EIC-ECCE Detector Design Optimization with AI

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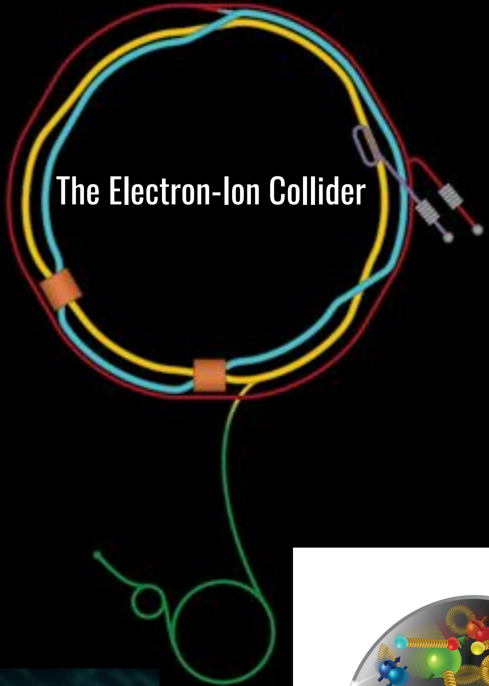
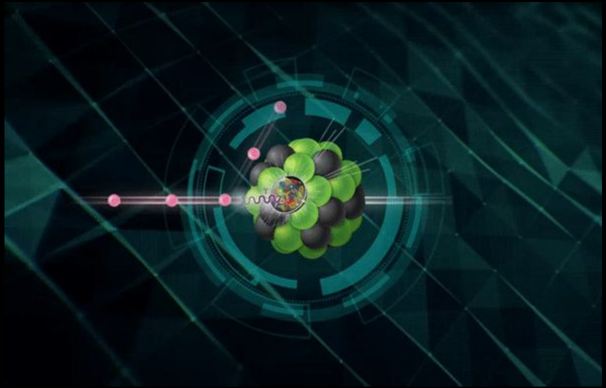
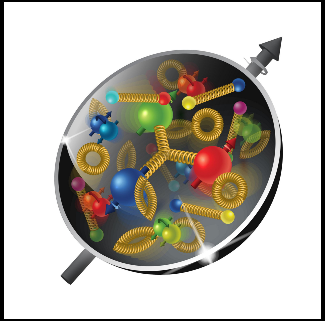
Outline

- ❑ EIC- Electron Ion Collider
- ❑ "Generic" Detector system for EIC
- ❑ Inner tracking detector in ECCE
- ❑ Multi Objective Optimisation (MOO) and Results
- ❑ Summary and next steps

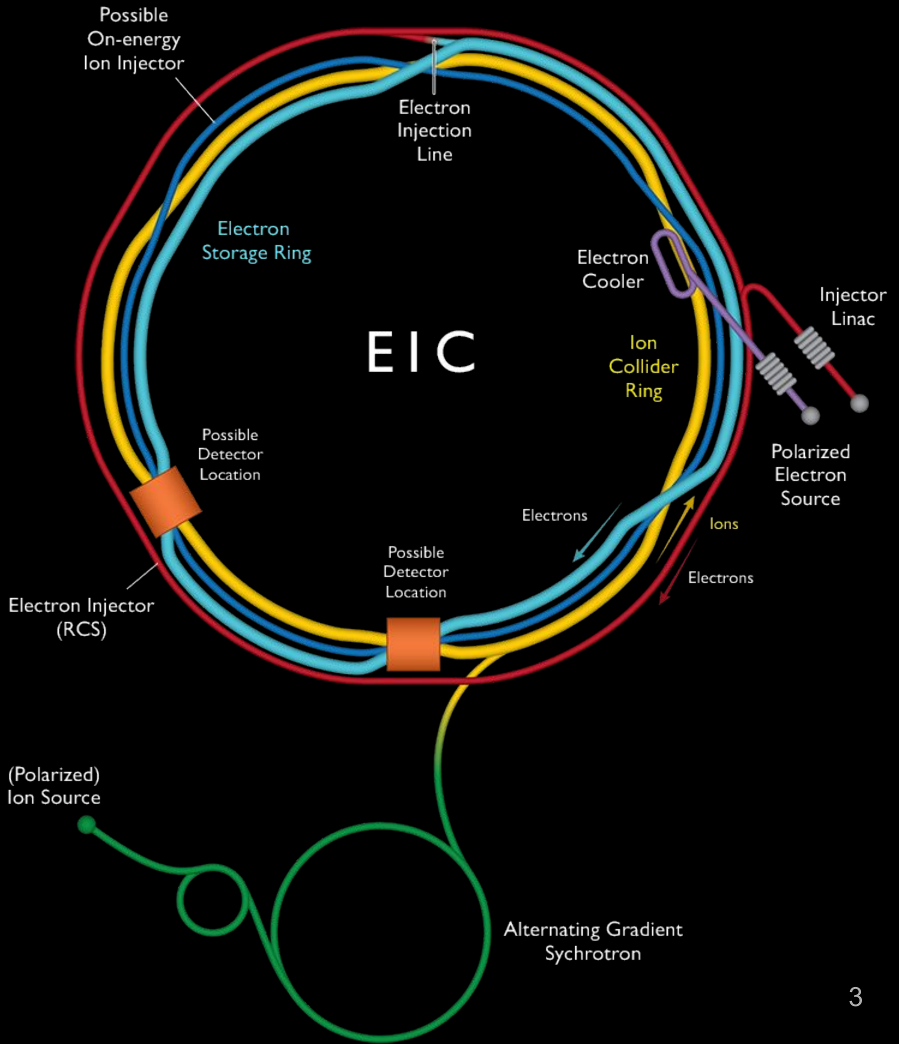






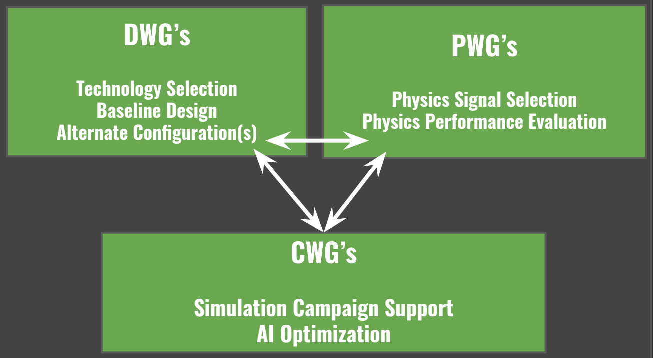
Electron-Ion Collider (EIC)

- To be built at BNL ([Brookhaven National Laboratory]) using existing infrastructure of RHIC.
- Physics Goal : Structure and dynamics of matter at high luminosity and energy using polarised beams. Wide range of nuclei [arXiv:1212.1701]
- The machine will be capable to perform
    - High luminosity measurements ($10^{33}\,cm^{-2}\,s^{-1}$ - $10^{34}\,cm^{-2}\,s^{-1}$)
    - Flexible center-of-mass energy range. $\sqrt{s} = \sqrt{4E_eE_p}$ (20-140 GeV)
    - Deliver highly polarised electron and proton/ light ion
    - Almost a 4π detector to measure particles scattering in all directions and at wide range of energies



AI at EIC https://eic.ai

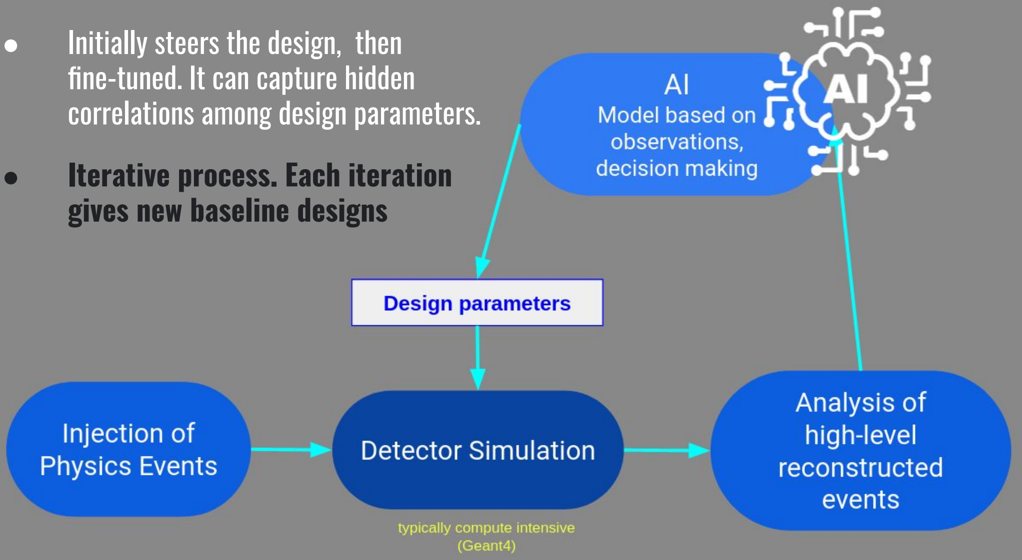
Role of AI



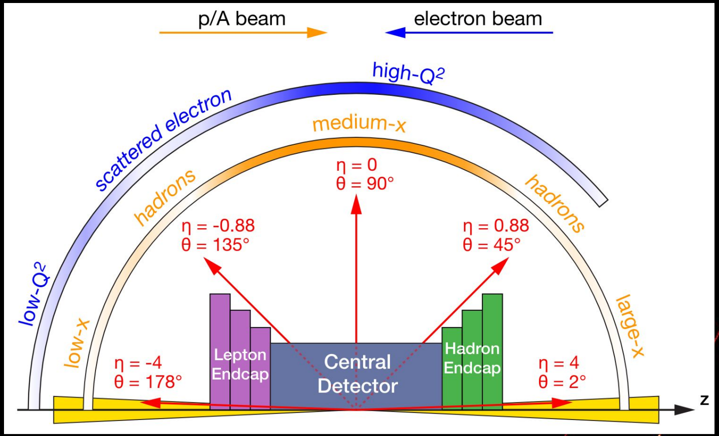
- **Detector Design optimisation, challenging due to dimensionality & constraints**
- **AI deployed at almost all stages of the project**
- **AI4EIC workshop**

Detector Optimisation Workflow

- AI can assist in designing more efficiently detectors (performance, costs).
- Potential applications - Medical Physics
- Initially steers the design, then fine-tuned. It can capture hidden correlations among design parameters.
- **Iterative process. Each iteration gives new baseline designs**

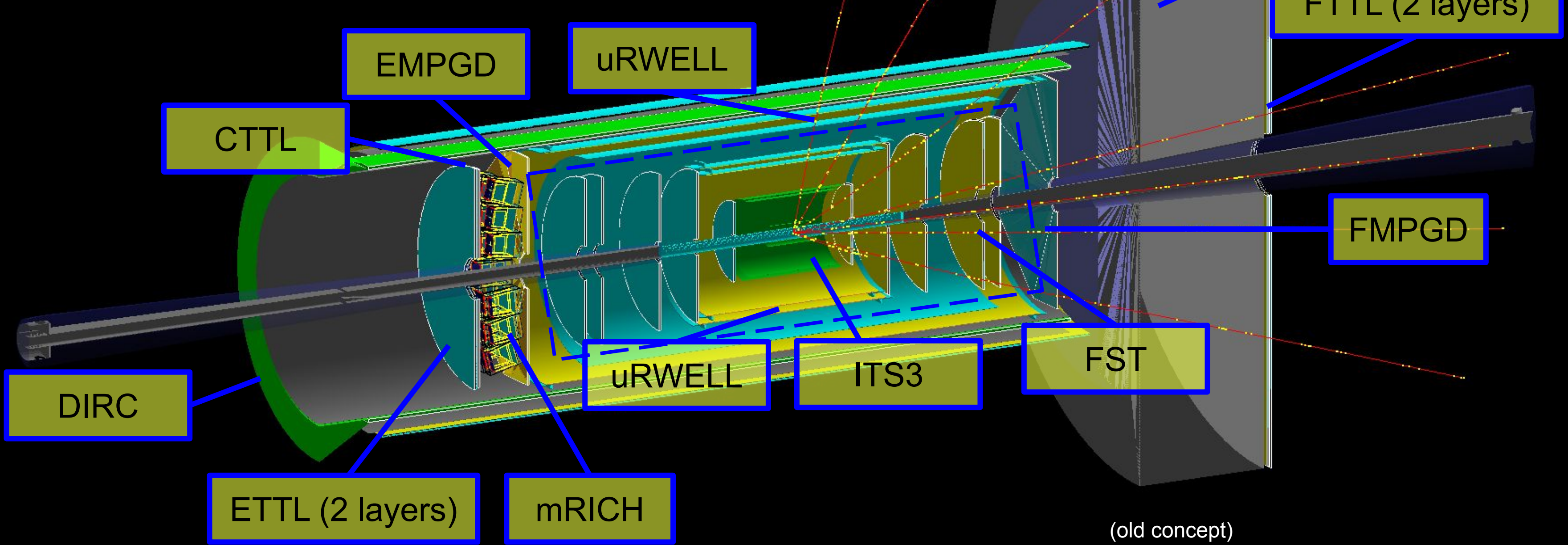


The ECCE Tracking System optimisation



Pseudorapidity

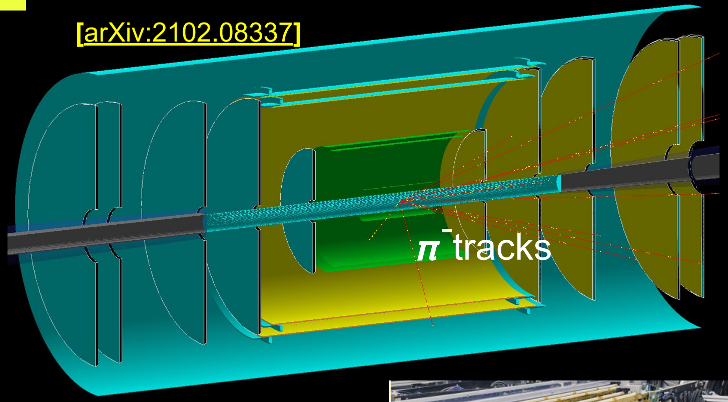
$$\eta \equiv -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$



(old concept)

Start with inner tracker

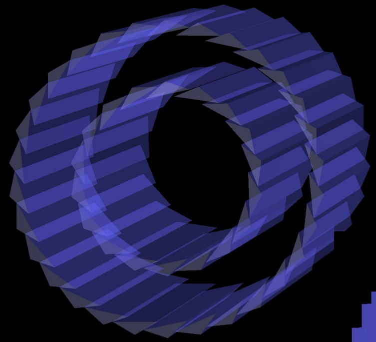
[arXiv:2102.08337]

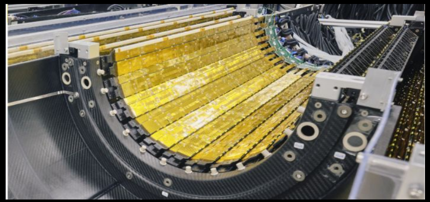


- The performance of tracker characterised by detector's response (eg. resolution, reconstruction efficiency for the tracks). Often more than one metric.
- Geometric/Design parameters have significant impact in the performance of the tracker.
- Optimisation is a continuous and iterative process. Each time add more subsystems when available. 11 parameters in this example.

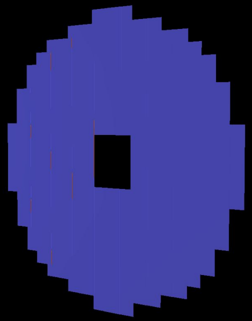
B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	B_9	B_{10}	B_M

- Efficient parameterisation of the detector to reduce dimensionality of design parameters.
- Encode different geometric and mechanical constraints; ITS3 (ITS2) constrained due to fixed strip length

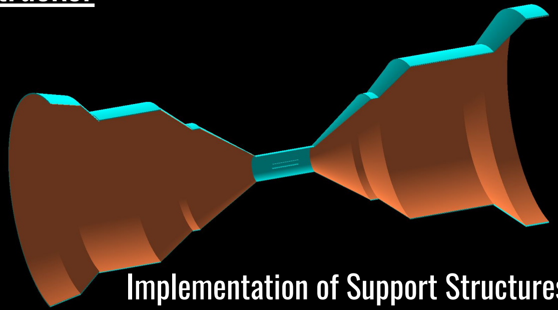




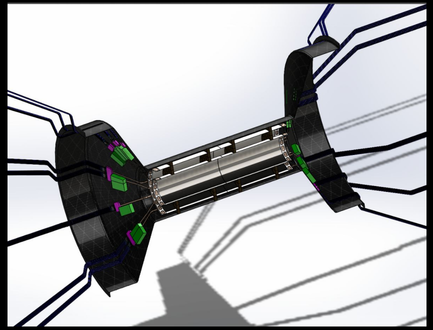
ALICE Si Vertex tracker



Fine grained implementation

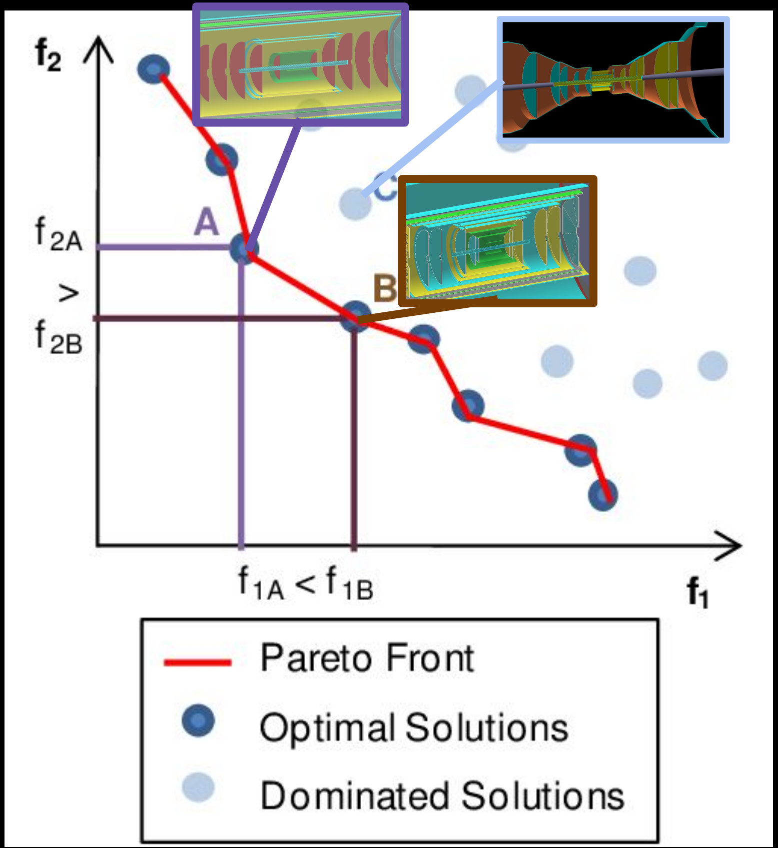


Implementation of Support Structures with realistic material Budgets.



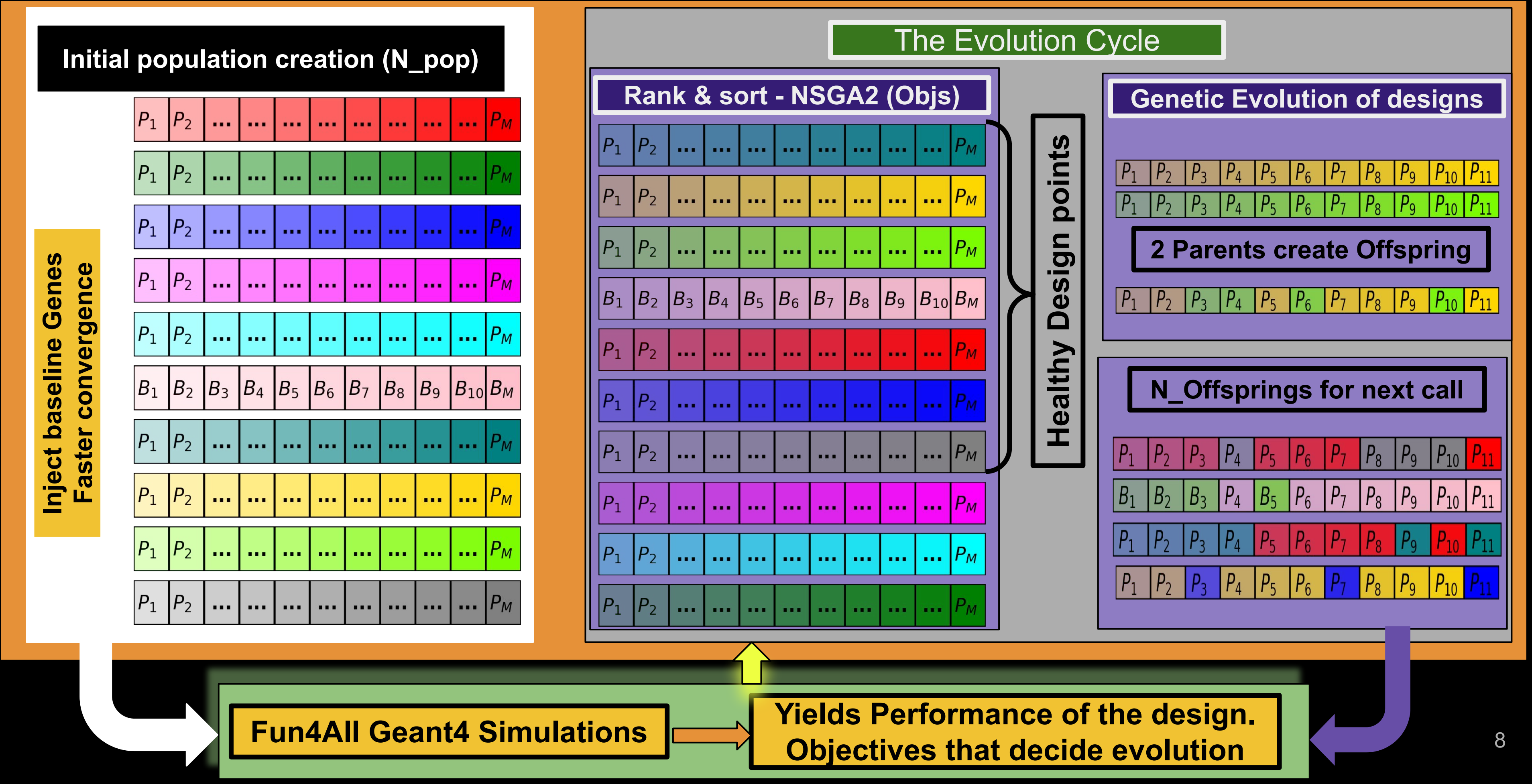
Multi Objective Optimization

- The performance of tracker determined by multiple "objectives", e.g., weighted avg momentum resolution, θ resolution, KF efficiency, projected θ resolution at PID location. Objectives could be conflicting.
- In the figure, f_1 and f_2 are two objectives. Points corresponds to one set of design parameters. The objectives are to be minimised.
- In solving such problems, with or without constraints, yields trade-off optimal solutions, popularly known as Pareto-optimal solutions. Locus of points in Objective Space which are non-dominating to one another.
- Due to multiplicity in solutions, Evolutionary Algorithm (EA) is preferred since it uses a population based approach to converge.
- Developed a pipeline for optimisation with pymoo (MOGA) to optimise and "Fun4All" (Geant4 based framework) to simulate and analyse the detector response.

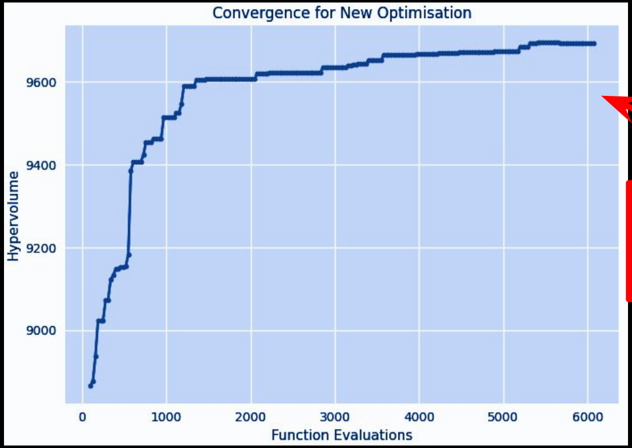


- N_vars (Design params M) ≥ 11
- N_gen (calls) = 200
- N_pop = 100
- Offspring ≥ 30
- N_Objs ≥ 3

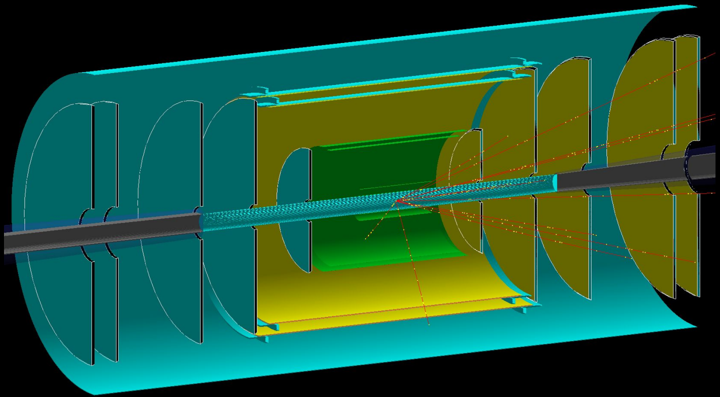
The Summary of MOGA Pipeline

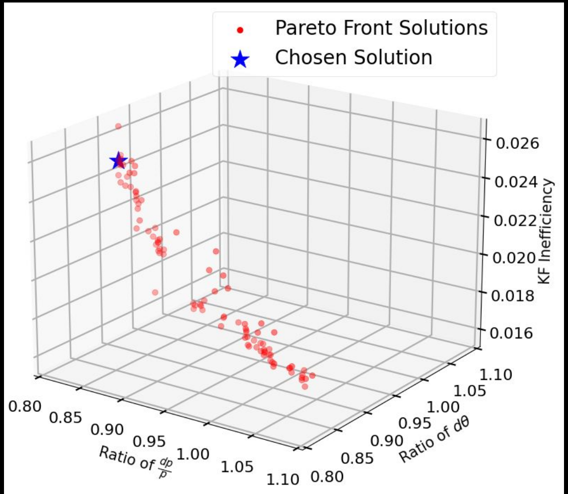


Optimal Detector Design Solutions



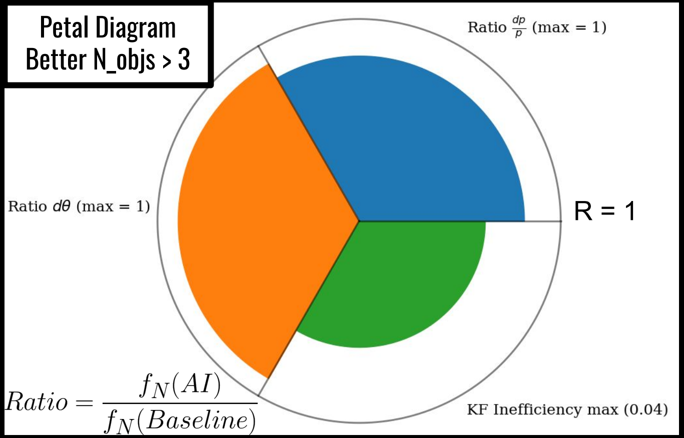
Inferring solutions at any stage of optimisation



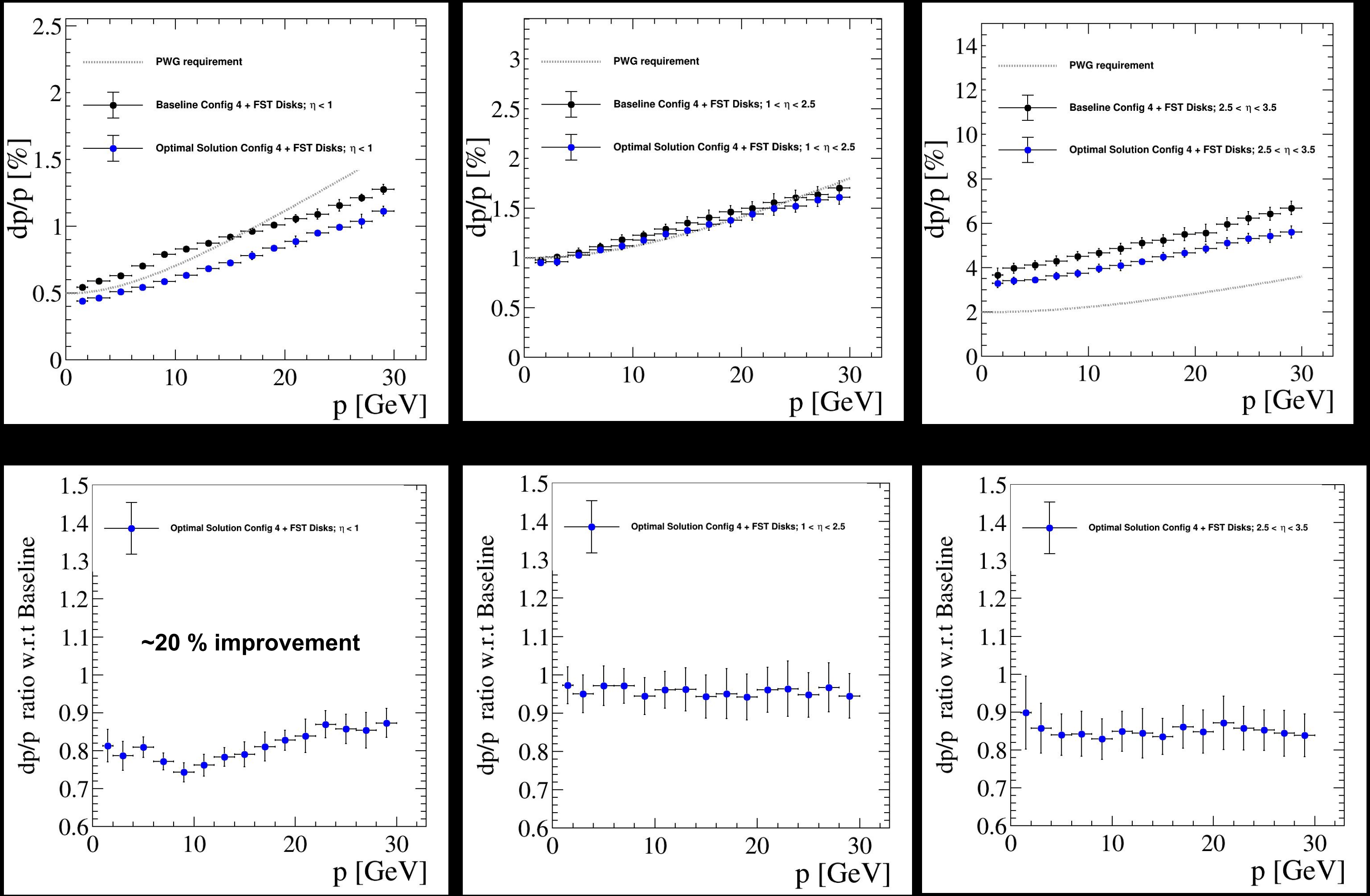


Example of solution

Performance of the chosen Solution

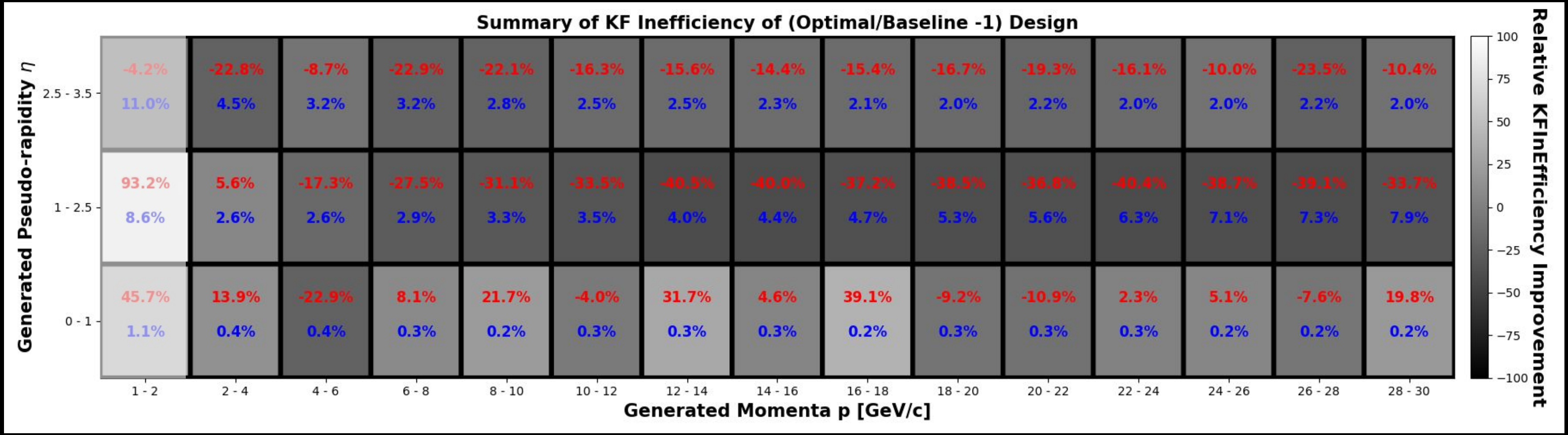


Momentum Resolution

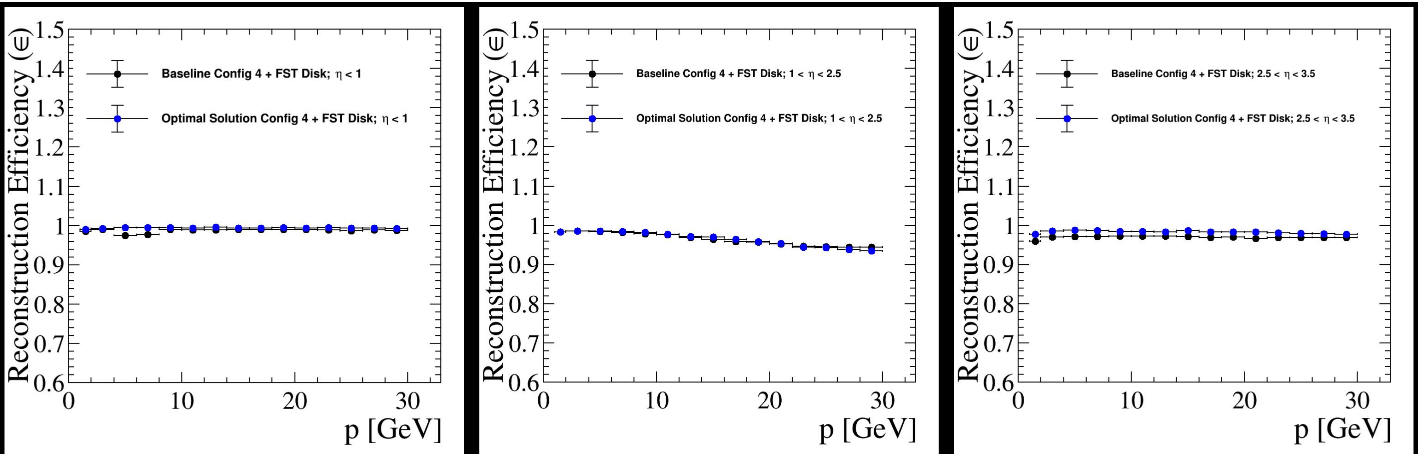


KF Inefficiency Improvement

- Optimal/baseline -1
- Baseline Ineff



Validation Reconstruction Efficiency

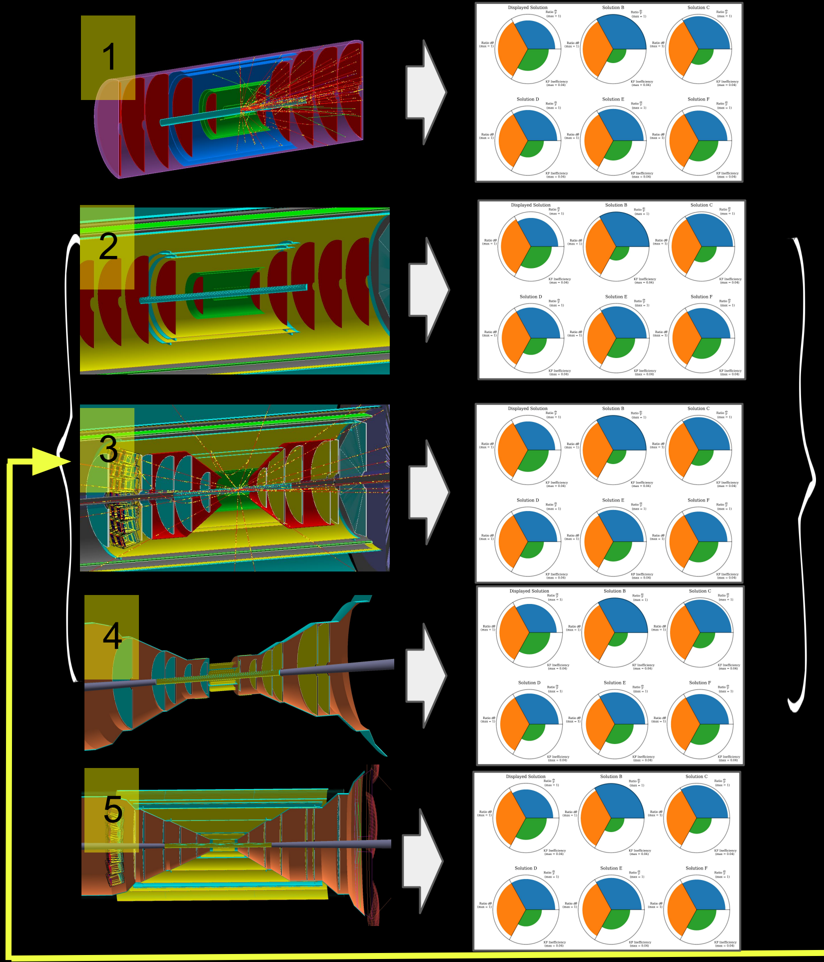


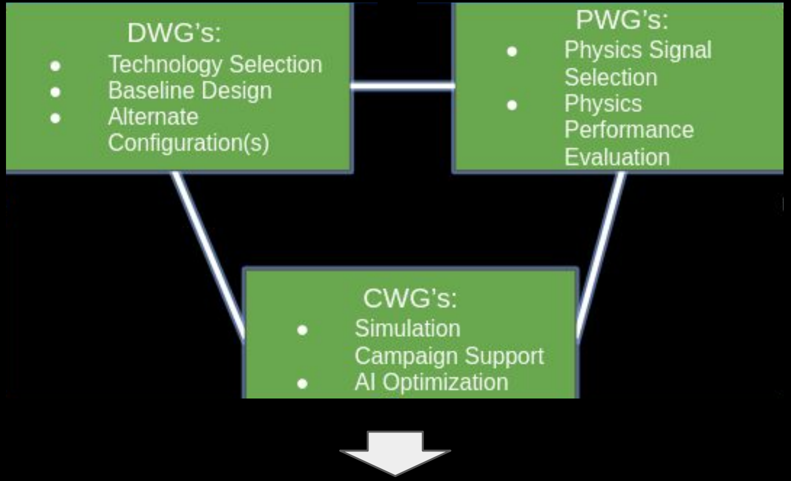
Phases of Optimisation

Tracker Optimisation timeline.

- 1: Optimisation of Barrel alone. Made technological choices.
- 2: Optimisation of Barrel+Disks. Without any support structures. Symmetric design
- 3. Optimisation of Barrel+Disks. With fixed support structures. Asymmetric design
- 4. Optimisation of Barrel+Disks and support structure. Asymmetric design
- 5. Full tracking system optimisation.

Phases of Optimisation

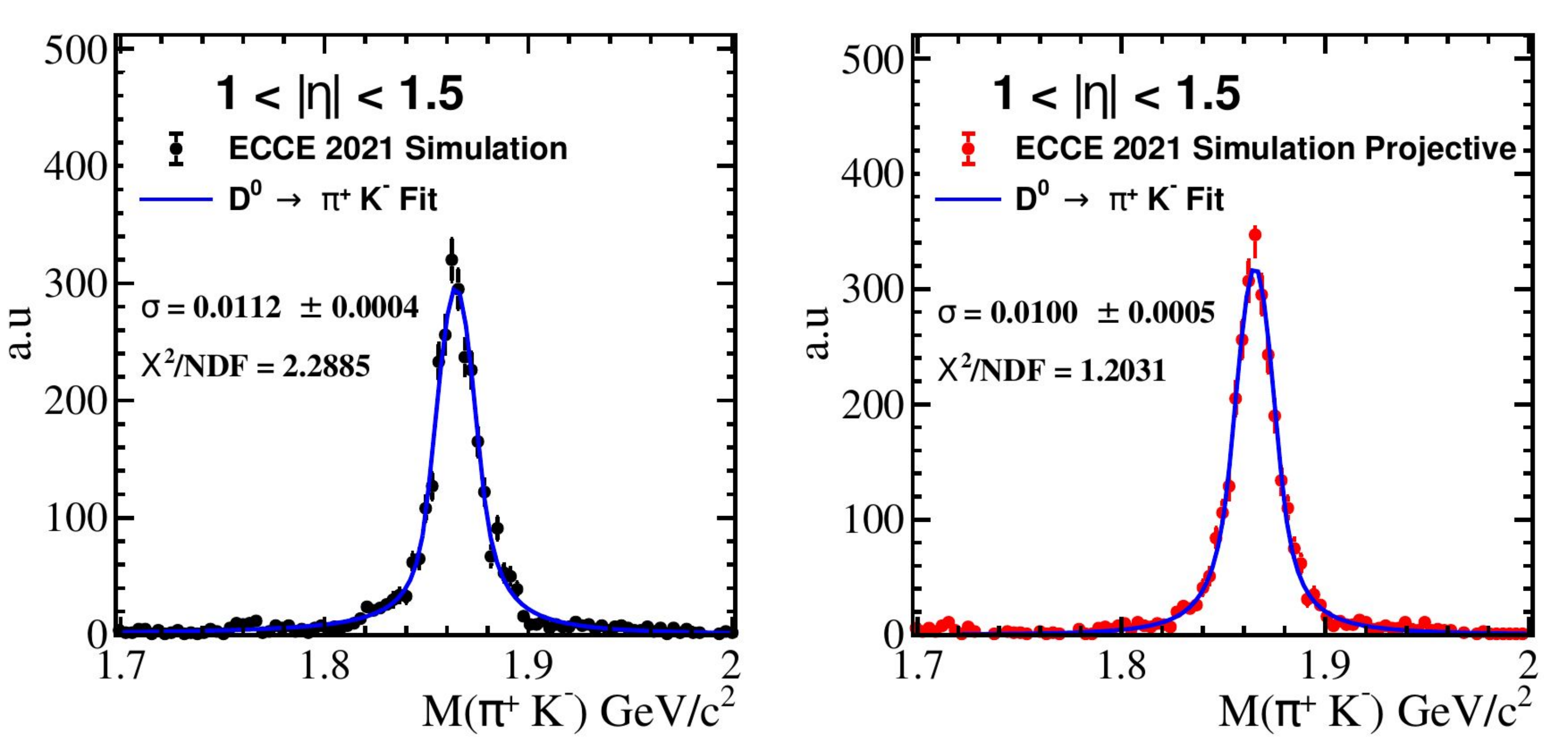




updated configurations with any additional requirements

Optimisation phases

Validation with Physics simulation



The π+K- invariant mass obtained from the SIDIS events with updated baseline and recent optimised projective geometry. A region of eta that is sensitive due to considerable materials for support structure was also taken in to account for this optimisation.

Summary

- EIC can be one of the first experiments to be designed with the support of AI
- The current tracking system in proposed by ECCE for EIC is an AI-assisted one.
- For the "first" time a framework integrating the full detector design using Geant4-based simulation coupled to MOO has been developed. This framework can be massively parallelized.
  - The developed framework is modular enough it can be effectively used within ECCE EIC software stack.
  - The decision making from the Pareto solutions are intentionally manual to effectively explore the feasibility of the design based on qualitative factors like cost, engineering realisation etc.
- ECCE-EIC tracker optimisation is a continuous and an iterative process. AI had assisted in making technological choices for the tracker design and also had assisted in the current design of the ECCE-EIC tracker.
- Currently developing framework to include different optimisers (e.g. MOBO, MOEA.)

Thank You

AI4EIC