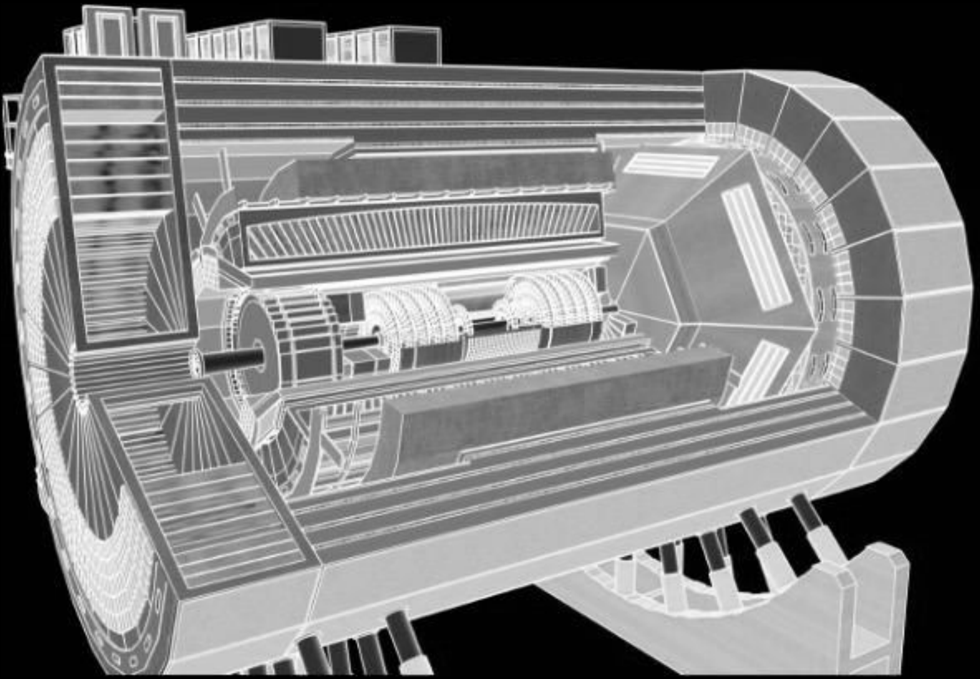
AI Updates on Tracking



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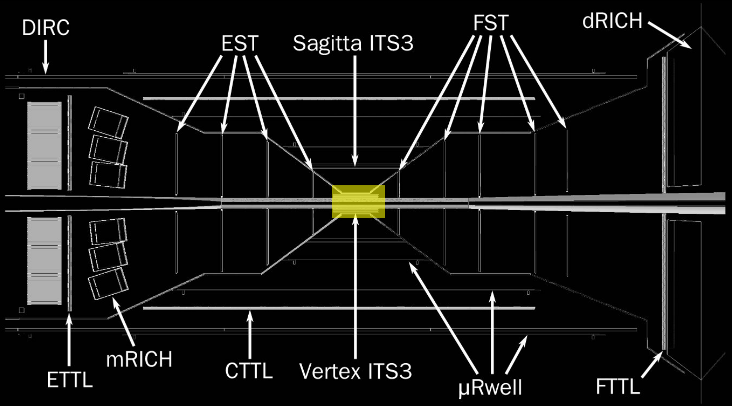
Outline

- First part (1):
  - Studies of the current reference design (non-projective)
  - Compare it to the projective design (ongoing R&D)
  - Introduce parametrization (which includes support structure) from which we get both non-projective and projective

    Looking for feedback on parameters to implement: see (2)

- Second part (2) — only few slides (N.b.: there will be an AI talk on that [link1,link2]!):
  - AI framework/pipeline is already developed and ready [see 2205.09185]
    - We can integrate / accommodate any new updates and always more realistic details in the simulation; include new parameters, constraints etc
  - AI is one of the best ways to steer a multi-dimensional compute intensive complex design (made by several sub-detectors) by optimizing simultaneously competing objectives
    - Resolutions, efficiencies, other FoMs based on physics results over the entire detector phase-space

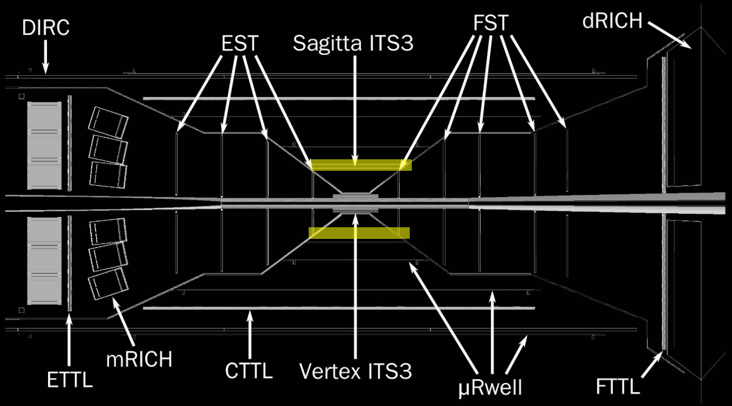


Click on hyperlinks

Vertex Si Barrel

			Reference		Ongoing R&D	
Barrel	**X/X0 [%]**	**Pitch [um]**	**Radii [cm]**	**Length [cm]**	**Radii [cm]**	**Length [cm]**
Layer 1	0.05	10	3.3	27	3.3	27
Layer 2	0.05	10	4.35	27	4.35	27
Layer 3	0.05	10	5.4	27	5.4	27

Values being used in these slides

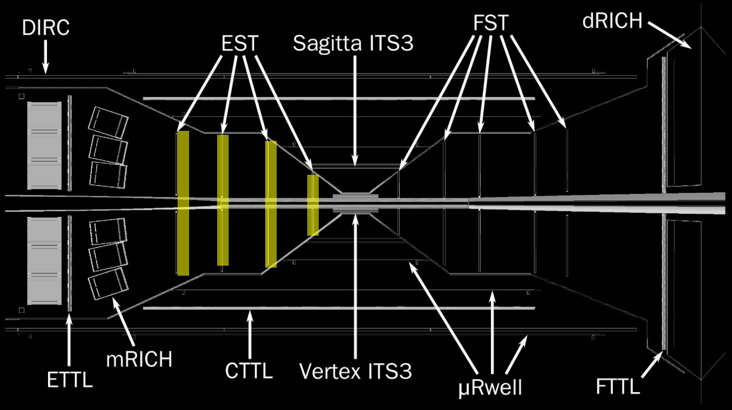


Sagitta Si Barrel

			Reference		Ongoing R&D	
Barrel	X/X0 [%]	Pitch [um]	Radii [cm]	Length [cm]	Radii [cm]	Length [cm]
Layer 1	0.05 (0.2, 0.55)	10	21	54	14.0	54
Layer 2	0.05 (0.2, 0.55)	10	22.68	54	15.5	54

*Also studied these XX0 values for this update

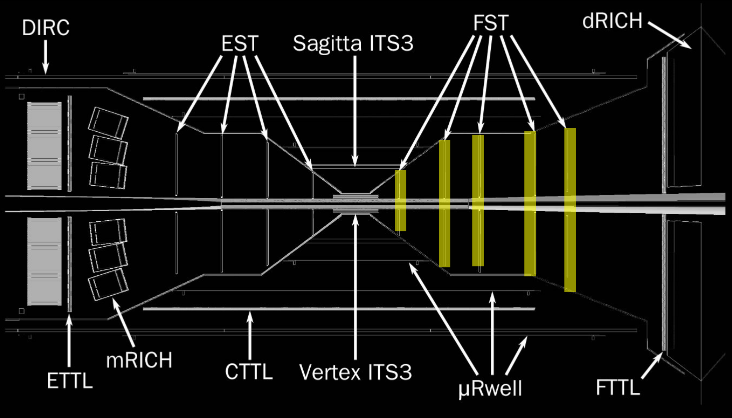
another potential parameter to optimize?



Additional thickness for services, cooling is given here

EST Disks

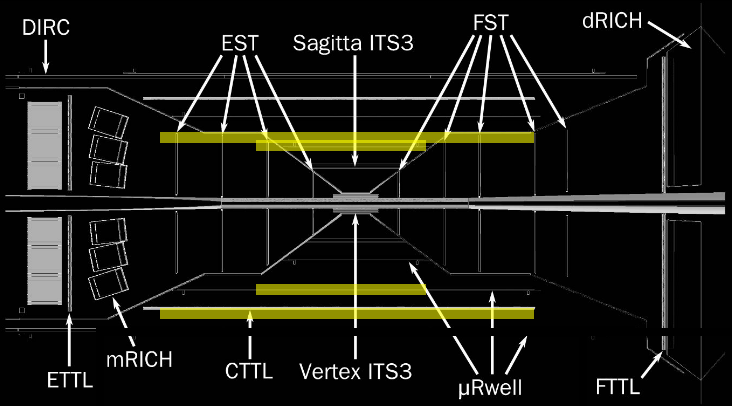
			Reference			Ongoing R&D		
Disk	Si Thickness[um]	Pitch[um]	RMin [cm]	RMax[cm]	ZPos[cm]	RMin [cm]	RMax [cm]	ZPos[cm]
EST 4	35	10	5.5	41.5	-106	6.0	48.0	-107.4
EST 3	35	10	4.5	40.5	-79	4.8	35.25	-80.05
EST 2	35	10	3.5	36.5	-52	3.3	27.3	-58.29
EST 1	35	10	3.5	18.5	-25	3.3	15.3	-33.2



Additional thickness for services, cooling is given here

FST Disks

			Reference			Ongoing R&D		
Disk	**Si Thickness [um]**	**Pitch [um]**	**RMin [cm]**	**RMax [cm]**	**ZPos [cm]**	**RMin [cm]**	**RMax [cm]**	**ZPos [cm]**
FST 5	35	10	7.5	43.5	125	8.2	62.2	144
FST 4	35	10	5.5	41.5	106	5.8	49.8	115
FST 3	35	10	4.5	40.5	73	4.8	34.8	79.85
FST 2	35	10	3.5	36.5	49	3.5	27.5	58.29
FST 1	35	10	3.5	18.5	25	3.5	15.5	33.2



μRwell Cylinder

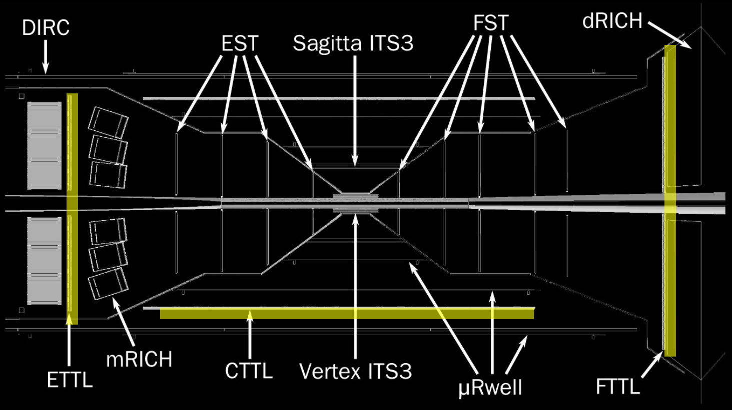
Additional thickness for services, cooling is given here

Kapton 0.0175 cm (0.06125% XX0);
Cu 0.002 cm (0.13928% XX0);
pcb 0.01 cm (0.06XX0% ???);
Prepreg 0.005 cm (0.031% XX0???)

			Reference		Ongoing R&D	
Barrel	Res [um]	Thickness [cm]	Radii [cm]	Length [cm]	Radii [cm]	Length [cm]
Layer 1	55(85, 100)	0.03	33.14	80	33.14	140
Layer 2	55(85, 100)	0.03	51.00	212	51.00	230
Layer 3	55(85, 100)	0.03	77.02	342	77.02	342

*Also studied these resolutions values for this update studies

another potential parameter to optimize?



TOF Detectors

TOF TTL	Si Thickness [um]	Pitch [um]	Reference			Ongoing R&D		
			RMin [cm]	RMax [cm]	ZPos/ Length [cm]	RMin [cm]	RMax [cm]	ZPos [cm]
CTTL	85	30	64	-	140	64	-	140
ETTL	85	30	8	64	-155.5	8	64	-169
FTTL	85	30	7	87	182	7	87	182

Additional thickness for services, cooling is given here

Reference Design

µRwell resolution = 55µm

1.5M Events with 5 π^- tracks /event

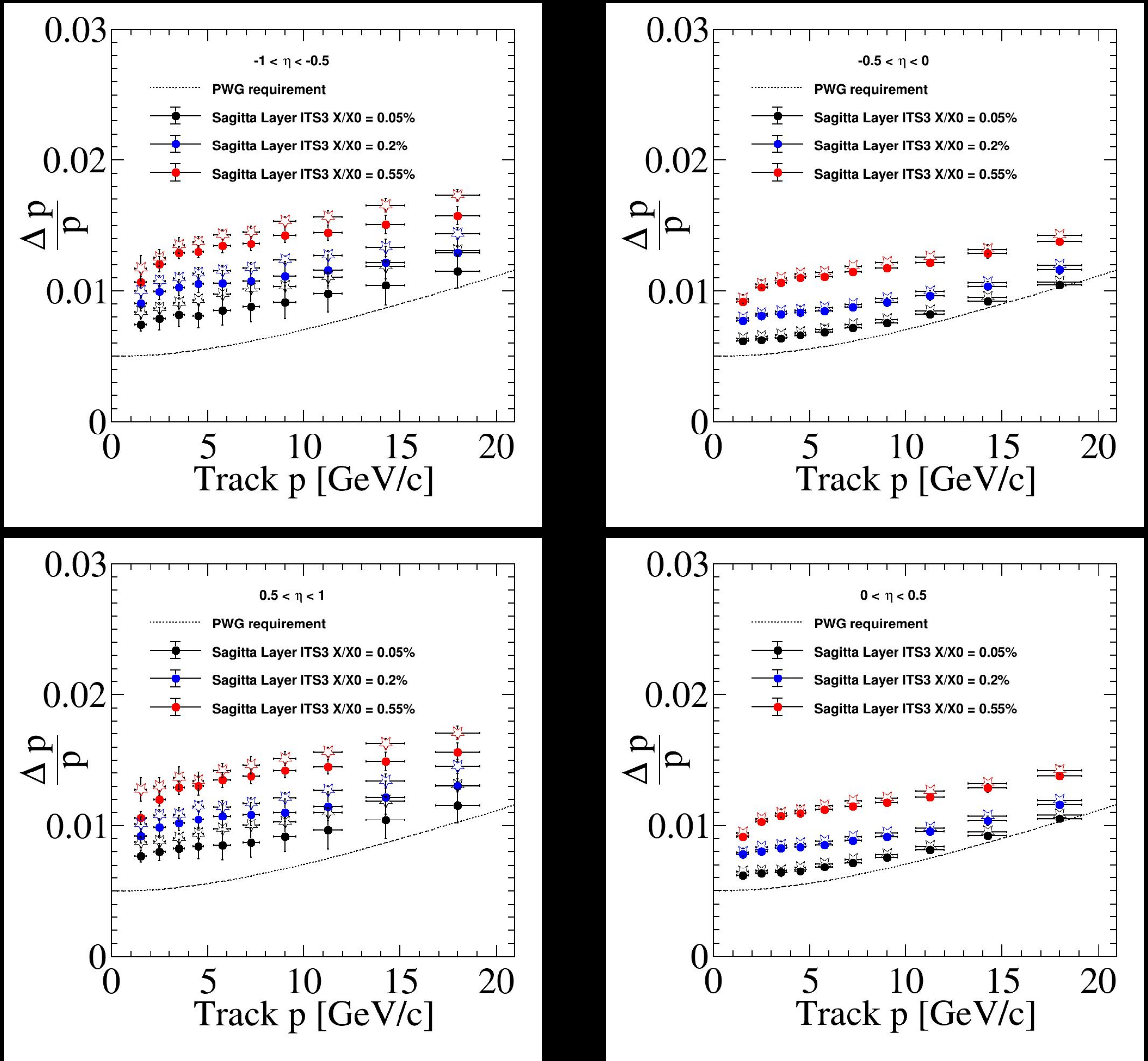
Fun4All Framework

Both Sagitta Layer X/X0 are changed in the same way

Single Gaussians fits (solid colors) have large uncertainty

Double Gaussians fits (hollow)

Distribution near support structure is not gaussian.



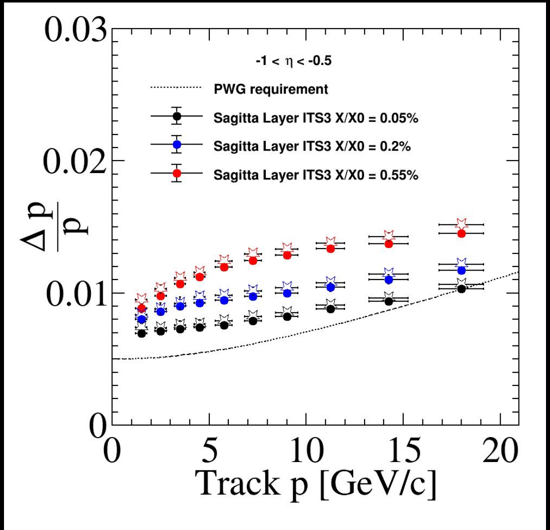
Projective Design

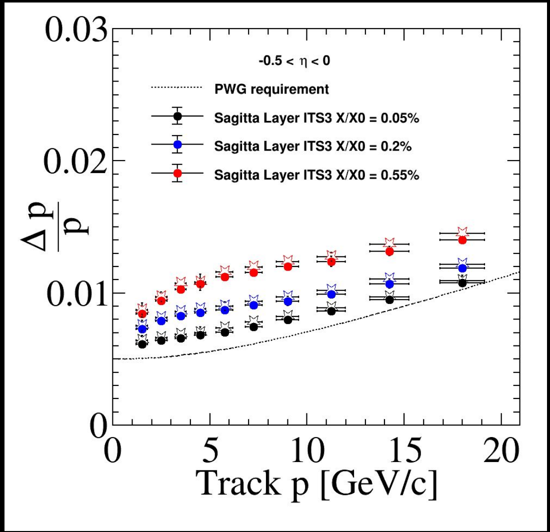
μRwell resolution = 55μm

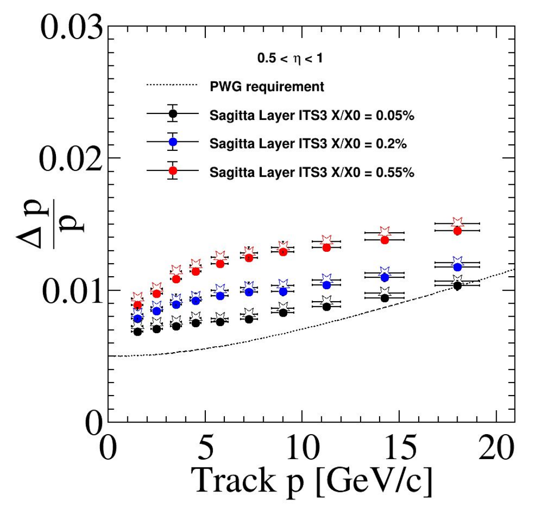
1.5M Events with 5 π^- tracks /event

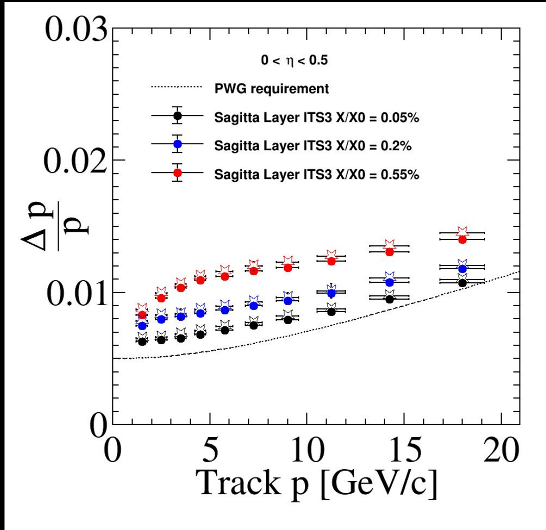
Fun4All Framework

Both Sagitta Layer (X/X0) are changed in the same way









Reference Design

μRwell resolution = 85μm

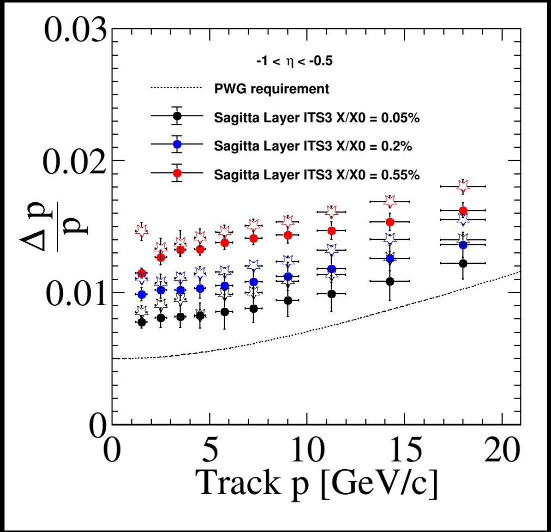
1.5M Events with 5 π^- tracks /event

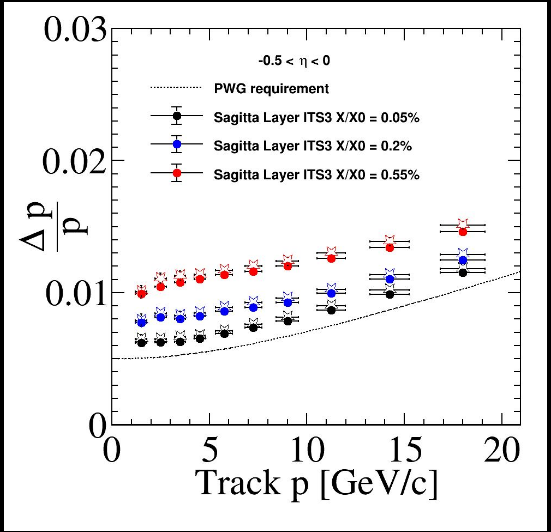
Fun4All Framework

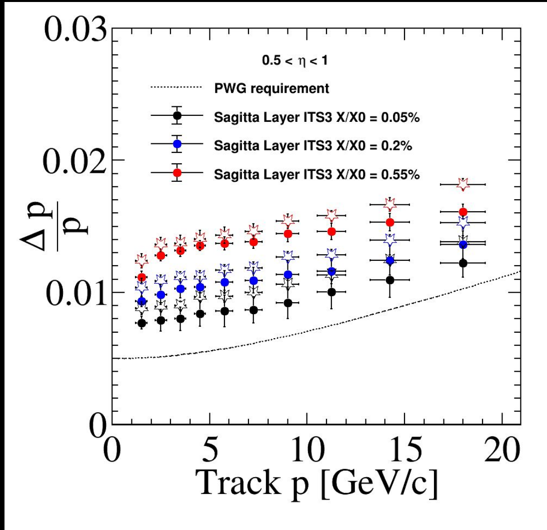
Both Sagitta Layer (X/X0) are changed in the same way

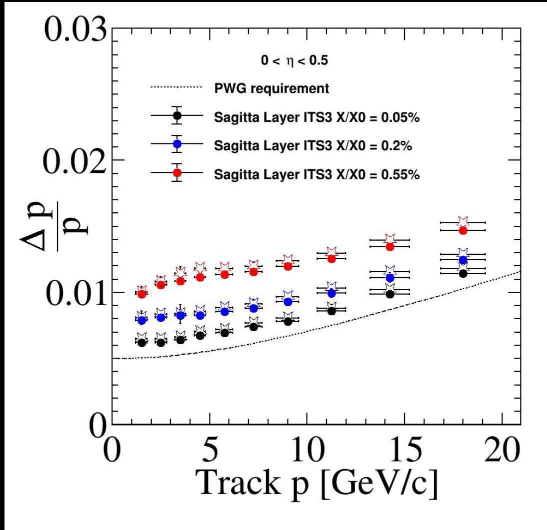
Solid Colors have large uncertainty

Distribution near support structure is not gaussian.









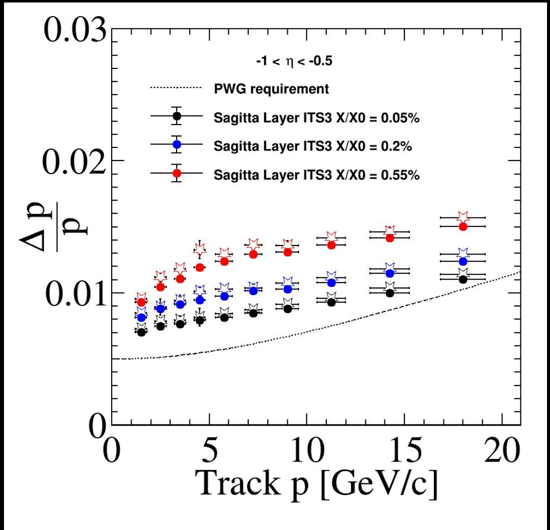
Projective Design

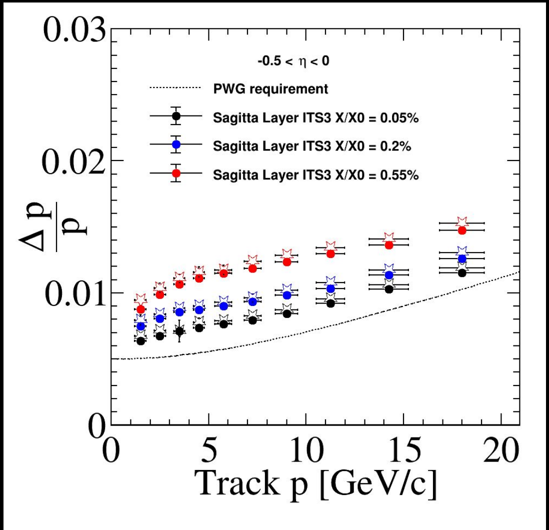
µRwell resolution = 85µm

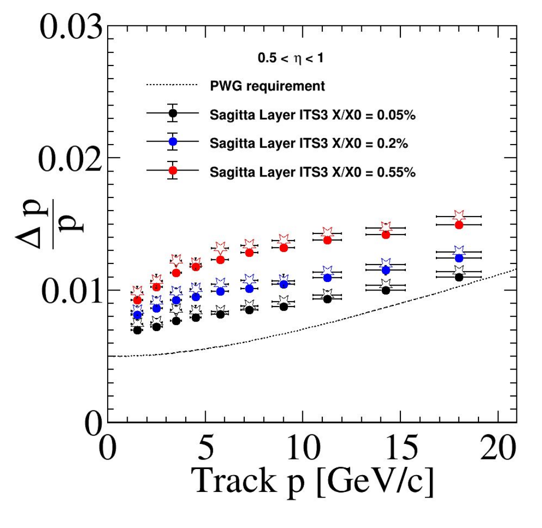
1.5M Events with 5 π^- tracks /event

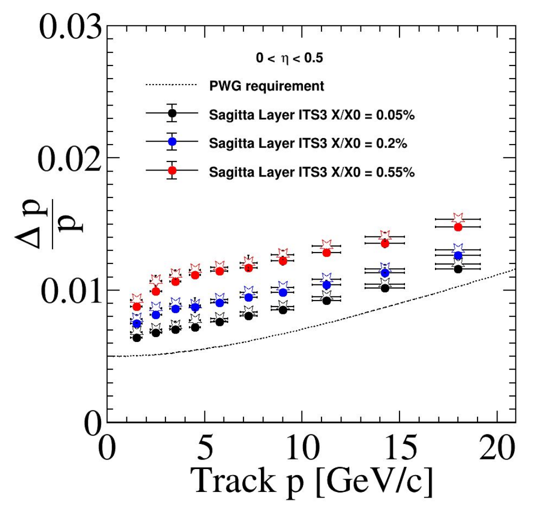
Fun4All Framework

Both Sagitta Layer (X/X0) are changed in the same way









Reference Design

μRwell resolution = 100μm

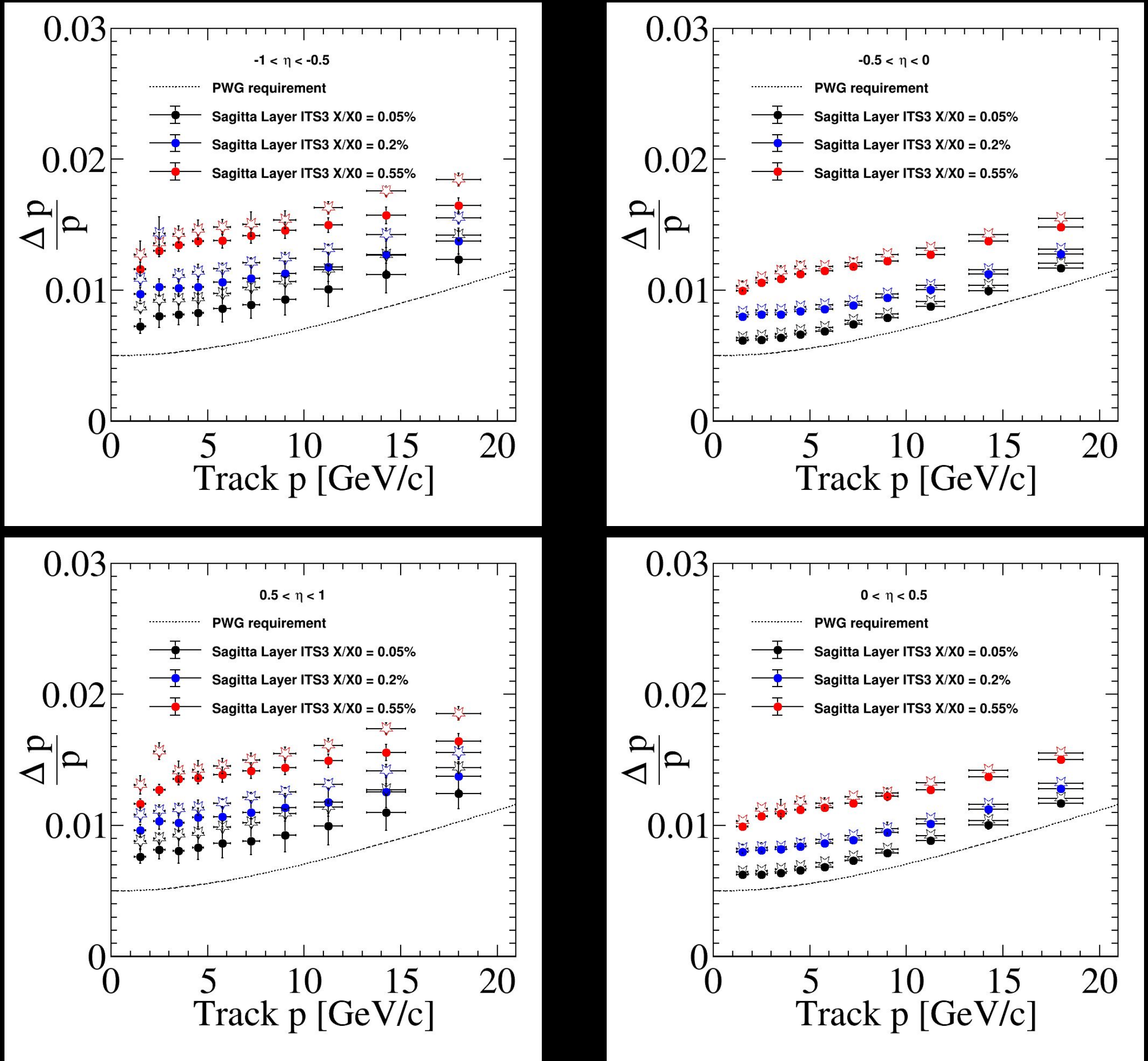
1.5M Events with 5 π^- tracks /event

Fun4All Framework

Both Sagitta Layer (X/X0) are changed in the same way

Solid Colors have large uncertainty

Distribution near support structure is not gaussian.



Projective Design

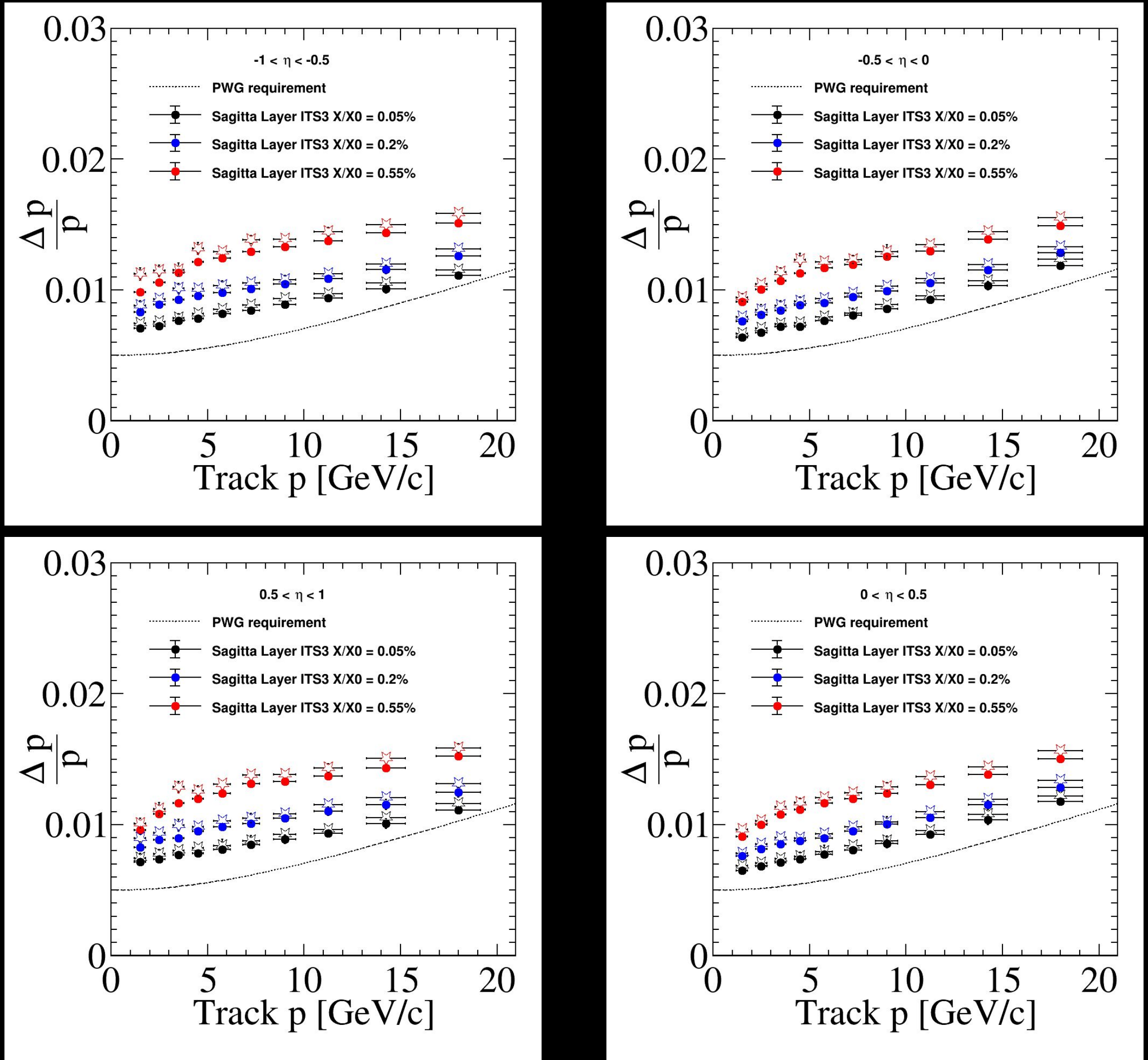
µRwell resolution = 100µm

1.5M Events with 5 π^- tracks /event

Fun4All Framework

Both Sagitta Layer (X/X0) are changed in the same way

Impact of XX0 sagitta is more significant compared to the spatial resolution of the uRwell barrels.



Reference Design
Hit Eff Studies

µRwell resolution = 55µm
Sagitta Layer ITS X/X0 = 0.05%

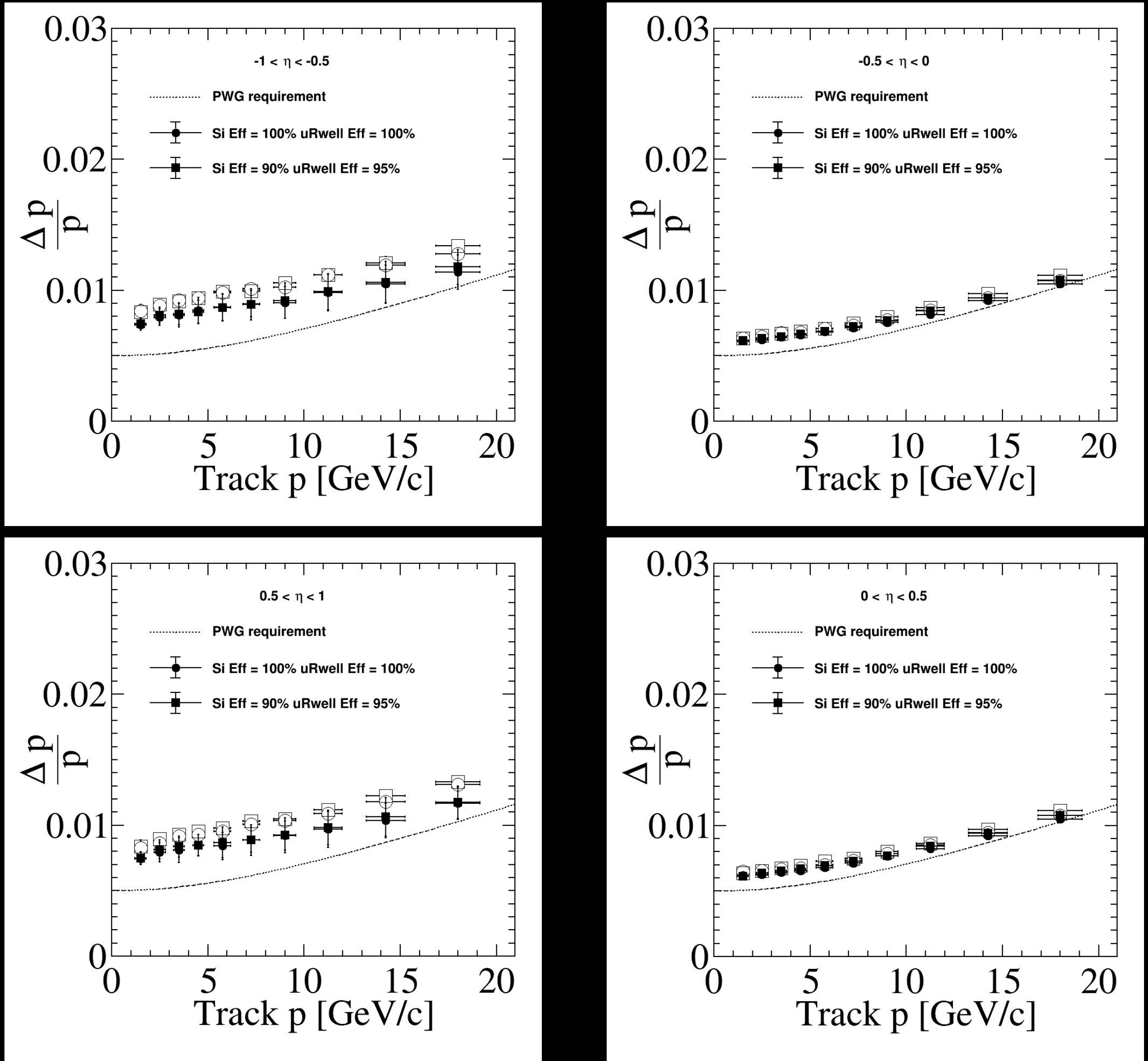
1.5M Events with 5 π^- tracks /event

Fun4All Framework

Both Sagitta Layer (X/X0) are changed in the same way

Hit Efficiencies include all Si Detectors (TTL included)

For each layer, Hit Efficiency is modelled during the Track Fitting procedure.



Reference Design Hit Eff Studies

μRwell resolution = 55μm
Sagitta Layer ITS X/X0 = 0.2%

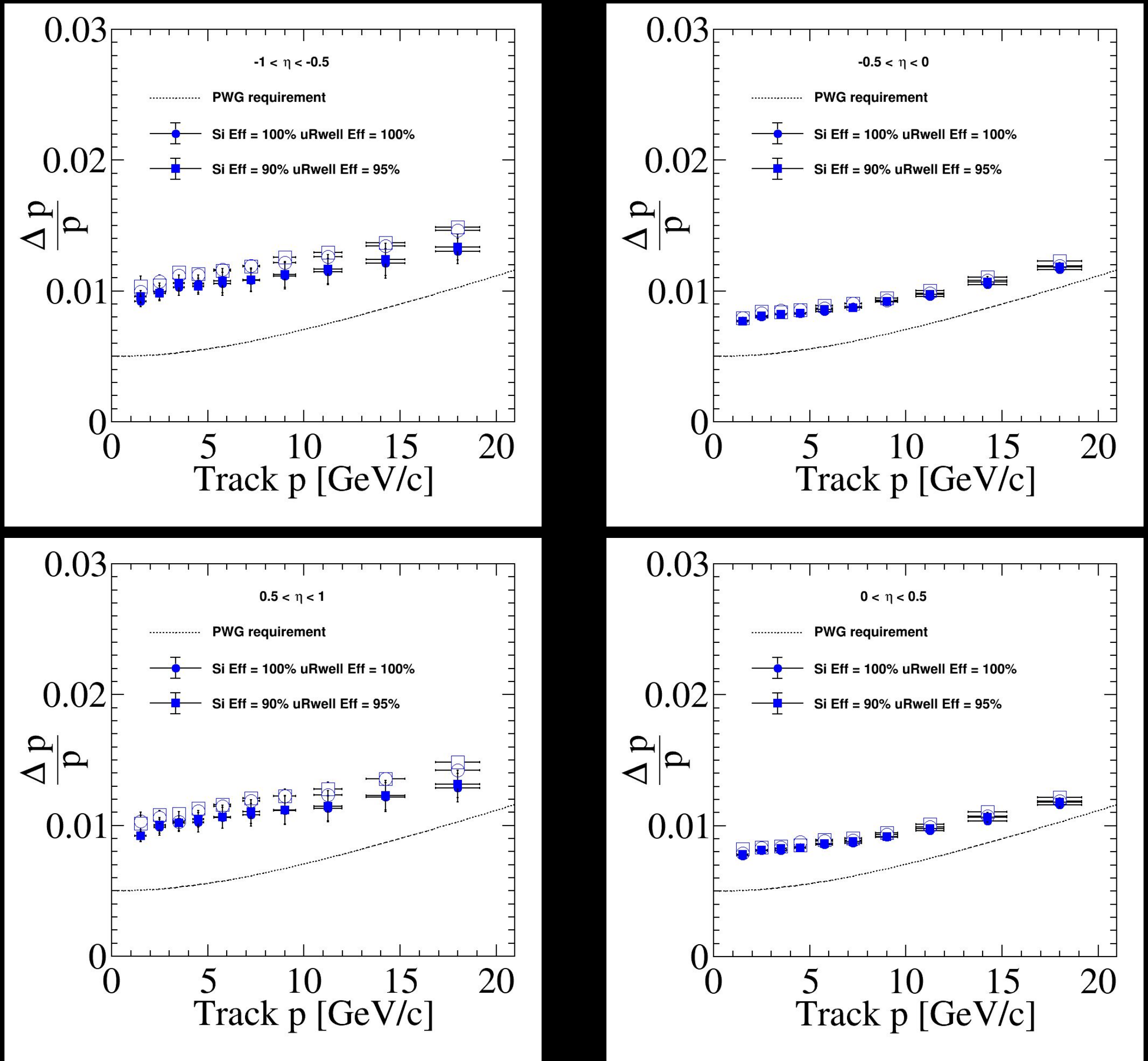
1.5M Events with 5 π^- tracks /event

Fun4All Framework

Both Sagitta Layer (X/X0) are changed in the same way

Hit Efficiencies include all Si Detectors (TTL included)

For each layer, Hit Efficiency is modelled during the Track Fitting procedure.



Reference Design
Hit Eff Studies

μRwell resolution = 55μm
Sagitta Layer ITS X/X0 = 0.55%

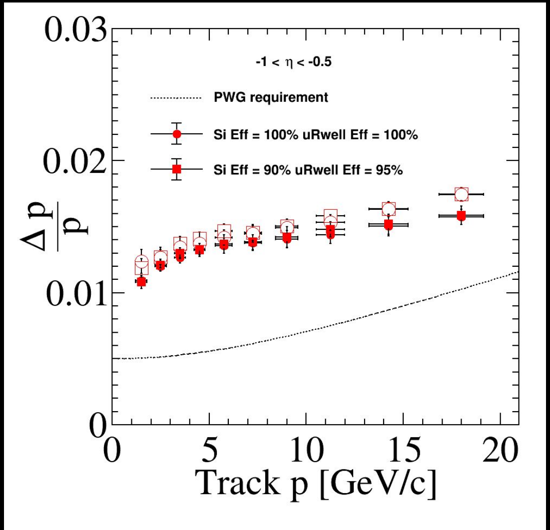
1.5M Events with 5 π^- tracks /event

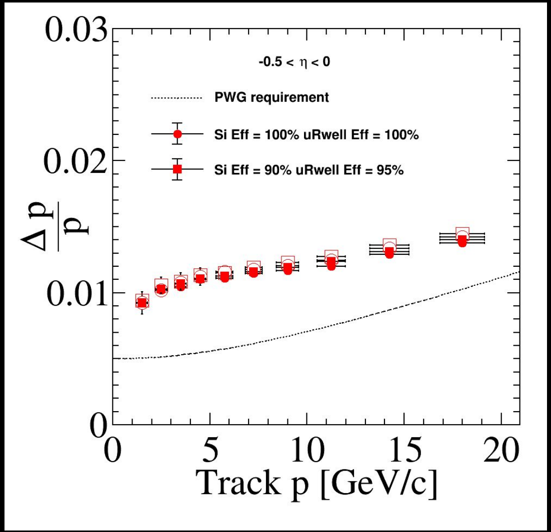
Fun4All Framework

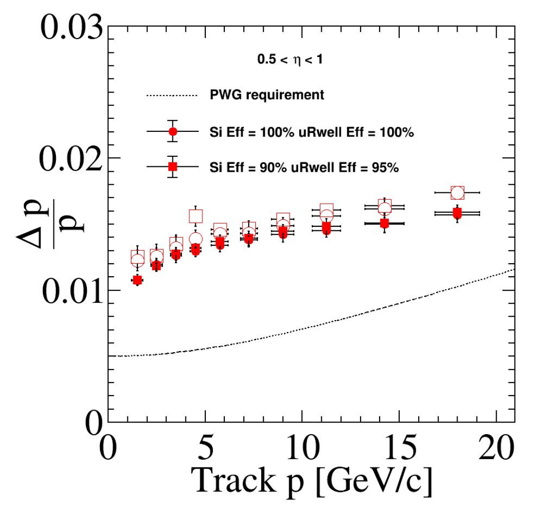
Both Sagitta Layer (X/X0) are changed in the same way

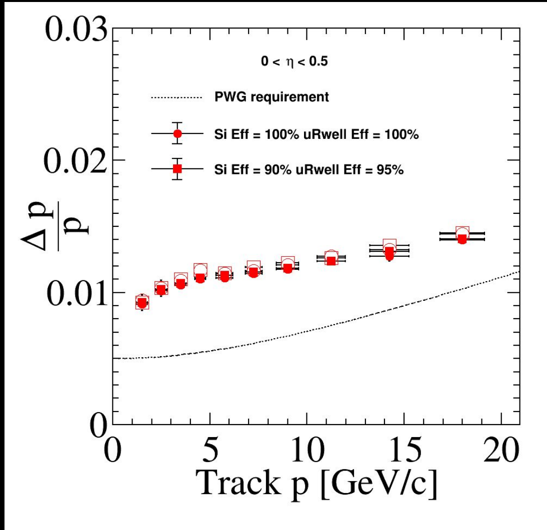
Hit Efficiencies include all Si Detectors (TTL included)

For each layer, Hit Efficiency is modelled during the Track Fitting procedure.



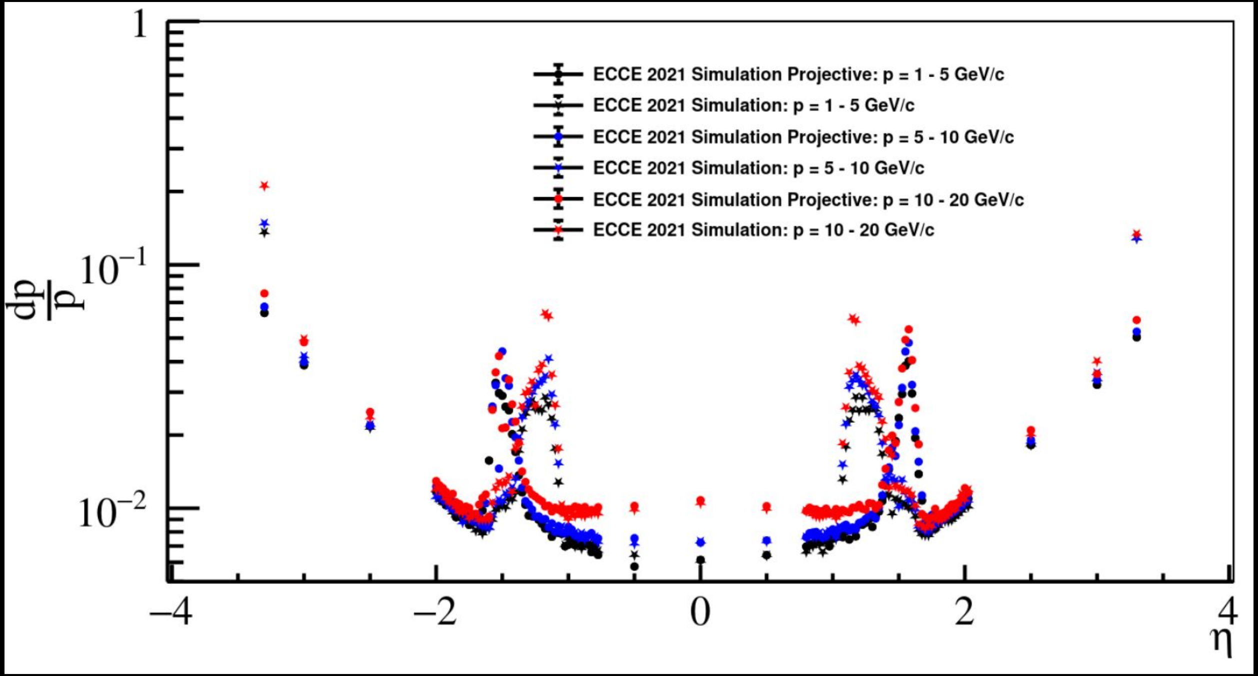






Projective Vs Non-projective design

arXiv:2205.09185



Projective design concentrate the material budget in a smaller region of the phase-space, resulting in better resolution in the transition region.

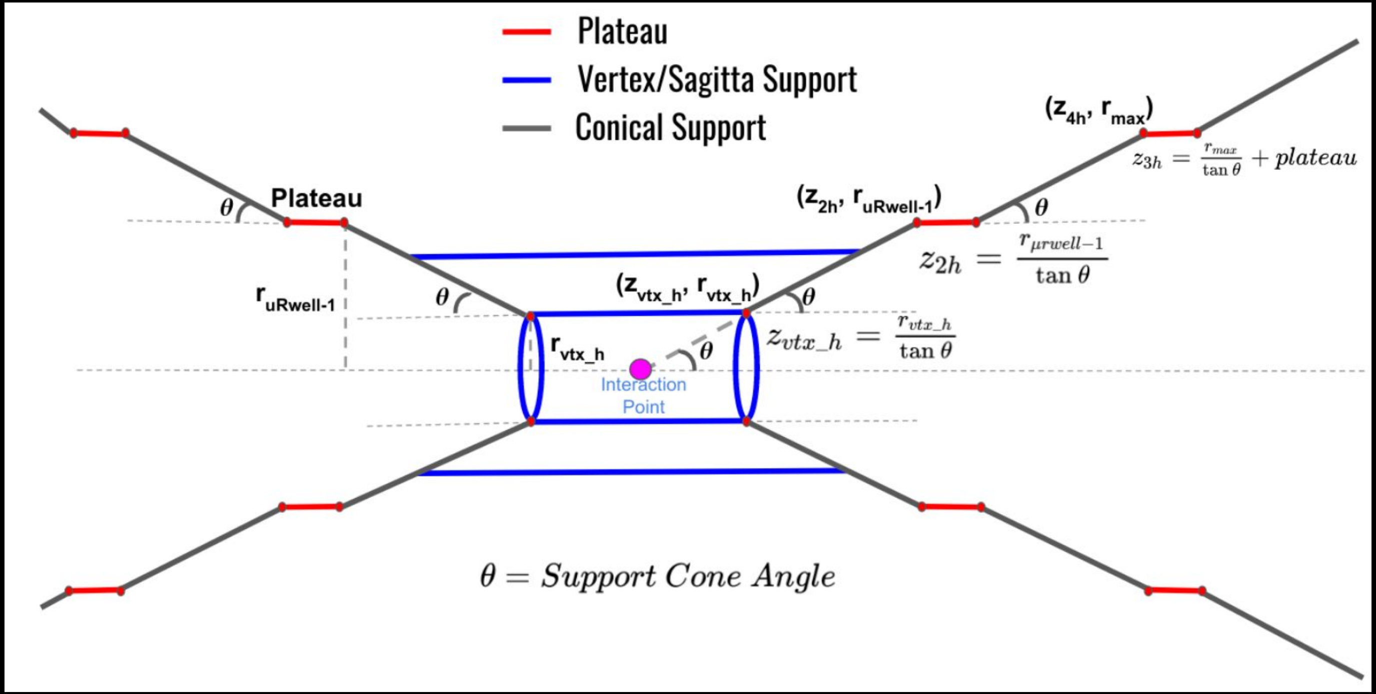
From these studies

- Sagitta thickness has the major impact on the momentum resolution in the barrel
- uRWELL resolution has less significant impact on the momentum resolution in the barrel
- Hit Efficiency no significant impact within the uncertainties
- Projective concentrates material of support structure in smaller region of η and provides better performance in transition region
- Optimization studies cannot be limited to barrel, important to look at endcaps too simultaneously and through different objectives (resolutions, efficiencies, etc.)…

Parametrization

arXiv:2205.09185

Parametrization of the support structure



Parametrization of disks radii and TTL

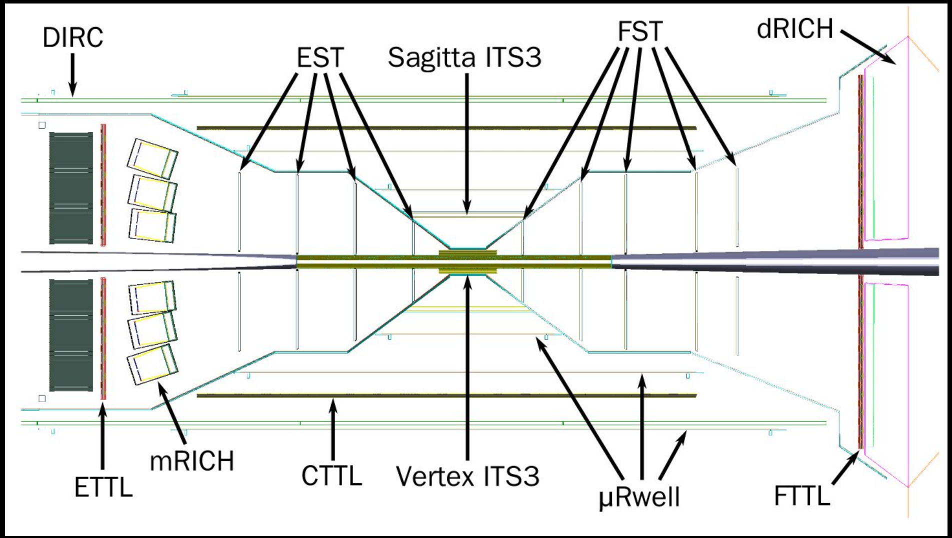
Implementation of Geometric Constraints

RMax and RMin of the disks are then calculated based on the support structure.

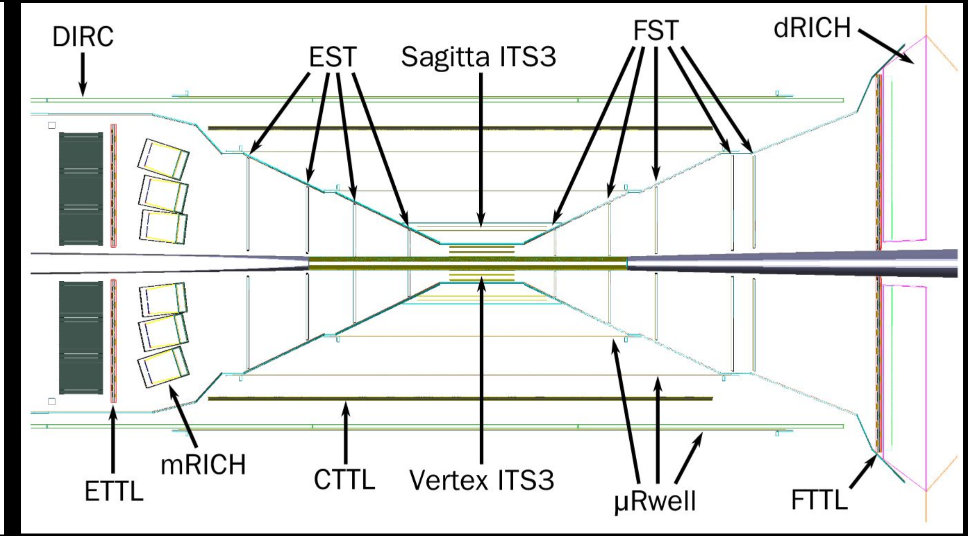
Sagitta Length fixed and Radius changed based on the support cone angle.

Parametrization underlies the AI-assisted design and can explore non-projective as well as projective

Reference Design

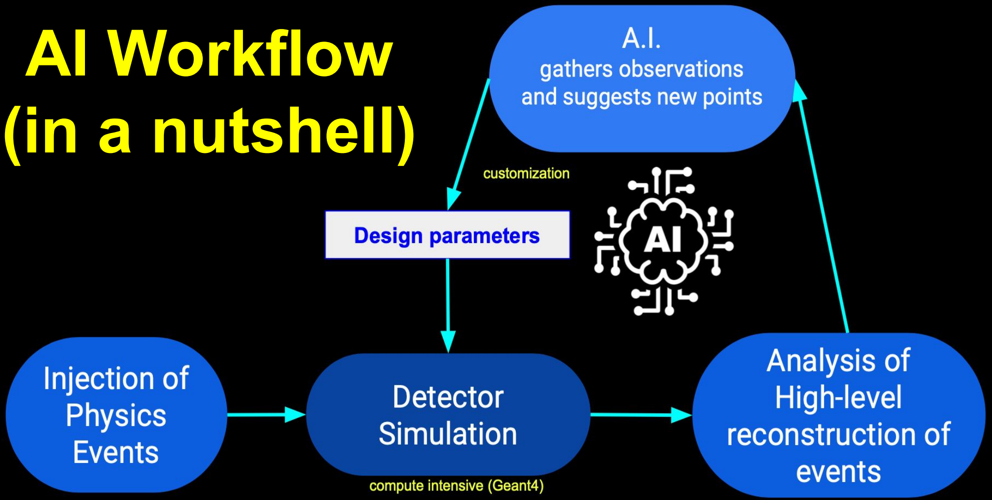


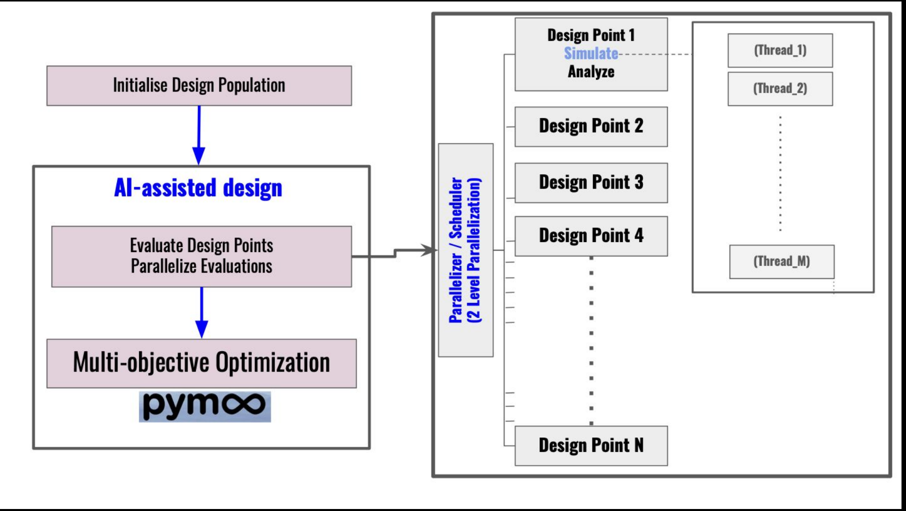
Projective Design



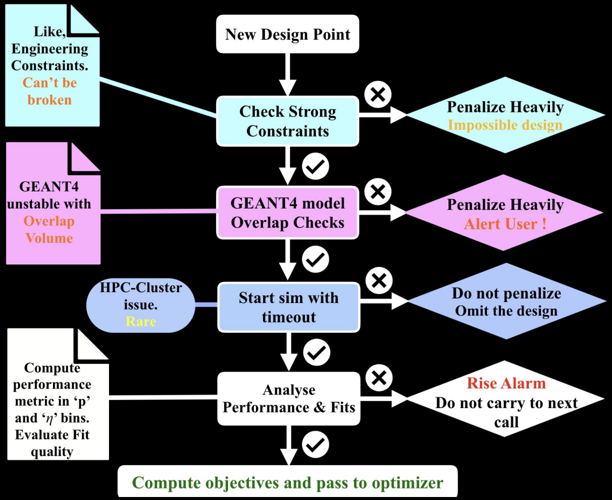
Parametrization underlies the AI-assisted design and can explore non-projective as well as projective

AI Workflow (in a nutshell)



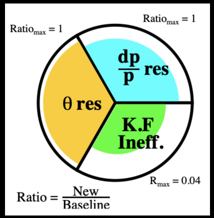


Feasibility of Design



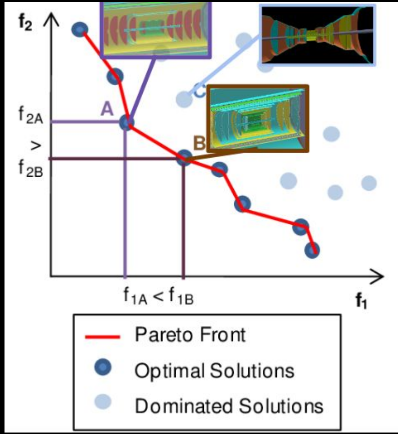
Multi-objective Optimization with constraints

$$
\begin{aligned}
&\min \mathbf{f_m}(\mathbf{x}) && m = 1, \cdots, M \\
s.t.\ &\mathbf{g_j}(\mathbf{x}) \leq 0, && j = 1, \cdots, J \\
&\mathbf{h_k}(\mathbf{x}) = 0, && k = 1, \cdots, K \\
&x_i^L \leq x_i \leq x_i^U, && i = 1, \cdots, N
\end{aligned}
$$

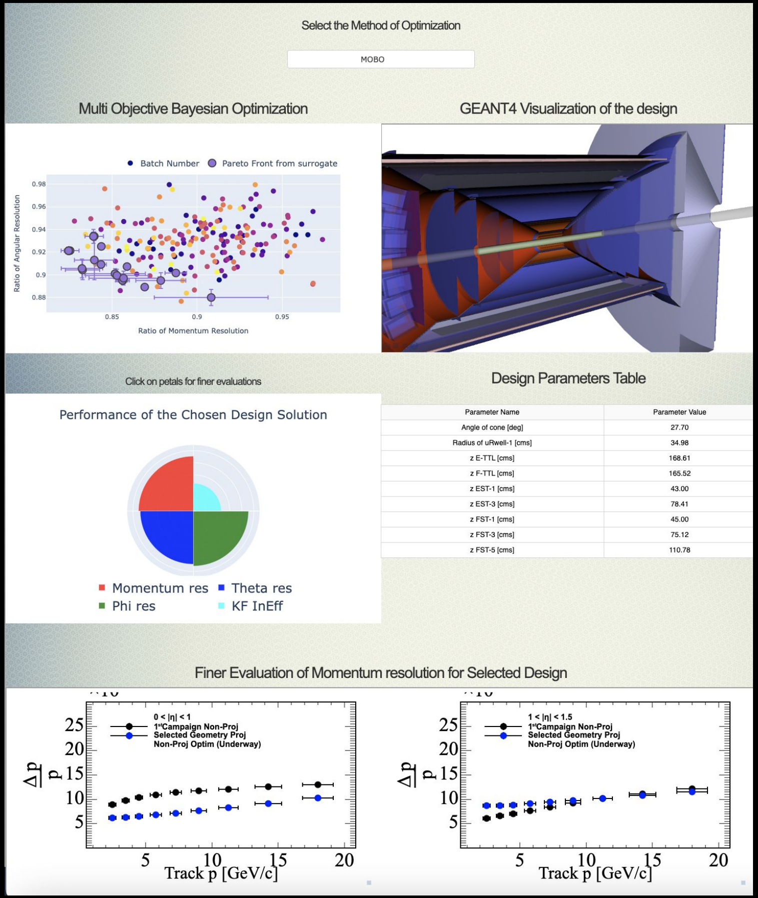


This framework has been used to design the entire tracker (arXiv:2205.09185) and can accommodate any new updated and more realistic requirement

Pareto Front: multiple tradeoff design solutions!



- When working with multiple competing objectives looking at the global design over the <u>entire phase-space</u>
- Visualization of results from approximated Pareto front
- Facilitate study/comparison of trade-off solutions
- Provide insights on hidden correlations



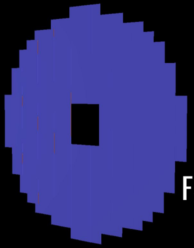
The AI-driven approach is more than just fine-tuning! That will happen only when we converge on the final design

https://ai4eicdetopt.pythonanywhere.com

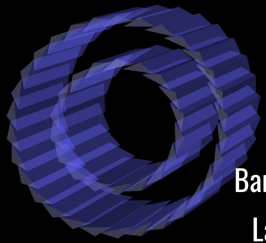
BACKUP

Extensive details at arXiv:2205.09185

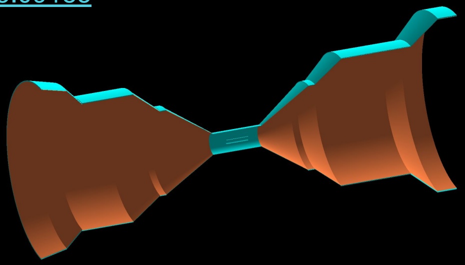
Constraints



FST/EST Disks



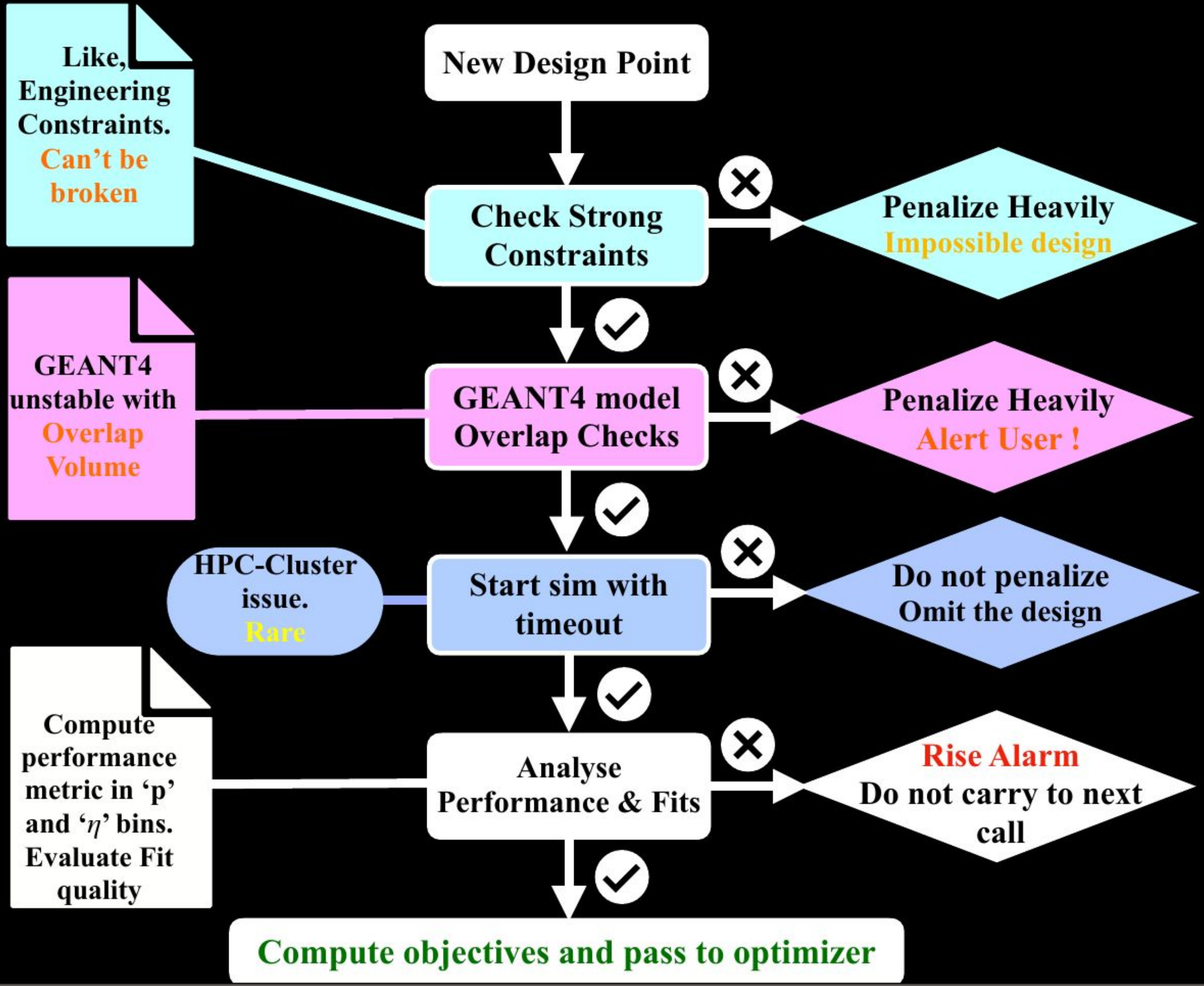
Barrel Si Layer



- **Design Parameters** ($n\_pars \geq 9$)
  - Based on an extensive parameterization.
- **Constraints** being used ($n\_const \geq 3$)
  - STRONG The minimum distance between any 2 disks should be >= 10 cm (giving room for services)
  - SOFT The Rmax-Rmin for the disks have to be multiple of 3.00 cms and 1.8 cms (Tiling of pixels)
- **Overlaps checked**
  - GEANT4 unstable when overlaps are detected in volumes.
  - Overlaps are checked for every design explored and penalized.

sub-detector	constraint	description
EST/FST disks	$min\left\{\sum_i^{disks}\left\|\frac{R^i_{out}-R^i_{in}}{d} - \left[\frac{R^i_{out}-R^i_{in}}{d}\right]\right\|\right\}$	**soft constraint**: sum of residuals in sensor coverage for disks; sensor dimensions: $d = 17.8$ (30.0) mm
EST/FST disks	$z_{n+1} - z_n >= 10.0$ cm	**strong constraint**: minimum distance between 2 consecutive disks
sagitta layers	$min\left\{\left\|\frac{2\pi r_{sagitta}}{w} - \left[\frac{2\pi r_{sagitta}}{w}\right]\right\|\right\}$	**soft constraint**: residual in sensor coverage for every layer; sensor strip width: $w = 17.8$ mm
μRWELL	$r_{n+1} - r_n >= 5.0$ cm	**strong constraint**: minimum distance between μRwell barrel layers

ECCE design (non-projective)	
Design Parameter	**Range**
μRWELL 1 (Inner) (r) Radius	[17.0, 51.0 cm]
μRWELL 2 (Inner) (r) Radius	[18.0, 51.0 cm]
EST 4 z position	[-110.0, -50.0 cm]
EST 3 z position	[-110.0, -40.0 cm]
EST 2 z position	[-80.0, -30.0 cm]
EST 1 z position	[-50.0, -20.0 cm]
FST 1 z position	[20.0, 50.0 cm]
FST 2 z position	[30.0, 80.0 cm]
FST 3 z position	[40.0, 110.0 cm]
FST 4 z position	[50.0, 125.0 cm]
FST 5 z position	[60.0, 125.0 cm]
ECCE ongoing R&D (projective)	
Design Parameter	**Range**
Angle (Support Cone)	[25.0°, 30.0°]
μRWELL 1 (Inner) Radius	[25.0, 45.0 cm]
ETTL z position	[-171.0, -161.0 cm]
EST 2 z position	[45, 100 cm]
EST 1 z position	[35, 50 cm]
FST 1 z position	[35, 50 cm]
FST 2 z position	[45, 100 cm]
FST 5 z position	[100, 150 cm]
FTTL z postion	[156, 183 cm]

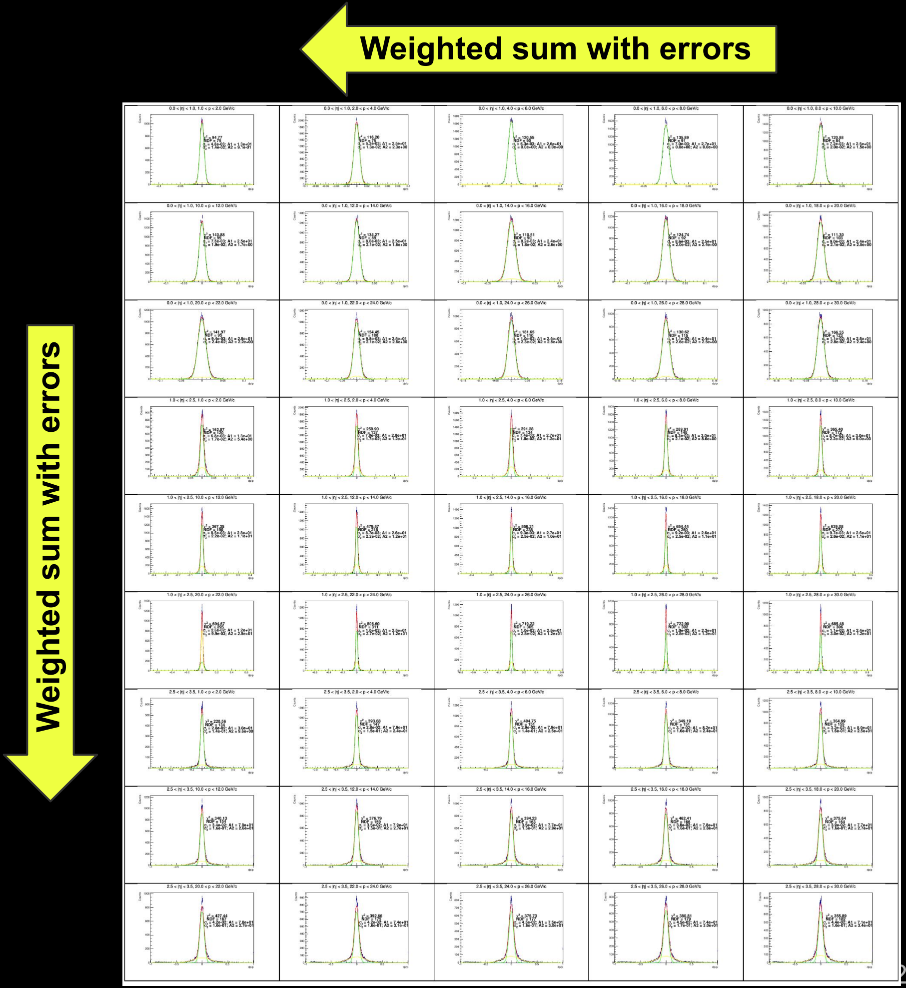


New Design Point
Like, Engineering Constraints. Can't be broken
Check Strong Constraints
Penalize Heavily Impossible design
GEANT4 unstable with Overlap Volume
GEANT4 model Overlap Checks
Penalize Heavily Alert User !
HPC-Cluster issue. Rare
Start sim with timeout
Do not penalize Omit the design
Compute performance metric in 'p' and 'η' bins. Evaluate Fit quality
Analyse Performance & Fits
Rise Alarm Do not carry to next call
Compute objectives and pass to optimizer

Implementation

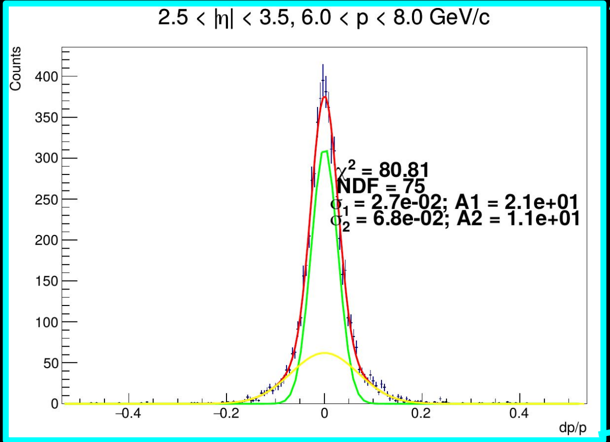
- **Objective functions** Average of Weighted Averages (n_obj ≥ 3)
  - **Momentum resolution dp/p**
  - **Theta resolution dθ/θ**
  - **Projected dθ/θ at PID location.**
  - **Kalman Filtering inefficiency** (improving the tracking reconstruction ability of the algorithm)

- **Validation** of the solutions
  - Validate by comparing optimal vs baseline dφ resolution, vertex resolution and reconstruction efficiency



Implementation

Weighted sum with errors



Propagate uncertainties from fits

$$\bar{x_\eta} = \frac{\sum_p x_p w_p}{\sum_p w_p}$$

Average objective in a η bin

Sum in bins of P 14 bins

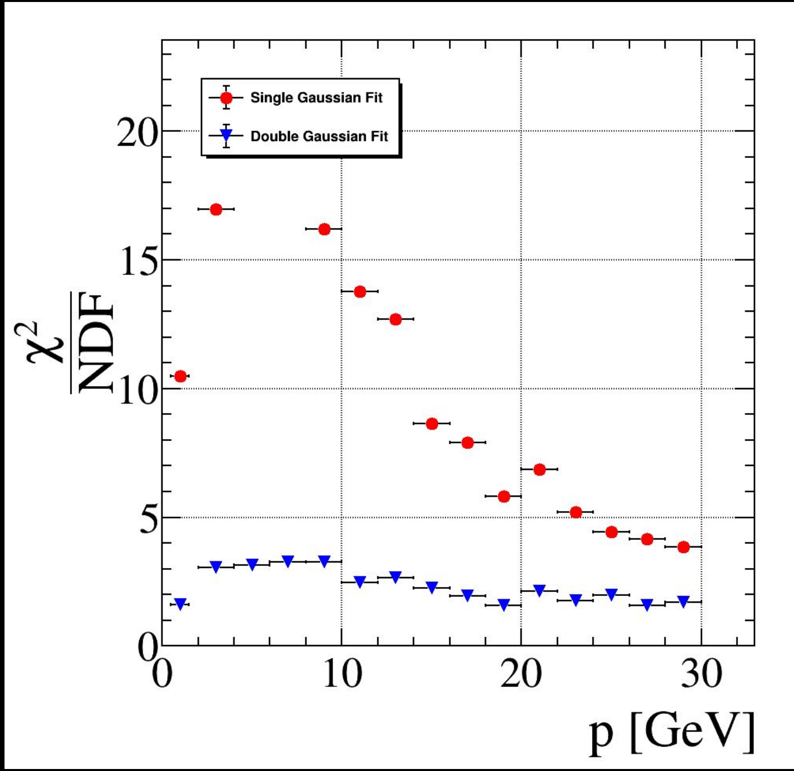
$$\bar{x} = \frac{\sum_\eta^{N_\eta} \bar{x_\eta}}{N_\eta}$$

6 η bins

$$R(f) = \frac{1}{N_\eta} \sum_\eta \left(\frac{\sum_p w_{p,\eta} \cdot R(f)_{p,\eta}}{\sum_p w_{p,\eta}} \right)$$

Weighted sum with errors

Single Vs Double Gaussian



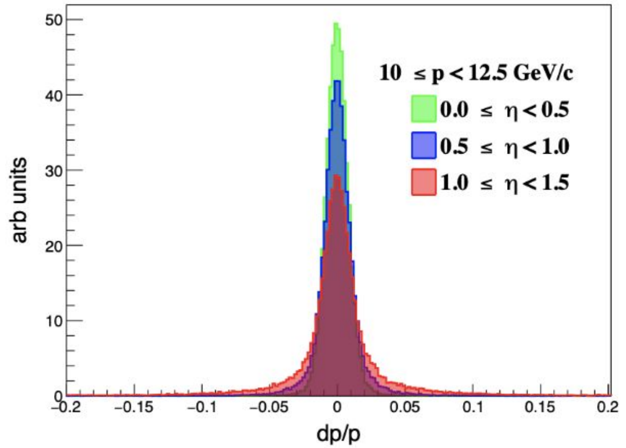


Figure 6: **Fit strategy:** a double-Gaussian fit function is utilized to extract the resolutions. Such a fit function provided good reduced χ^2 and more stable extractions compared to single-Gaussian fits. The resolution is obtained as an average of the two σ's weighted by the relative areas of the two Gaussians according to Eq. (3). The figure represents the results corresponding to a particular bin in η and p.

Non-Projective VS Projective, actually…

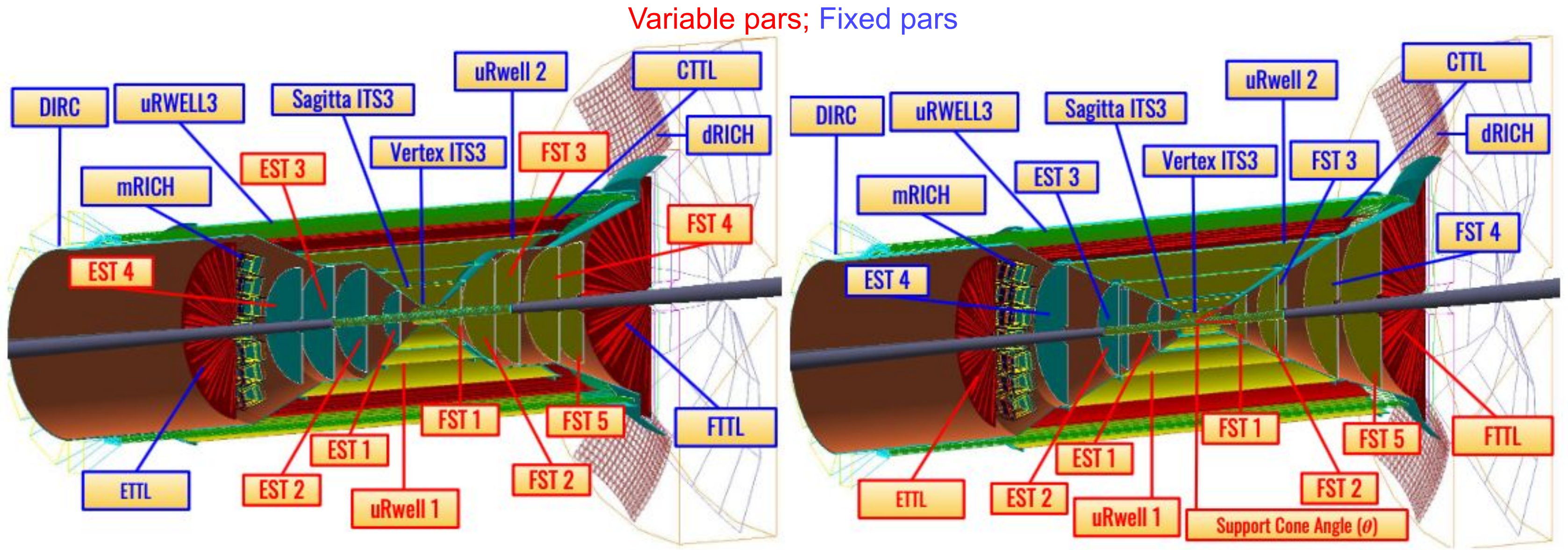
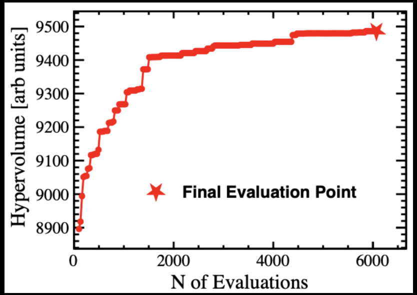


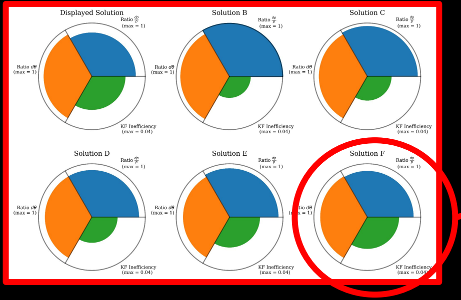
Figure 5: **Tracking and PID system in the non-projective (left) and the ongoing R&D projective (right) designs:** the two figures show the different geometry and parametrization of the ECCE non-projective design (left) and of the ongoing R&D projective design to optimize the support structure (right). Labels in red indicate the sub-detector systems that were optimized, while the labels in blue are the sub-detector systems that were kept fixed due to geometrical constraint. The non-projective geometry (left) is a result of an optimization on the inner tracker layers (labeled in red) while keeping the support structure fixed, The angle made by the support structure to the IP is fixed at about 36.5°. The projective geometry (right) is the result of an ongoing project R&D to reduce the impact of readout and services on tracking resolution.

“Navigate” Pareto Front

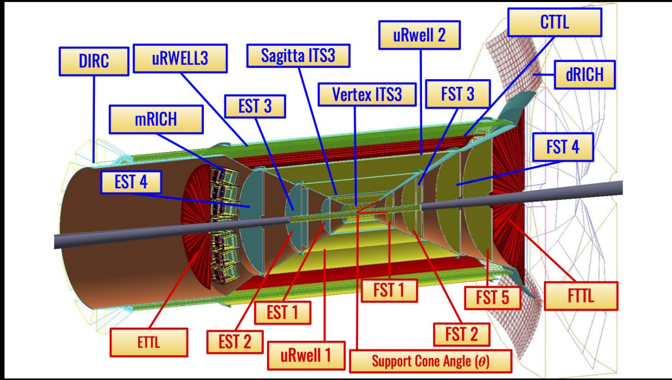
1 Can take a snapshot any time during evaluation



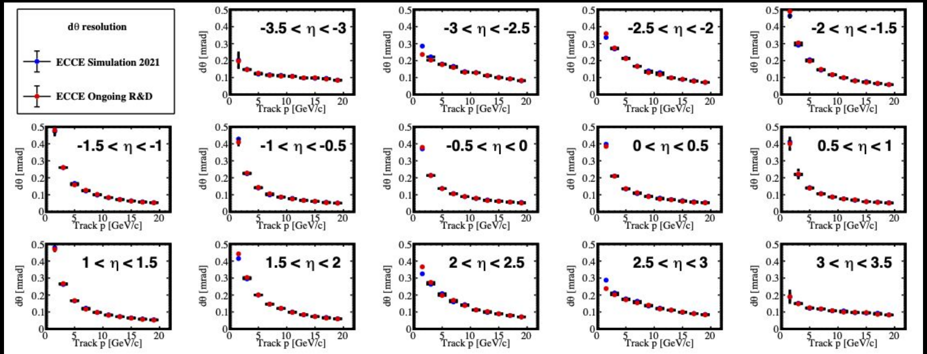
2 Updated Pareto Front at time t

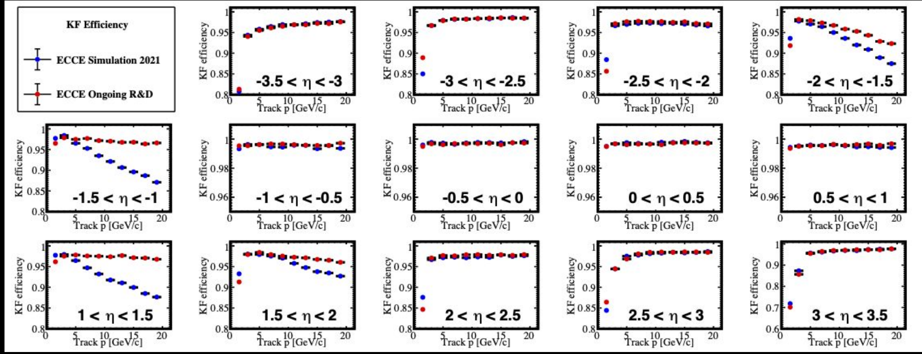


3 At each point in the Pareto front corresponds a design

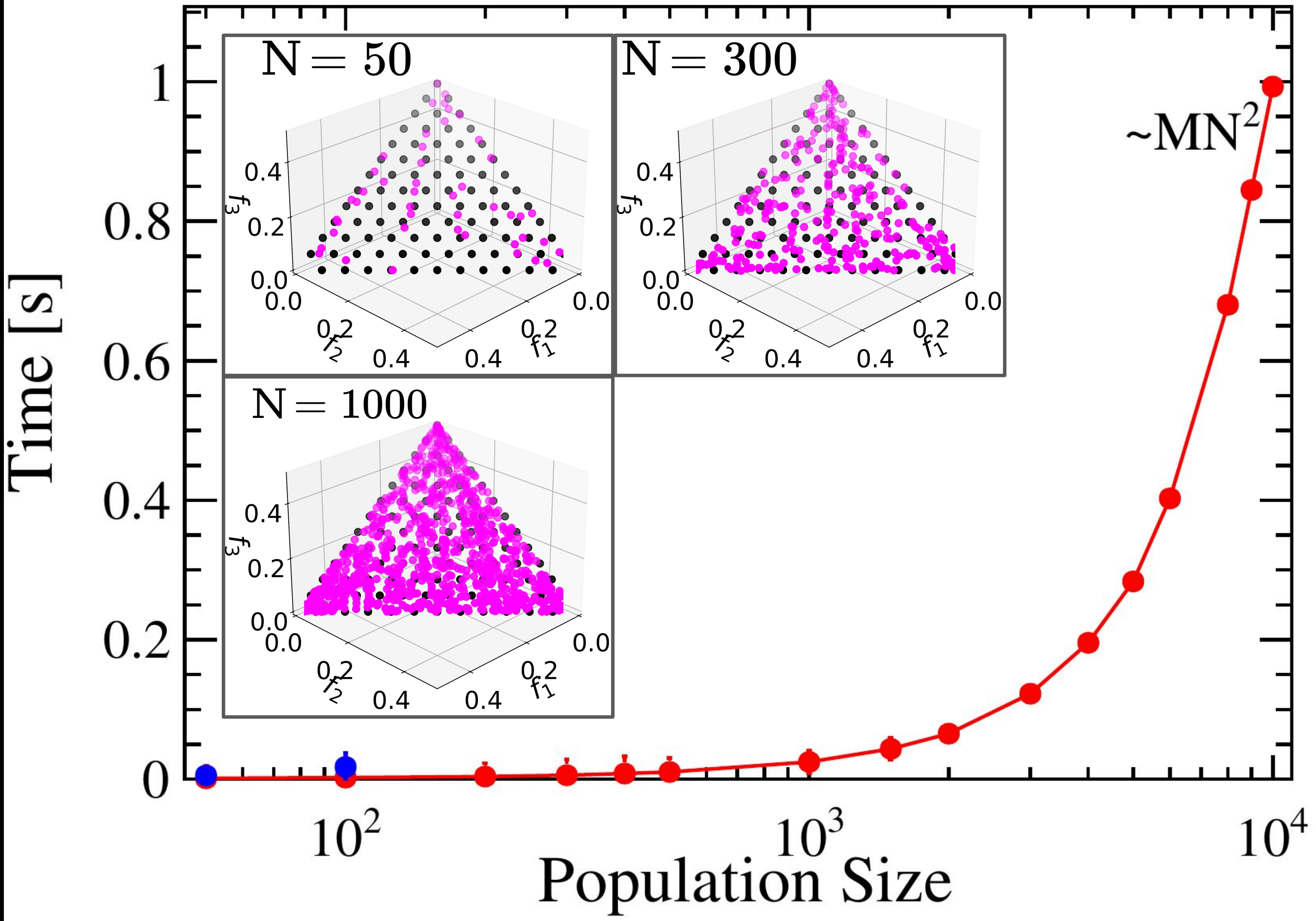


4 Analysis of Objectives (momentum resolution, angular resolution, KF efficiency)

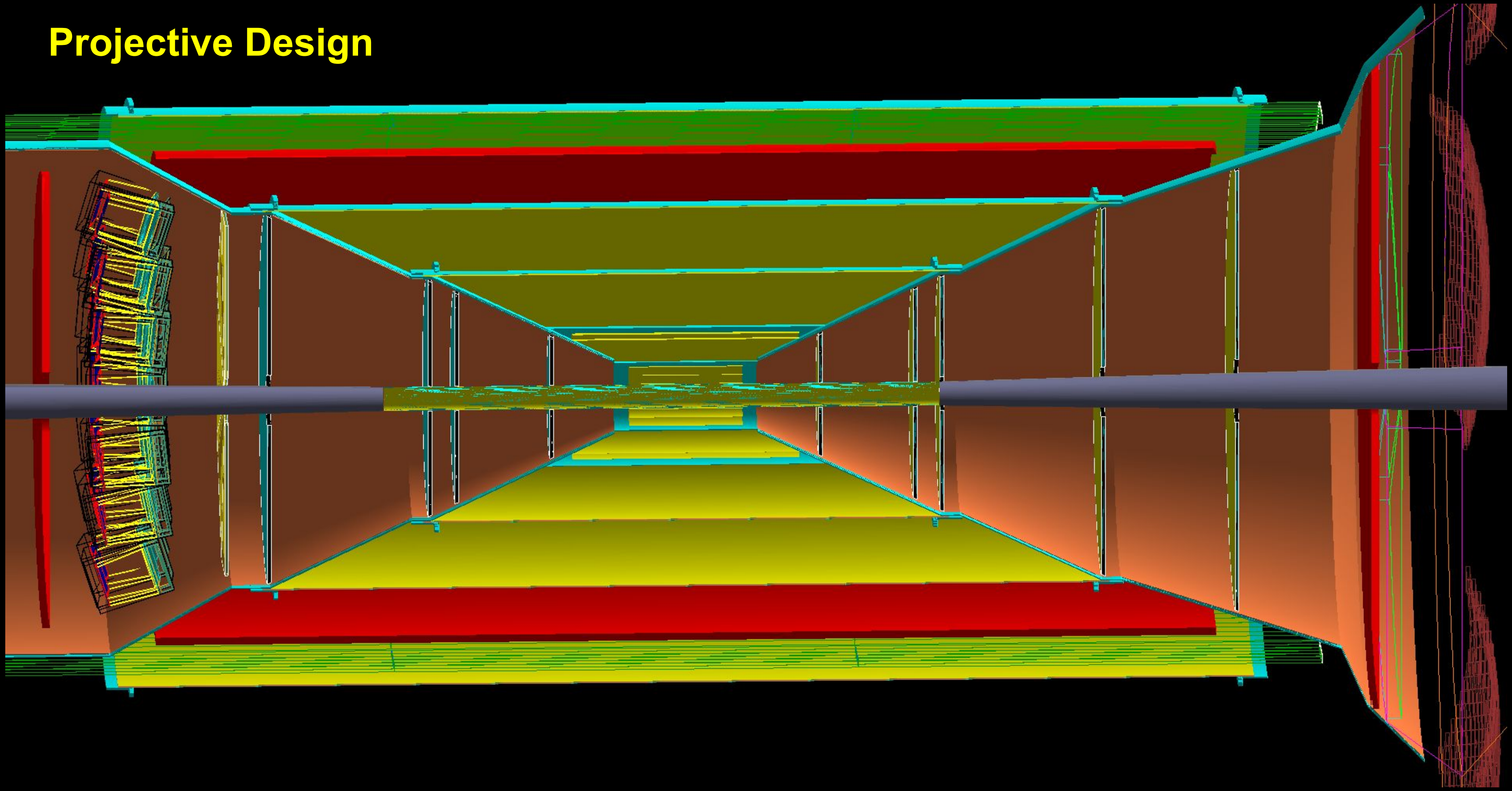




NSGA2
Computing
Study



Projective Design



Reference Design

Sagitta ITS3 X/X0 = 0.05

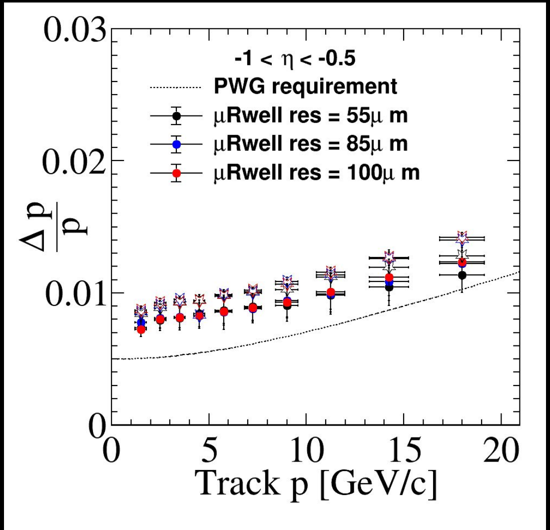
1.5M Events with 5 π^- tracks /event

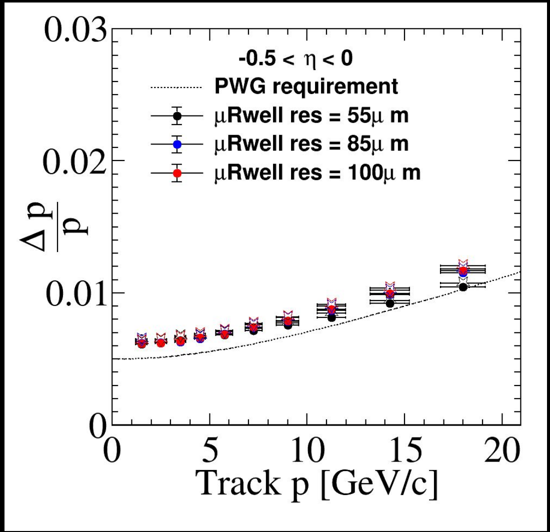
Fun4All Framework

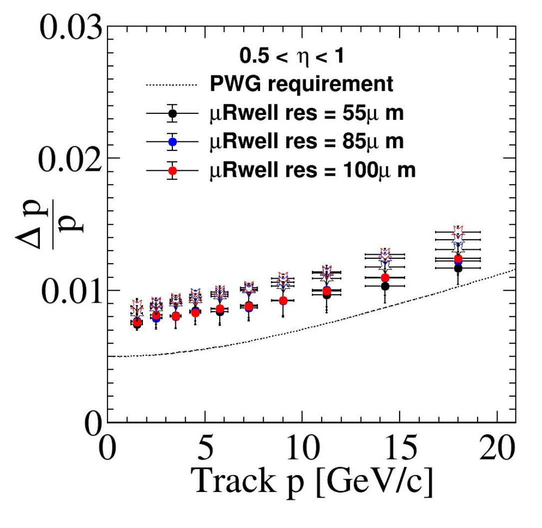
Both Sagitta Layer (X/X0) are changed in the same way

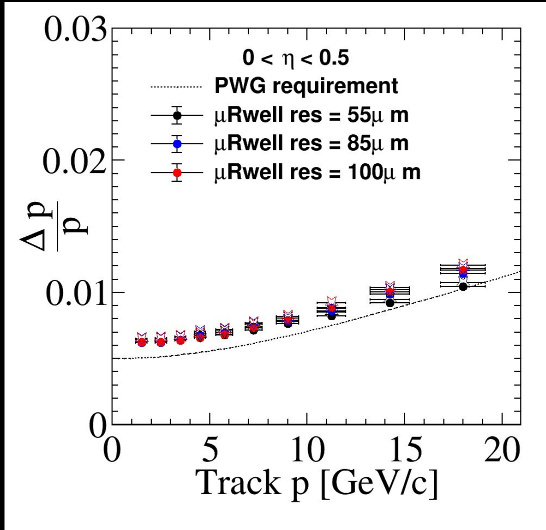
Solid Colors have large uncertainty

Distribution near support structure is not gaussian.









Reference Design

Sagitta ITS3 X/X0 = 0.2

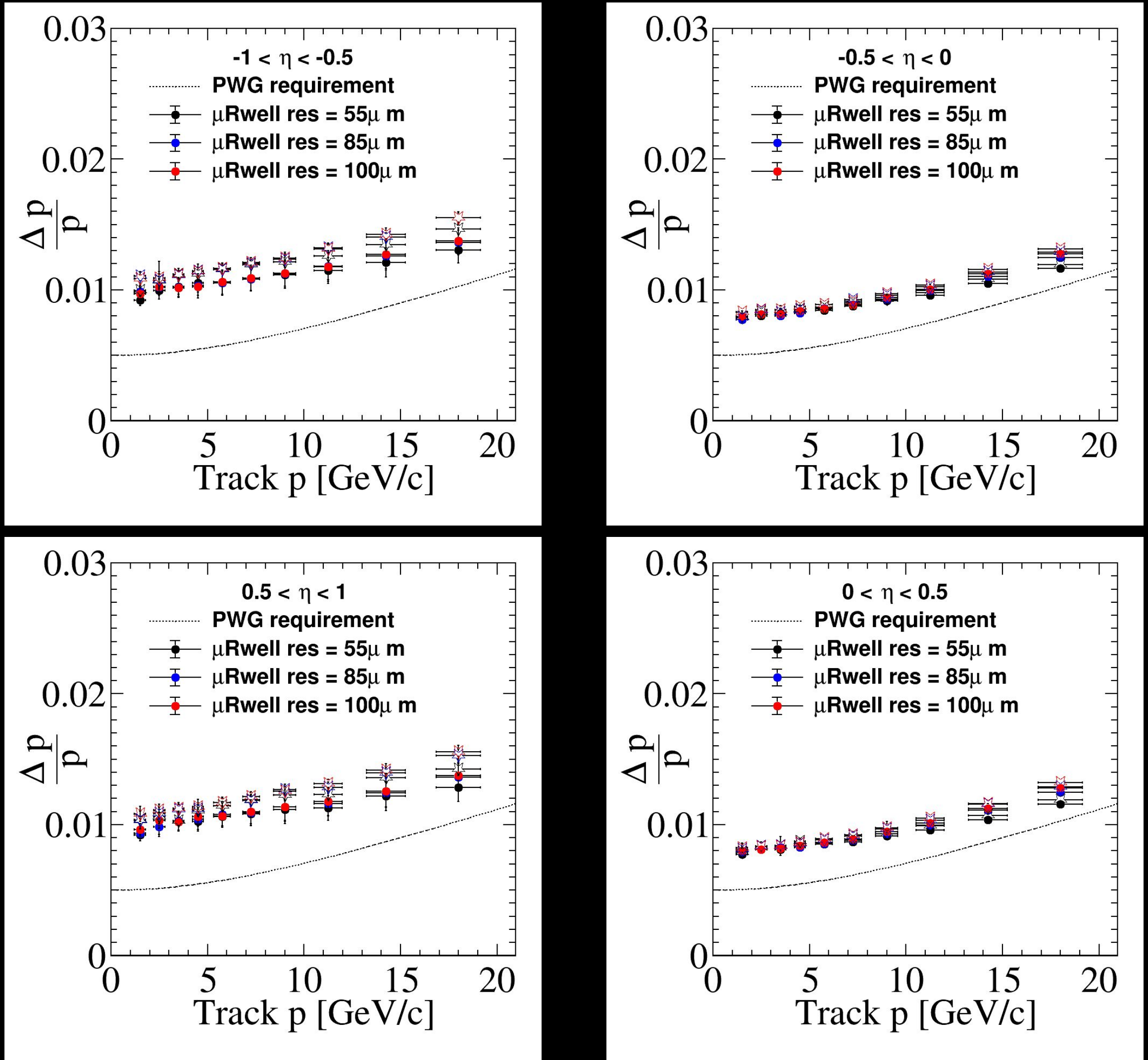
1.5M Events with 5 π^- tracks /event

Fun4All Framework

Both Sagitta Layer (X/X0) are changed in the same way

Solid Colors have large uncertainty

Distribution near support structure is not gaussian.



Reference Design

Sagitta ITS3 X/X0 = 0.55

1.5M Events with 5 π^- tracks /event

Fun4All Framework

Both Sagitta Layer (X/X0) are changed in the same way

Solid Colors have large uncertainty

Distribution near support structure is not gaussian.