Statistical Analysis of CFD Solutions from the 3rd AIAA Drag Prediction Workshop

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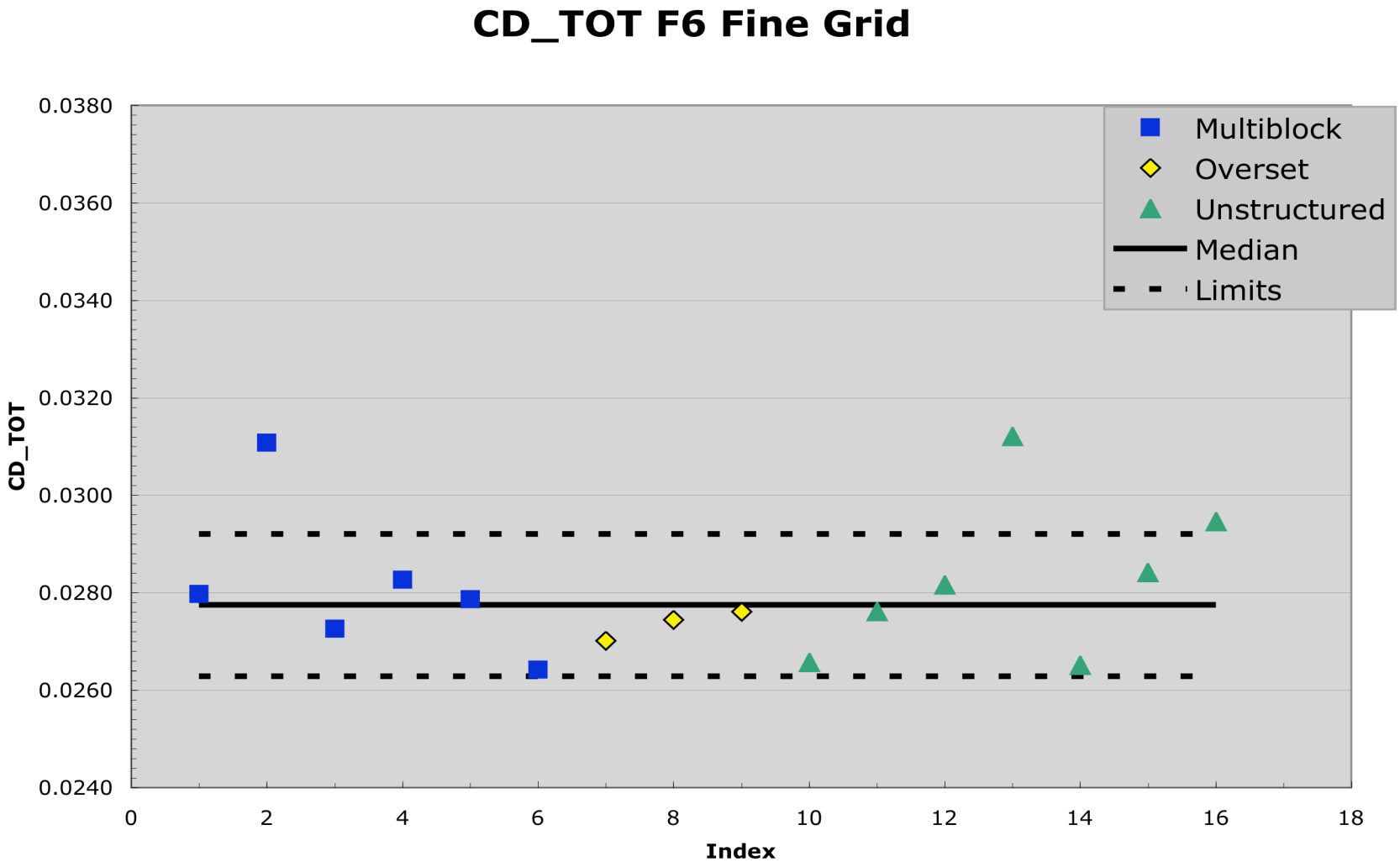
Outline of the talk DPW-3

- Method for analyzing the collective
- Case 1 DLR-F6 and FX2B Fairing
  - Individual Solution Analysis
  - Grid Convergence Study
  - Comparison with DPW-2
- Case 2 Grid Convergence Study for DPW-W1
- Summary
- Concluding Remarks

Analysis Method DPW-3

- Grid Convergence for nested solutions
  - Reduction in spread?
  - Reduction in scatter of “core” solutions?
  - Significant changes in medians?
  - Compare DPW-2 and DPW-3 spread and scatter

Analysis Method (2) DPW-3



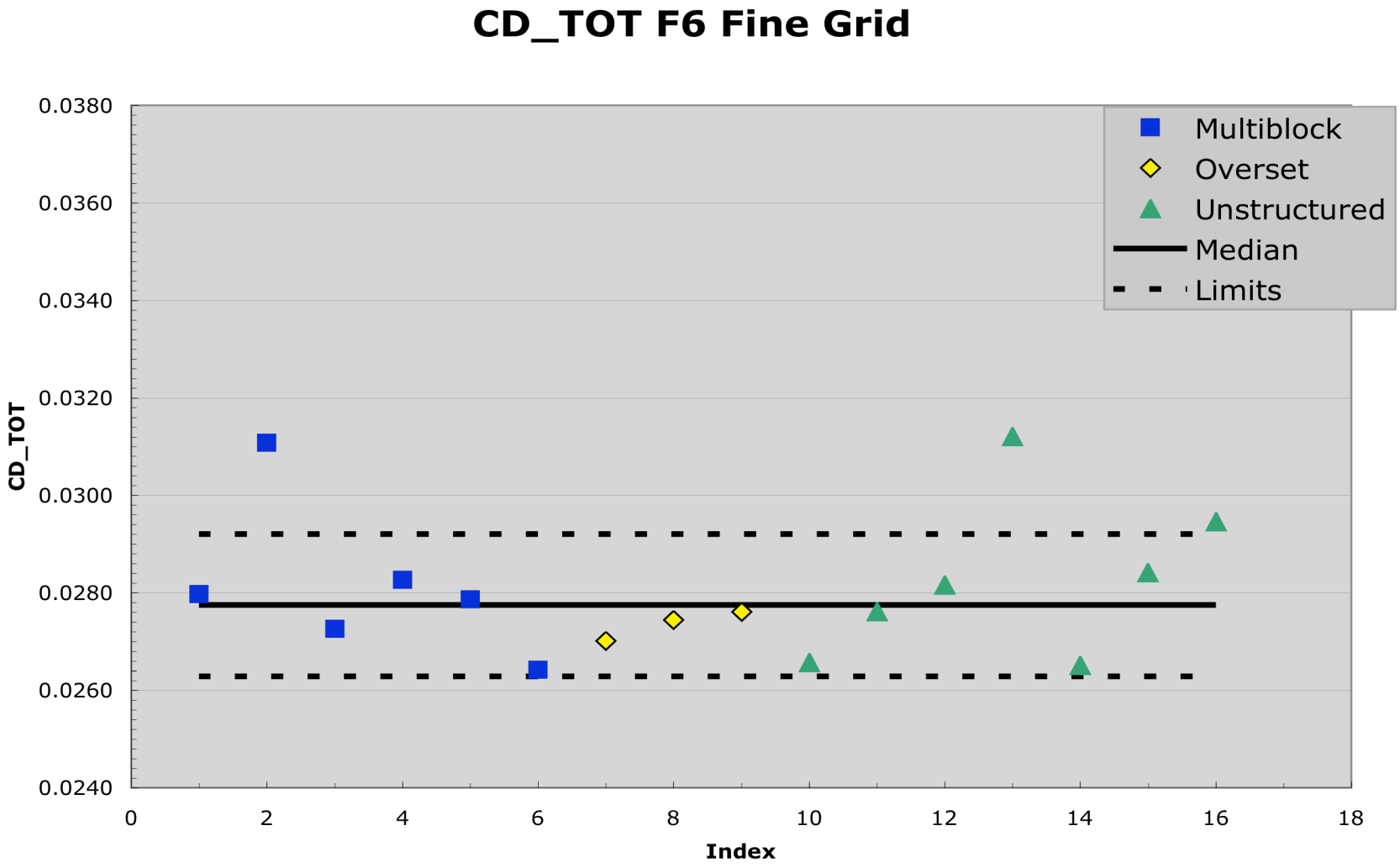
The median gives a robust estimate of the population mean.

Case 1: DLR-F6 Wing Body and DLR-F6 with FX2B Fairing

Case 1 Solution Statistics DPW-3

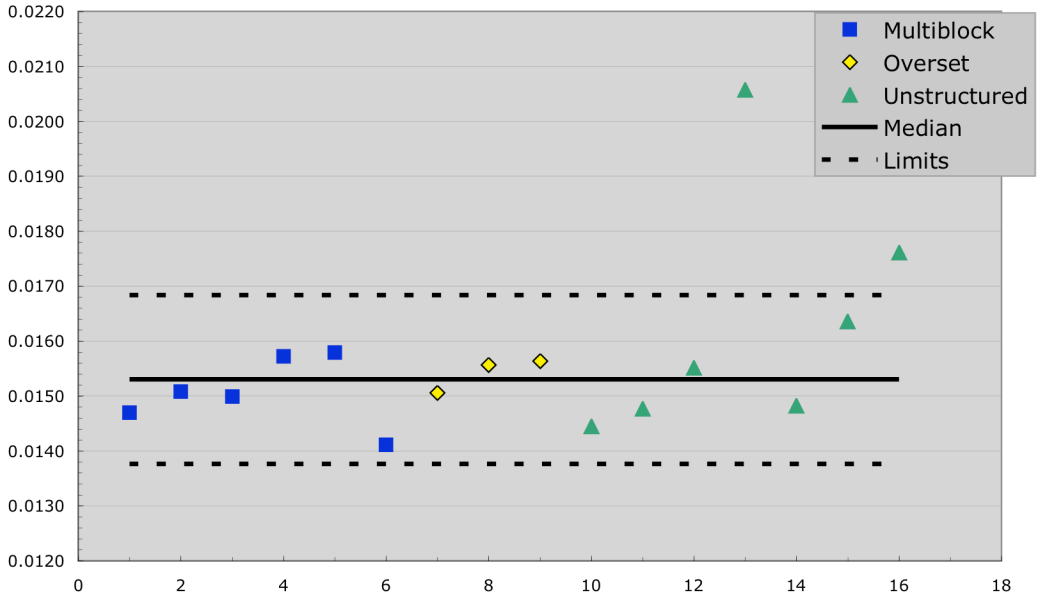
	DPW-2		DPW-3	
	Nested	Core	Nested	Core
Solutions	16	13	16	14
Authors	15	12	12	11
Institutions	14	11	10	10
Codes	15	12	12	11

Solution Analysis DPW-3

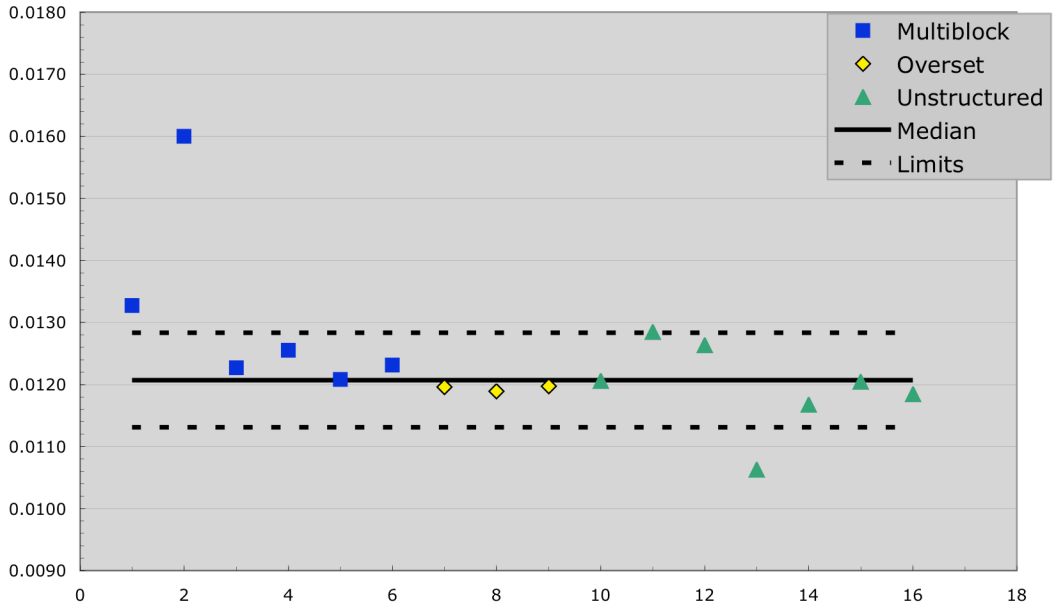


Solution Analysis (2) DPW-3

CD_PR

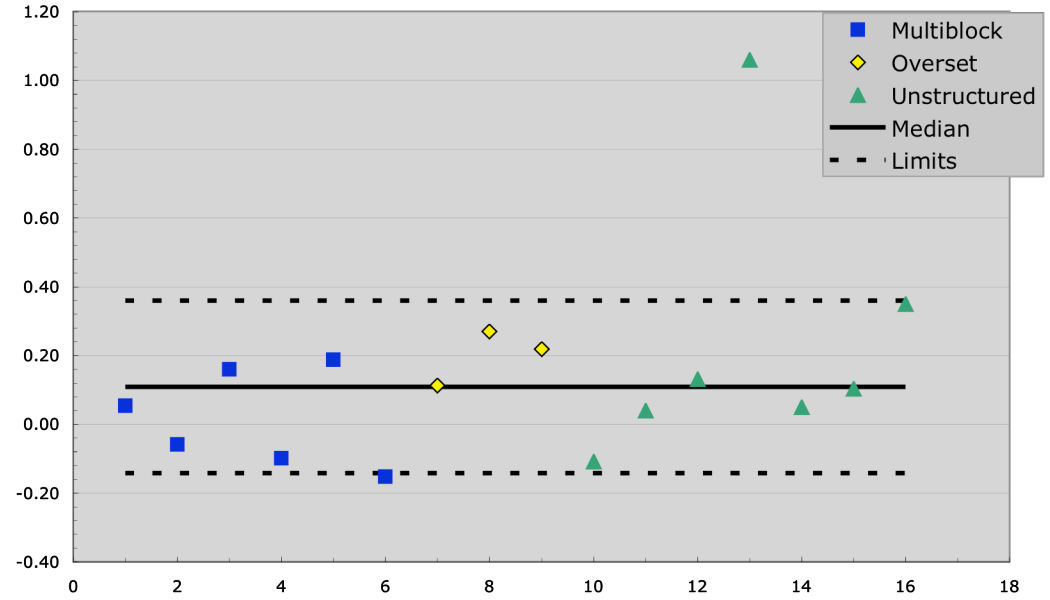


CD_SF

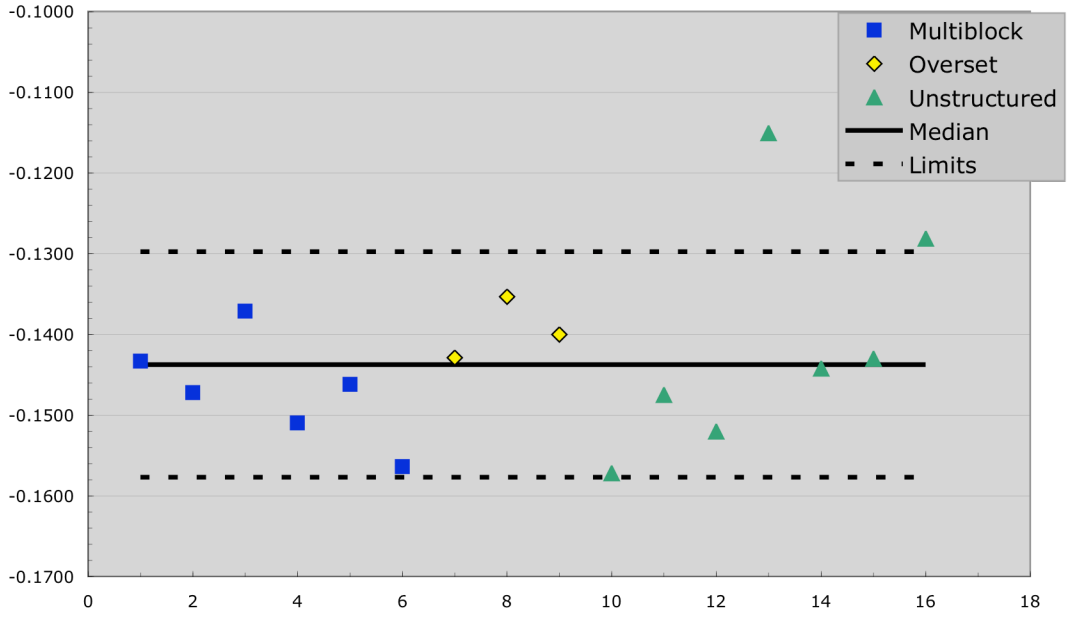


Solution Analysis (3) DPW-3

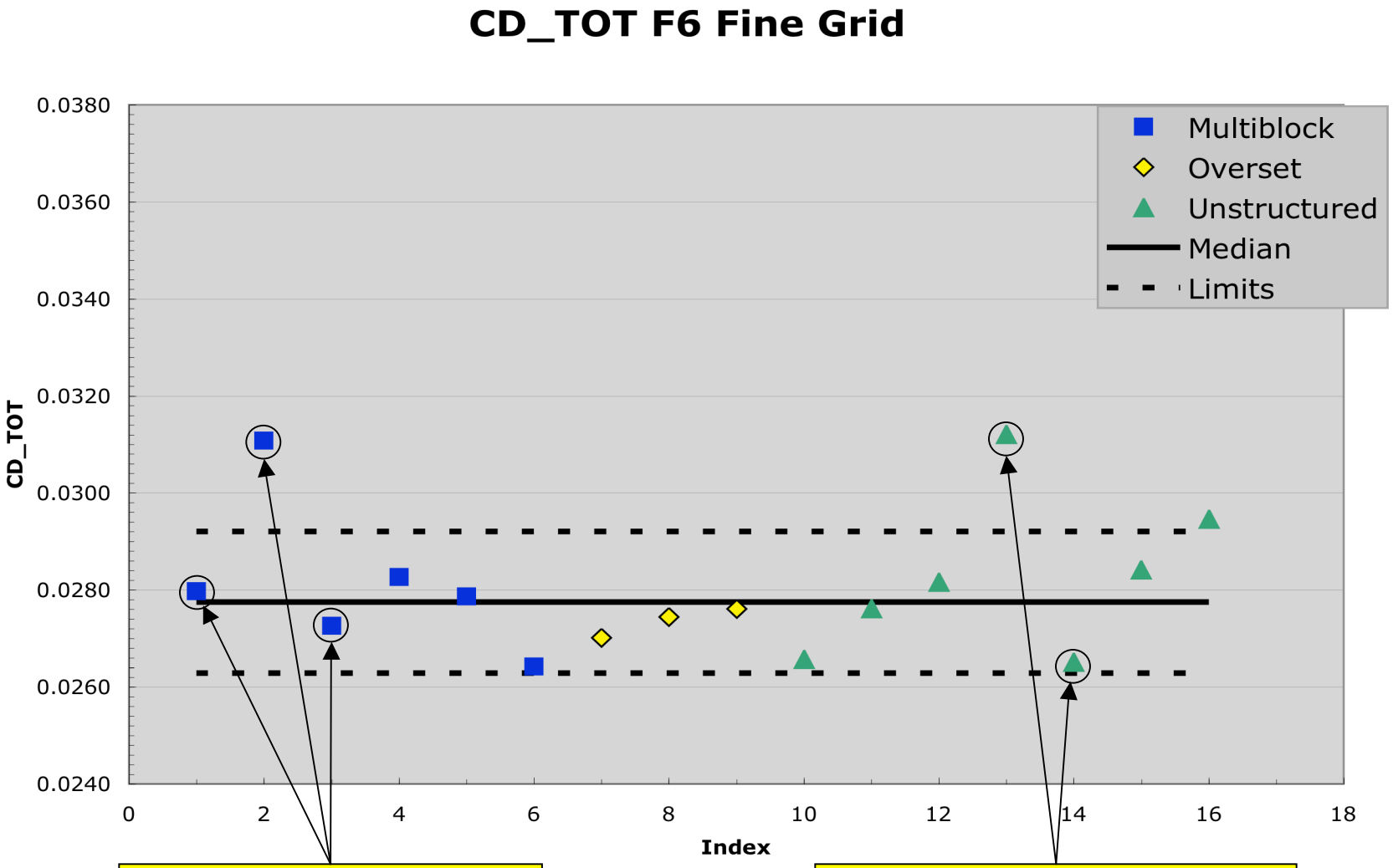
ALPHA



CM_TOT



Solution Analysis (4) DPW-3



Same Code
Same Grid
Different Turbulence Models

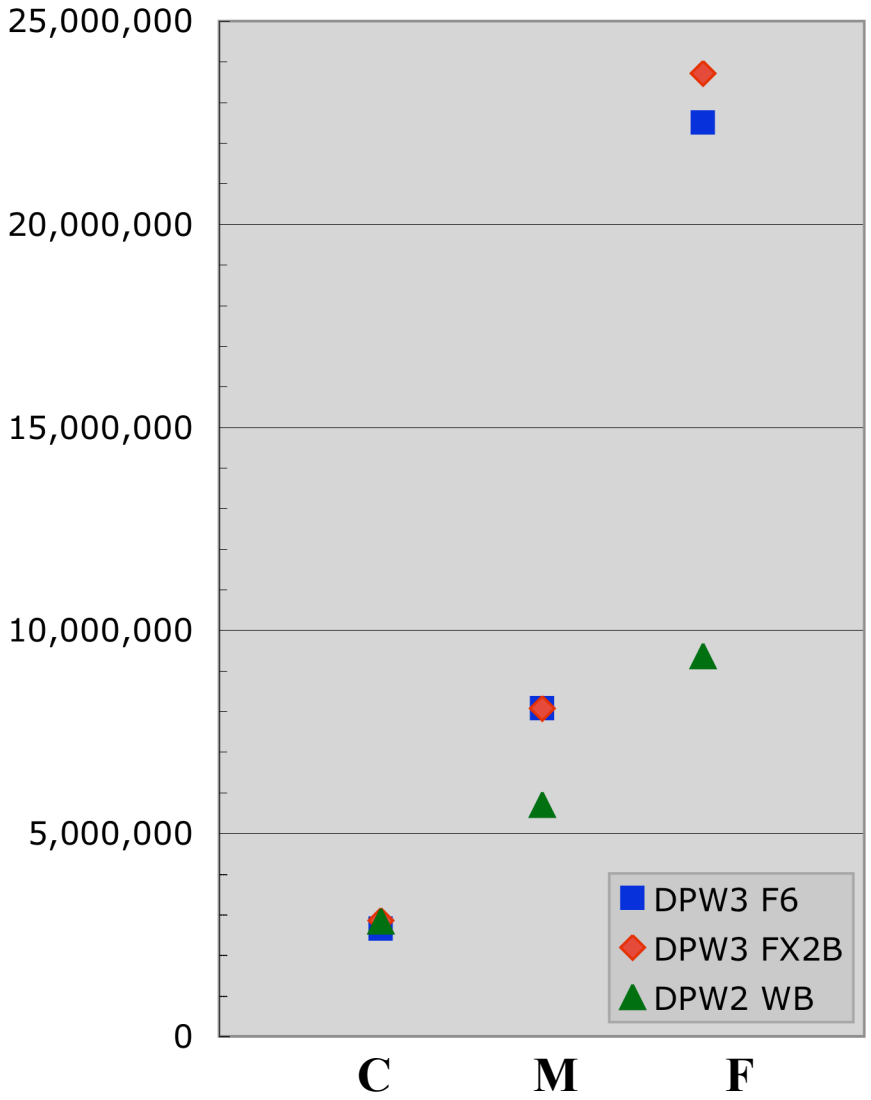
Same Grid Nodes; Different Cells
Same Turbulence Model
Different Code

What does convergence look like? DPW-3

- **Scatter in solutions is due to:**
  - **Numerical error**
  - **Modeling error (e.g. physics models, computational models)**
  - **User errors**
  - **Code errors**
- **For grid convergence, numerical error asymptotically approaches zero leaving the other three contributors**
- **For the collective to show convergence, the following would have to happen:**
  - The ranges for the configurations would approach a constant as the grid “improved”.
  - The scatter (standard deviation) of the “core” solutions would approach a constant as the grid improved.
  - The medians of the core solutions would change asymptotically.

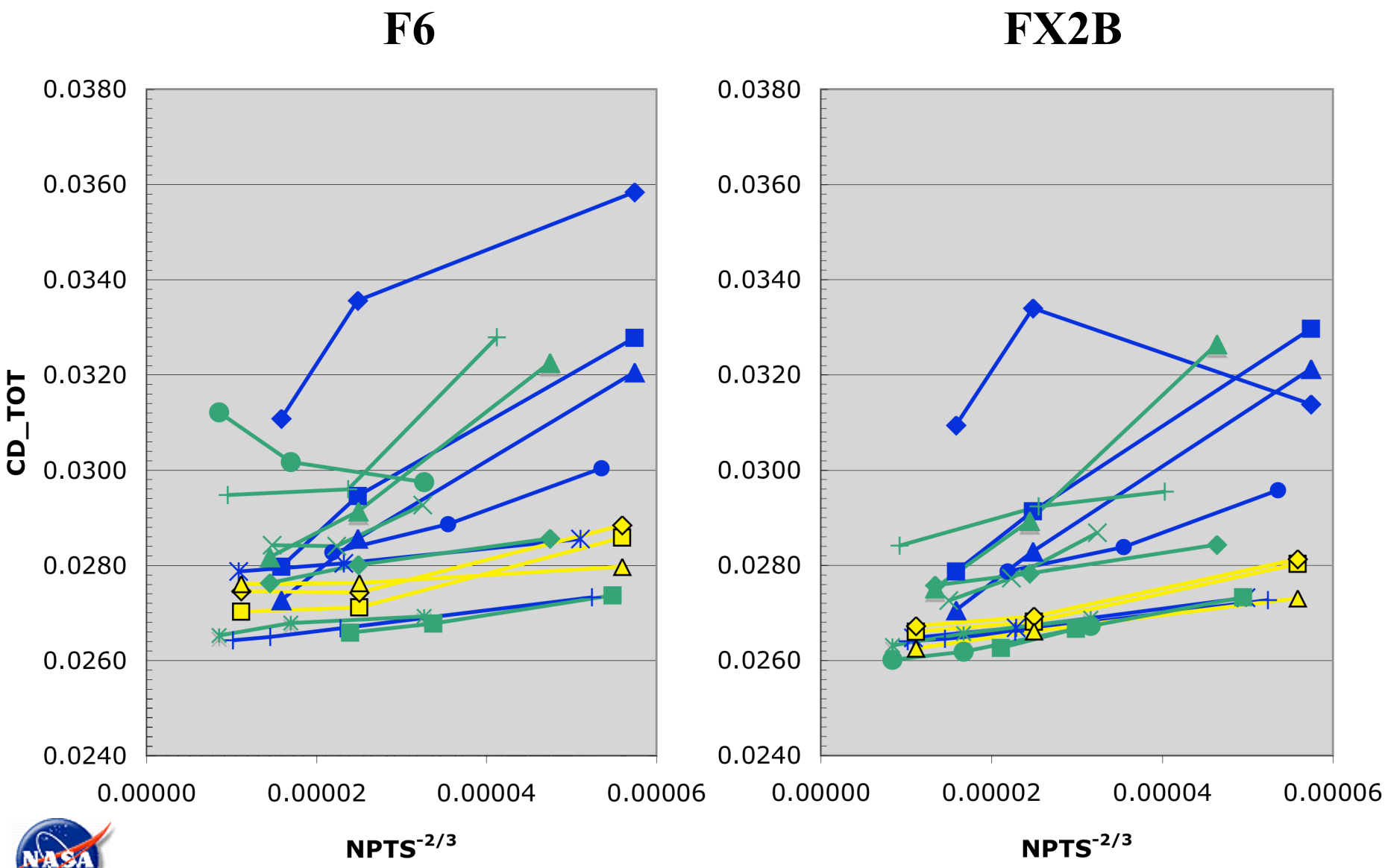
Grid Sizes

DPW-3

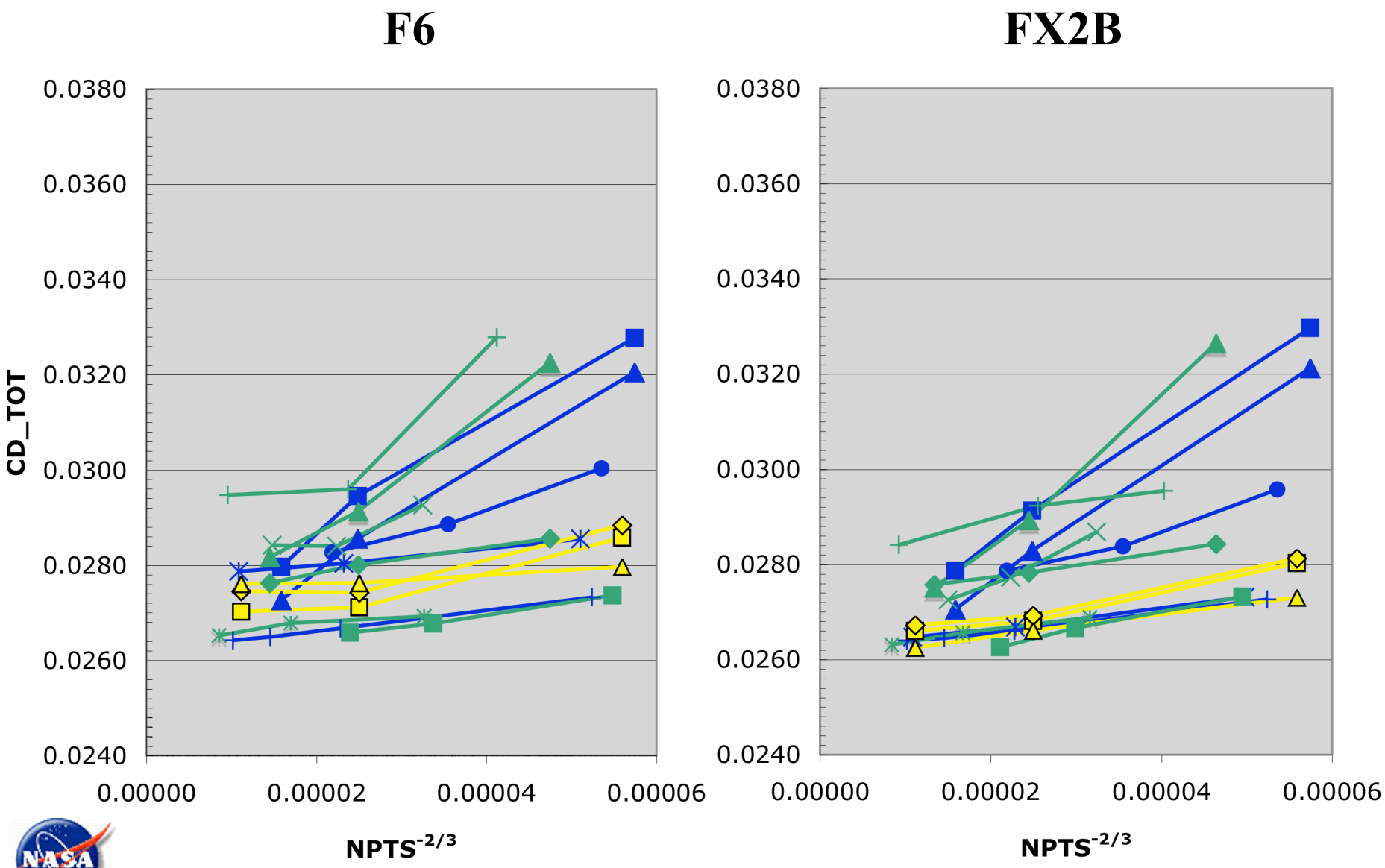


Nested CD_TOT

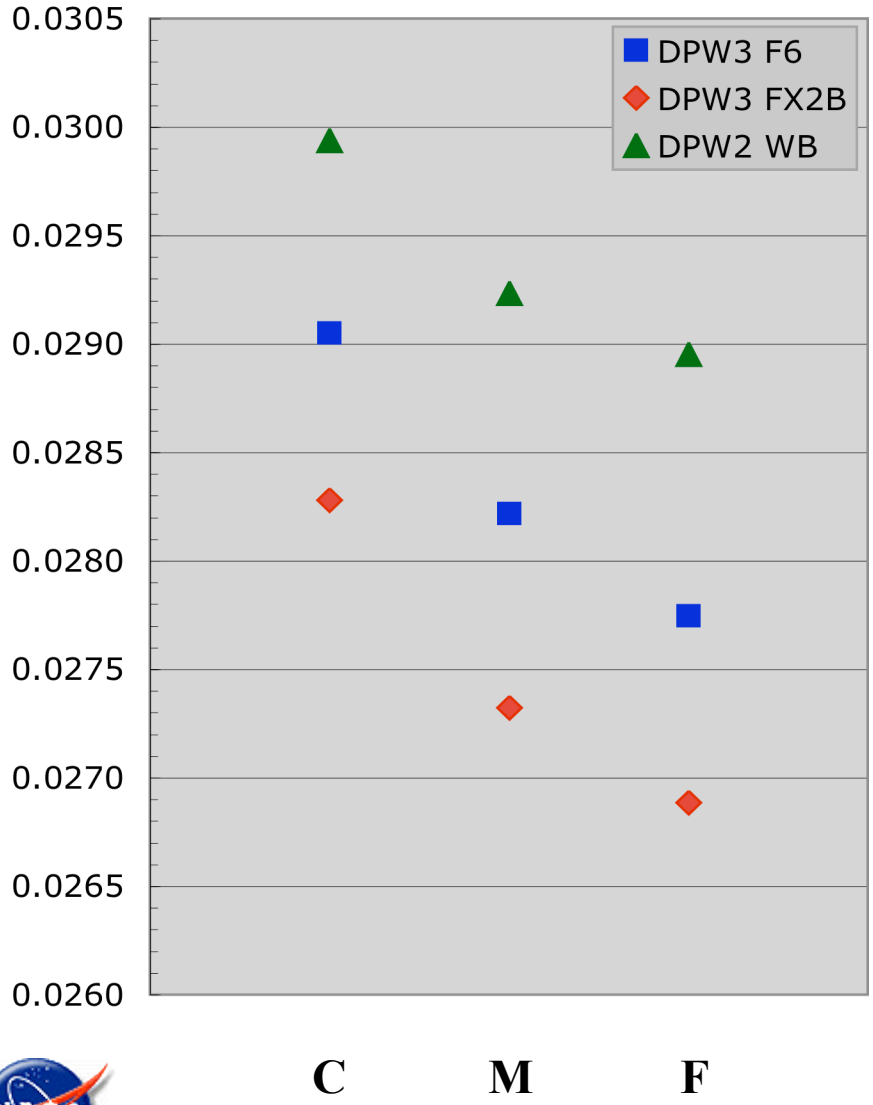
DPW-3

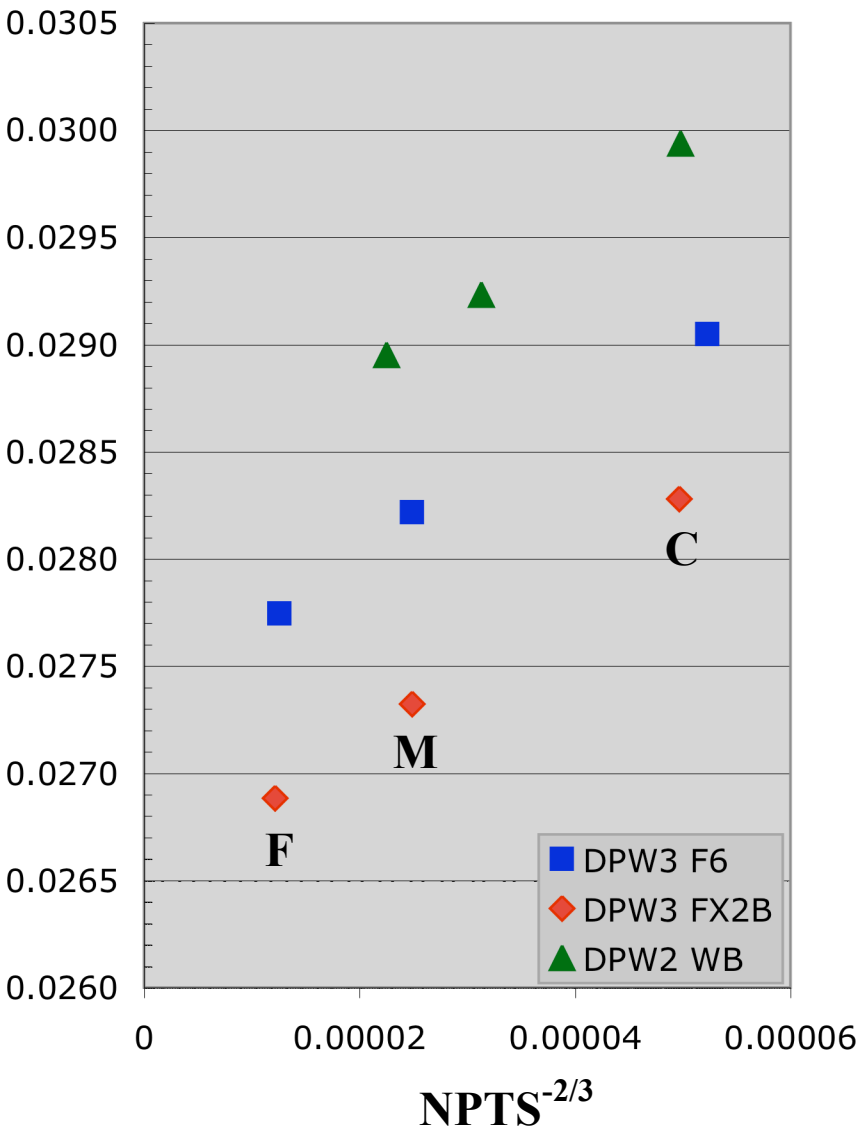


Nested CD_TOT minus Outliers DPW-3

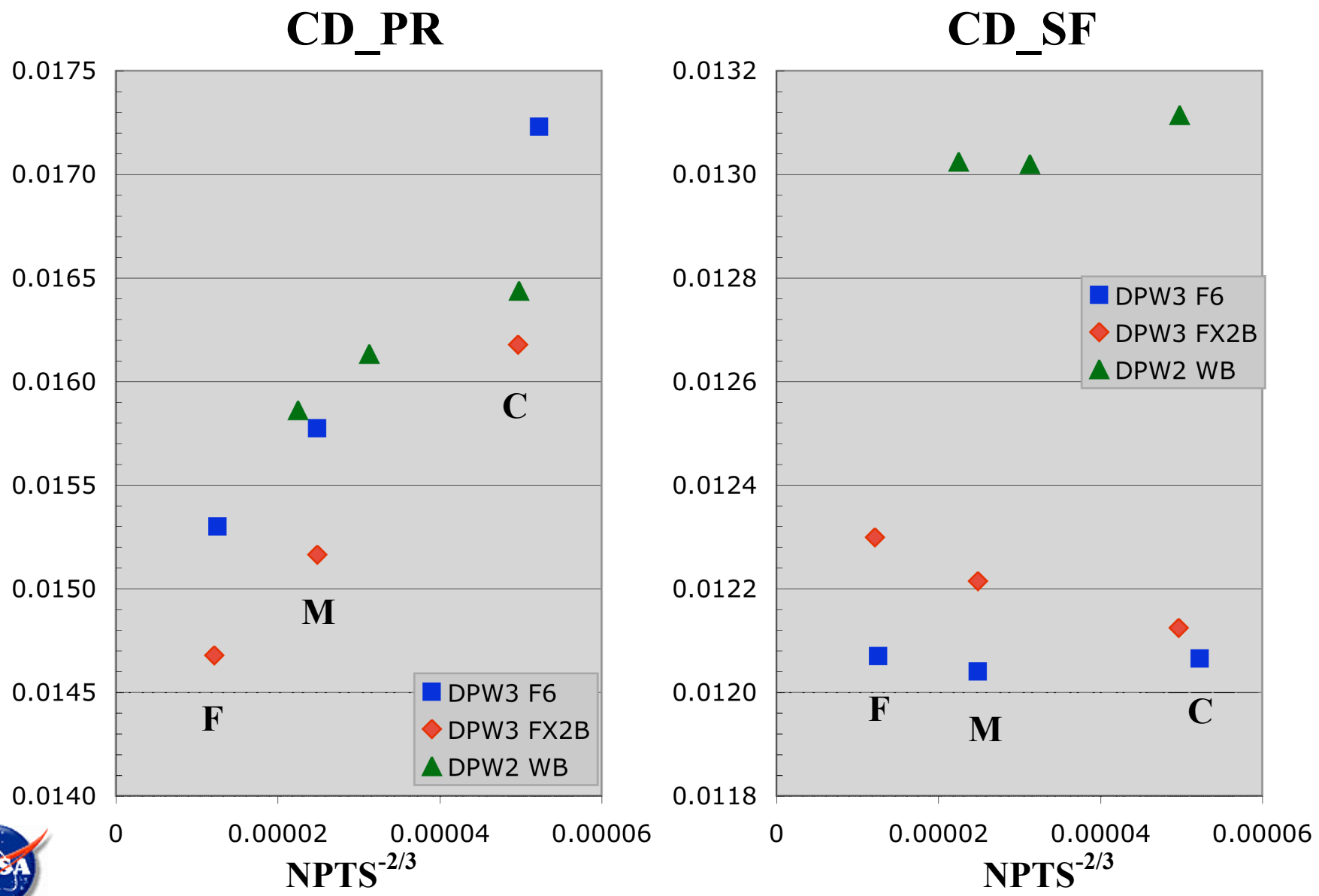


Convergence of CD_TOT DPW-3

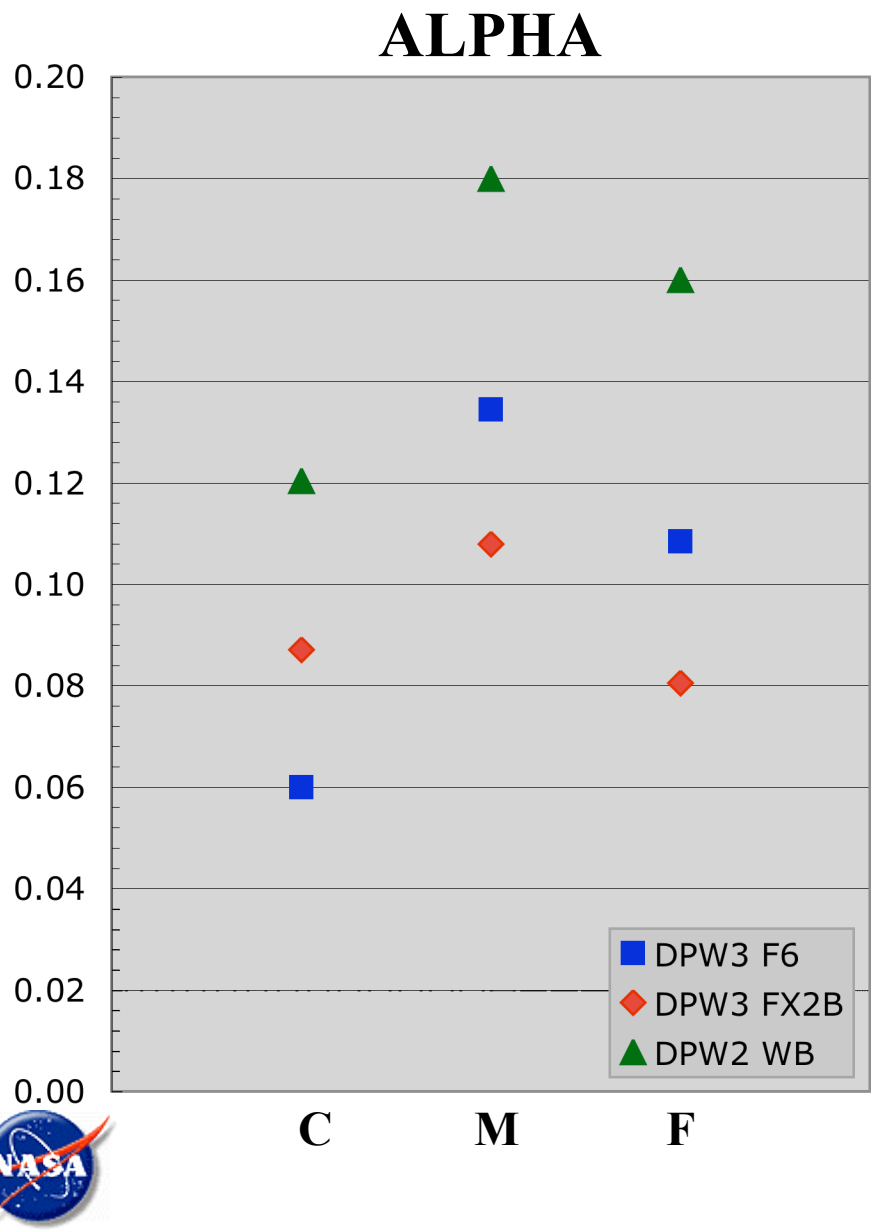


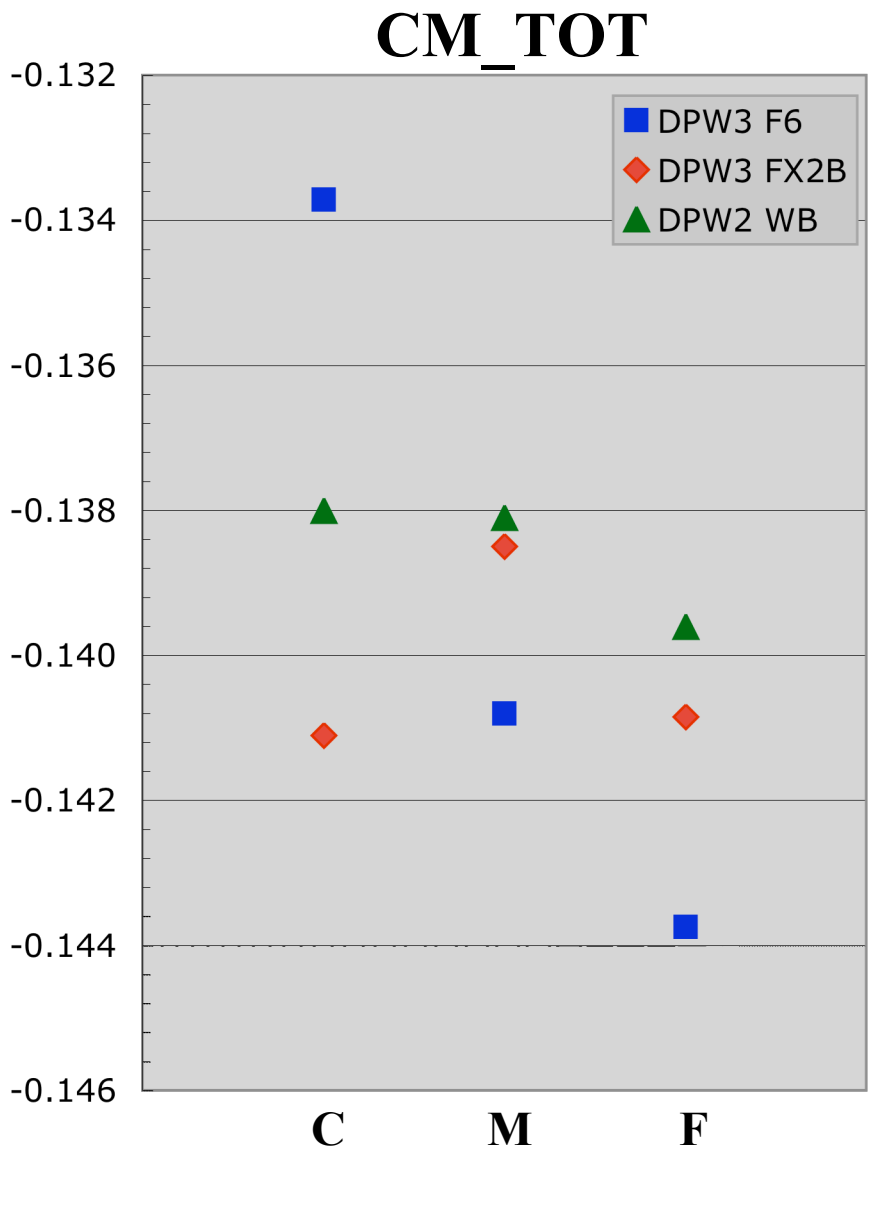


Convergence CD_PR, CD_SF DPW-3

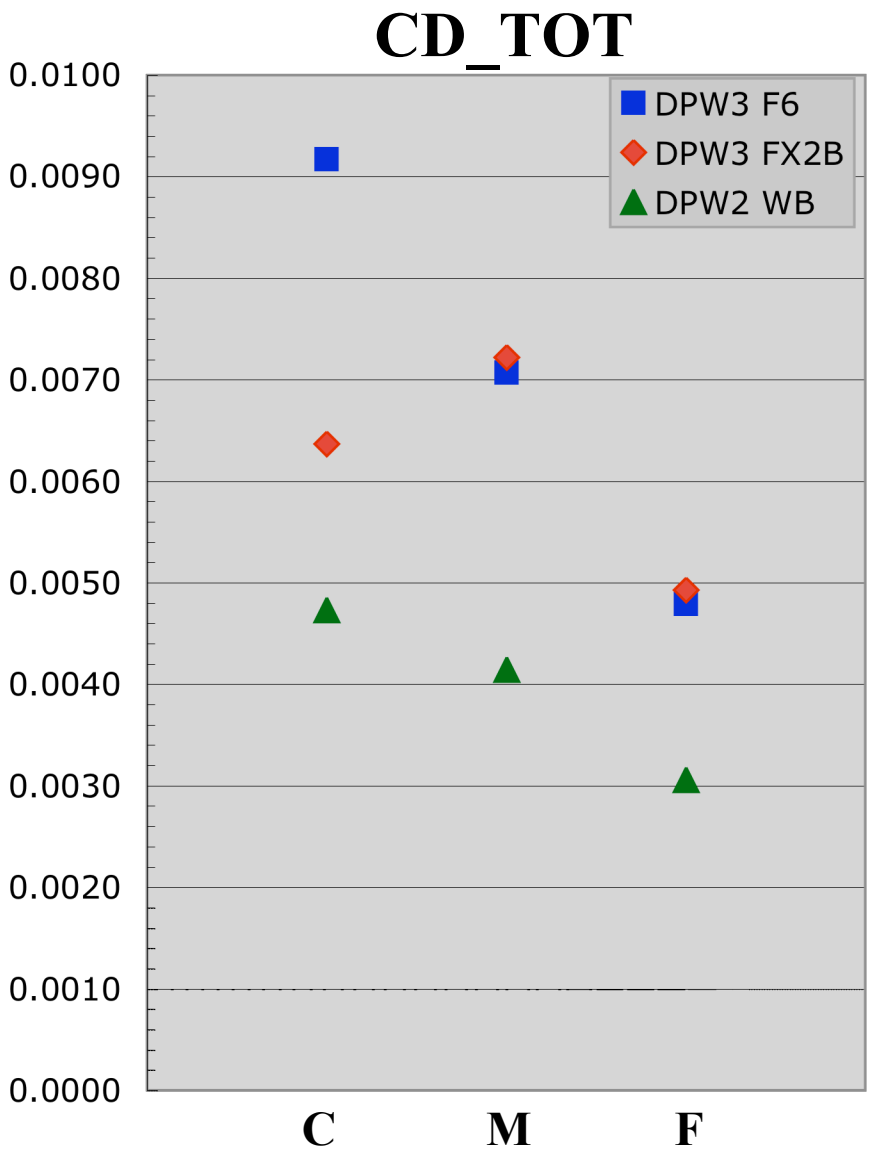


Convergence of ALPHA & CM_TOT DPW-3

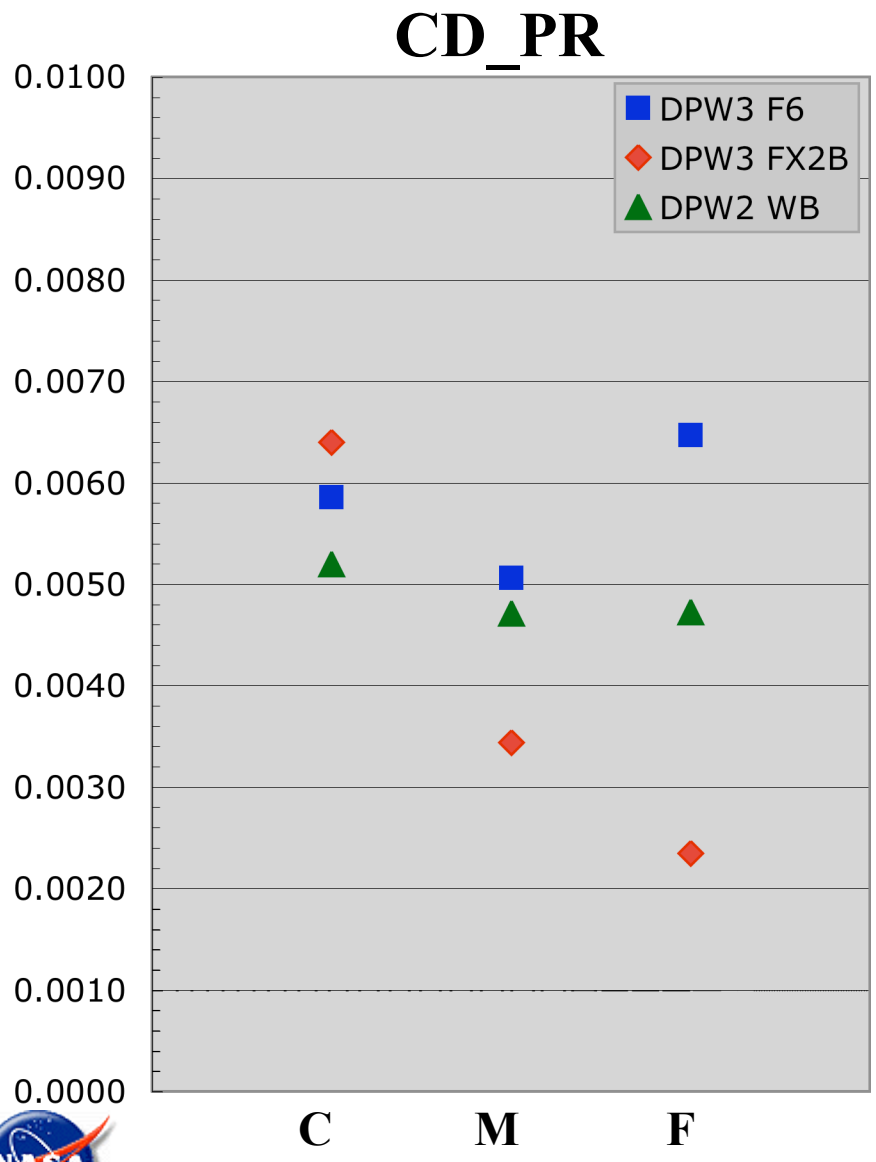


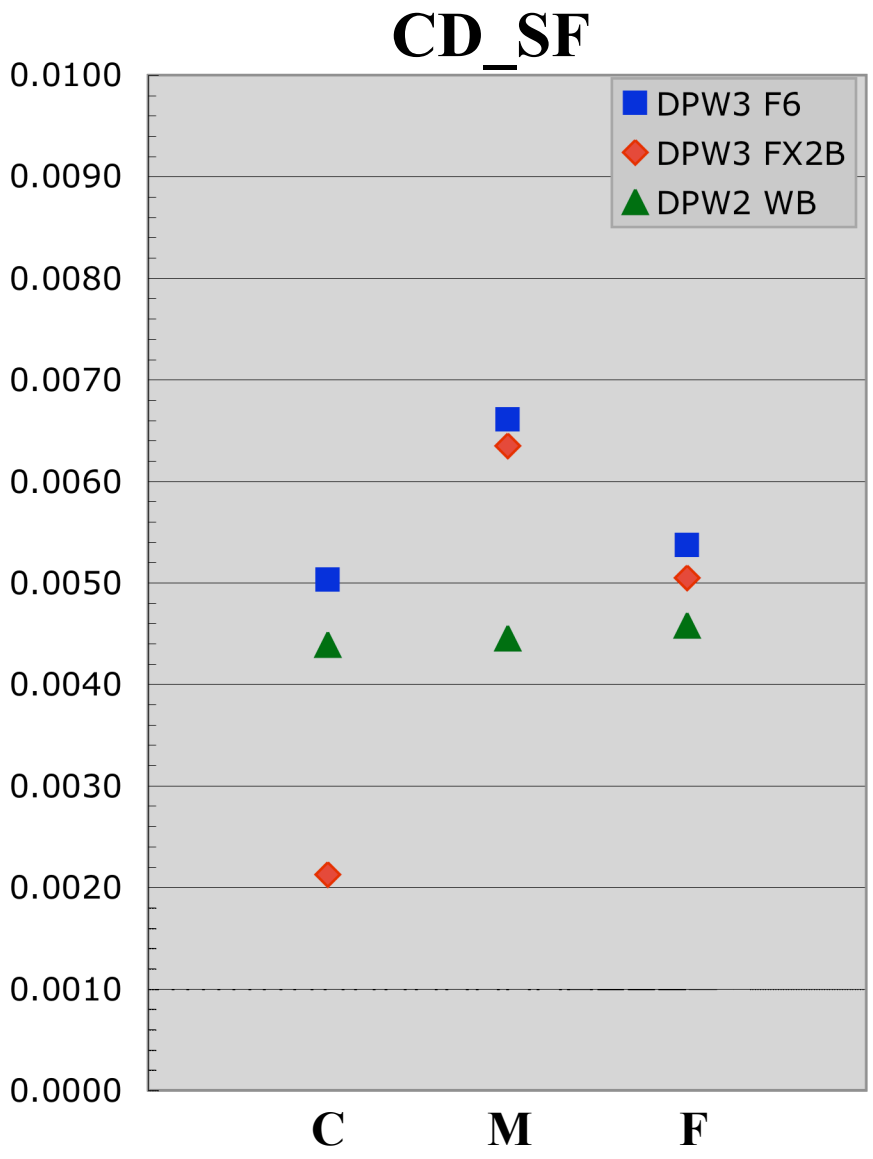


Convergence of Spread DPW-3

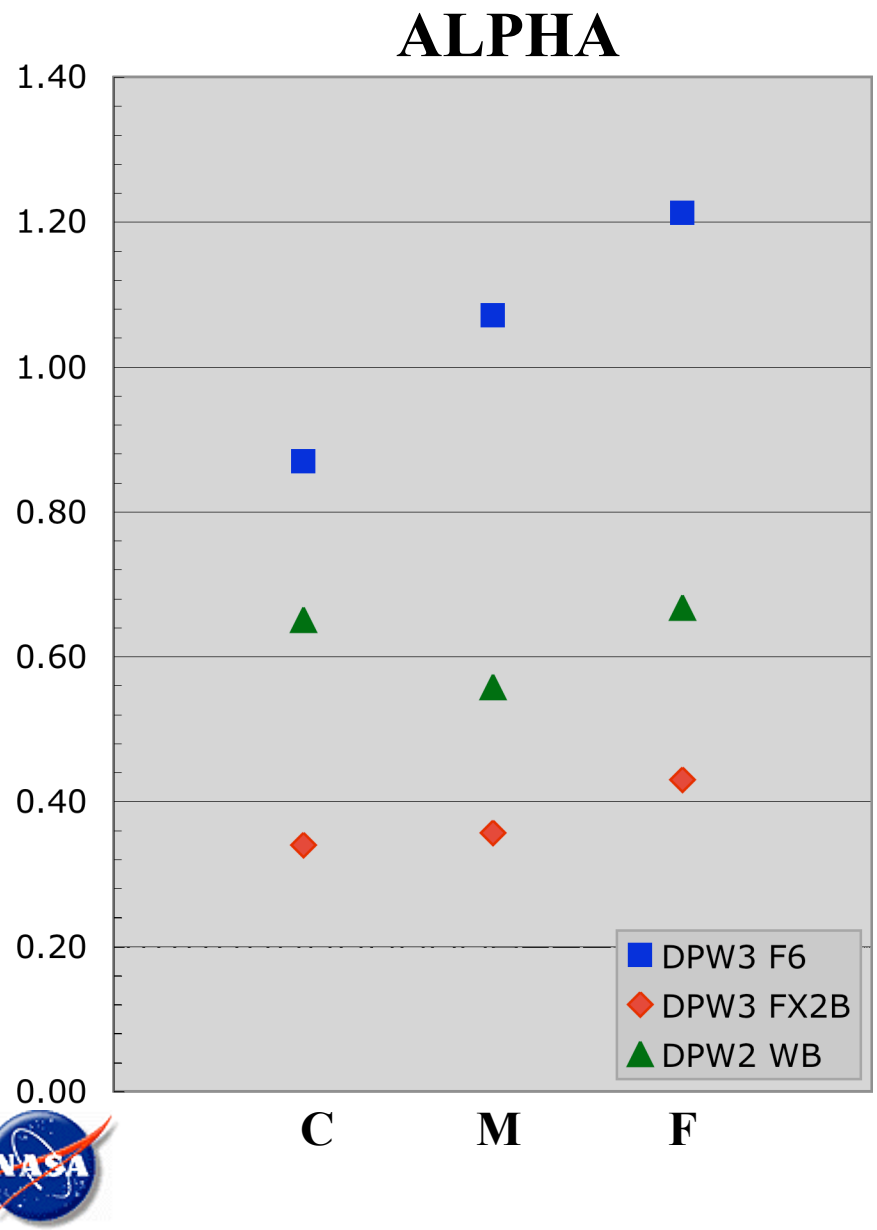


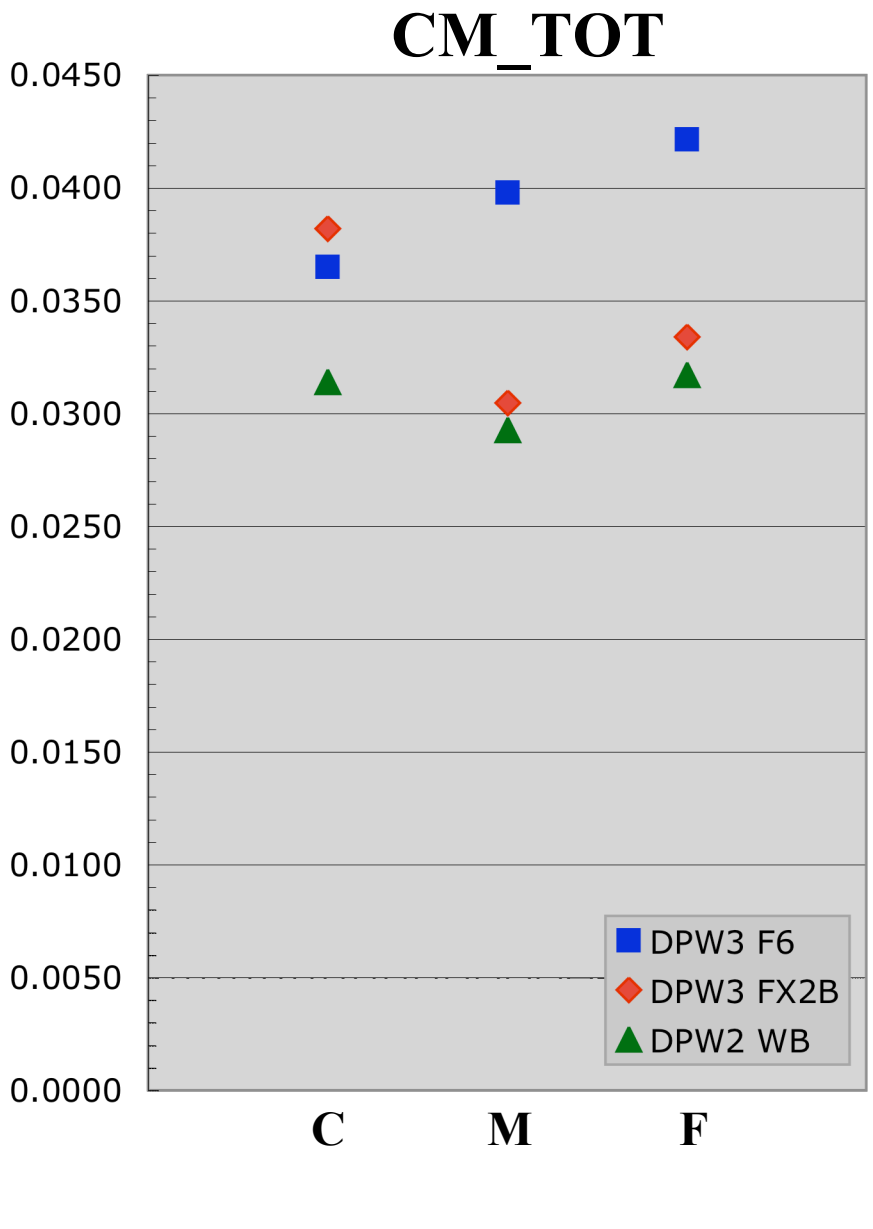
Convergence of Spread (2) DPW-3



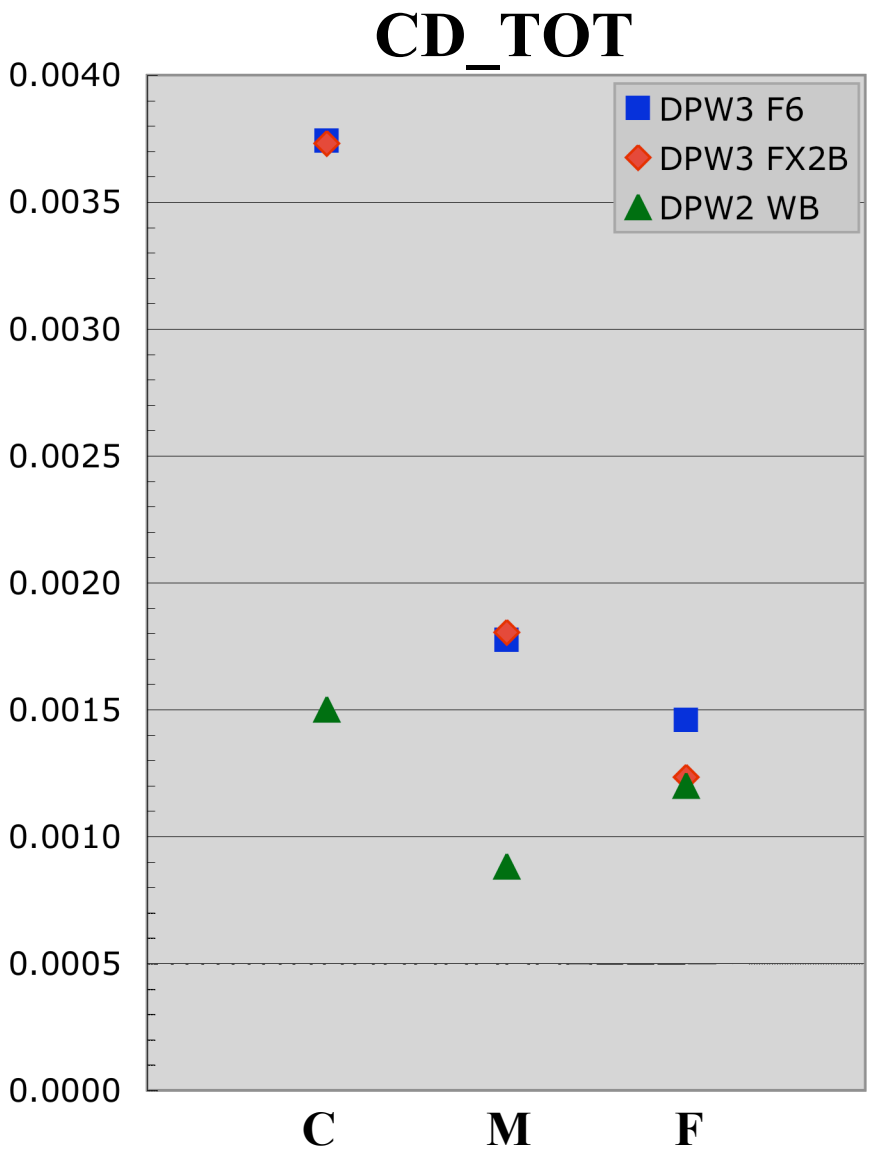


Convergence of Spread (3) DPW-3

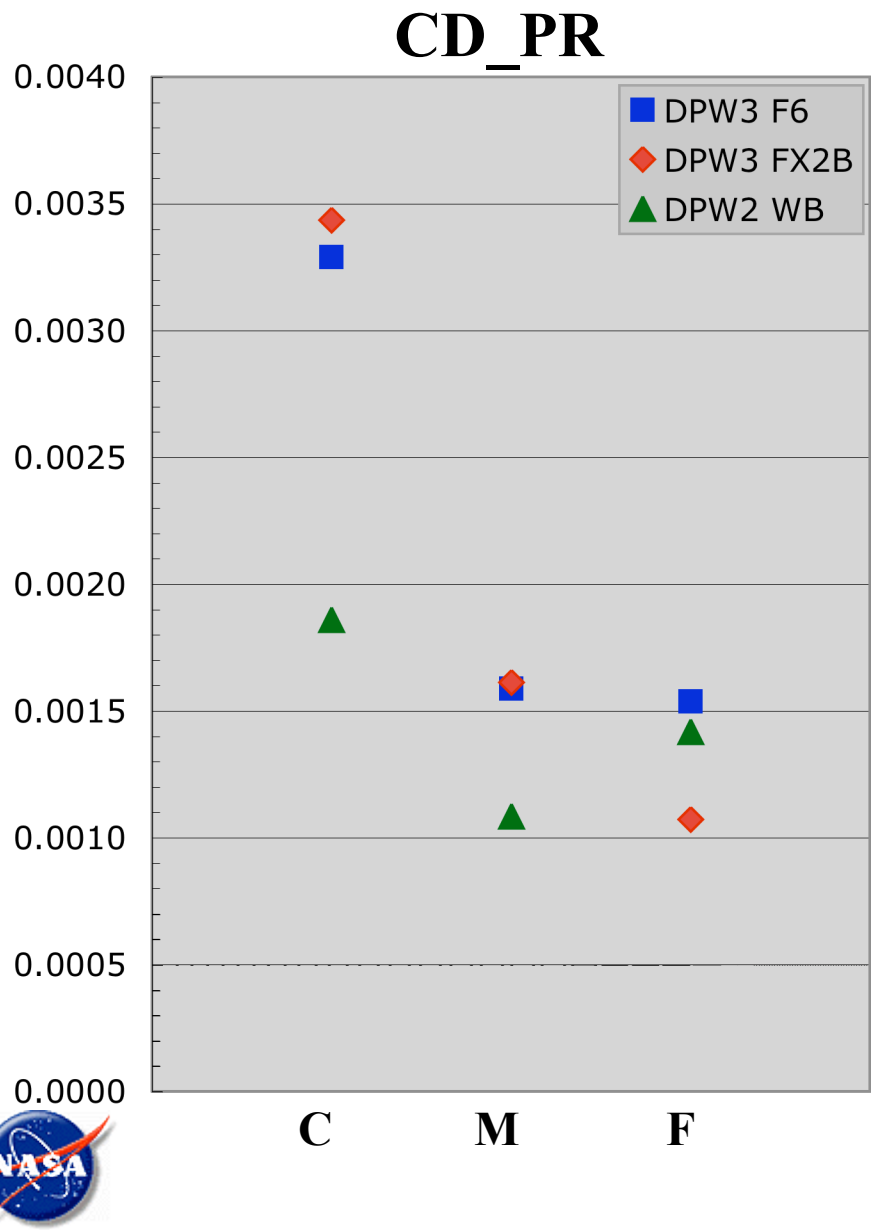


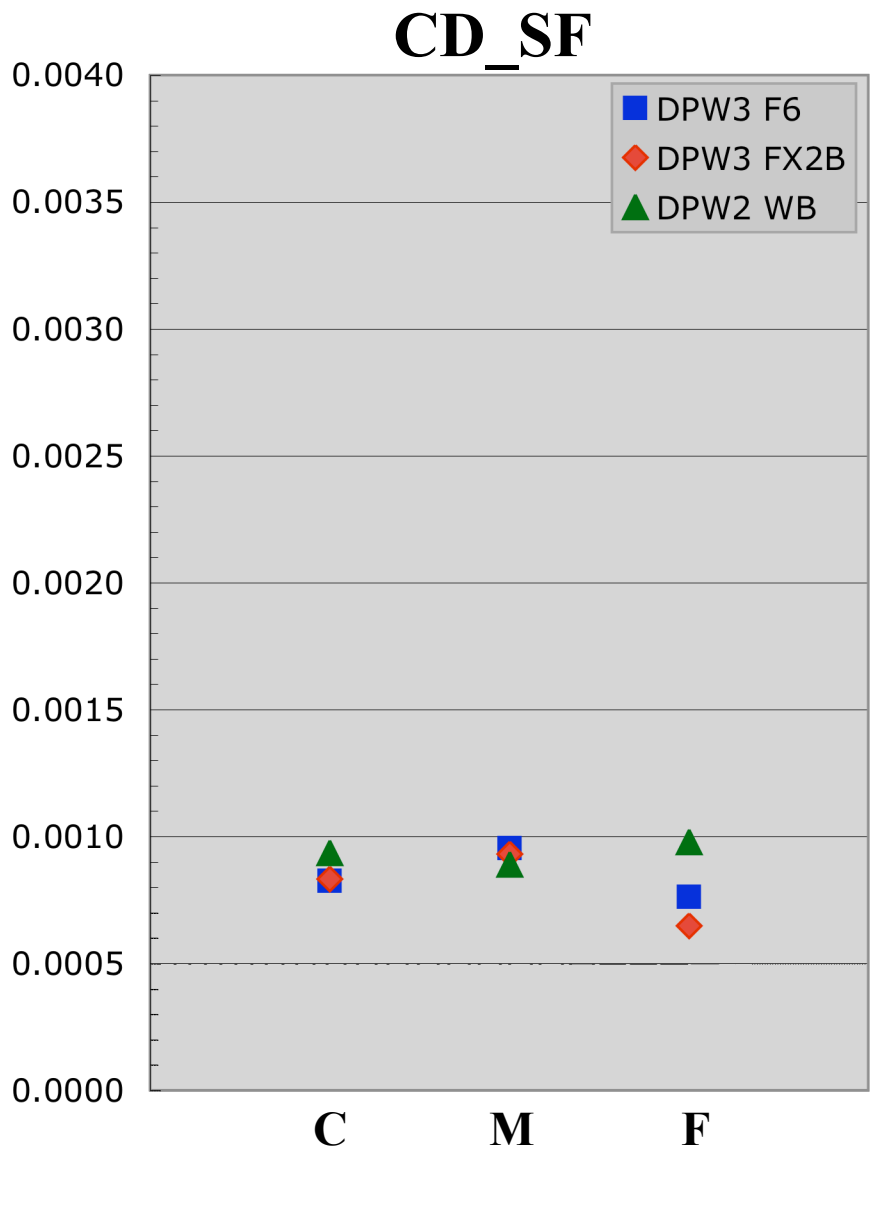


Convergence of Core Interval DPW-3

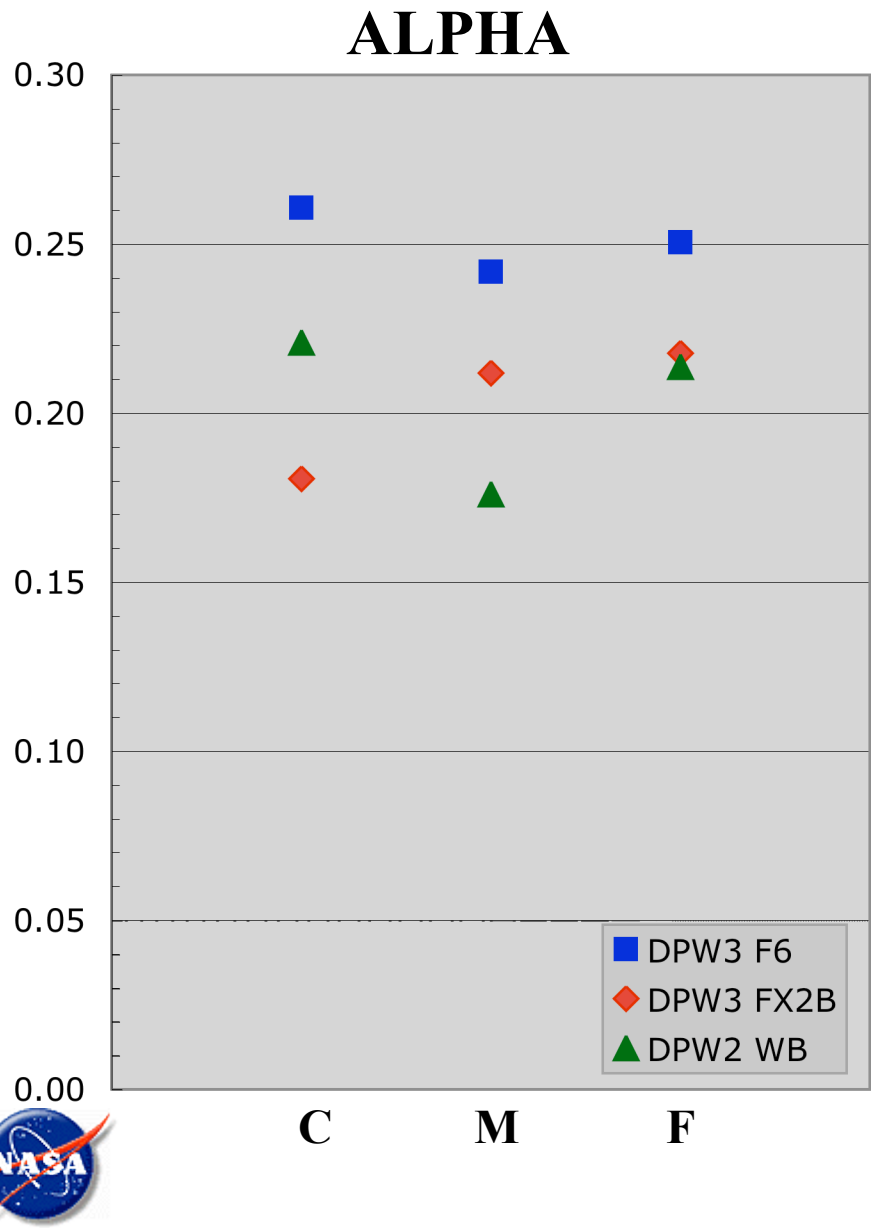


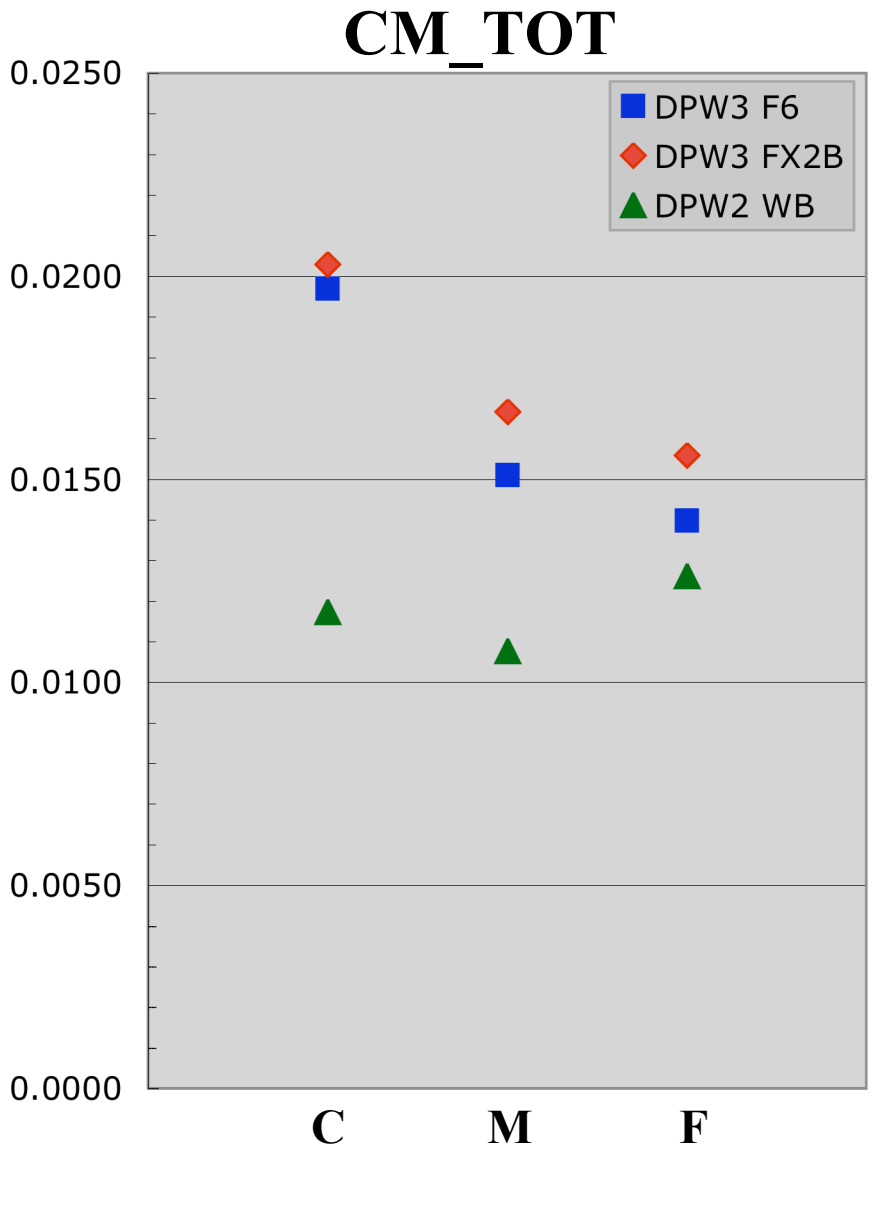
Convergence of Core Interval (2) DPW-3





Convergence of Core Interval (3) DPW-3





Case 2: DPW-W1 Wing Alone

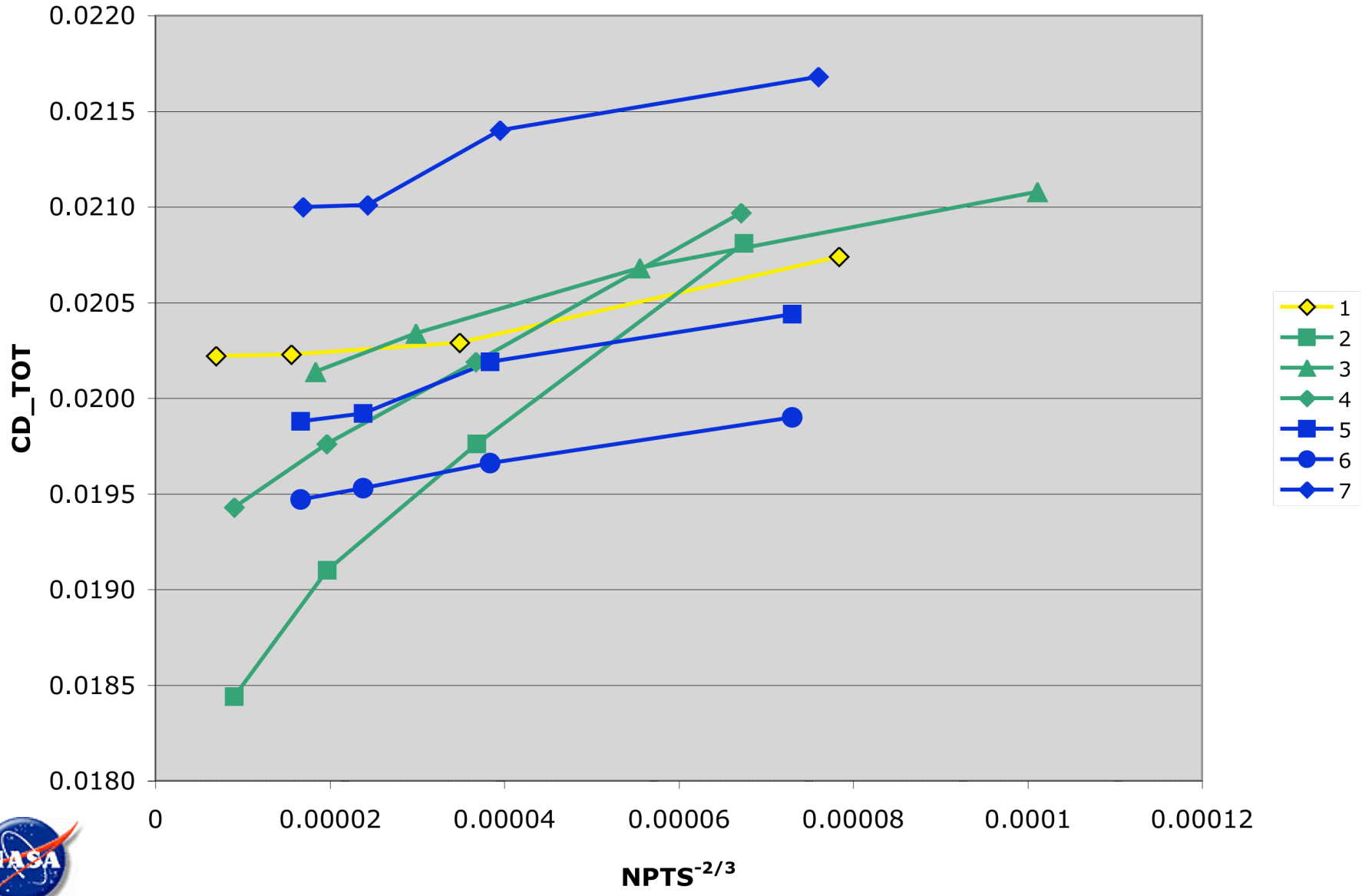
N.B. DPW-W2 has not been analyzed

Case 2 Solution Statistics DPW-3

	DPW-W1 Wing Alone	
	Nested	Core
Solutions	7	7
Authors	6	6
Institutions	6	6
Codes	6	6

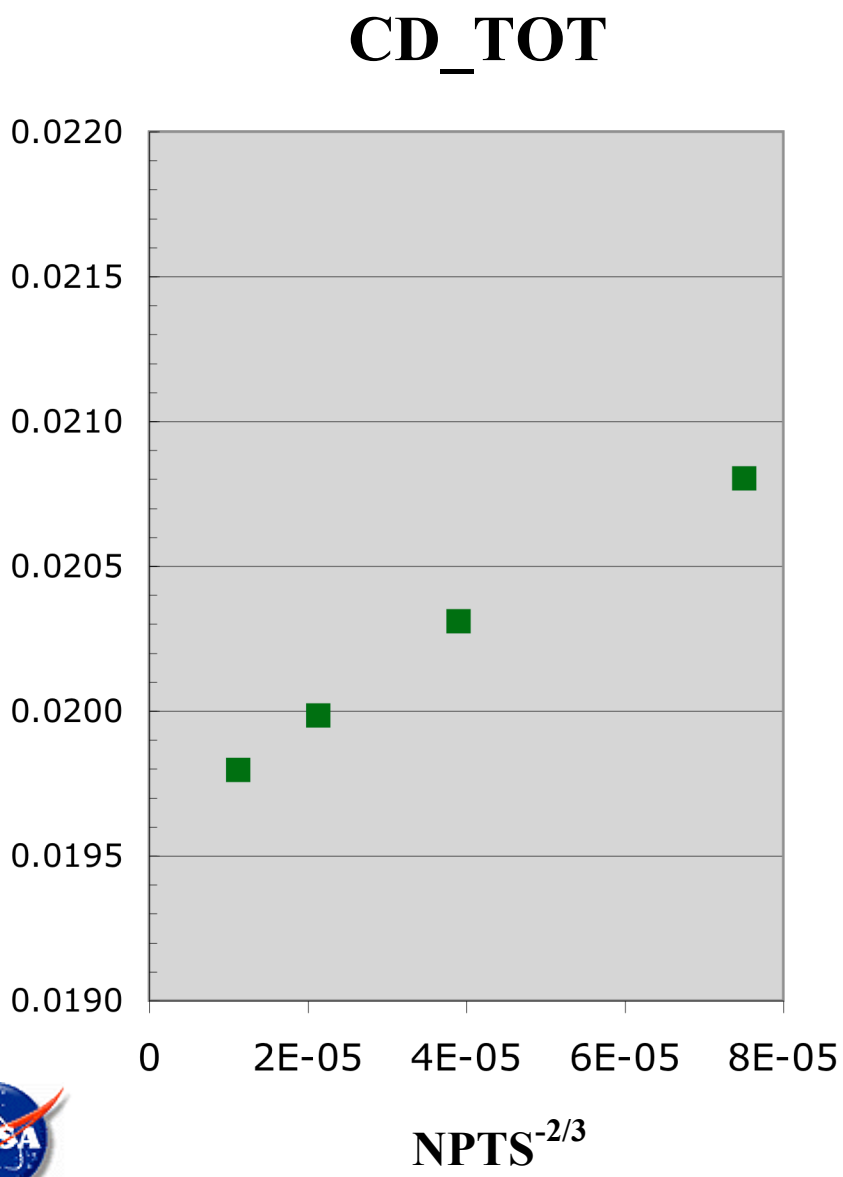
W1 Nested CD_TOT

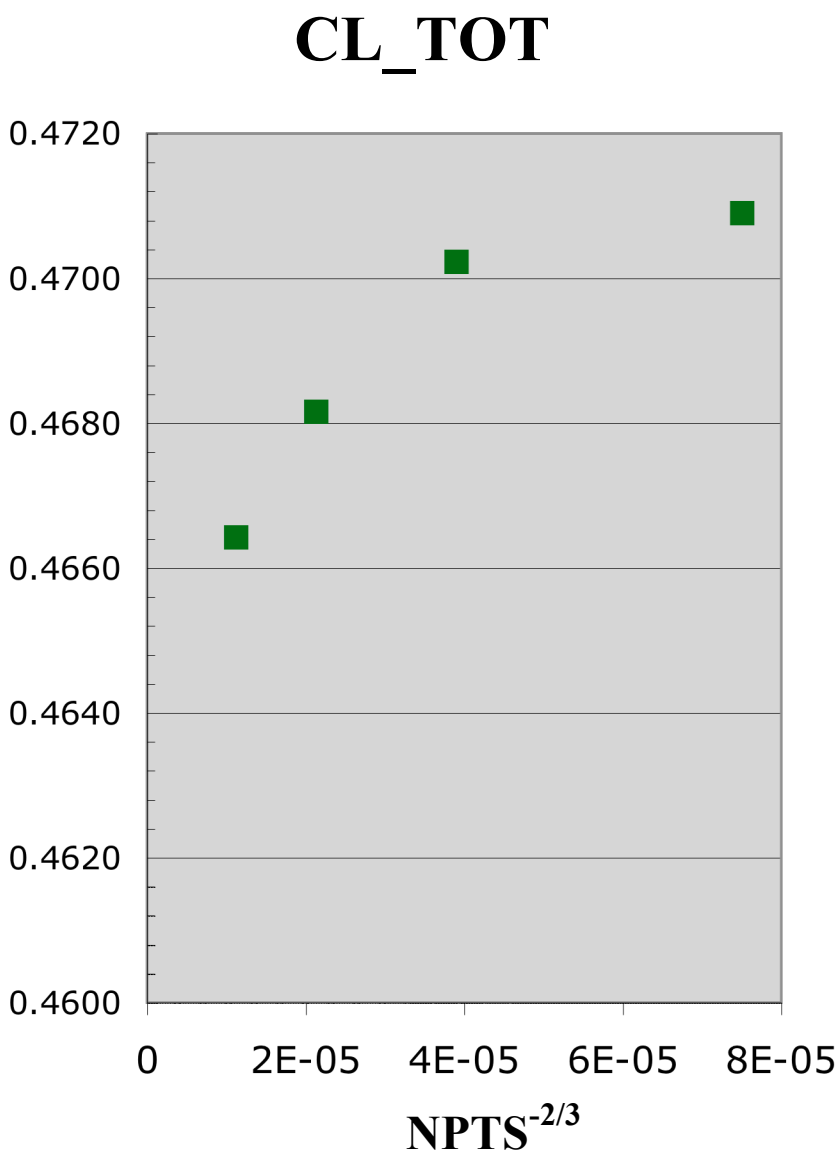
DPW-3



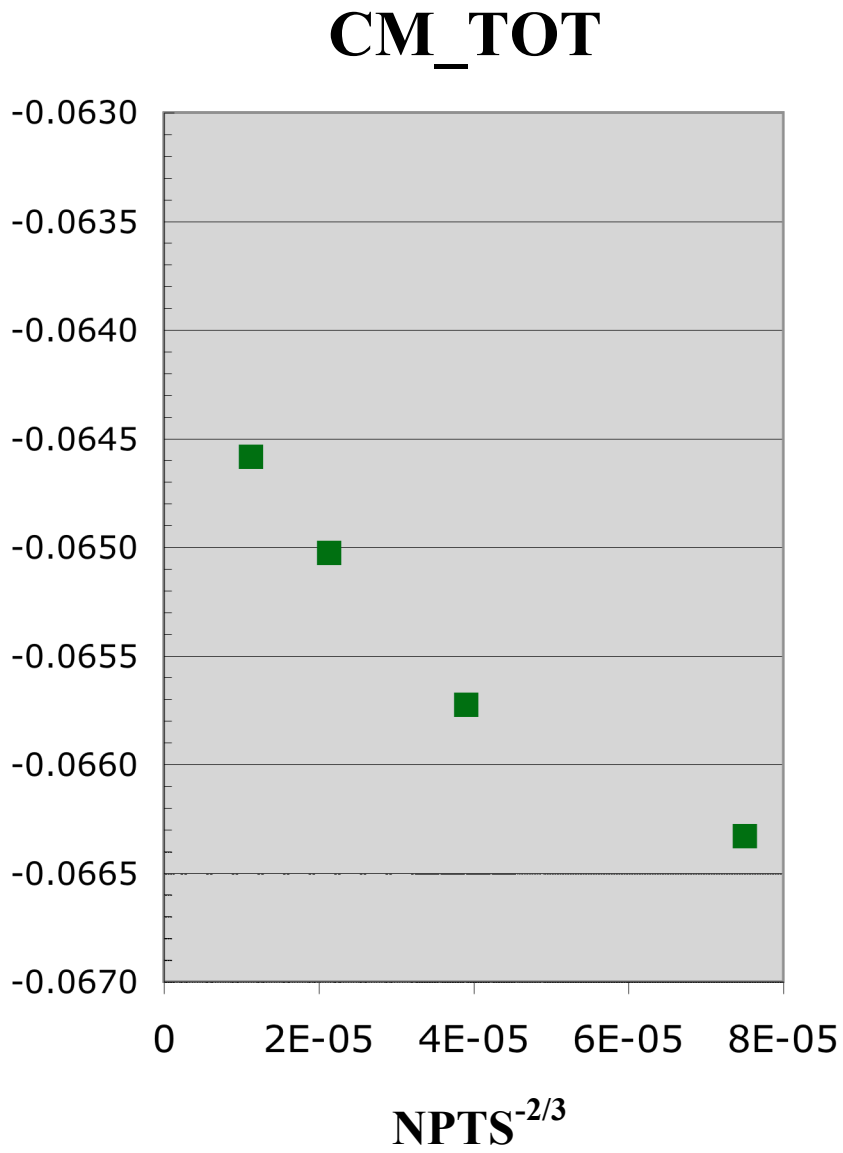
Convergence of CD_TOT, CL_TOT

DPW-3



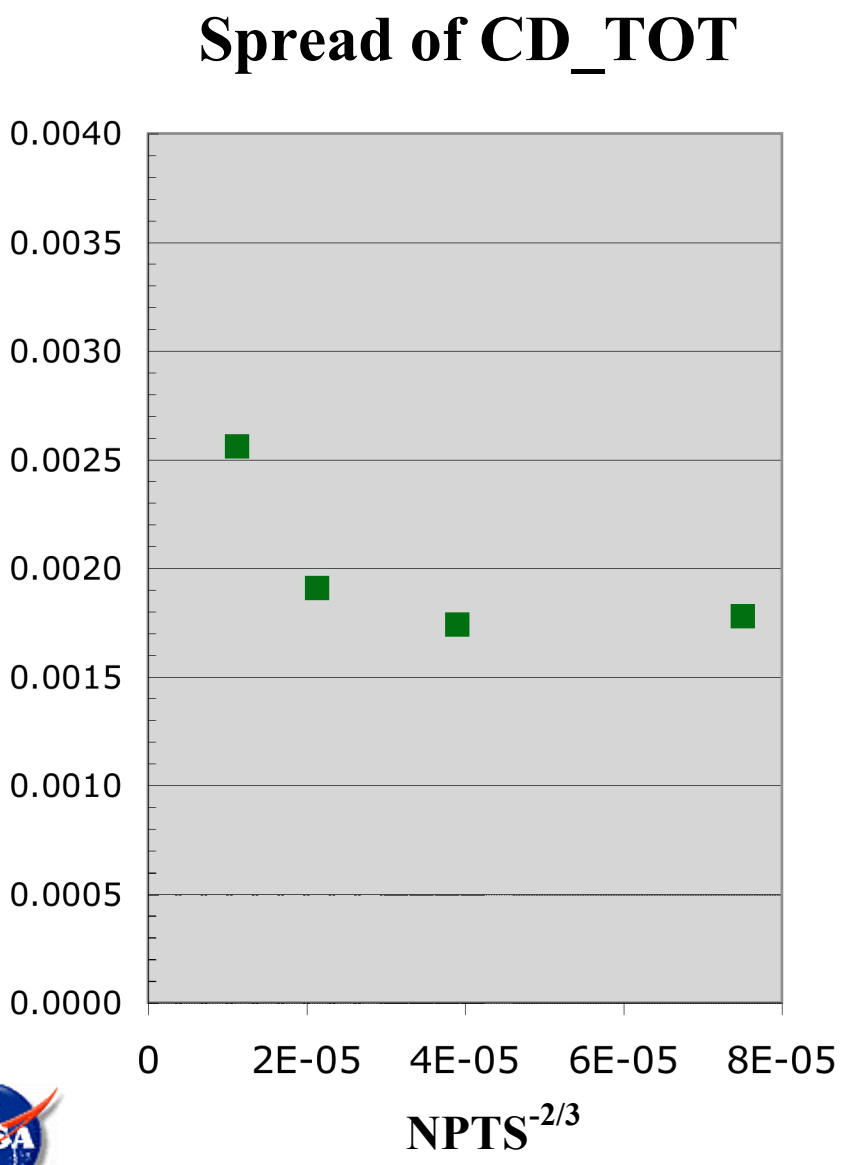


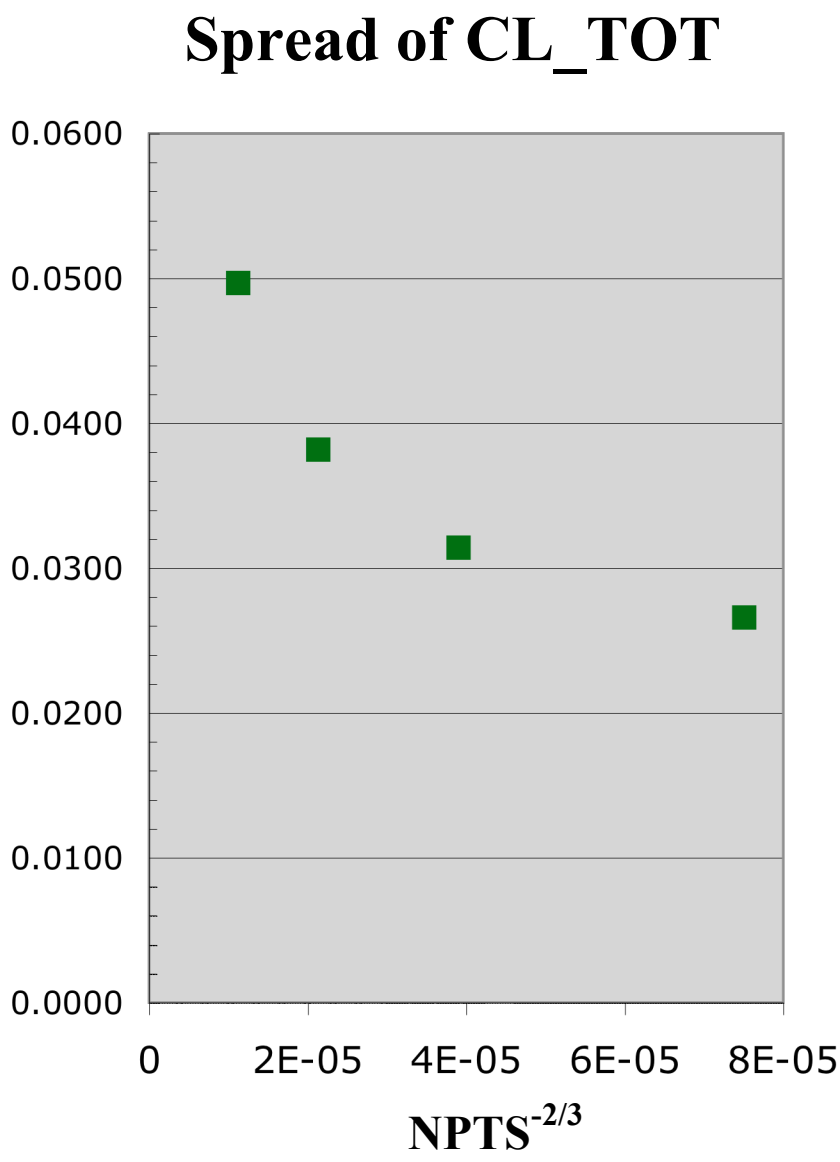
Convergence of CM_TOT DPW-3



Spread of CD_TOT, CL_TOT

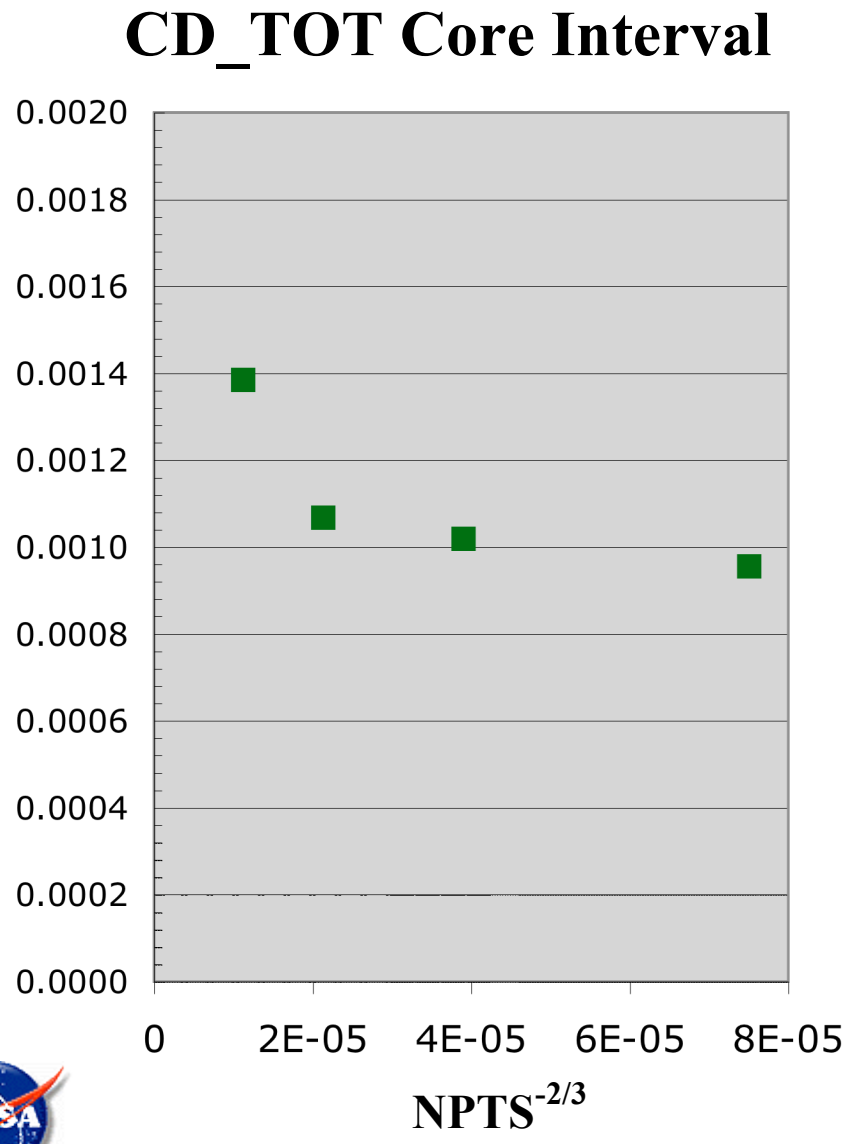
DPW-3

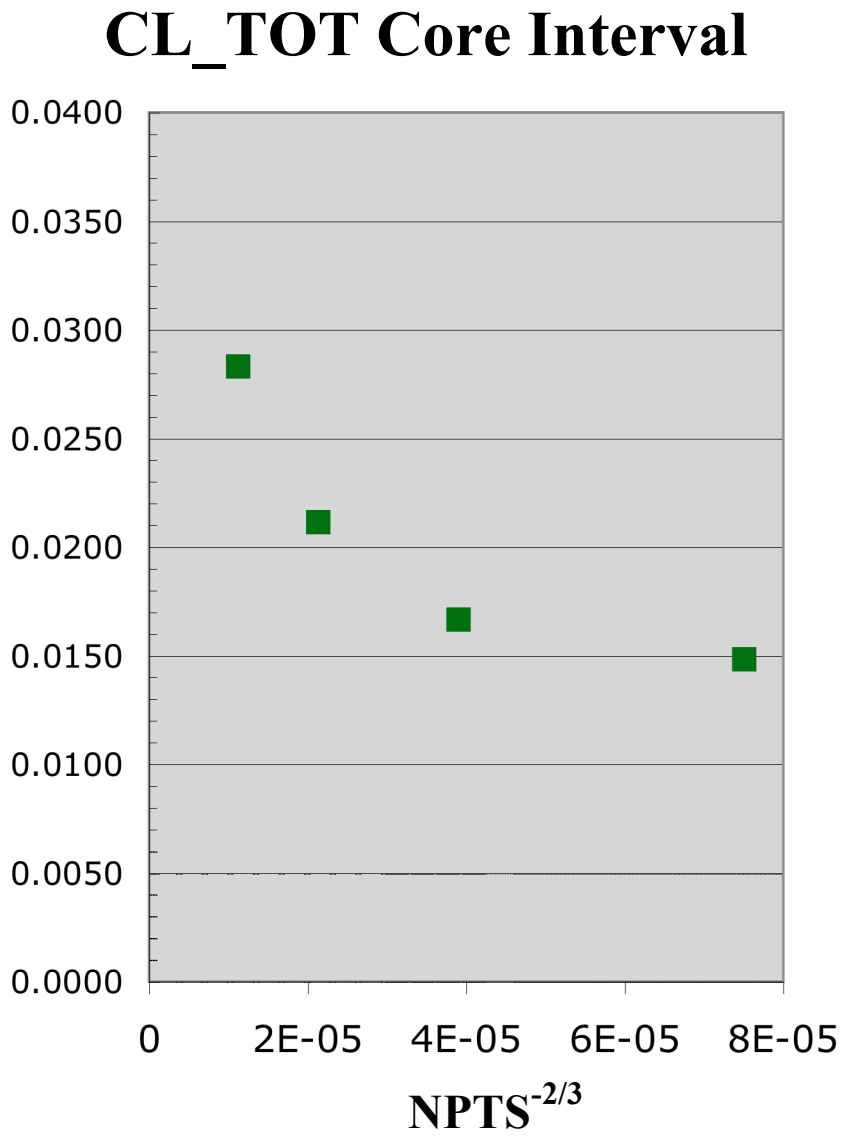




CD_TOT, CL_TOT Core Interval

DPW-3

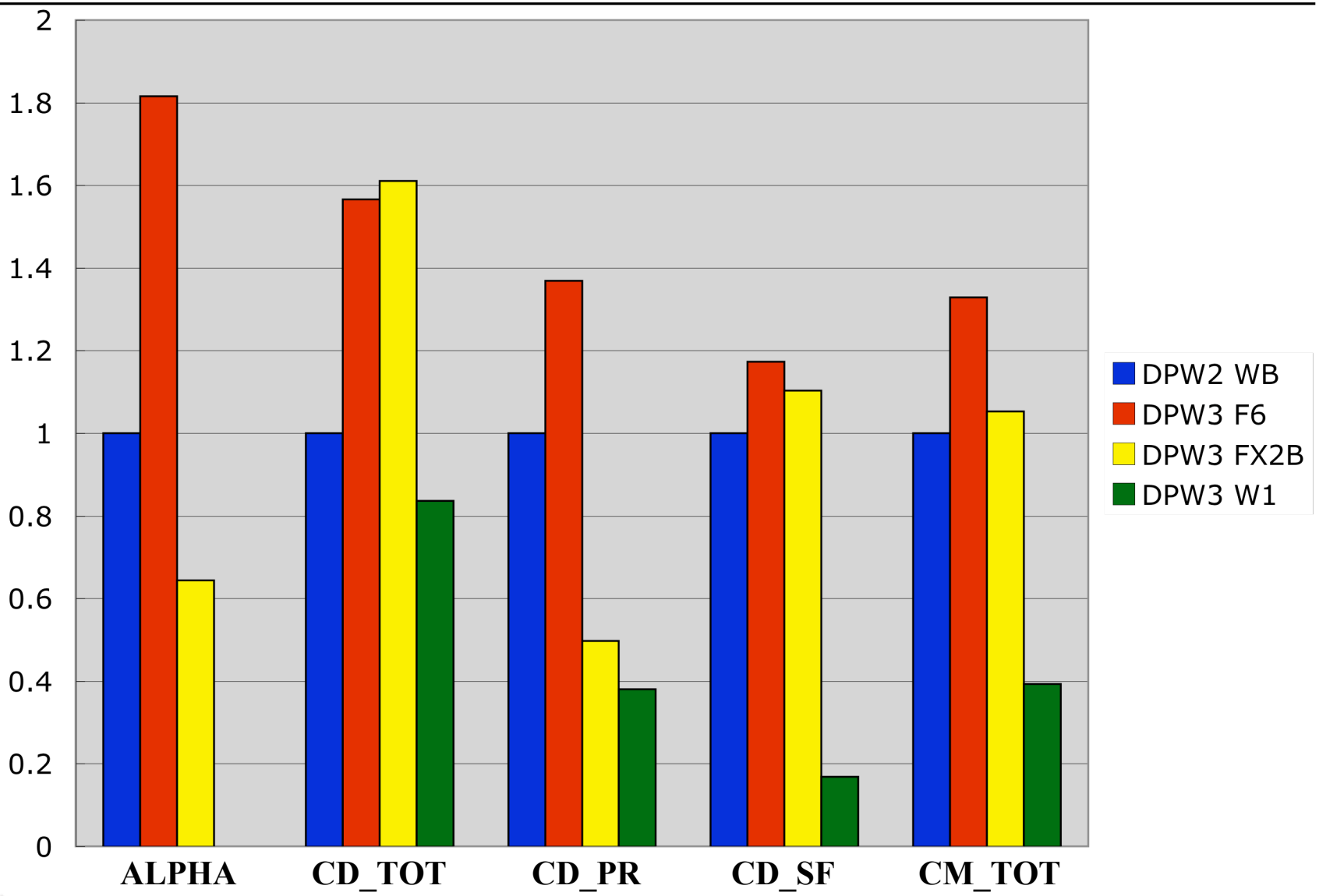




Summary

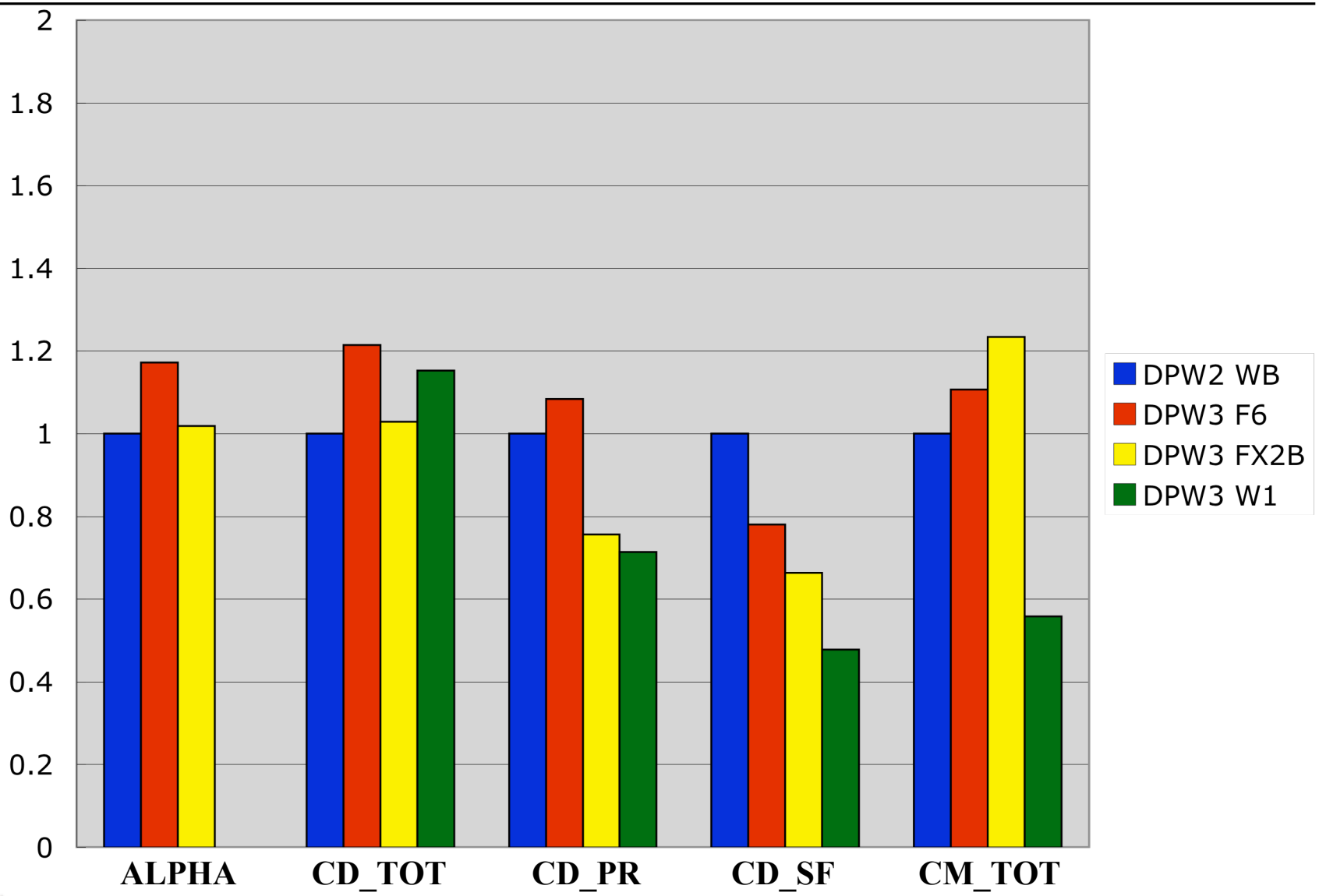
Spread (of nested data) for Finest Grid

DPW-3



Core Interval for Finest Grid

DPW-3



Concluding Remarks DPW-3

- The Good News:
  - **DPW-3 was a "blind test", i.e. no experimental data existed to "guide" solutions. The results were about as good for the blind test as for DPW-2.**
  - **DPW-W1 might be showing evidence that it is in the asymptotic range**

- The Less Good News:
  - Have not demonstrated convergence of medians, spread or core interval for F6/FX2B despite increased grid sizes
  - F6 spread and core interval have not improved from DPW-2
  - FX2B spread and core interval are not substantially better than F6
  - DPW-W1 spread and core interval are not showing convergence
  - After 3 drag prediction workshops, grids remain a leading order issue

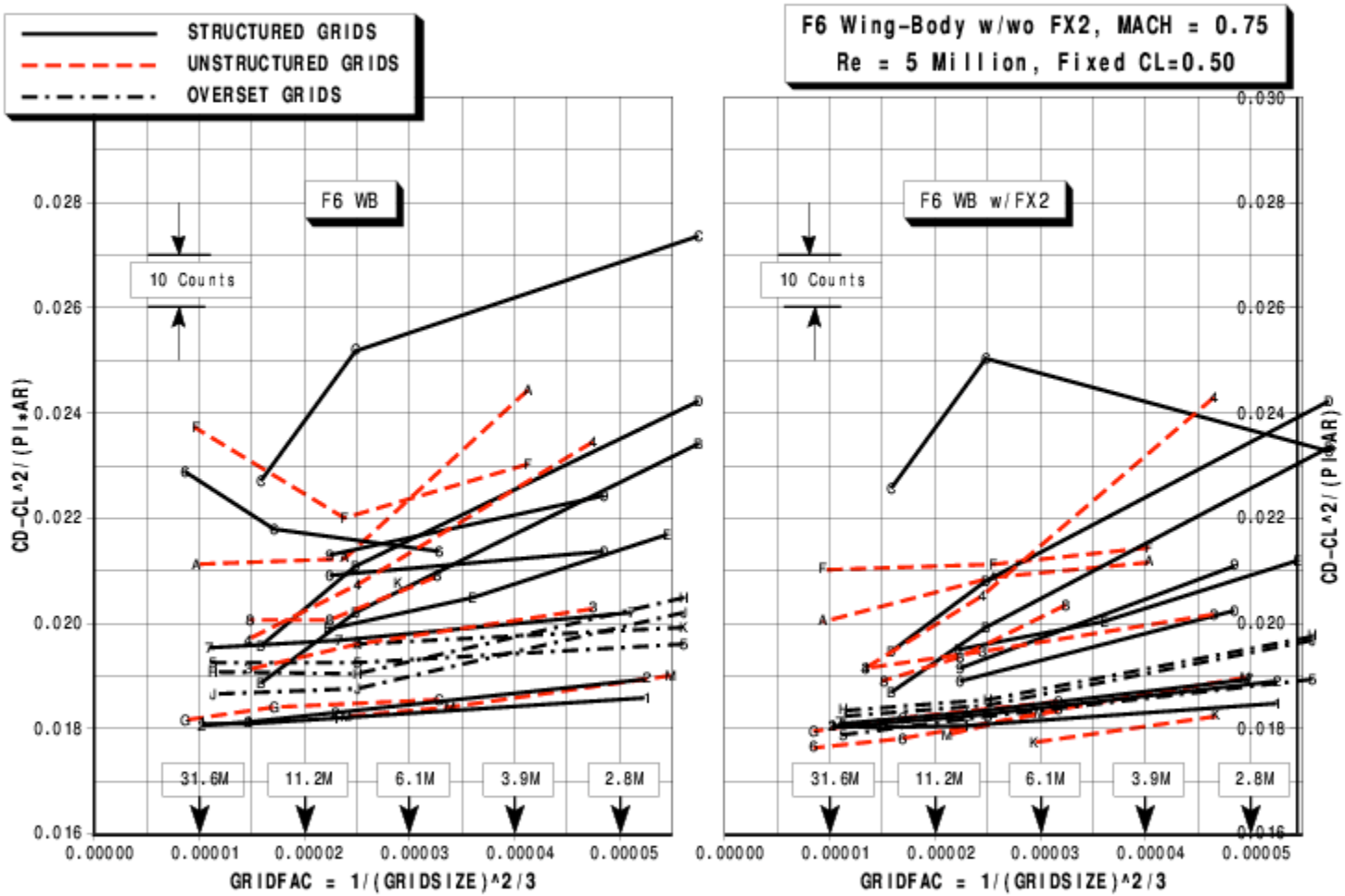
Concluding Remarks (2) DPW-3

Hemsch's remarks from DPW-2 still apply:

- Regarding grid convergence for the collective:
  - **There is no reduction in spread;**
  - **There is no reduction in core scatter;**
  - **The medians MAY be converging, although it can't be proven with the present results.**

Some Recommendations DPW-3

- We must make a concerted effort to understand the differences in the codes and models
- We must make a concerted effort to understand the effects of grid quality and grid resolution
- We must analyze and improve our processes

Fini?

Grid Convergence – All Solutions