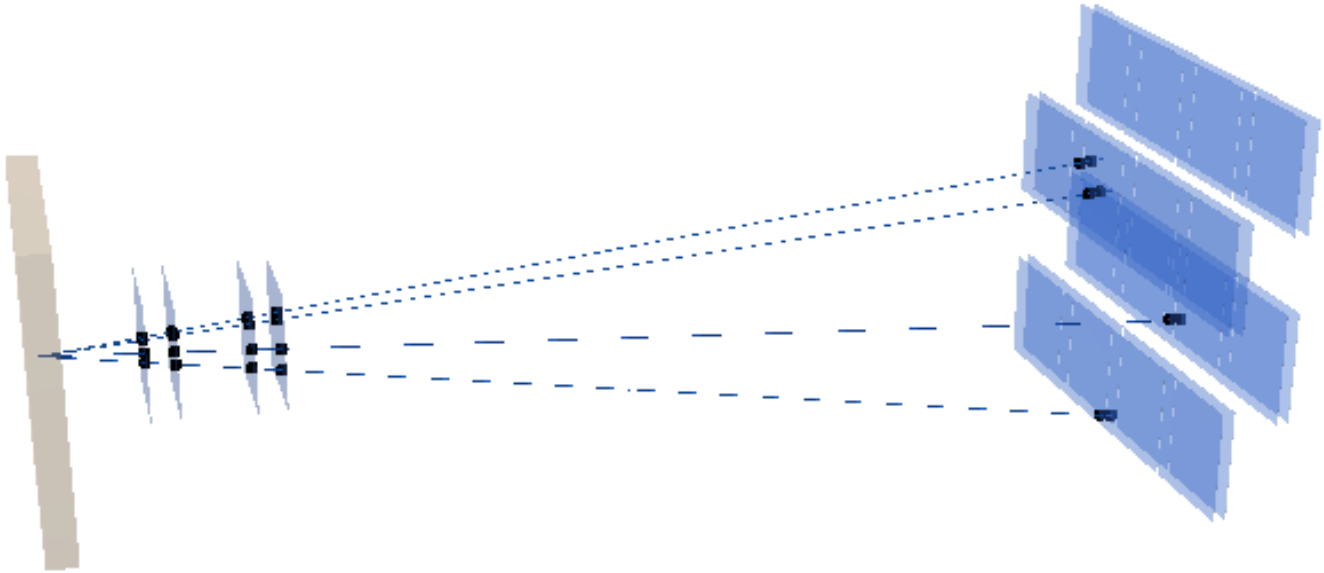
➡ Extrapolate vertex (valid) tracks to ITR, add cluster to track if cluster close enough

IR Tracking (ii)

- MC data:
  - Reaction: ^{12}C beam @ 200 MeV on 5 mm graphite
  - Beam: center at 0, σ = 2 mm
  - Generation: 100k fragmented events with Geant4 interface

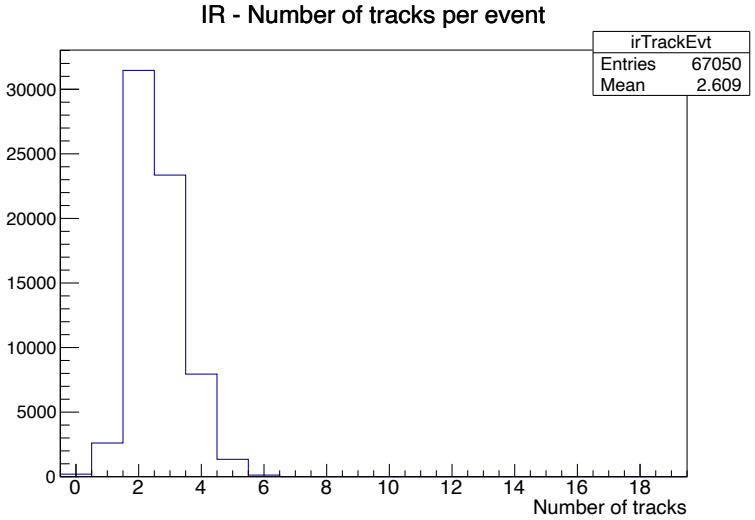
➡ TAIRntuTrack will be used as input for ITR alignment

➡ Selected only valid vertexes (no single straight track)



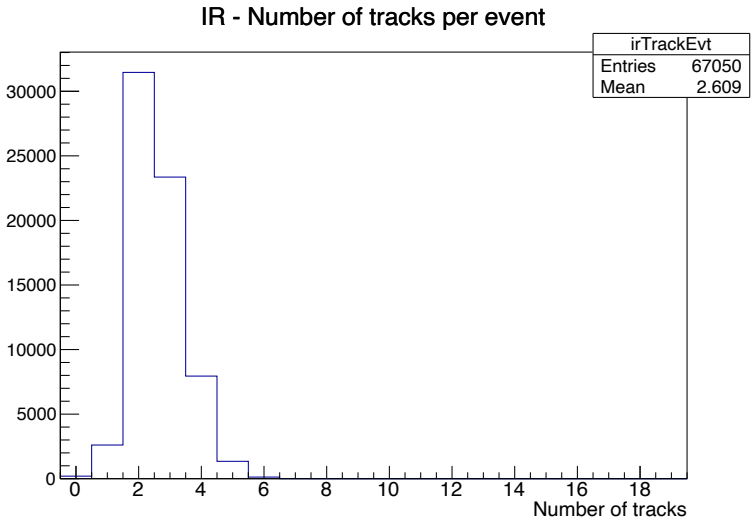
IR Tracking (iii)

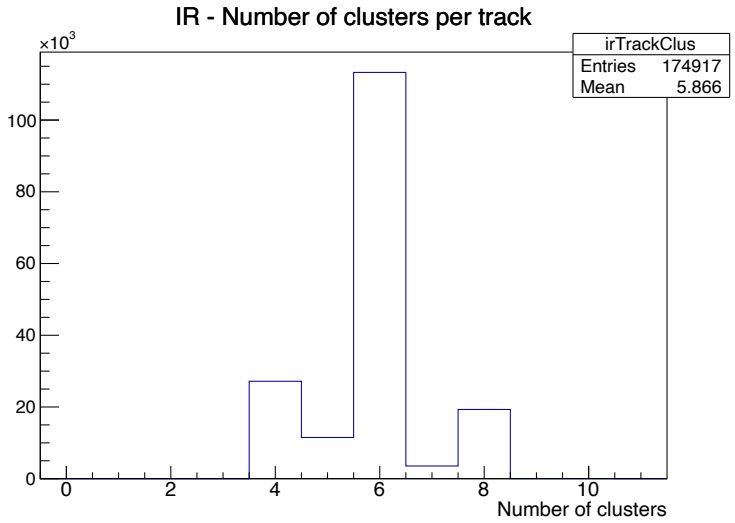
- Control plots:



IR Tracking (iii)

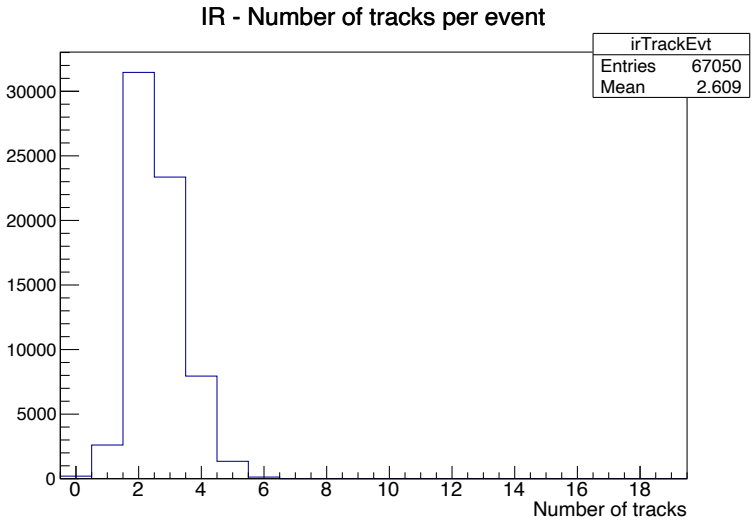
- Control plots:

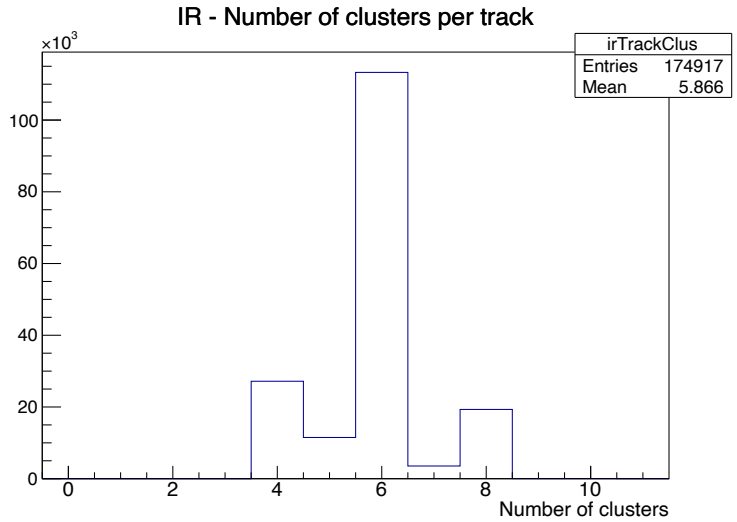


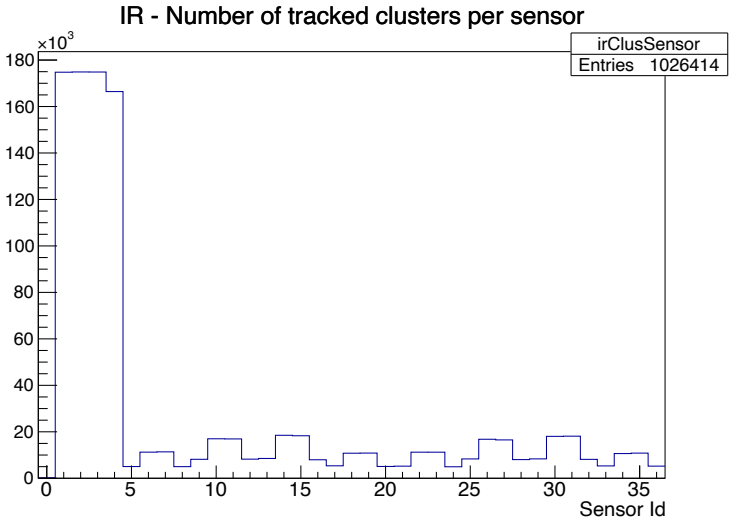


IR Tracking (iii)

- Control plots:

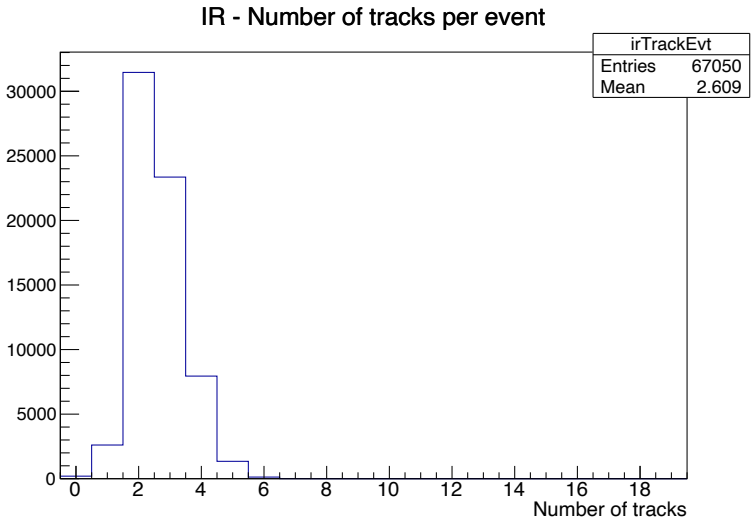


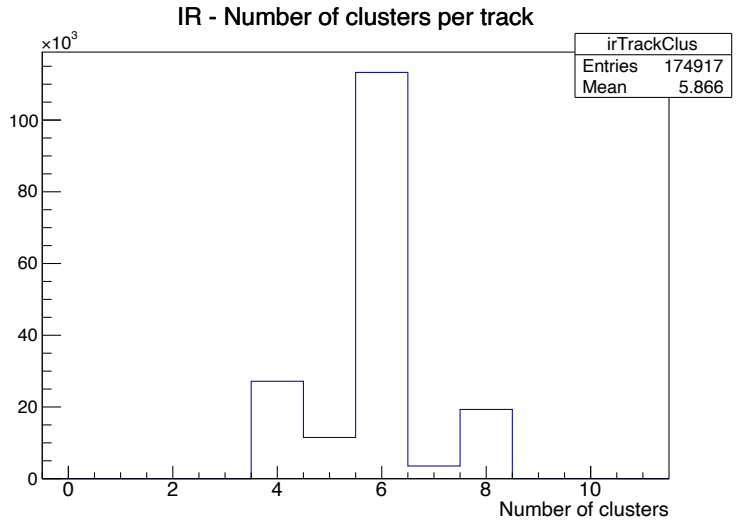


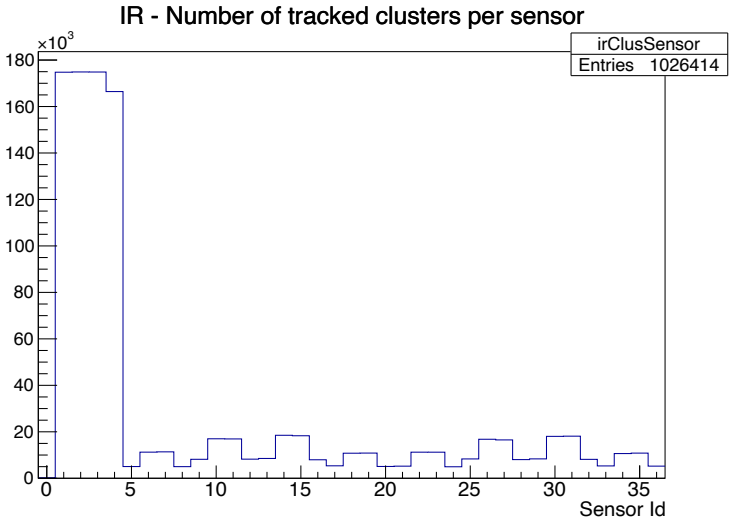


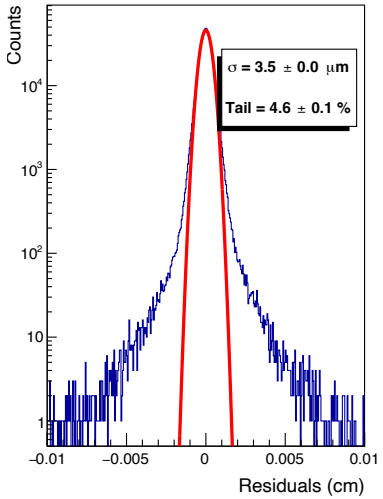
IR Tracking (iii)

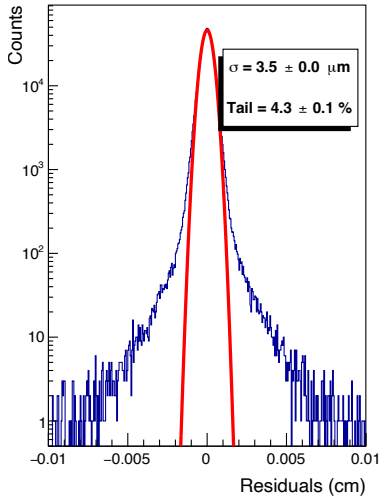
- Control plots:





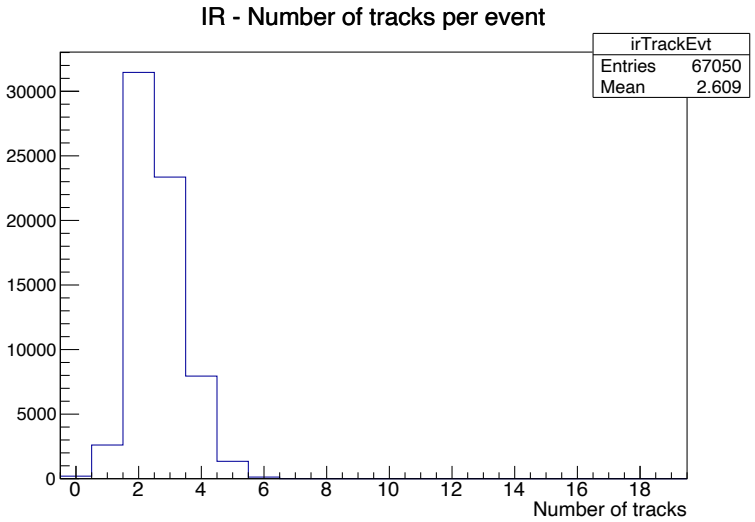


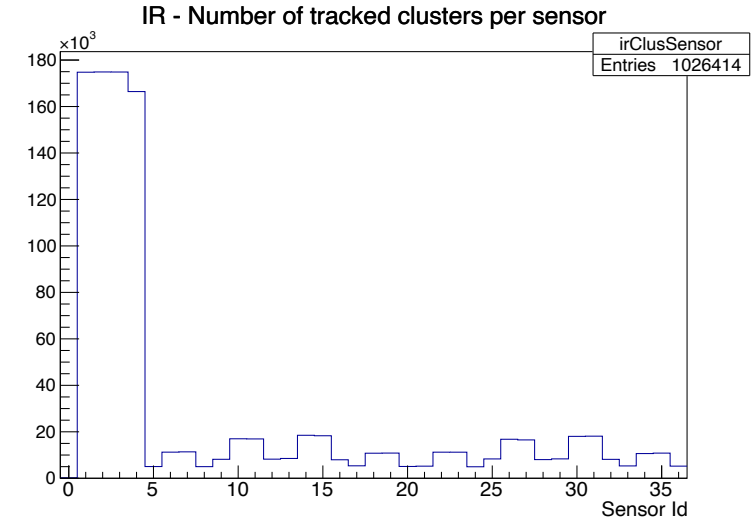


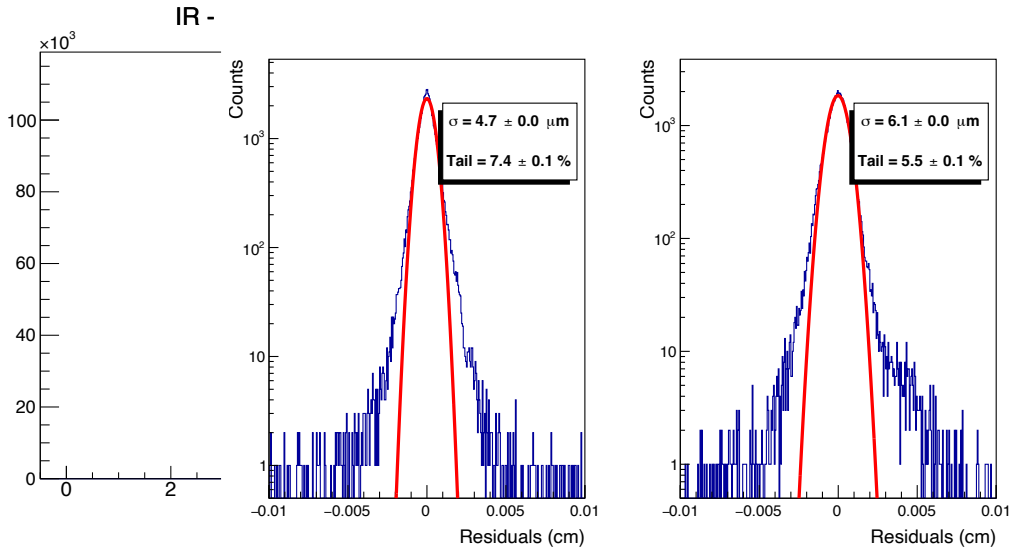


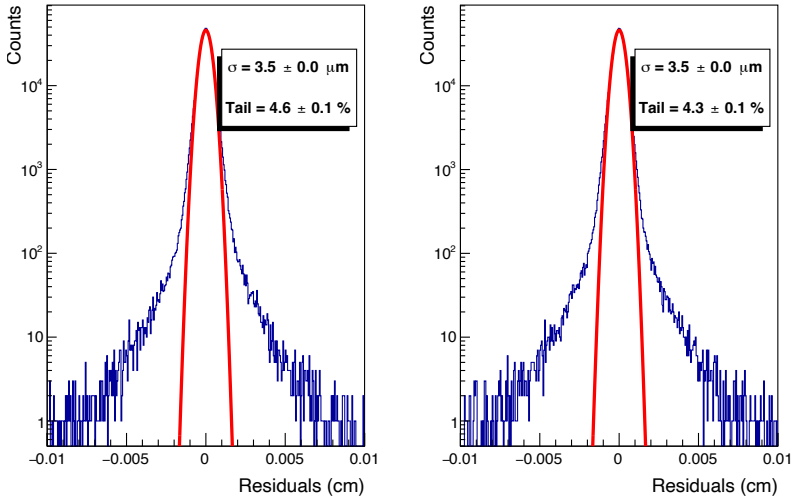
IR Tracking (iii)

- Control plots:



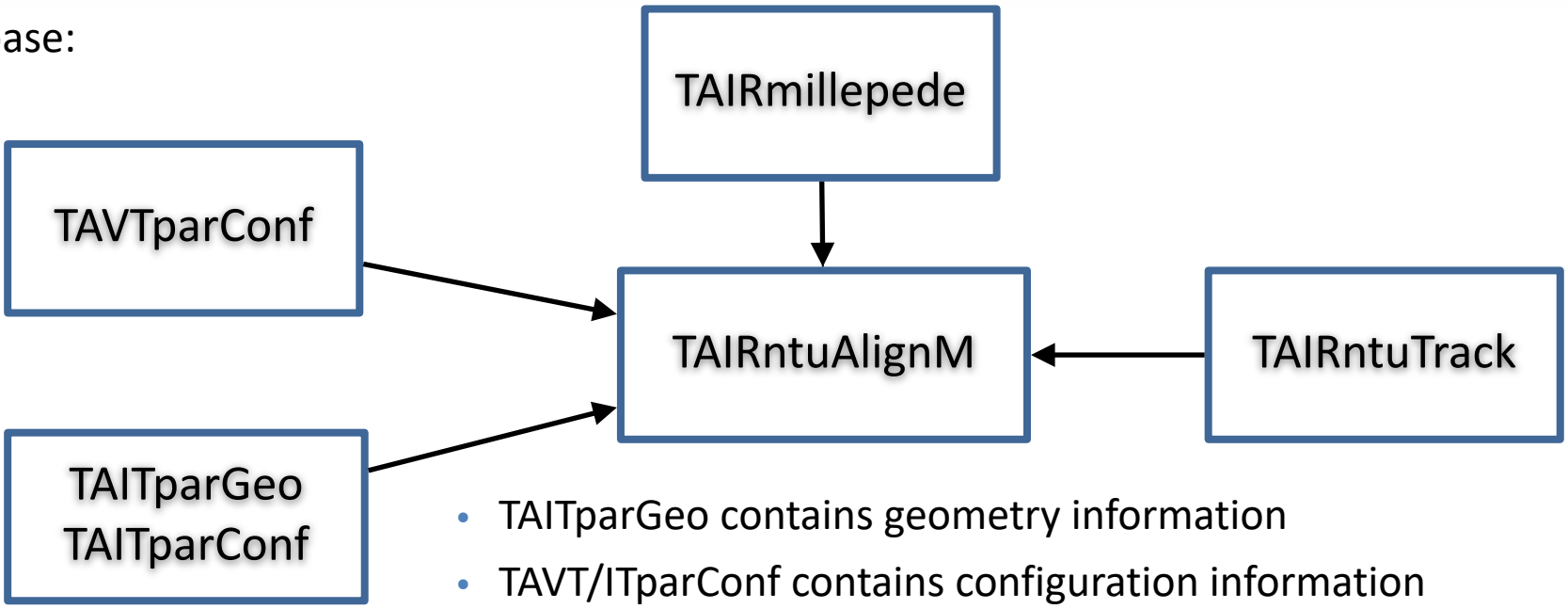






ITR alignment (i)

❑ TAIRbase:

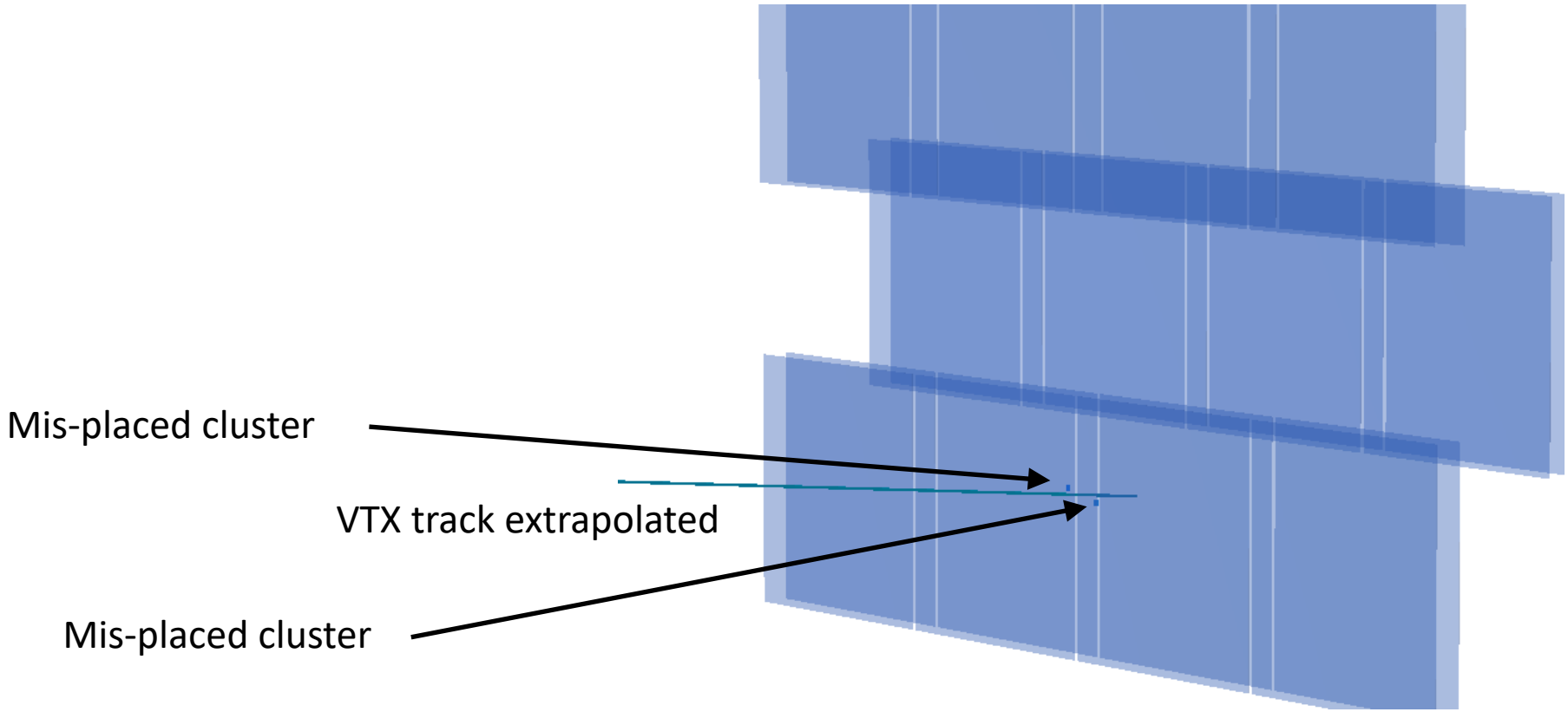


- TAITparGeo contains geometry information
- TAVT/ITparConf contains configuration information
- TAIRntuTrack contains IR tracks

- Method published by V. Blobel, C. Kleinwort, F. Meier,
  "Fast alignment of a complex tracking detector using advanced track models"
  Computer Physics Communications (2011)
  - ➡ Adapted for shoe interfaces
  - ➡ Compute from track positions reconstructed with TAIRactNtuTrack

ITR alignment (ii)

- Mis-alignment (with MC data):
  - Fix 4 VTX sensors (would be aligned with TAIRalignC class)
  - IT sensor 3: ΔY[0] = 200 µm, ΔY[1] = 500 µm, ΔΦ = 0.0º
  - IT sensor 19: ΔY[0] = -300 µm ΔY[1] = -500 µm, ΔΦ = 0.0º



ITR alignment (iv)

- Configuration:
  - Fix VTX and free ITR parameters

```
//
// This is a Configuration File for FOOT Vertex Detector
//
. . .
// -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*- Plane 1  -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-
InputNumber:                1
Status:                     1
MinNofPixelsInCluster:      0
MaxNofPixelsInCluster:      400
DeadPixels:                -1

// -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-
InputNumber:                2
Status:                     1
MinNofPixelsInCluster:      0
MaxNofPixelsInCluster:      400
DeadPixels:                -1
. . .
```

```
//
// This is a Configuration File for FOOT Inner tracker
//
. . .
// -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*- Plane 1  -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-
InputNumber:                1
Status:                     2
MinNofPixelsInCluster:      0
MaxNofPixelsInCluster:      400
DeadPixels:                -1

// -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*- Plane 2  -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-
InputNumber:                2
Status:                     2
MinNofPixelsInCluster:      0
MaxNofPixelsInCluster:      400
DeadPixels:                -1
. . .
```

Millepede (va)

- Results (100 kEvents):

```
fNSensors: 36    fNGlobal: 108    fNLocal: 4
Parameters initialized to zero
Initial cut factor is 20.000000
Init Global Parameters
Number of constraints increased to 1
Adding constraint
Number of total entries: 1000000
Number of events: 1000000                    VTX fixed sensors
1        0 (    0)mu         0 (    0)mu   0.00 ( 0.00) deg
2        0 (    0)mu         0 (    0)mu   0.00 ( 0.00) deg
3        0 (    0)mu         0 (    0)mu   0.00 ( 0.00) deg
4        0 (    0)mu         0 (    0)mu   0.00 ( 0.00) deg
...
7      205 (    0)mu       499 (    0)mu  -0.00 ( 0.00) deg
23    -303 (    0)mu      -499 (    0)mu  -0.00 ( 0.00) deg
```

- First 4 sensors fixed (VTX)
- So sensor 7 and 23 displaced (need to add +4 corresponding to VTX [1-4])

➡ Best alignment within 5 microns

Millepede (vb)

- Results (50 kEvents):

```
fNSensors: 36    fNGlobal: 108    fNLocal: 4
Parameters initialized to zero
Initial cut factor is 20.000000
Init Global Parameters
Number of constraints increased to 1
Adding constraint
Number of total entries: 1000000
Number of events: 500000                    VTX fixed sensors
1        0 (    0)mu        0 (    0)mu   0.00 ( 0.00) deg
2        0 (    0)mu        0 (    0)mu   0.00 ( 0.00) deg
3        0 (    0)mu        0 (    0)mu   0.00 ( 0.00) deg
4        0 (    0)mu        0 (    0)mu   0.00 ( 0.00) deg
…
7      211 (    2)mu      498 (    2)mu  -0.02 ( 0.00) deg
```

➡ Best alignment within 10 microns

➡ Sensitive to statistics

Millepede (via)

- Results (100 kEvents):

- Put displacements by hand on hit level

```
displX[] = {0.01, 0.02, 0.03, 0.04,
            0.05, 0.06, 0.01,. . .    }

displY[] = {-0.01, 0.02, -0.03, 0.04,
            -0.05, 0.06, -0.01, . . . }
```

Millepede (via)

- Results (100 kEvents):

```
5     100 (    1)mu      -99 (    1)mu   0.00 ( 0.00) deg
6     201 (    1)mu      200 (    1)mu   0.00 ( 0.00) deg
7     307 (    1)mu     -301 (    1)mu  -0.00 ( 0.00) deg
8     405 (    1)mu      403 (    1)mu   0.00 ( 0.00) deg
9     499 (    1)mu     -499 (    1)mu  -0.00 ( 0.00) deg
10    599 (    0)mu      600 (    0)mu   0.00 ( 0.00) deg
11    107 (    0)mu     -100 (    0)mu  -0.00 ( 0.00) deg
12    207 (    1)mu      200 (    1)mu   0.00 ( 0.00) deg
13    303 (    1)mu     -301 (    1)mu   0.00 ( 0.00) deg
14    401 (    0)mu      400 (    0)mu   0.00 ( 0.00) deg
15    495 (    0)mu     -500 (    0)mu  -0.00 ( 0.00) deg
16    594 (    1)mu      599 (    1)mu   0.00 ( 0.00) deg
17    102 (    1)mu      -98 (    1)mu   0.00 ( 0.00) deg
18    203 (    1)mu      200 (    1)mu  -0.00 ( 0.00) deg
19    295 (    1)mu     -300 (    1)mu   0.00 ( 0.00) deg
20    394 (    1)mu      398 (    1)mu  -0.00 ( 0.00) deg
21    497 (    1)mu     -496 (    1)mu   0.00 ( 0.00) deg
22    599 (    1)mu      603 (    1)mu   0.00 ( 0.00) deg
23     95 (    1)mu      -99 (    1)mu  -0.00 ( 0.00) deg
24    198 (    1)mu      206 (    1)mu   0.00 ( 0.00) deg
25    298 (    1)mu     -298 (    1)mu  -0.00 ( 0.00) deg
26    400 (    1)mu     -399 (    0)mu   0.00 ( 0.00) deg
27    495 (    0)mu     -499 (    0)mu  -0.00 ( 0.00) deg
28    597 (    1)mu      601 (    1)mu   0.00 ( 0.00) deg
29    101 (    1)mu     -100 (    1)mu   0.00 ( 0.00) deg
30    200 (    0)mu      201 (    0)mu   0.00 ( 0.00) deg
31    305 (    0)mu     -300 (    0)mu  -0.00 ( 0.00) deg
32    403 (    1)mu      400 (    1)mu   0.00 ( 0.00) deg
33    502 (    1)mu     -496 (    1)mu   0.00 ( 0.00) deg
34    599 (    1)mu      603 (    1)mu  -0.00 ( 0.00) deg
35    105 (    1)mu      -97 (    1)mu   0.00 ( 0.00) deg
36    203 (    1)mu      201 (    1)mu  -0.00 ( 0.00) deg
```

- Put displacements by hand on hit level

```
displX[] = {0.01, 0.02, 0.03, 0.04,
            0.05, 0.06, 0.01,. . .    }

displY[] = {-0.01, 0.02, -0.03, 0.04,
            -0.05, 0.06, -0.01, . . . }
```

➡ Work within ~5 μm

Millepede (vib)

- Output file (TAITdetector.geo_new):

```
// -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*- Plane 1  -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-
Inputs:            1
Type:              0
PositionsX:       -3.0534  PositionsY:   -2.4314  PositionsZ:  -0.6155
Tilt1:             0.0000  Tilt2:         0.0000   Tilt3:       0.00
AlignementU:       0.0097
AlignementV:      -0.0102
AlignementTilt:    0.00

// -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*- Plane 2  -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-
Inputs:            2
Type:              0
PositionsX:       -1.0294  PositionsY:   -2.4314  PositionsZ:  -0.6155
Tilt1:             0.0000  Tilt2:         0.0000   Tilt3:       0.00
AlignementU:       0.0200
AlignementV:       0.0198
AlignementTilt:    0.00

// -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*- Plane 3  -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-
Inputs:            3
Type:              0
PositionsX:        0.9946  PositionsY:   -2.4314  PositionsZ:  -0.6155
Tilt1:             0.0000  Tilt2:         0.0000   Tilt3:       0.00
AlignementU:       0.0308
AlignementV:      -0.0304
AlignementTilt:   -0.00
. . .
```

➡ Directly write down the alignment parameters in a new file

Noisy pixels

- CNAO2024:
  - Macro ProjItrNoisyPixel.C: search for noisy pixels (for a given threshold rate) and write in cfg file.

Noisy pixels

- CNAO2024:
  - Macro ProjItrNoisyPixel.C: search for noisy pixels (for a given threshold rate) and write in cfg file.

TAITdetector_6800.cfg

```
// -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*- Plane  8 -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-
InputNumber:               8
Status:                    1
MinNofPixelsInCluster:     0
MaxNofPixelsInCluster:     400
DeadPixels:               448,304; 448,308; 448,319-320; 448,329; 448,342; 449,304; 449,308; 449,319-320;
449,329; 449,342; 450,304; 450,308; 450,319-320; 450,329; 450,342; 451,304; 451,308; 451,319-320; 451,329;
451,342; 451,347-351; 452,304; 452,308; 452,319-320; 452,329; 452,342; 452,346; 453,304; 453,308; 453,319-320;
453,329; 453,342; 453,344-345; 454,304; 454,308; 454,319-320; 454,329; 454,341-342; 454,345; 455,304; 455,308;
455,319-320; 455,329; 455,339; 455,345; 456,304; 456,308; 456,319-320; 456,329; 457,304; 457,308; 457,319-320;
457,329; 457,337; 458,304; 458,308; 458,319-320; 458,329; 458,331-333; 458,341; 458,344; 459,304; 459,308;
459,319-320; 459,327-333; 461,311; 462,310; 491,239; 496,228; 577,148; 723,433; 724,428-436; 724,438; 725,427;
725,434; 725,437; 807,421; 829,223; 840,269; 865,172; 866,241;
```

Noisy pixels

- CNAO2024:
  - Macro ProjItrNoisyPixel.C: search for noisy pixels (for a given threshold rate) and write in cfg file.

TAITdetector_6800.cfg

```
// -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*- Plane  8 -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-
InputNumber:                8
```

TAITdetector_6928.cfg

```
// -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*- Plane  8 -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-
InputNumber:                8
Status:                     1
MinNofPixelsInCluster:      0
MaxNofPixelsInCluster:      400
DeadPixels:                448,329; 448,342; 449,329; 449,342; 450,329; 450,342; 451,329; 451,342;
451,347-351; 452,329; 452,342; 452,346; 453,329; 453,342; 453,344-345; 454,329; 454,341-342; 454,345;
455,329; 455,339; 455,345; 456,329; 457,329; 457,337; 458,329; 458,331-333; 458,341; 458,344;
459,327-333; 460,310-314; 460,321-331; 460,333-334; 460,336-337; 461,311; 496,228; 577,148; 723,433;
724,428-435; 724,438; 725,434;
```

Noisy pixels

- CNAO2024:
  - Macro ProjItrNoisyPixel.C: search for noisy pixels (for a given threshold rate) and write in cfg file.

TAITdetector_6800.cfg

```
// -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*- Plane  8 -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-
InputNumber:                8
```

TAITdetector_6928.cfg

```
// -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*- Plane  8 -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-
InputNumber:                8
```

TAITdetector_6961.cfg

```
// -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*- Plane  8 -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-
InputNumber:                8
Status:                     1
MinNofPixelsInCluster:      0
MaxNofPixelsInCluster:      400
DeadPixels:                448,329; 448,342; 449,329; 449,342; 450,329; 450,342; 451,329; 451,342;
451,347-351; 452,329; 452,342; 452,346; 453,329; 453,342; 453,344-345; 454,329; 454,341-342; 454,345;
455,329; 455,339; 455,345; 456,329; 457,329; 457,337; 458,329; 458,331-333; 458,341; 458,344;
459,327-333; 460,310-314; 460,321-331; 460,333-334; 460,336-337; 461,311; 496,228; 577,148; 723,433;
724,428-435; 724,438; 725,434;
```

Noisy pixels

- CNAO2024:
  - Macro ProjItrNoisyPixel.C: search for noisy pixels (for a given threshold rate) and write in cfg file.

TAITdetector_6800.cfg

```
// -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*- Plane  8 -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-
InputNumber:                8
```

TAITdetector_6928.cfg

```
// -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*- Plane  8 -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-
InputNumber:                8
```

TAITdetector_6961.cfg

```
// -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*- Plane  8 -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-
InputNumber:                8
```

TAITdetector_7073.cfg

```
// -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*- Plane  8 -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-
InputNumber:                8
Status:                     1
MinNofPixelsInCluster:      0
MaxNofPixelsInCluster:      400
DeadPixels:                448,304; 448,308; 448,319-320; 448,329; 448,342; 449,304; 449,308;
449,319-320; 449,329; 449,342; 450,304; 450,308; 450,319-320; 450,329; 450,342; 451,304; 451,308;
451,319-320; 451,329; 451,342; 451,347-351; 452,304; 452,308; 452,319-320; 452,329; 452,342; 452,346;
453,304; 453,308; 453,319-320; 453,329; 453,342; 453,344-345; 454,304; 454,308; 454,319-320; 454,329;
454,341-342; 454,345; 455,304; 455,308; 455,319-320; 455,329; 455,339; 455,345; 456,304; 456,308;
456,319-320; 456,329; 457,304; 457,308; 457,319-320; 457,329; 457,337; 458,304; 458,308; 458,319-320;
458,329; 458,331-333; 458,341; 458,344; 459,304; 459,308; 459,319-320; 459,327-333; 461,311; 462,310;
491,239; 496,228; 577,148; 723,433; 724,428-436; 724,438; 725,434; 725,437;
```

Noisy pixels

- CNAO2024:
  - Macro ProjItrNoisyPixel.C: search for noisy pixels (for a given threshold rate) and write in cfg file.

TAITdetector_6800.cfg

```
// -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*- Plane  8 -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-
InputNumber:                 8
```

TAITdetector_6928.cfg

```
// -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*- Plane  8 -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-
InputNumber:                 8
```

TAITdetector_6961.cfg

```
// -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*- Plane  8 -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-
InputNumber:                 8
```

TAITdetector_7073.cfg

```
// -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*- Plane  8 -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-
InputNumber:                 8
Status:                      1
MinNofPixelsInCluster:       0
MaxNofPixelsInCluster:       400
DeadPixels:                  448,304; 448,308; 448,319-320; 448,329; 448,342; 449,304; 449,308;
449,319-320; 449,329; 449,342; 450,304; 450,308; 450,319-320; 450,329; 450,342; 451,304; 451,308;
```

TAITdetector_7003.cfg

```
// -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*- Plane  8 -*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-
InputNumber:                 8
Status:                      1
MinNofPixelsInCluster:       0
MaxNofPixelsInCluster:       400
DeadPixels:                  577,148; 717,434; 718,434; 719,430; 722,432; 722,434; 723,433-434;
724,428-435; 724,438; 724,442; 725,434; 725,439; 829,223; 840,269;
```

  - ➡ Need to understand the threshold values for the given runs

Conclusion

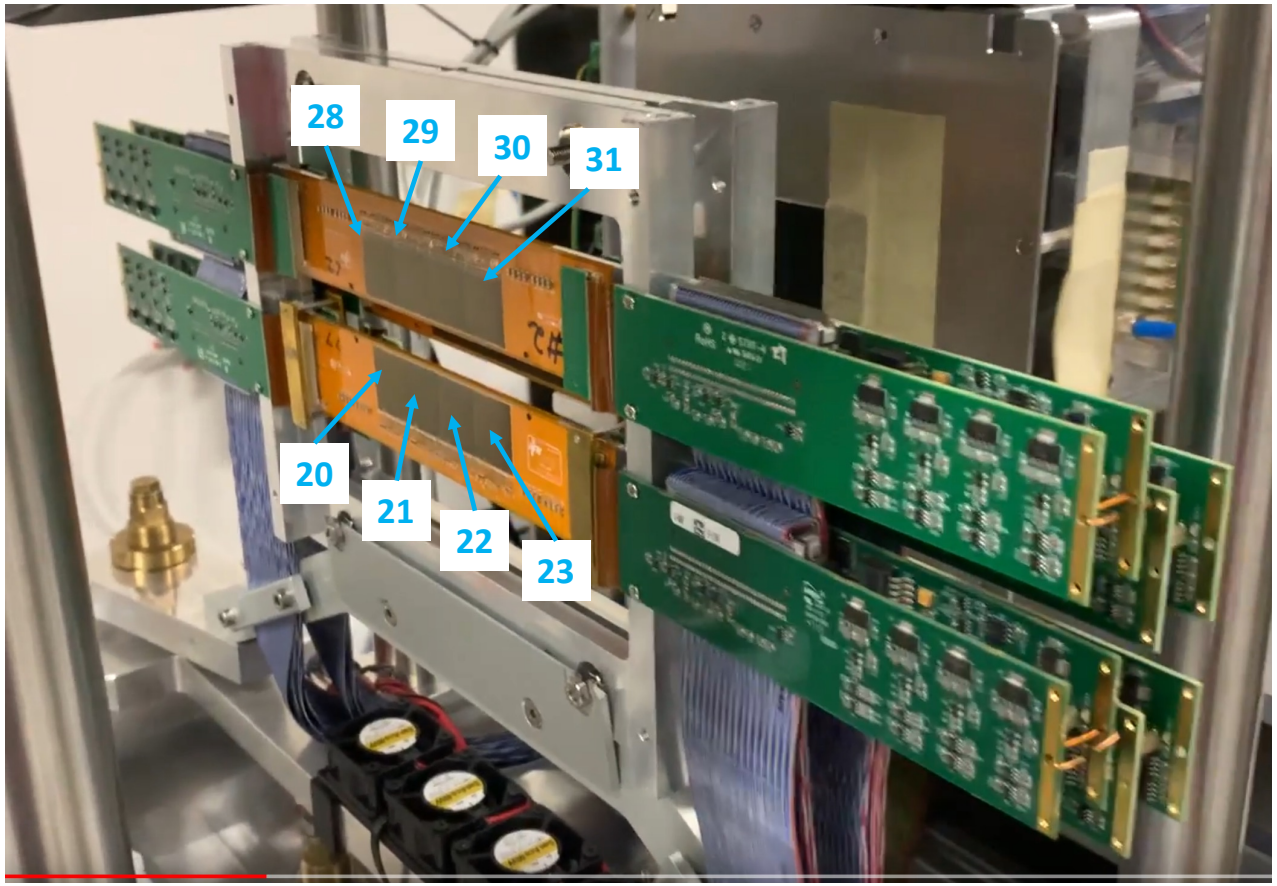
- Revive Geant4 simulated interface
- New alignment works for VTX, tested with CNAO2024 raw data
- Revive Millepede package in shoe
- Tested Millepede package for ITR with CNAO2023 MC data
  - ➡ Need more test/debugging with MC data
  - ➡ Test on real raw data

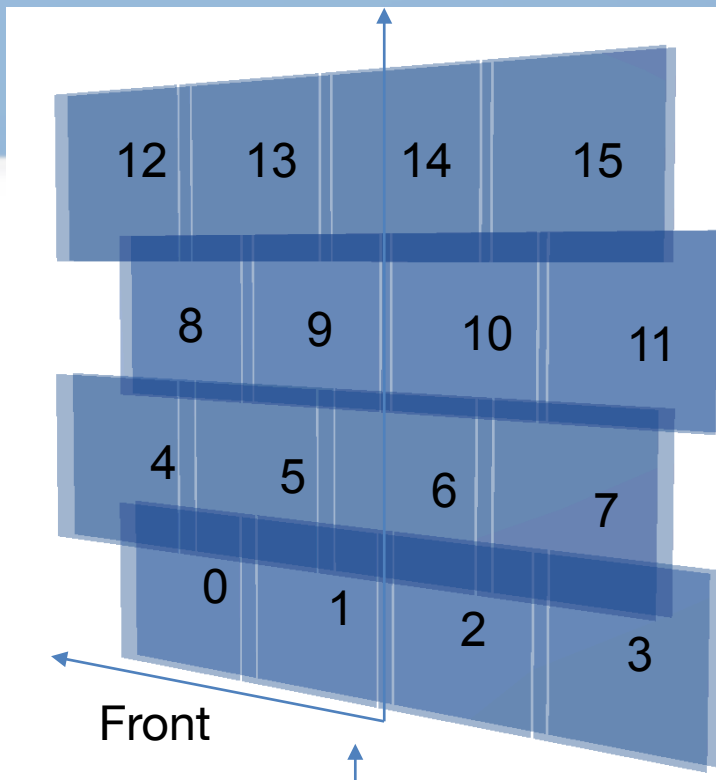
- Noisy pixels computing for CNAO024
  - ➡ Need to understand the put threshold

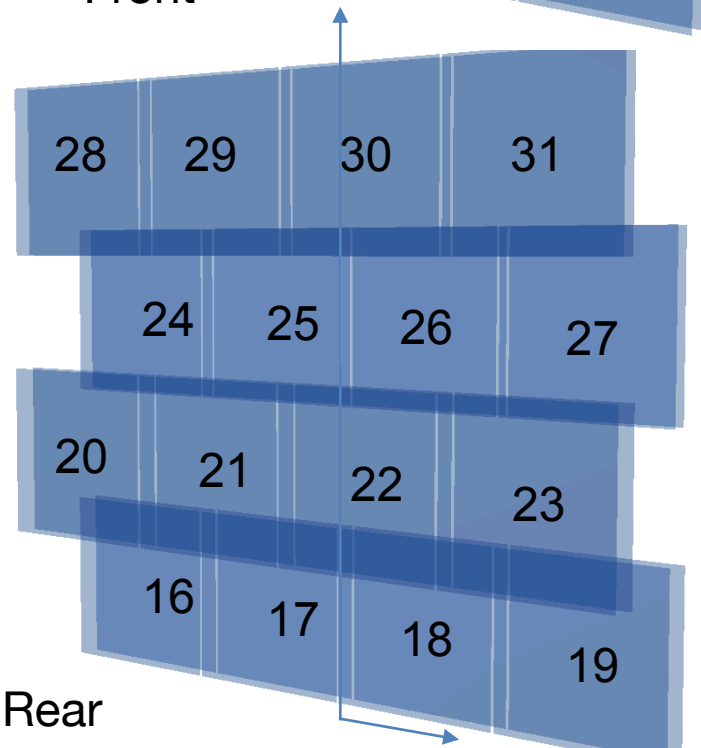
Backup

Numbering

- Sensor view

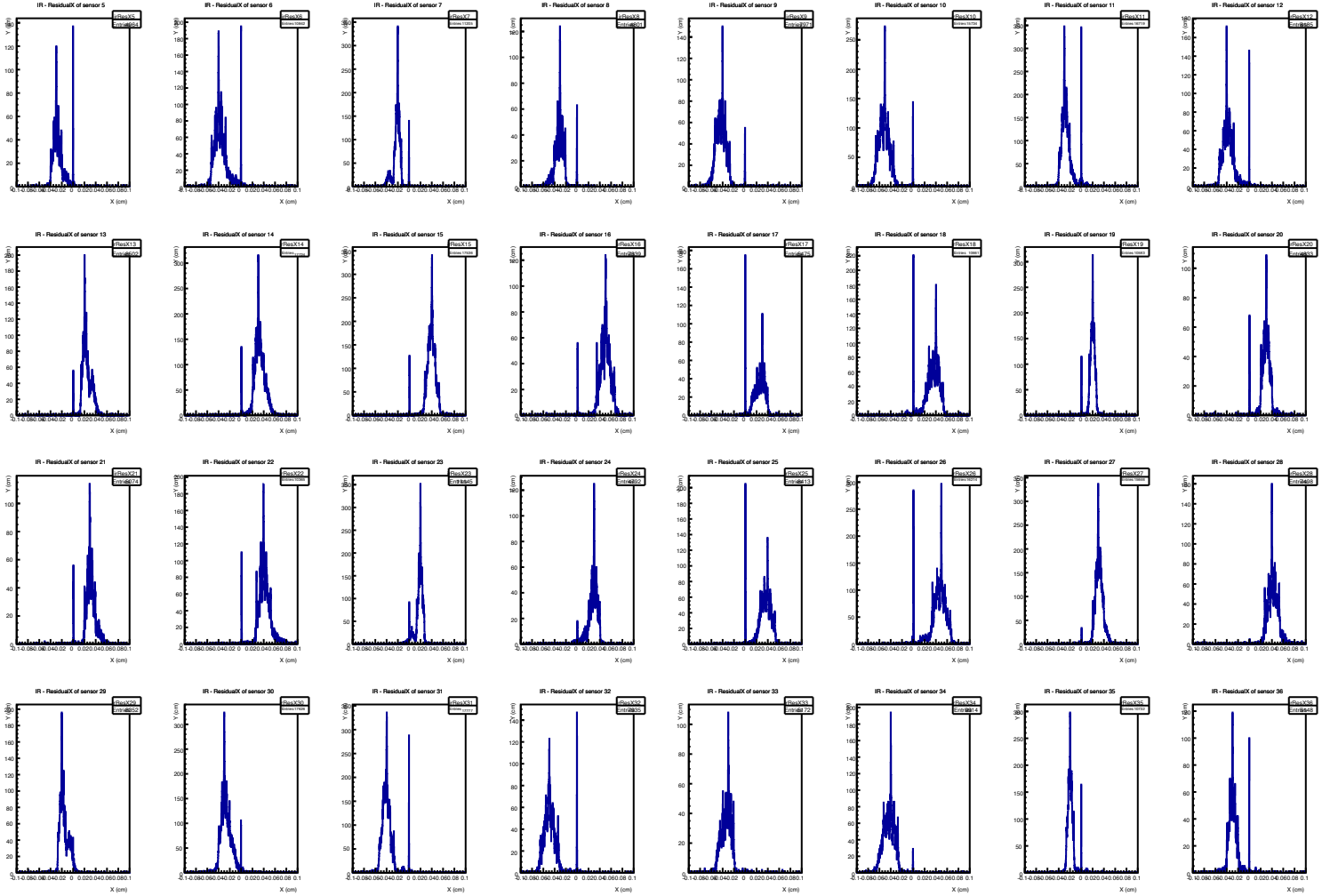






Millepede (vii)

- Residuals



VTX alignment (ii)

- GSI2019 MC data with TAIRntuAlignC:
  - Mis-alignment: ΔY[1] = 100 µm, ΔΦ = 0.5º, 12C beam at 400 MeV

```
Number of events: 10000
Loaded Event:: 0
Sensor: 1 OffsetU:   0.0 OffsetV:   0.0 TiltW:  0.000
Sensor: 2 OffsetU:   0.7 OffsetV: 100.0 TiltW:  0.407
Sensor: 3 OffsetU:   0.5 OffsetV:   0.1 TiltW: -0.373
Sensor: 4 OffsetU:   0.0 OffsetV:   0.0 TiltW: -0.470
Number of events for iteration 1: 9947 / 10000
------------------------------------------------------------
-------------------- Alignment RESULT --------------------
------------------------------------------------------------
------------------------------------------------
Sensor: 1 AlignmentU:   0.0 AlignmentV:   0.0 TiltW:  0.000 status 1
------------------------------------------------
Sensor: 2 AlignmentU:   0.5 AlignmentV: 100.0 TiltW:  0.496 status 1
------------------------------------------------
Sensor: 3 AlignmentU:   0.5 AlignmentV:   0.2 TiltW: -0.029 status 1
------------------------------------------------
Sensor: 4 AlignmentU:   0.0 AlignmentV:   0.0 TiltW: -0.037 status 1
```

- Criteria convergence: ΔX = ΔY < 5 µm and ΔΦ < 0.1º

➡ Successfully aligned