$B^0(B_s^0) \to \pi\pi\ \mu\mu$ Angular Analysis

MWAPP Group Meeting

Alex Ward - 24/05/2021

3D Angular Distribution

3D Distribution

$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}q^2\mathrm{d}\cos\theta_\ell\mathrm{d}\cos\theta_K\mathrm{d}\Phi} = \frac{9}{32\pi}\Big[S_1^s\sin^2\theta_K + S_1^c\cos^2\theta_K + S_2^s\sin^2\theta_K\cos 2\theta_\ell + S_2^c\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\Phi + S_4\sin 2\theta_K\sin 2\theta_\ell\cos\Phi + A_5\sin 2\theta_K\sin\theta_\ell\cos\Phi + A_6\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\Phi + A_8\sin 2\theta_K\sin 2\theta_\ell\sin\Phi + A_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\Phi\Big], \quad (1)$$

- Investigate the angular distribution in the b->s decay, in other decays this appears to be incompatible with the SM predictions.
- Look at the angular structure of the b->d decay to test the underlying theory.
- Cannot tell the flavour of the B from the final state so measuring both modes.
- Currently evaluating sensitivities using toy datasets and collating MC samples.

1D Projections:

$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^2\Gamma}{\mathrm{d}q^2\,\mathrm{d}\cos\theta_K} = \frac{3}{4}(1-F_\mathrm{L})(1-\cos^2\theta_K) + \frac{3}{2}F_\mathrm{L}\cos^2\theta_K$$

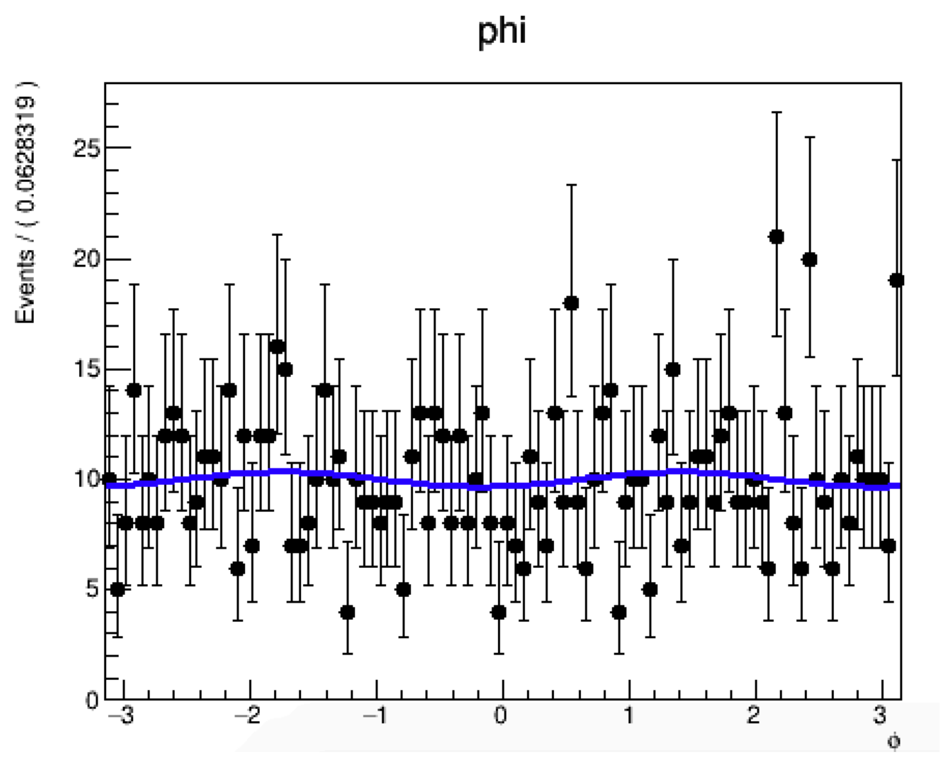
$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^2\Gamma}{\mathrm{d}q^2\,\mathrm{d}\cos\theta_\ell} = \frac{3}{8}(1-F_\mathrm{L})(1+\cos^2\theta_\ell) + \frac{3}{4}F_\mathrm{L}(1-\cos^2\theta_\ell) + \frac{3}{4}A_6\cos\theta_\ell$$

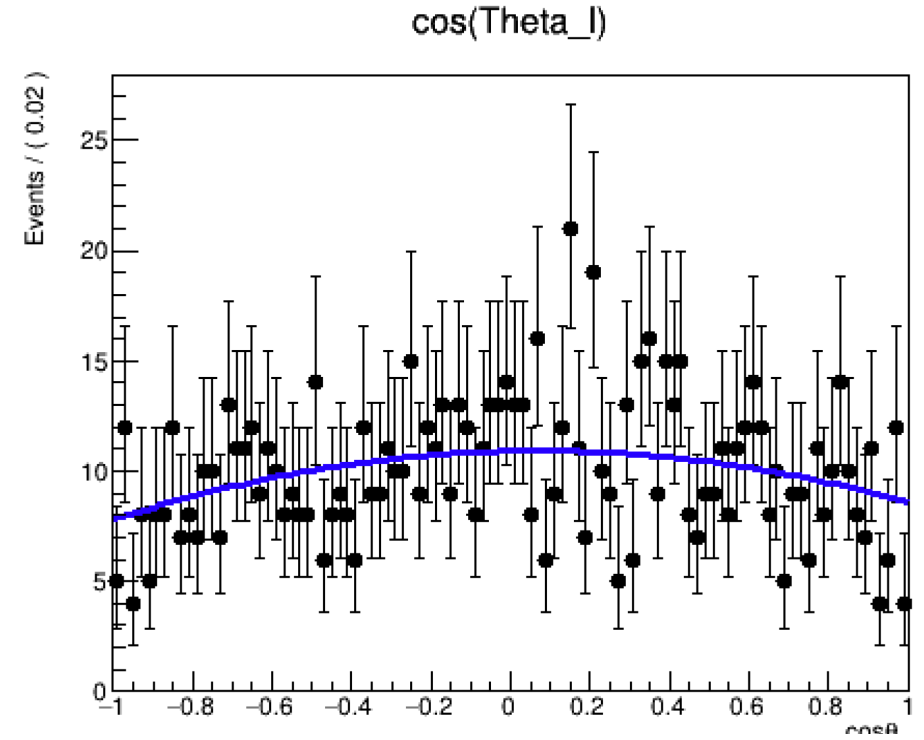
Integrate 3D over two angles

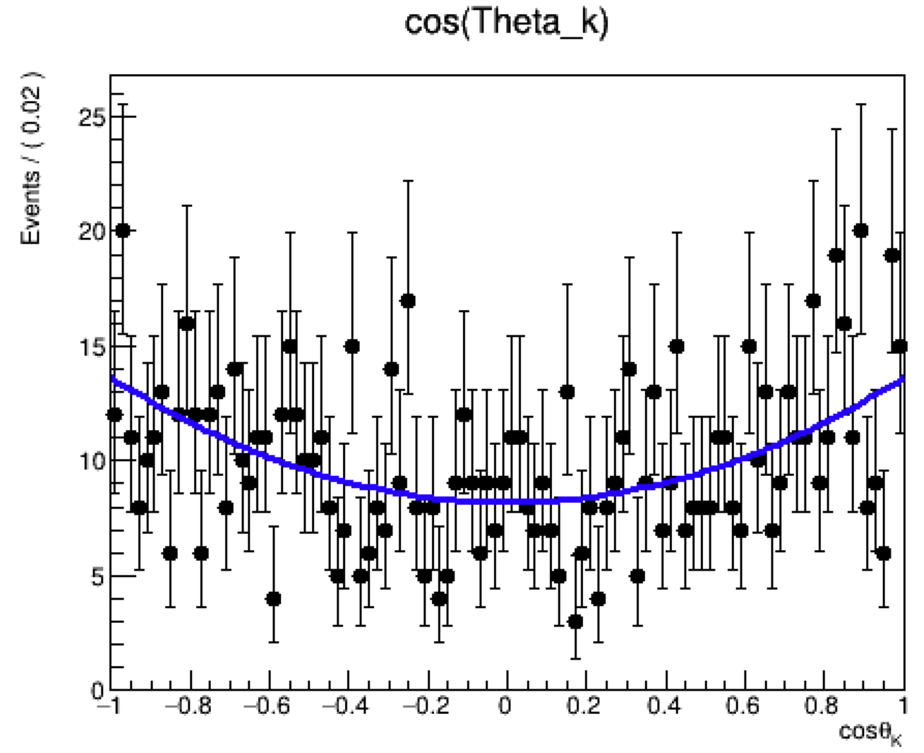
$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^2\Gamma}{\mathrm{d}q^2\,\mathrm{d}\Phi} = \frac{1}{2\pi} + \frac{1}{2\pi}S_3\cos 2\Phi + \frac{1}{2\pi}A_9\sin 2\Phi$$

The structure of the ϕ, $cos\theta_l$, and $cos\theta_k$ angles present in the angular distributions obtained via 1D projections

Projections produced with fixed, true, values for Fl = 0.5 and others = 0.0







Folded, 3D Projections:

$$\frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi} = \frac{9}{8\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi\Big]$$

$$\frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi} = \frac{9}{8\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_5\sin 2\theta_K\sin\theta_\ell\cos\phi\Big]$$

$$\frac{1}{\Gamma}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi\,\mathrm{d}q^2} = \frac{9}{8\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi\Big]$$

$$\frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi} = \frac{9}{8\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi\Big]$$

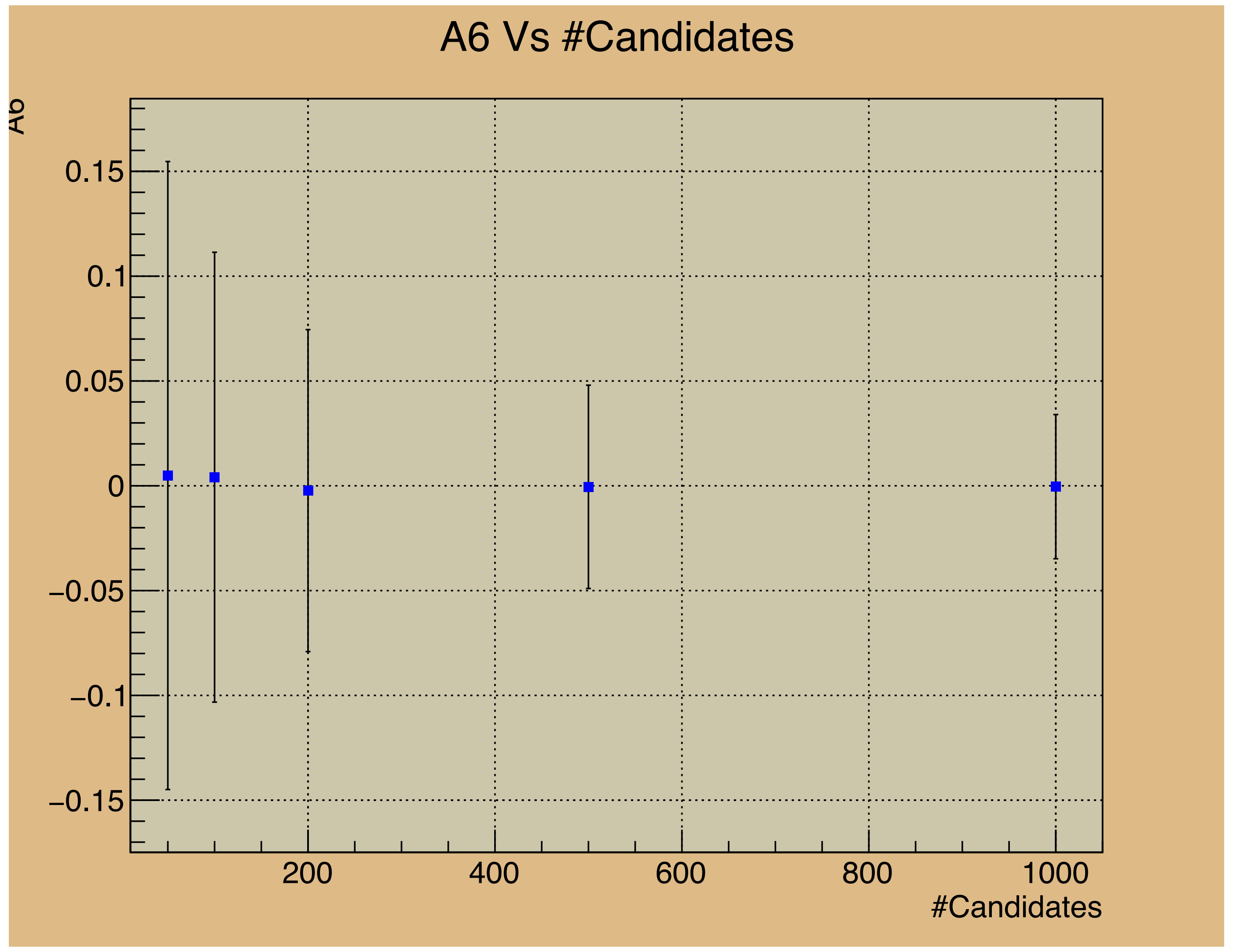
Measuring S4

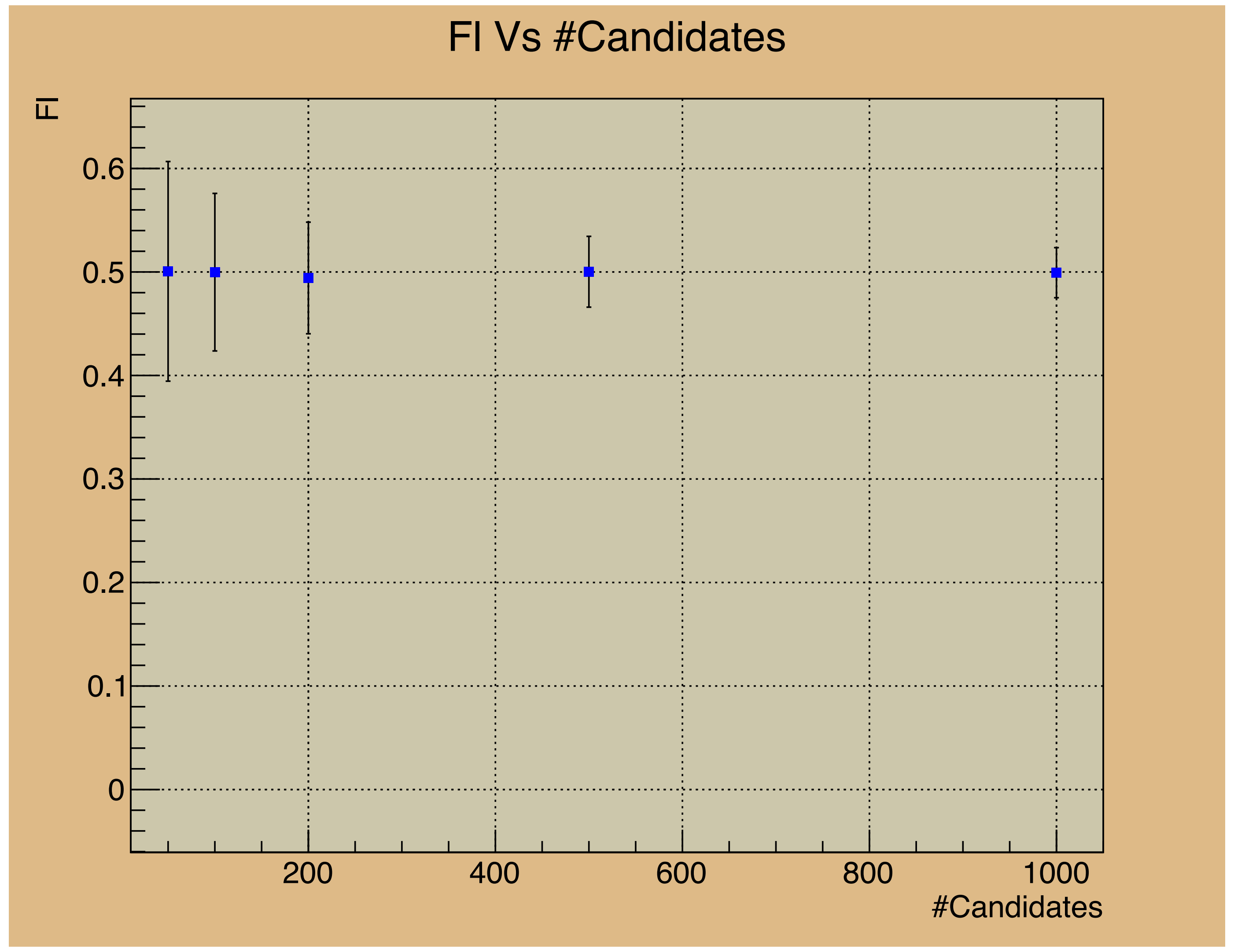
Applying the transformations:

$$\phi \rightarrow -\phi \text{ (for } \phi < 0)$$
$$\phi \rightarrow \pi - \phi \text{ (for } \theta_l > \pi/2)$$
$$\theta_l \rightarrow \pi - \theta_l \text{ (for } \theta_l > \pi/2)$$

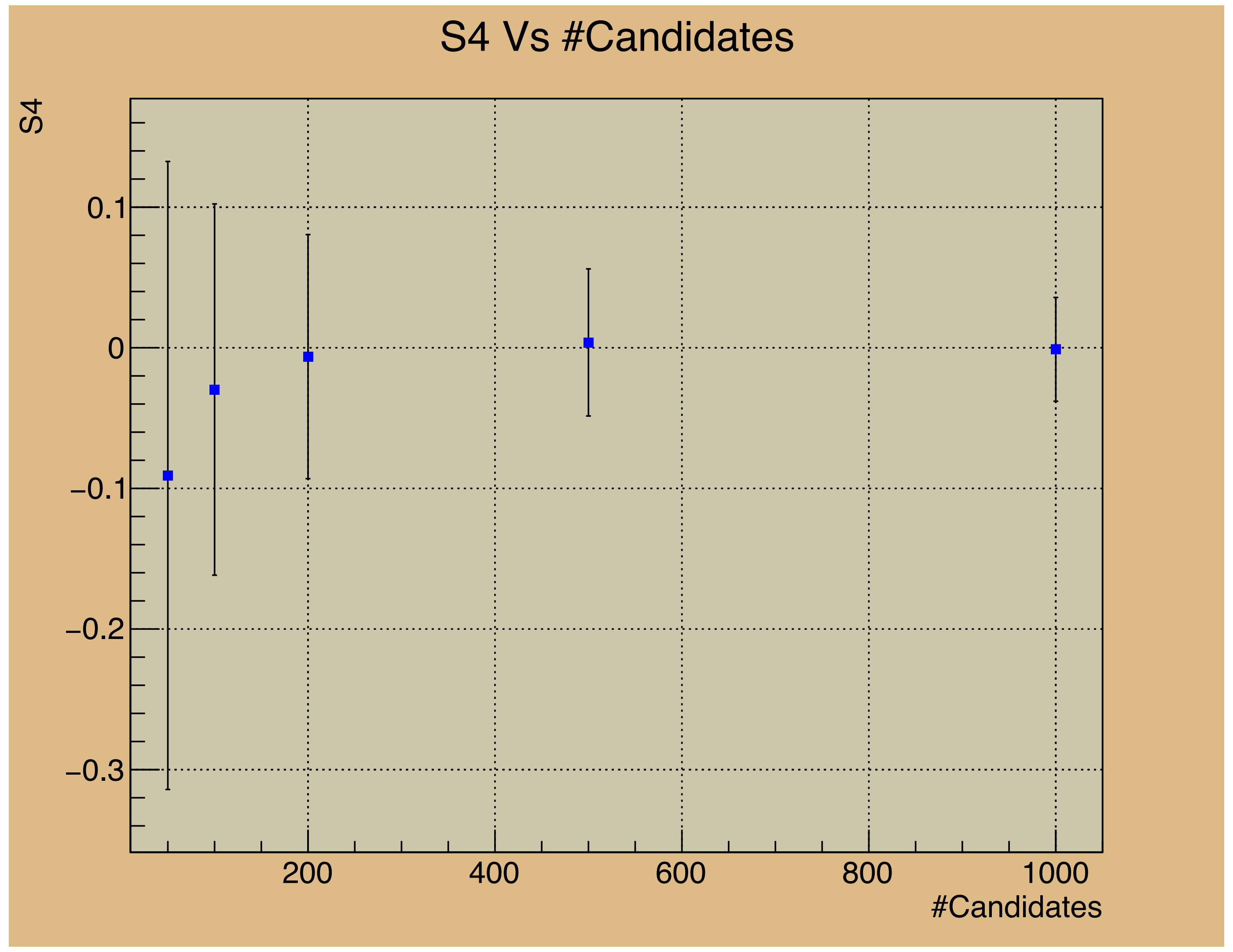
Observables Values - 1000 Toys

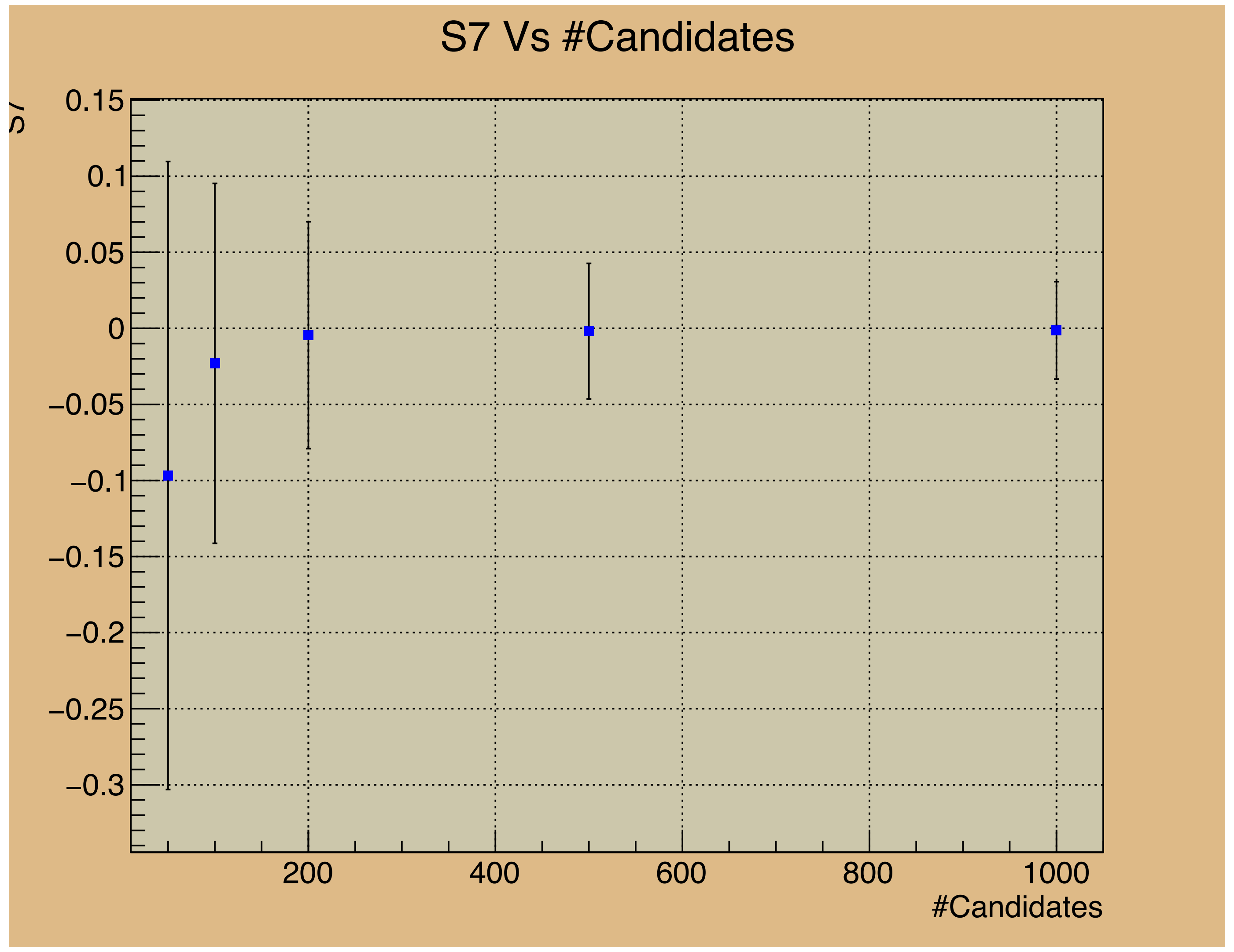
For the un-folded angles the fits behave well and the observables behave similarly for all #Candidates





For the folded angles the fits behave poorly and the observables behave poorly for < 200 Candidates





Full set of plots in backup

P Transformations

$$P_1 = \frac{S_3}{1-F_L}$$
$$P_2 = \frac{S_6}{1-F_L}$$
$$P_3 = \frac{S_9}{1-F_L}$$
$$P'_4 = \frac{S_4}{\sqrt{F_L(1-F_L)}}$$
$$P'_5 = \frac{S_5}{\sqrt{F_L(1-F_L)}}$$
$$P'_6 = \frac{S_7}{\sqrt{F_L(1-F_L)}}$$
$$P'_8 = \frac{S_8}{\sqrt{F_L(1-F_L)}}$$

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$$P'_4, S_4: \begin{cases} \phi \to -\phi & \text{for } \phi < 0 \\ \phi \to \pi - \phi & \text{for } \theta_\ell > \pi/2 \\ \theta_\ell \to \pi - \theta_\ell & \text{for } \theta_\ell > \pi/2, \end{cases} \quad (3)$$

$$P'_5, S_5: \begin{cases} \phi \to -\phi & \text{for } \phi < 0 \\ \theta_\ell \to \pi - \theta_\ell & \text{for } \theta_\ell > \pi/2, \end{cases} \quad (4)$$

$$P'_6, S_7: \begin{cases} \phi \to \pi - \phi & \text{for } \phi > \pi/2 \\ \phi \to -\pi - \phi & \text{for } \phi < -\pi/2 \\ \theta_\ell \to \pi - \theta_\ell & \text{for } \theta_\ell > \pi/2, \end{cases} \quad (5)$$

$$P'_8, S_8: \begin{cases} \phi \to \pi - \phi & \text{for } \phi > \pi/2 \\ \phi \to -\pi - \phi & \text{for } \phi < -\pi/2 \\ \theta_K \to \pi - \theta_K & \text{for } \theta_\ell > \pi/2 \\ \theta_\ell \to \pi - \theta_\ell & \text{for } \theta_\ell > \pi/2. \end{cases} \quad (6)$$

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$$\frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi} = \frac{9}{8\pi}\Bigg[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + \frac{1}{2}(1-F_L)A_T^{(2)}\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + \sqrt{F_L(1-F_L)}P'_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi\Bigg].$$

$$\frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi} = \frac{9}{8\pi}\Bigg[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + \frac{1}{2}(1-F_L)A_T^{(2)}\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + \sqrt{F_L(1-F_L)}P'_5\sin 2\theta_K\sin\theta_\ell\cos\phi\Bigg].$$

$$\frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi} = \frac{9}{8\pi}\Bigg[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + \frac{1}{2}(1-F_L)A_T^{(2)}\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + \sqrt{F_L(1-F_L)}P'_6\sin 2\theta_K\sin\theta_\ell\sin\phi\Bigg].$$

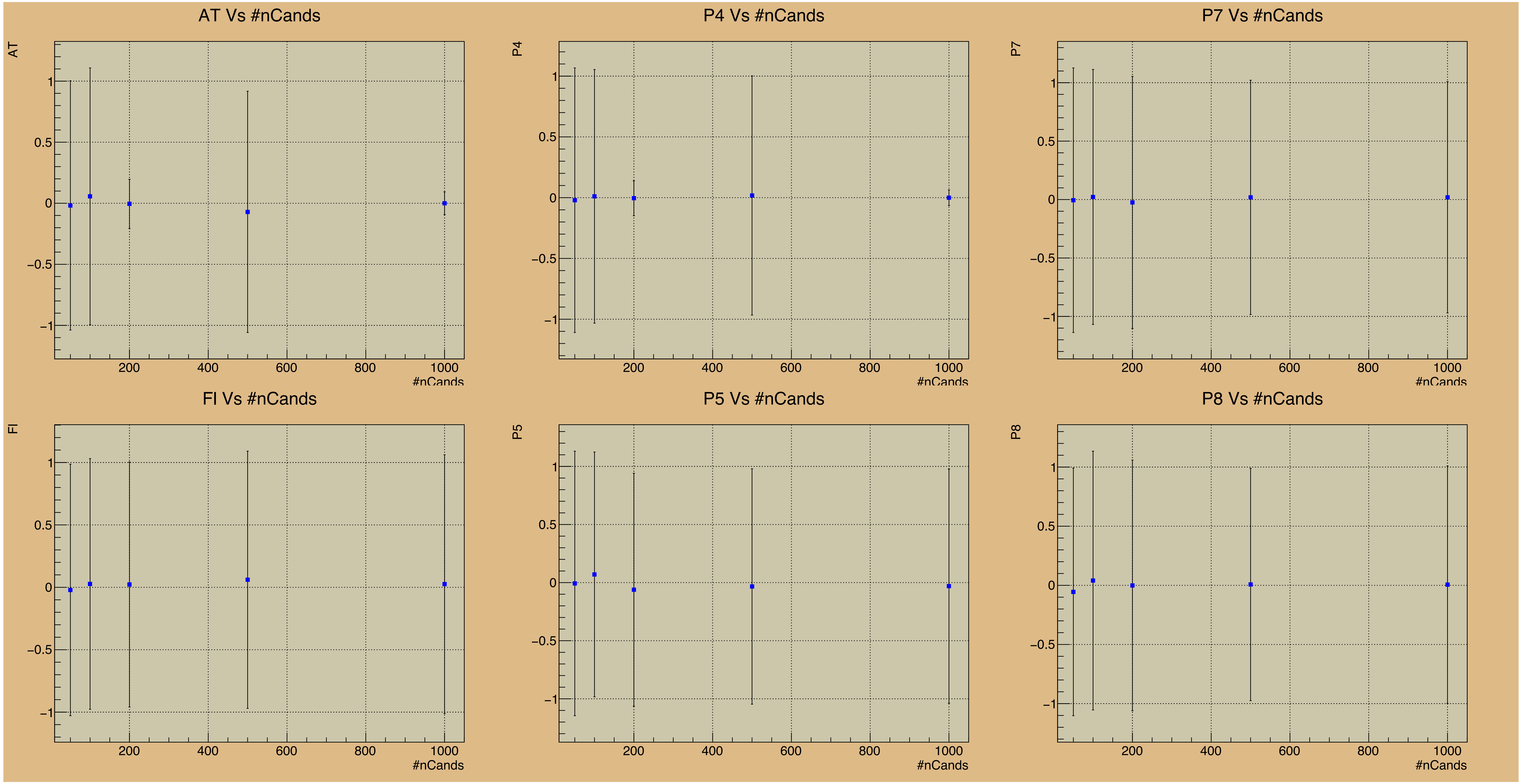
$$\frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi} = \frac{9}{8\pi}\Bigg[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + \frac{1}{2}(1-F_L)A_T^{(2)}\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + \sqrt{F_L(1-F_L)}P'_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi\Bigg].$$

Common terms, only P′ value differs between 3D P′ observable projections

$$\frac{9}{8\pi}\Bigg[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + \frac{1}{2}(1-F_L)A_T^{(2)}\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi +$$

P Observables Values - 1000 Toys

P Observables Pulls - 1000 Toys

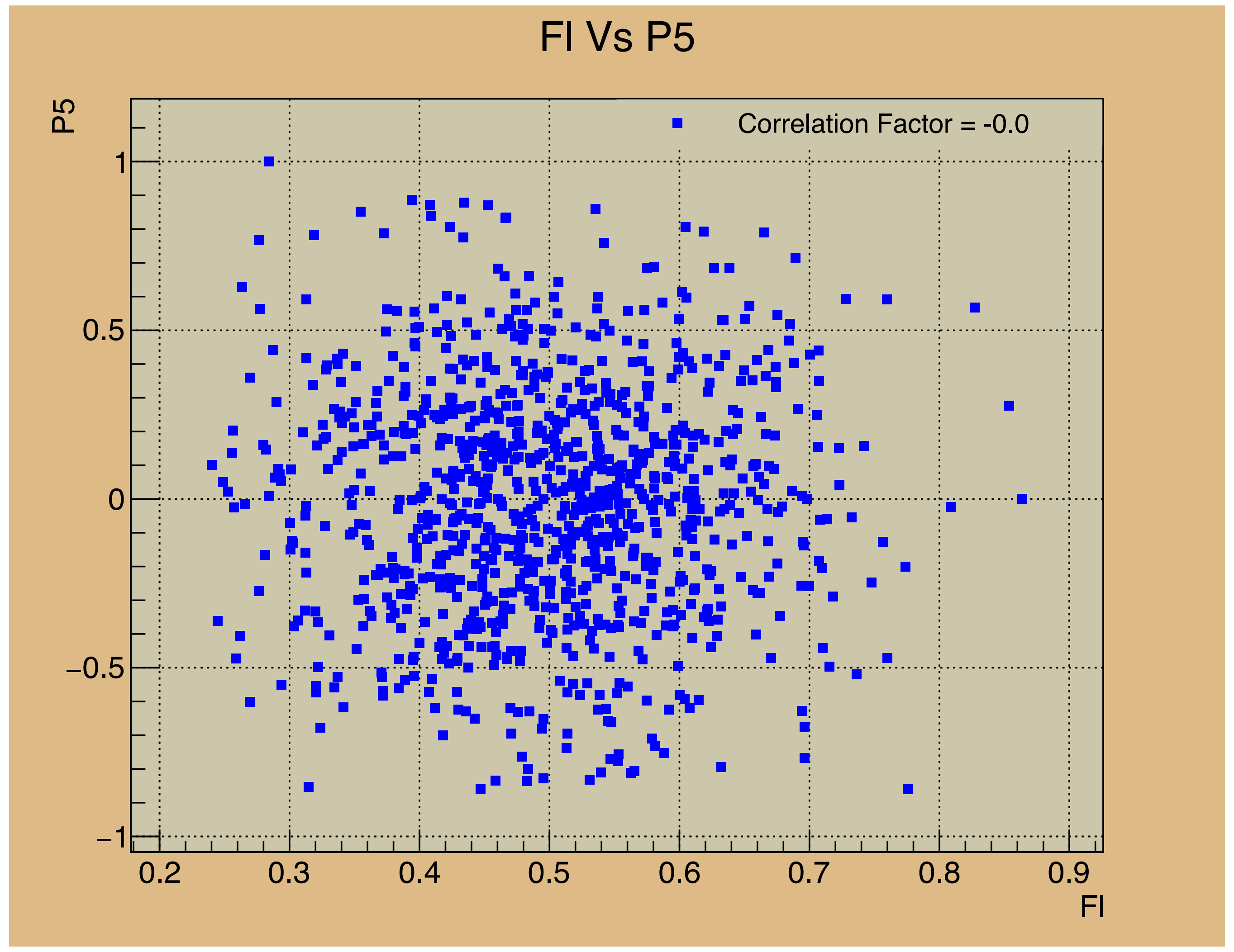


At 50 Events there are a couple of toys with a pull mean of order 10^5, these aren't within the scope of the pull plots (range -10,10) so are excluded here, but will investigate.

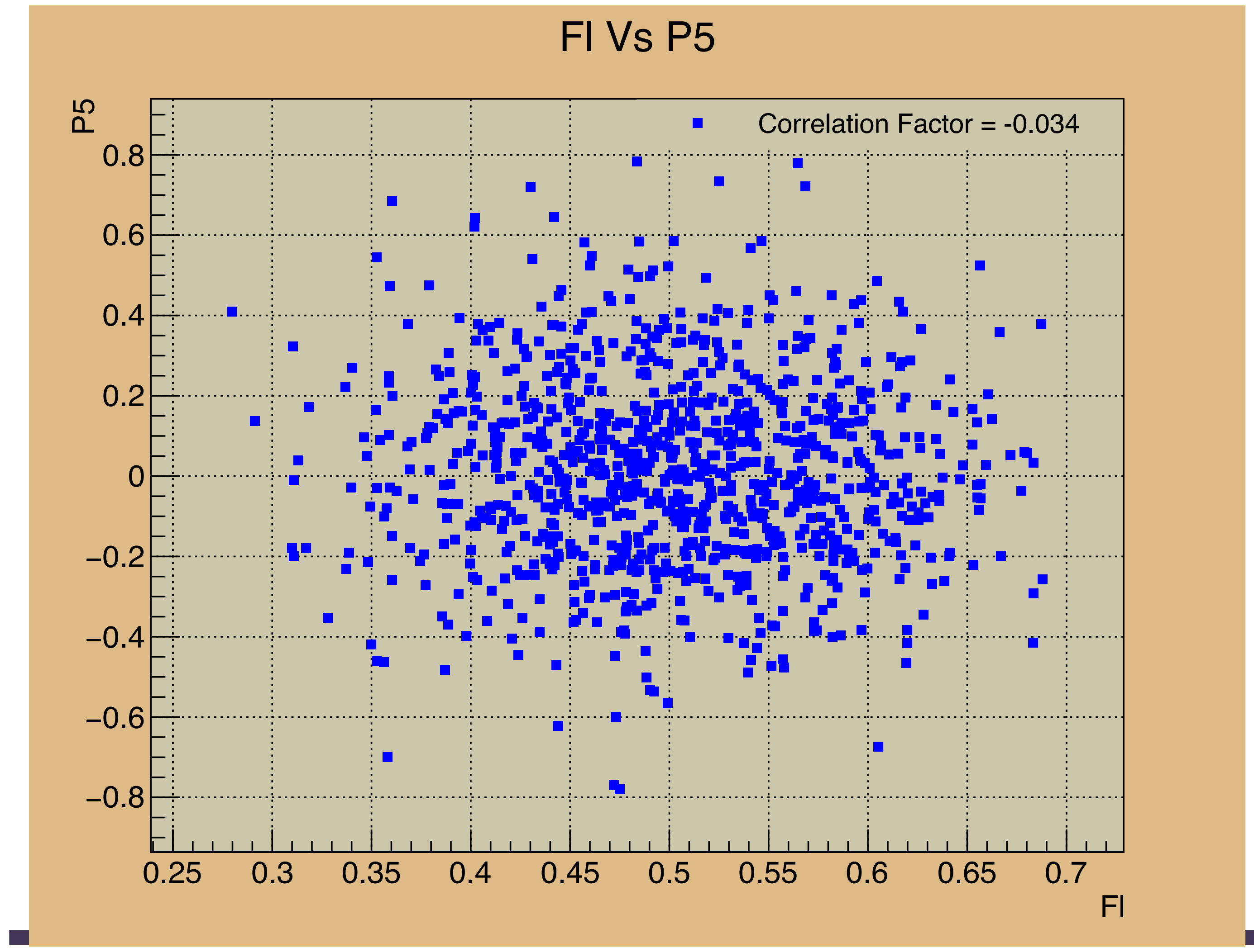
Scatter Plots - FI Vs Others - 1000 Toys w/ 200 Candidates

Scatter Plots - FI Vs P5 - 1000 Toys

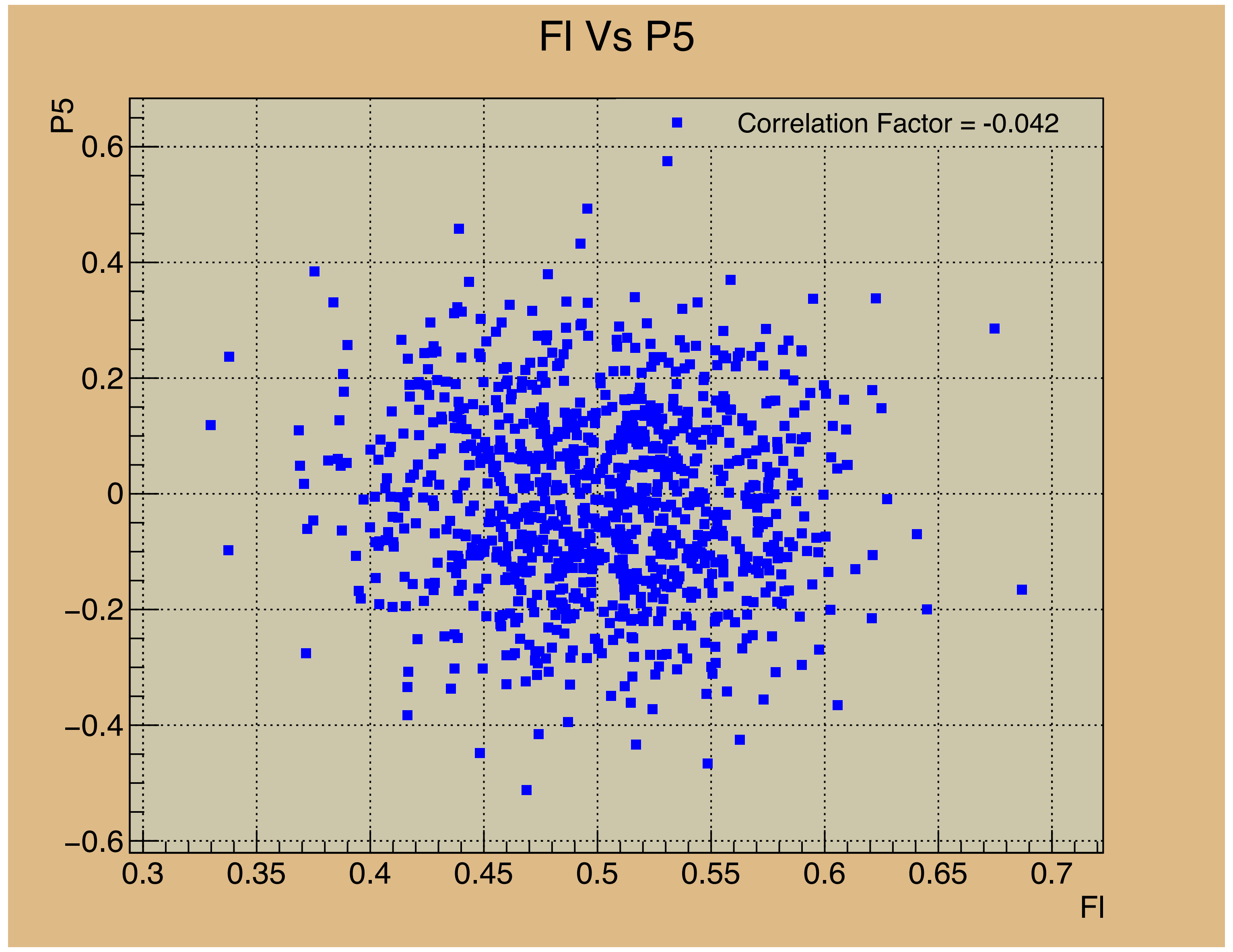
50 Candidates



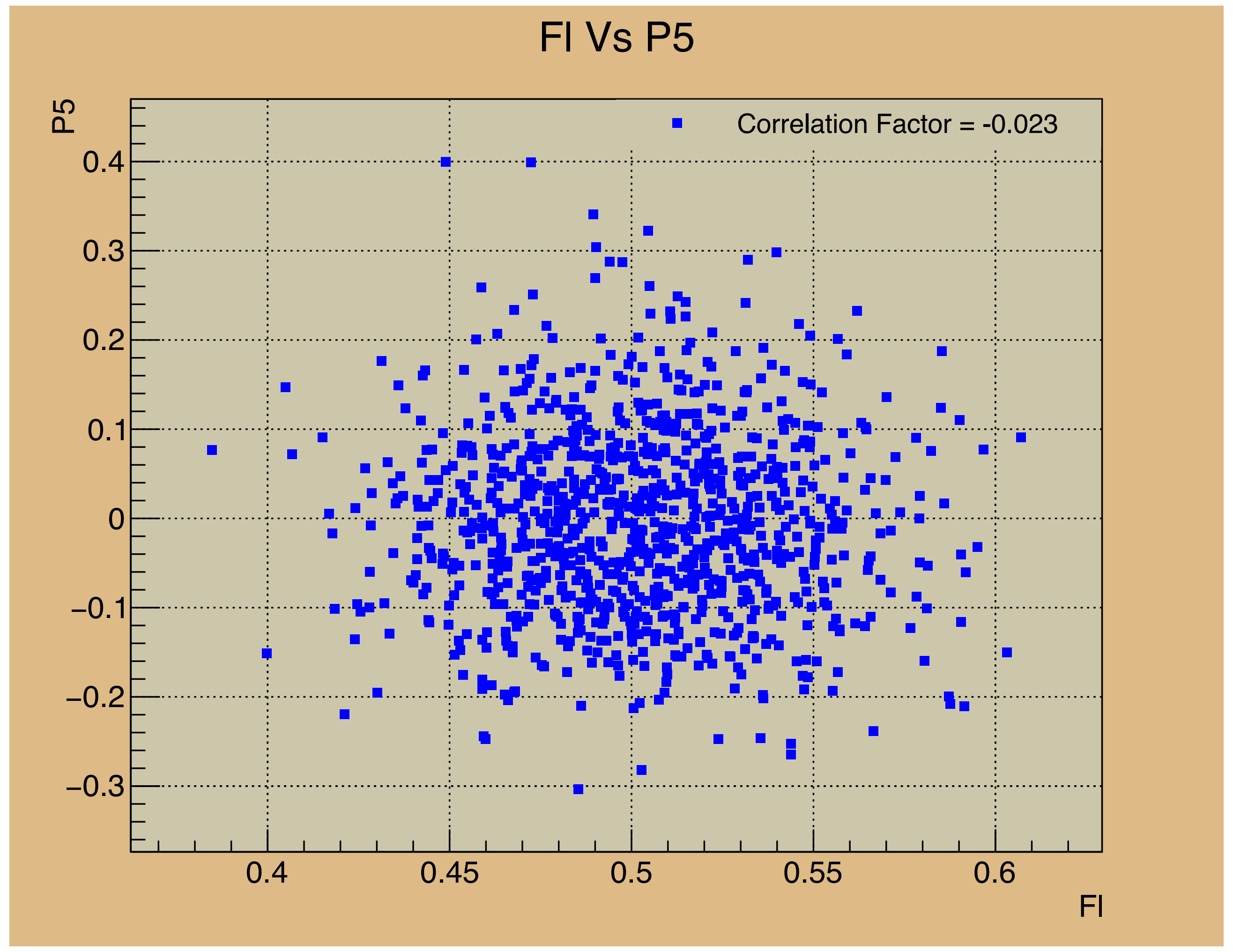
100 Candidates



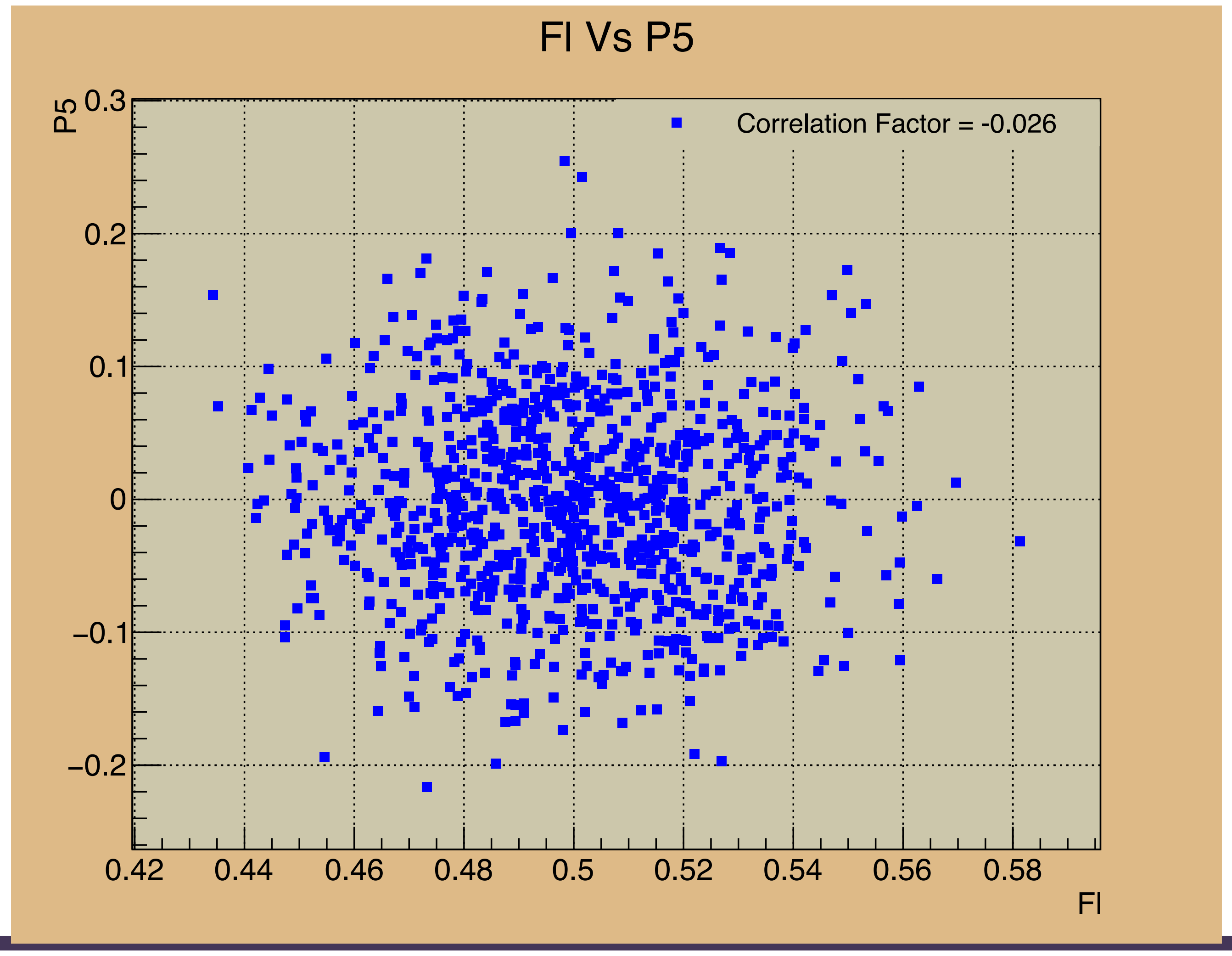
200 Candidates



500 Candidates



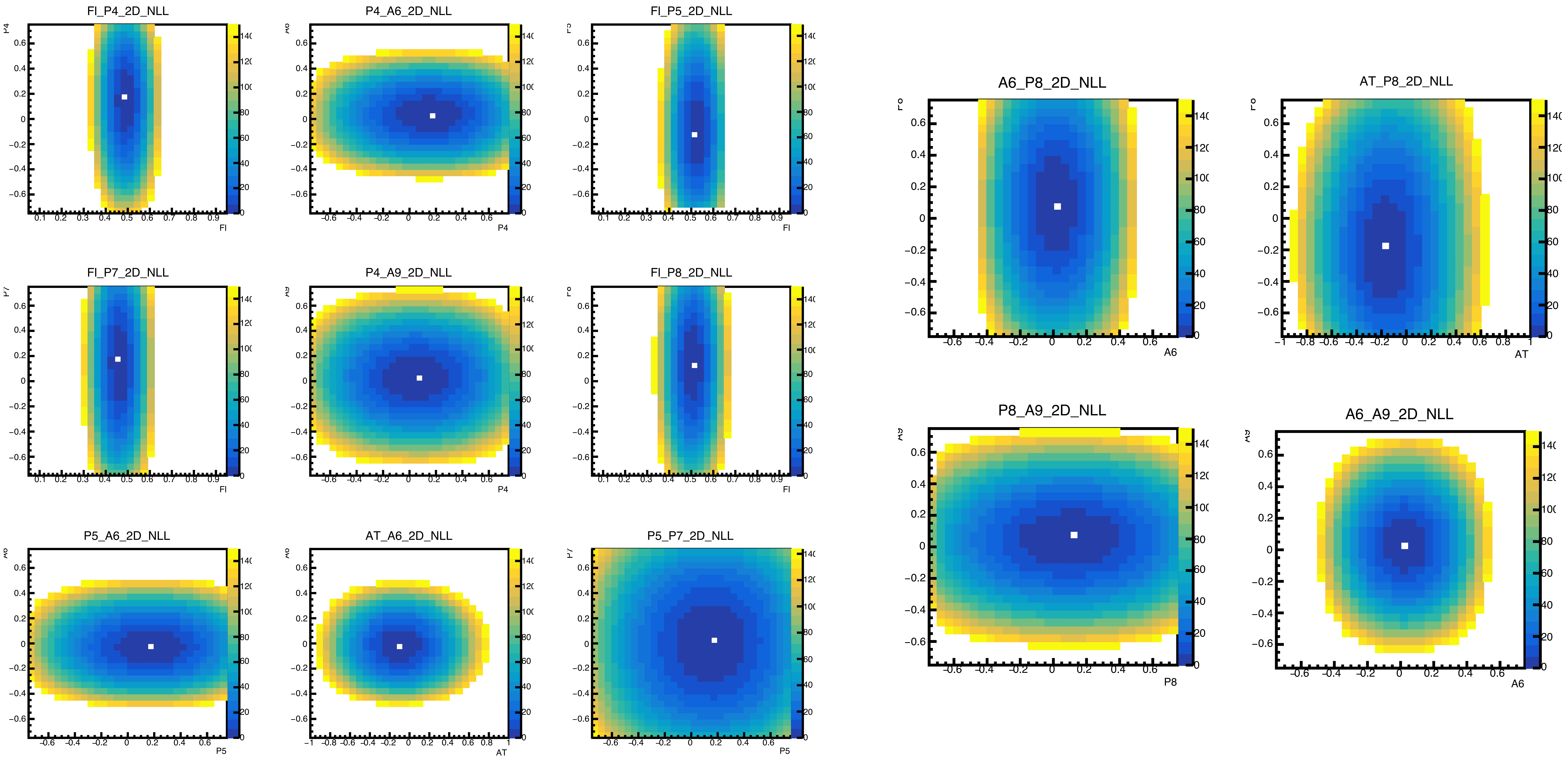
1000 Candidates



P Observables - NLL - 1000 Toys, 200 Events

P Observables - 2D NLL - 1000 Toys, 1000 Events

P Observables - 2D NLL - 1000 Toys, 1000 Events



Next Steps

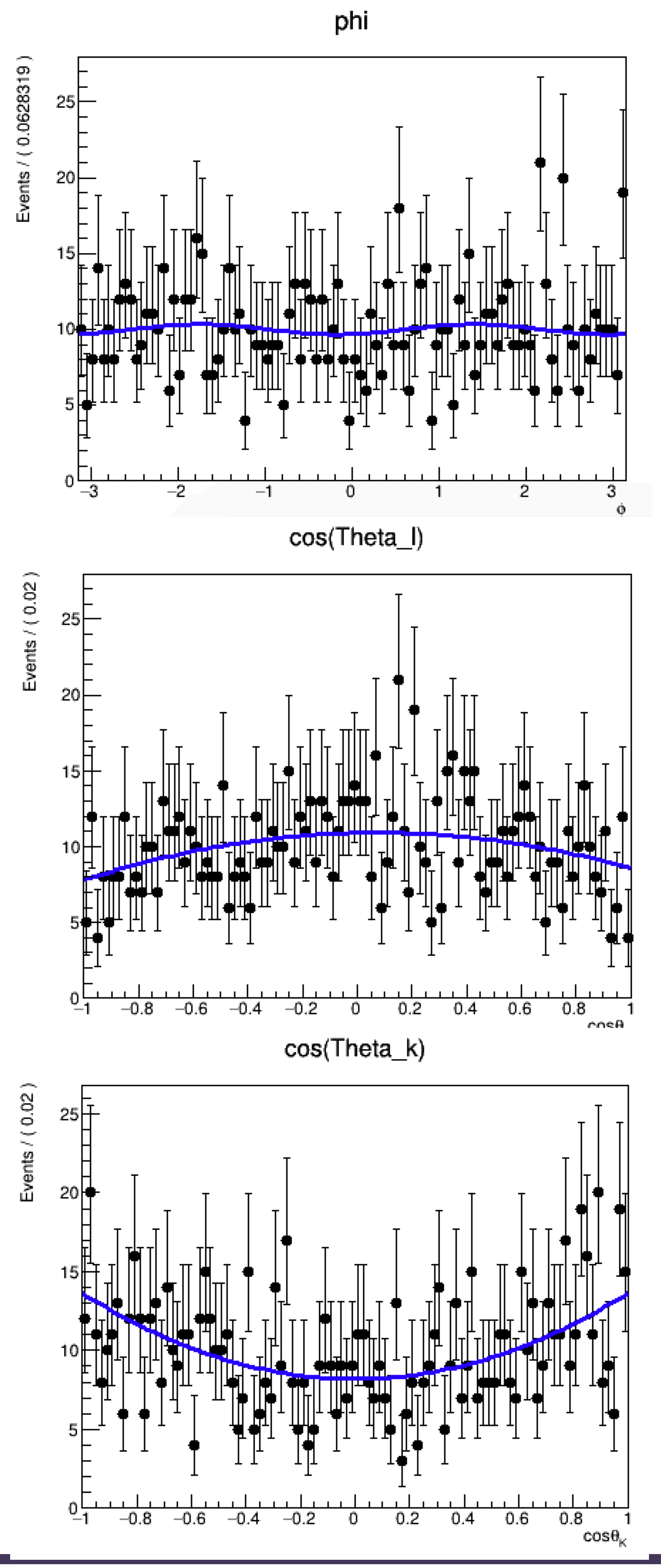
- Add fourth dimension - Mass
- Add background component
- Finalise data selection

Thanks for listening

Backup Slides

- Investigate the angular distribution in the b->s decay, in other decays this appears to be incompatible with the SM predictions.
- Look at the angular structure of the b->d decay to test the underlying theory.
- Cannot tell the flavour of the B from the final state so measuring both modes.
- Measure CP asymmetries via some of the terms in the angular distribution using 1D projections.
- Full Run 1 & 2 datasets with B2XMuMu stripping line with L0 Muon/ Dimuon + Topo HLT triggers for ~200 events each.
- Currently evaluating sensitivities using toy datasets and collating MC samples.

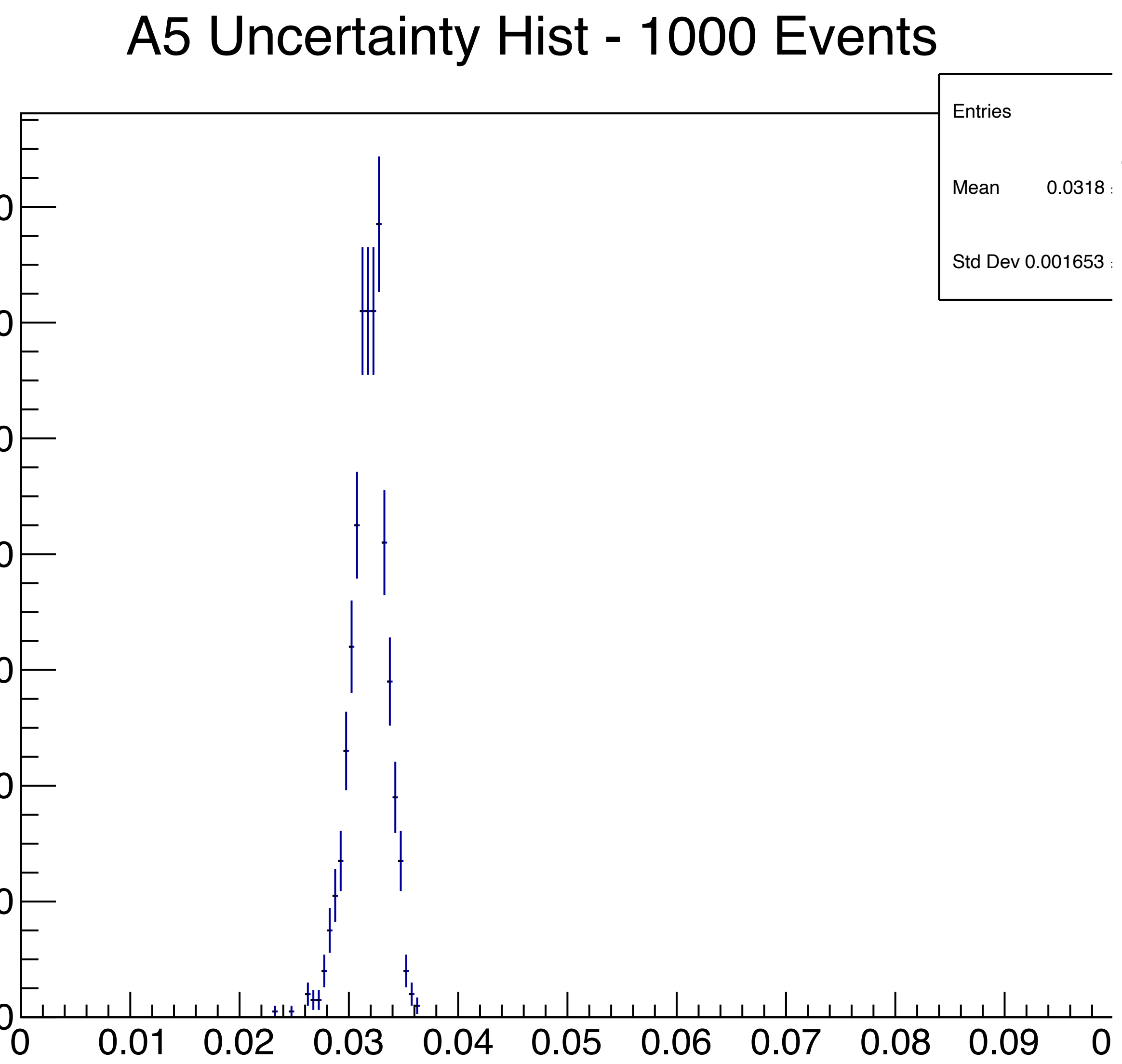
- The structure of the ϕ, $cos\theta_l$, and $cos\theta_k$ angles present in the angular distributions obtained via 1D projections
- These projection are produced with fixed values for Fl = 0.5 and all other observables = 0.

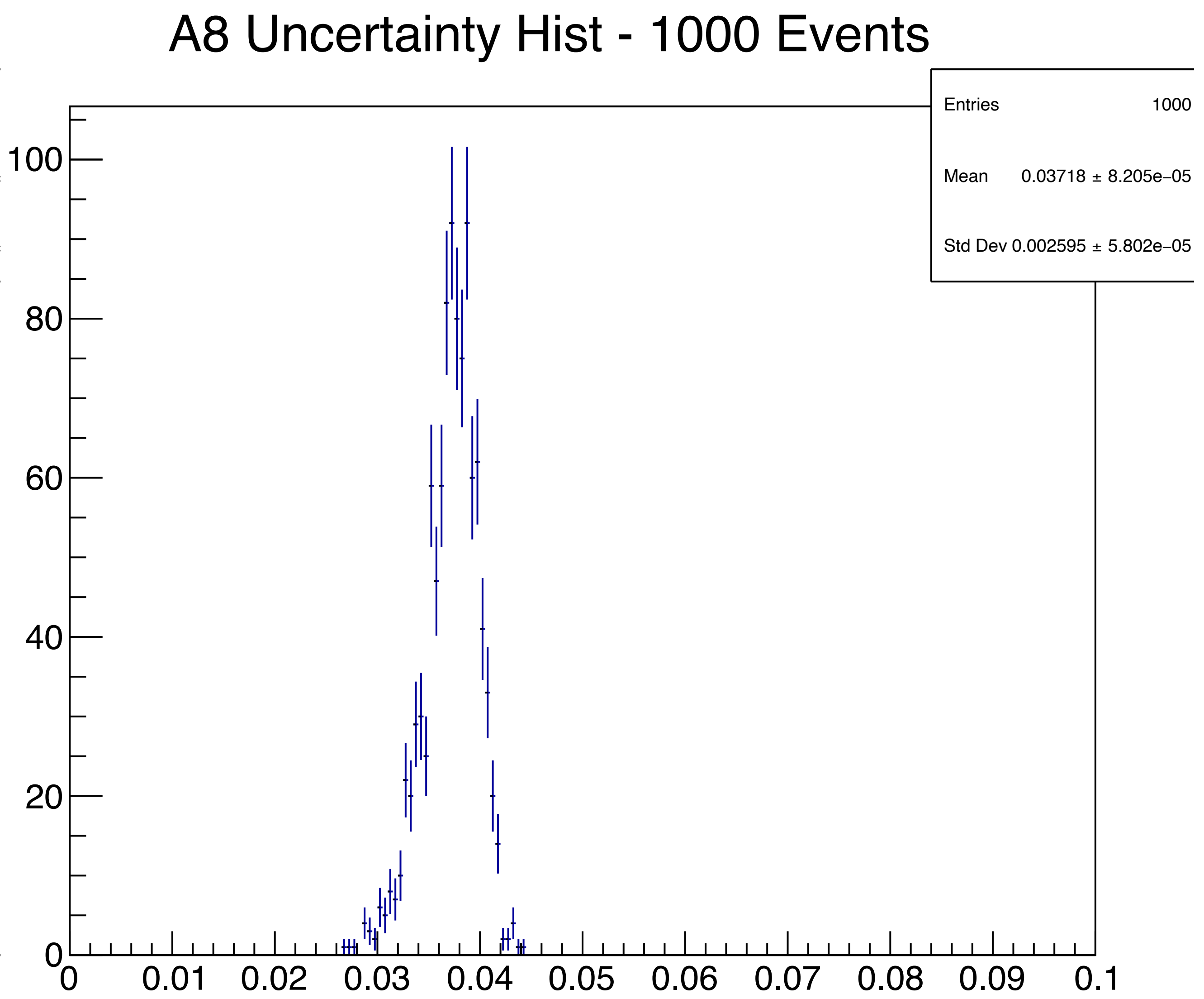


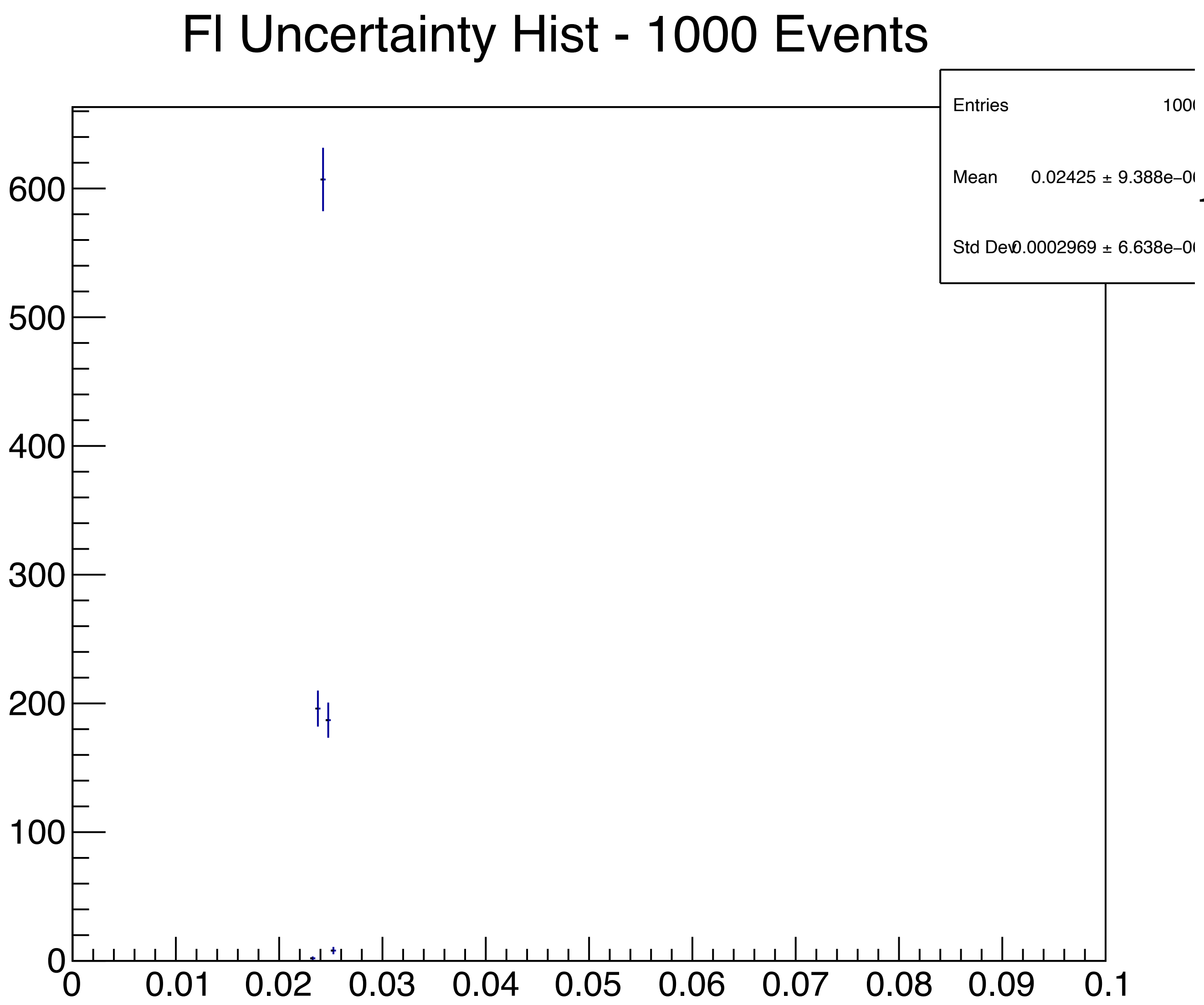
S OBSERVABLES

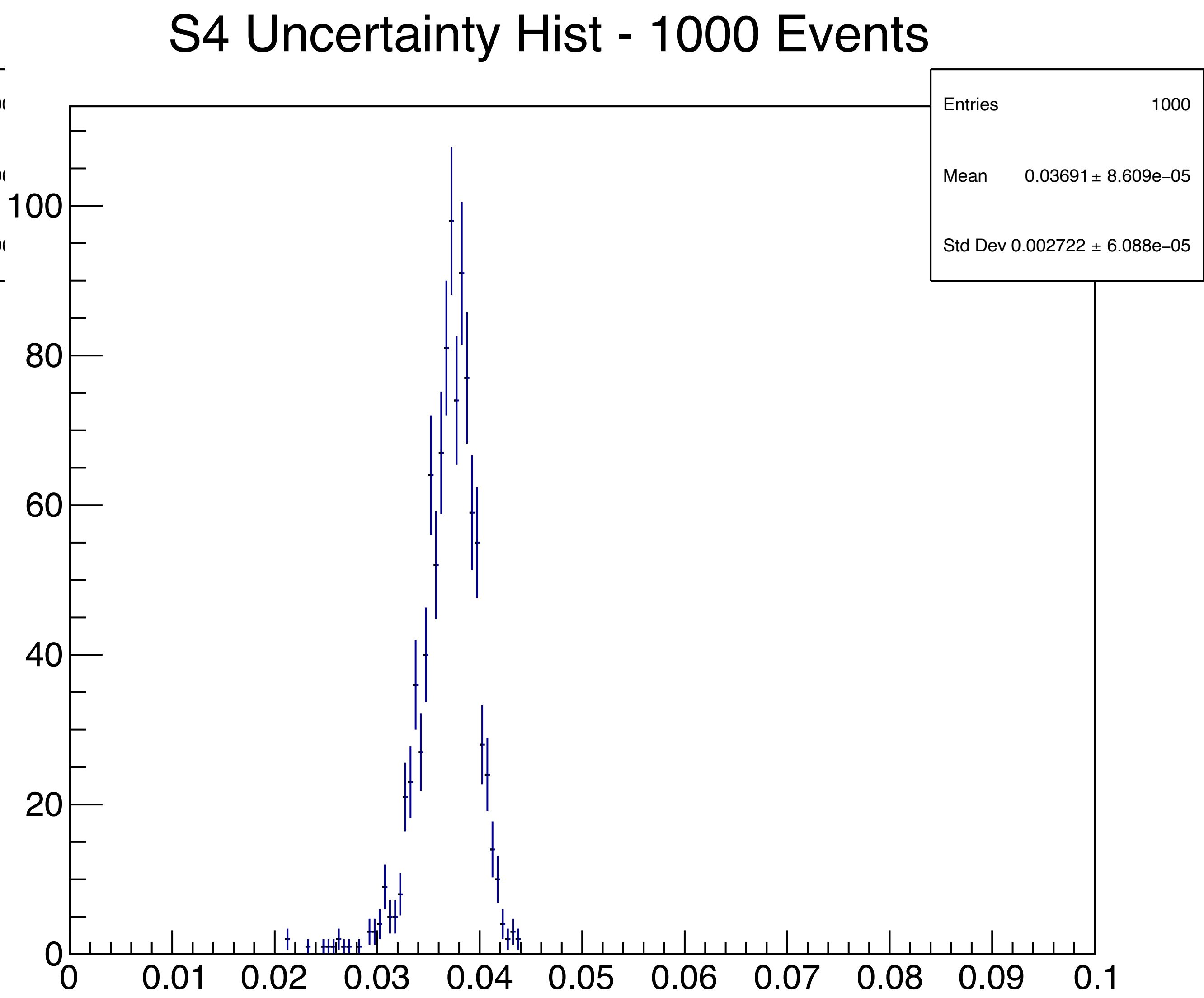
Value Plots - 1000 Toys , 1000 Candidates

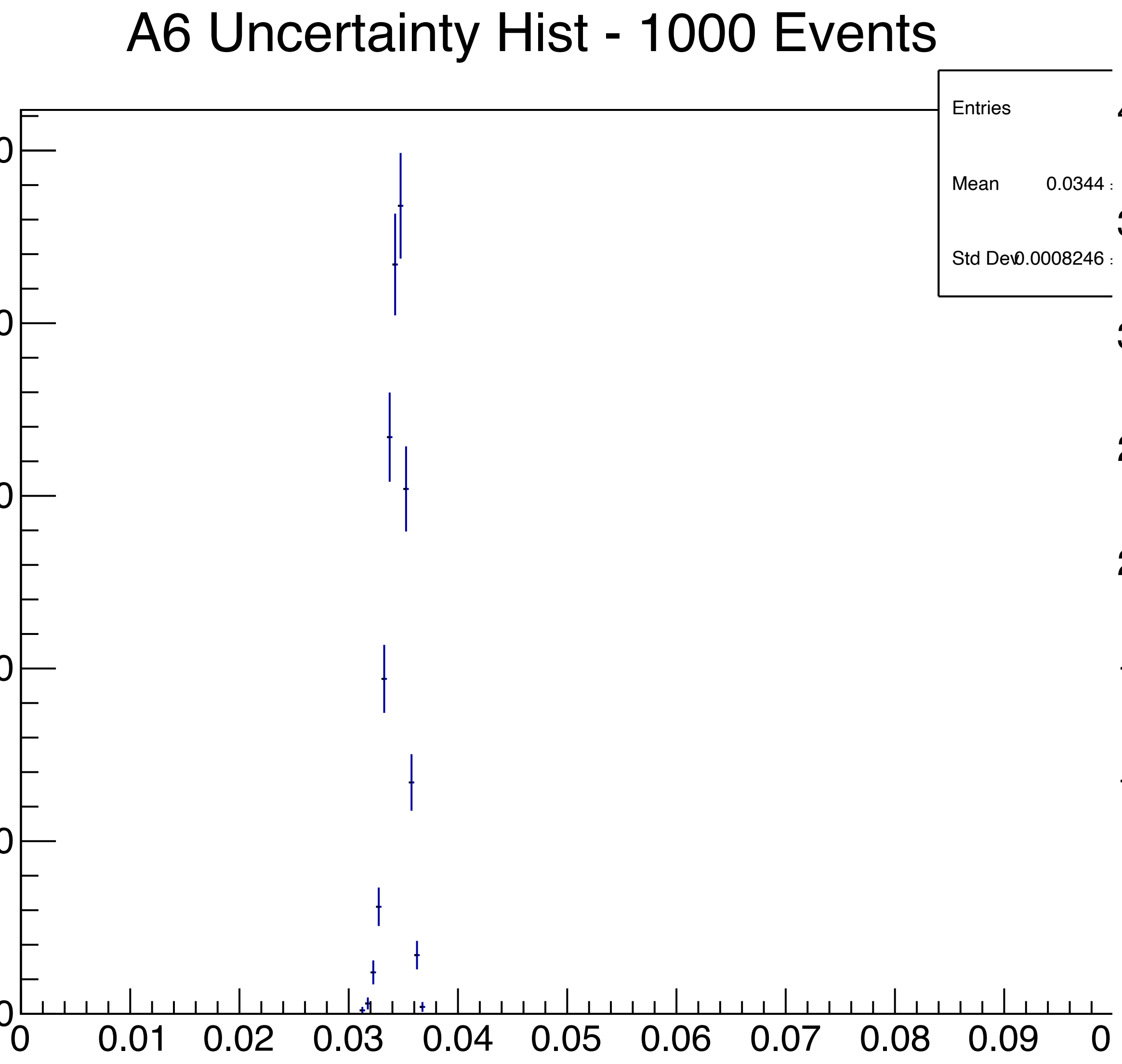
Uncertainty Plots - 1000 Toys , 1000 Candidates

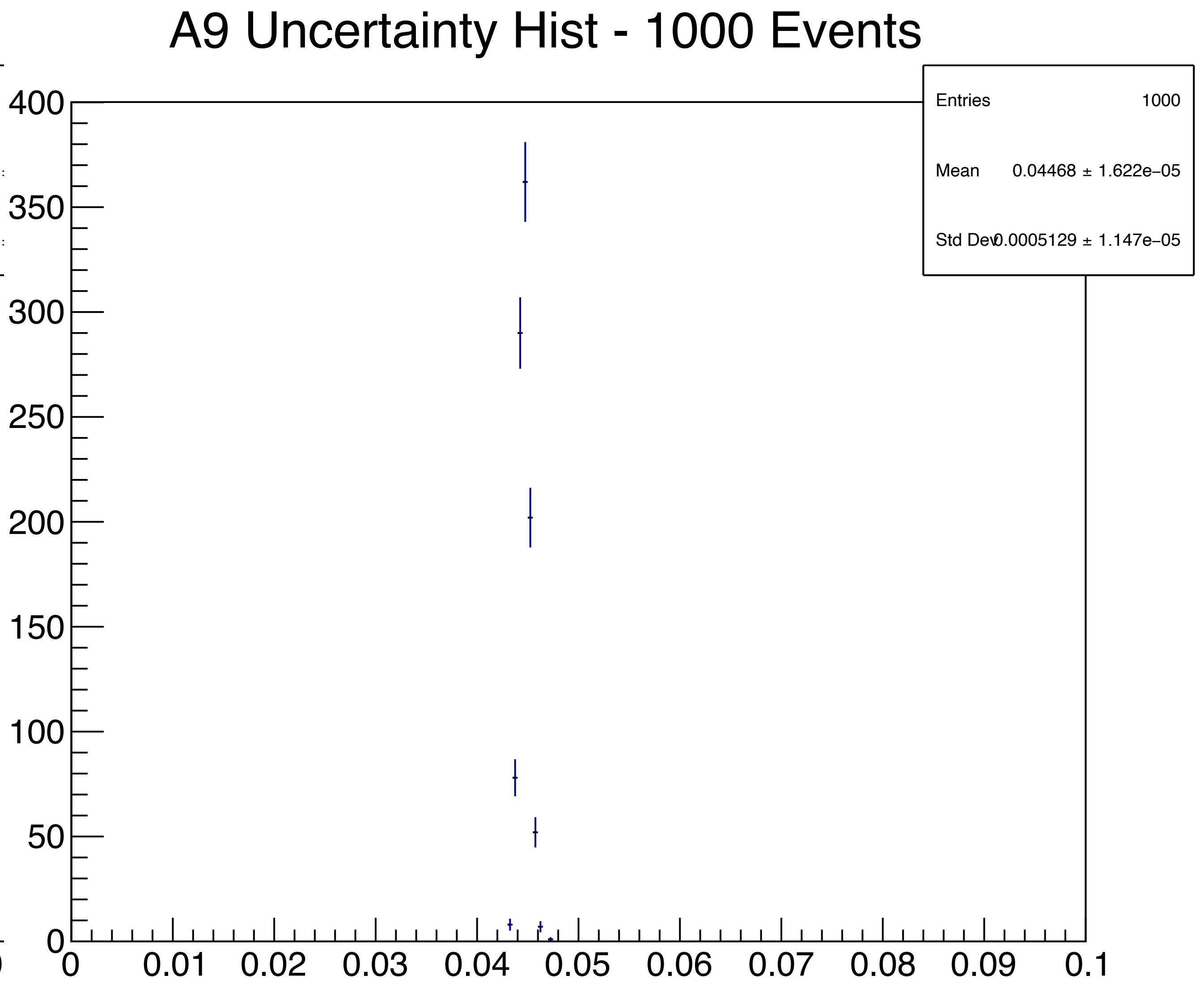


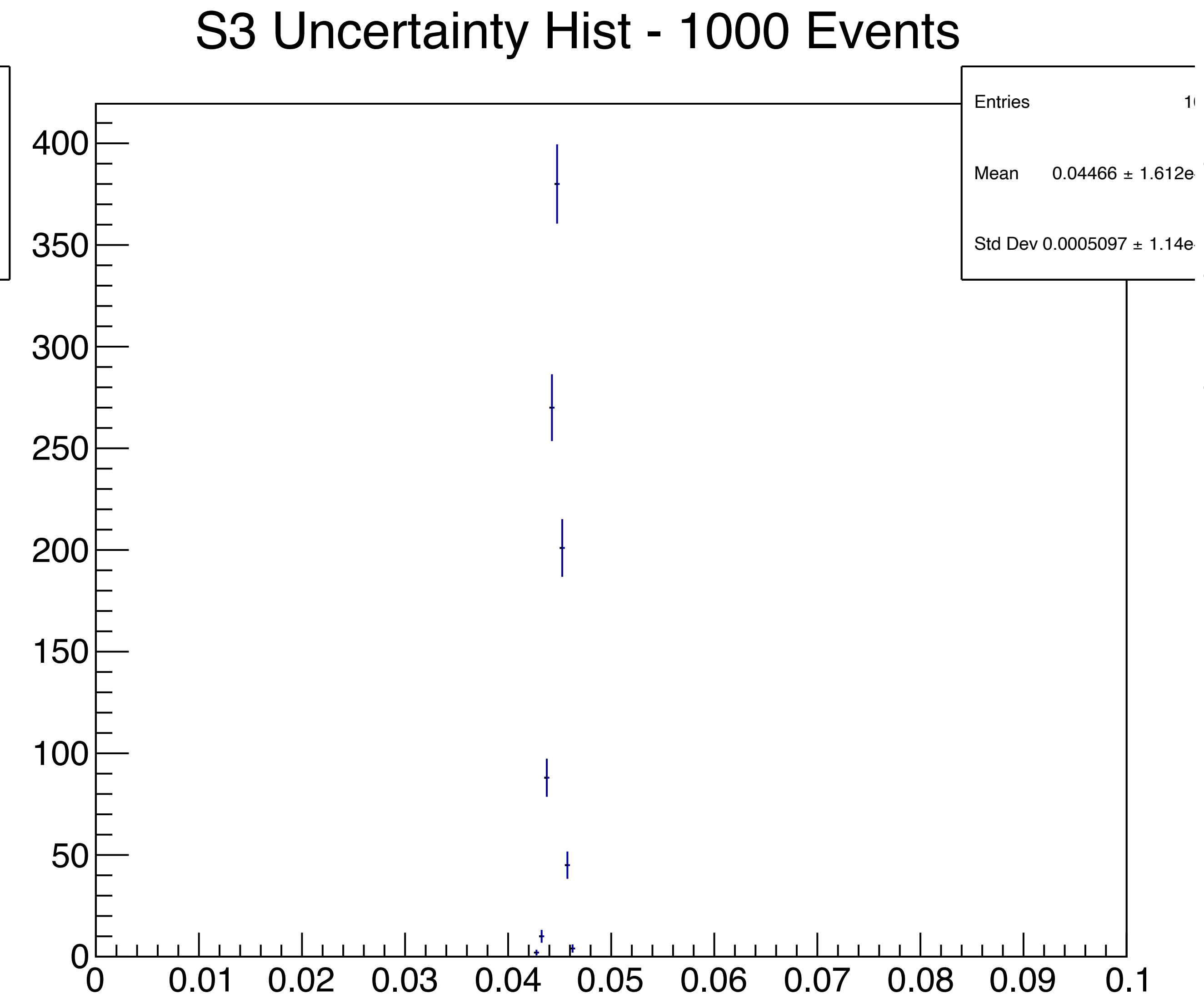


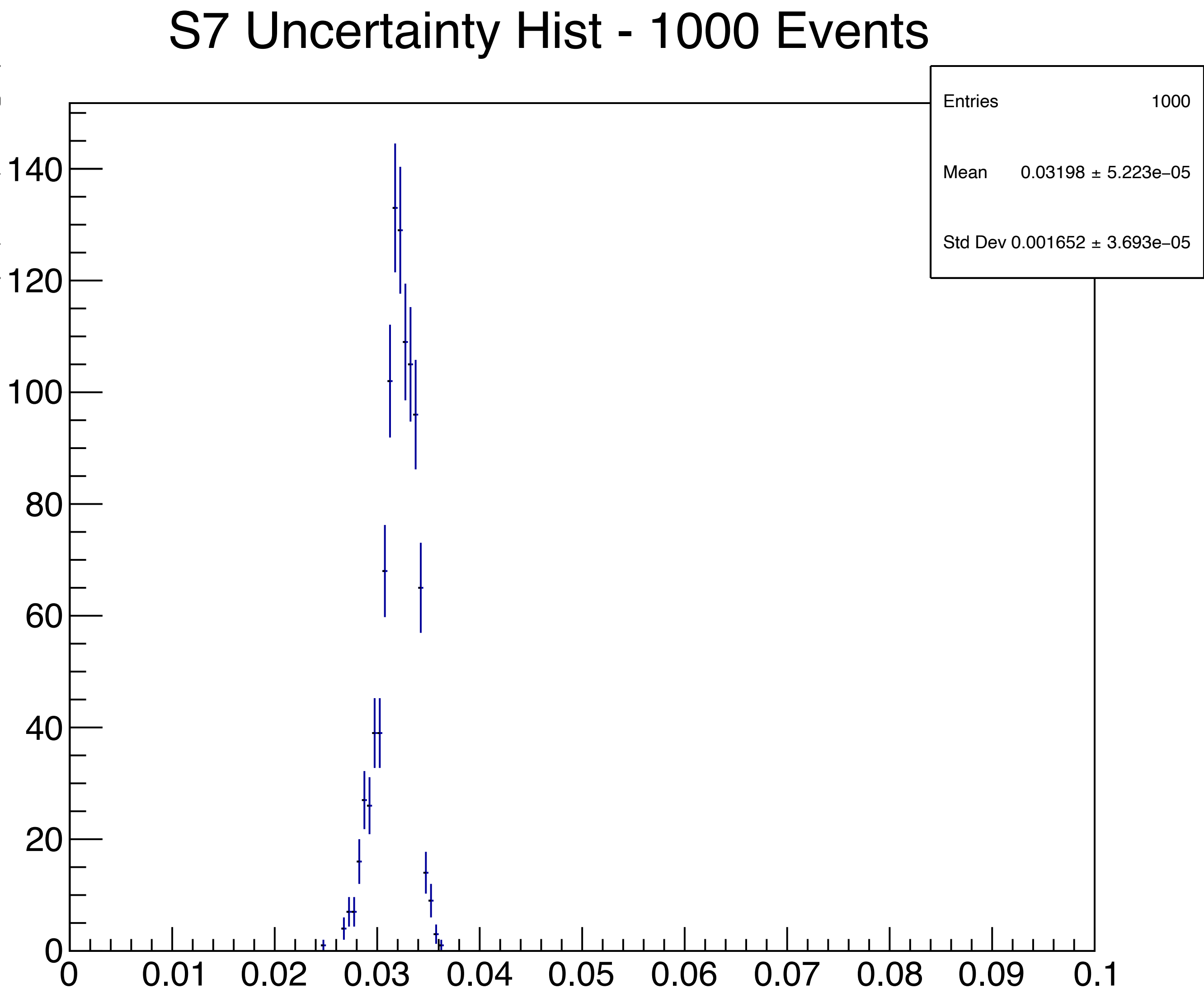












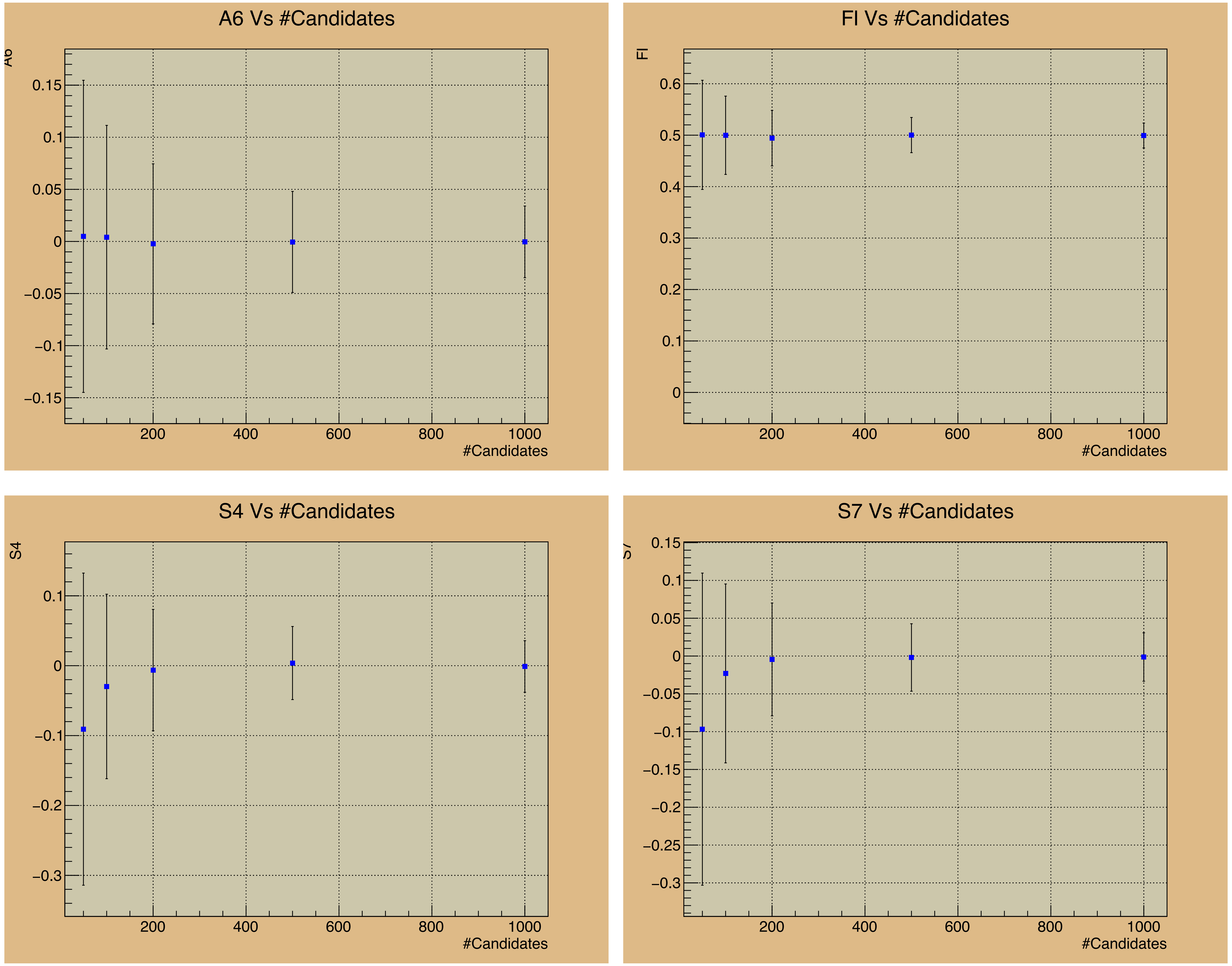
Observables Values - 1000 Toys

	#Candidates				
	50	100	200	500	1000
Angular Observable	Mean Observable Value				
FI	0.5006 ± 0.1061	0.4998 ± 0.0761	0.4942 ± 0.0539	0.5002 ± 0.0342	0.4993 ± 0.0242
S3	0.0049 ± 0.1958	0.0073 ± 0.1396	0.0012 ± 0.0993	0.0015 ± 0.0631	-0.0031 ± 0.0447
S4	-0.0908 ± 0.2233	-0.0297 ± 0.132	-0.0063 ± 0.0868	0.0038 ± 0.0523	-0.0011 ± 0.0369
S7	-0.0967 ± 0.2064	-0.023 ± 0.1183	-0.0045 ± 0.0746	-0.0019 ± 0.0446	-0.0013 ± 0.032
A5	-0.0886 ± 0.2063	-0.0261 ± 0.119	-0.0053 ± 0.0751	0.0026 ± 0.0448	-0.0012 ± 0.0318
A6	0.0049 ± 0.1498	0.0041 ± 0.1073	-0.0023 ± 0.0768	-0.0005 ± 0.0485	-0.0004 ± 0.0344
A8	-0.0974 ± 0.2241	-0.0236 ± 0.133	-0.0043 ± 0.086	-0.0008 ± 0.0521	-0.0026 ± 0.0372
A9	0.0065 ± 0.196	0.0059 ± 0.1399	-0.0001 ± 0.0995	0.0015 ± 0.0631	0.0 ± 0.0447

Observables Values - 1000 Toys

For the un-folded angles the fits behave well and the observables behave similarly for all #Candidates

For the folded angles the fits behave poorly and the observables behave poorly for < 200 Candidates



Pull Plots - 1000 Toys, 1000 Candidates

Pull Values - 1000 Toys

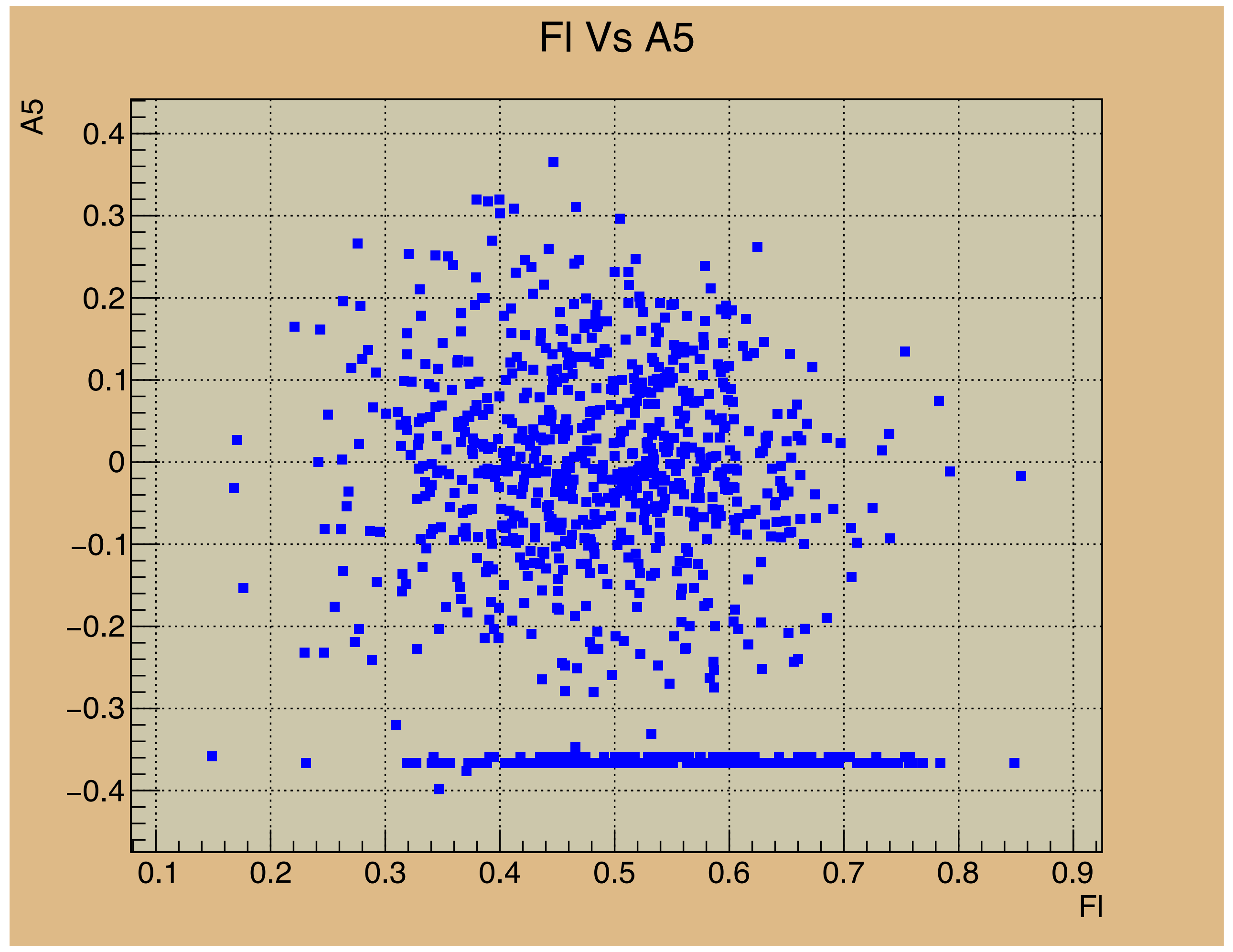
	#Candidates				
	50	100	200	500	1000
Angular Observable	Pull Mean , Pull Width				
FI	0.013 , 1.077	-0.016 , 1.026	0.023 , 0.981	0.061 , 1.03	-0.024 , 0.997
S3	0.031 , 1.081	-0.027 , 1.031	-0.021 , 0.999	-0.07 , 0.986	0.033 , 1.01
S4	0.24 , 0.742	-0.09 , 0.896	-0.006 , 1.016	0.006 , 0.984	0.018 , 0.992
S7	0.289 , 0.847	-0.064 , 1.006	-0.028 , 1.042	-0.032 , 1.03	-0.008 , 1.009
A5	0.212 , 0.845	-0.079 , 0.981	-0.027 , 1.019	-0.011 , 0.954	-0.019 , 1.016
A6	0.026 , 1.087	0.068 , 1.004	-0.039 , 1.051	0.005 , 1.043	0.009 , 1.012
A8	0.279 ,0.737	-0.096 , 0.893	-0.050 , 1.036	-0.026 , 1.028	-0.02 , 1.029
A9	0.041 ,1.069	0.06 , 1.018	-0.032 , 1.047	0.019 , 1.017	-0.002 , 0.997

S Observables - 1000 Toys

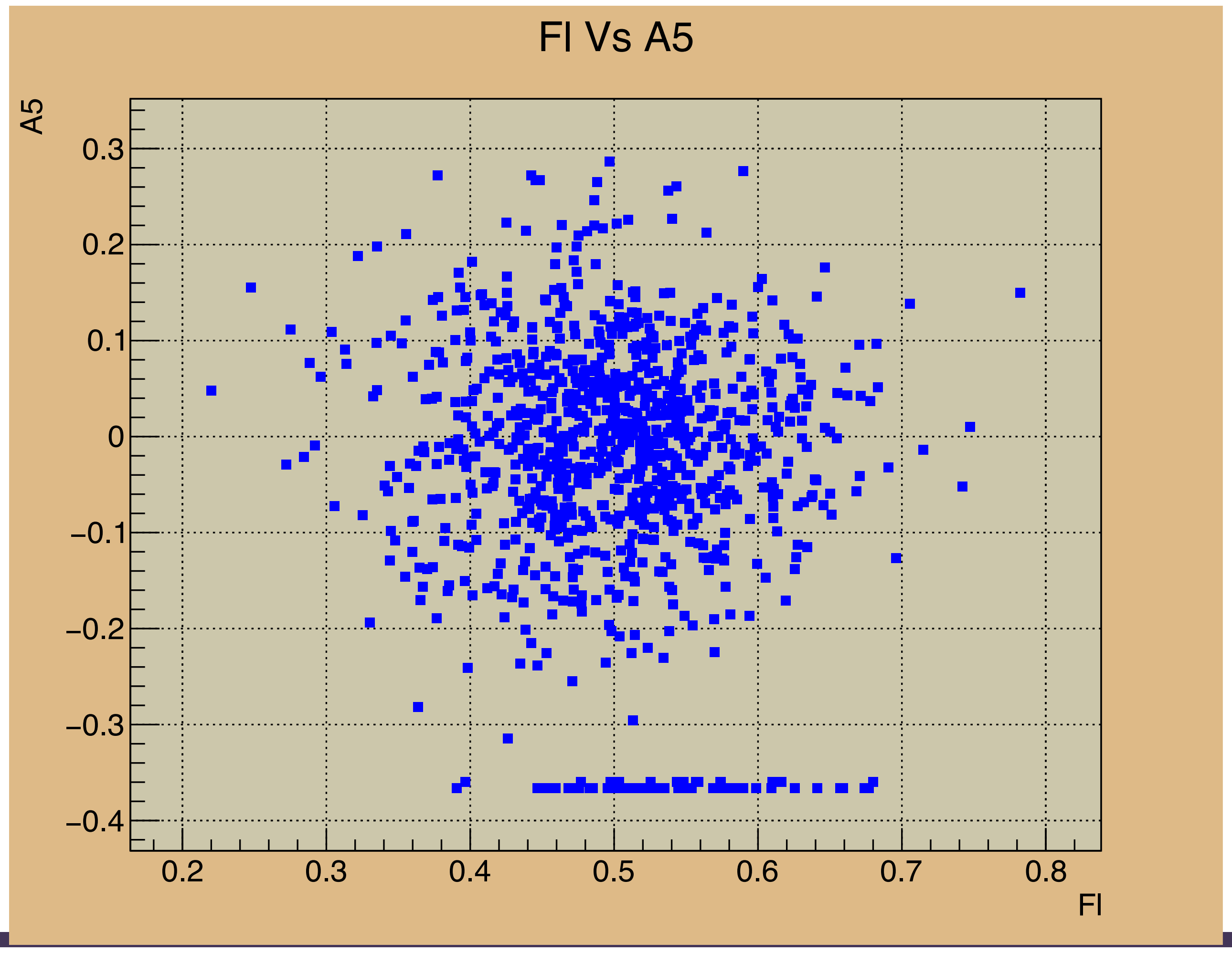
Scatter Plots - FI Vs Others - 1000 Toys w/ 200 Candidates

Scatter Plots - FI Vs A5 - 1000 Toys

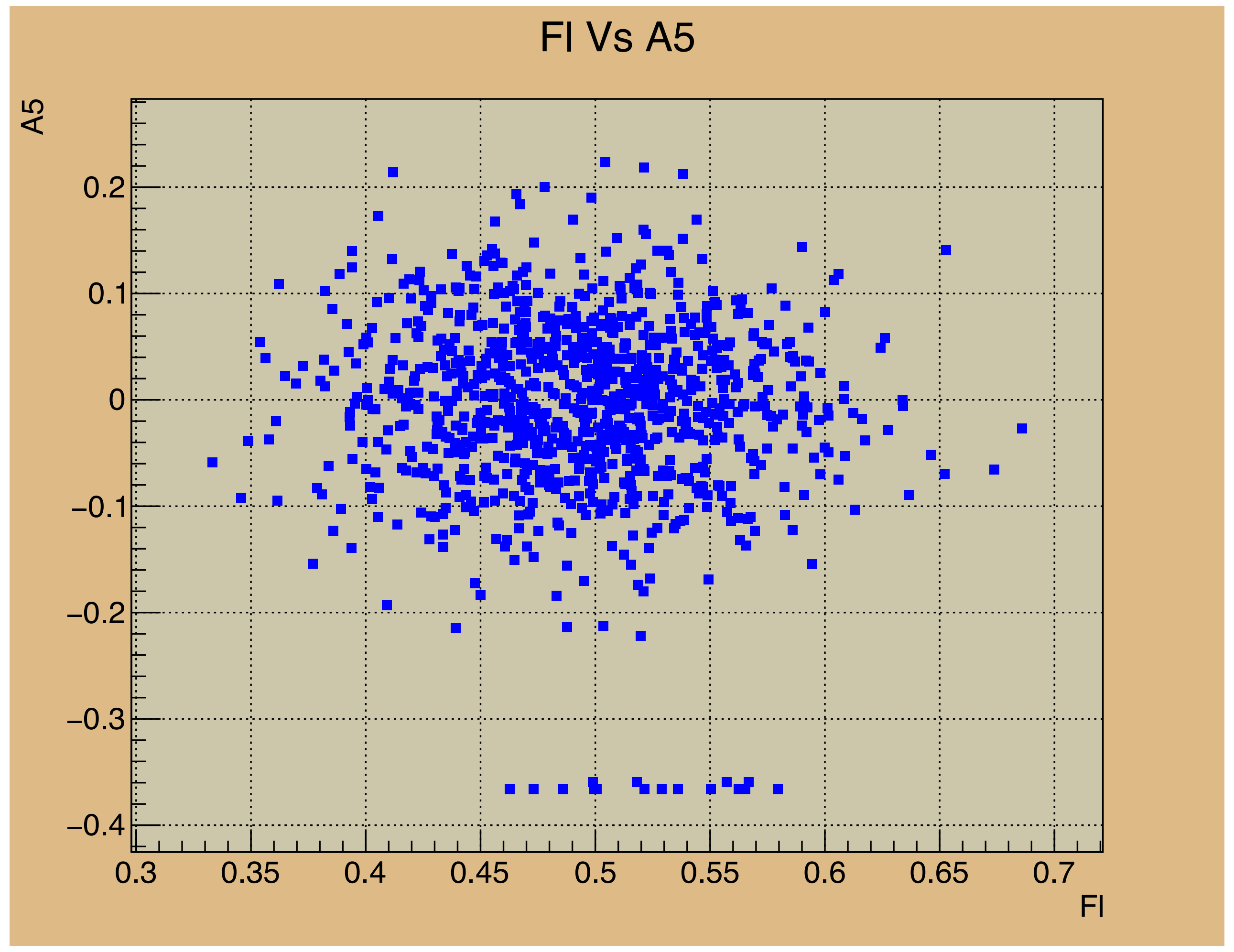
50 Candidates



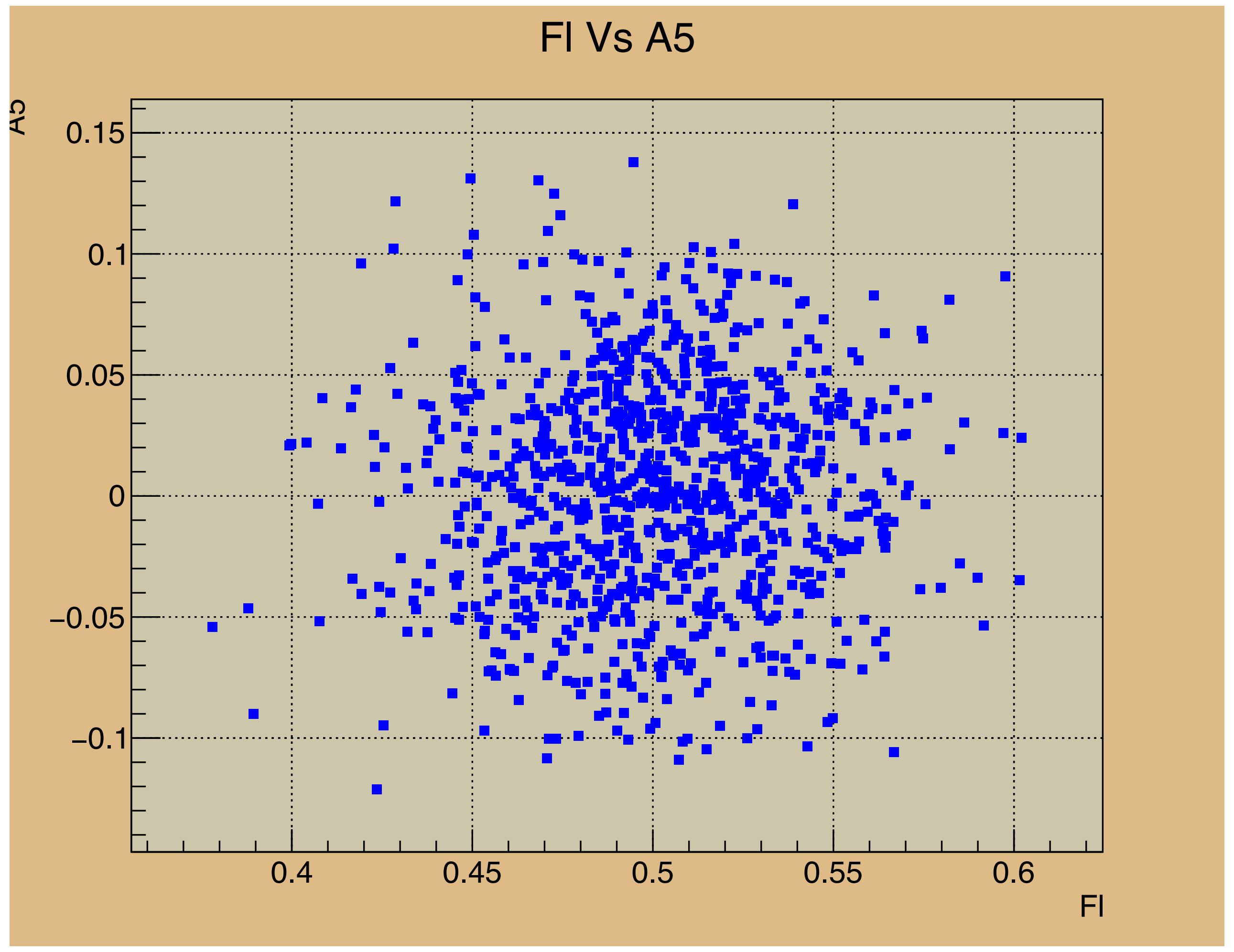
100 Candidates



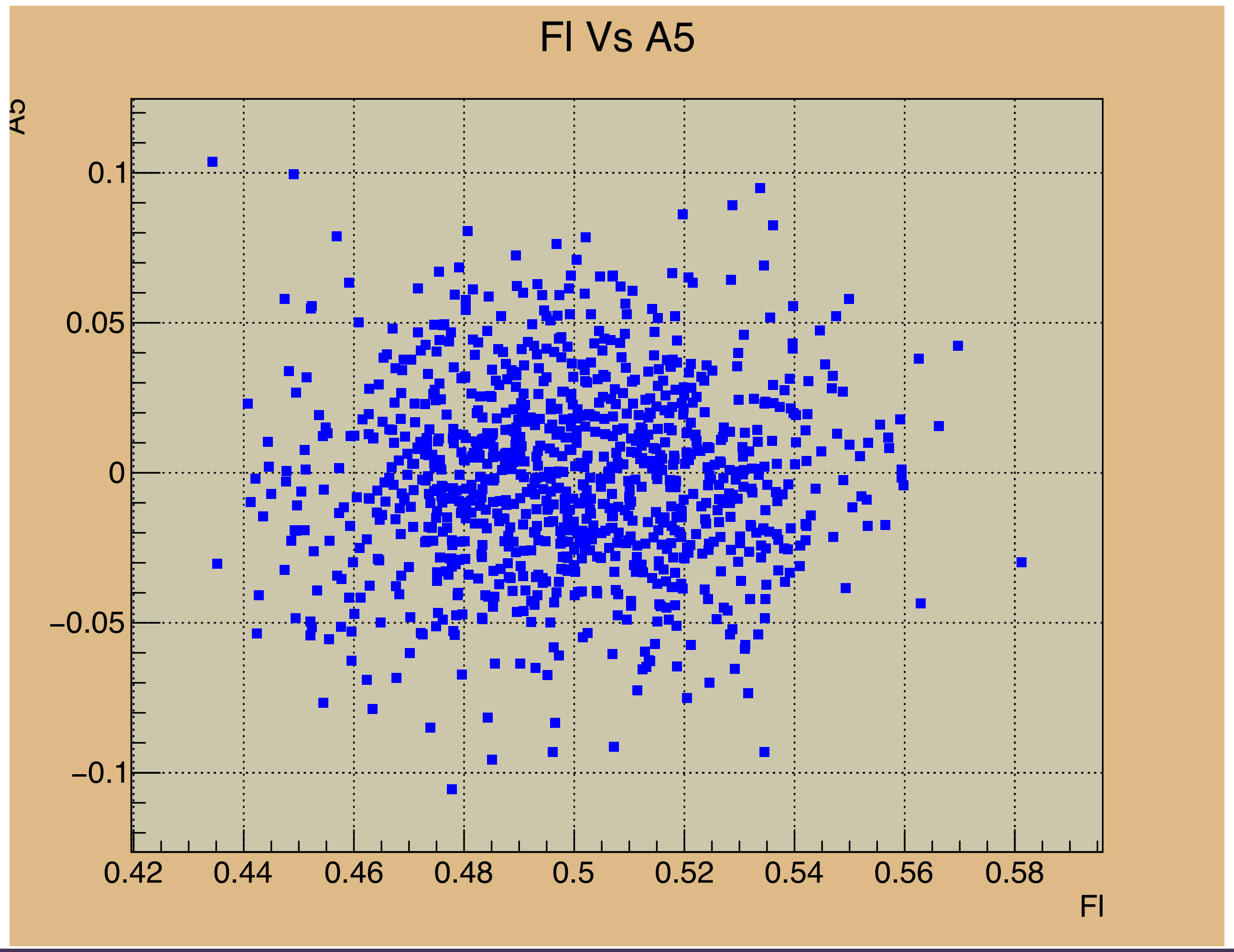
200 Candidates



500 Candidates



1000 Candidates



P OBSERVABLES

P Transformations

$$P_1 = \frac{S_3}{1-F_L}$$
$$P_2 = \frac{S_6}{1-F_L}$$
$$P_3 = \frac{S_9}{1-F_L}$$
$$P'_4 = \frac{S_4}{\sqrt{F_L(1-F_L)}}$$
$$P'_5 = \frac{S_5}{\sqrt{F_L(1-F_L)}}$$
$$P'_6 = \frac{S_7}{\sqrt{F_L(1-F_L)}}$$
$$P'_8 = \frac{S_8}{\sqrt{F_L(1-F_L)}}$$

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$$P'_4,\, S_4\colon \begin{cases} \phi \to -\phi & \text{for } \phi < 0 \\ \phi \to \pi - \phi & \text{for } \theta_\ell > \pi/2 \\ \theta_\ell \to \pi - \theta_\ell & \text{for } \theta_\ell > \pi/2, \end{cases} \qquad (3)$$

$$P'_5,\, S_5\colon \begin{cases} \phi \to -\phi & \text{for } \phi < 0 \\ \theta_\ell \to \pi - \theta_\ell & \text{for } \theta_\ell > \pi/2, \end{cases} \qquad (4)$$

$$P'_6,\, S_7\colon \begin{cases} \phi \to \pi - \phi & \text{for } \phi > \pi/2 \\ \phi \to -\pi - \phi & \text{for } \phi < -\pi/2 \\ \theta_\ell \to \pi - \theta_\ell & \text{for } \theta_\ell > \pi/2, \end{cases} \qquad (5)$$

$$P'_8,\, S_8\colon \begin{cases} \phi \to \pi - \phi & \text{for } \phi > \pi/2 \\ \phi \to -\pi - \phi & \text{for } \phi < -\pi/2 \\ \theta_K \to \pi - \theta_K & \text{for } \theta_\ell > \pi/2 \\ \theta_\ell \to \pi - \theta_\ell & \text{for } \theta_\ell > \pi/2. \end{cases} \qquad (6)$$

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$$\frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi} = \frac{9}{8\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + \frac{1}{2}(1-F_L)A_T^{(2)}\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + \sqrt{F_L(1-F_L)}P'_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi\Big].$$

$$\frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi} = \frac{9}{8\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + \frac{1}{2}(1-F_L)A_T^{(2)}\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + \sqrt{F_L(1-F_L)}P'_5\sin 2\theta_K\sin\theta_\ell\cos\phi\Big].$$

$$\frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi} = \frac{9}{8\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + \frac{1}{2}(1-F_L)A_T^{(2)}\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + \sqrt{F_L(1-F_L)}P'_6\sin 2\theta_K\sin\theta_\ell\sin\phi\Big].$$

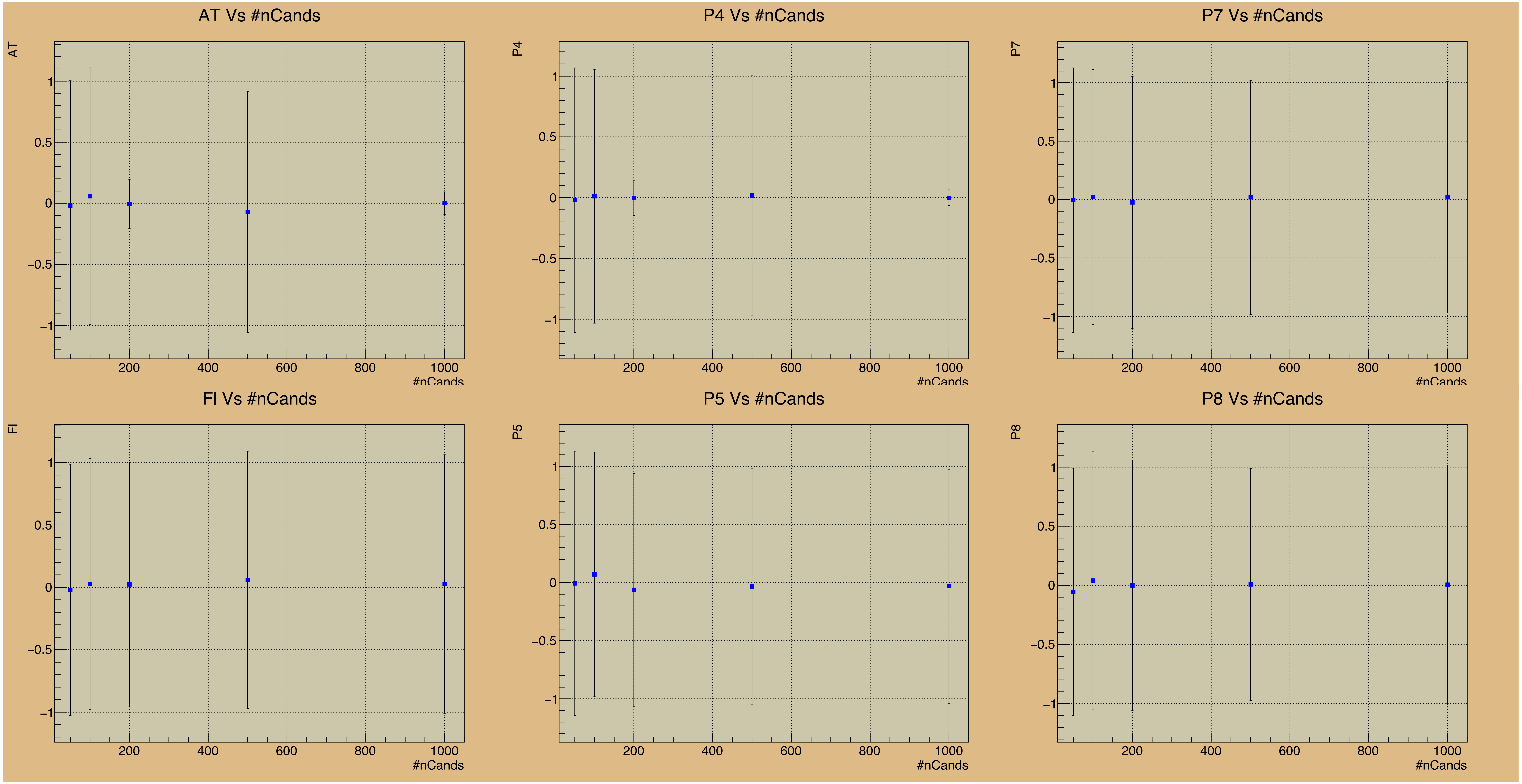
$$\frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi} = \frac{9}{8\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + \frac{1}{2}(1-F_L)A_T^{(2)}\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + \sqrt{F_L(1-F_L)}P'_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi\Big].$$

Common terms, only P′ value differs between 3D P′ observable projections

$$\frac{9}{8\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + \frac{1}{2}(1-F_L)A_T^{(2)}\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi +$$

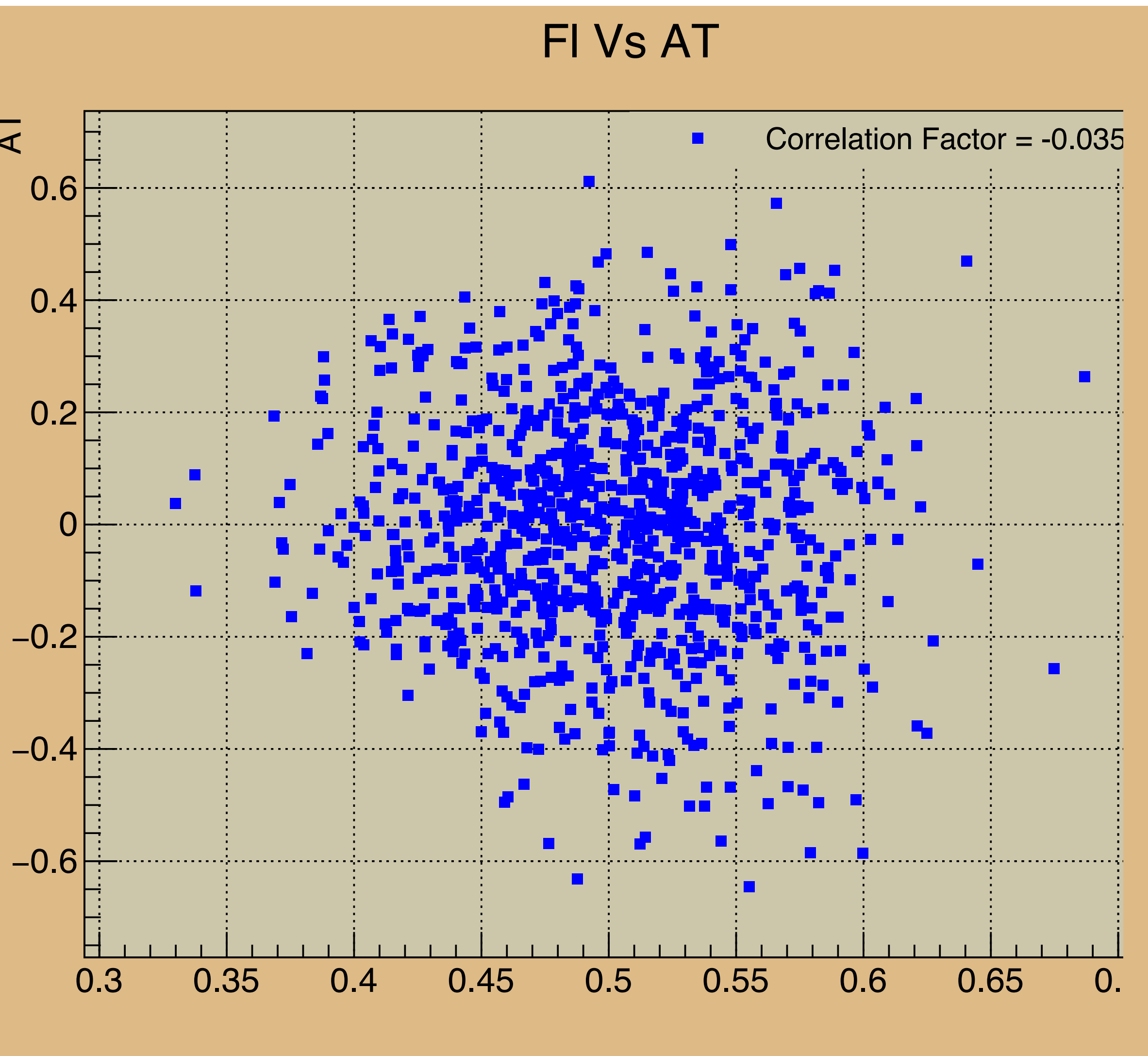
P Observables - 1000 Toys

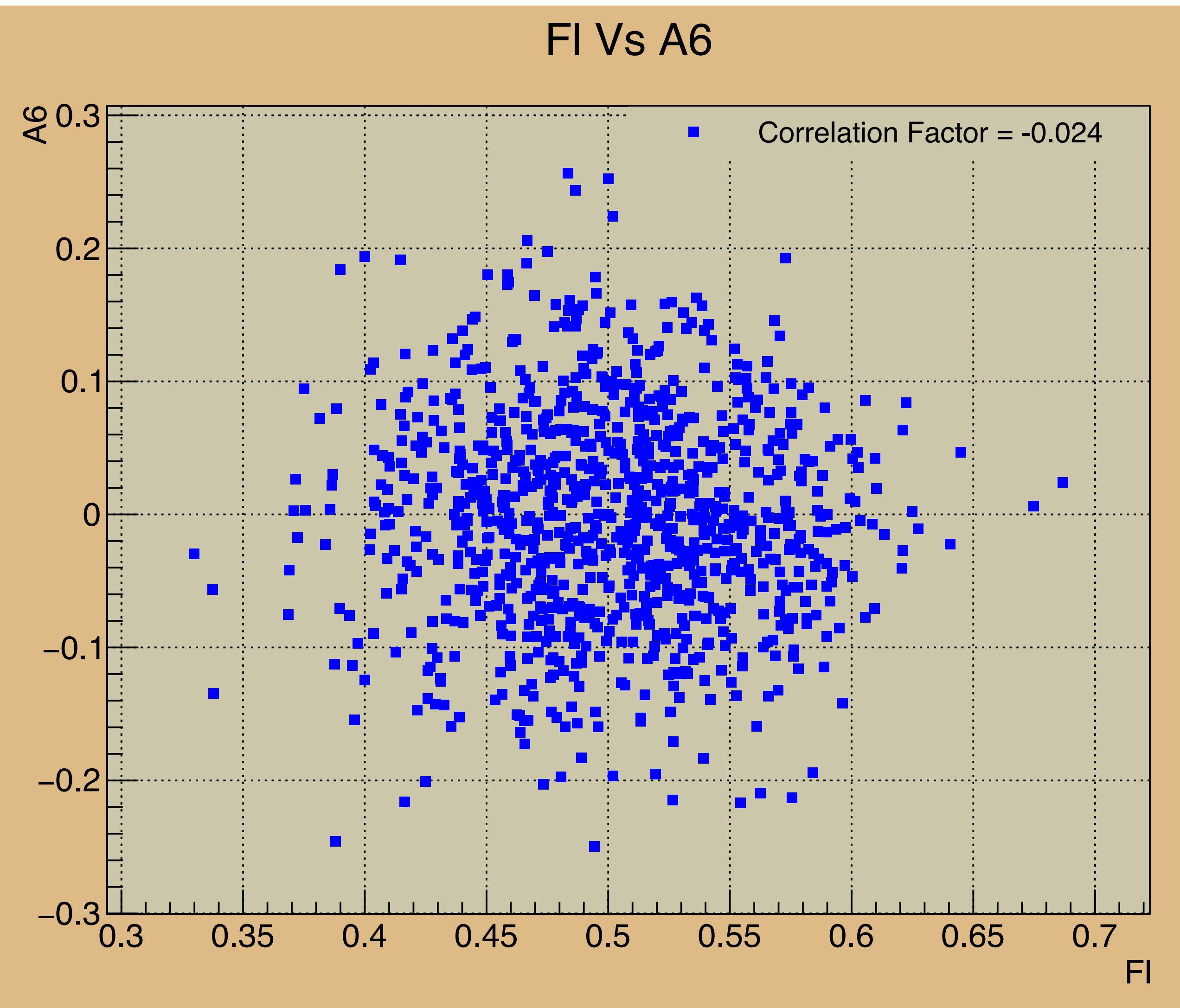
P Observables - Pulls - 1000 Toys

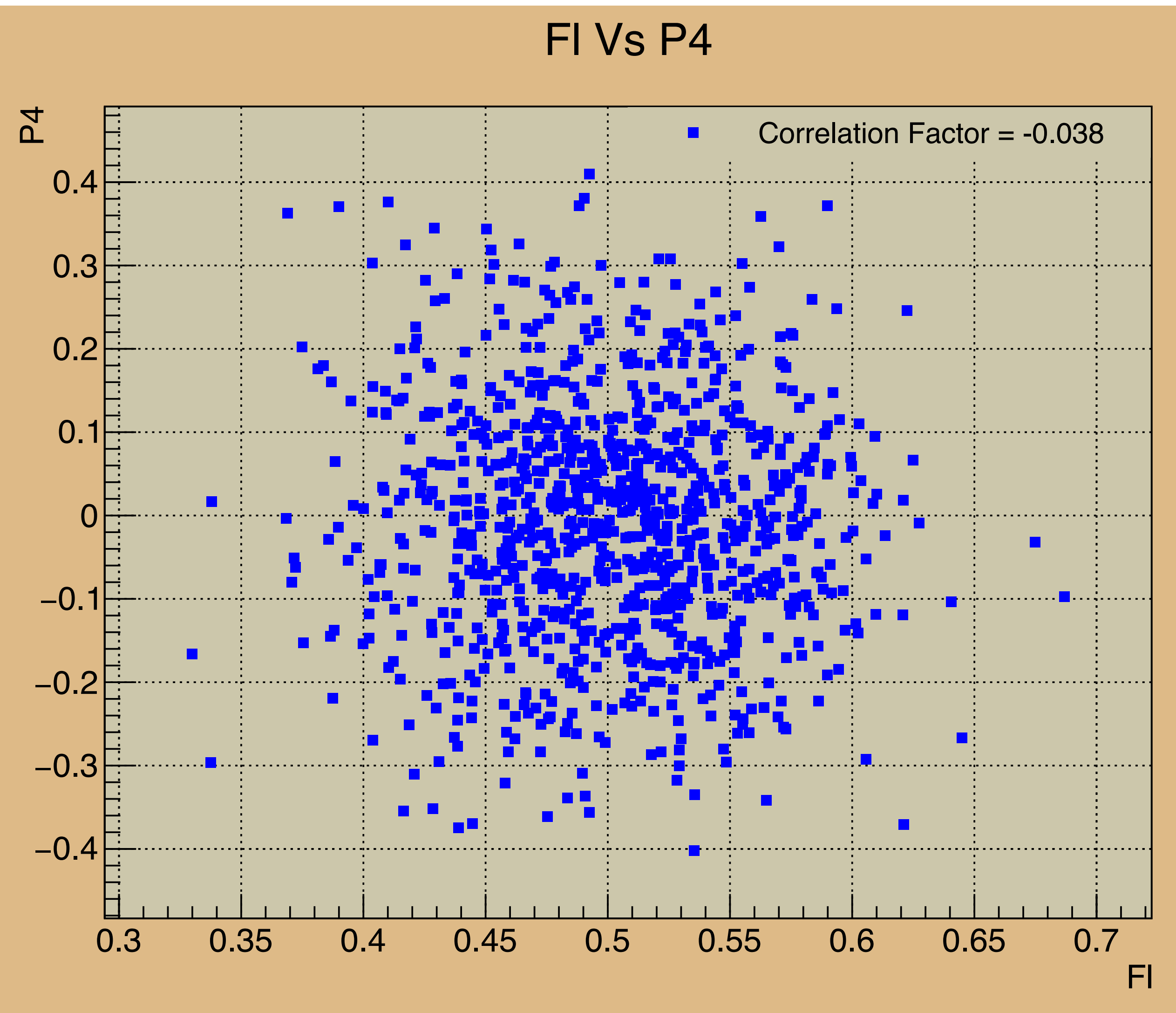


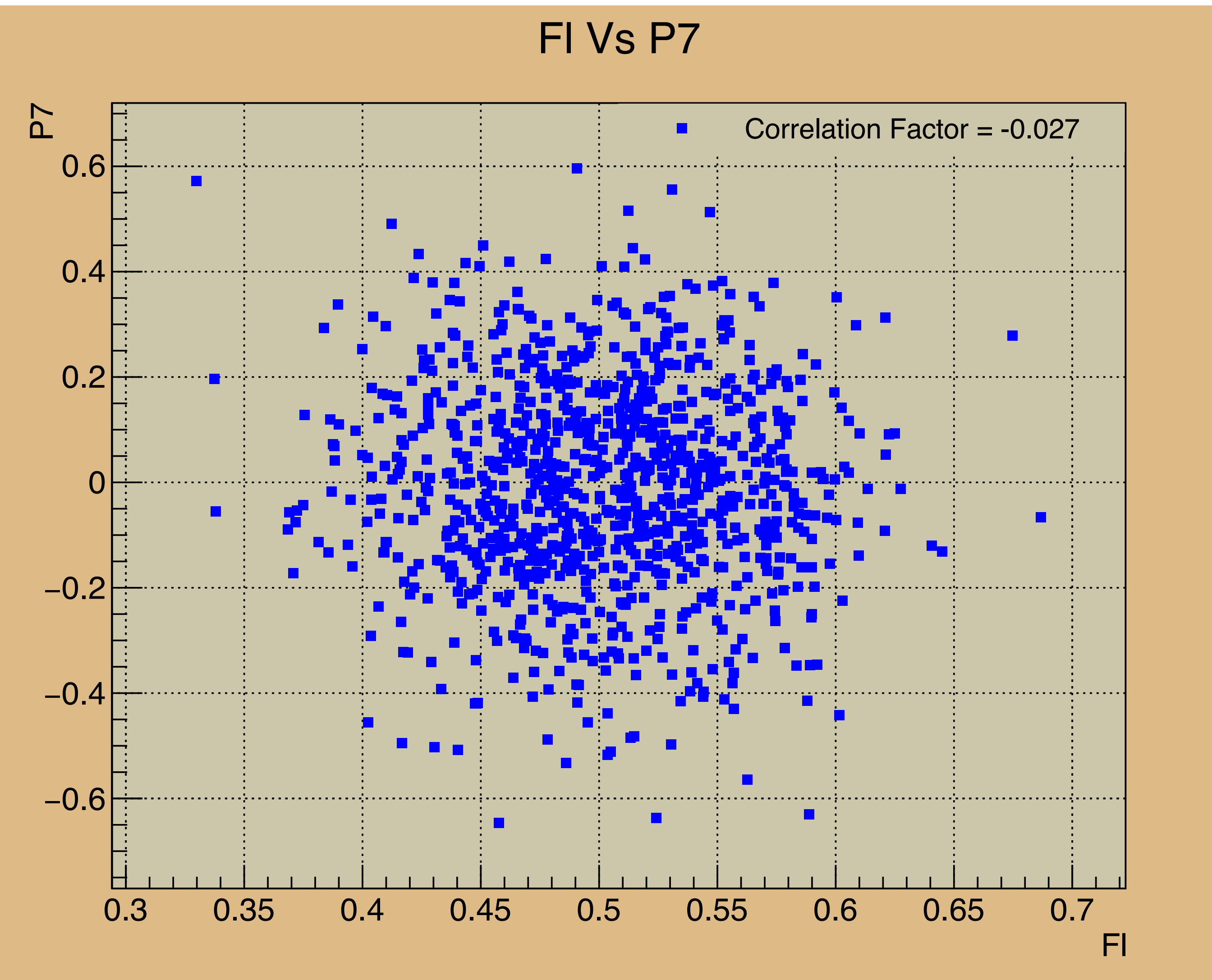
At 50 Events there are a couple of toys with a pull mean of order 10^5, these aren't within the scope of the pull plots (range -10,10) so are excluded here, but will investigate.

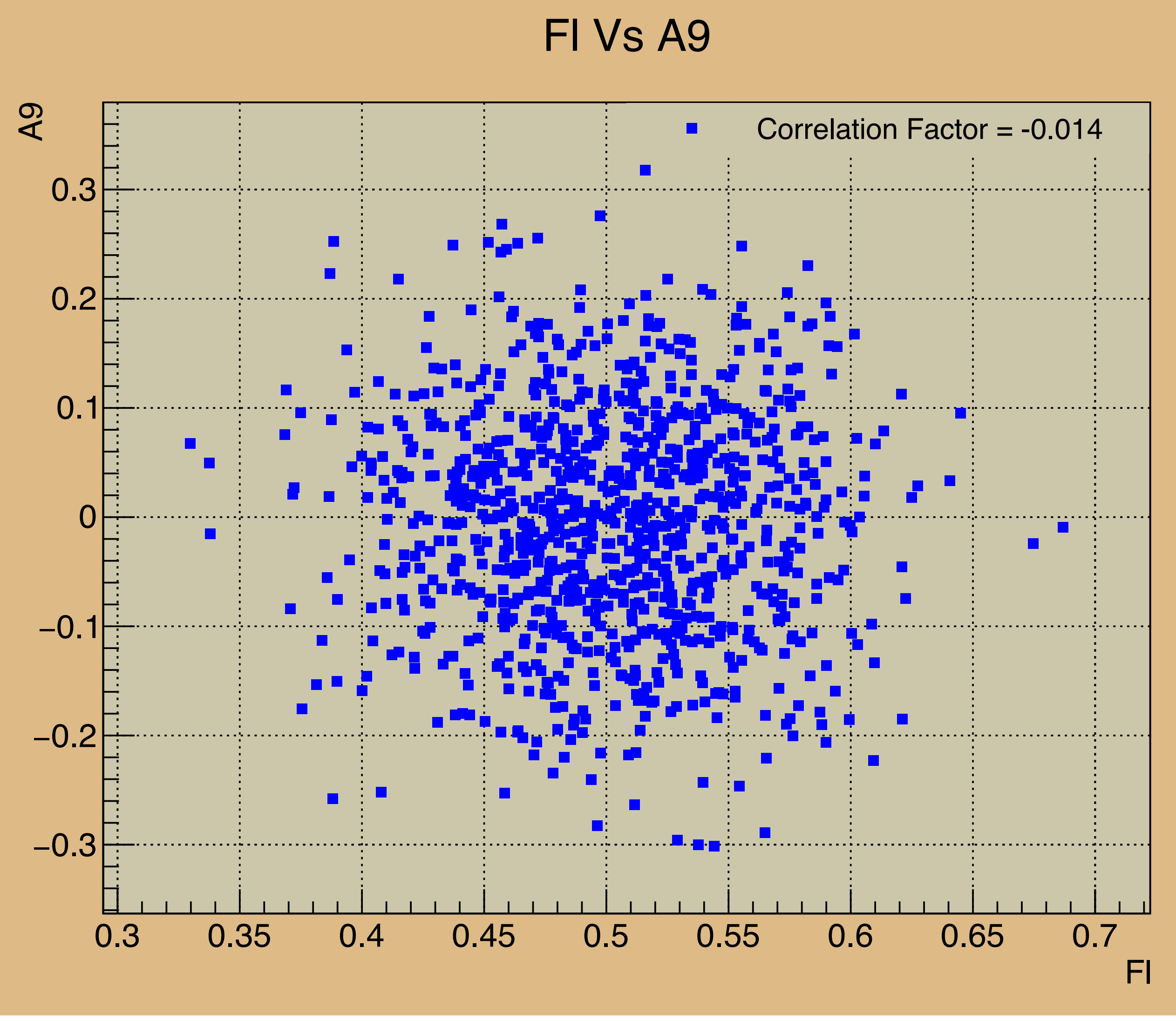
Scatter Plots - FI Vs Others - 1000 Toys w/ 200 Candidates

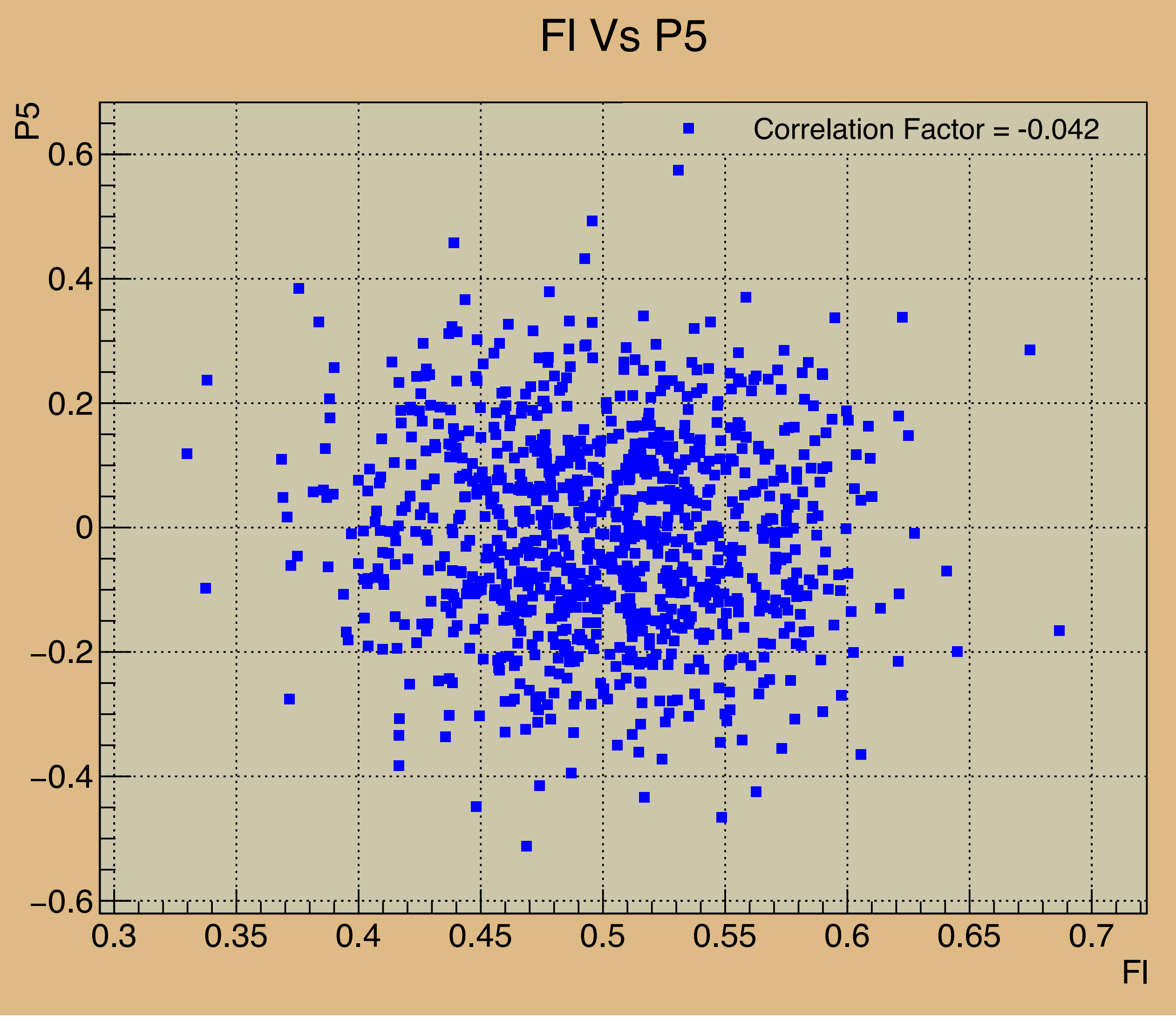


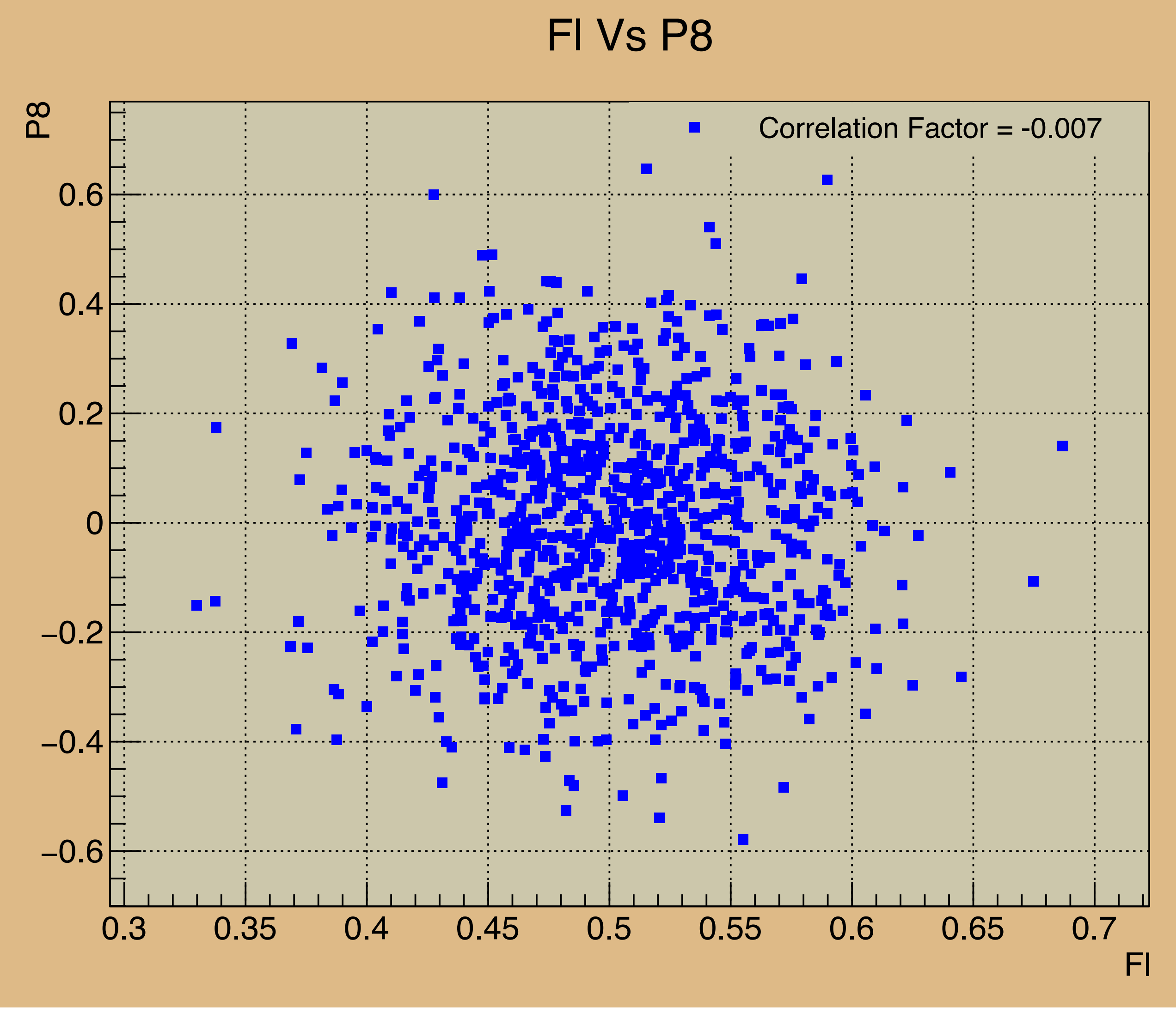






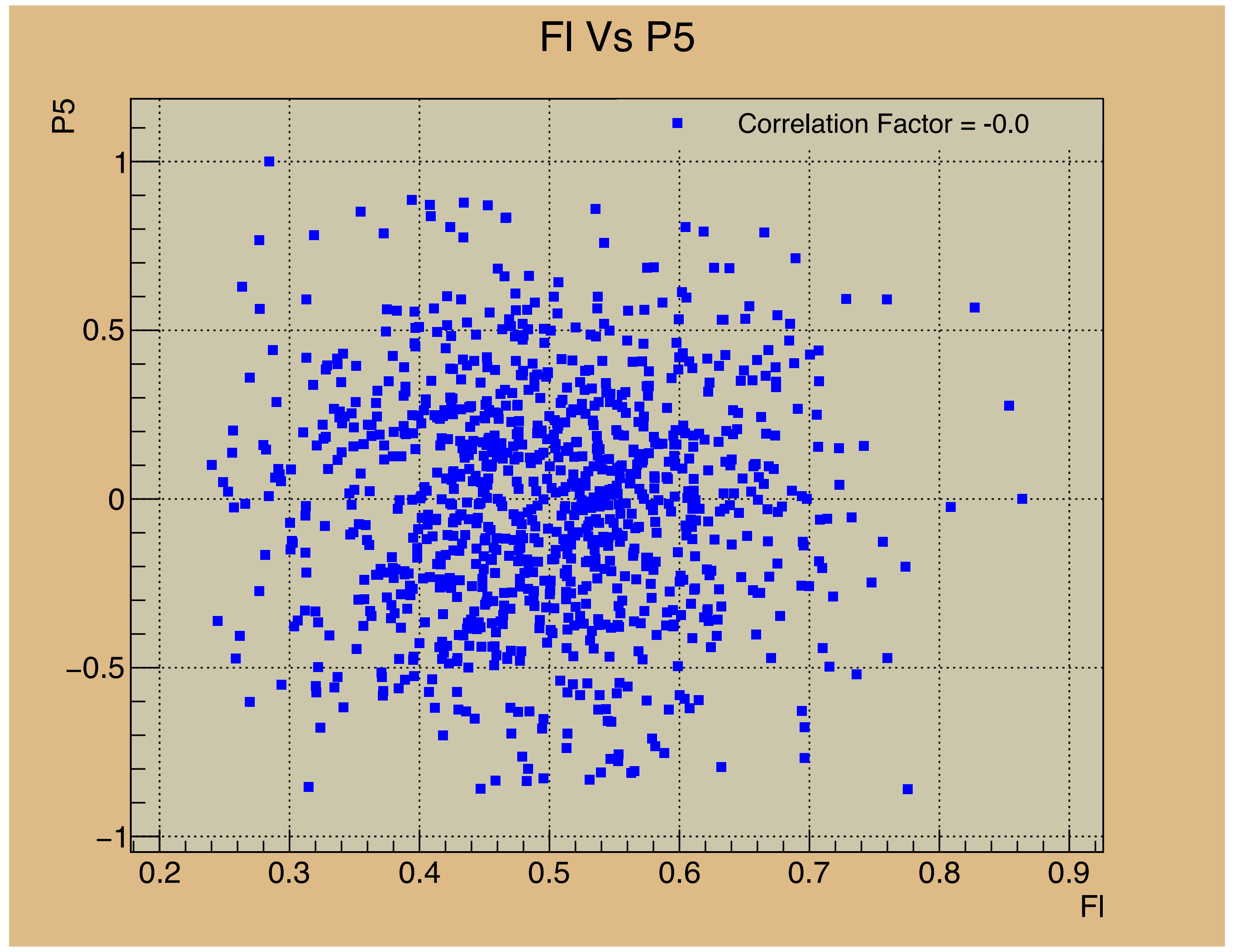




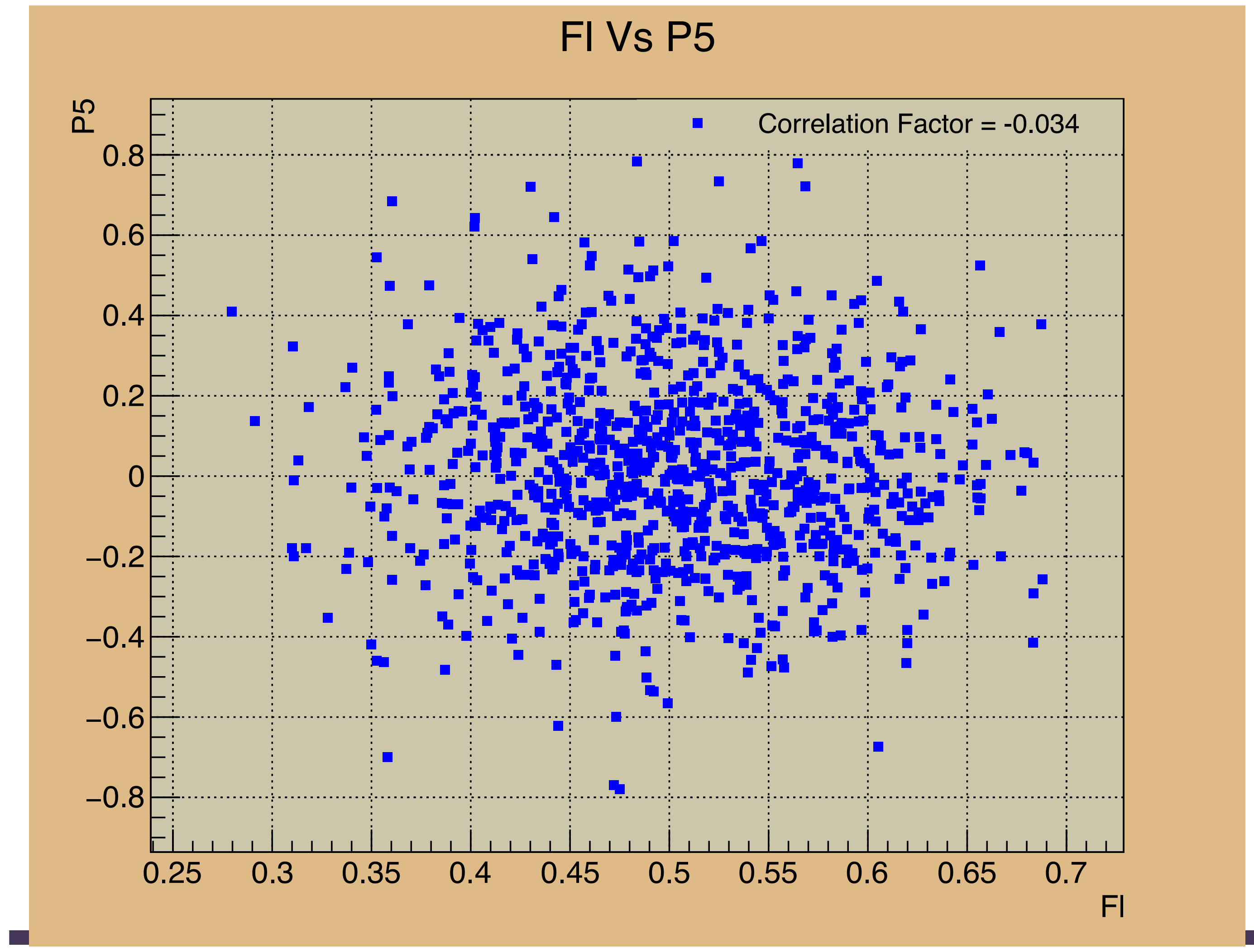


Scatter Plots - FI Vs P5 - 1000 Toys

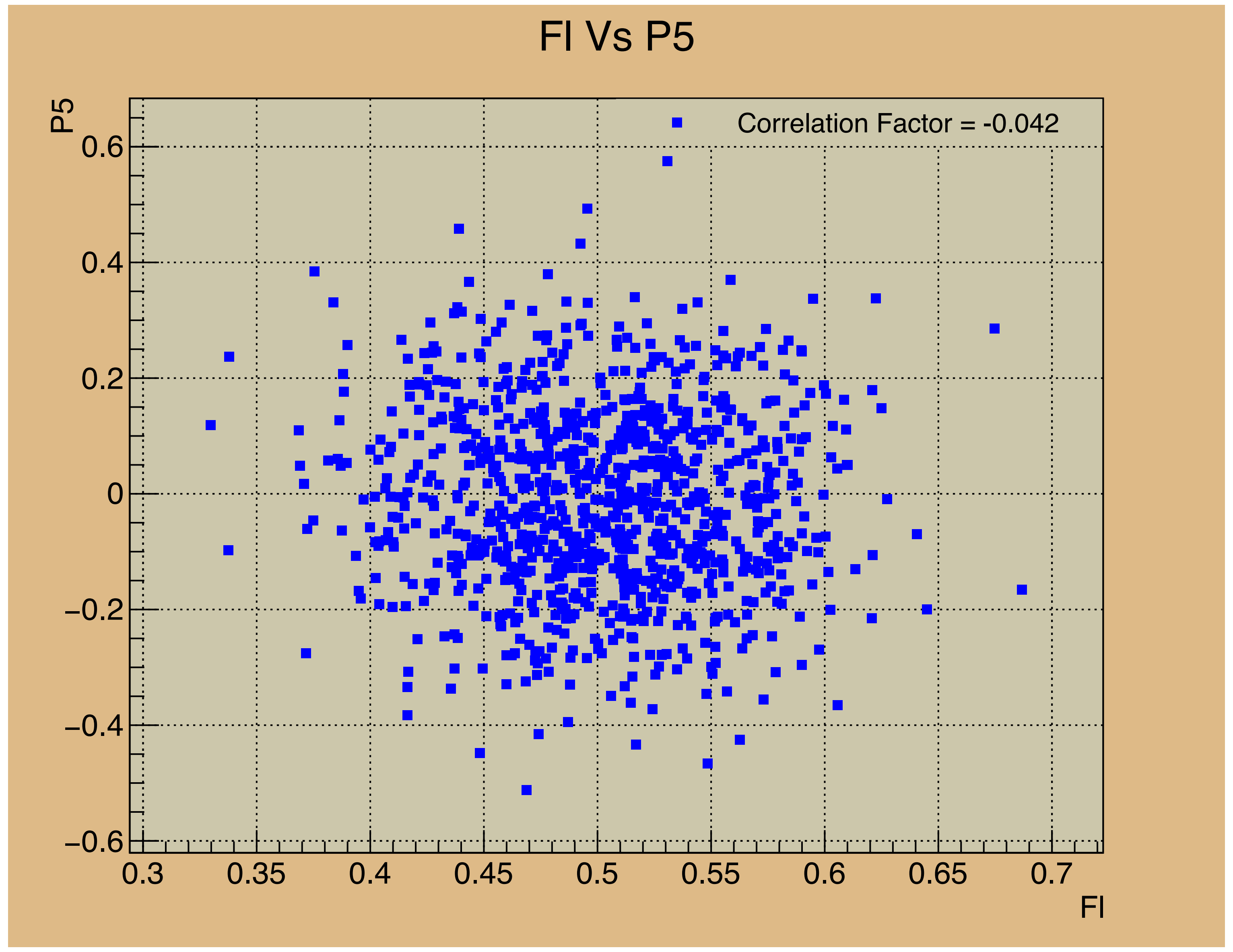
50 Candidates



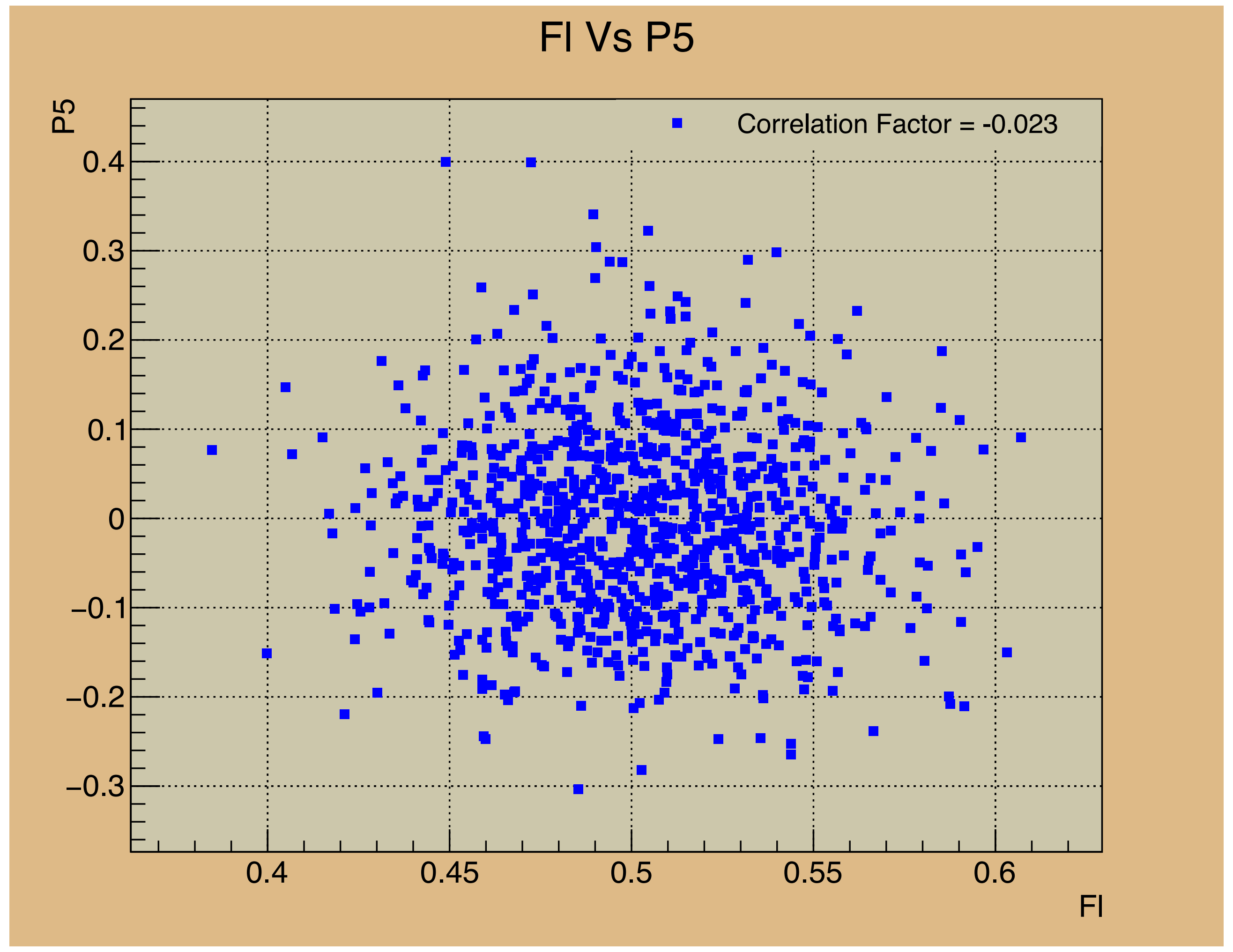
100 Candidates



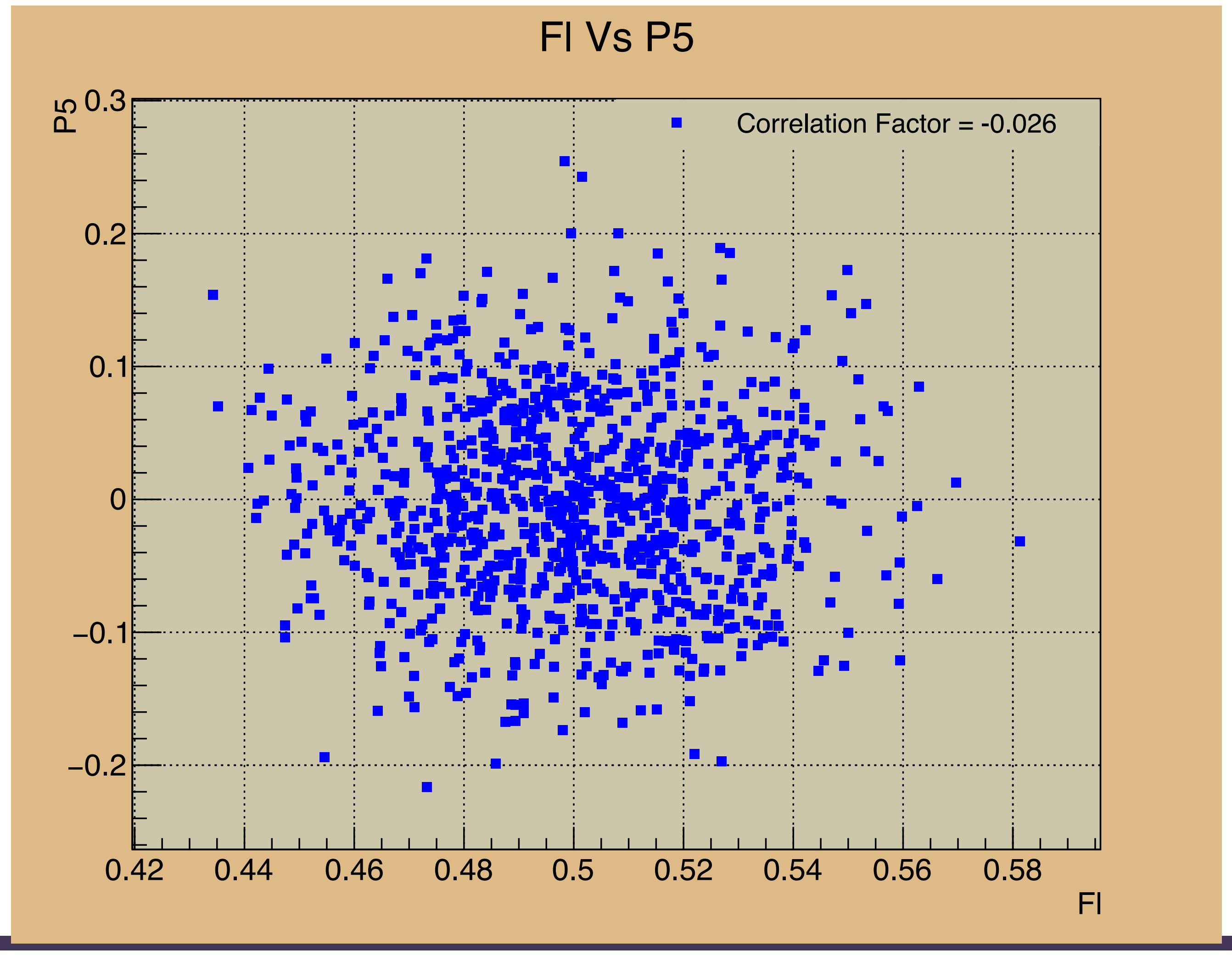
200 Candidates



500 Candidates



1000 Candidates



P Observables - Correlation

Correlation - 1000 Toys, 200 Events

	FI	AT	P4	P5	A6	P7	P8	A9
FI	1.0	-0.035	-0.038	-0.042	-0.024	-0.027	-0.007	-0.014
AT		1.0	0.047	-0.013	-0.063	-0.041	0.008	0.021
P4			1.0	0.235	0.011	-0.343	0.574	-0.021
P5				1.0	0.05	0.285	0.024	-0.015
A6					1.0	0.026	0.006	0.056
P7						1.0	-0.006	0.012
P8							1.0	-0.023
A9								1.0

P Observables - NLL - 1000 Toys, 200 Events

UPDATES

1000 Toys

# Candidates	Run time
50	3 days, 11:51:45
100	1 day, 8:19:02
200	4:35:41
500	0:44:43
1000	0:39:31

$$\frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi} = \frac{9}{8\pi}\left[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_5\sin 2\theta_K\sin\theta_\ell\cos\phi\right]$$

$$\frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi} = \frac{9}{8\pi}\left[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi\right]$$

$$\frac{1}{\Gamma}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi\,\mathrm{d}q^2} = \frac{9}{8\pi}\left[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi\right]$$

With a low number of candidates the fit becomes unphysical. As the folded angles are calculated from Fl and S3 the PDF for S4 could be forced into unphysical regions as Minuit handles negative PDFs

Issues Update (28/04/2021)

1000 Toys - S Observables

# Candidates	Run time
50	6:13:32
100	17:51:25
200	2:15:42
500	0:16:55
1000	0:17:25

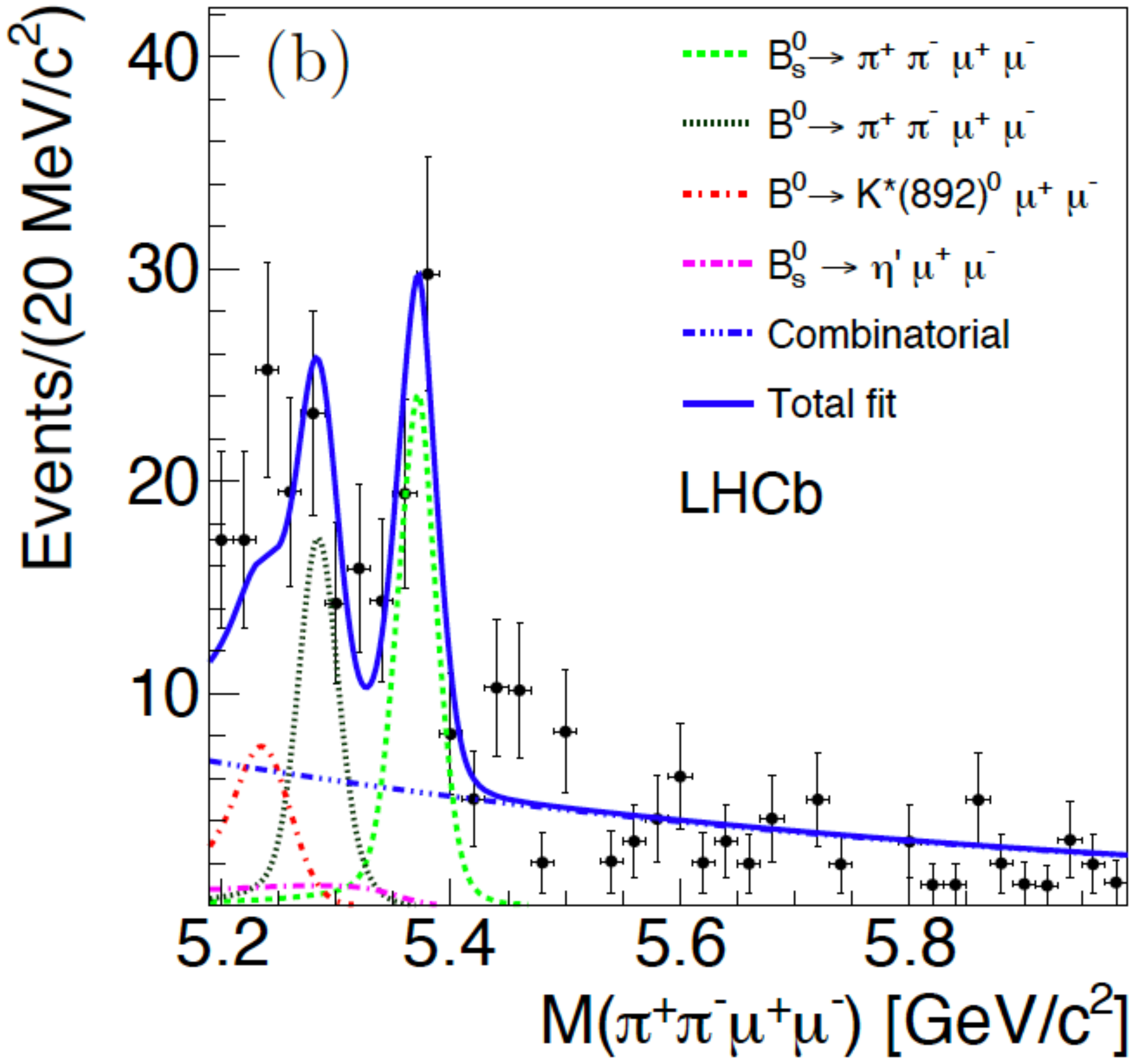
1000 Toys - P Observables

# Candidates	Run time
50	1:16:57
100	0:39:53
200	0:14:13
500	0:14:39
1000	0:14:48

BACKUP

- Several terms in angular distributions measure the CP asymmetries, therefore perform measurements using several 1D projections
- Currently looking at options for angular transformations for measurements of other terms
- No access to A_{FB}
- Analysis similar to $B^0 \rightarrow K^* \mu\mu$ measurements (LHCB-PAPER-2013-037)

From Run 1 analysis



LHCB-PAPER-2014-063

Angular Folding

Obtained from LHCB-PAPER-2013-037, there may be differences in S's and A's naming.

2.1 Measuring P_4'

Applying the transformations:

$$\begin{aligned} \phi &\rightarrow -\phi \text{ (for } \phi < 0) \\ \phi &\rightarrow \pi - \phi \text{ (for } \theta_l > \pi/2) \\ \theta_l &\rightarrow \pi - \theta_l \text{ (for } \theta_l > \pi/2) \end{aligned}$$

These angular transformations ('foldings') are chosen to simplify the pdfs as much as possible, reducing the free parameters in the fit without losing any experimental sensitivity.

$$\frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi} = \frac{9}{8\pi}\left[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi\right]$$

2.2 Measuring P_5'

Applying the following set of transformations:

$$\begin{aligned} \phi &\rightarrow -\phi \text{ (for } \phi < 0) \\ \theta_l &\rightarrow \pi - \theta_l \text{ (for } \theta_l > \pi/2) \end{aligned}$$

$$\frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi} = \frac{9}{8\pi}\left[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_5\sin 2\theta_K\sin\theta_\ell\cos\phi\right]$$

2.3 Measuring P_7'

Starting from Eq. 1 and applying the following set of transformations:

$$\begin{aligned} \phi &\rightarrow \pi - \phi(\phi > \pi/2) \\ \phi &\rightarrow -\pi - \phi(\phi < -\pi/2) \\ \theta_l &\rightarrow \pi - \theta_l(\theta_l > \pi/2) \end{aligned}$$

$$\frac{1}{\Gamma}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi\,\mathrm{d}q^2} = \frac{9}{8\pi}\left[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi\right]$$

2.4 Measuring P_8'

Applying the following transformations:

$$\begin{aligned} \phi &\rightarrow \pi - \phi(\phi > \pi/2) \\ \phi &\rightarrow -\pi - \phi(\phi < -\pi/2) \\ \theta_l &\rightarrow \pi - \theta_l(\theta_l > \pi/2) \\ \theta_K &\rightarrow \pi - \theta_K(\theta_l > \pi/2) \end{aligned}$$

$$\frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi} = \frac{9}{8\pi}\left[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi\right]$$

All include 'nuisance' parameters Fl , S3