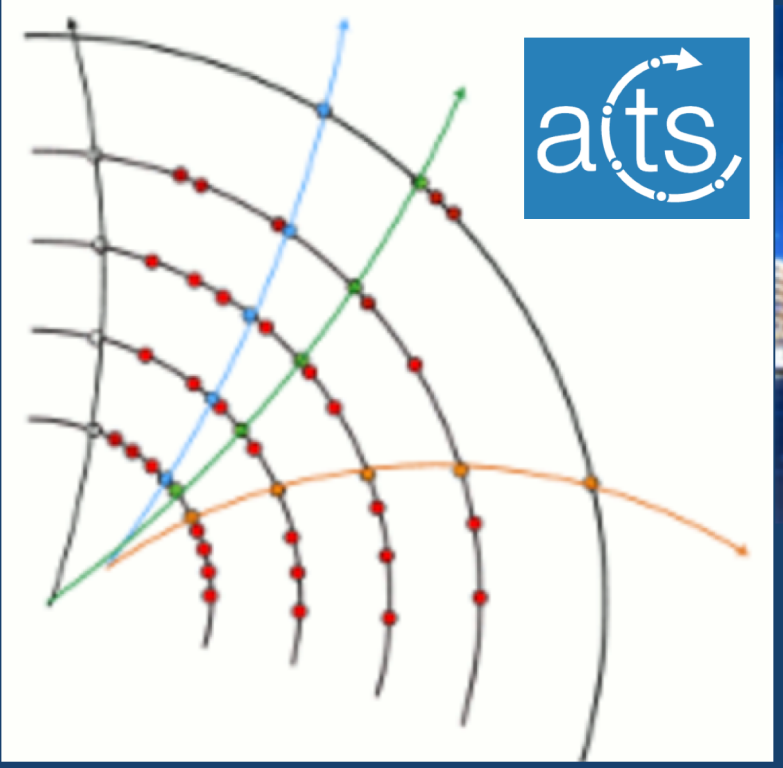
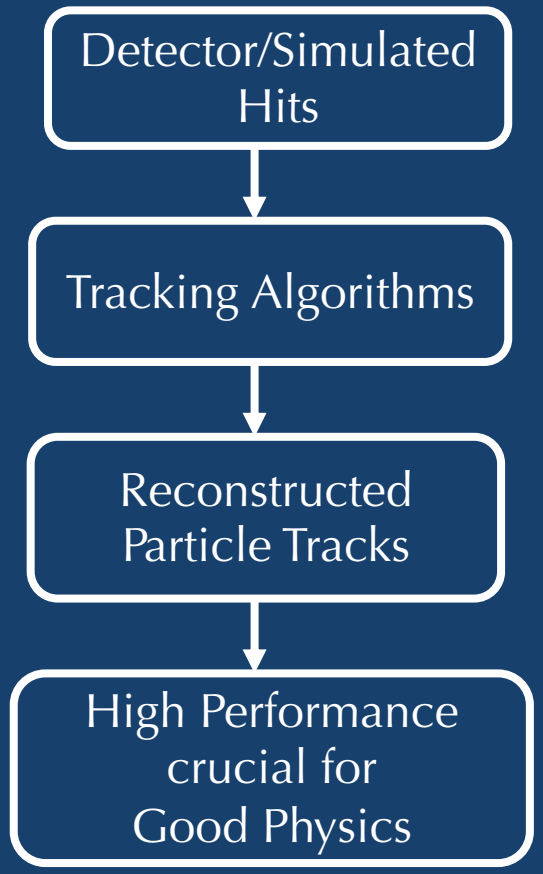


Potentiality of automatic parameter tuning suite available in ACTS track reconstruction software framework

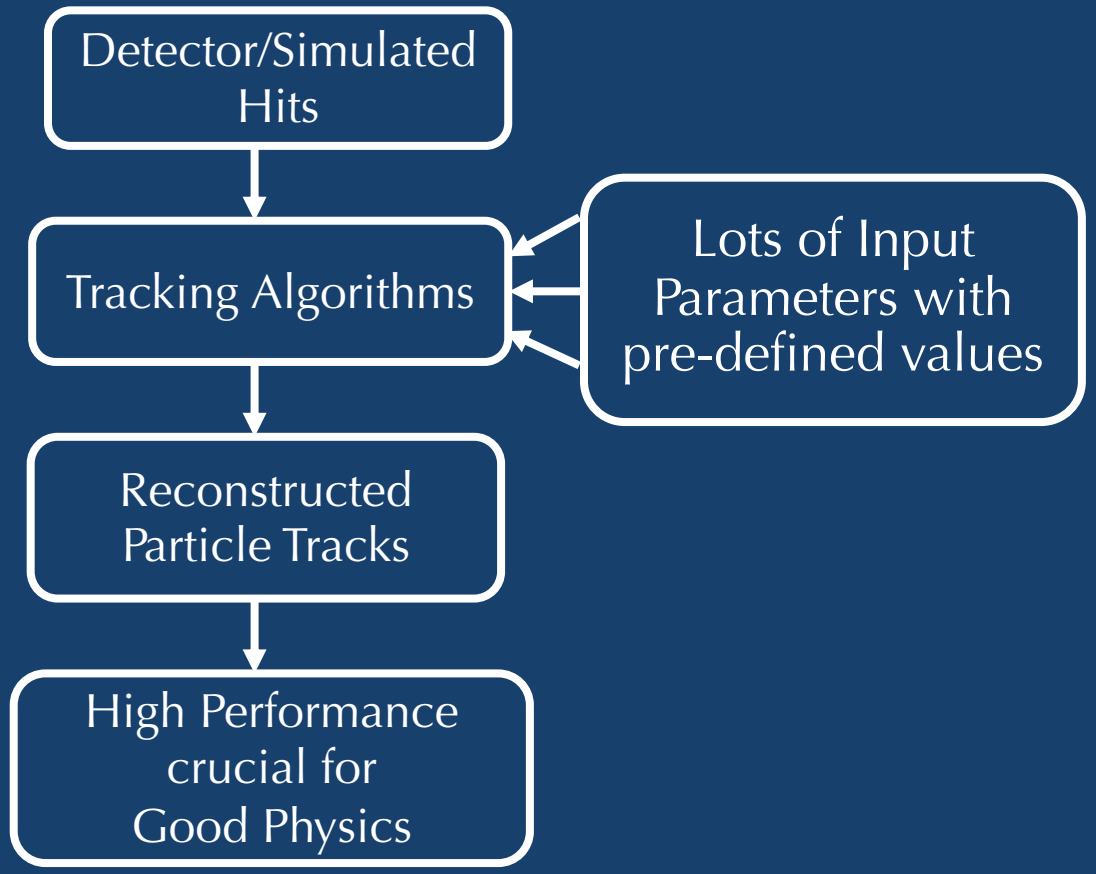
Rocky B Garg[1], Corentin Allaire[2], Andreas Salzburger[3], Hadrien Grasland[2], Lauren Tompkins[1], Elyssa F Hofgard[1]

[1]Stanford University, [2]Université Paris-Saclay, [3]CERN

Motivation


Detector/Simulated Hits
Tracking Algorithms
Reconstructed Particle Tracks
High Performance crucial for Good Physics

Motivation


Detector/Simulated Hits
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Lots of Input Parameters with pre-defined values
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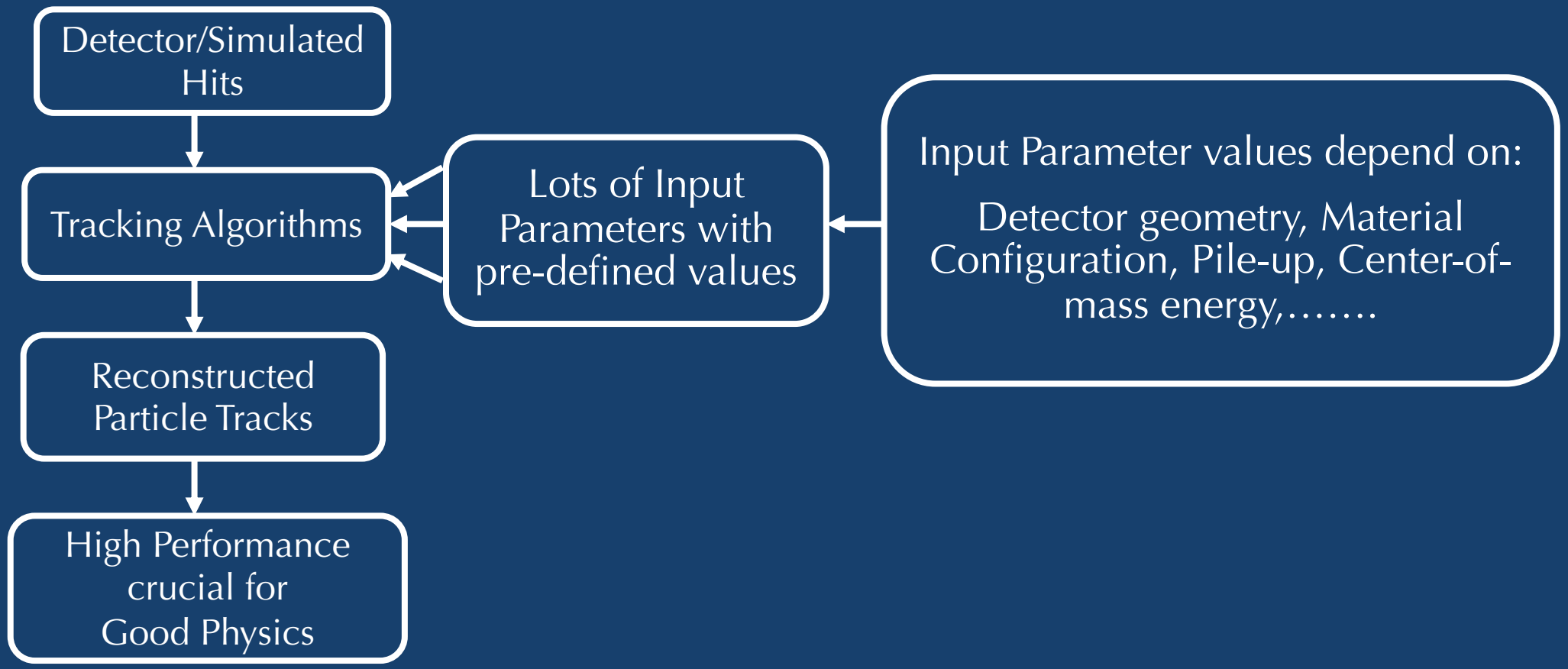
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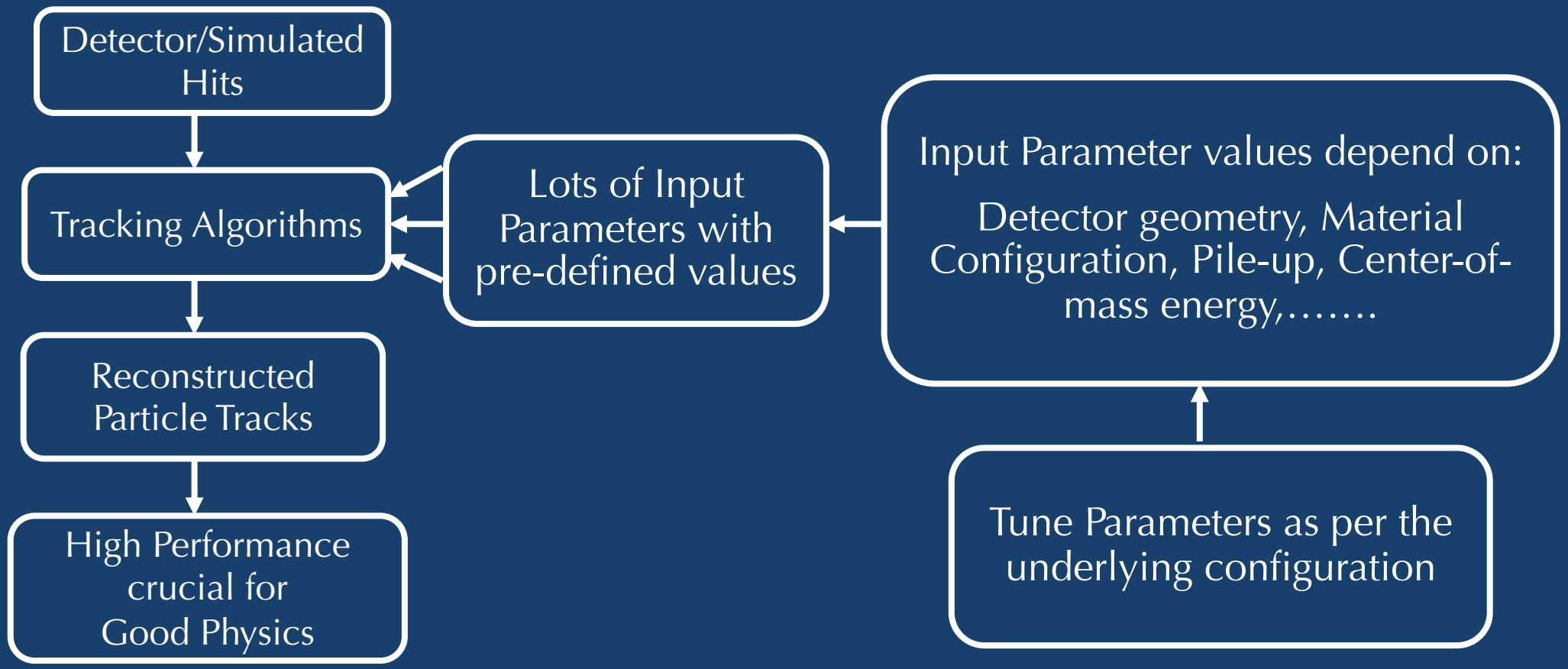
Lots of Input Parameters with pre-defined values
Input Parameter values depend on:
Detector geometry, Material Configuration, Pile-up, Center-of-mass energy,…….

Motivation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High Performance crucial for Good Physics
Lots of Input Parameters with pre-defined values
Input Parameter values depend on:
Detector geometry, Material Configuration, Pile-up, Center-of-mass energy,…….
Tune Parameters as per the underlying configuration

Motivation

MOST COMMON APPROACH

Detector/Simulated Hits

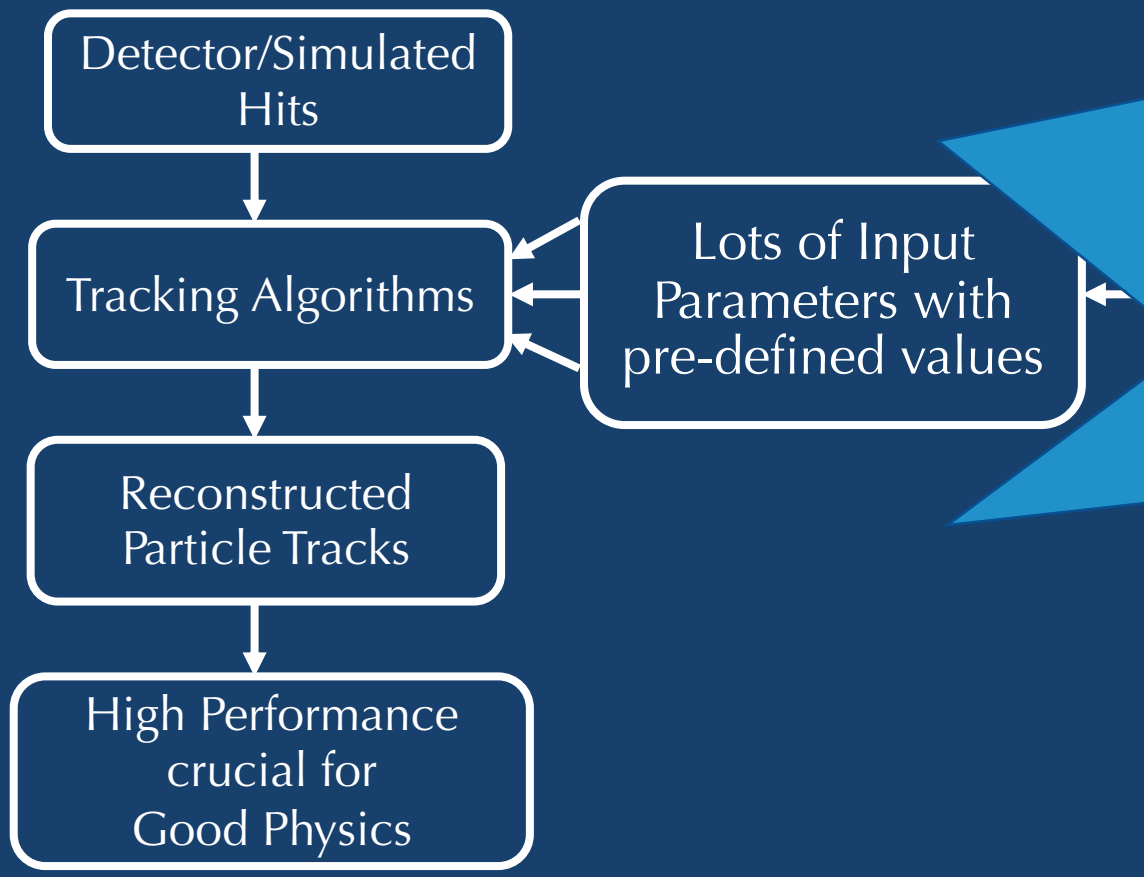
Tracking Algorithms

Lots of Input Parameters with pre-defined values

Reconstructed Particle Tracks

High Performance crucial for Good Physics

Motivation



NOT AN IDEAL APPROACH

Rely on previous studies

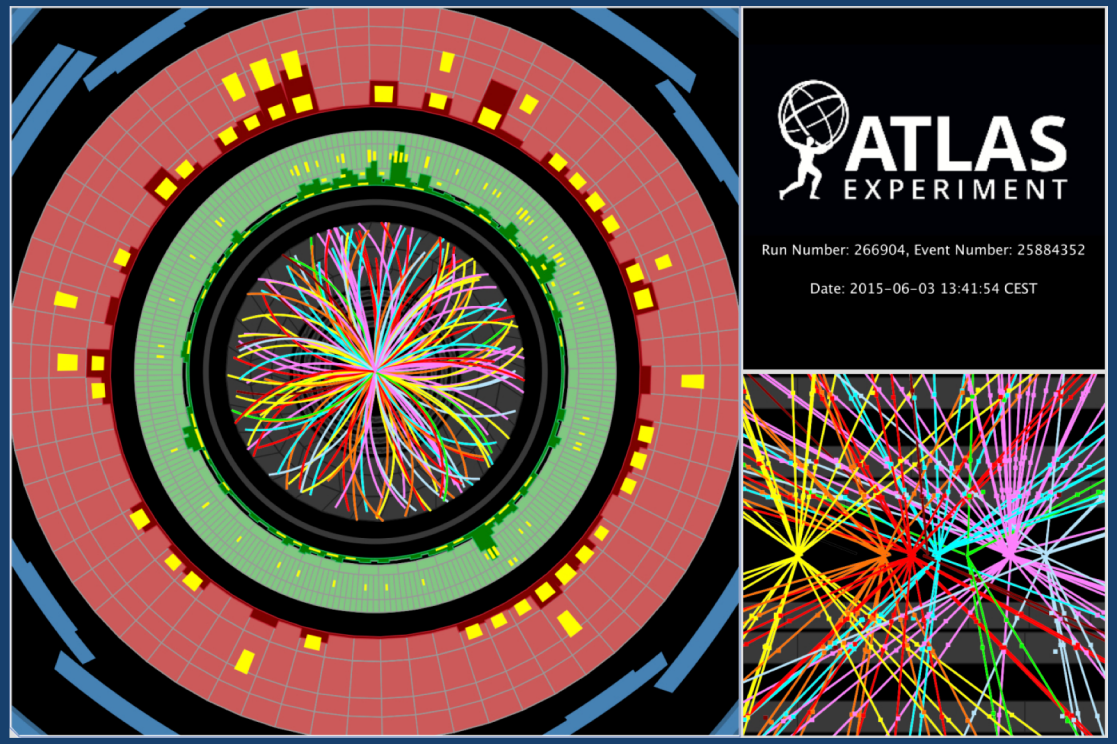
Potential to provide good configuration but very time consuming

Need Re-tuning when underlying configuration changes

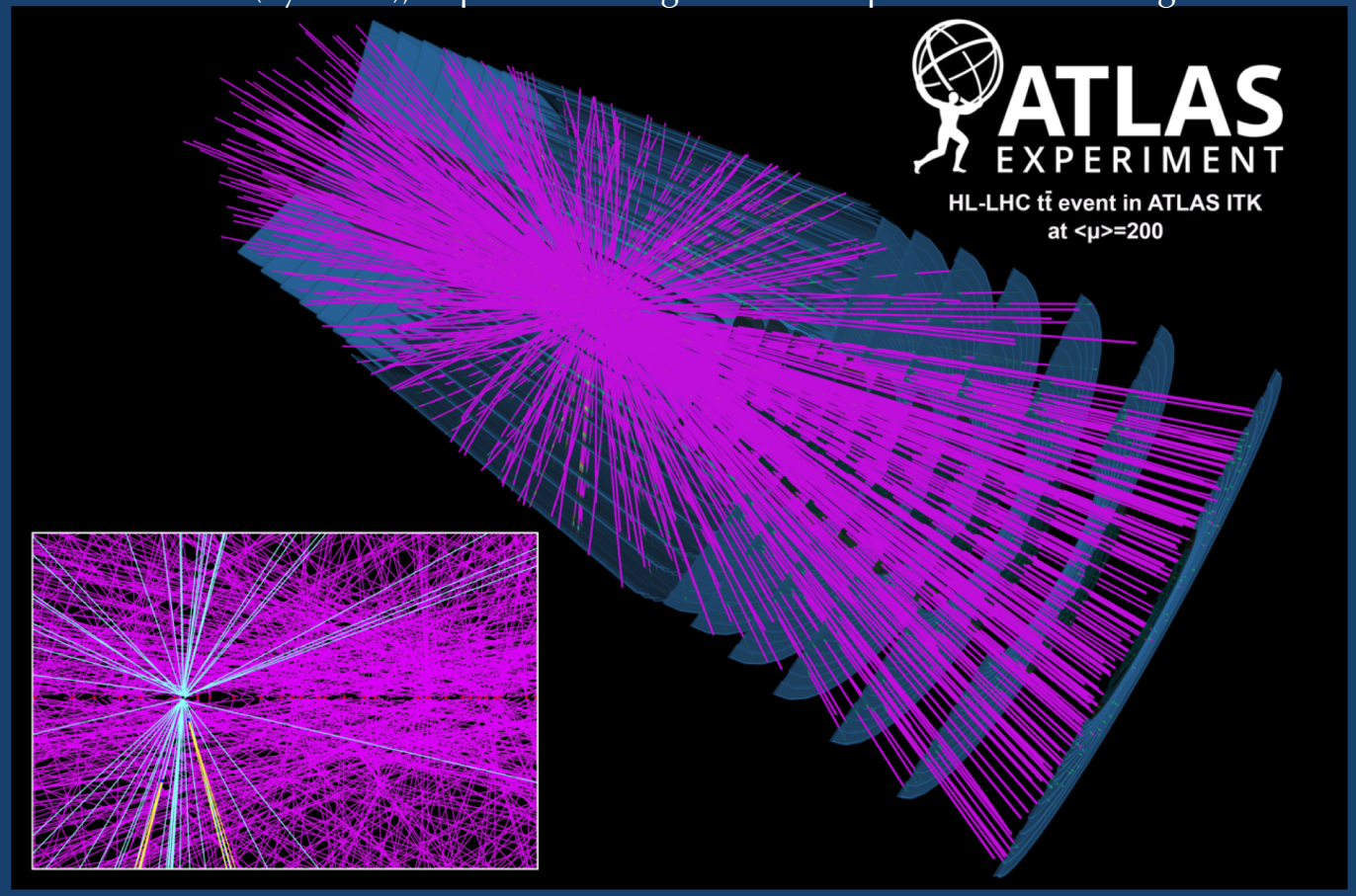
Tracking in High Luminosity LHC (HL-LHC) environment

- More complex tracking environment
- Efficient parameter optimization needed along with other measures

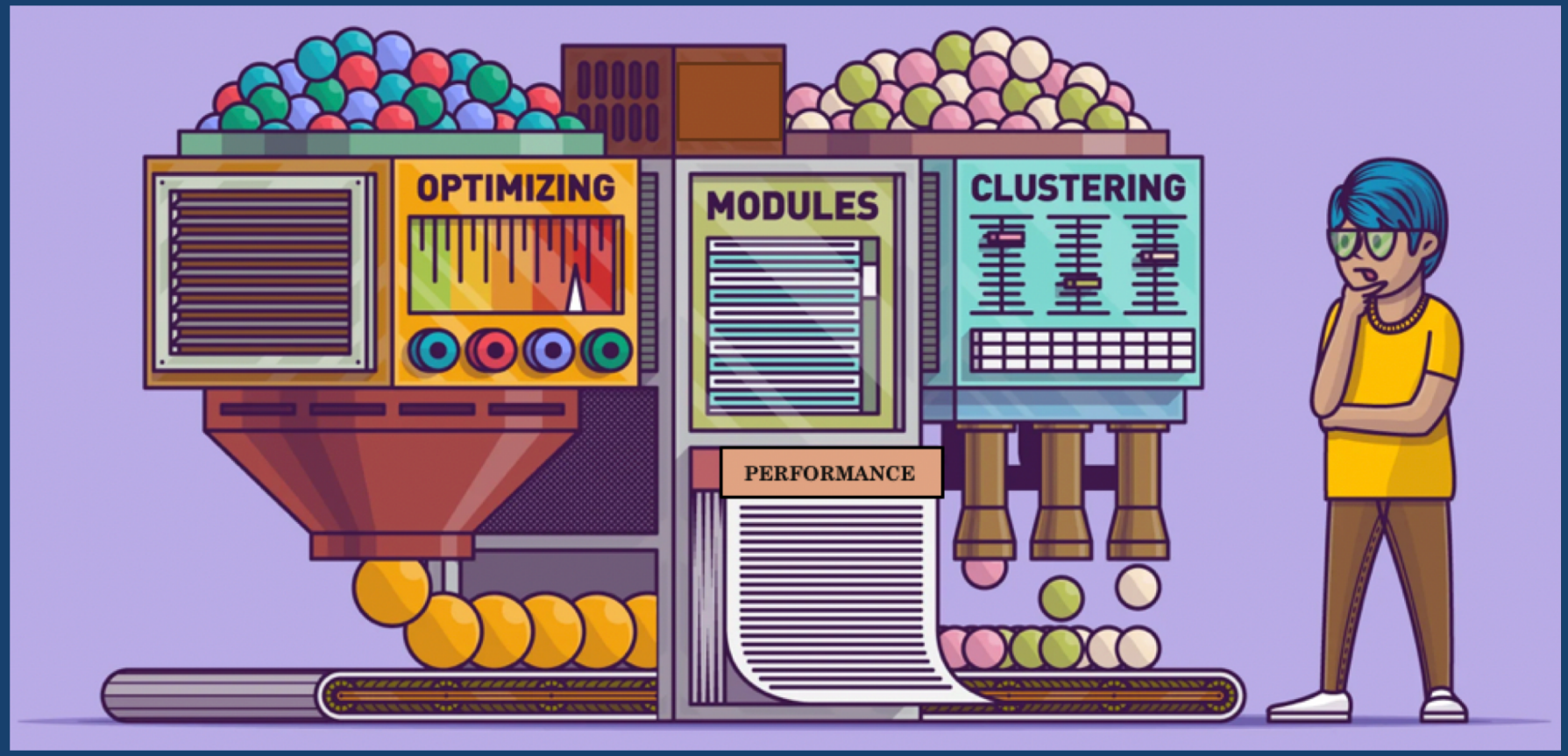
In 2015, Average collisions per bunch–crossing ≅ 20



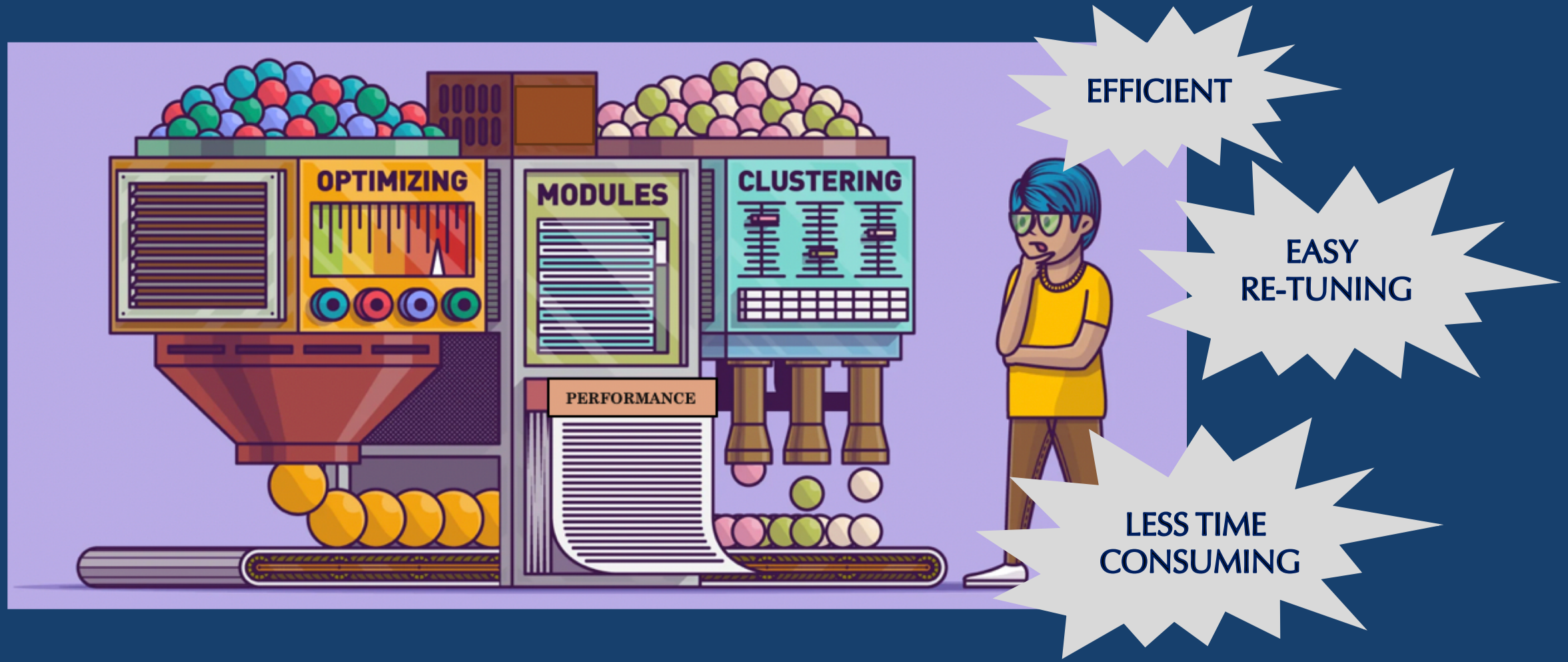
In HL-LHC (by 2030), expected average collisions per bunch–crossing ≅ 200



Automatic Parameter Optimization????



Automatic Parameter Optimization????

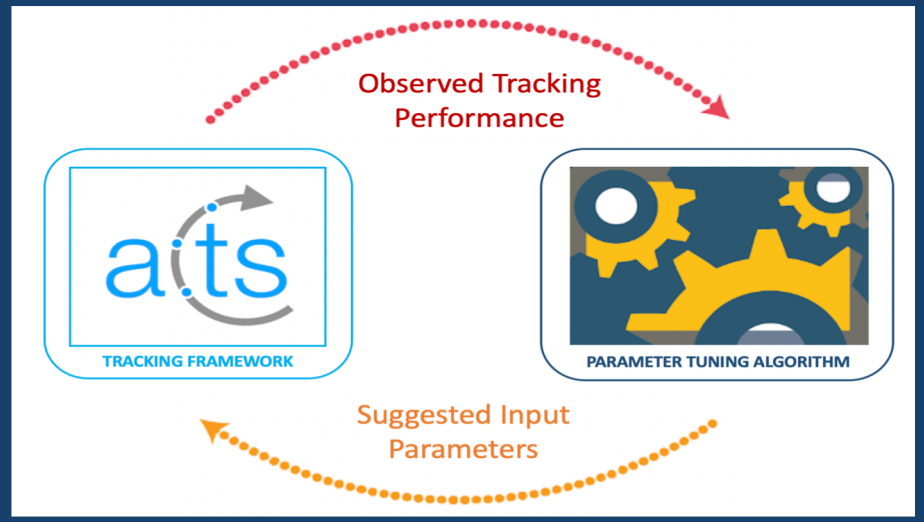


Automatic Parameter Optimization in ACTS

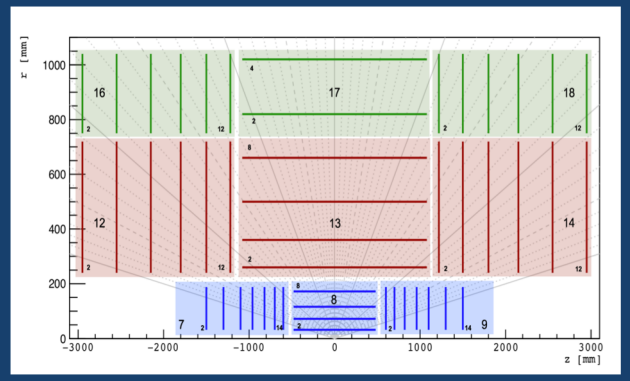
- With this motivation in mind, we implemented some automatic parameter optimization techniques within ACTS software framework
- Python scripts: evaluate on tracking performance and provide best performing parameters
- Three tracking algorithms: Track Seeding, Vertexing and Material Mapping
- Two optimization algorithms: Orion and Optuna

ACTS: A Common Tracking Software

- Open source tracking framework
- High level track reconstruction modules
- Agnostic to detector geometries
- Inbuilt data generator/simulator

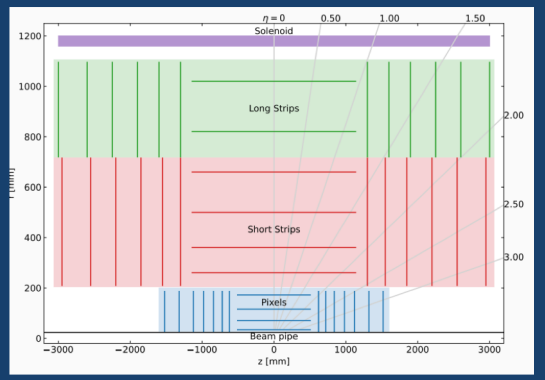


TrackML/Generic Detector



Used in Kaggle TrackML challenge (1904.06778, 2105.01160)

Open Data Detector



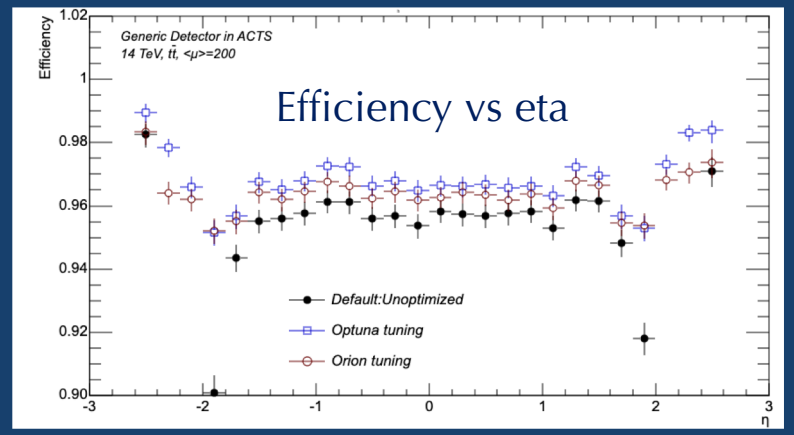
Similar layout as TrackML detector
Realistic material model

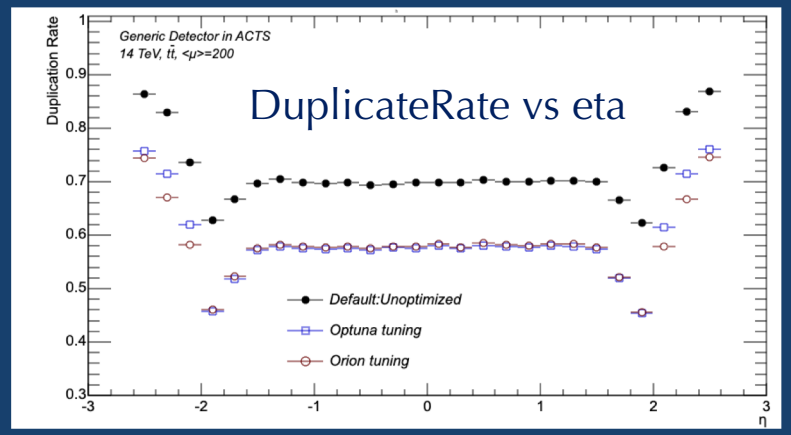
Track Seeding

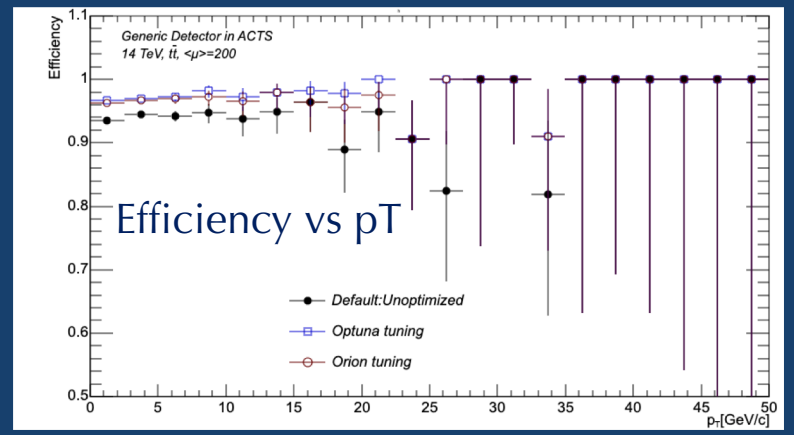
Generic Detector

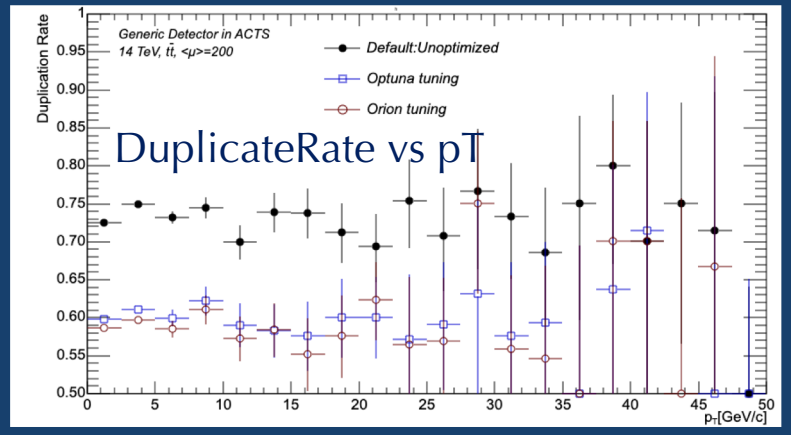
- Optimized 8 Track Seeding Parameters
- Computed performance on full track reconstruction
- Compared results with default configuration

	Default	Optuna	Orion
Efficiency	0.936	0.967	0.963
Duplicate Rate	0.726	0.598	0.587
Fake Rate	5.56E-05	5.2E-05	8.8E-05
Total(sec) time/event	50.2	46.8	33.9







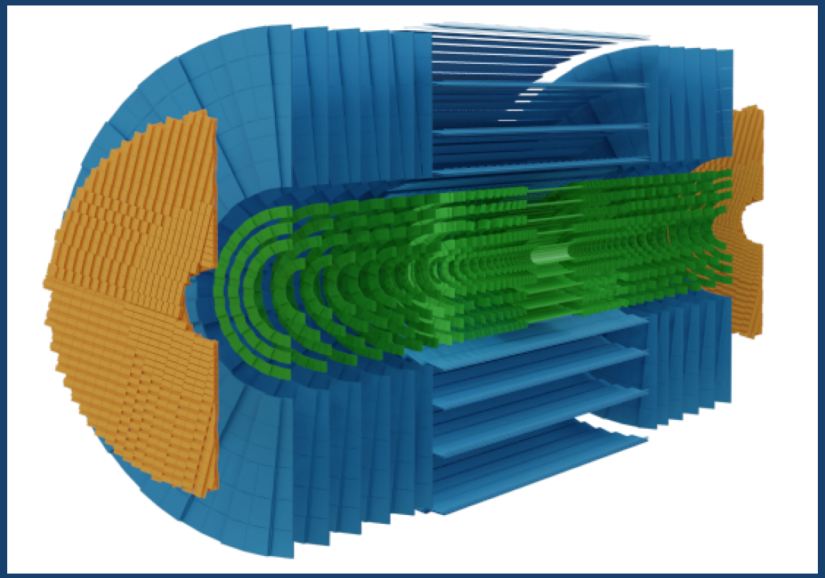


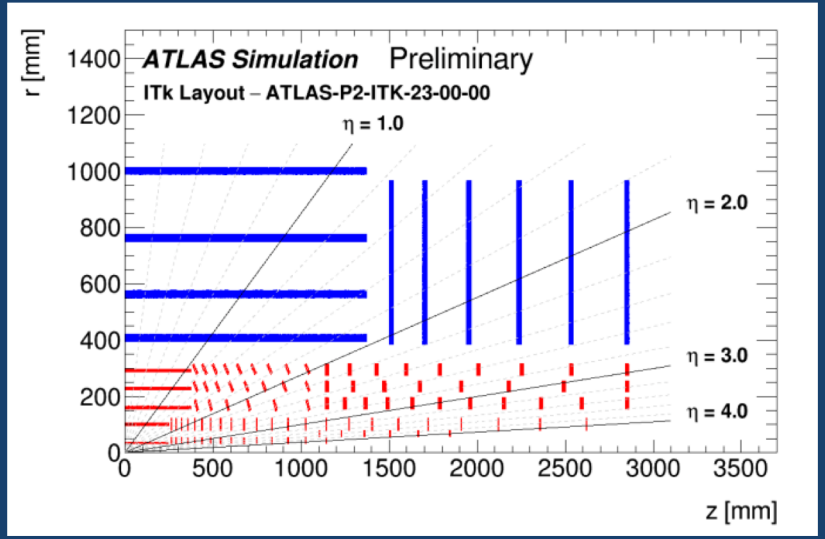
Track Seeding

ATLAS – ITk Geometry

- We tested our optimization algorithms by plugging-in a real detector geometry – ATLAS ITk geometry (ATLAS tracking geometry for HL-LHC)
- Optimized same 8 parameter and computed performance over full reconstruction

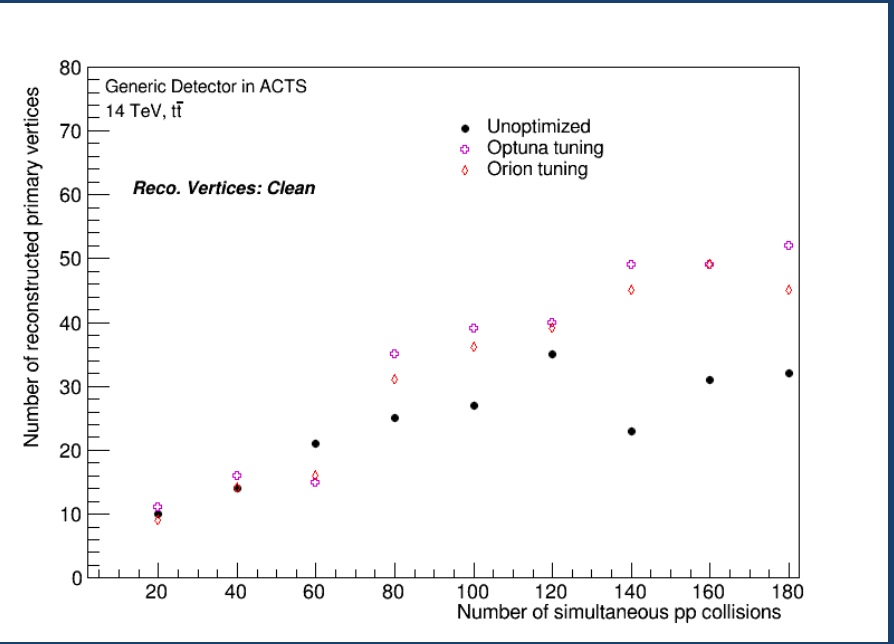
- The results can be seen here:
  - Link1
  - Link2

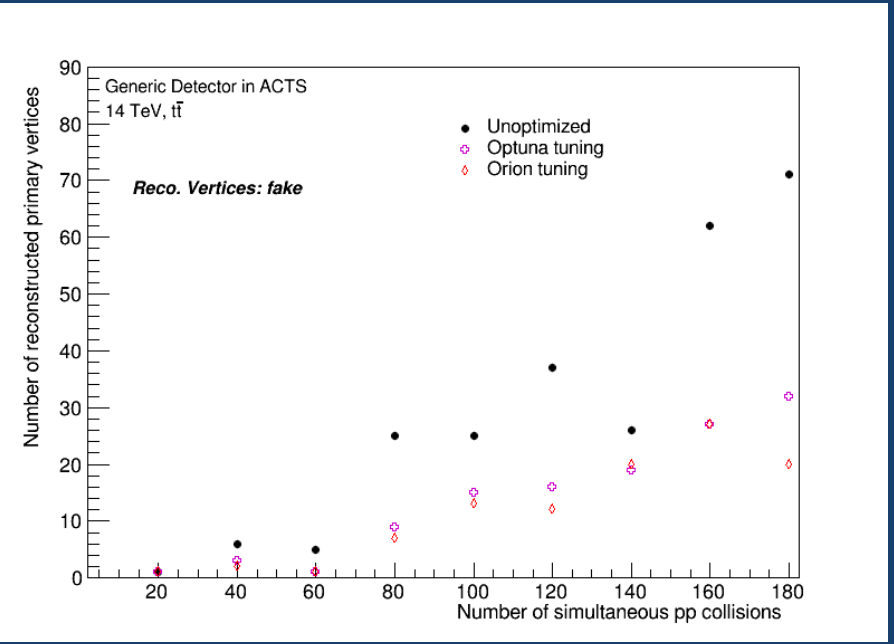




Vertexing
Generic Detector

- Optimized 5 parameters of Adaptive Multi Vertex Finder (AMVF) algorithm
- Computed the performance over a pile-up range of 20 – 180
- Compared the results default configuration

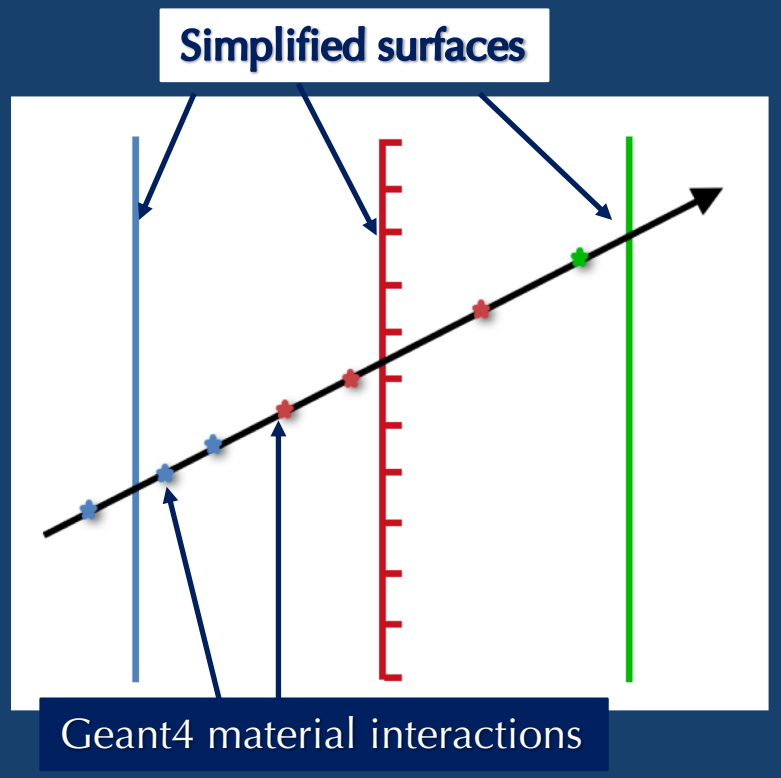


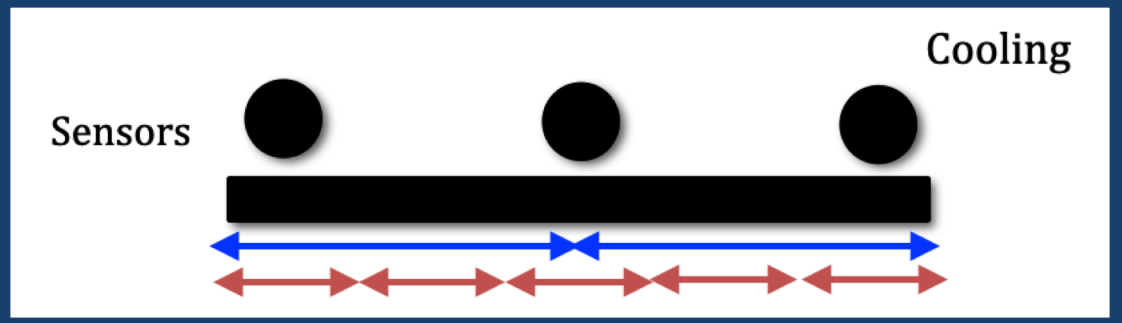


Optimization in Material mapping

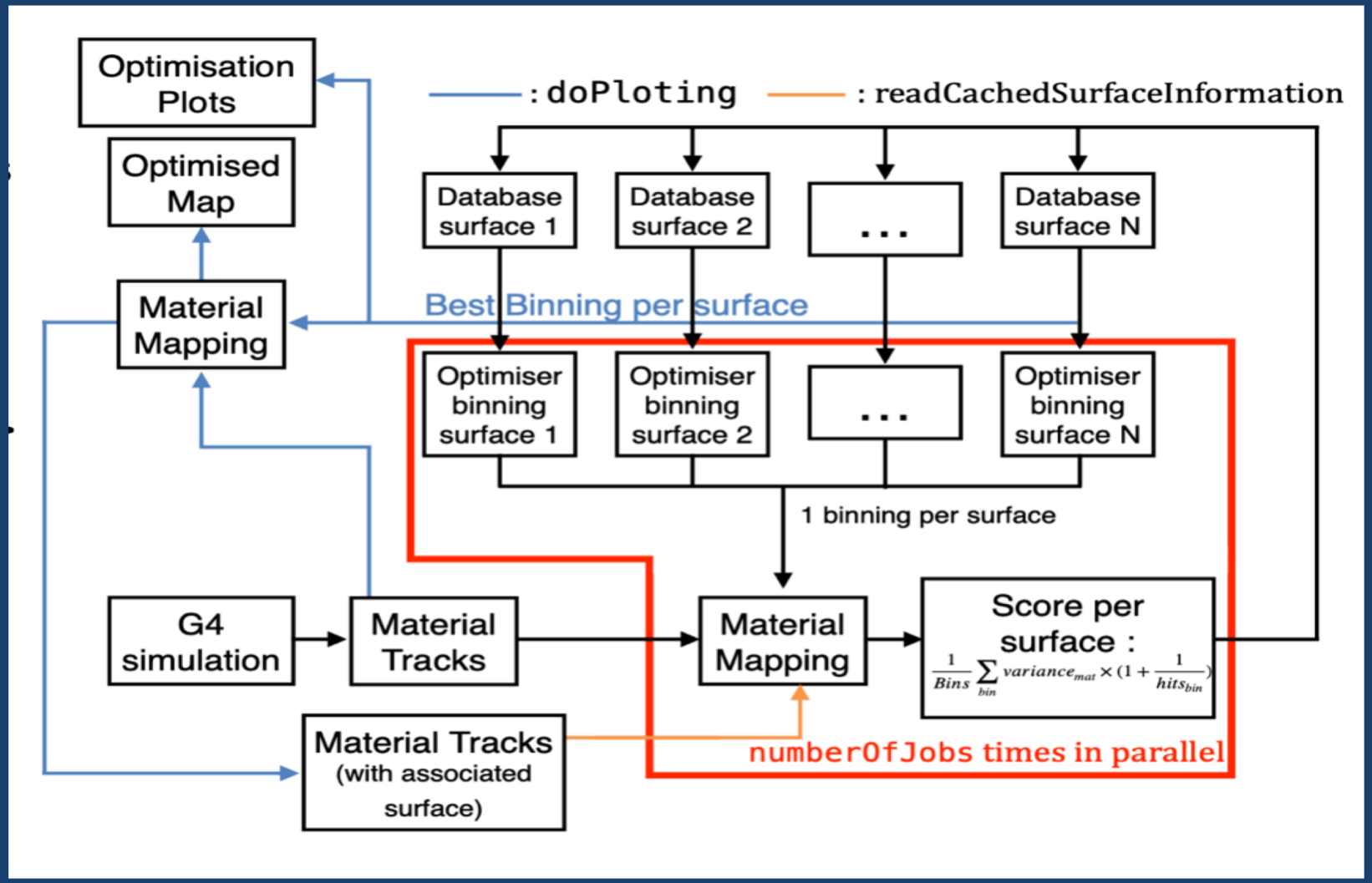
Open Data Detector

- Material map from Geant4 is very precise but not useable in tracking due to time constraints
- Need a simplified material map obtained by projecting material onto the binned surfaces
- Proper binning of surfaces is needed to account for proper geometry
- Manual optimization of binning takes a long time and need expert intervention
- Automatic optimization algorithm Orion has been employed to automatically provide the binning with even material distribution





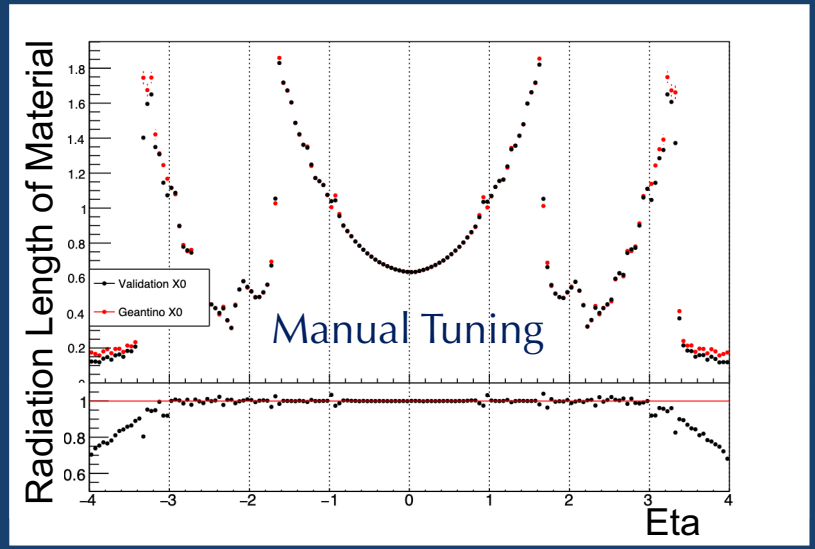
Parallelization is possible

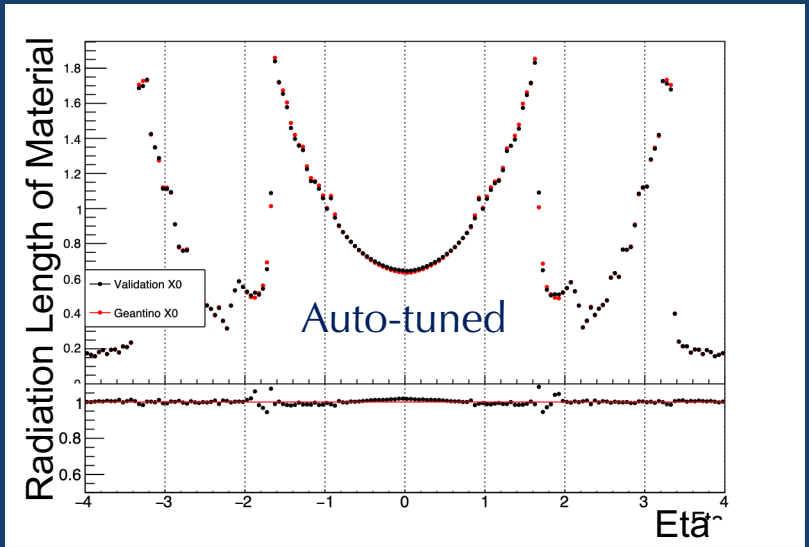


Optimization results

- Manual Tuning of material map in ODD detector took around 1 week
- Auto tuning was fast and does not require expert's input
- Performance of Auto-tuning is comparable to manual tuning
- More precise prediction in endcap with auto tuning
- Easy to configure with different geometries

Geant4 vs Binned Surface





Summary

- ACTS comes with auto-tuning suite integrated in it
- Usable with different geometries
- We have demonstrated the proof-of-principle by considering three different auto tuning examples
- We encourage you to use these auto-tuning algorithms for your studies

Thank you !!!!

Back-up

Performance Evaluation: Score/Objective Function

- Based on the performance metrics of underlying tracking algorithm
- Positive weights are given to quantities we want to increase
- Negative weights are given to quantities we want to decrease

Performance metrics for CKF

- Tracking Efficiency
- Duplicate Rate
- Fake Rate
- Run-time

Performance metrics for AMVF

- Total number of reconstructed vertices
- Reconstructed vertices tagged as
  - Clean
  - Merged
  - Split
  - Fake
- Vertex Resolution in x, y and z

Output from an optimization method is highly dependent on the score function used

Performance Evaluation: Score/Objective Function

Combinatorial Kalman Filter (CKF)

$$\text{Score Function} = \mathit{Efficiency} - \left(\mathit{FakeRate} + \frac{\mathit{DuplicateRate}}{K} + \frac{\mathit{RunTime}}{K}\right),$$

(K = 7 for all algorithms)

Adaptive Multi Vertex Finder (AMVF)

$$\text{Score Function} = (\mathit{Eff}_{Total} + 2\mathit{Eff}_{Clean}) - (\mathit{Merged} + \mathit{Split} + \mathit{Fake} + \mathit{Resolution})$$

List of parameters considered for Track Seeding optimization

- **maxPtScattering:** upper PT limit for scattering angle calculations
- **impactMax:** maximum value for impact parameter
- **deltaRMin:** minimum distance in r between two measurements within one seed
- **deltaRMax:** maximum distance in r between two measurements within one seed
- **sigmaScattering:** number of sigma used for scattering angle calculations
- **radLengthPerSeed:** average radiation lengths of material on the length of a seed
- **maxSeedsPerSpM:** number of space-points in top and bottom layers considered for compatibility with middle space-point
- **cotThetaMax:** maximum cotTheta between two space-points in a seed to be considered compatible

List of parameters considered for AMVF optimization

- **tracksMaxZinterval:** maximum z-interval used for adding tracks to multi-vertex fit
- **maxVertexChi2:** maximum chi2 value for tracks to be compatible with fitted vertex
- **maxMergeVertexSignificance:** maximum significance on the distance between two vertices to allow merging
- **minWeight:** minimum track weight for the track to be considered compatible with vertex candidate
- **maximumVertexContamination:** maximum vertex contamination value

Performance metrics of Tracking algorithms

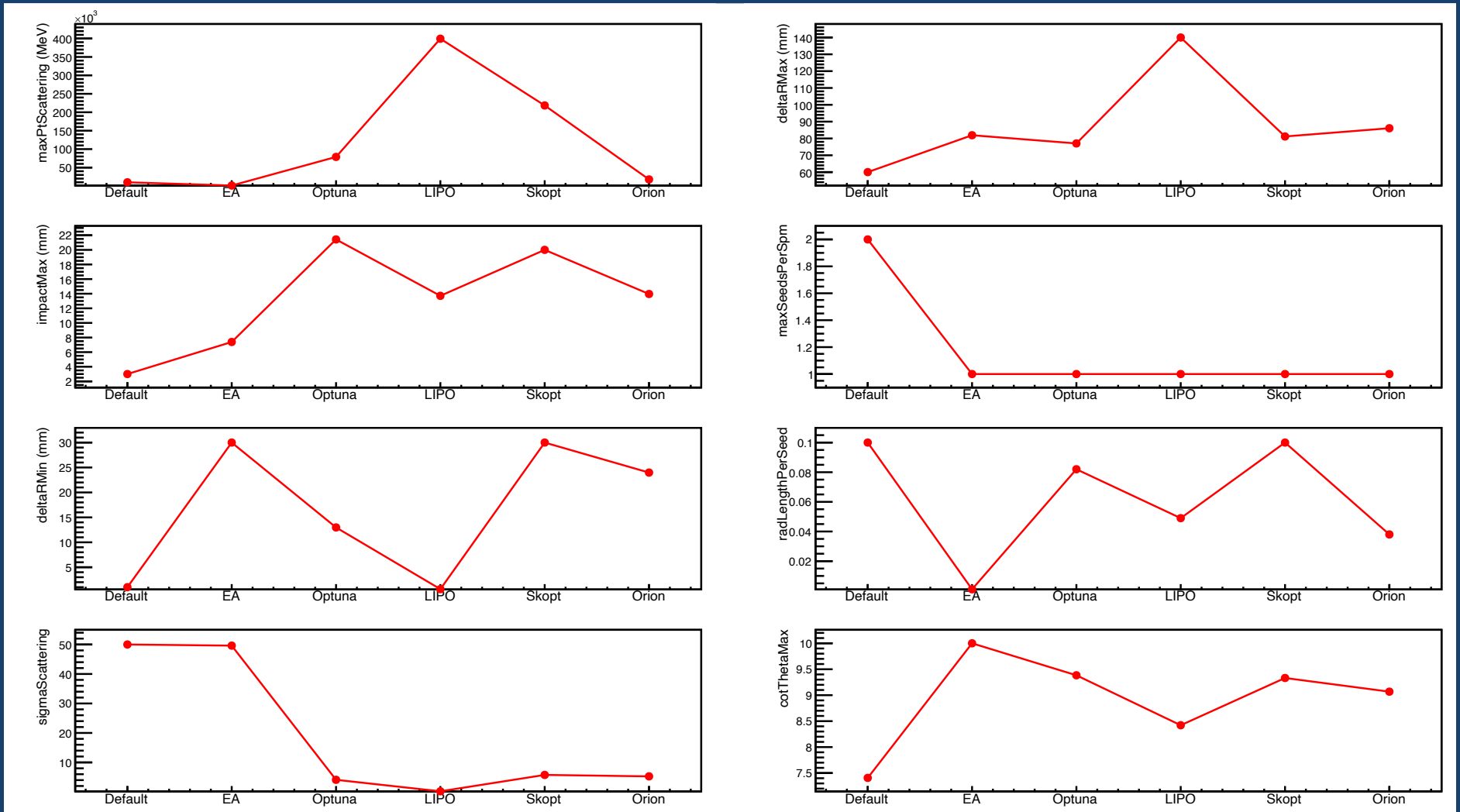
CKF:

- Track reconstruction efficiency: fraction of generated particles that have created at least 9 measurements on the traversed detectors and are associated with tracks
- Fake rate: Fraction of reconstructed tracks not associated with any truth particle
- Duplicate rate: Fraction of multiple reconstructed tracks associated with same truth generated particle

AMVF:

- Eff_total: No. of vertices reconstructed by AMVF out of total detector accepted vertices
- Clean: reconstructed vertices associated to one truth generated particle
- Split: More than one reconstructed vertices associated with same truth particle
- Merge: One reconstructed vertex associated with more than one truth particle
- Fake: reconstructed vertices not associated to any truth particle
- Resolution: deltaR/R = $((reco_x\text{-}true_x)^2 + (reco_y\text{-}true_y)^2 + (reco_z\text{-} true_z)^2)/(true_x^2 + true_y^2 + true_z^2)$

CKF Parameters for Generic Detector: Default and Optimized



AMVF Parameters: Default and Optimized