Zhang Groups: Integration of threading and deep-learning for protein structure prediction

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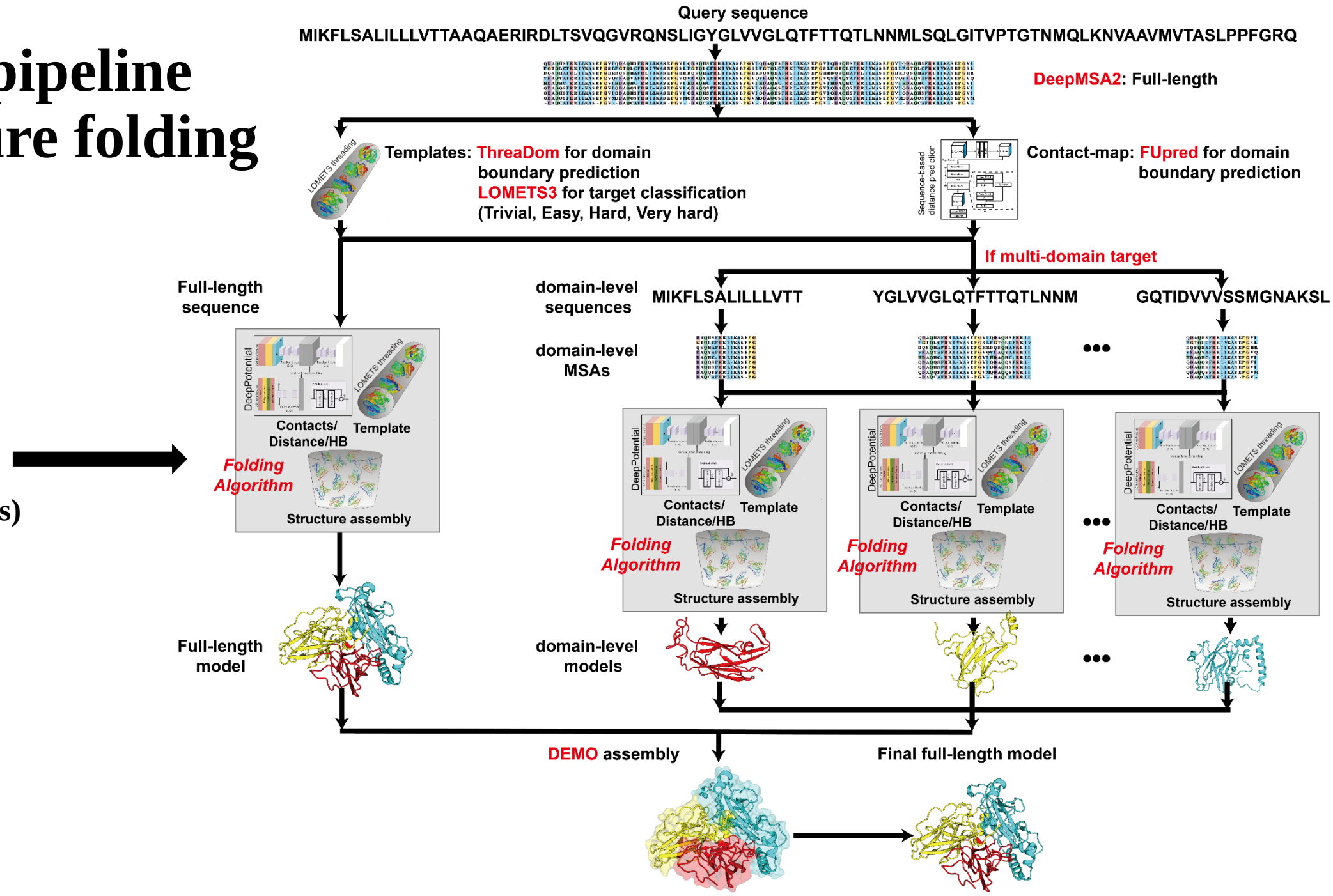
Methods

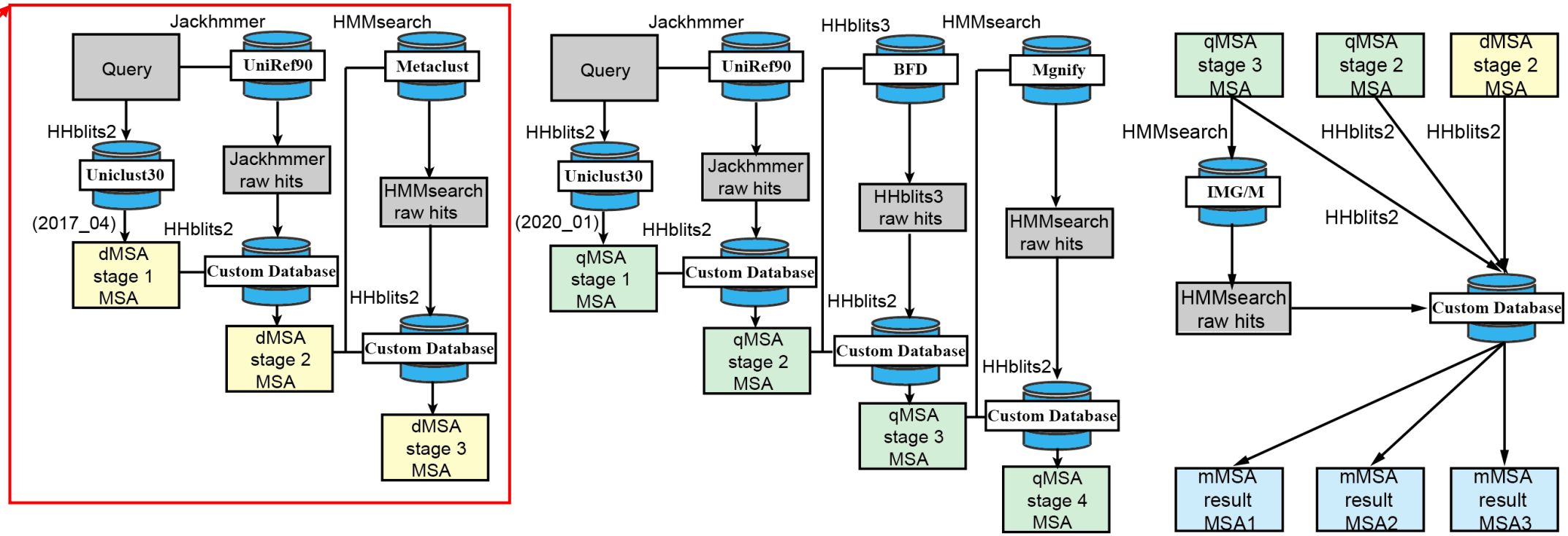
Overall pipeline for structure folding

Zhang (h)
Zhang-Server (s)
QUARK (s)
Zhang-CEthreader (s)

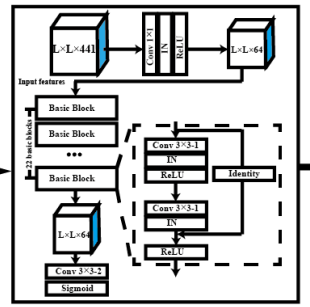


DeepMSA2 for MSA construction

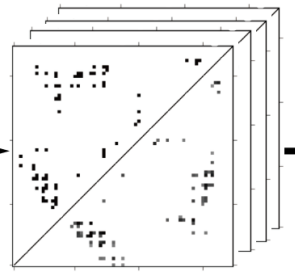
DeepMSA pipeline



(D) MSA selection



TripletRes

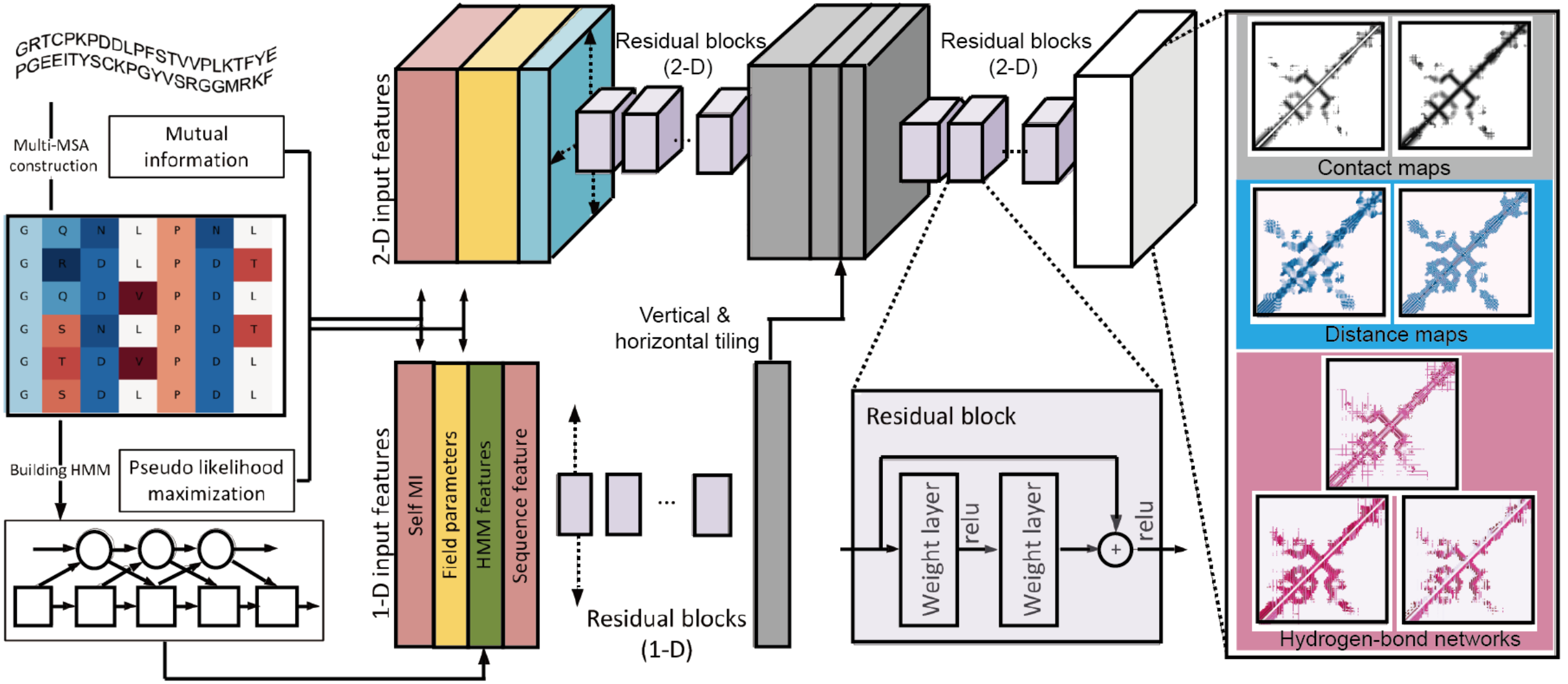


Ranking MSAs
by the sum of top 10L
predicted contact probablities

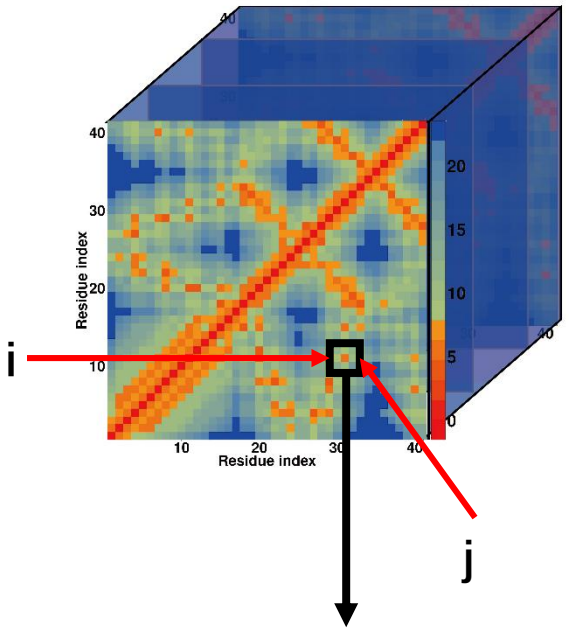
Final MSA

$$Neff = \frac{1}{\sqrt{L}} \sum_{n=1}^{N} \frac{1}{1 + \sum_{m=1, m \neq n}^{N} I[S_{m,n} \geq 0.8]}$$

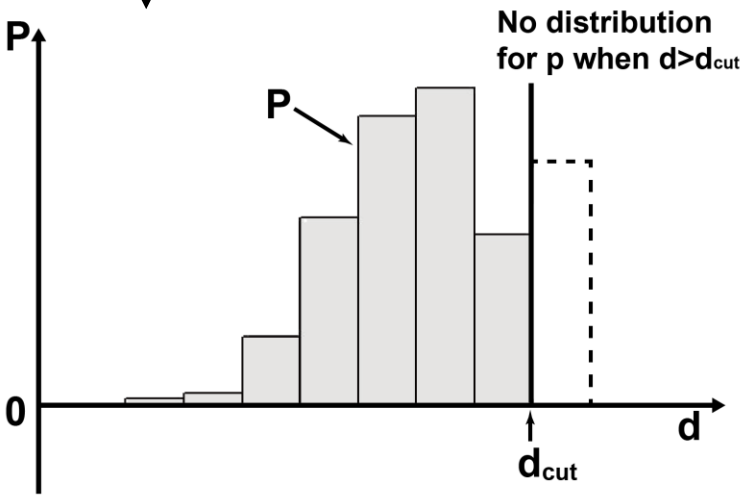
DeepPotential for contact/distance/HB-network prediction



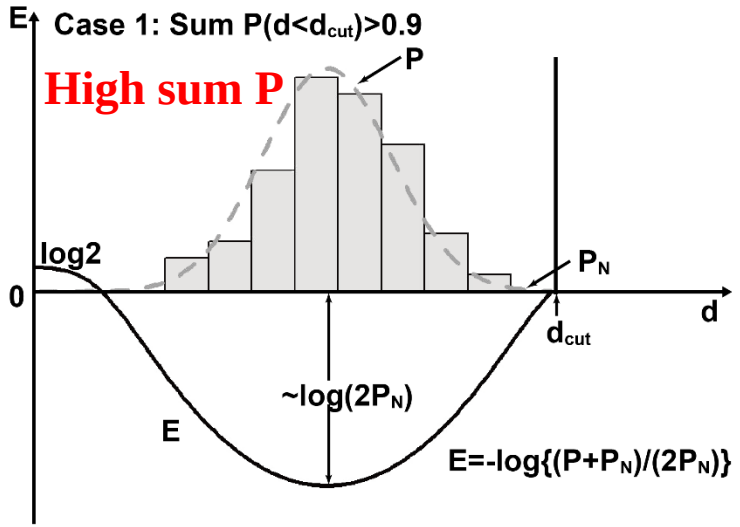
Distance potential in D-I-TASSER

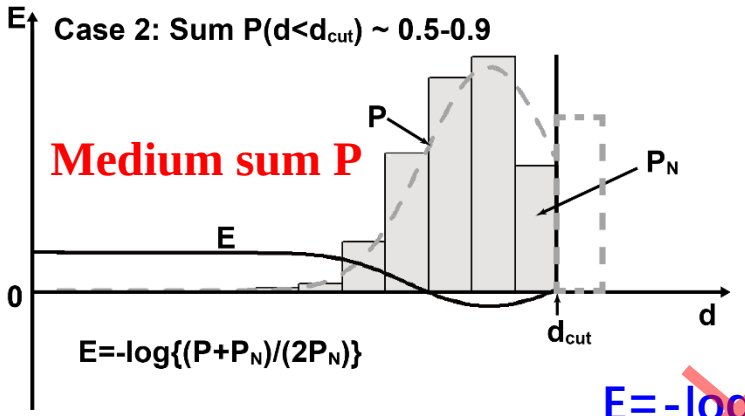


Distance distributions prediction from DeepPotential

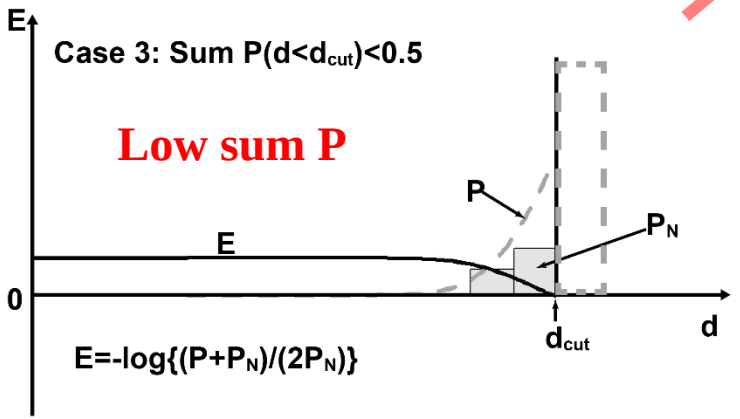


Potential

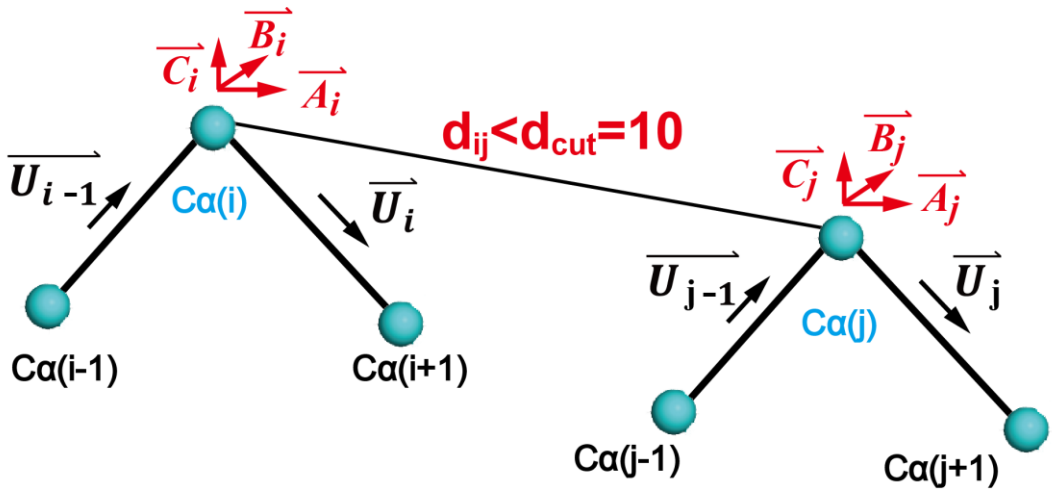




E=-log(P)



Hydrogen-bond potential in D-I-TASSER



$$\overrightarrow{A_i} = \frac{\overrightarrow{U_{i-1}} + \overrightarrow{U_i}}{\left|\overrightarrow{U_{i-1}} + \overrightarrow{U_i}\right|}$$

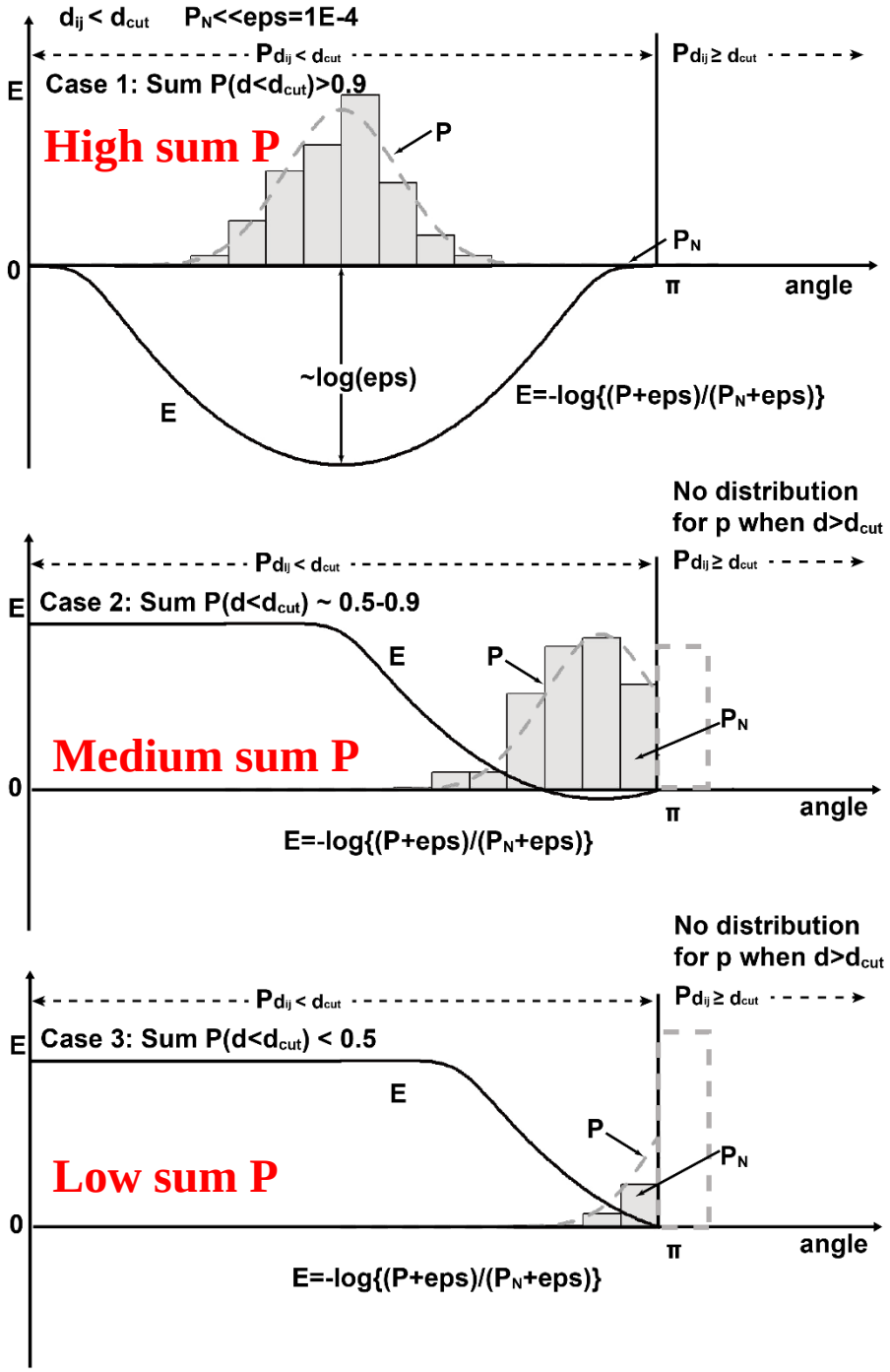
$$\overrightarrow{B_i} = \frac{\overrightarrow{U_{i-1}} \times \overrightarrow{U_i}}{\left|\overrightarrow{U_{i-1}} \times \overrightarrow{U_i}\right|}$$

$$\overrightarrow{C_i} = \frac{\overrightarrow{U_{i-1}} - \overrightarrow{U_i}}{\left|\overrightarrow{U_{i-1}} - \overrightarrow{U_i}\right|}$$

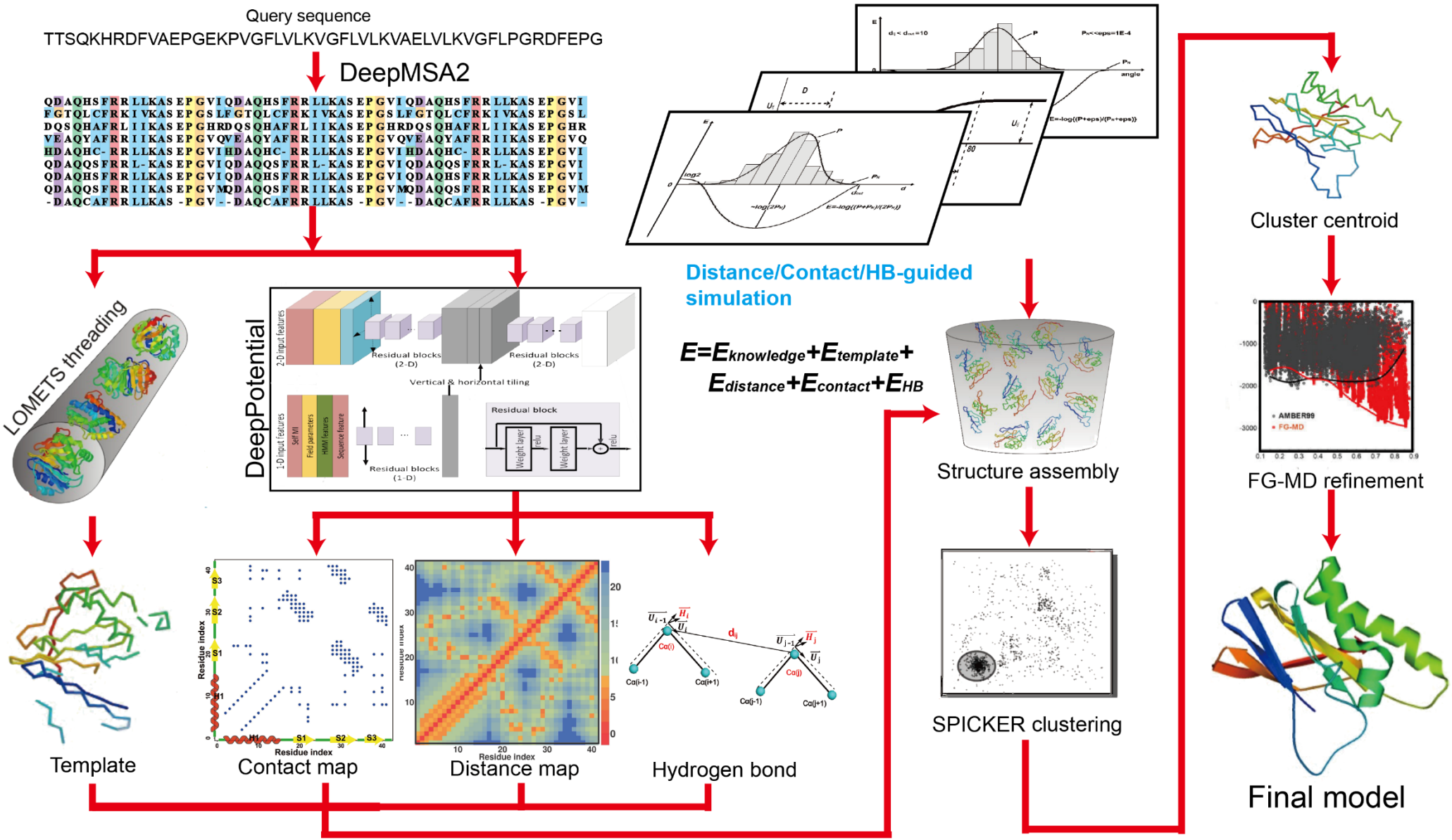
$$AA = arccos(\overrightarrow{A_i} * \overrightarrow{A_j})$$

$$BB = arccos(\overrightarrow{B_i} * \overrightarrow{B_j})$$

$$CC = arccos(\overrightarrow{C_i} * \overrightarrow{C_j})$$

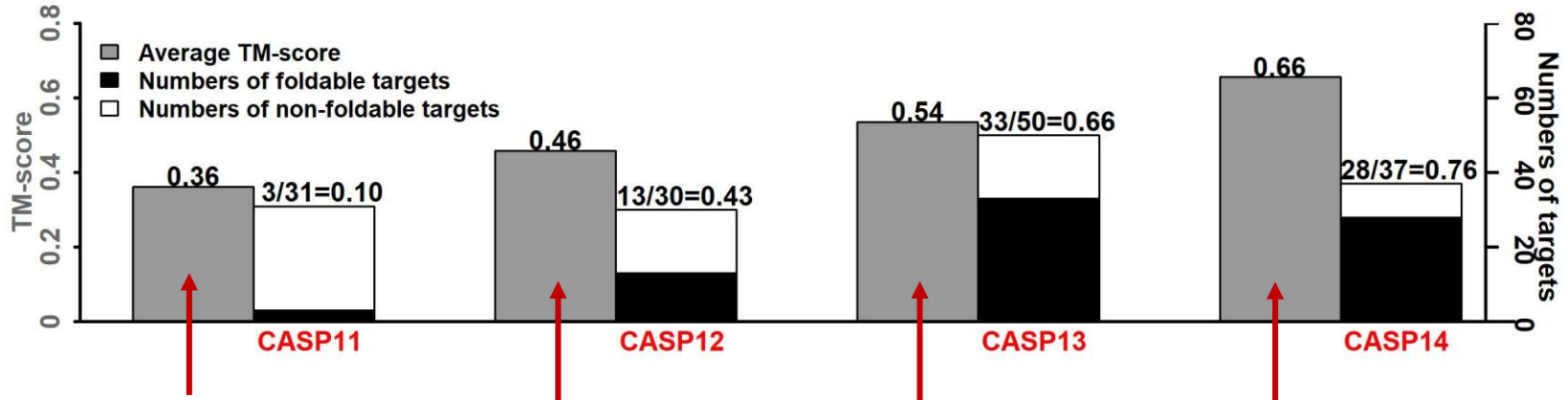


Zhang-Server pipeline built from D-I-TASSER



Results

Summary of FM targets folded by Zhang group



Fragment assembly-based

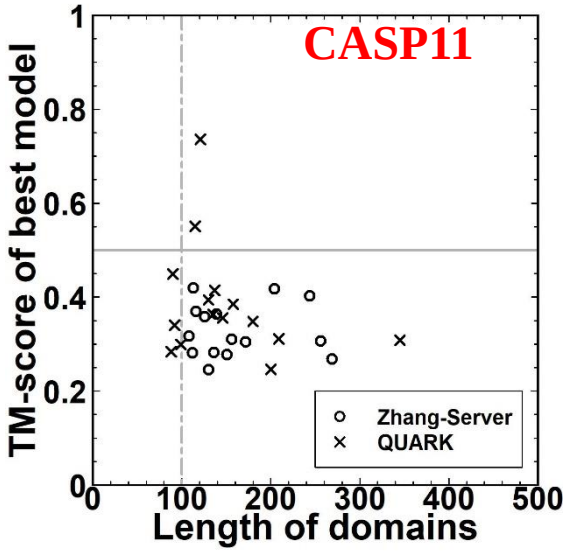
Direct coupling analysis-based contacts added

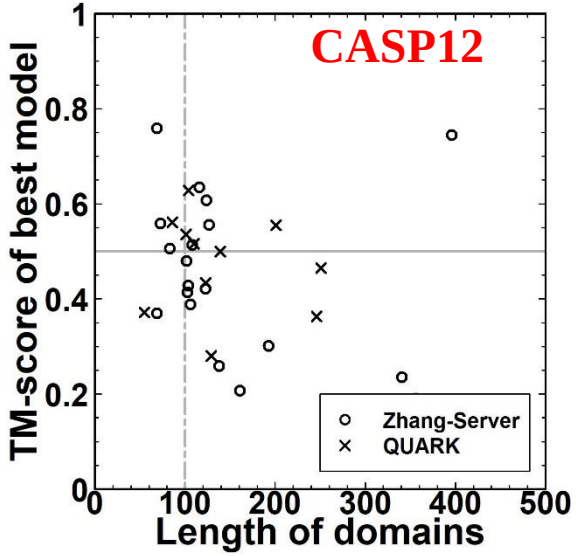
Deep-learning-based contacts added

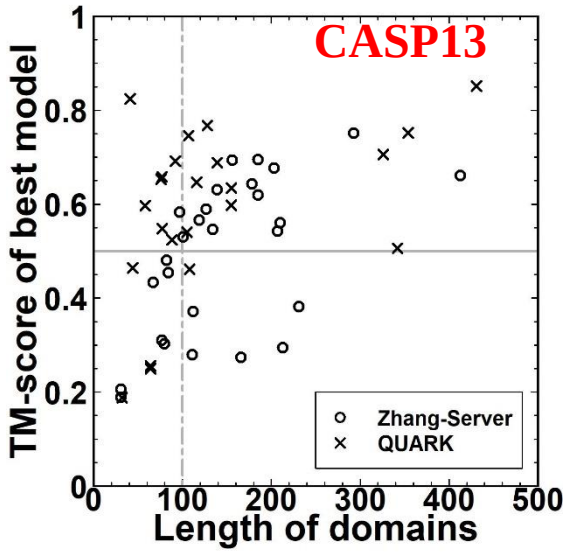
Deep-learning-based distances added

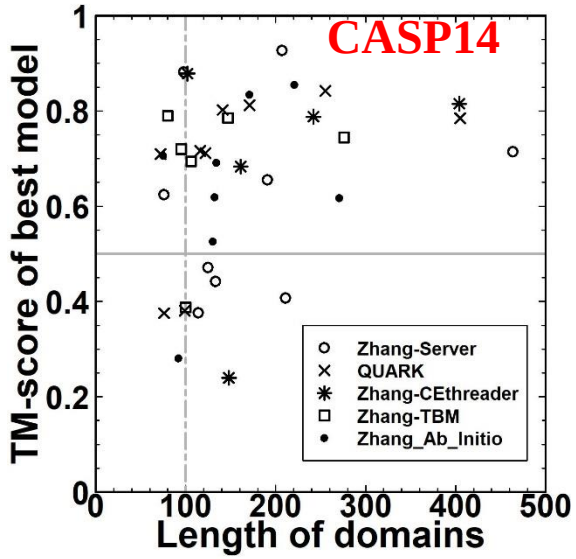
23 FM targets and 14 FM/TBM targets are classified as "FM" targets in the following analysis

76% targets are foldable based on best server models from Zhang group in CASP14

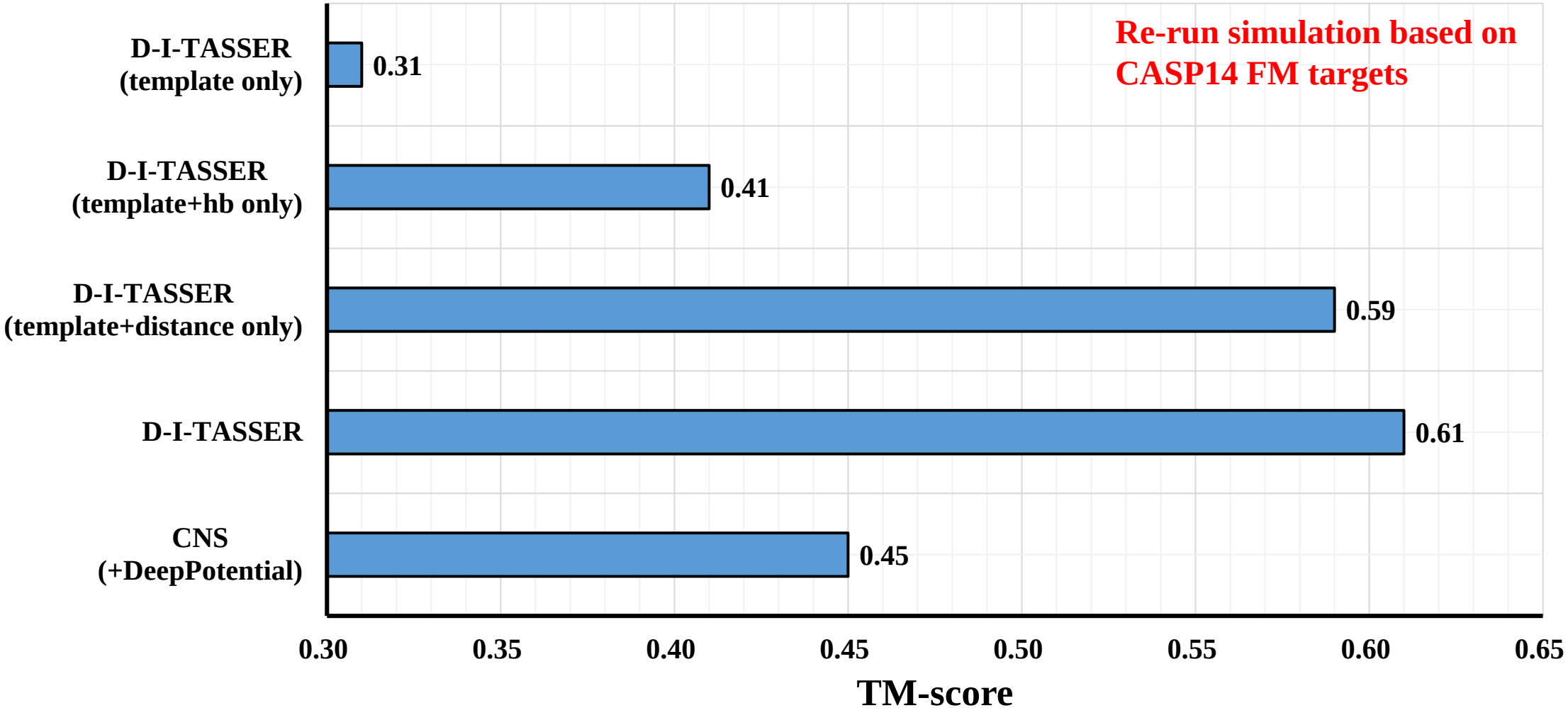




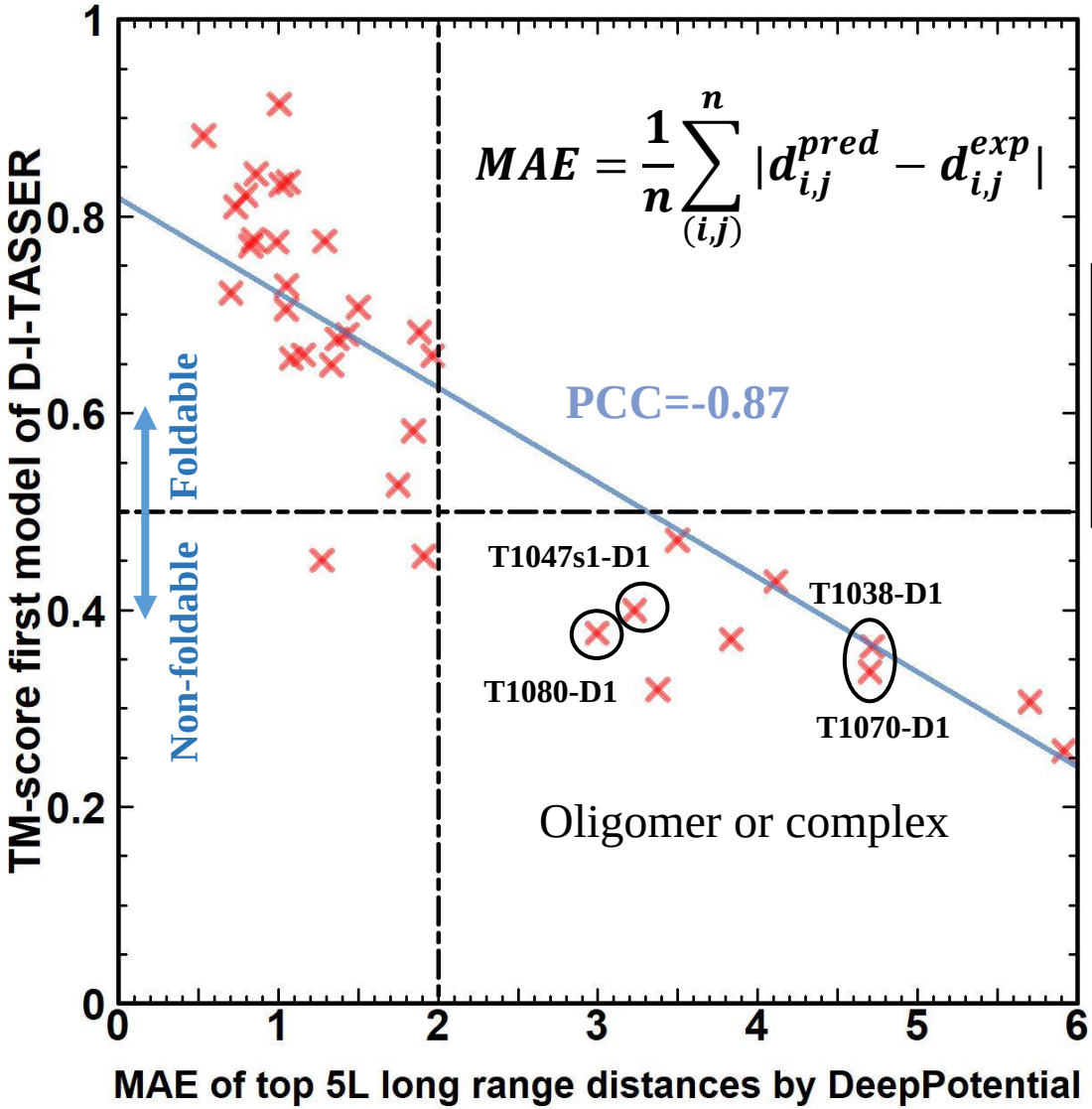




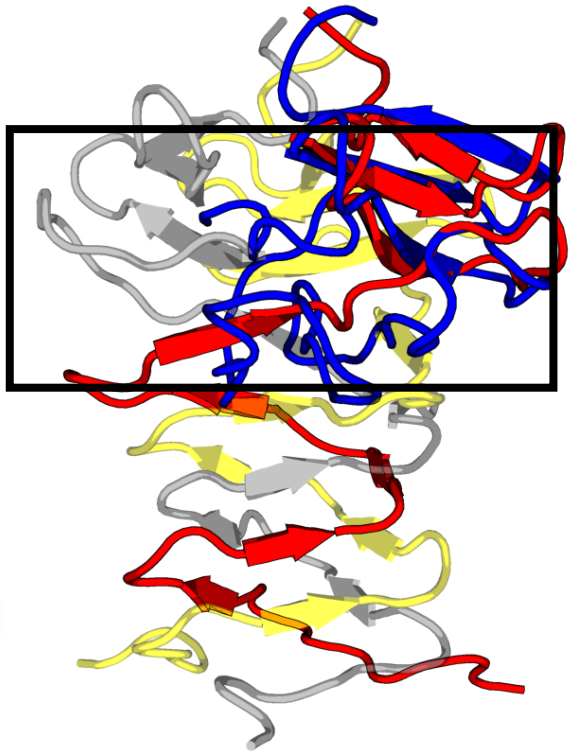
Impact of different energy components on D-I-TASSER for FM targets



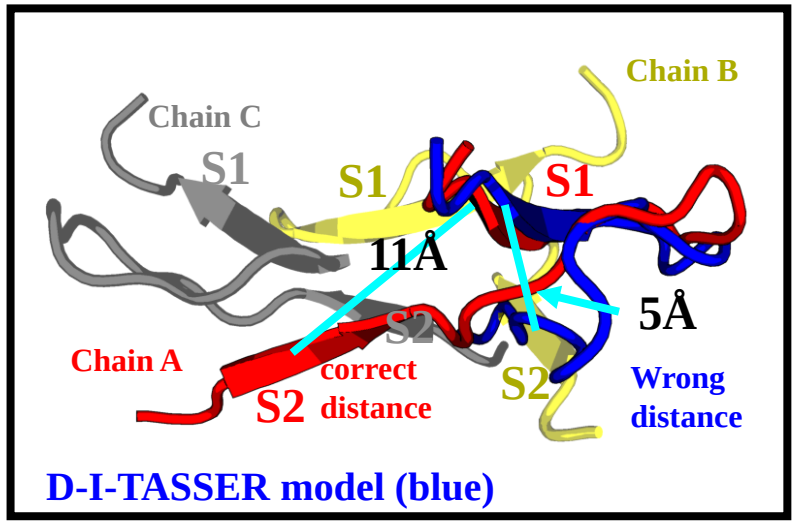
Impact of distance prediction on D-I-TASSER for FM targets

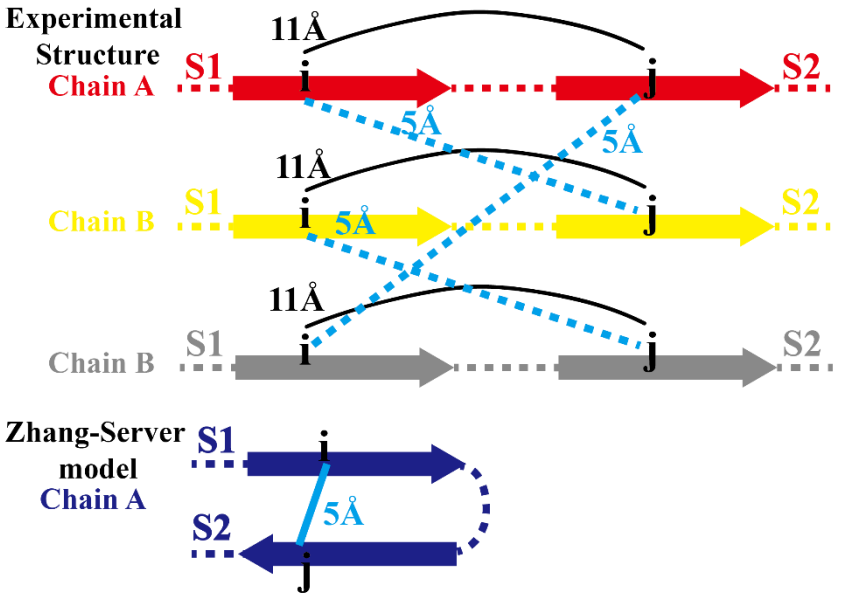


T1070-D1 oligomer (red, yellow, gray)
D-I-TASSER model (blue)
TM-score=0.34



Alignment of MSA is sparse

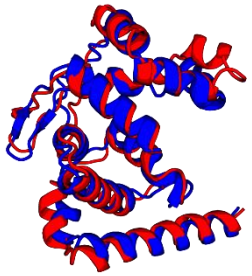




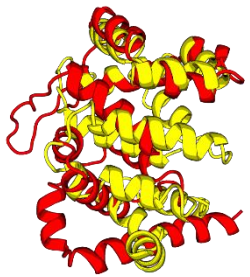
Impact of DeepMSA2 on the D-I-TASSER for FM targets

Experimental structure (red)

T1096-D2, FM target, L=171AA

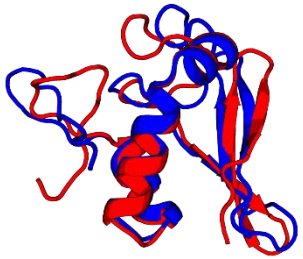


TM-score=0.83
Neff=28.11
DeepMSA2

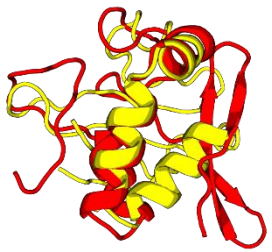


TM-score=0.32
Neff=0.99
DeepMSA

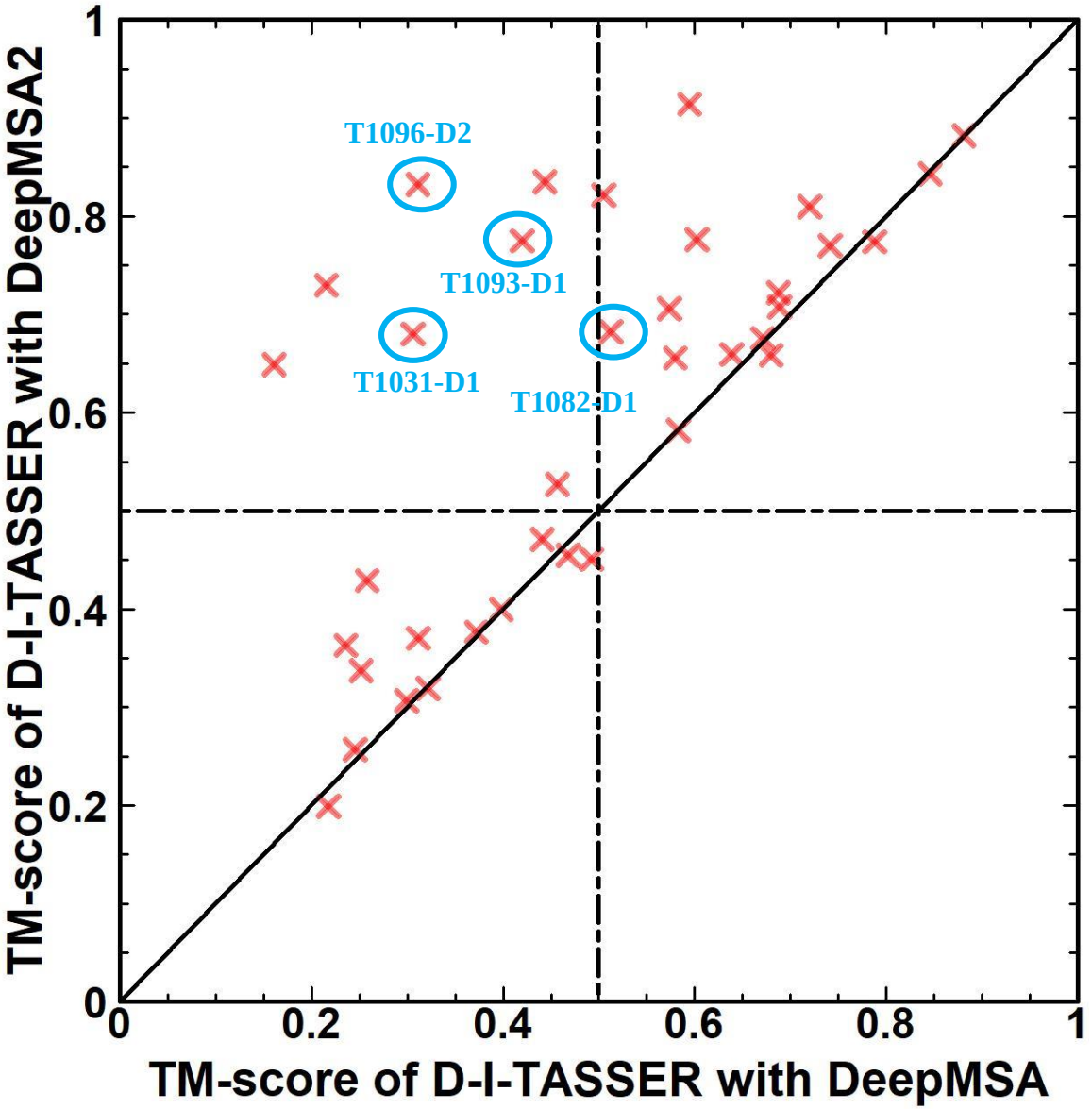
T1031-D1, FM target, L=95AA



TM-score=0.68
Neff=45.41
DeepMSA2

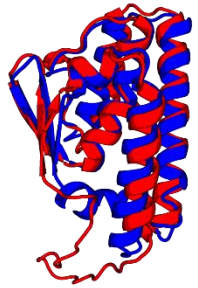


TM-score=0.31
Neff=1.03
DeepMSA

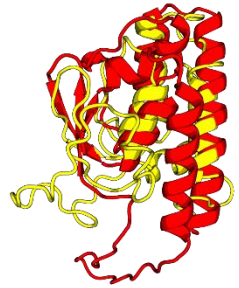


Experimental structure (red)

T1093-D1, FM target, L=141AA

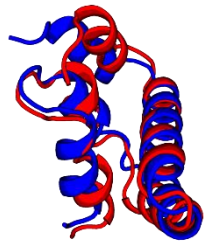


TM-score=0.77
Neff=10.87
DeepMSA2

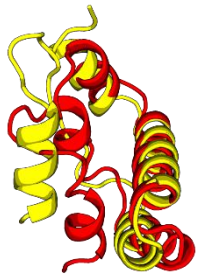


TM-score=0.42
Neff=0.42
DeepMSA

T1082-D1, FM/TBM target, L=75AA



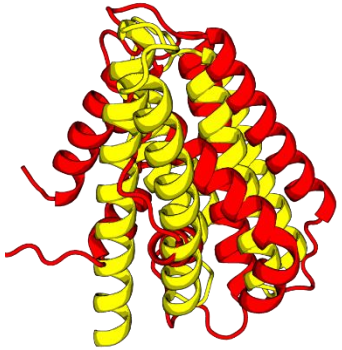
TM-score=0.68
Neff=1.78
DeepMSA2



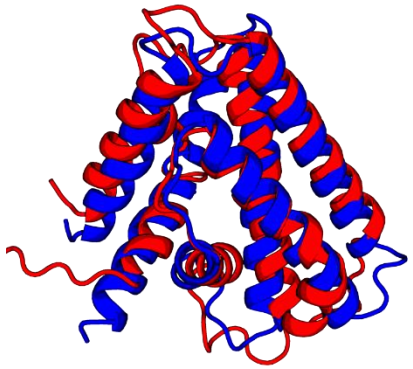
TM-score=0.51
Neff=1.32
DeepMSA

T1039-D1 by Zhang-Server and Zhang-CEthreader

T1039-D1 is an FM target with 161 residues

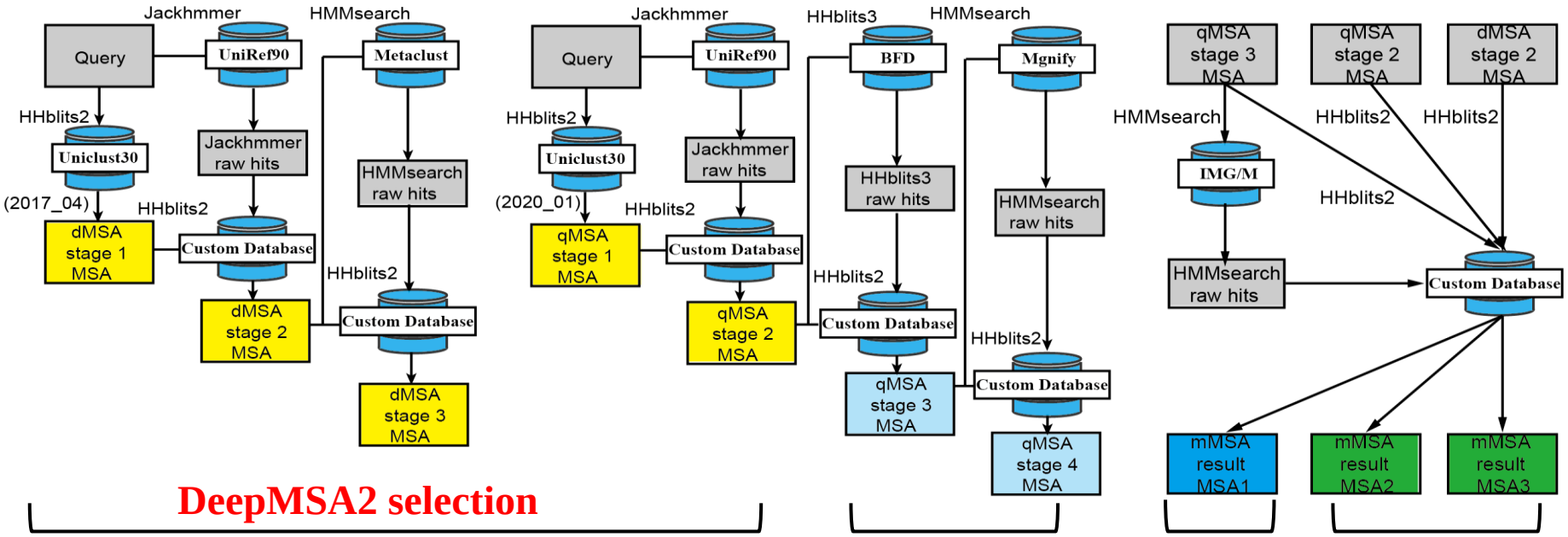


Zhang-Server model1
TM-score=0.31



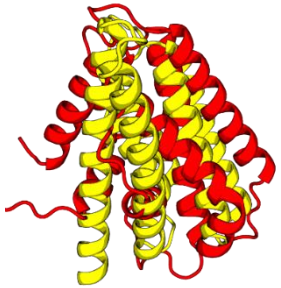
Zhang-CEthreader model1
TM-score=0.68

Experimental structure (red)
Models (blue, cyan, yellow, green)



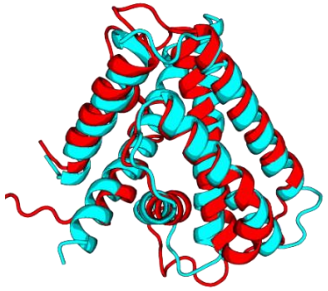
DeepMSA2 selection

Neff=0.08
Contact probability score=614.3



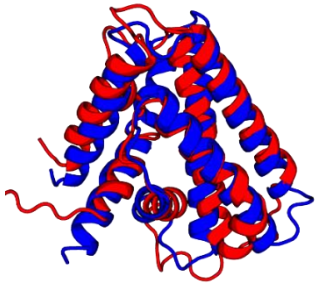
TM-score=0.31

Neff=1.10
Contact probability score=614



TM-score=0.681

Neff=1.34
Contact probability score=613



TM-score=0.683

Neff=0.39
Contact probability score=600.6

TM-score=0.52

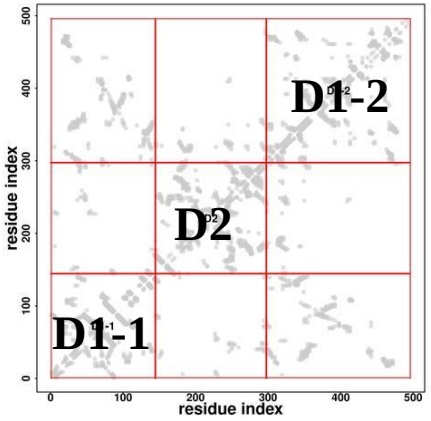
Impact of domain partition

T1094, two domain target

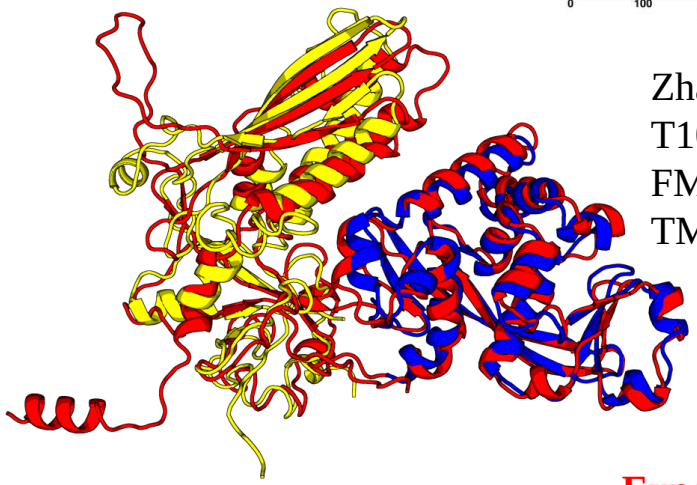
Domain from CASP

T1094-D1 T1094-D2

Zhang group domain by FUpred



Zhang-Server model1
T1094-D1
TBM-hard
TM-score=0.64



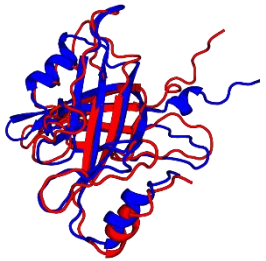
Zhang-Server model1
T1094-D2
FM
TM-score=0.91

T1061-D1, FM/TBM target, discontinuous domain

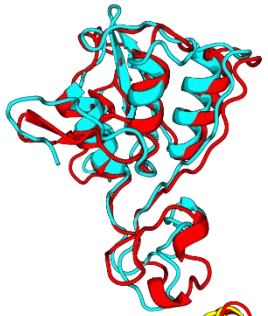
Domain from CASP

Zhang group domain

T1061-D1_f1
TM-score=0.76

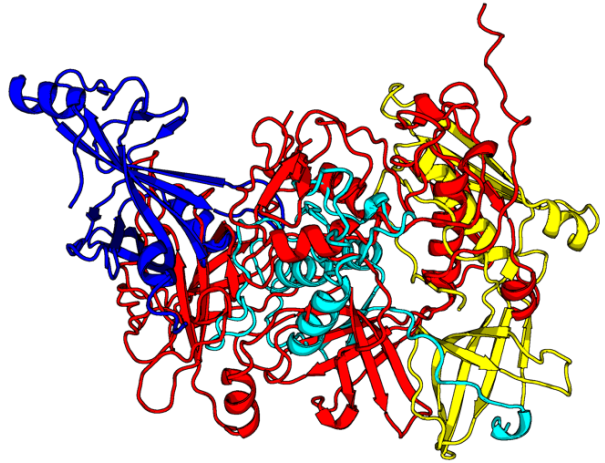


T1061-D1_f2
TM-score=0.67



T1061-D1_f3
TM-score=0.74

Zhang-Server model1
TM-score=0.45



Experimental structure (red), Models (blue, yellow, cyan)

Summary

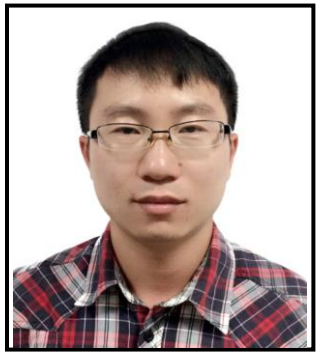
- **What works**
  - Distance and hydrogen-bond prediction by DeepPotential
  - Advanced structure assembly simulations by I-TASSER/QUARK
  - DeepMSA2 for deeper MSA generation
- **What needs to be improved**
  - Modeling oligomers
  - Selecting good MSA
  - Partitioning domains

Acknowledgements

Yang Zhang

Yang Li

Chengxin Zhang



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Xiaoqiang Huang

Robin Pearce

Eric W. Bell

Jonathan Poisson

National Science Foundation

National Institutes of Health

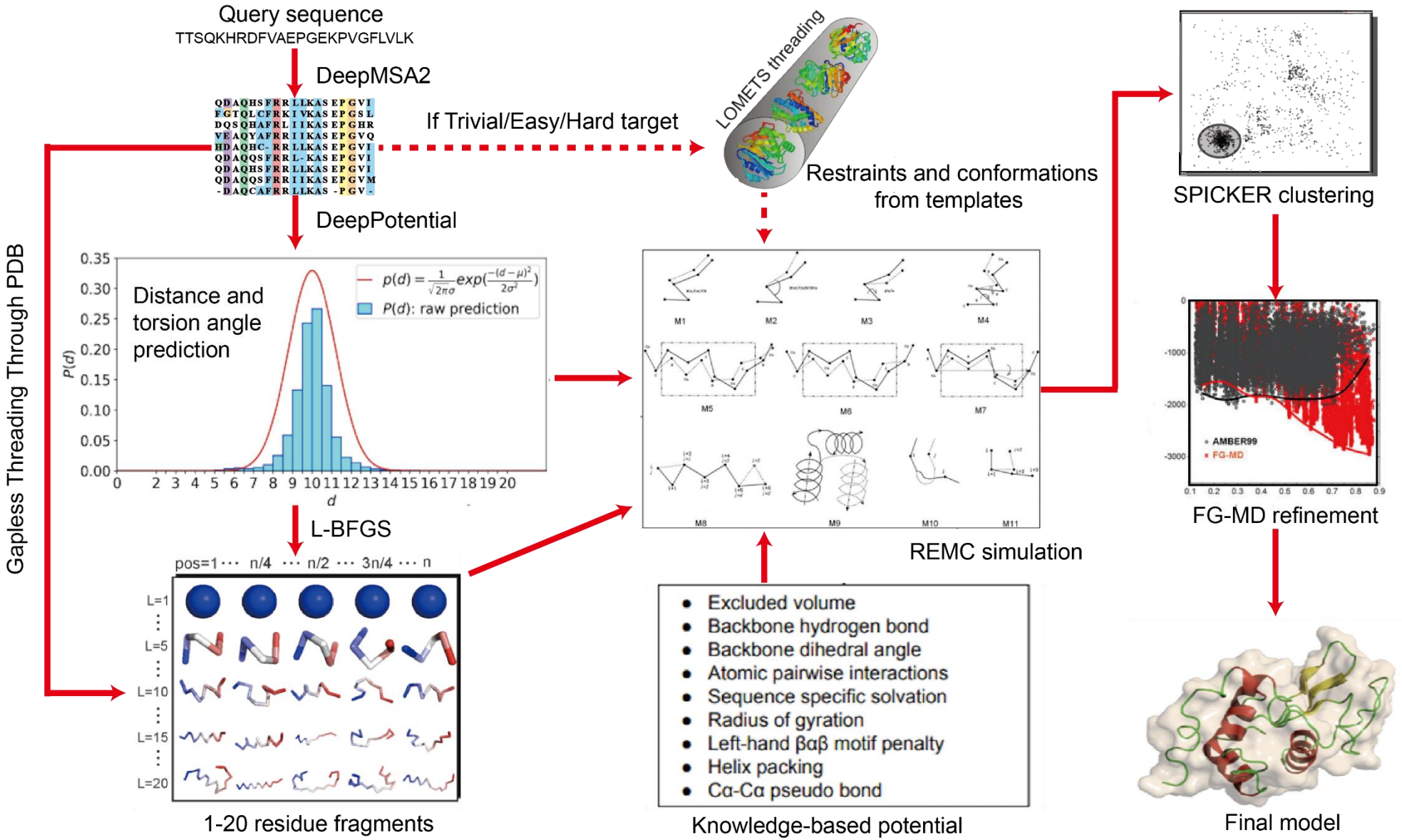
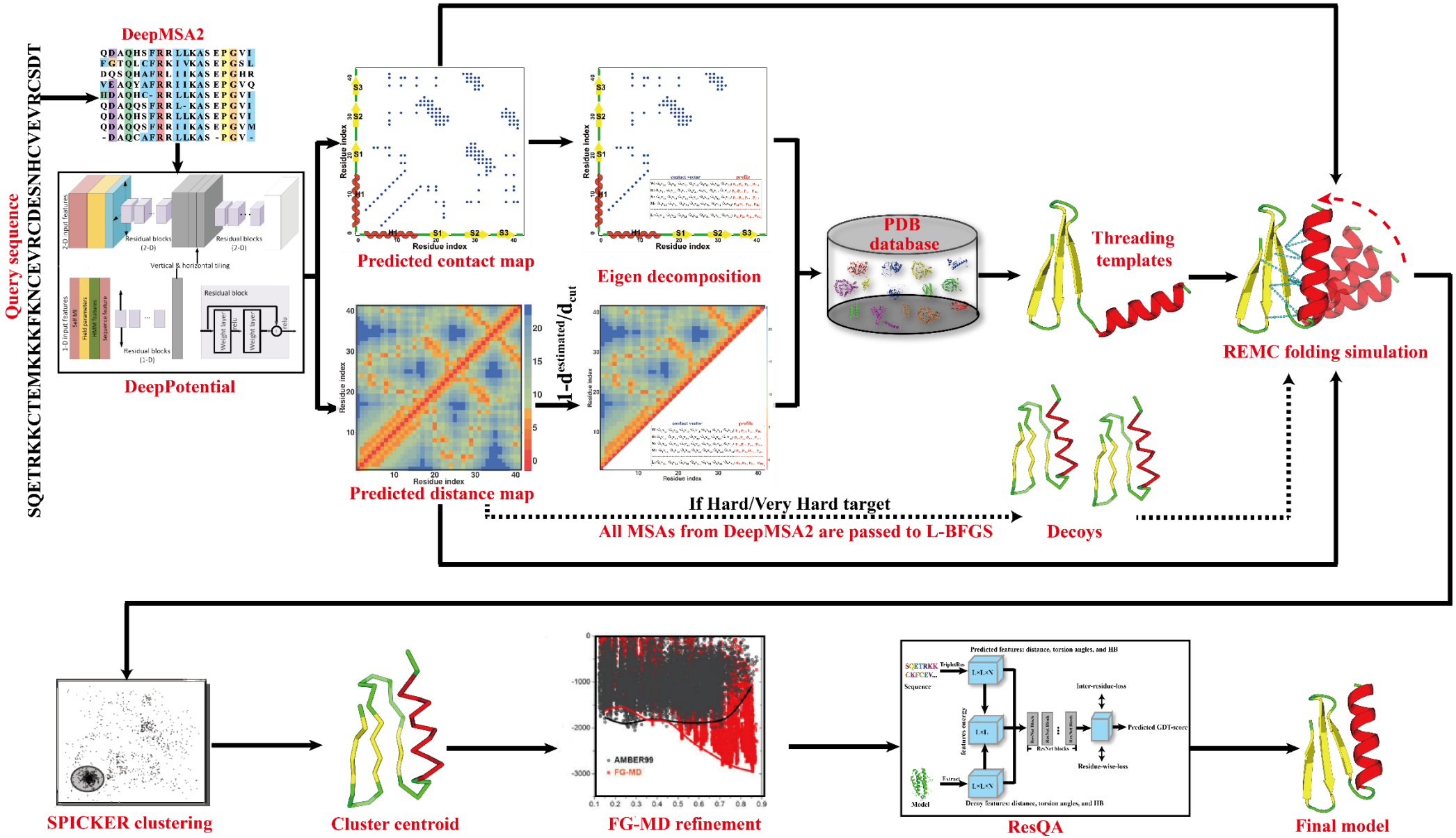
POWERED BY XSEDE
Extreme Science and Engineering Discovery Environment

- CASP Organizers
- Experimentalists that shared their structures

Thank you!

Appendix

QUARK pipeline built from D-QUARK



Zhang-CEthreader pipeline built from DEthreader and D-I-TASSER simulation