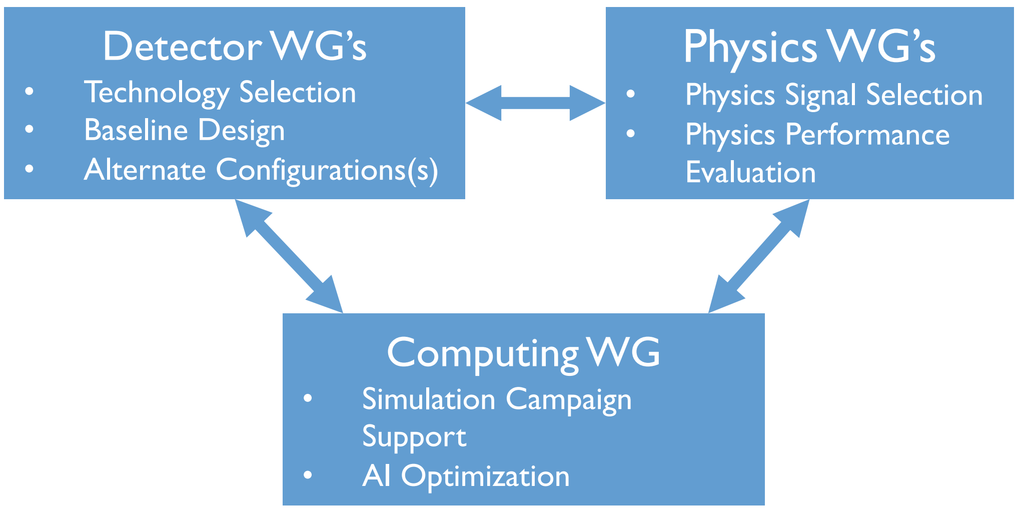
ECCE DESIGN OPTIMIZATION WITH AI

William Phelps for the ECCE AI Working Group

Christopher Newport University/Jefferson Lab

ECCE AI Working Group

- AI Working group was founded as an initial part of ECCE (March 2021)
- During the proposal phase we are working with other working groups (physics and detector) to assist in detector design optimization
- In the future this scope could be expanded to include other AI applications as well (AI assisted tracking, etc.)



ECCE AI Working Group

- Active group comprised of members from 6 institutions with more looking to participate

Active Projects

- Tracking (Brunel/MIT/Regina)
- DIRC (CNU/MIT)
- Zero Degree Calorimeter (JLab/Duquesne)
- Barrel Calorimetry (Regina/MIT)

University of Regina

Christopher Newport University

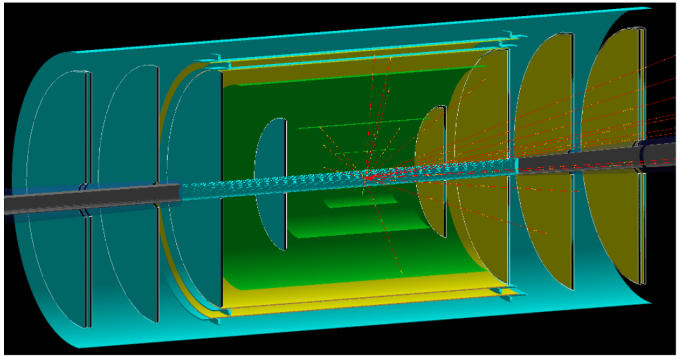
Duquesne University

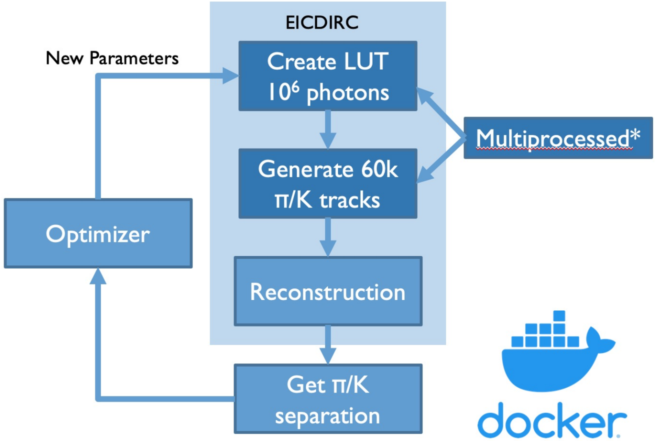
Brunel University London

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Detector Optimization Projects

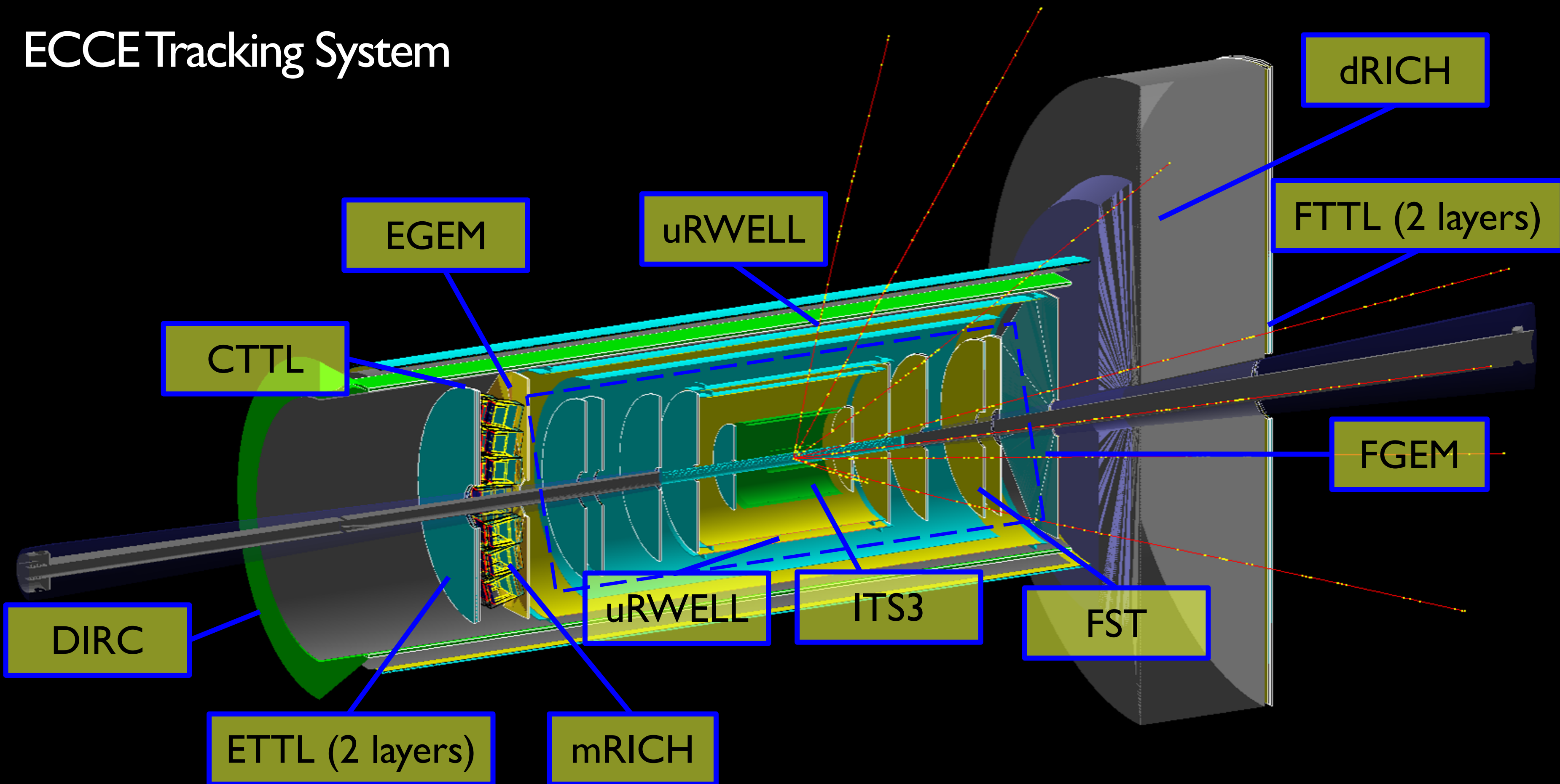
- Forward/Barrel Tracker optimization (Cristiano Fanelli and Karthik Suresh)
- DIRC Optimization (Andru Quiroga and W. Phelps)
  - Framework completed and ready to go, will work with DIRC group on future steps
  - Could use similar framework for other detector optimization projects as similar steps will need to be multiprocessed



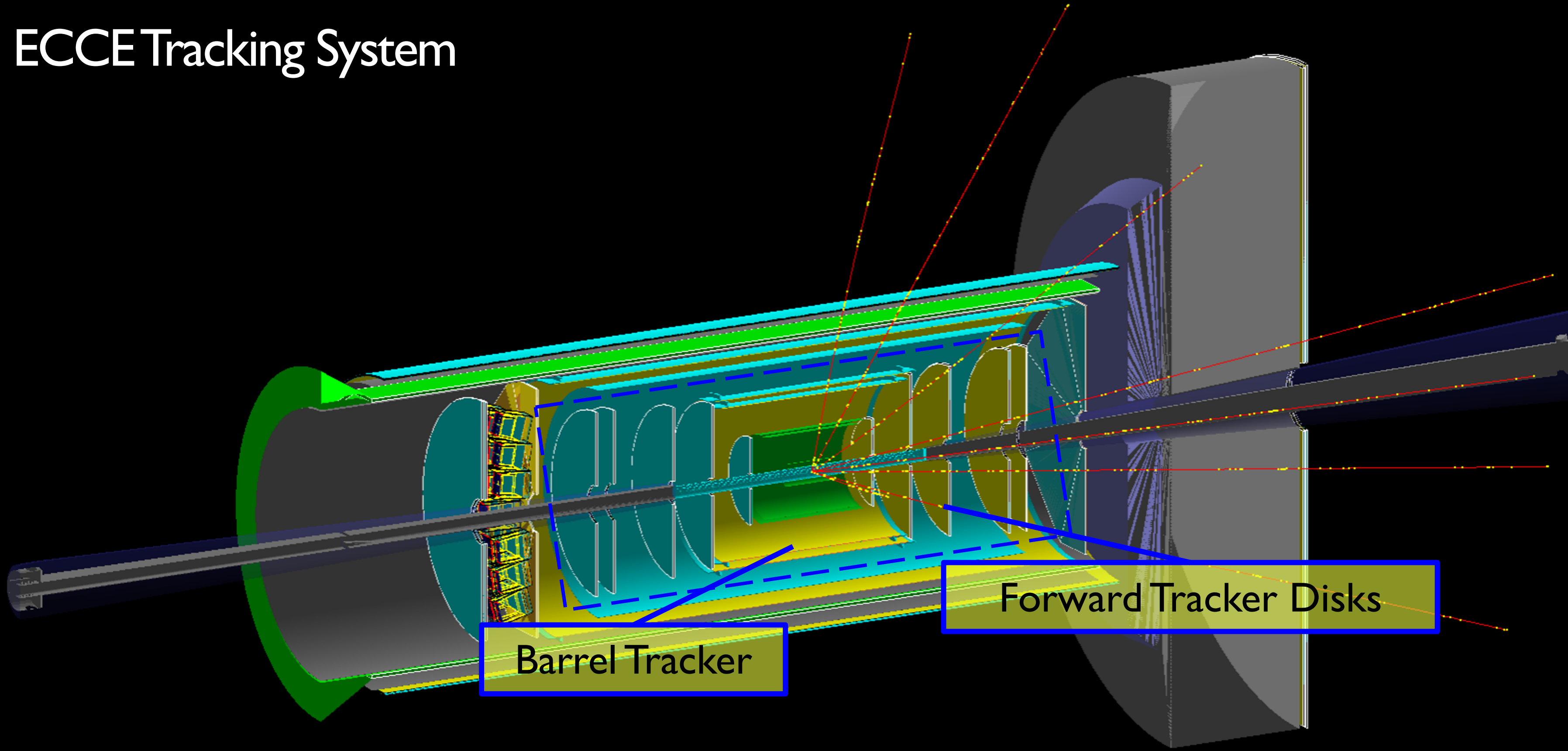


All results shown are preliminary!

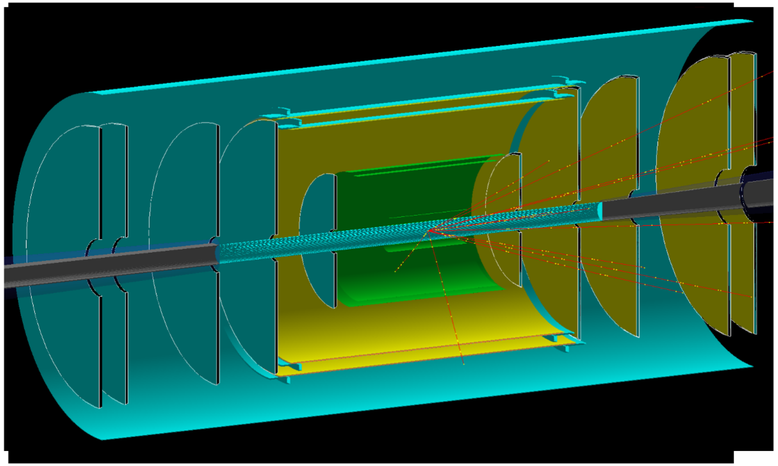
ECCE Tracking System



ECCE Tracking System



ECCE Tracking system Baseline Inner tracker



Barrel	Radii [cms]	Length [cms]
Layer 1	3.3	30.0
Layer 2	5.7	30.0
Layer 3	21.0	54.0
Layer 4	22.68	60.0
Layer 5	39.3	105.0
Layer 6	43.3	114.0

Forward Disks	Z position [cms]	RMin [cms]	RMax [cms]
Disk 1	25.0	3.18	18.48
Disk 2	49.0	3.18	36.28
Disk 3	73.0	3.50	43.2
Disk 4	97.0	4.70	43.2
Disk 5	112.0	5.90	43.2

P range	1 - 30 GeV/c
η range	0 - 3.5 no units
Magnetic Field	1.4 T BaBar
PID	Single π^- tracks

- Geometric Parameters have significant impact in the performance of the trackers.
- The performance can be characterized by detector response (resolution, reconstruction efficiency, etc. for the tracks).
- A total of 11 geometric parameters (6 barrel radii and 5 disks) were deduced which could define the tracking design geometry for the inner tracker
- Along with the geometric parameters, different combinations of the technologies for barrels and disks could also affect the performance of the Tracker.
- 11 parameter along with the combinations of the technologies need to be explored efficiently to optimize the tracker design

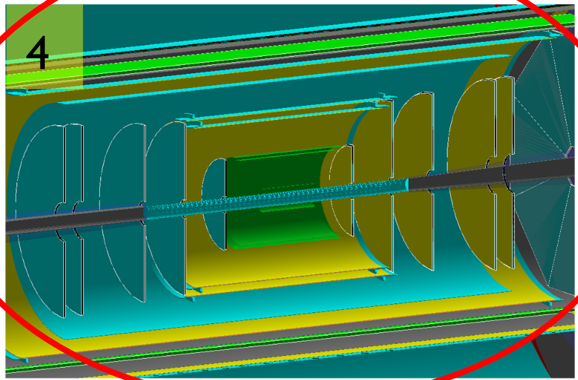
Could Multi Objective Optimization using Evolutionary Algorithm yield a design that performs better than the current baseline?

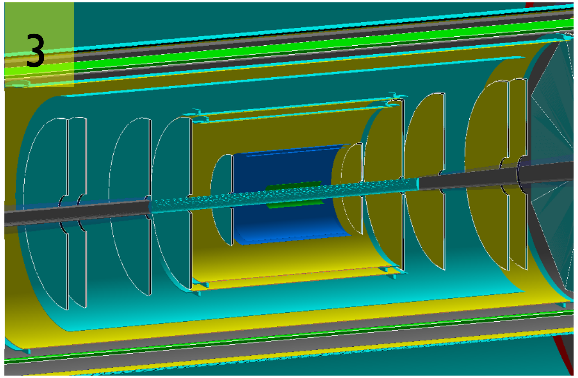
Inner Tracker: Optimization Pipelines

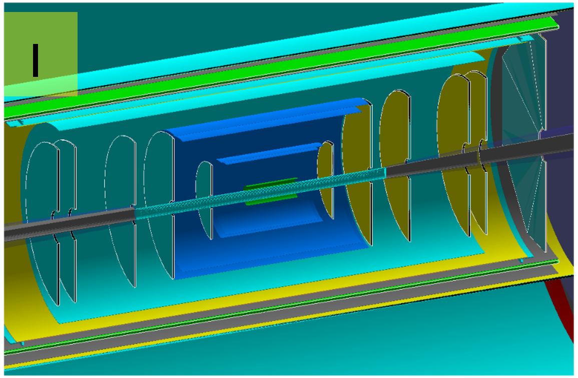
Inner Tracker

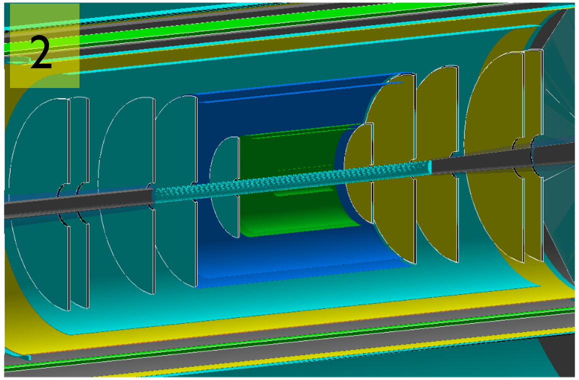
All with FST Disks

- Configuration 1: 2-vtx (ITS3) + 2-sagitta (ITS2) + 2-outer layer (ITS2)
- Configuration 2: 2-vtx (ITS3) + 2-sagitta (ITS3) + 2-outer layer (ITS2)
- Configuration 3: 2-vtx (ITS3) + 2-sagitta (ITS2) + 2-outer layer (uRwell)
- Configuration 4: 2-vtx (ITS3) + 2-sagitta (ITS3) + 2-outer layer (uRwell)



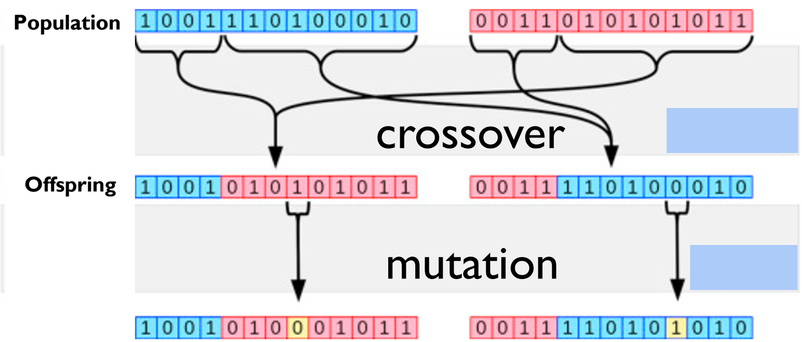


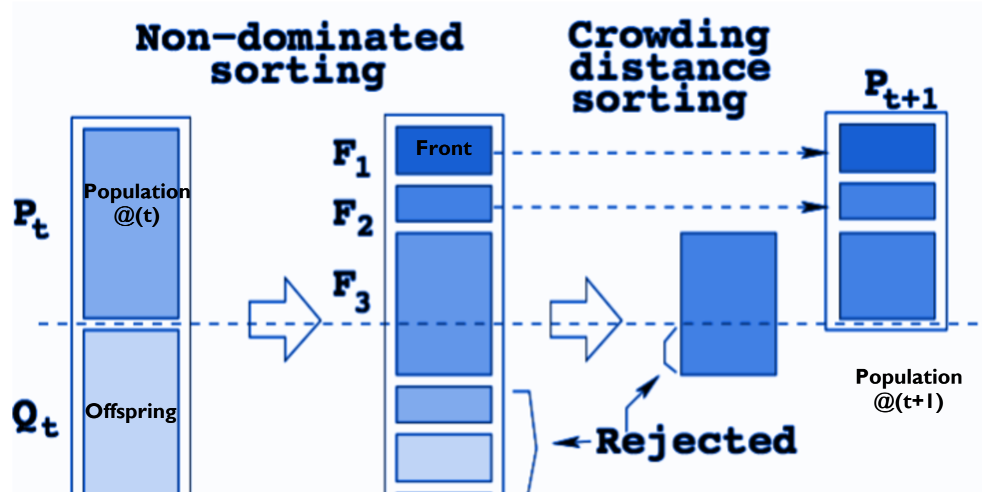




* (Shown baseline designs)
* Configurations with alternative Si Disk technology has also been explored
* Results shown for configuration 4

Elitist Non-Dominated Sorting Genetic

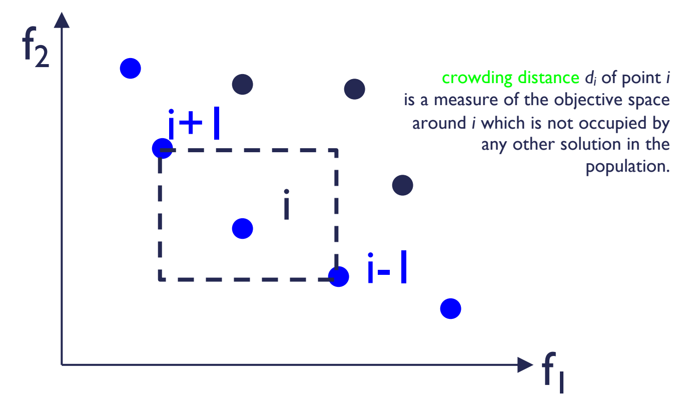




[1] Deb, K., et al. "A fast and elitist multiobjective genetic algorithm" *IEEE transactions on evolutionary computation* 6.2 (2002): 182-197.

This is one of the most popular approach (>35k citations on google scholar), characterized by:

- Use of an elitist principle
- Explicit diversity preserving mechanism
- Emphasis in non-dominated solutions



The population R_t is classified in non-dominated fronts.
Not all fronts can be accommodated in the N slots of available in the new population P_{t+1}. We use **crowding distance** to keep those points in the last front that contribute to the highest diversity.

Optimization Workflow

- **Objective functions** that are used for optimization (n_obj = 3)
  - **Momentum resolution dp/p**
  - **Theta resolution dθ/θ**
  - **Kalman Filtering inefficiency** (improving the tracking reconstruction ability of the algorithm)
  - We currently use average quantities for the objectives (see fig.)
    - dp/p, dθ, are ratios with respect to the baseline
    - Weights are based on errors on each of the objectives
- **Constraints** being used (n_const = 5)
  - The outermost barrel layer should be less than 51 cm
  - The max outer vertex layer (2nd Barrel layer) should be less than 15 cm
  - The 4th layer should be less than 45 cm
  - The forward most z has to be less than z = 125 cm
  - The minimum distance between any 2 layers/disks should be >= 1 cm (giving room for services)
- Validation of the solutions
  - Validate by comparing optimal vs baseline dφ resolution, vertex resolution and reconstruction efficiency

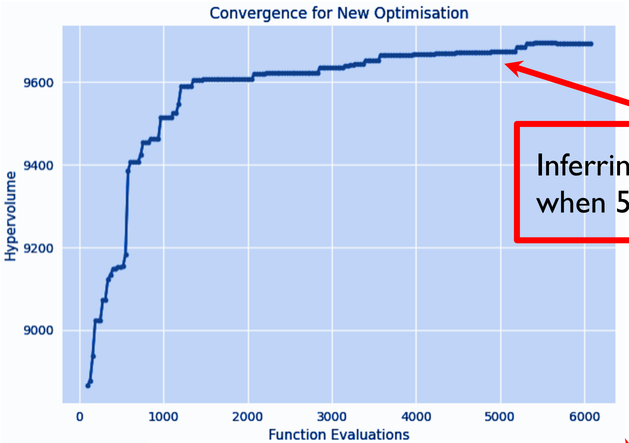
$$\bar{x_\eta} = \frac{\sum_p x_i w_i}{\sum_p w_i}$$

$$\bar{x} = \frac{\sum_\eta^{N_\eta} \bar{x_\eta}}{N_\eta}$$

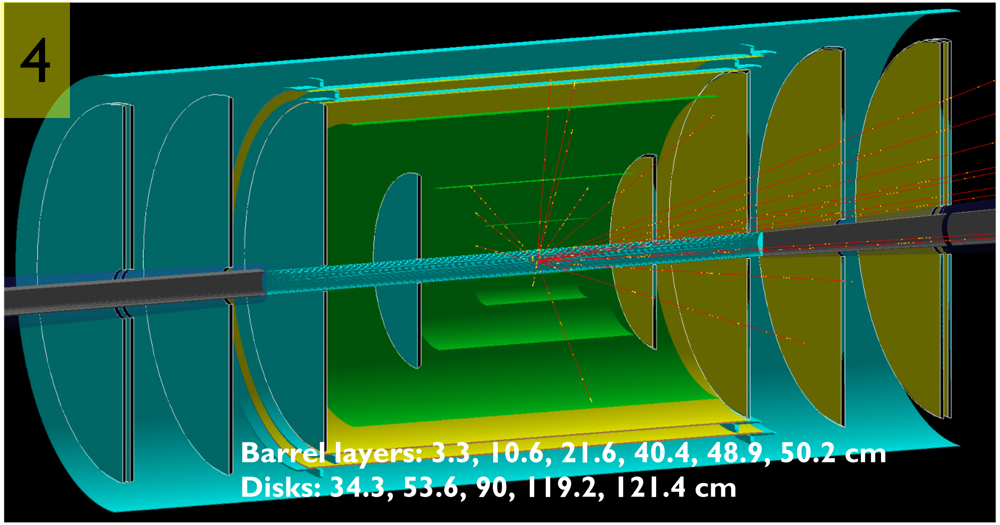
Optimization:
- N_{vars} = 11
- N_{gens} = 200
- $N_{population}$ = 100
- Offspring = 50
- # Cores = 50

(Slurm at JLAB)

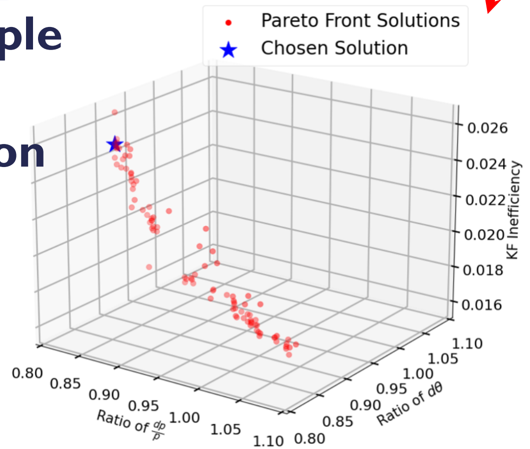
Optimal Detector Design with MOO



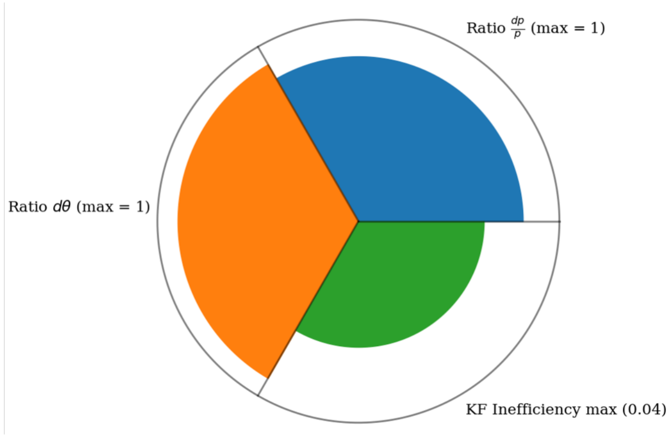
Inferring solutions at when 50% done



Example of solution

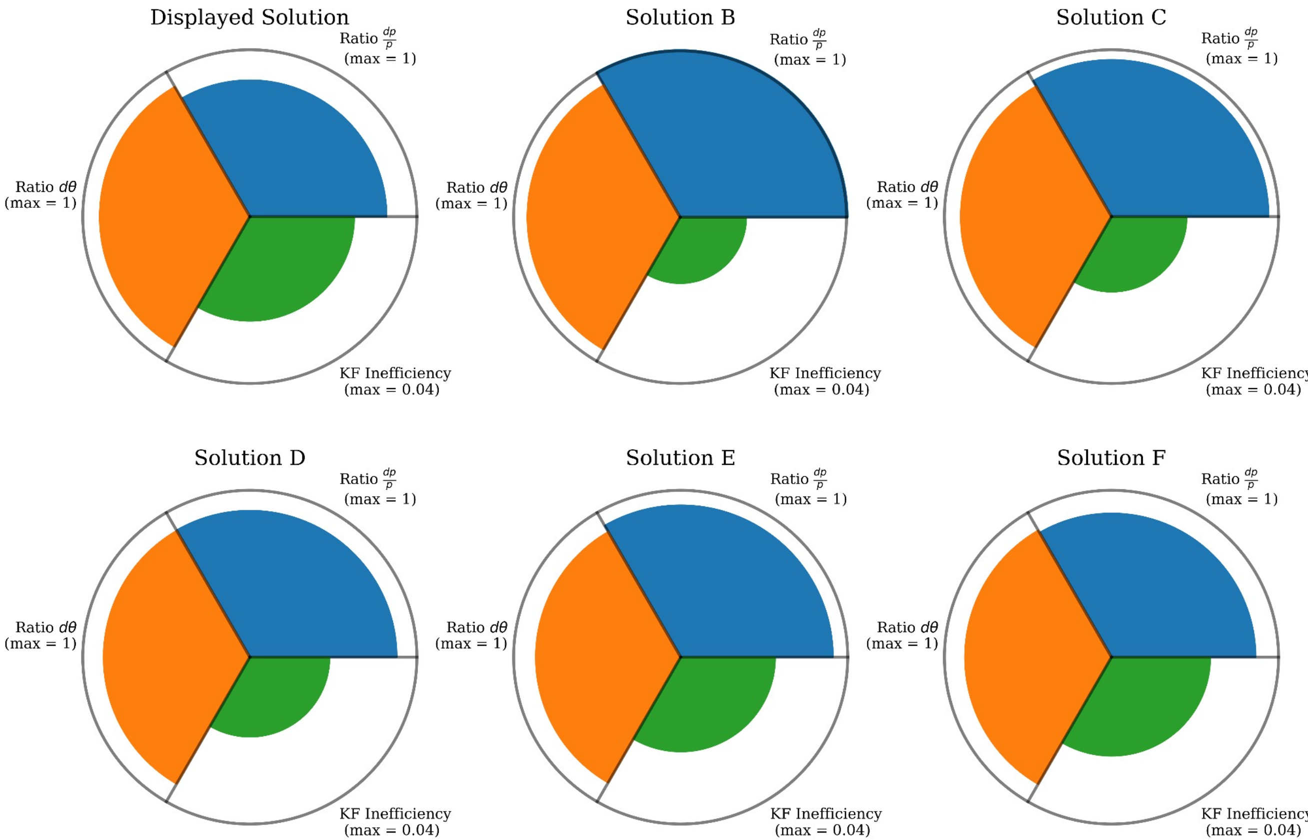


Performance of the chosen Solution



dθ/dp are scaled w.r.t baseline. Smaller is better!

Pareto front solutions performance...



dθ/dp are scaled w.r.t baseline. Smaller is better!

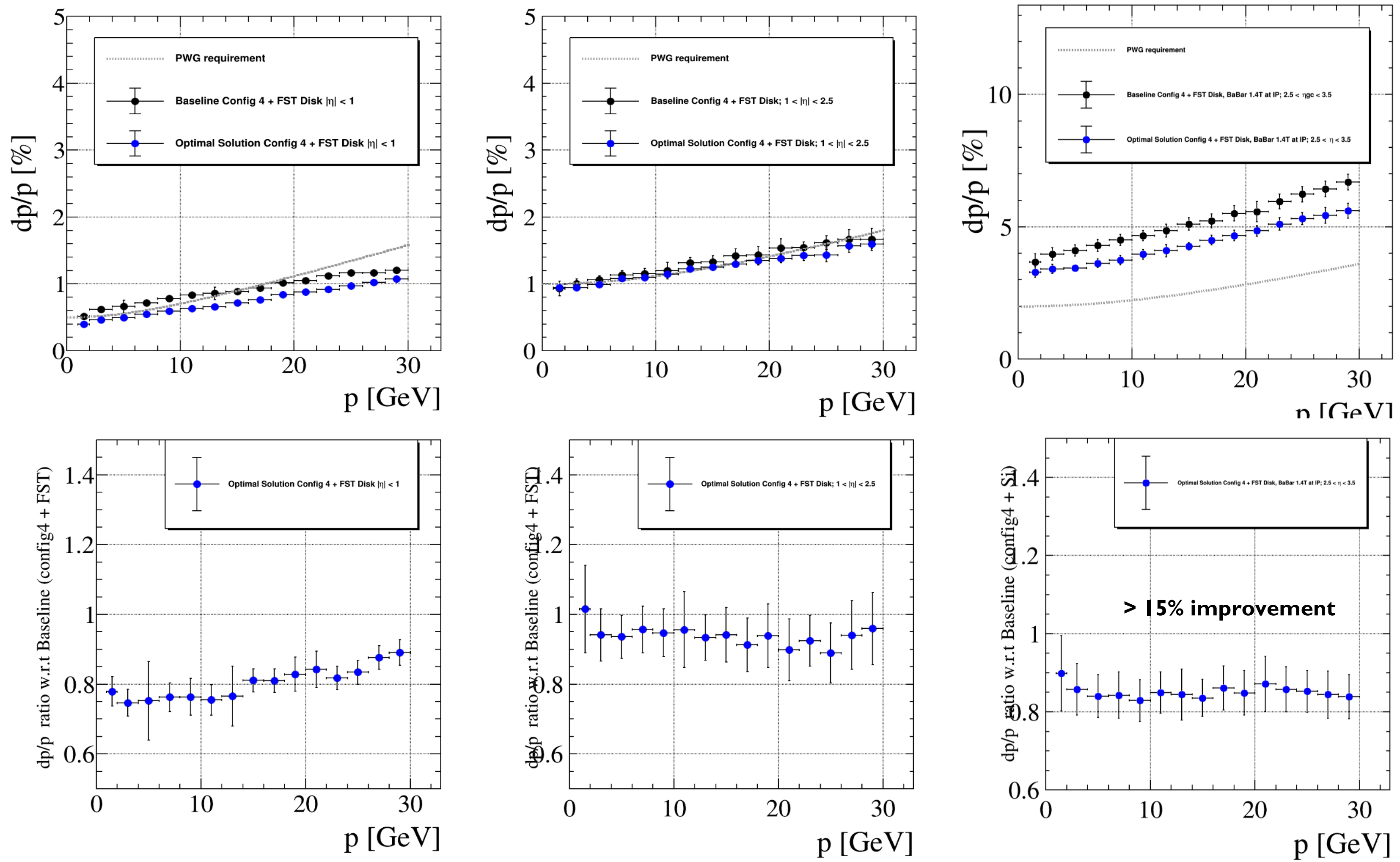
Optimal Design Solution

Barrel	Radii [cm]	Length [cm]
Layer 1	3.3	30.0
Layer 2	10.6	30.0
Layer 3	21.6	57.8
Layer 4	40.4	108.1
Layer 5	48.9	130.8
Layer 6	50.2	134.2

Forward FST Disks	Z position [cm]	RMin [cm]	RMax [cm]	Pitch [um]	Si Thickness [um]
Disk 1	34.3	3.18	25.38	10	35
Disk 2	53.60	3.5	46.15	10	35
Disk 3	90	4.9	50.2	10	35
Disk 4	119.2	6.5	50.2	36.4	85
Disk 5	121.4	6.6	50.2	36.4	85

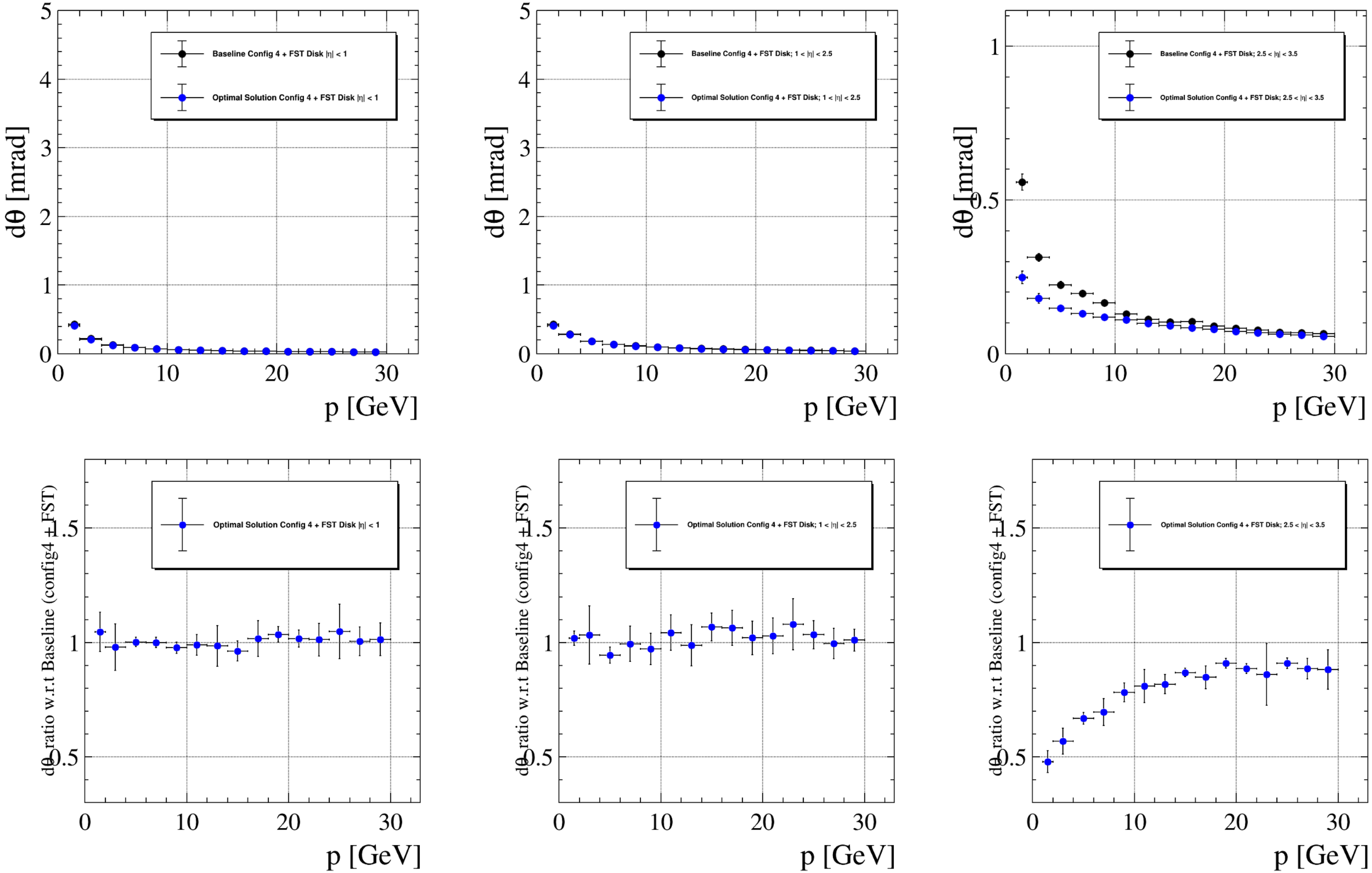
Magnetic Field = BaBar Field Map (1.4T @ Interaction Point)
300k Single π^- tracks used for the optimisation

Momentum Resolution



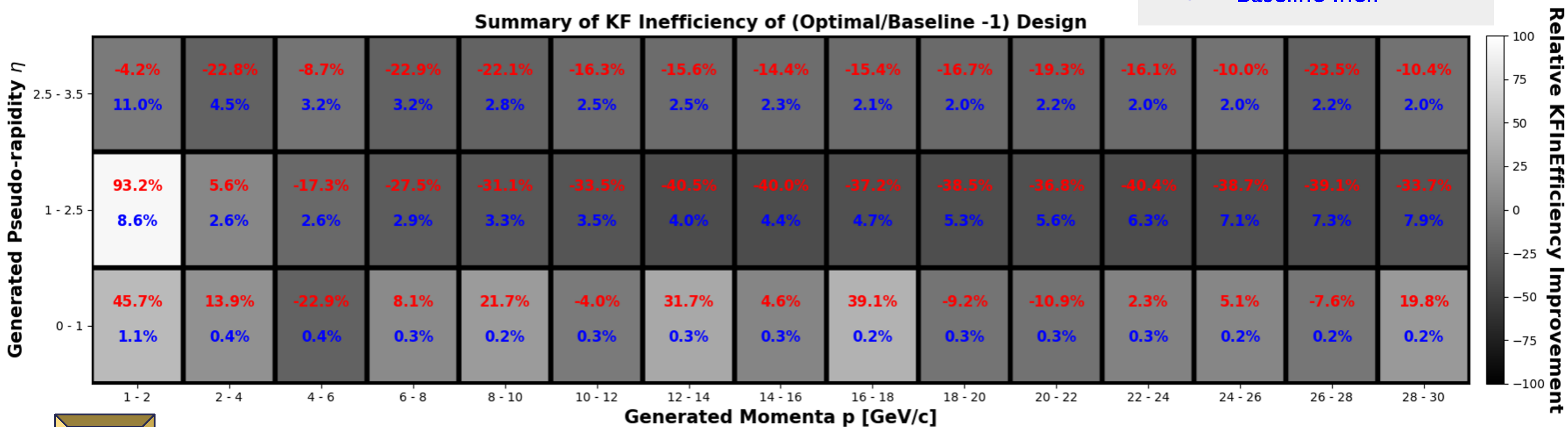
> 15% improvement

θ Resolution [mrad]

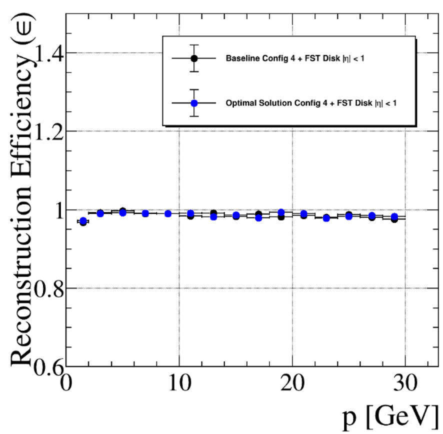


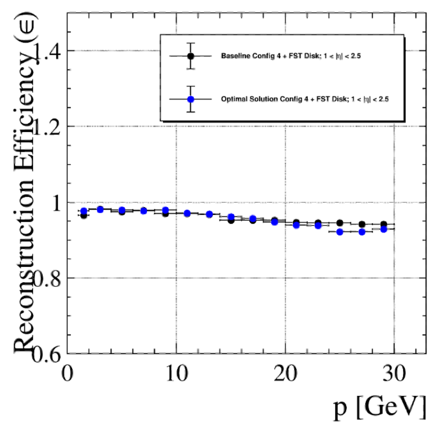
KF Inefficiency Improvement

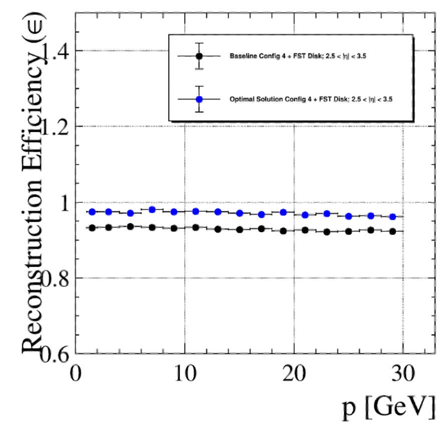
- Optimal/baseline -1
- Baseline Ineff



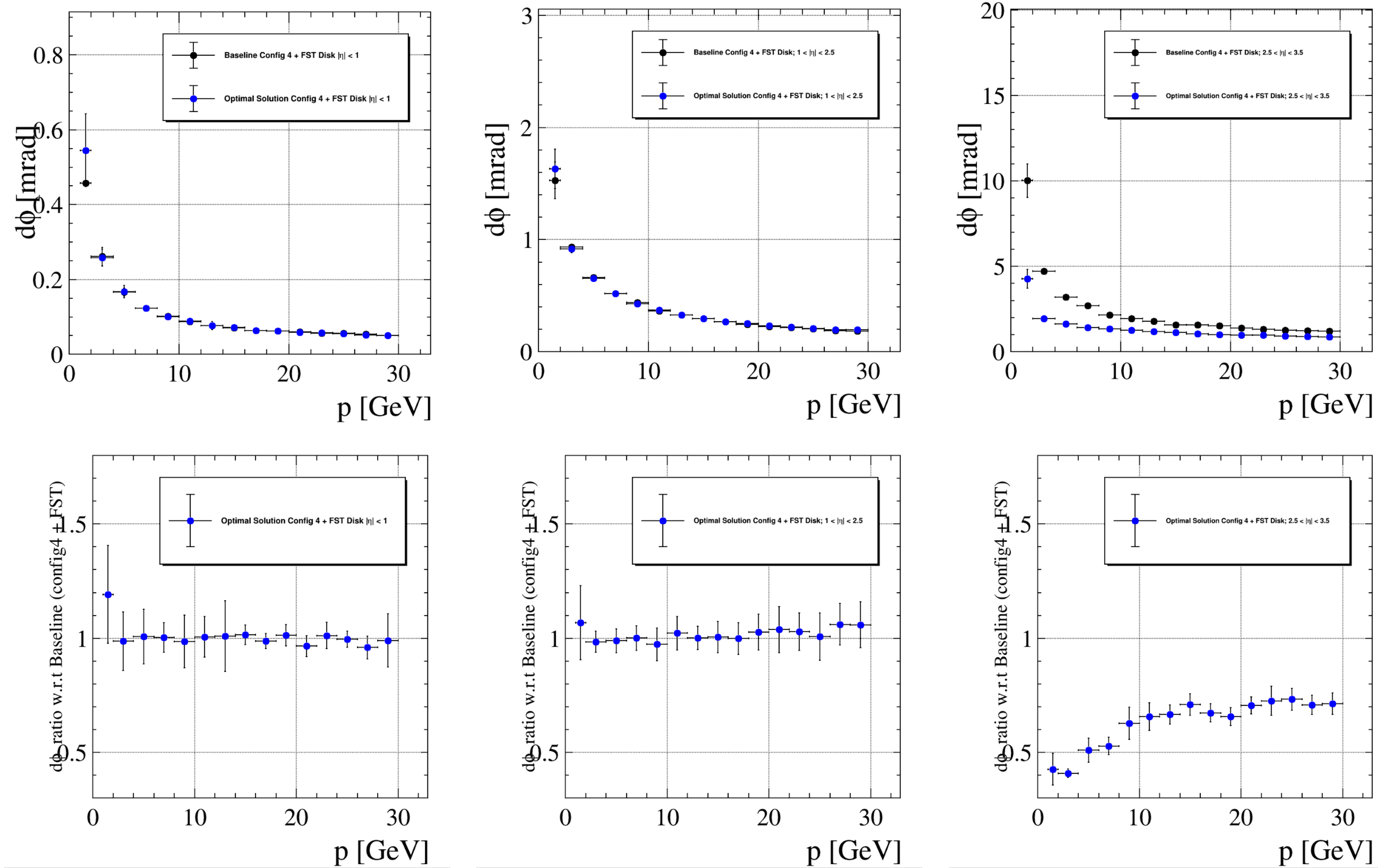
Validation Reconstruction Efficiency







Validation φ Resolution [mrad]



Summary

- We have several ongoing AI detector optimization projects and an active AI working group in ECCE
- There are very promising results from the tracking detector optimization (C. Fanelli and K. Suresh)
  - Studying different detector configurations and keep seeing significant improvements!
- The tracking optimization framework is built to approximate the Pareto front solutions.
- Currently we are supporting 3 objectives (tracking resolutions, efficiency). The decision making is post hoc --- some solutions from the Pareto front can be rejected based on cost, risks etc. considerations.
  - We are optimizing the design space made only by geometry parameters. We can include other types of parameters and explore new technology/solutions as a part of optimization.
- An optimization on the backward region (with an asymmetric design compared to forward) is underway.