ECCE All Si Tracker Design Optimisation

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July 20 2021

AI WG Meeting

Design with Multiple Objectives

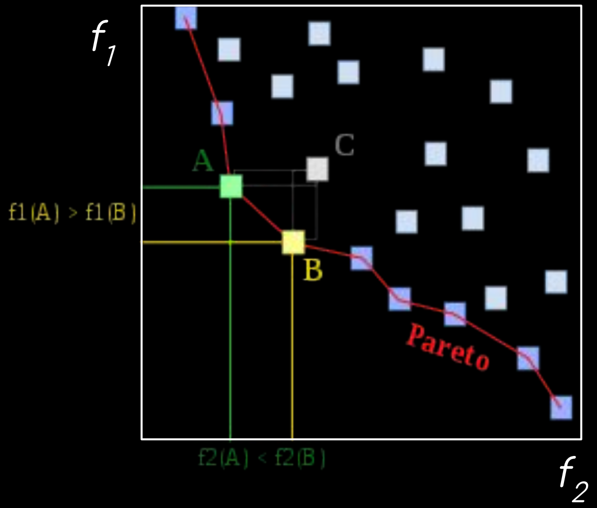
Optimization of the inner tracker (barrel + forward/backward simultaneously)

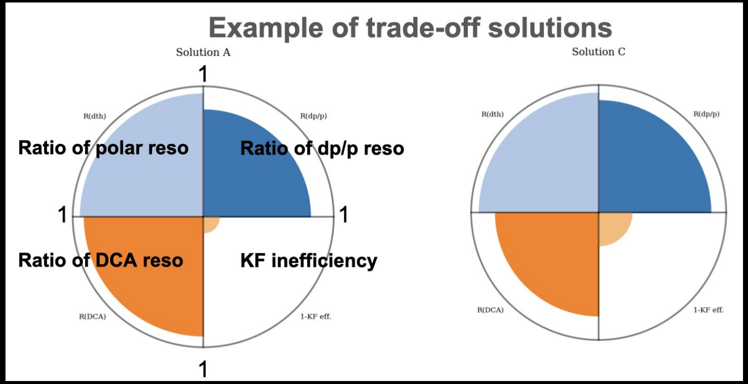
- Extended the design criteria to include simultaneously KF efficiency, pointing resolution, along with momentum and angular resolutions.
- Mechanical constraints

11 parameters
4 objectives
Population size 100
Offspring distributed over 30 cores

Each proposed design is <u>consistent with baseline Aluminum support shell</u> (not displayed)

Trade-off solutions

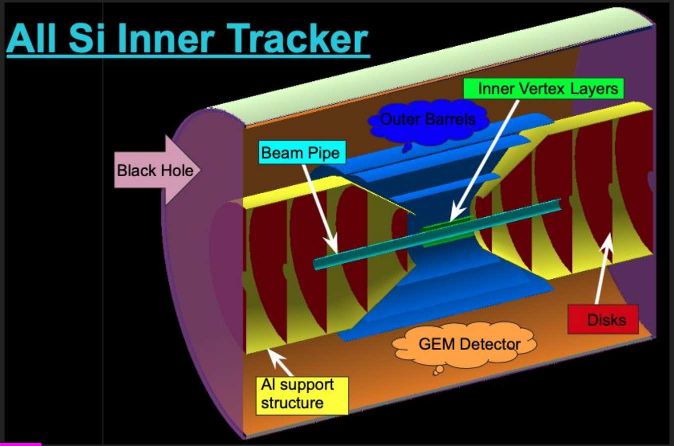




Ratios are with respect the LBNL all Si baseline

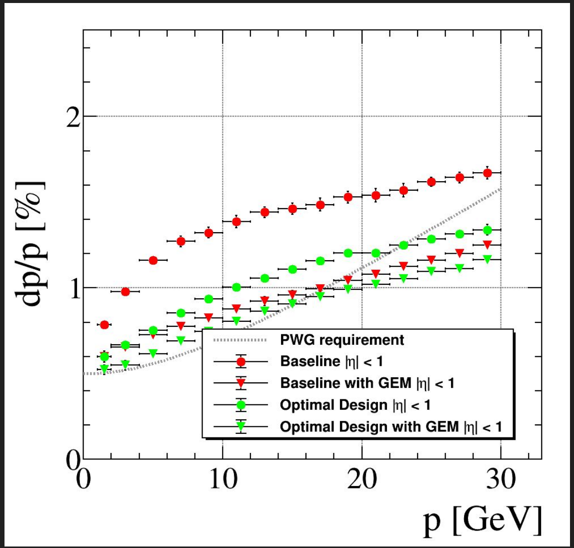
Timeline of "global" Optimisation of ECCE Si Tracker

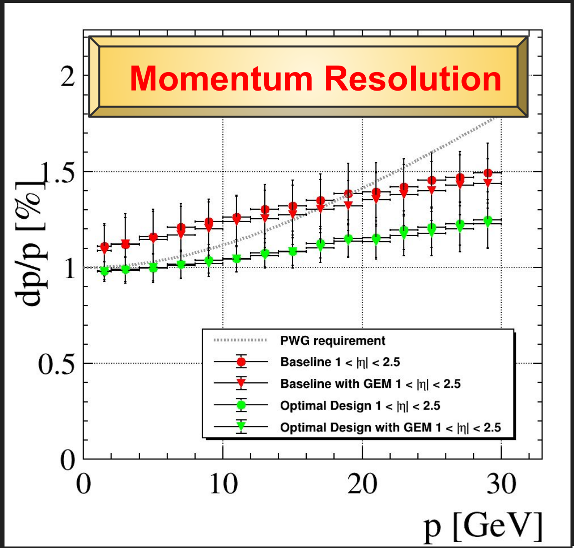
- Before JLUO (June 23 2021) we did not do any "global" optimisation
- Starting with presenting at JLUO we had done the first global optimisation
- The global optimisation history
  - **June 22 For JLUO**
    - This was done on selene (URegina)
    - Baseline is the old baseline from YR; B = 1.5T
    - Had 4 Objectives dp/p, dθ, dca2d and Global KF Inefficiency
    - All resolutions are single gaussian fits
    - **Had 2 constraints**,
      - outer barrel radii less than 51 cm
      - Vertex layer radii less than 15 cm
  - **June 28**
    - This was done on Selene (URegina)
    - Baseline is the old baseline from YR; B = 1.5
    - Max Disk Radii is set to be the max outer Barrel radii.
    - All resolutions were single gaussian initially
      - A study was made with double gaussian to prove that double gaussian was more stable.
    - Had 4 Objectives dp/p, dθ, dca2d and Global KF Inefficiency
    - **Had 3 constraints**,
      - Outer barrel radii less than 51 cm
      - Vertex layer radii less than 15 cm
      - Farthest disk Z position less than 125 cm

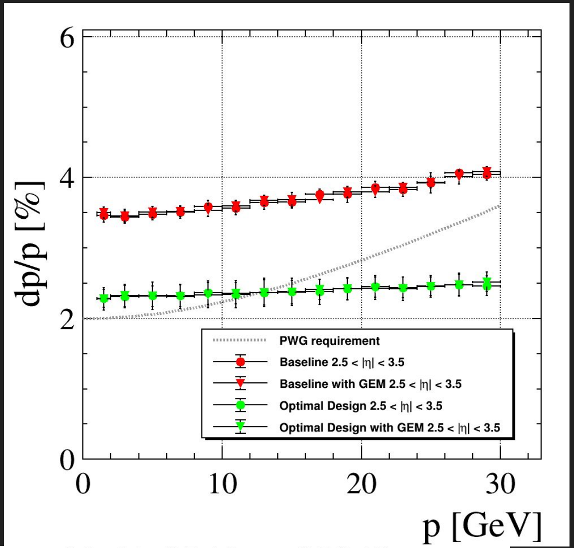


  - **July 15**
    - This was done on JLAB Slurm
    - New baseline from Rey (1-4 with X/X0=0.05%);
    - B = BaBar 1.4T max
    - Max Disk Radii is set to be the max outer Barrel radii.
    - Had 4 Objectives dp/p, dθ, dca2d and Global KF Inefficiency
    - **Had 4 constraints**,
      - Outer barrel radii less than 51 cm
      - Vertex layer radii less than 15 cm
      - Farthest disk Z position less than 125 cm
      - The 4th Barrel layer radius less than 45 cm

Plots shown in JLUO







June 22 For JLUO

- This was done on selene (URegina)
- Baseline is the old baseline from YR; B = 1.5 T
- Had 4 Objectives dp/p, dθ, dca2d and Global KF Inefficiency
- All resolutions are single gaussian fits
- Had 2 constraints,
  - outer barrel radii less than 51 cm
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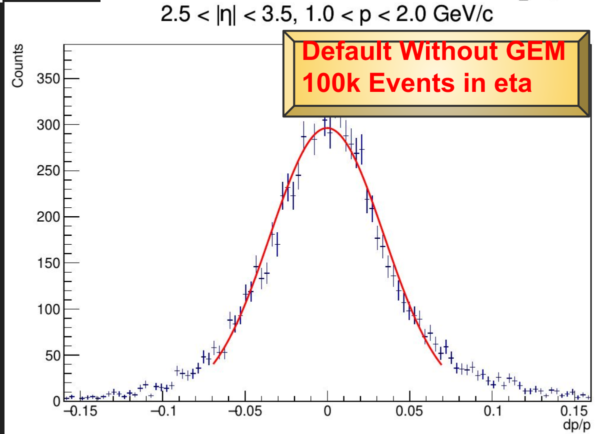
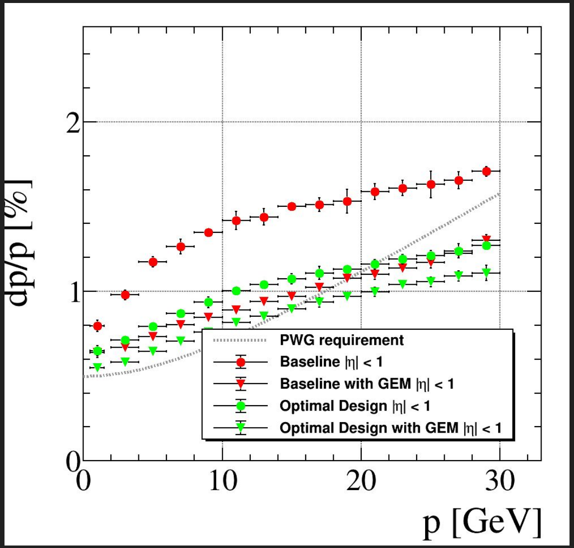
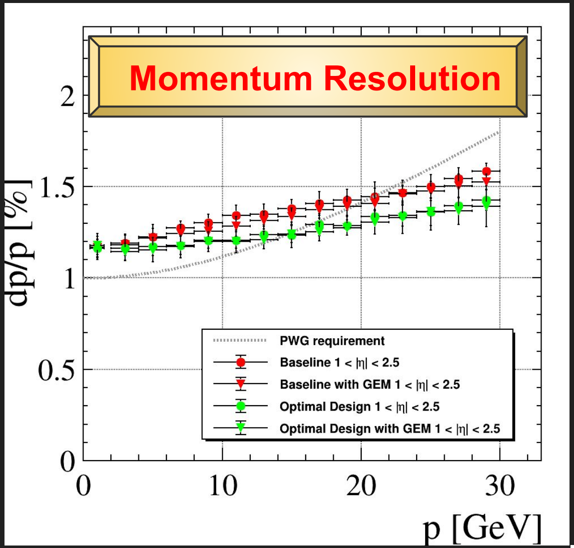
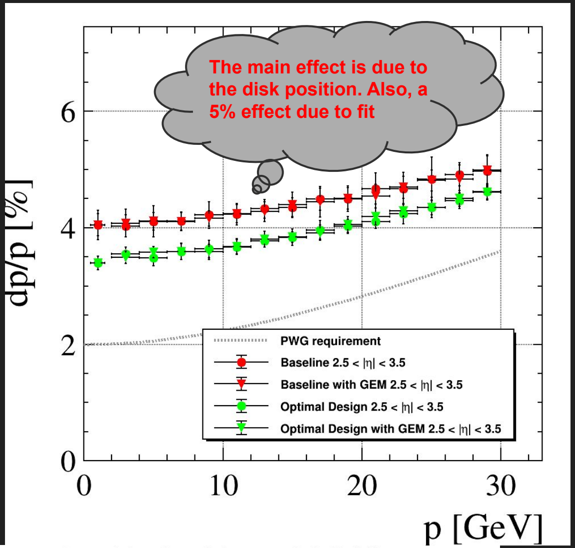


Plot for June 28 Optimisation

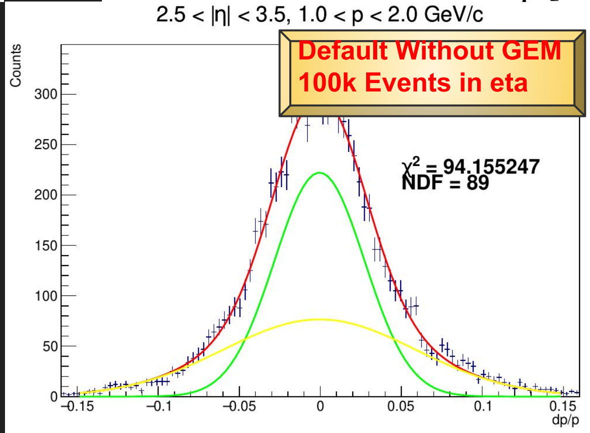






June 28

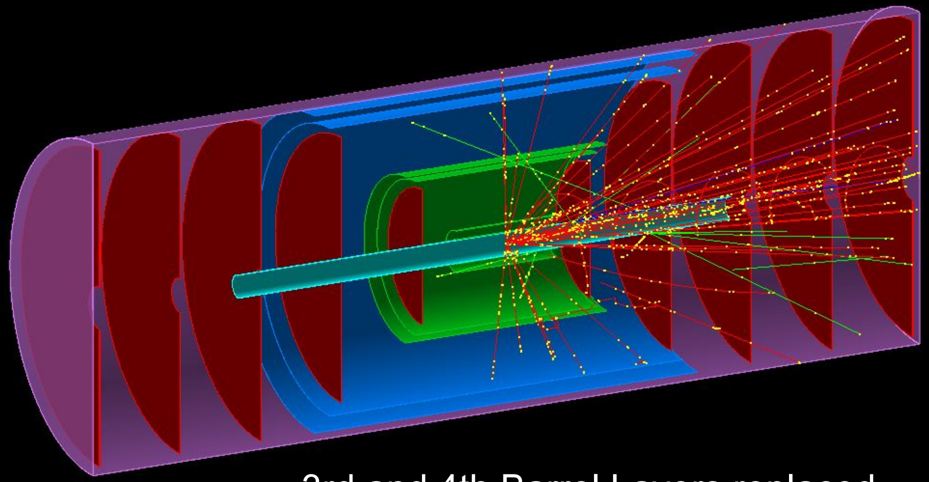
- This was done on selene (URegina)
- Baseline is the old baseline from YR; B = 1.5 T
- Had 4 Objectives dp/p, dθ, dca2d and Global KF Inefficiency
- All resolutions are double gaussian fits
- Had 3 constraints,
  - outer barrel radii less than 51 cm
  - Vertex layer radii less than 15 cm
  - Farthest Disk Z position less than 125 cm



The “new” Baseline

- Rey showed results with replacing the 3rd and 4th Barrel layers with Vertex layer technology (X/X0 = 0.05%).
- All the other tracker params are the same as shown in the table from previous slides.
- A new optimisation is being currently run with the new vertex budget for 3rd and 4th layer as the baseline design
- Find an optimal set of design parameters which could have better performance compared to this new baseline

https://github.com/reynier0611/g4lblvtx



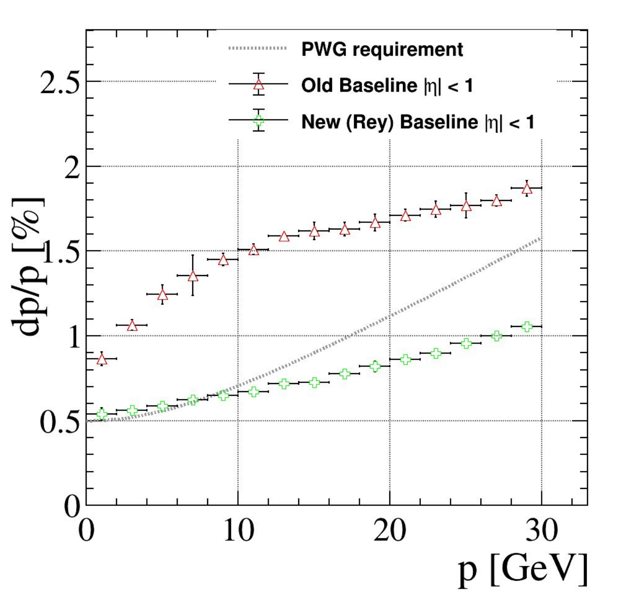
3rd and 4th Barrel Layers replaced with vertex technology

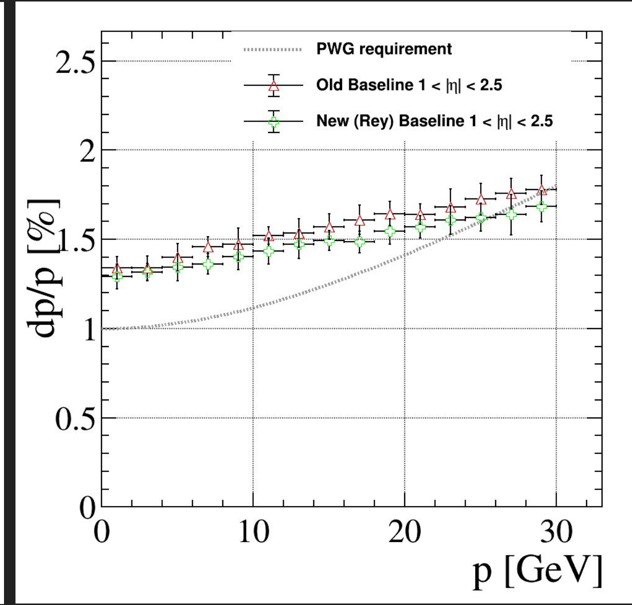
Vertex Budget Barrel [1 - 4] (X/X0)	0.05 %
Barrel Budget Barrel [5 - 6] (X/X0)	0.55%
Disk Budget (X/X0)	0.24 %

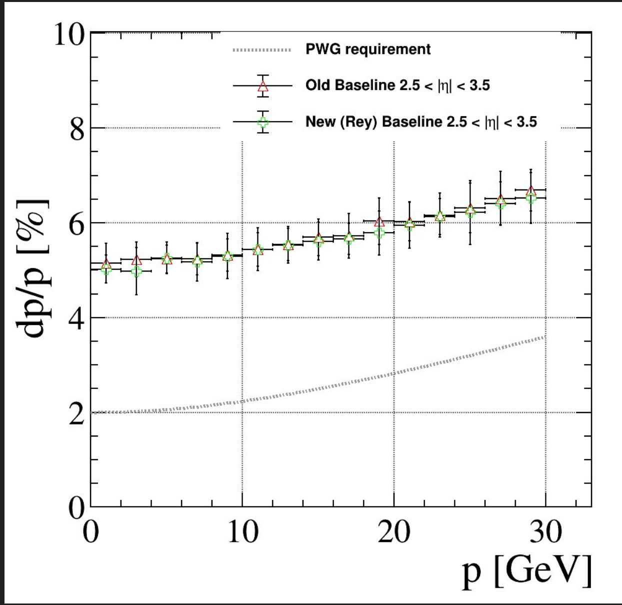
The Detector geometry is the same as the Baseline Design except

1. No GEM
2. Barrel layers 3 and 4 are replaced with Vertex Technology

Momentum Resolution for Old and New baseline

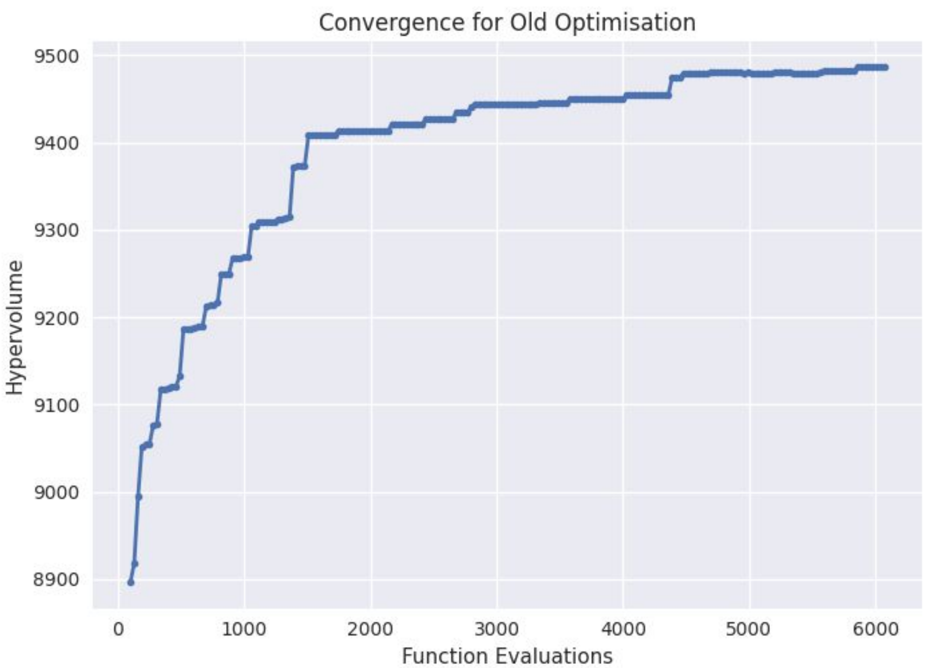


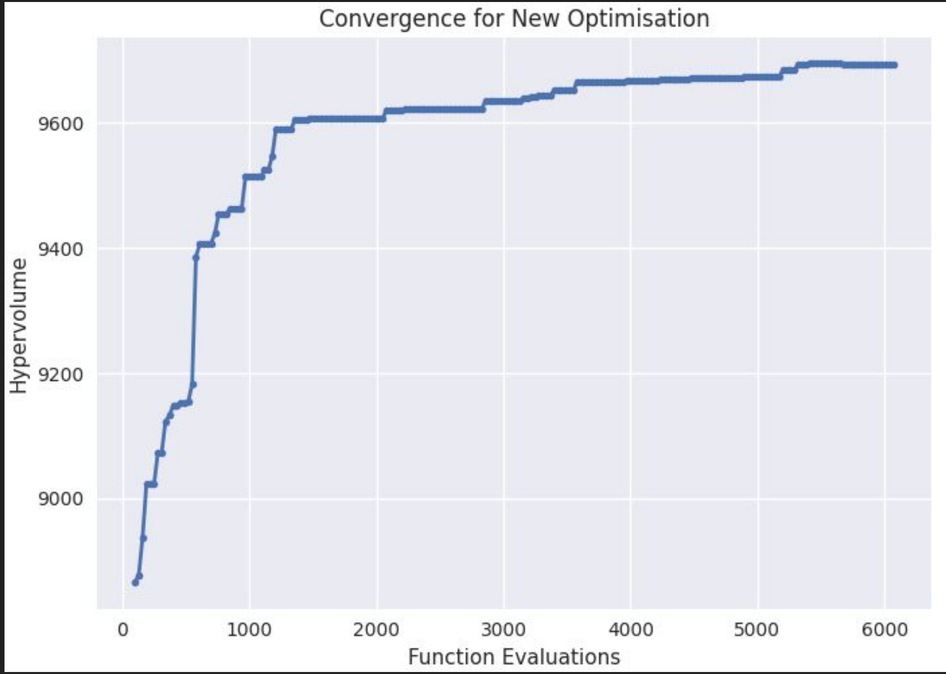




Baselines used for comparison during the optimization

Comparing convergence for old and new optimisation





Convergence studies for old and new optimizations
based on metric defined on hypervolumes

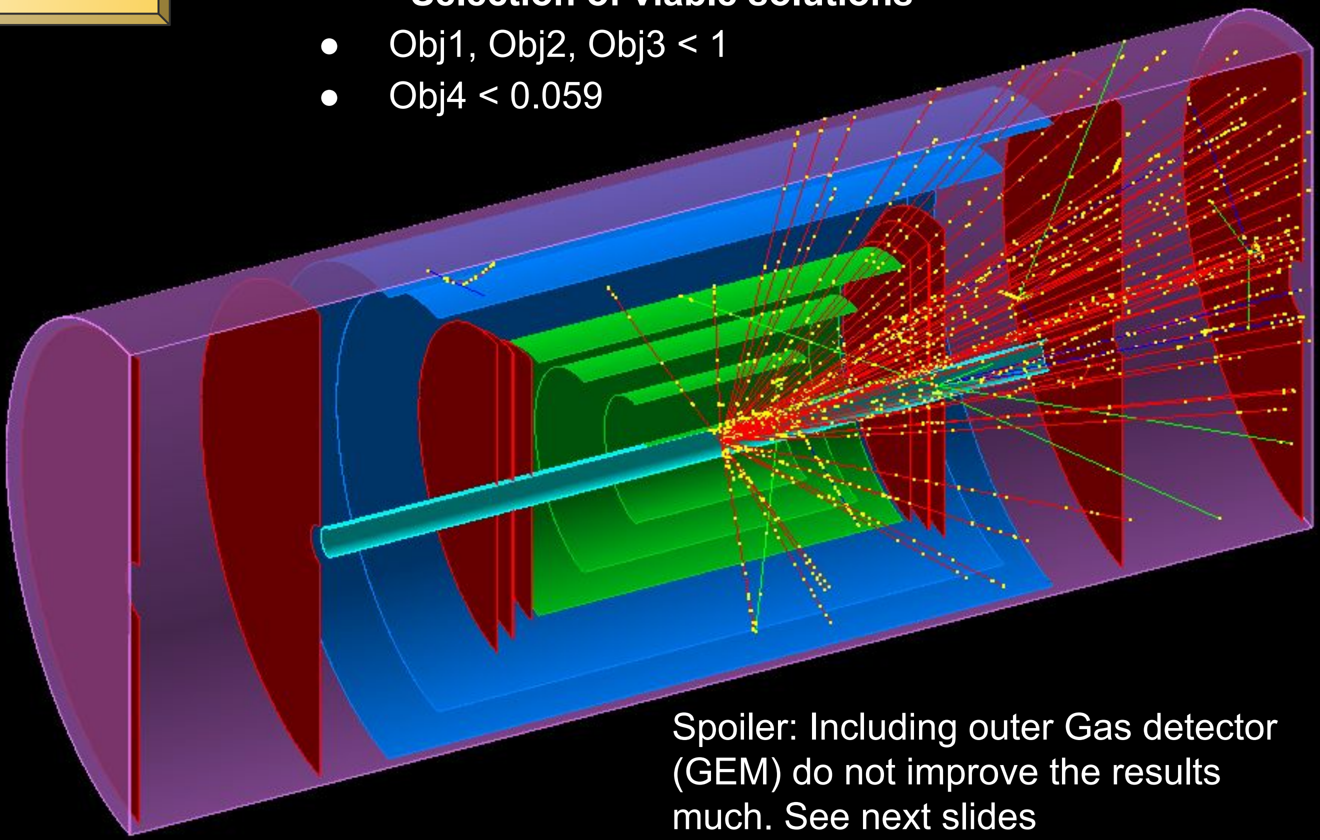
New optimization:
Comparing trade-off design solutions

Optimised Design 1

Objective Function	Baseline	Optimal design
Obj1 (dpp)	1	0.91
Obj2 (dtheta)	1	0.95
Obj3 (dphi)	1	0.91
Obj4 (KF ineff)	0.059	0.057

Selection of viable solutions

- Obj1, Obj2, Obj3 < 1
- Obj4 < 0.059



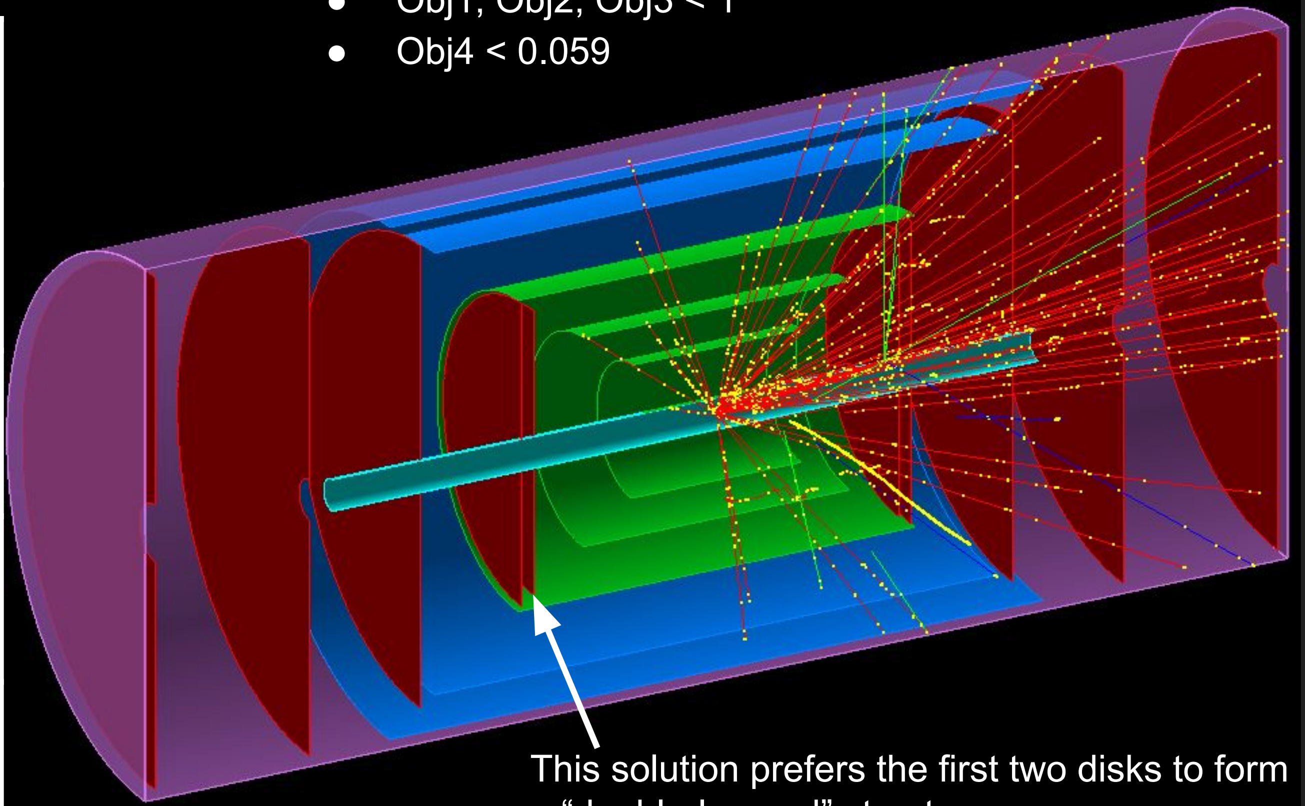
Spoiler: Including outer Gas detector (GEM) do not improve the results much. See next slides

Optimised Design 2

Objective Function	Baseline	Optimal design
Obj1 (dpp)	1	0.96
Obj2 (dtheta)	1	0.95
Obj3 (dphi)	1	0.98
Obj4 (KF ineff)	0.059	0.02

Selection of viable solutions

- Obj1, Obj2, Obj3 < 1
- Obj4 < 0.059



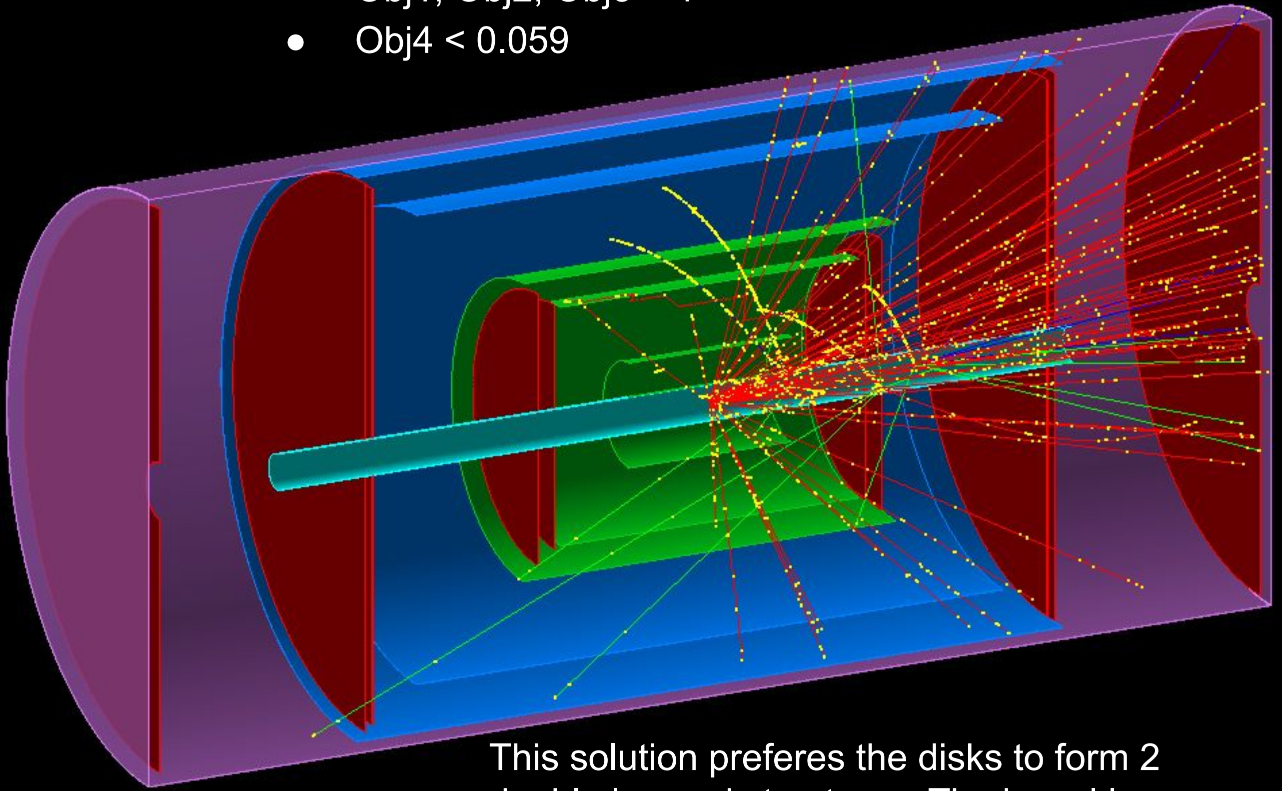
This solution prefers the first two disks to form a “double-layered” structure.
The barrel layers have not changed much.

Optimised Design 3

Objective Function	Baseline	Optimal design
Obj1 (dpp)	1	0.96
Obj2 (dtheta)	1	0.97
Obj3 (dphi)	1	0.69
Obj4 (KF ineff)	0.059	0.04

Selection of viable solutions

- Obj1, Obj2, Obj3 < 1
- Obj4 < 0.059



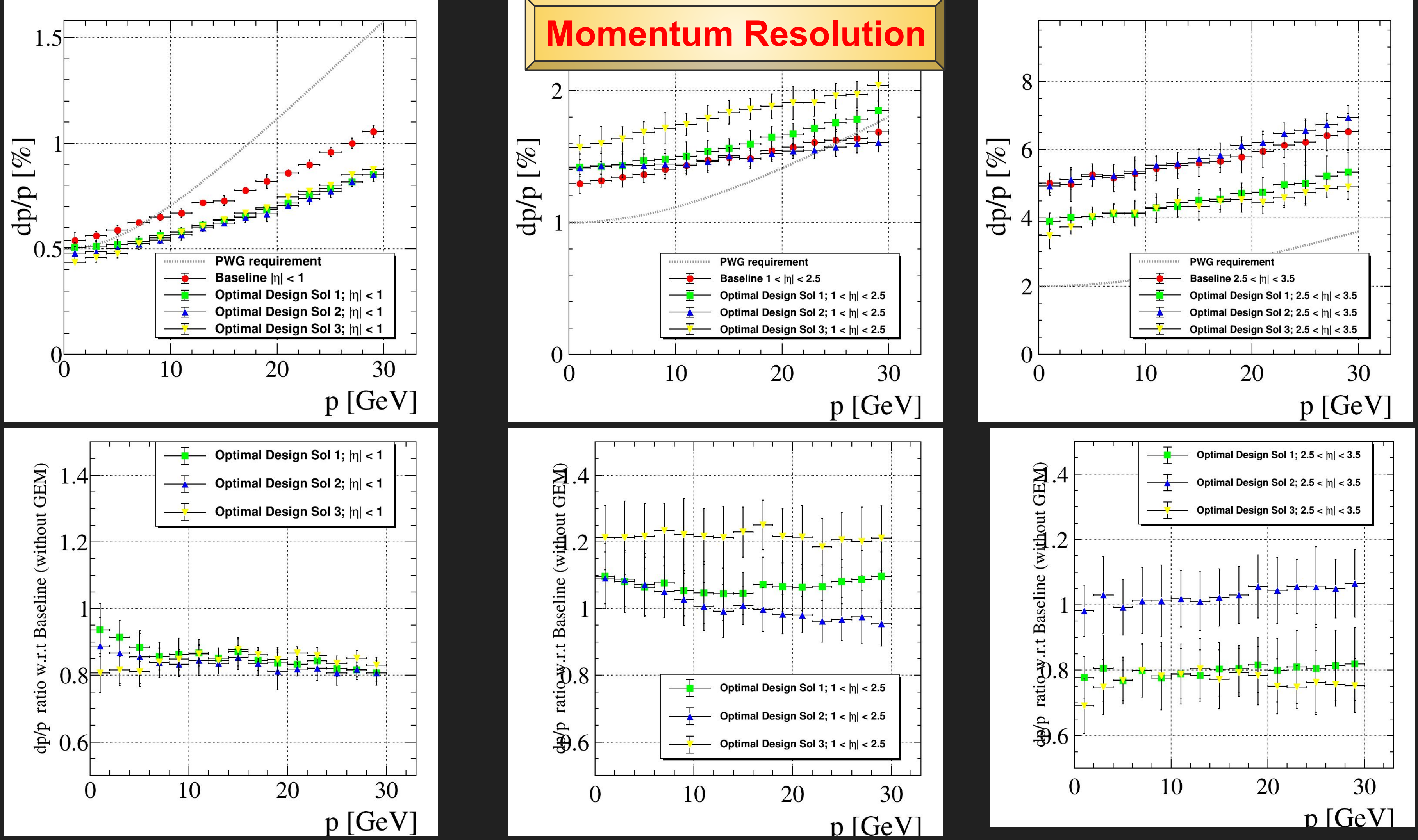
This solution preferes the disks to form 2 double layered structures. The barrel layers have not changed much.

Comparing All Optimal Design Parameters

Parameter	Design 1 [cm]	Design 2 [cm]	Design 3 [cm]
Si Vertex Layer 1 Radius	3.3	3.2	3.18
Si Vertex Layer 2 Radius	13.0	13.2	9.05
Barrel Layer 3 Radius	20.8	20.7	20.6
Barrel Layer 4 Radius	27.7	30.8	25.7
Barrel Layer 5 Radius	43.0	43.7	40.4
Barrel Layer 6 Radius	50.5	50.7	48.6
Forward Disk 1 Z position	**28.5**	**38.0**	**28.6**
Forward Disk 2 Z position	**42.3**	**40.4**	**31.7**
Forward Disk 3 Z position	**45.3**	**61.5**	**62.2**
Forward Disk 4 Z position	**81.5**	**84.4**	**63.6**
Forward Disk 5 Z position	**118.1**	**116.6**	**101.5**

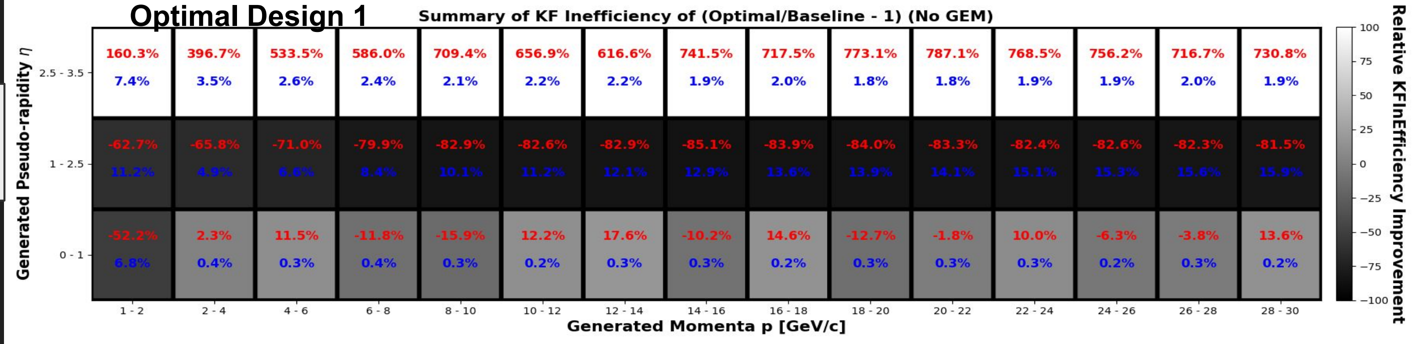
- The most sensitive parameters that change are the disk z positions
- The algorithm prefers double layered disks
- The performance of dp/p in a given eta bin depend on the double layer

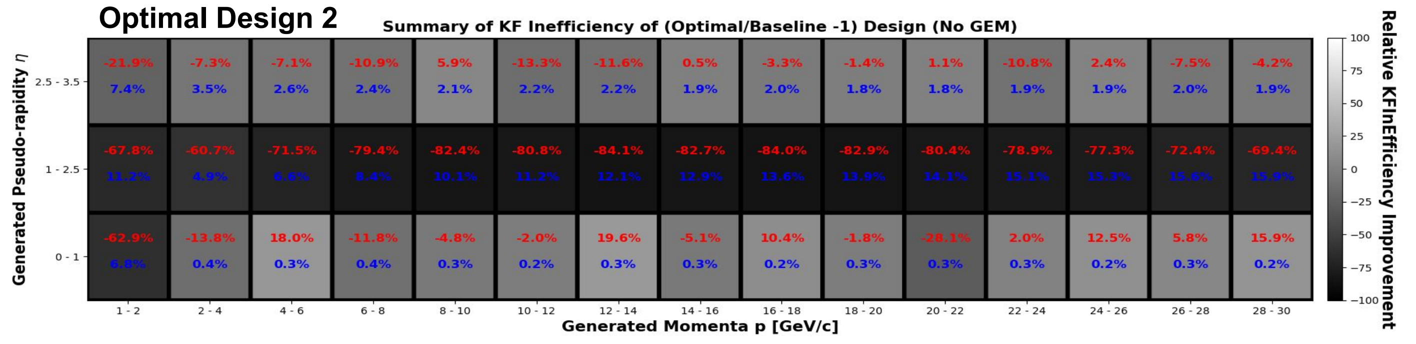
Momentum Resolution

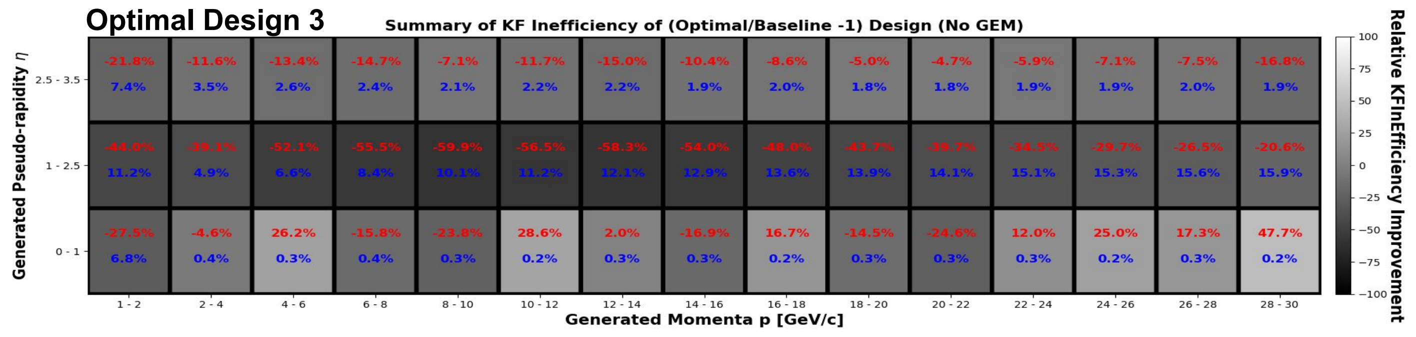


- Optimal/baseline -1
- Baseline Ineff

KF Inefficiency



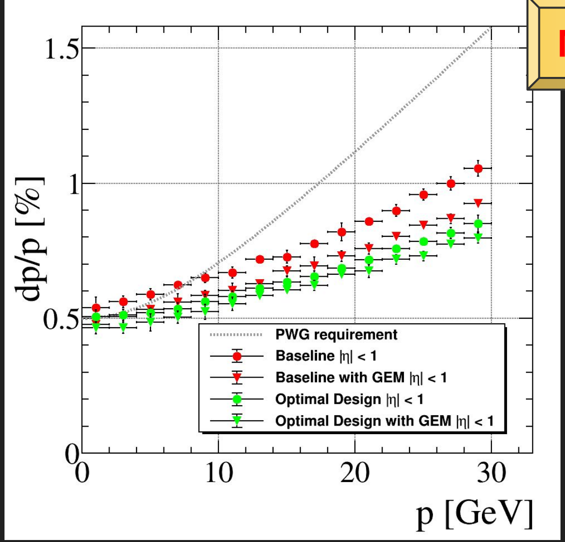


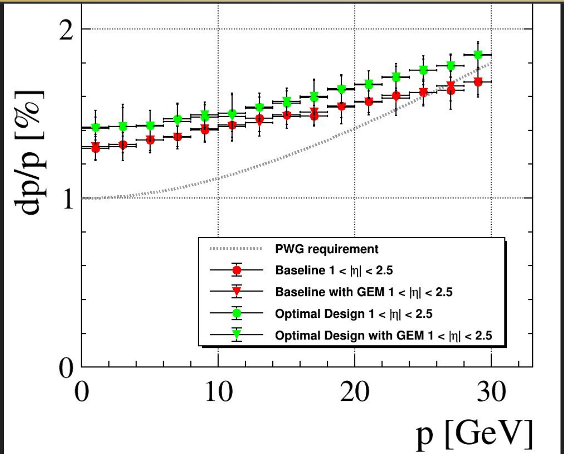


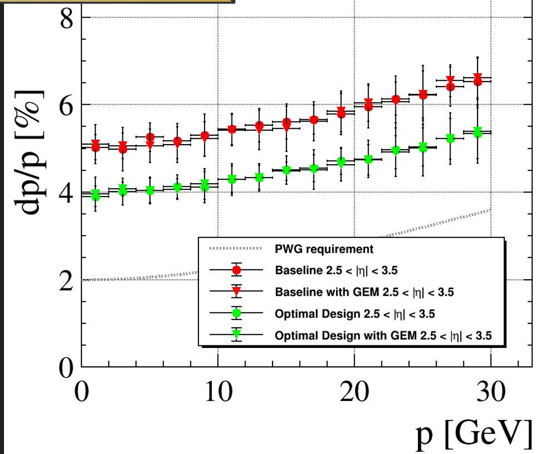
Including outer Gas detector (GEM) do not improve the results much.

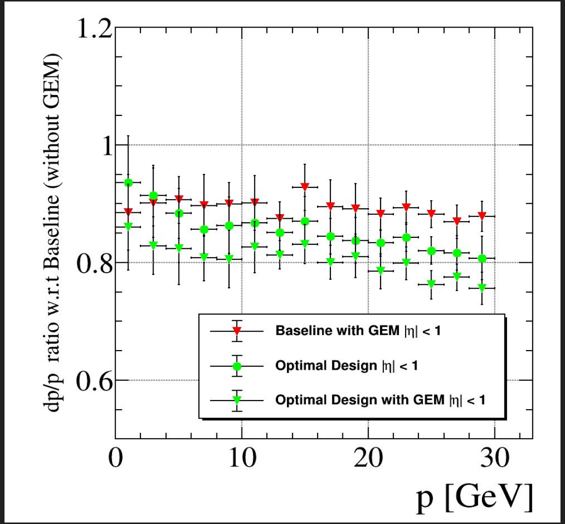
Next slides show this for one optimal design, similar conclusions for the other trade-off solutions (backup slides)

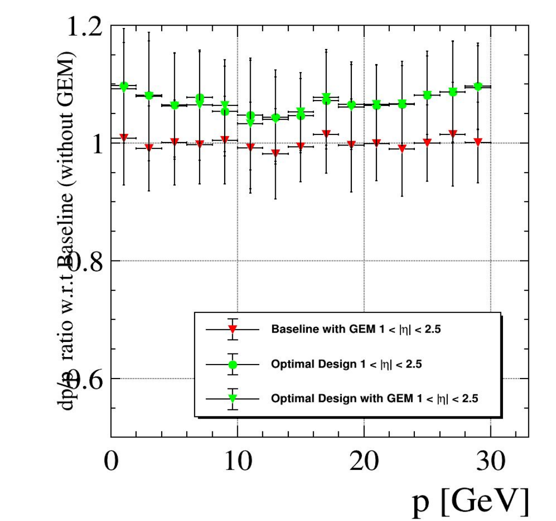
Momentum Resolution (comparison with GEM)

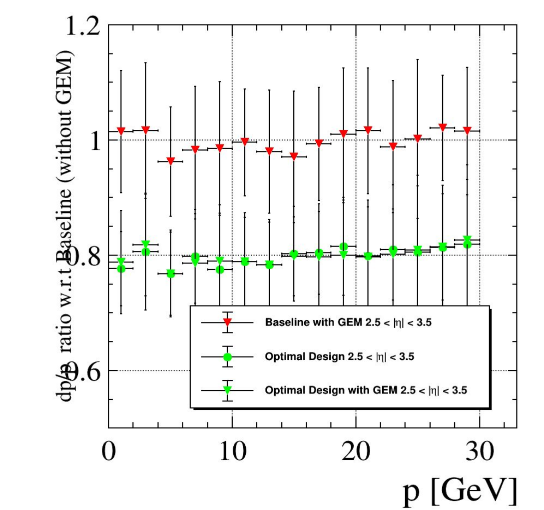




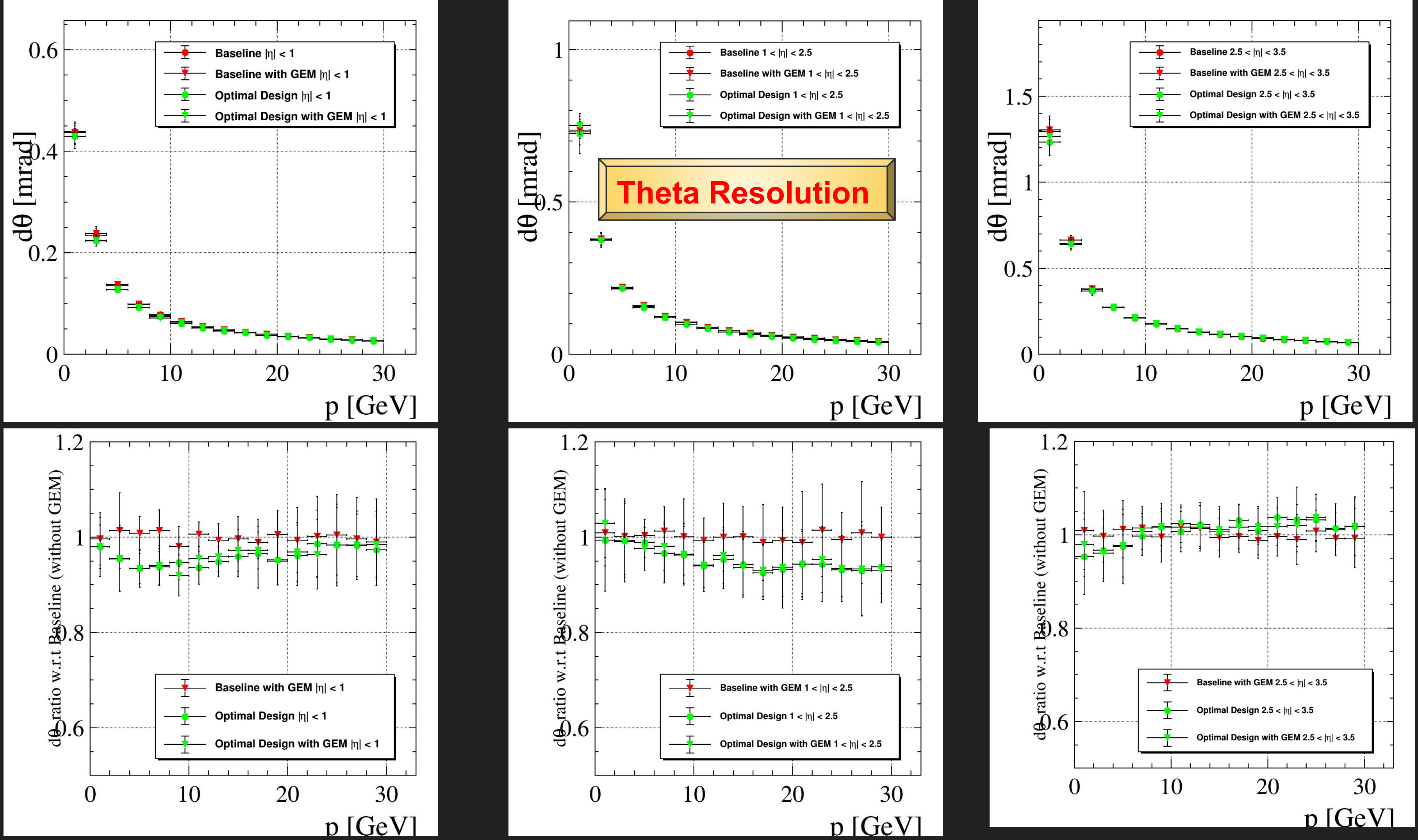


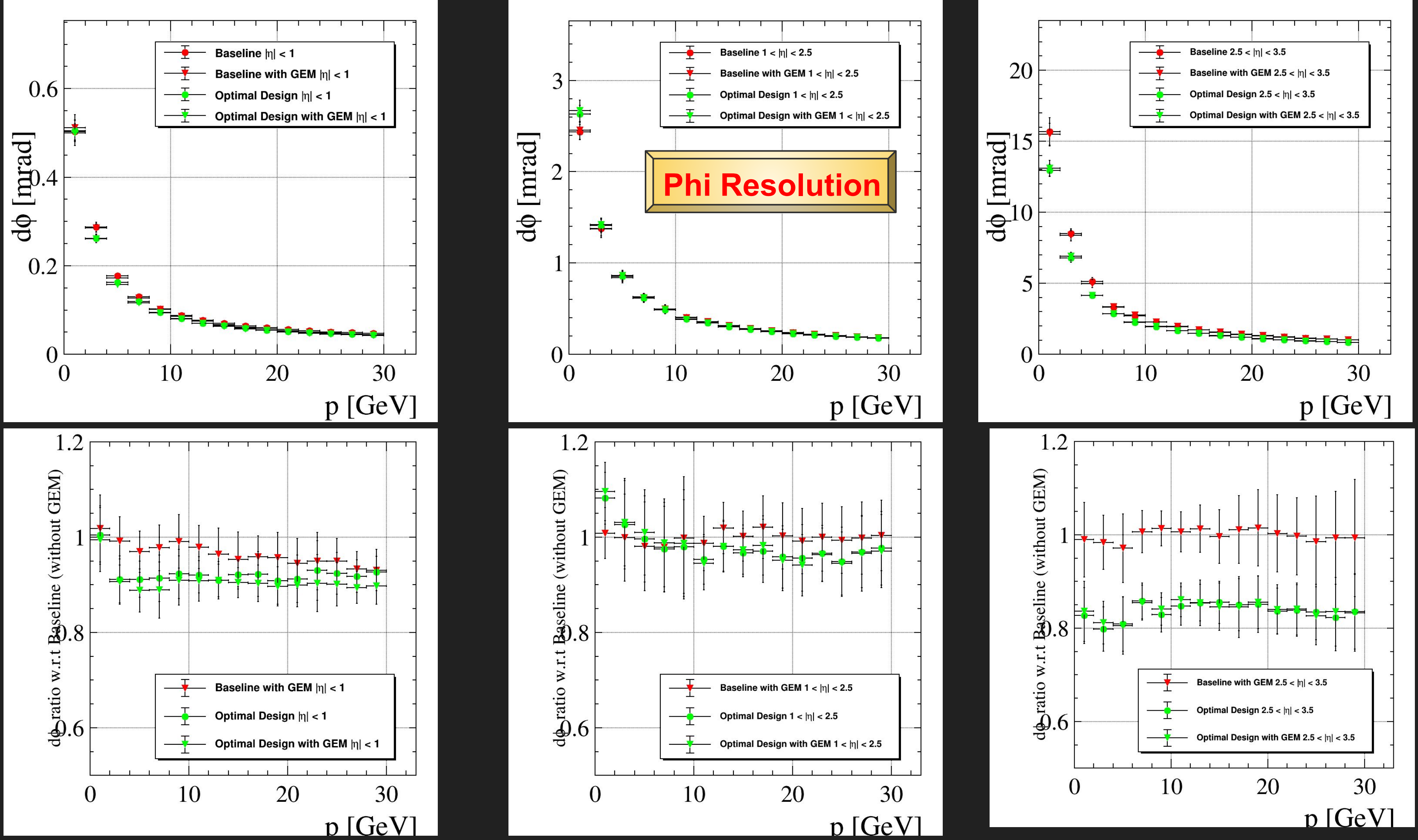






Theta Resolution



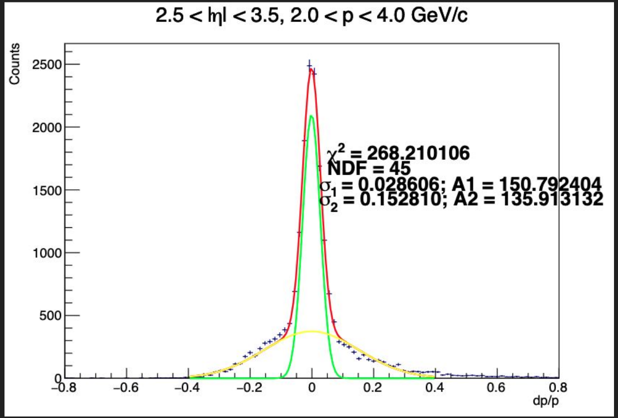

Phi Resolution
dϕ [mrad]
p [GeV]
Baseline |η| < 1
Baseline with GEM |η| < 1
Optimal Design |η| < 1
Optimal Design with GEM |η| < 1
Baseline 1 < |η| < 2.5
Baseline with GEM 1 < |η| < 2.5
Optimal Design 1 < |η| < 2.5
Optimal Design with GEM 1 < |η| < 2.5
Baseline 2.5 < |η| < 3.5
Baseline with GEM 2.5 < |η| < 3.5
Optimal Design 2.5 < |η| < 3.5
Optimal Design with GEM 2.5 < |η| < 3.5
dϕ ratio w.r.t Baseline (without GEM)

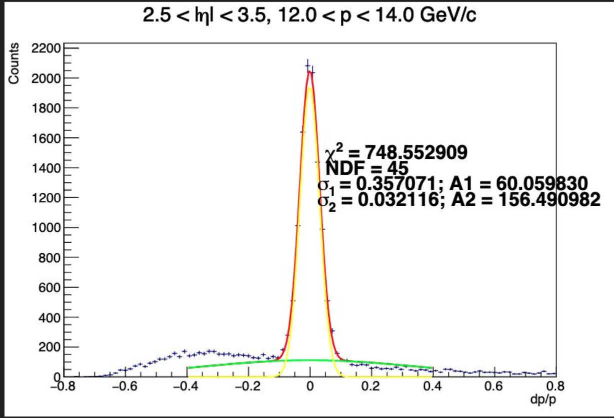
Summary

- The Newly Optimised Detector design does not consider any constraints on spacing between the layers with vertex technology (X/X0 = 0.05%)
    - From the tracking meeting (July 6 2021). Rey had pointed out that the space between the vertexing layer cannot be arbitrarily varied. This could affect the Material Budget (X/X0)
    - Is there a functional form for this variation?
- Having the outer Gas detector does not improve results significantly in baseline and optimal designs
- Since the AI returns non-dominating solutions, multiple solutions are equally optimal
- The Objective space is not fully explored since solution is only from 200 generations
- Currently exploring another optimization with 6 disks instead of 5.

Notes on Fitting Procedure: A Posteriori Studies

For some design configuration





Notice these plots do not correspond to any of the optimal solutions we showed

Fitting with single gaussian can artificially provide better resolution as it does not take into account all tracks that passed the KF

More complicated structures can build beneath the peak in some bins of the phase-space

Maximizing the number of “well” reconstructed tracks in the peak can be another figure of merit to include