Multi-mirror dRICH studies and optimization updates

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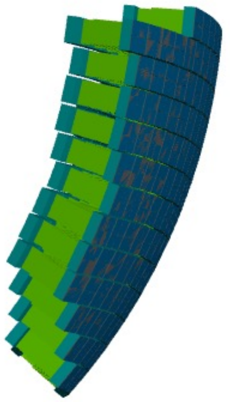
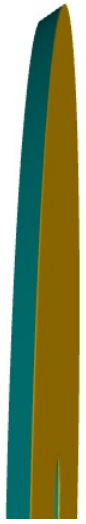
dRICH Simulation meeting

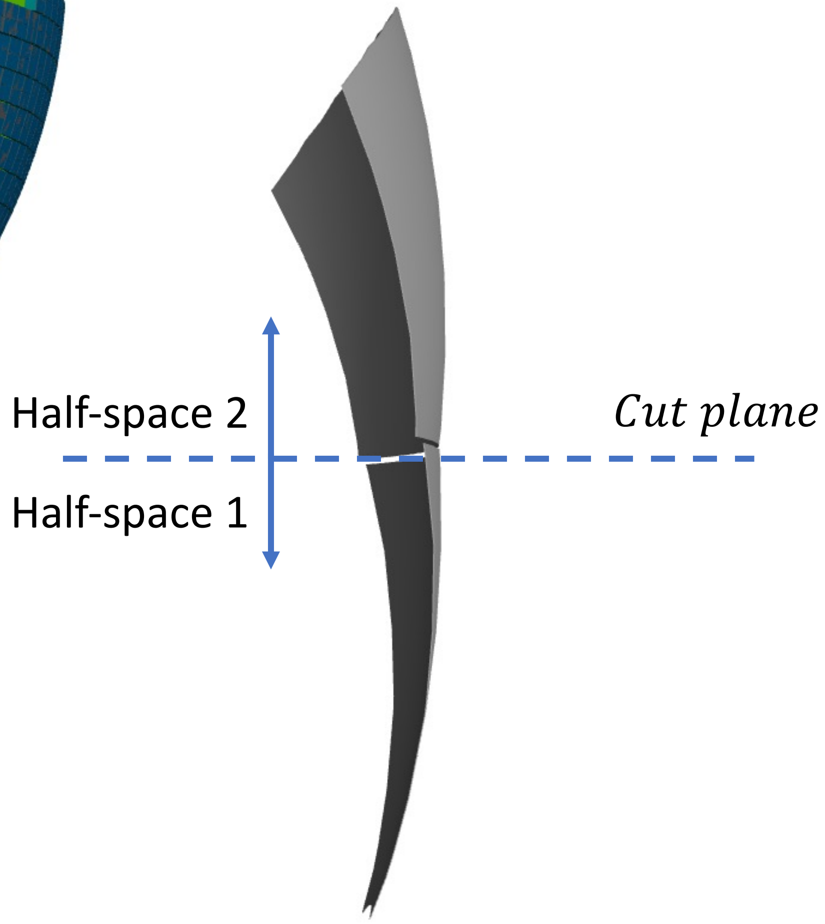
9-12-24

Multi-mirror geometry

- Multi-mirror geometry based on previous PRs by Chandra and Chris
- Using large G4Box to place mirrors in a specified half-space
  - In Chandra/Chris implementation, half-space was exact plane of intersection of mirror spheres
  - Here, simplified: **simple cut in x prior to sector rotation for each mirror**
    - Avoids potential weird mirror shapes

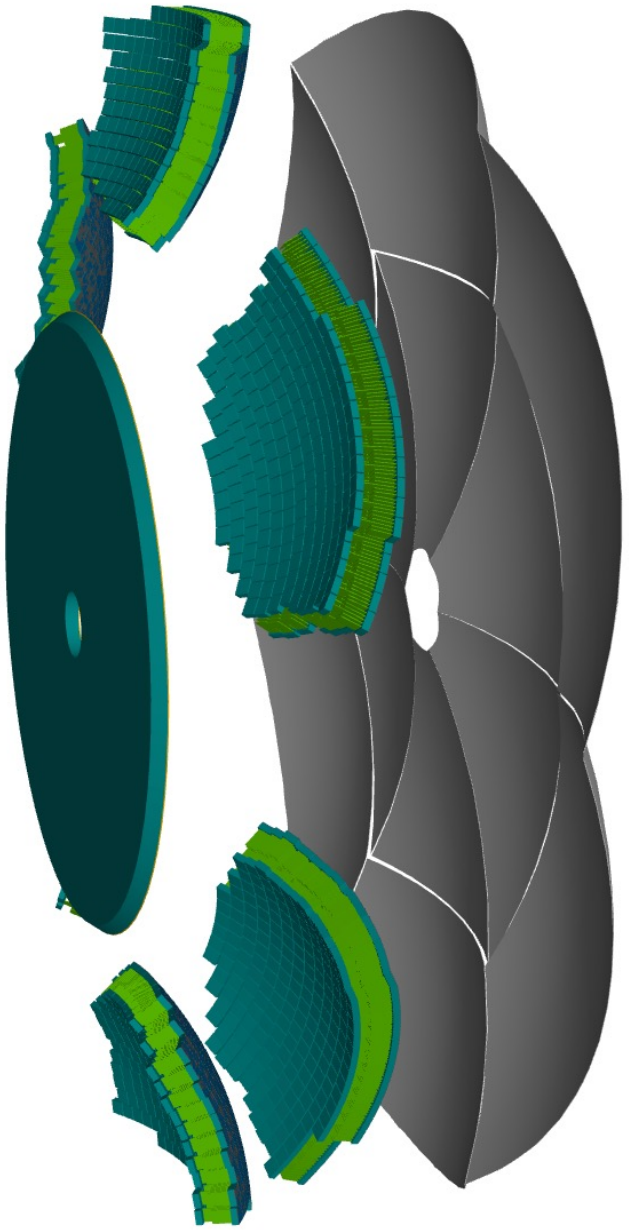






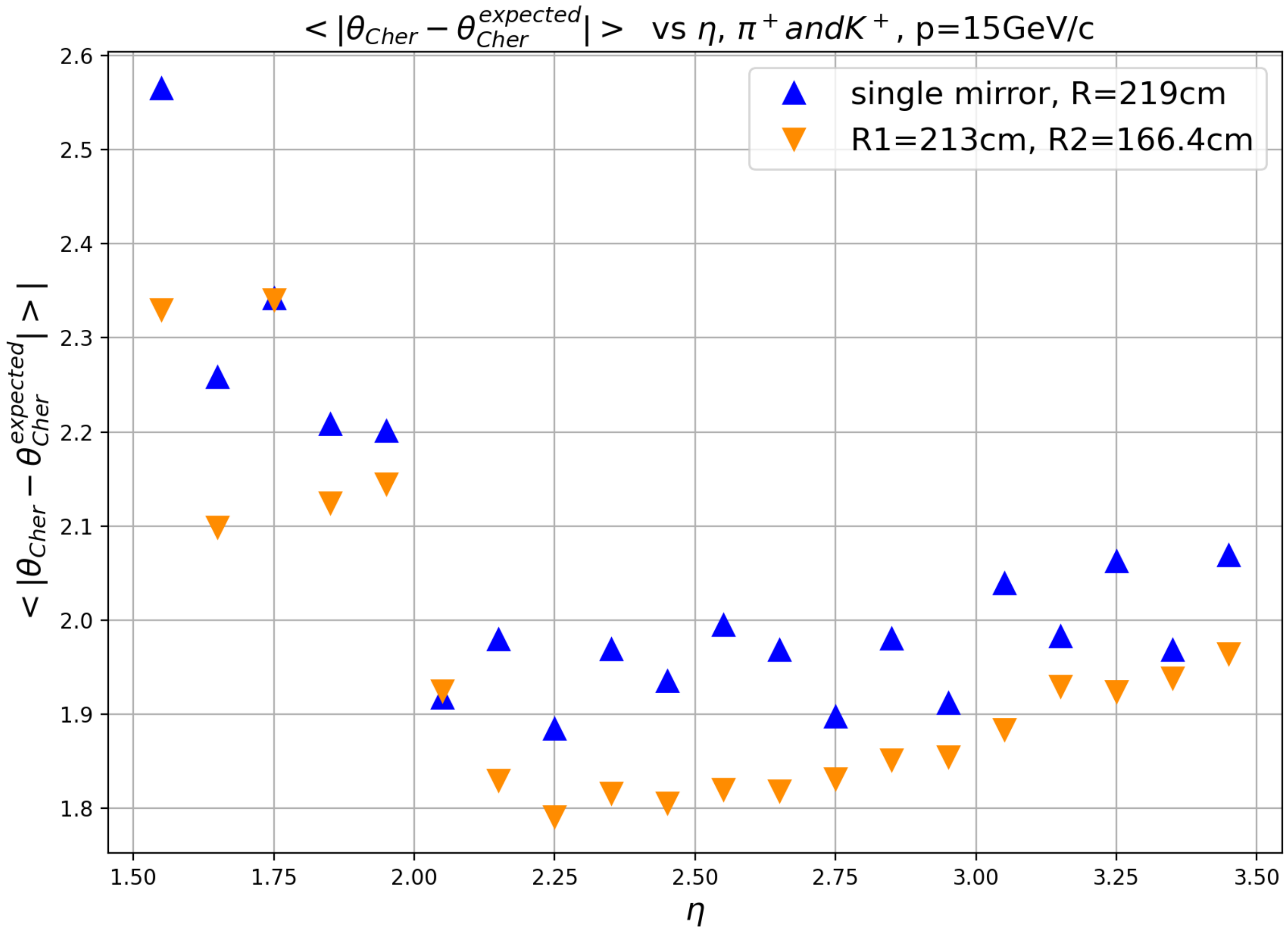
Multi-mirror geometry

- Mirror sphere radii, x positions completely independent
- Sphere z-positions constrained such that:
  - Gap at mirror borders is minimized
  - Mirrors are as close as possible to dRICH back wall



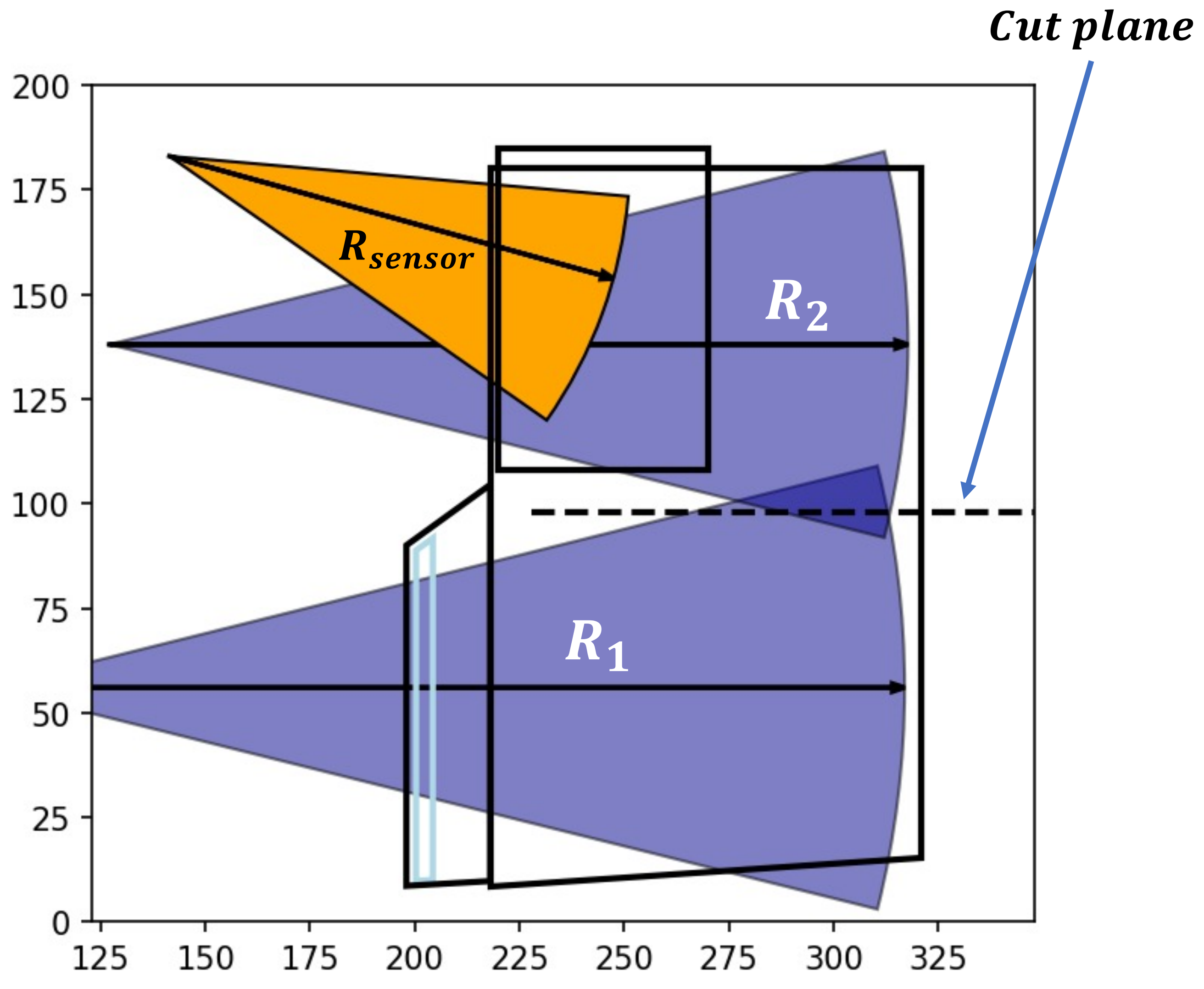
Multi-mirror IRT updates

- Necessary updates made to IRT (v1) for multiple mirrors/radii (PR here)
  - Uses same Boolean-volume logic as geometry to determine mirror radius for reflection
  - Could easily be generalized to other shapes defining mirror patches, 3 mirrors, etc.
- Right: mean absolute error of Cherenkov angle (pi+ and K+) with example 2 mirror geometry



Optics optimization: updated design space

- As presented before, using multi-objective Bayesian optimization (MOBO) to optimize dRICH optics
- Design parameters (8 total):
  - **Mirrors**: Mirror radii, center x positions, position of mirror cut plane
  - **Sensors**: Sensor sphere radius, center x position, position within sensor box (z)



Optics optimization: objectives

- For MOBO approach, dRICH performance needs to be summarized maximum 3 metrics
  - Acquisition functions have scale poorly beyond 3 objectives
- Current used objectives:
  - Fraction of tracks with > 5 photons detected
  - Two values of $N_{MAE}^{\pi-K}$ (pion separation performance), either
    - Momentum averaged (two η ranges)

    OR

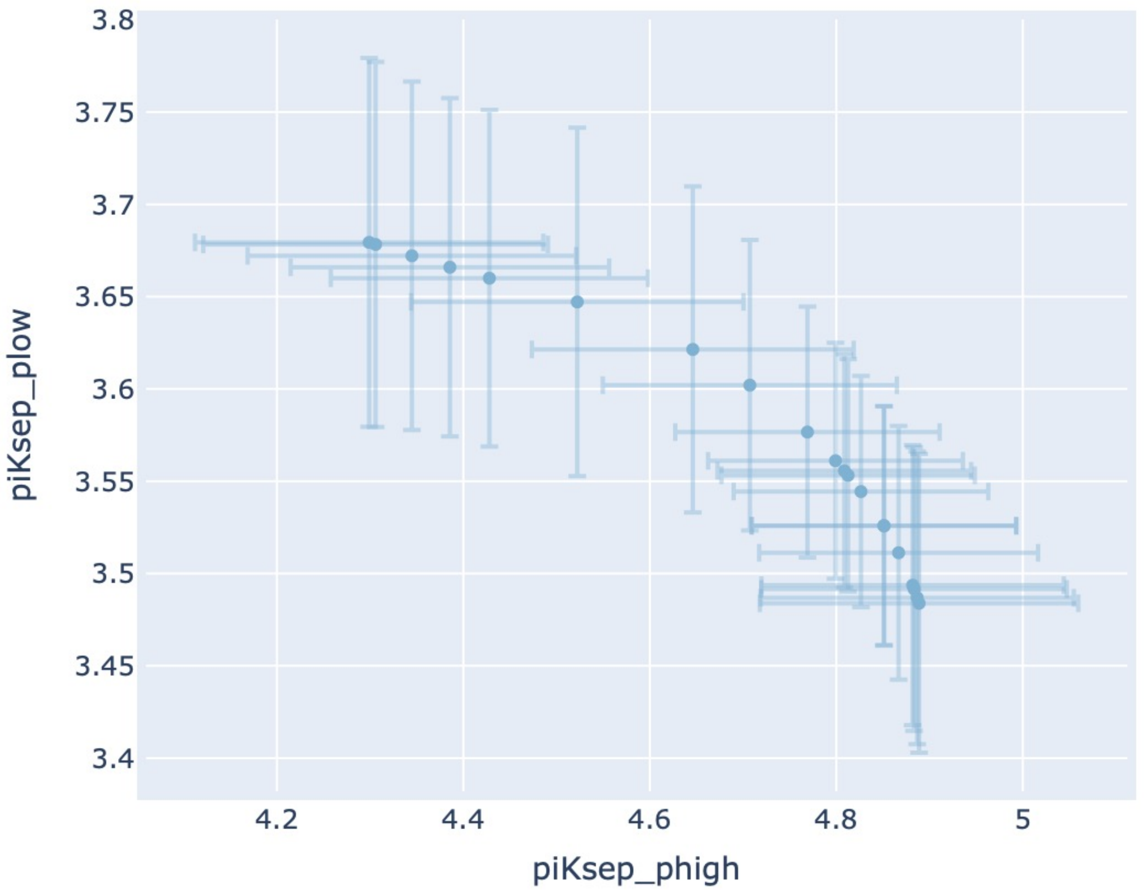
    - η averaged (two momentum points)

$$N_{MAE}^{\pi-K} = \frac{|\langle\theta_{Ch}^{\pi}\rangle - \langle\theta_{Ch}^{K}\rangle|\sqrt{N_{photons}}}{\langle|\theta_{Ch} - \theta_{Ch,expected}|\rangle}$$

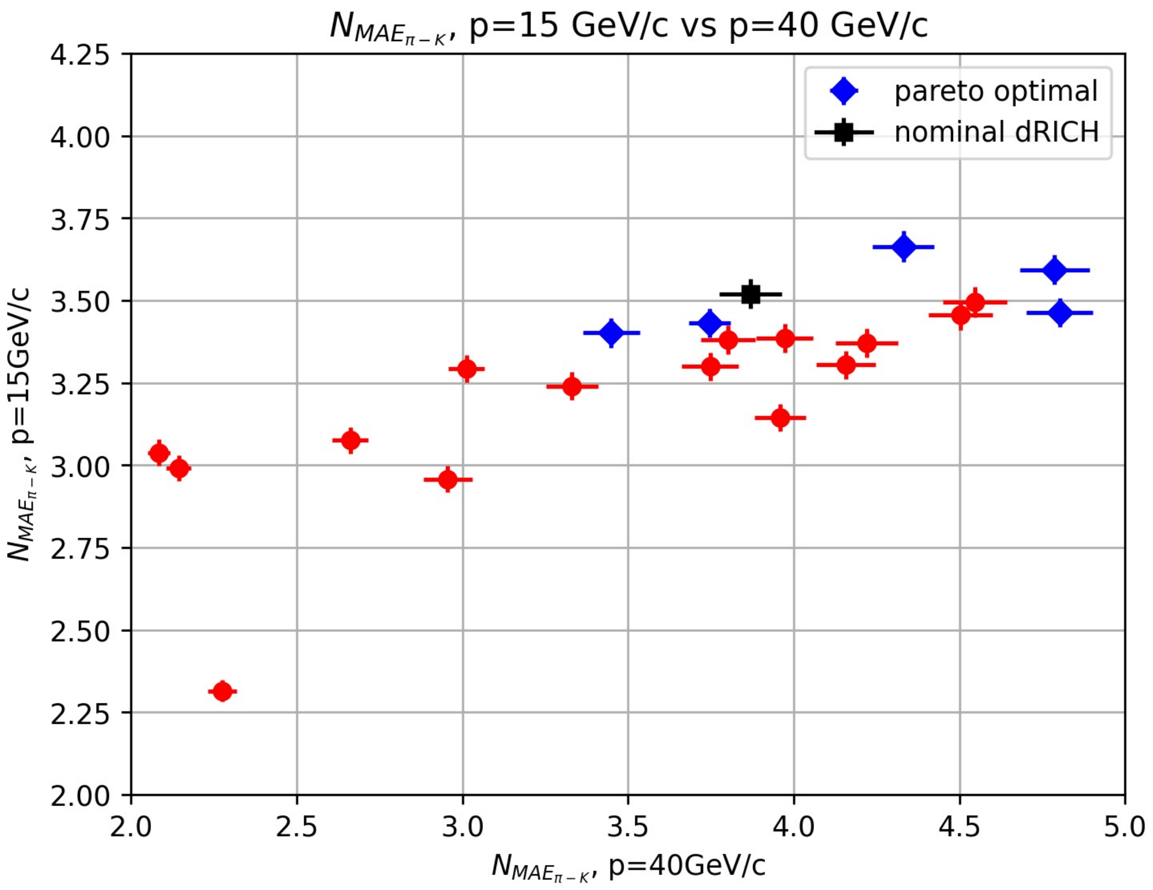
Optimization of two p points (η averaged)

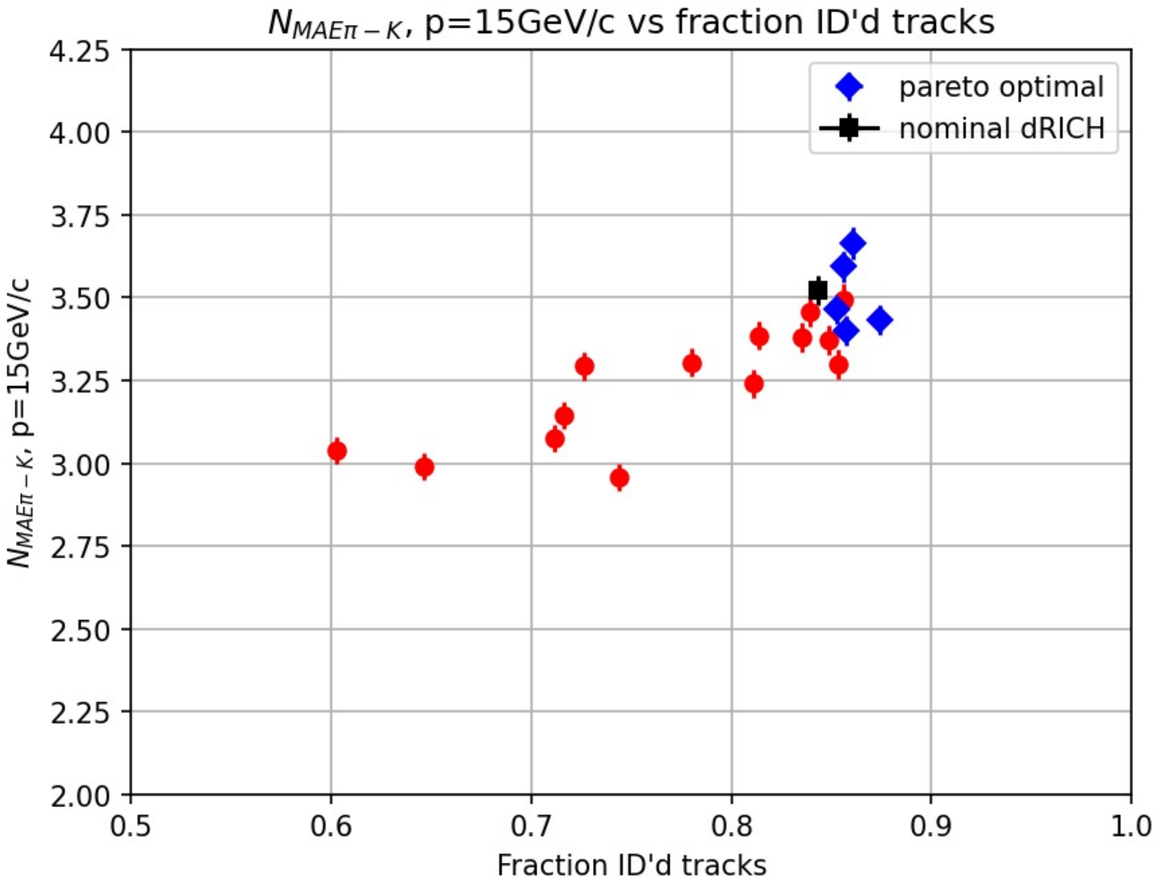
- First multi-mirror optimization PID objectives: $N_{MAE}^{\pi-K}$ **at** $p = 15GeV/c$ and $N_{MAE}^{\pi-K}$ **at** $p = 40GeV/c$
  - Simulate 1500 π^+ and 1500 K^+ at each p and $\eta = [1.5,2.0], [2.0,2.5], [2.5,3.5]$
  - MOBO algorithm steered to explore only region where objectives >= 0.9*nominal dRICH objective values
- 30 initialization trials + 20 MOBO-suggested design points

Pareto frontier from fit surrogate model



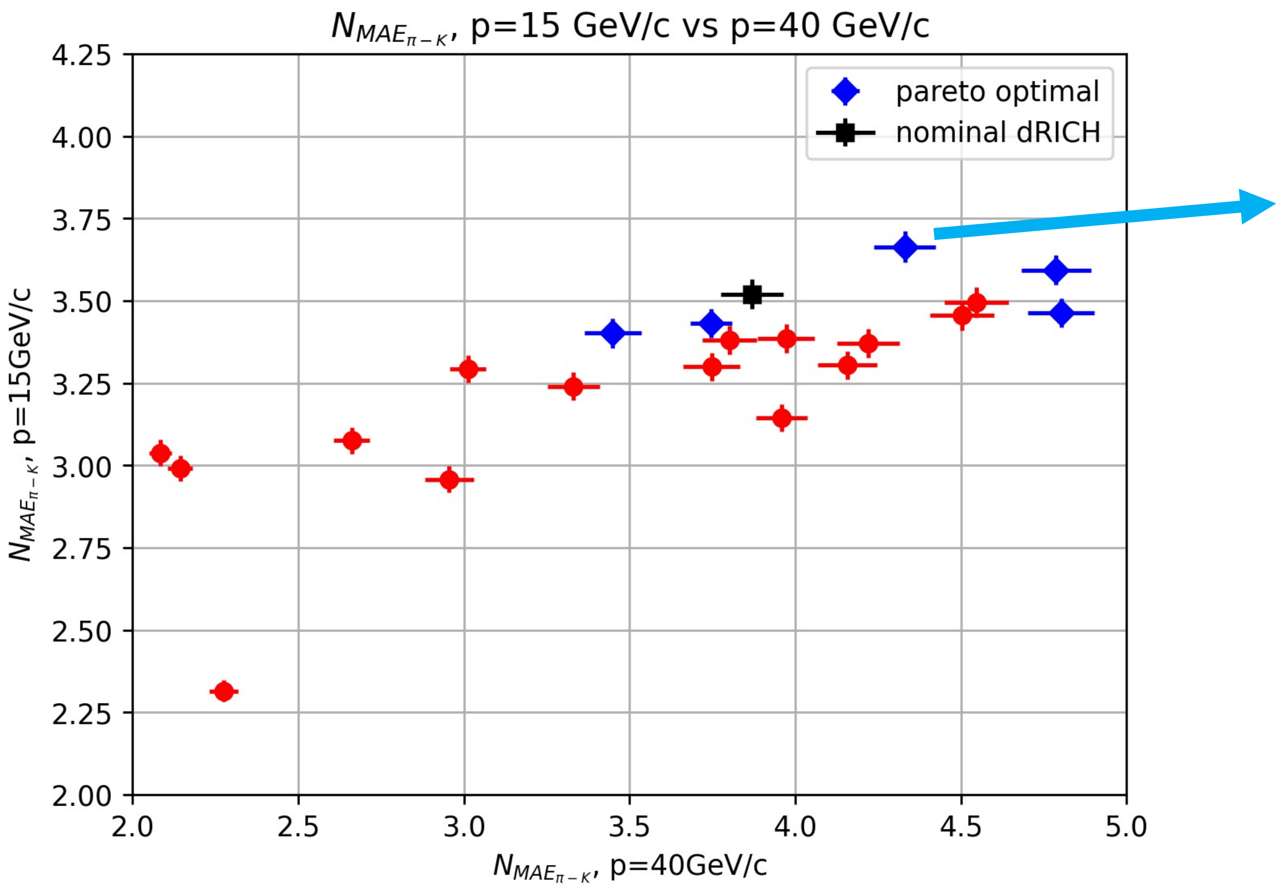
Optimization results (2D)

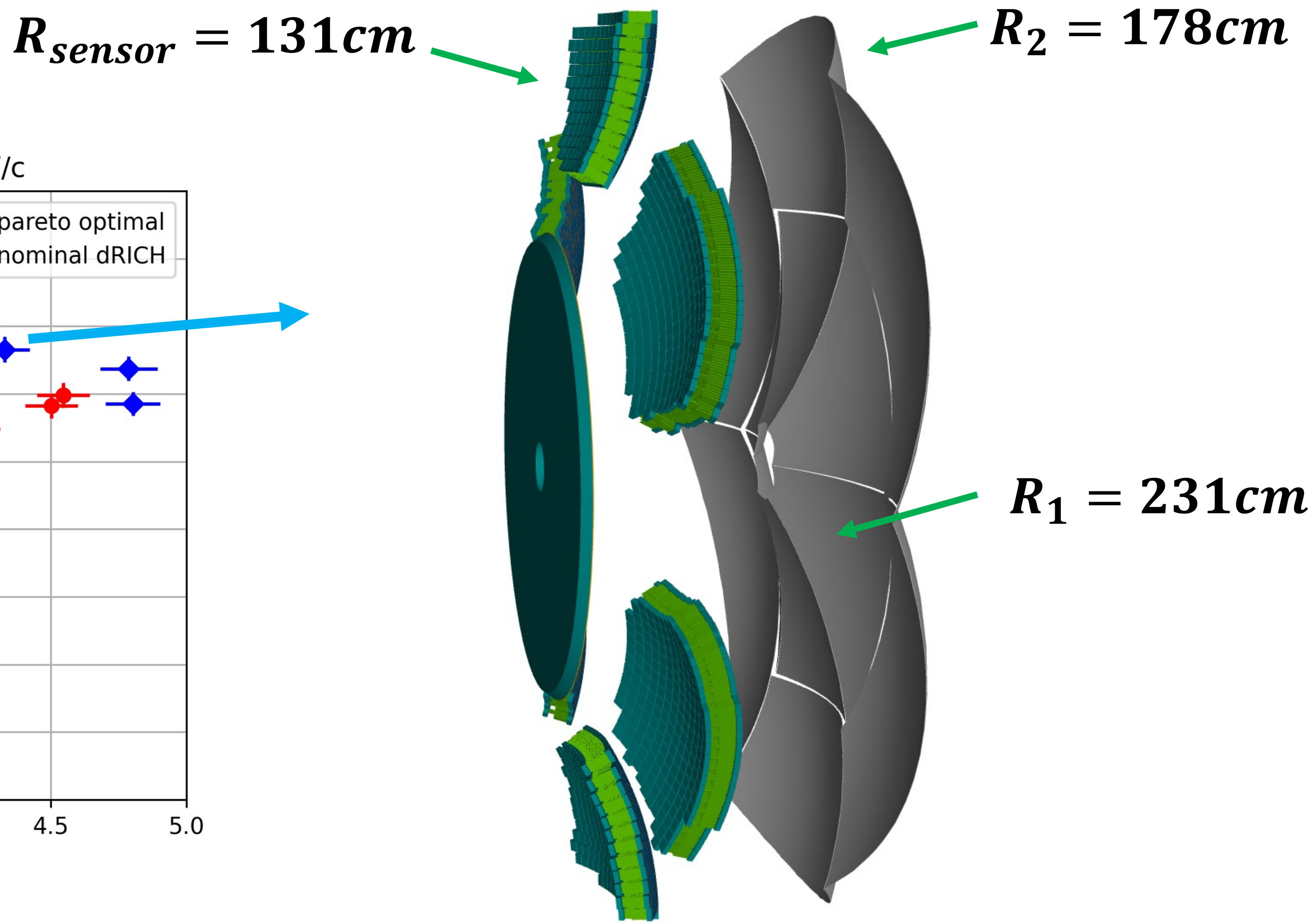




- 2D projections of 3-dimensional objective space

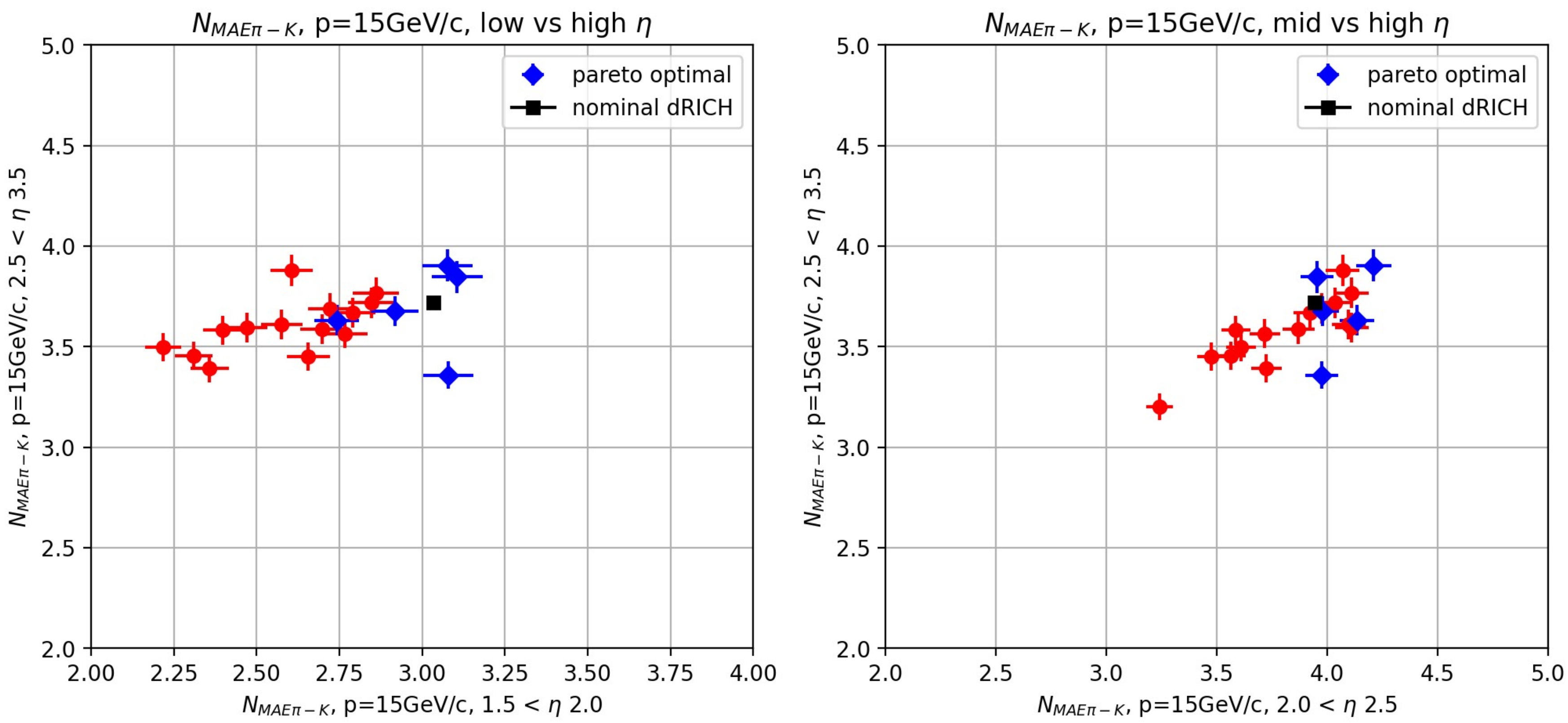
Candidate "optimal" geometry example





Optimization results: individual p/η bins, aerogel

- Blue points: pareto optimal based on averaged π/K separation variables (optimization metrics)
- Testing if optimizing "summary" metrics results in better performance across full p/eta range



Optimization results: individual p/η bins, gas

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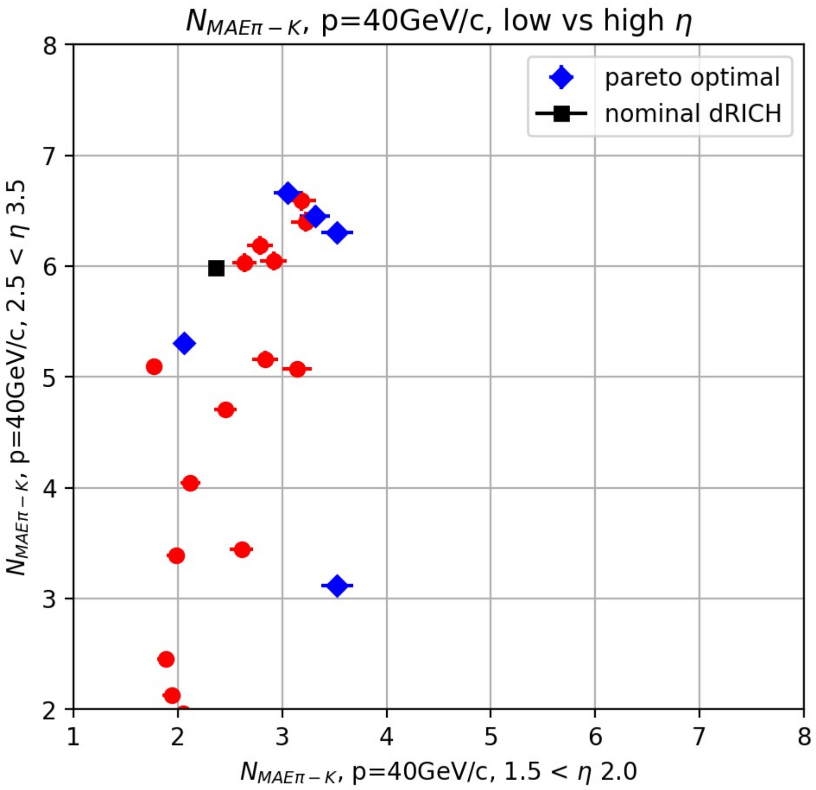
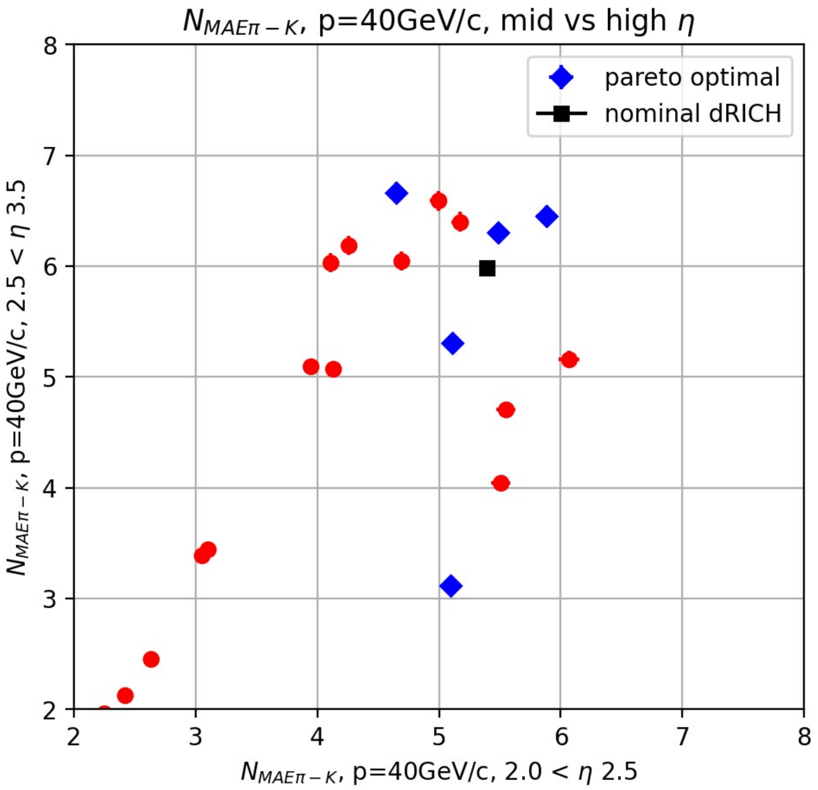


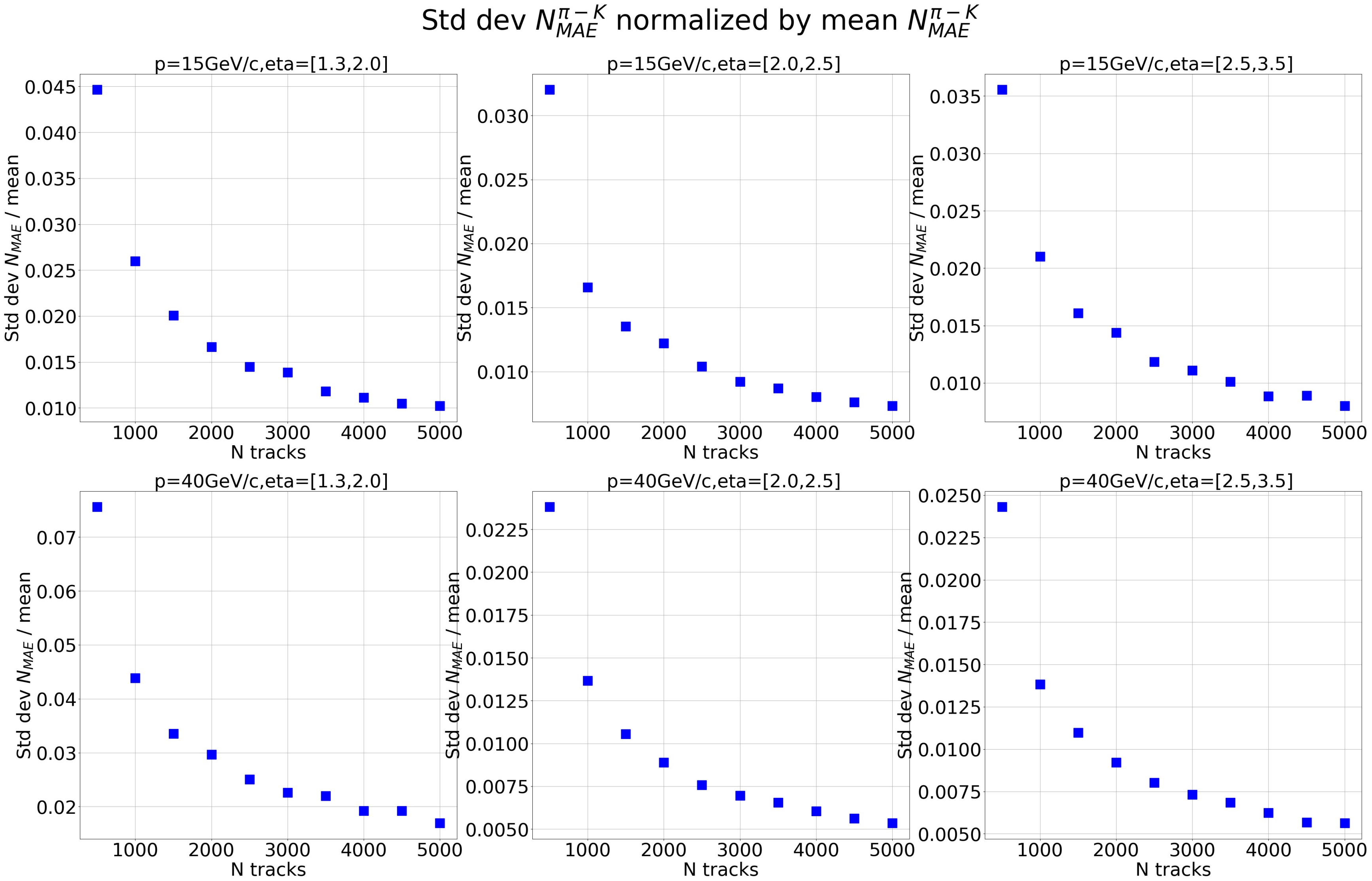


Next steps

- Further compare optimization of momentum-averaged and η-averaged objectives
- Working on putting together better visualization of optimal geometries
  - And surrogate model predictions of objectives as a function of design parameters
- Try to optimize more complex mirror tiling (is there a max number of radii we can use?)
- Can MOBO framework help map out trade-offs in trying to achieve overlap with DIRC around η=1.5?

Uncertainty studies, pi-K separation

- Nominal geometry
- Simulated 5k pi+ and 5k K+ tracks
- Re-sample N tracks out of this set 1000 times per N
- Plotted: std. dev.of objectives normalized by mean



Uncertainty studies, acceptance

Std dev of acceptance normalized by mean acceptance