

Learning from scanners: bias reduction and feature correction in Radiomics

SUPPLEMENTARY MATERIALS

A. Gammex phantom plug description

In our phantom setting, we placed the plugs according to figures A1-2 and table A1. The cylindrical ROI dimensions were approximately 25 mm (height) and 10 mm (diameter).

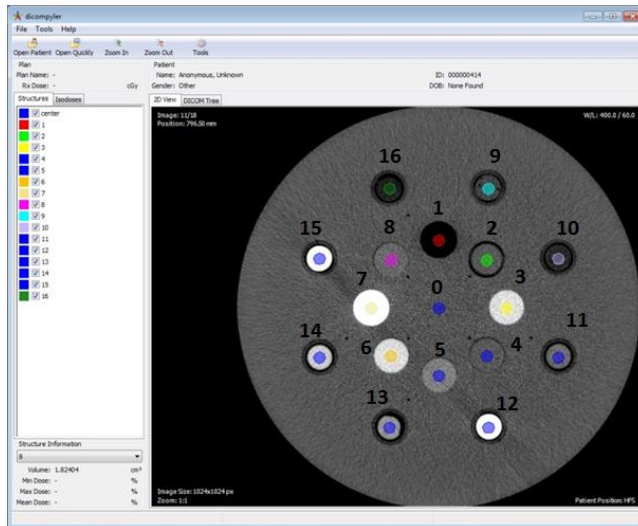


Figure A1 - Gammex phantom CT image with cylindrical delineations

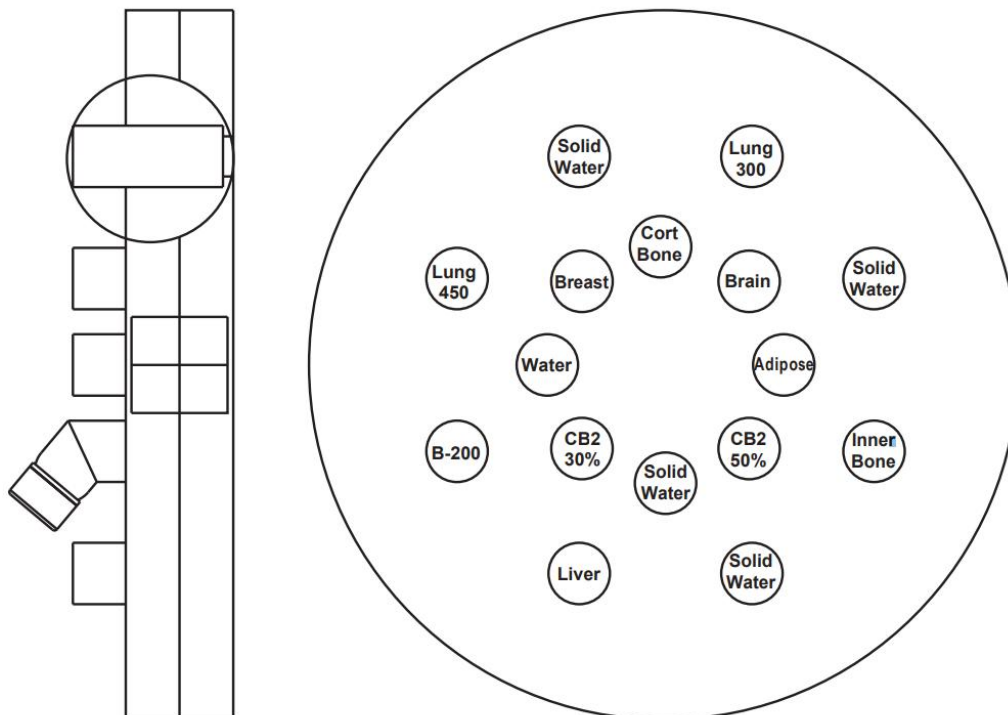


Figure A2 – original Gammex phantom plug configuration (ref. http://cspmedical.com/content/102-1492_tissue_phantom_user_guide.pdf).

Table A1 – Gammex phantom plug configuration.

Region-of-interest (ROI)	Plug material description
0 (center)	<i>Phantom – Solid water</i>
1	<i>SB3 Cortical Bone</i>
2	<i>BRN-SR2 Brain</i>
3	<i>AP6 Adipose</i>
4	<i>CB2 - 50% CaCO₃</i>
5	<i>CT Solid Water</i>
6	<i>CB2 - 30% CaCO₃</i>
7	<i>Water</i>
8	<i>BR-12 Breast</i>
9	<i>LN-300 Lung</i>
10	<i>CT Solid Water</i>
11	<i>IB Inner Bone</i>
12	<i>CT Solid Water</i>
13	<i>LV1 Liver</i>
14	<i>B200 Bone Mineral</i>
15	<i>LN-450 Lung</i>
16	<i>CT Solid Water</i>

B. Clinical relevance of the phantom

Table B1 – non-small cell lung cancer cohort description. The patient cohort is part of a research project that has been reviewed by the local ethics committee.

		221 patients
Median age (range) at diagnosis in years		66.0 (36-87)
Median GTV size (range) in cm³		88 (1-860)
Clinical T stage		
	<i>Less than 2</i>	119 (54%)
	<i>3 or greater</i>	85 (38%)
	<i>Unknown</i>	17 (8%)
Clinical N stage		
	<i>0</i>	49 (22%)
	<i>1</i>	16 (7%)
	<i>2 or greater</i>	137 (62%)
	<i>Unknown</i>	19 (9%)
Clinical M stage		
	<i>0</i>	200 (90%)
	<i>1 or greater</i>	21 (10%)
Histology		
	<i>Adenocarcinoma</i>	64 (29%)
	<i>Large-cell</i>	22 (10%)
	<i>Squamous cell carcinoma</i>	82 (37%)
	<i>Other, or not otherwise specified</i>	47 (21%)
	<i>Unknown</i>	6 (3%)
Outcomes		
	<i>Median follow-up in days</i>	595
	<i>Median survival time in days</i>	500
	<i>2-year overall survival rate</i>	41%

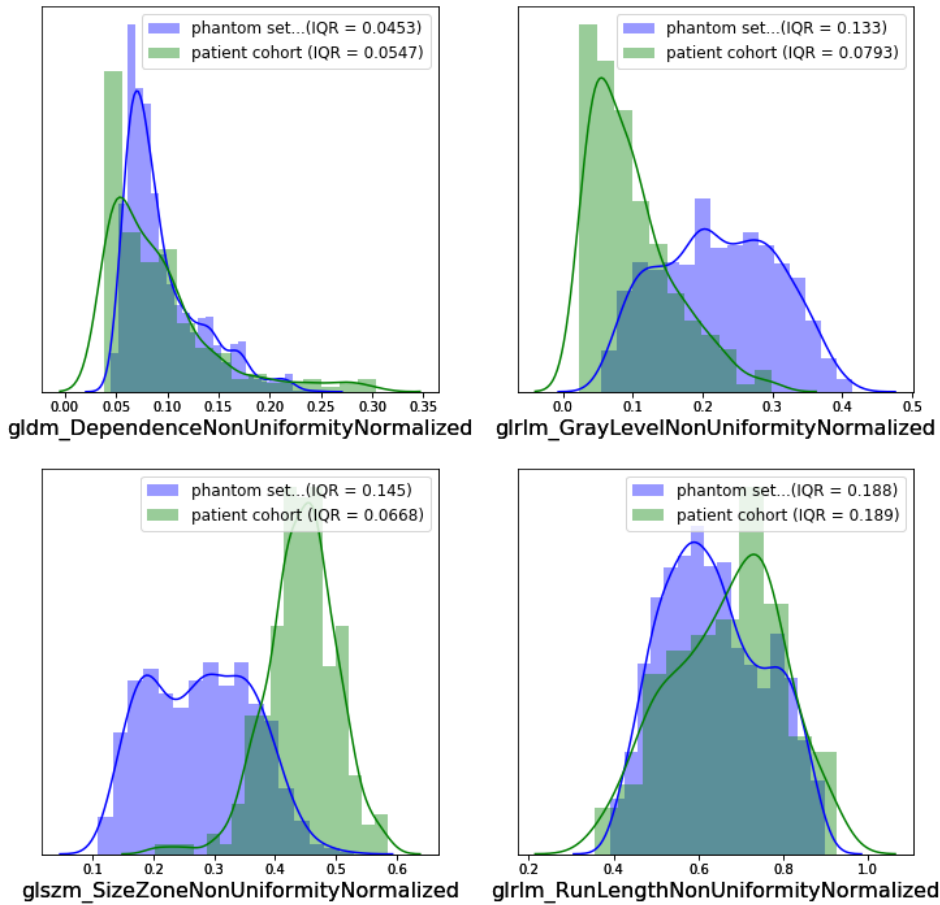


Figure B1 – distribution overlaps in 4 normalized radiomic features of the NSCLC patient cohort (green) and the phantom set (blue). The overlaps indicate that the features have similar values in both sets.

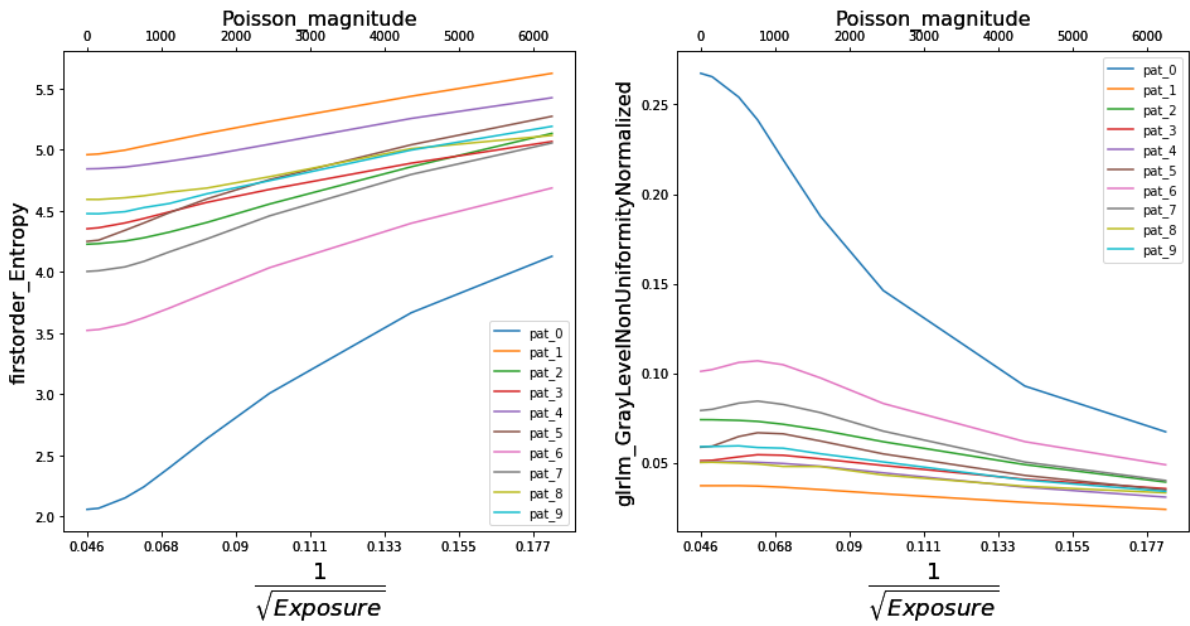


Figure B2 – scanner SNR trends in patient radiomics modeled with Poisson noise.

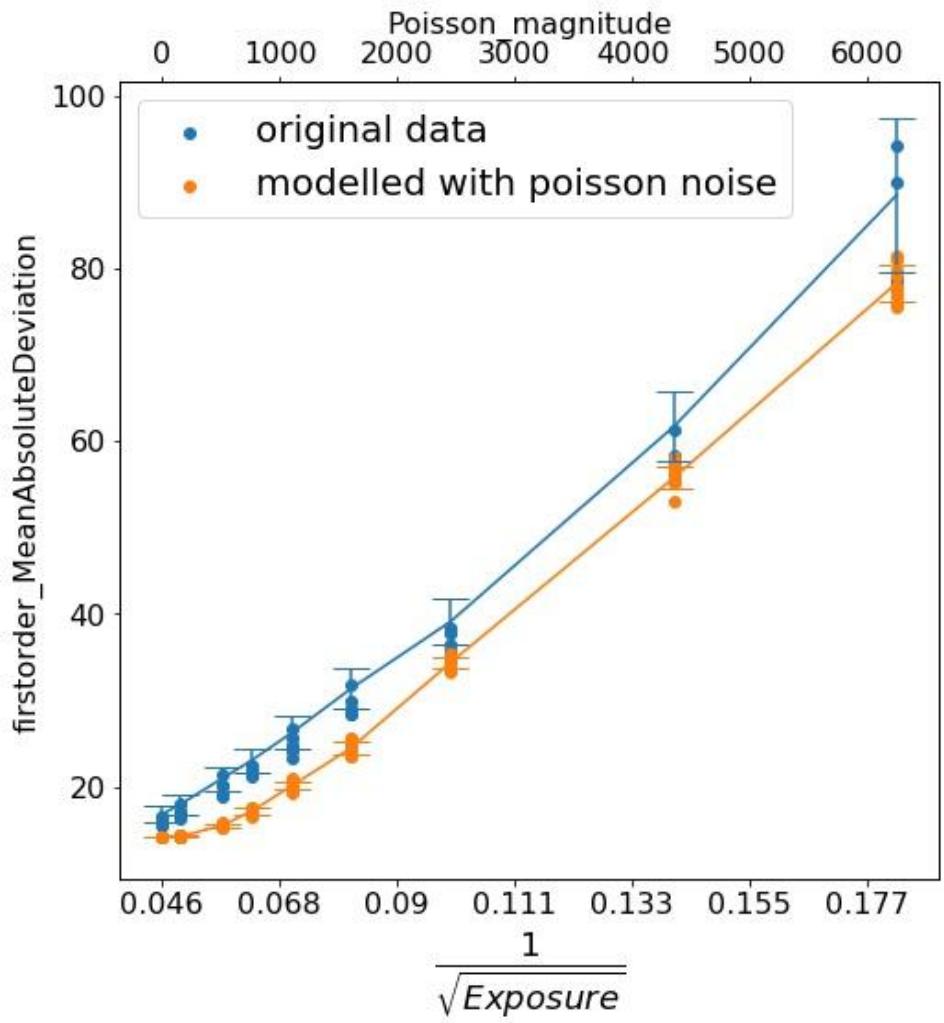


Figure B3 – Poisson noise magnitude calibration in Mean Absolute Deviation feature.

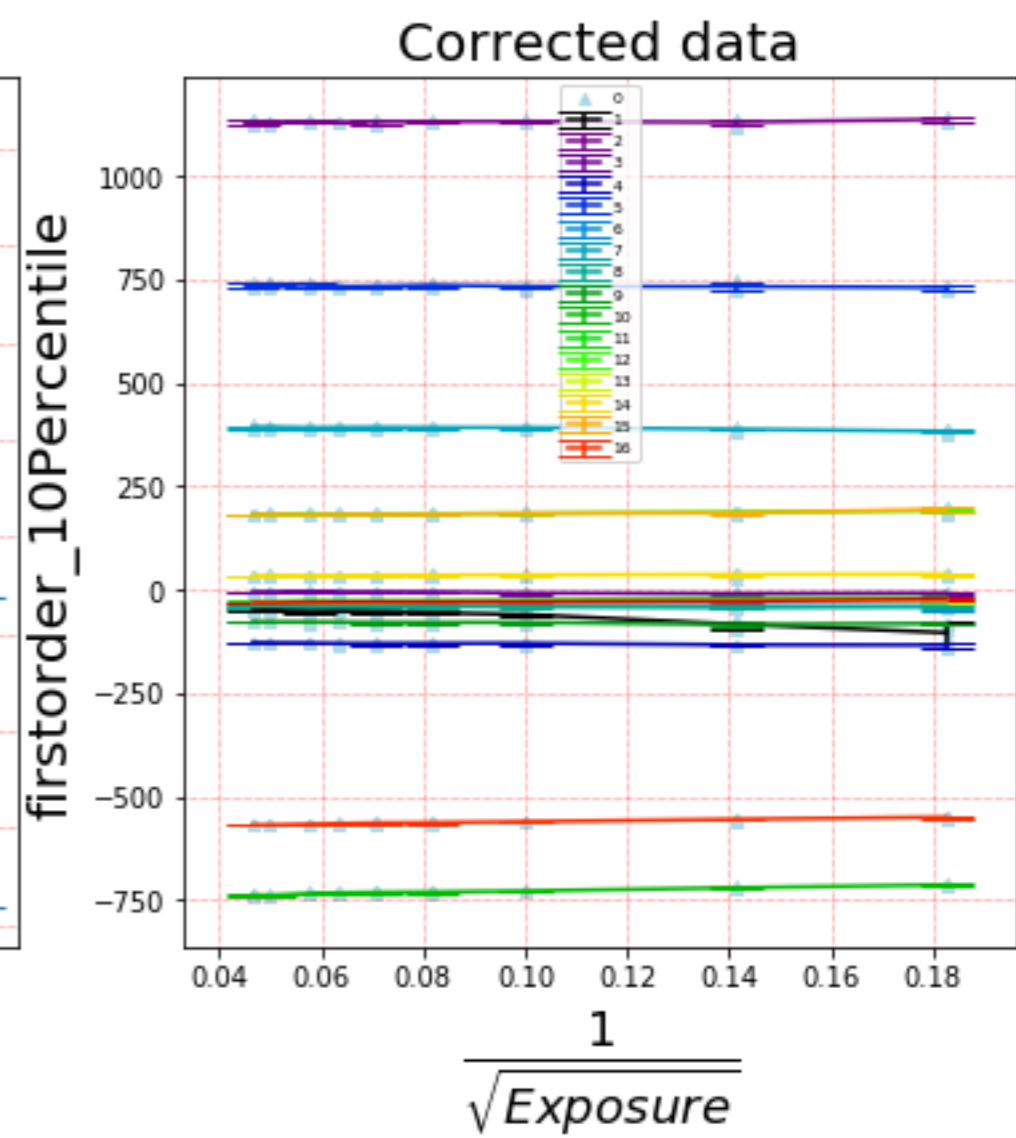
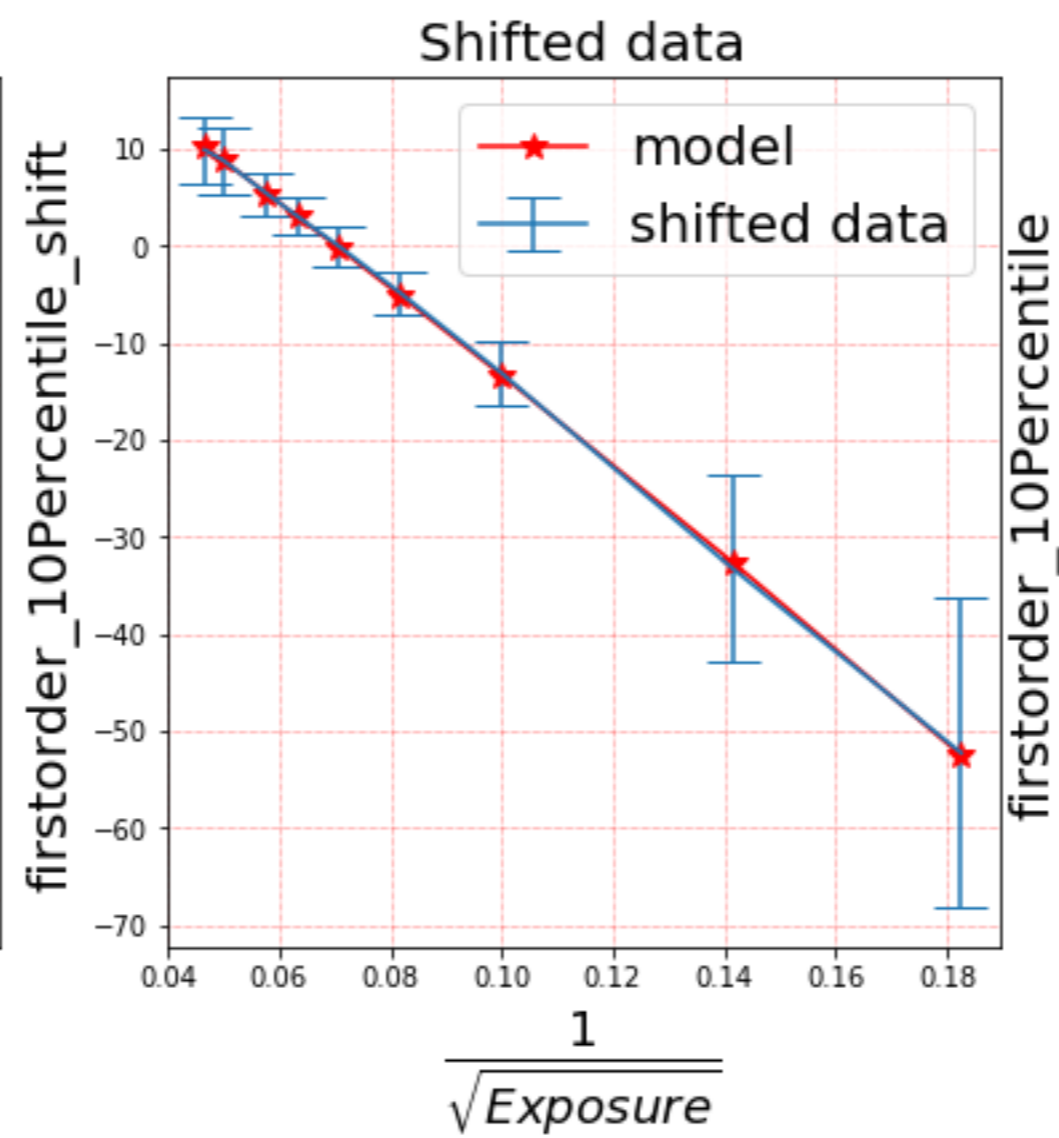
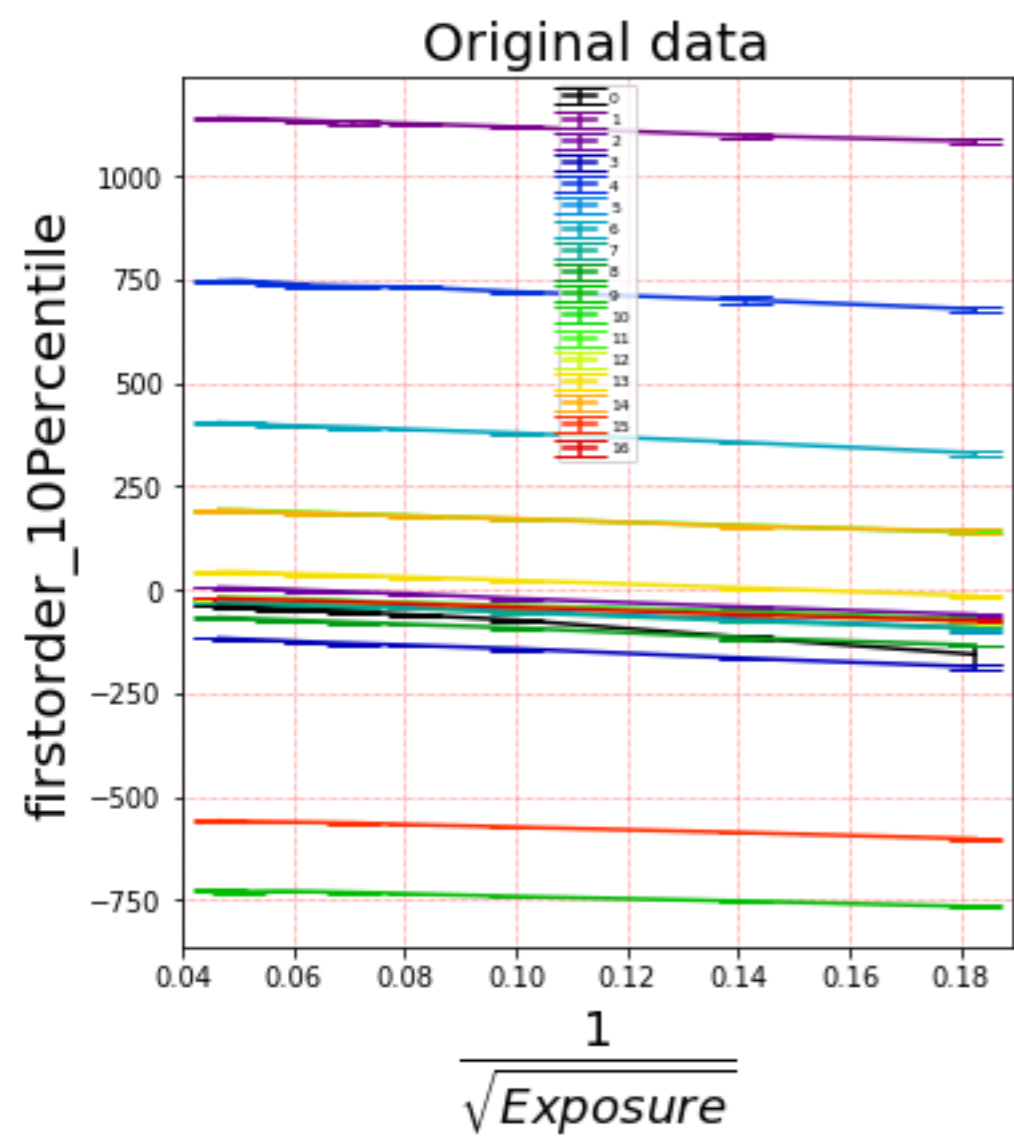
C. Correction of 92 radiomic features in the phantom set

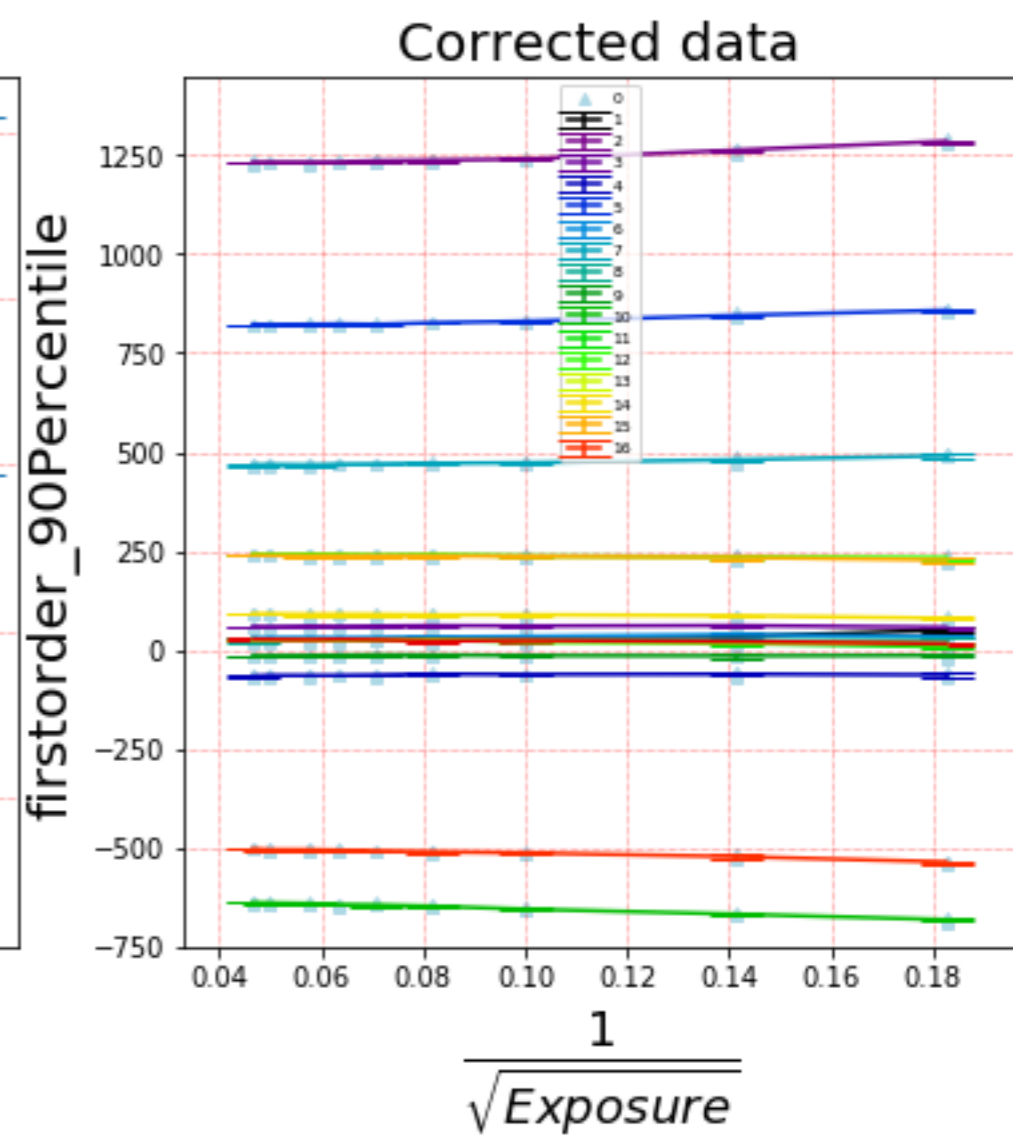
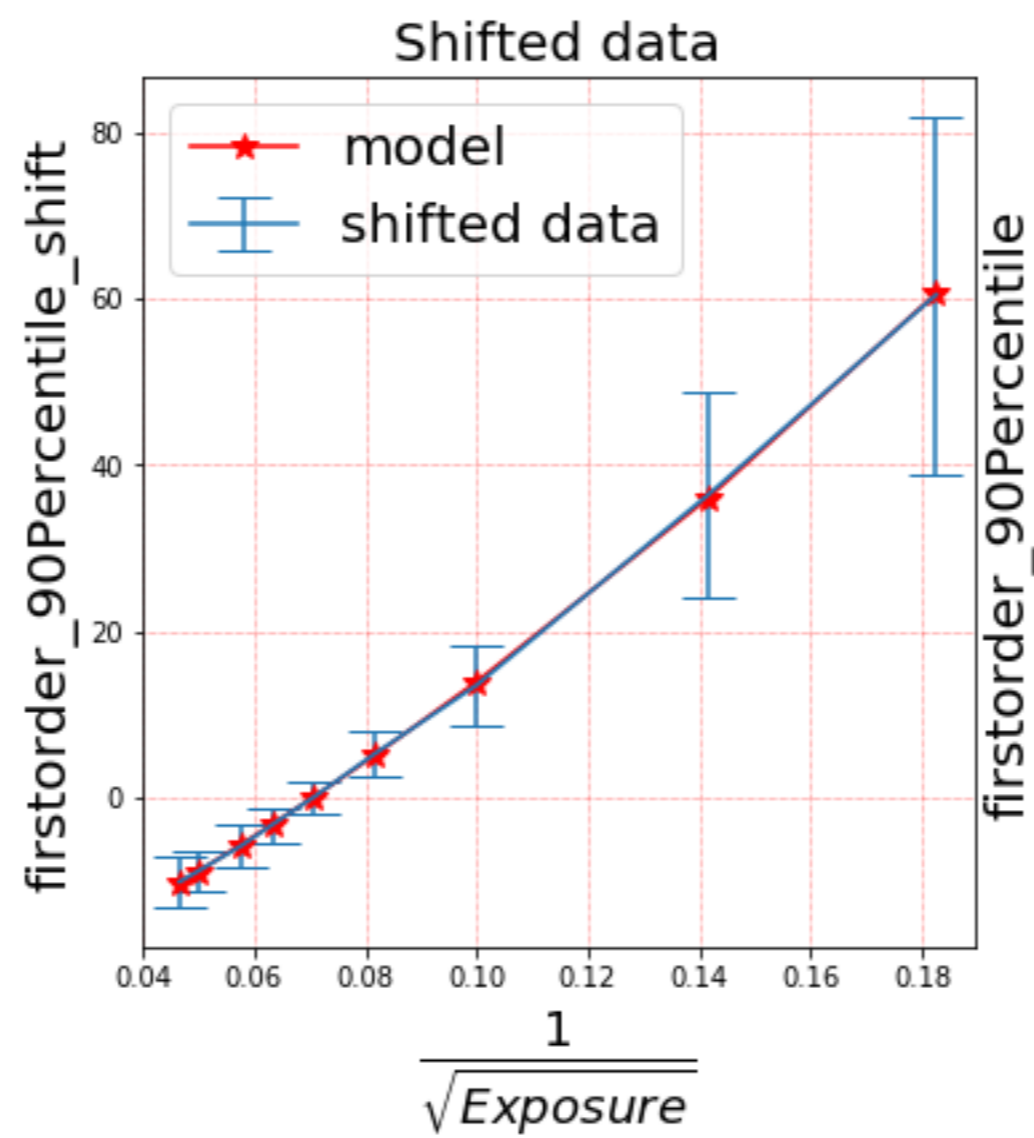
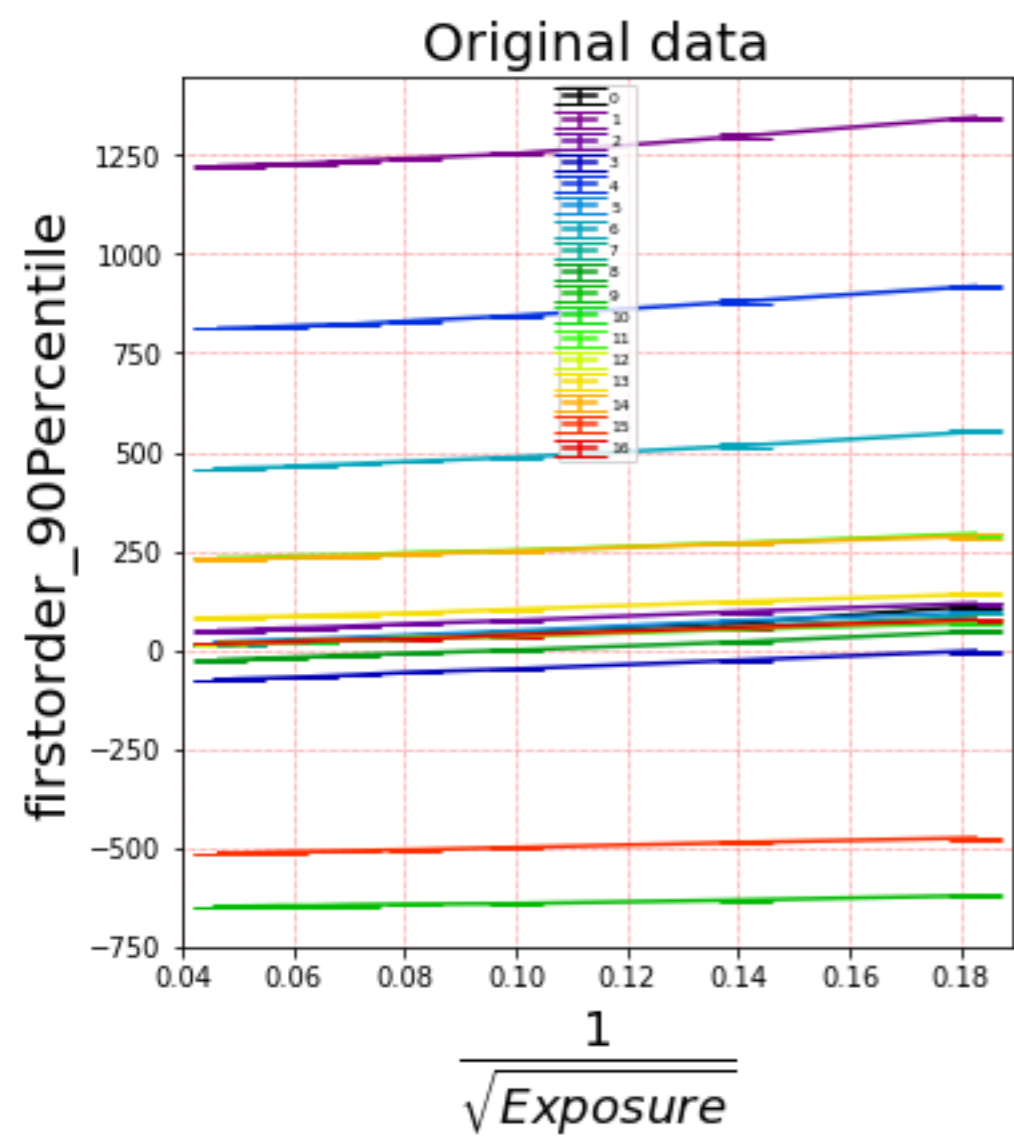
Table C1 – Intraclass correlation coefficients (3, 9) [Koo, T. K. & Li, M. Y. A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *J. Chiropr. Med.* 15, 155-163 (2016)] before and after correction, Wilcoxon test for ICC improvement (confidence intervals for means, p values), and model coefficients

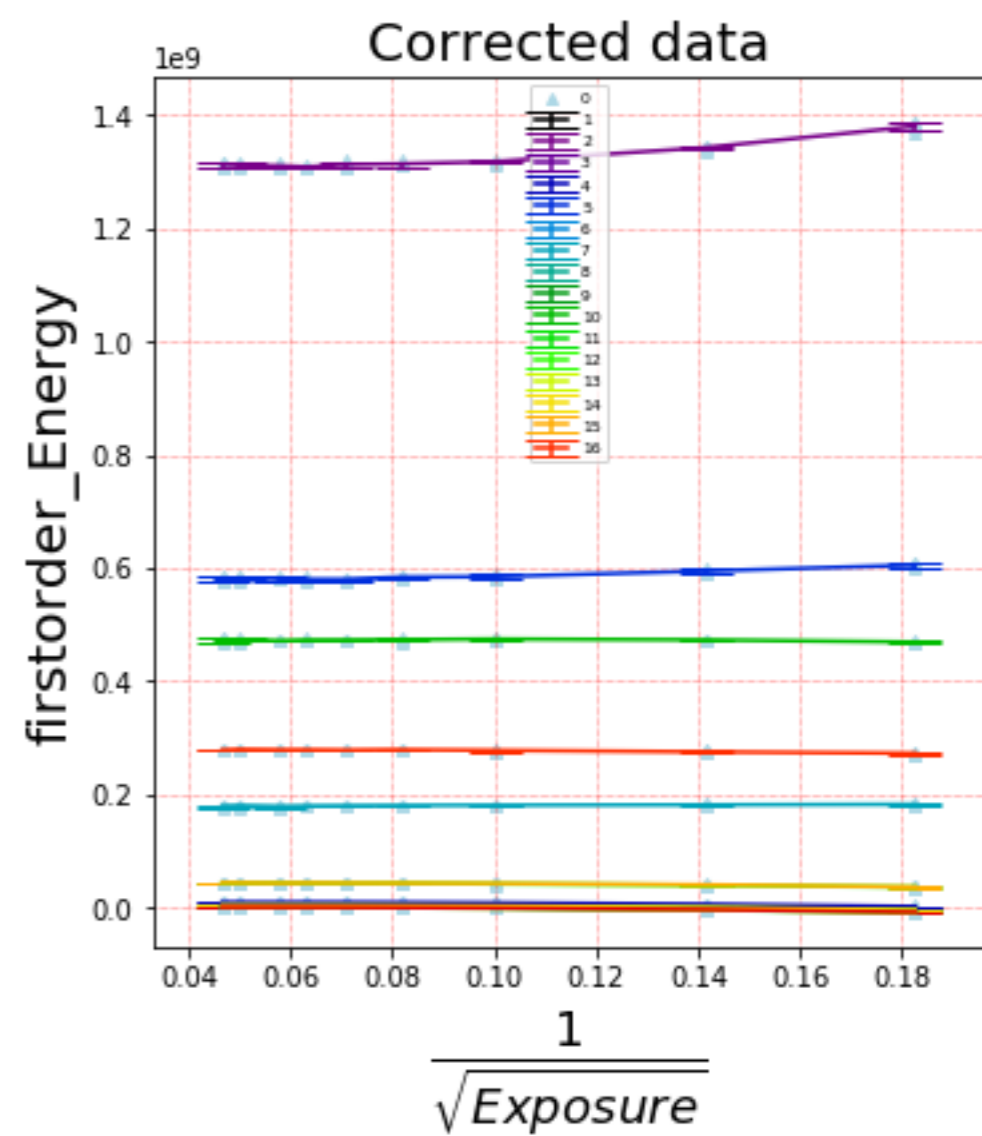
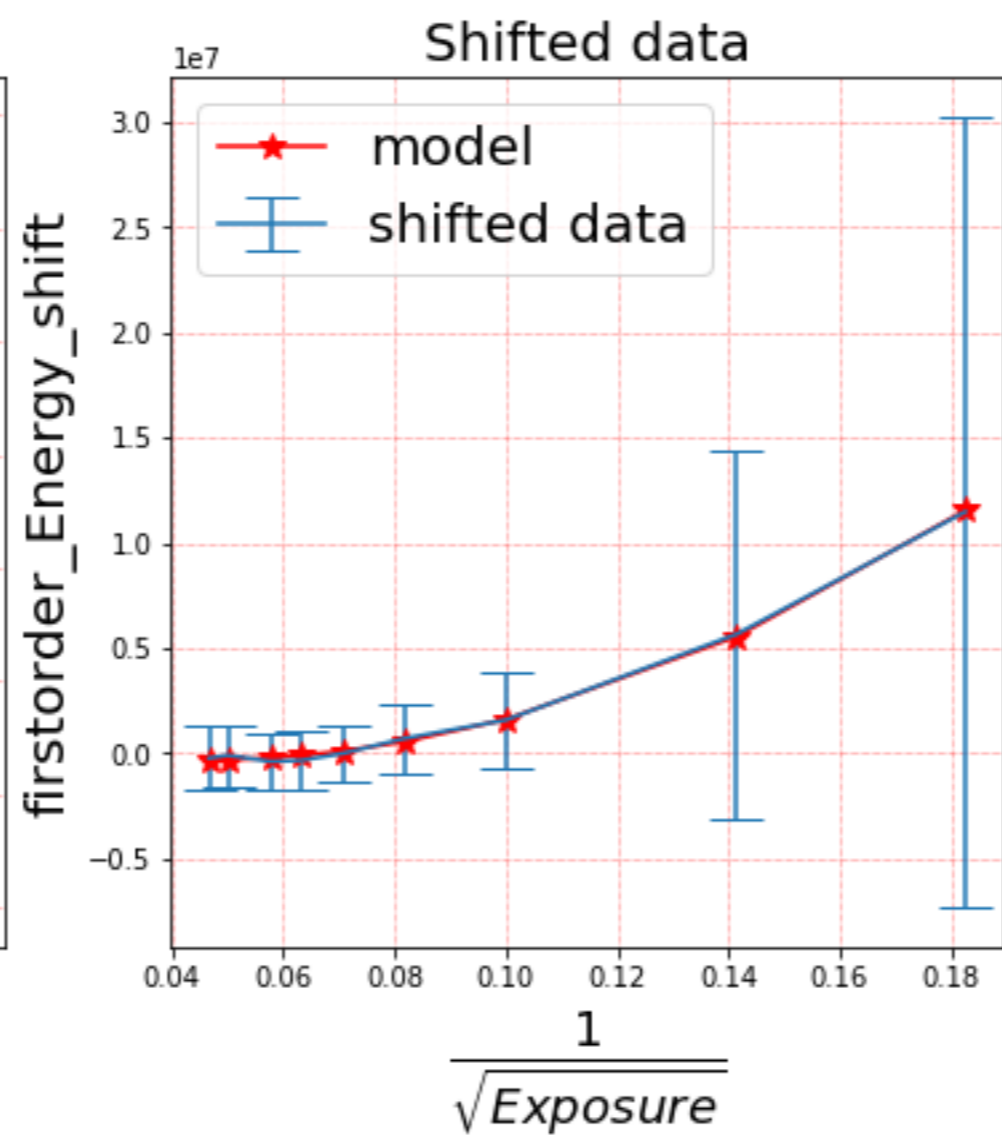
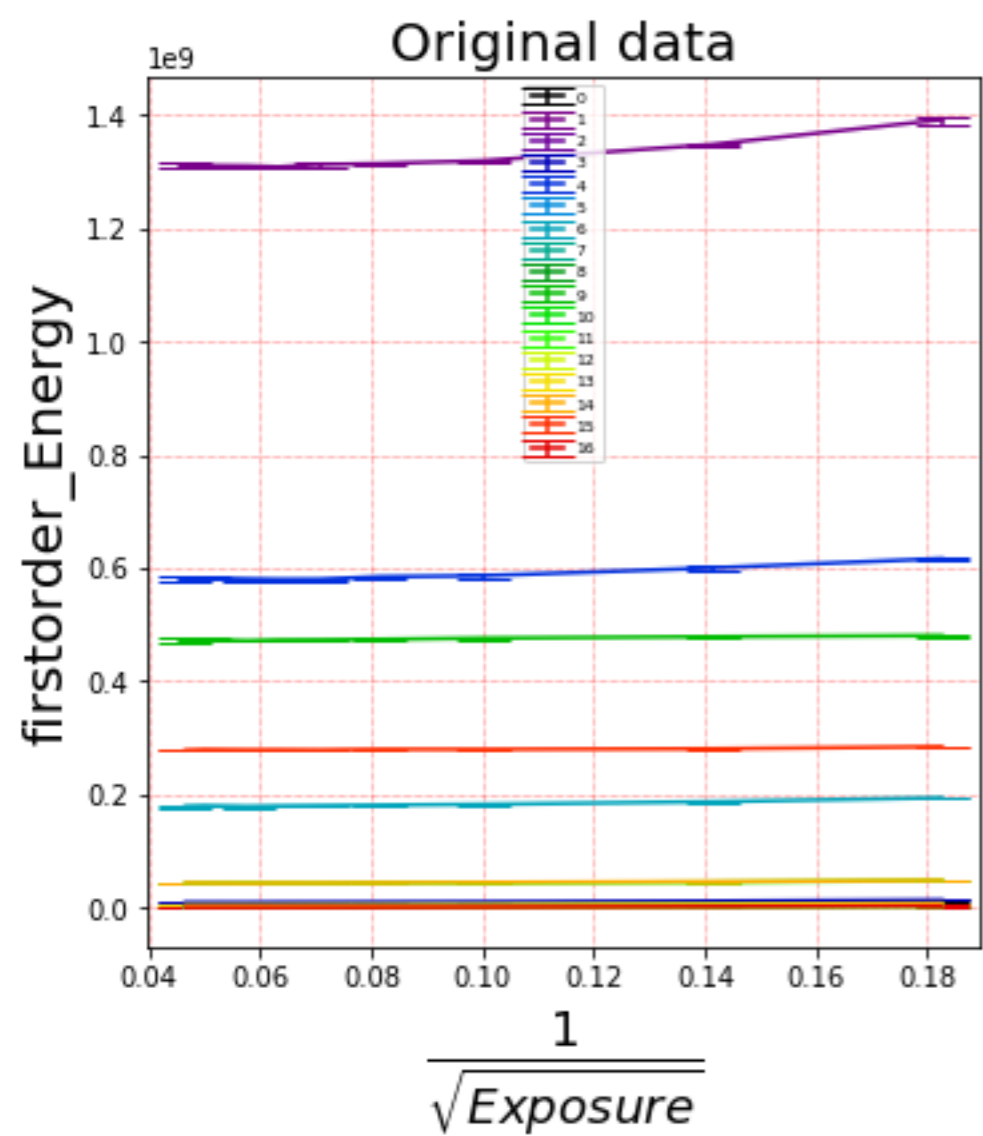
<i>features</i>	<i>ICC after</i>	<i>ICC before</i>	<i>ICC diff: mean CI lower</i>	<i>ICC diff: mean CI upper</i>	<i>ICC p-value Wilcoxon</i>	<i>coefficient_b</i>	<i>coefficient_w1</i>	<i>coefficient_w2</i>
firstorder_10Percentile	0,999844	0,999699	8,17E-05	9,47E-05	3,9E-18	29,70649	-405,864	-244,758
firstorder_90Percentile	0,999677	0,999501	9,86E-05	0,000112	3,9E-18	-27,6153	332,4447	825,2289
firstorder_Entropy	0,854644	0,674753	0,106402	0,117316	3,9E-18	-1,47697	24,16202	-47,7042
firstorder_InterquartileRange	0,692529	0,544985	0,08554	0,092001	3,9E-18	-30,9715	398,9943	547,162
firstorder_Maximum	0,997766	0,996747	0,000574	0,00066	3,9E-18	-73,9718	944,7416	1372,011
firstorder_MeanAbsoluteDeviation	0,695204	0,551633	0,083149	0,089616	3,9E-18	-17,815	228,9374	341,4874
firstorder_Minimum	0,998221	0,997263	0,000543	0,000633	3,9E-18	65,53846	-812,668	-1630,77
firstorder_Range	0,722629	0,623184	0,058771	0,06732	3,9E-18	-139,51	1757,41	3002,785
firstorder_RobustMeanAbsoluteDeviation	0,698178	0,550611	0,085516	0,09187	3,9E-18	-12,7414	164,2535	225,3668
firstorder_RootMeanSquared	0,999605	0,999545	3,22E-05	3,76E-05	3,9E-18	-9,23436	85,09279	686,8815
firstorder_Uniformity	0,789711	0,653375	0,078433	0,08711	3,9E-18	0,317926	-5,52798	16,0613
firstorder_Variance	0,371557	0,319388	0,028624	0,030829	3,9E-18	-309,633	-9838,47	198898,1
glcm_Autocorrelation	0,348418	0,306331	0,023179	0,026265	3,9E-18	-7,32594	-183,57	3856,381
glcm_ClusterTendency	0,373413	0,323849	0,027156	0,029525	3,9E-18	-1,04486	-35,7266	706,935
glcm_Contrast	0,300635	0,255236	0,025008	0,027062	3,9E-18	-0,91301	-27,7863	570,133
glcm_DifferenceAverage	0,607661	0,460836	0,08631	0,09311	3,9E-18	-0,9883	12,8707	16,65014
glcm_DifferenceEntropy	0,809049	0,591225	0,132266	0,144258	3,9E-18	-1,18202	19,06615	-32,982
glcm_DifferenceVariance	0,297207	0,253535	0,024	0,026029	3,9E-18	-0,32828	-9,96815	205,6752
glcm_Id	0,859951	0,627464	0,140949	0,15257	3,9E-18	0,284062	-4,75576	11,0194
glcm_Idm	0,858021	0,623568	0,142321	0,154137	3,9E-18	0,358518	-6,04847	14,3542
glcm_Imc2	0,787599	0,728256	0,033999	0,039624	3,9E-18	-0,09696	1,197467	3,078423

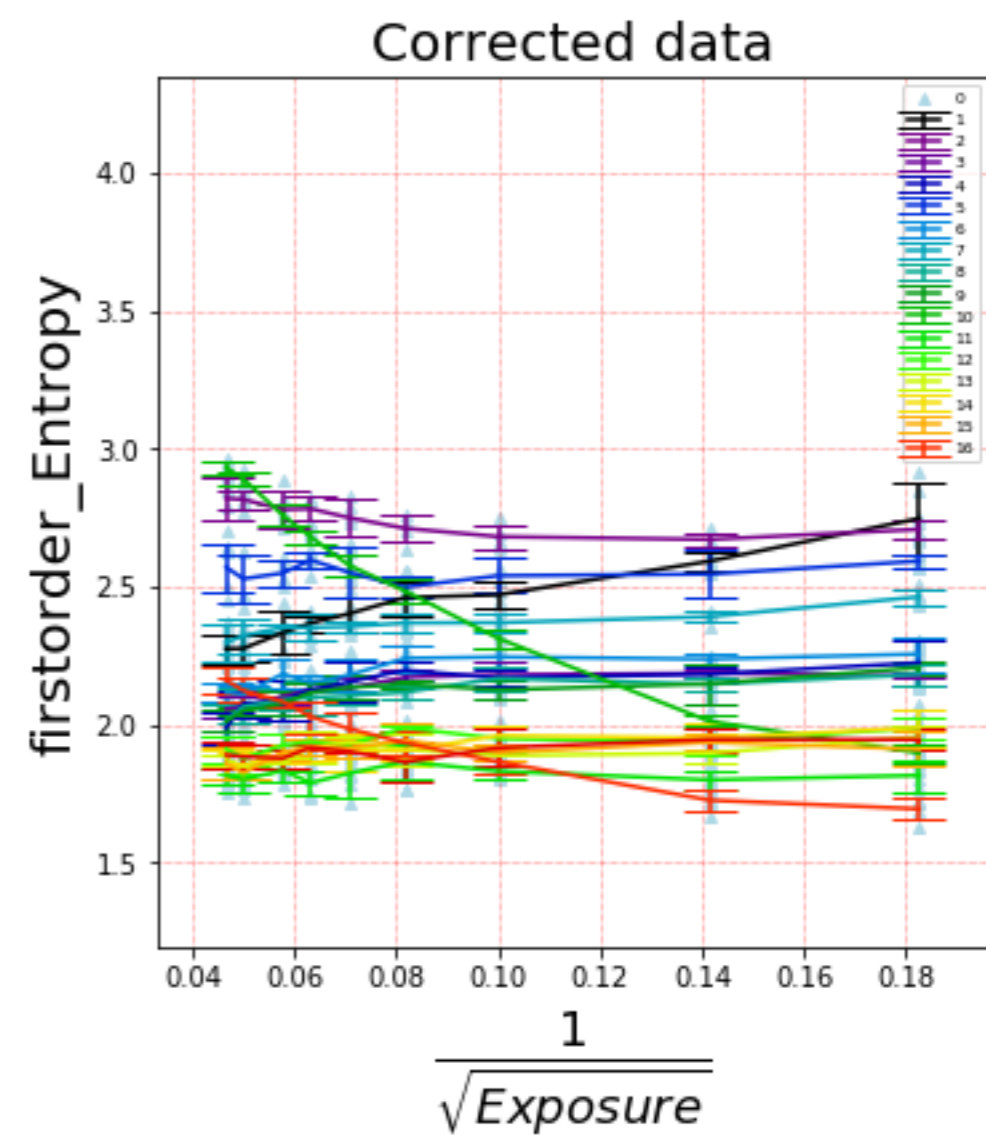
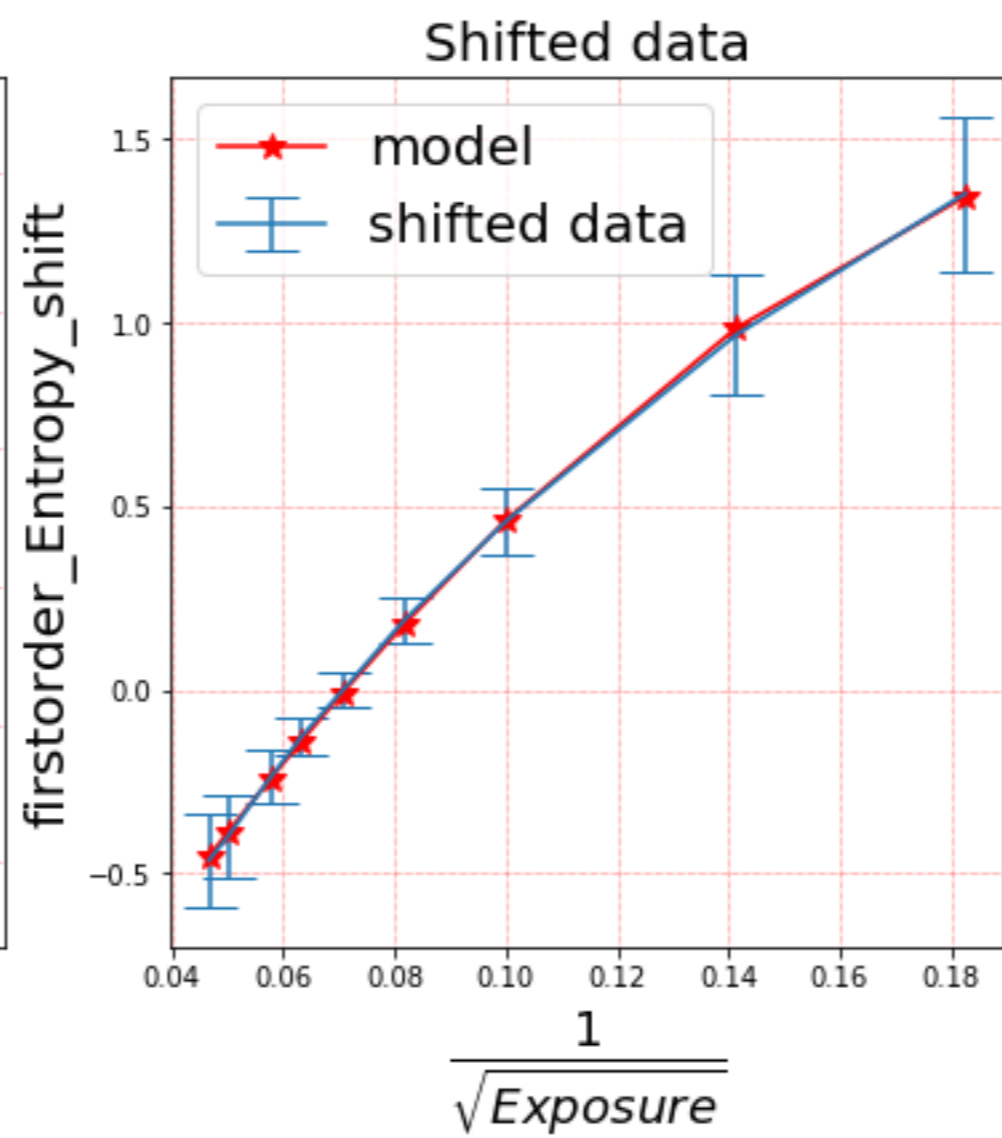
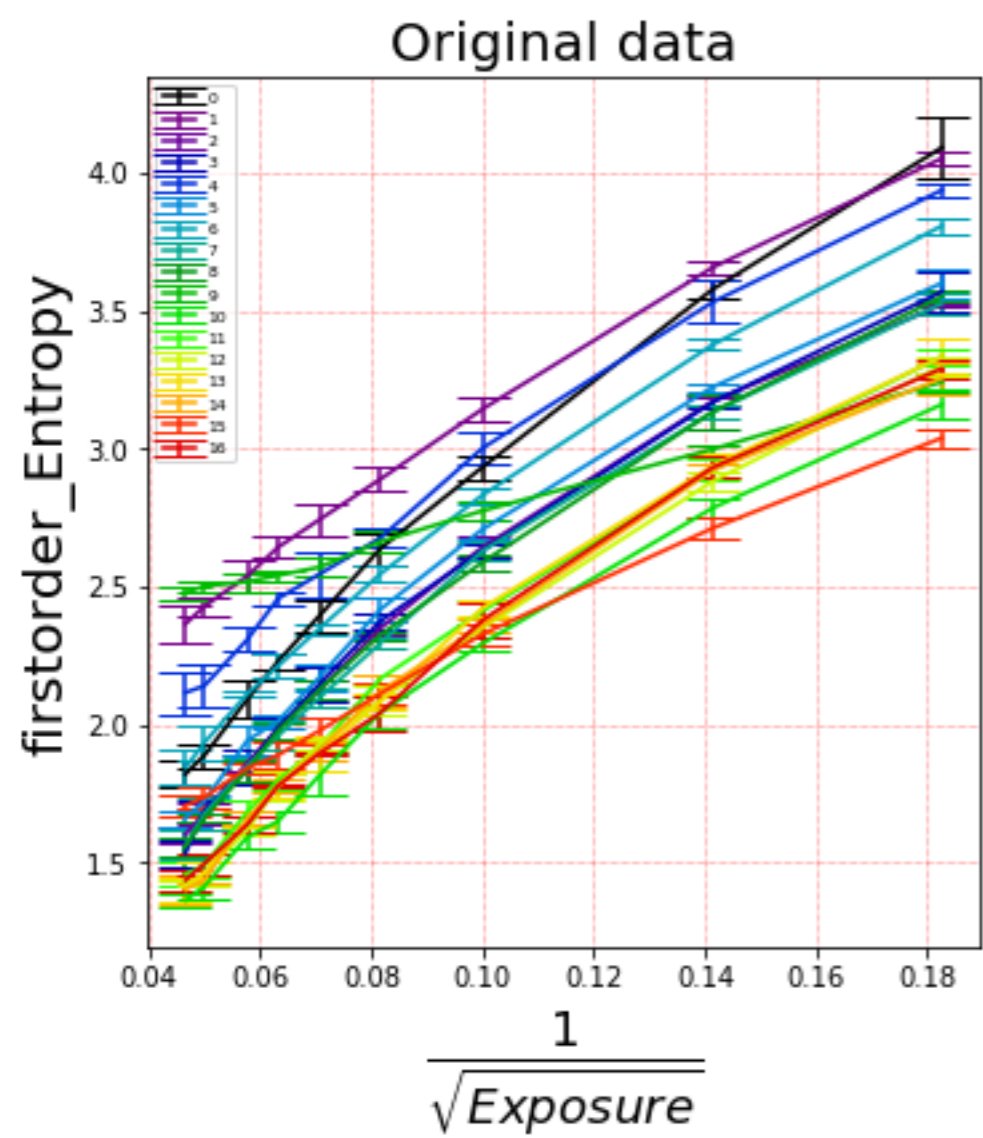
glcm_InverseVariance	0,441952	0,313603	0,076007	0,080382	3,9E-18	0,066535	-0,83746	-3,74005
glcm_JointAverage	0,587032	0,496116	0,05092	0,055766	3,9E-18	-2,50106	28,5788	87,0922
glcm_JointEnergy	0,660044	0,566185	0,052499	0,058119	3,9E-18	0,204299	-3,62147	11,98942
glcm_JointEntropy	0,850102	0,651211	0,11888	0,130284	3,9E-18	-2,99871	49,5002	-103,29
glcm_MaximumProbability	0,642679	0,55002	0,051413	0,055853	3,9E-18	0,325595	-5,74753	18,61485
glcm_SumAverage	0,587032	0,496116	0,05092	0,055766	3,9E-18	-5,00211	57,15759	174,1844
glcm_SumEntropy	0,844942	0,679239	0,097603	0,108145	3,9E-18	-1,4661	24,00416	-47,6823
glcm_SumSquares	0,345357	0,296066	0,027072	0,029242	3,9E-18	-0,48947	-15,8782	319,267
gldm_DependenceEntropy	0,815698	0,737105	0,044717	0,05115	3,9E-18	-0,43532	7,002626	-11,115
gldm_DependenceNonUniformity	0,676754	0,484426	0,115741	0,122984	3,9E-18	-57,2455	821,3003	-195,792
gldm_DependenceNonUniformityNormalized	0,683399	0,497977	0,110913	0,118248	3,9E-18	-0,05944	0,85266	-0,1997
gldm_DependenceVariance	0,588871	0,485252	0,058507	0,062532	3,9E-18	23,43175	-410,767	1310,482
gldm_GrayLevelNonUniformity	0,790402	0,655181	0,077639	0,086367	3,9E-18	306,2306	-5324,45	15470,06
gldm_GrayLevelVariance	0,371196	0,319111	0,028564	0,030759	3,9E-18	-0,49084	-15,8034	318,2753
gldm_HighGrayLevelEmphasis	0,327537	0,287177	0,022445	0,025689	3,9E-18	-7,59965	-200,289	4148,6
gldm_LargeDependenceEmphasis	0,686542	0,563838	0,069795	0,076008	3,9E-18	142,4245	-2514,95	8185,056
gldm_SmallDependenceEmphasis	0,587672	0,438376	0,088079	0,094471	3,9E-18	-0,087	1,129034	1,911433
gldm_SmallDependenceHighGrayLevelEmphasis	0,152496	0,139393	0,007177	0,008272	3,9E-18	6,154864	-245,679	2138,504
glrlm_GrayLevelNonUniformity	0,840947	0,687796	0,088798	0,098263	3,9E-18	104,2441	-1749,14	3698,811
glrlm_GrayLevelNonUniformityNormalized	0,802525	0,661768	0,081365	0,090254	3,9E-18	0,257051	-4,45352	12,46507
glrlm_GrayLevelVariance	0,376537	0,323803	0,028942	0,031206	3,9E-18	-0,55013	-15,1432	321,7815
glrlm_HighGrayLevelRunEmphasis	0,325602	0,285371	0,022392	0,025633	3,9E-18	-7,71224	-198,905	4150,346
glrlm_LongRunEmphasis	0,659344	0,552097	0,060334	0,065515	3,9E-18	2,694085	-47,4957	156,5878
glrlm_RunEntropy	0,773732	0,641547	0,076627	0,084903	3,9E-18	-0,40046	5,552661	5,231874
glrlm_RunLengthNonUniformity	0,853815	0,622957	0,140026	0,151096	3,9E-18	-406,202	6952,154	-18055,6
glrlm_RunLengthNonUniformityNormalized	0,844001	0,627976	0,129743	0,140487	3,9E-18	-0,34602	5,964525	-16,2278
glrlm_RunPercentage	0,806257	0,621098	0,109228	0,118549	3,9E-18	-0,28862	5,022242	-14,7172
glrlm_RunVariance	0,618345	0,524874	0,052084	0,056562	3,9E-18	1,116717	-19,7025	65,76918
glrlm_ShortRunEmphasis	0,803858	0,620116	0,108546	0,117764	3,9E-18	-0,23023	4,016781	-11,8638

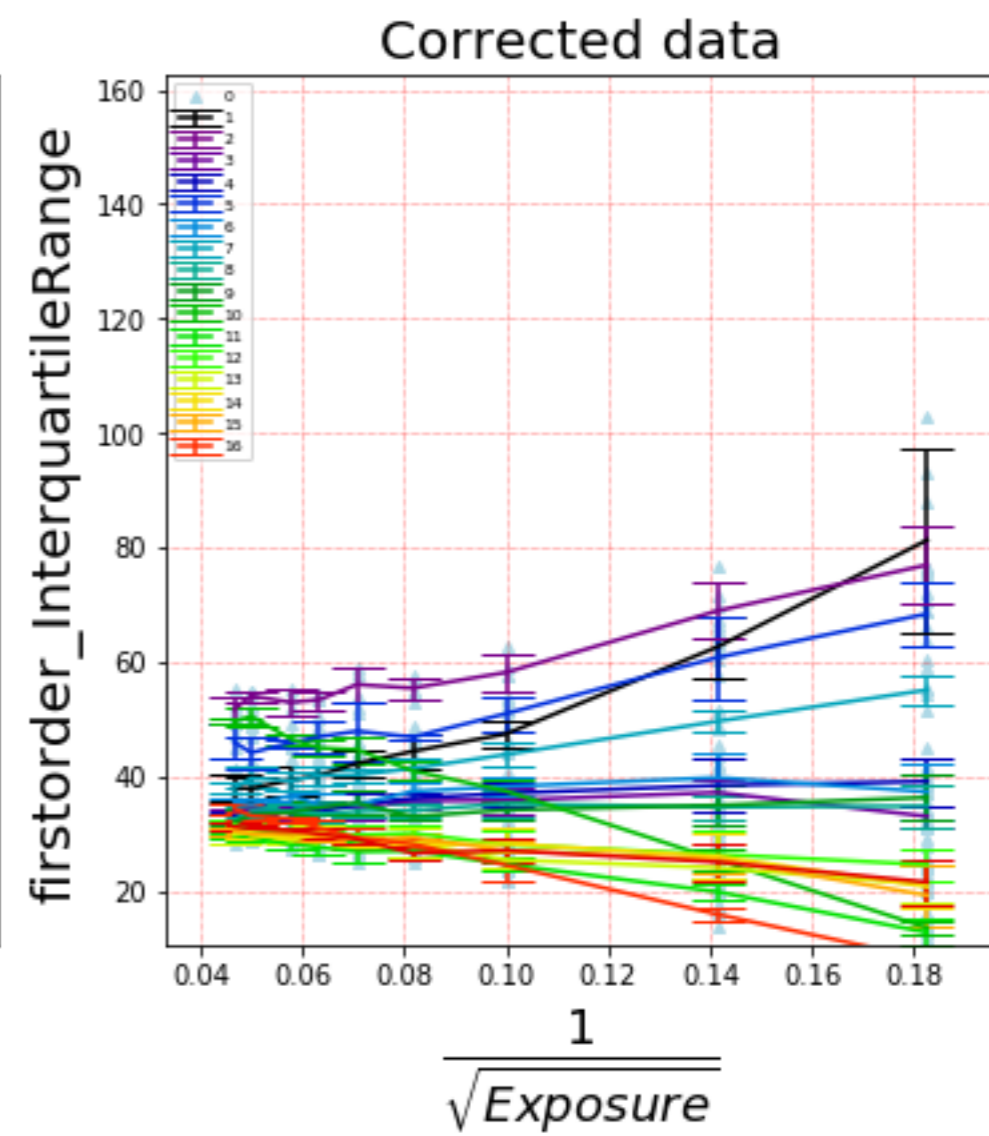
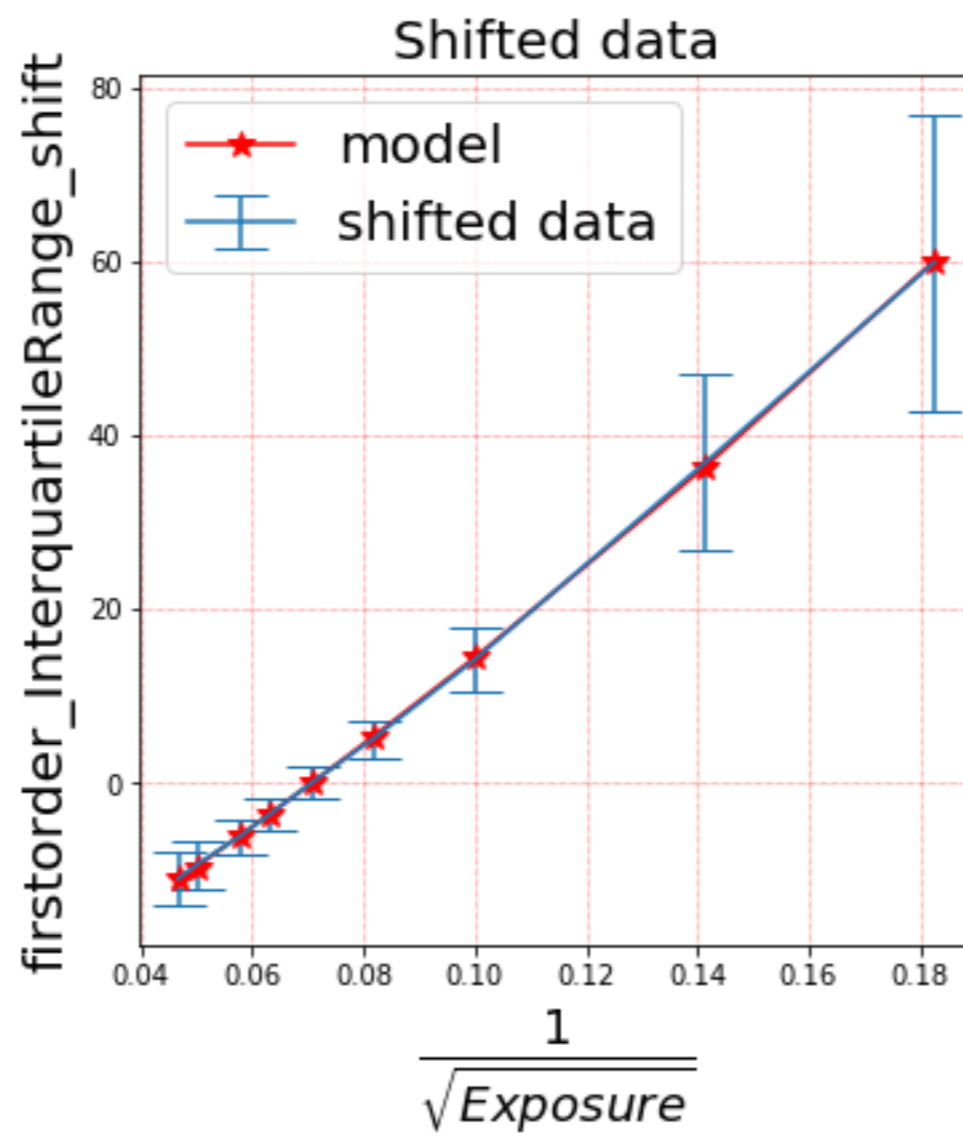
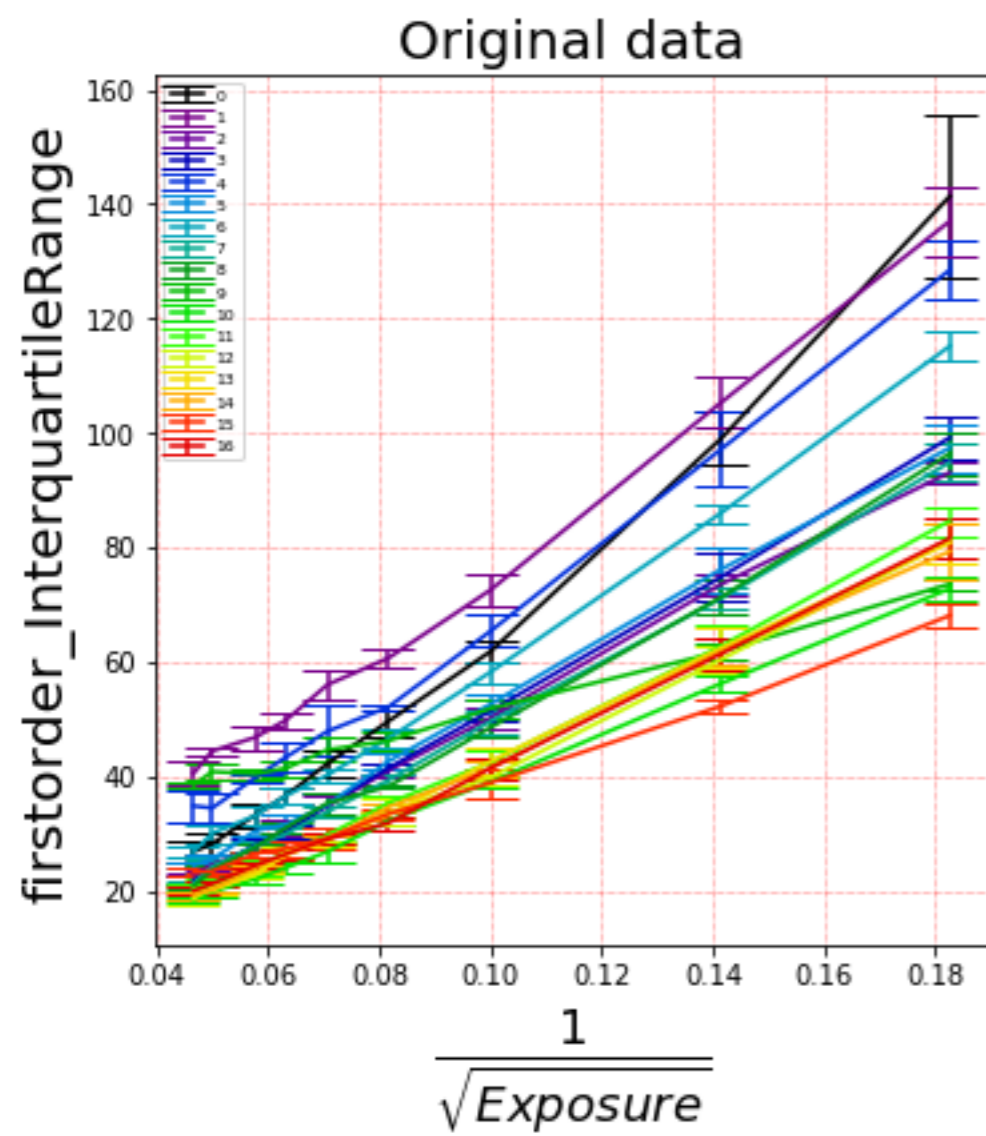
glrlm_ShortRunHighGrayLevelEmphasis	0,314571	0,275162	0,021979	0,025172	3,9E-18	-6,88037	-202,386	4045,983
glszm_GrayLevelVariance	0,572269	0,480798	0,051894	0,056856	3,9E-18	-4,54273	51,5895	189,301
glszm_HighGrayLevelZoneEmphasis	0,320077	0,278692	0,023263	0,026767	3,9E-18	-11,9471	-128,679	4006,484
glszm_LargeAreaEmphasis	0,532918	0,476769	0,03029	0,032921	3,9E-18	13983,81	-249735	852646
glszm_SizeZoneNonUniformity	0,428712	0,334942	0,053718	0,057667	3,9E-18	-21,4558	159,1109	2250,808
glszm_SmallAreaHighGrayLevelEmphasis	0,293086	0,256132	0,020763	0,024012	3,9E-18	-6,82579	-107,496	2783,871
glszm_ZoneEntropy	0,70759	0,600089	0,062252	0,069978	3,9E-18	-1,61697	26,33048	-54,4518
glszm_ZonePercentage	0,451811	0,351268	0,058092	0,062276	3,9E-18	-0,06269	0,549782	5,201372
glszm_ZoneVariance	0,54634	0,486838	0,032182	0,035071	3,9E-18	12881,71	-229975	783402,1
ngtdm_Complexity	0,194553	0,176047	0,009861	0,010892	3,9E-18	51,54616	-2204,37	19907,99
ngtdm_Contrast	0,568331	0,472776	0,053794	0,057241	3,9E-18	-0,02811	0,337579	1,055767
ngtdm_Strength	0,666044	0,621759	0,024698	0,028429	3,9E-18	-0,05731	-0,97016	24,3617

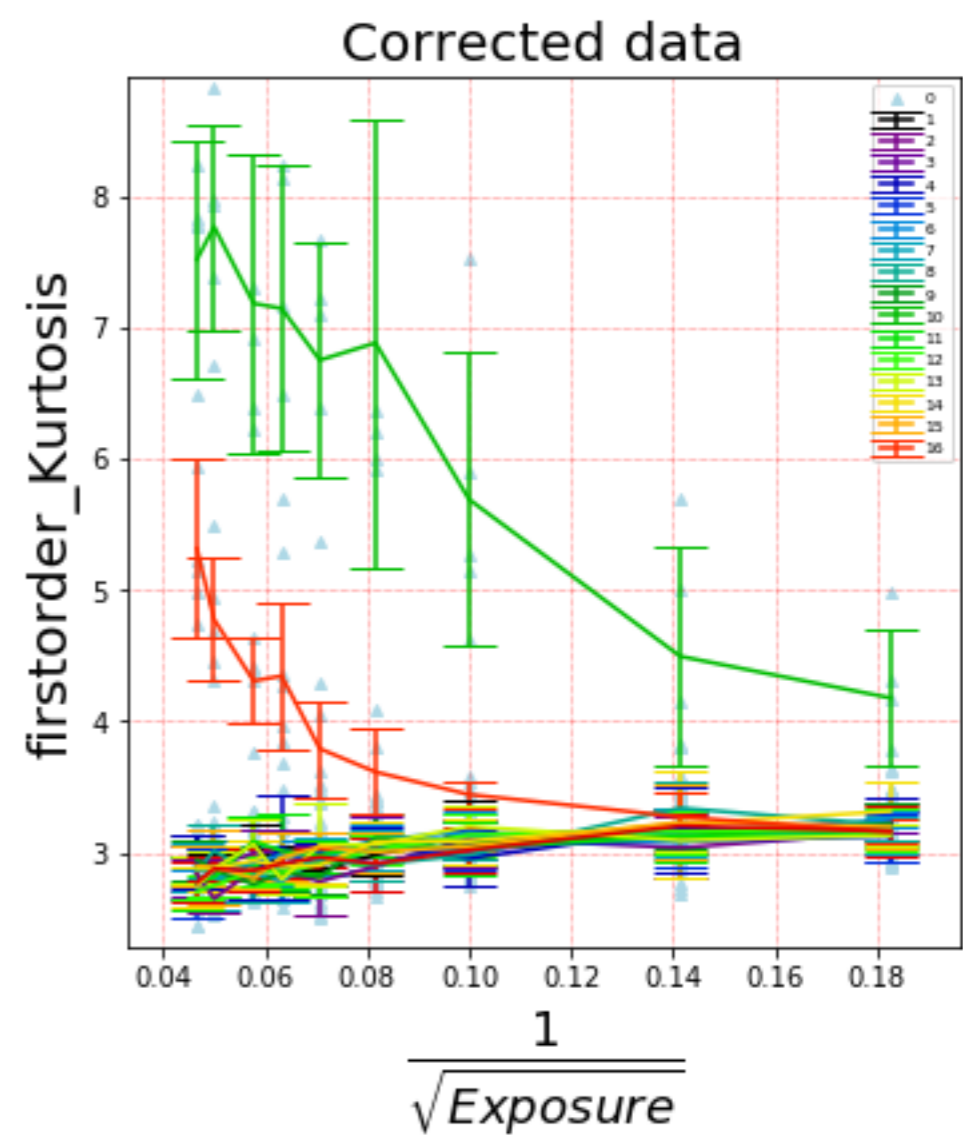
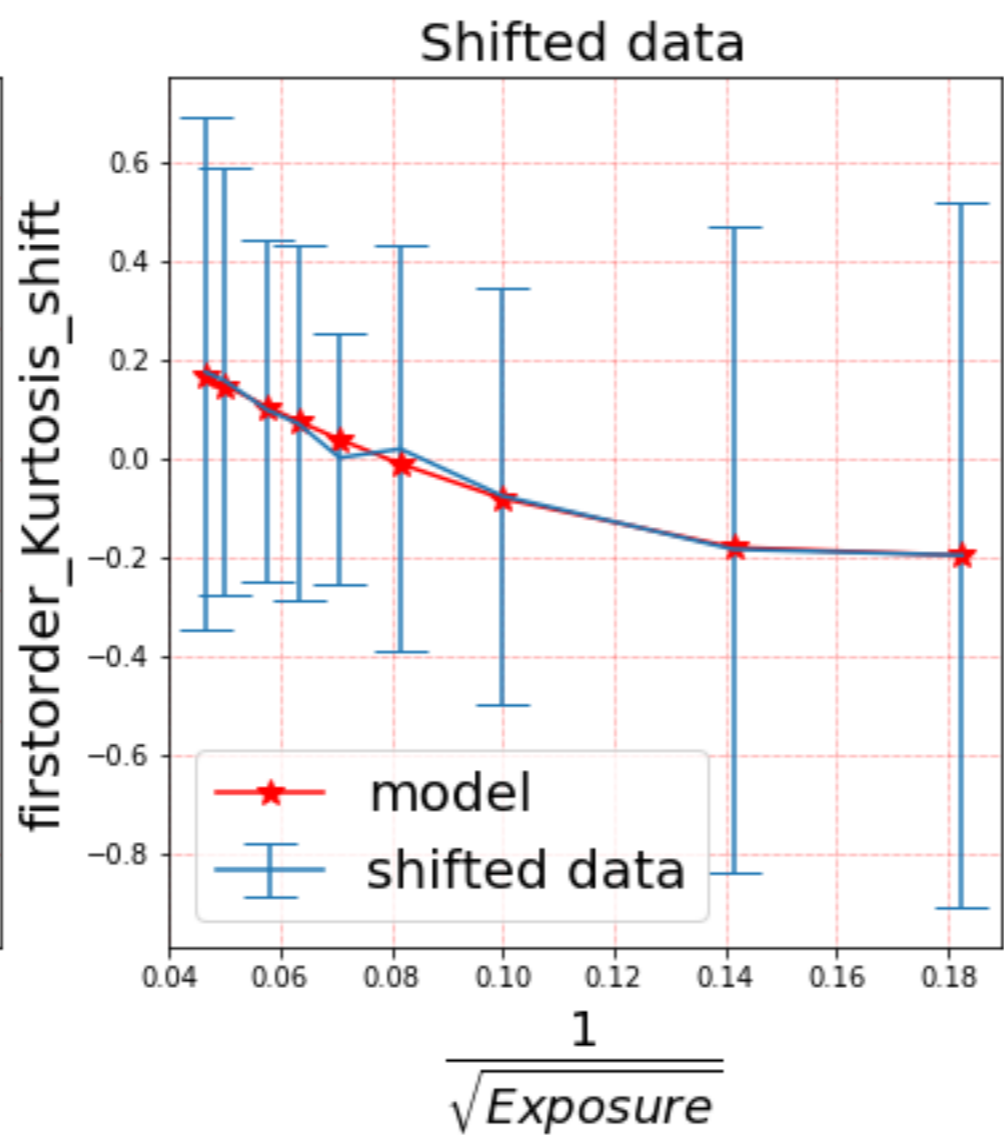
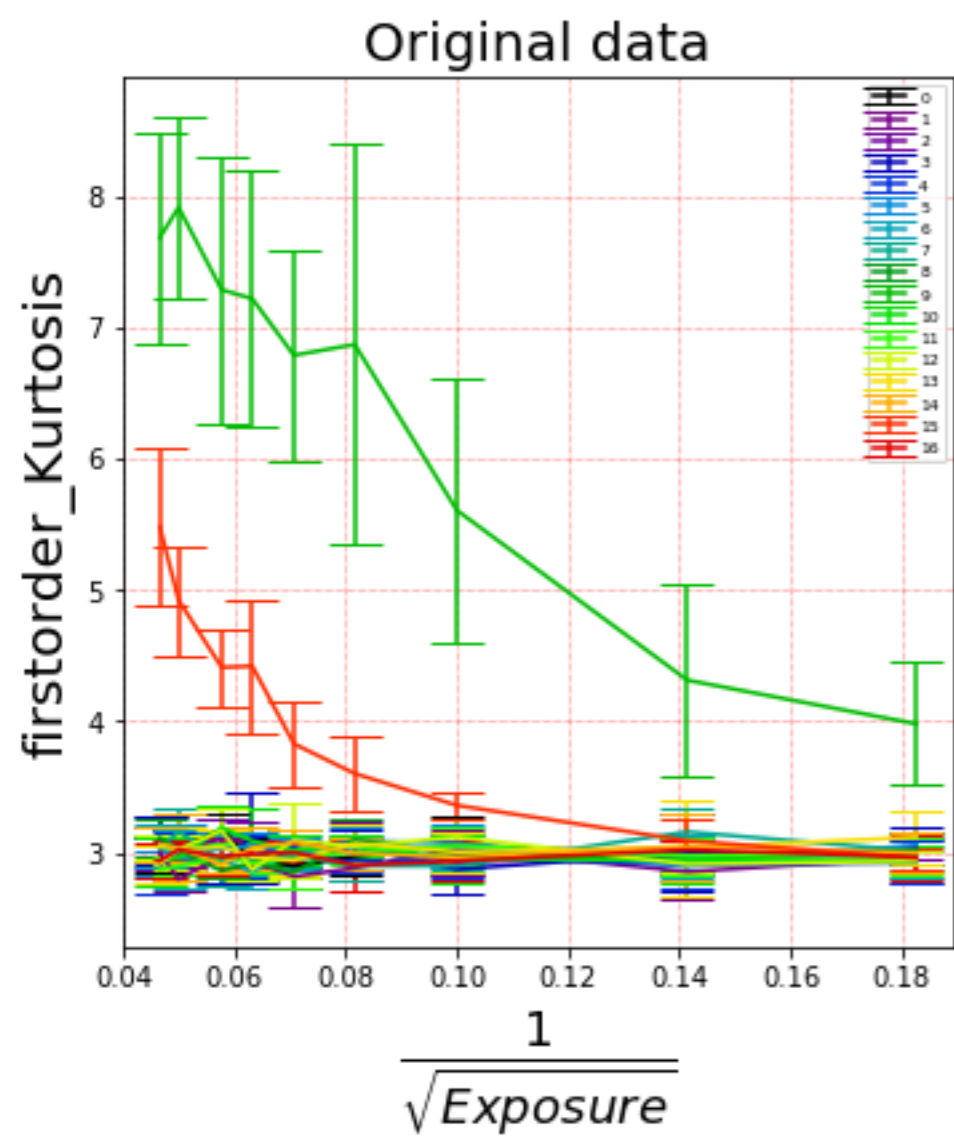


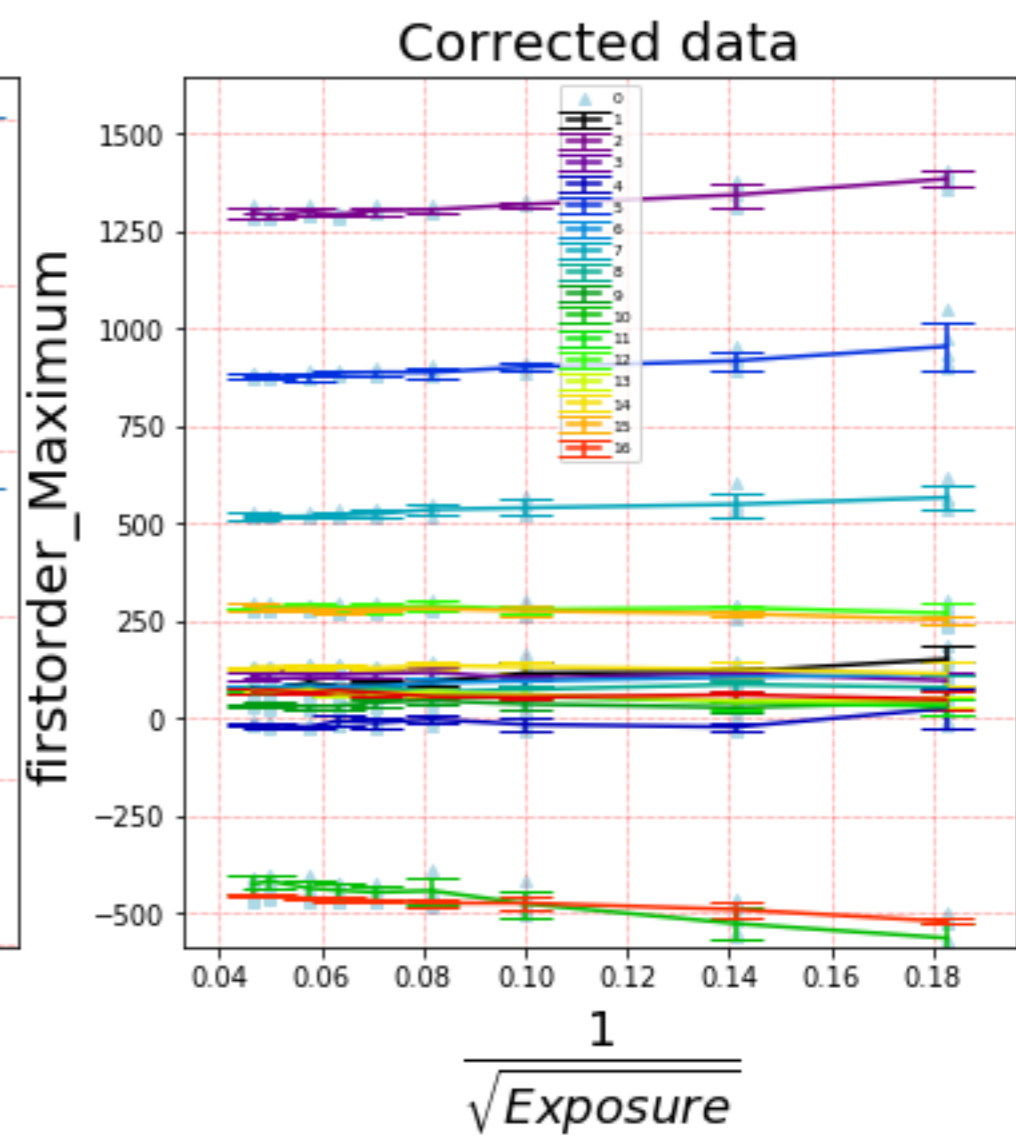
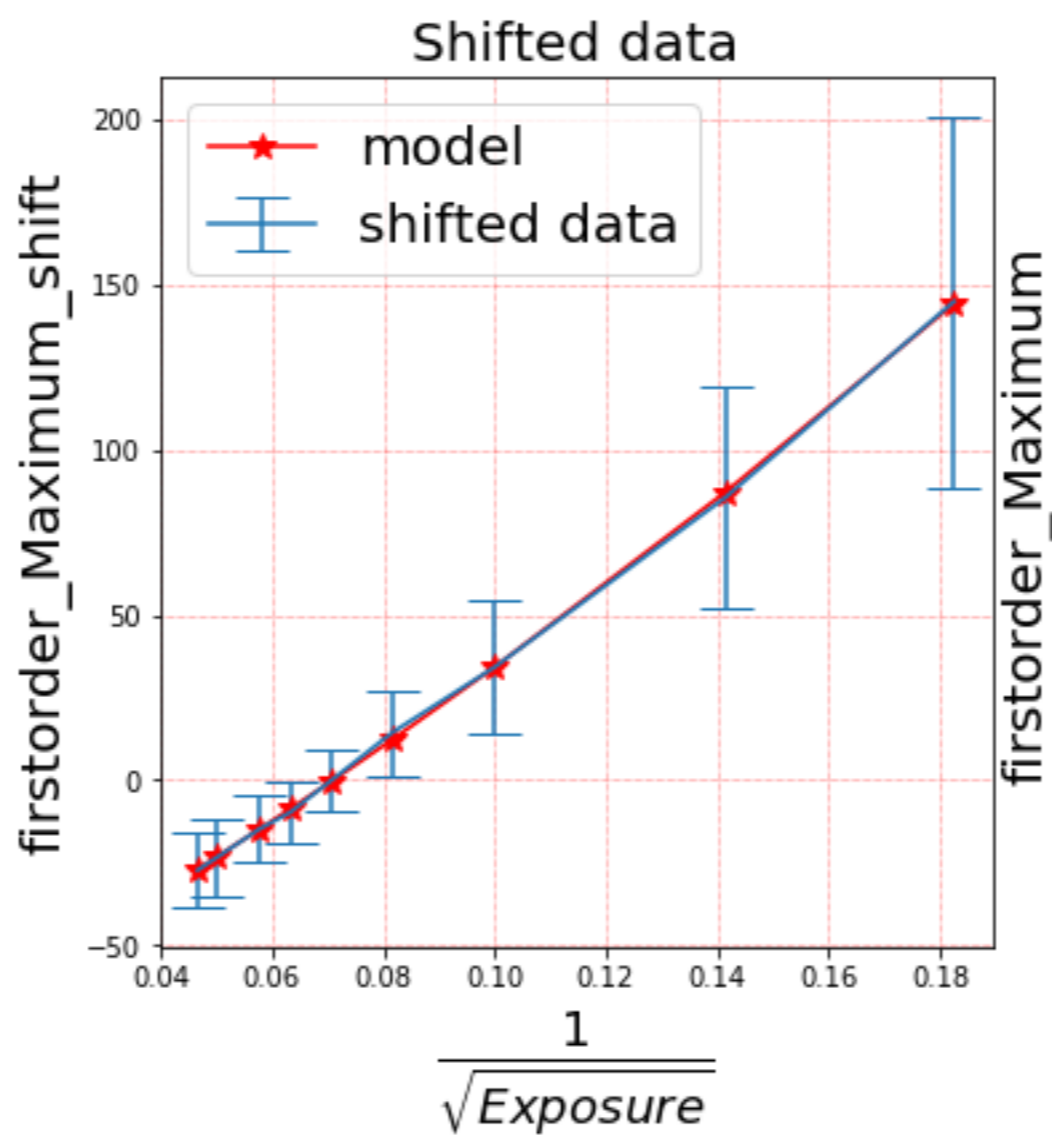
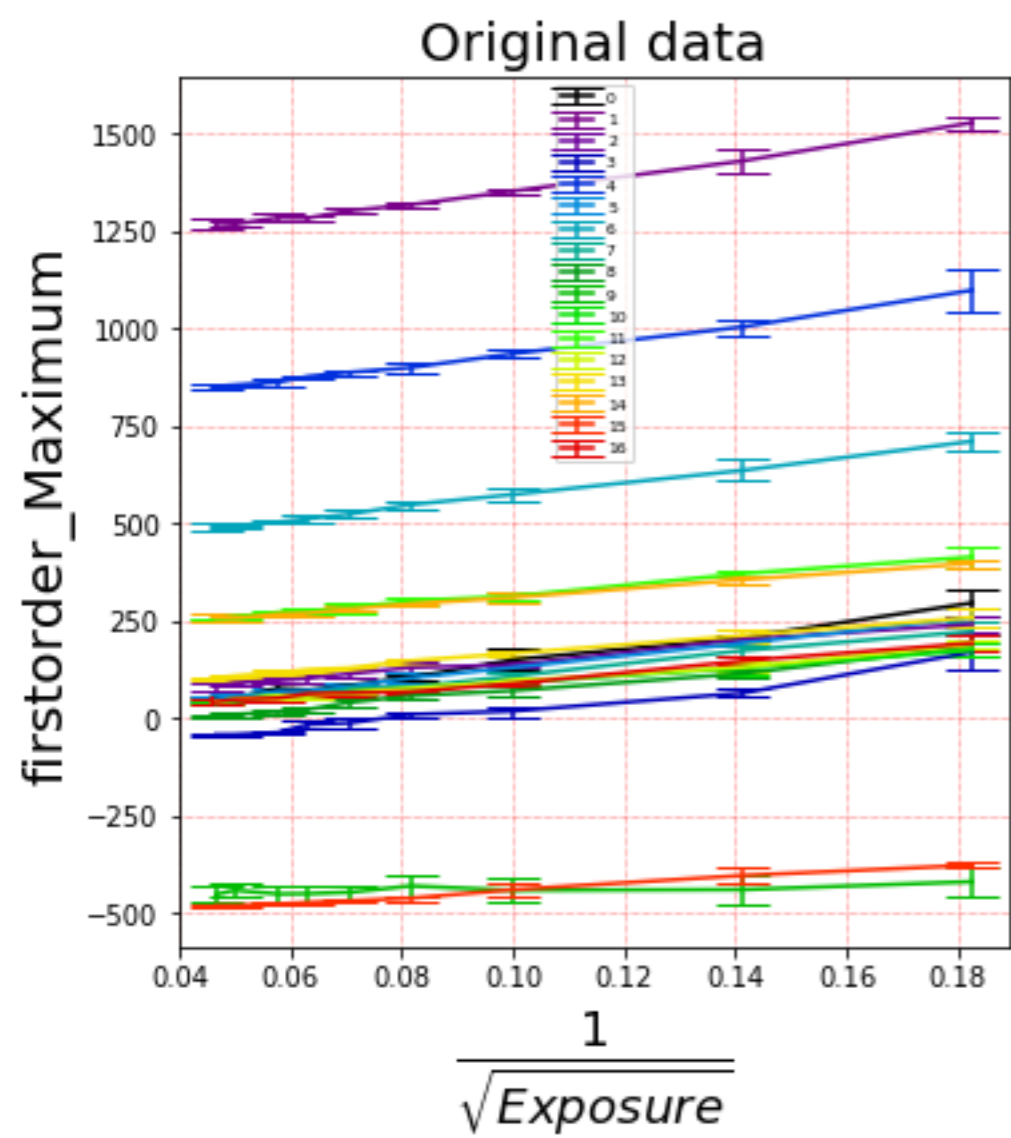


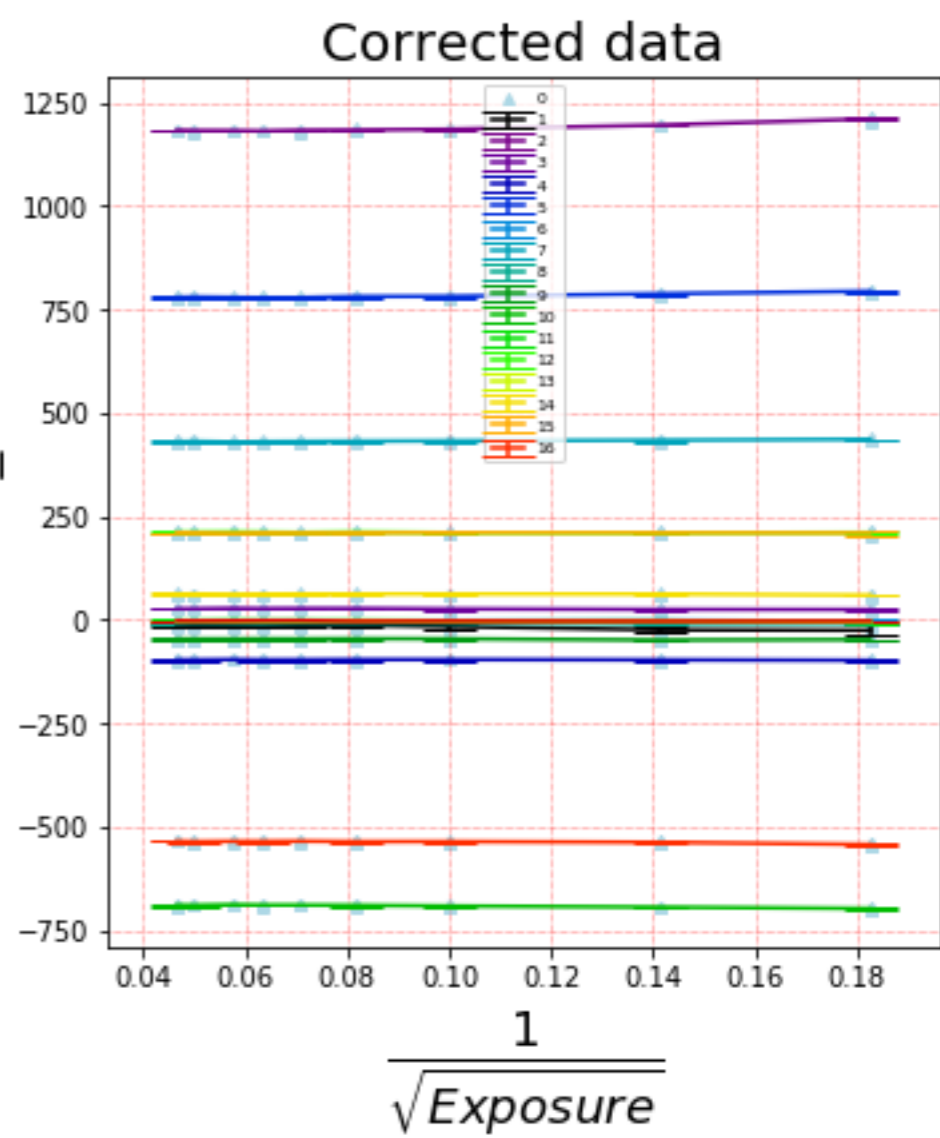
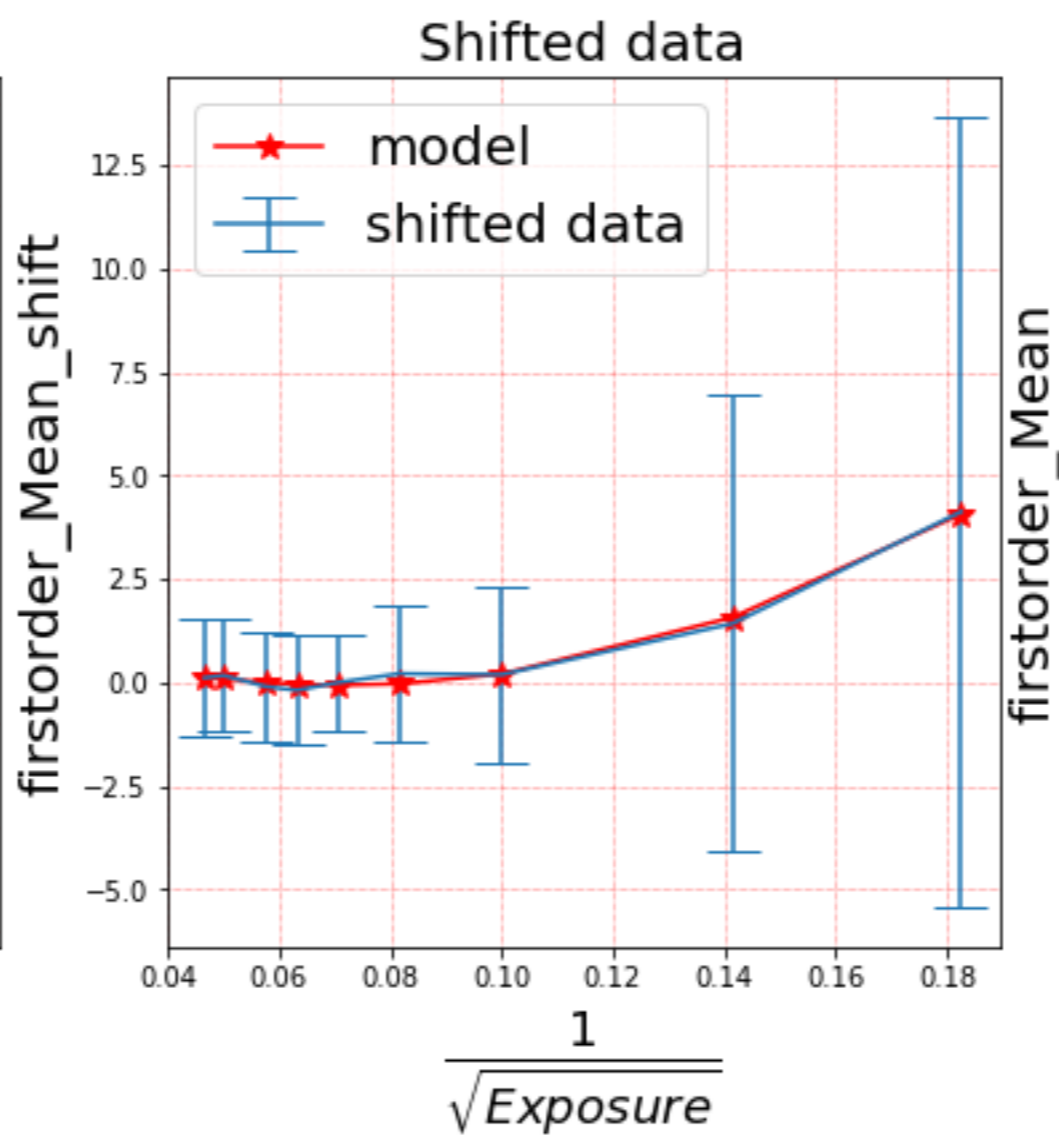
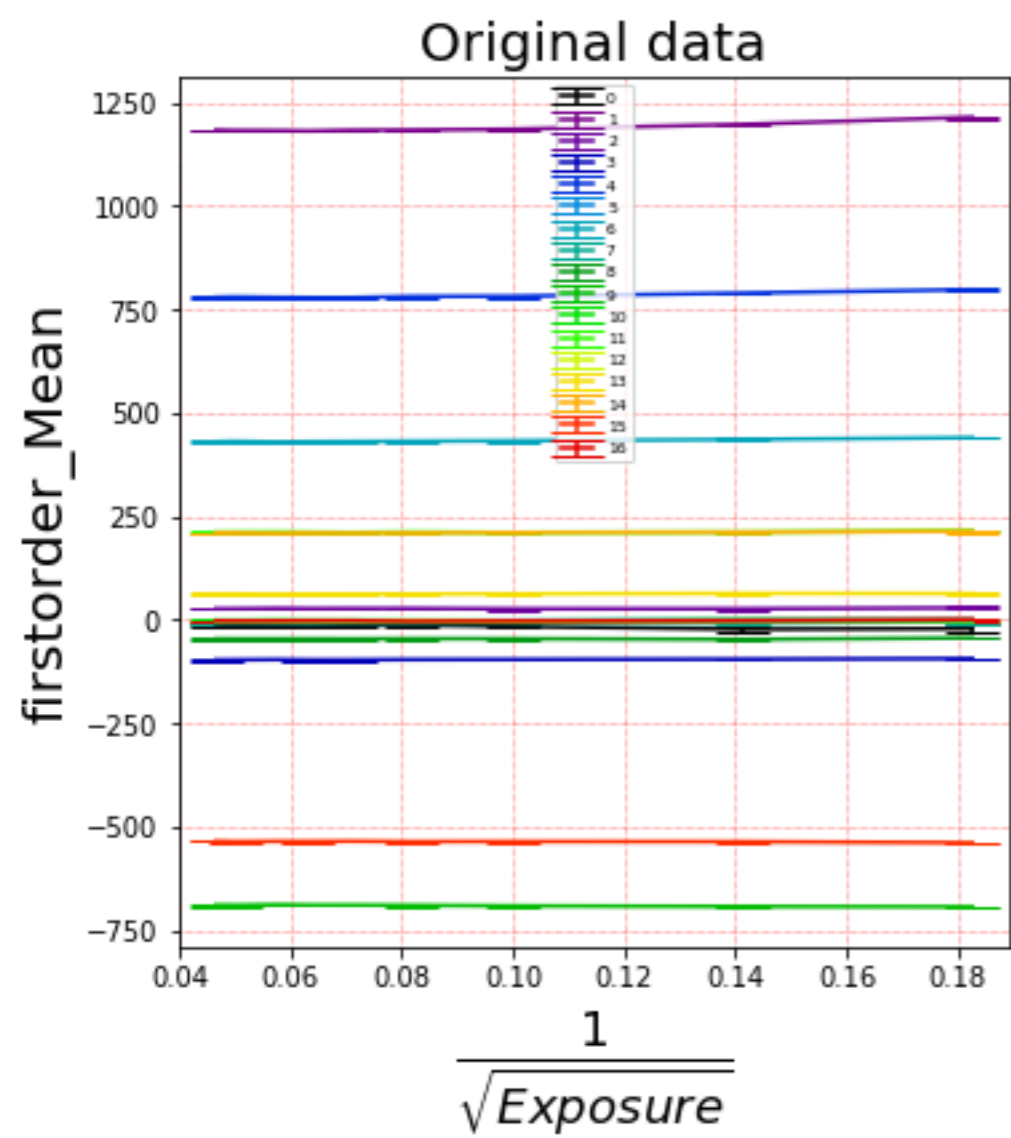


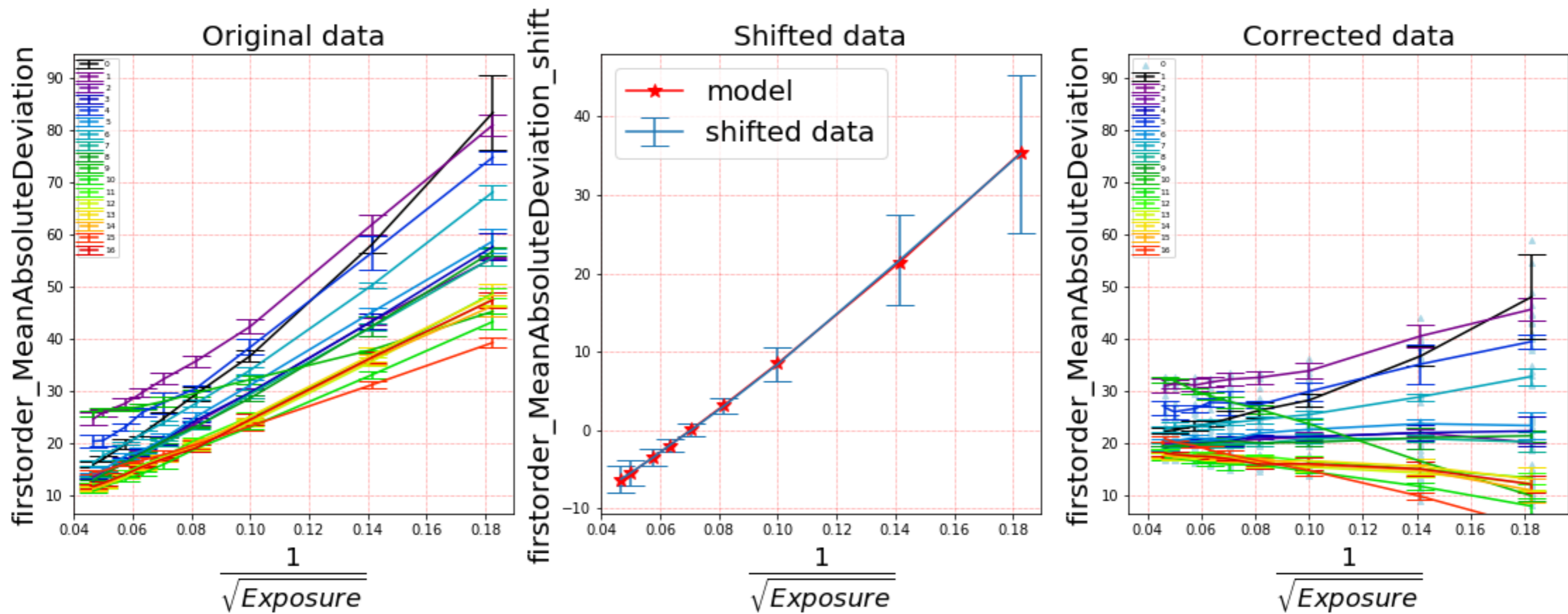


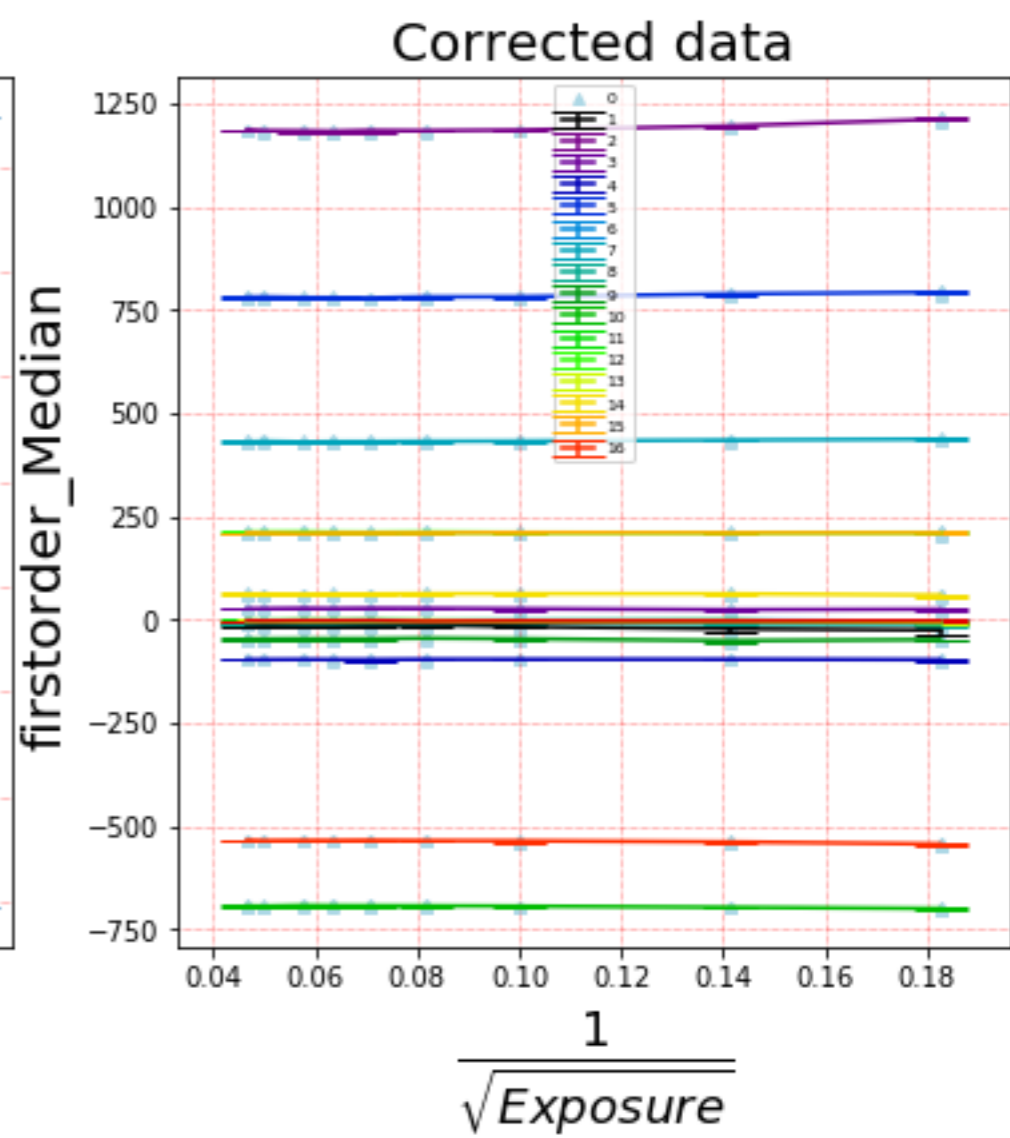
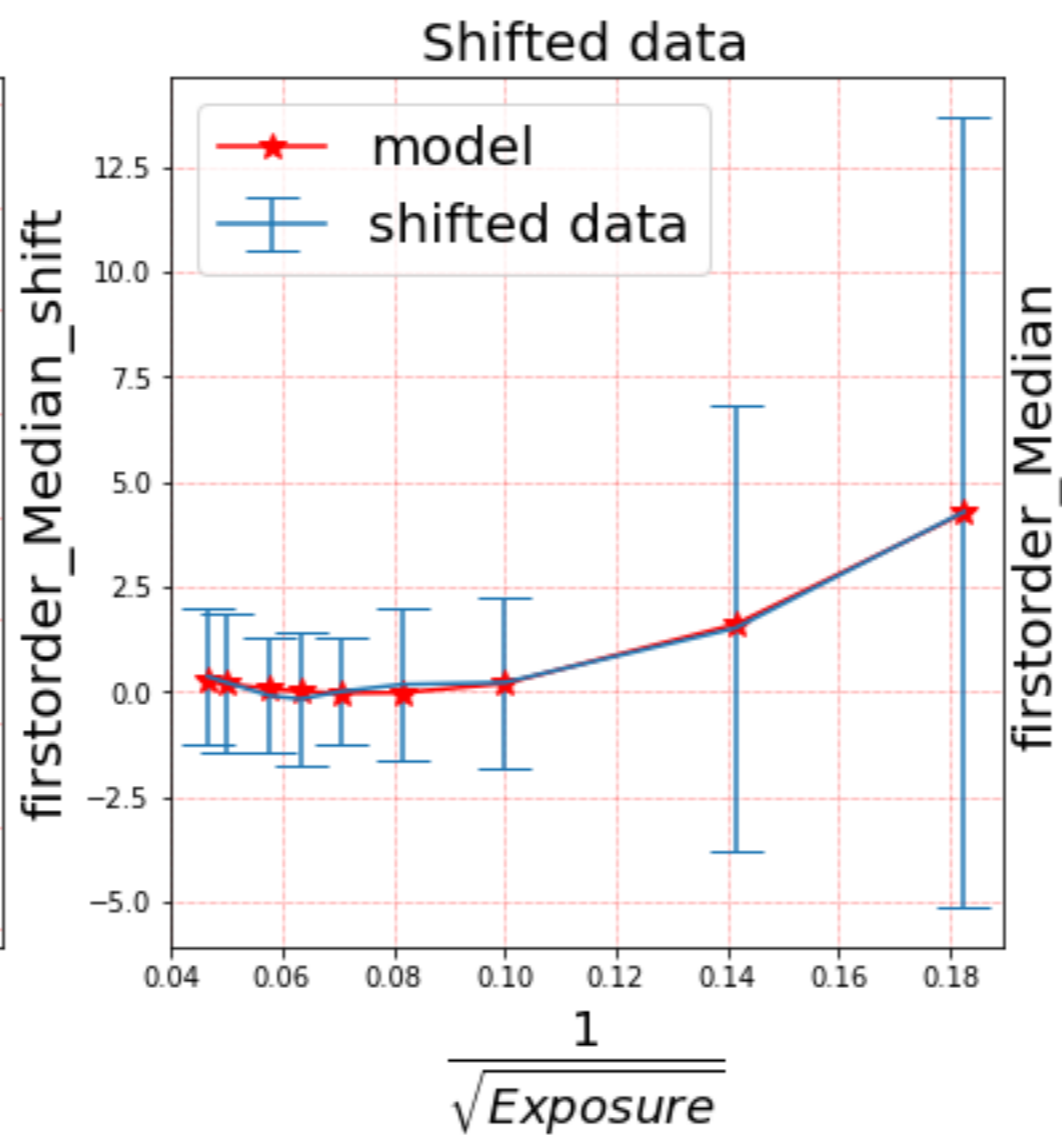
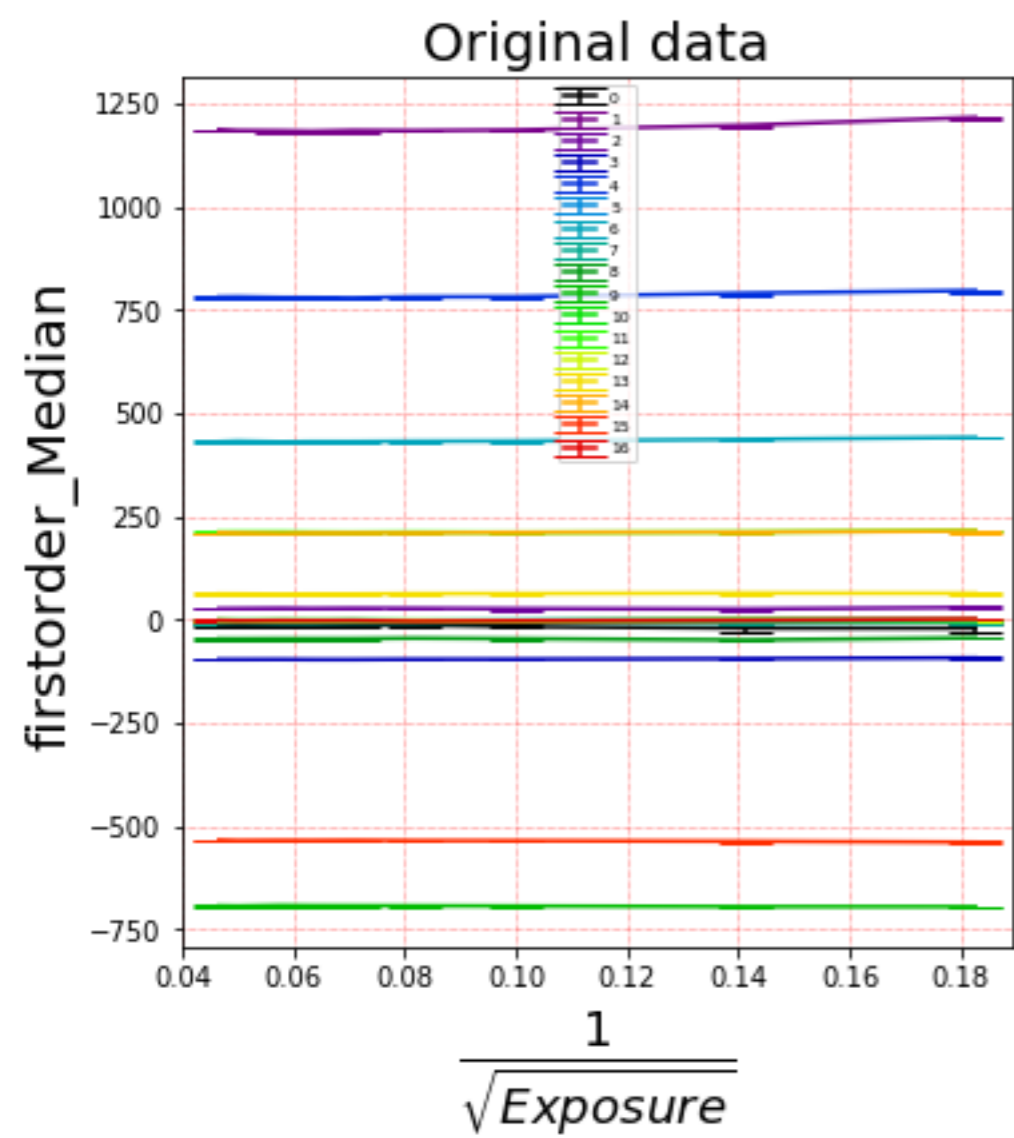


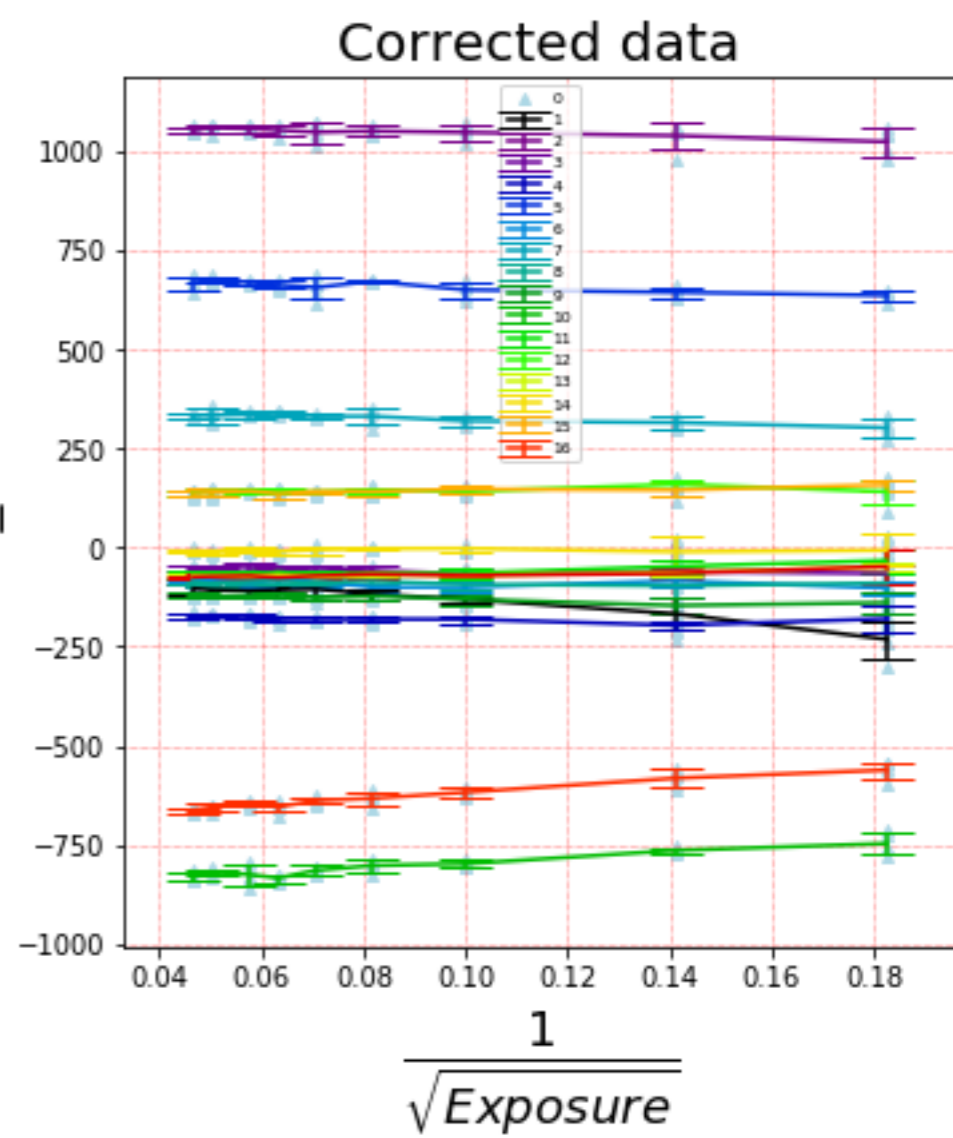
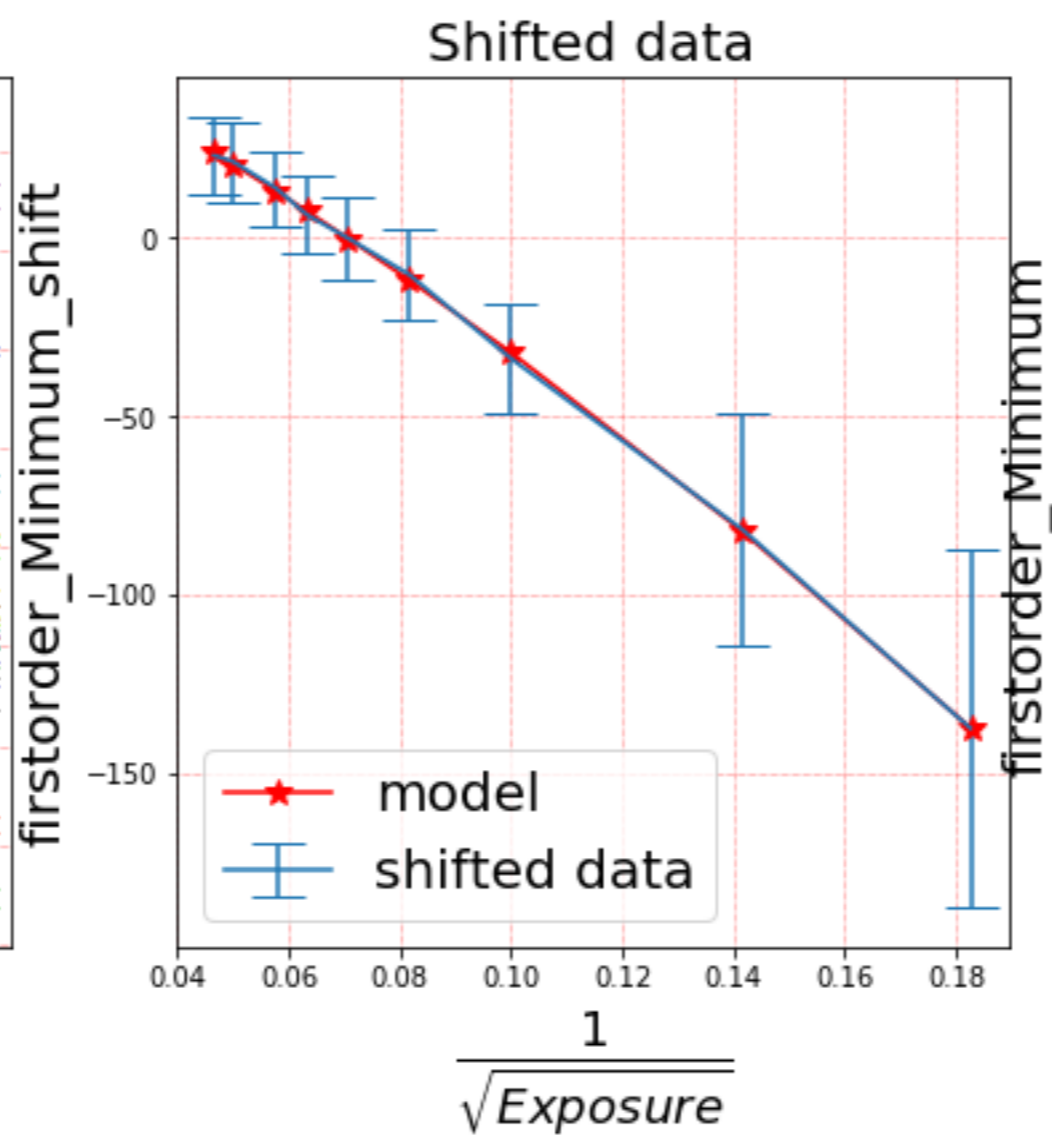
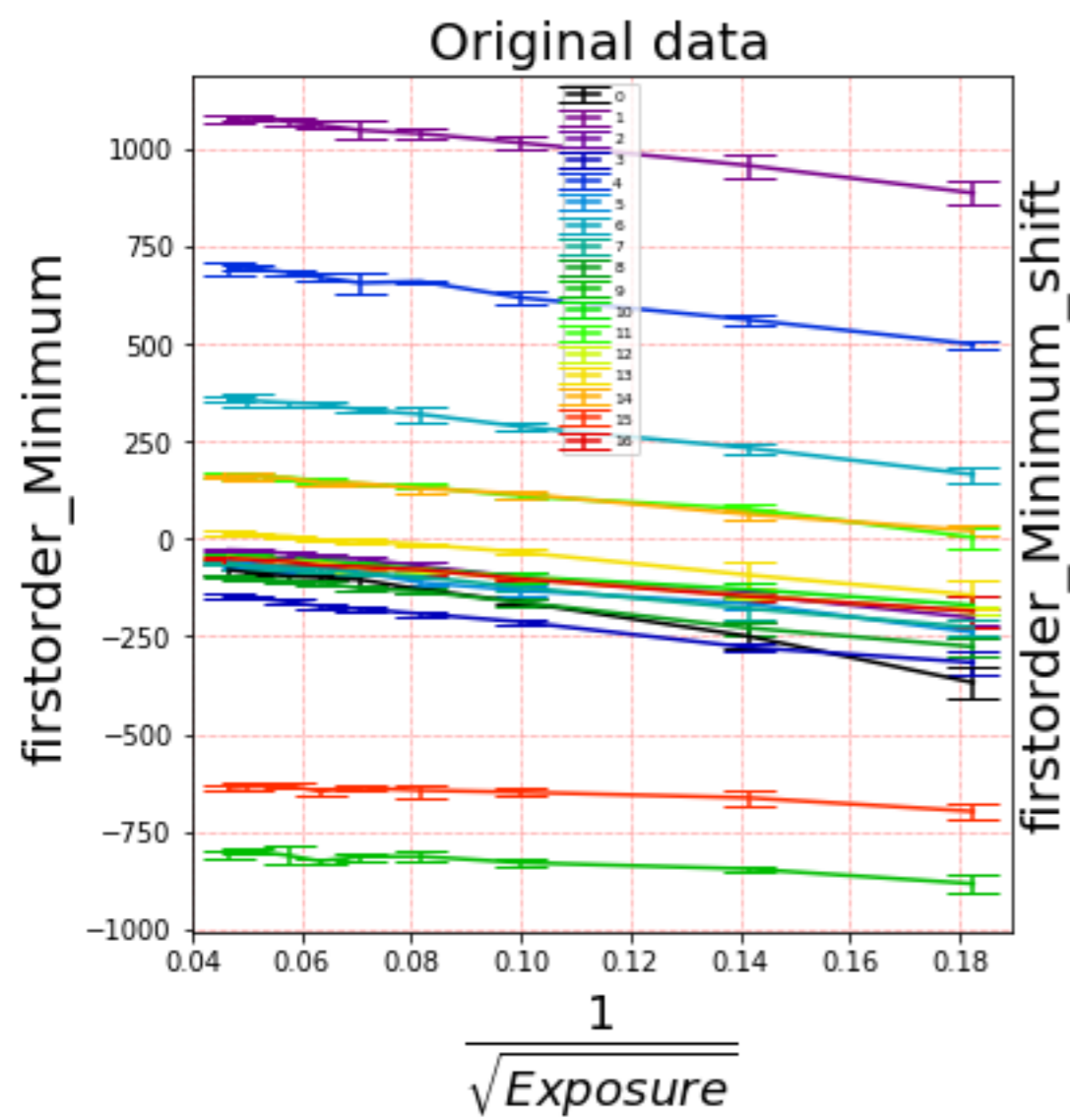


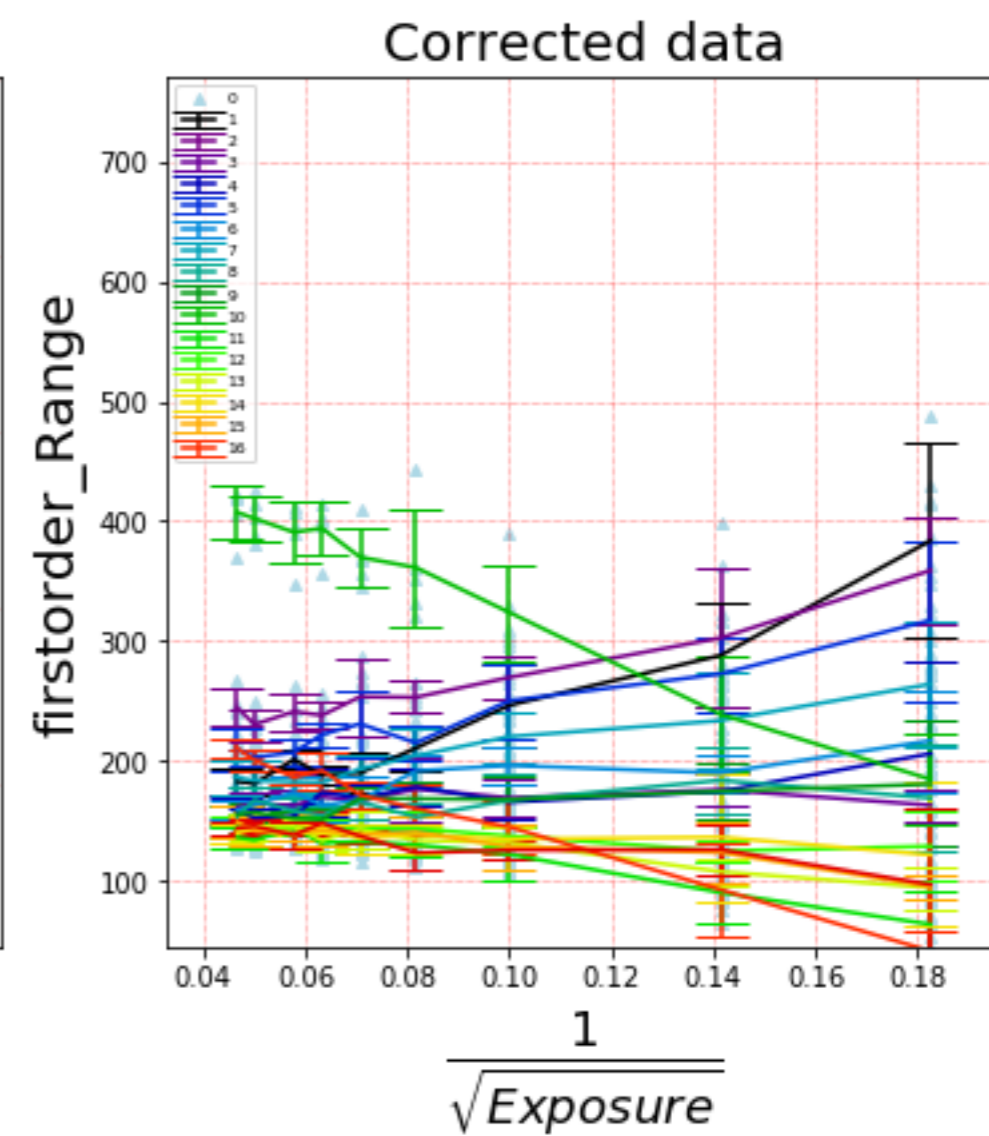
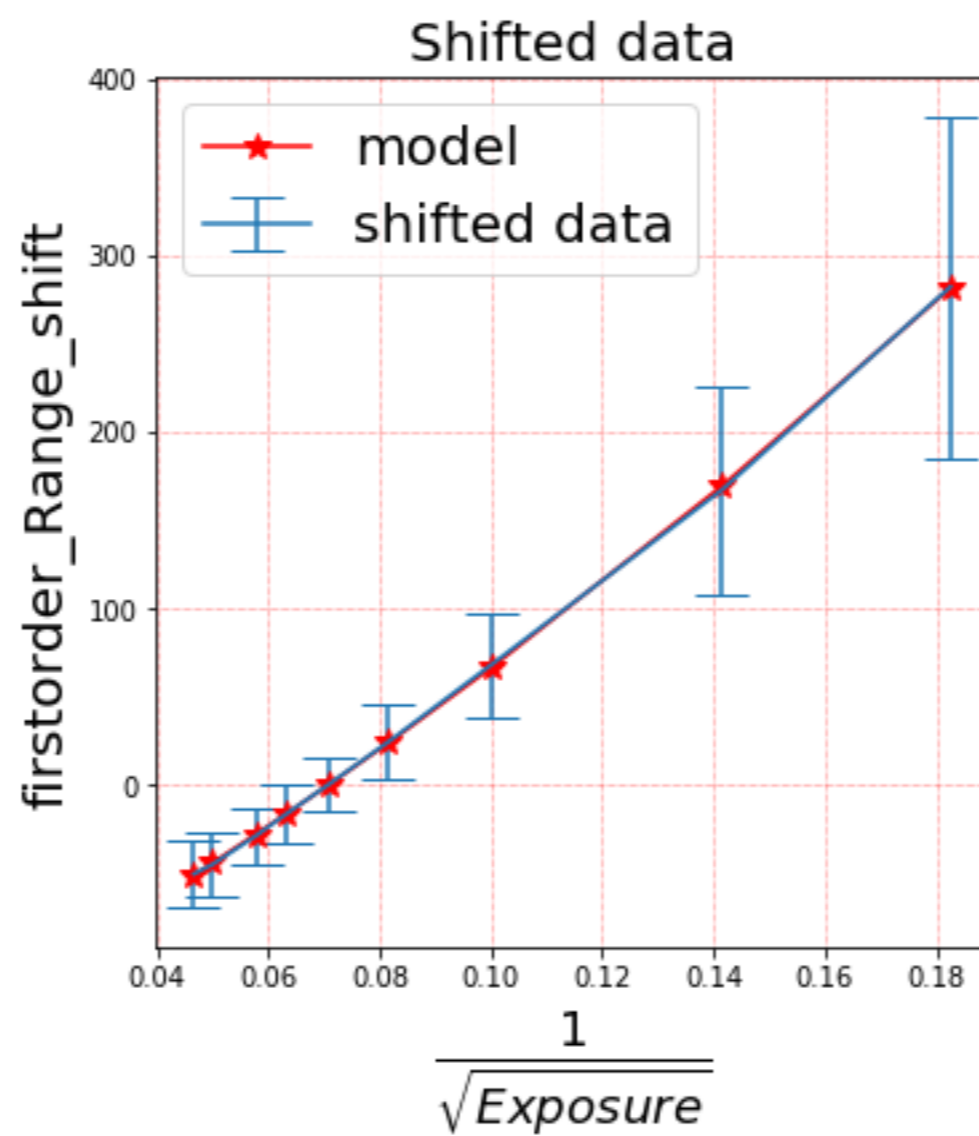
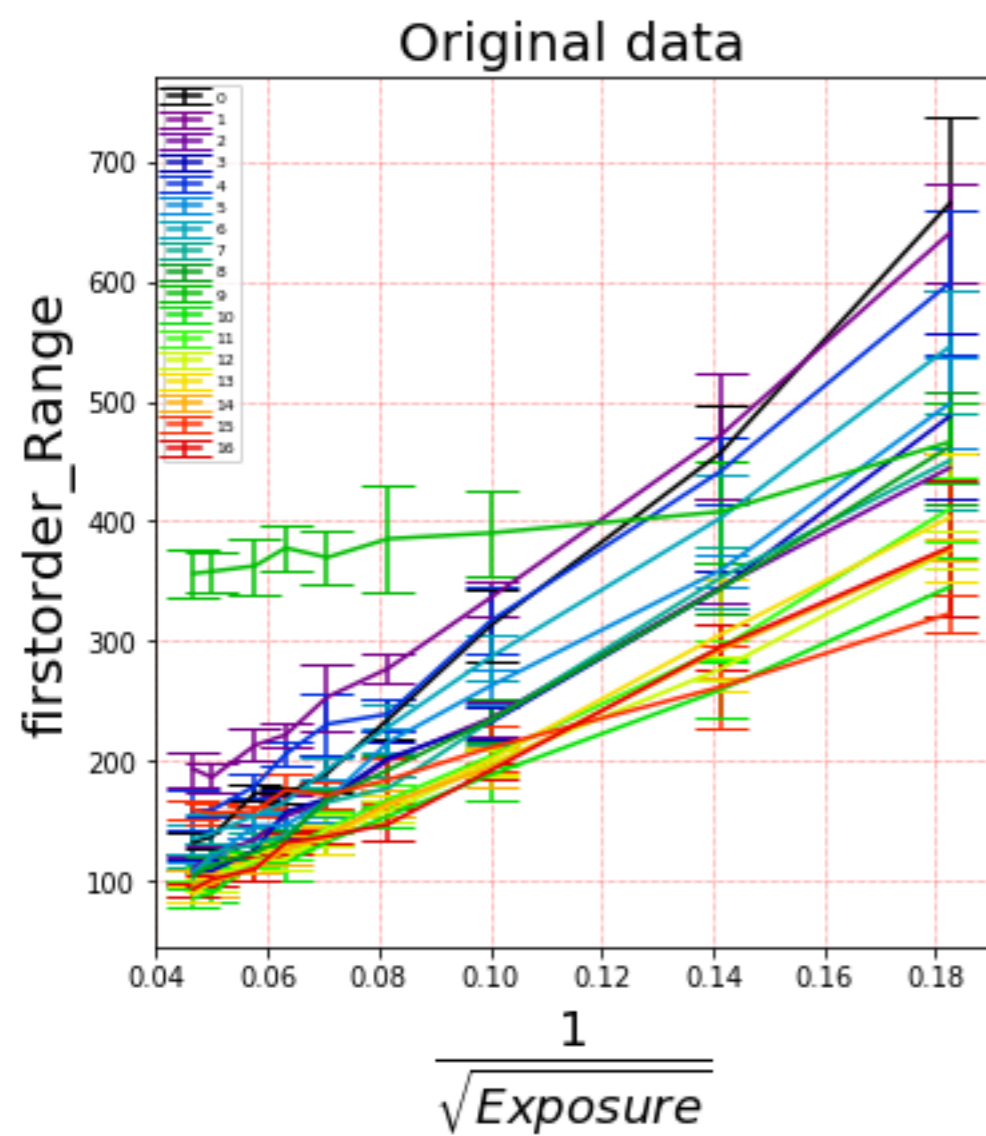






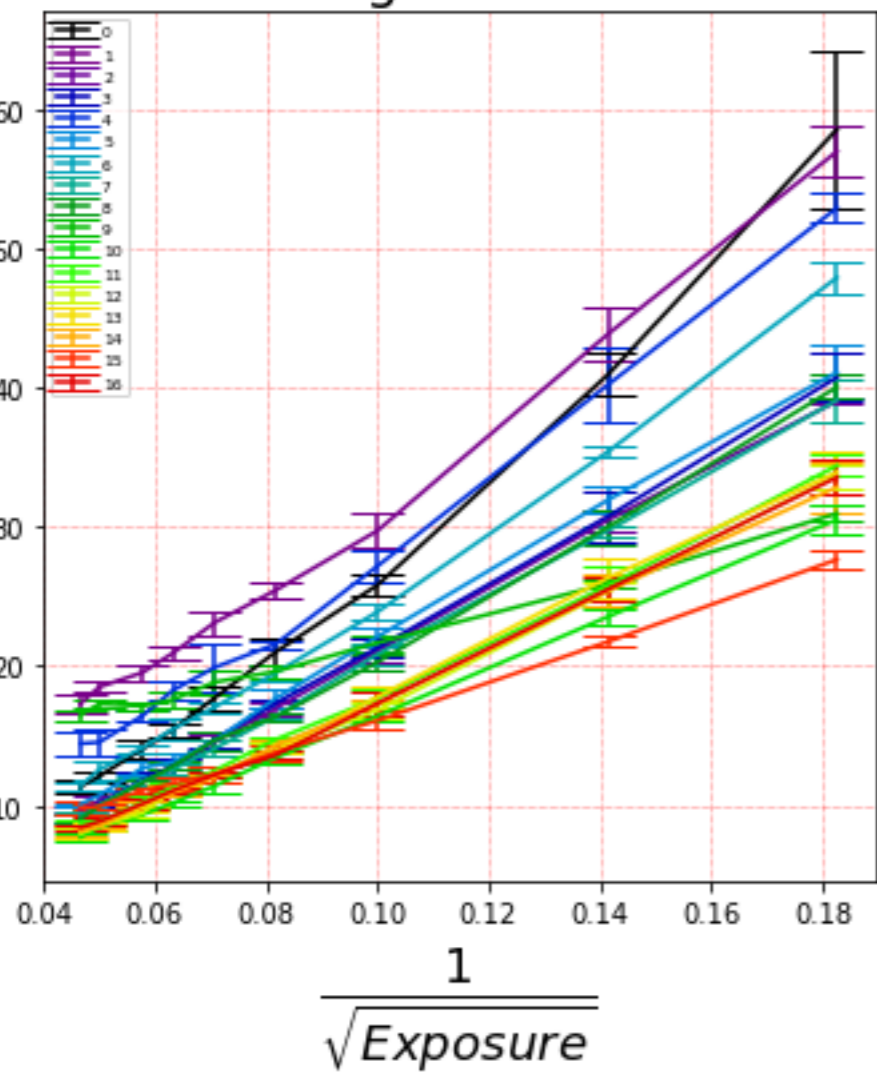






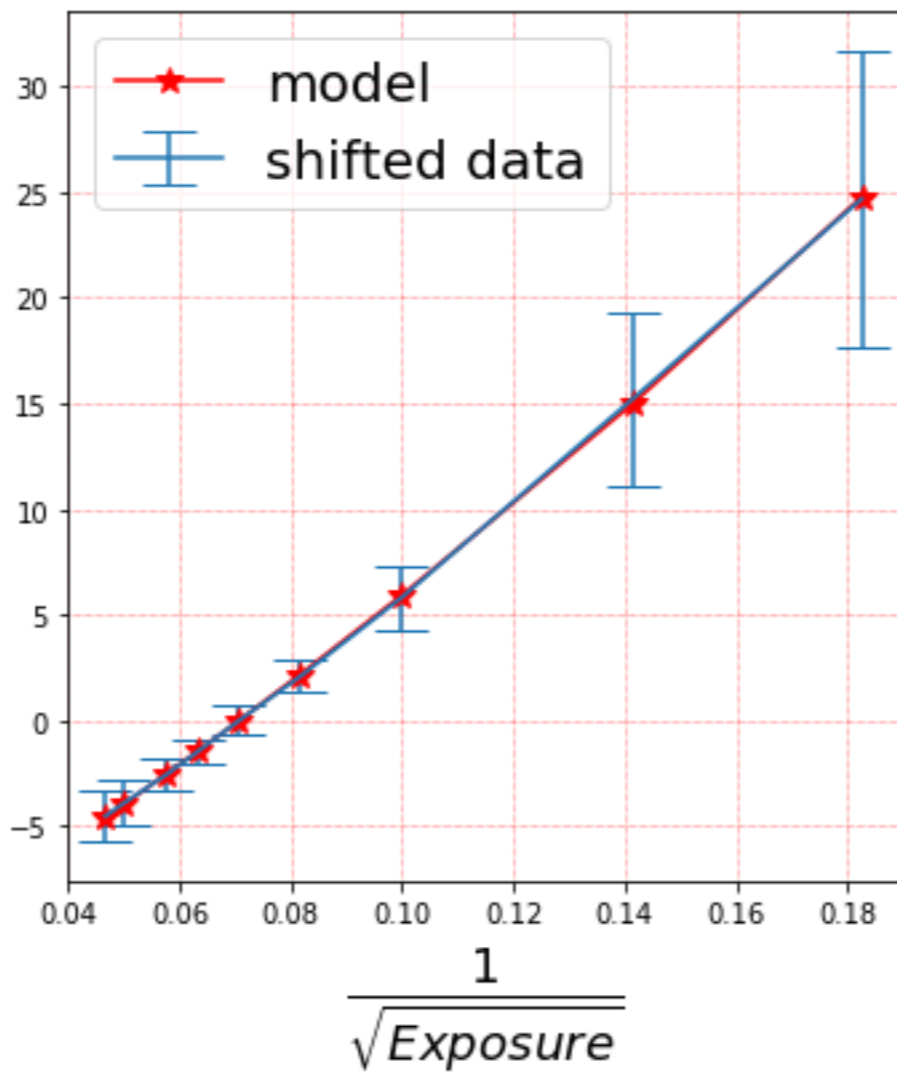
firstorder_RobustMeanAbsoluteDeviation

Original data



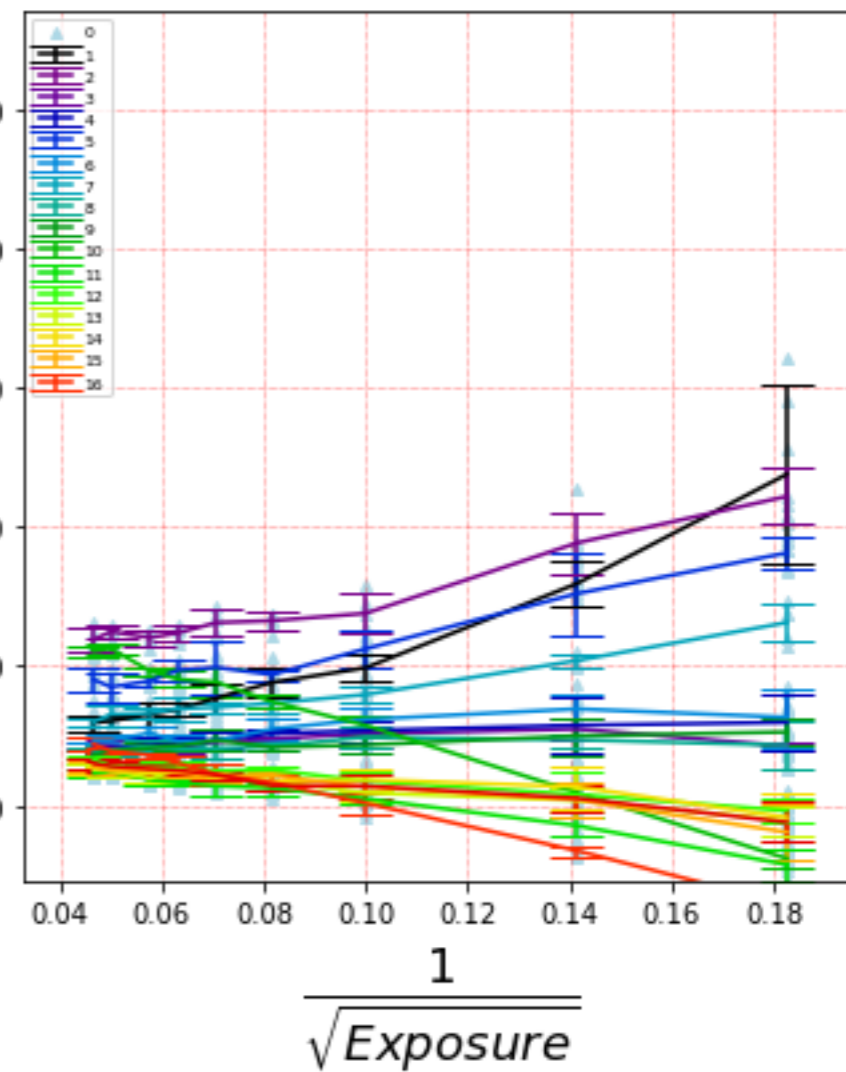
firstorder_RobustMeanAbsoluteDeviation_shift

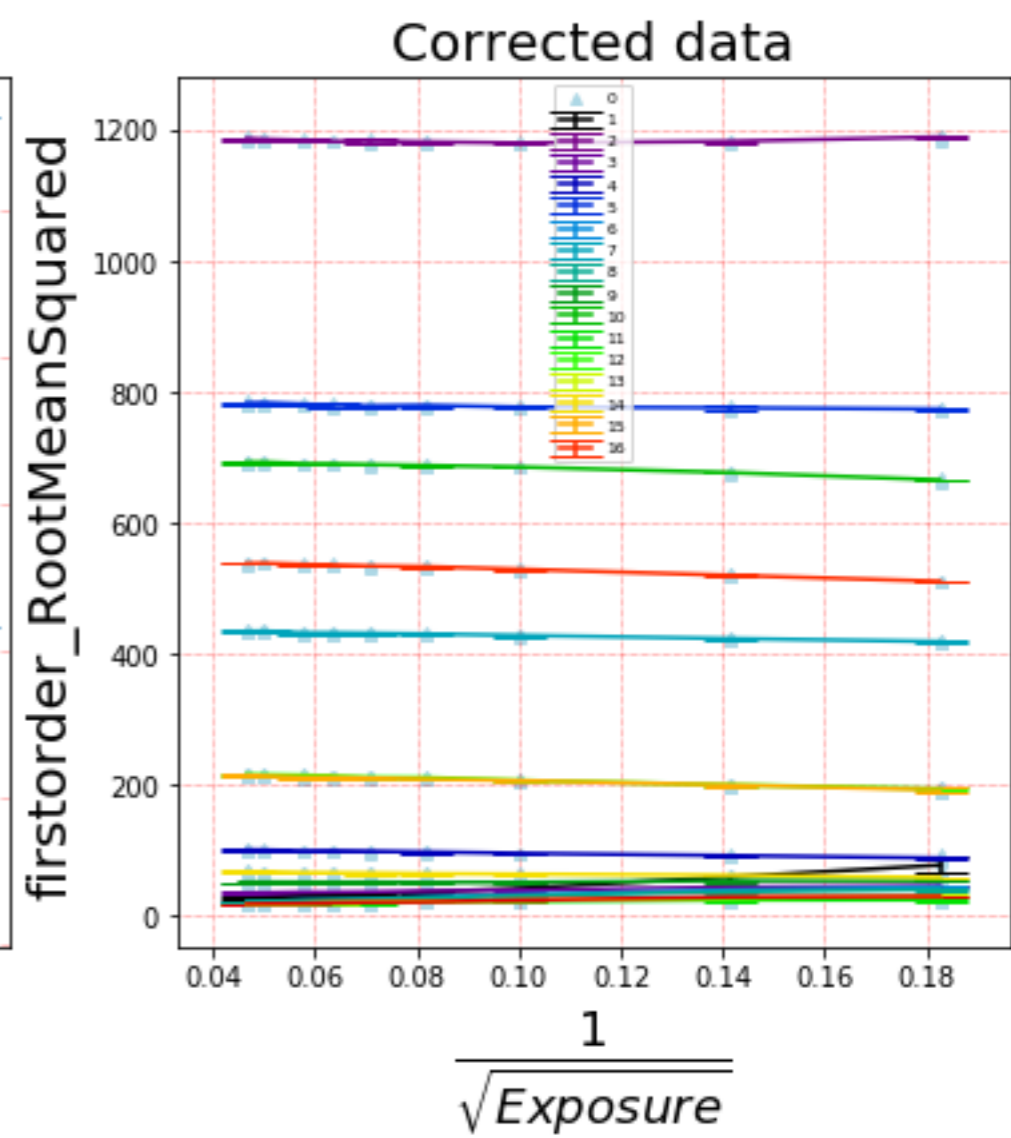
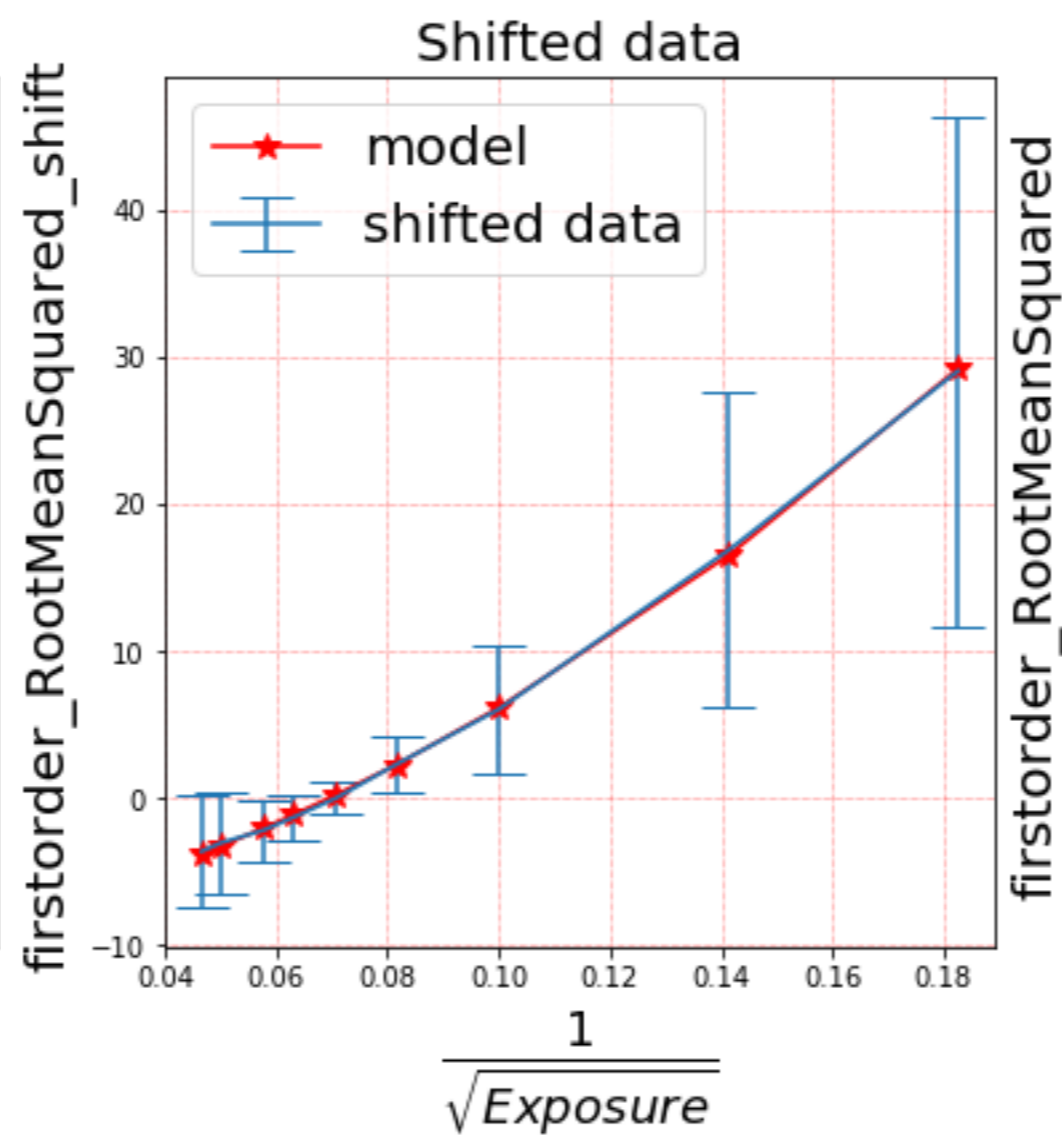
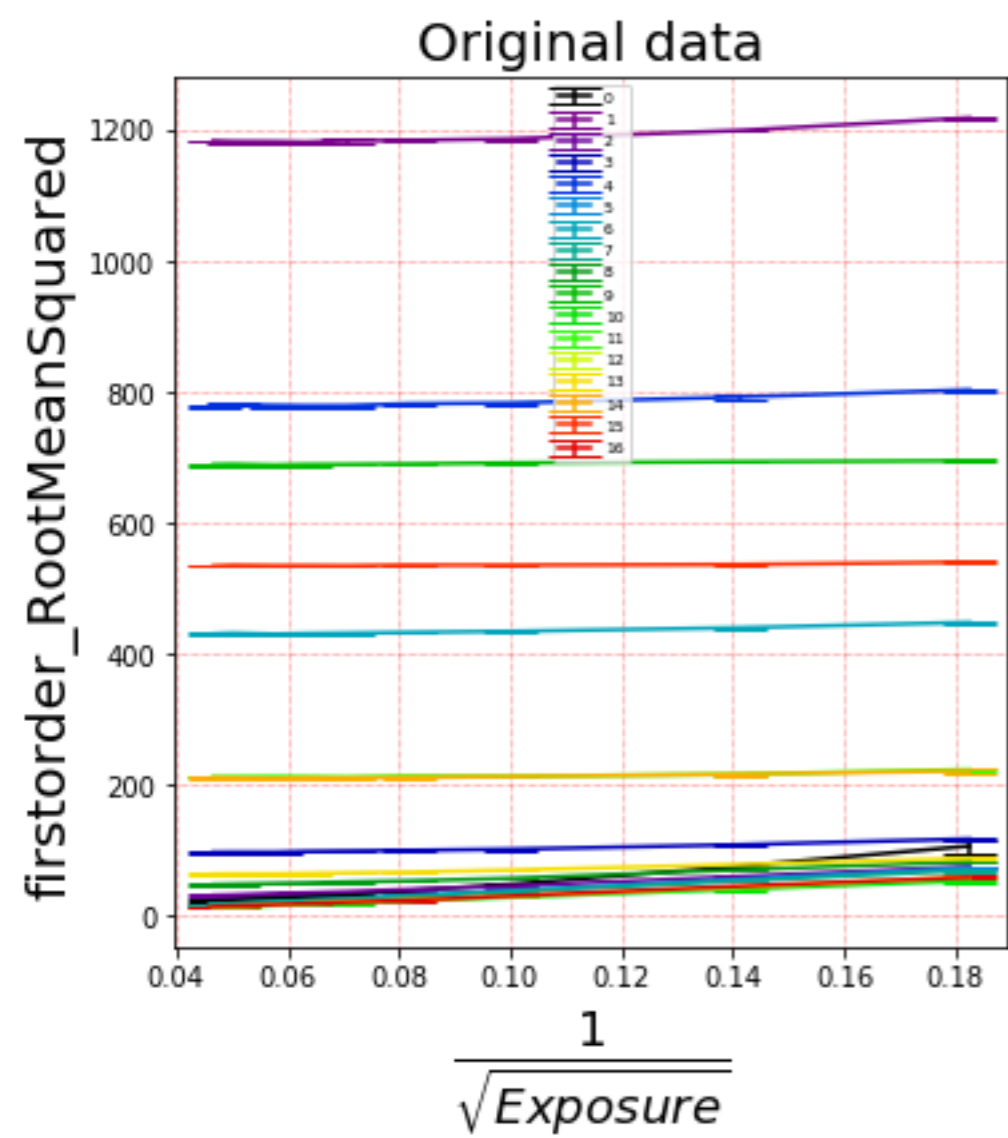
Shifted data

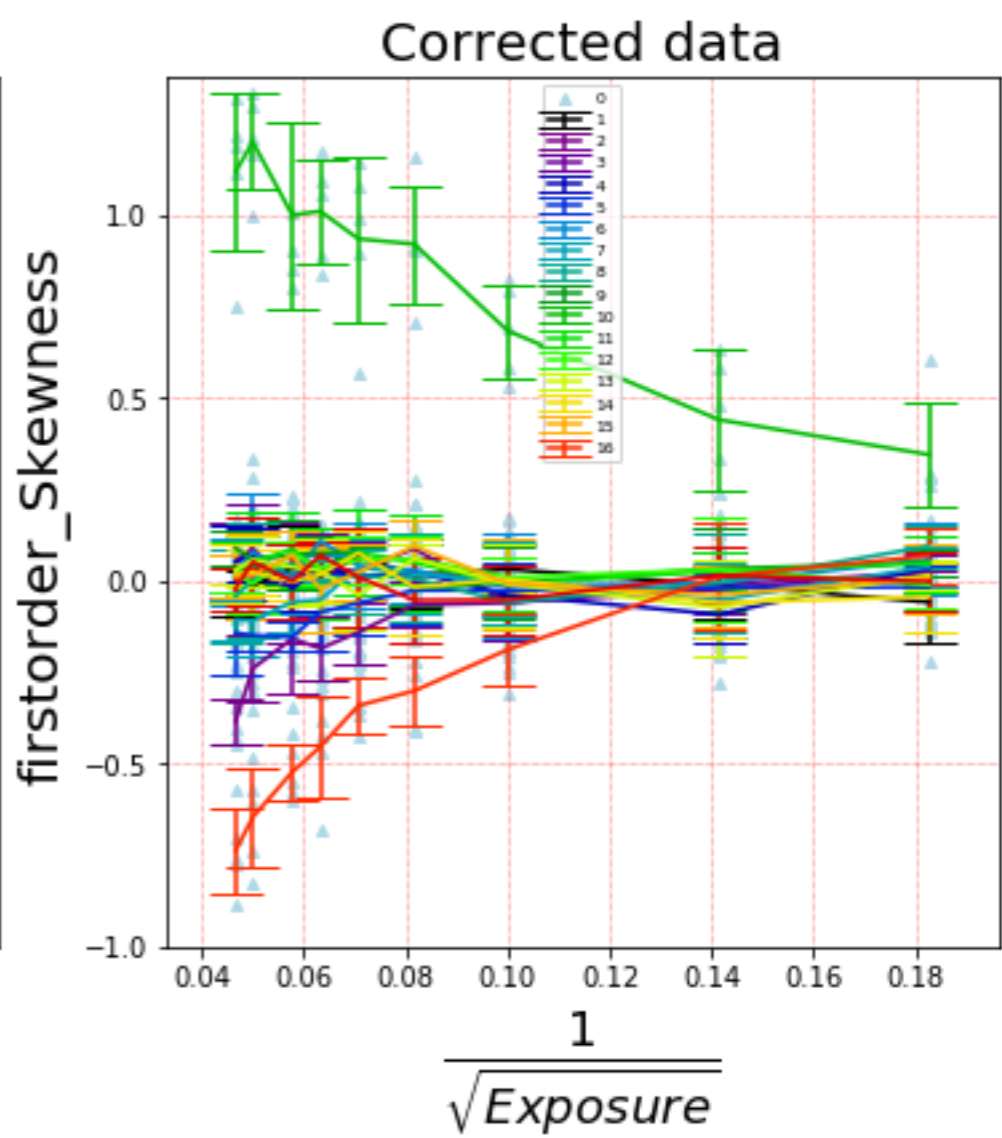
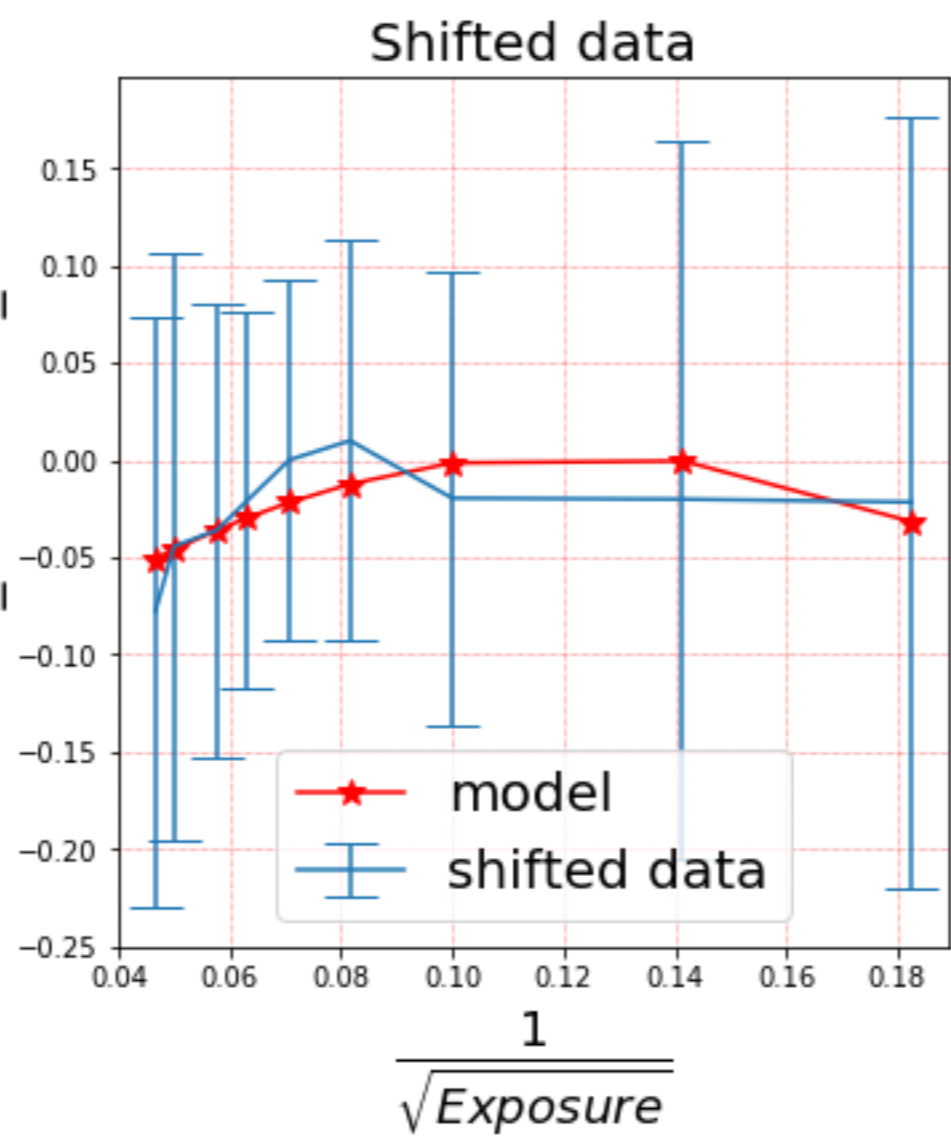
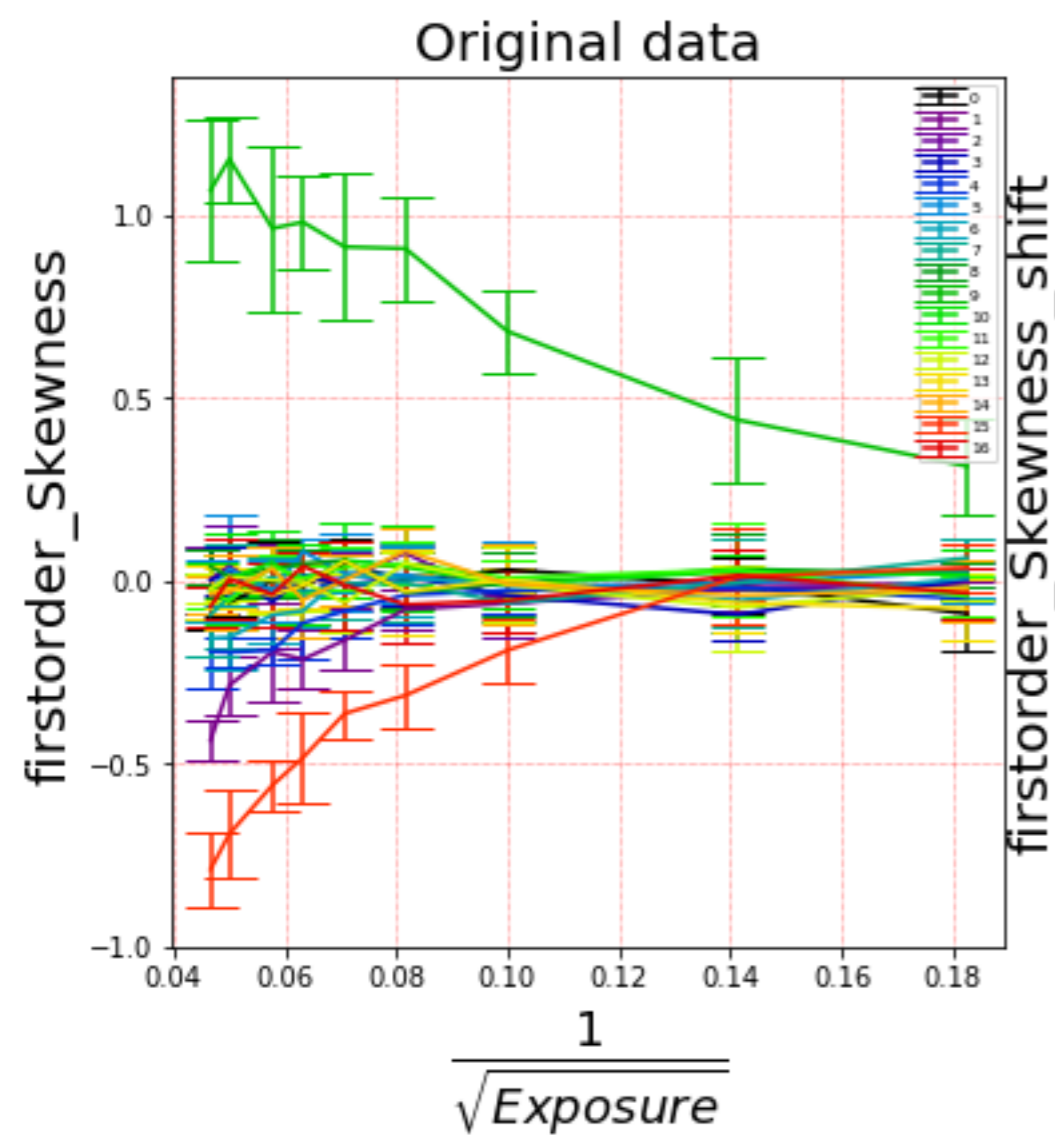


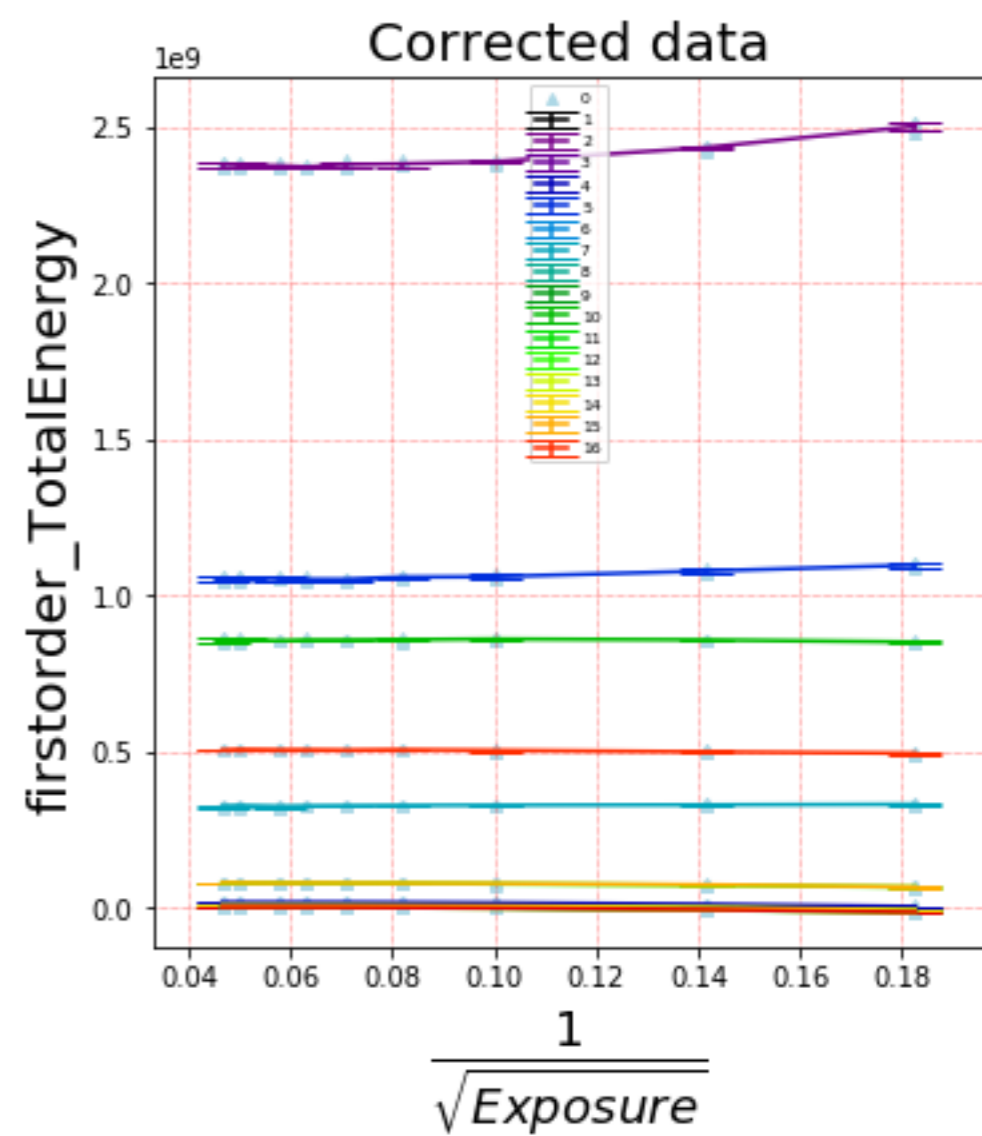
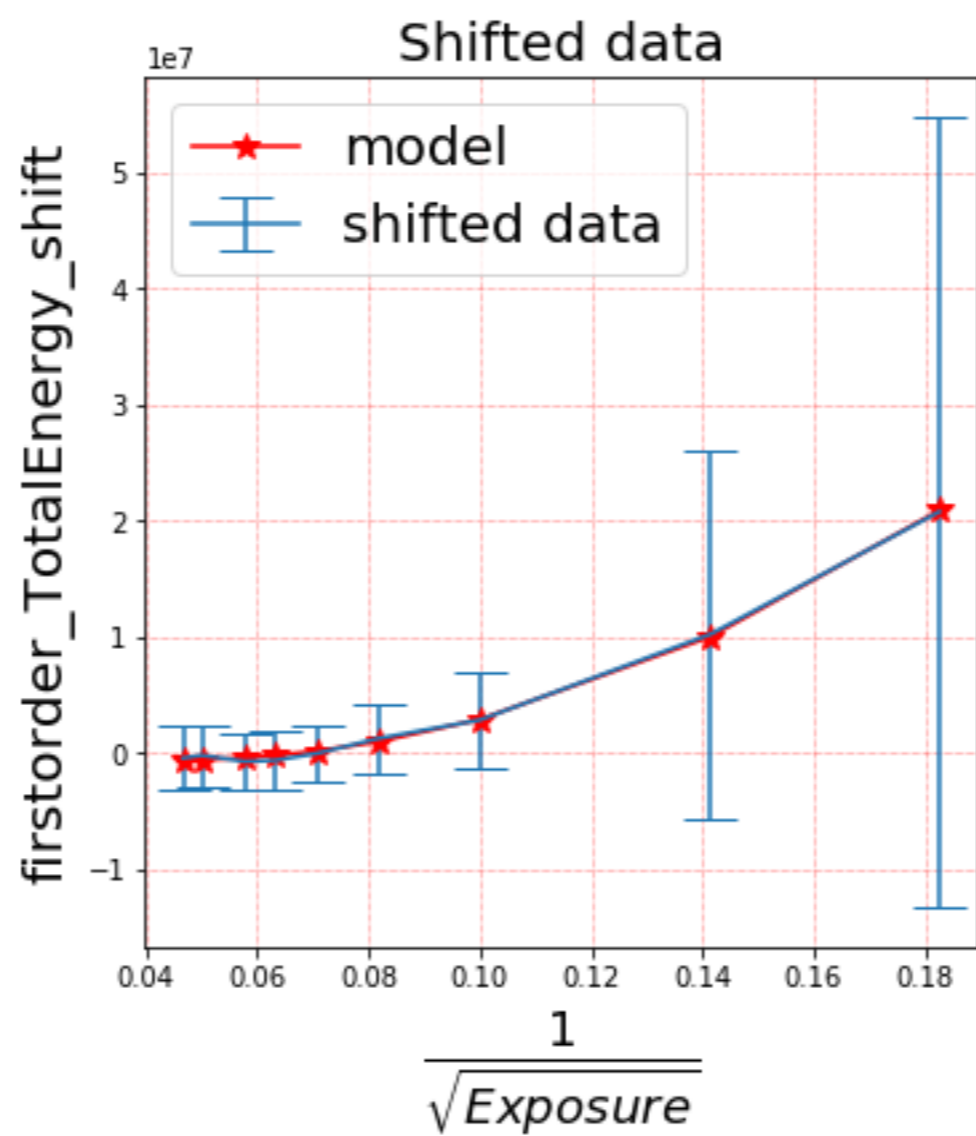
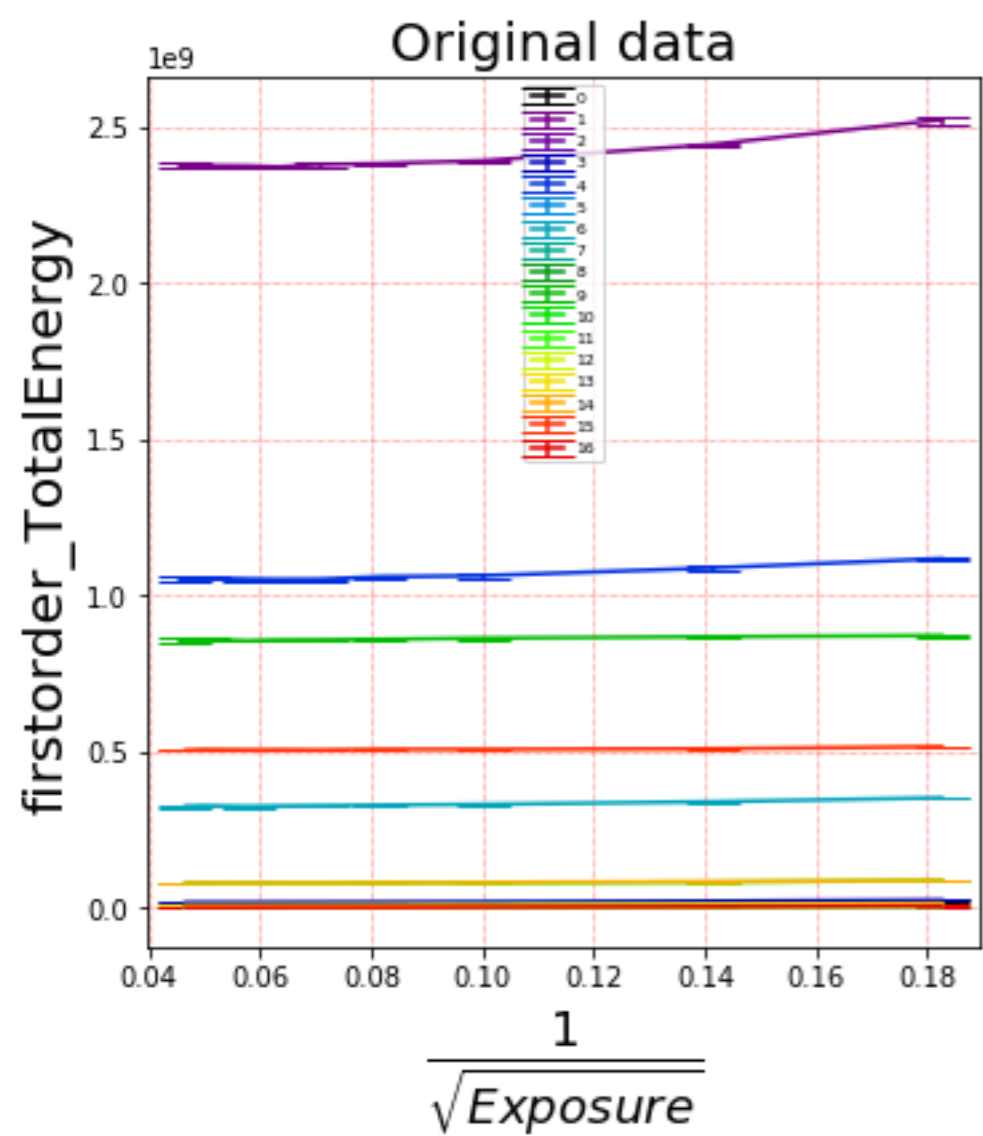
firstorder_RobustMeanAbsoluteDeviation

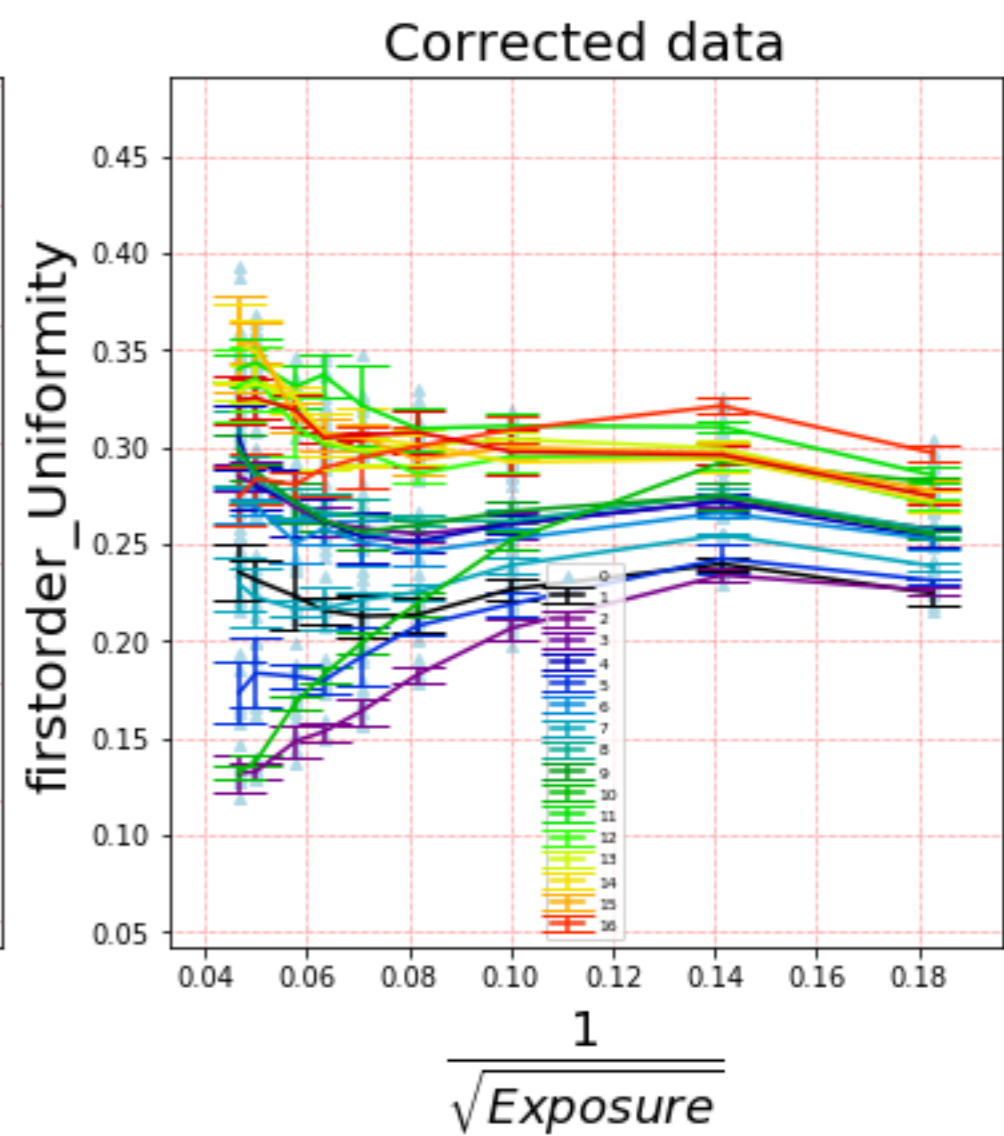
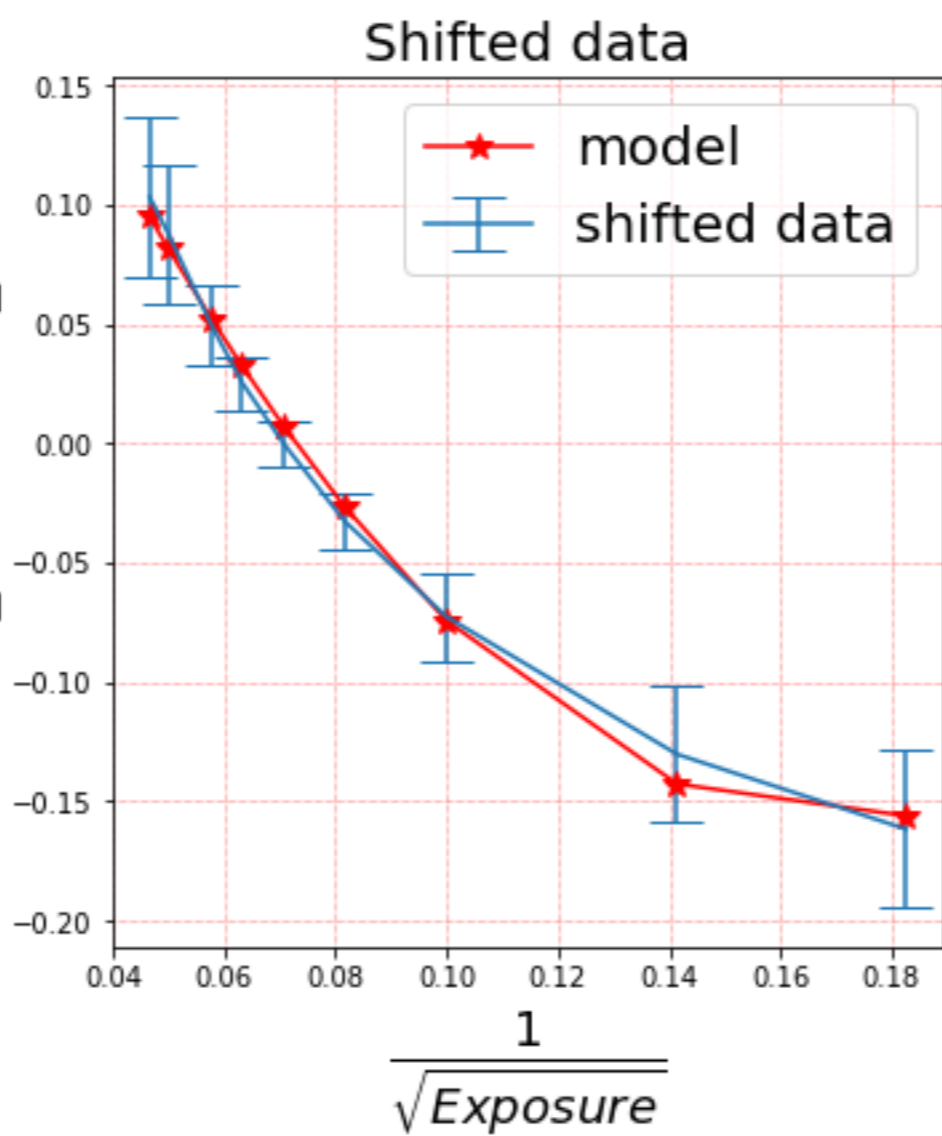
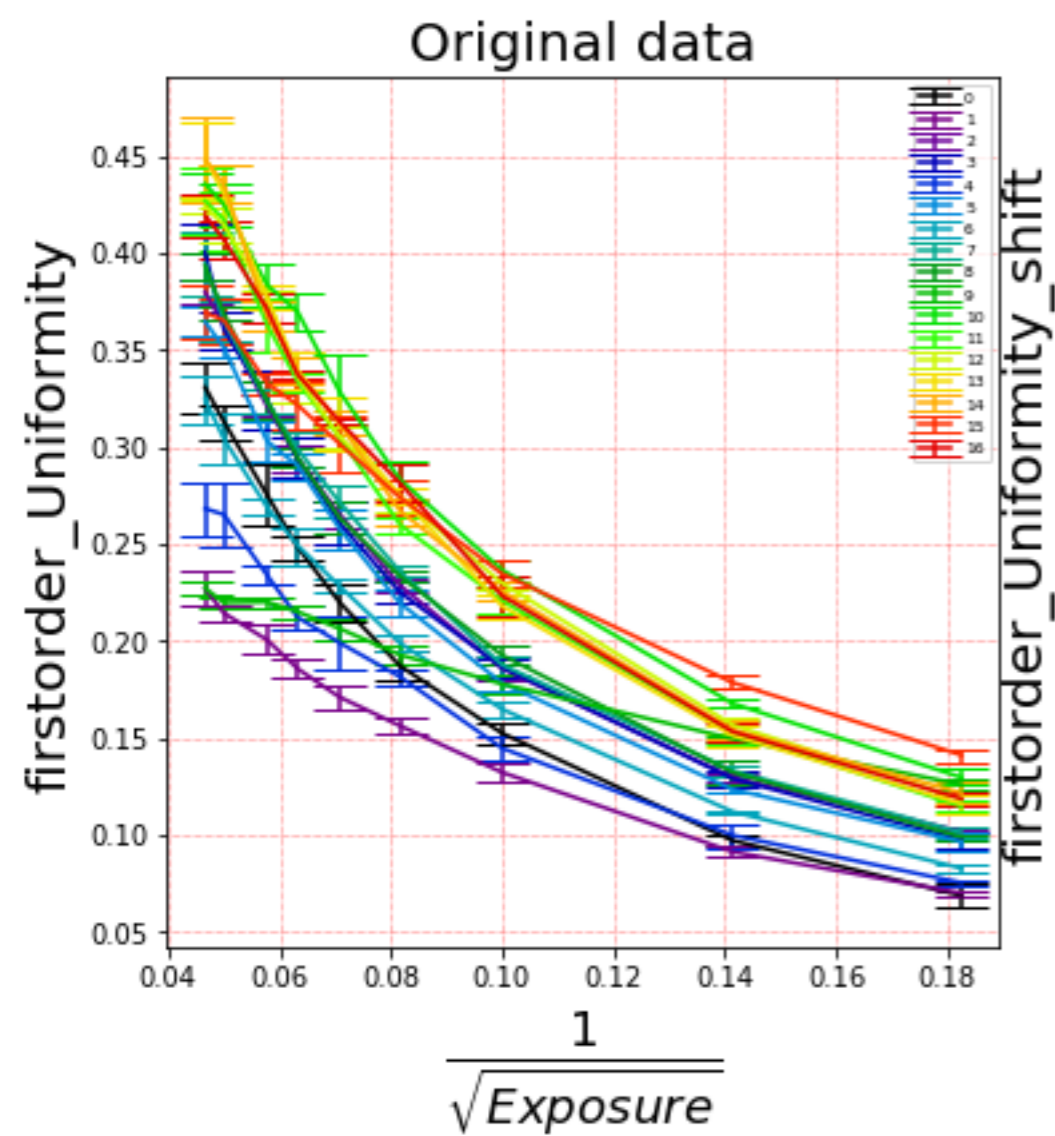
Corrected data

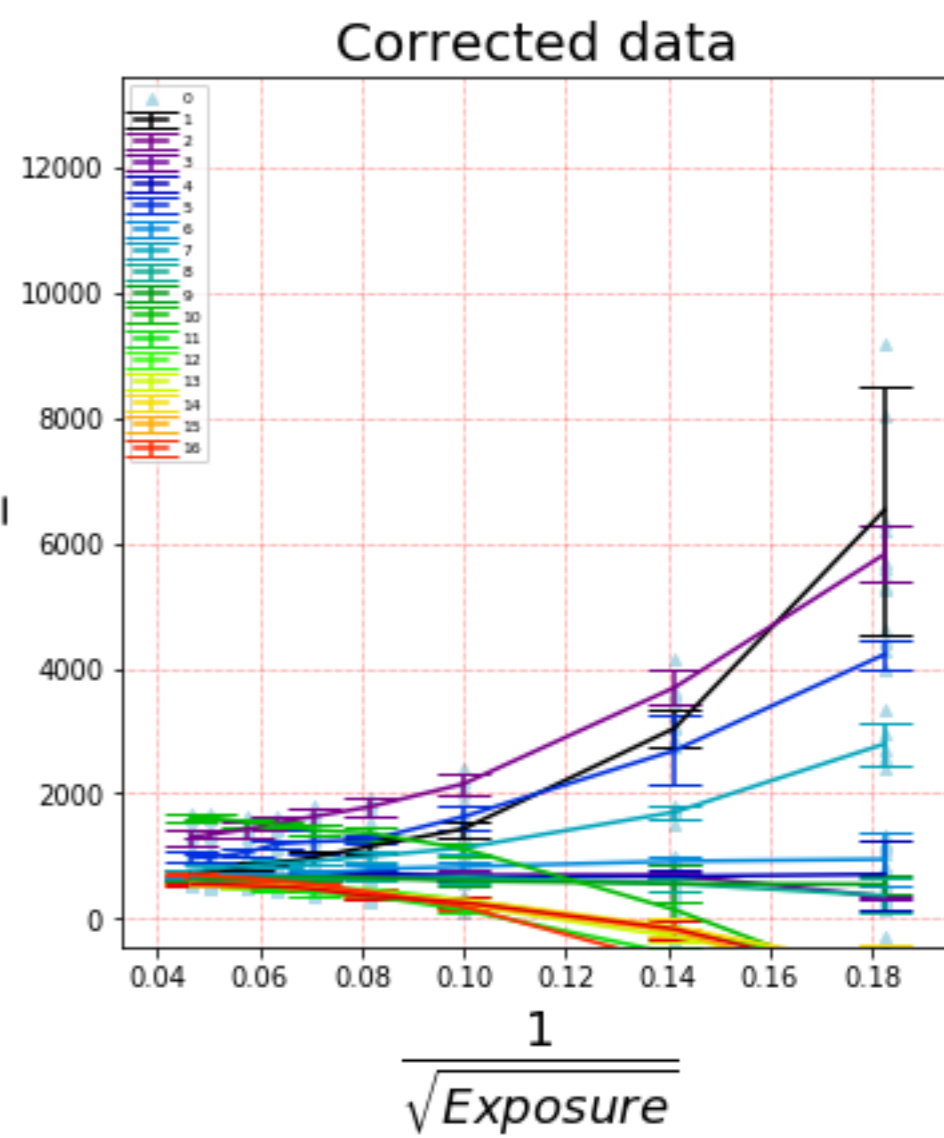
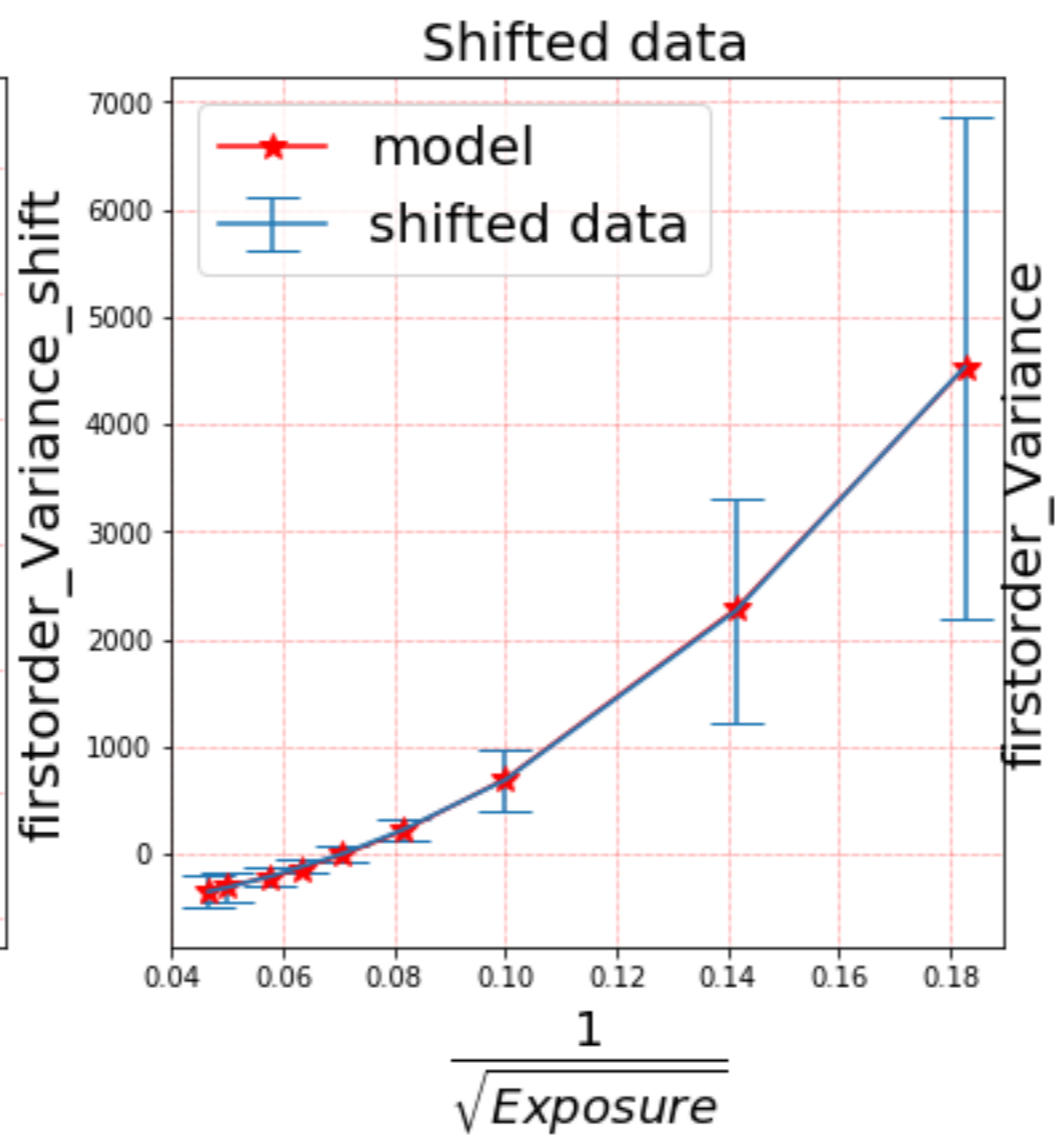
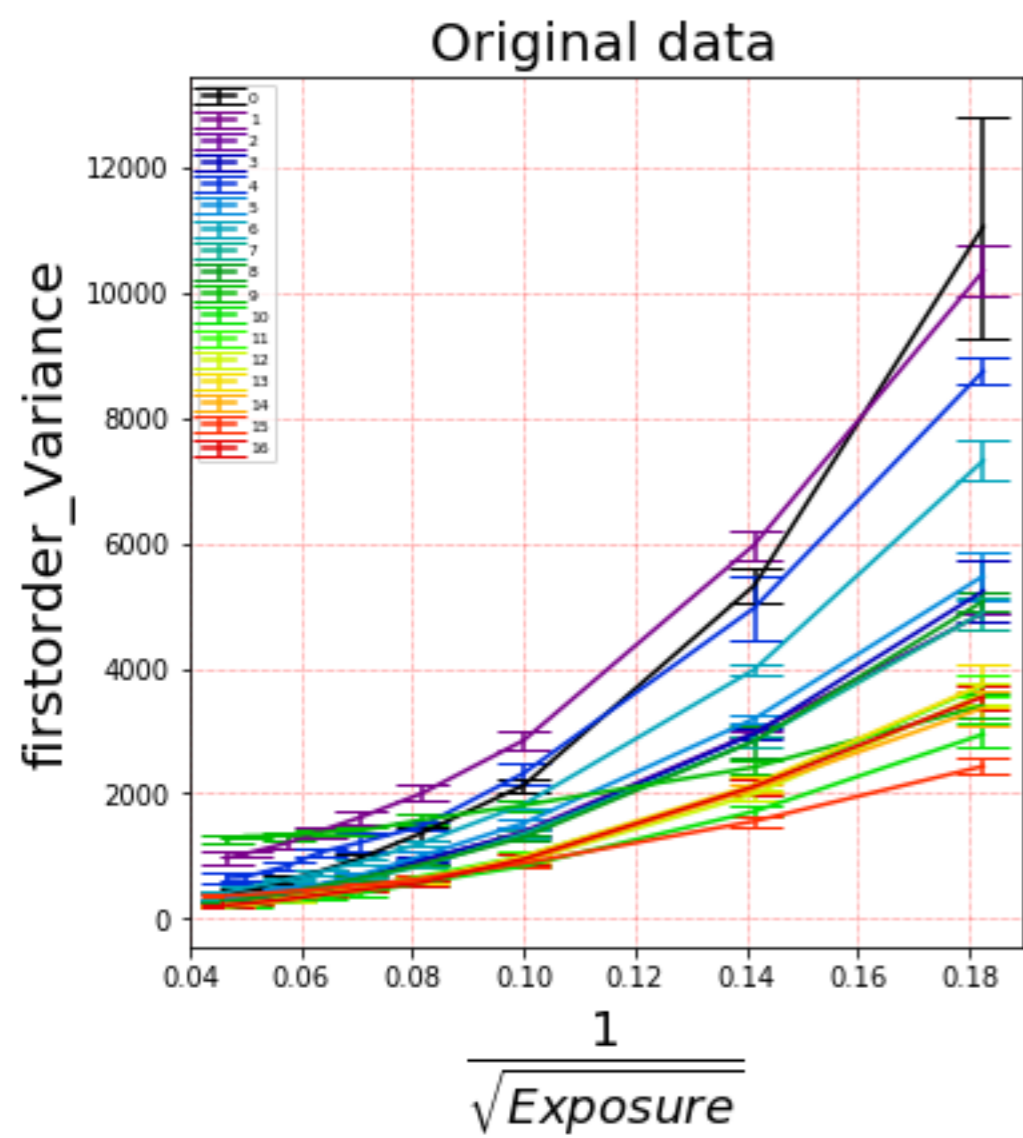


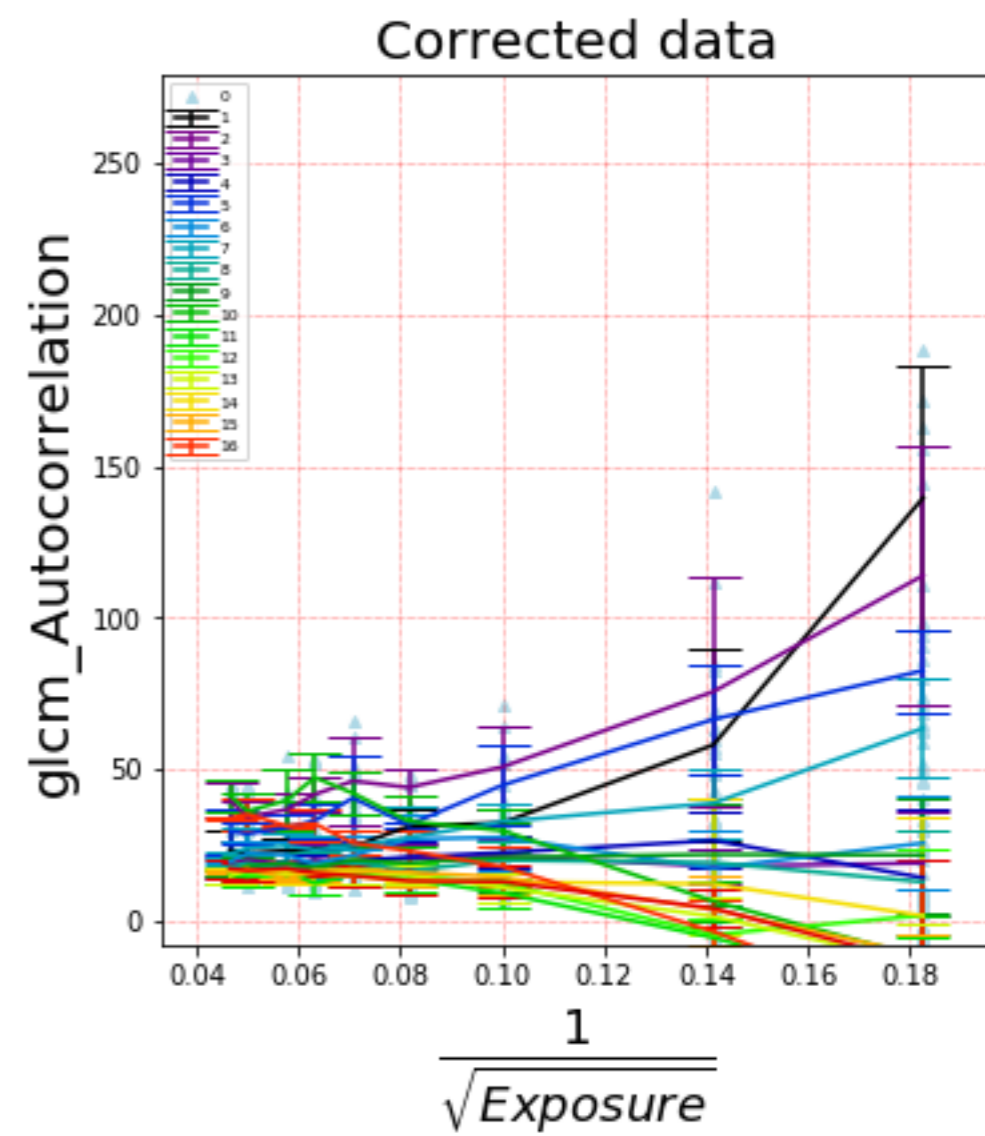
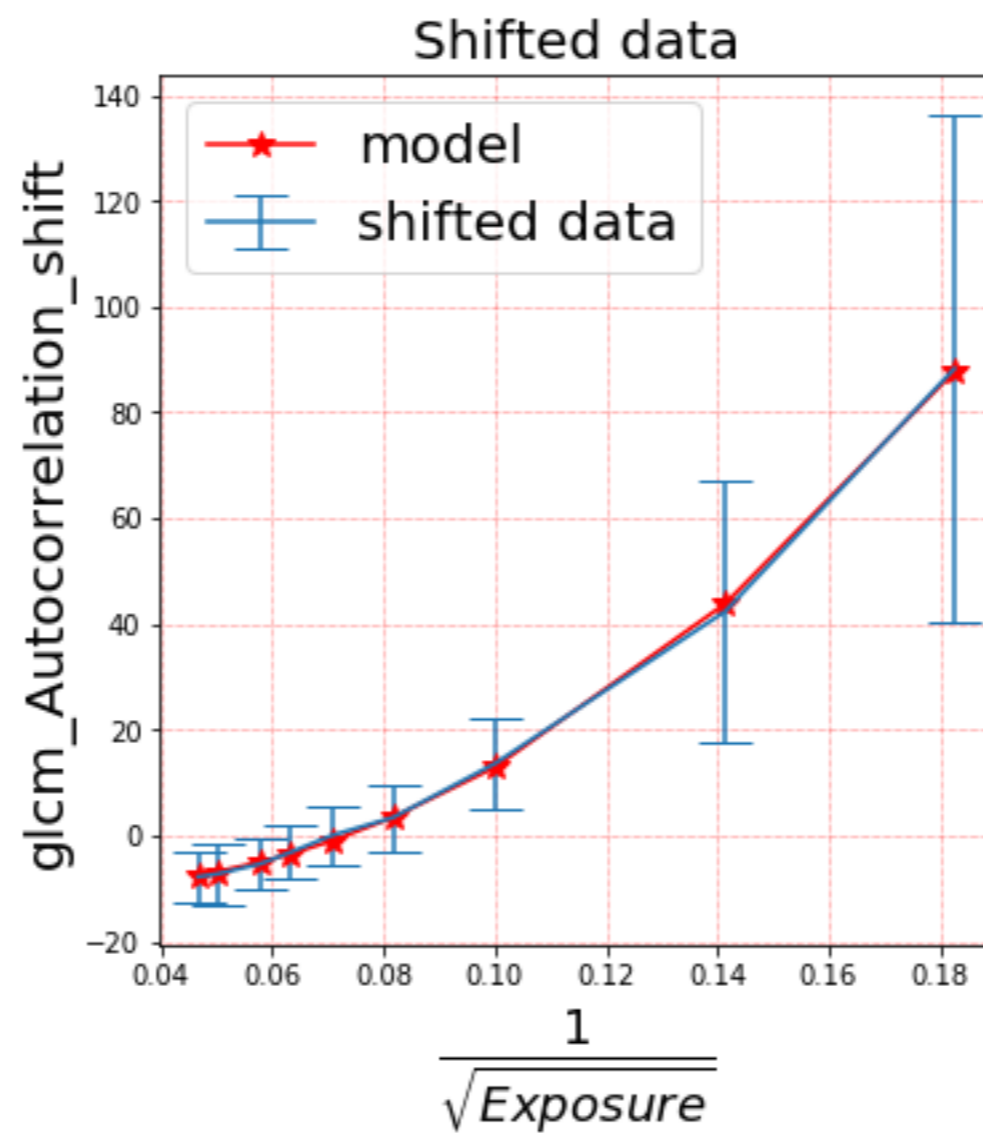
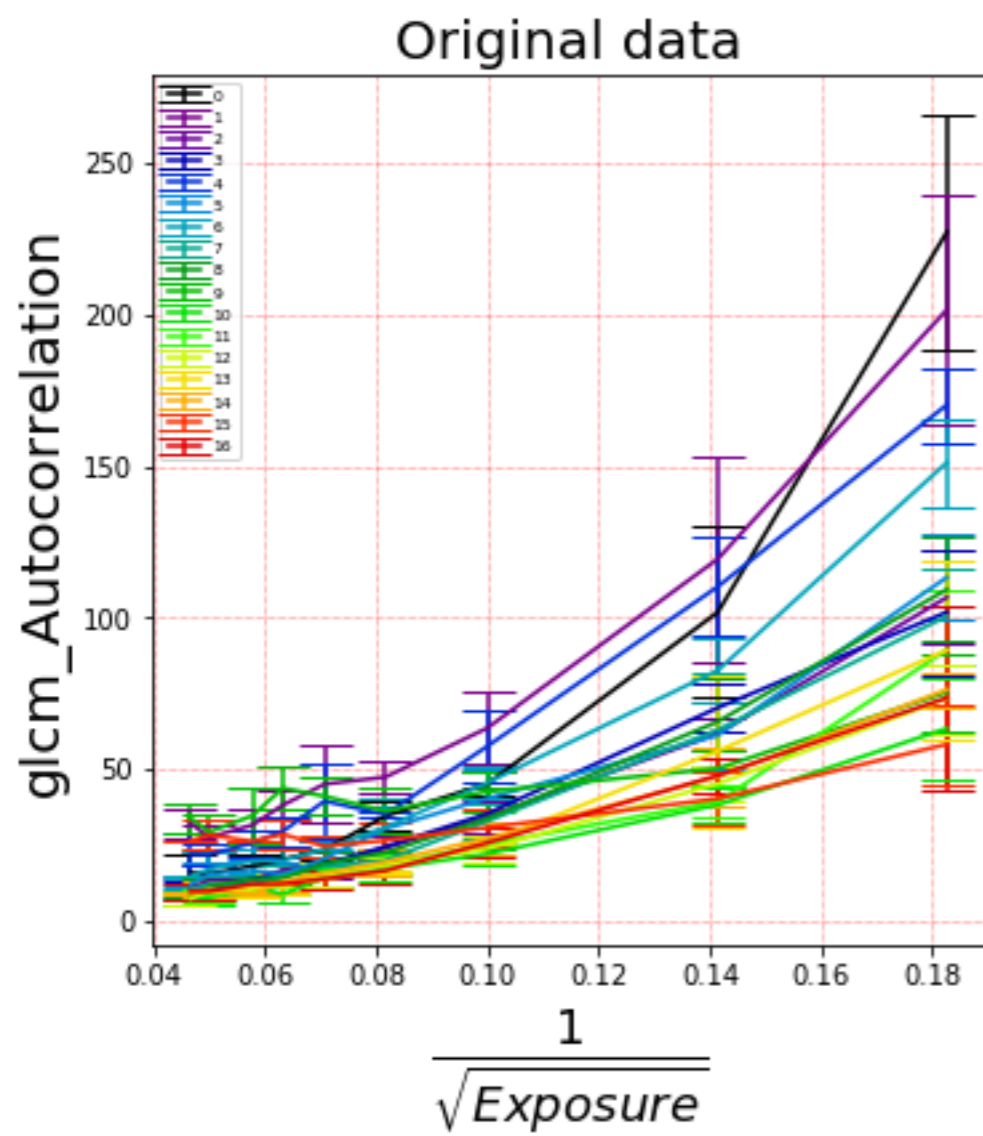




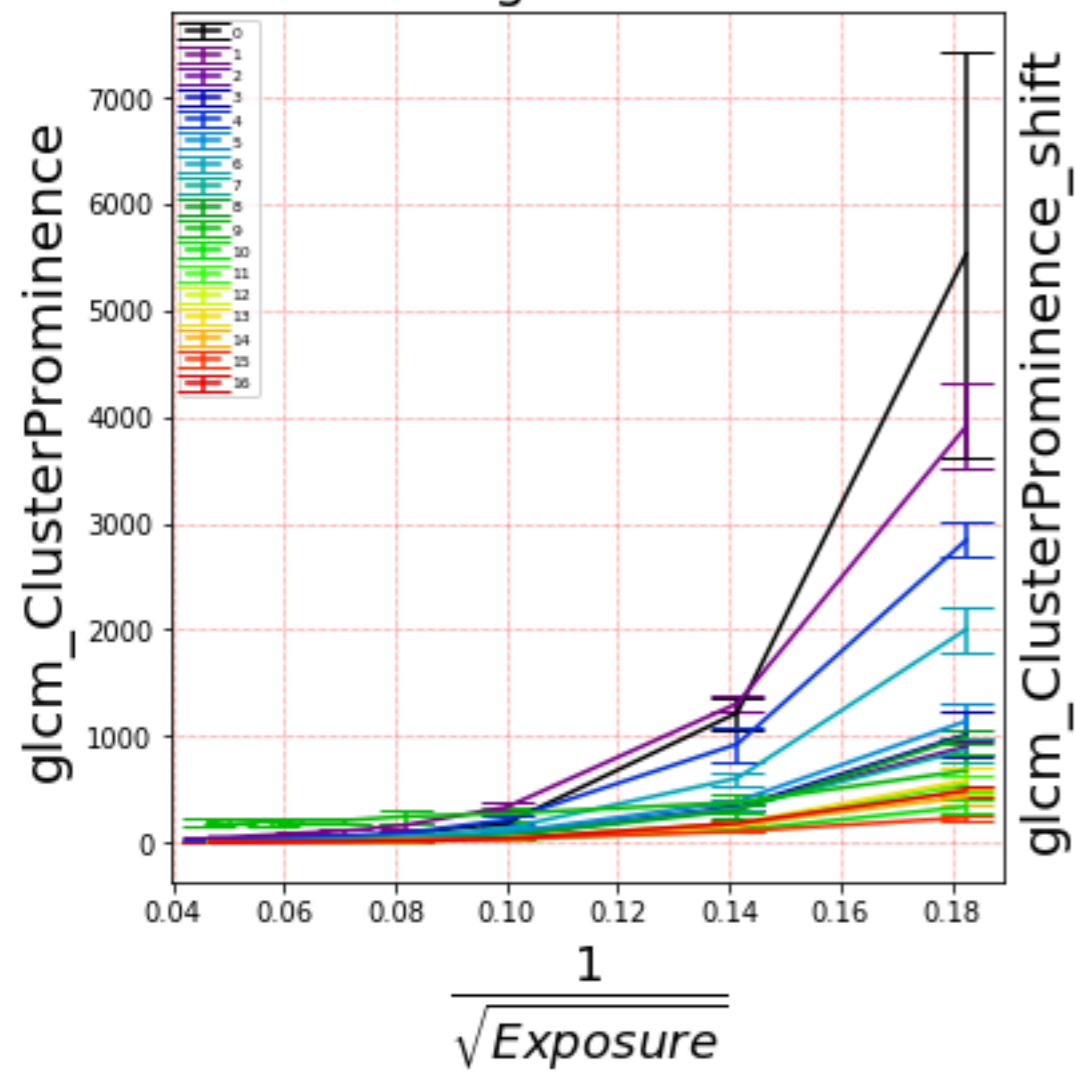




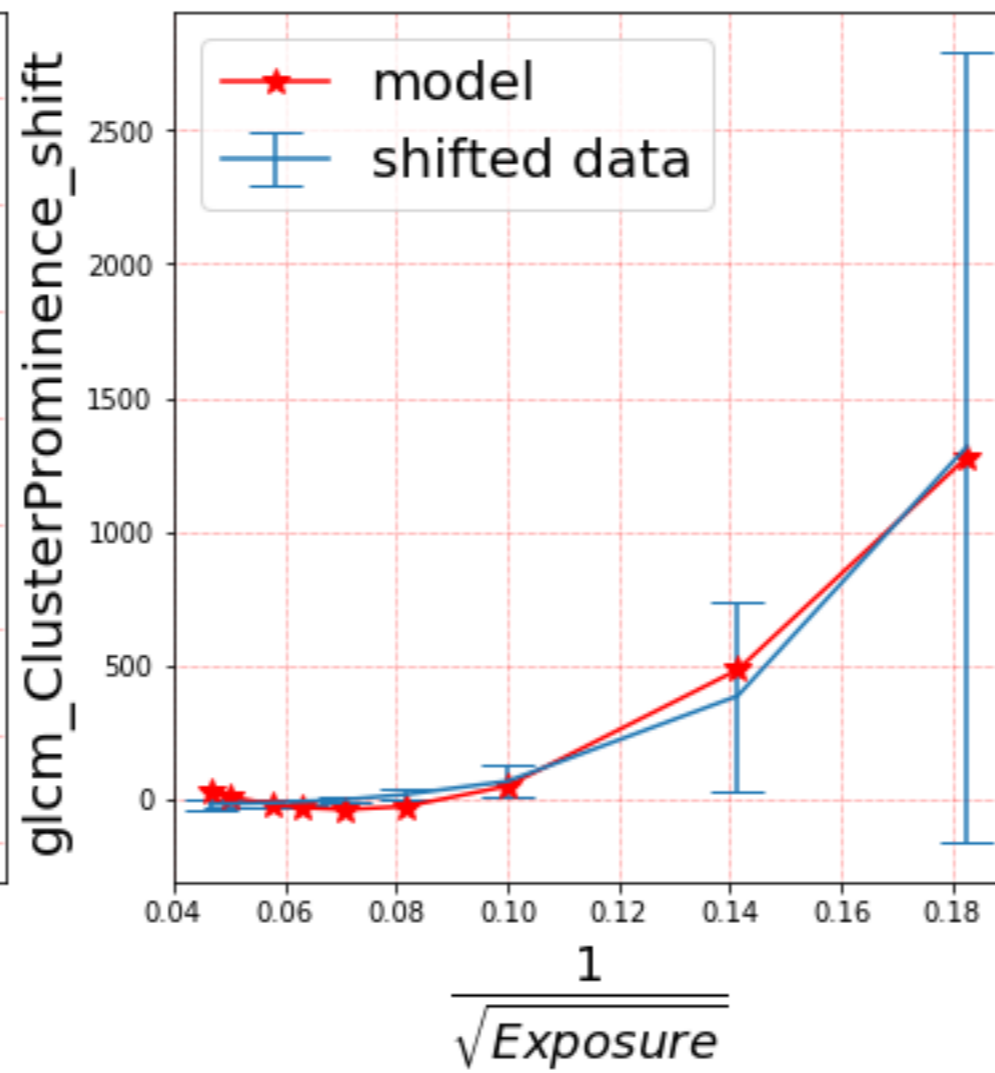




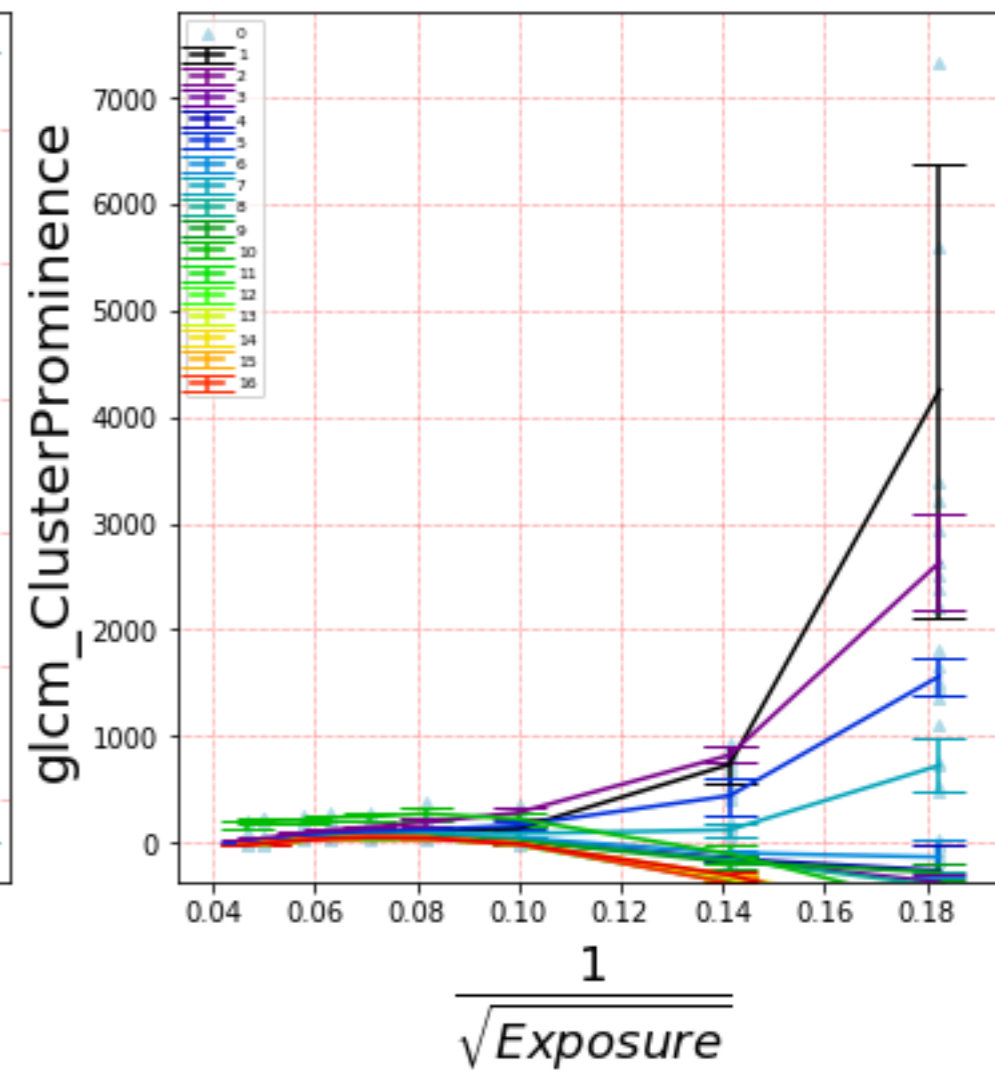
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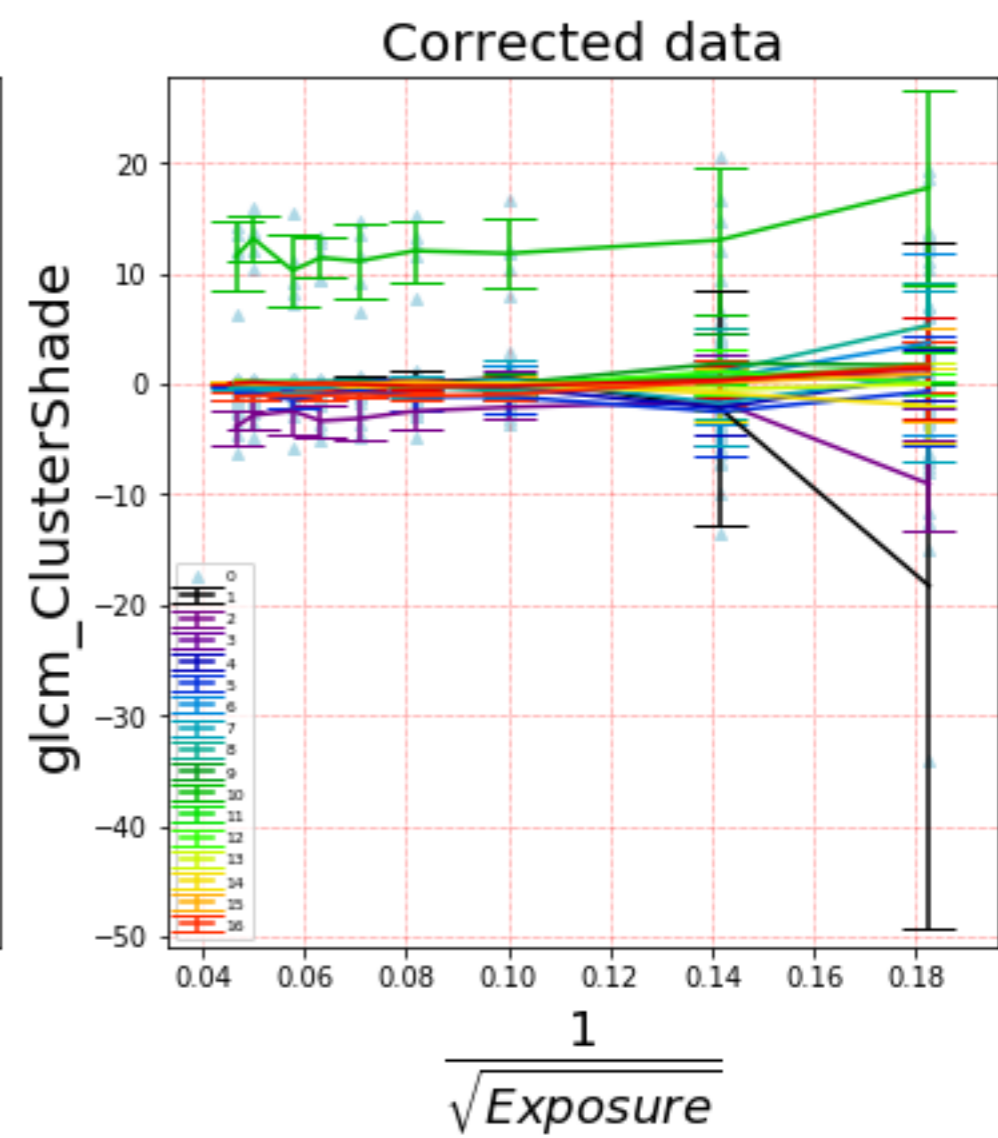
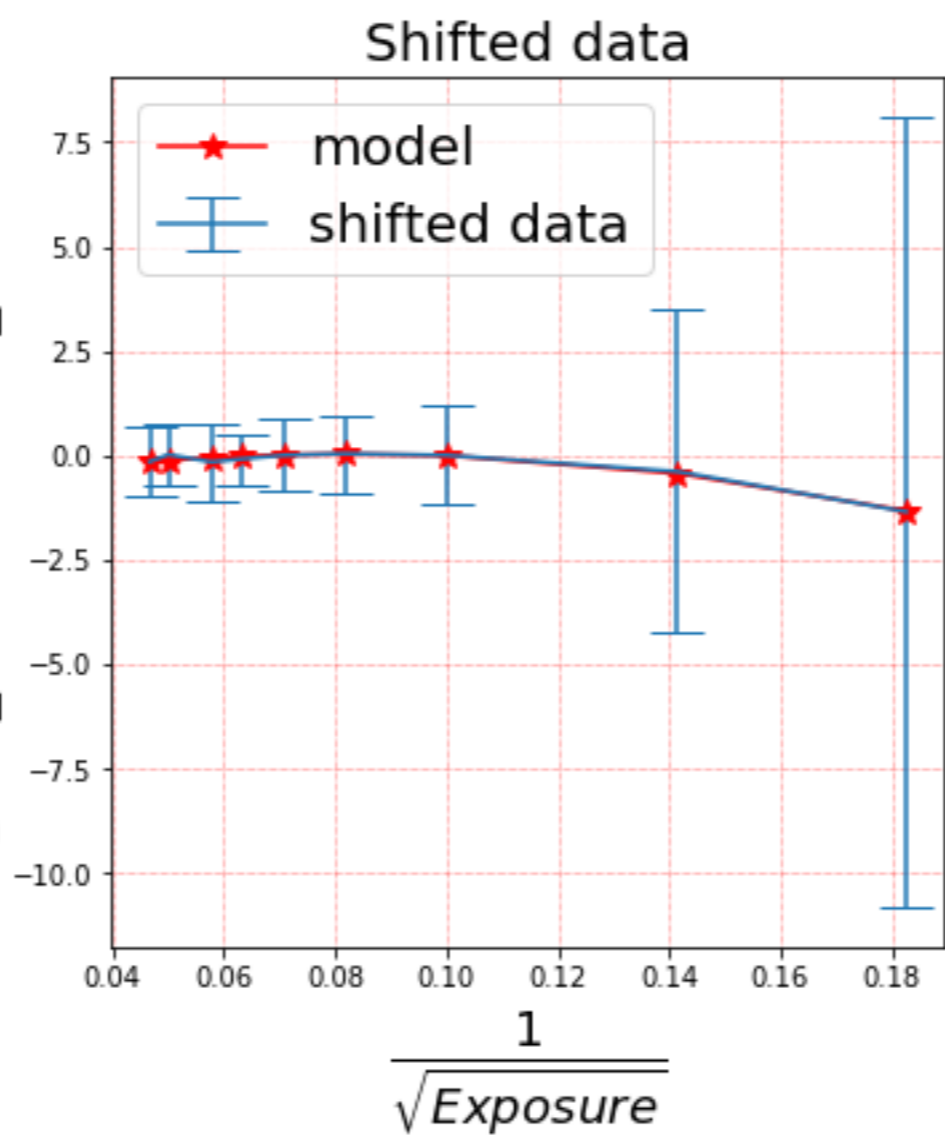
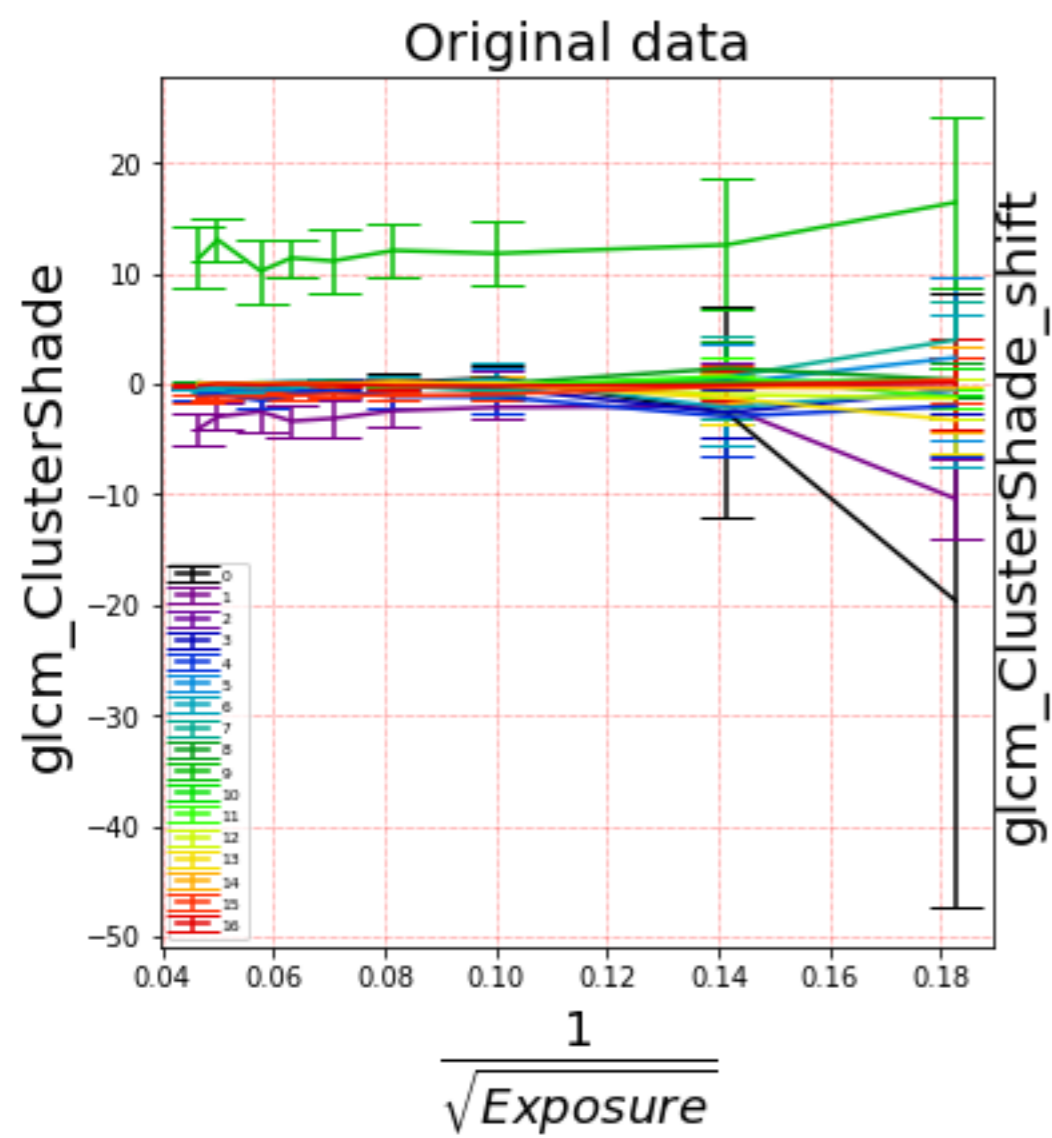


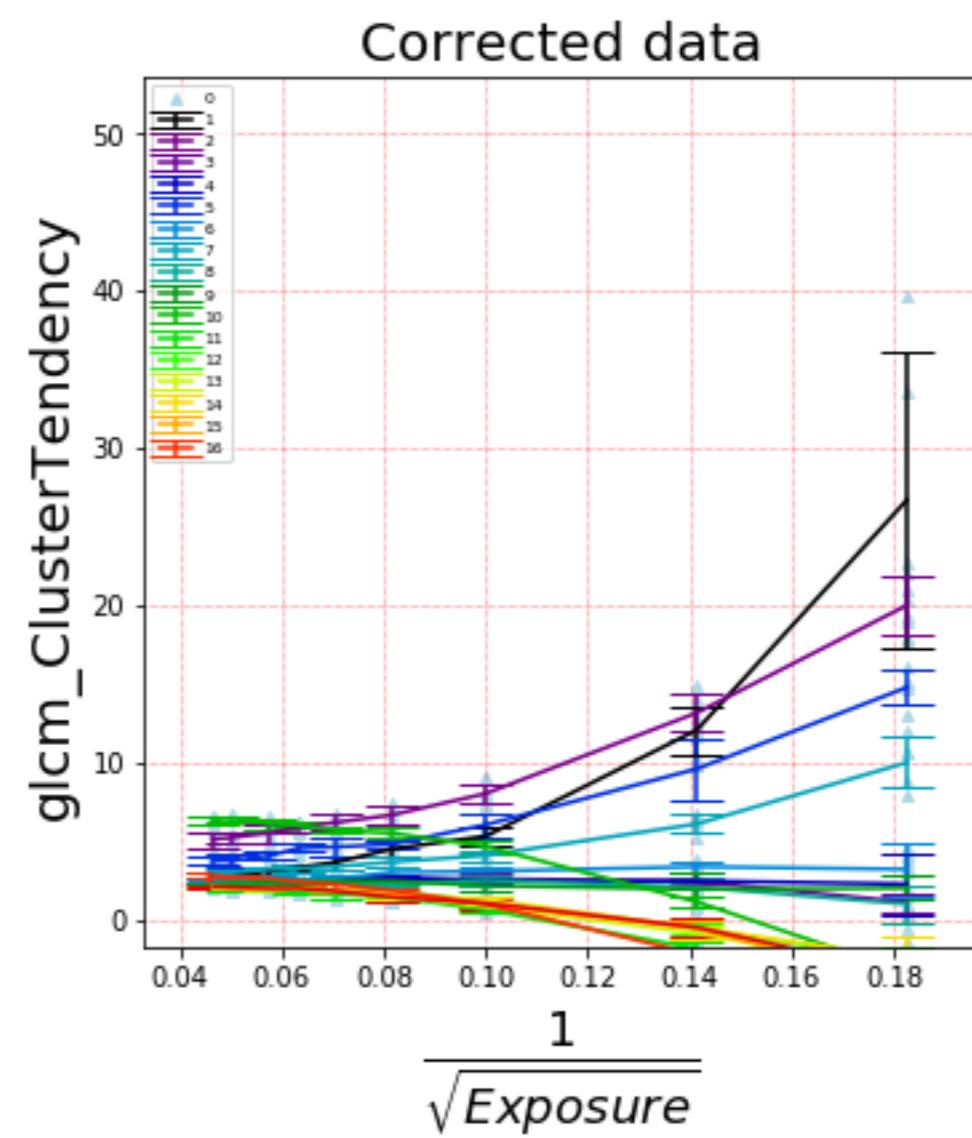
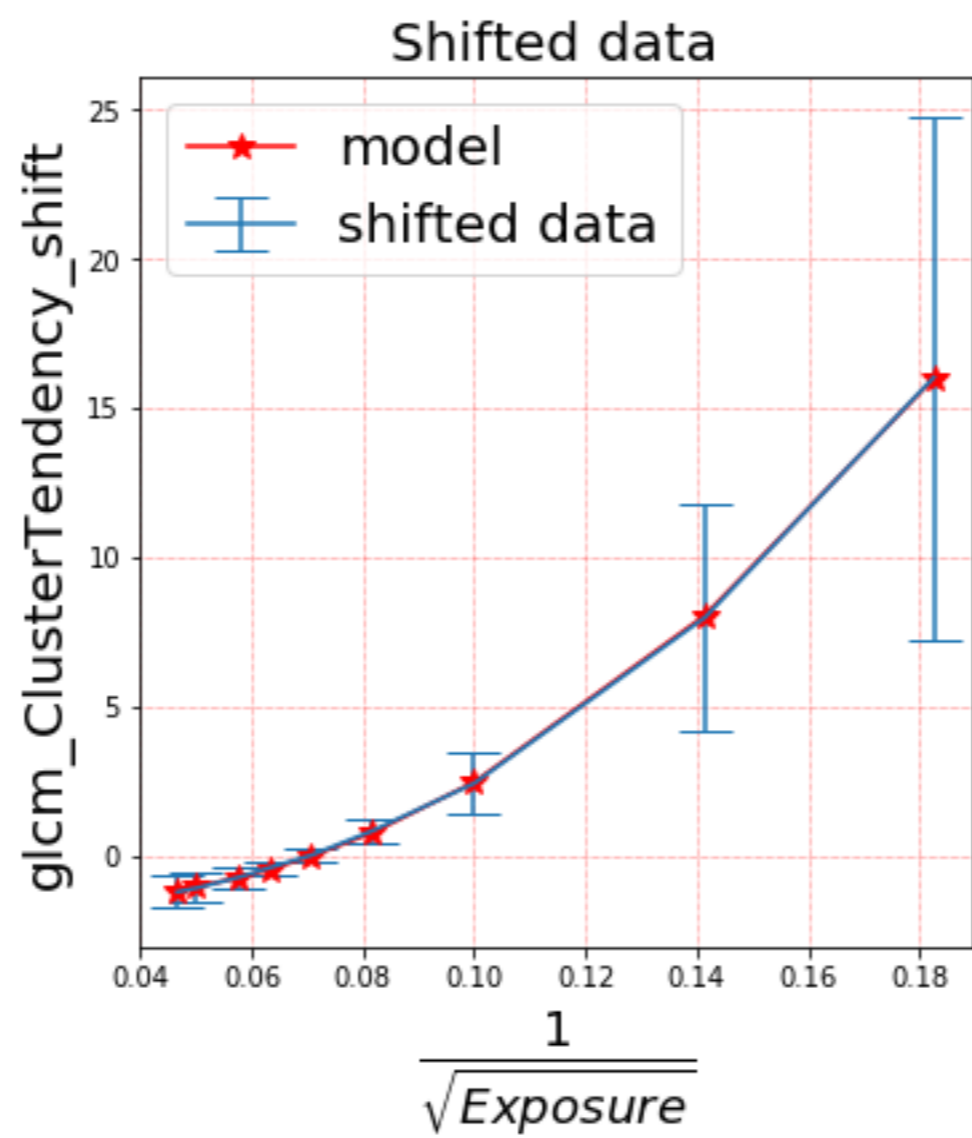
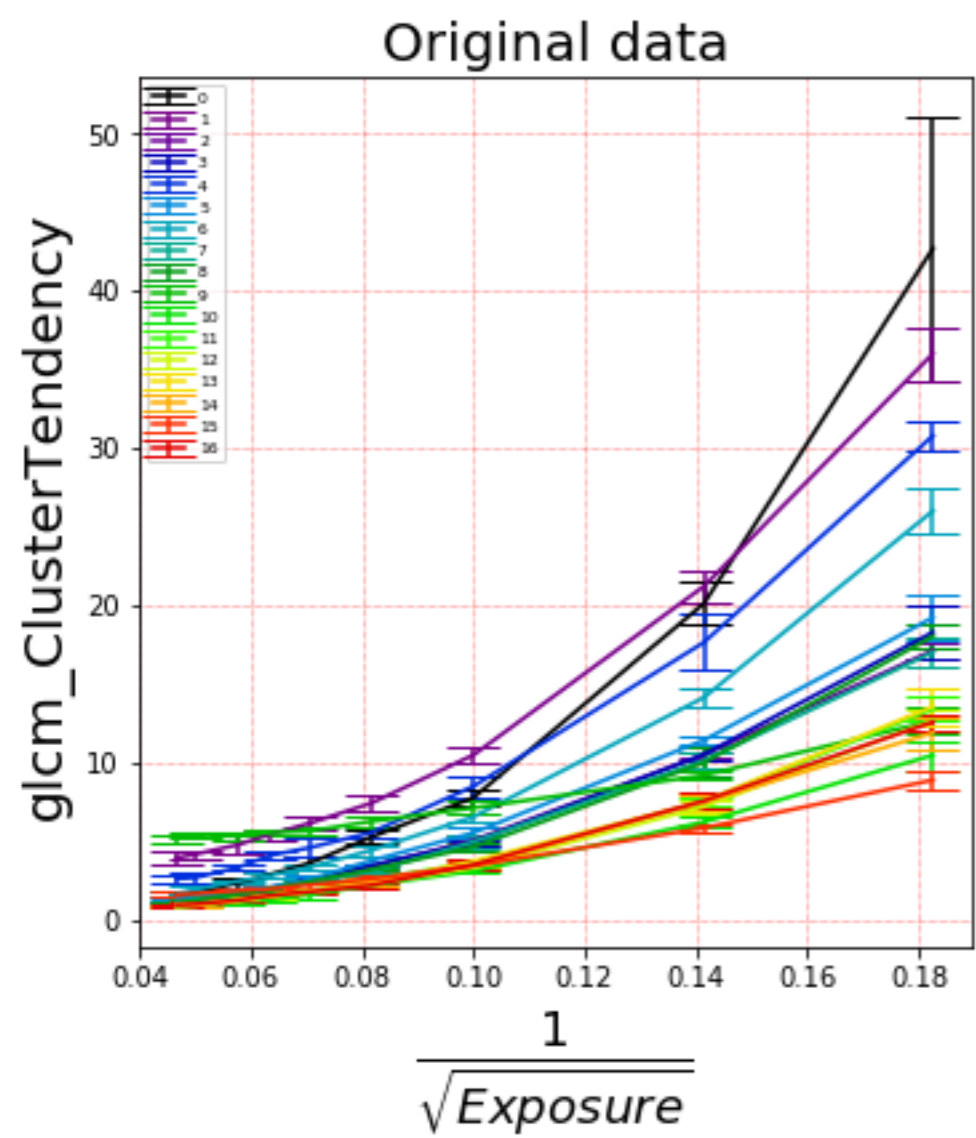
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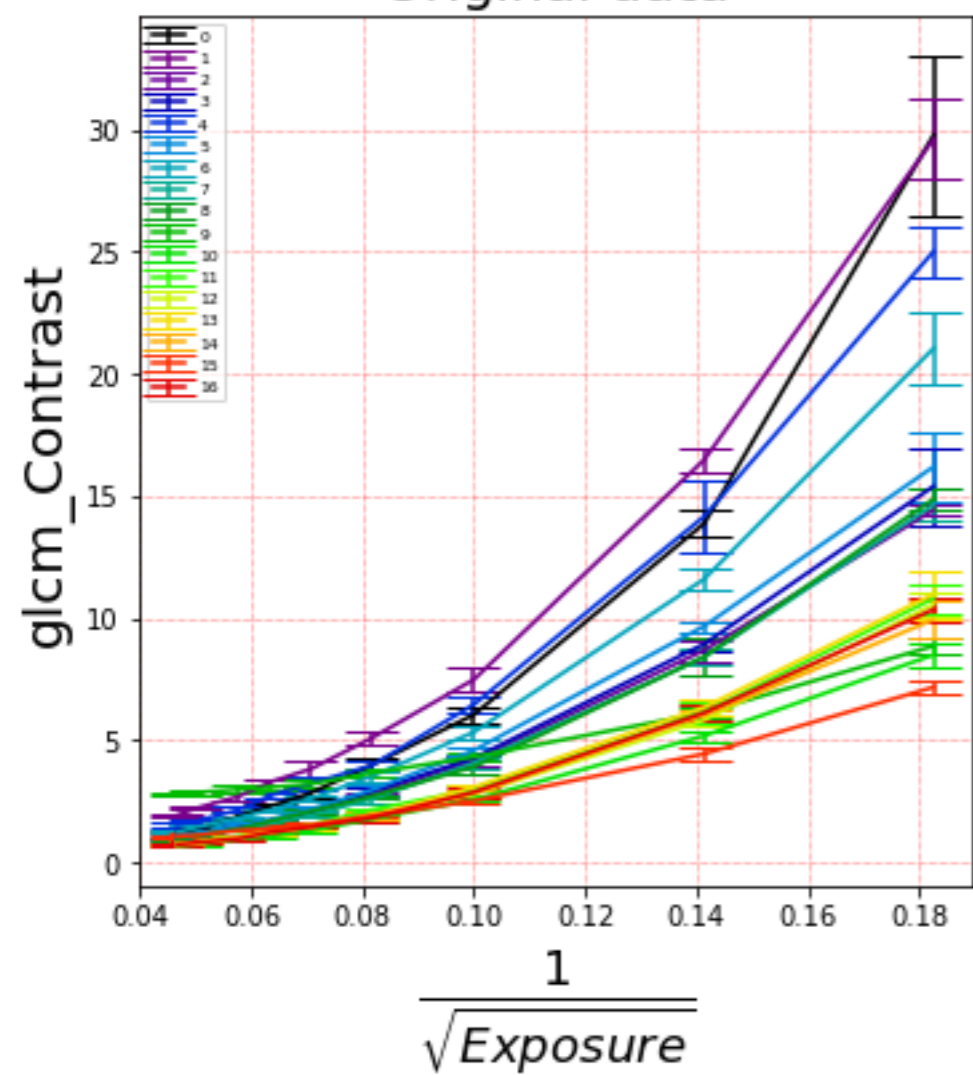
Corrected data



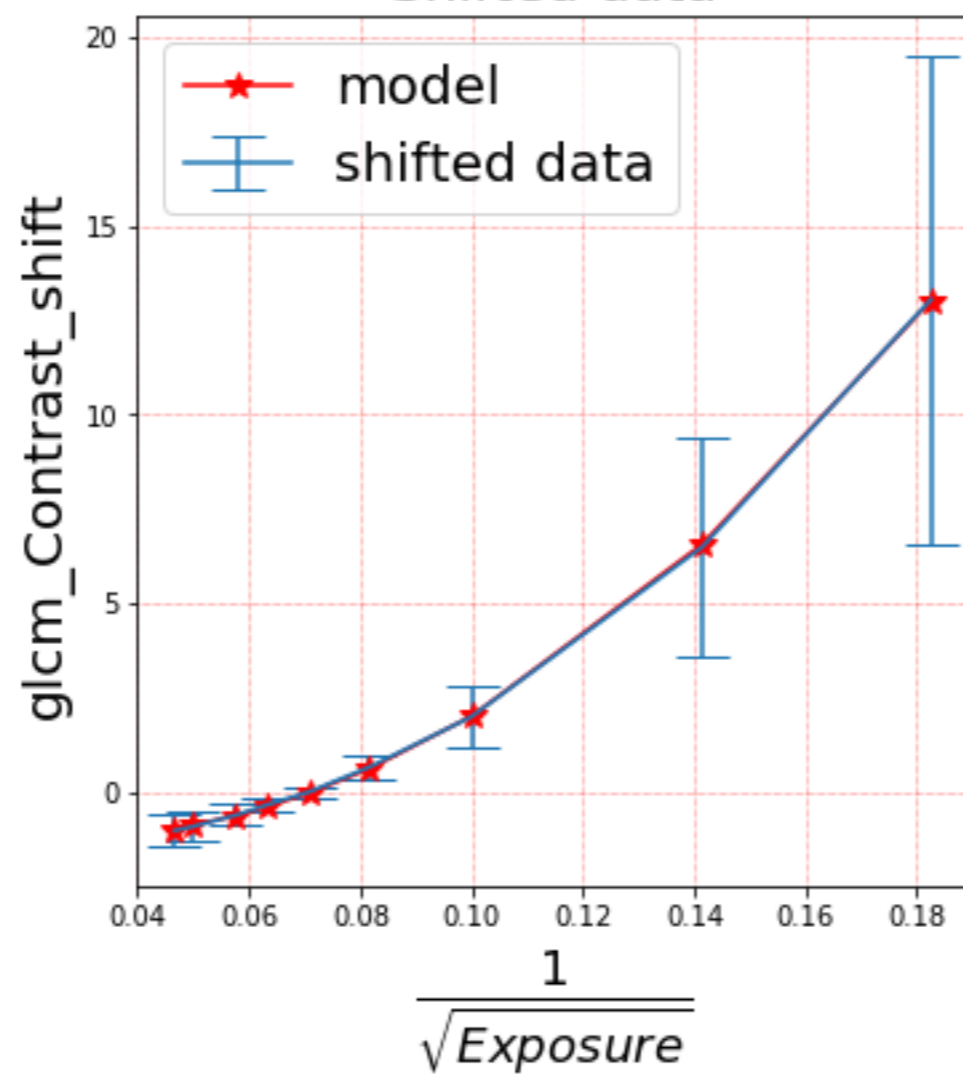




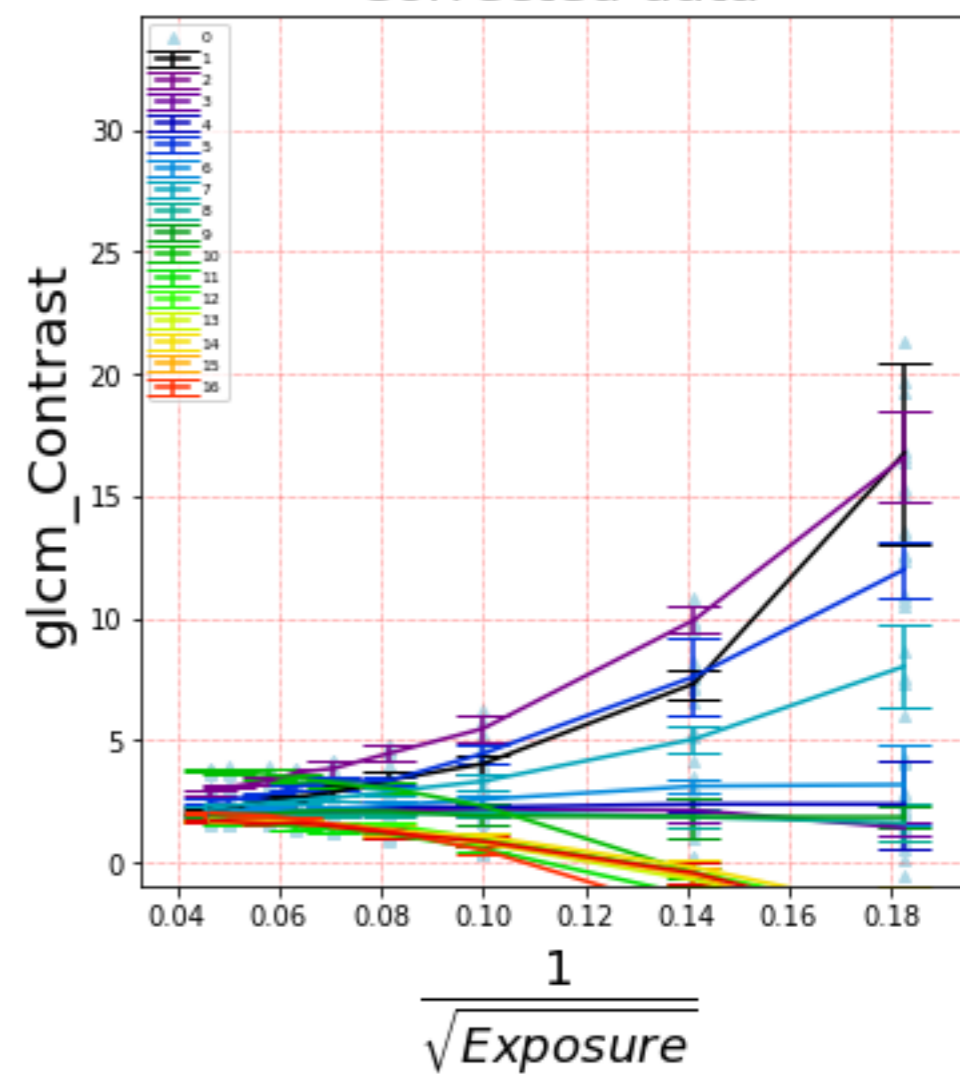
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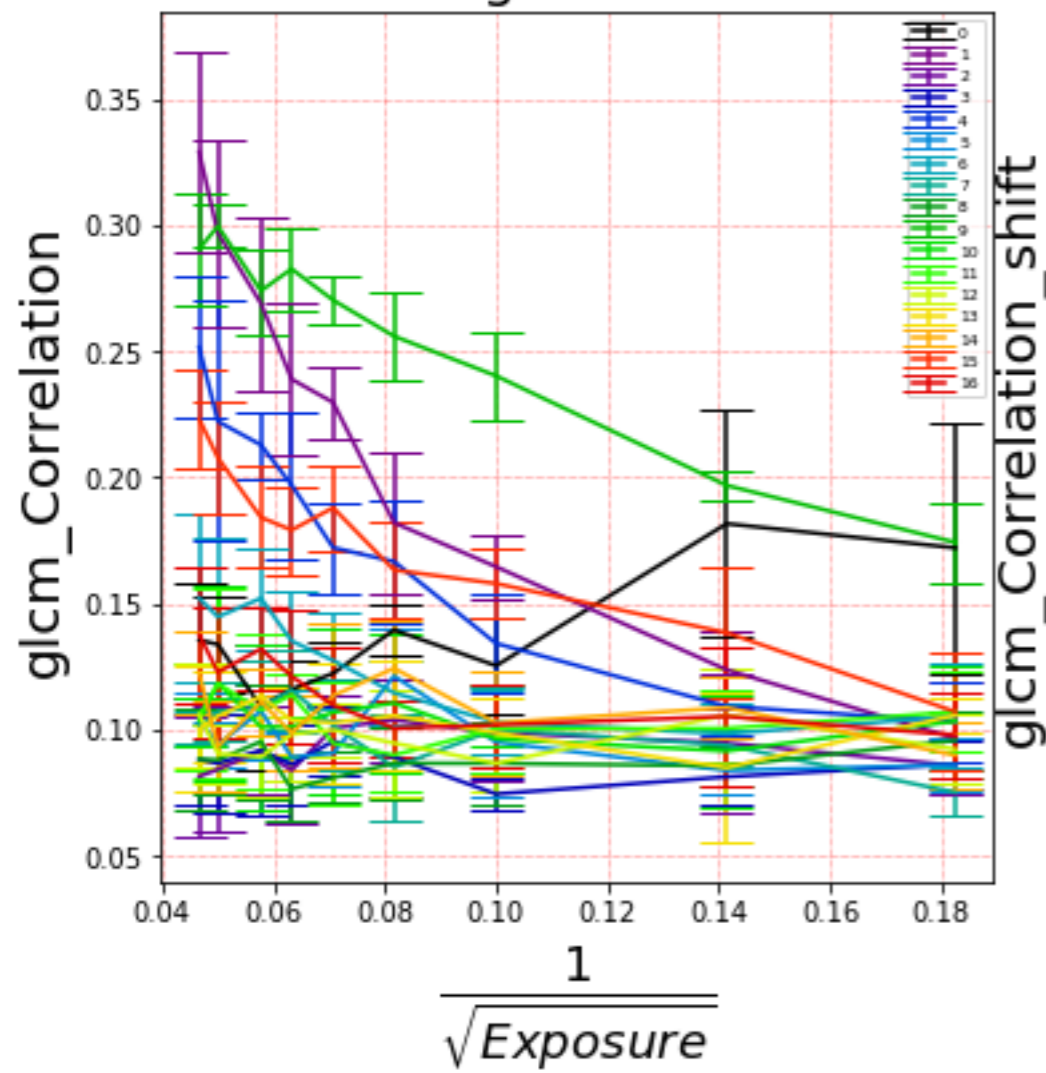
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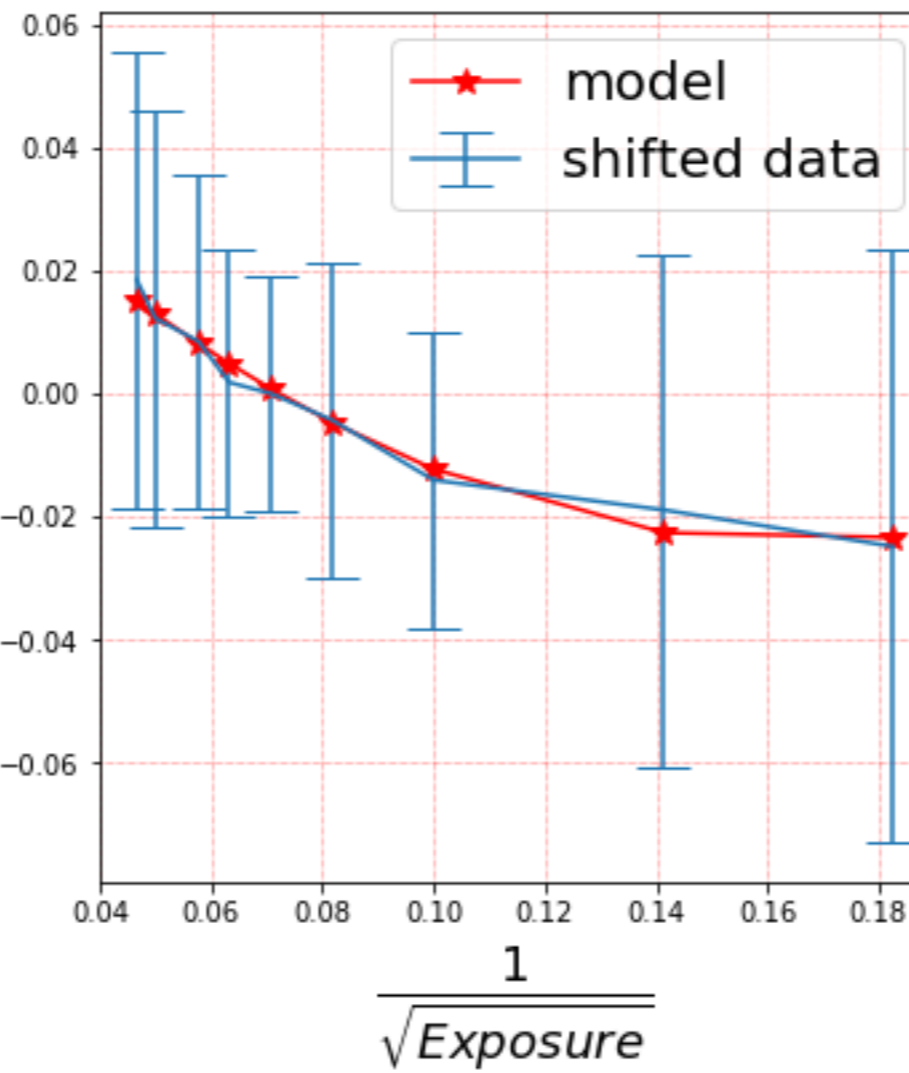
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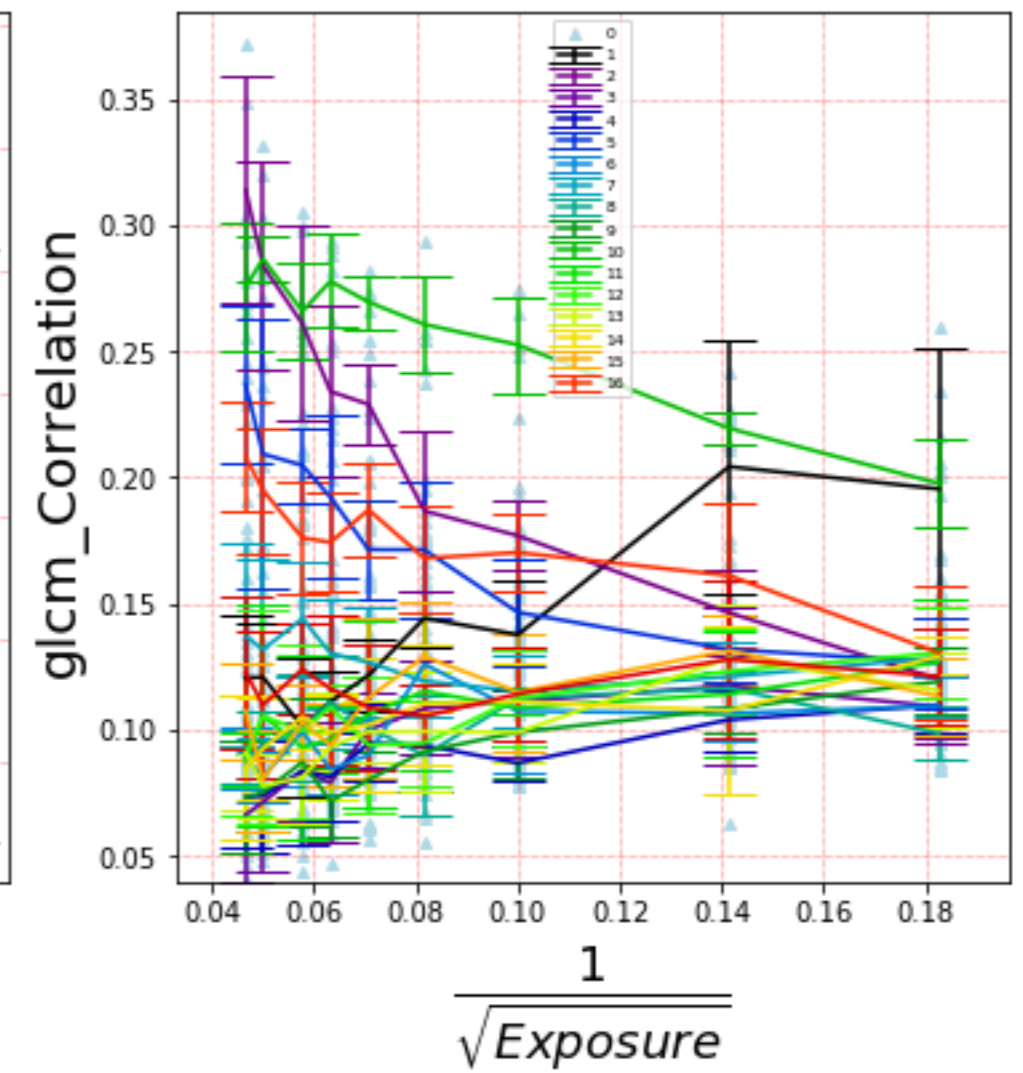
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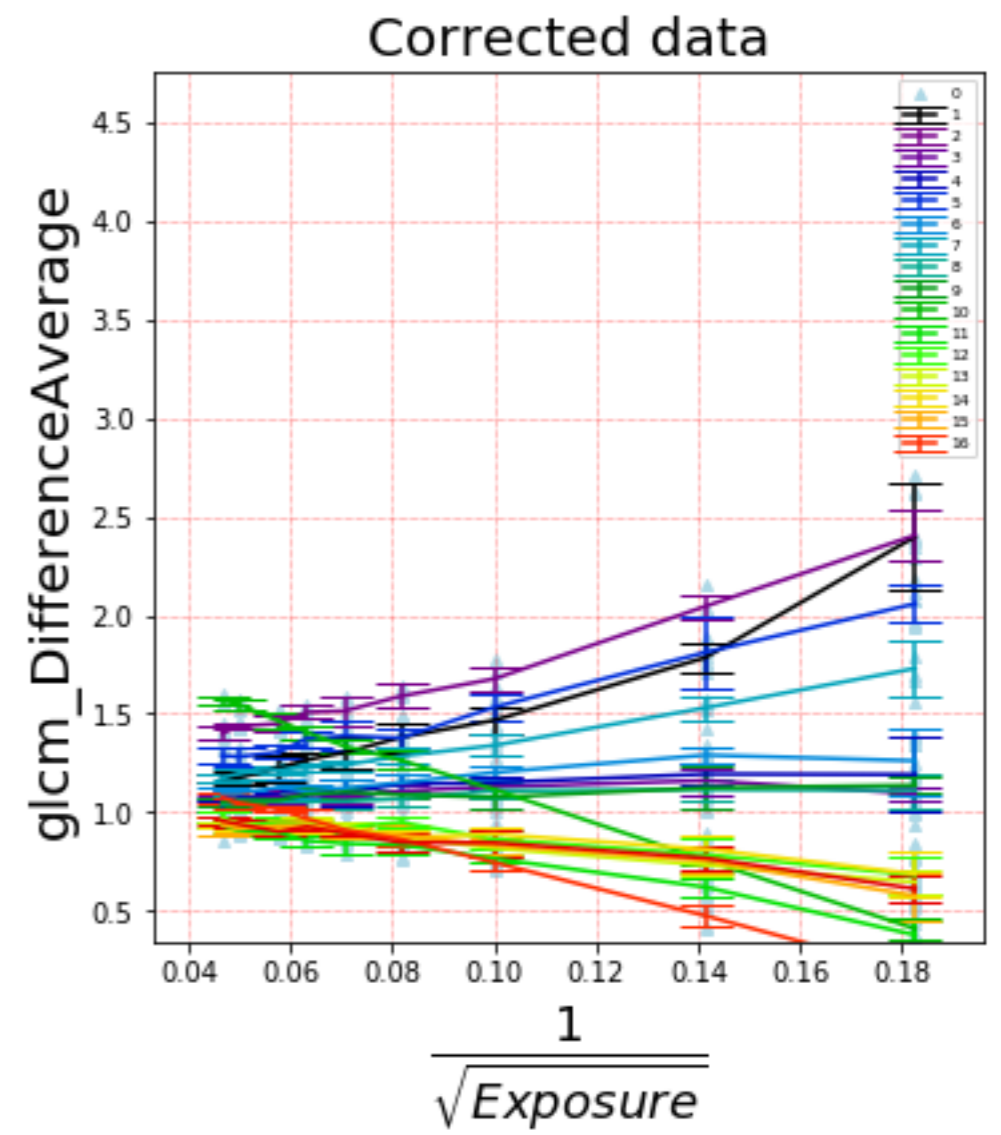
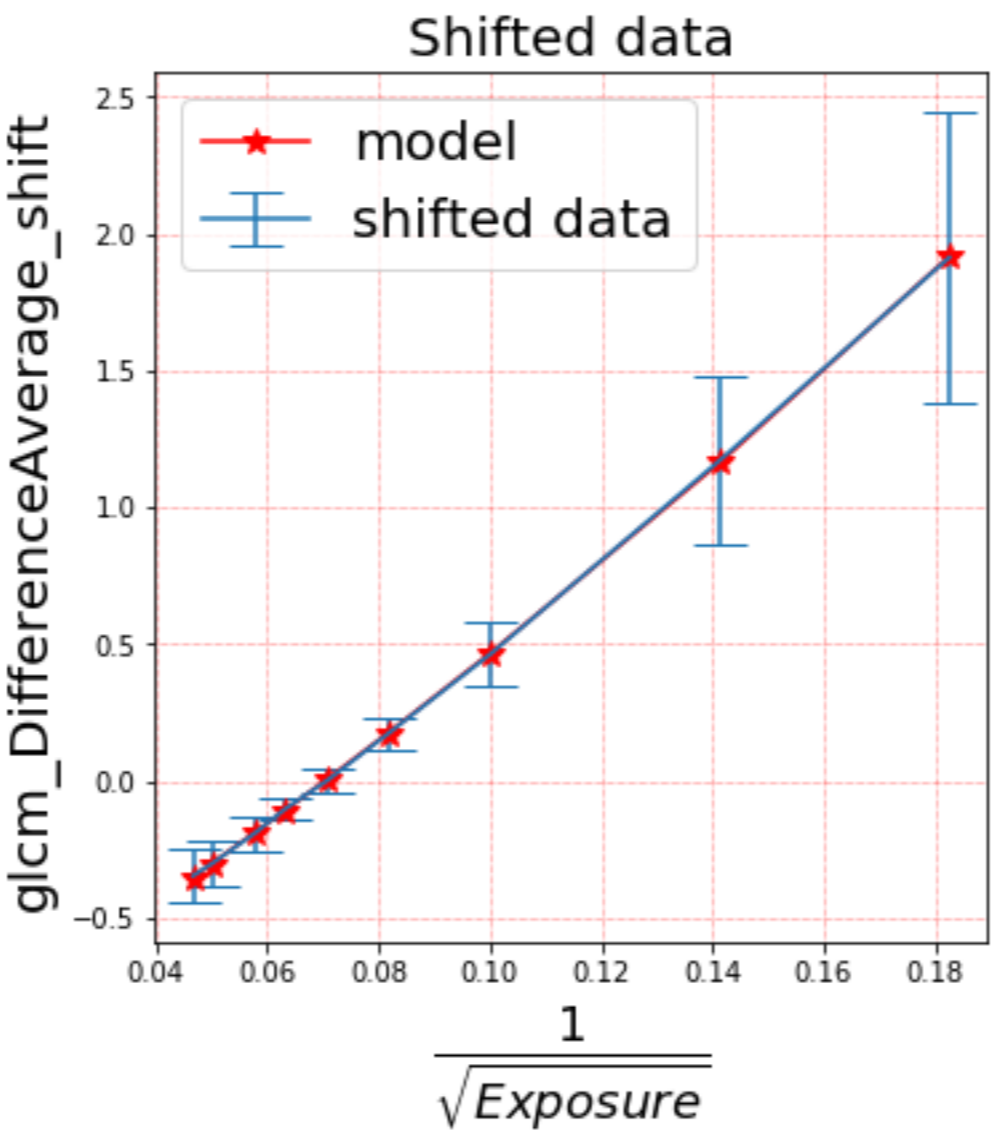
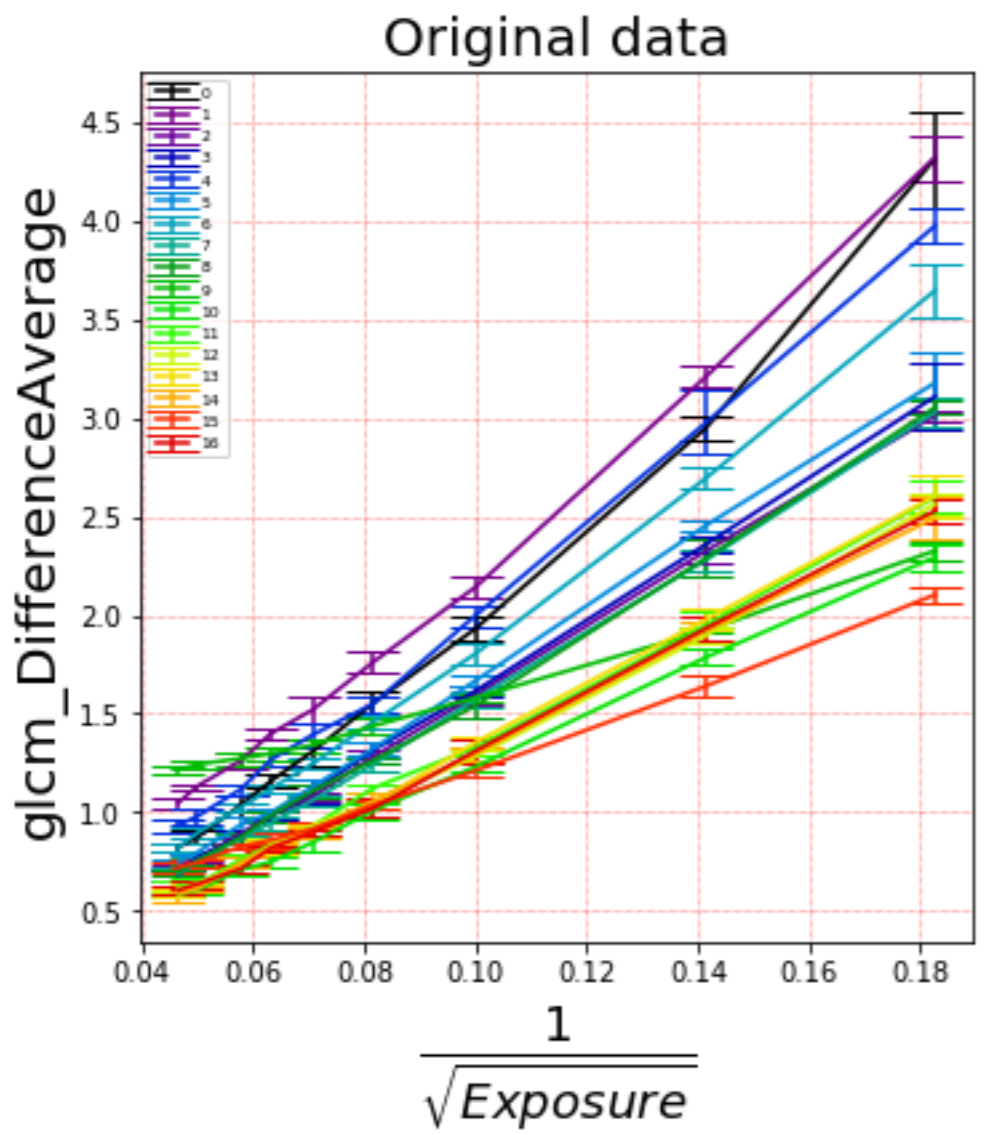


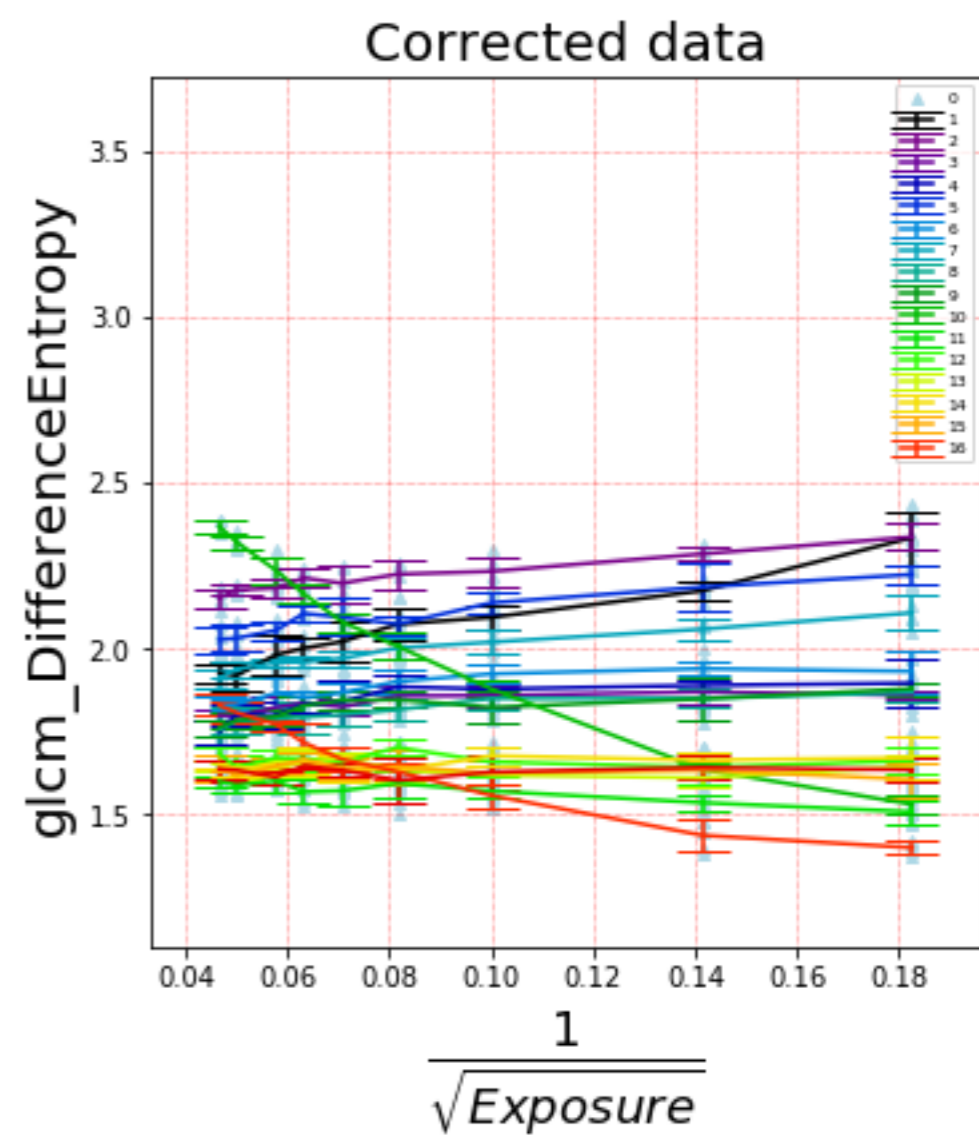
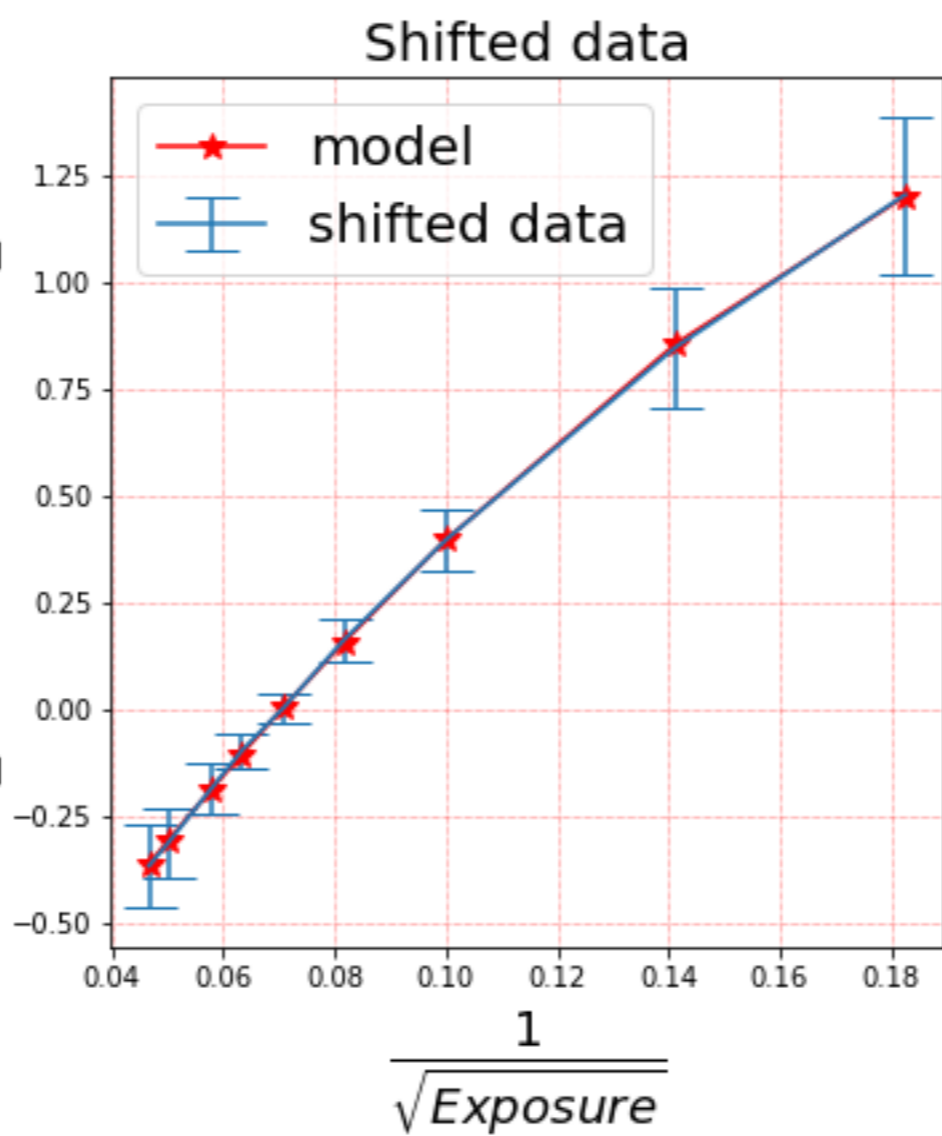
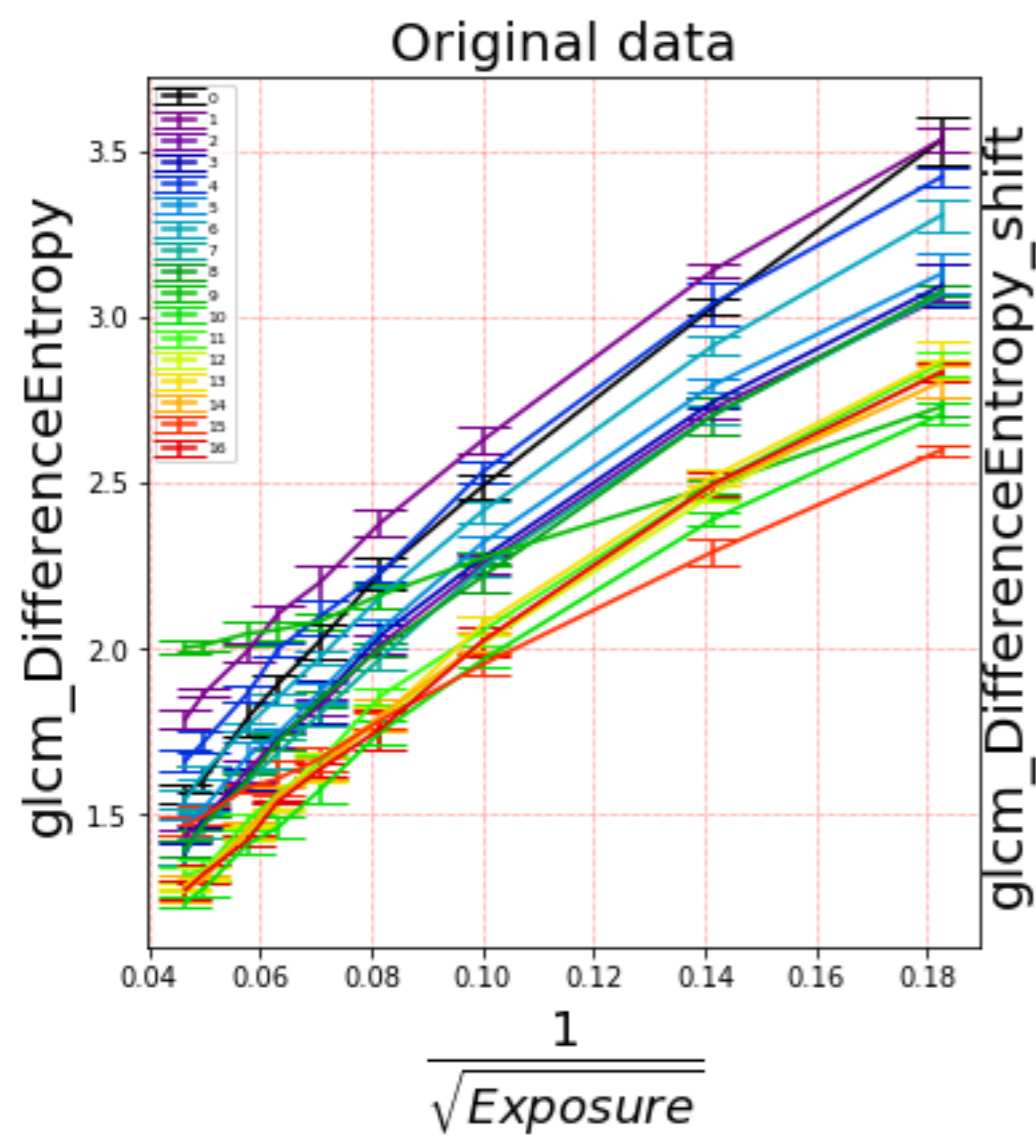
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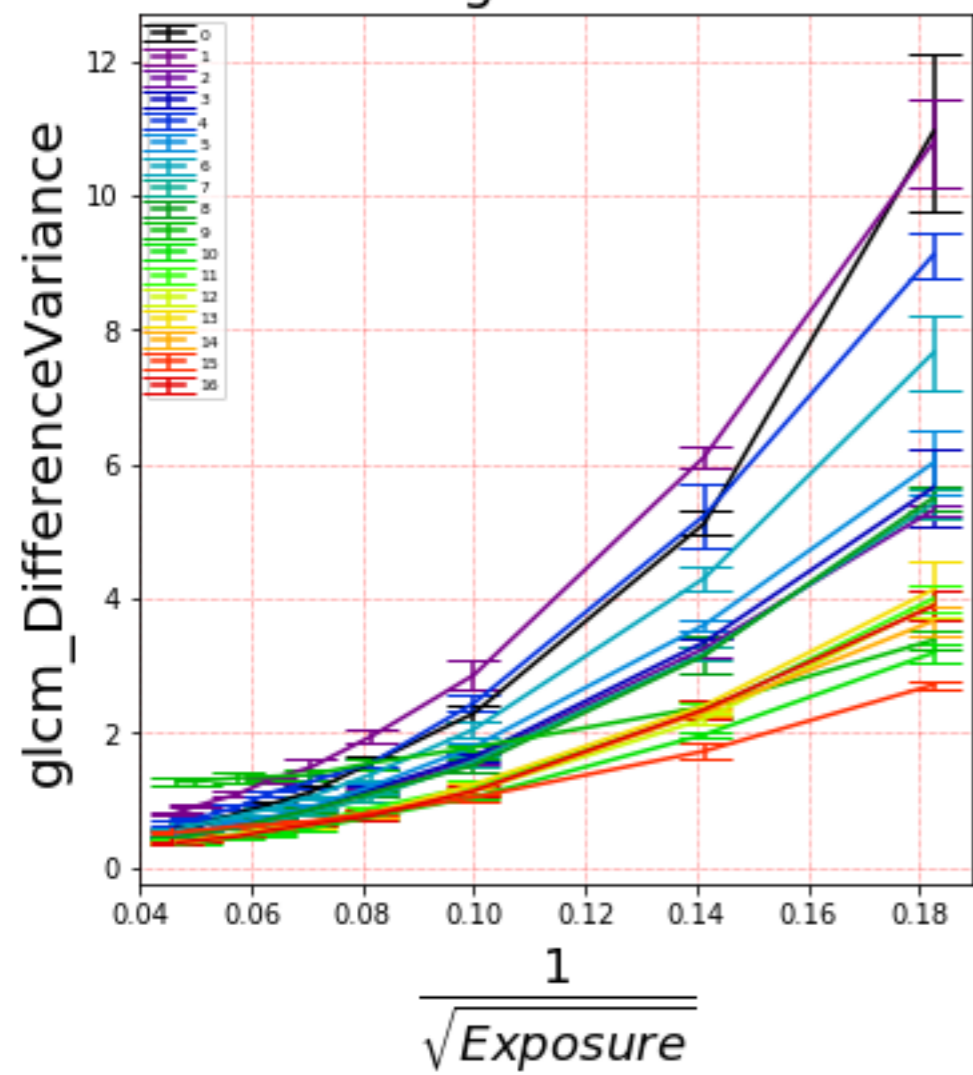
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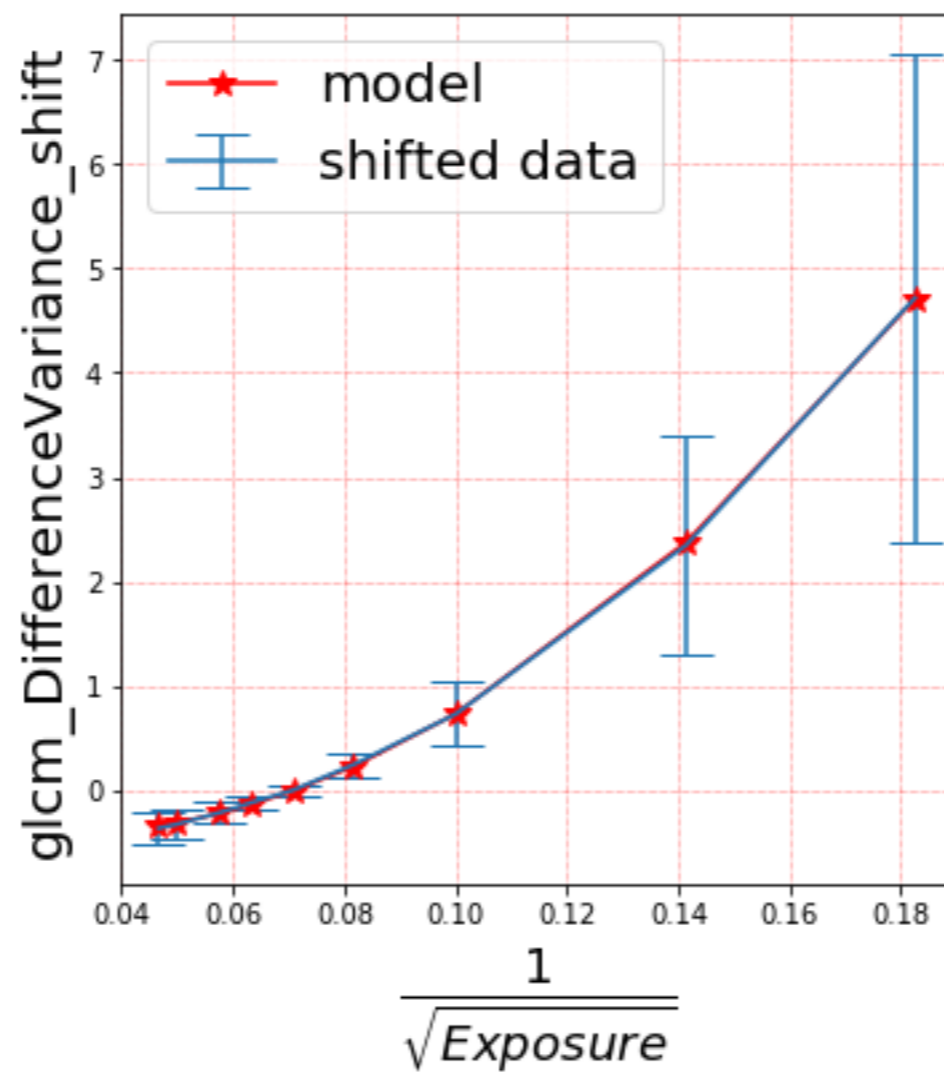




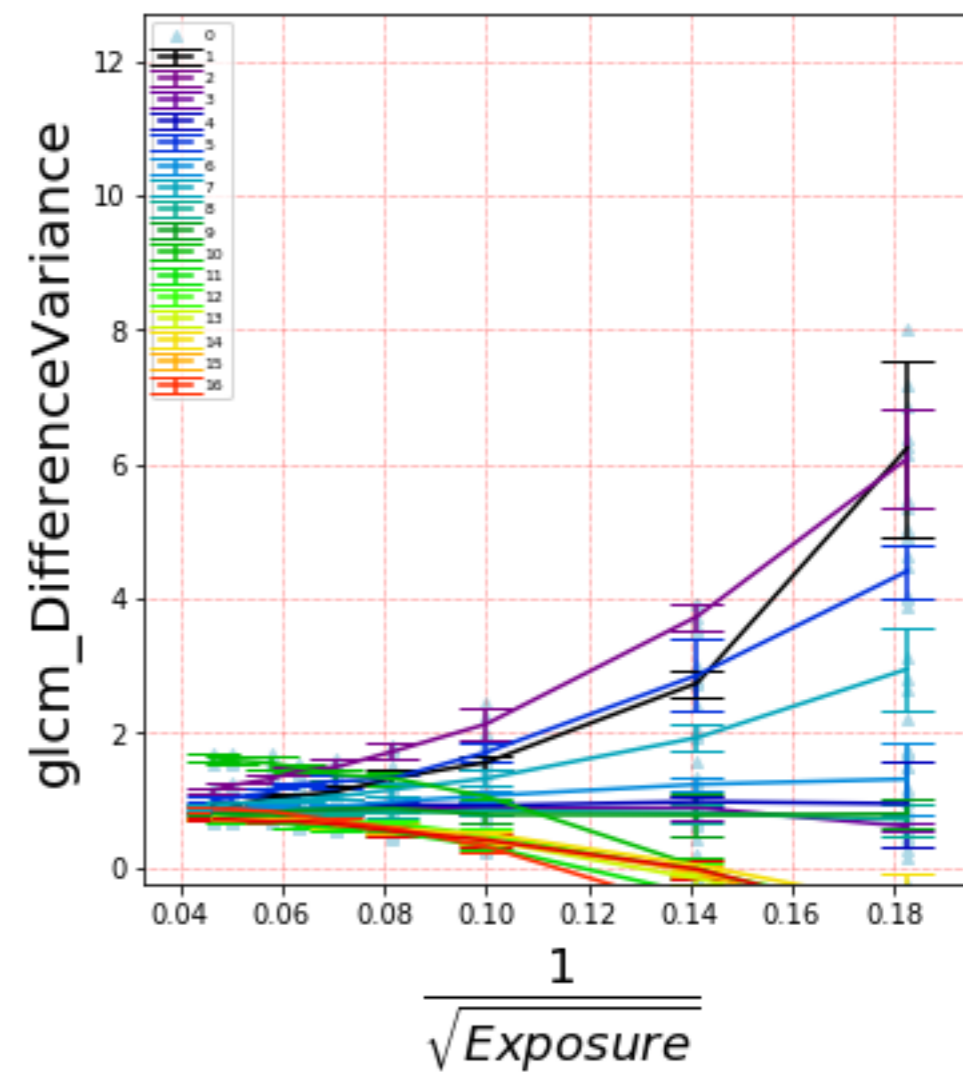
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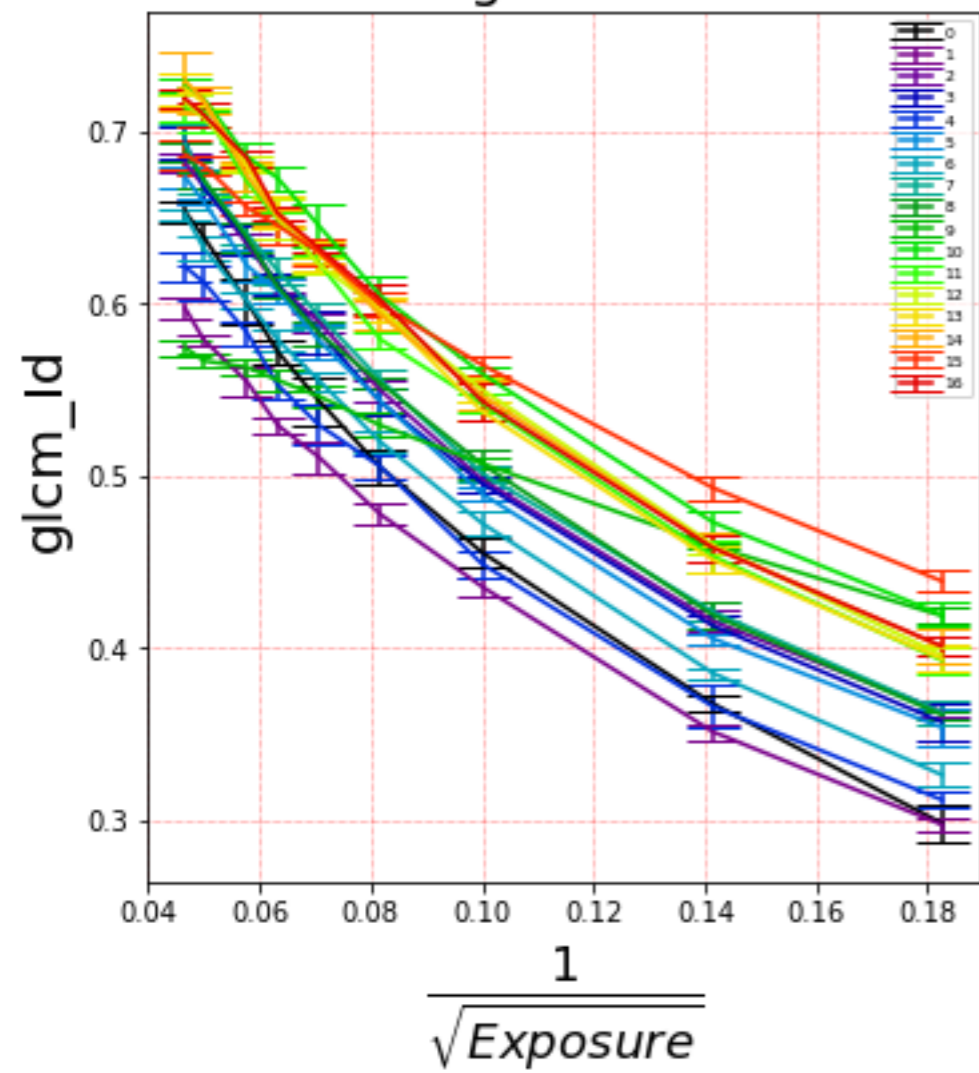
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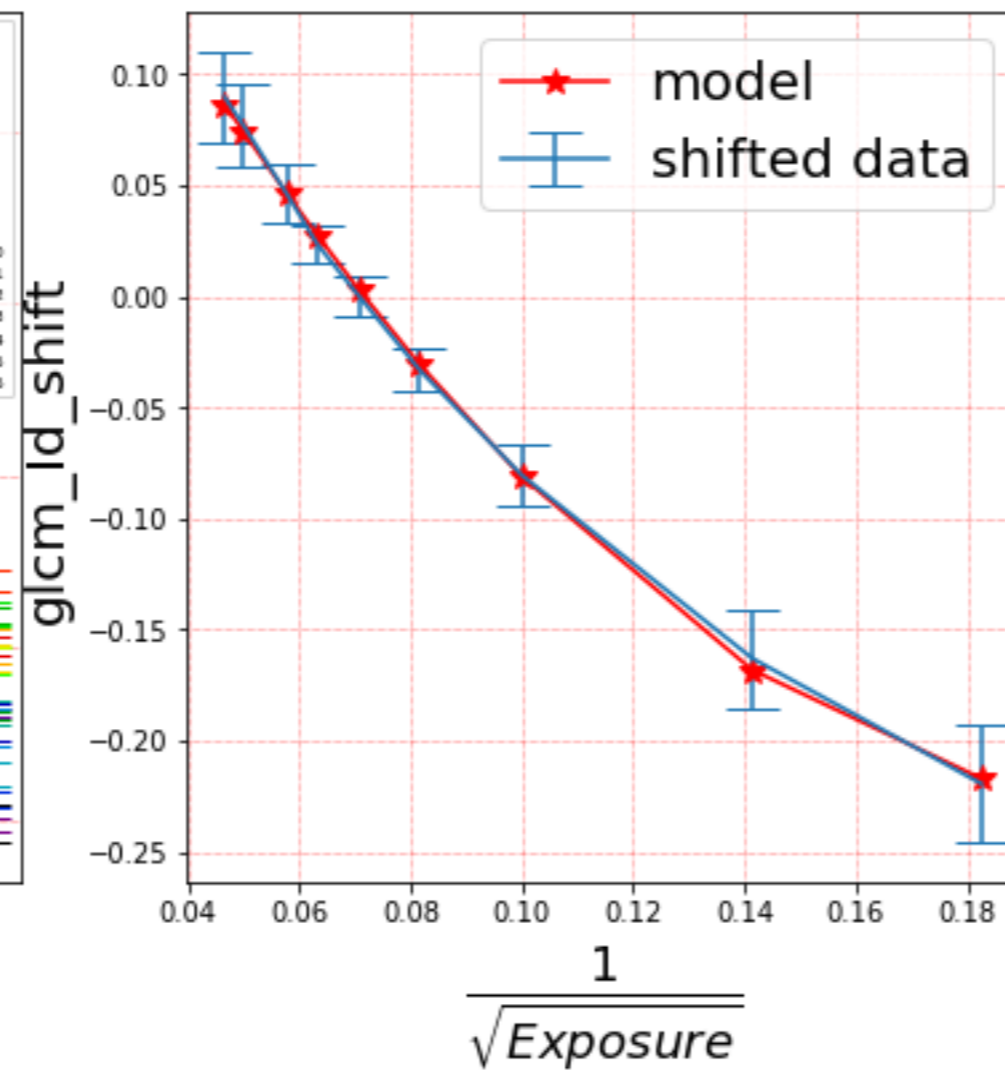
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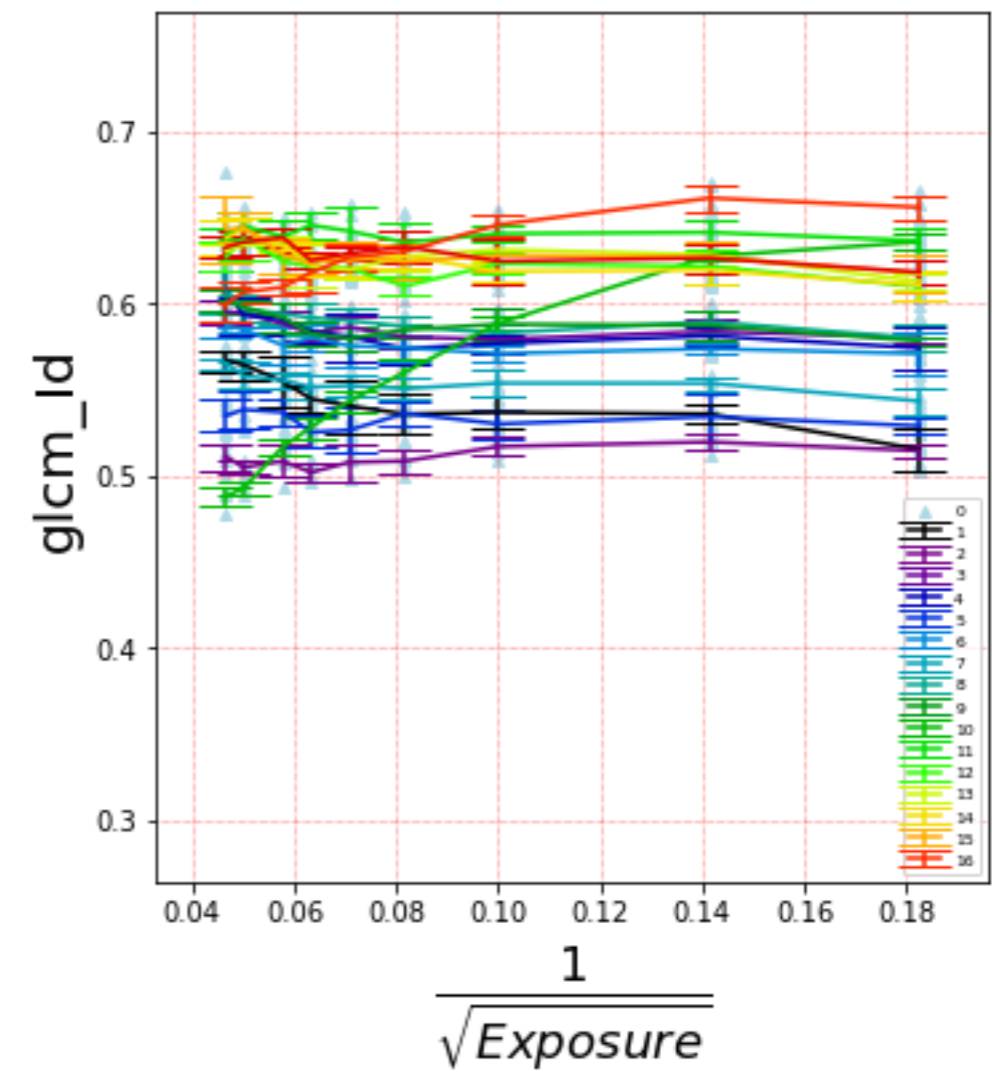
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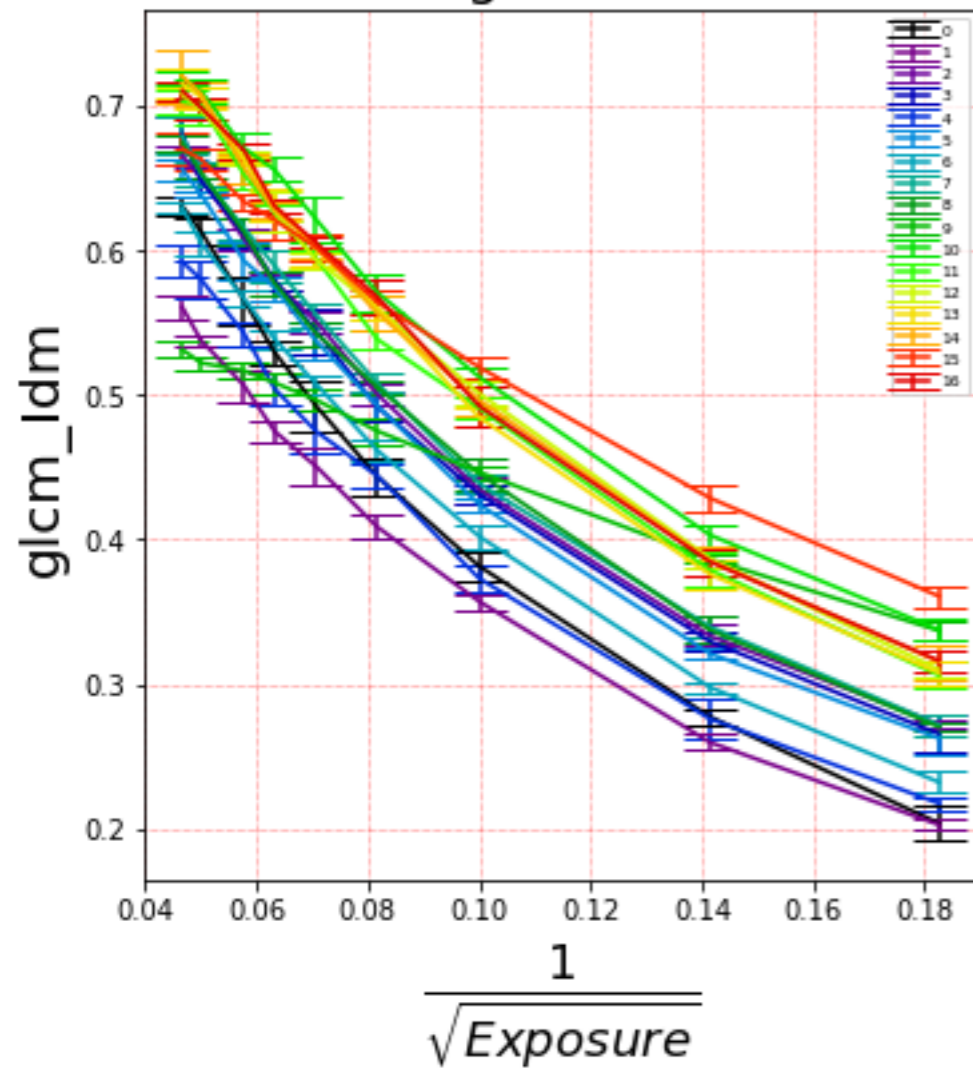
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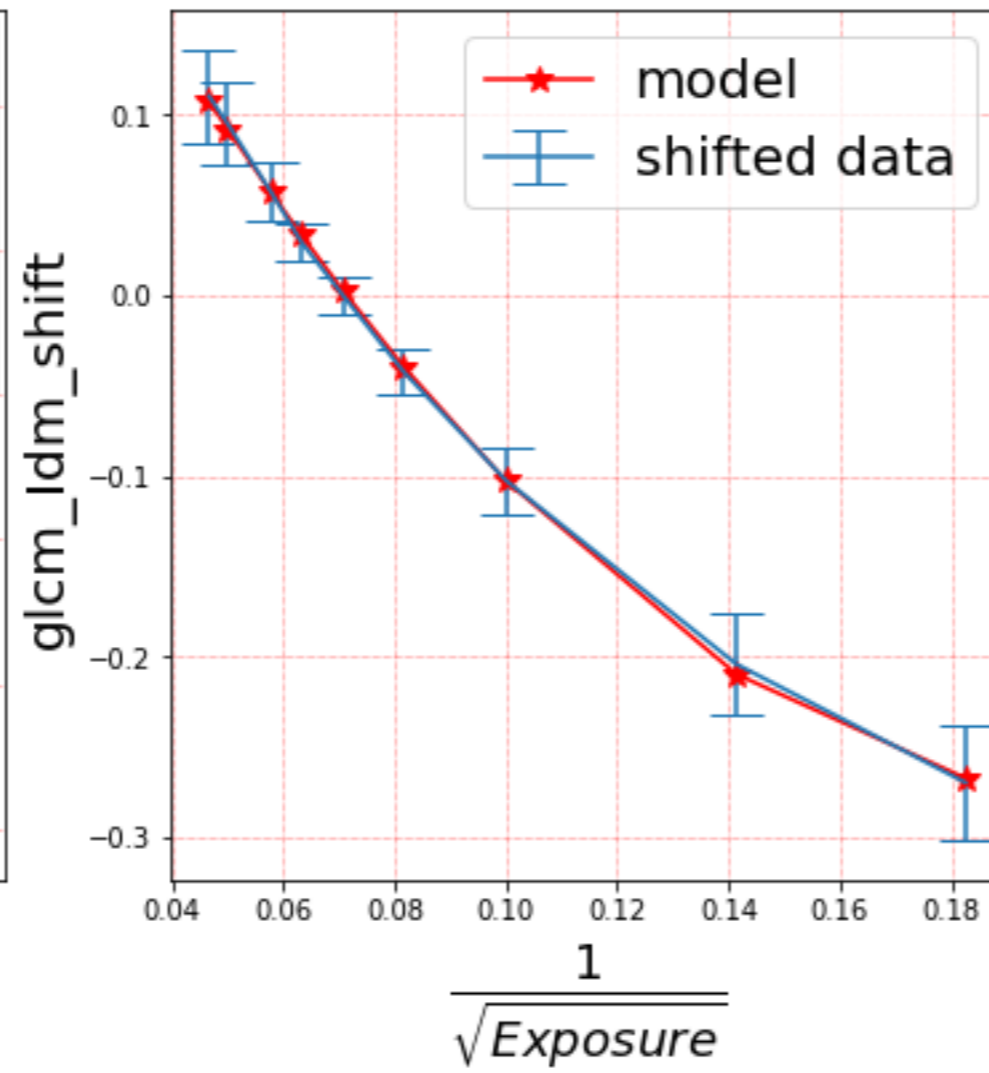
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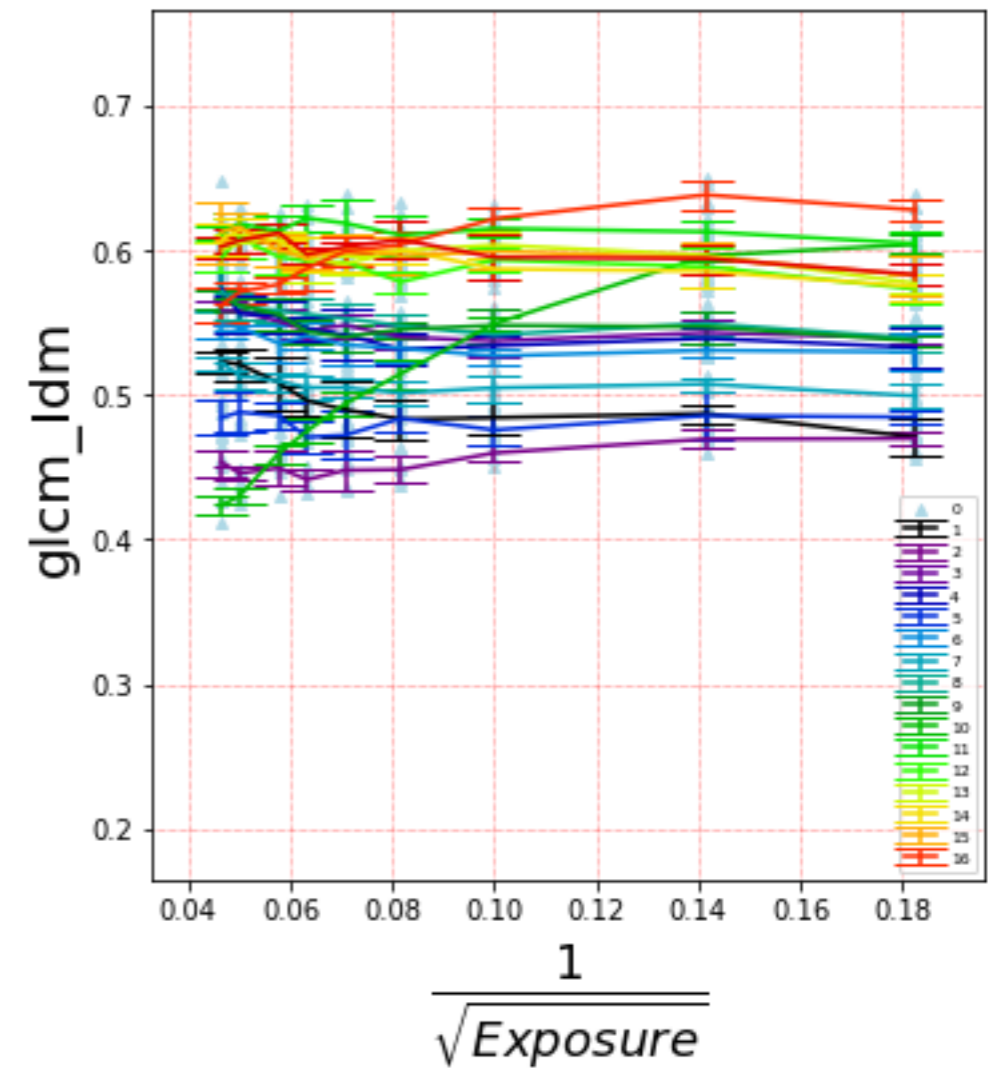
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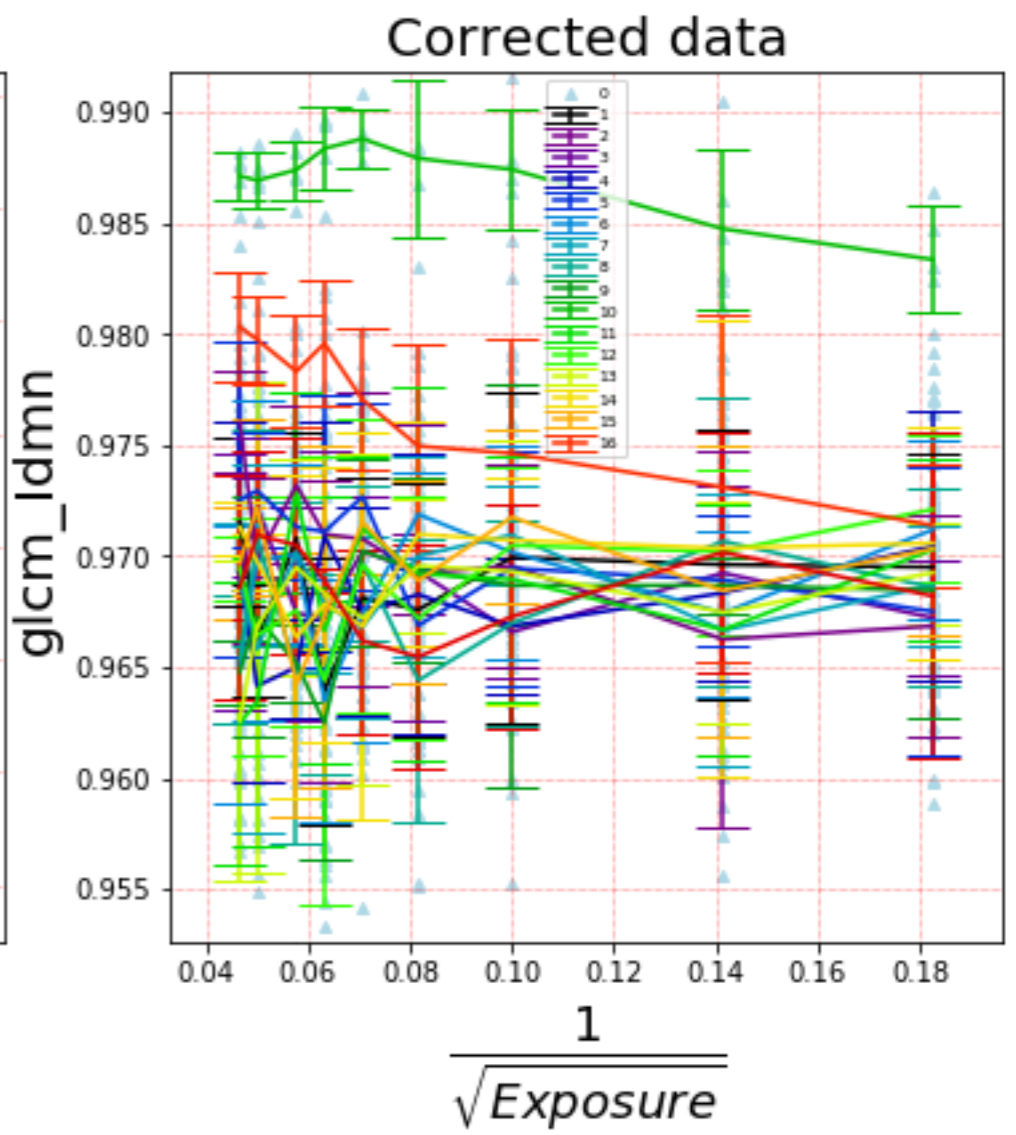
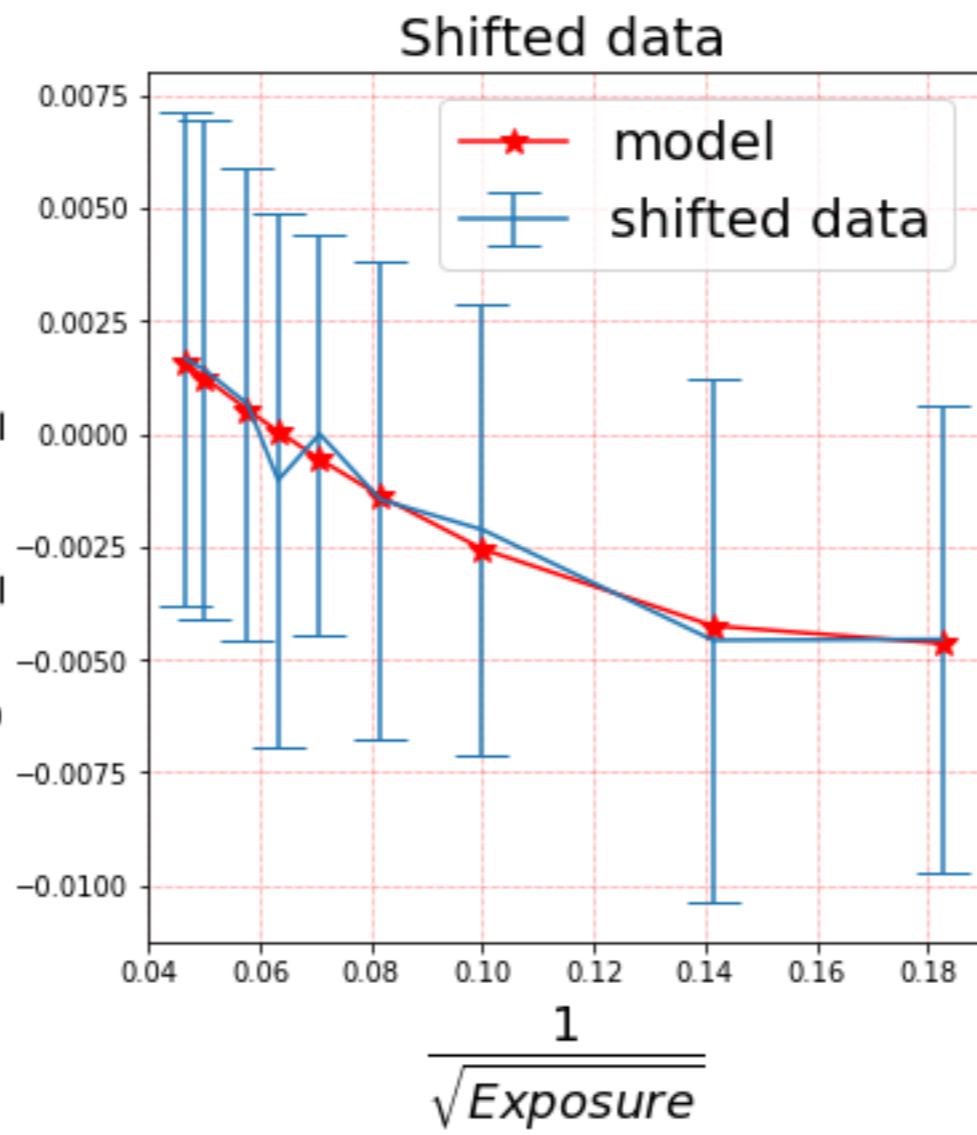
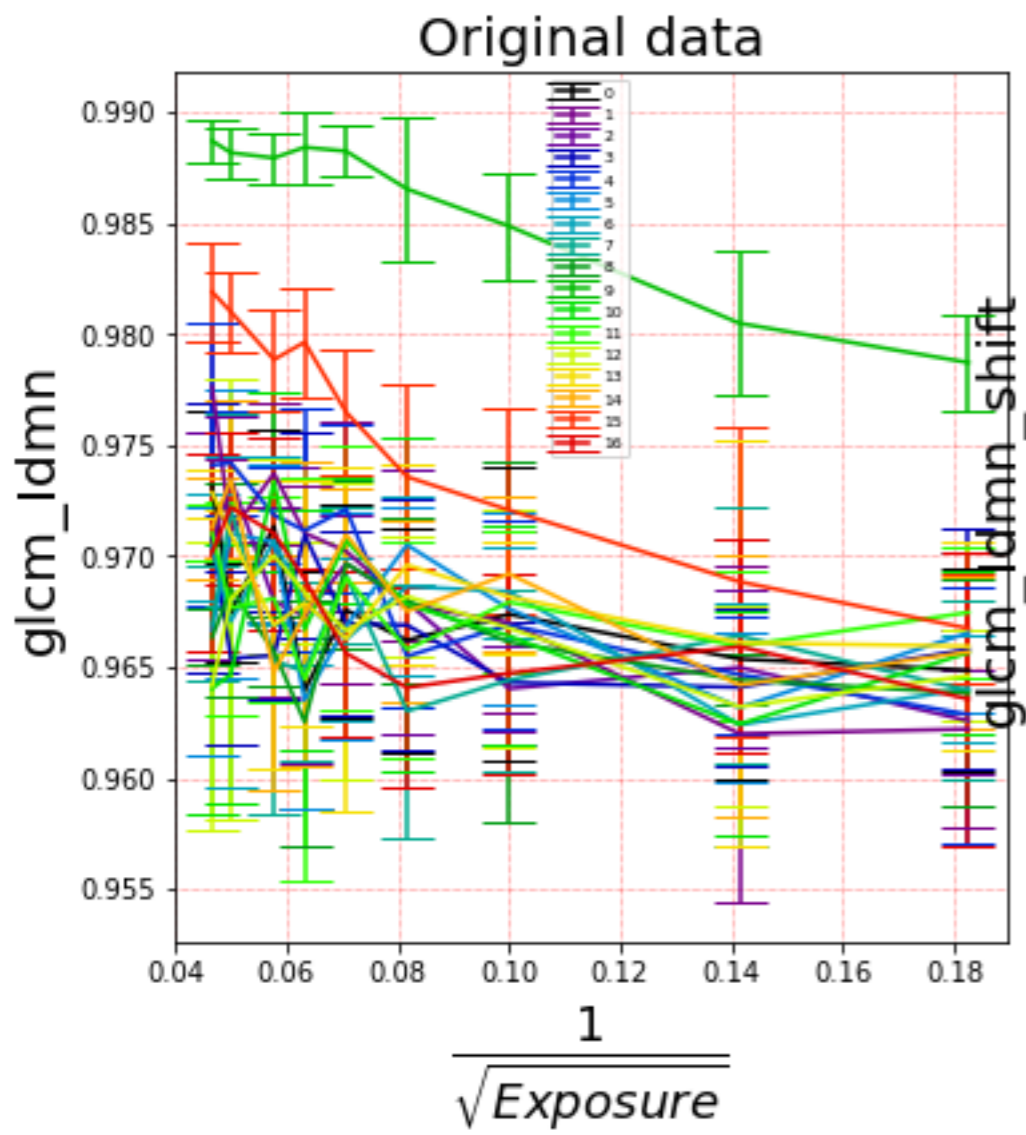


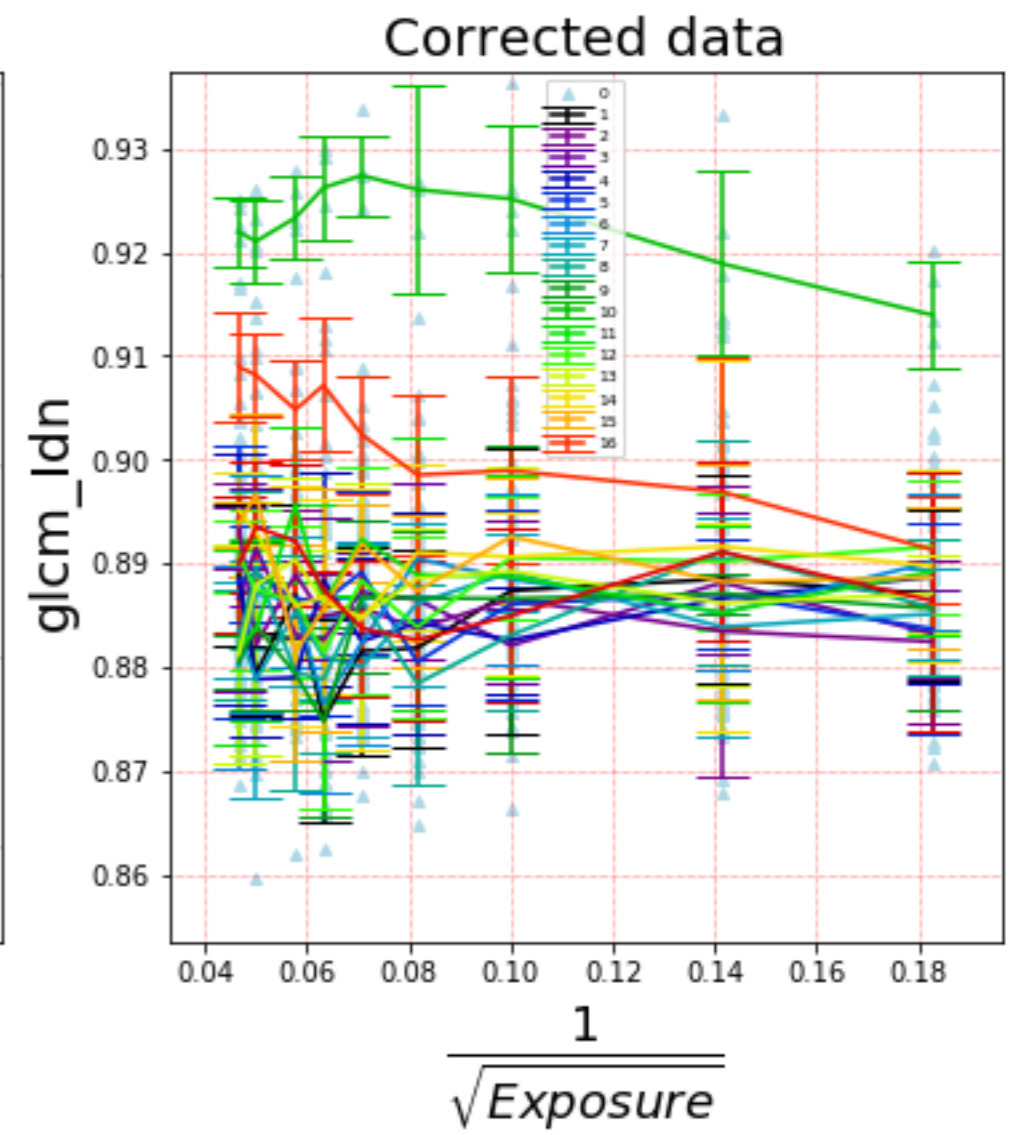
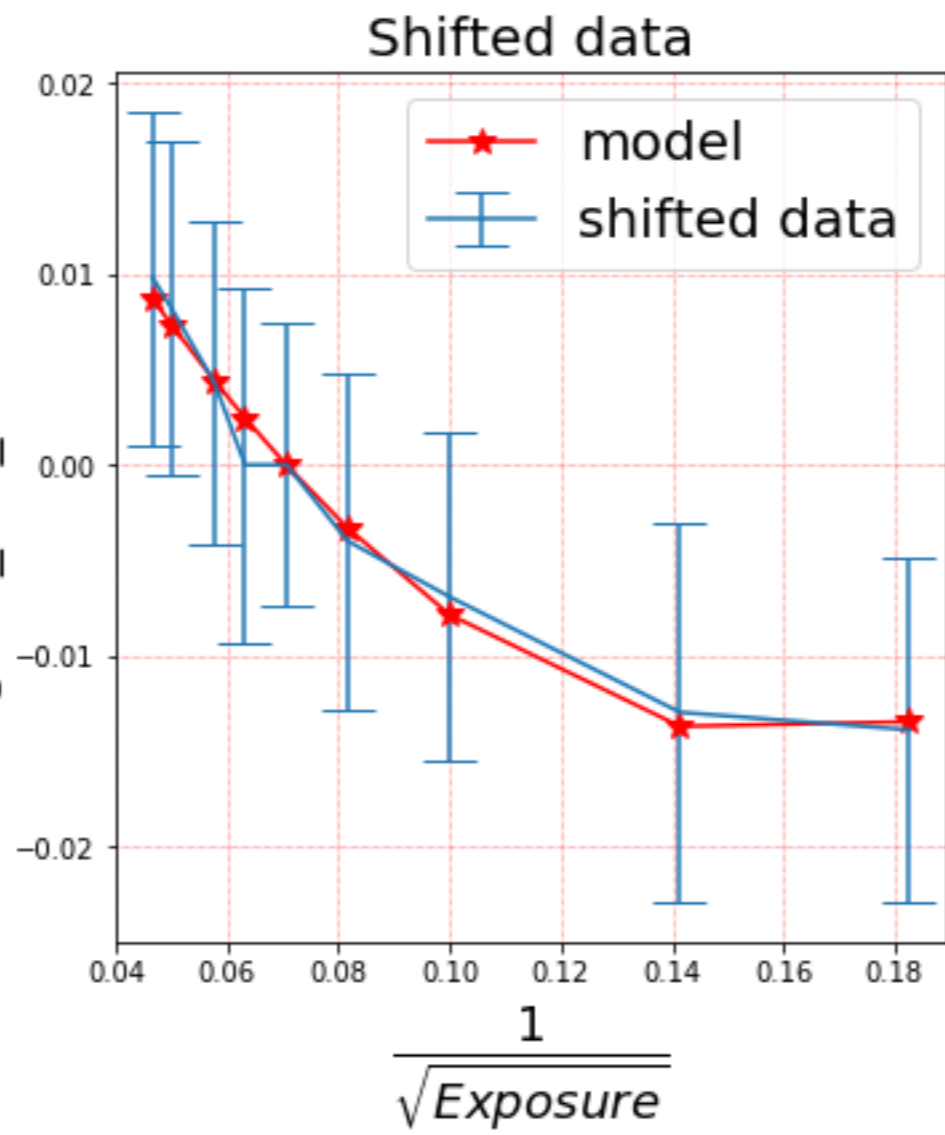
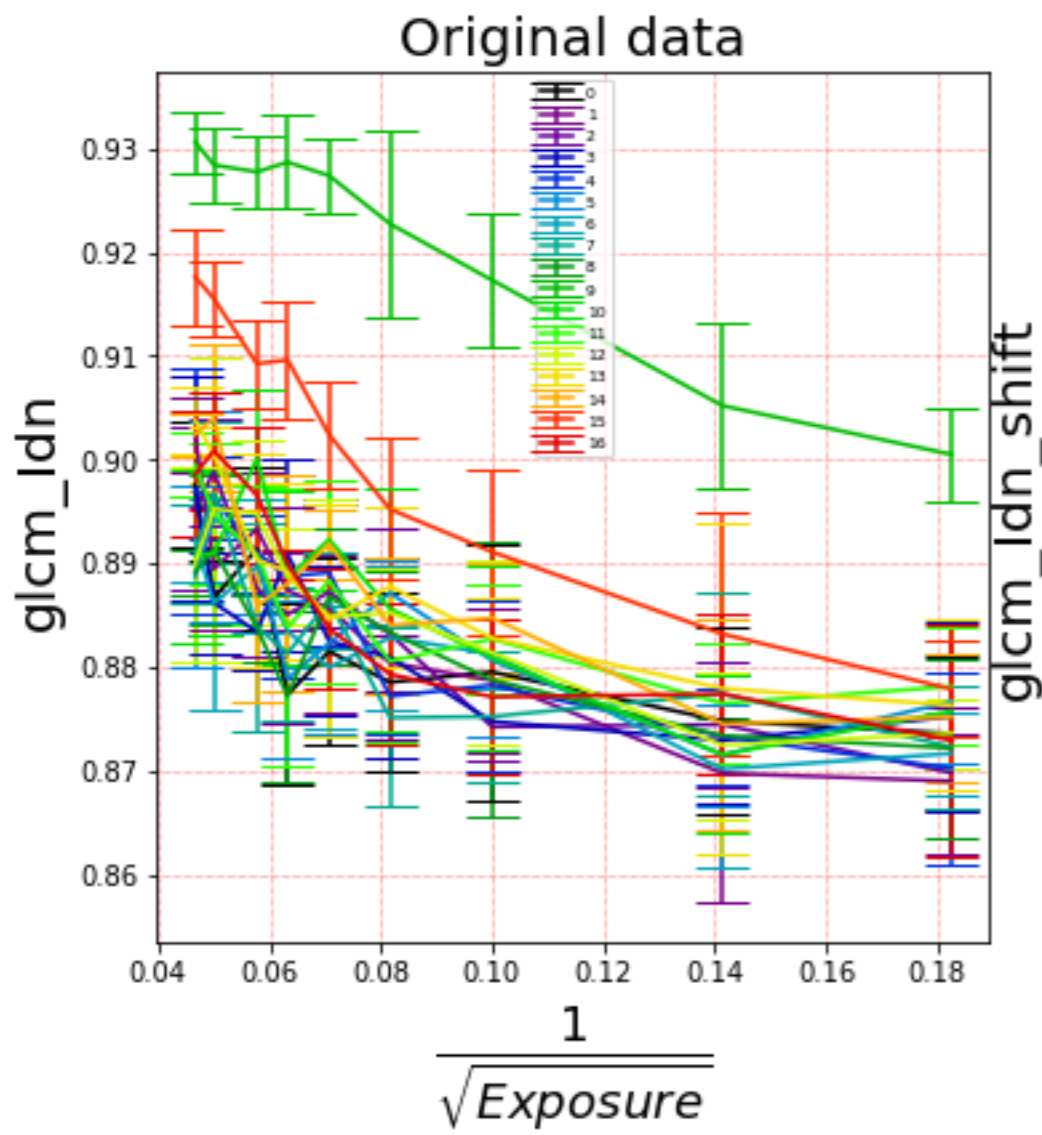
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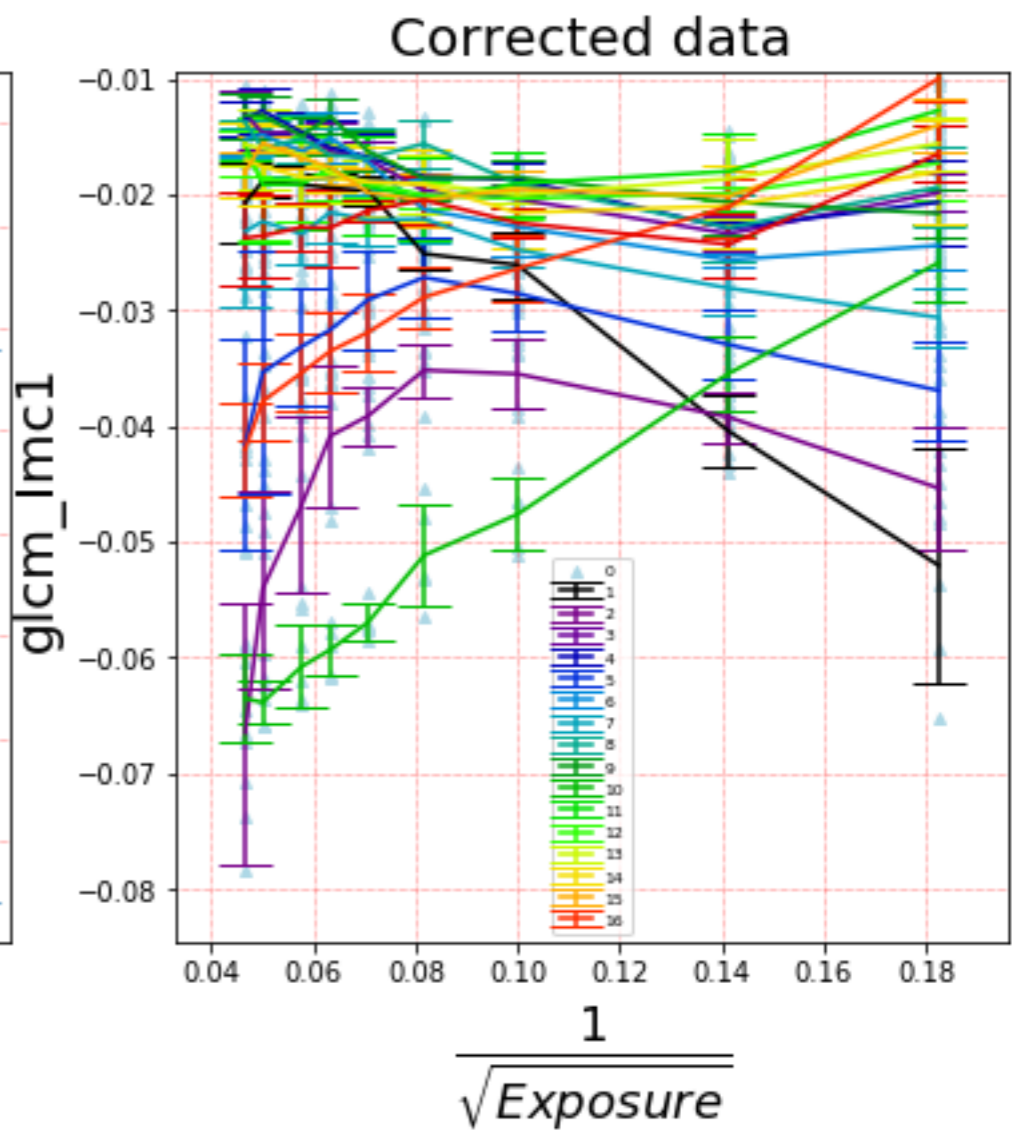
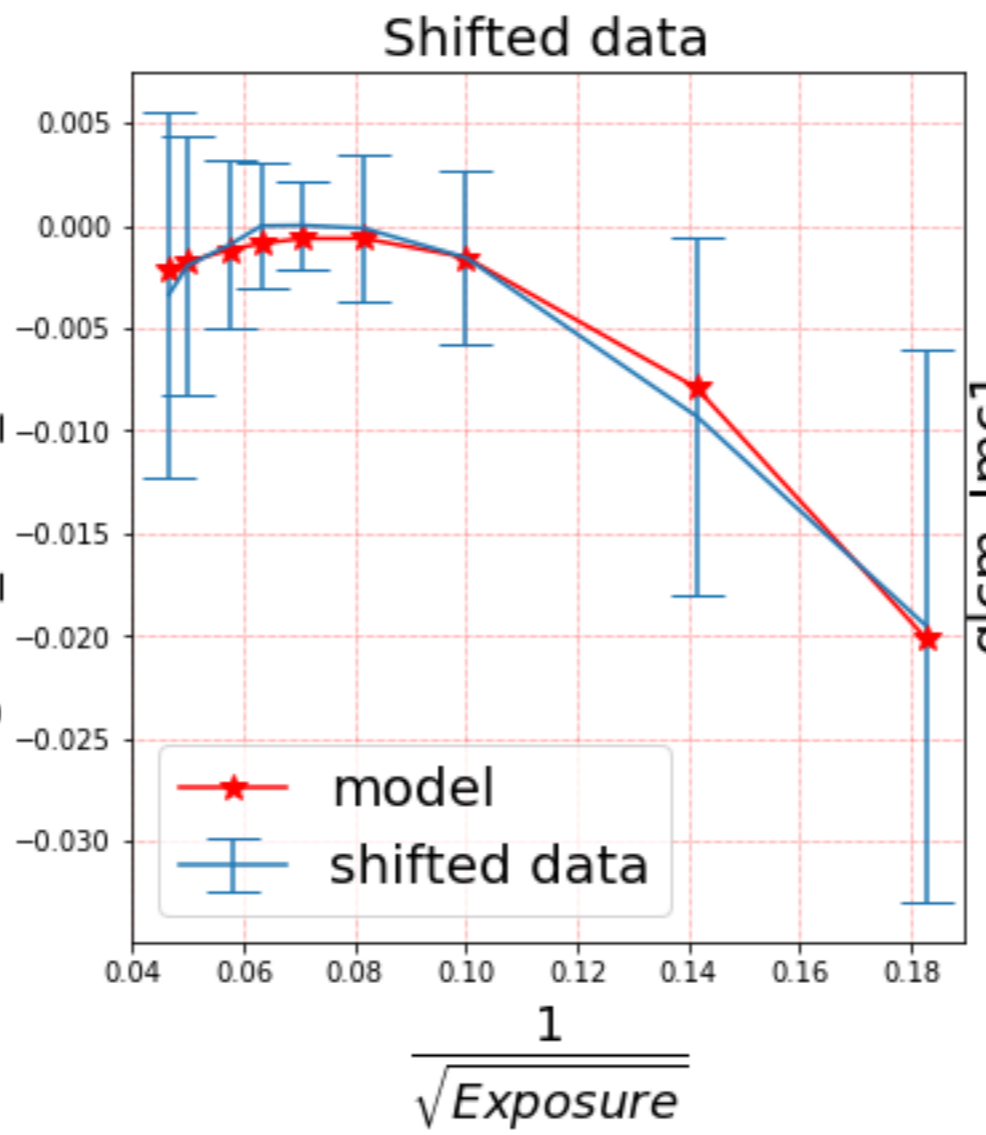
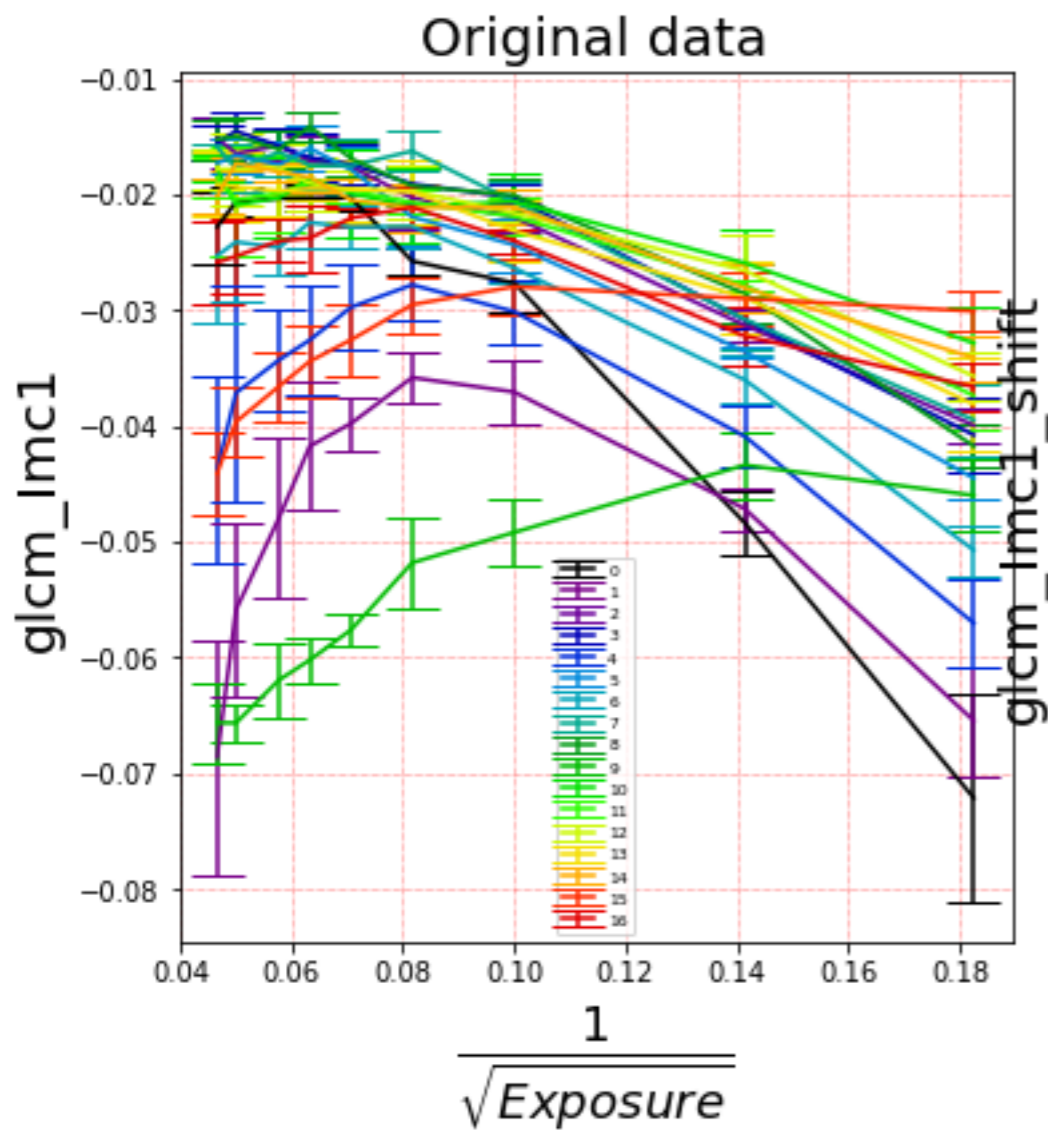


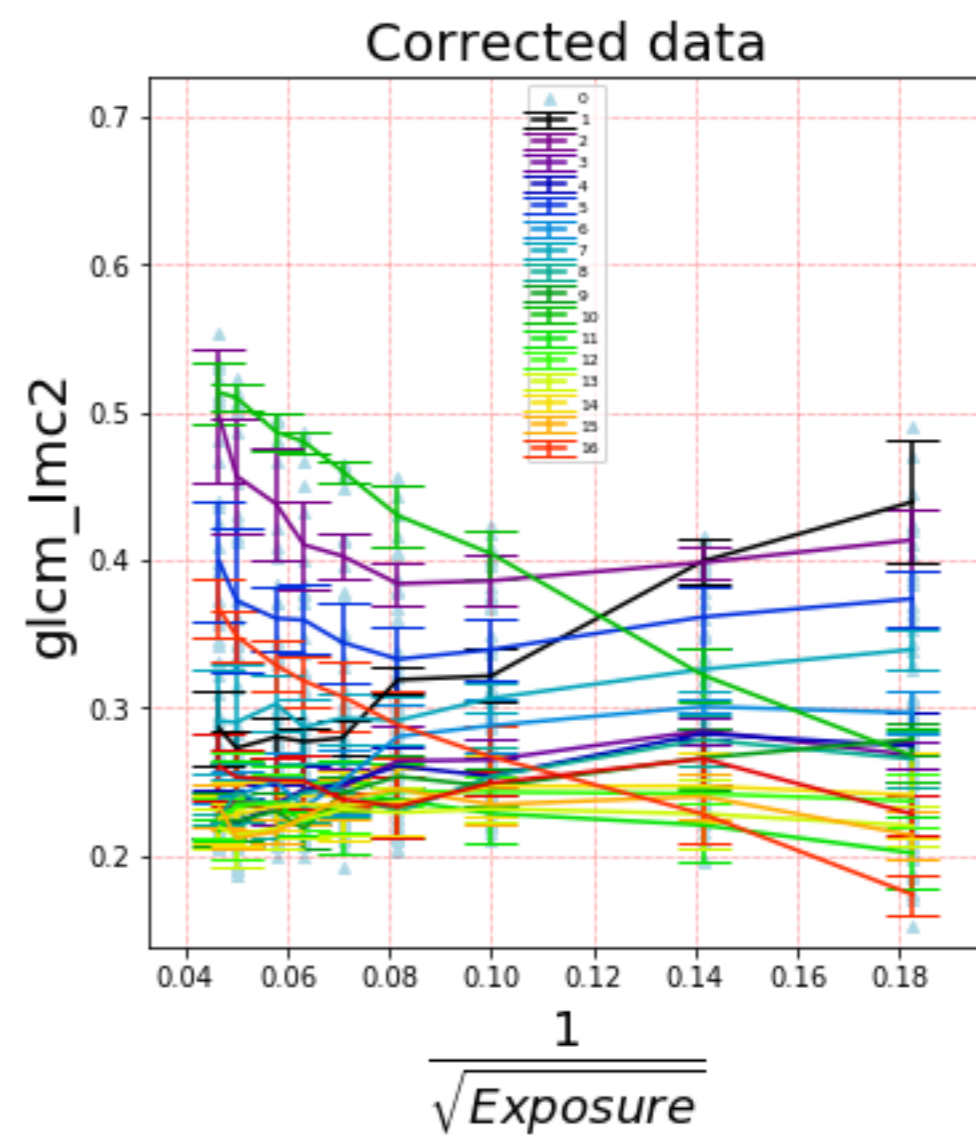
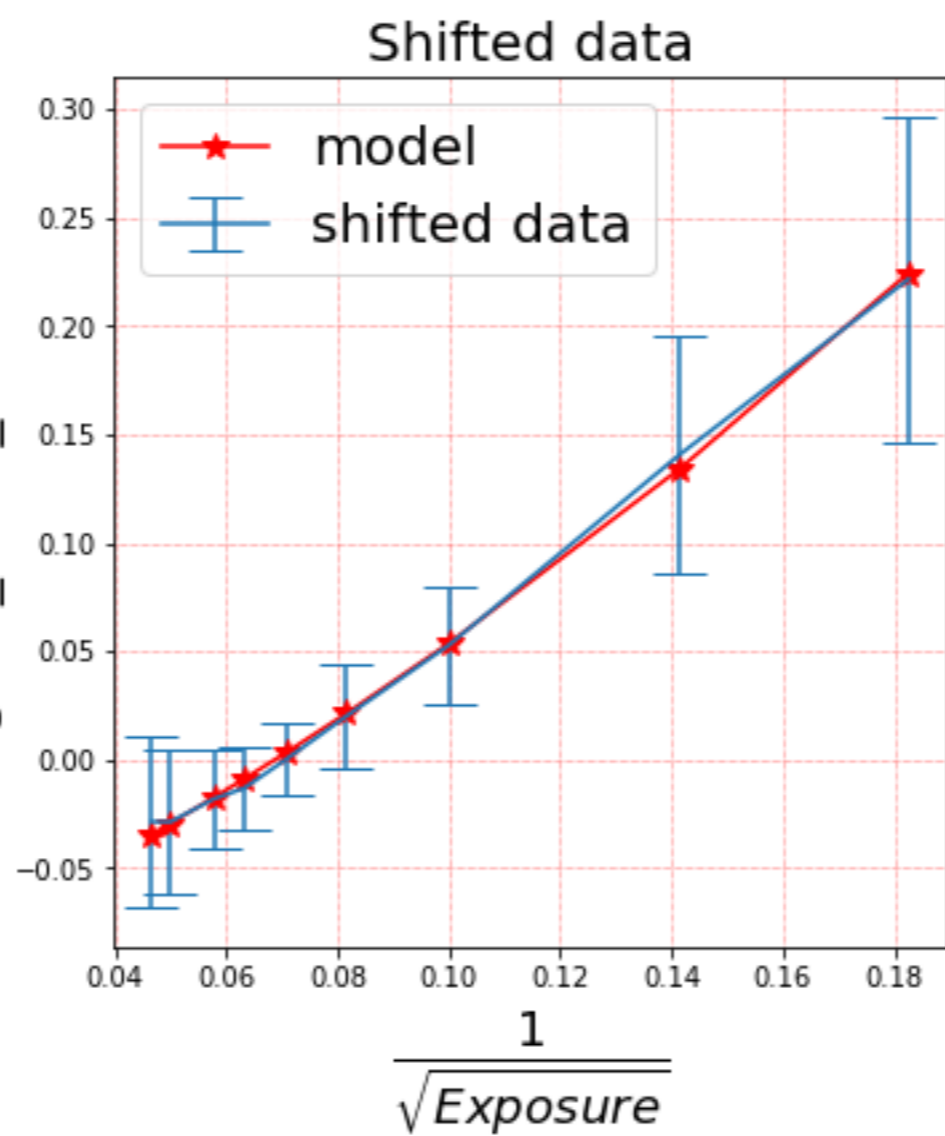
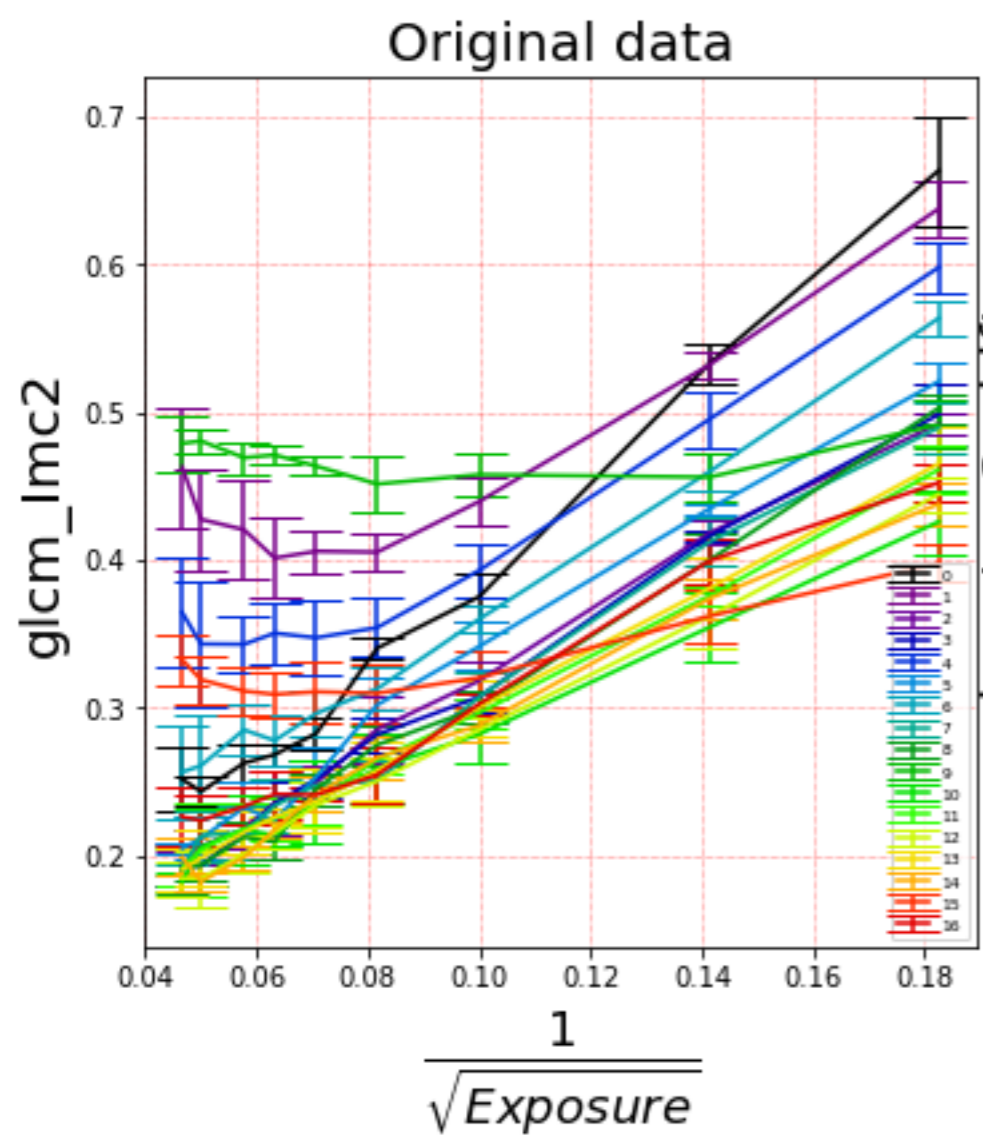
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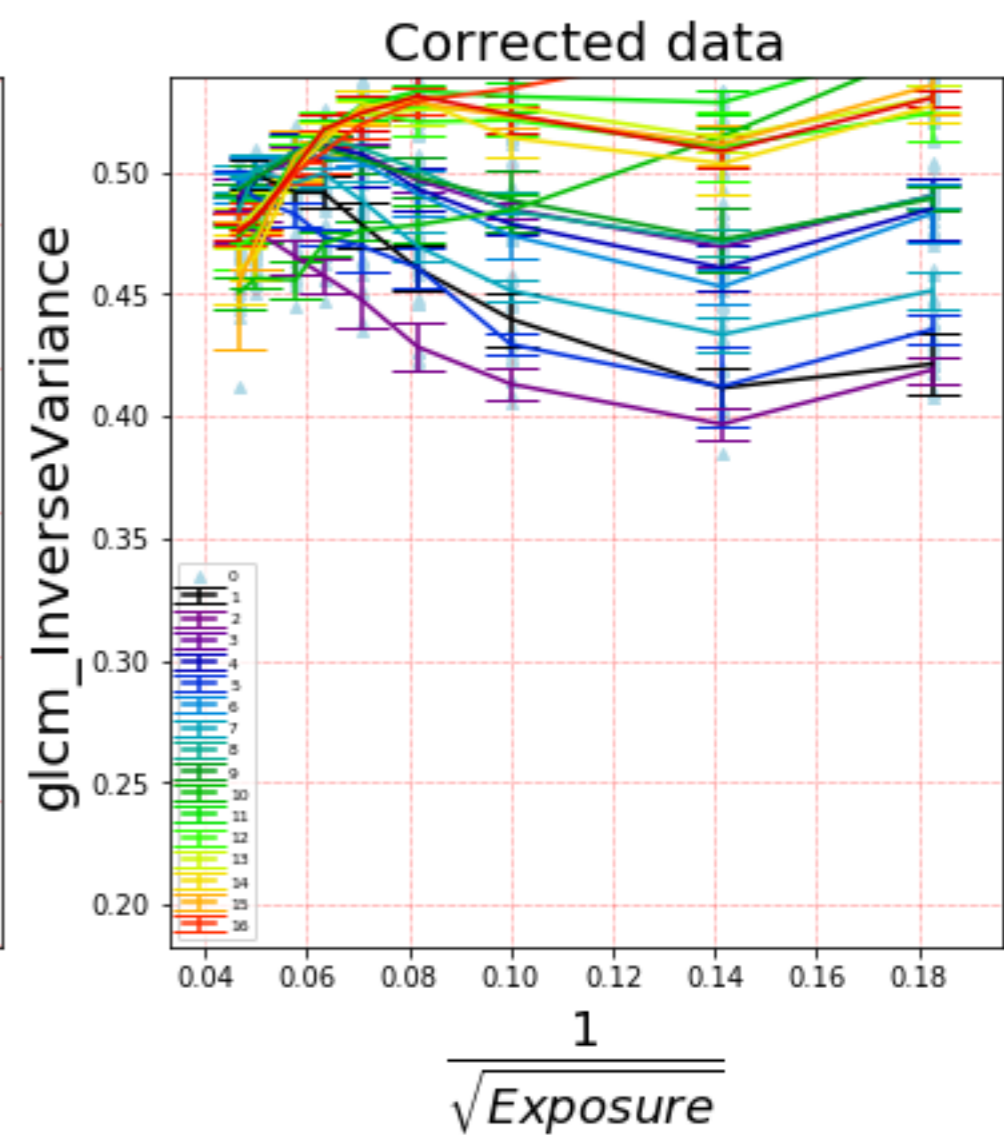
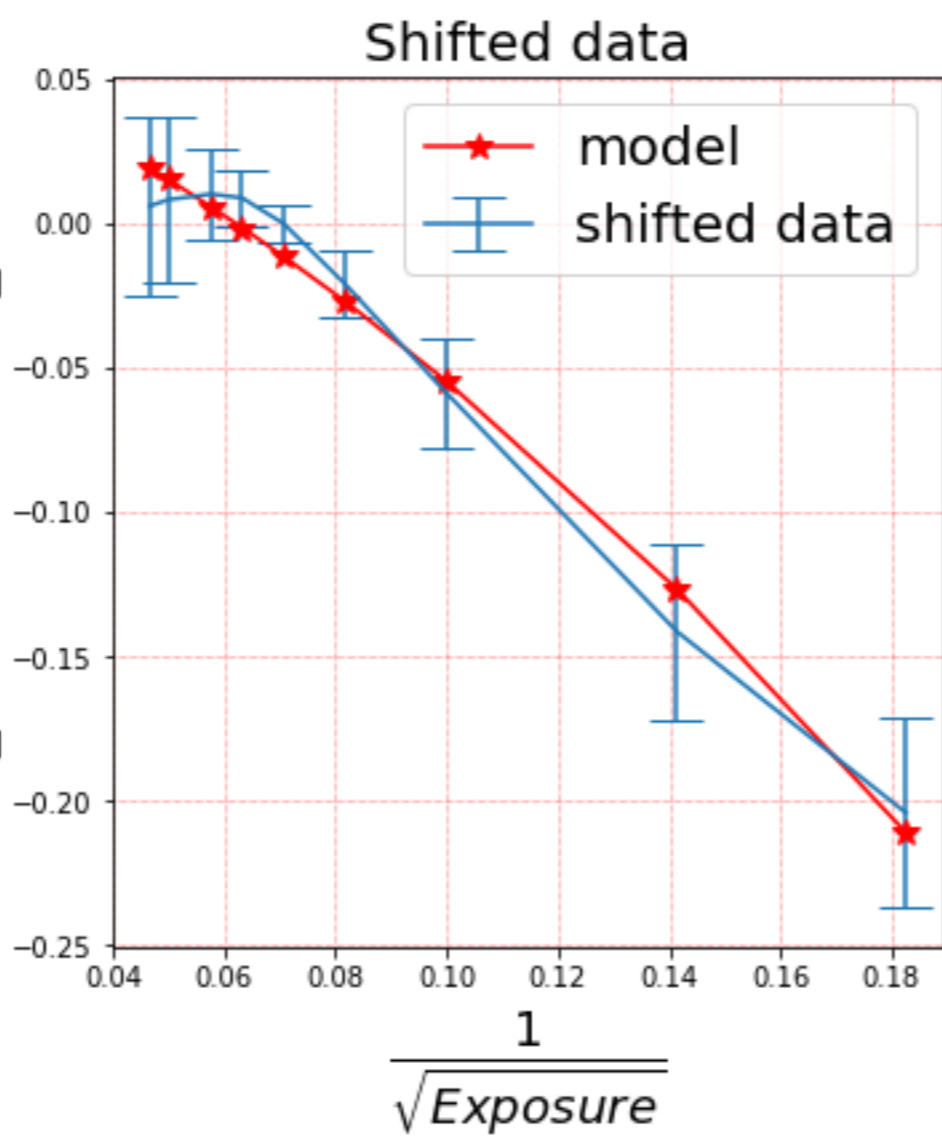
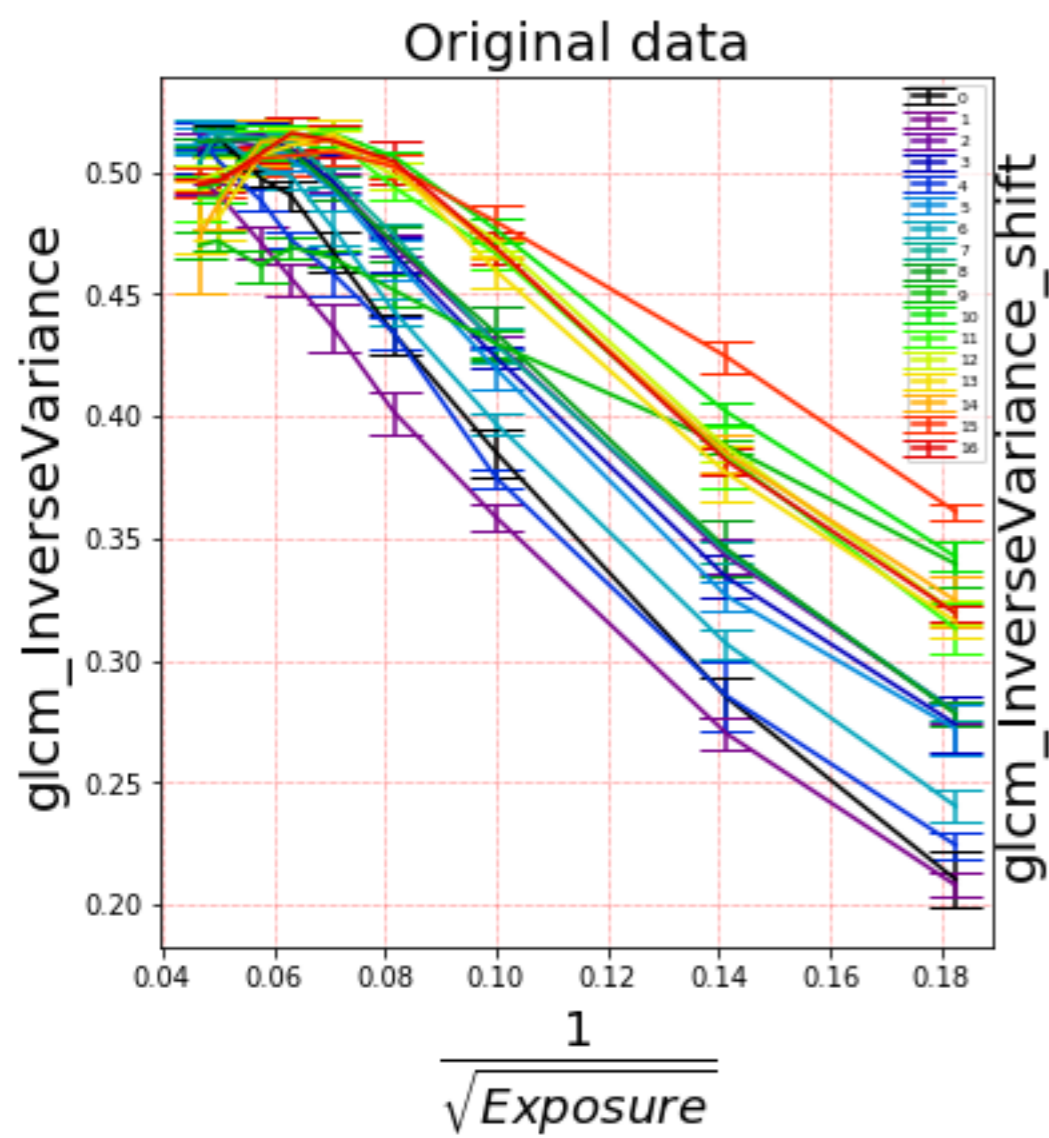




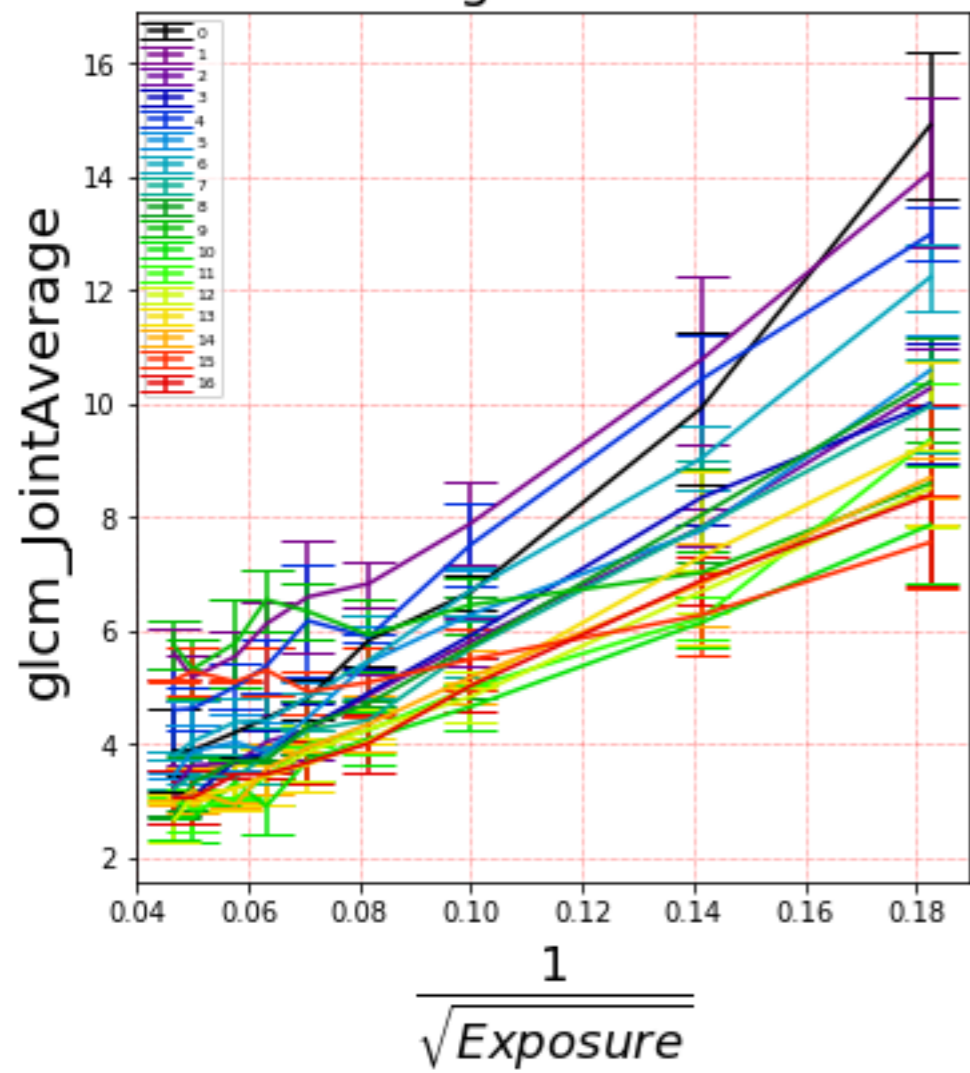




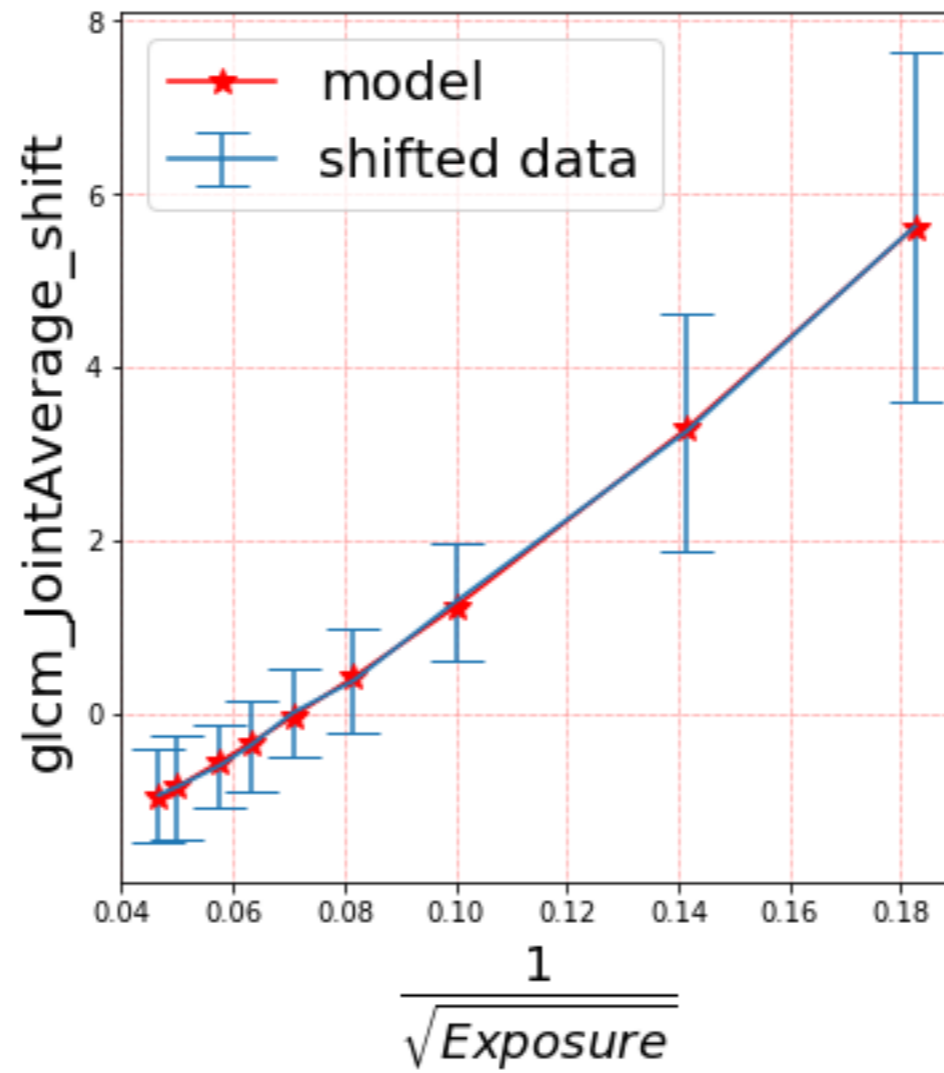




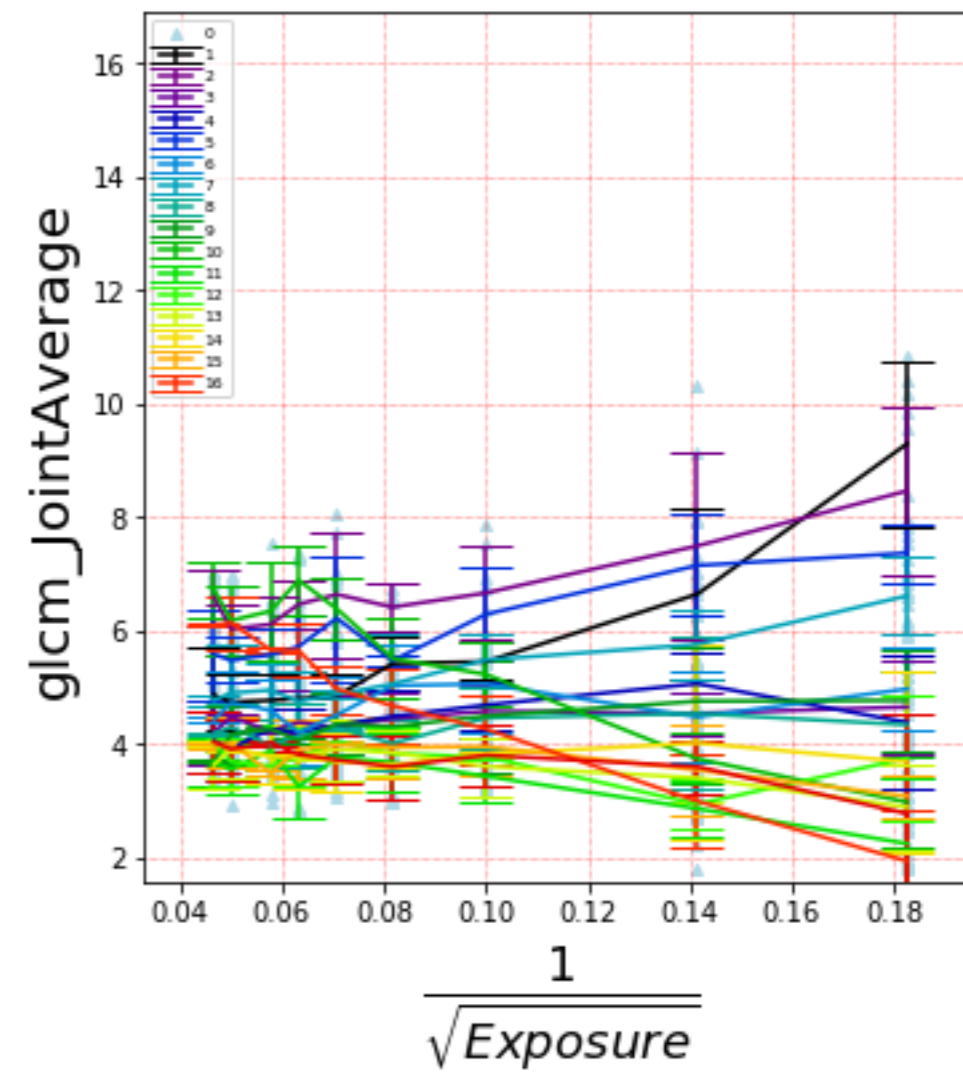
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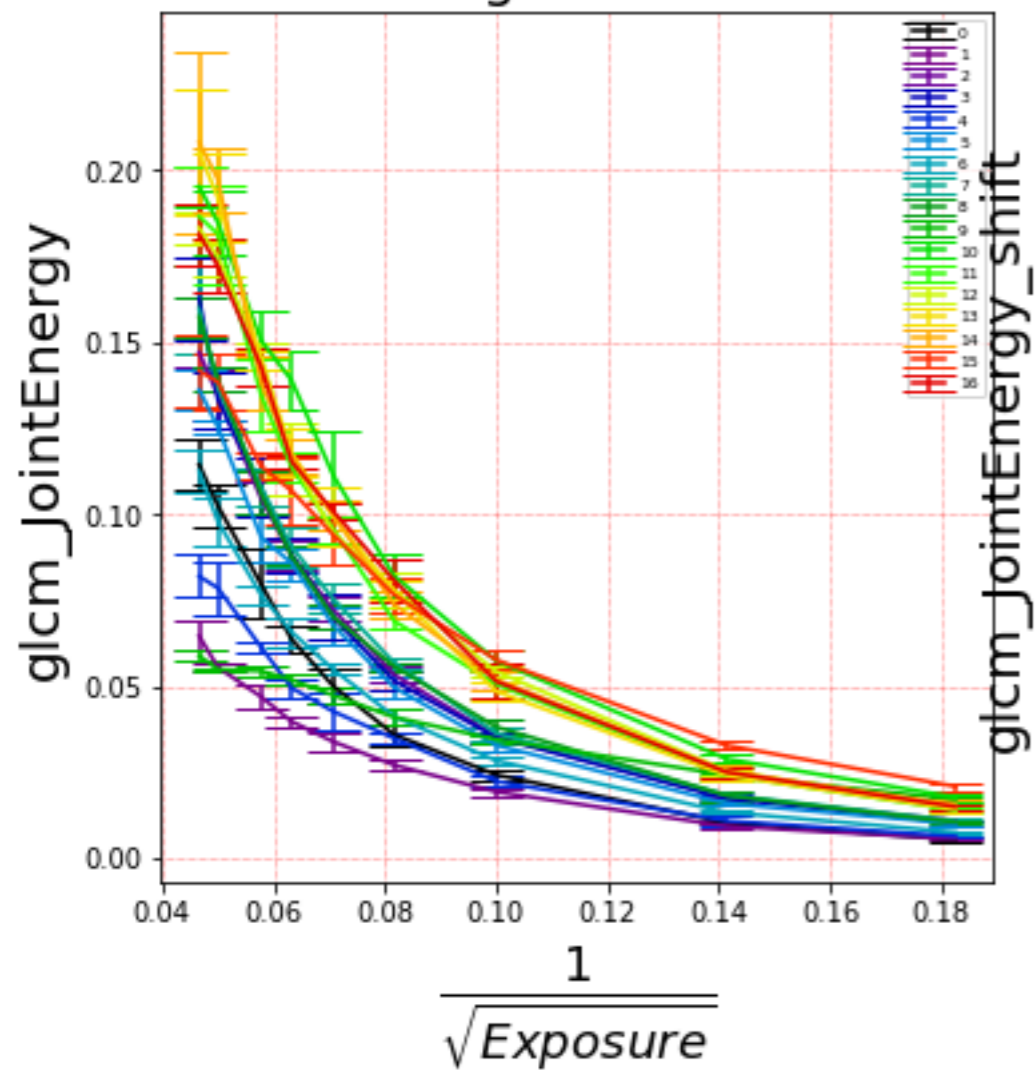
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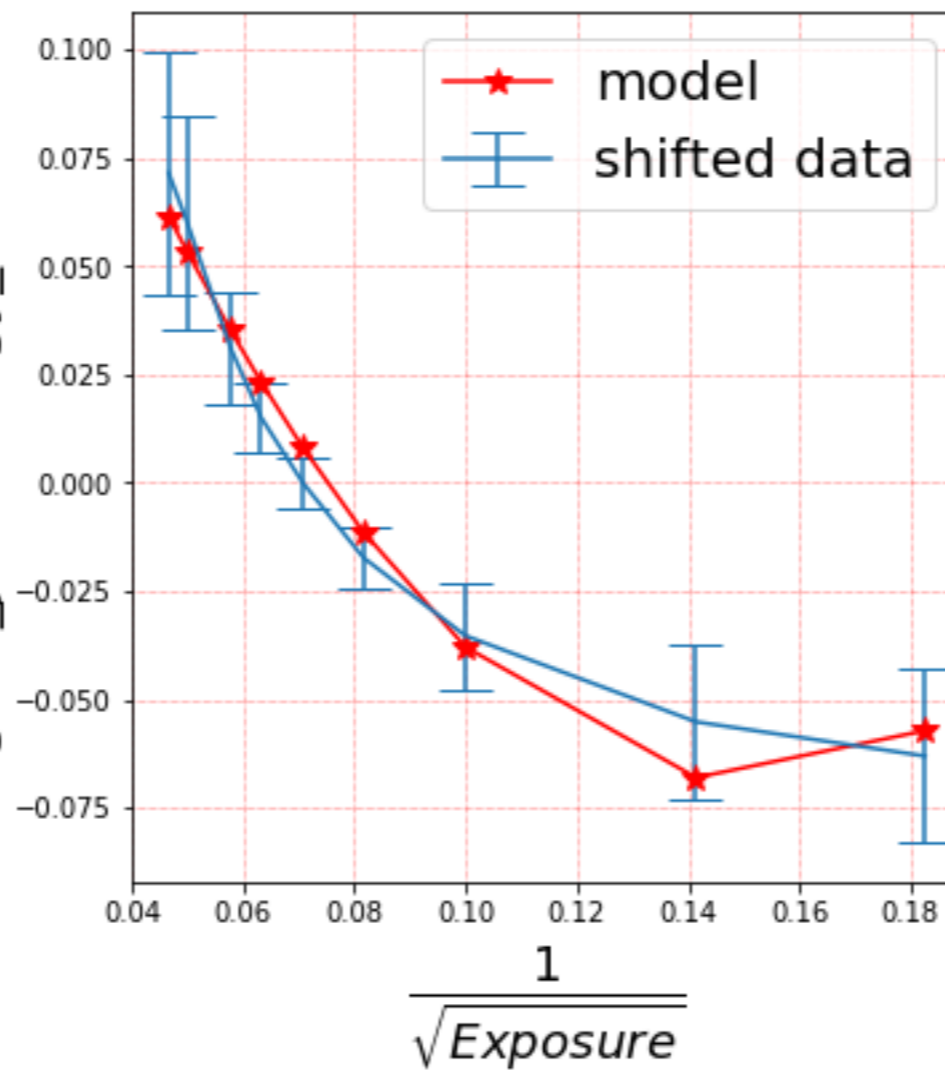
Corrected data



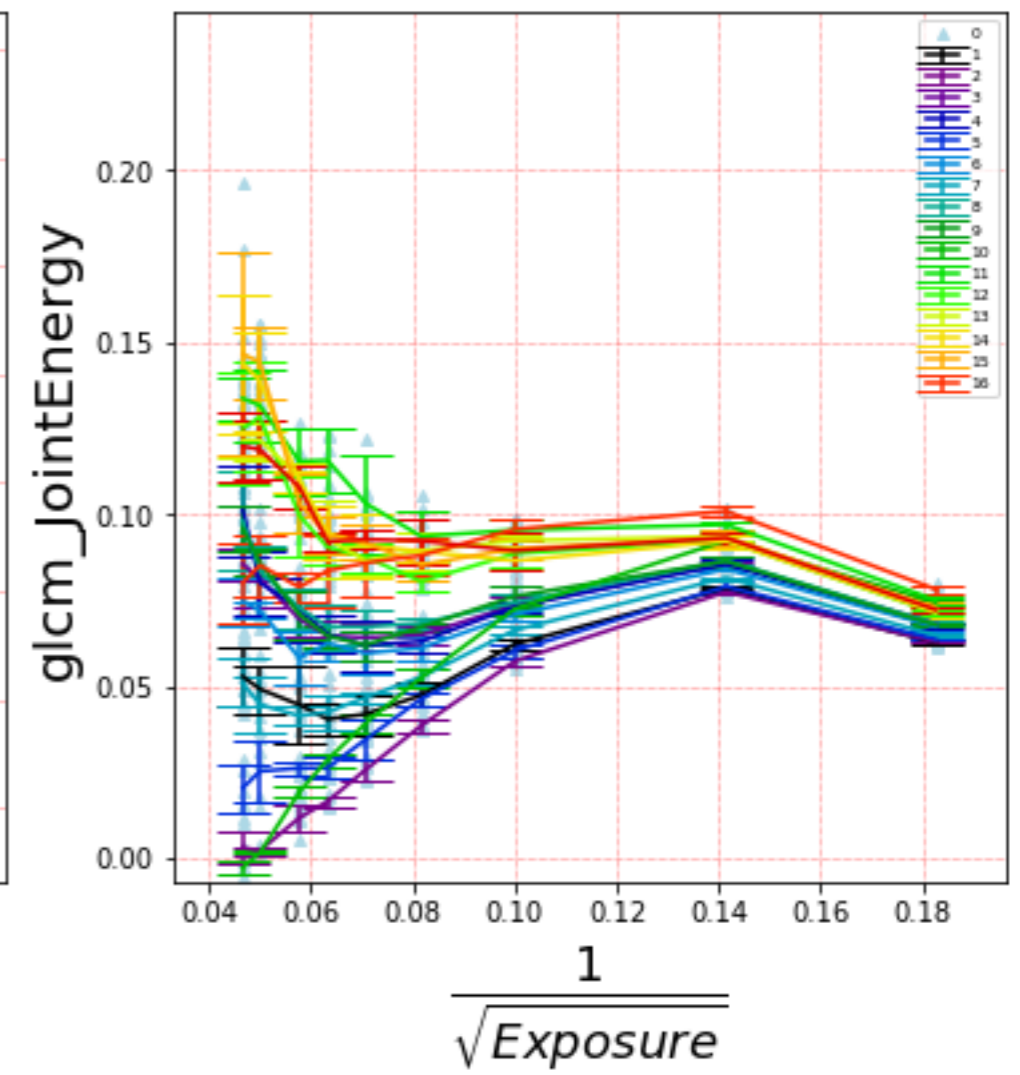
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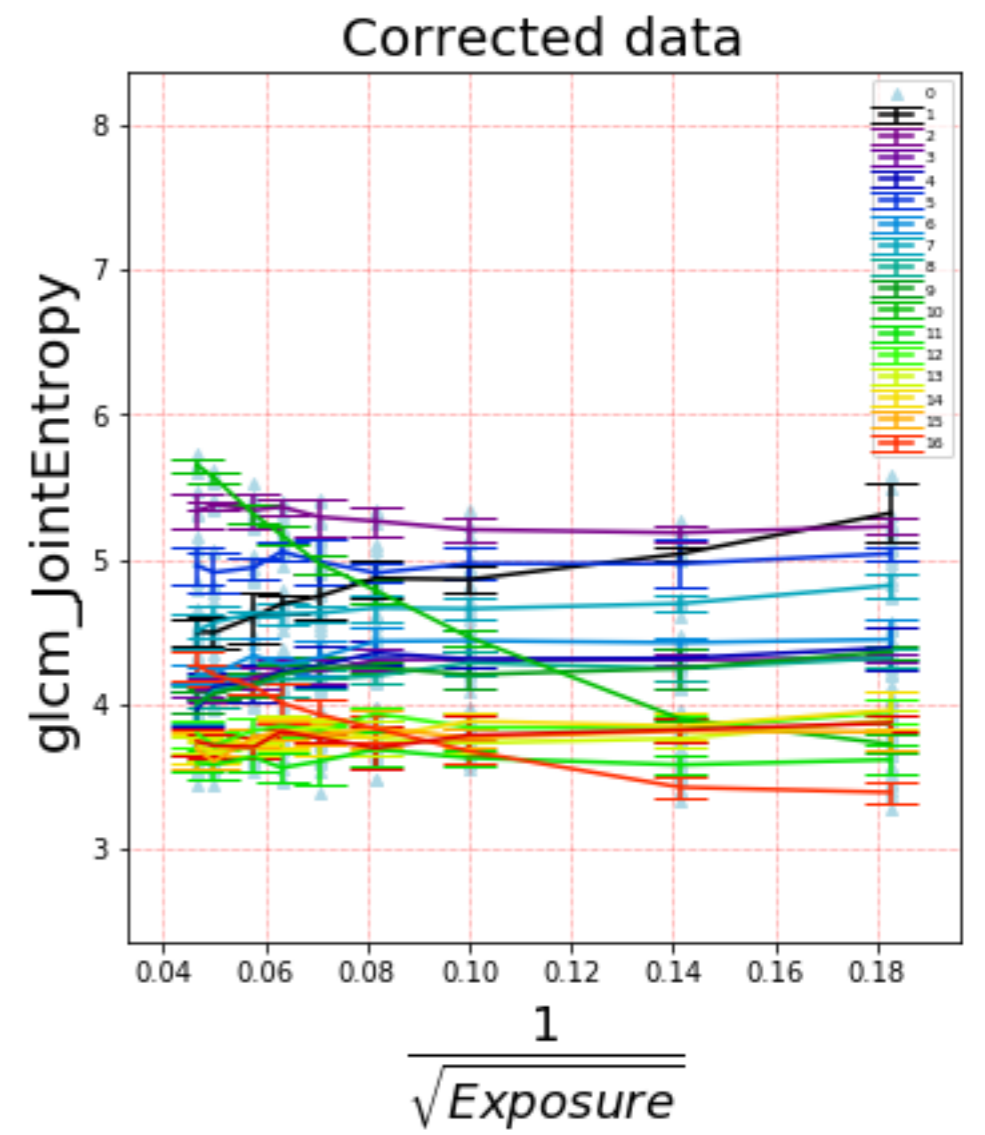
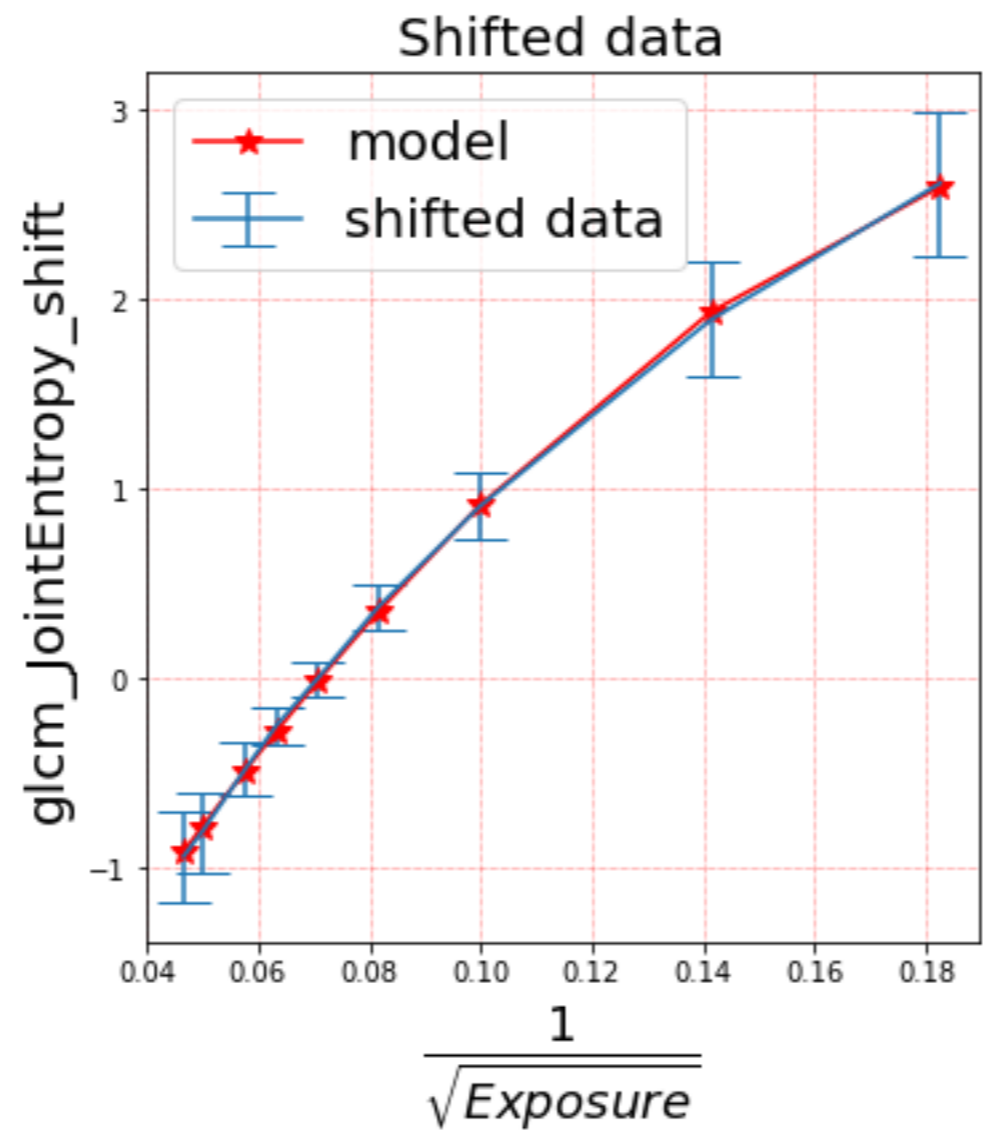
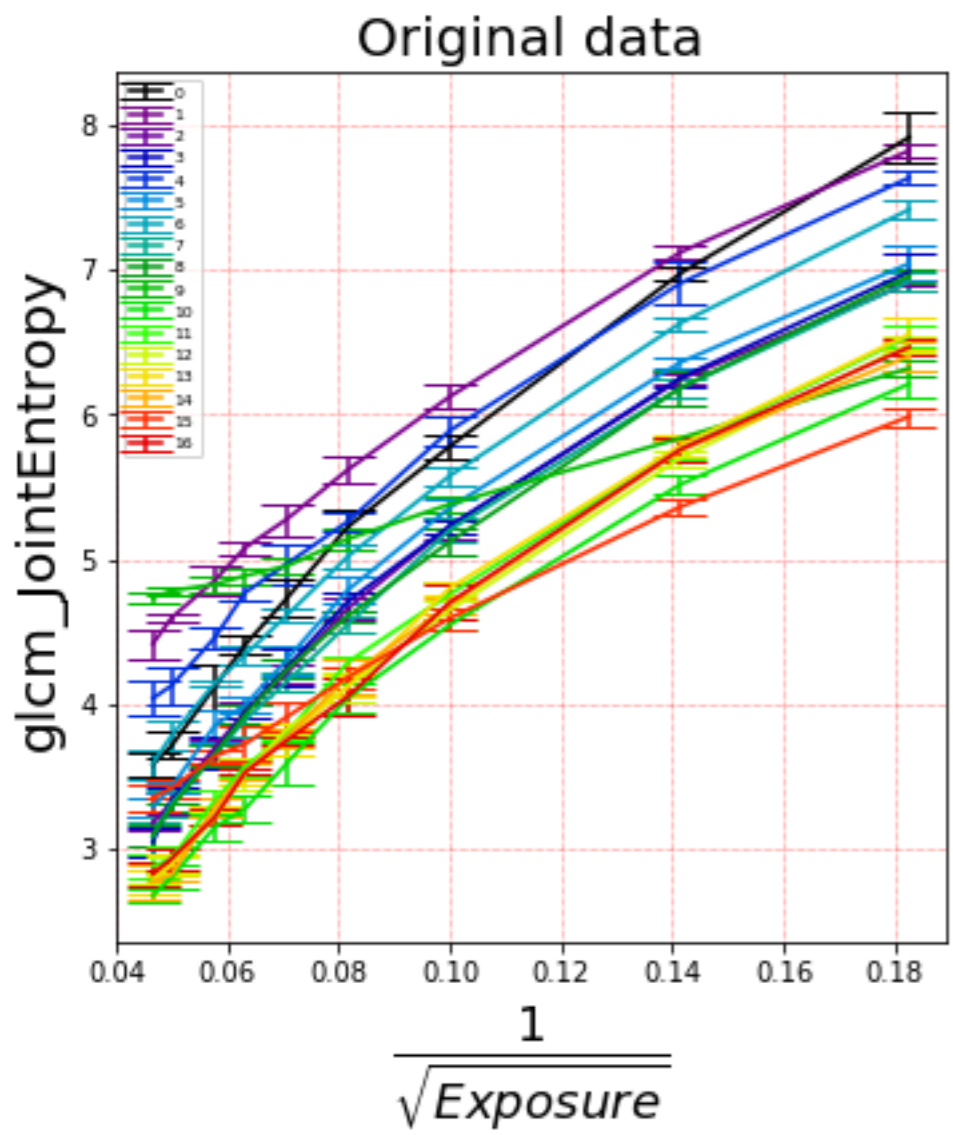


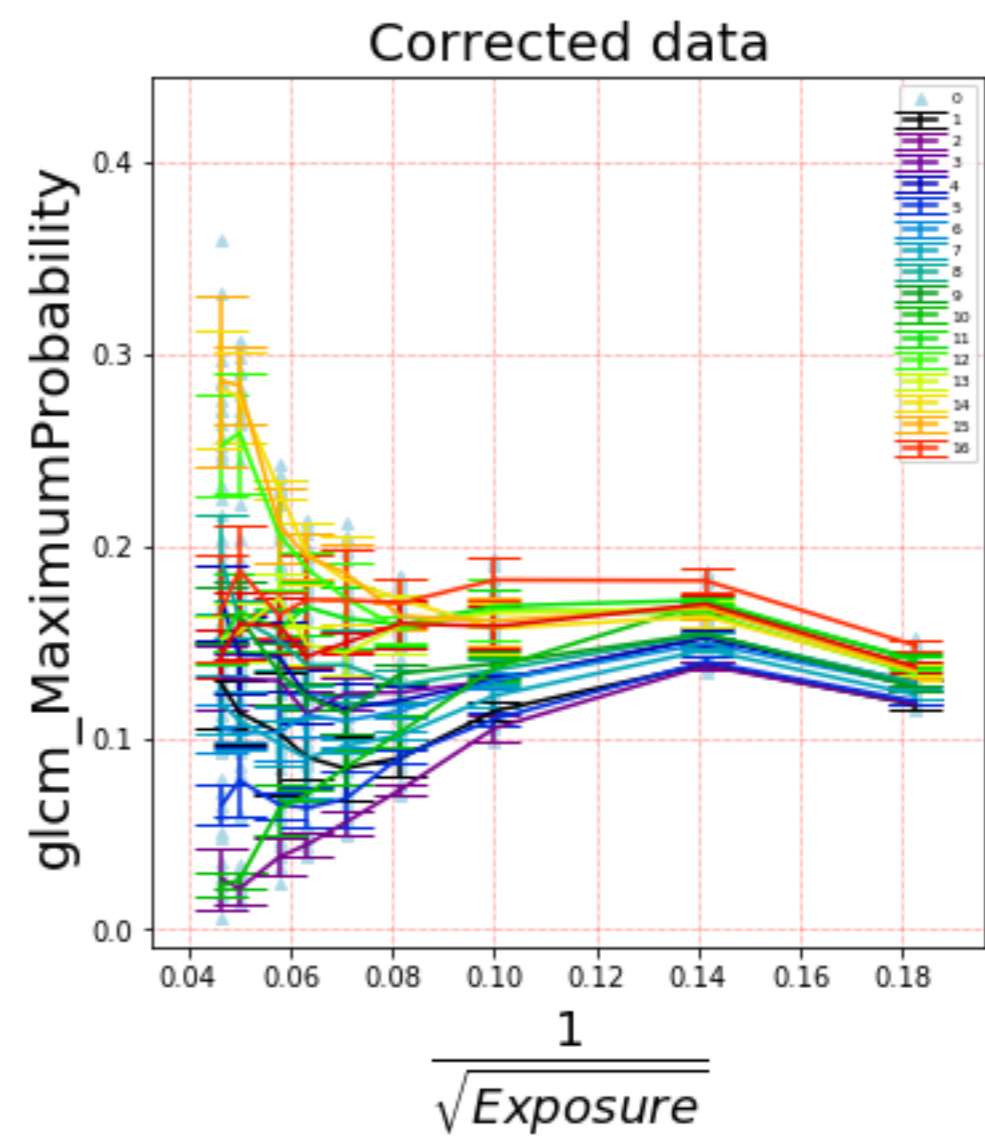
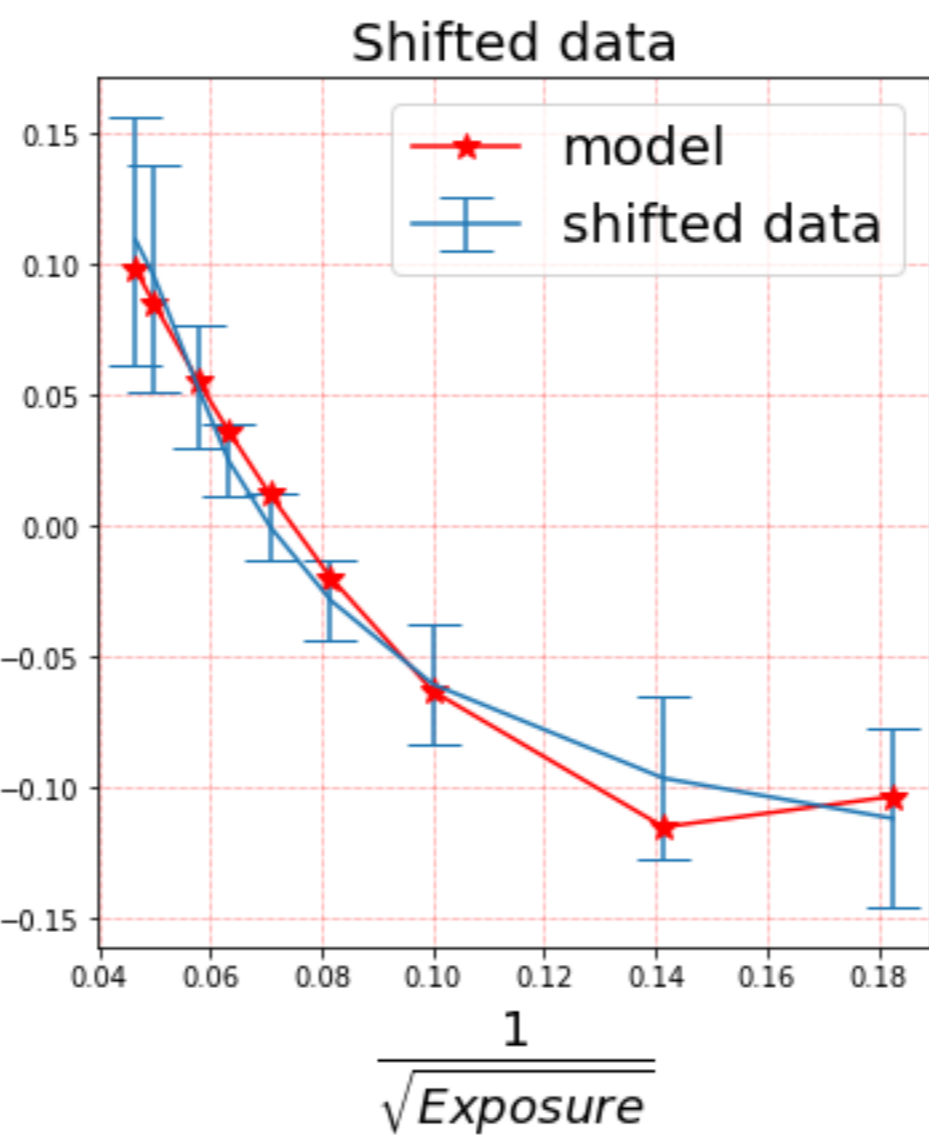
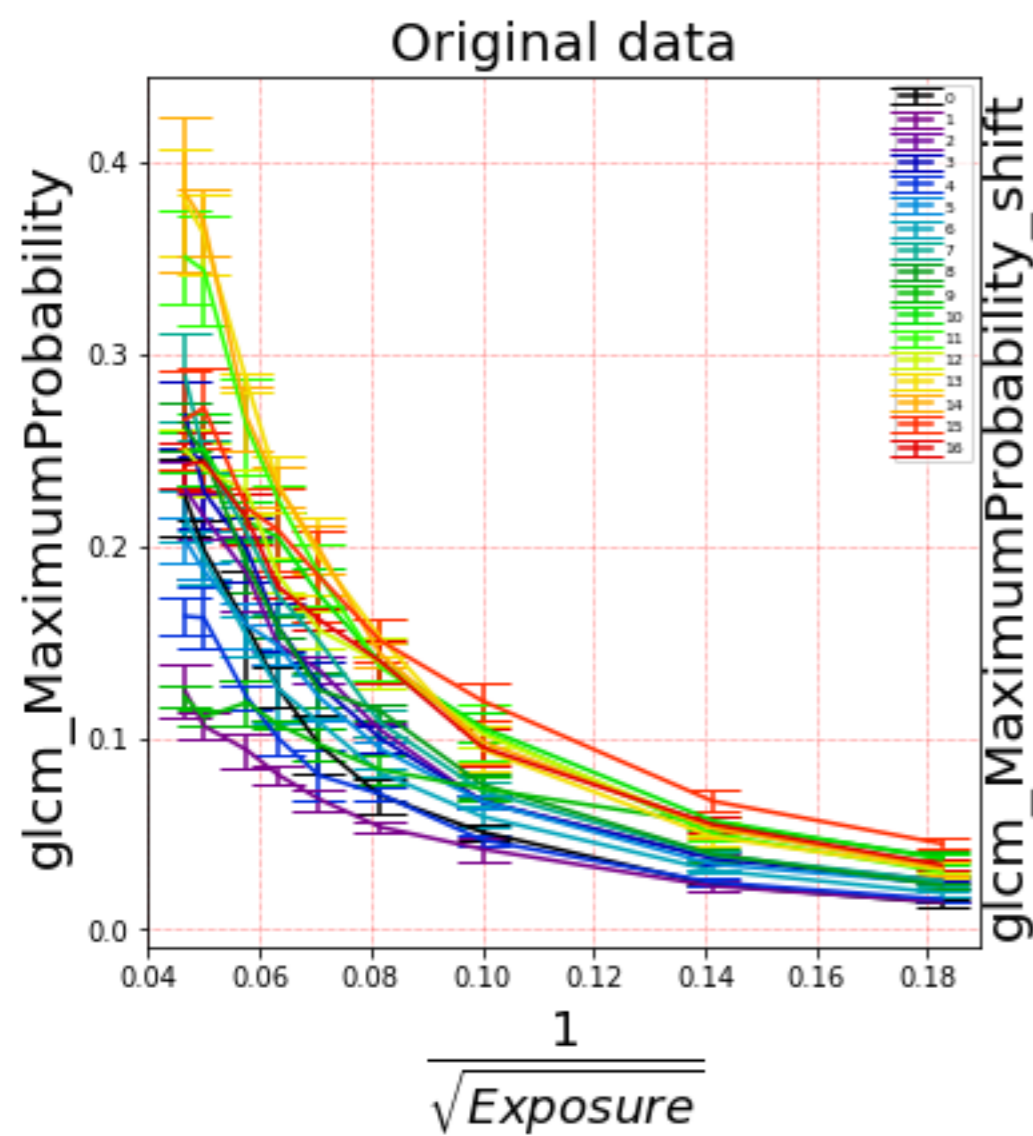
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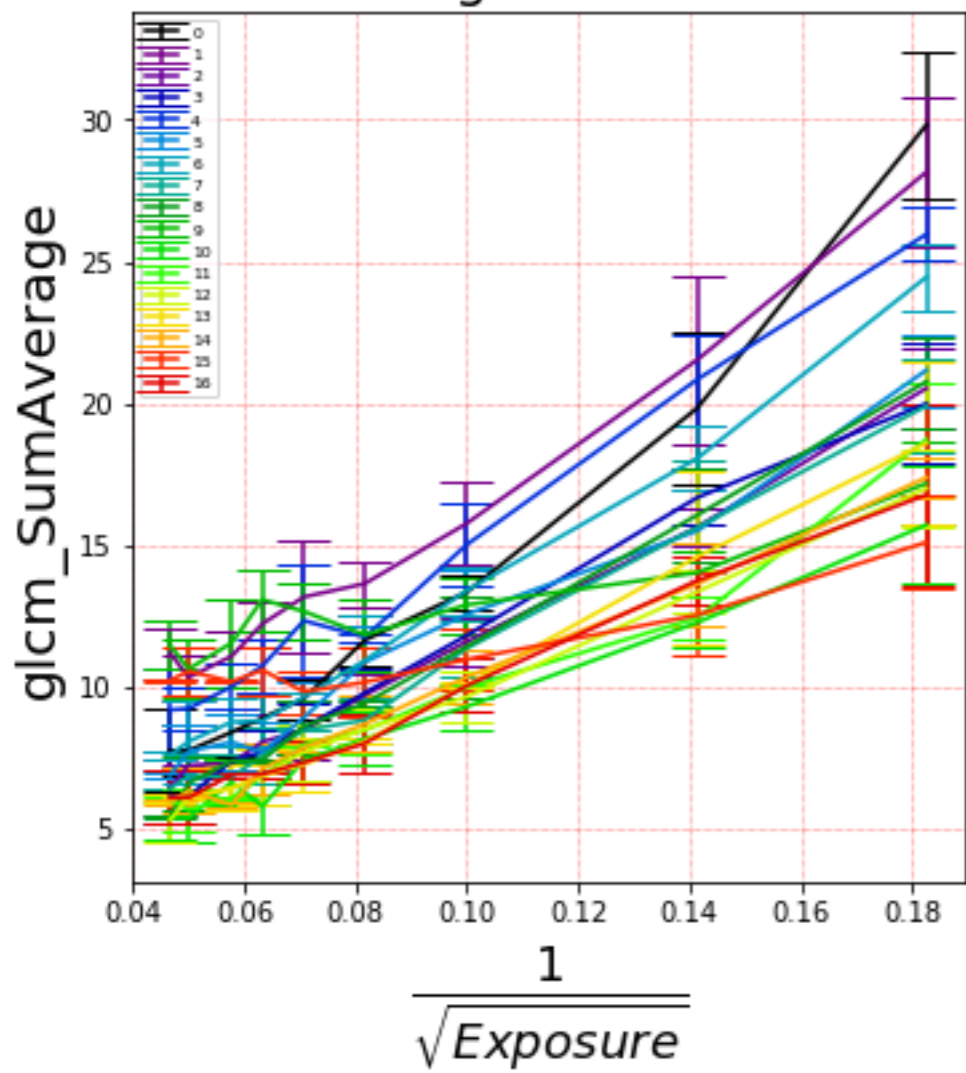
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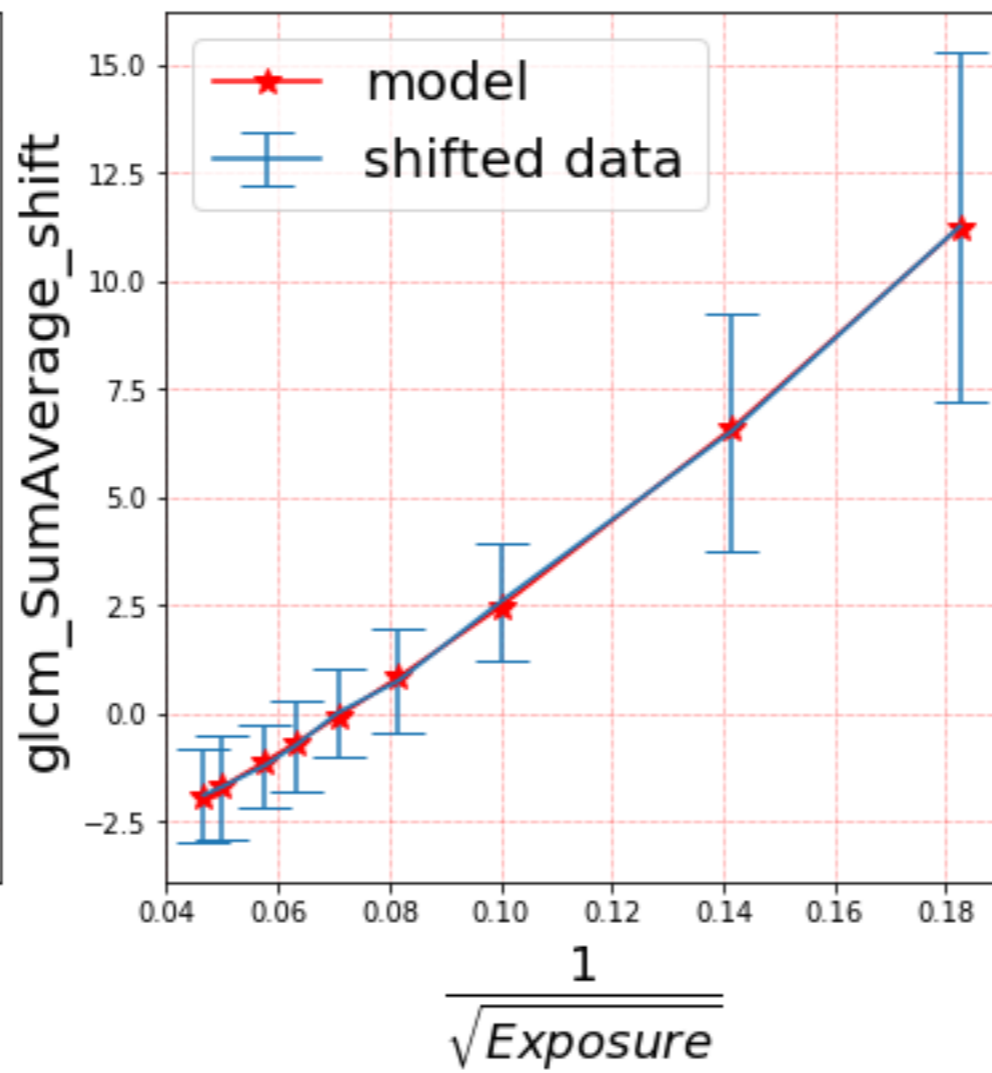




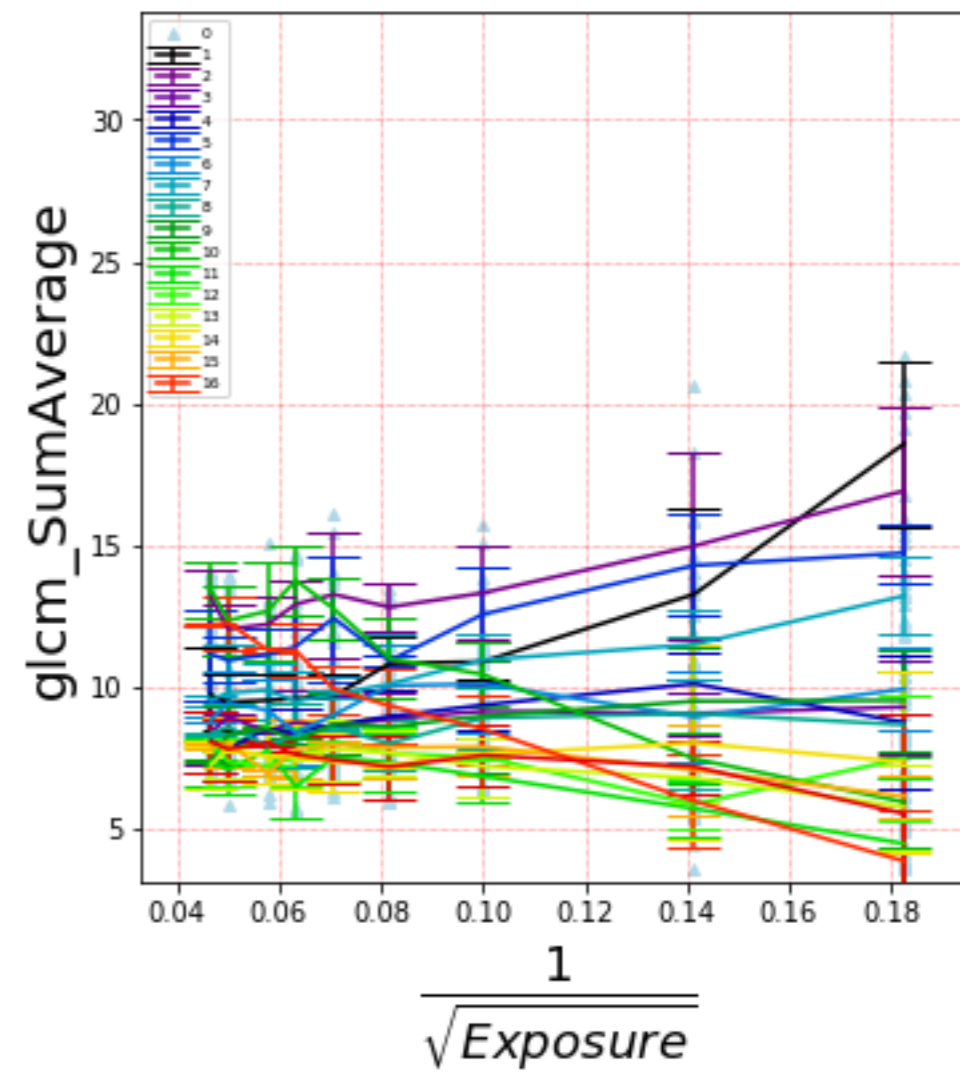
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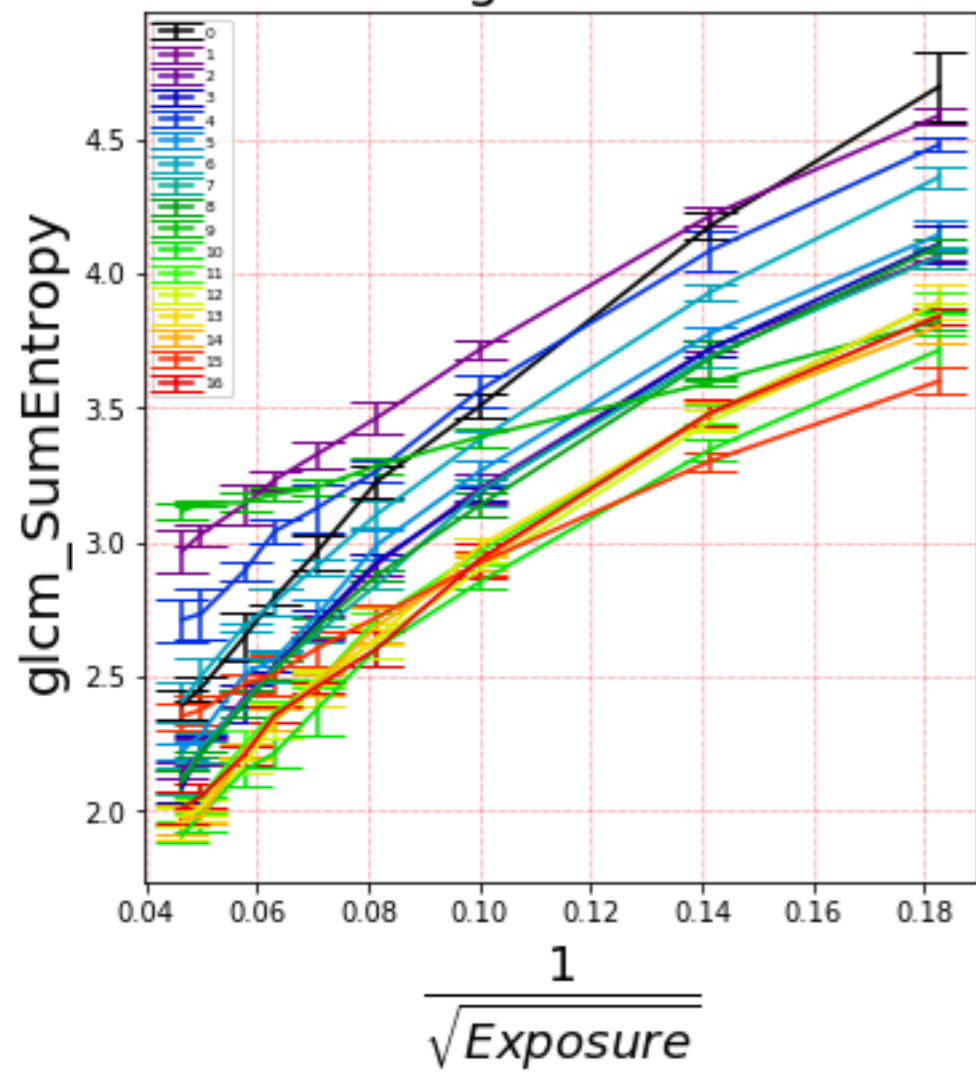
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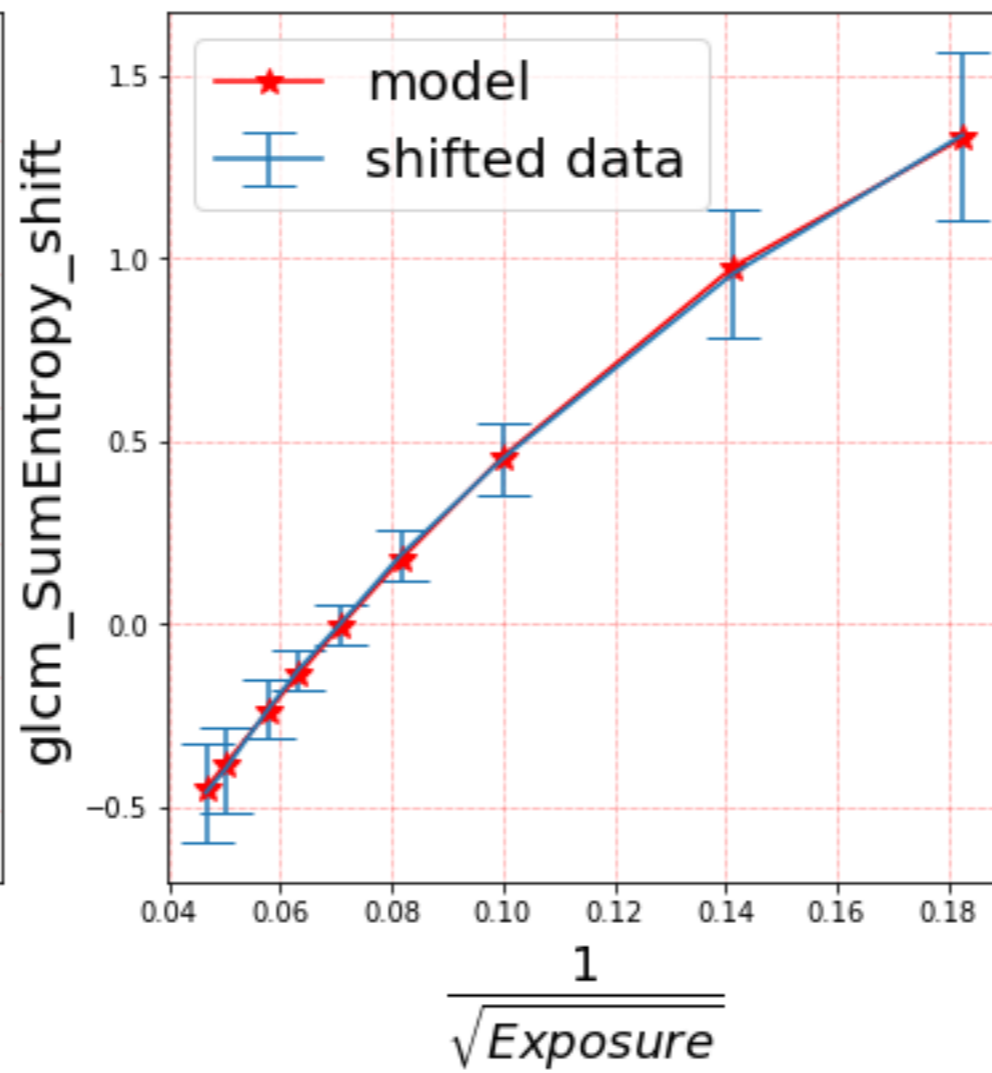
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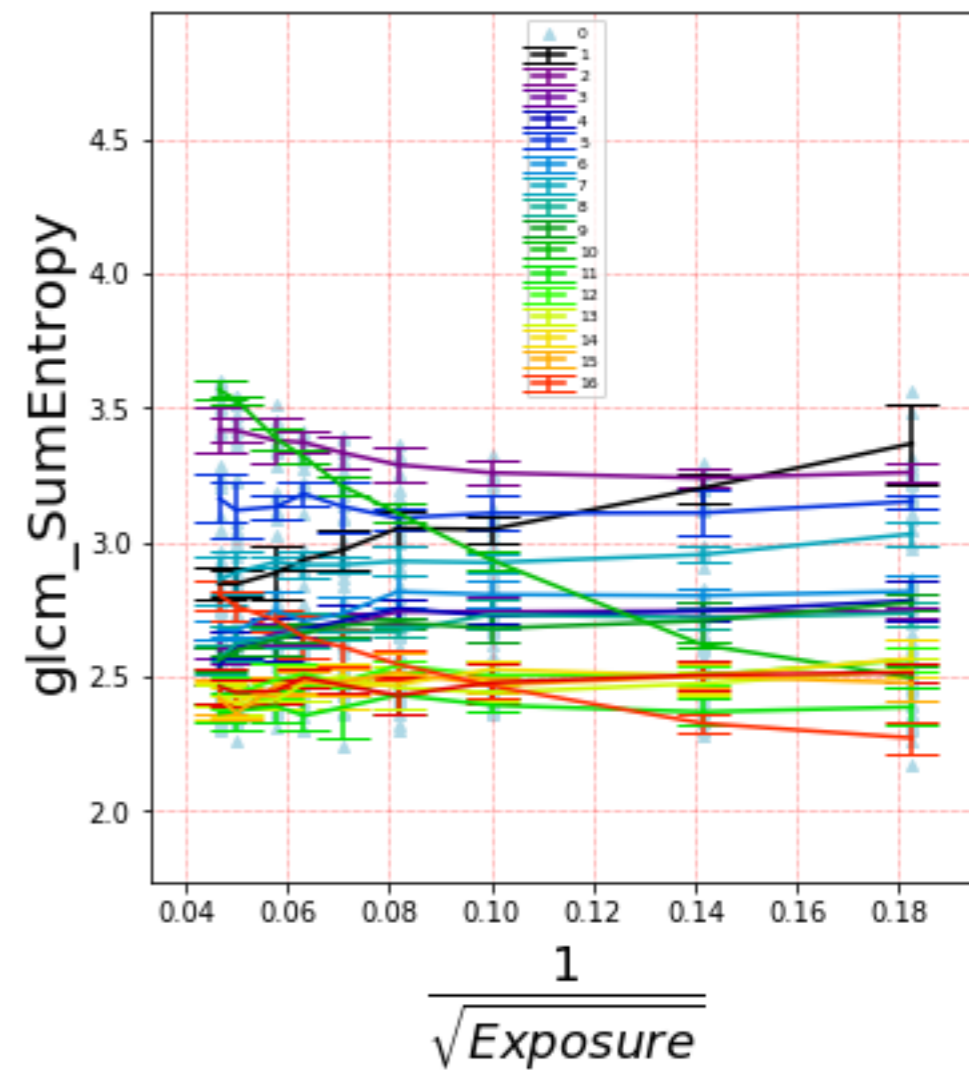
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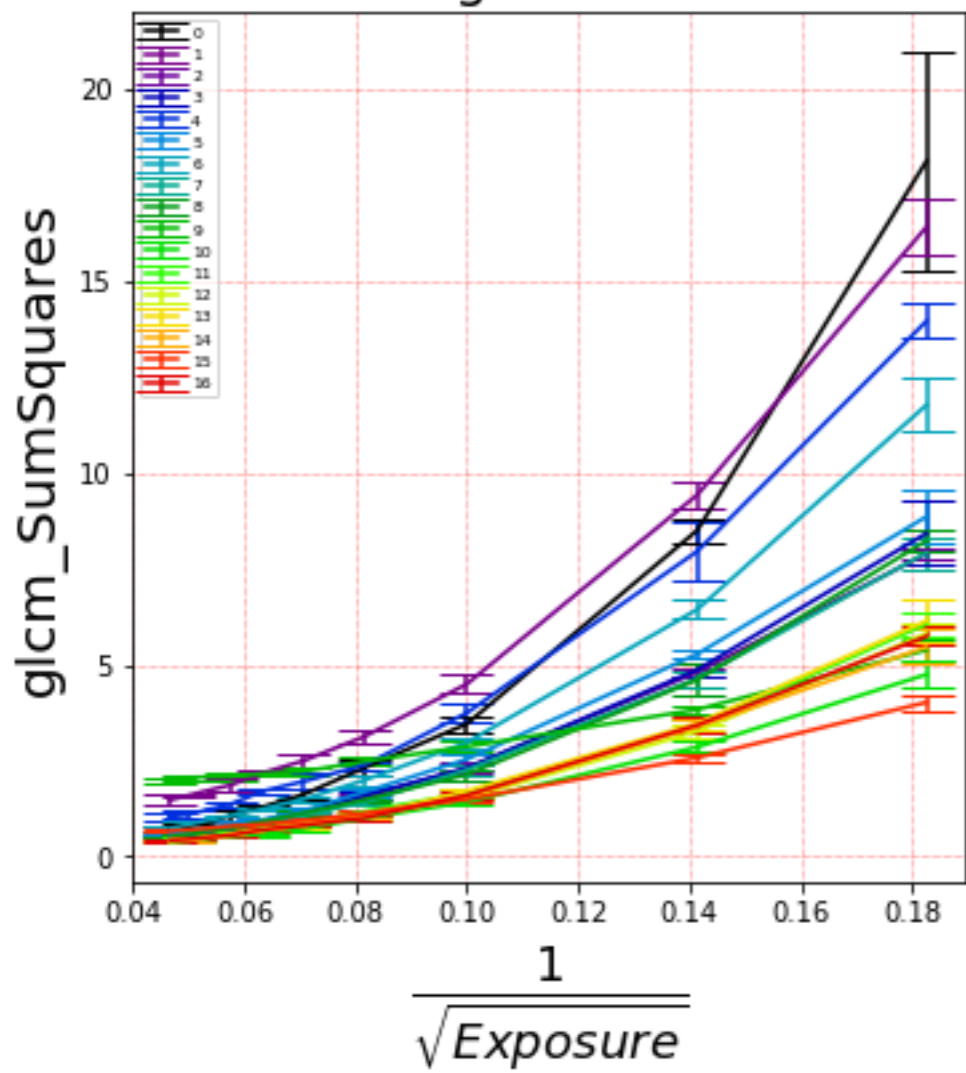
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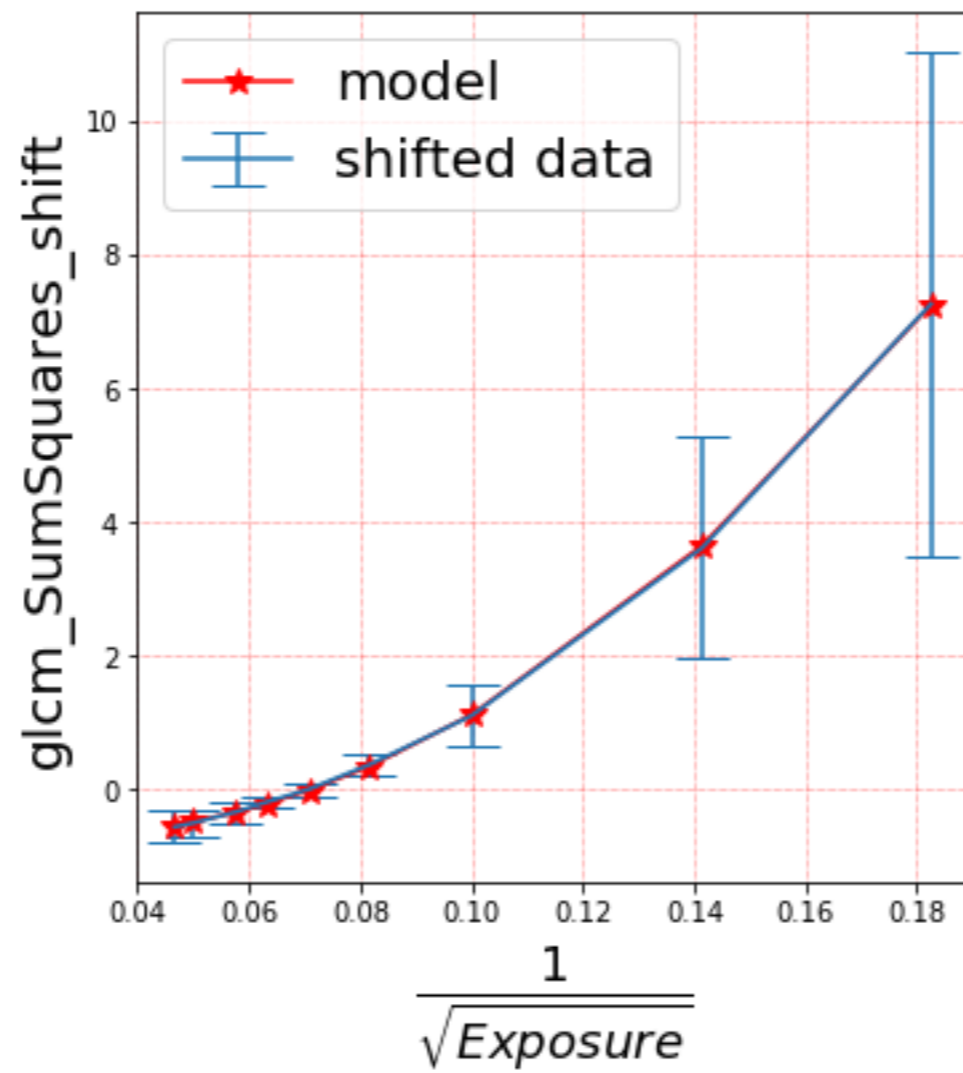
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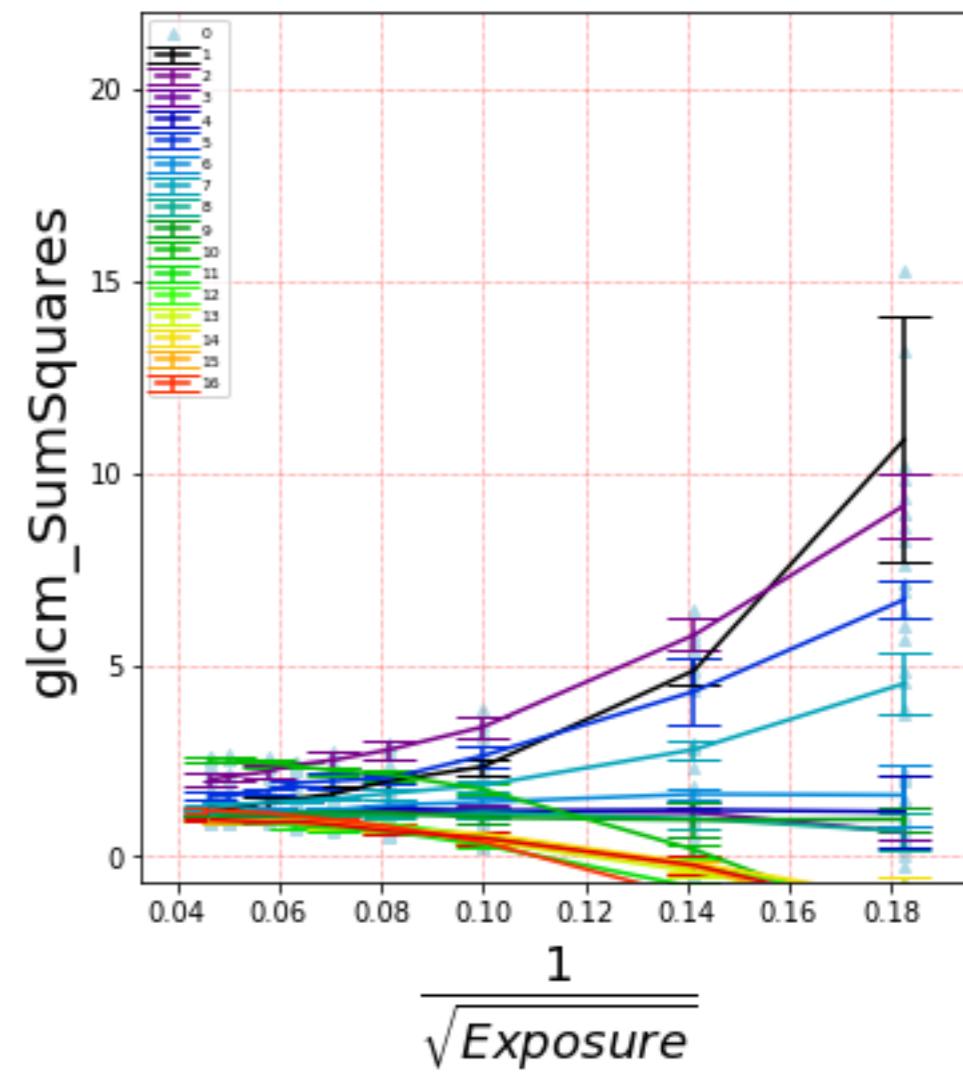
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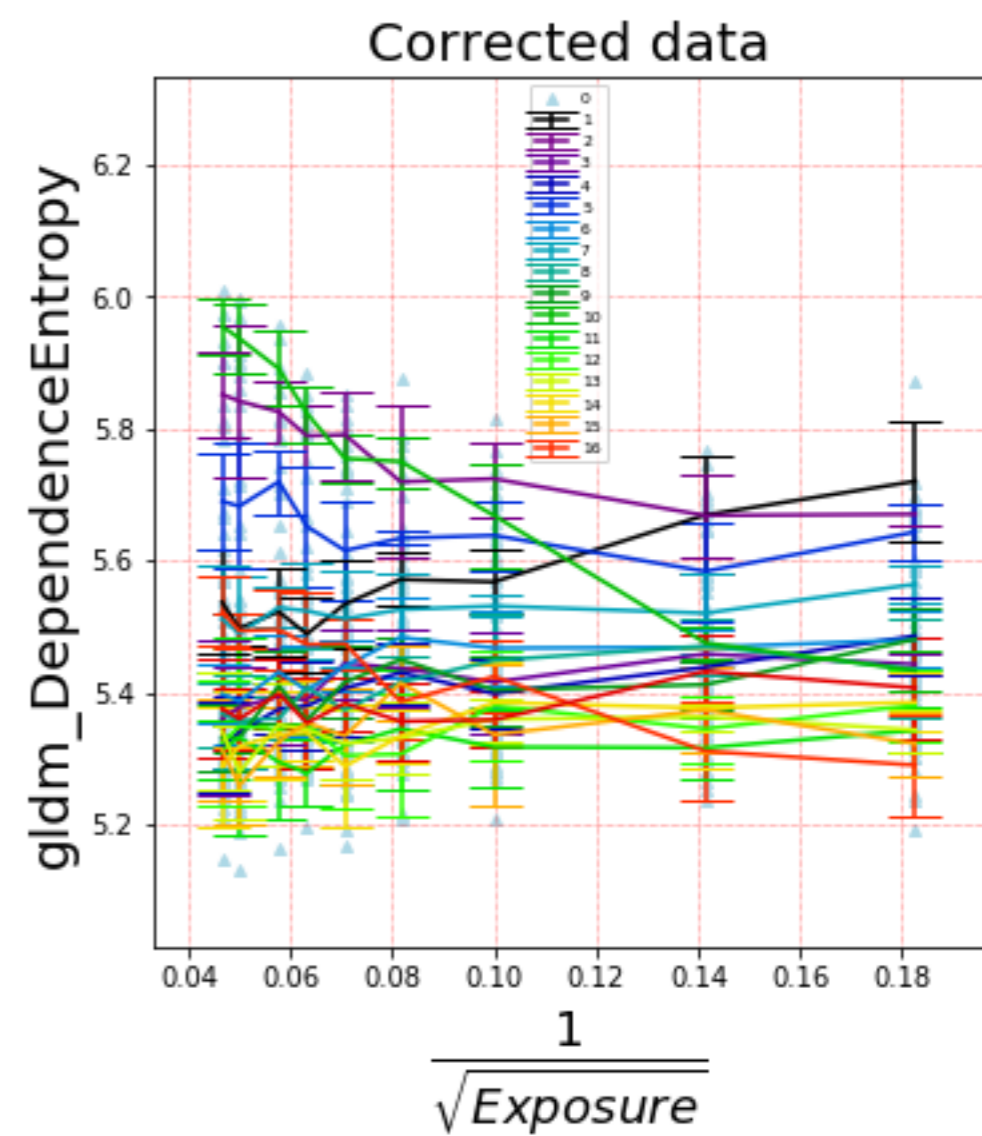
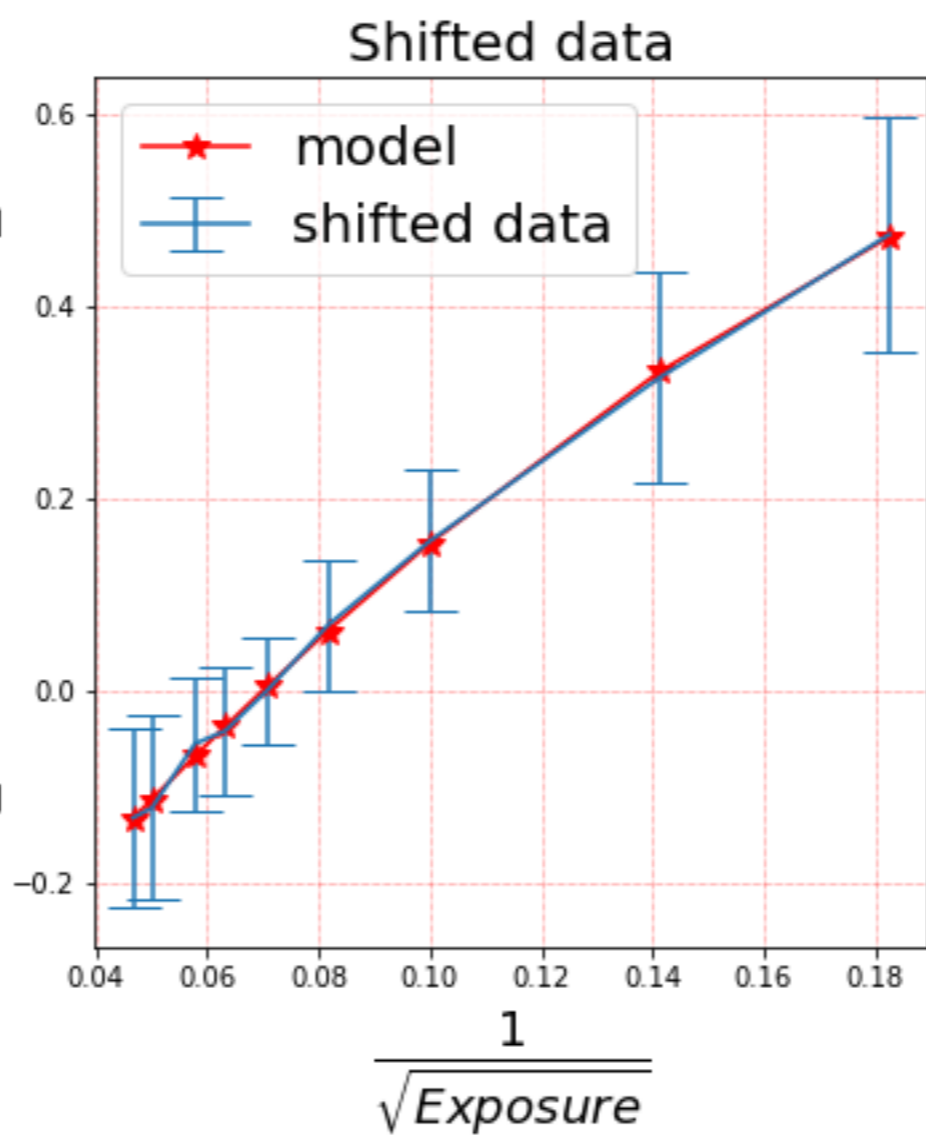
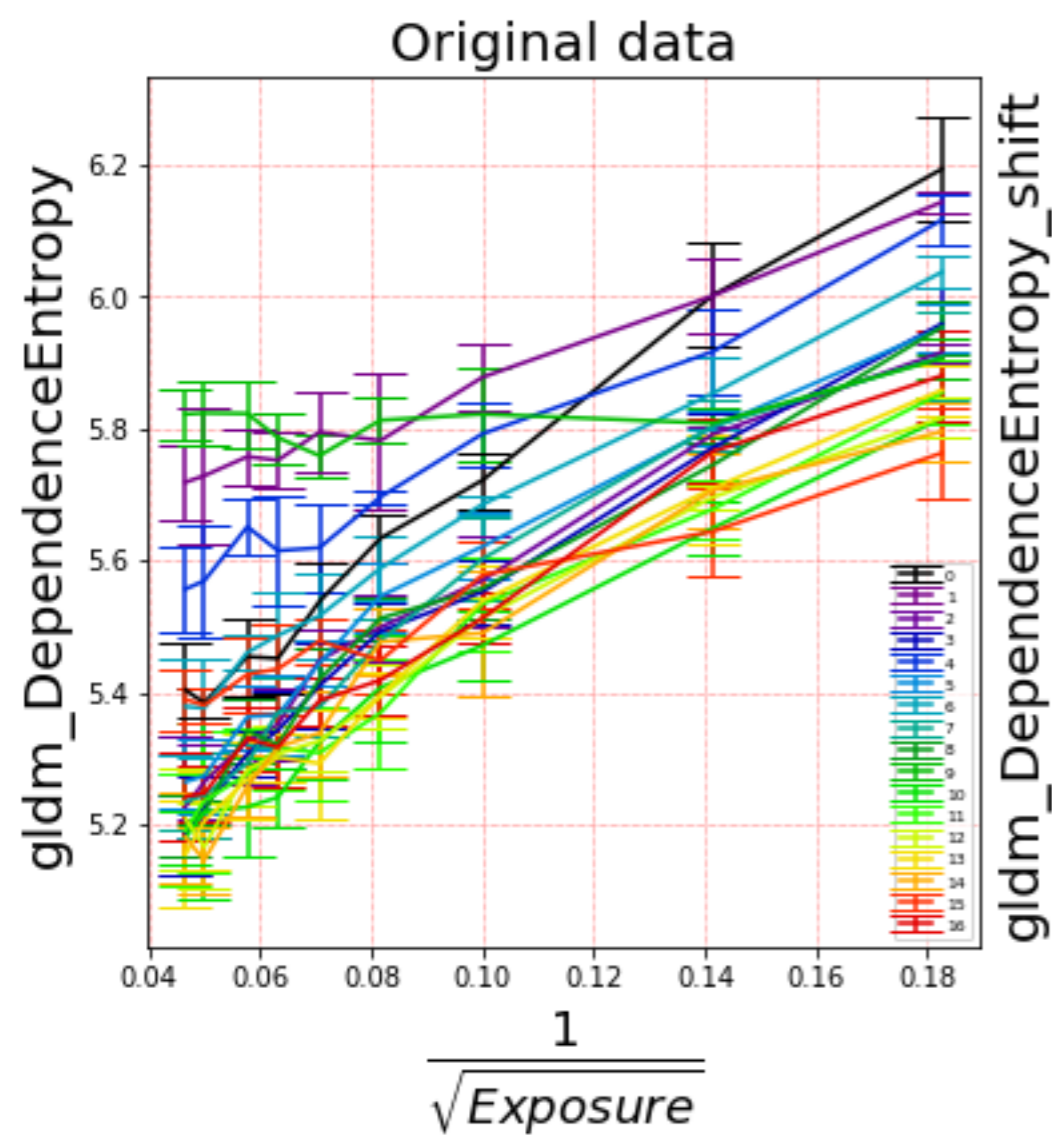


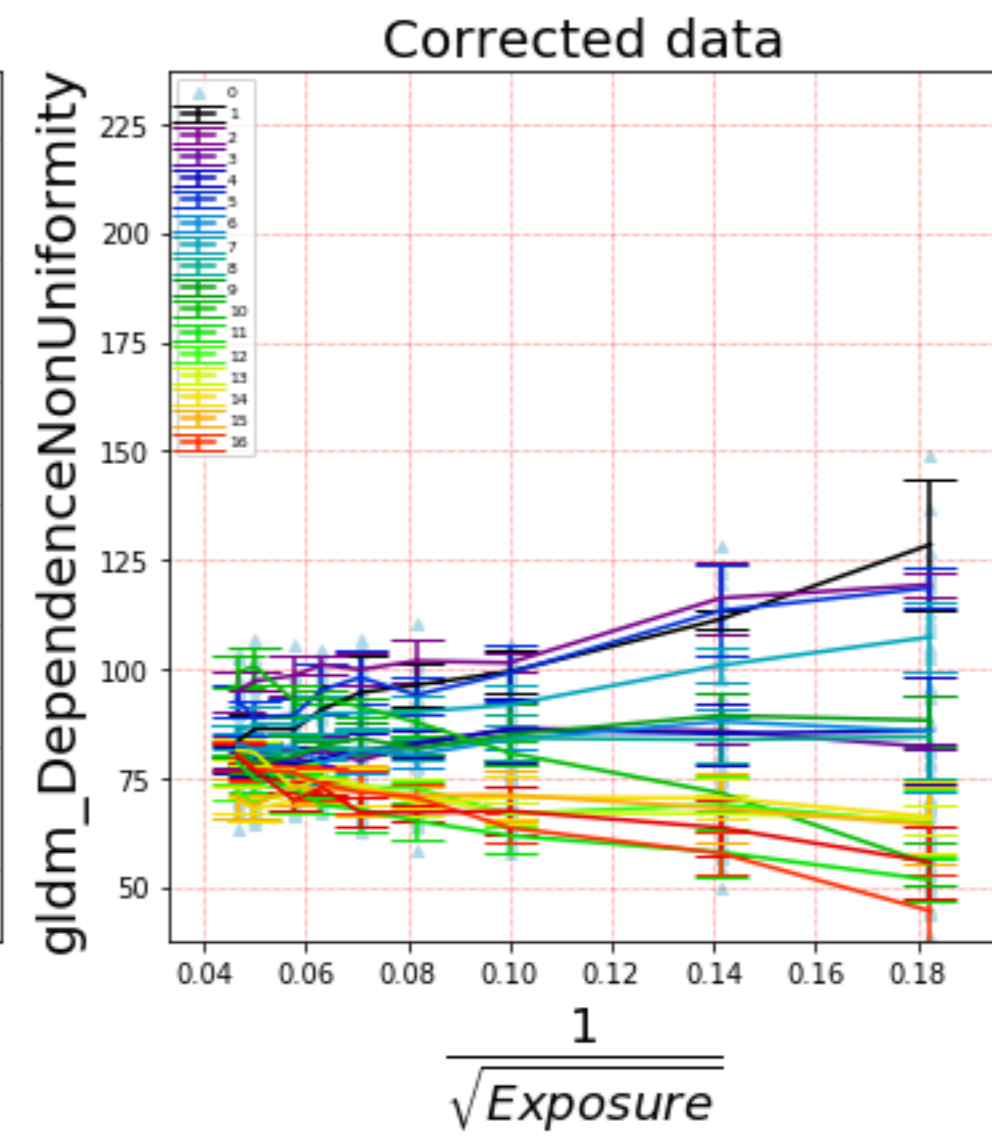
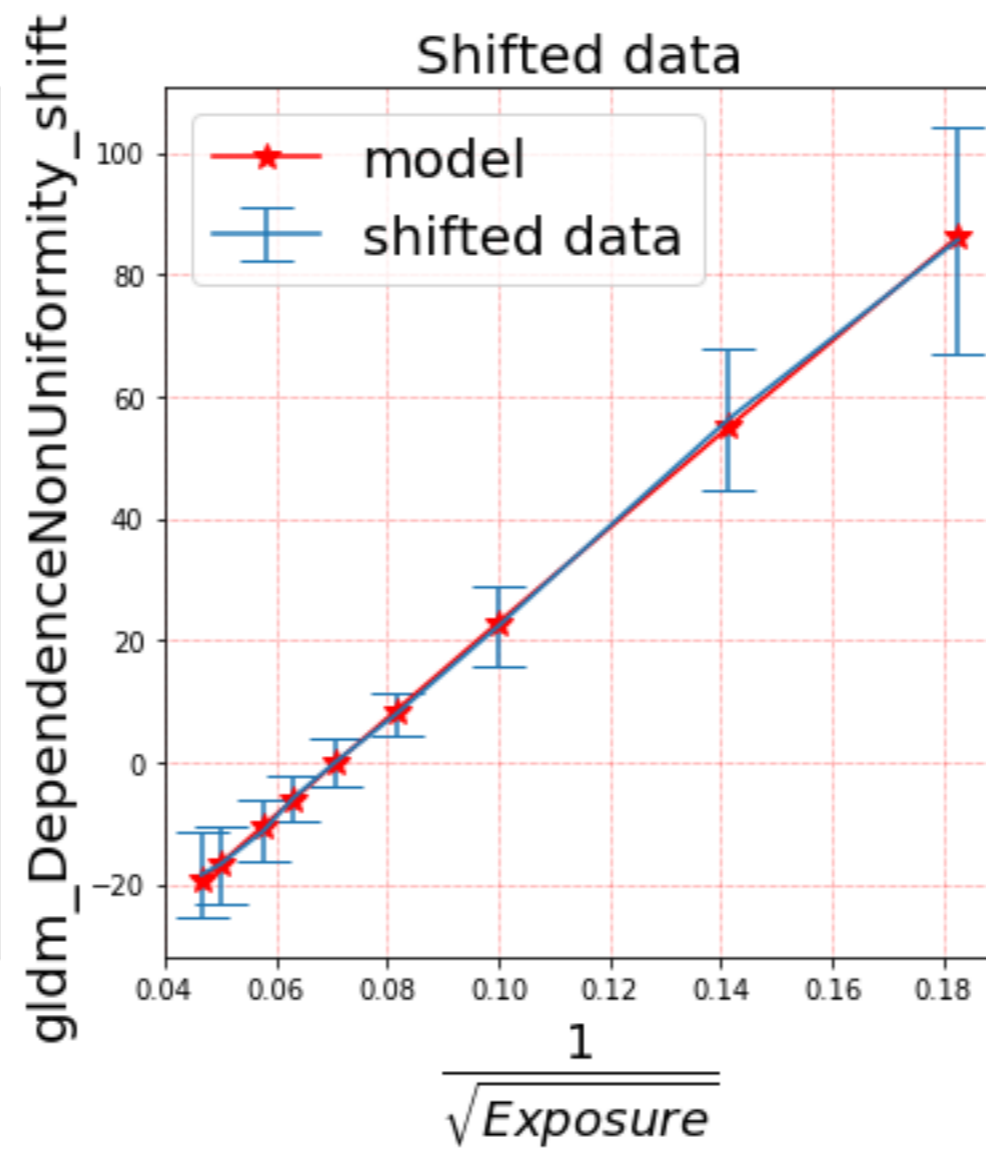
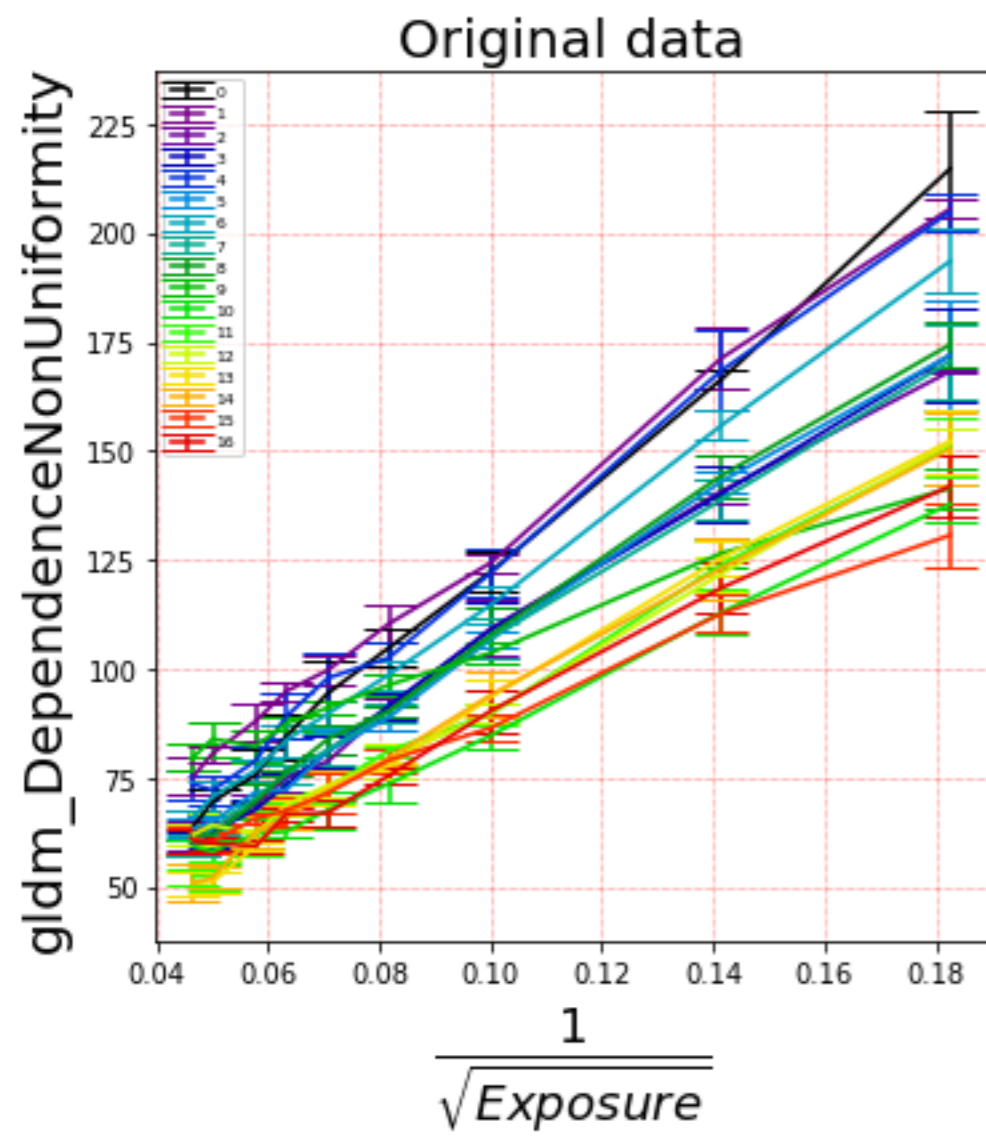
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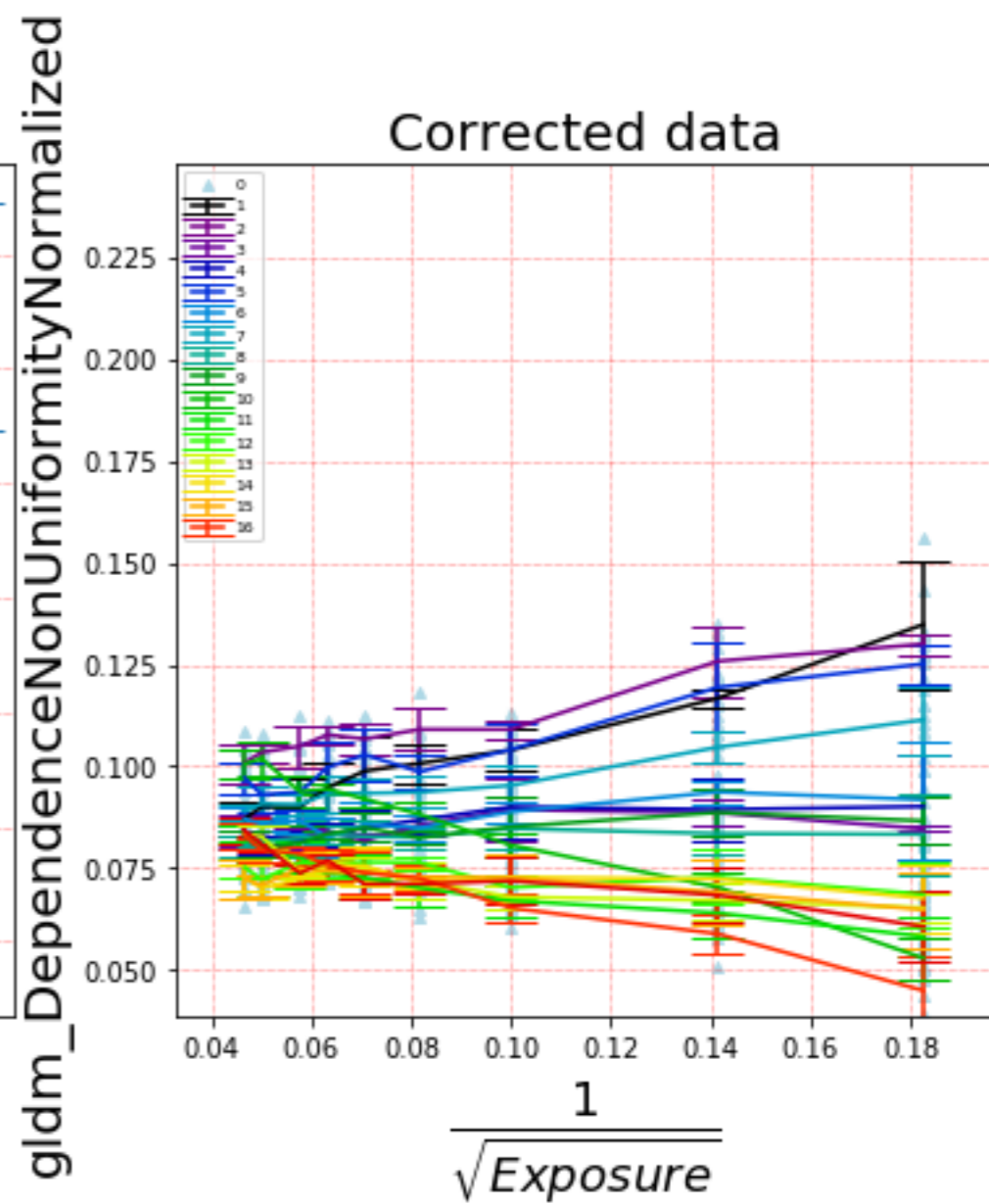
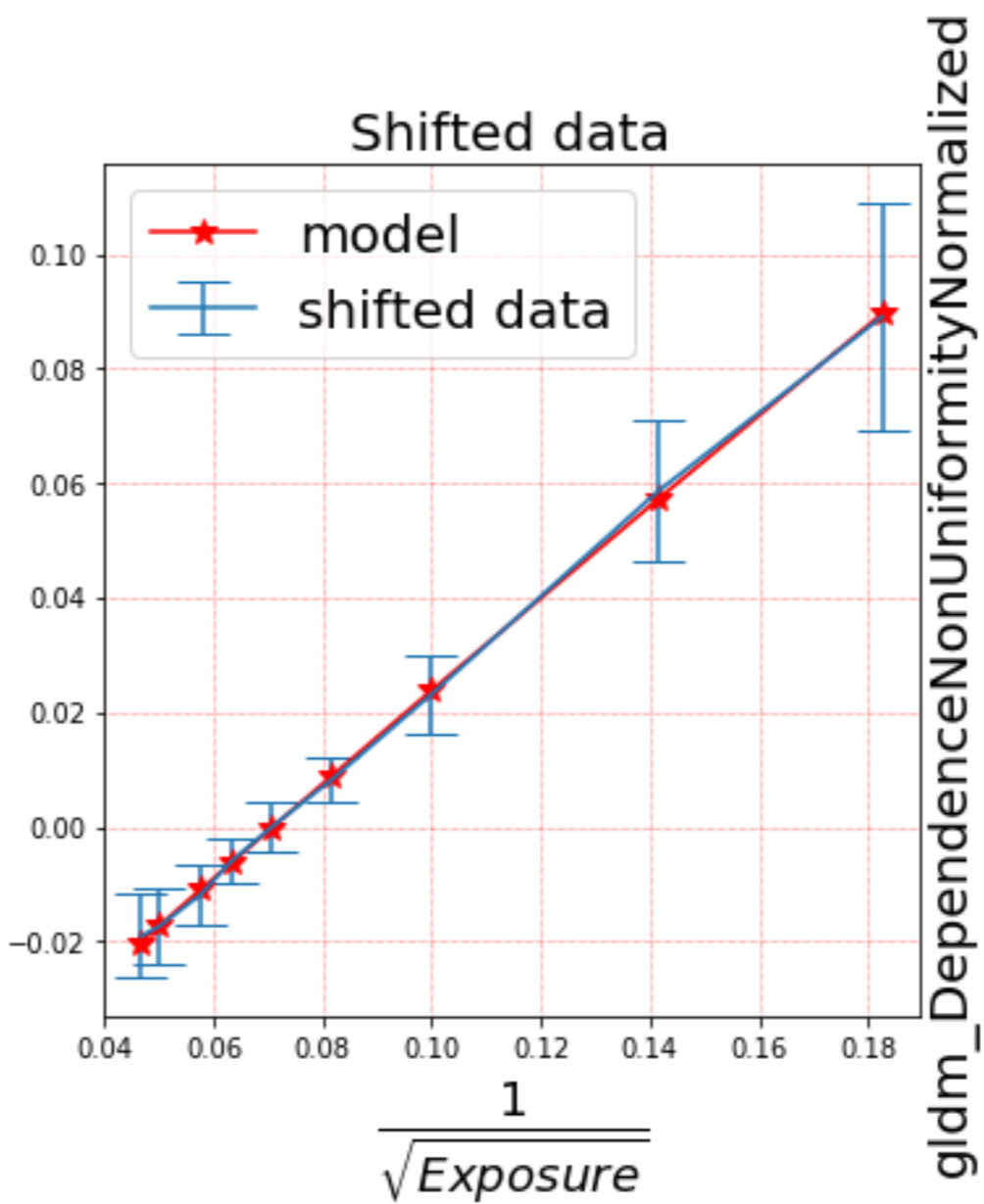
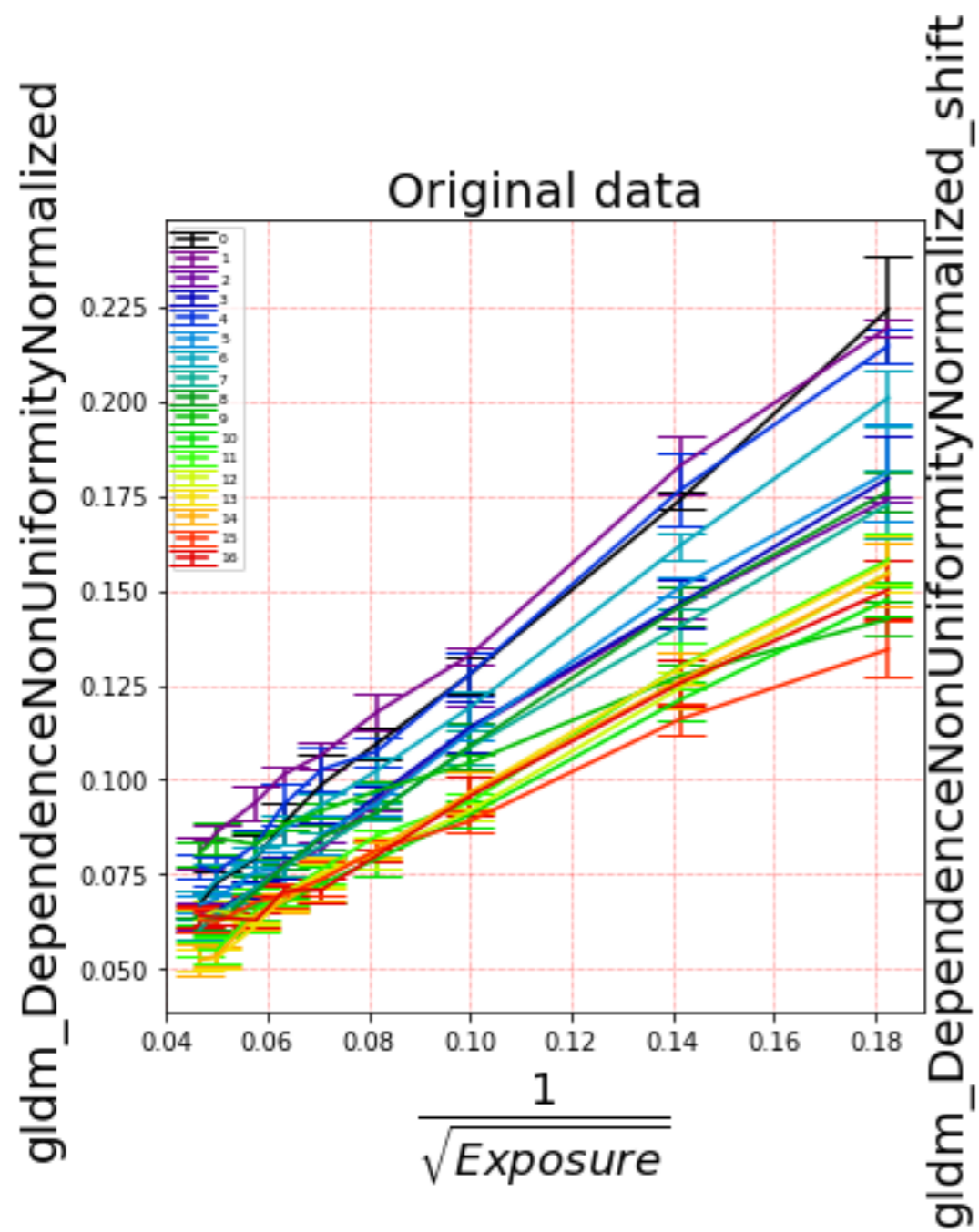


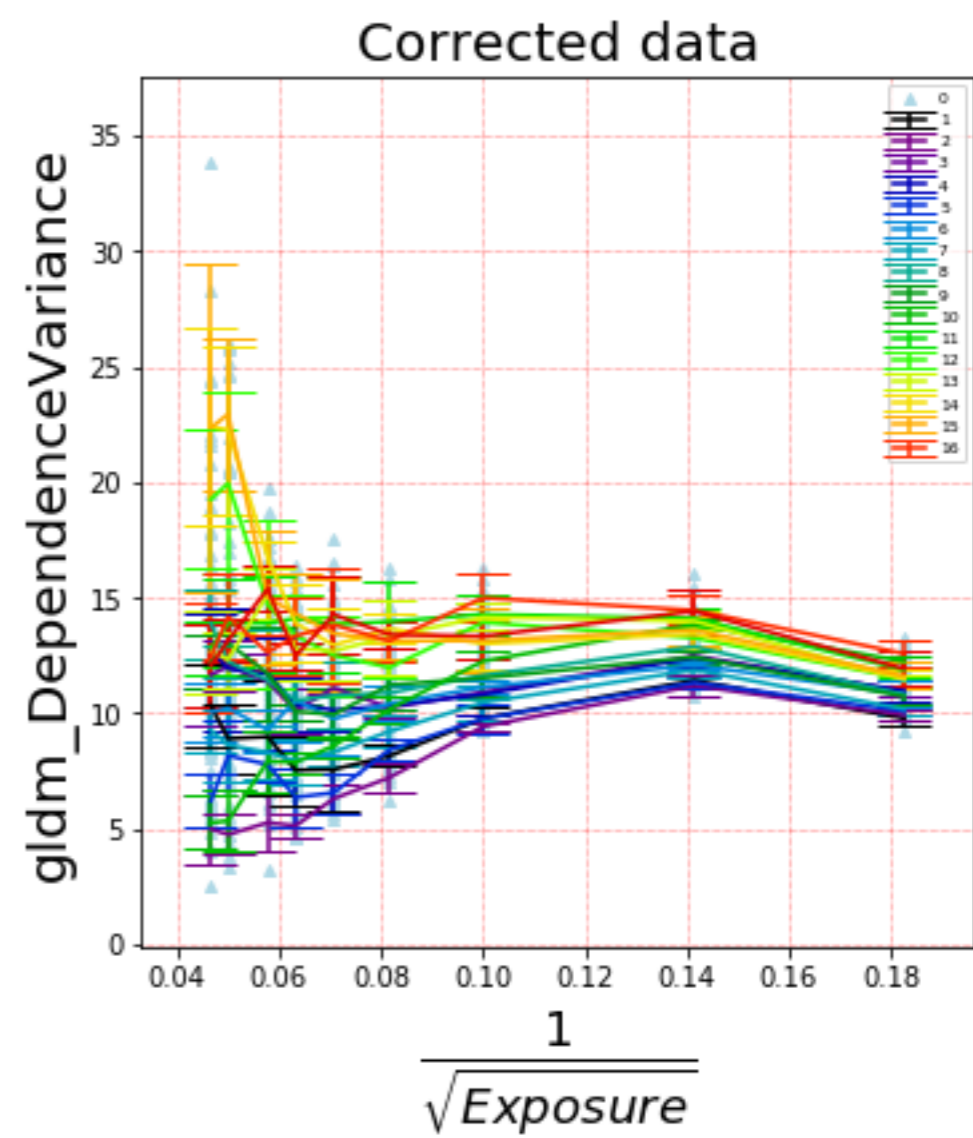
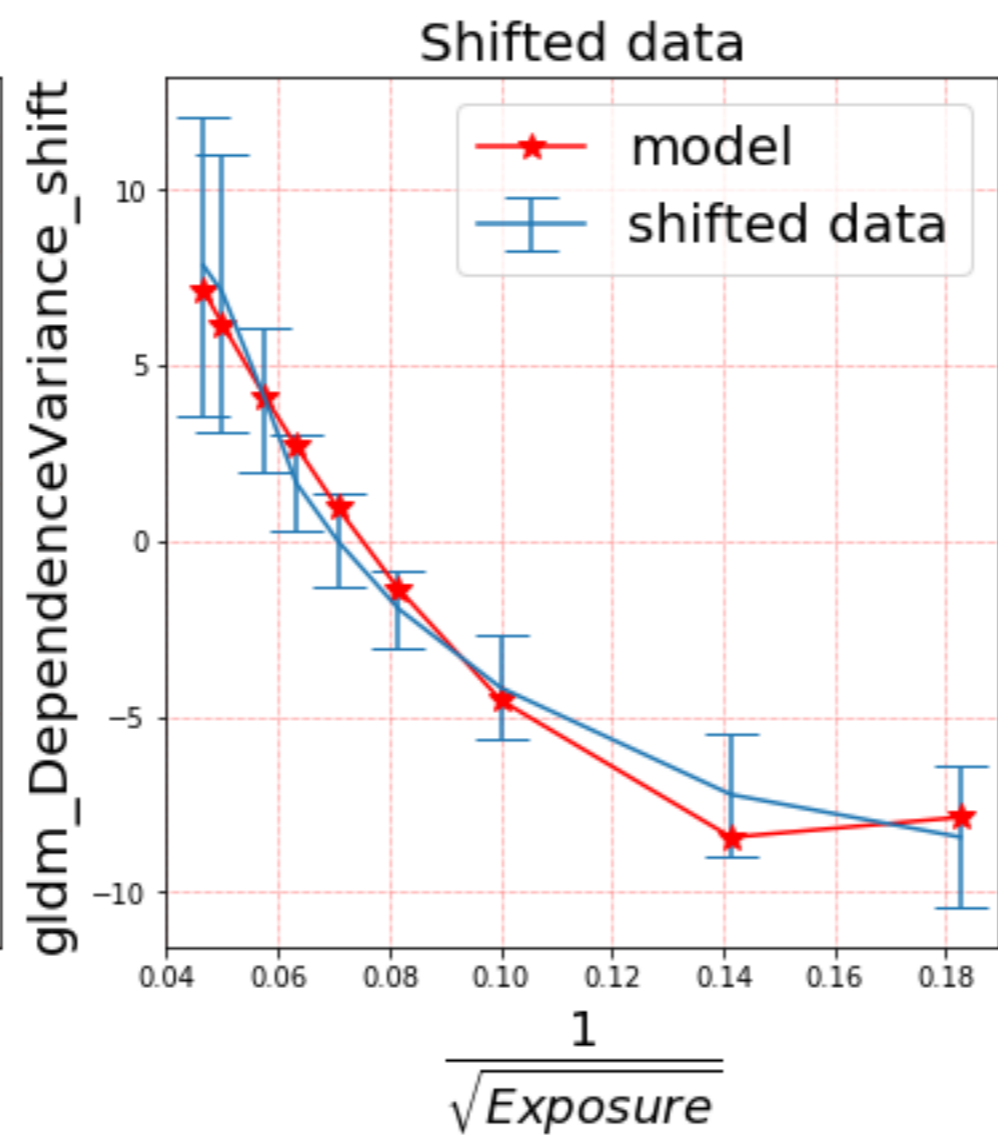
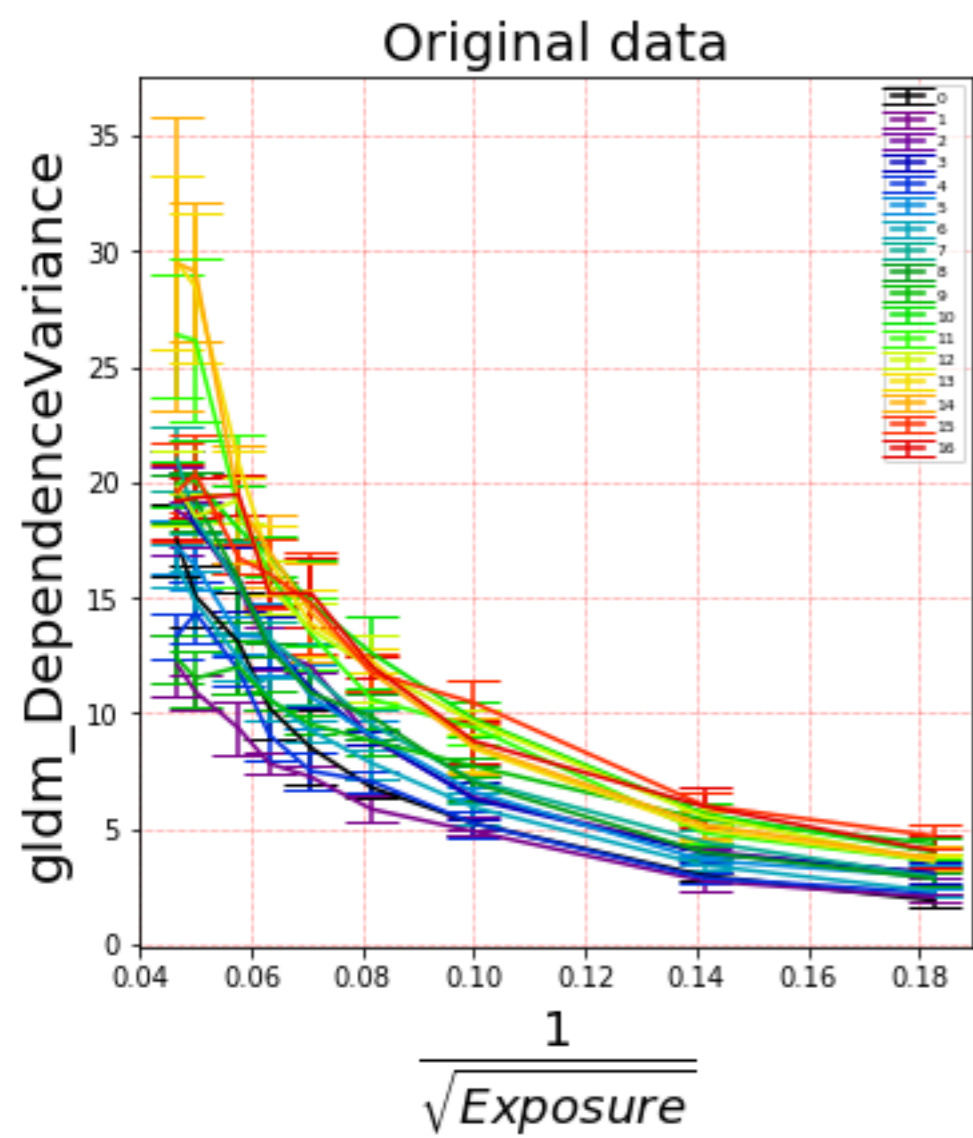
Corrected data

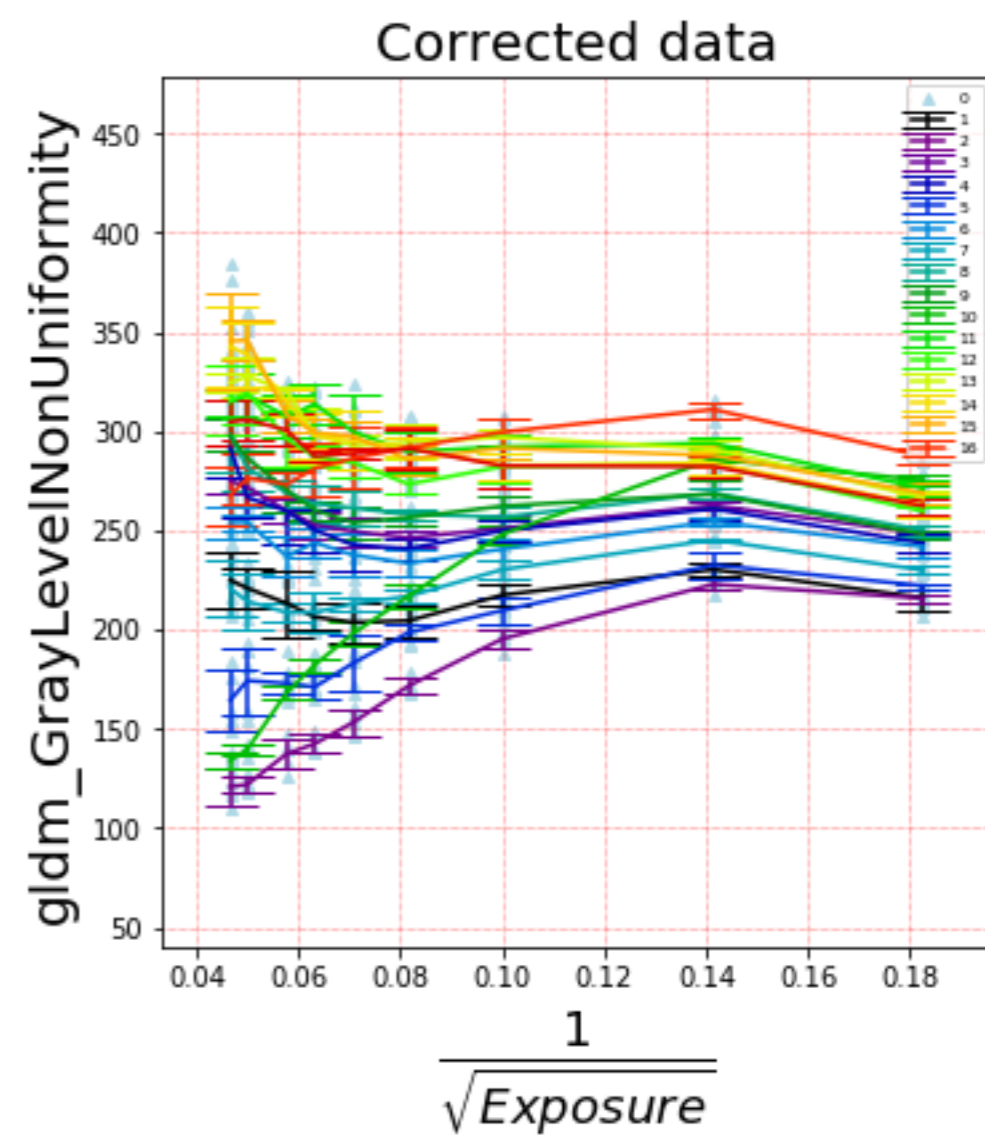
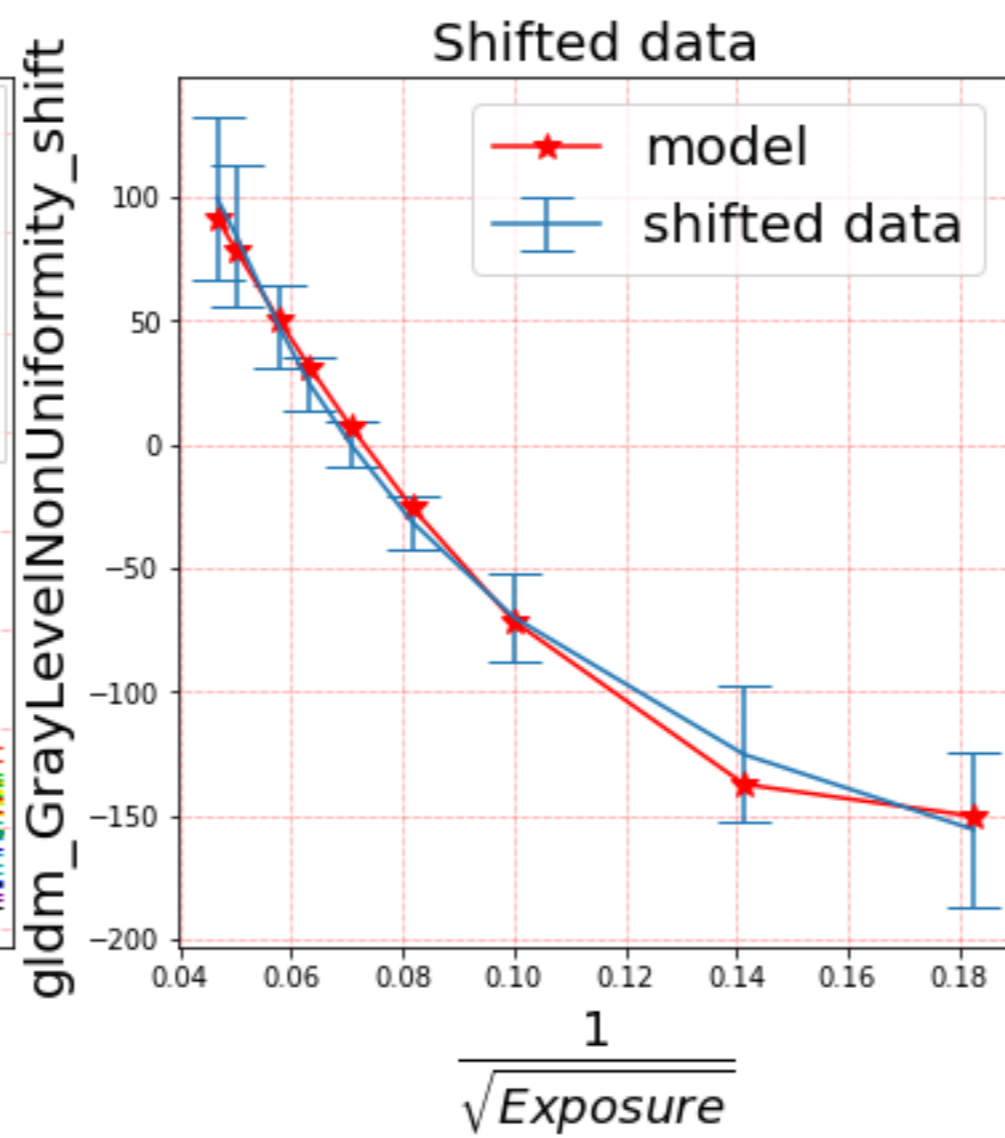
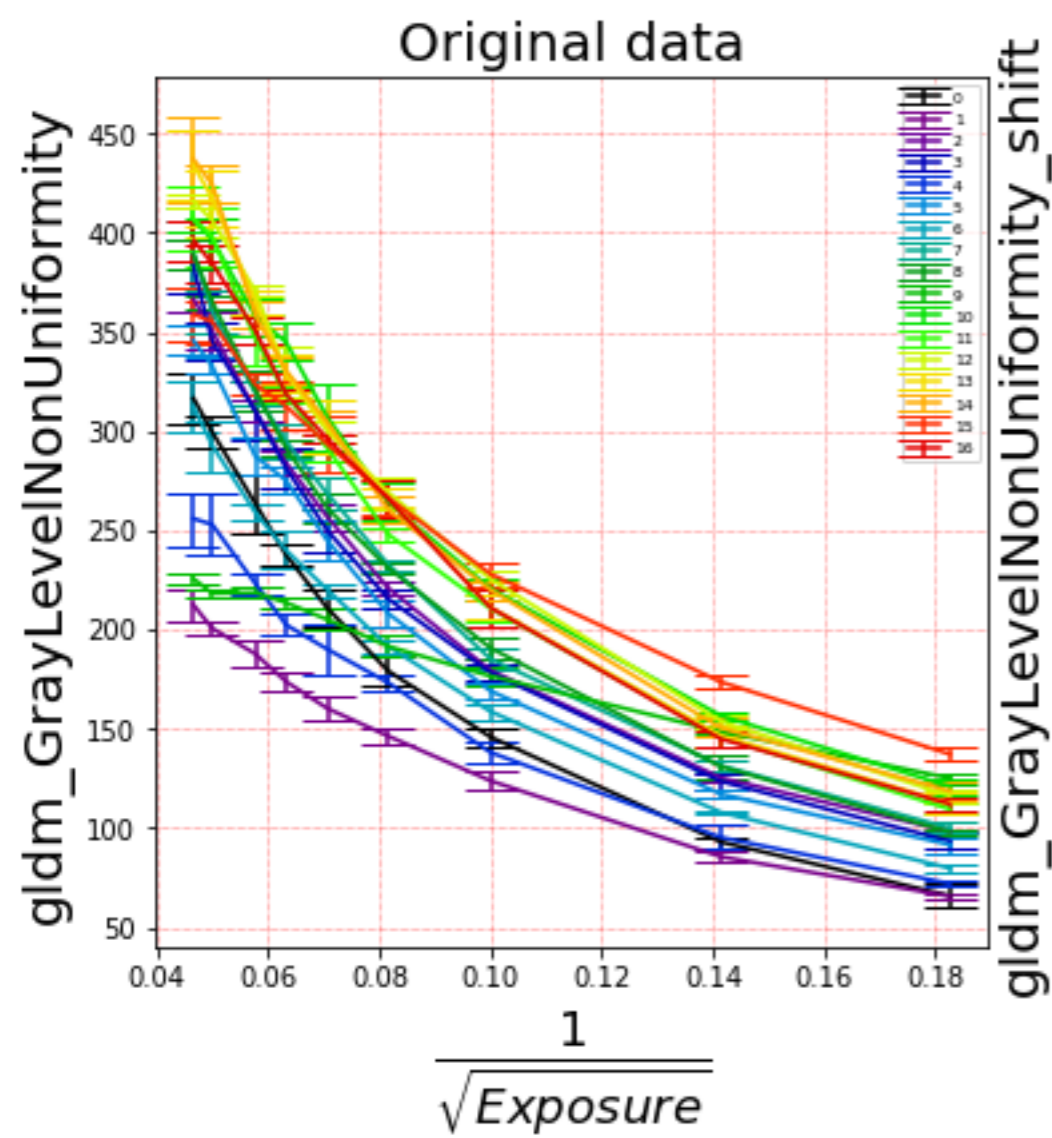




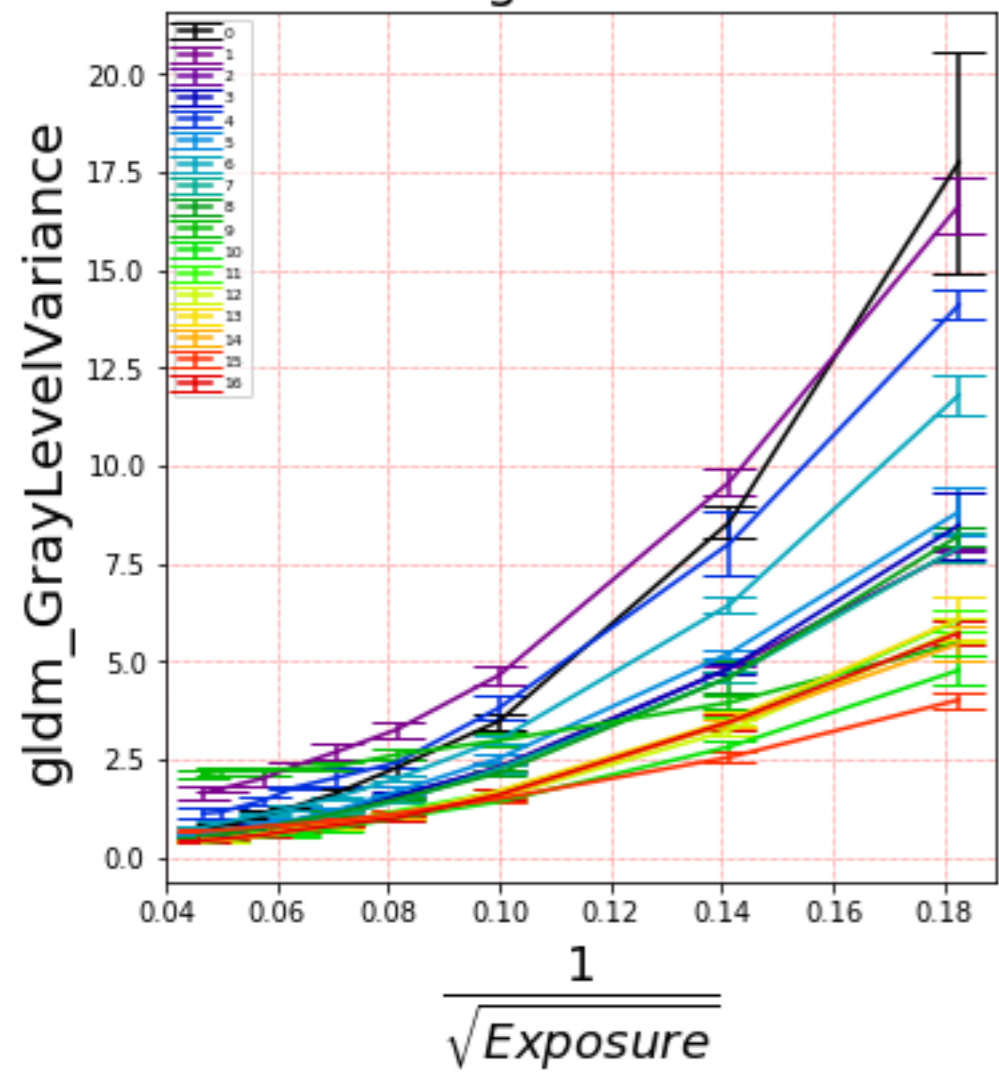




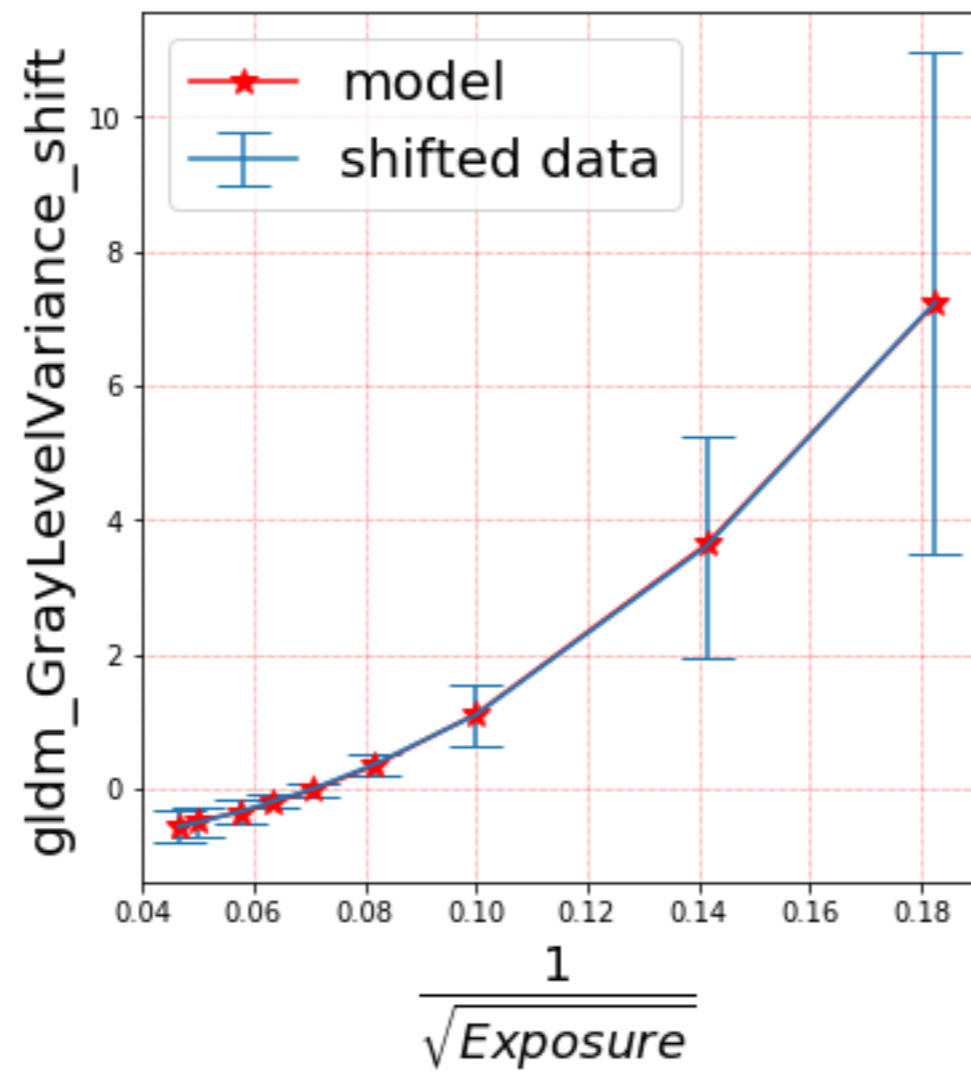




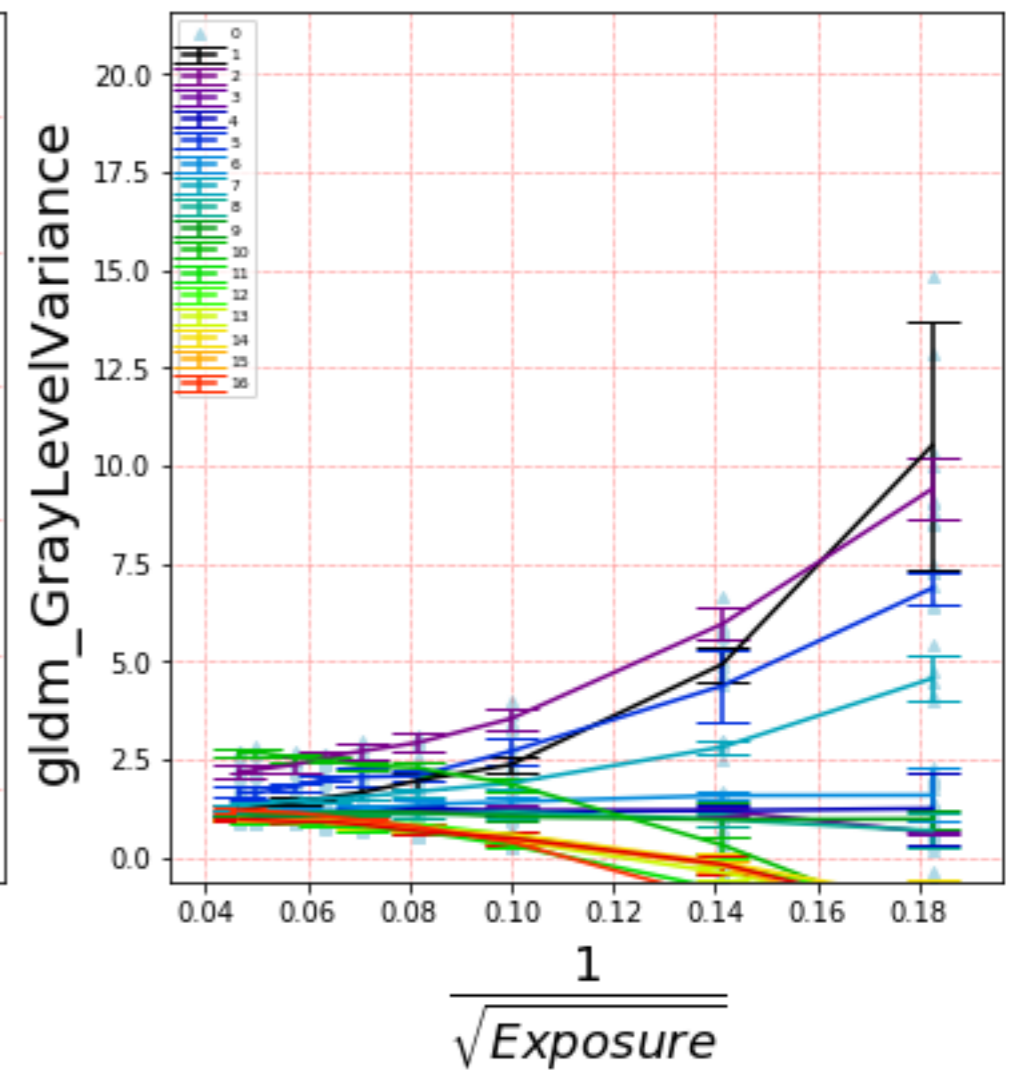
Original data

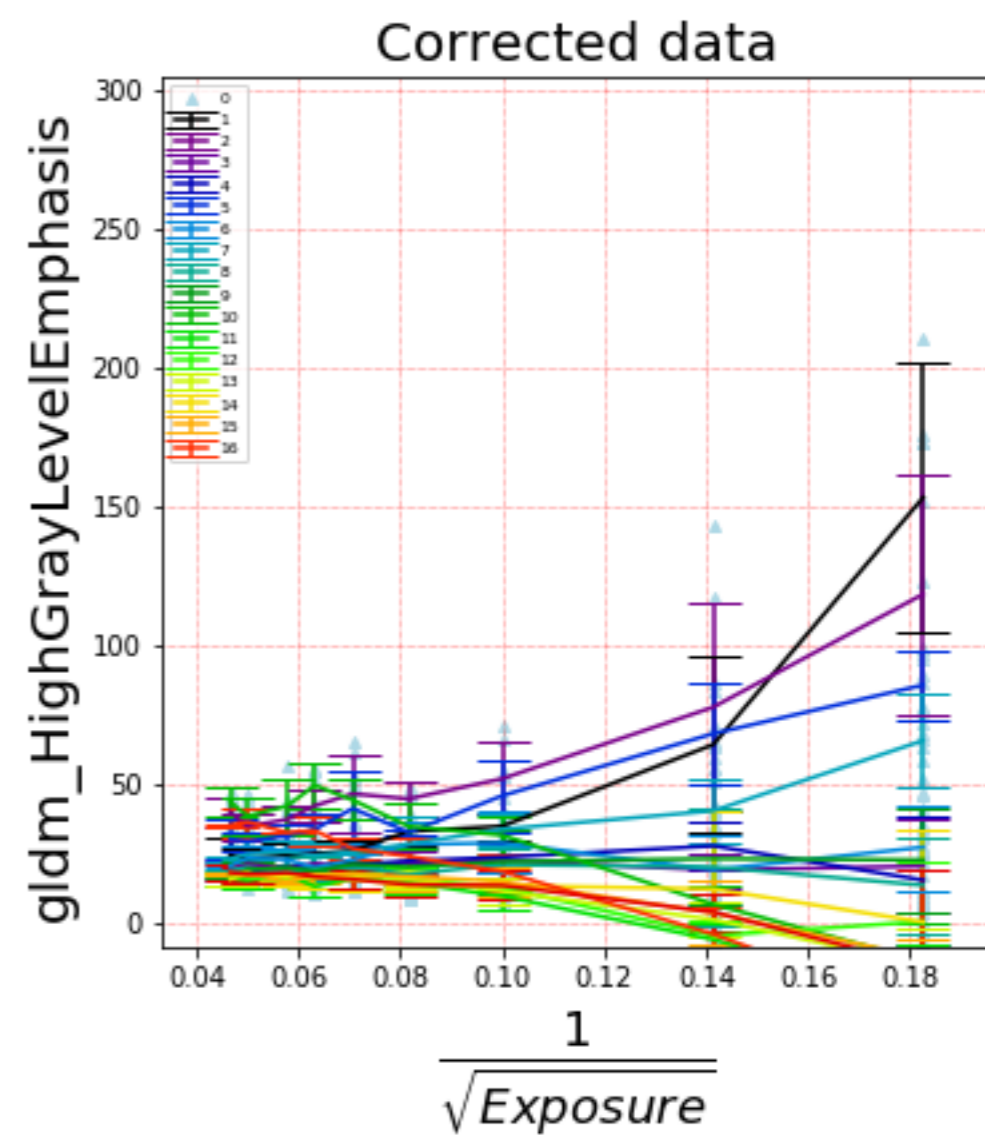
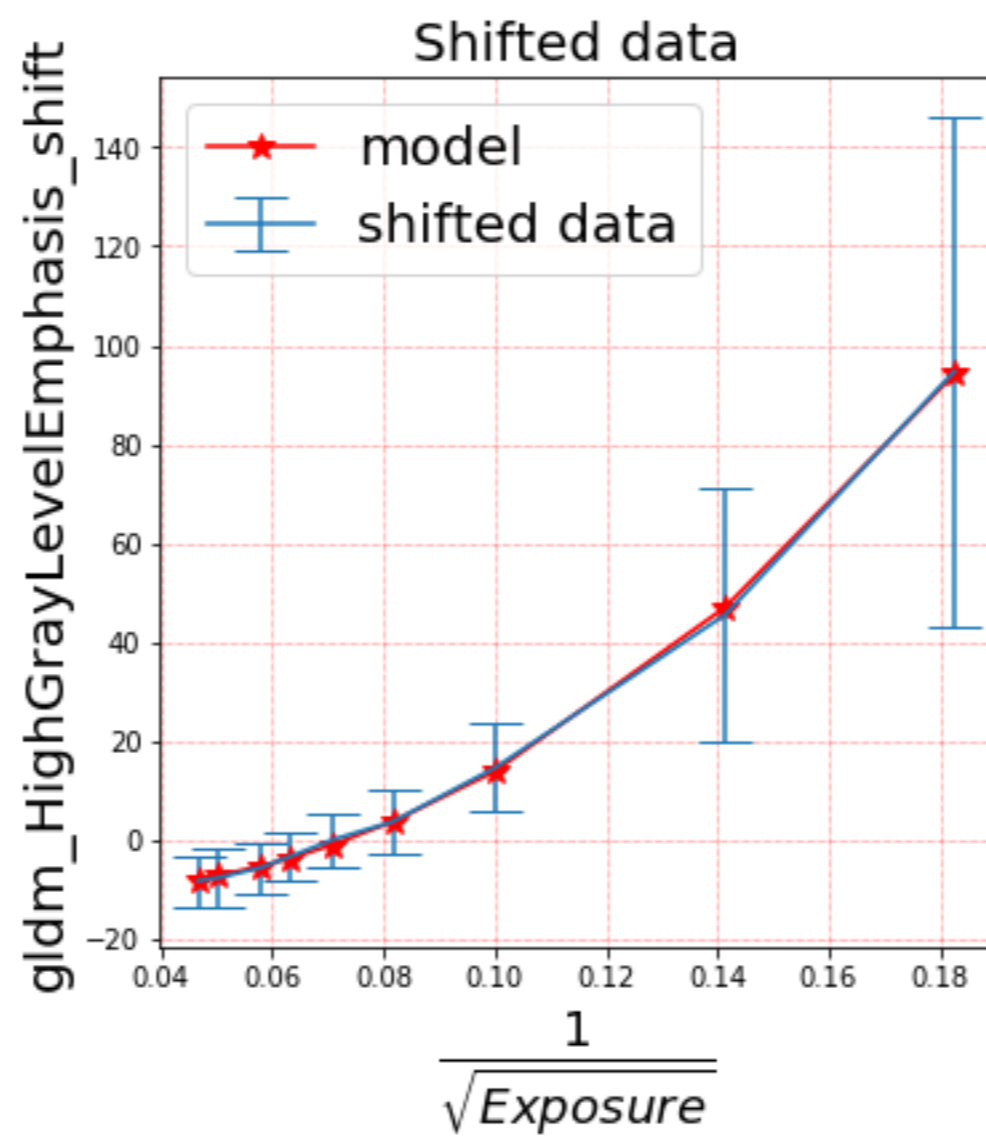
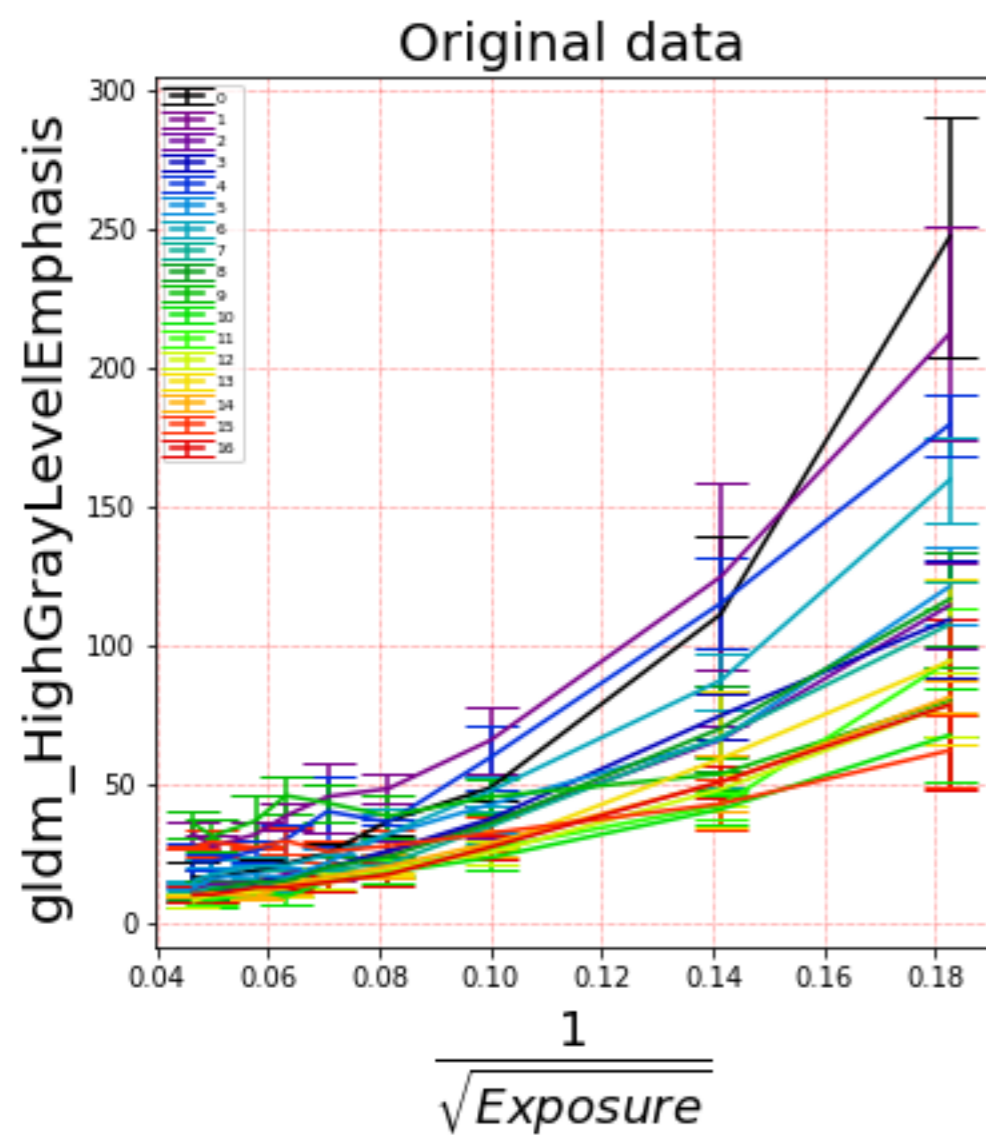


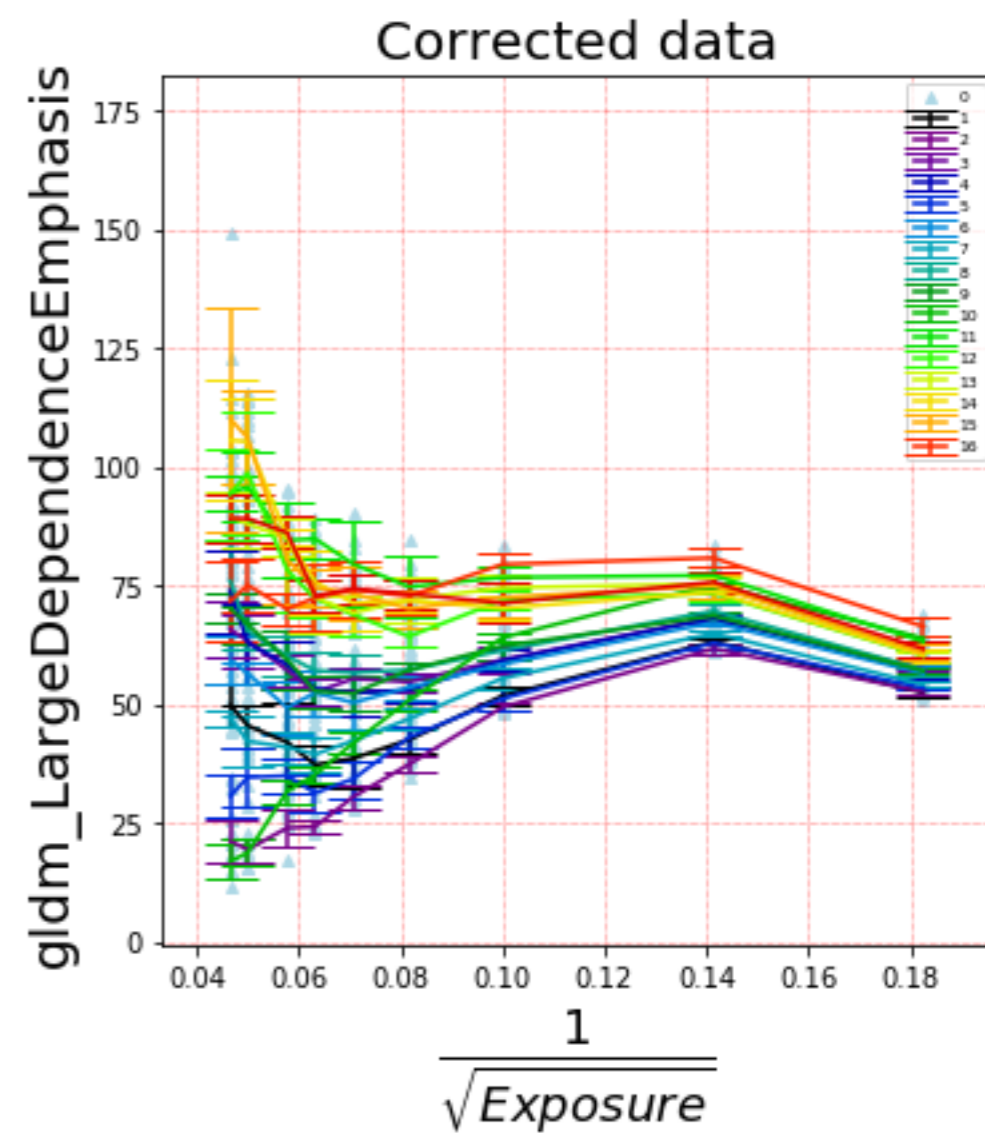
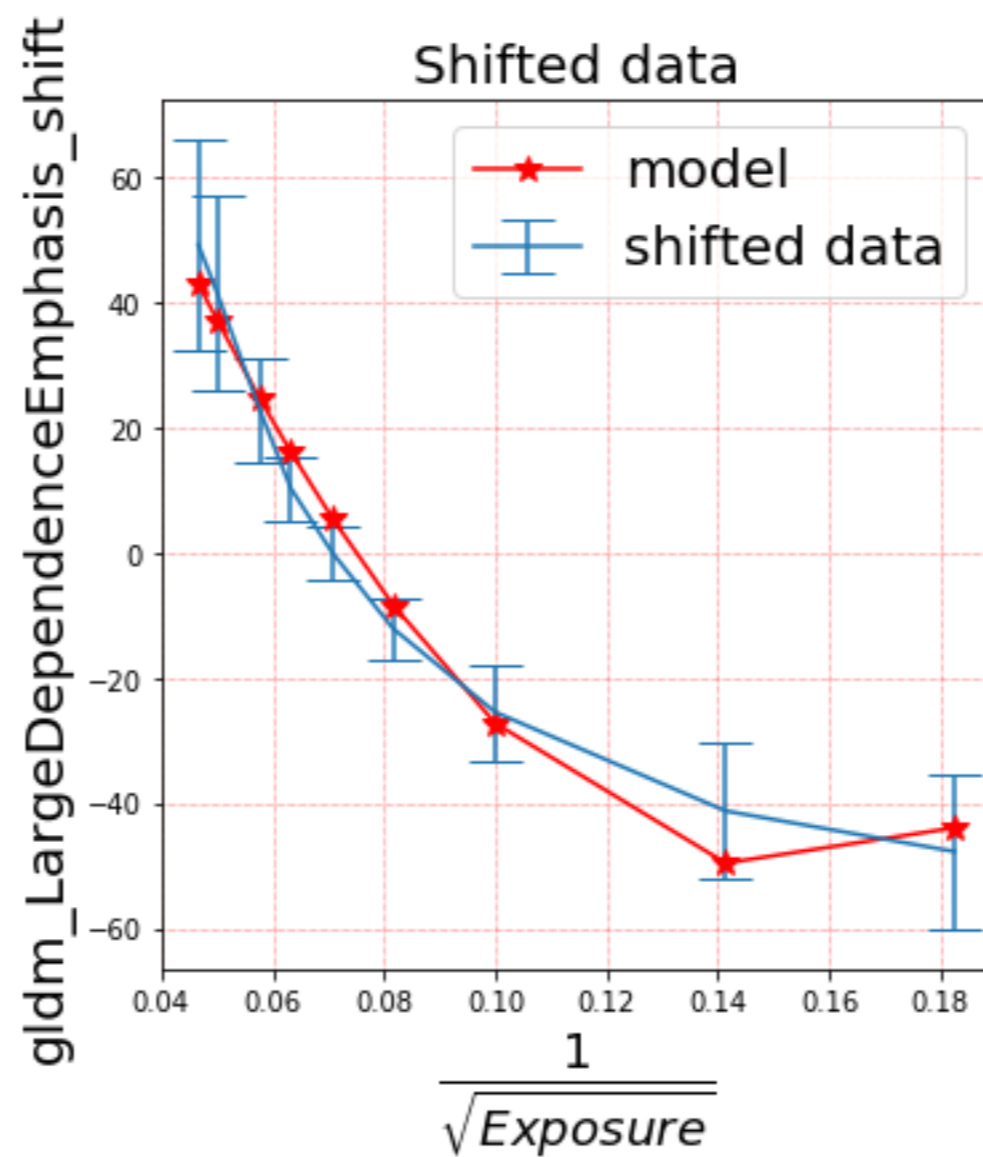
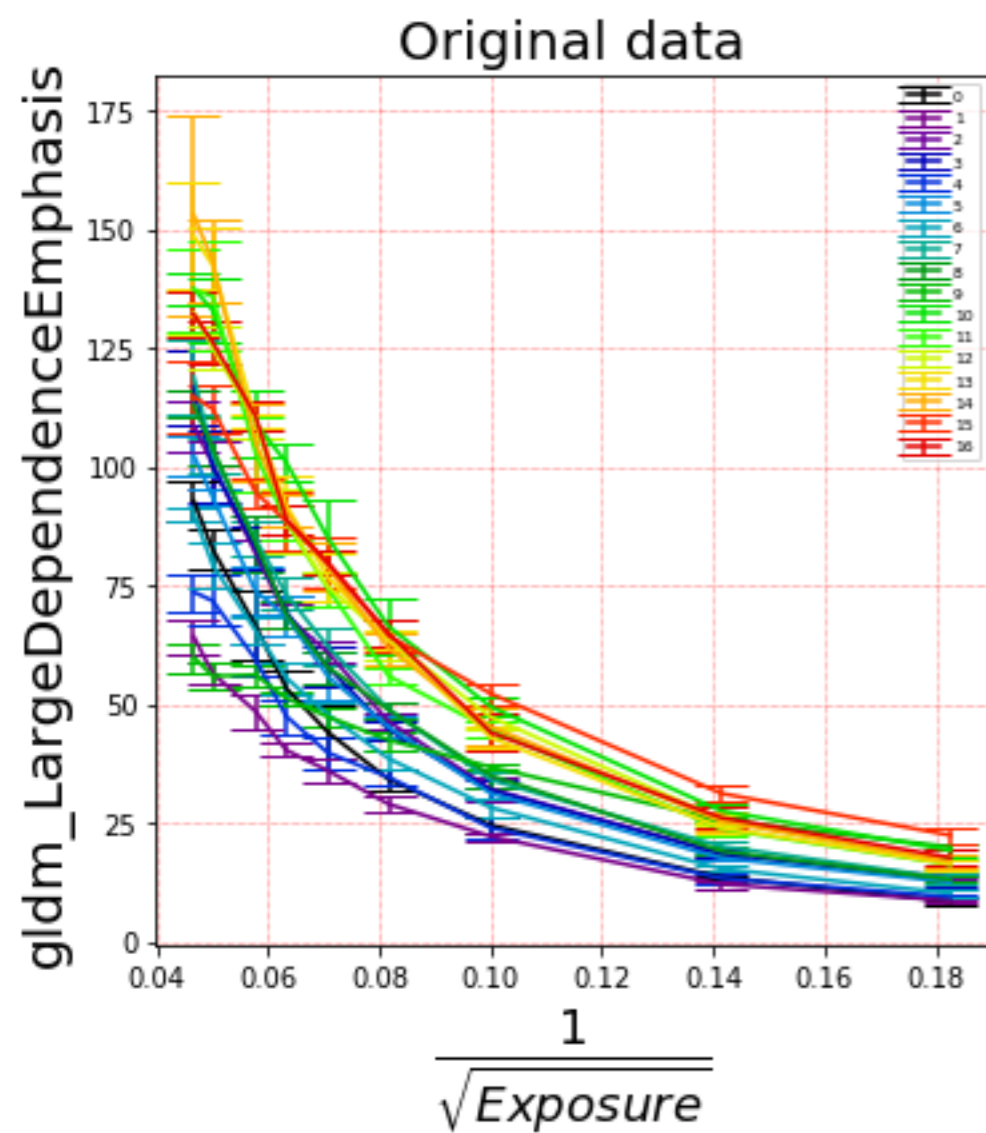
Shifted data



Corrected data

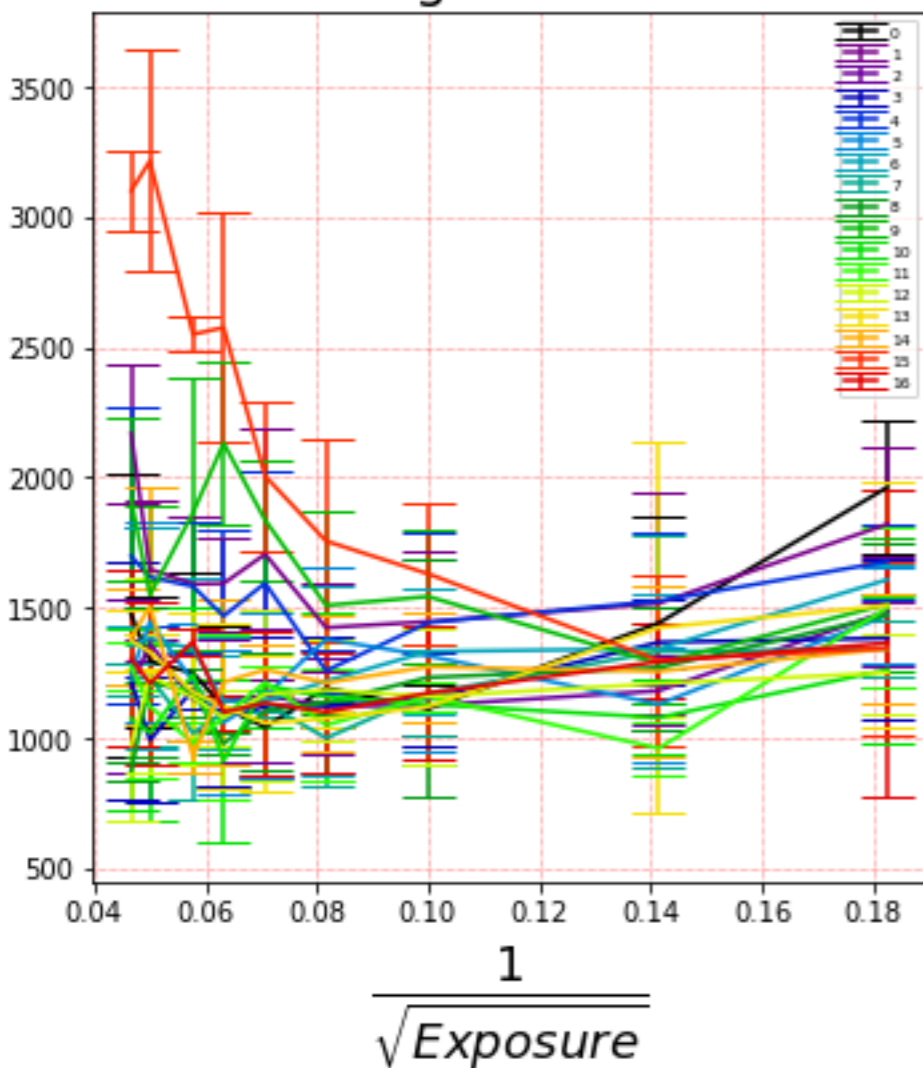






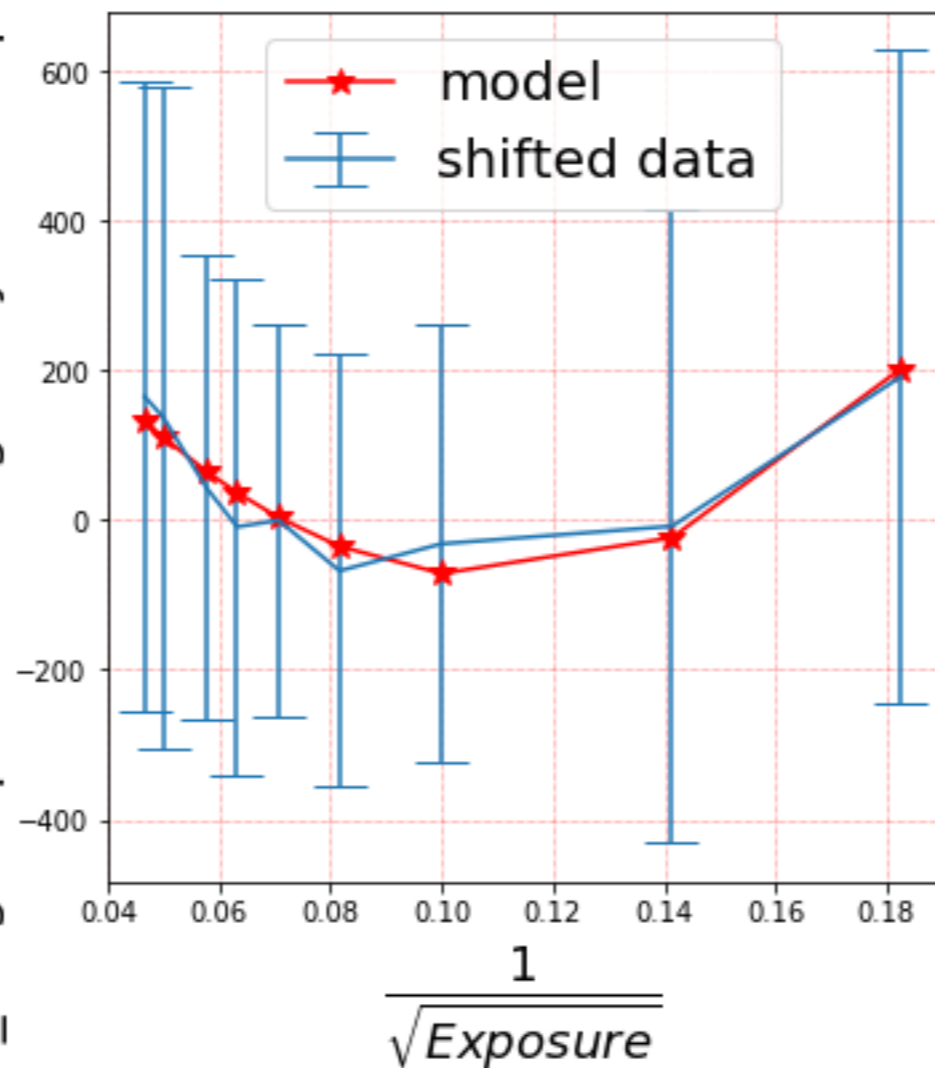
gldm_LargeDependenceHighGrayLevelEmphasis

Original data



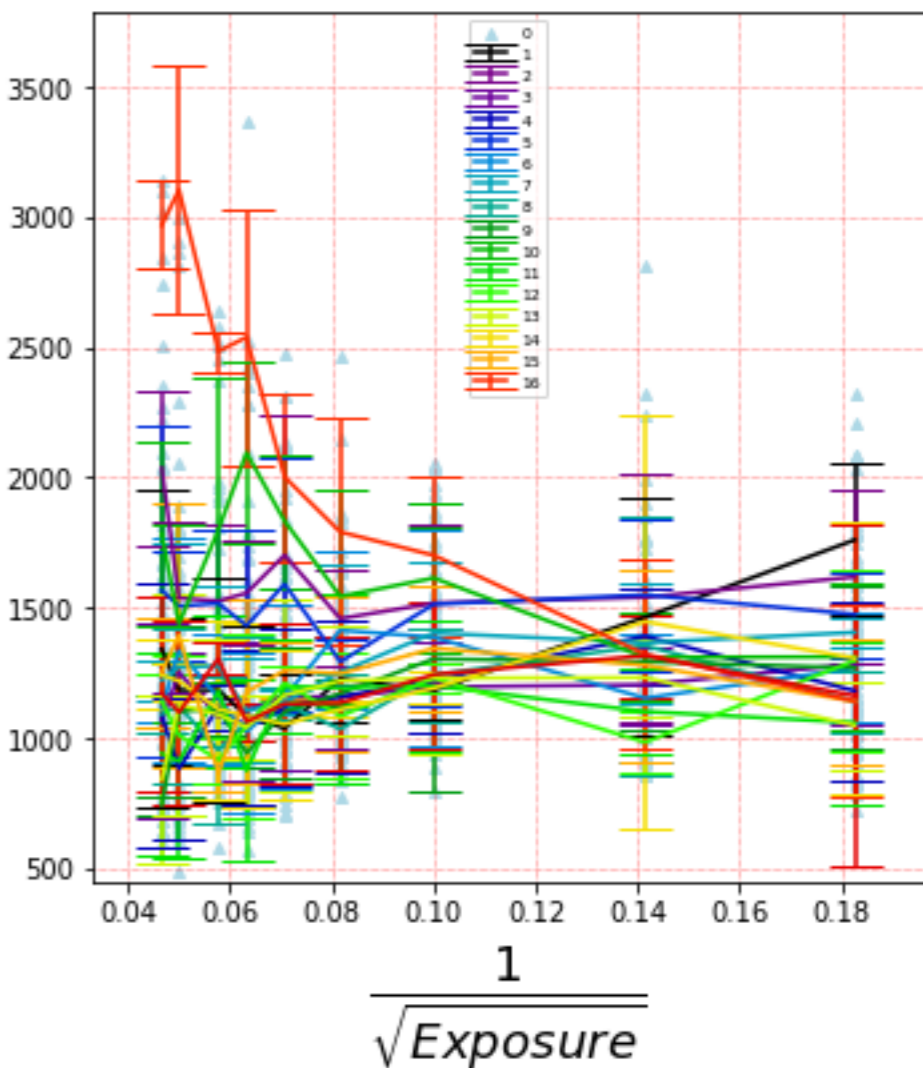
gldm_LargeDependenceHighGrayLevelEmphasis_shift

Shifted data



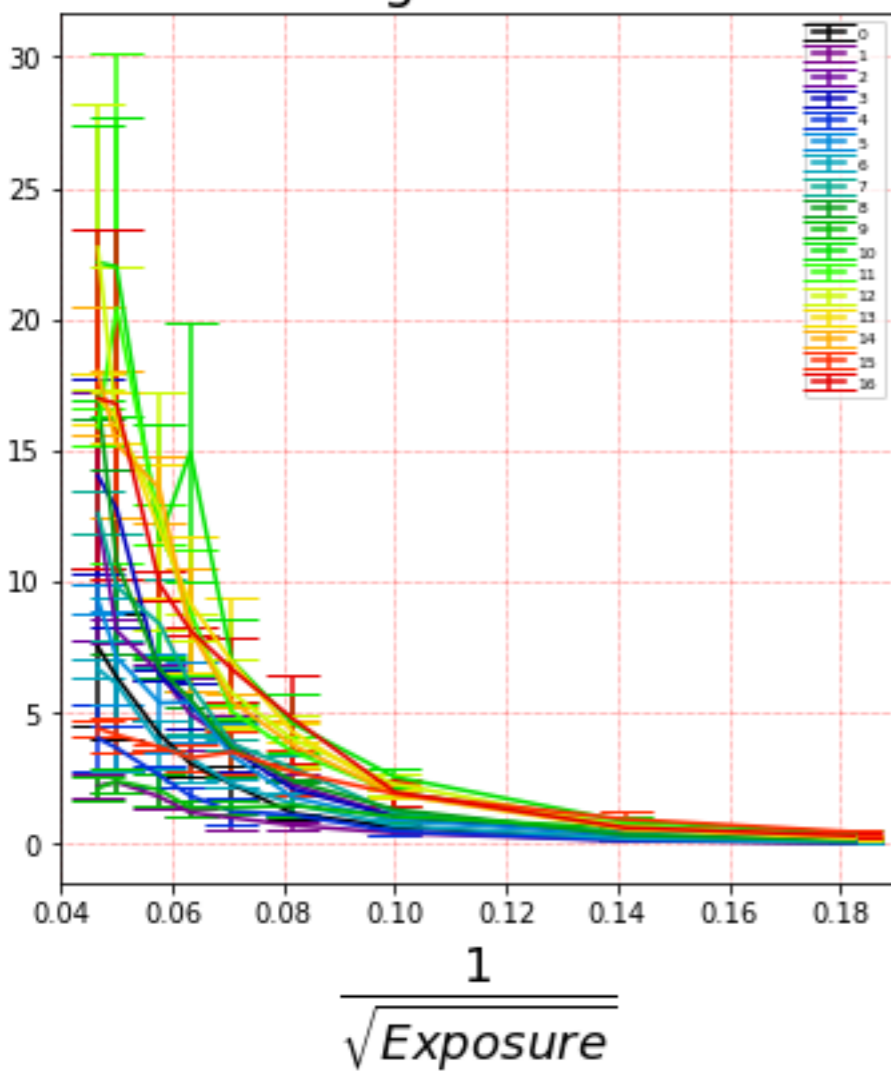
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Corrected data



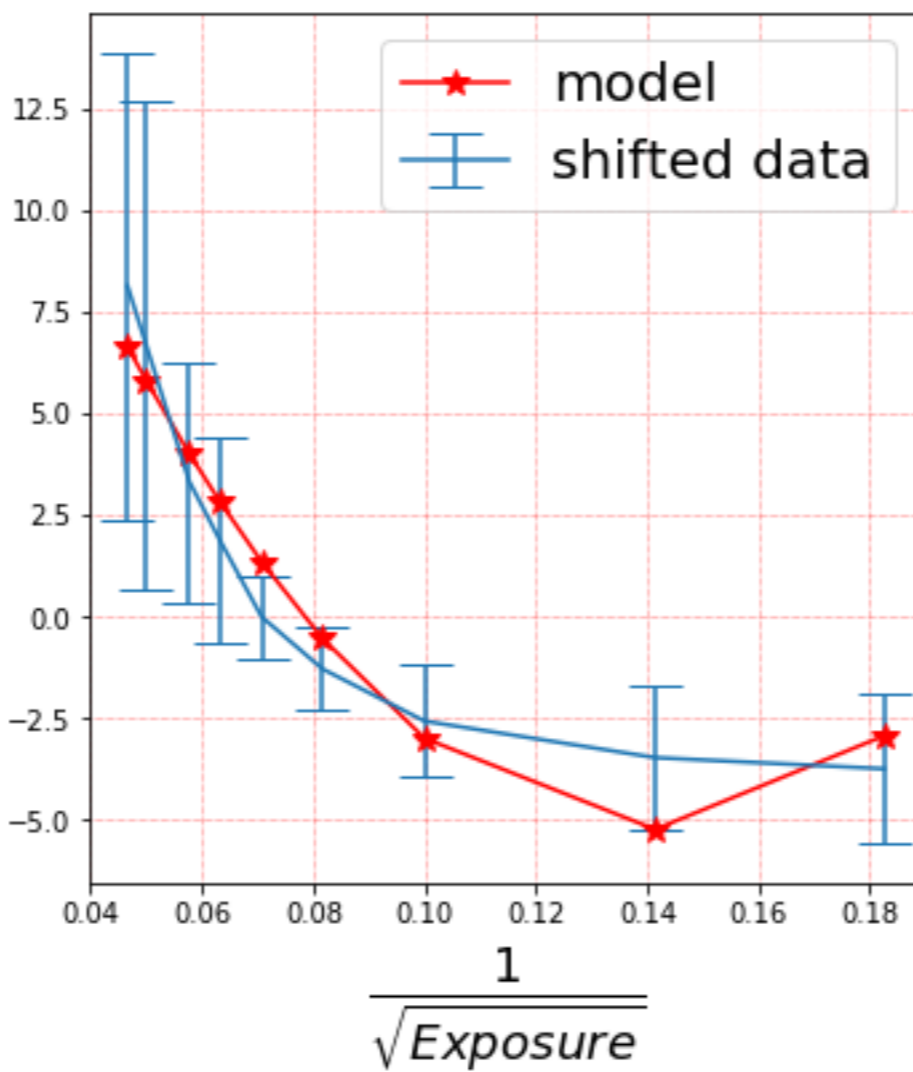
gldm_LargeDependenceLowGrayLevelEmphasis

Original data



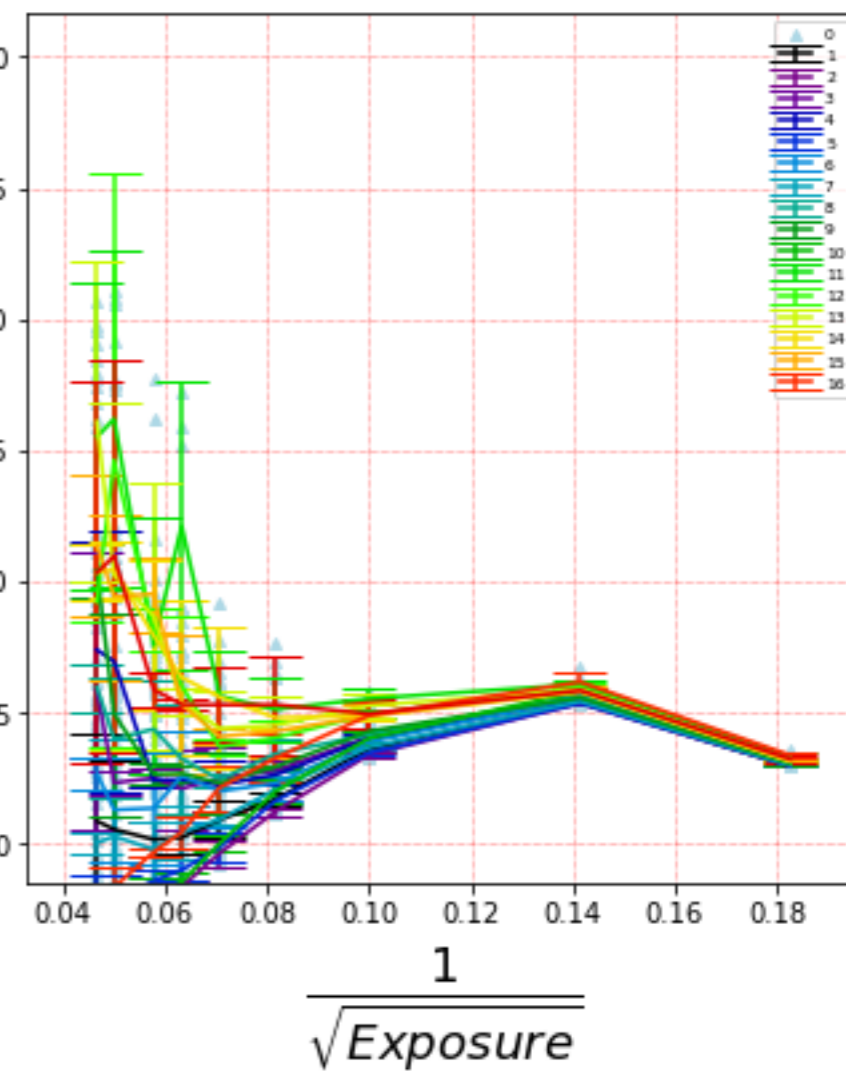
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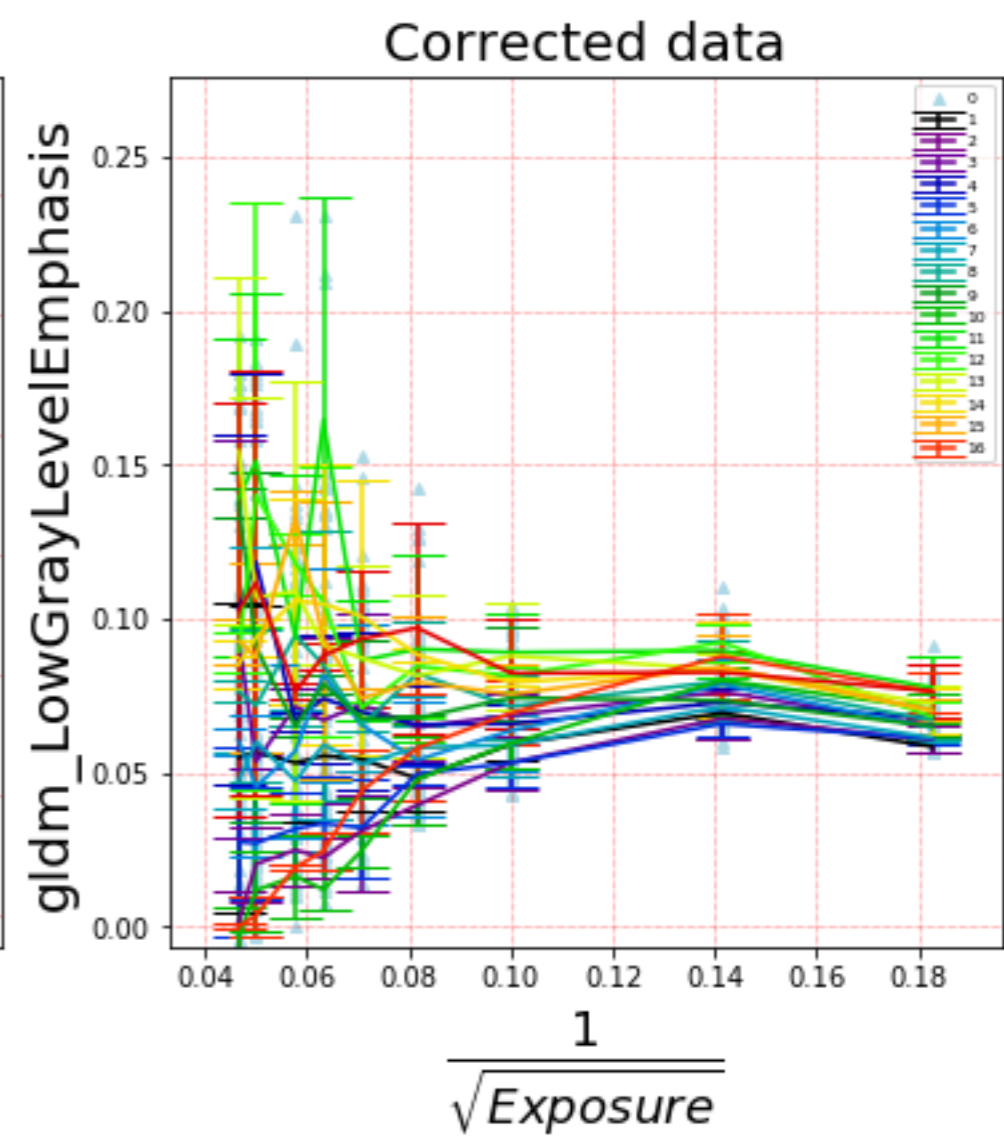
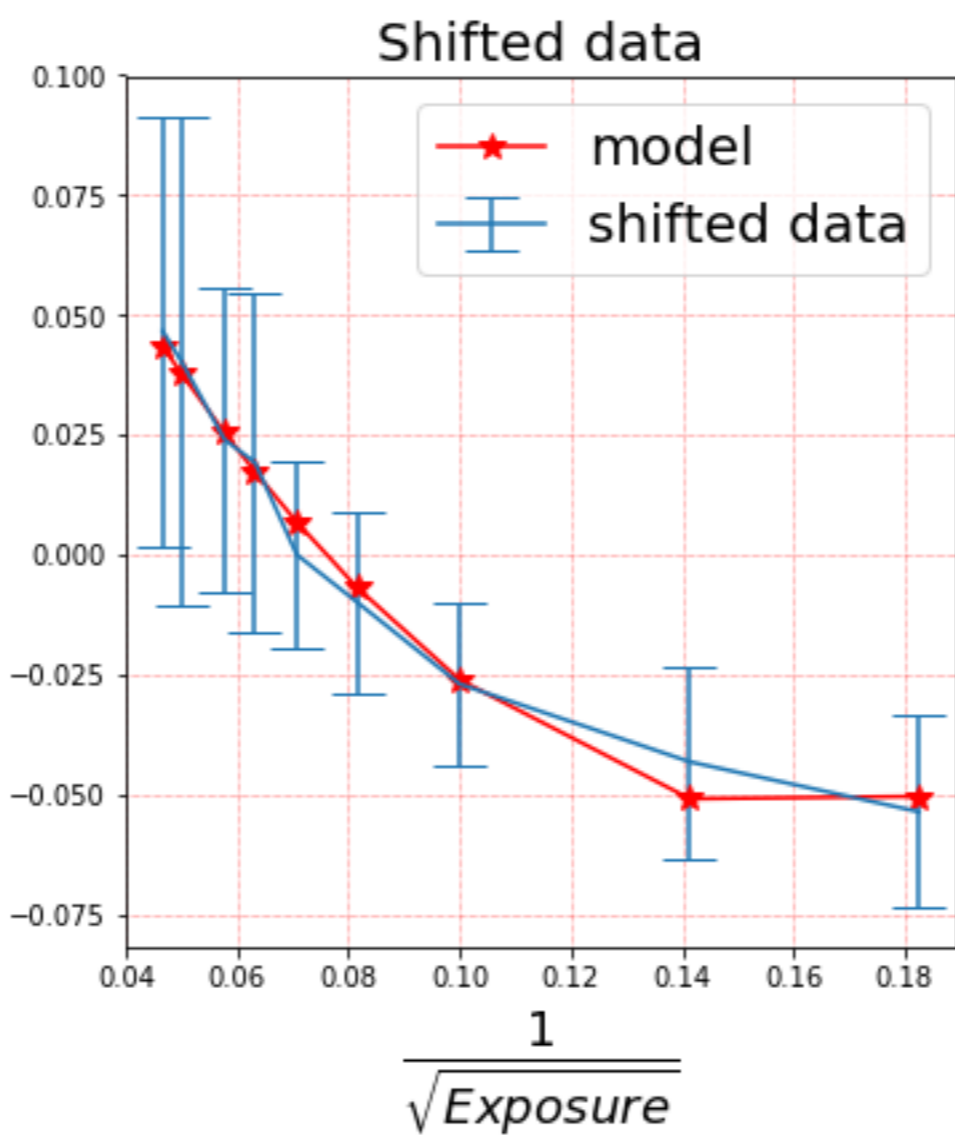
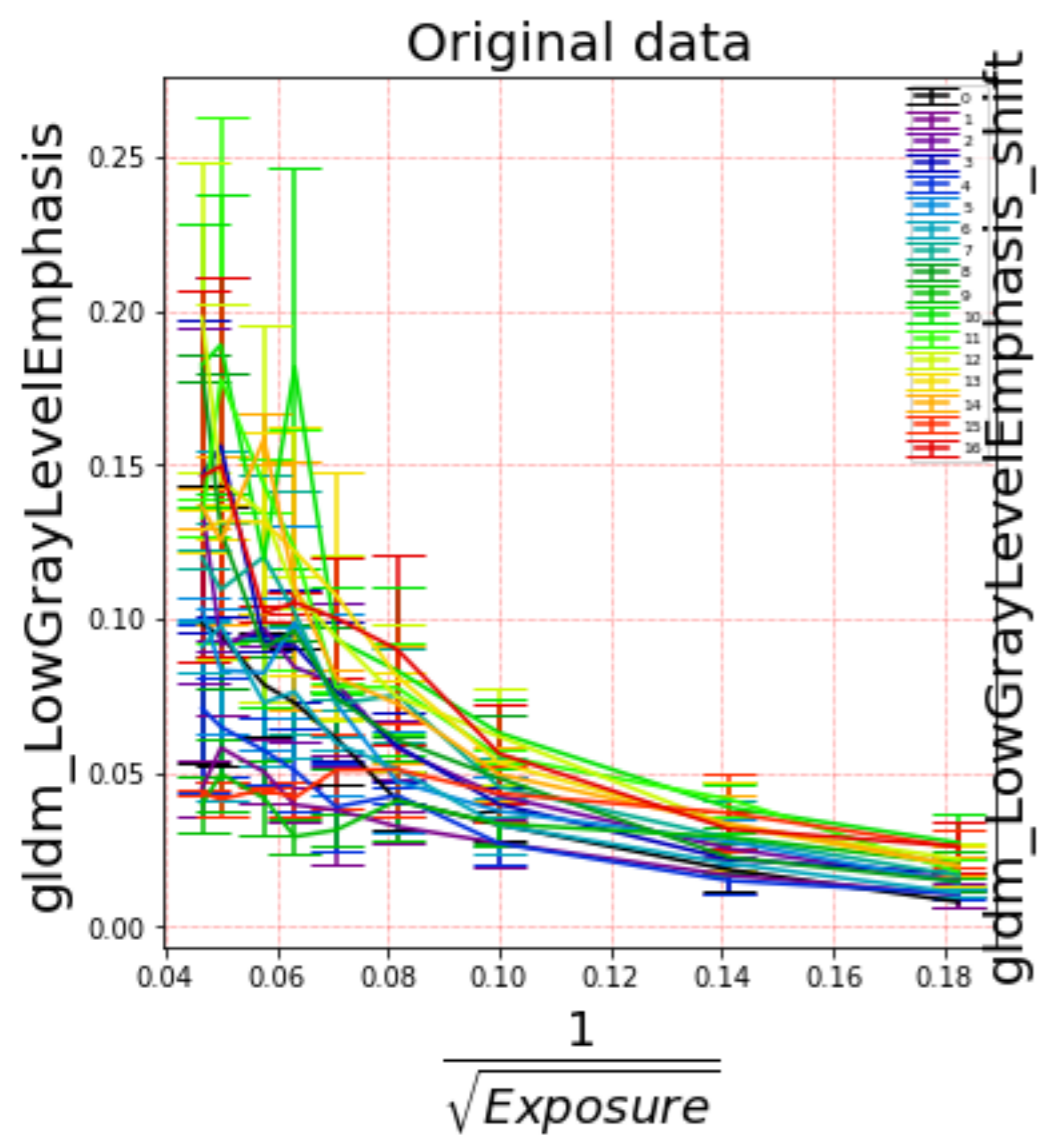
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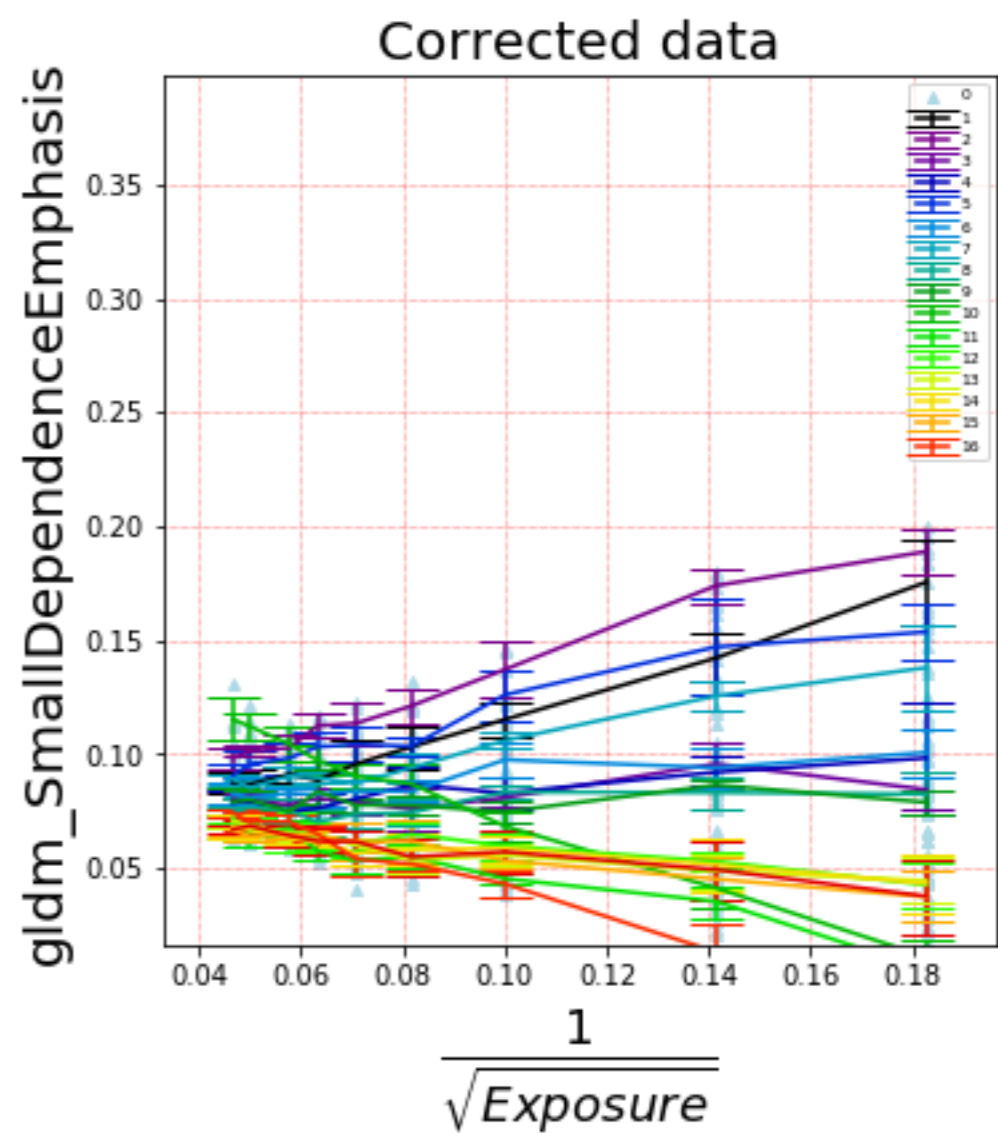
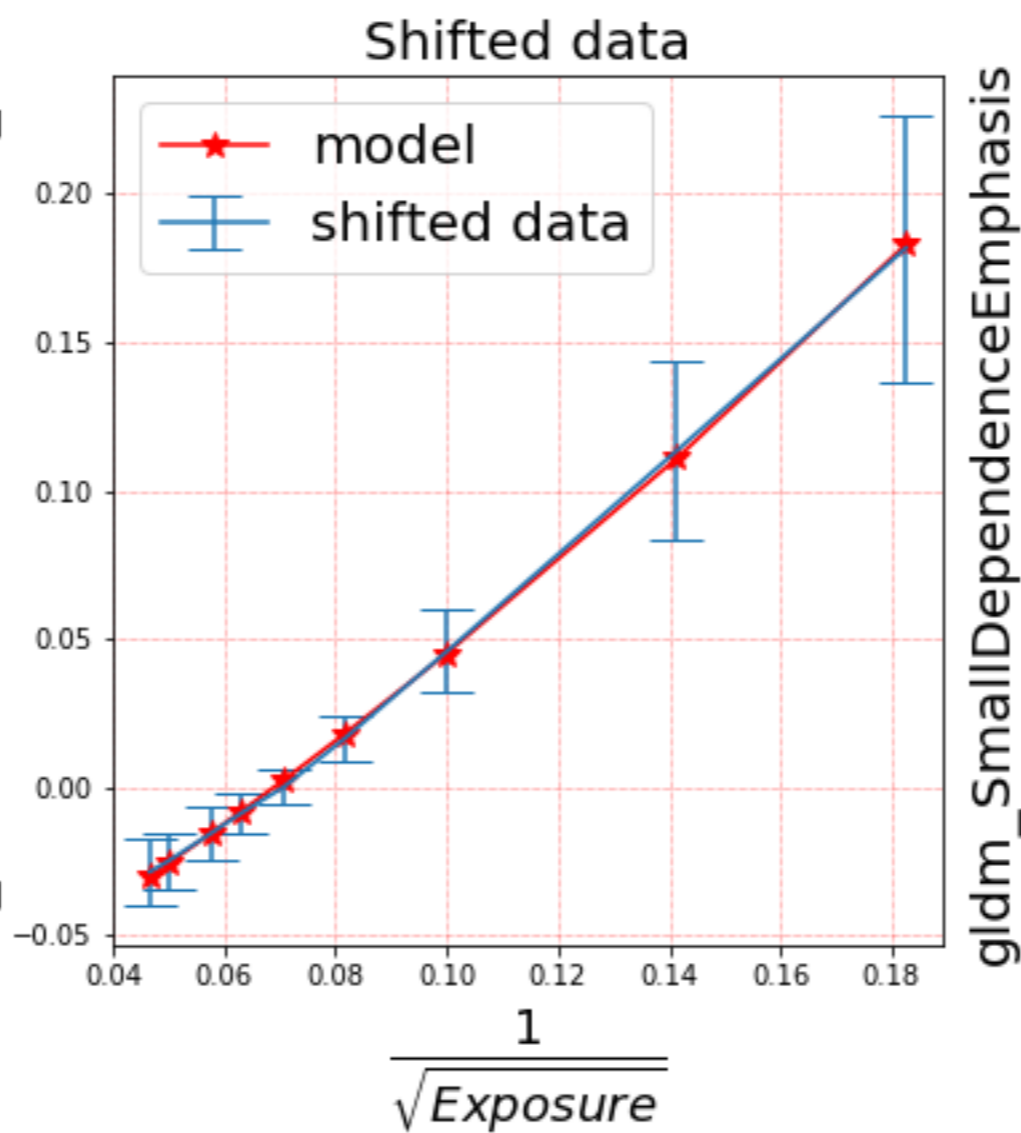
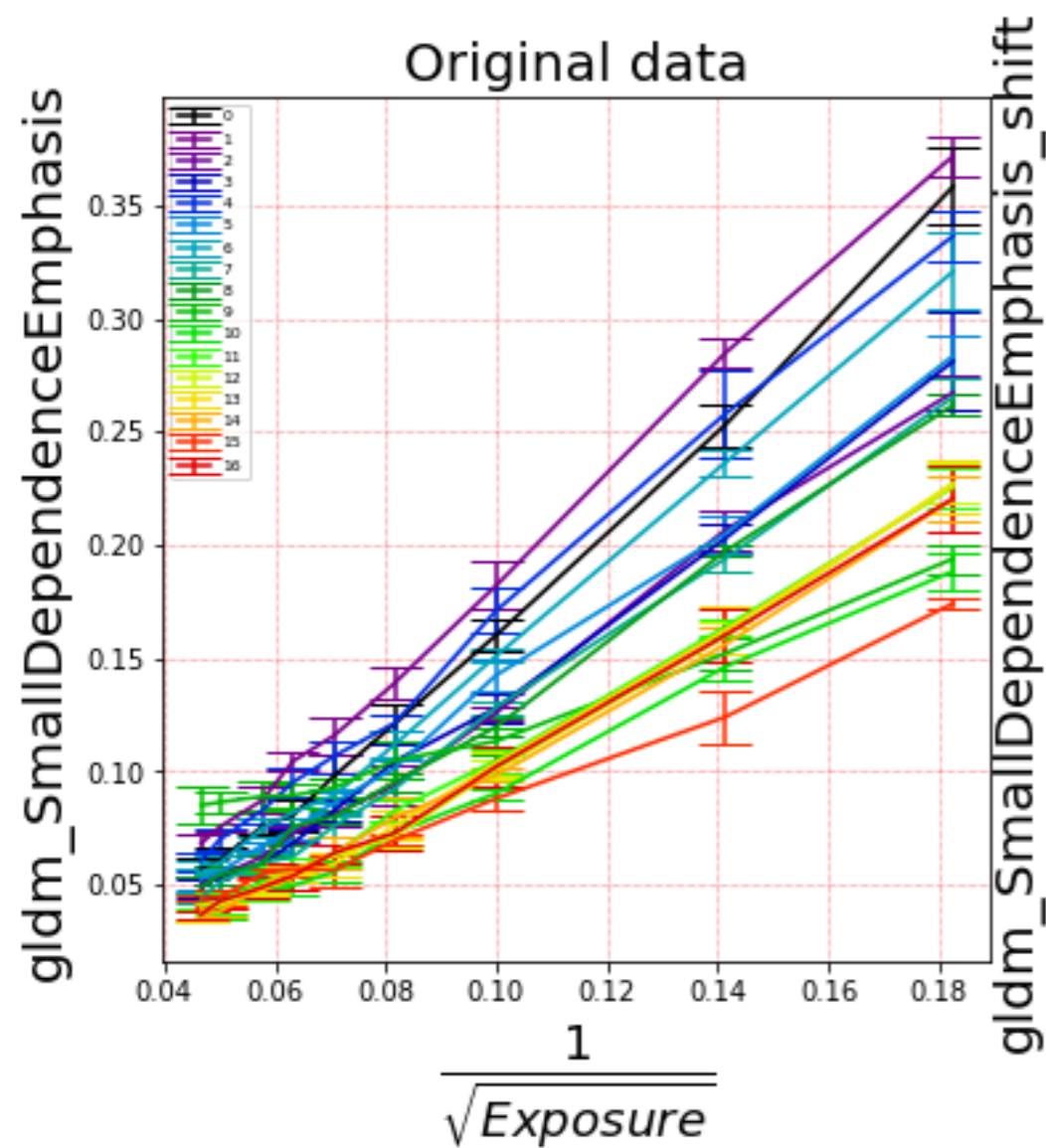


gldm_LargeDependenceLowGrayLevelEmphasis

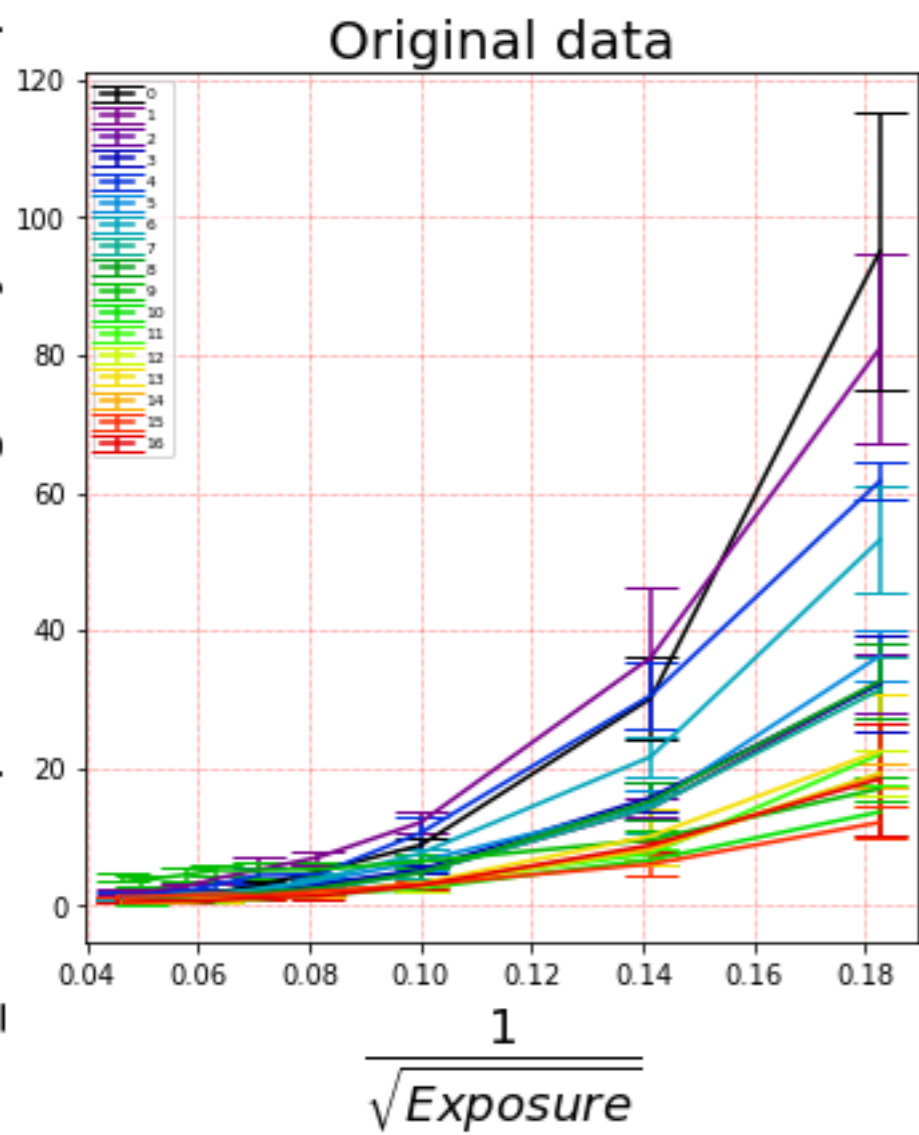
Corrected data



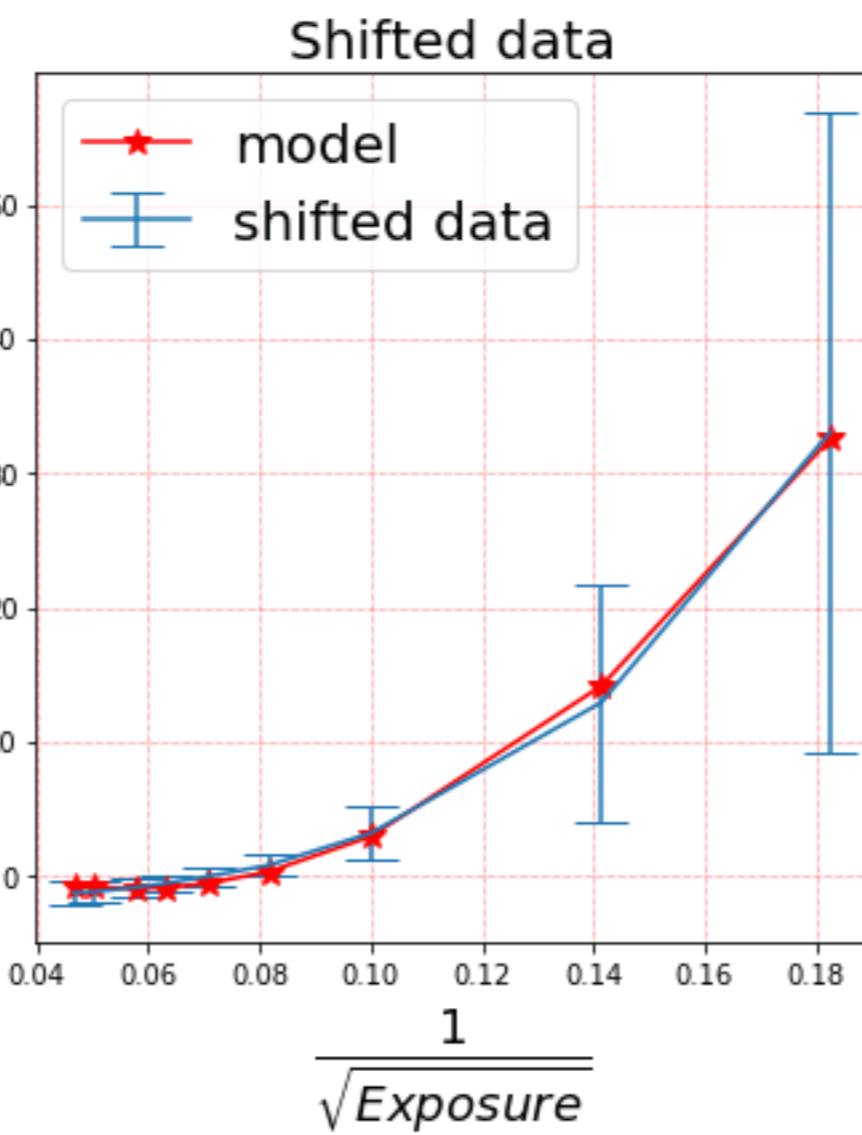




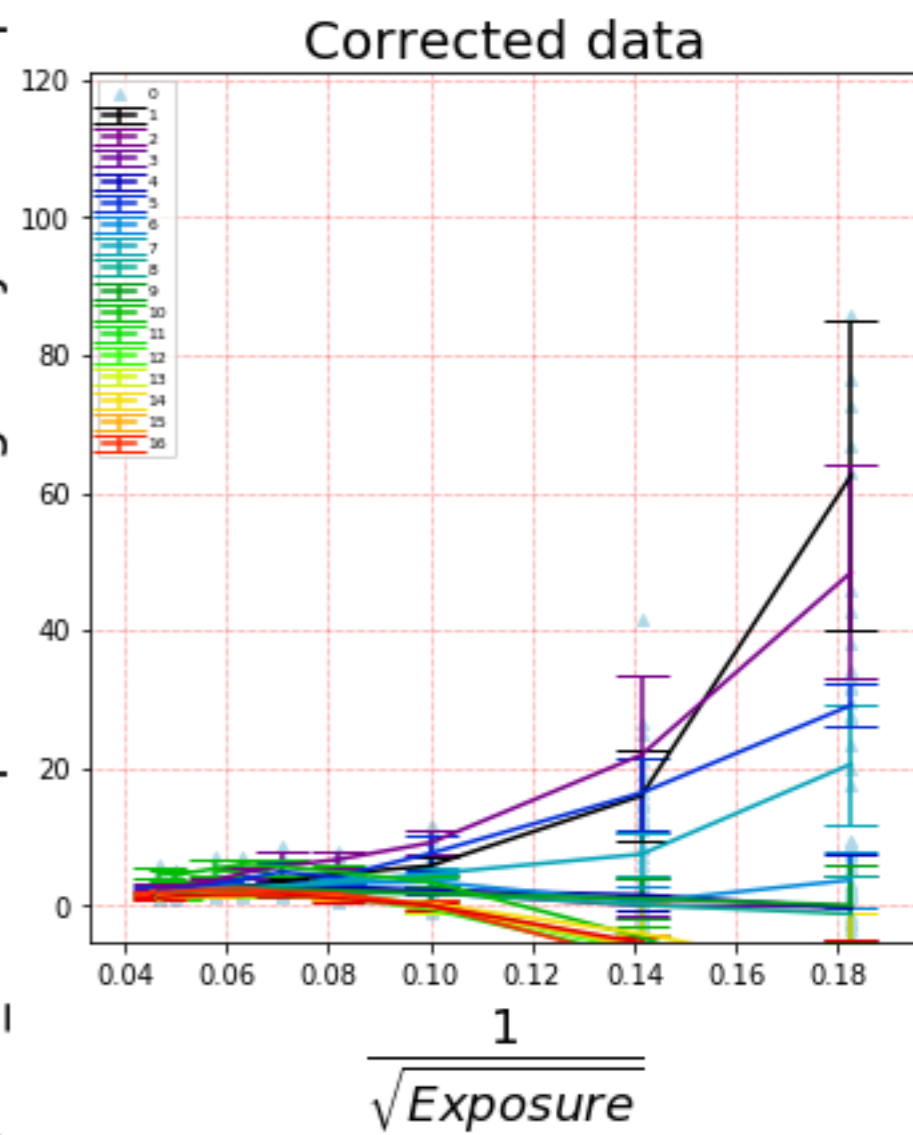
gldm_SmallDependenceHighGrayLevelEmphasis

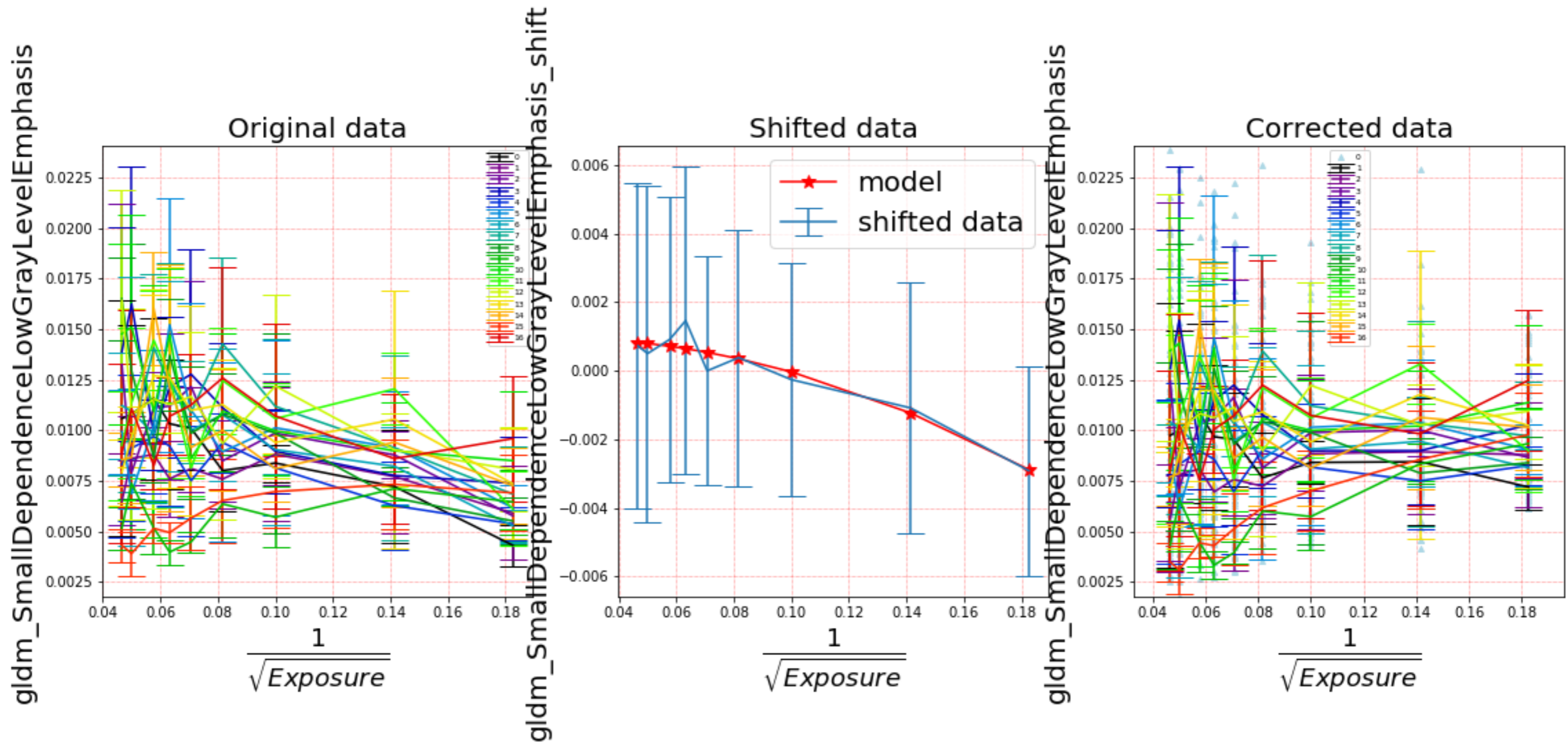


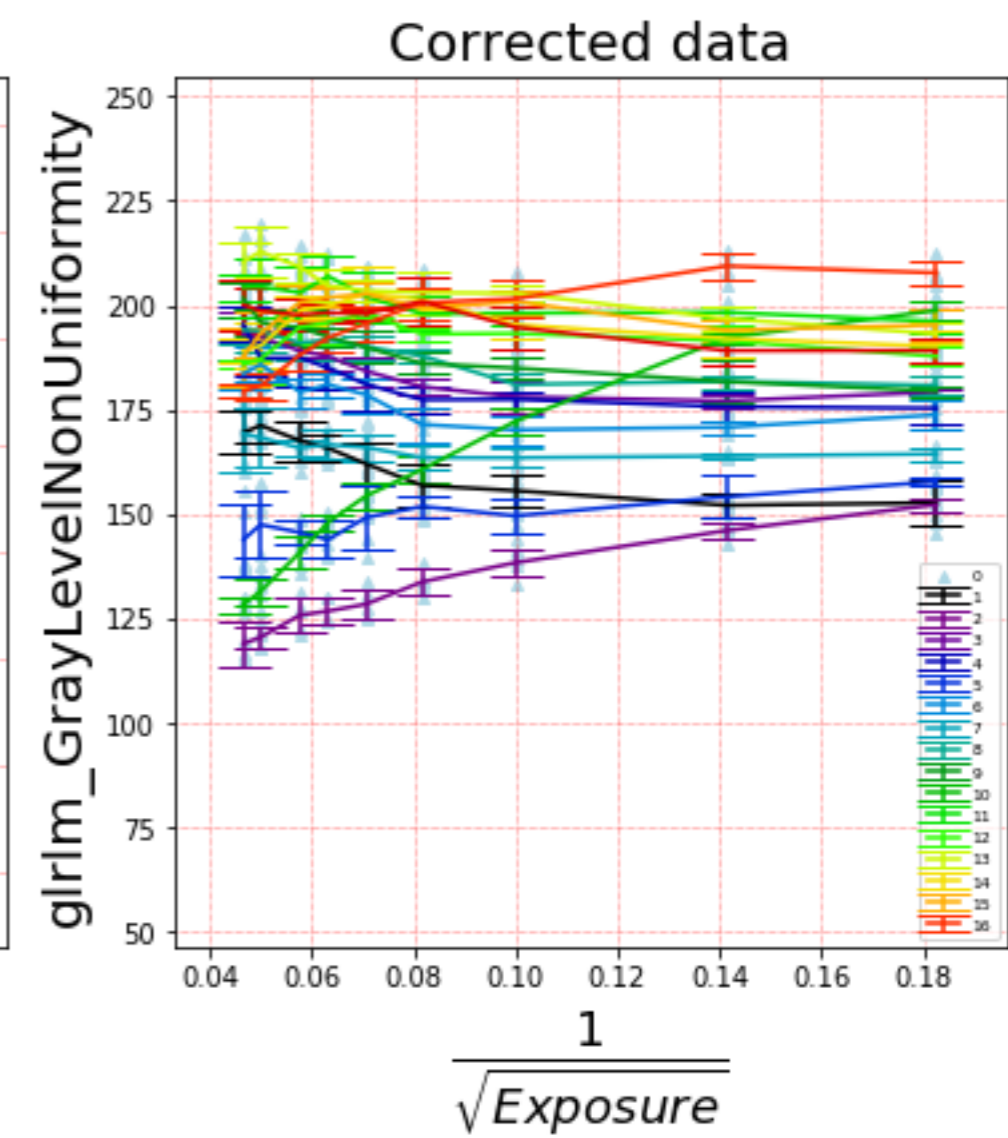
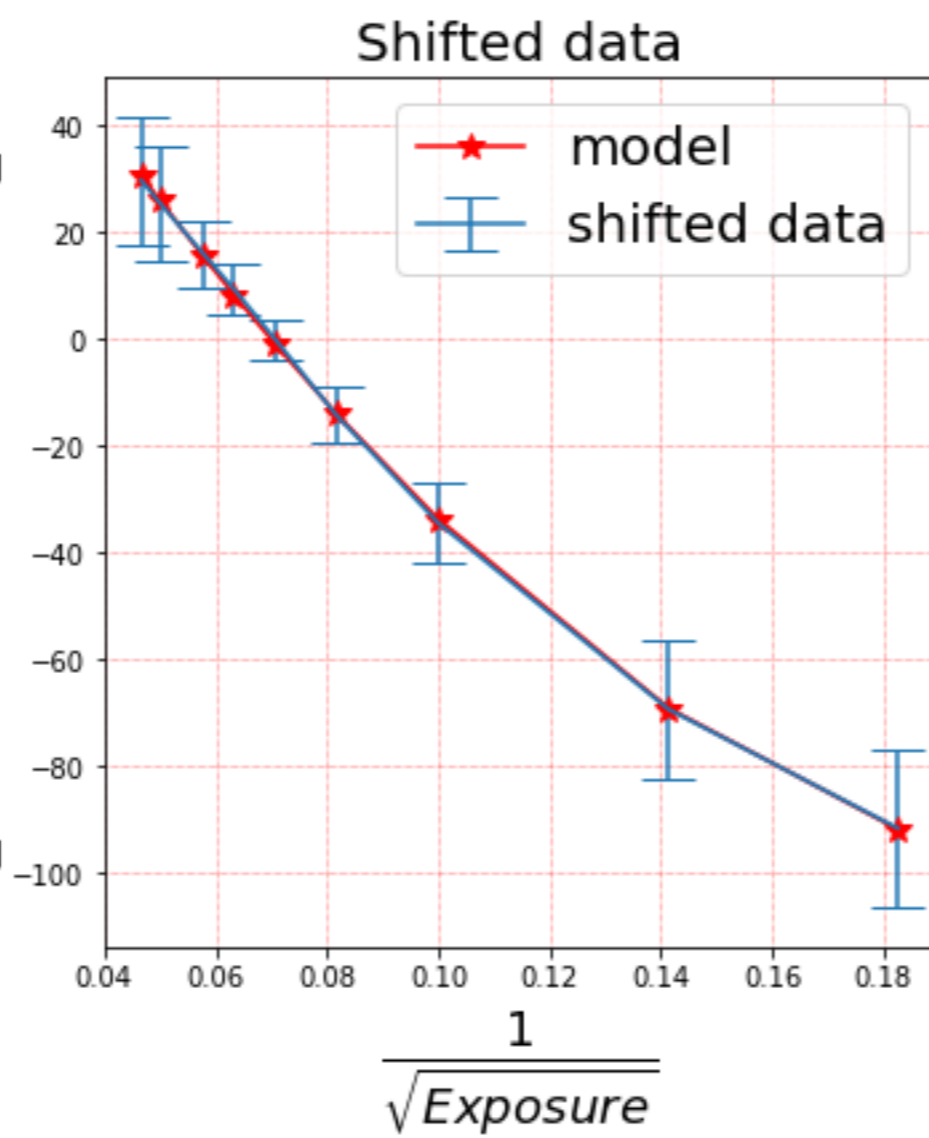
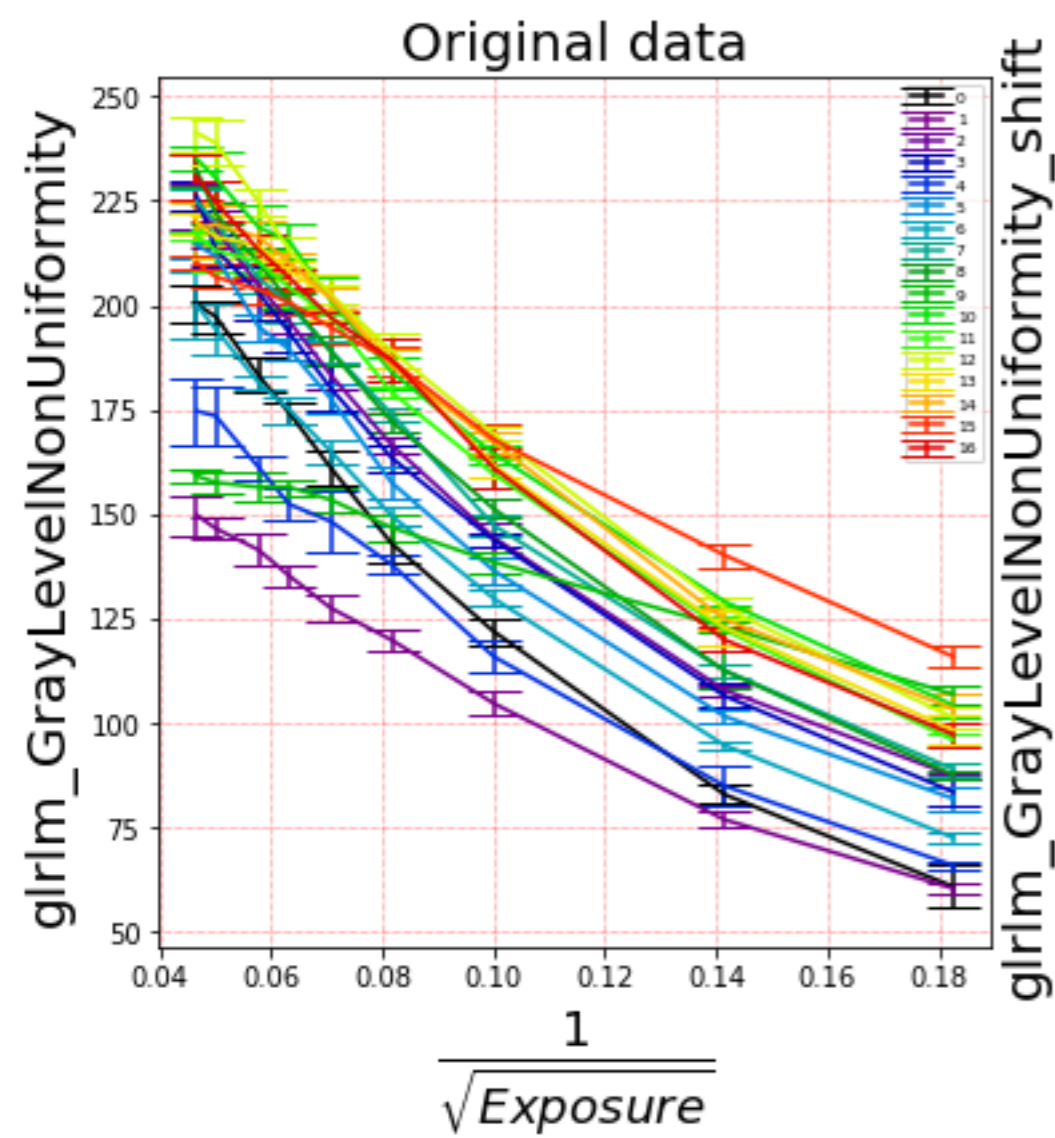
gldm_SmallDependenceHighGrayLevelEmphasis_shift

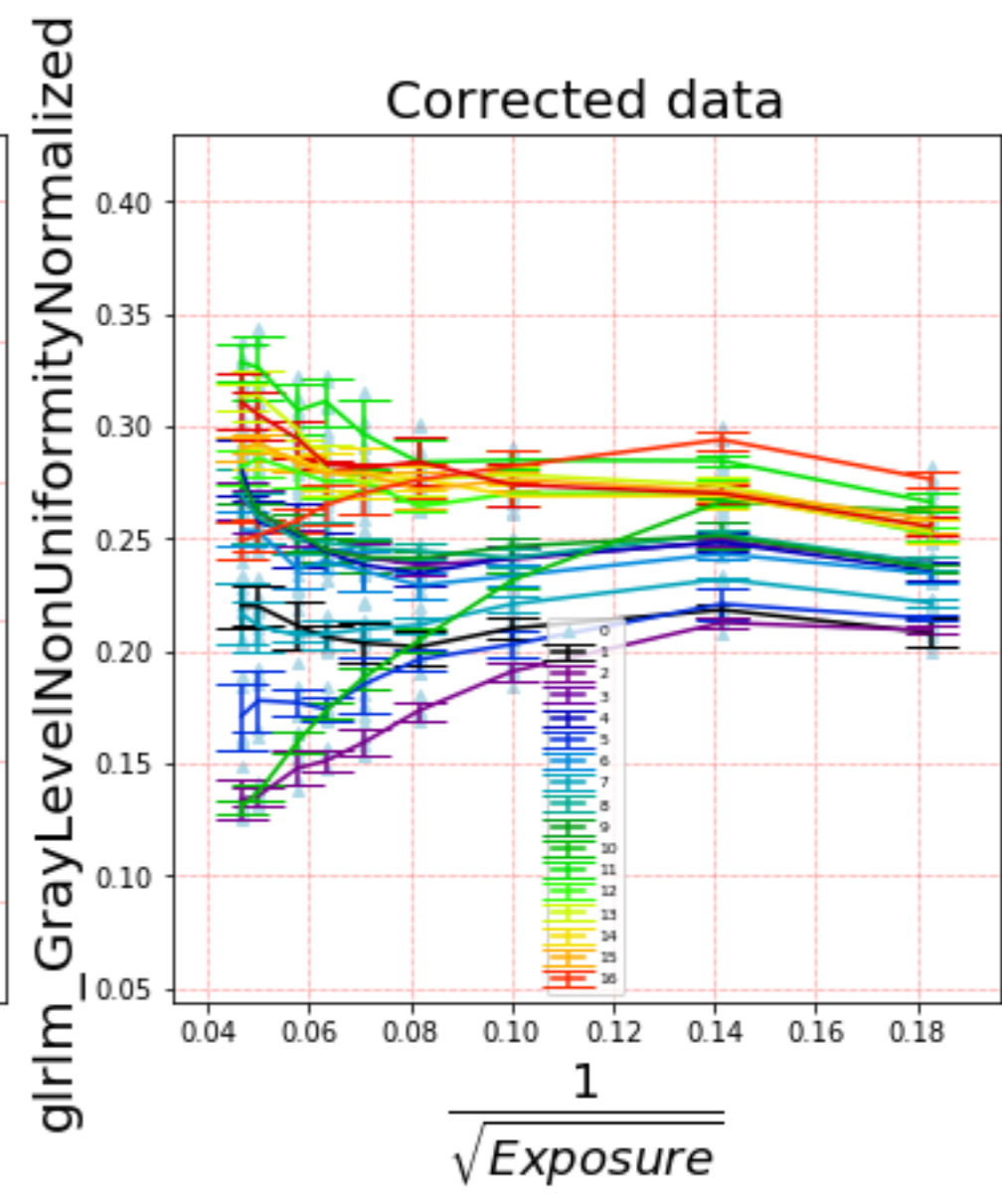
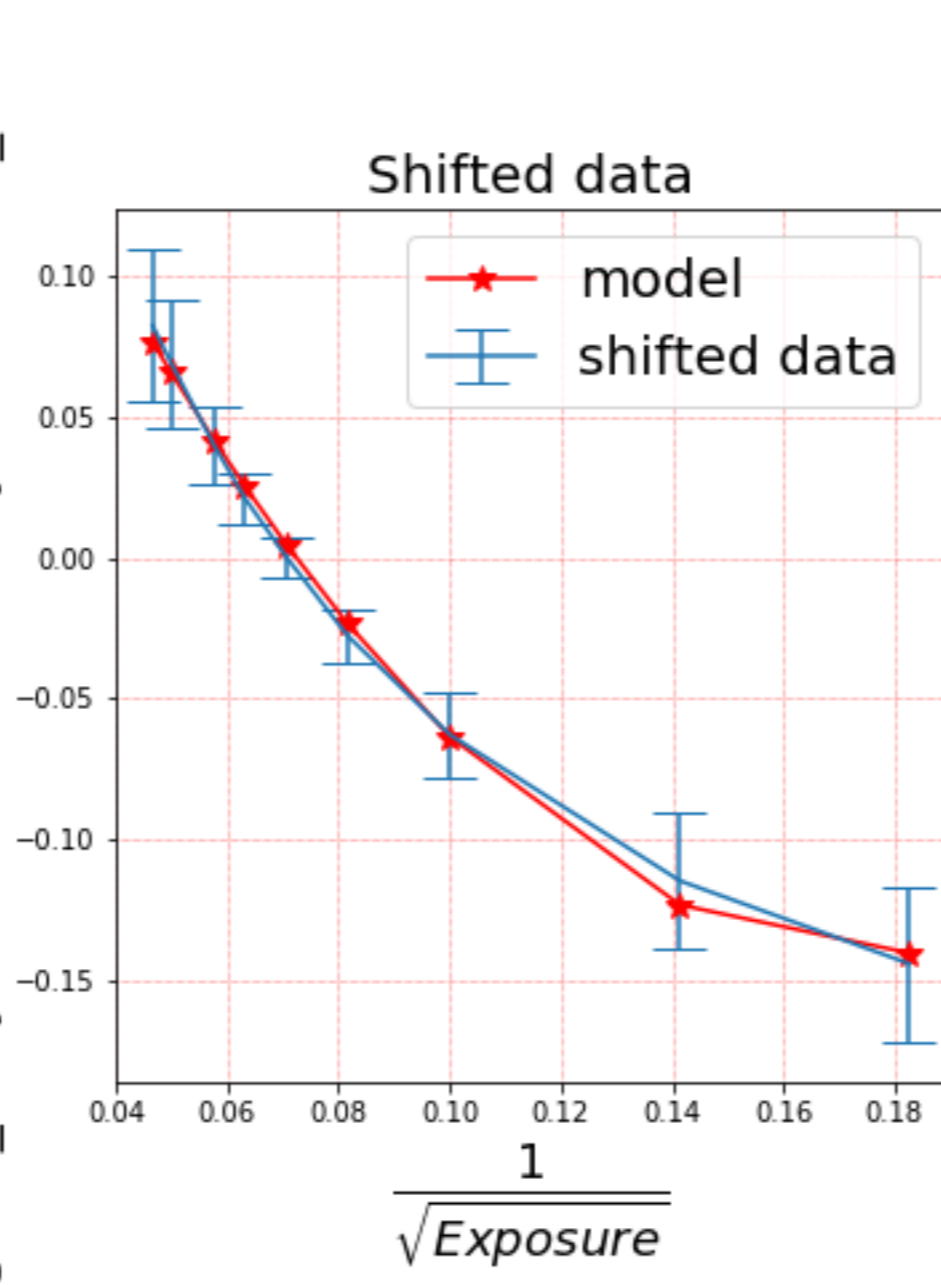
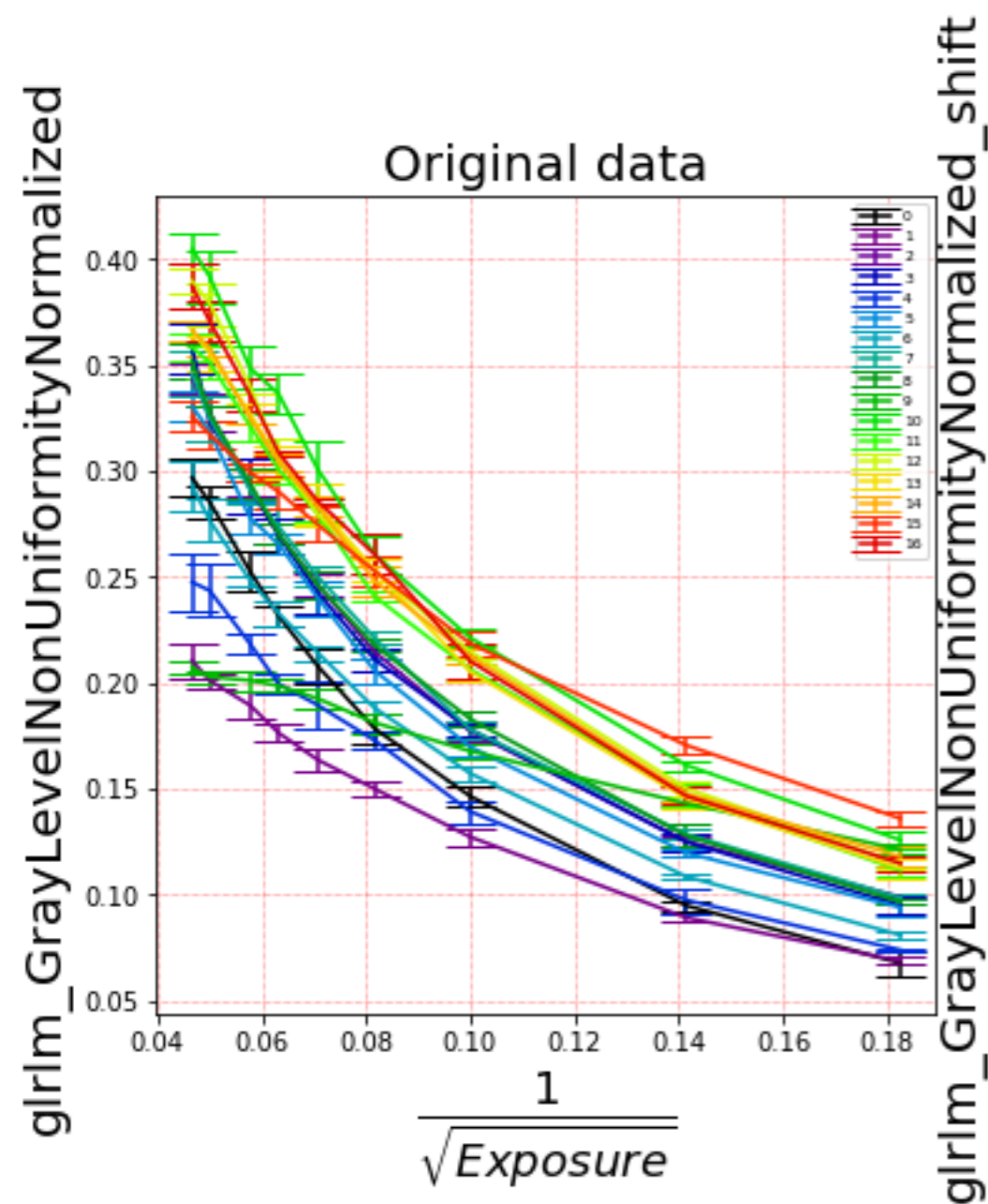


gldm_SmallDependenceHighGrayLevelEmphasis

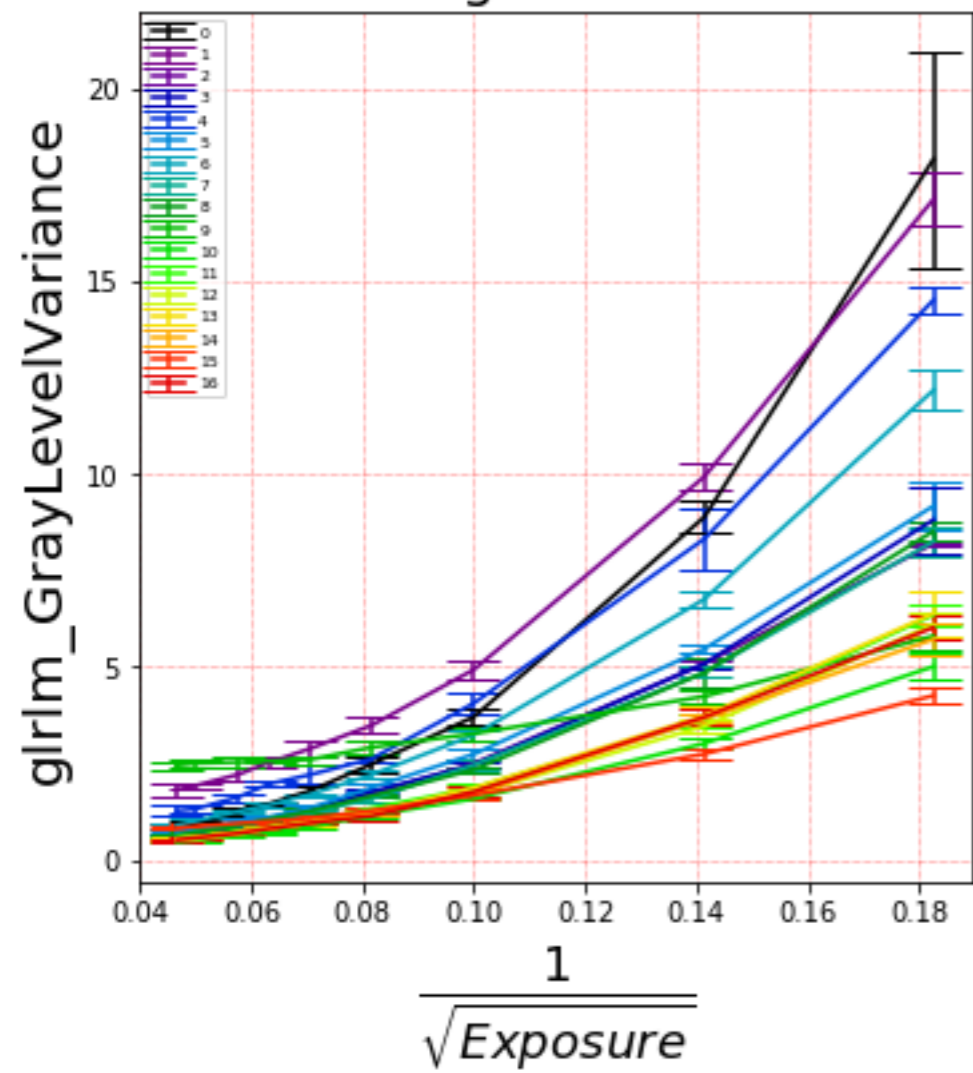




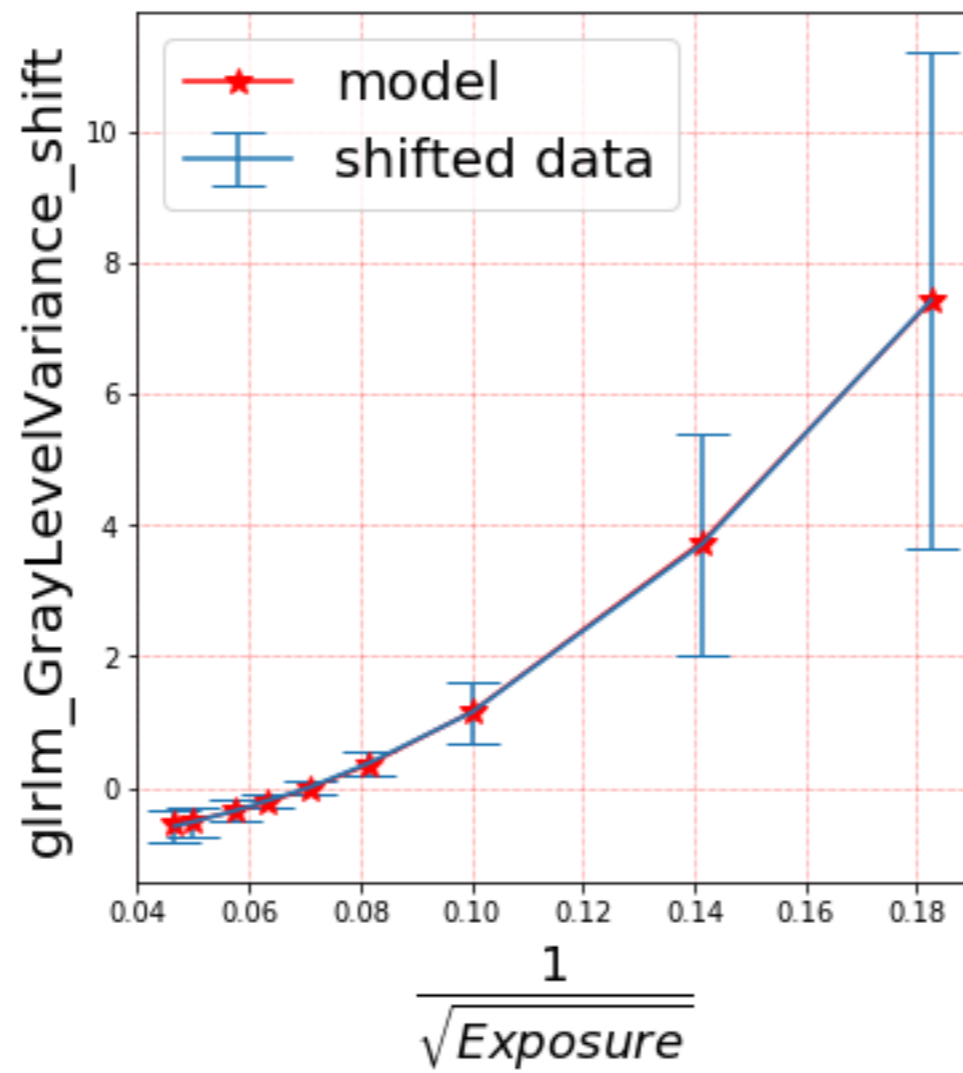




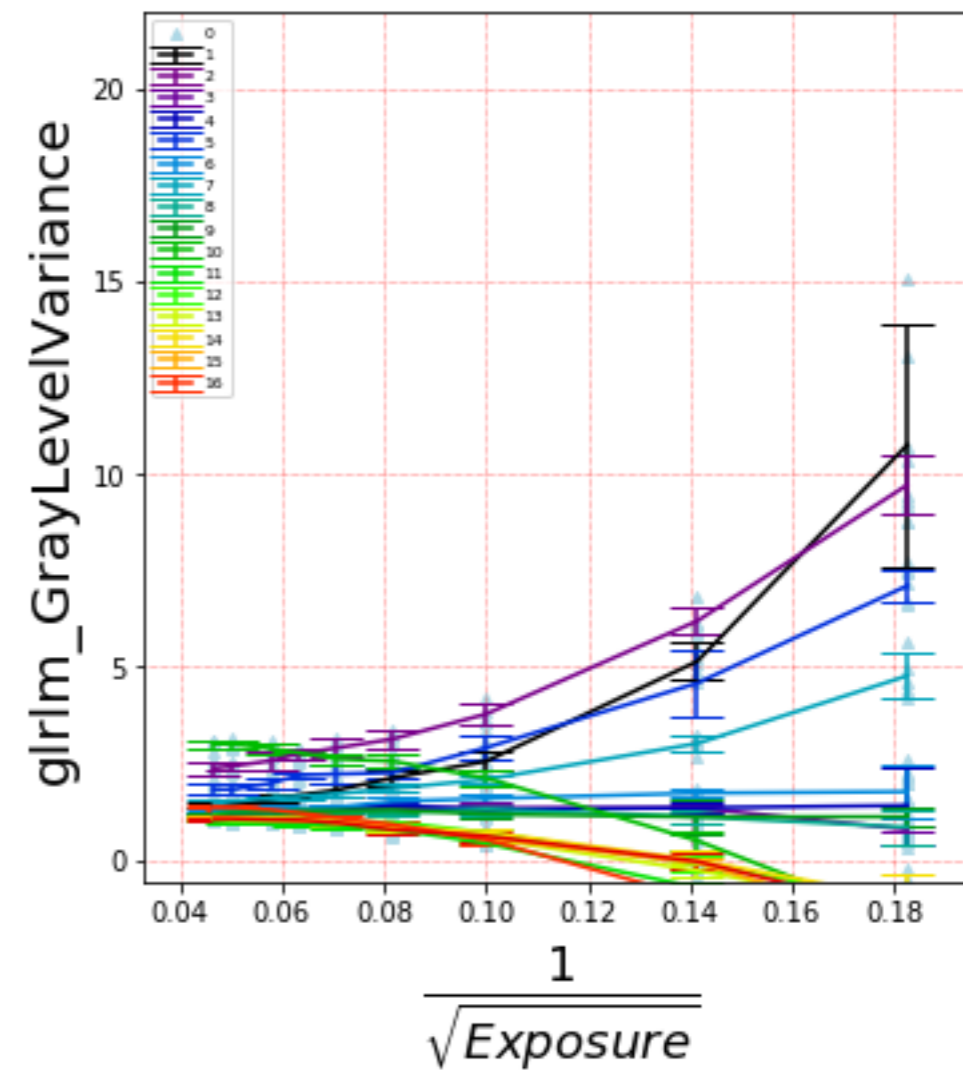
Original data

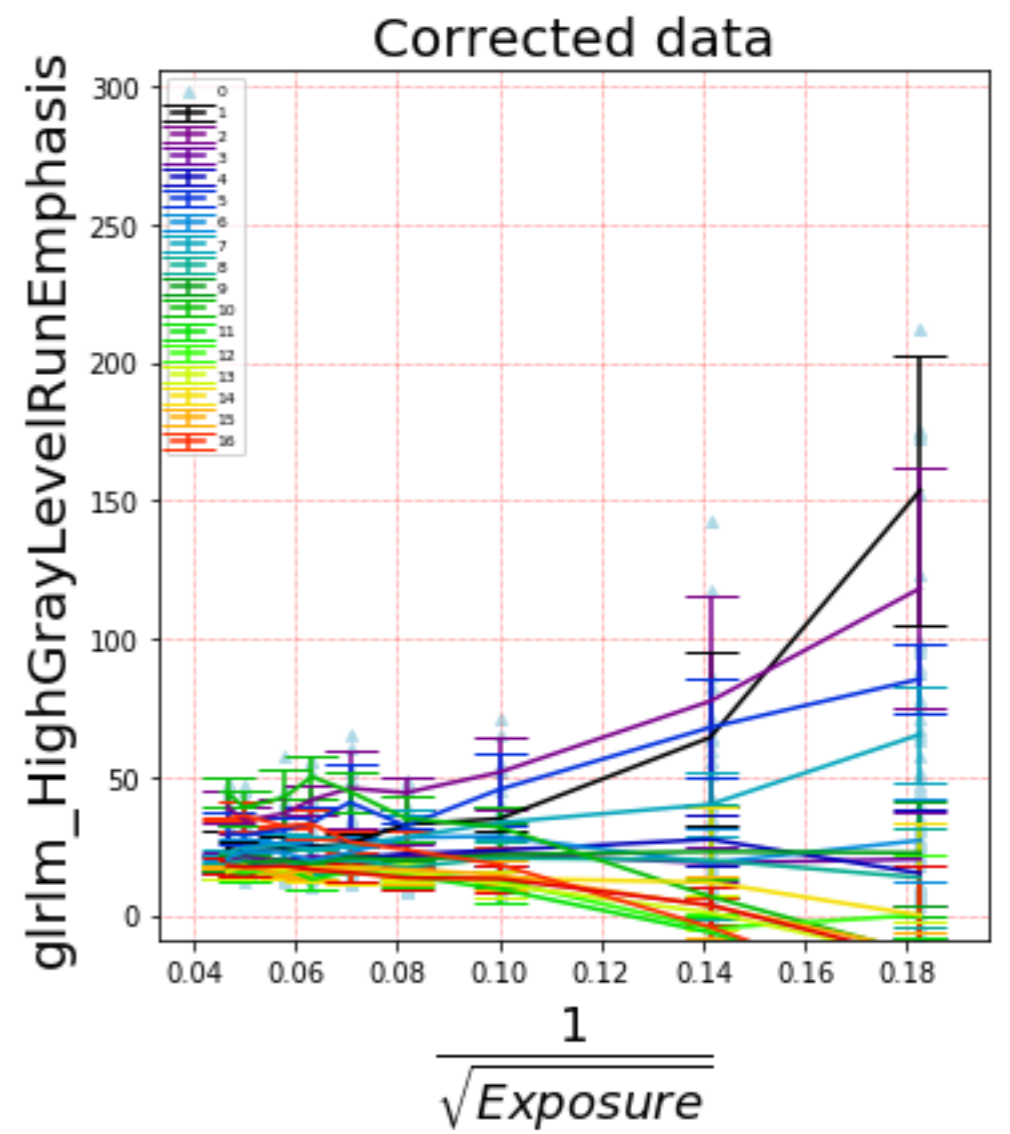
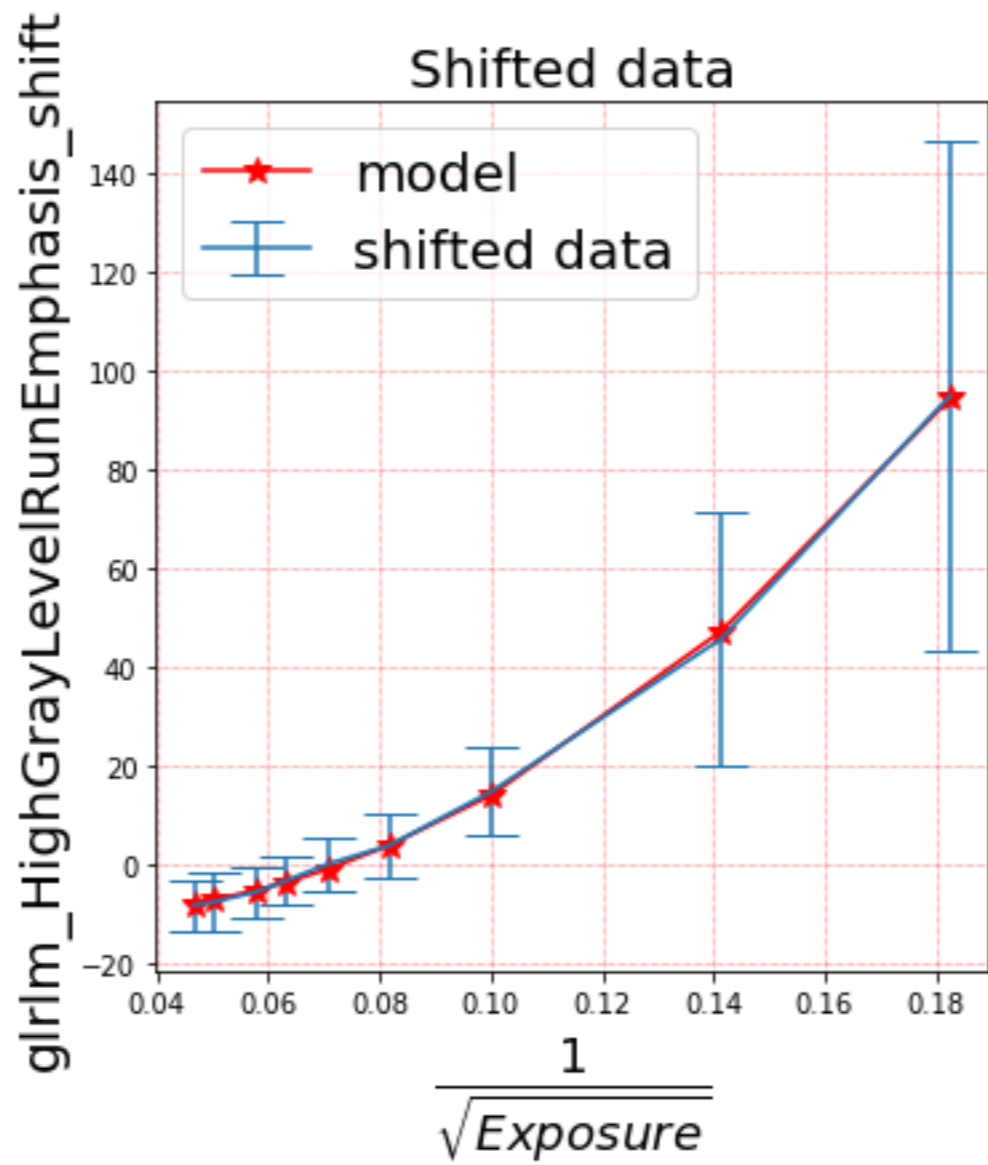
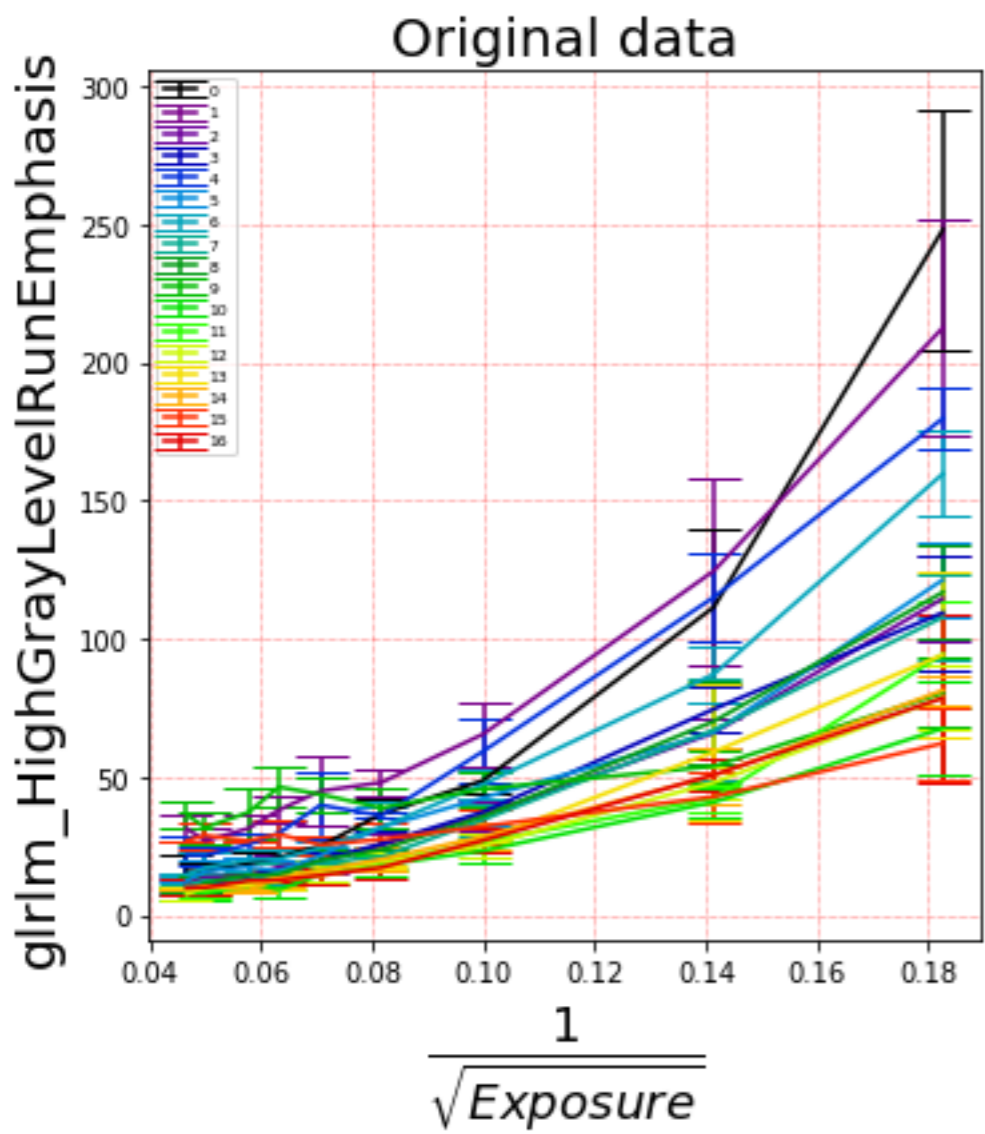


Shifted data

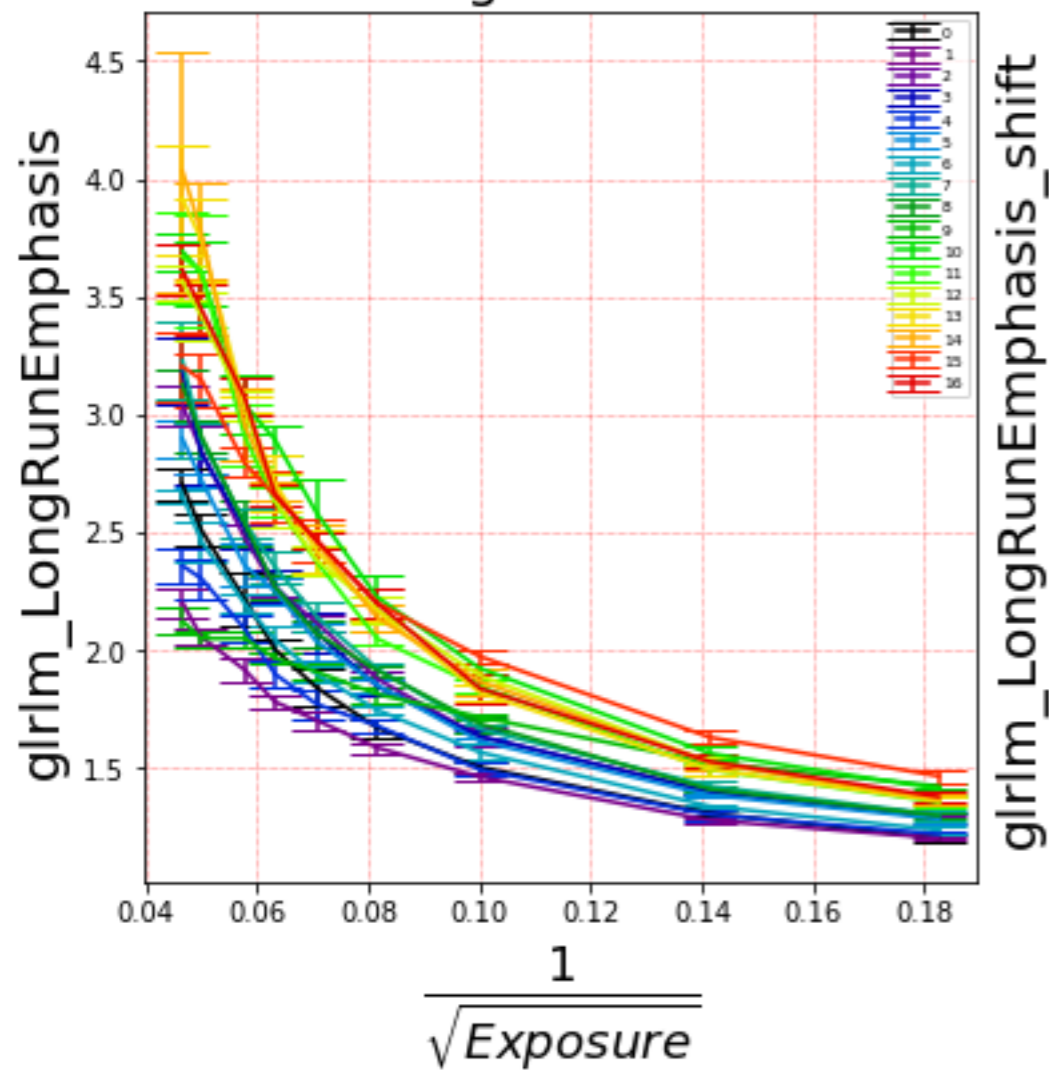


Corrected data

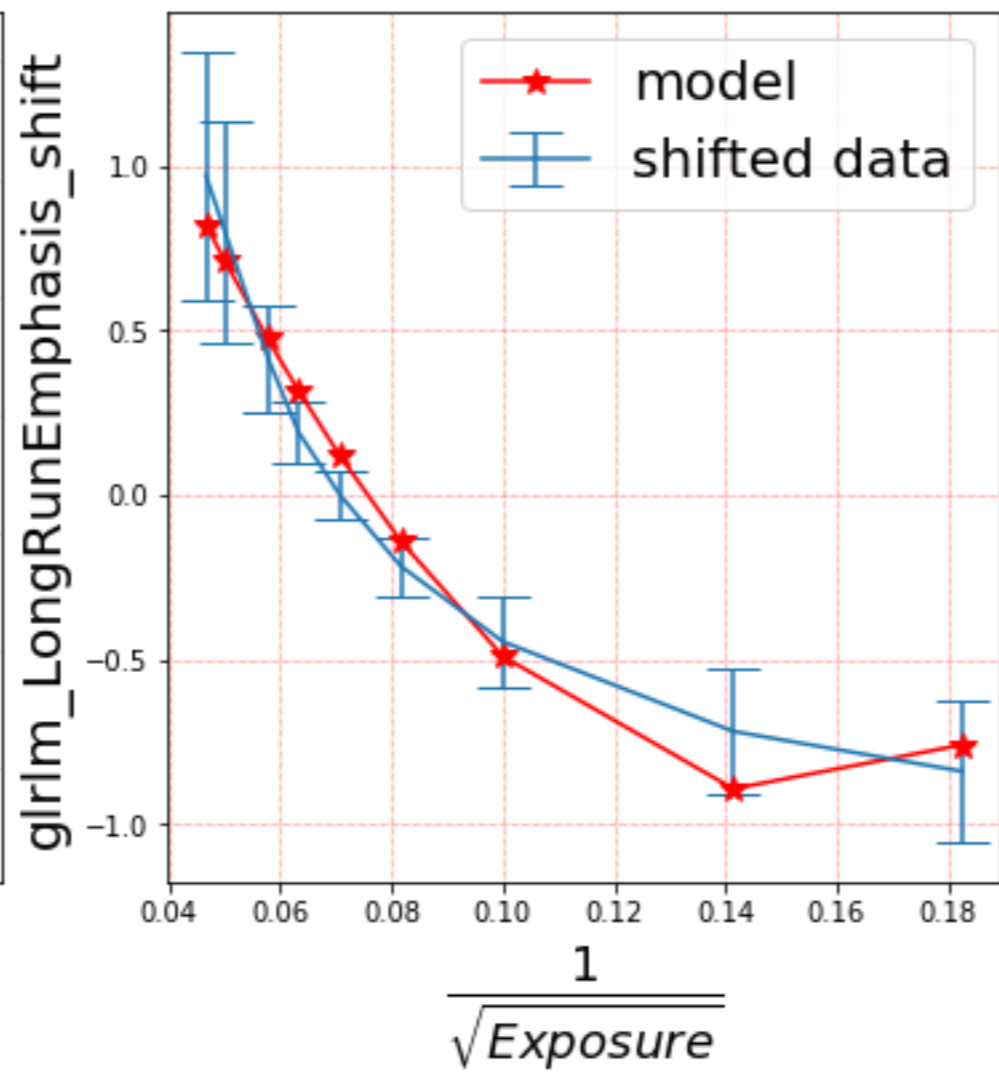




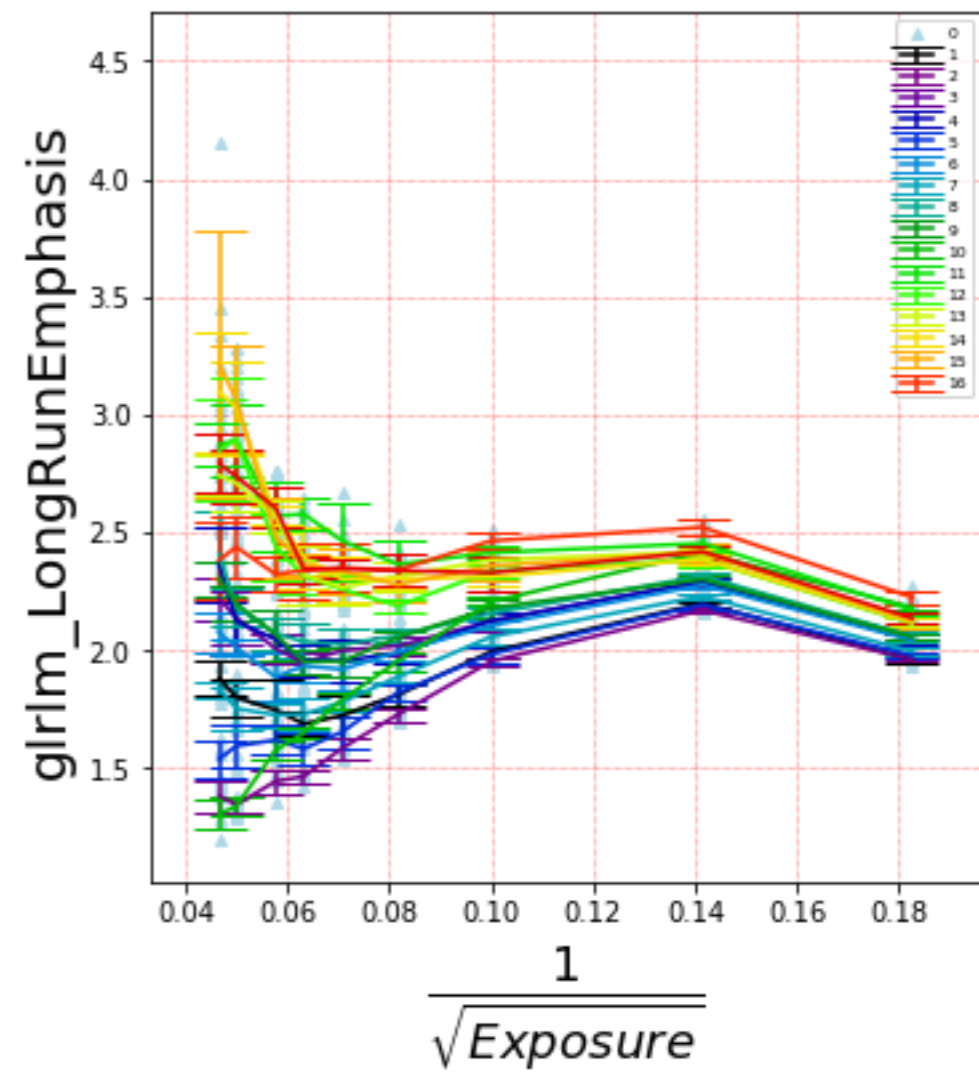
Original data



Shifted data

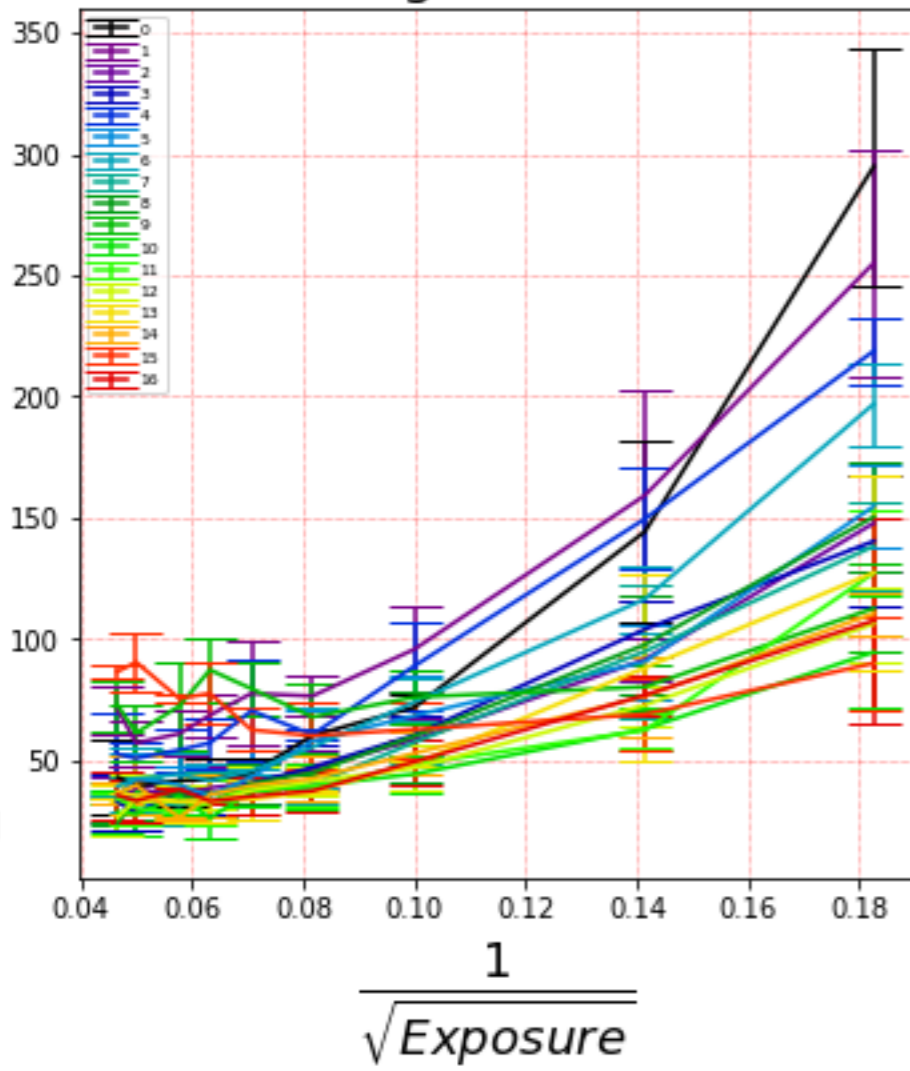


Corrected data



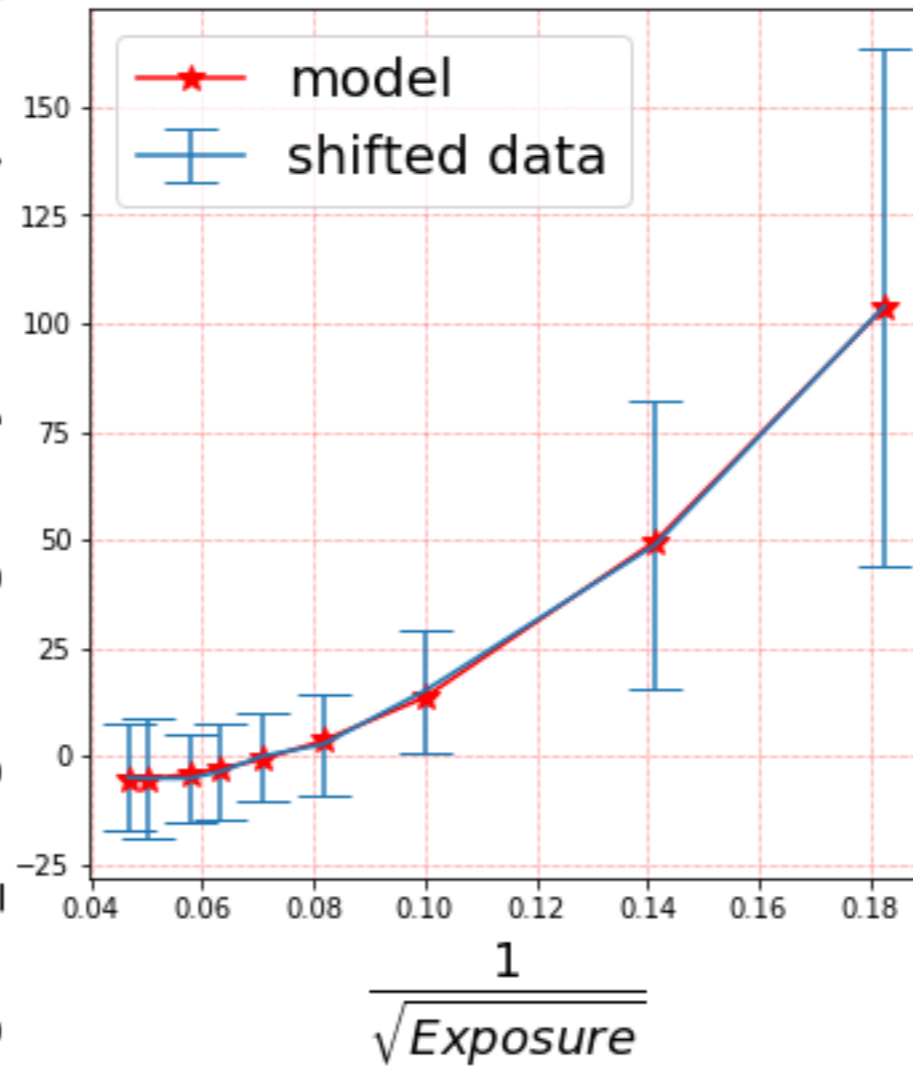
gllm_LongRunHighGrayLevelEmphasis

Original data



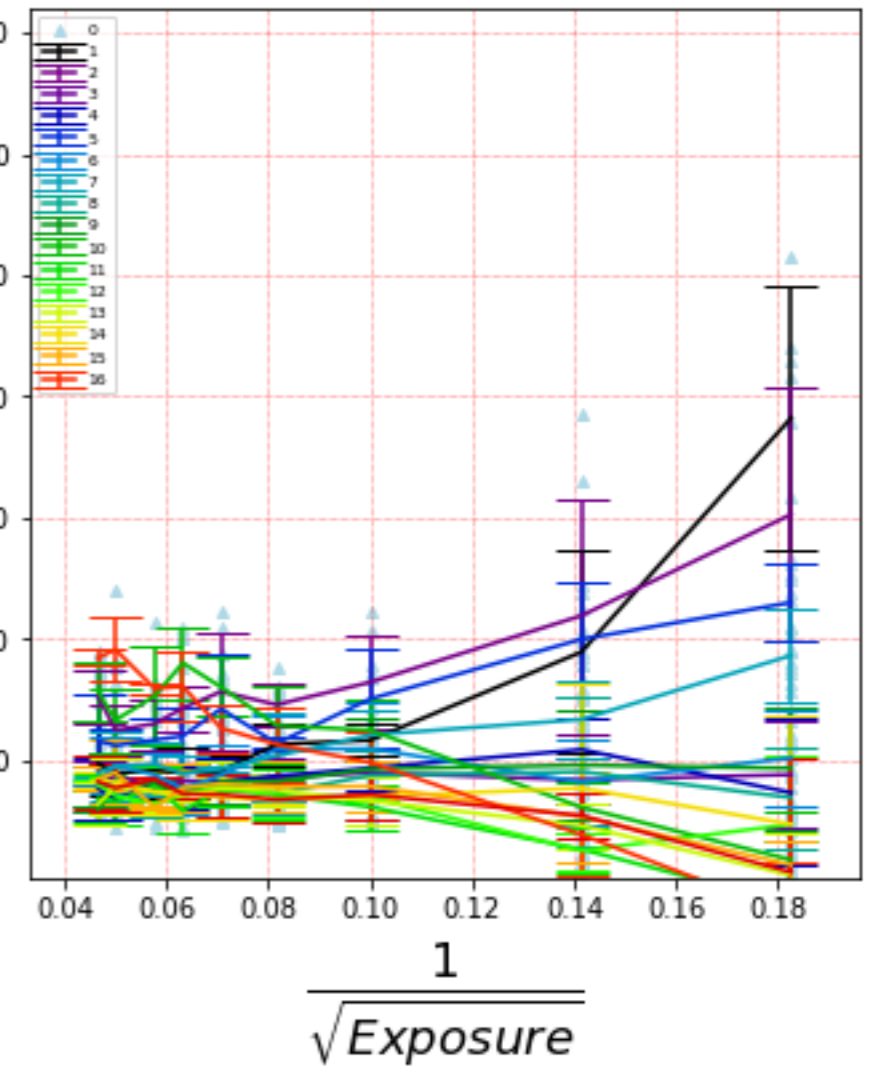
gllm_LongRunHighGrayLevelEmphasis_shift

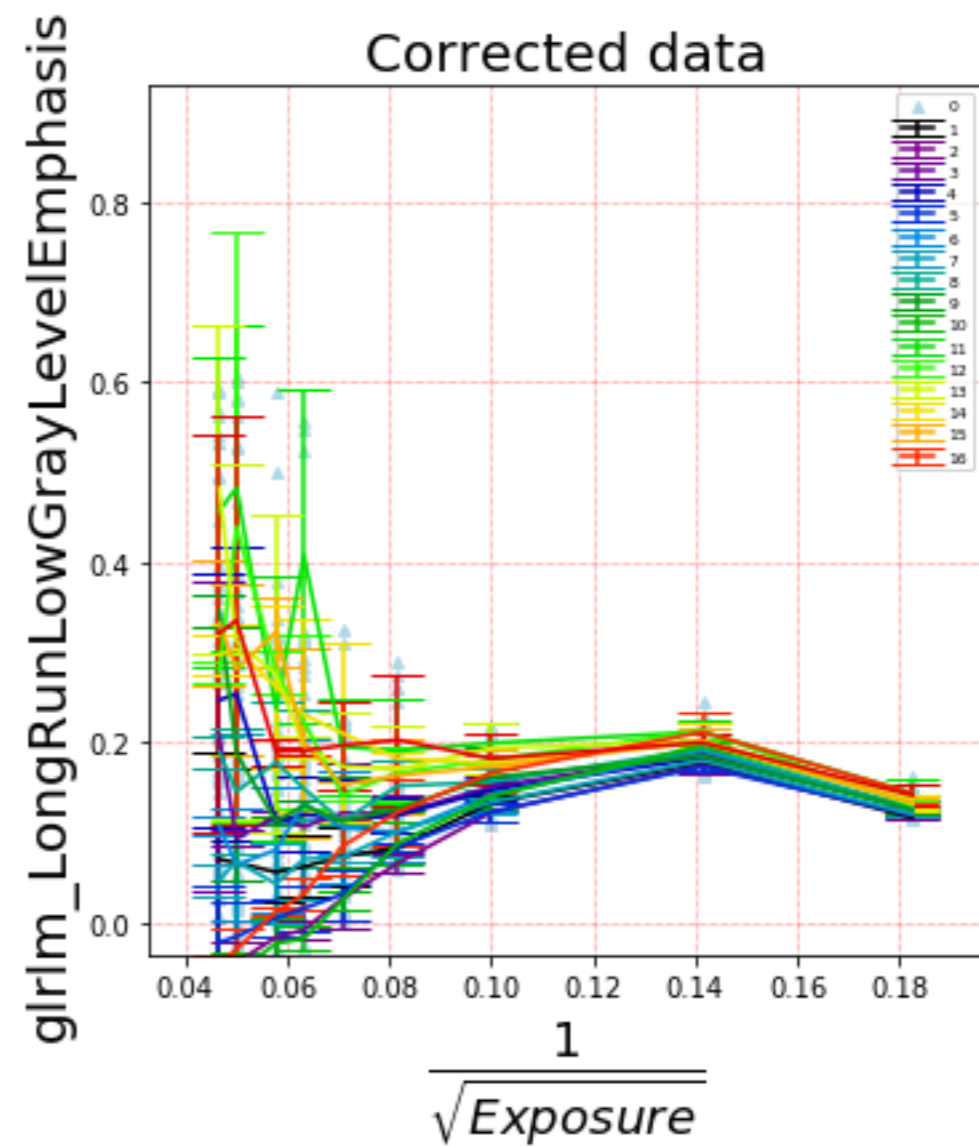
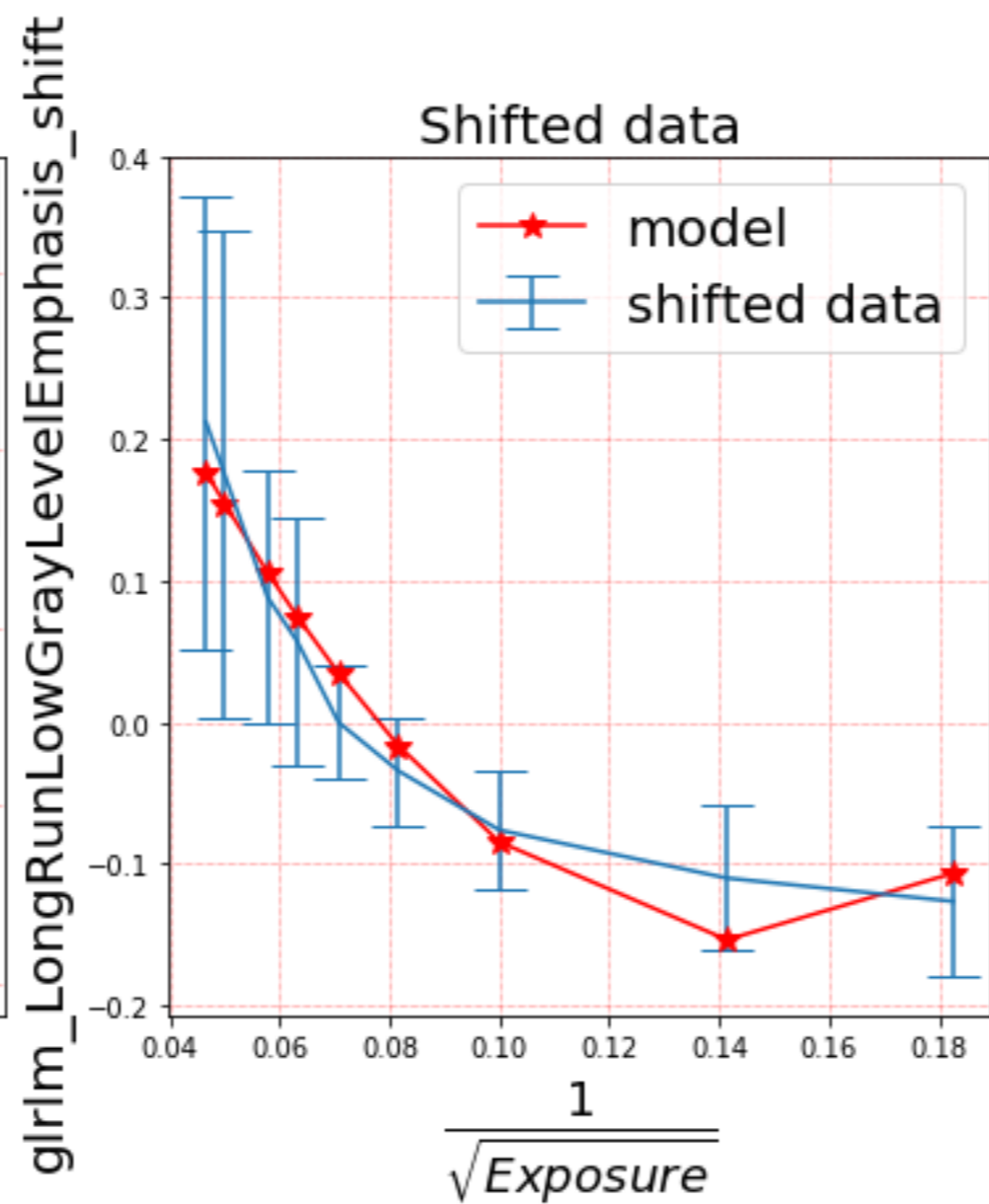
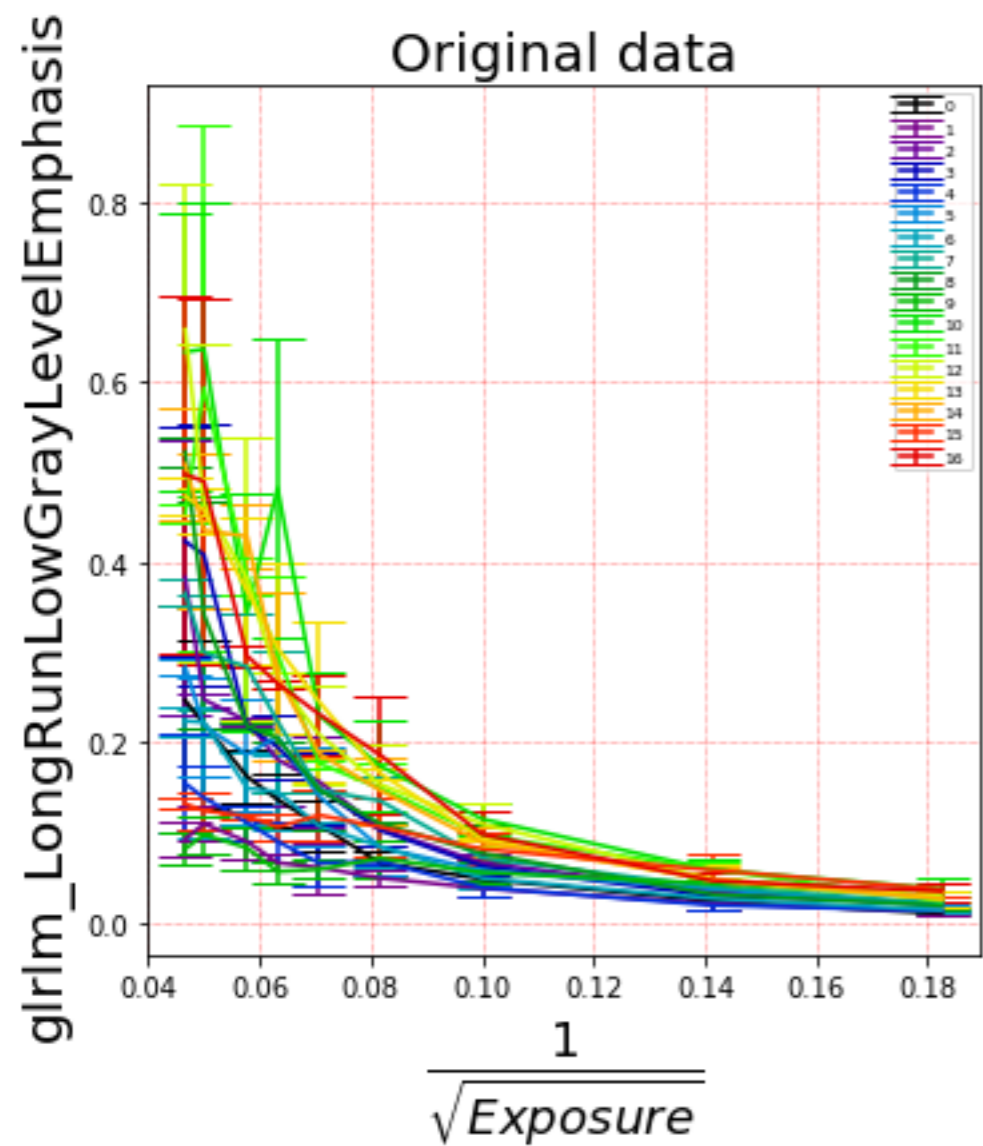
Shifted data

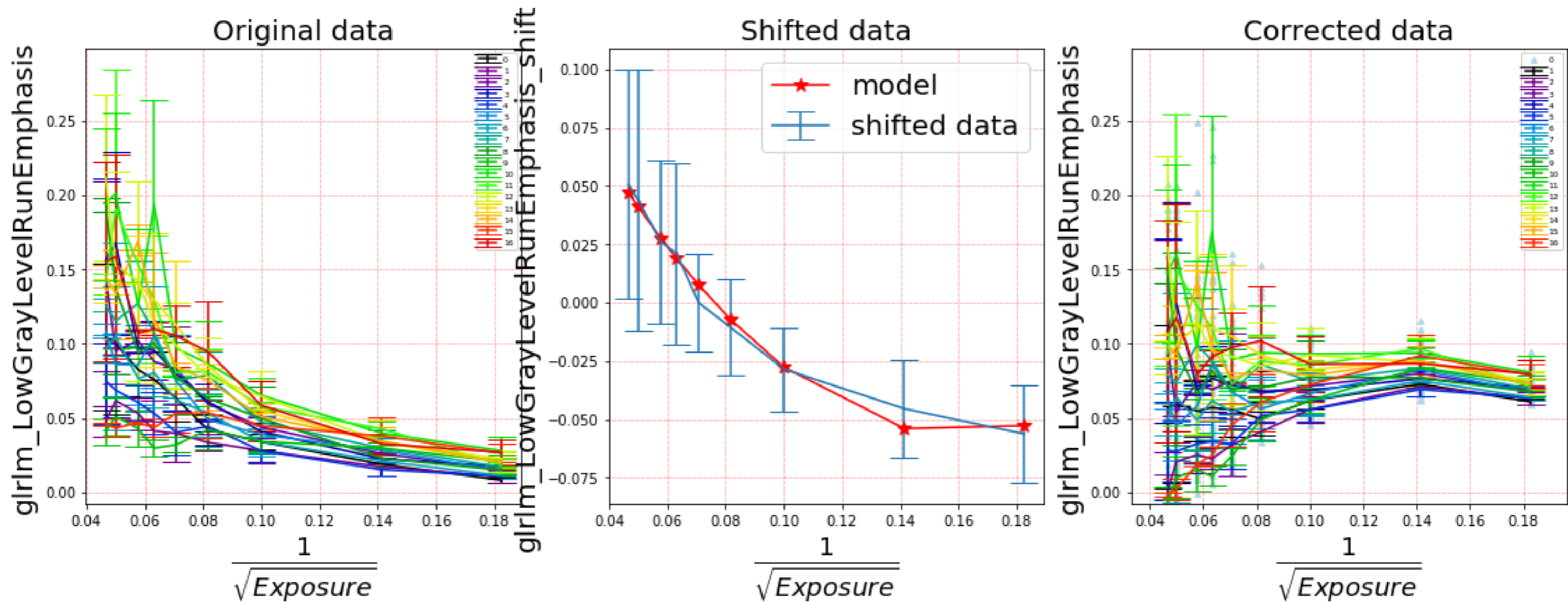


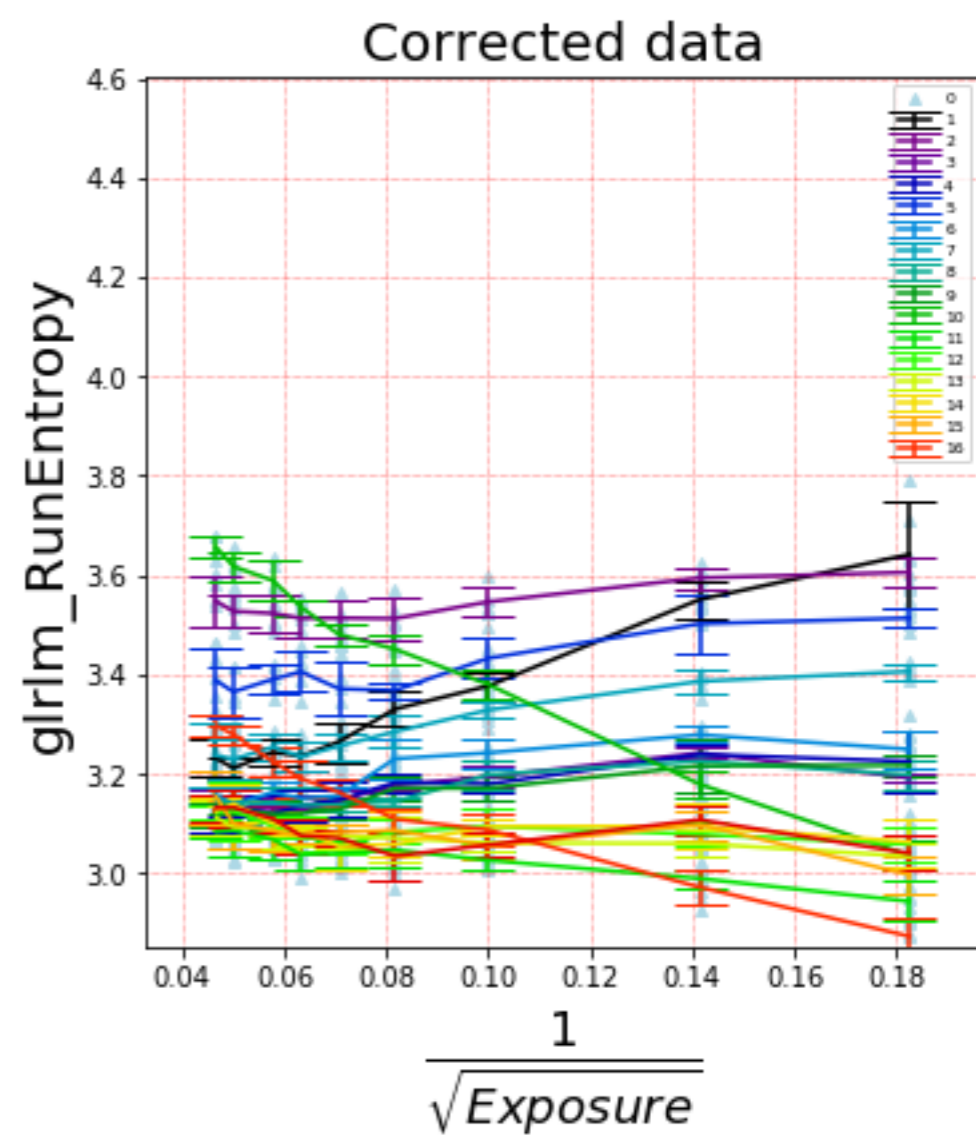
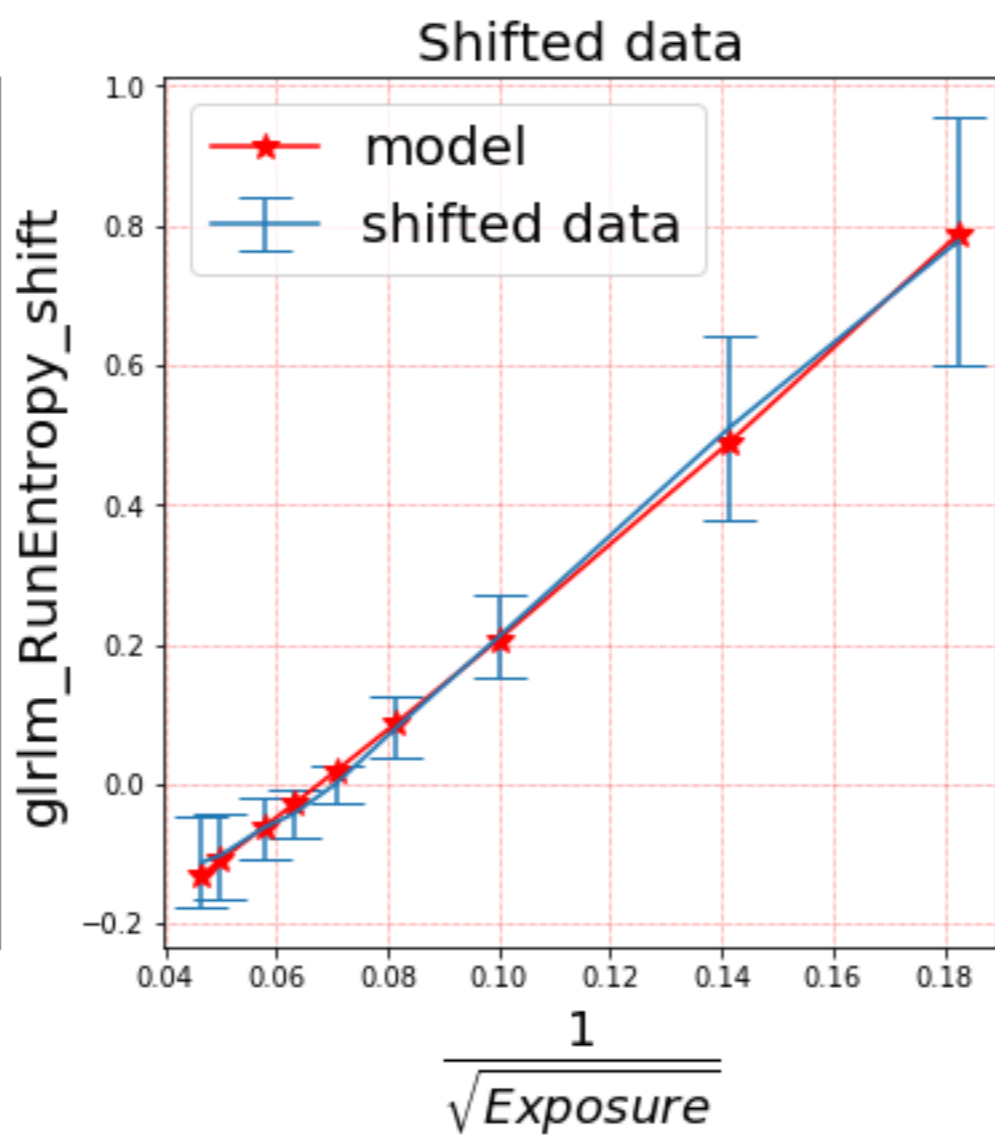
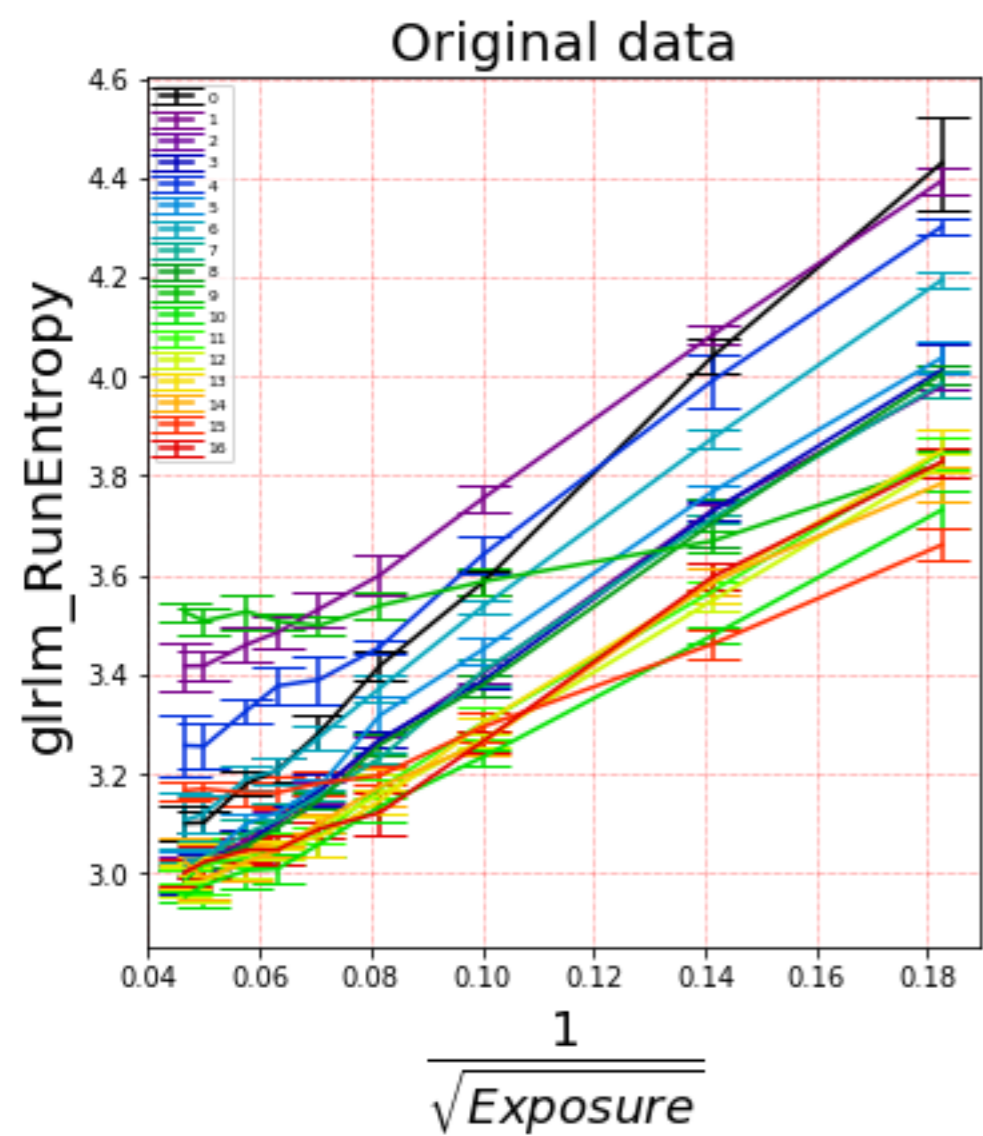
gllm_LongRunHighGrayLevelEmphasis

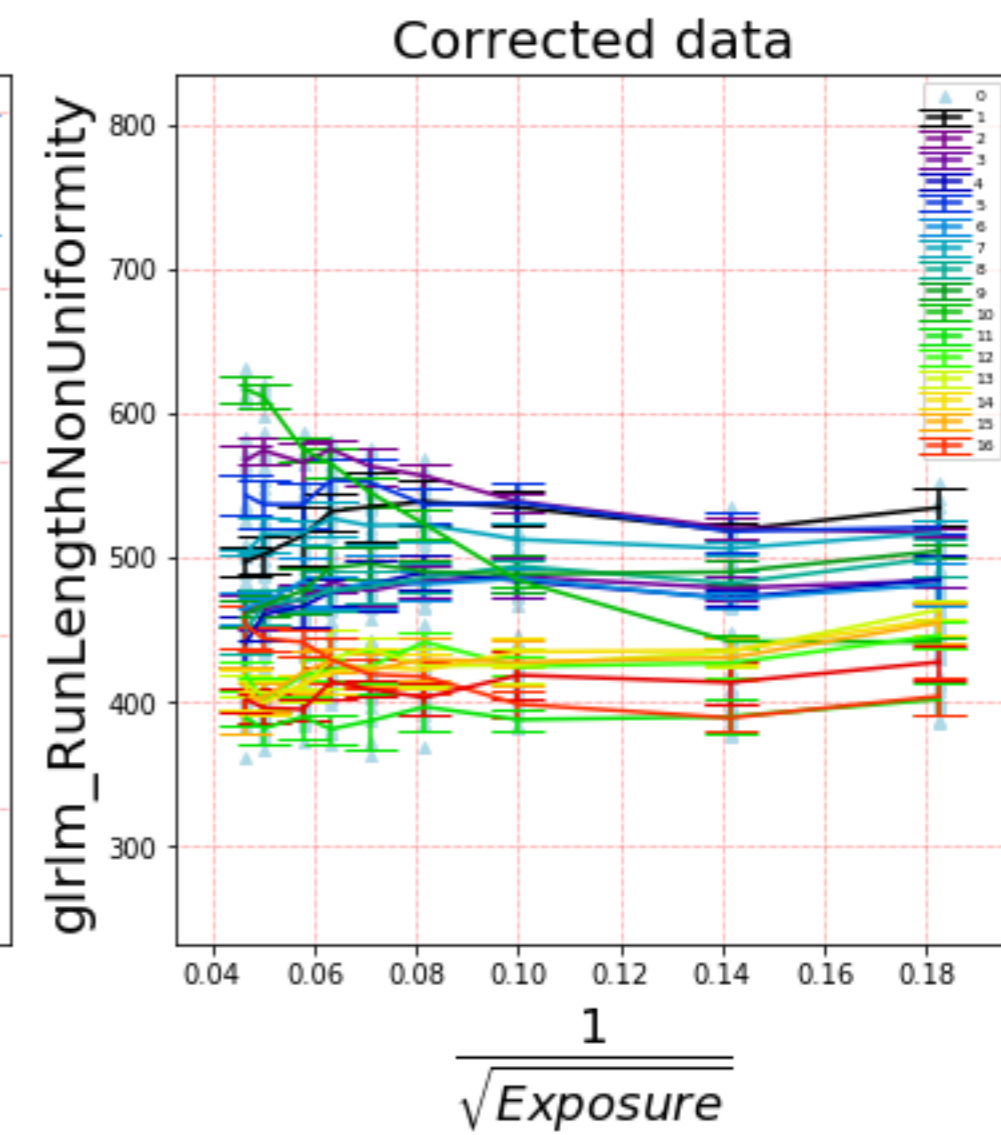
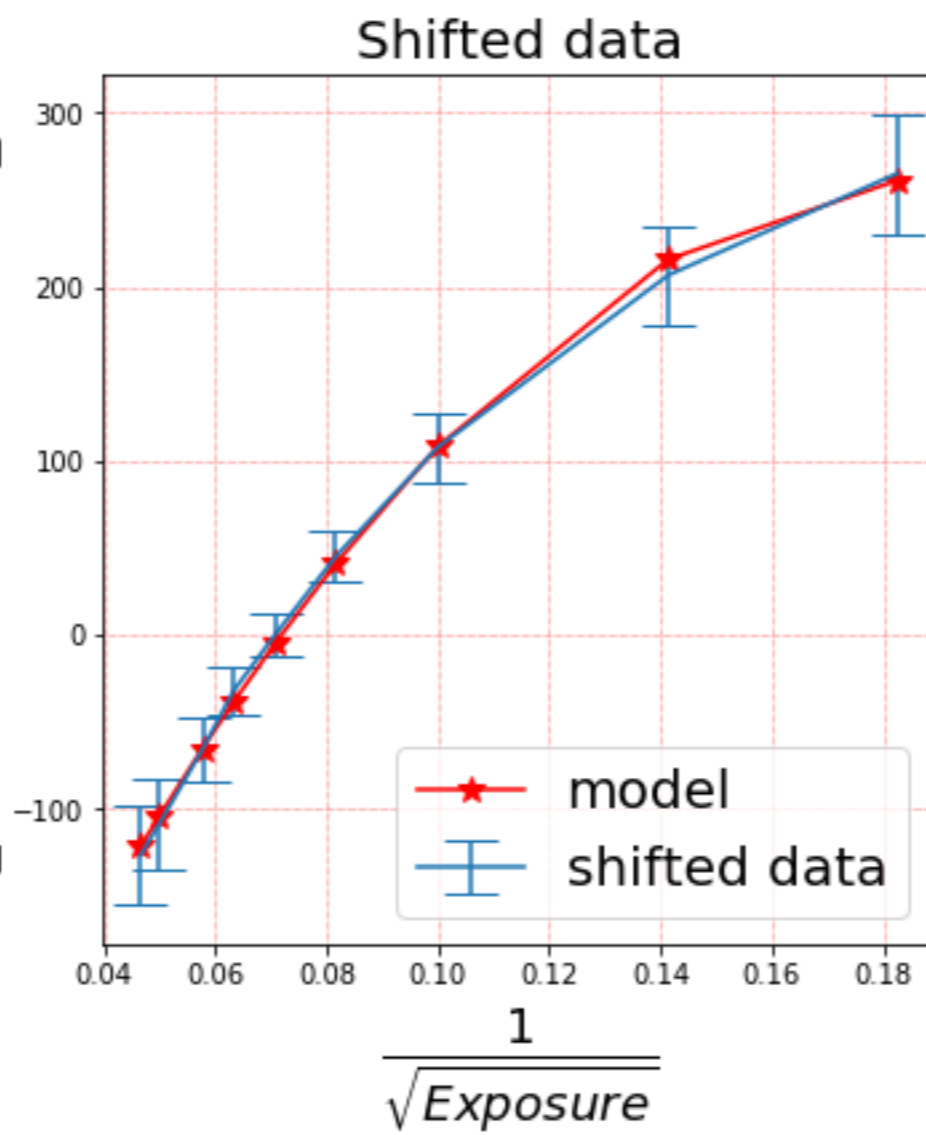
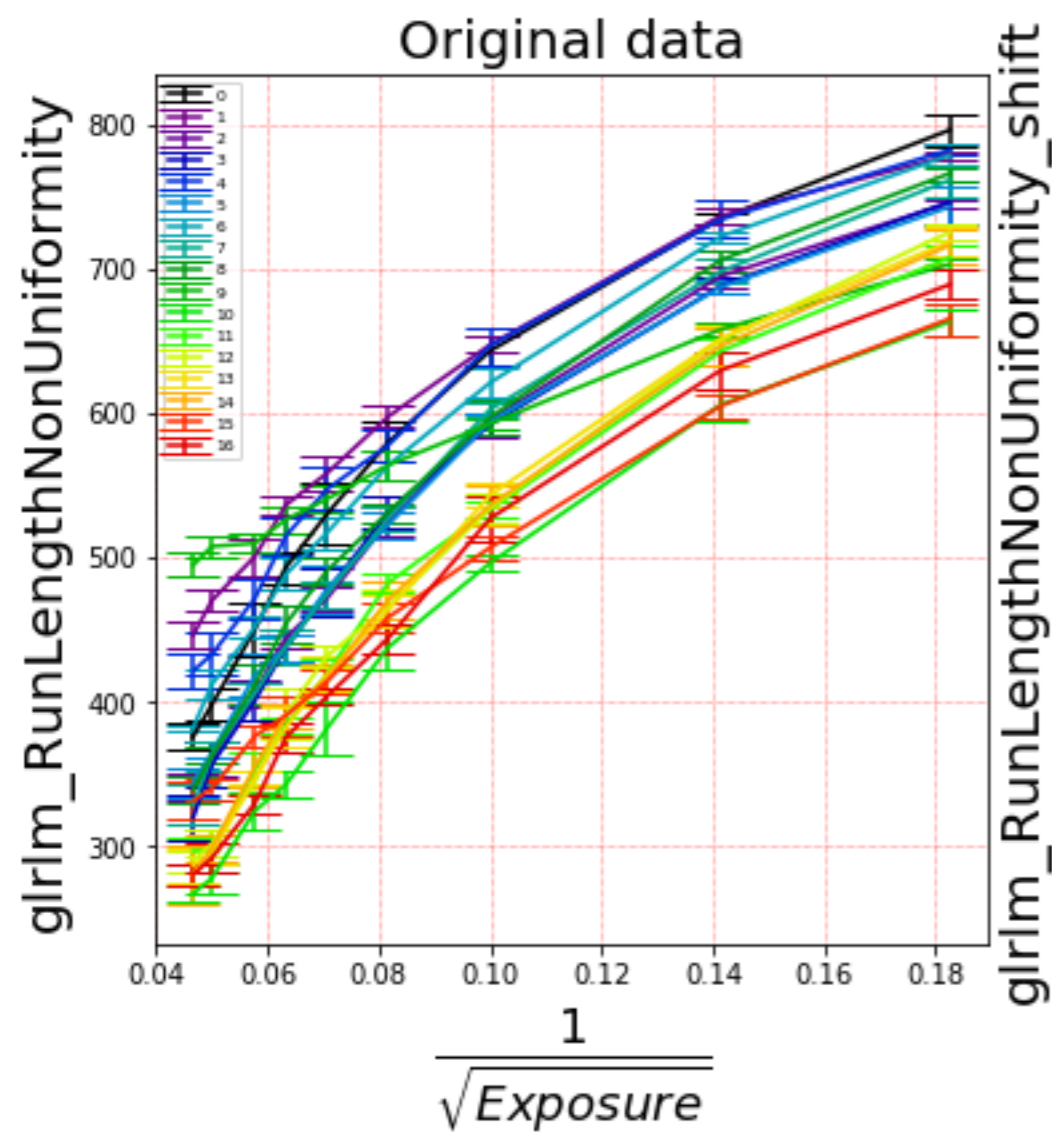
Corrected data

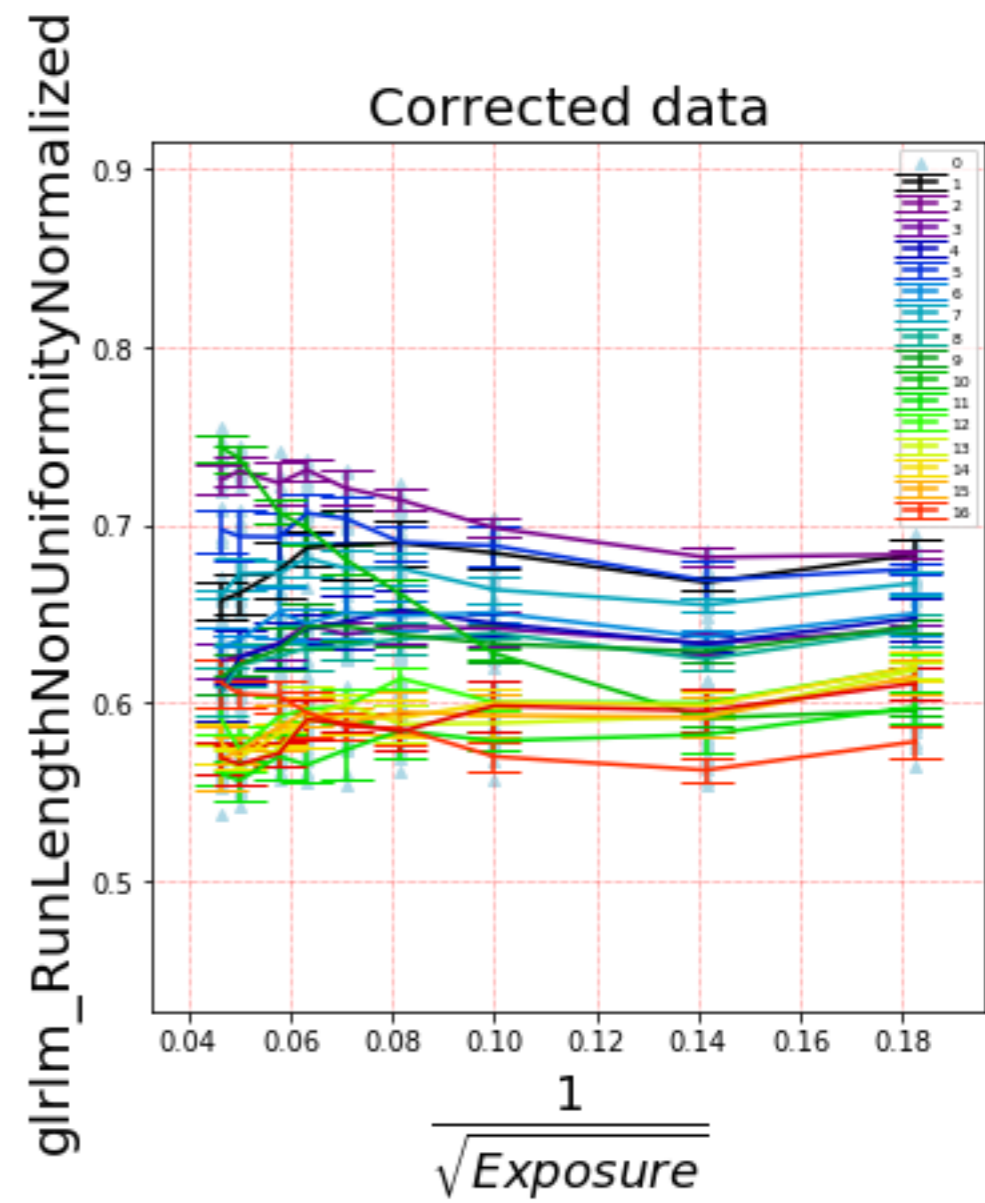
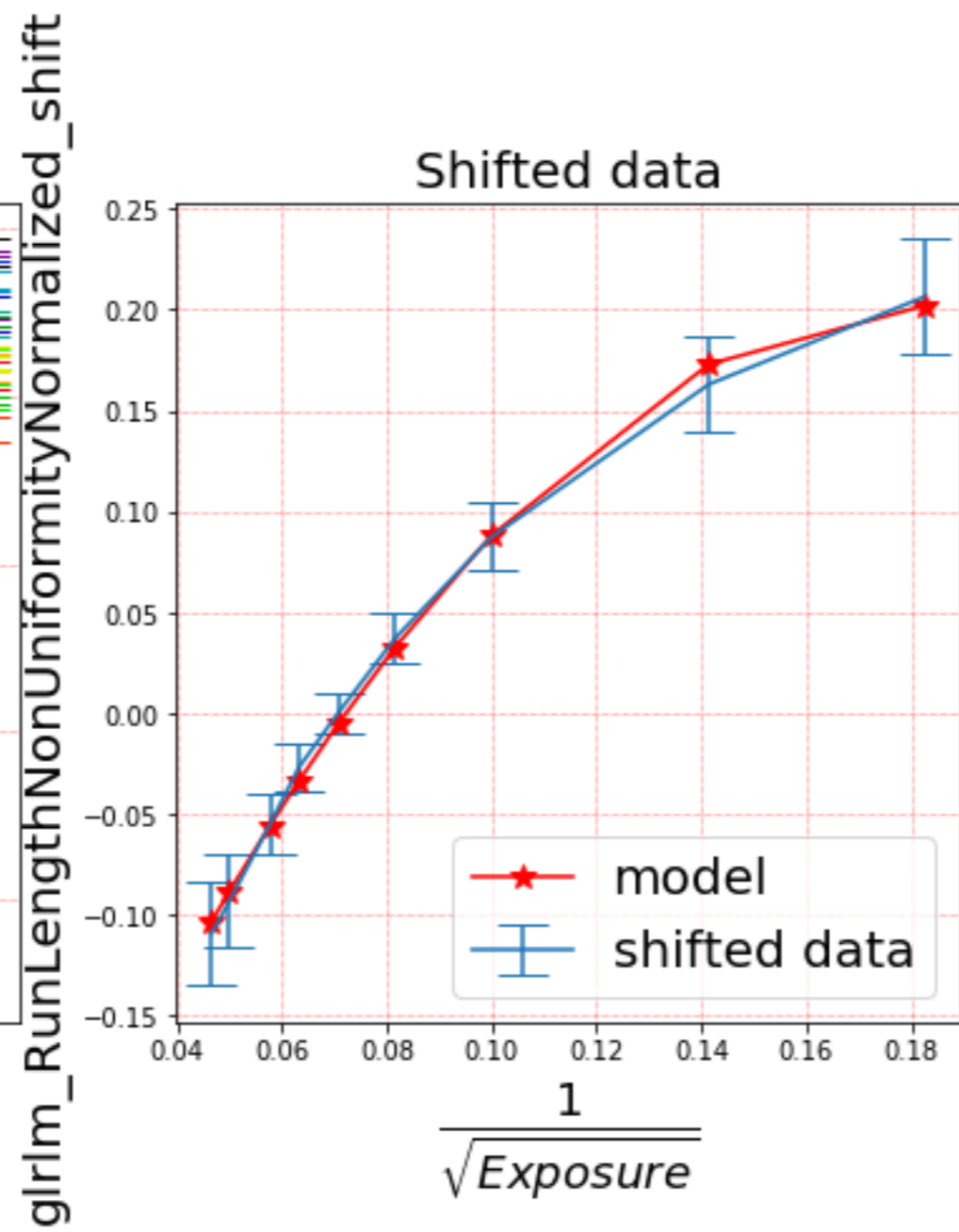
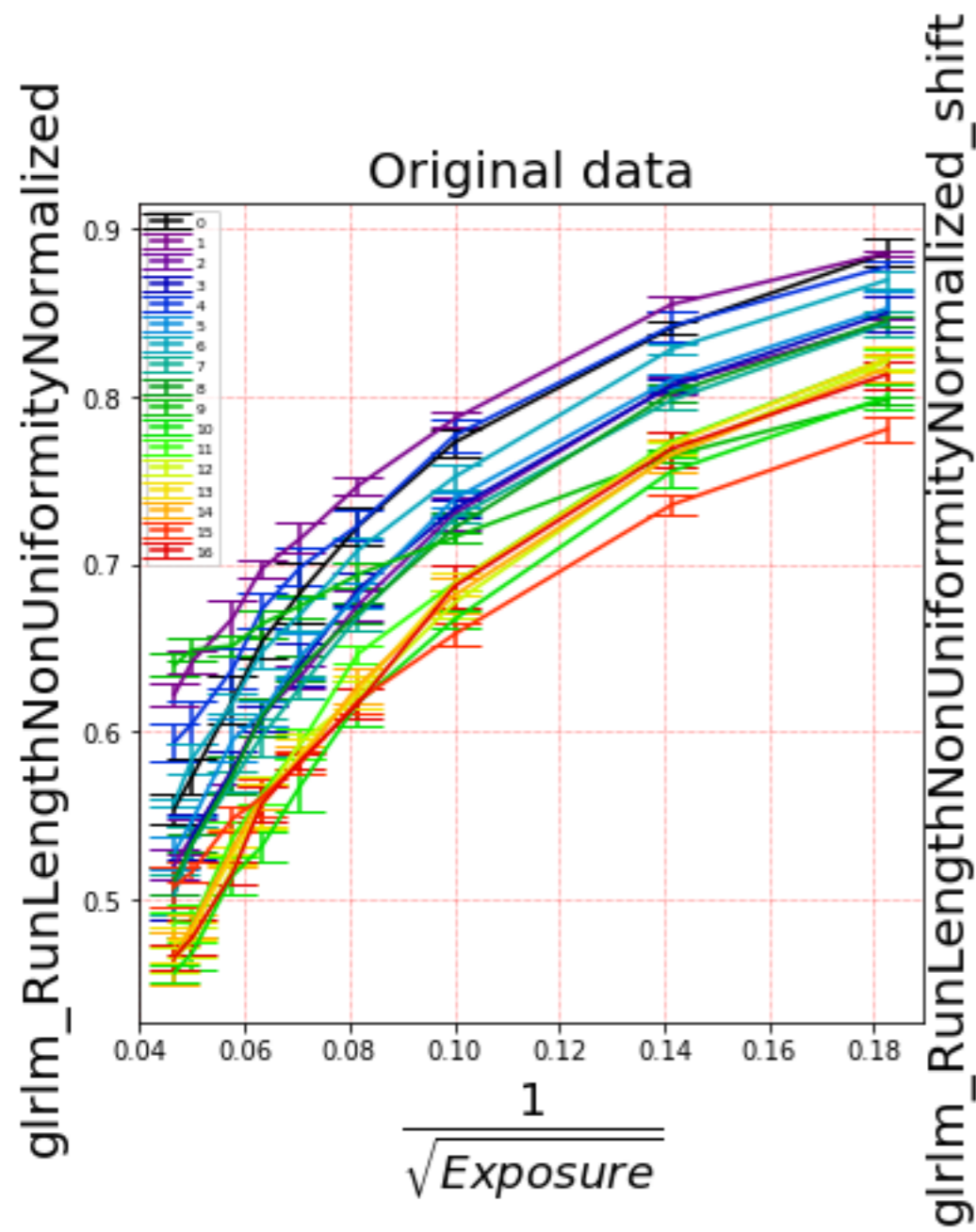


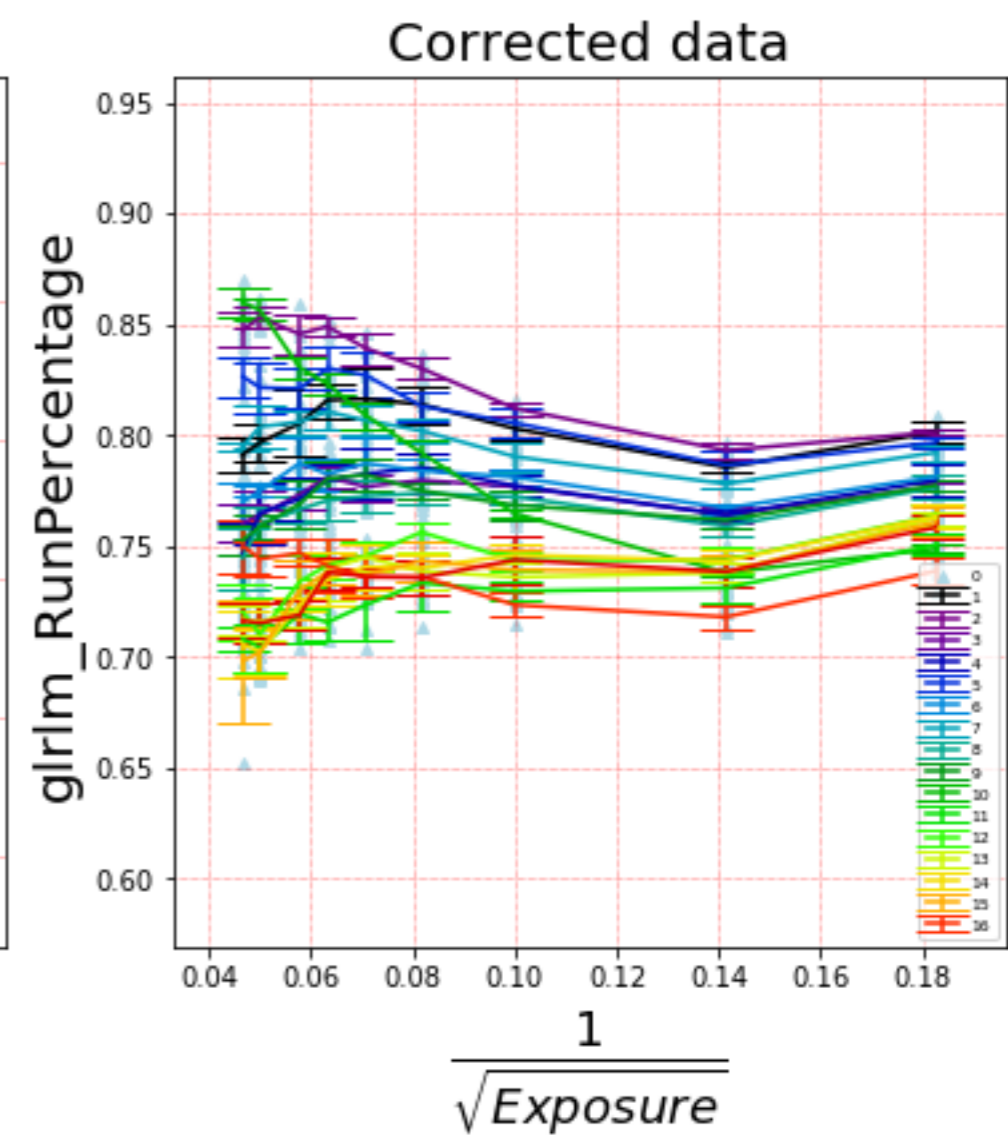
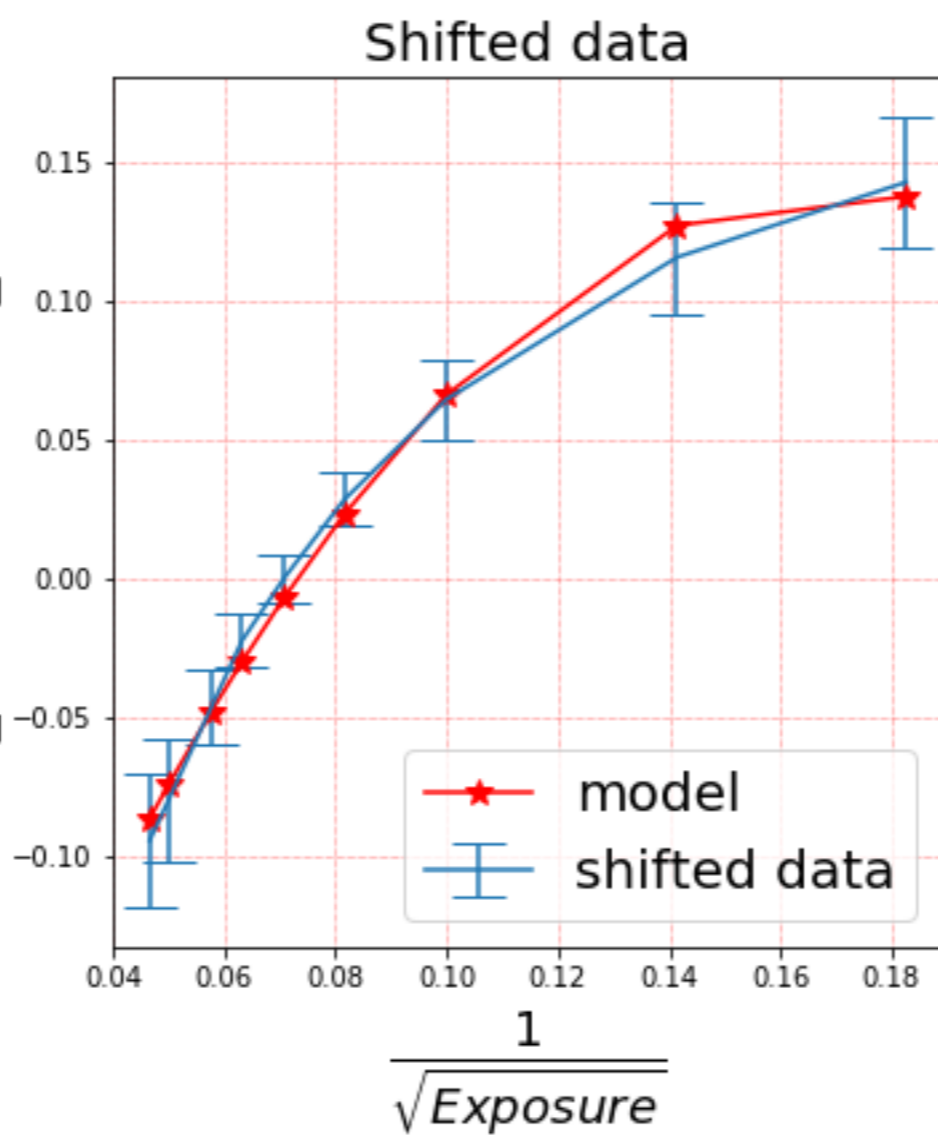
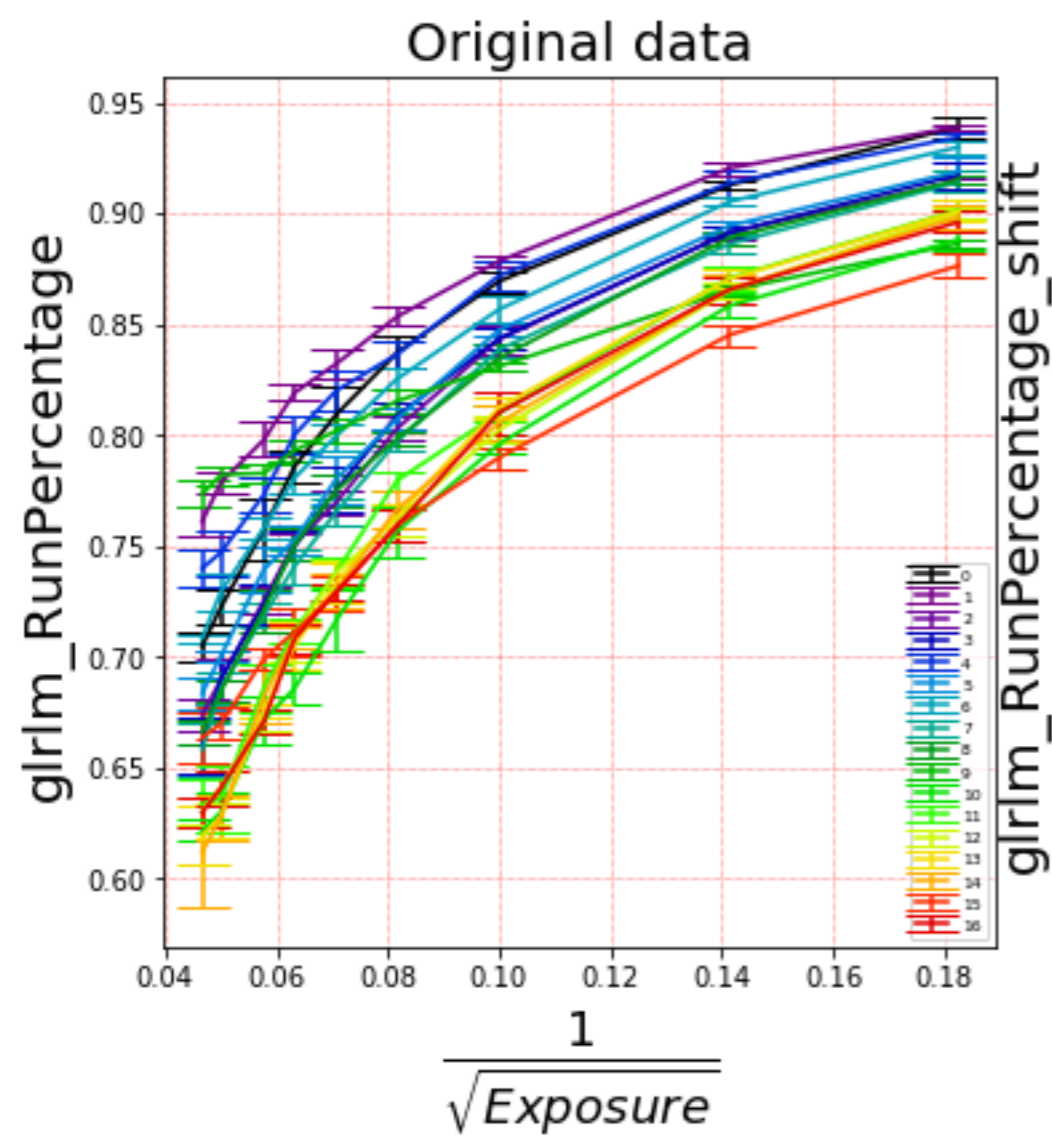




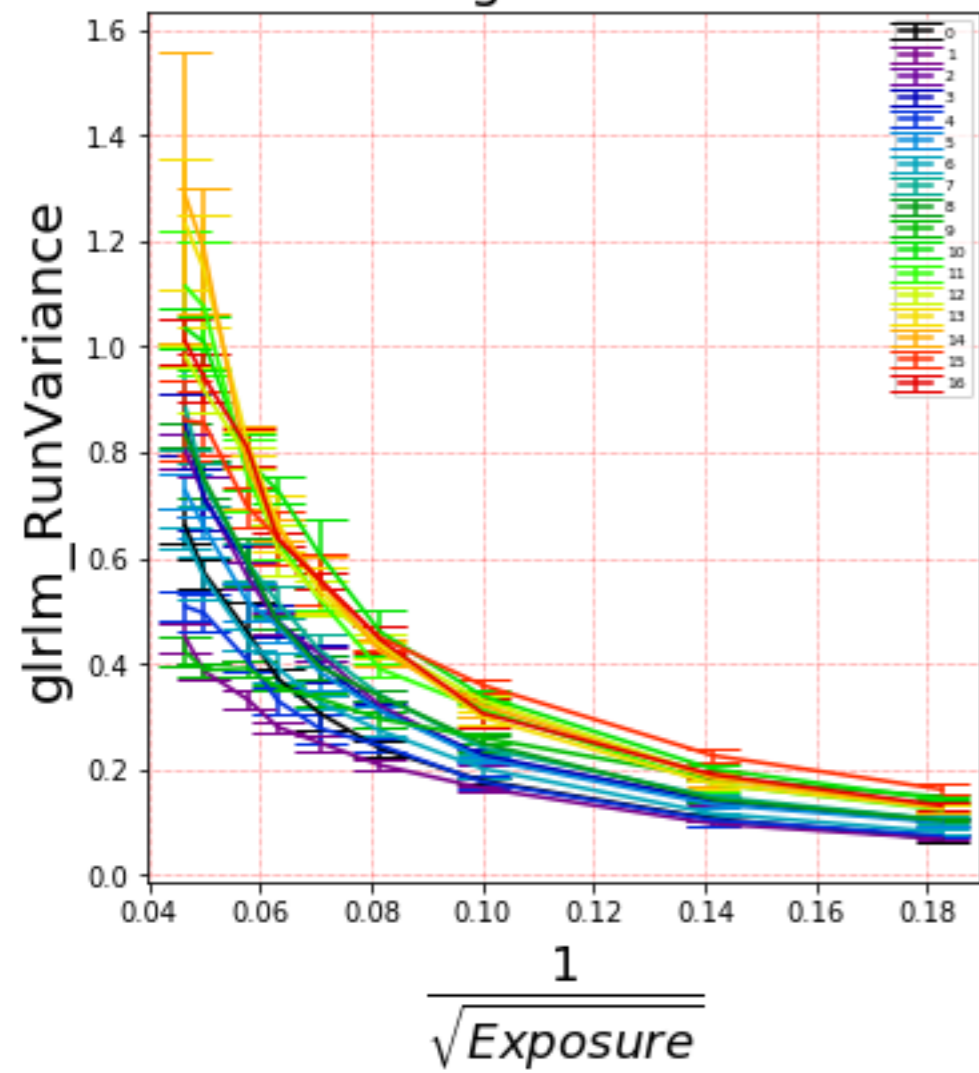




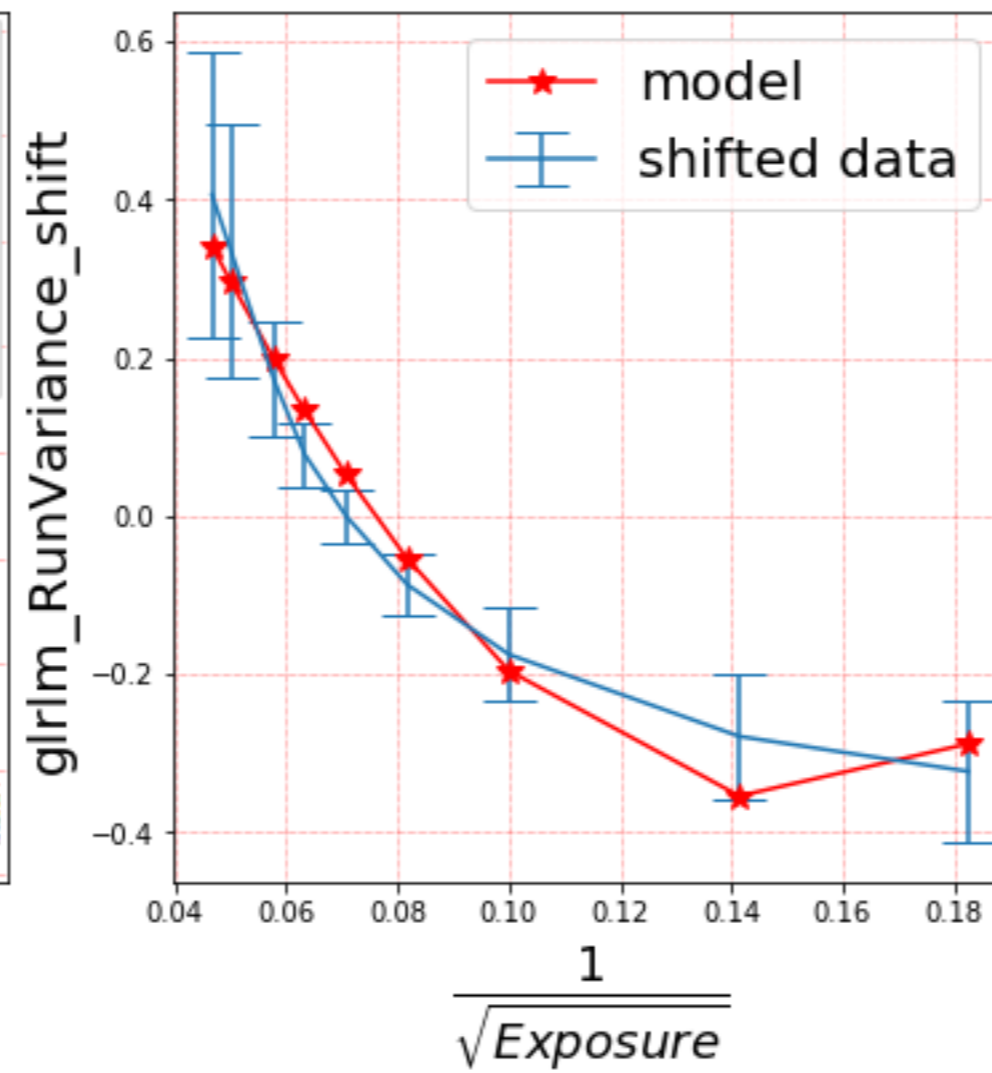




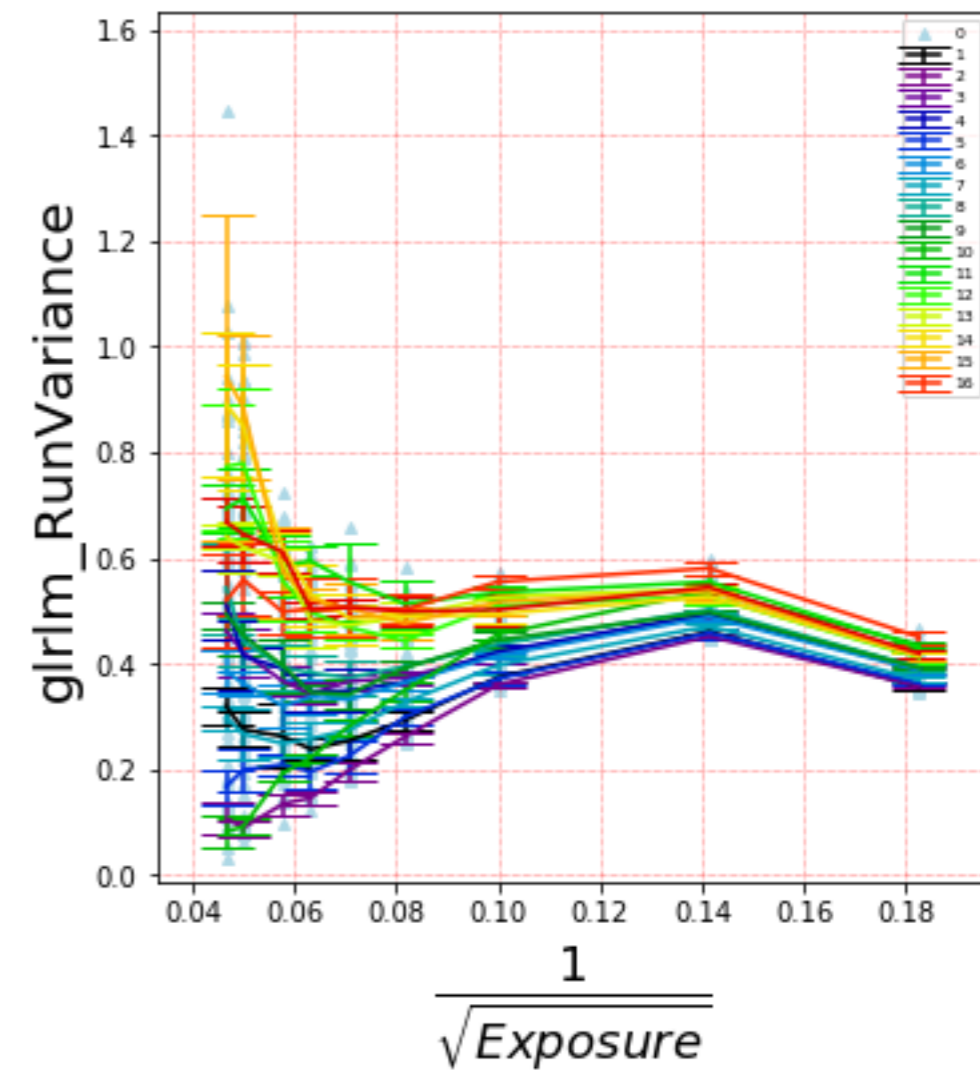
Original data

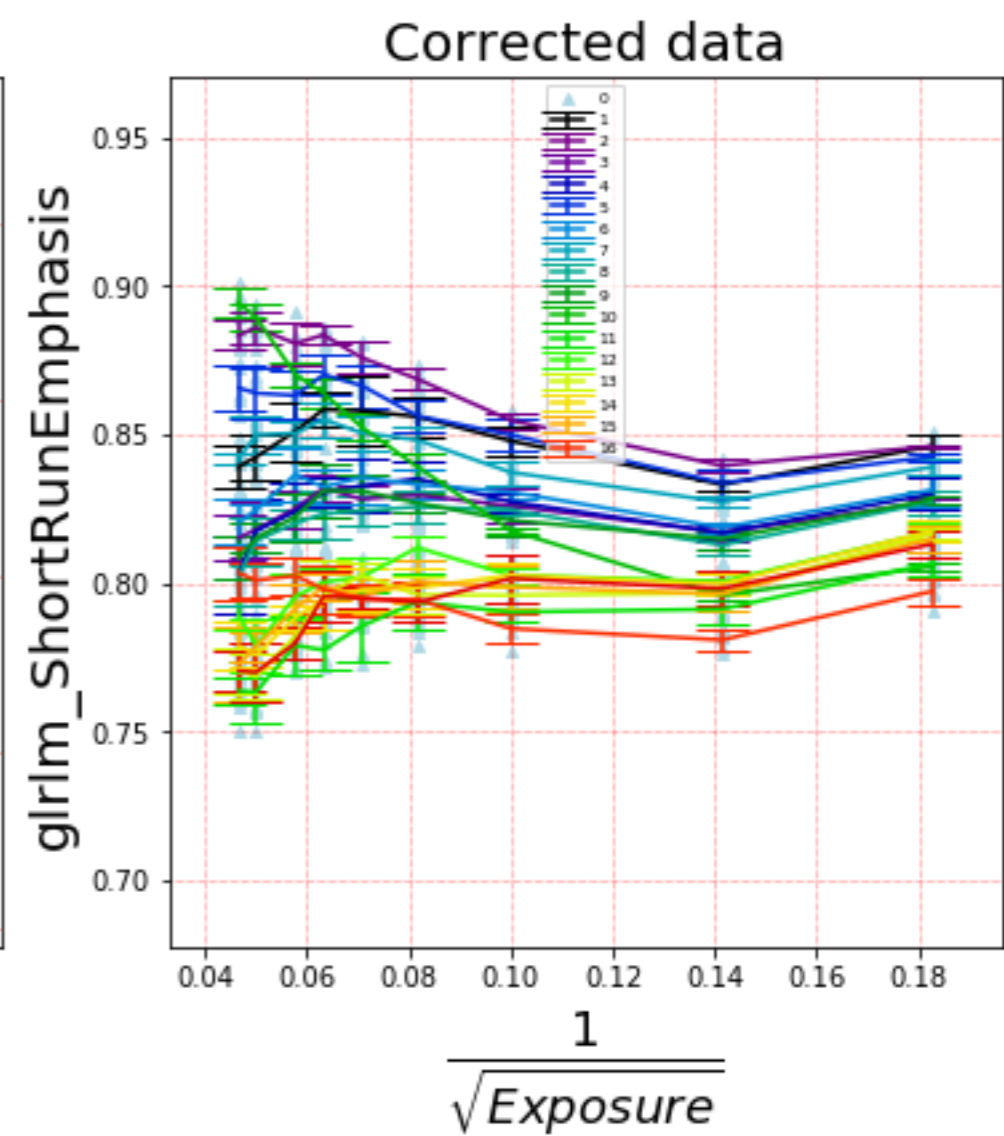
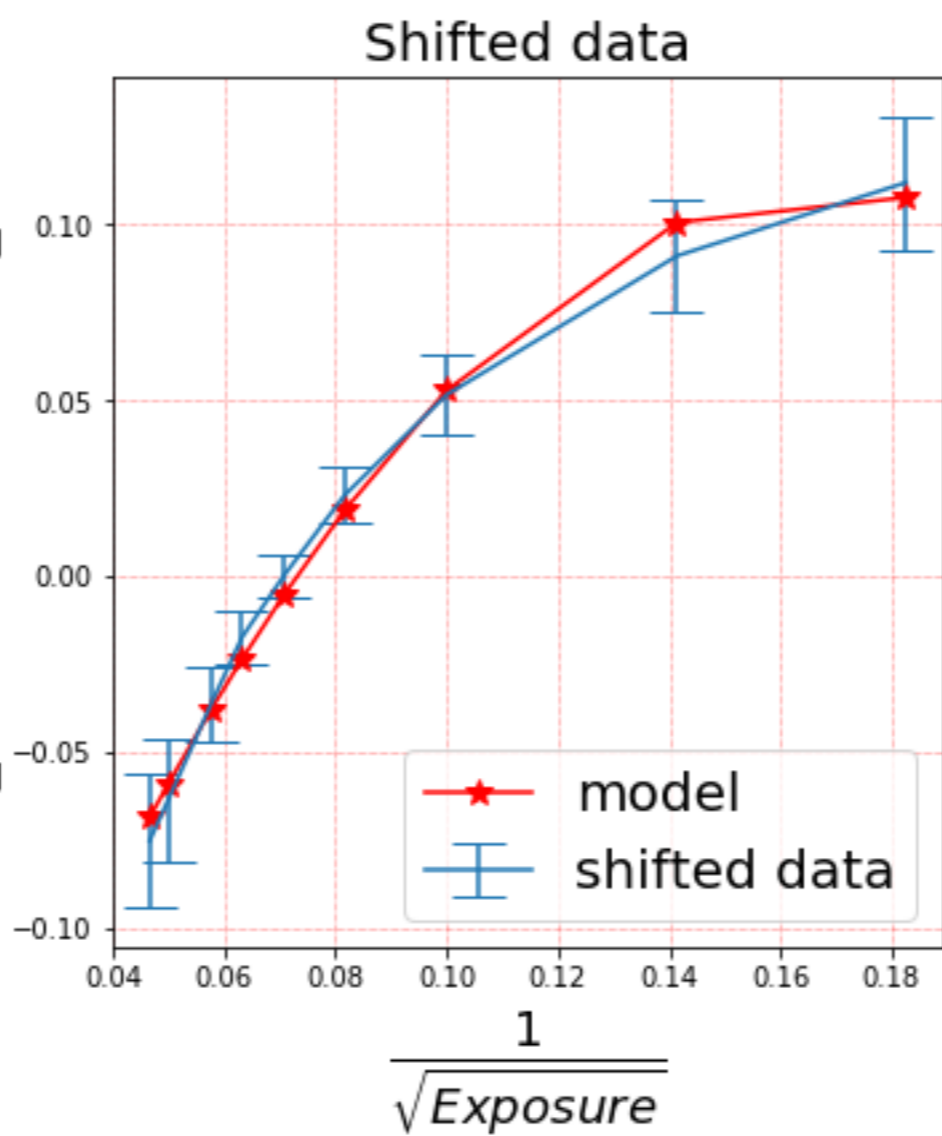
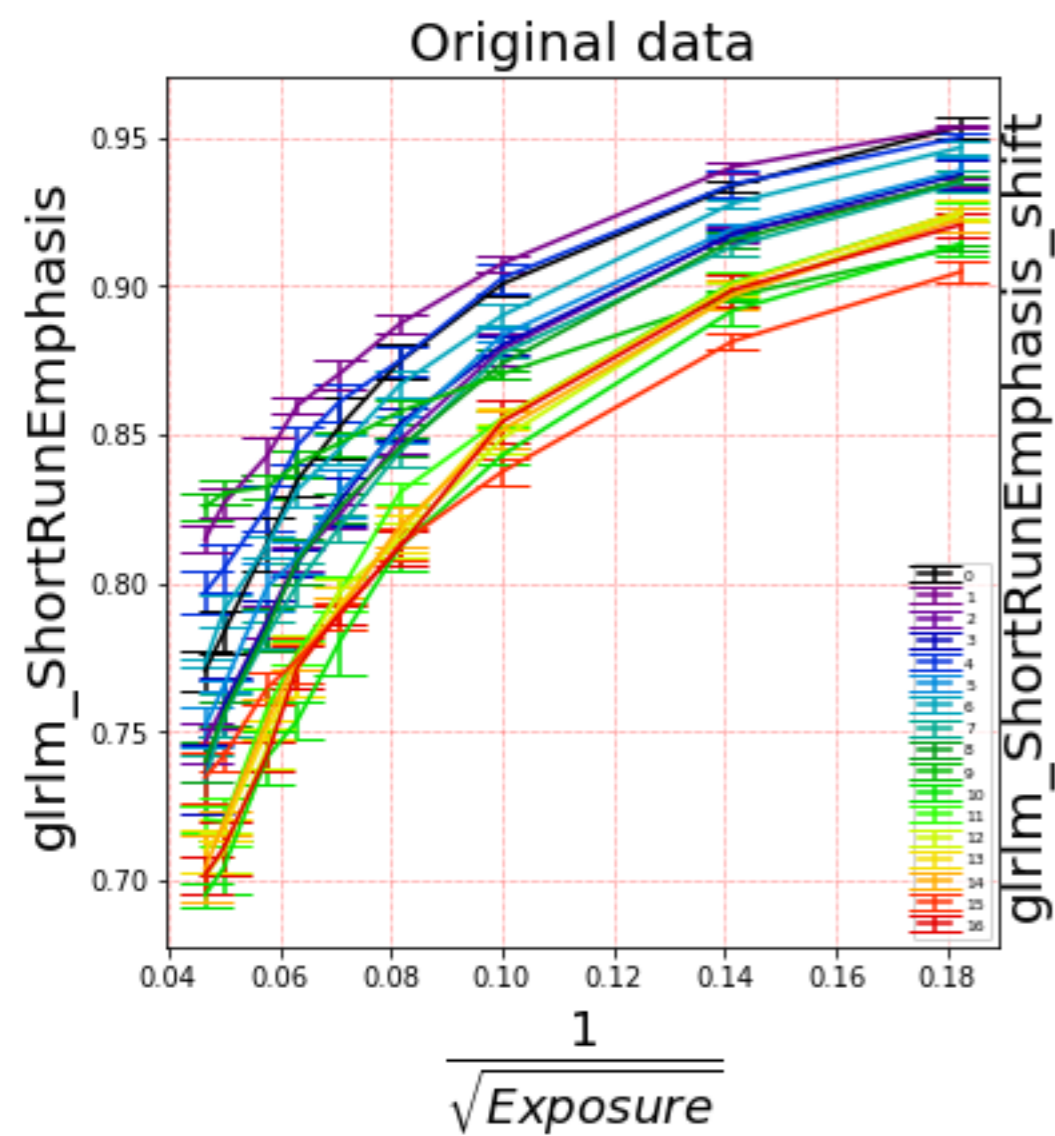


Shifted data



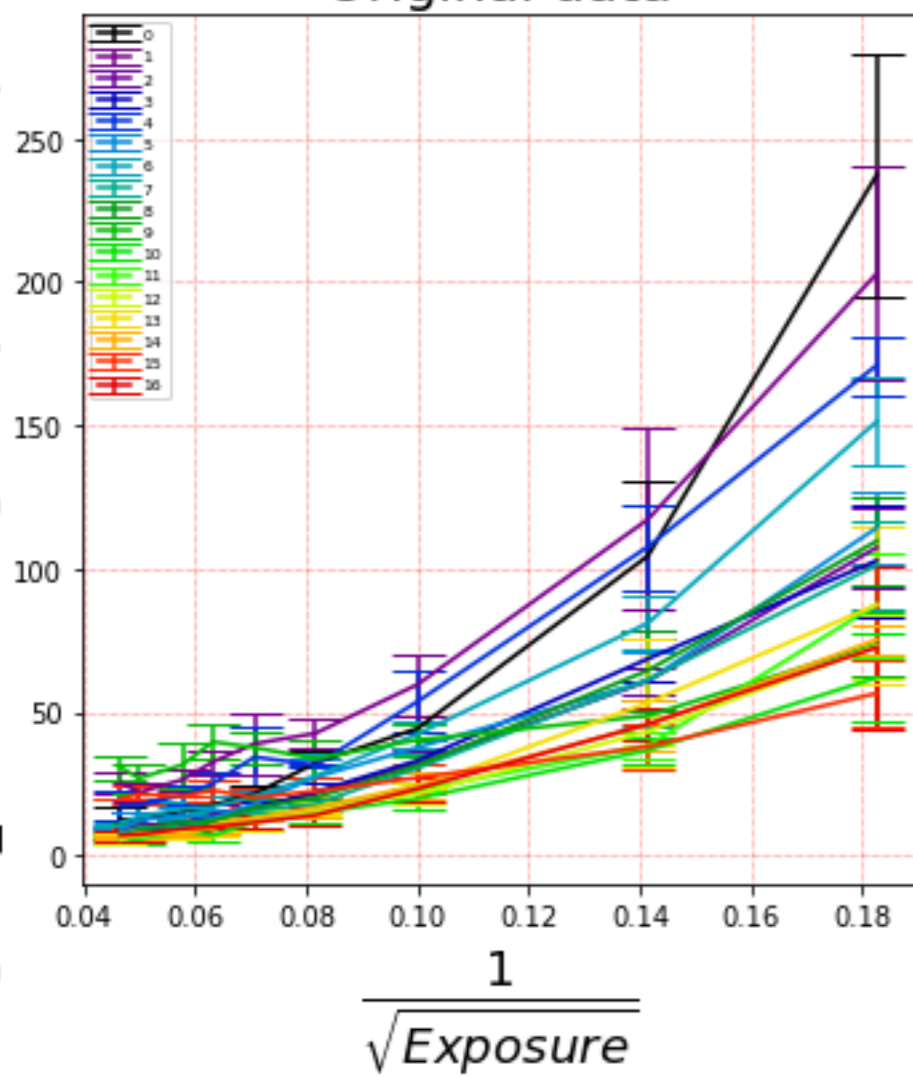
Corrected data





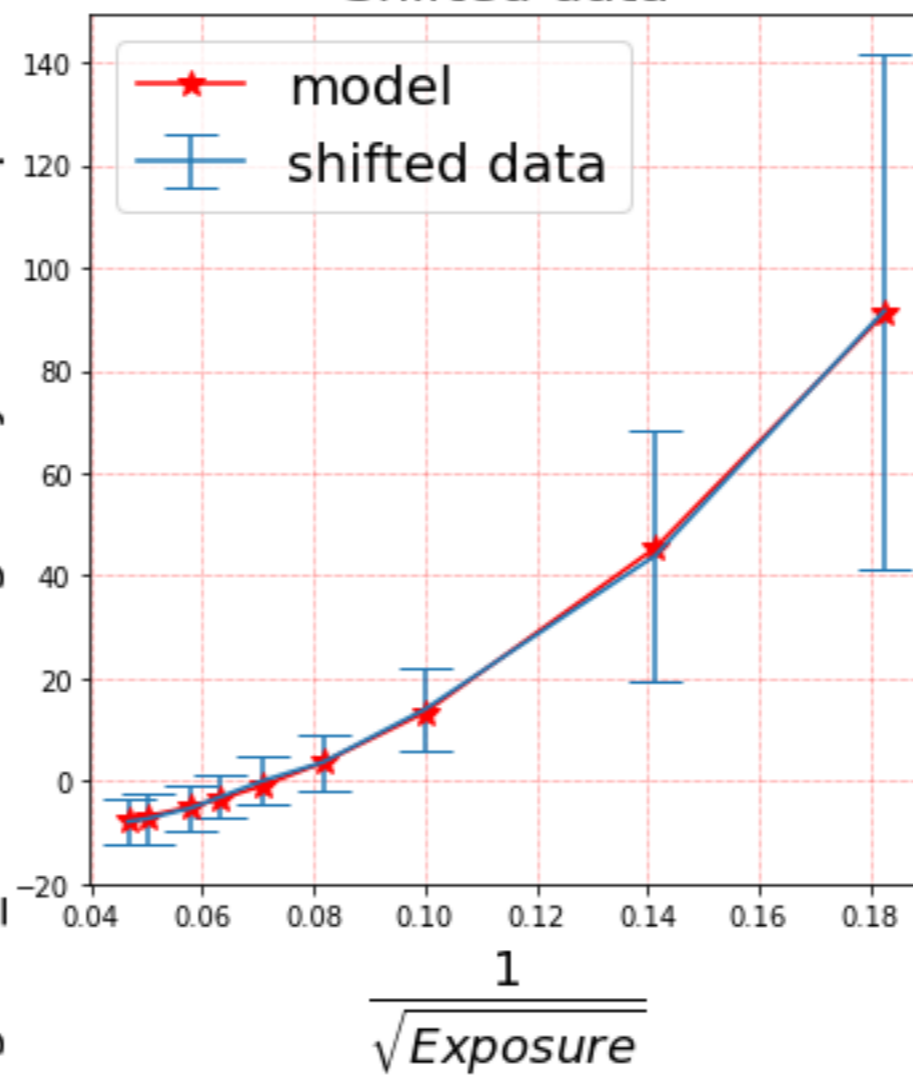
glim_ShortRunHighGrayLevelEmphasis

Original data



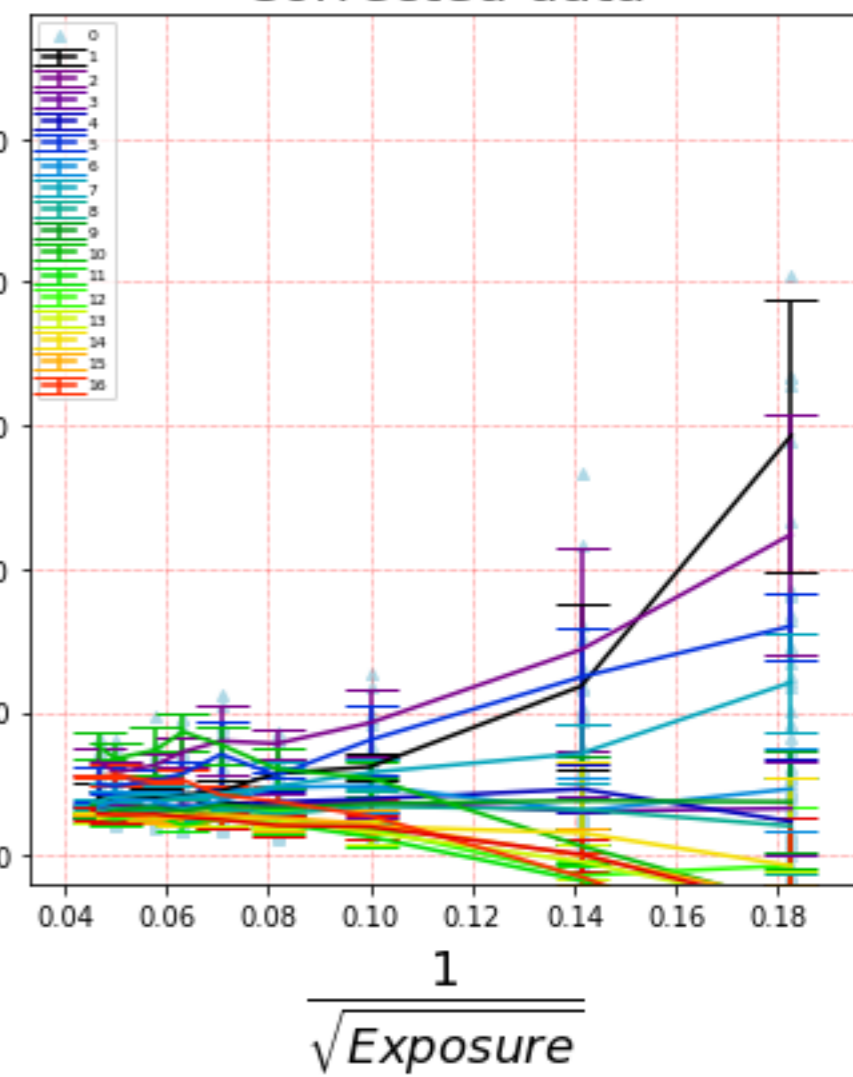
glim_ShortRunHighGrayLevelEmphasis_shift

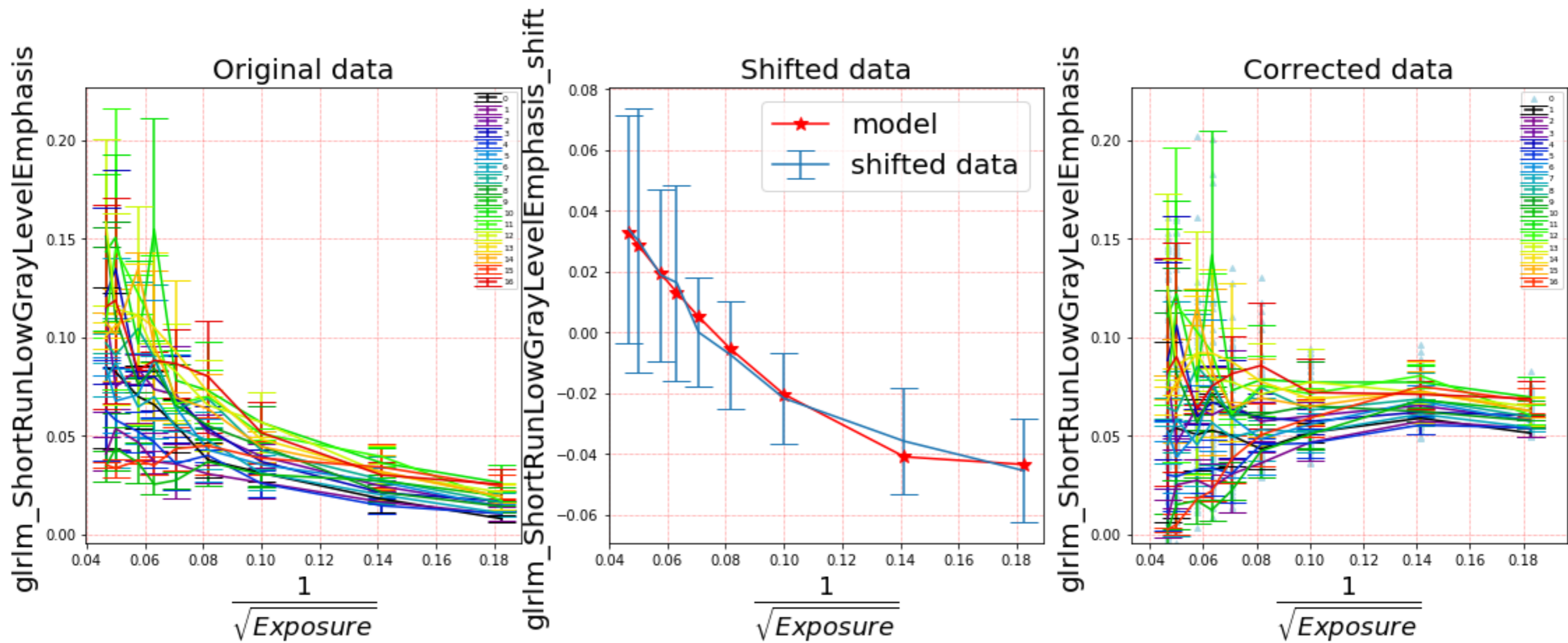
Shifted data

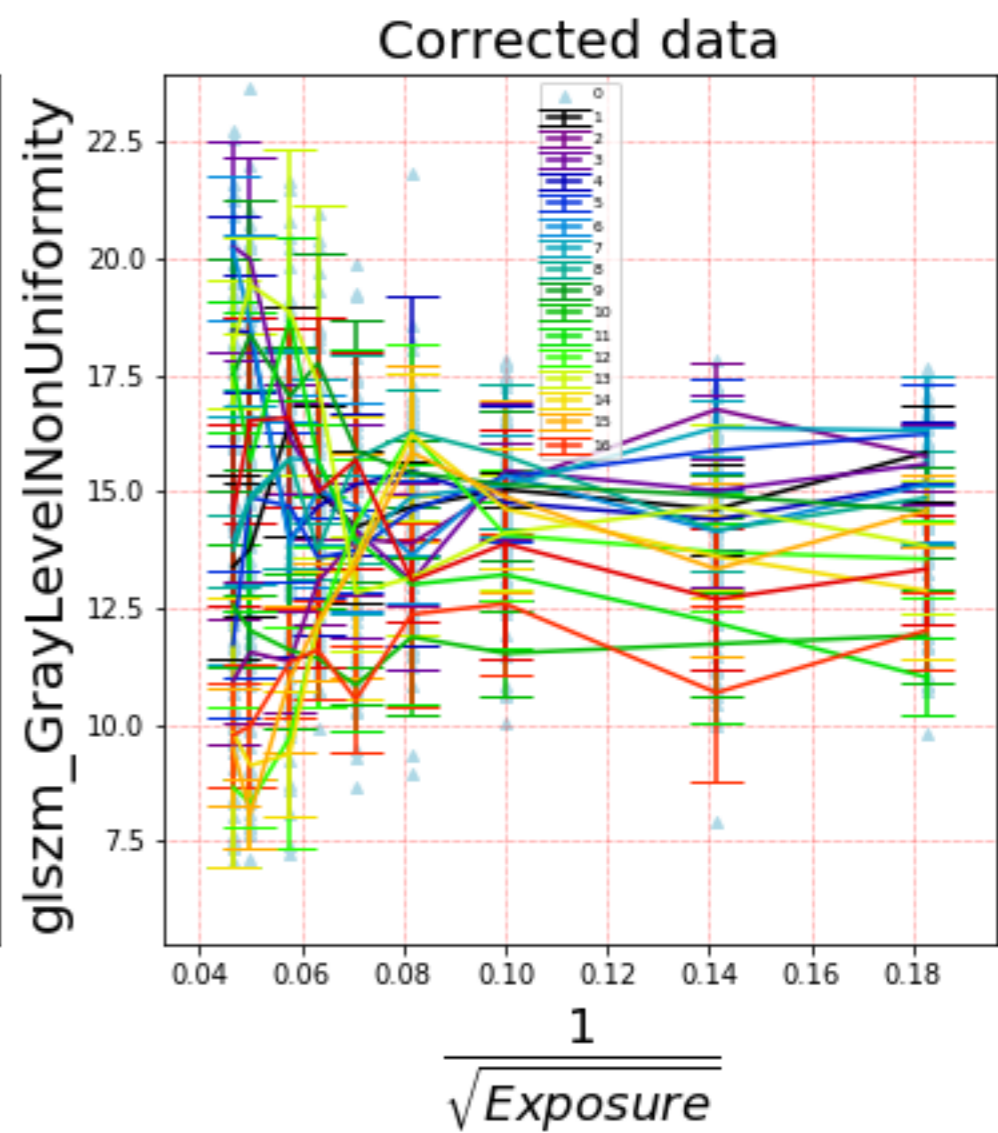
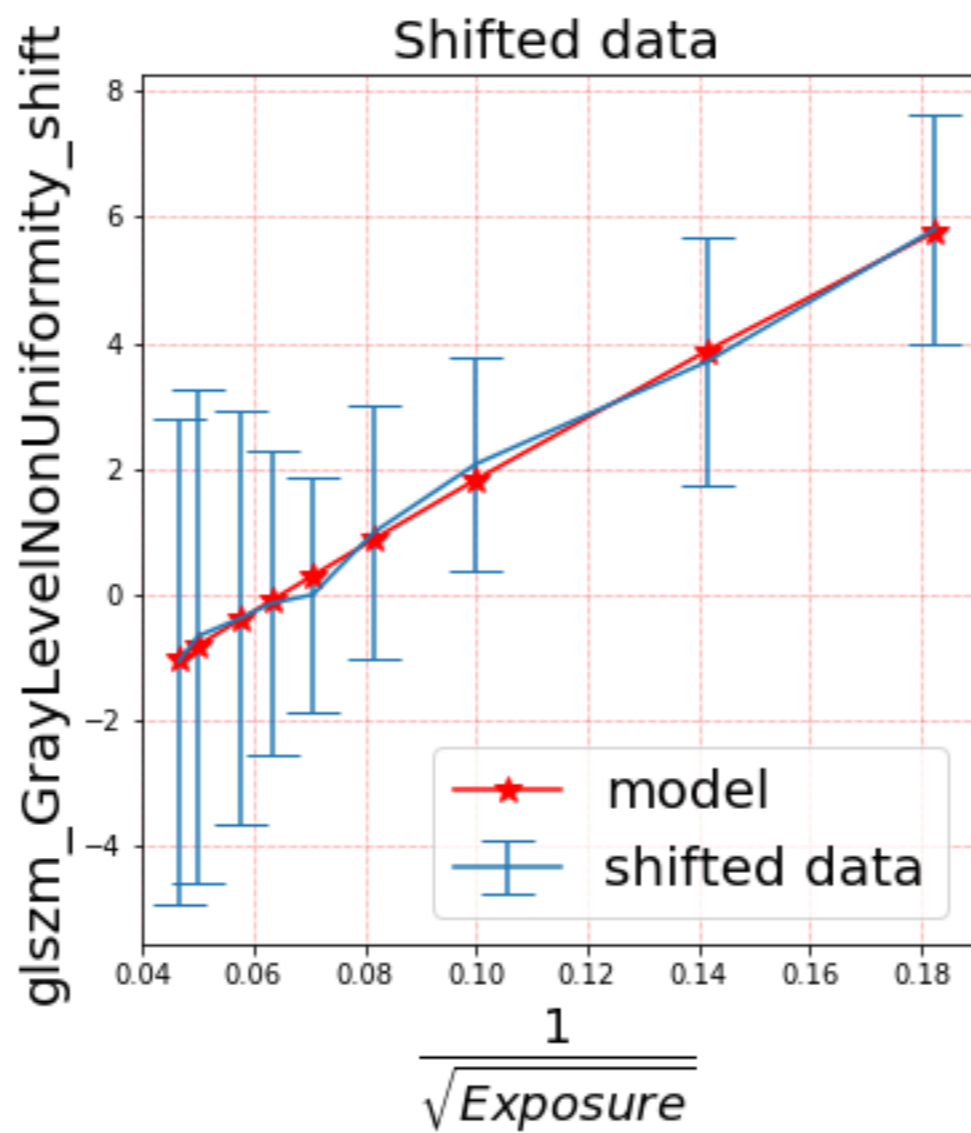
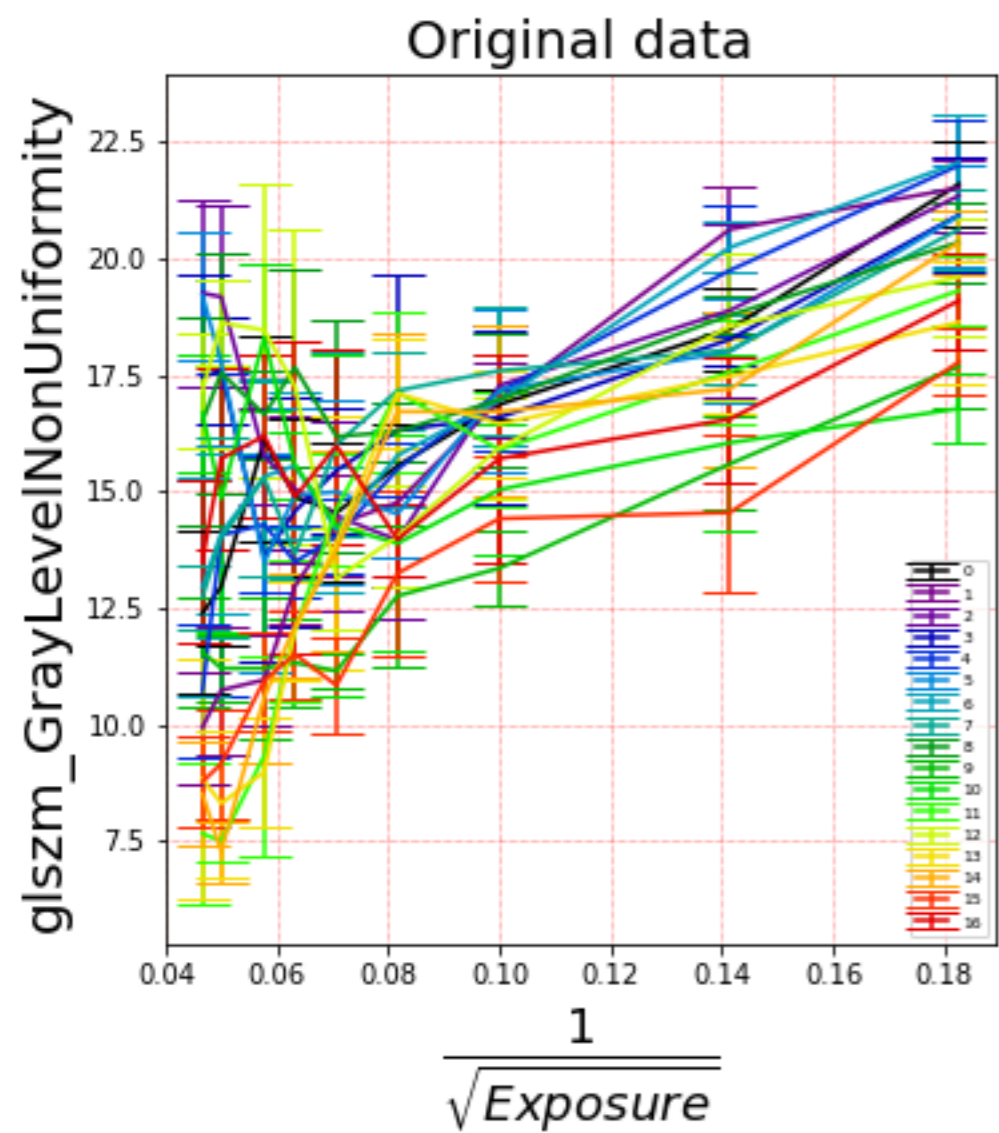


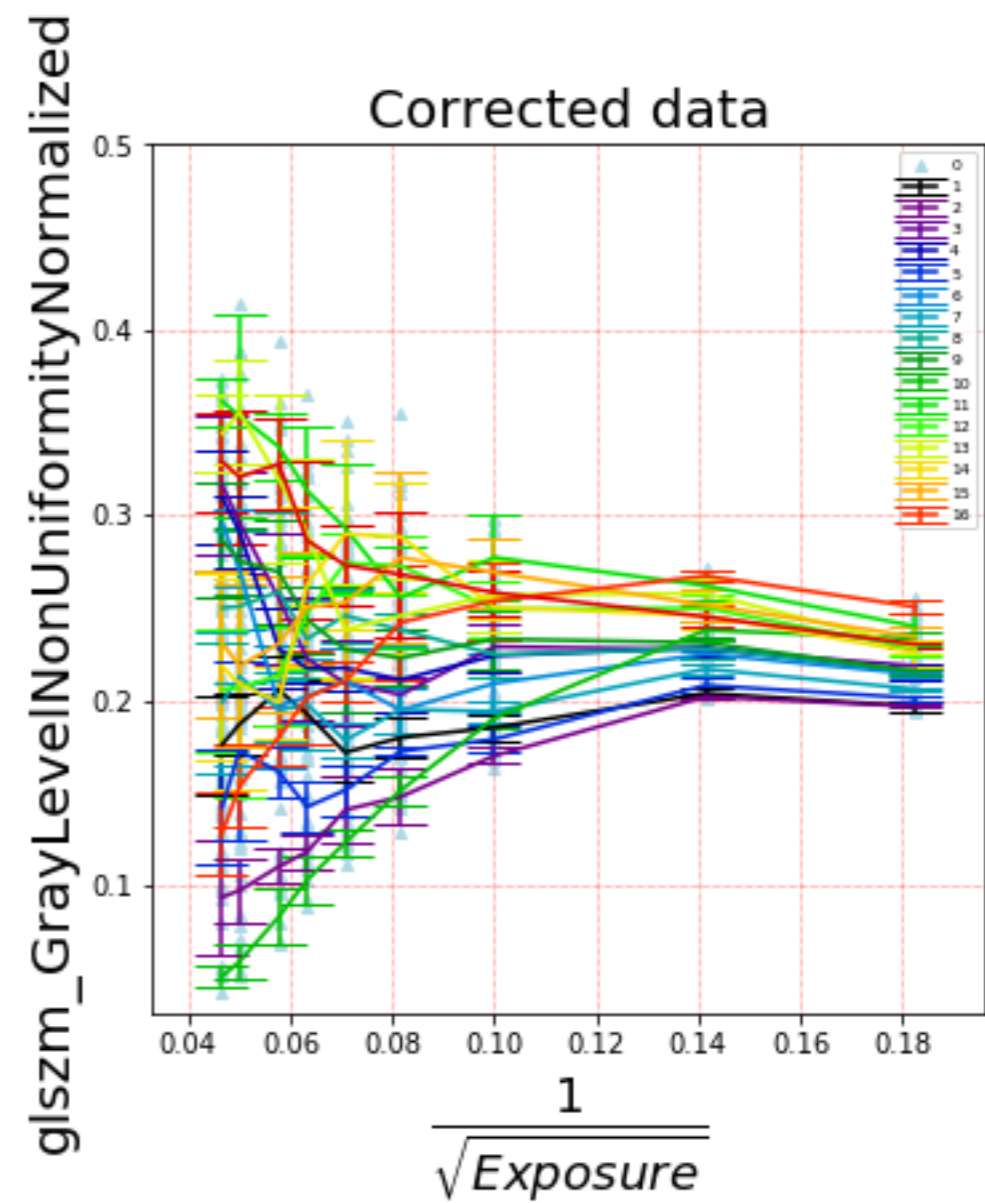
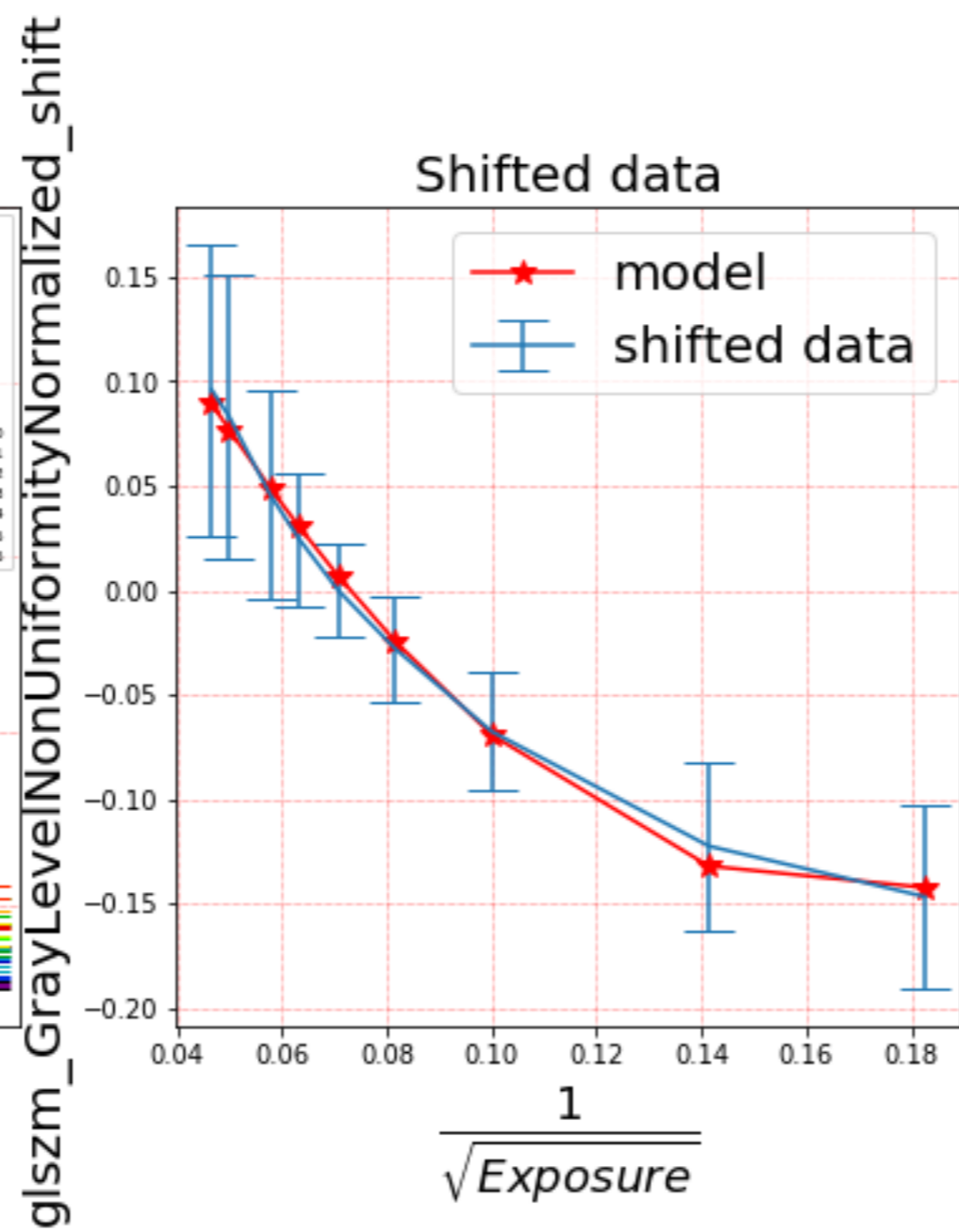
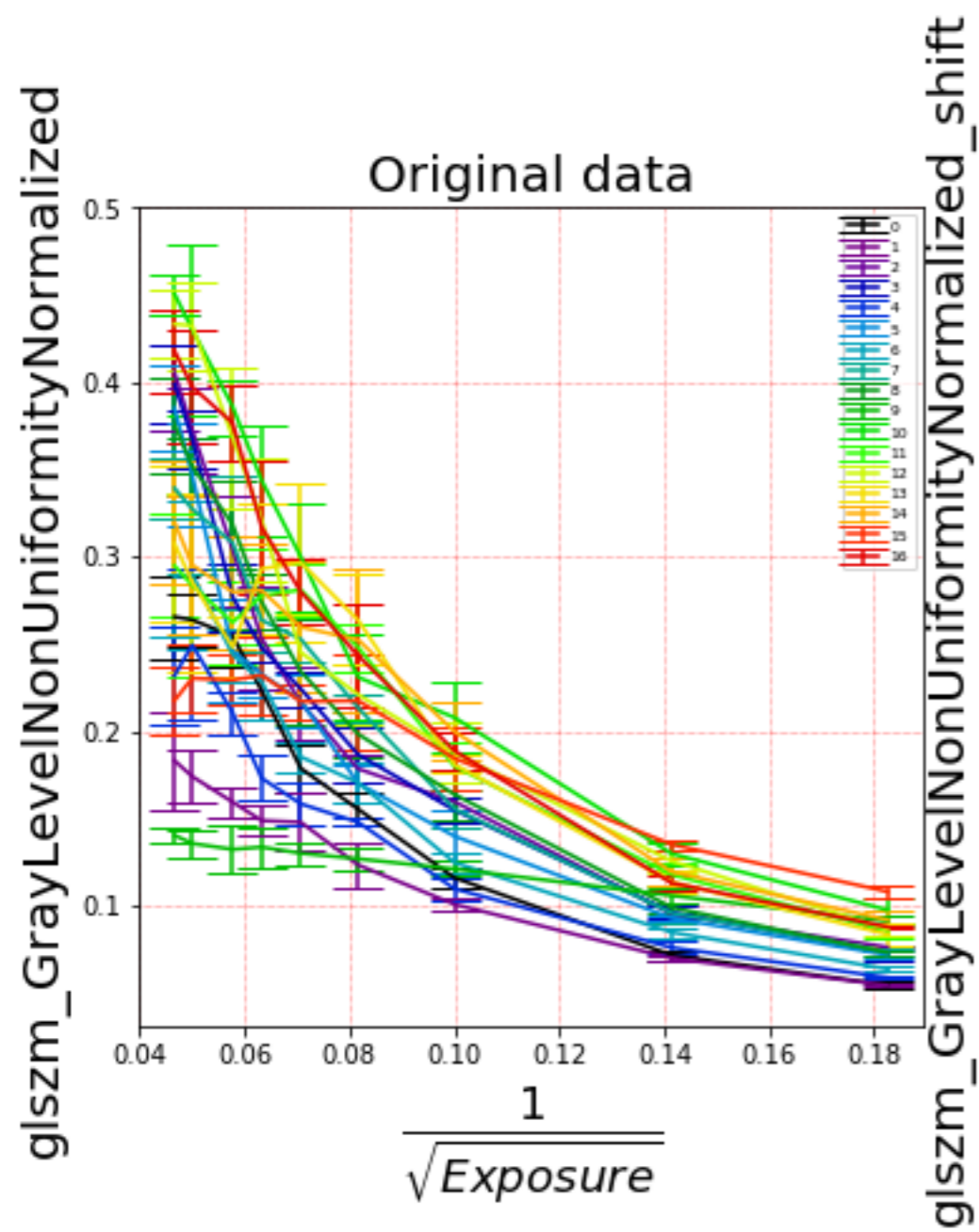
glim_ShortRunHighGrayLevelEmphasis

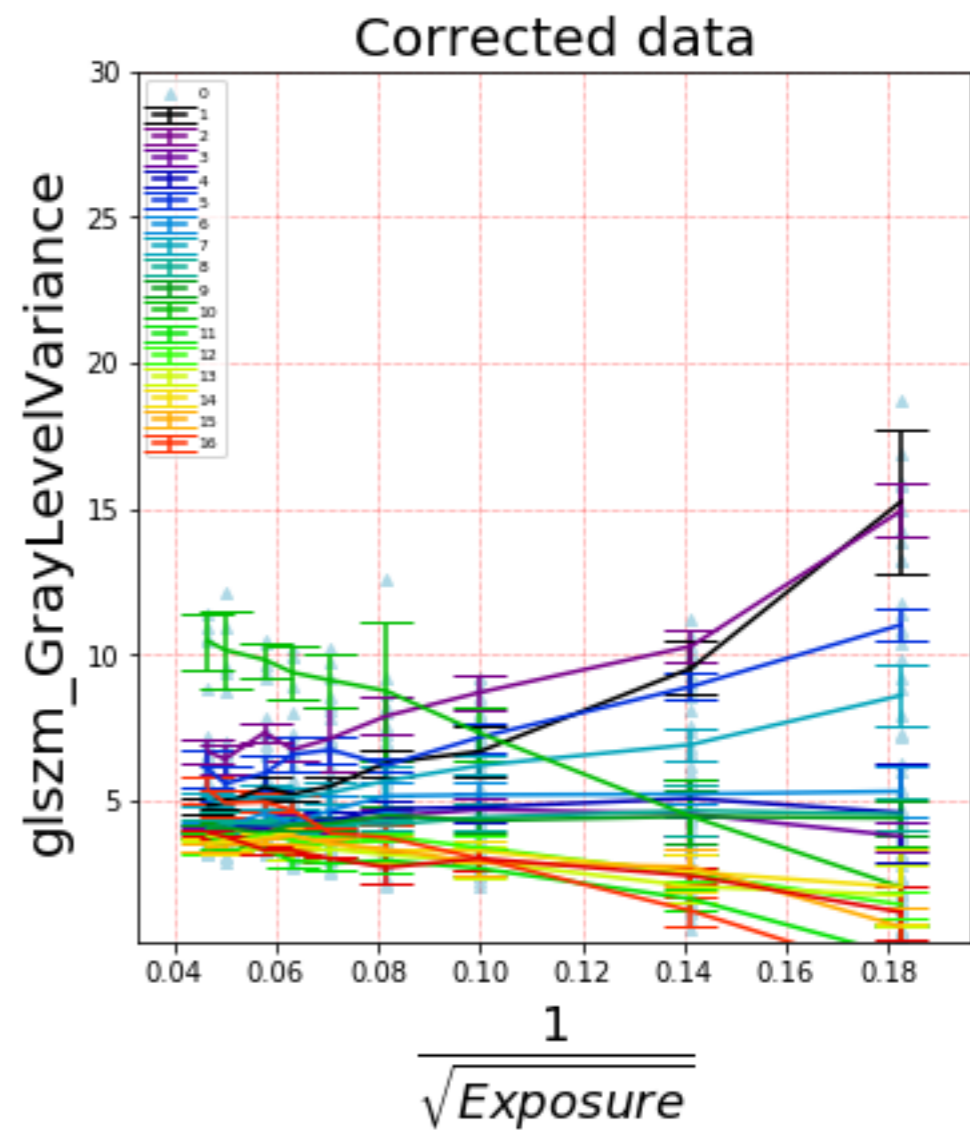
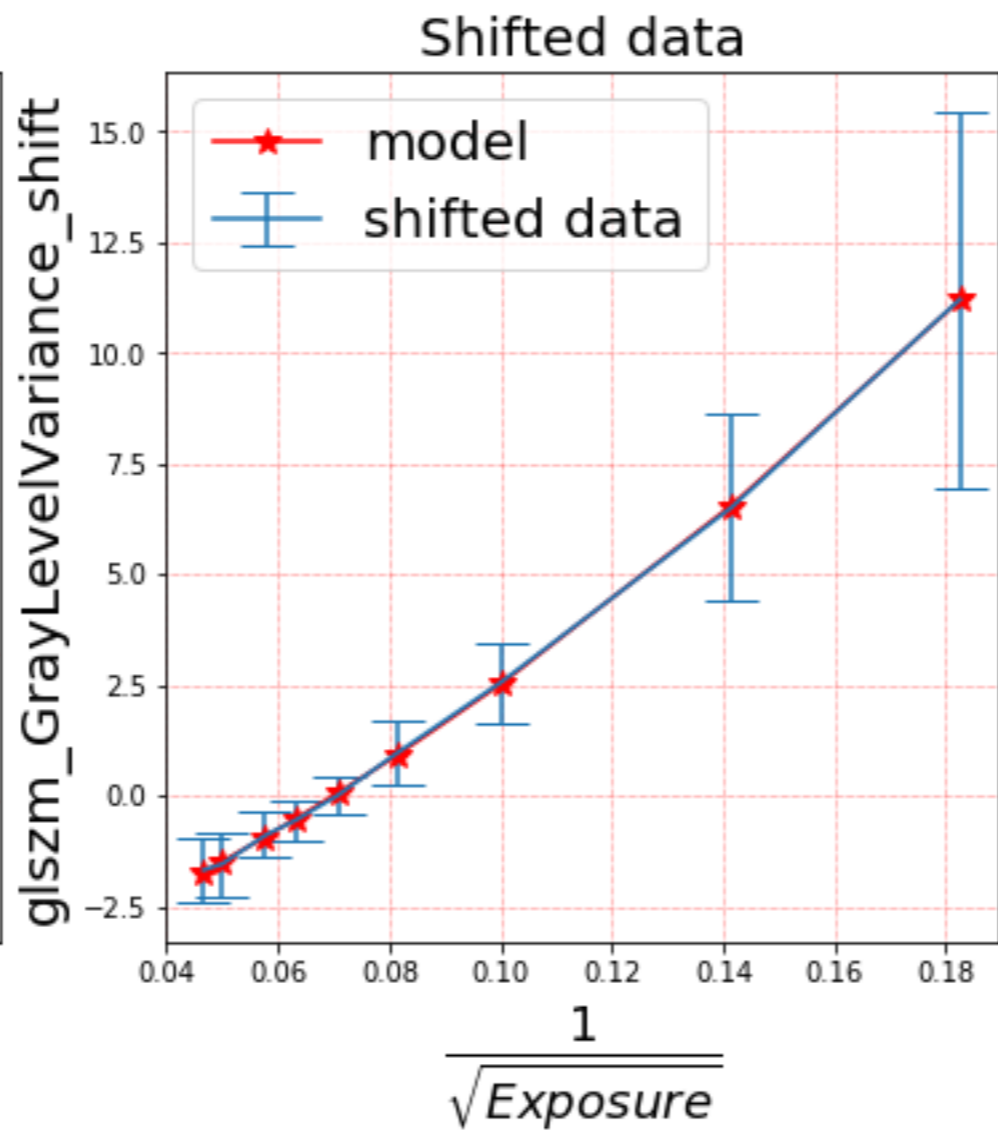
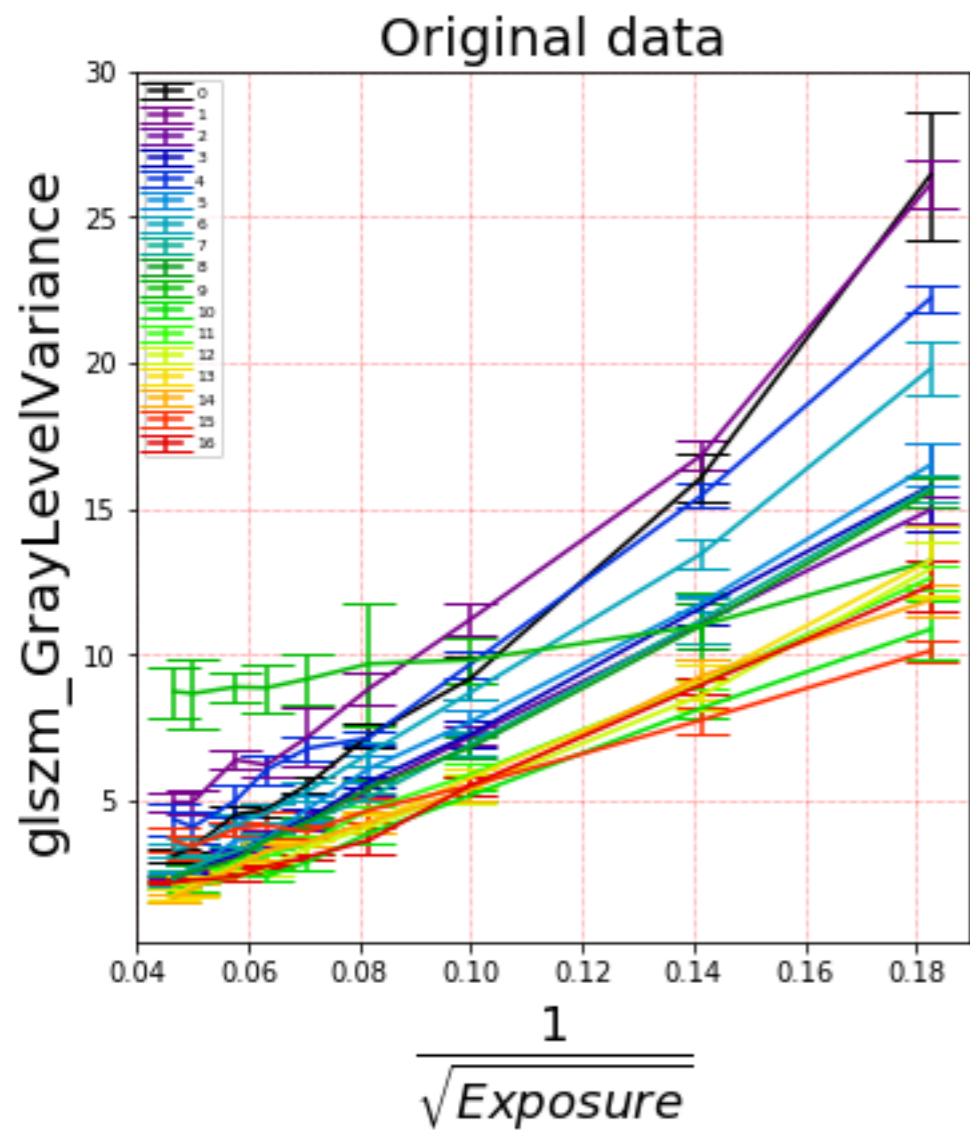
Corrected data

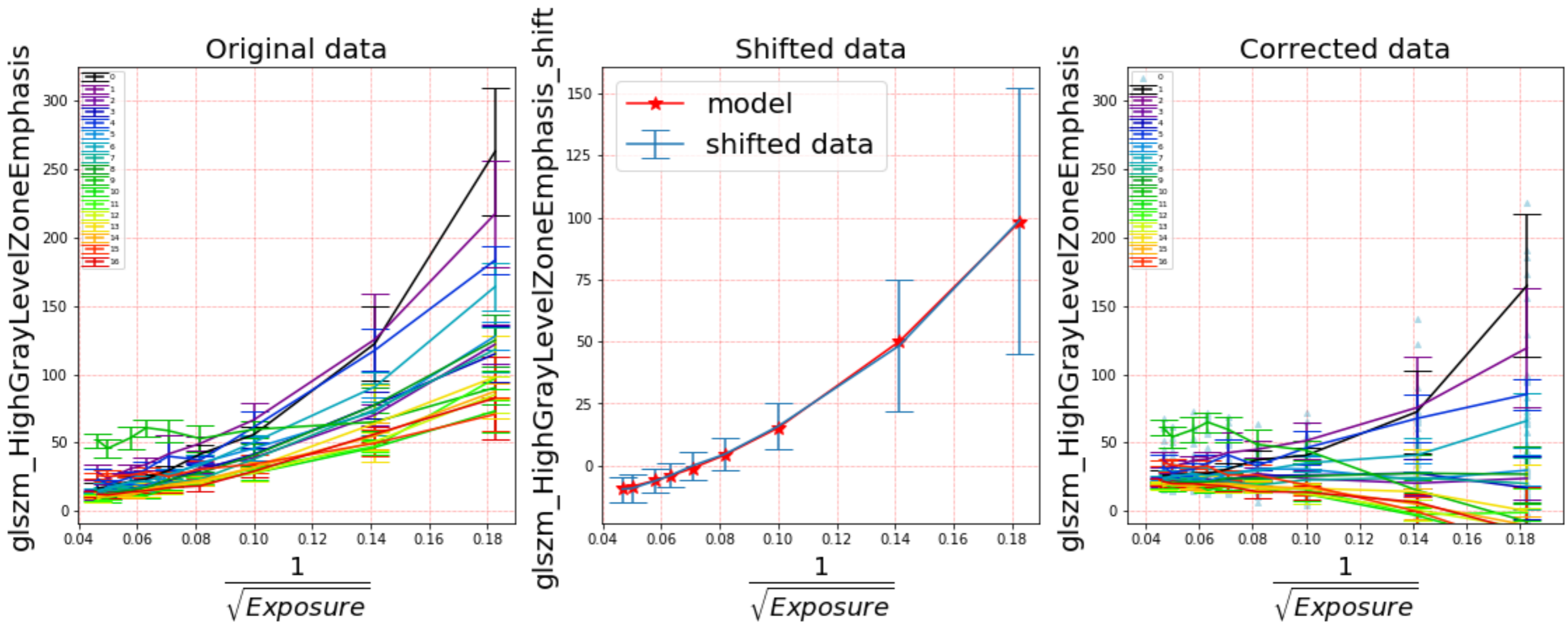


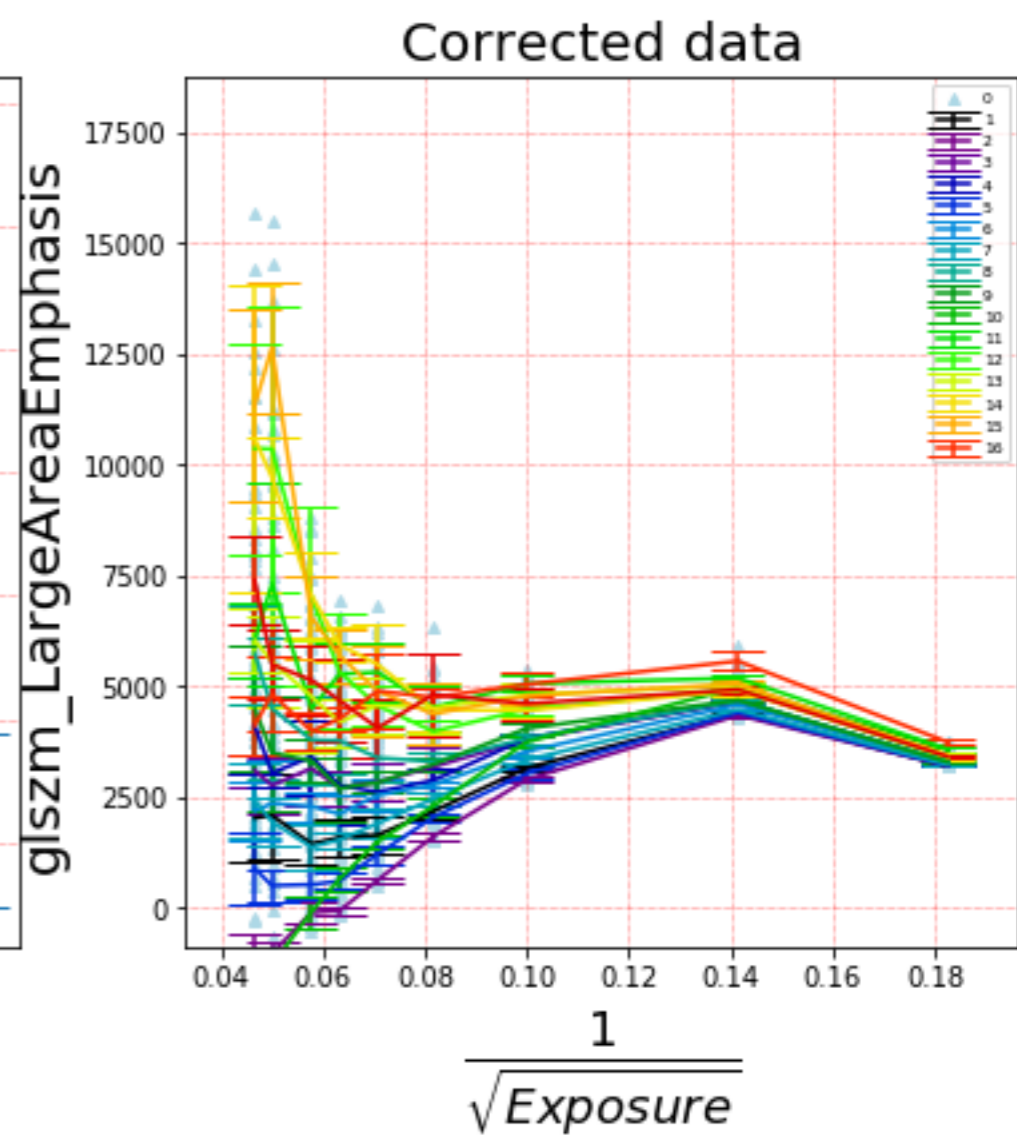
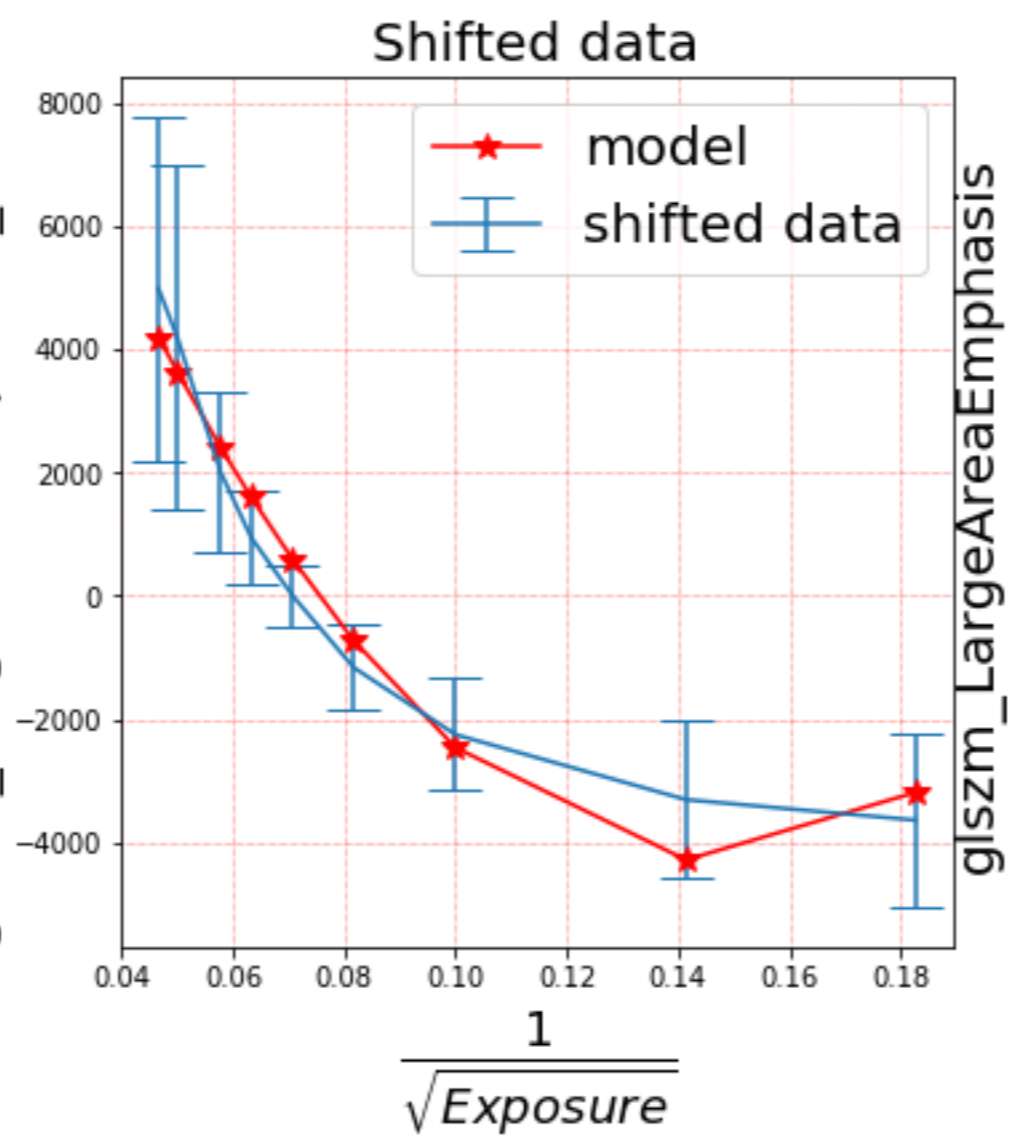
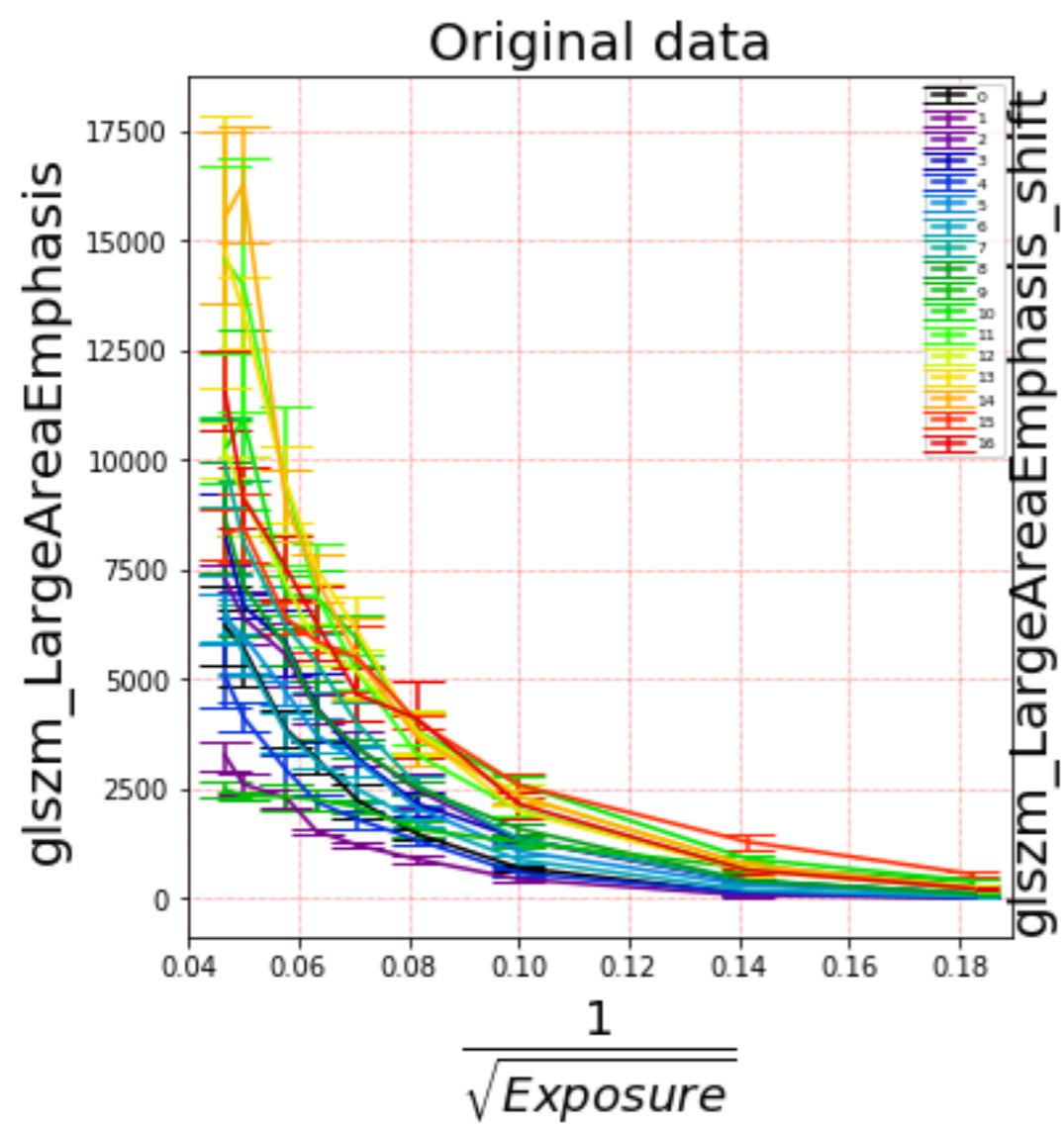






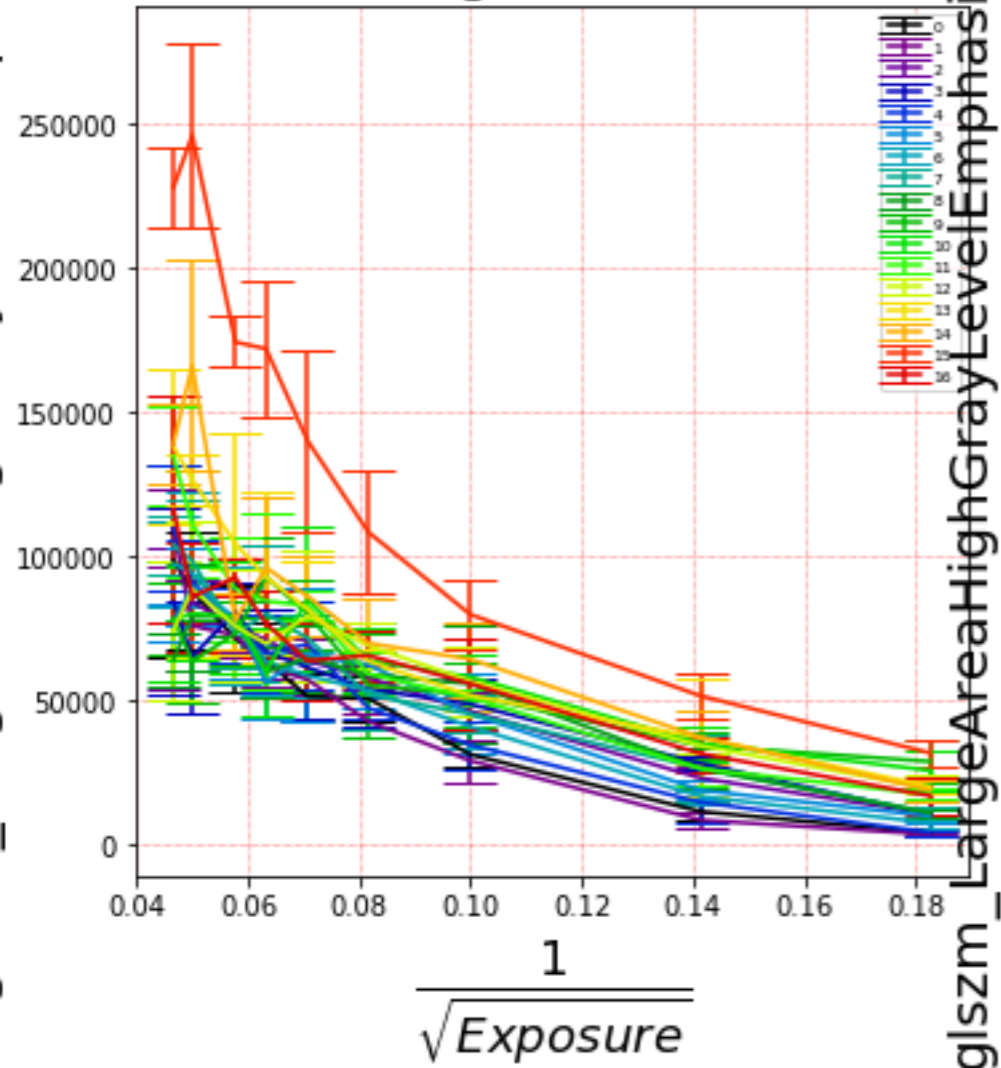






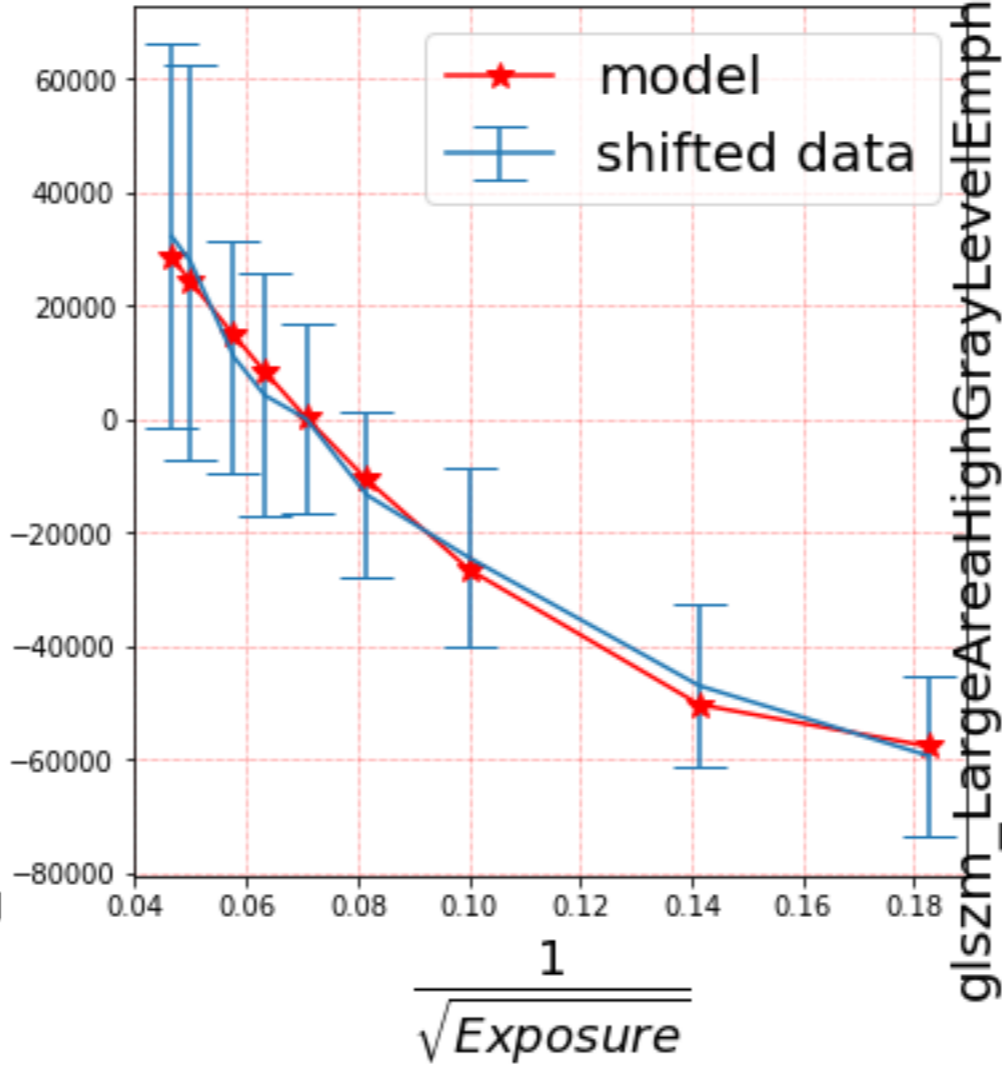
glszm_LargeAreaHighGrayLevelEmphasis

Original data



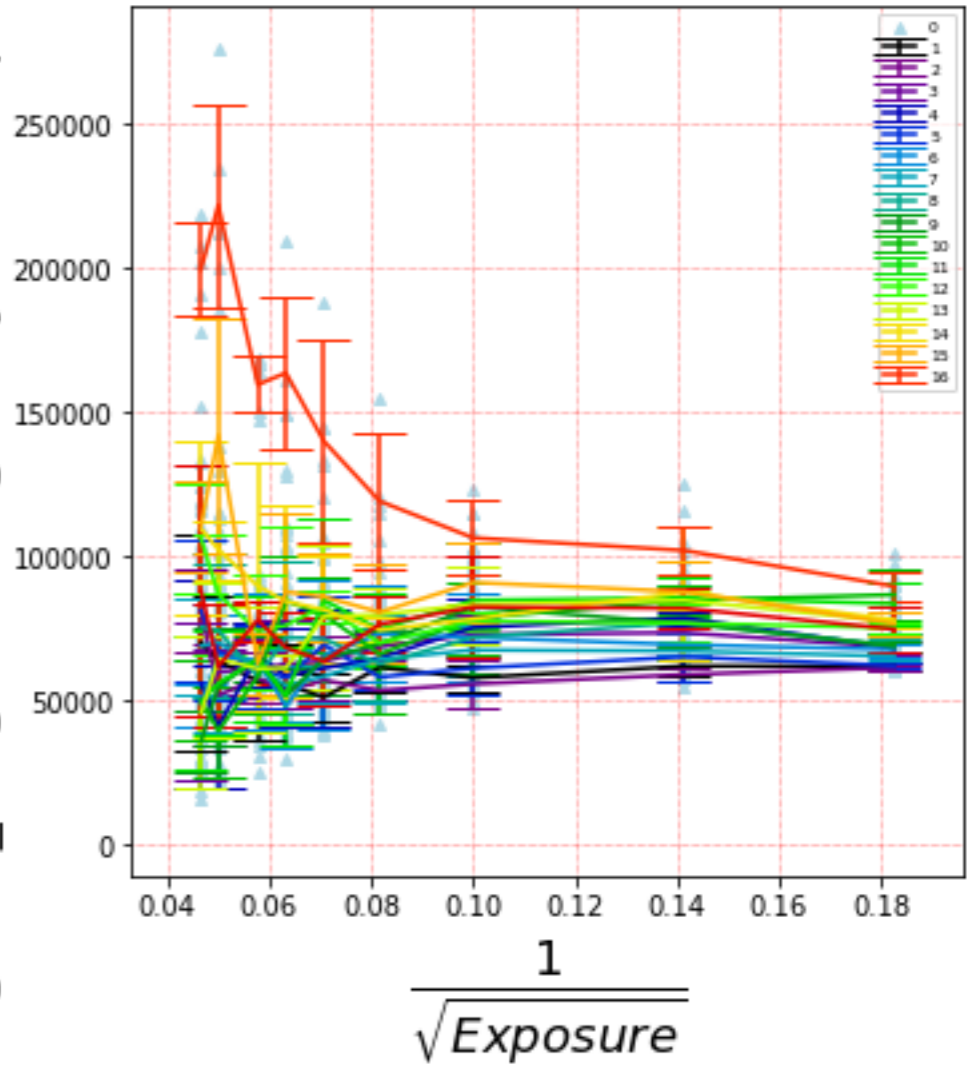
glszm_LargeAreaHighGrayLevelEmphasis_shift

Shifted data



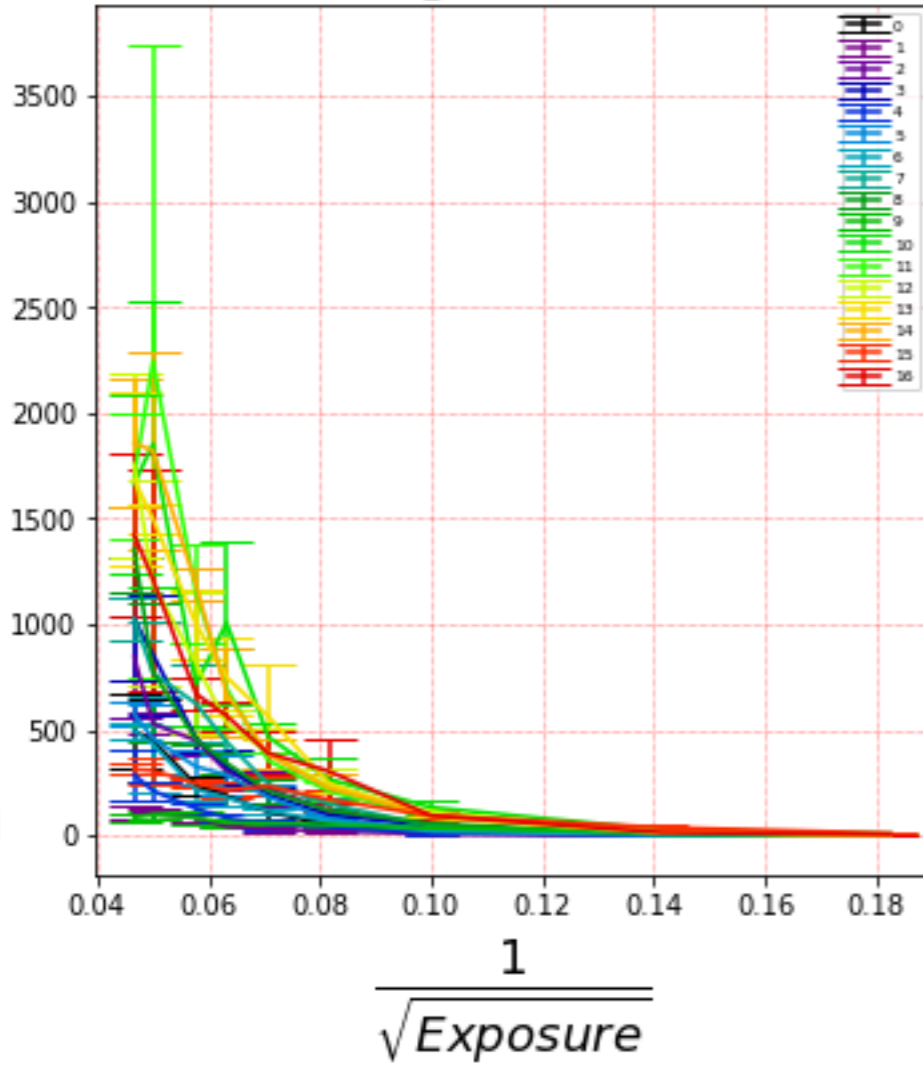
glszm_LargeAreaHighGrayLevelEmphasis

Corrected data



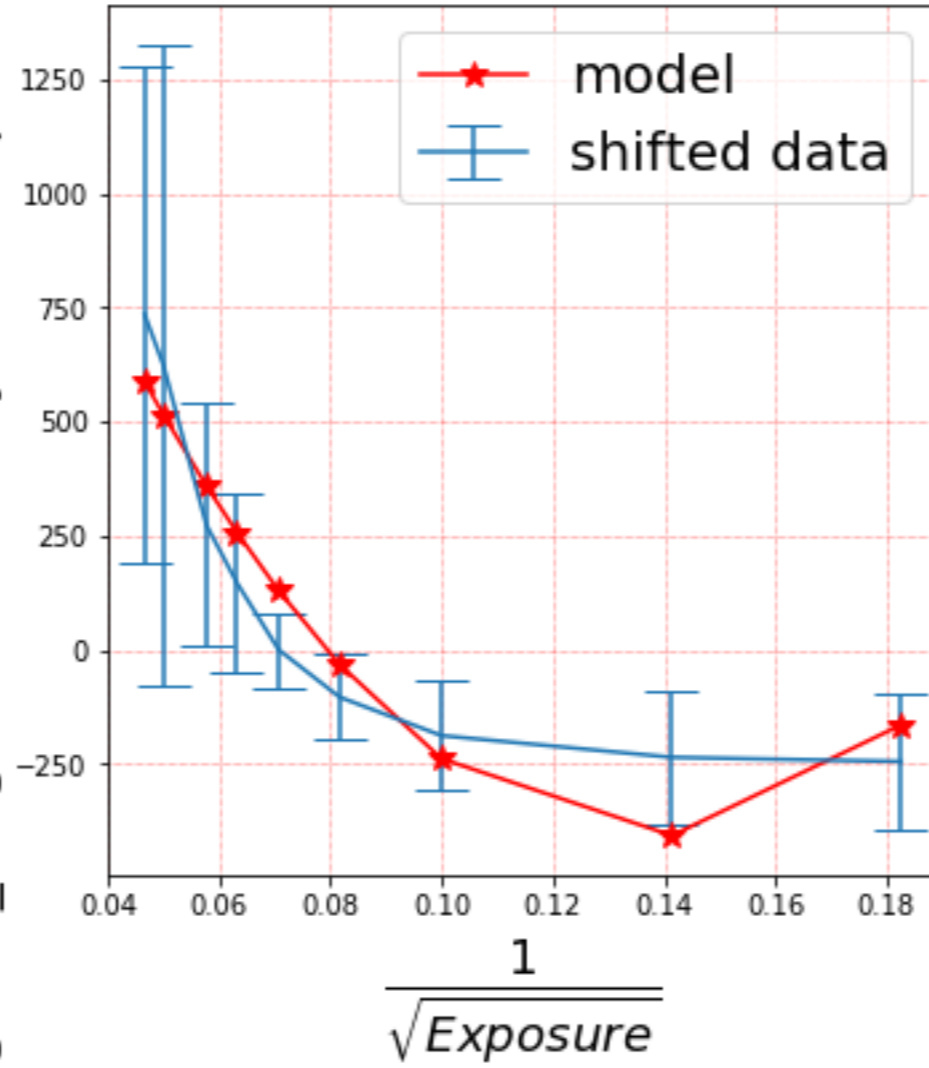
glszm_LargeAreaLowGrayLevelEmphasis

Original data



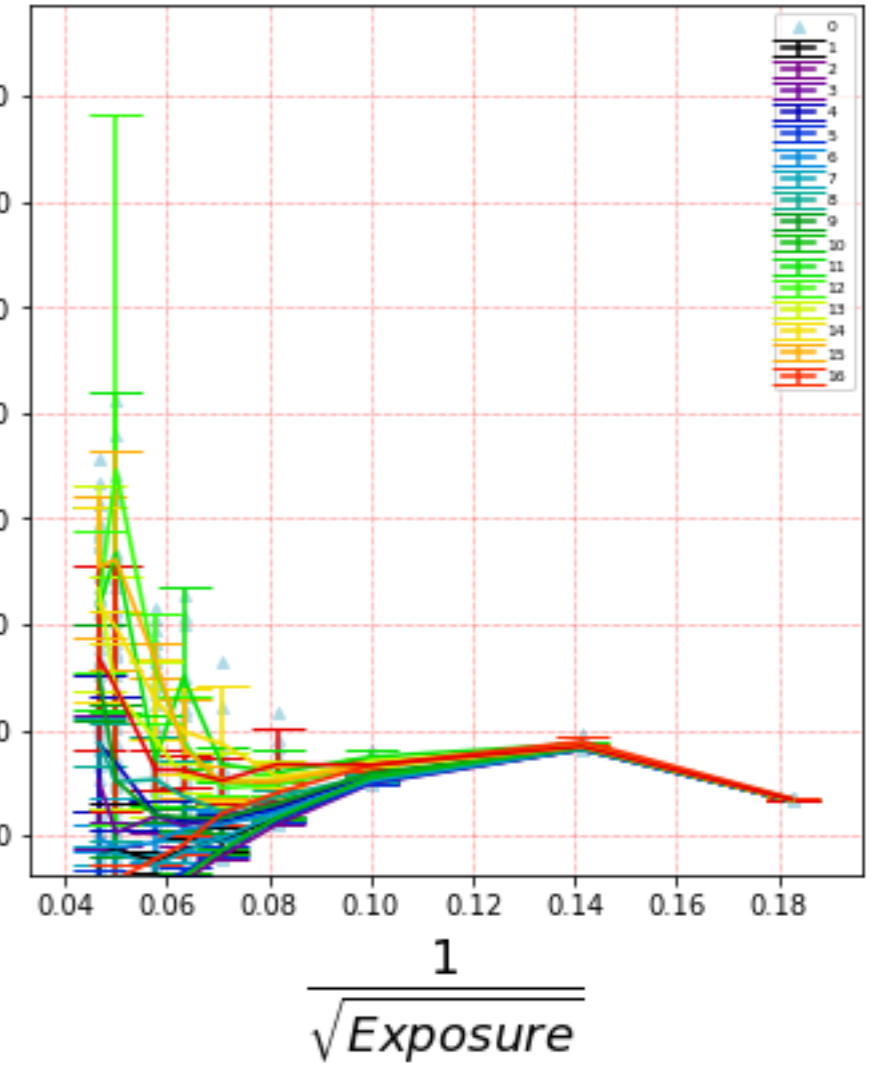
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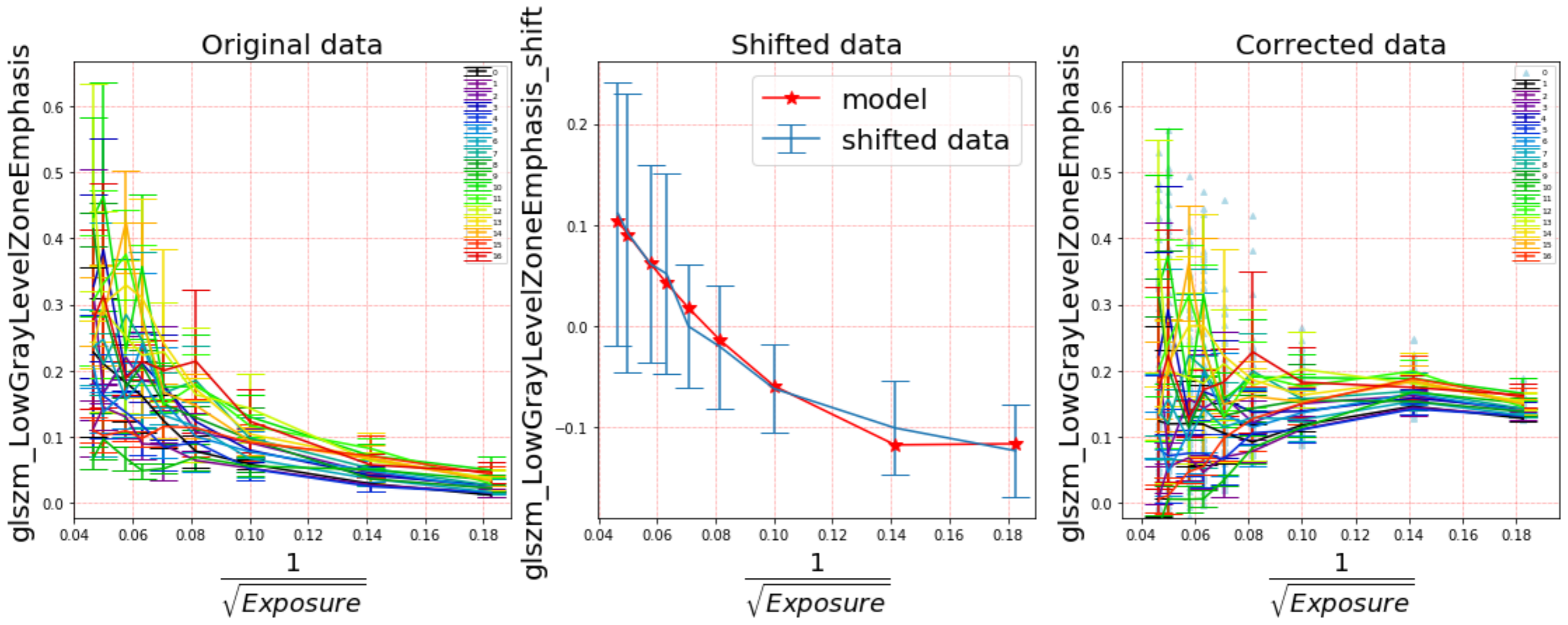
Shifted data

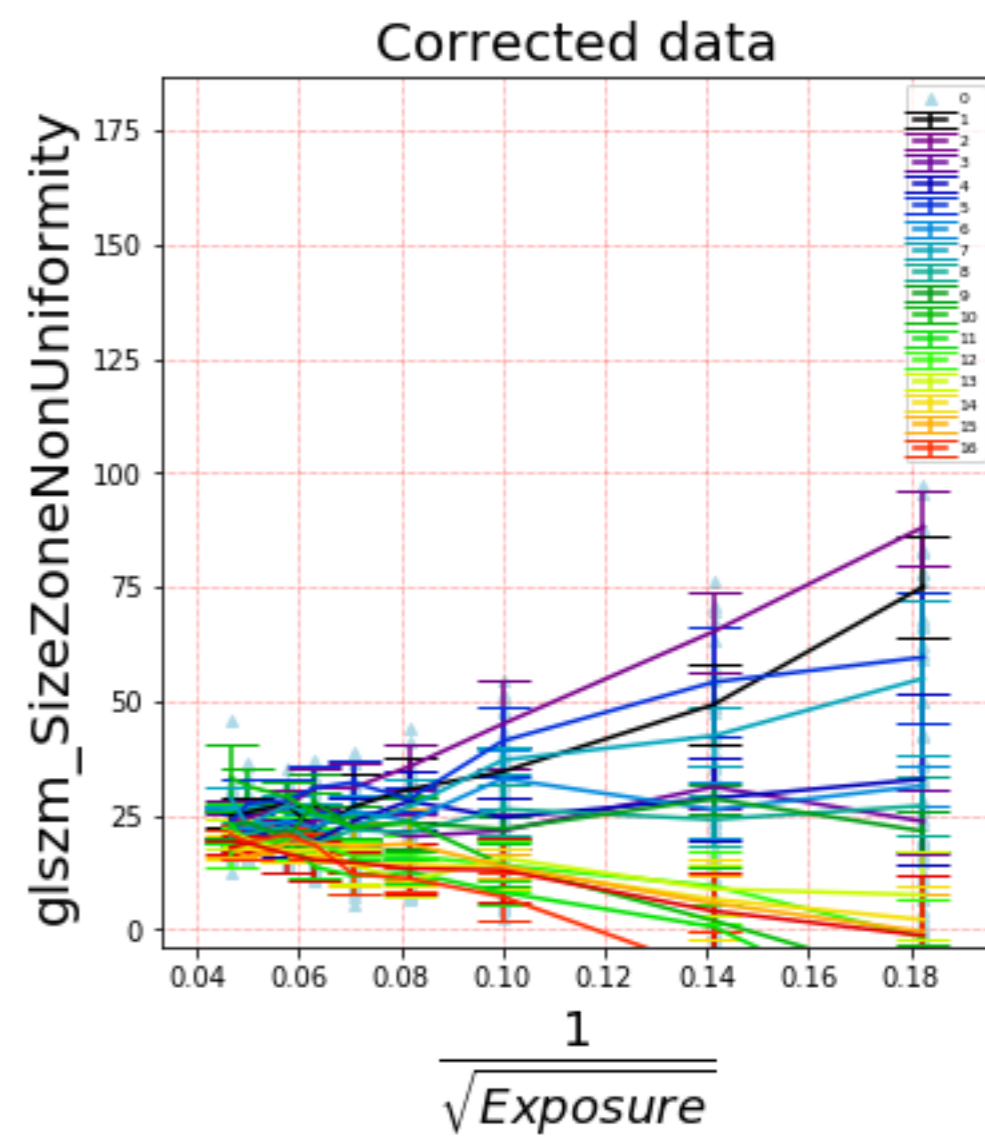
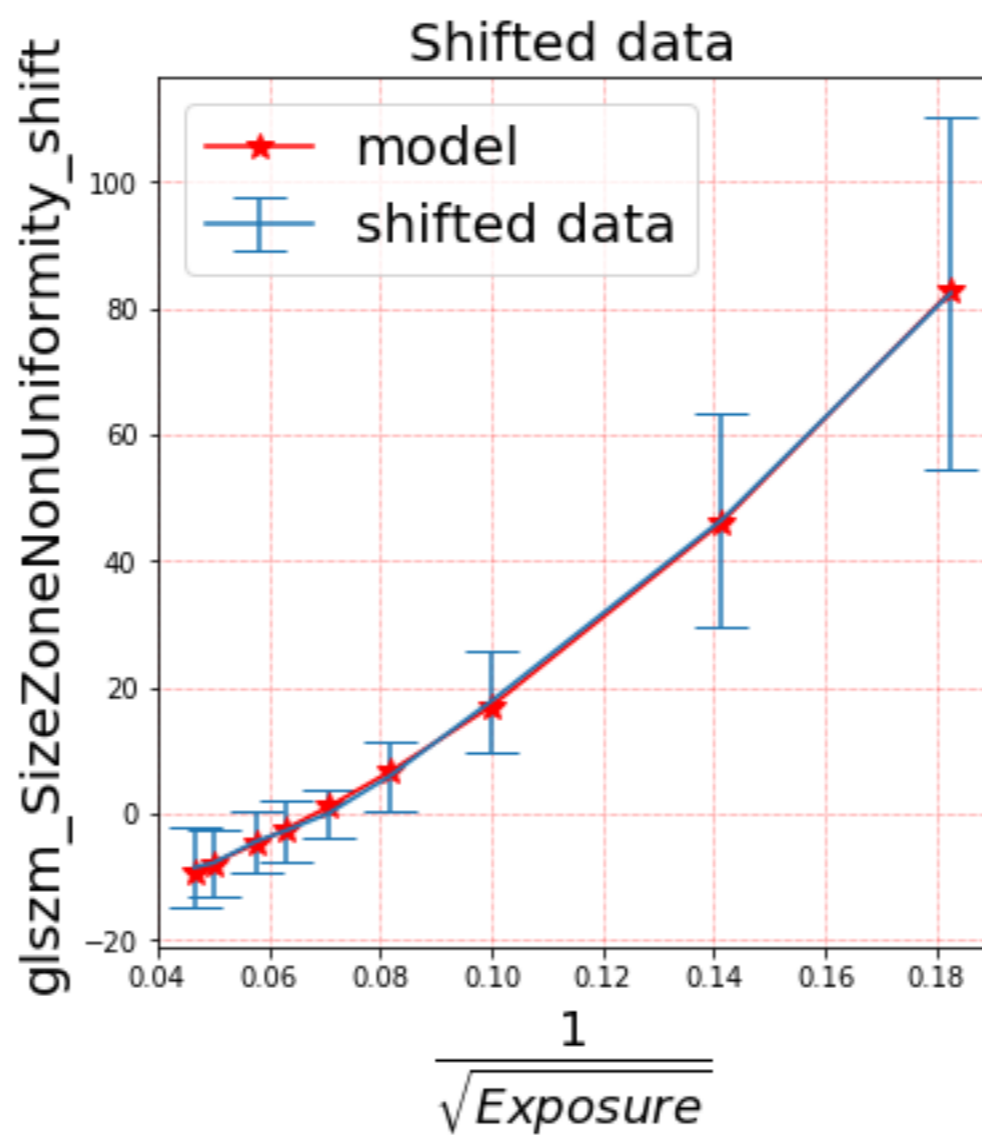
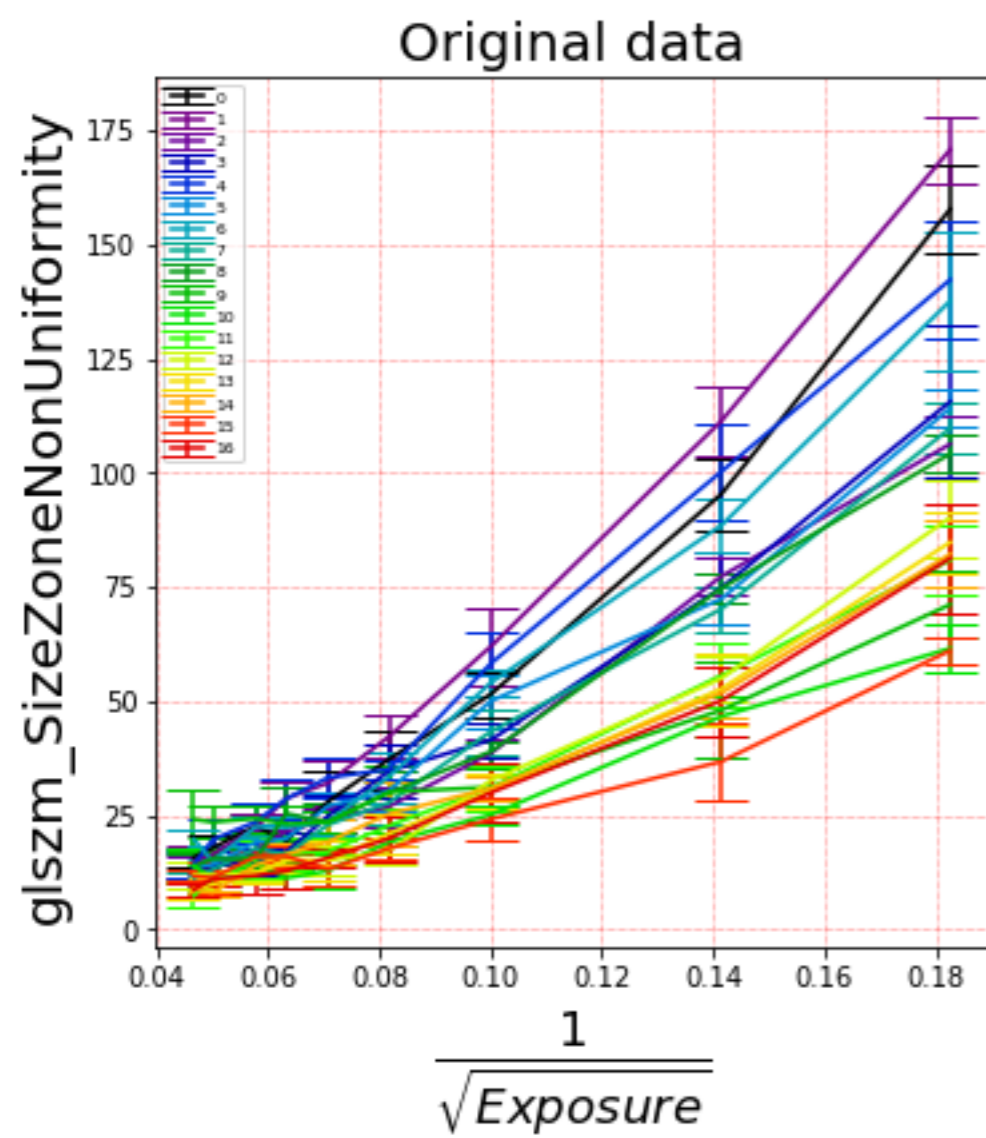


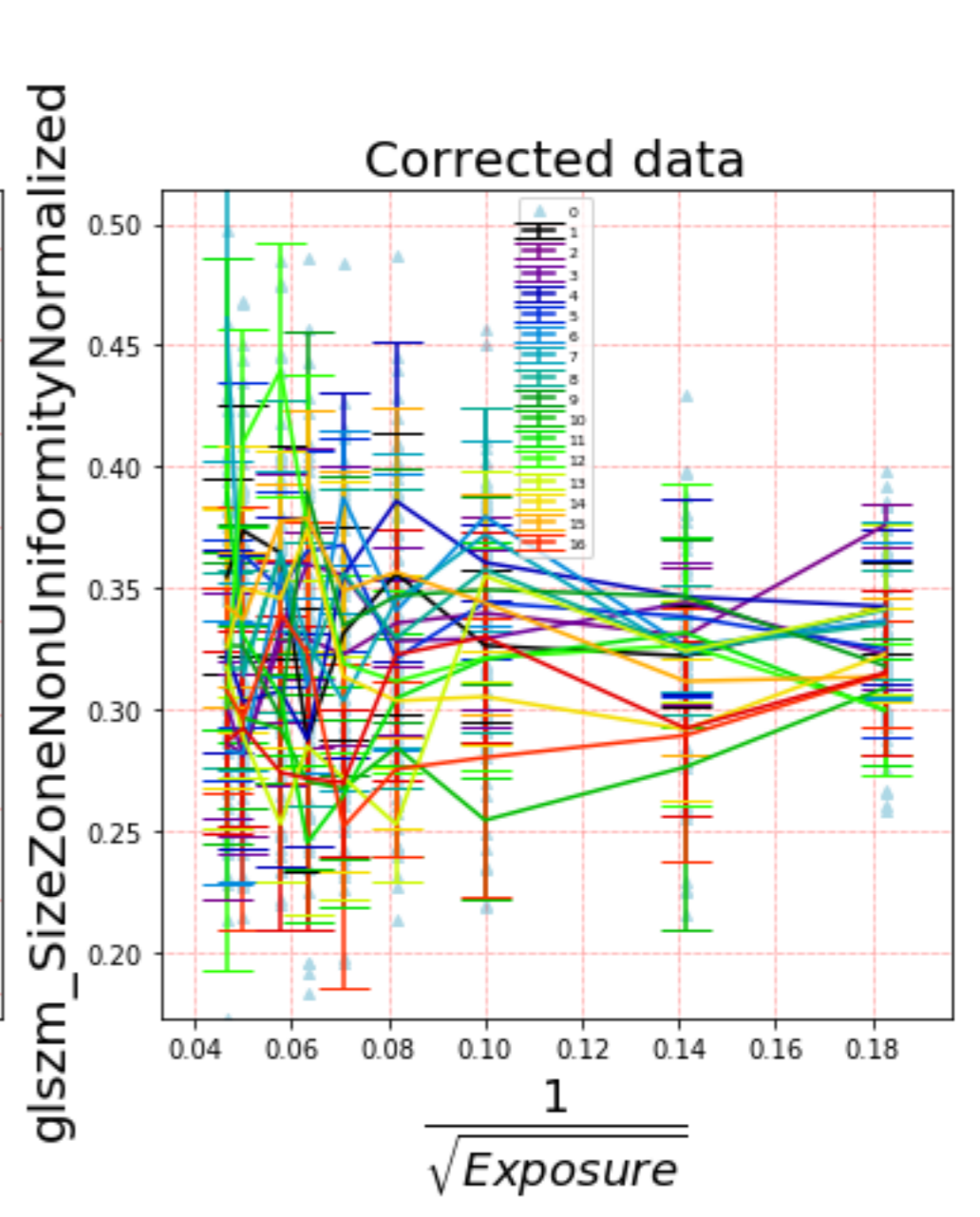
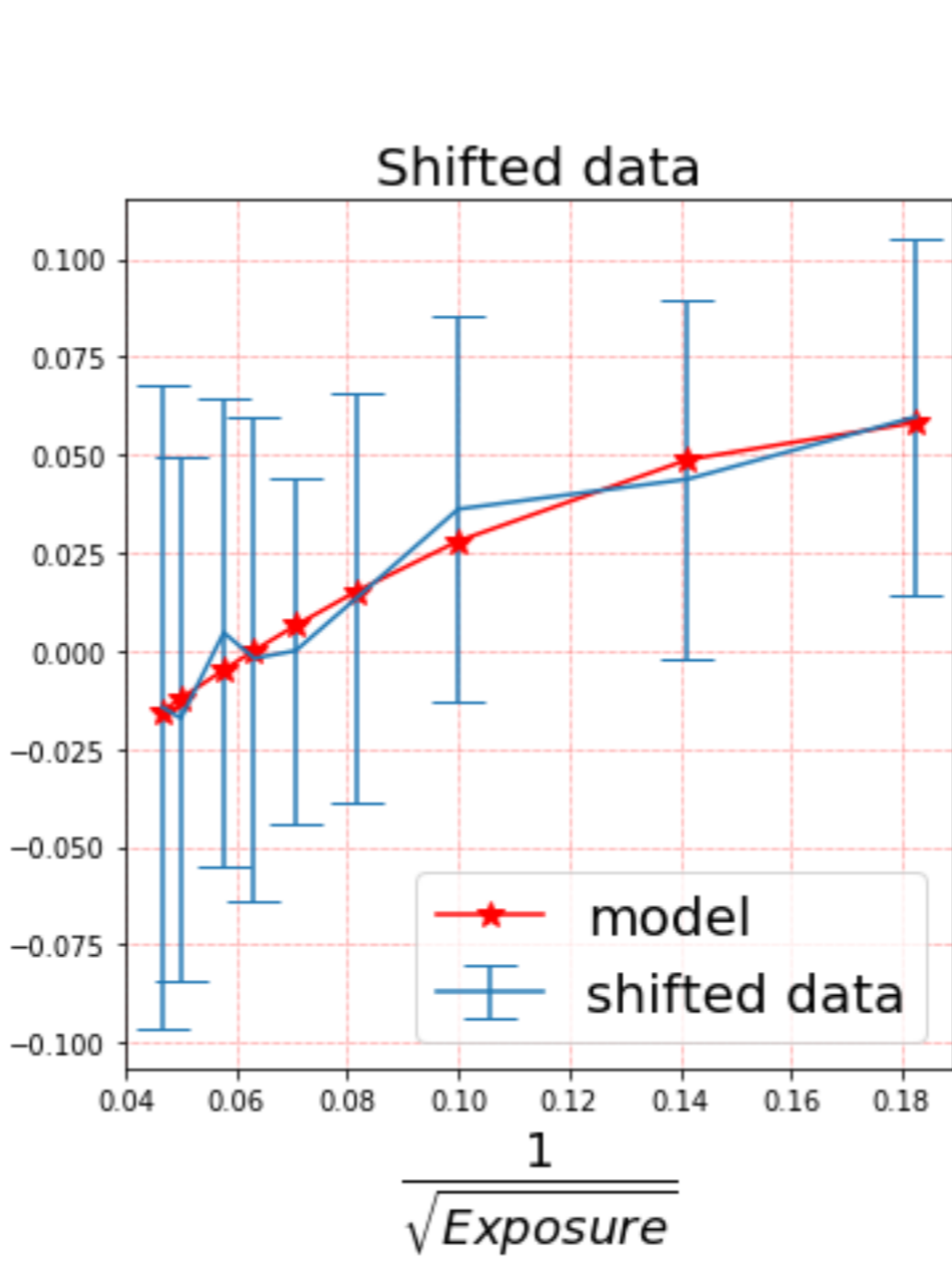
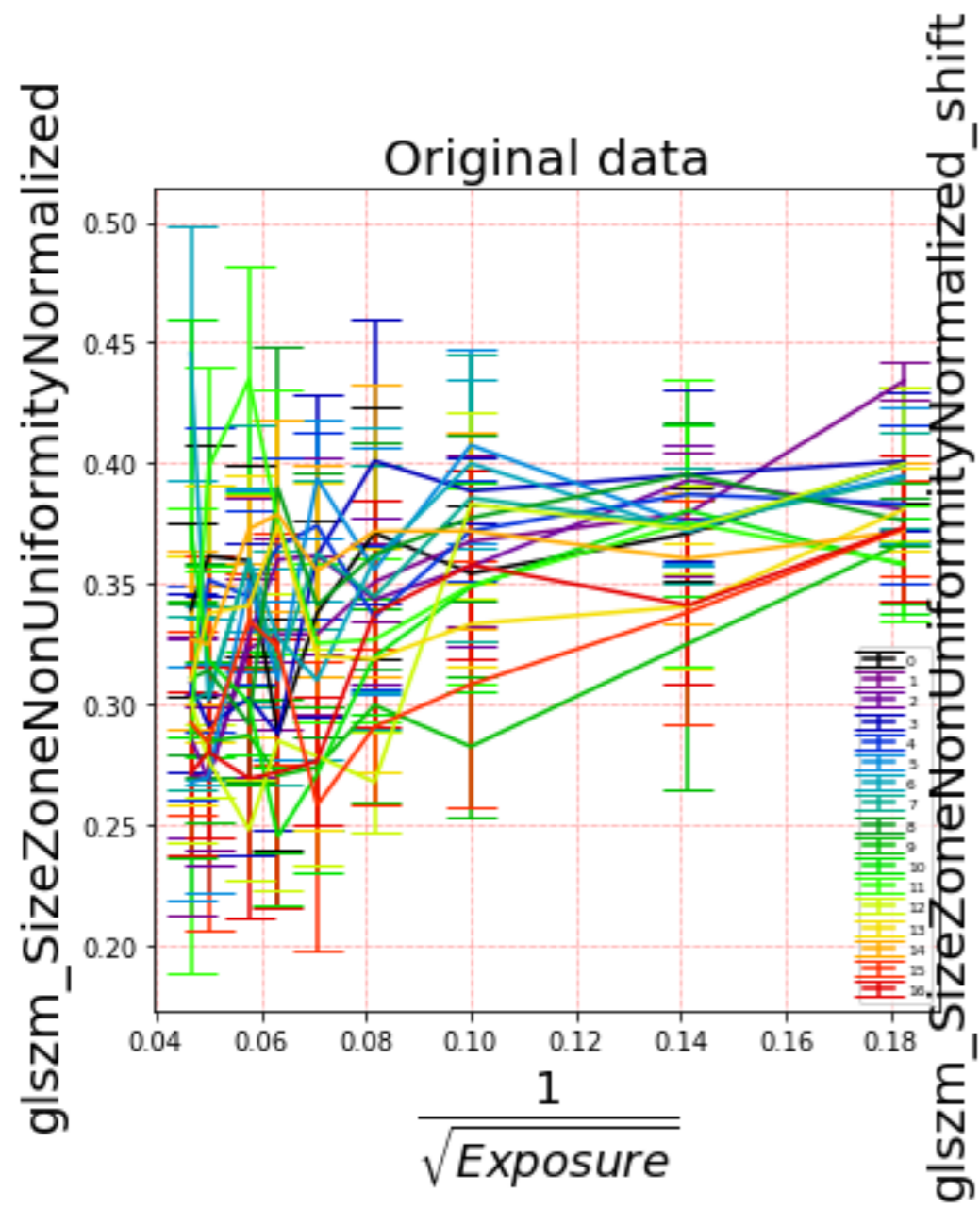
glszm_LargeAreaLowGrayLevelEmphasis

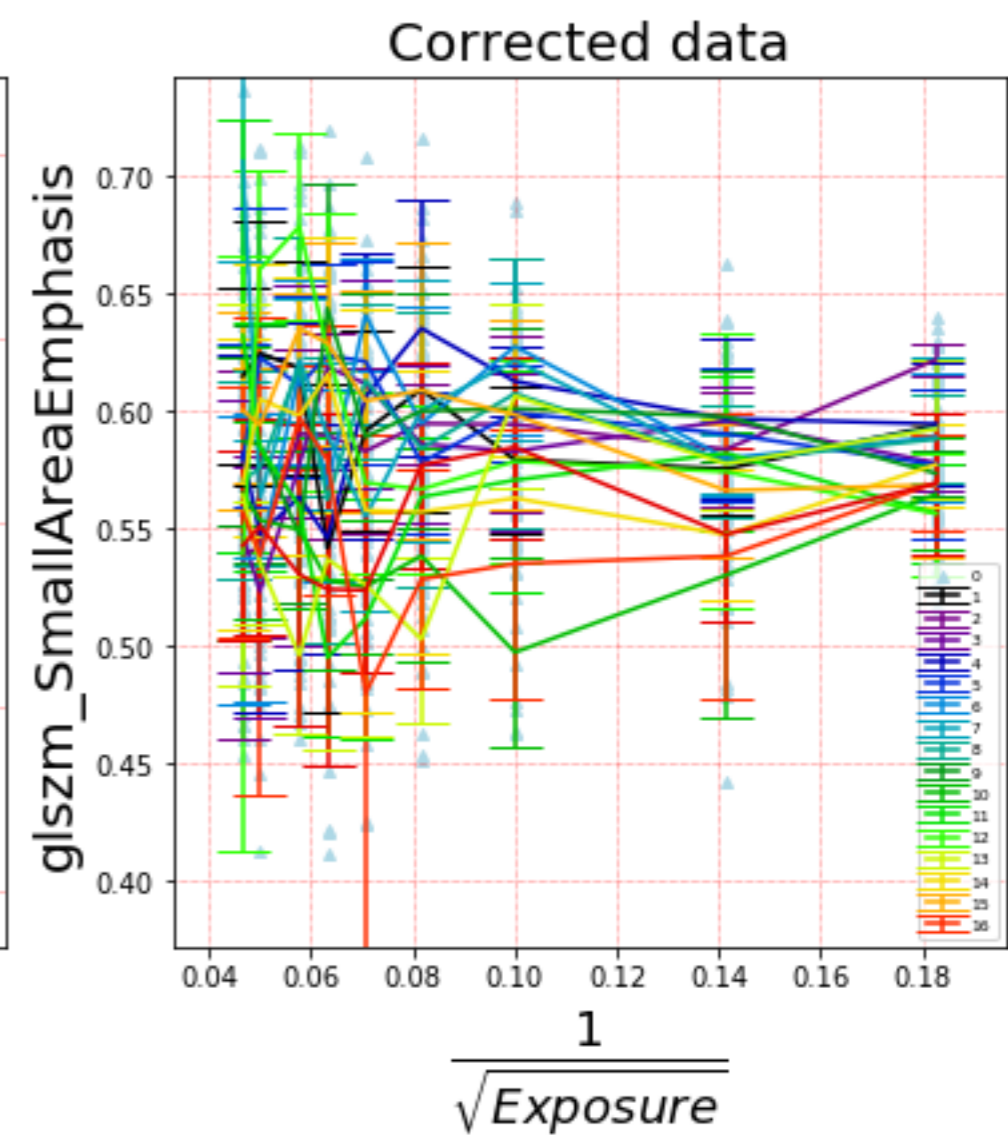
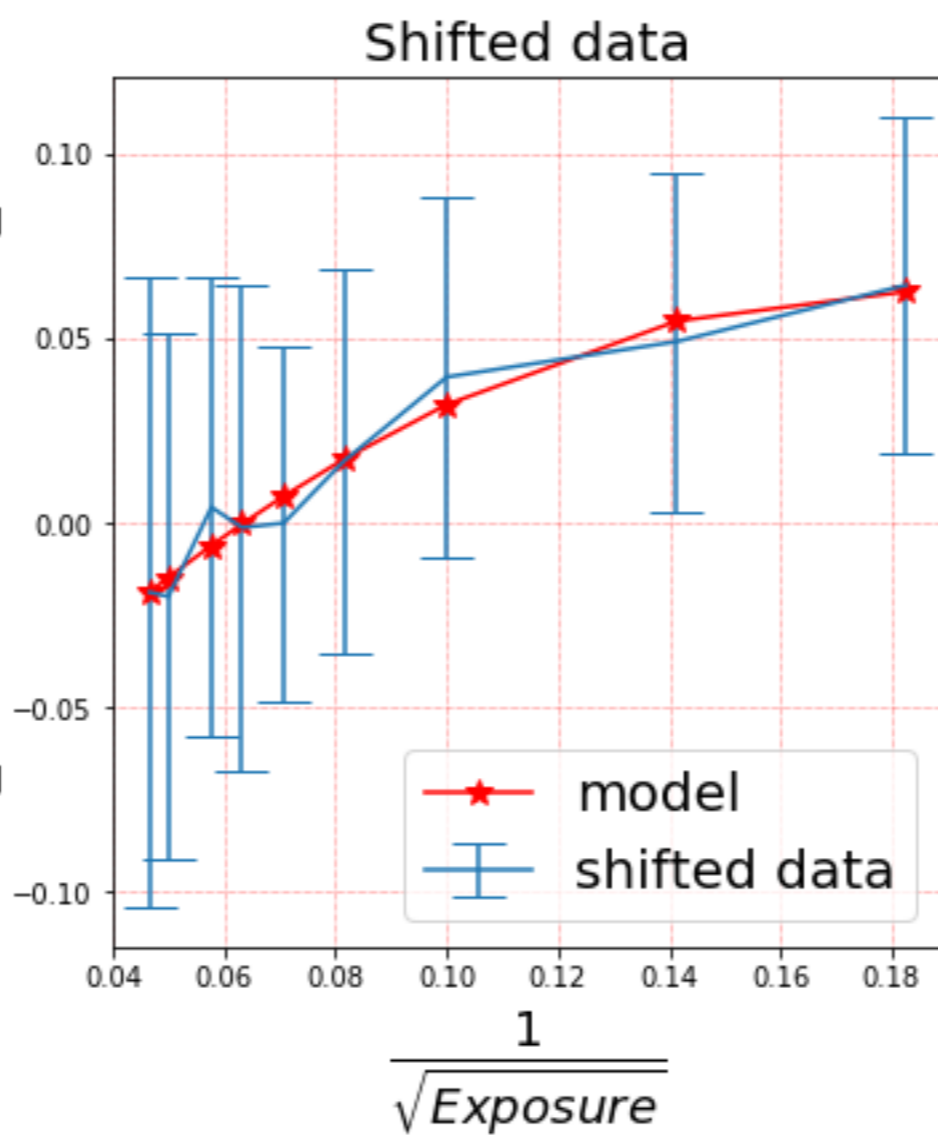
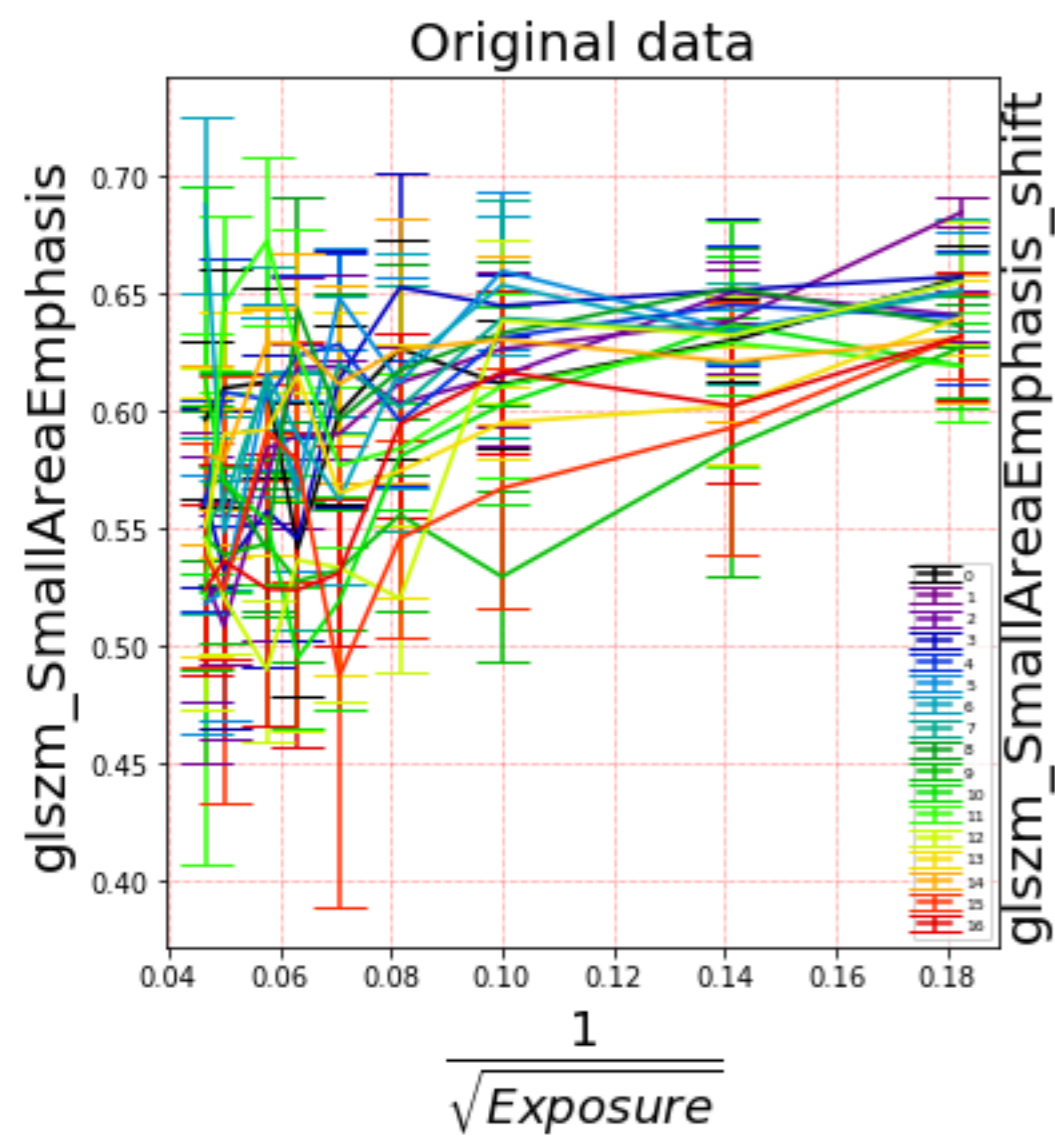
Corrected data





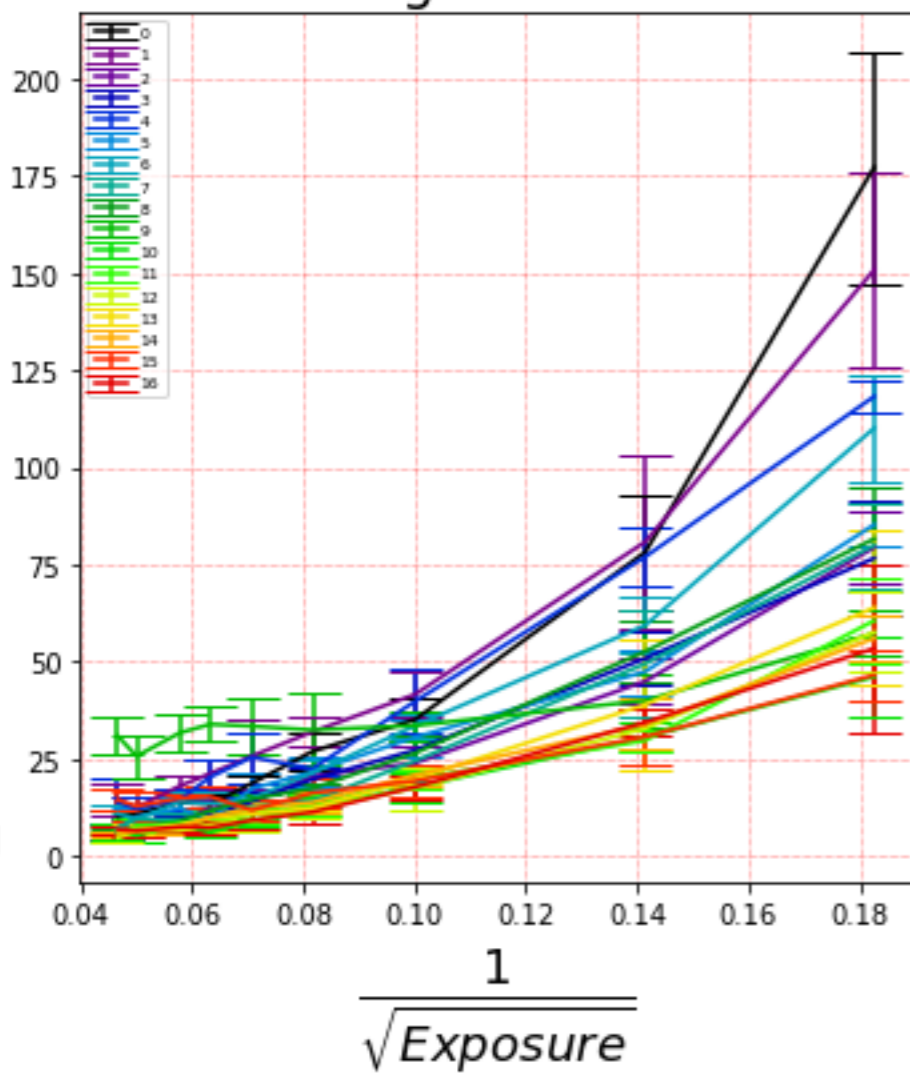






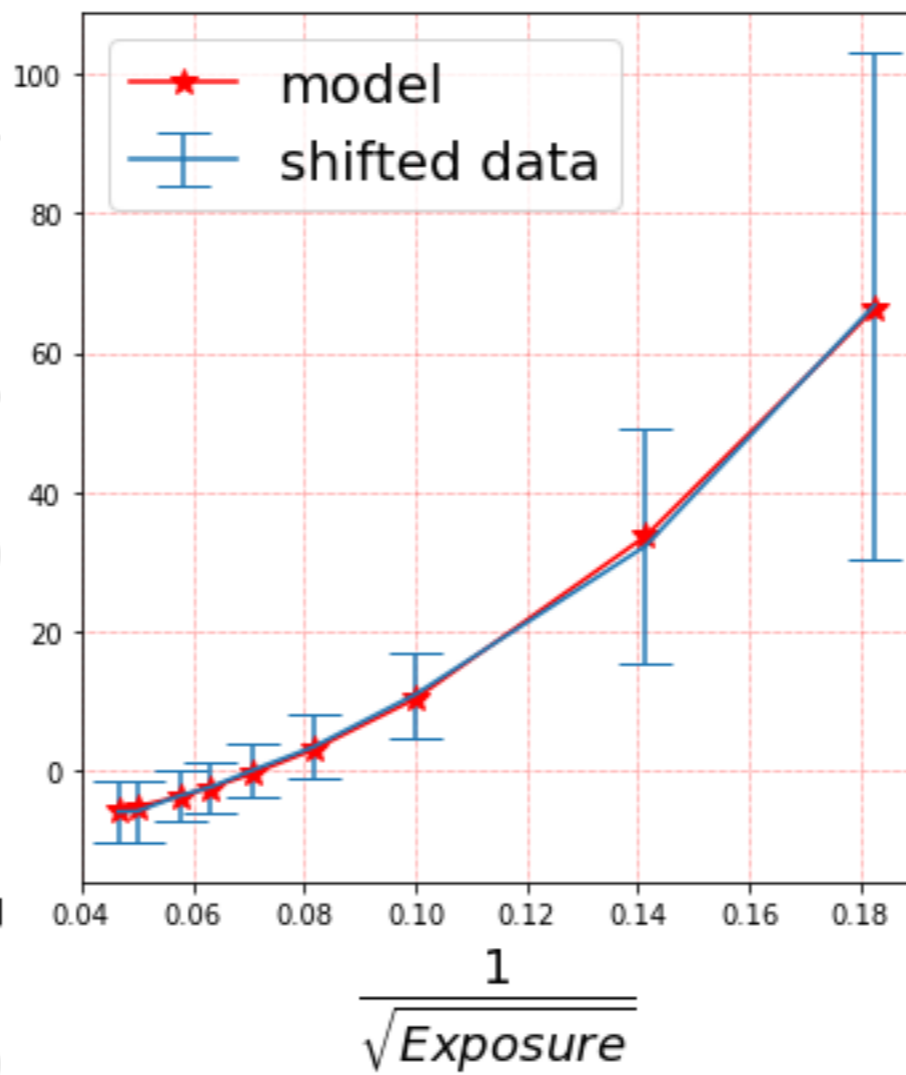
glszm_SmallAreaHighGrayLevelEmphasis

Original data



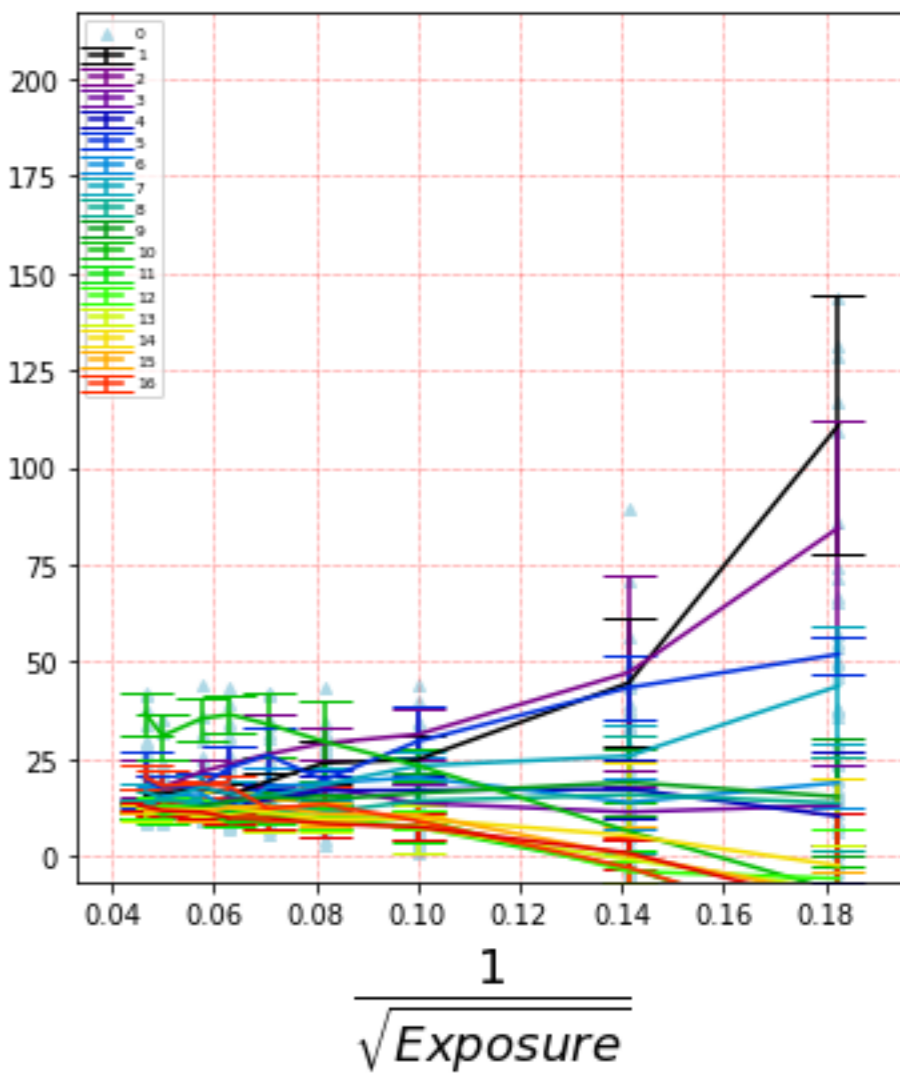
glszm_SmallAreaHighGrayLevelEmphasis_shift

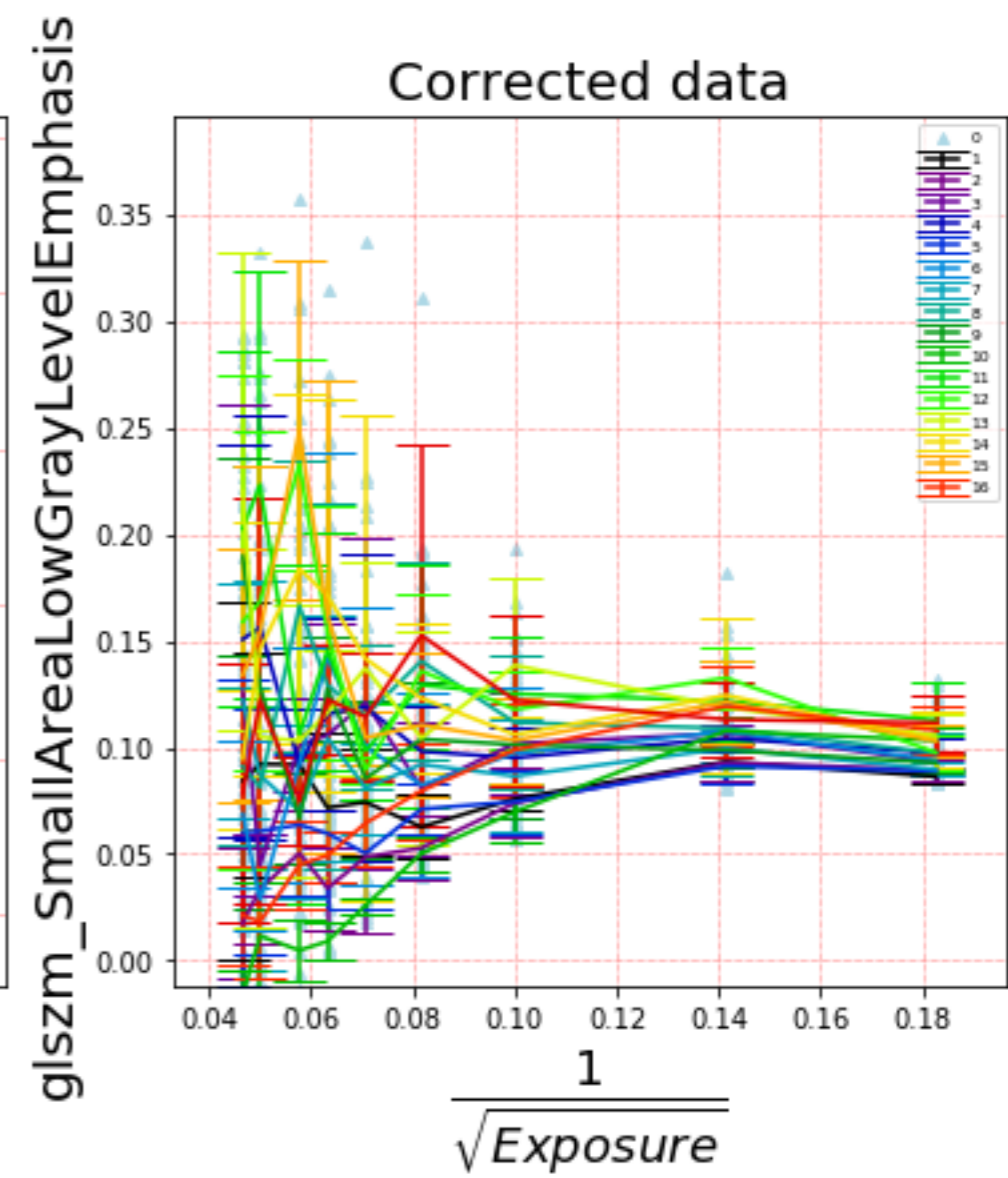
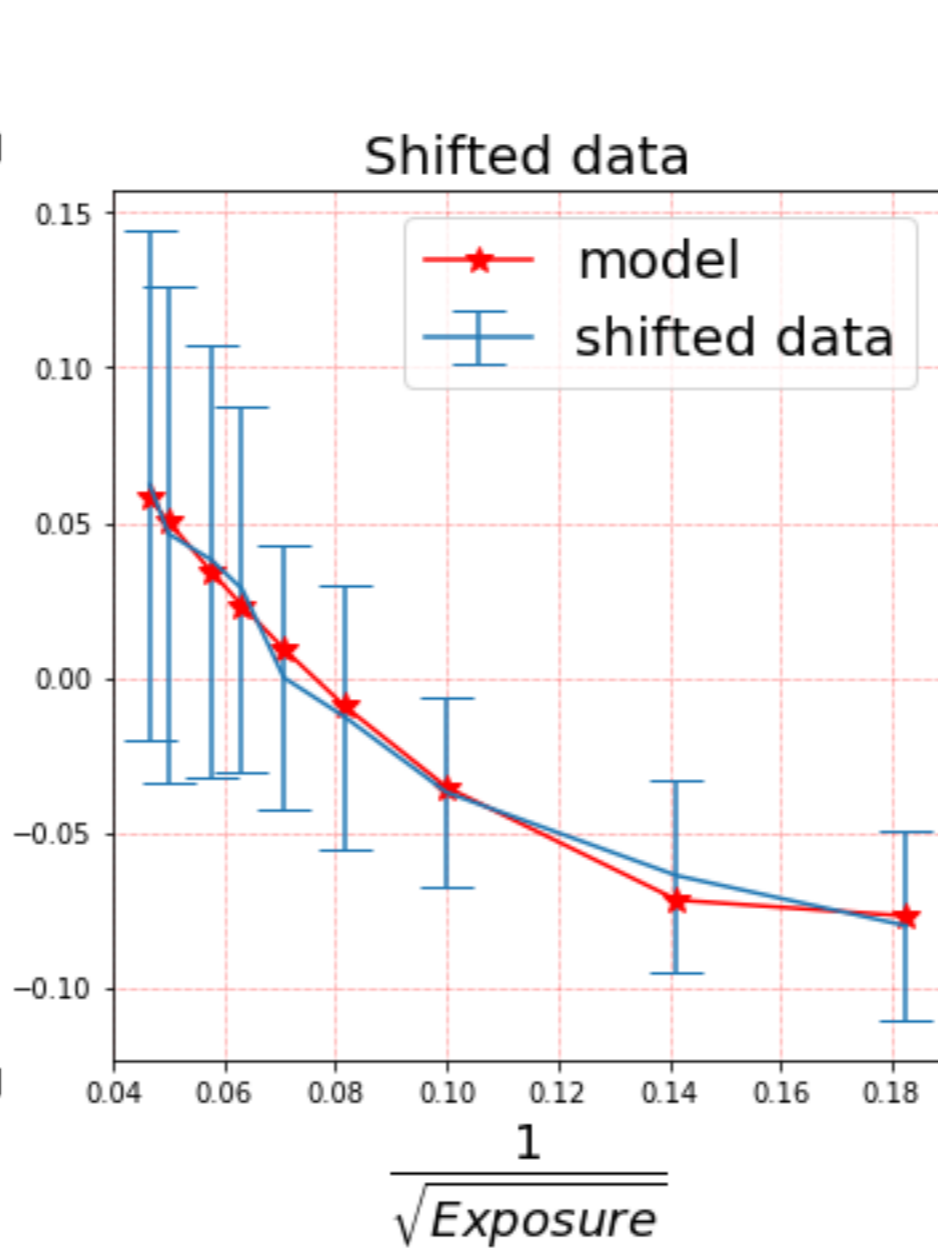
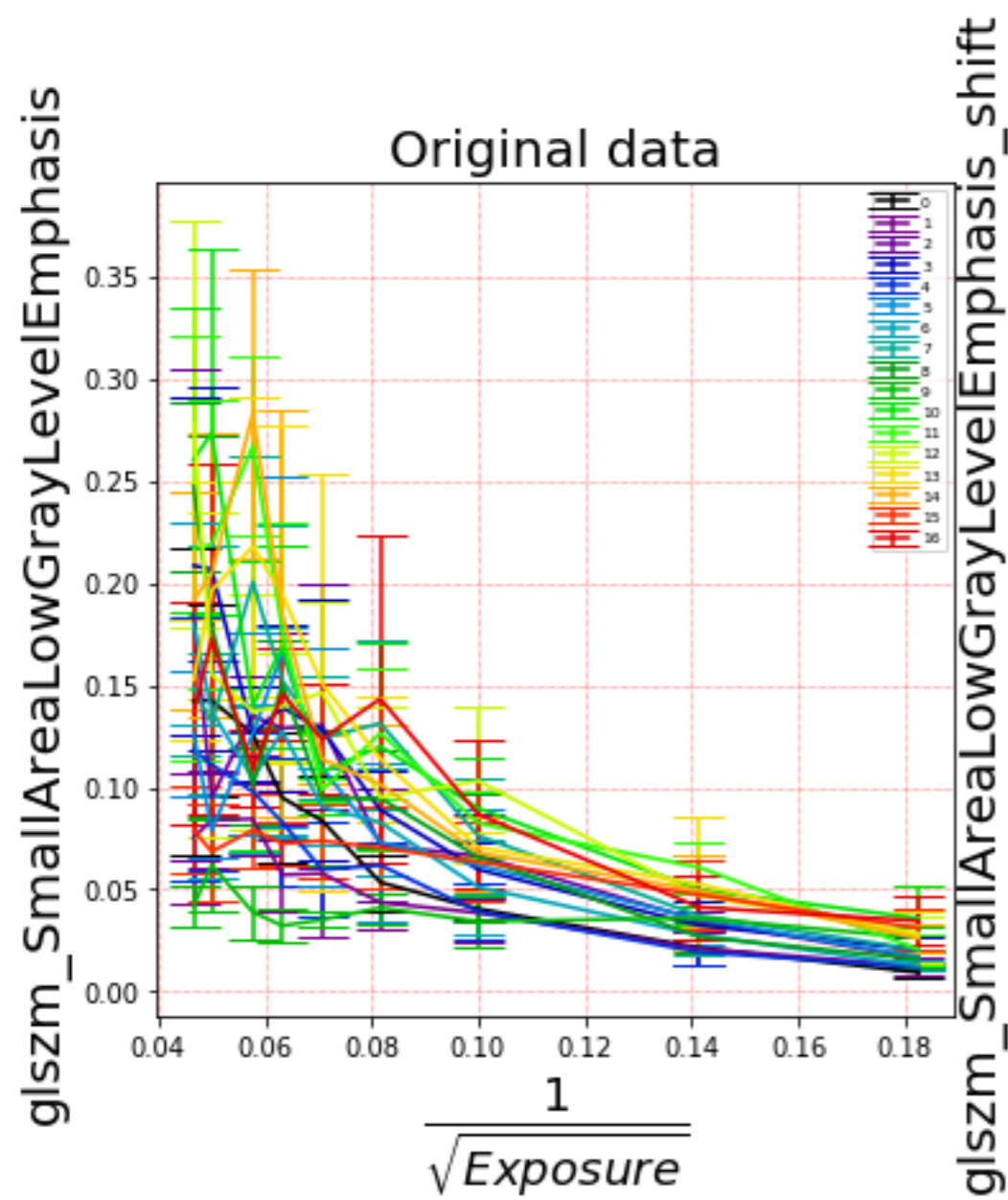
Shifted data

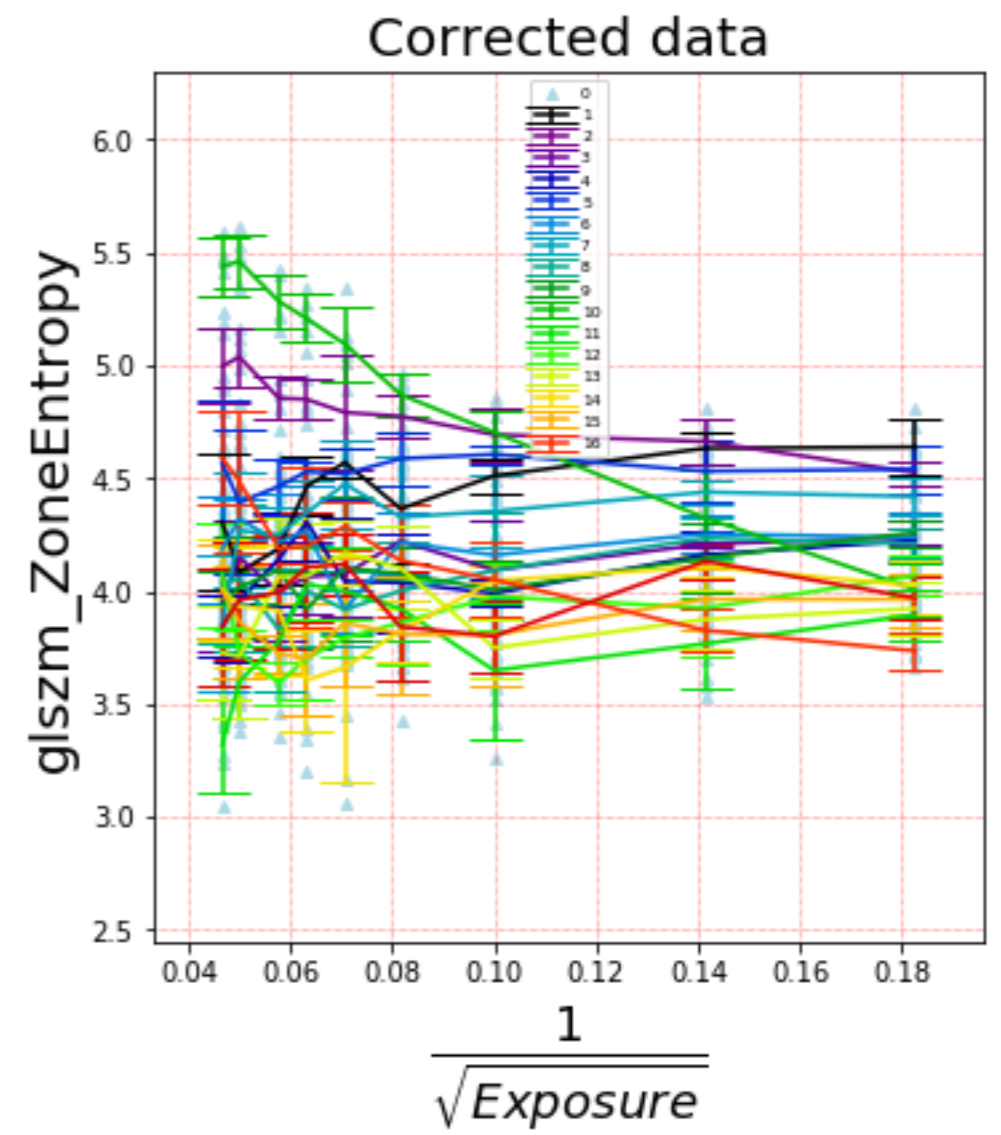
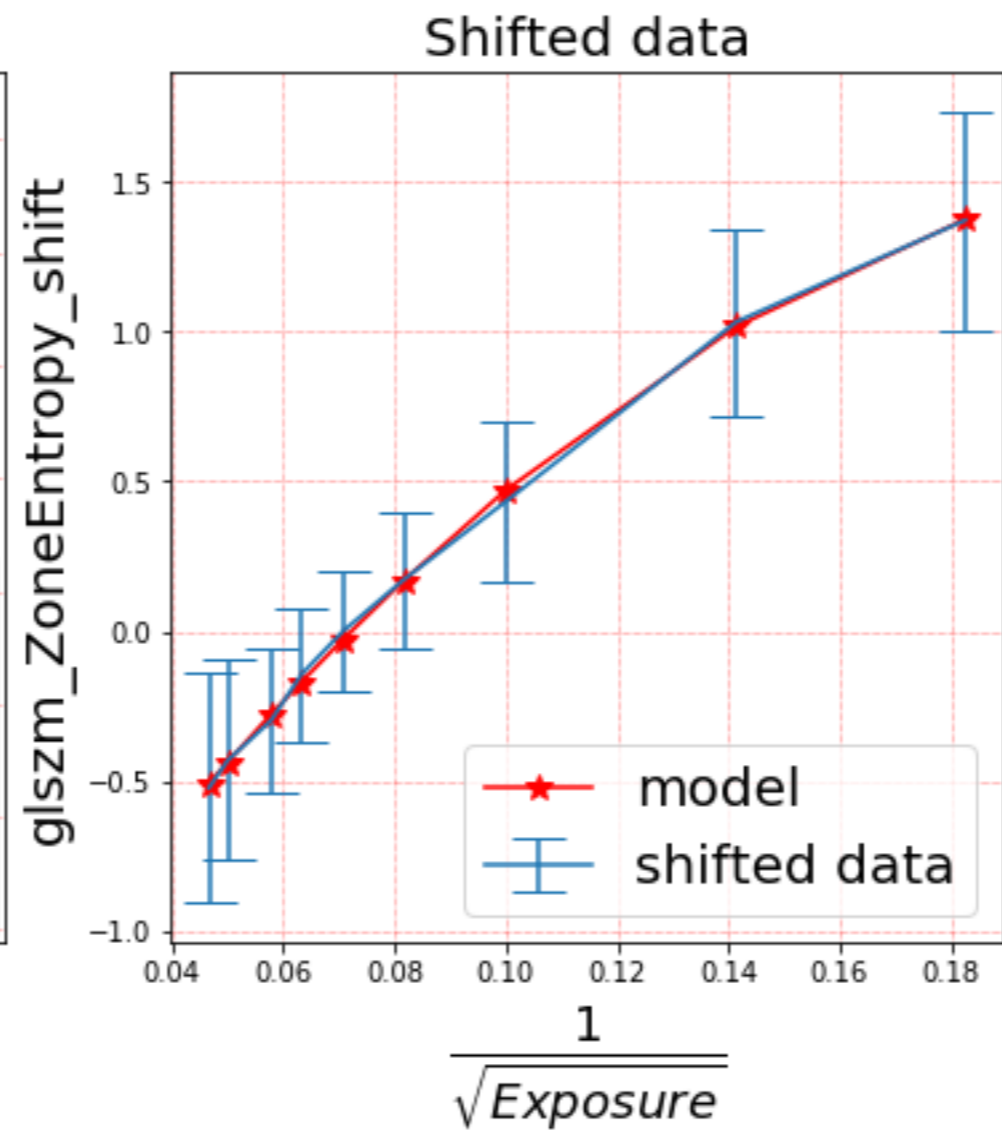
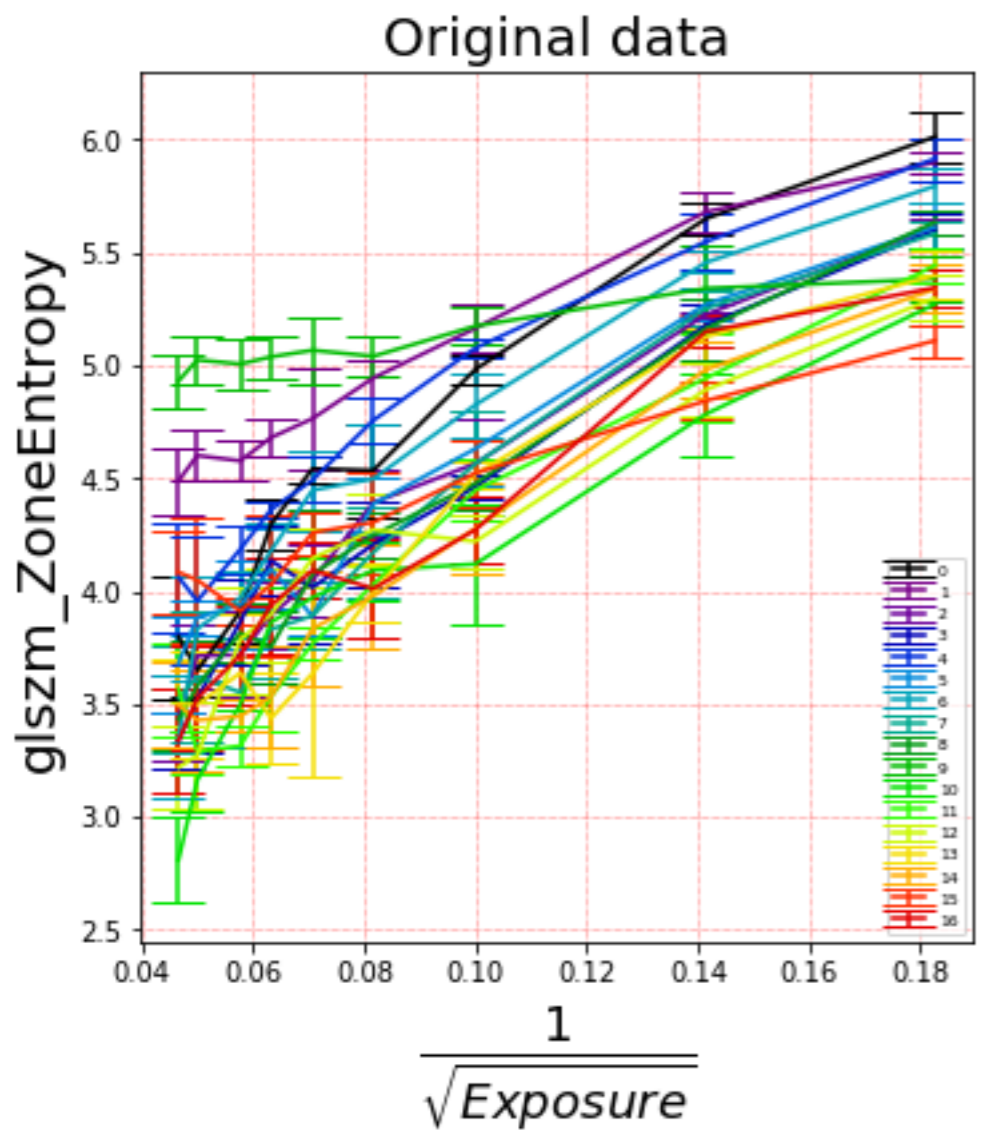


glszm_SmallAreaHighGrayLevelEmphasis

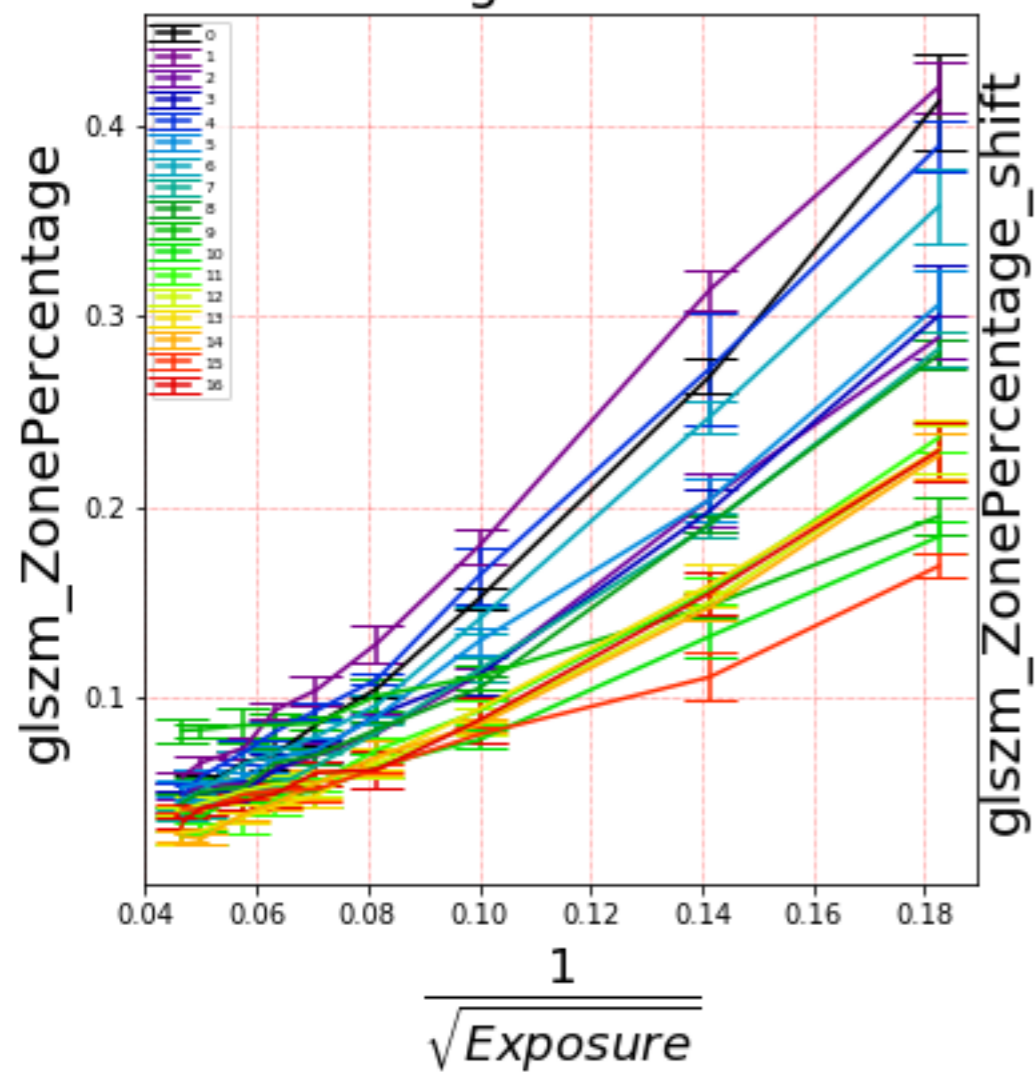
Corrected data



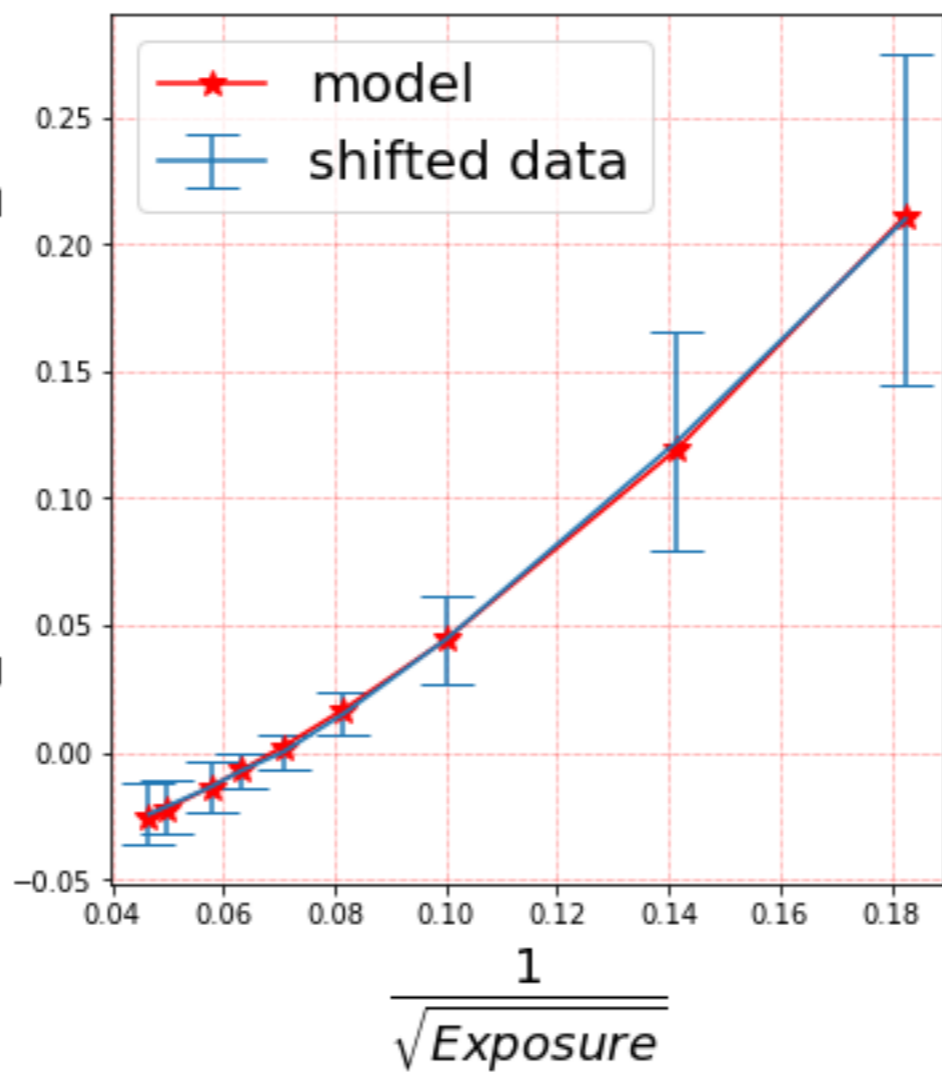




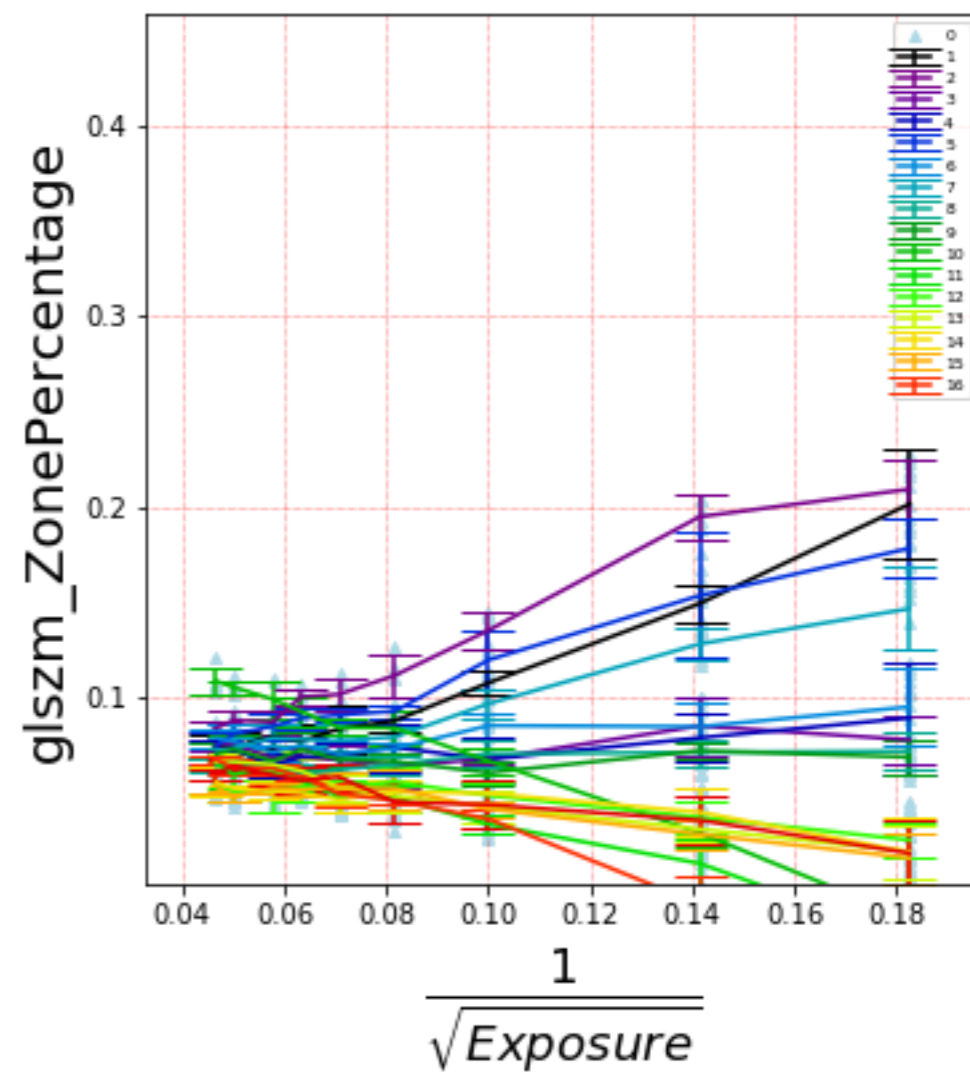
Original data



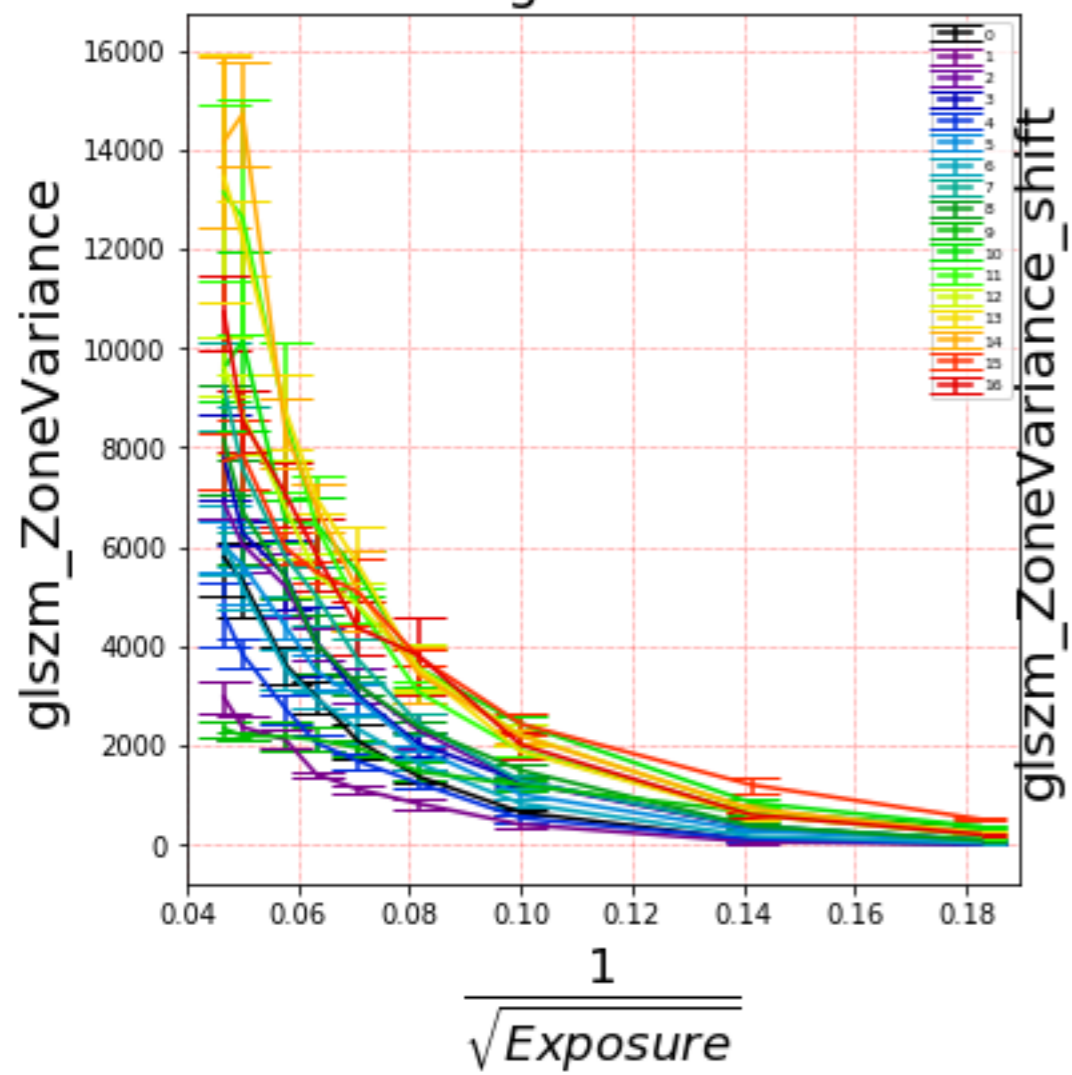
Shifted data



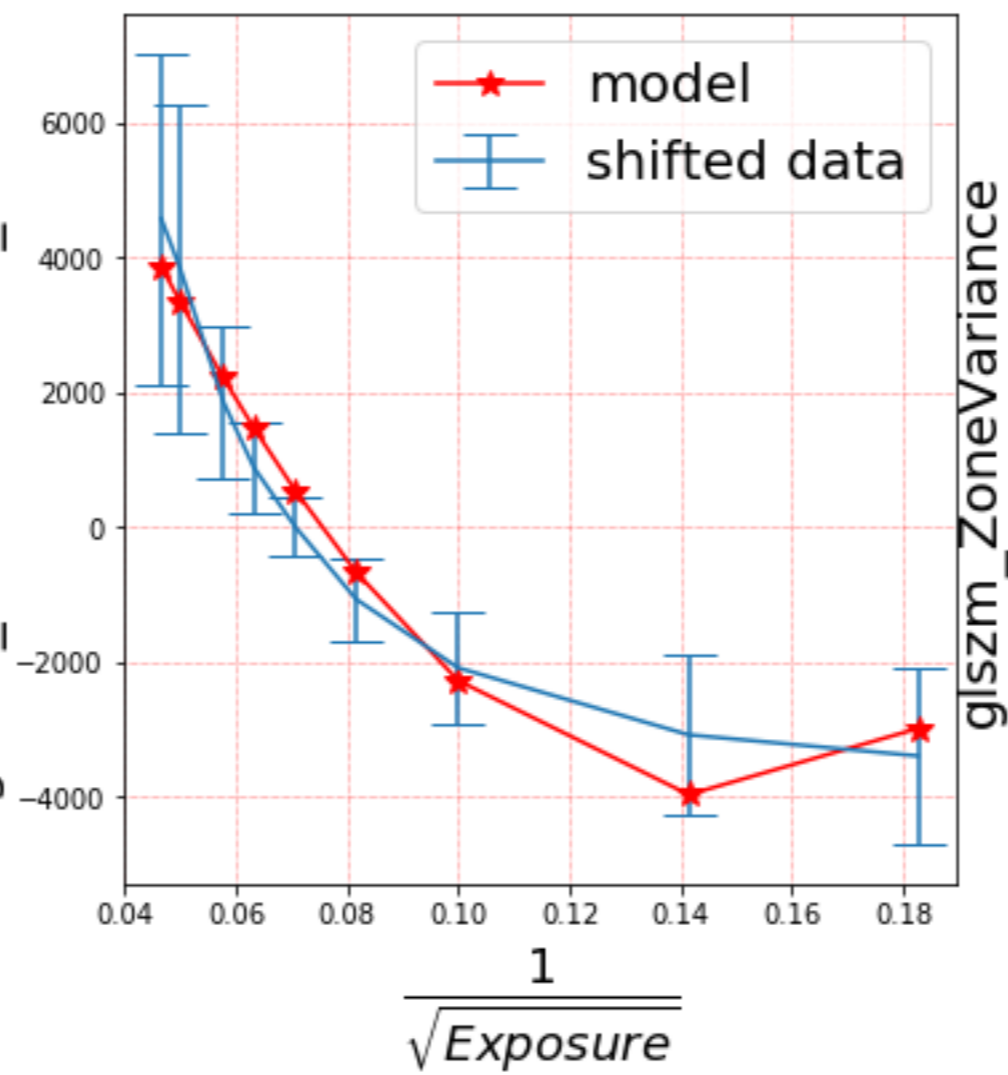
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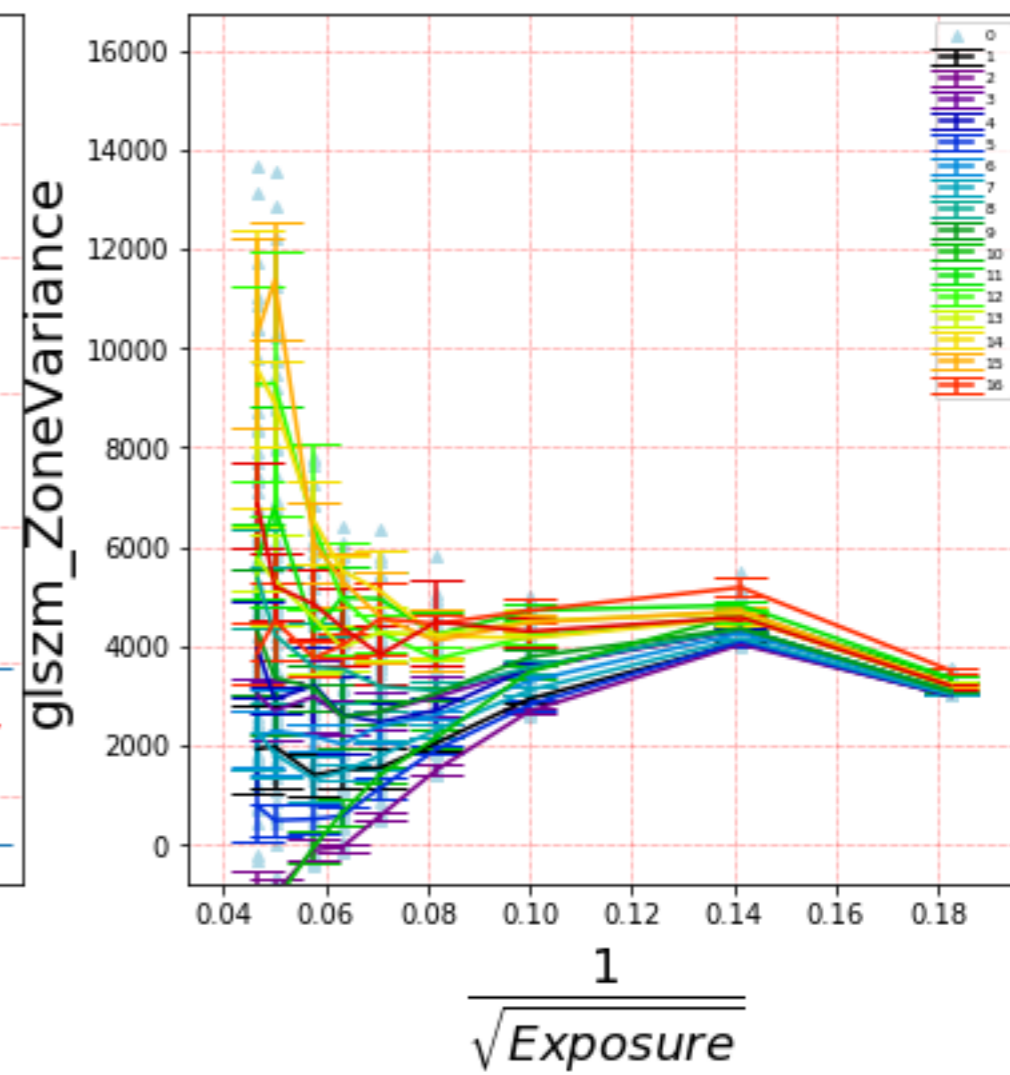
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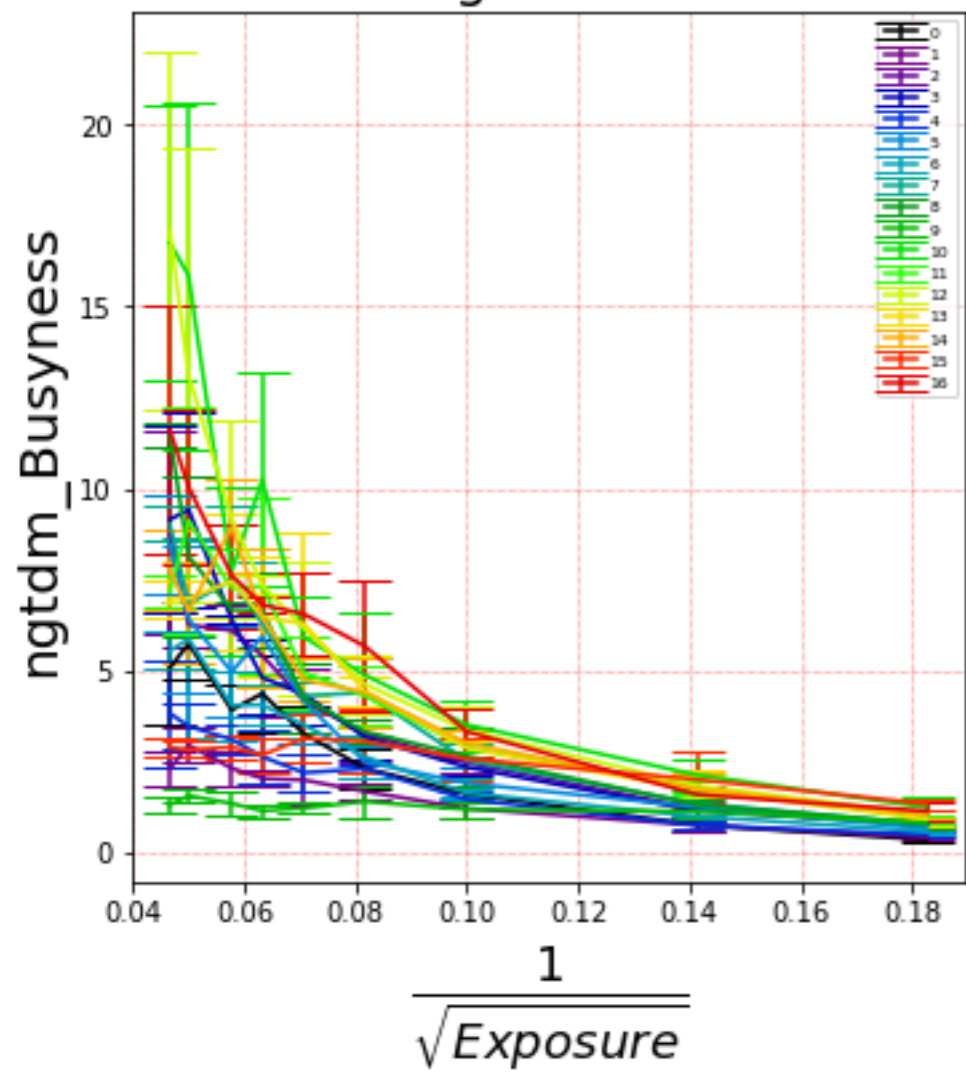
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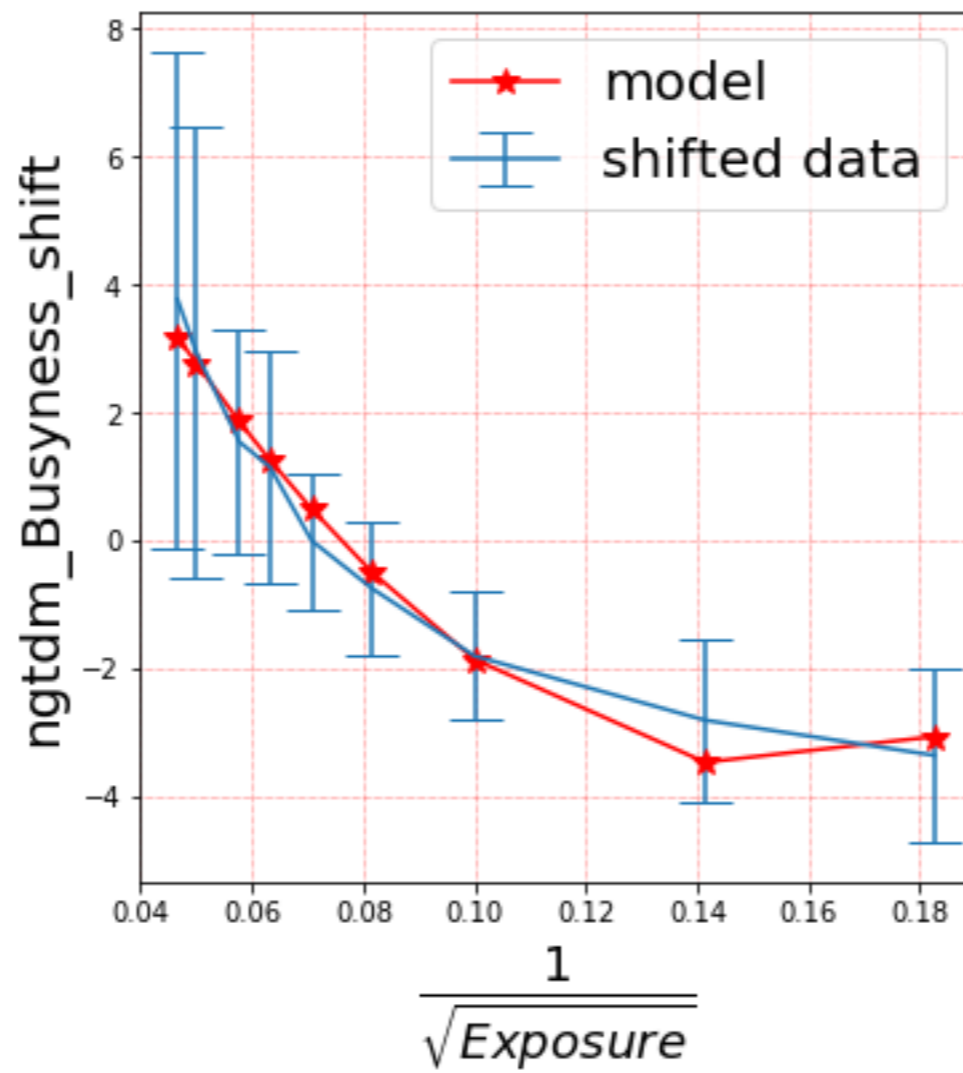
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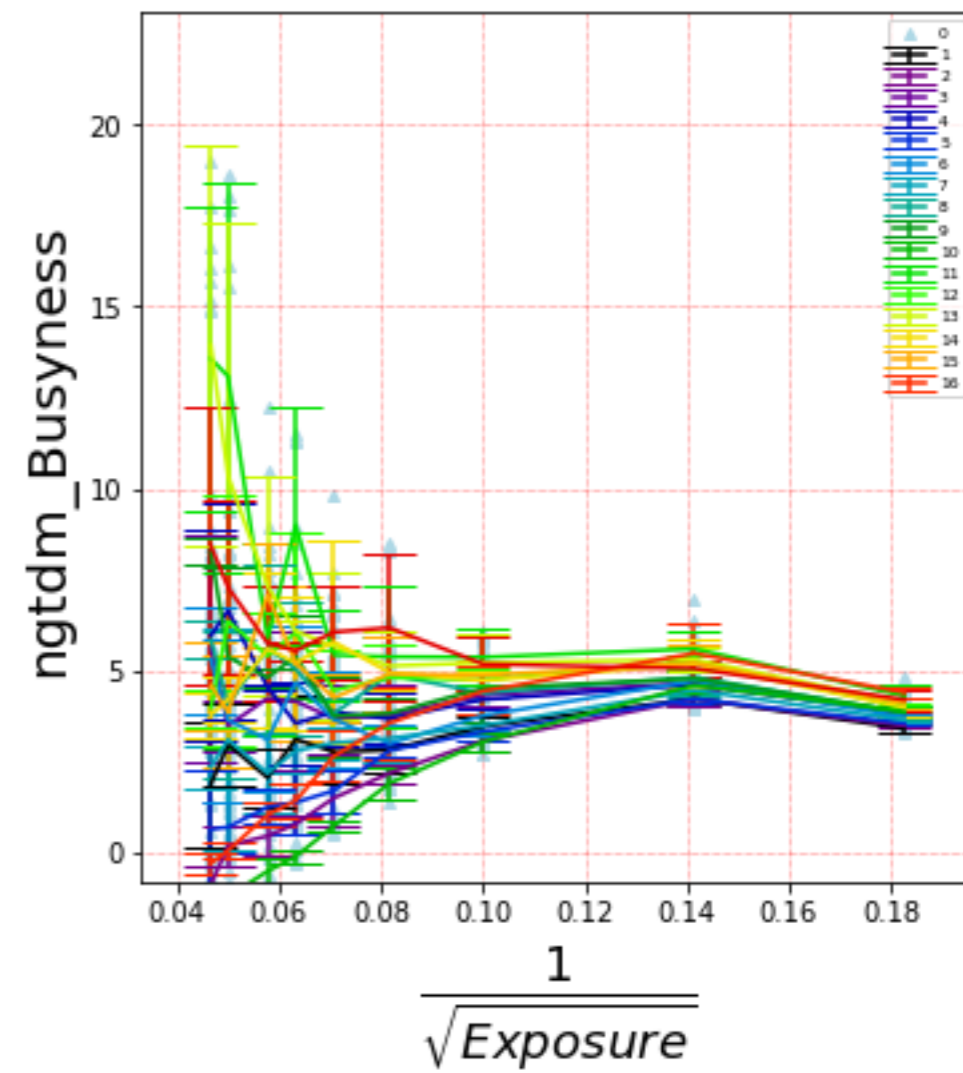
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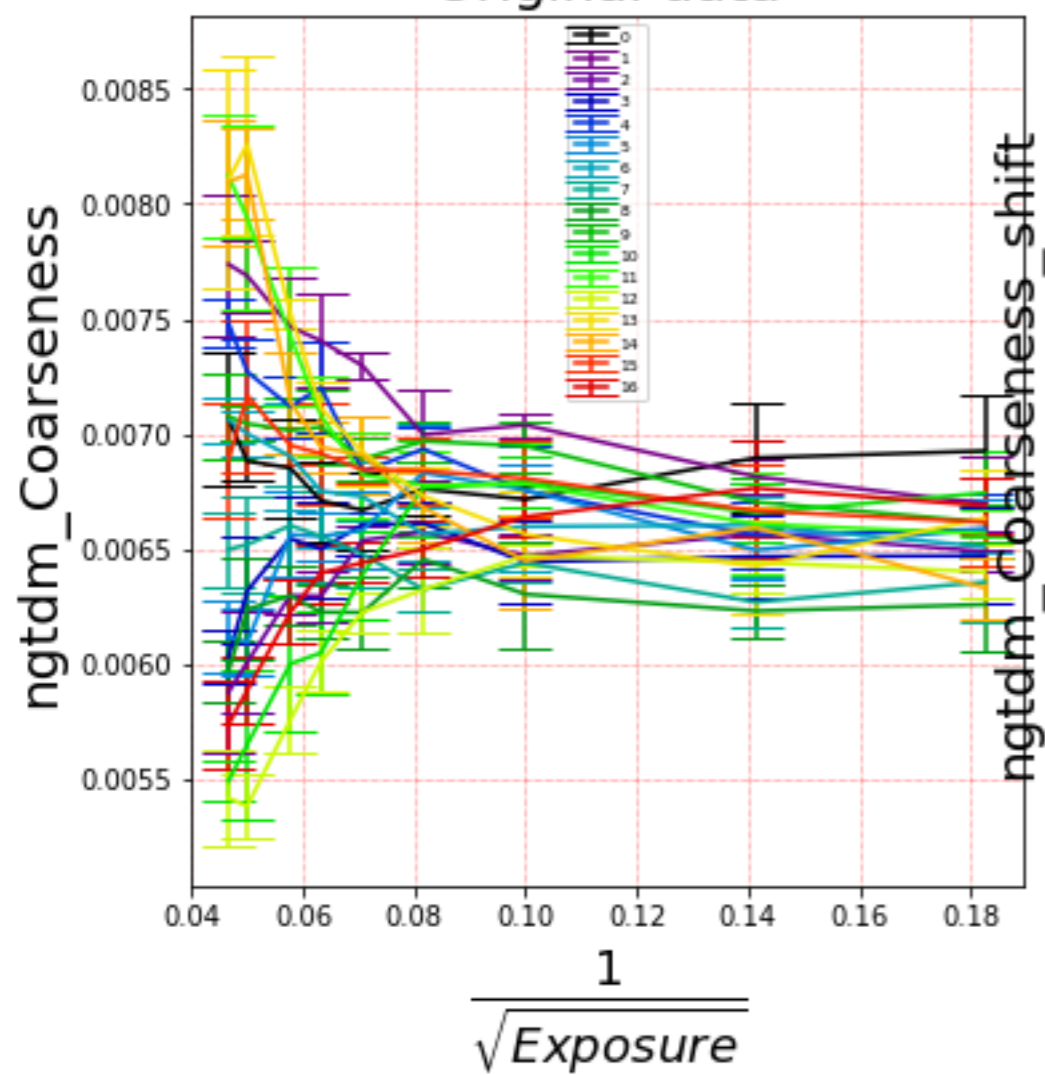
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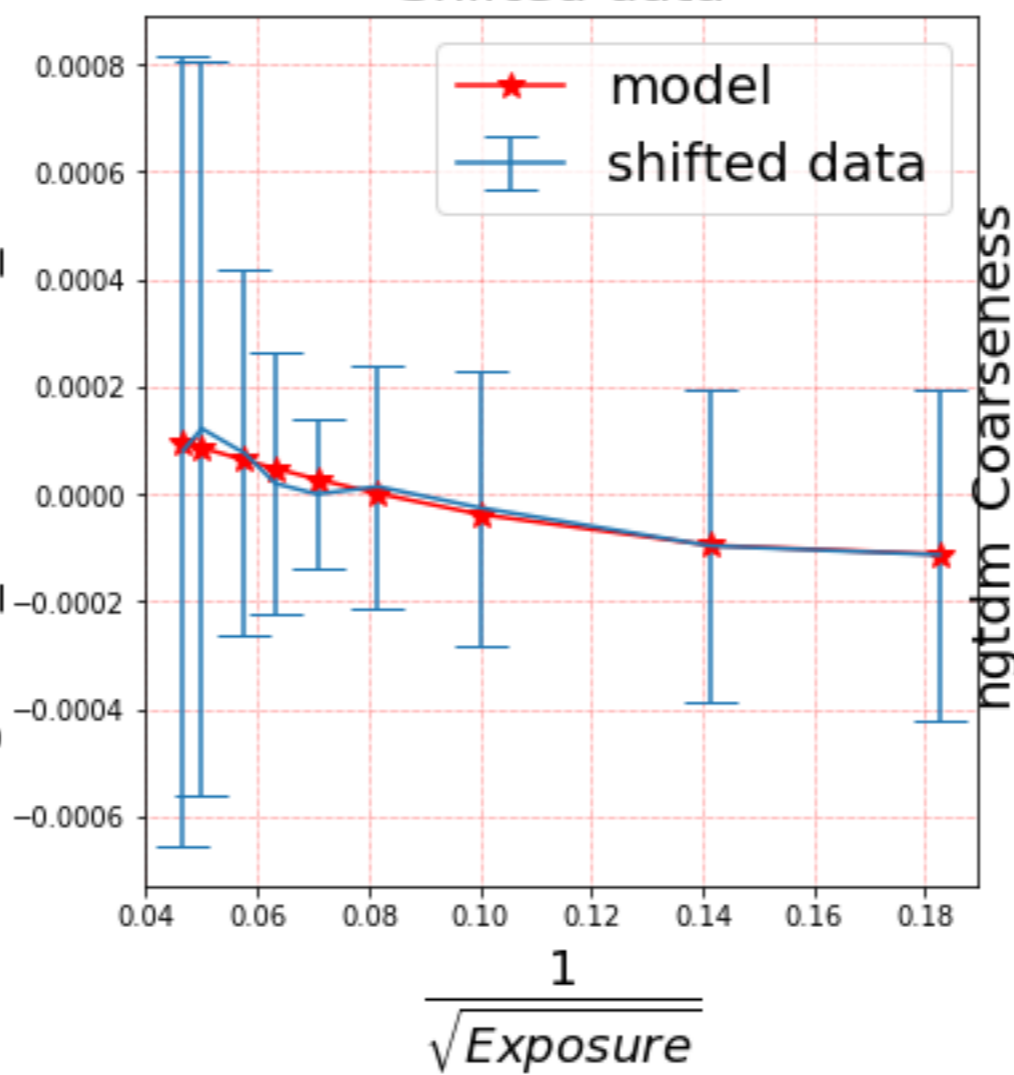
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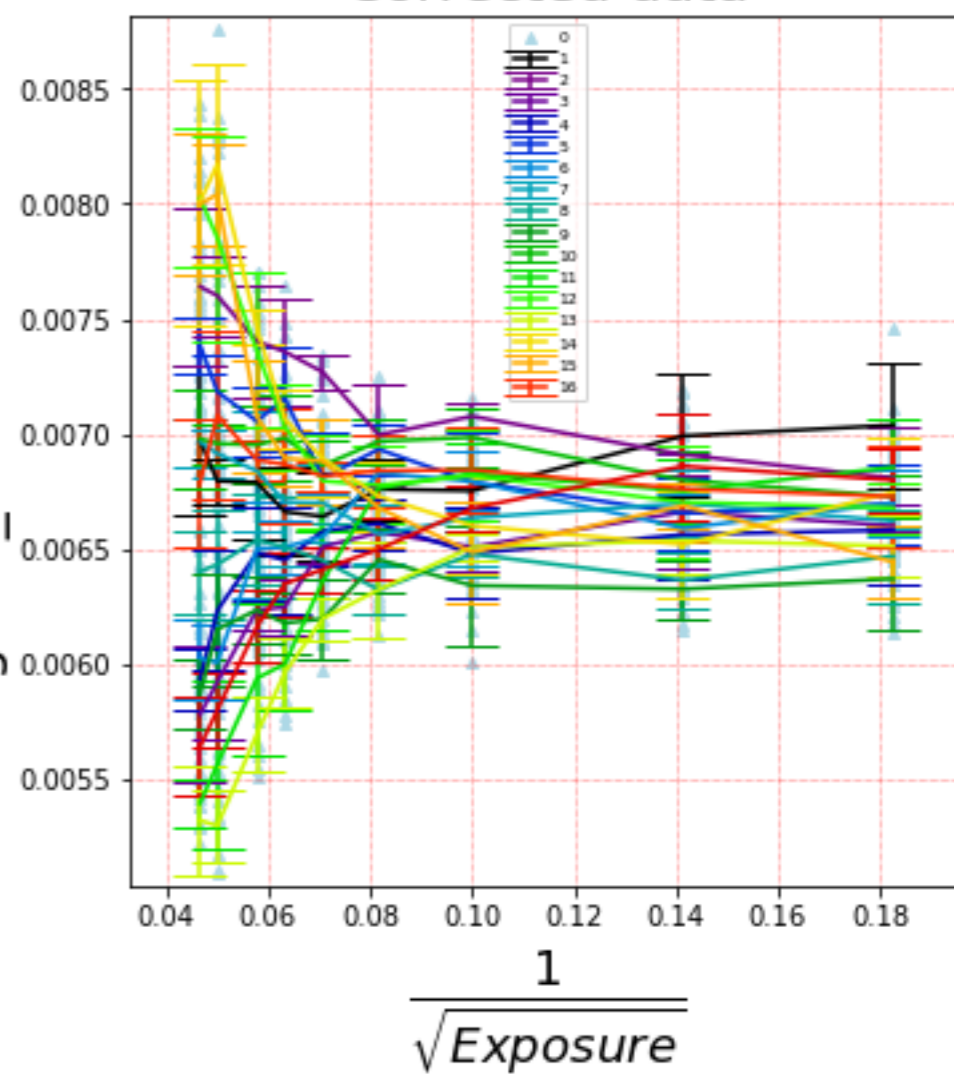
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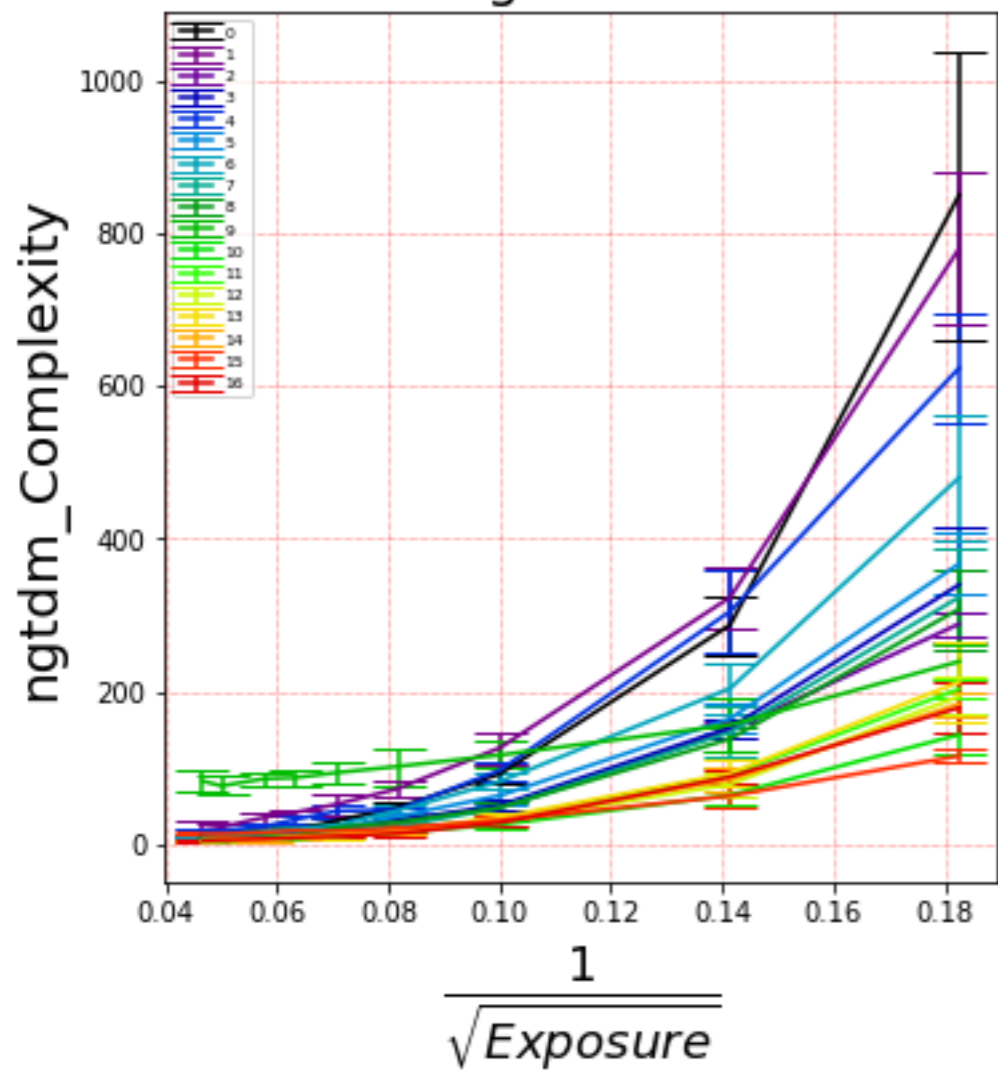
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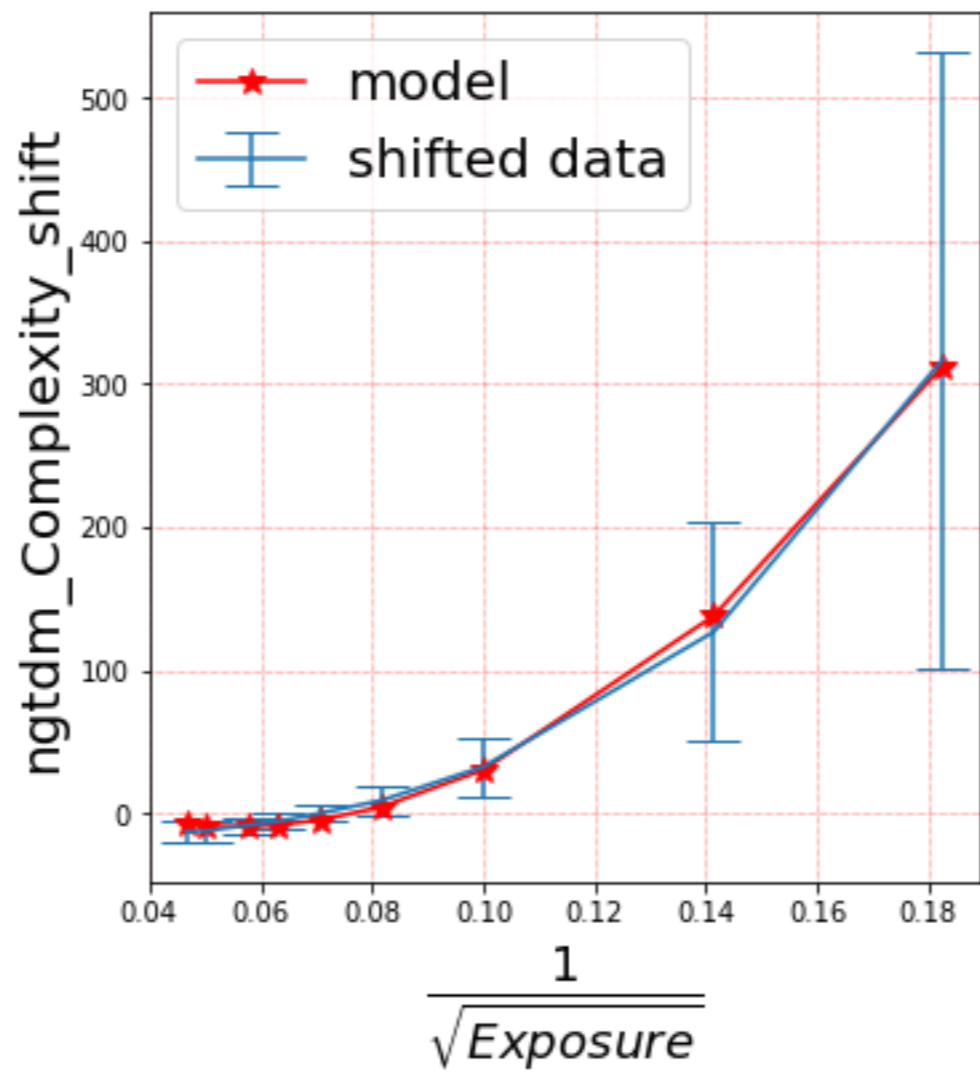
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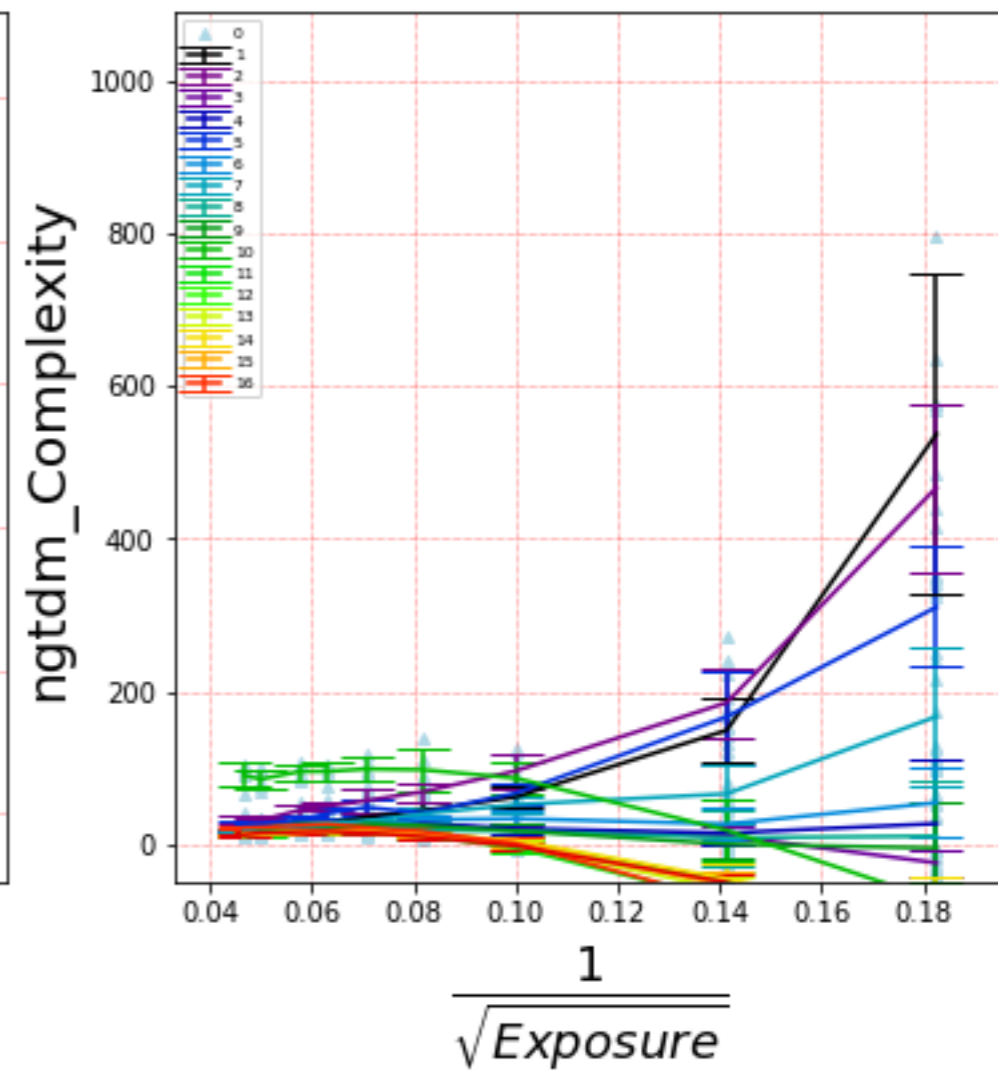
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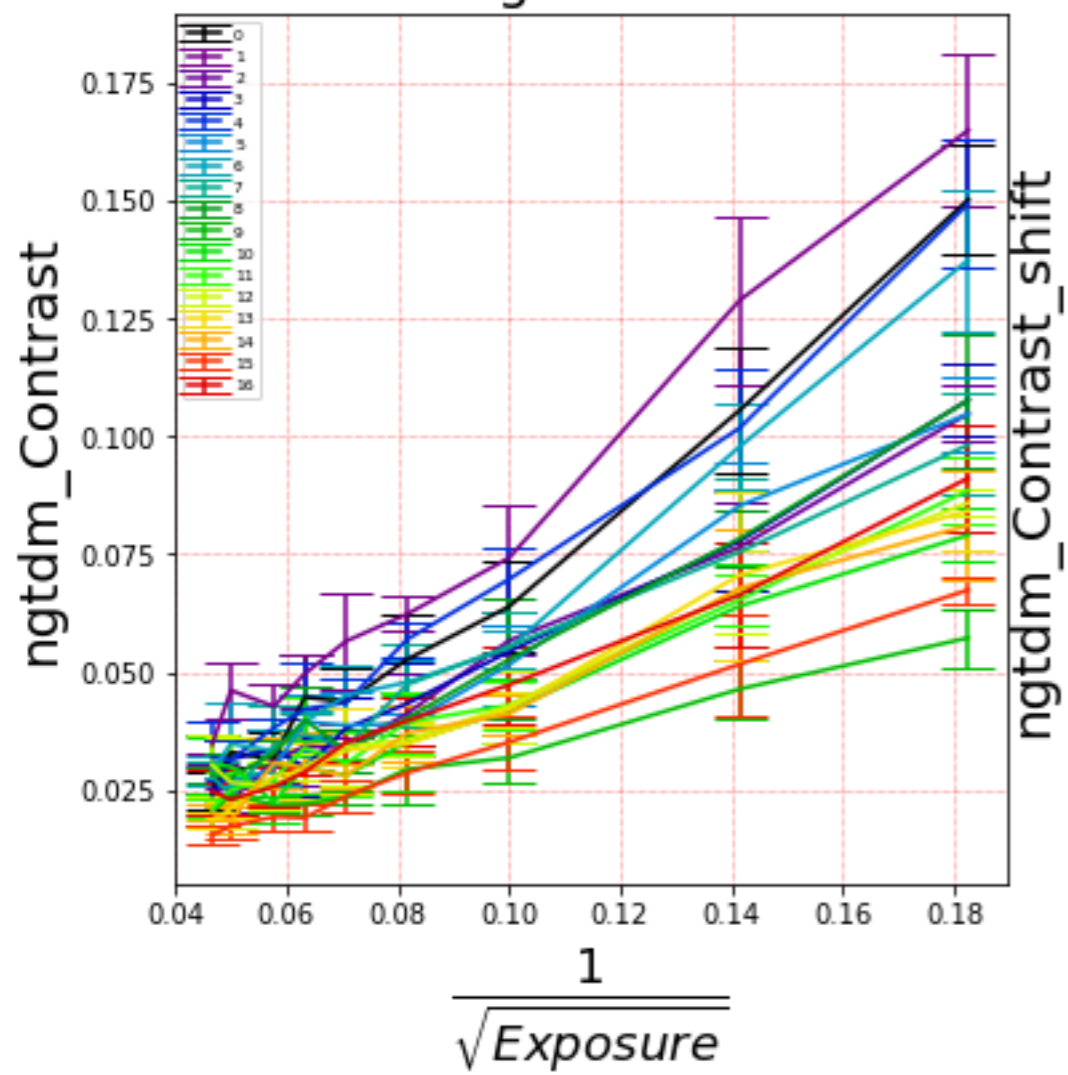
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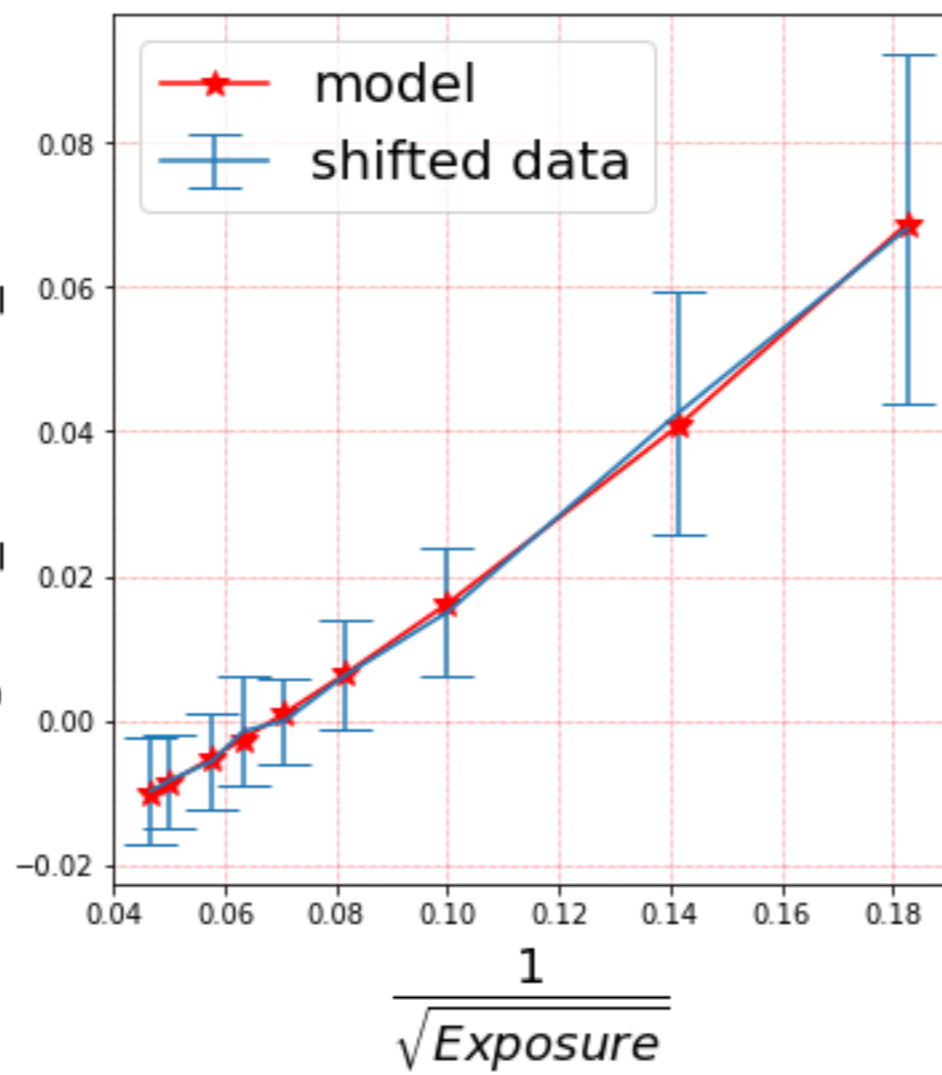
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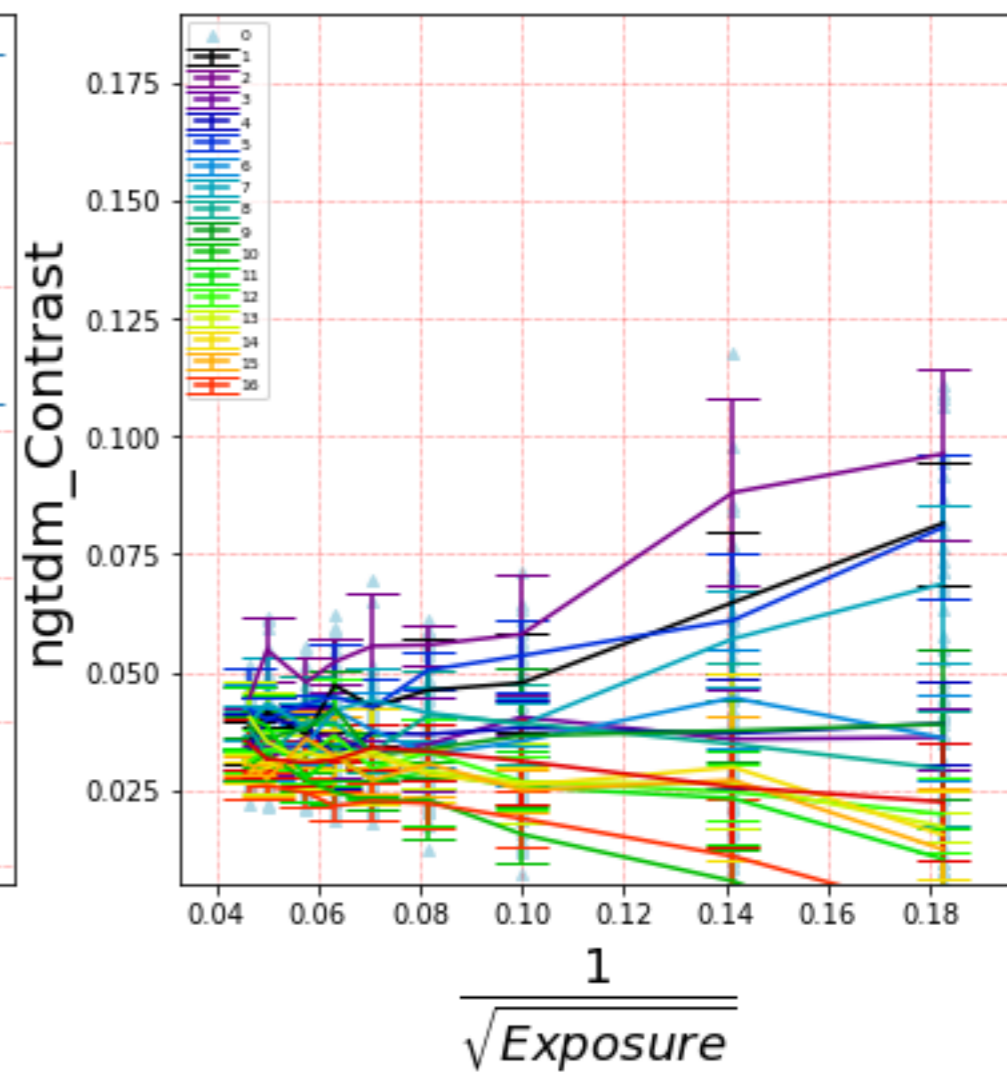
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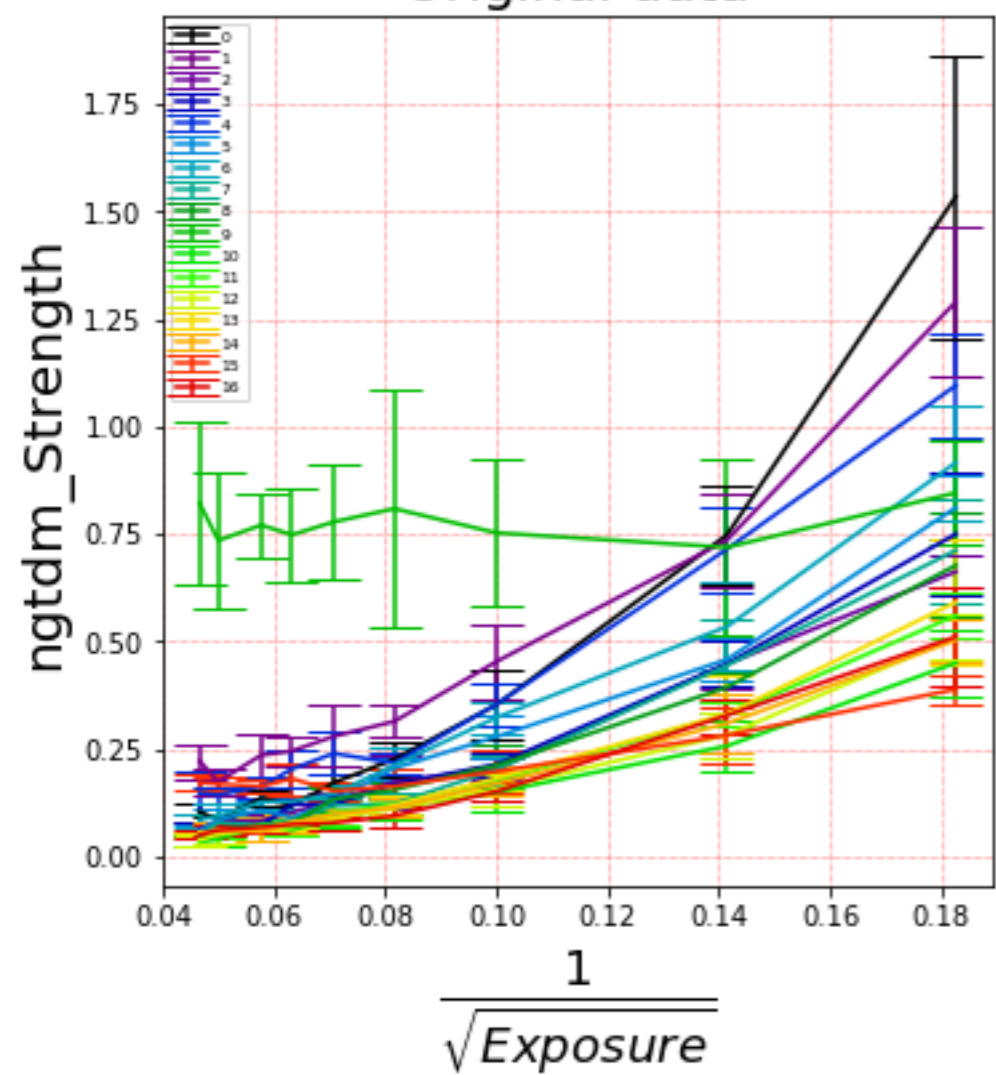
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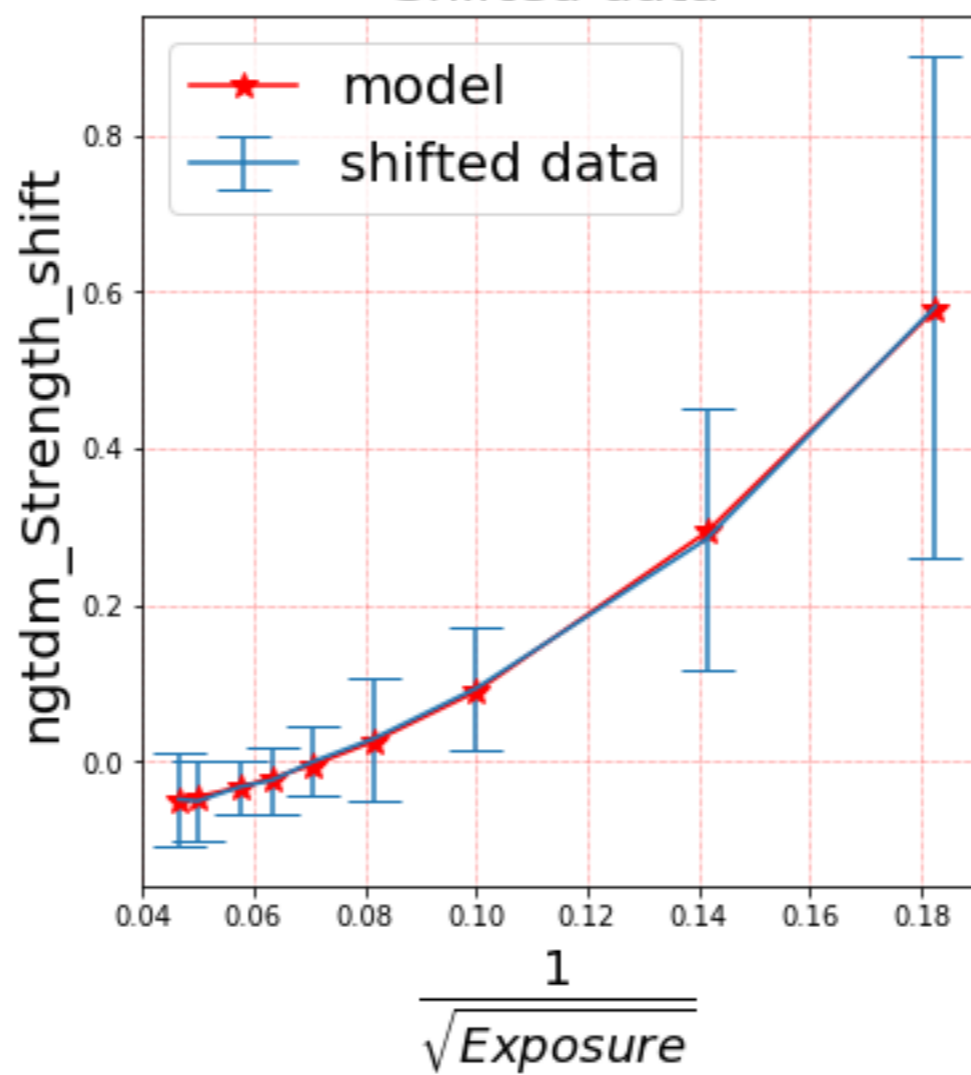
Corrected data



Original data



Shifted data



Corrected data

