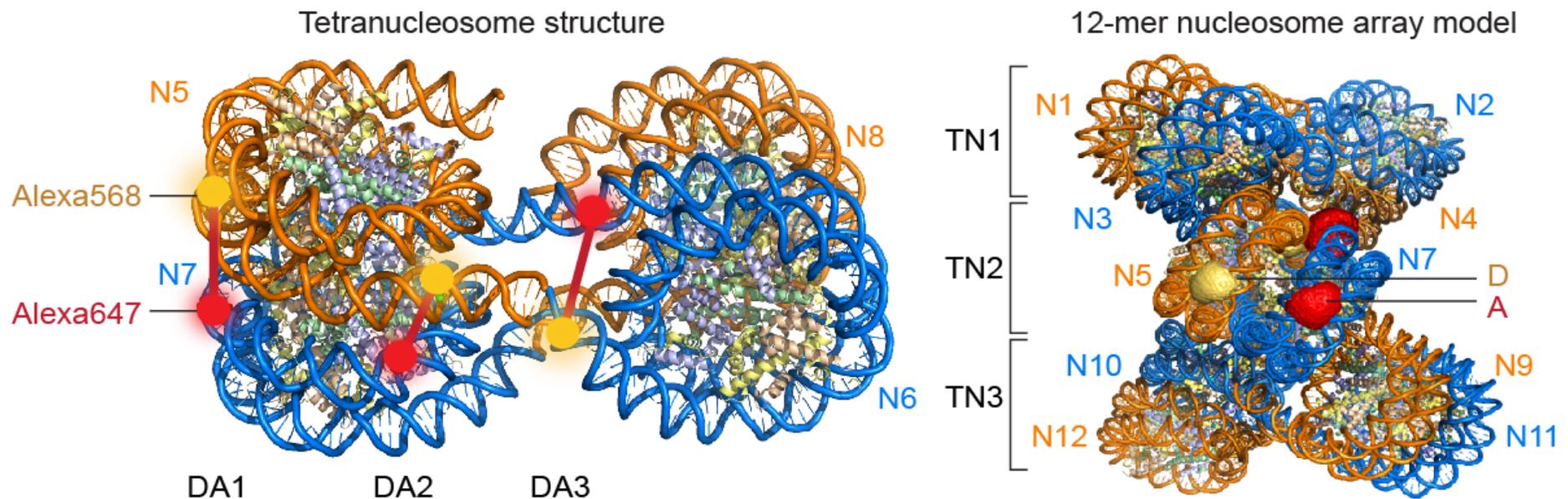


# Integrative dynamic structural biology with fluorescence spectroscopy

Claus A. M. Seidel

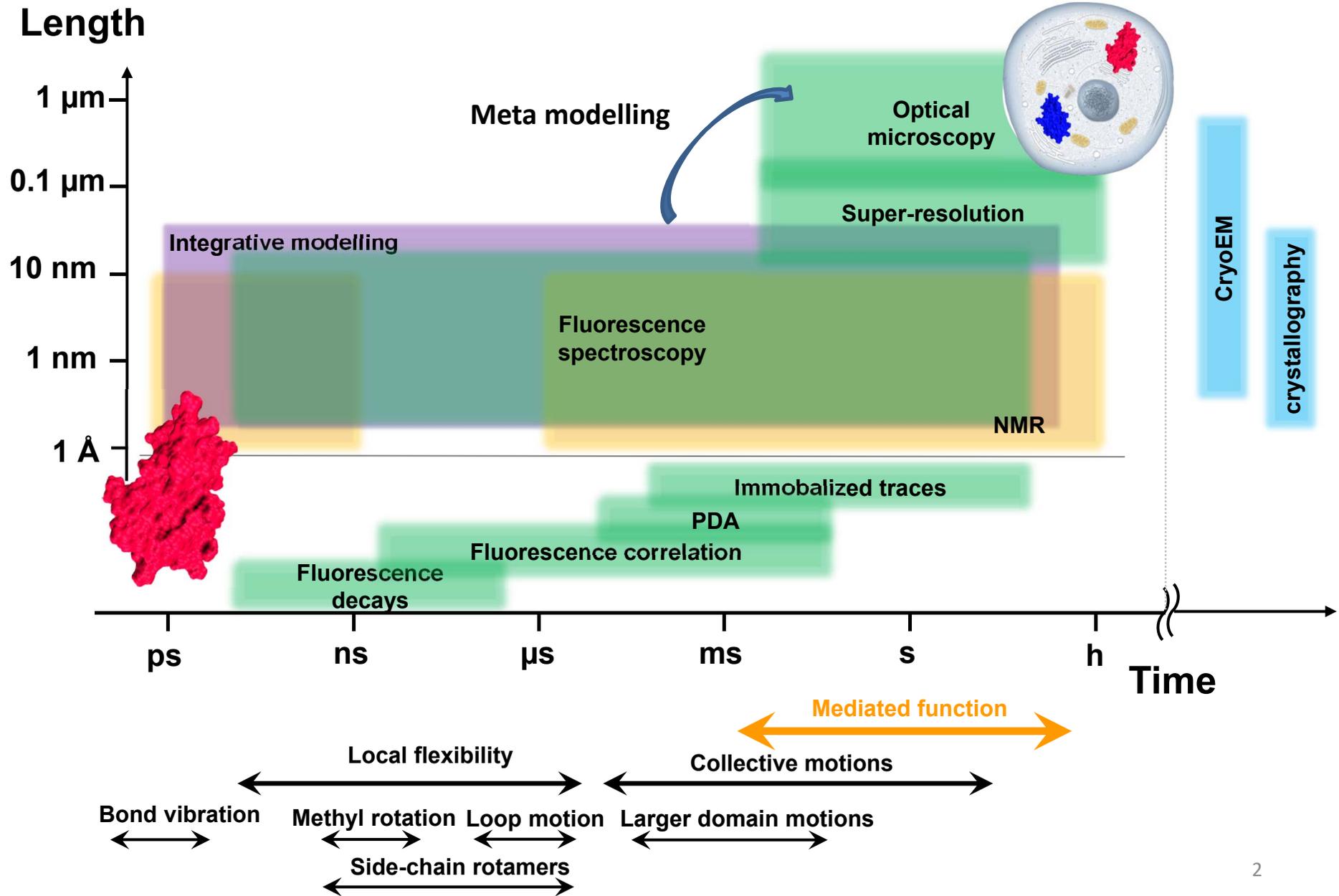
*Chair for molecular physical chemistry, Heinrich-Heine-Universität Düsseldorf;*

*cseidel@hhu.de*



## CASP Webinar October 4, 2018

# Spatiotemporal models of living systems



# Fluorescence dimensions and protein information

- Local structure

Spectral changes (polarity probes, ratiometric probes)	localization of the segment
Quenching	proximity of other segments, accessibility of sites
Polarization, anisotropy	order parameters (local flexibility)

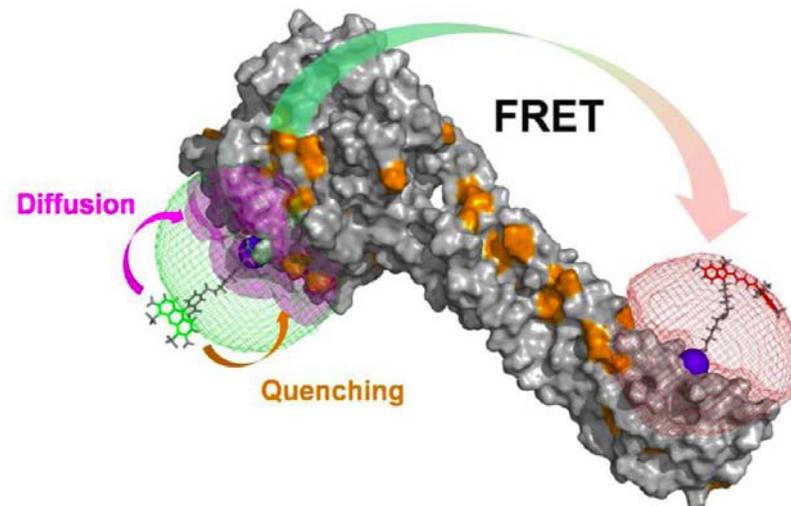
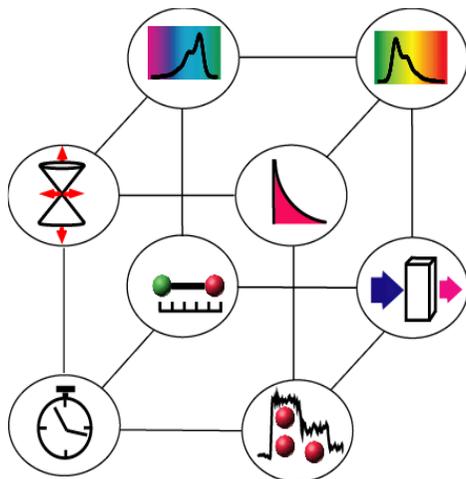
- Global structure

Förster energy transfer (FRET)	distances
Diffusion (translation and rotation)	shape

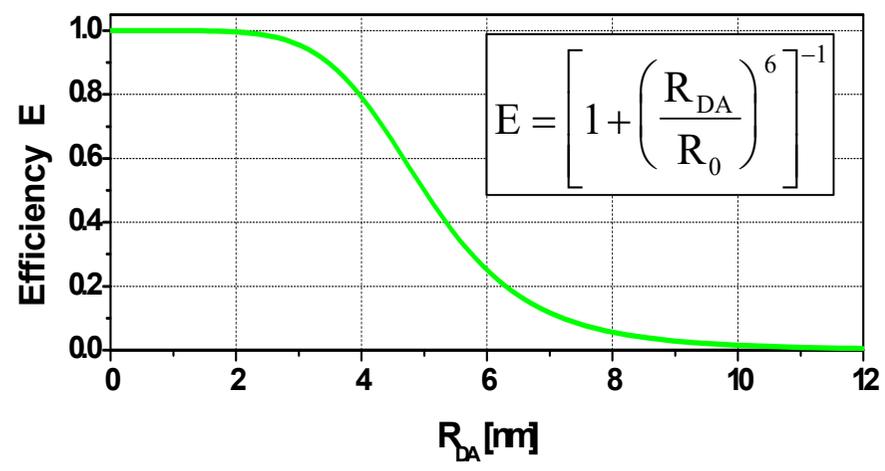
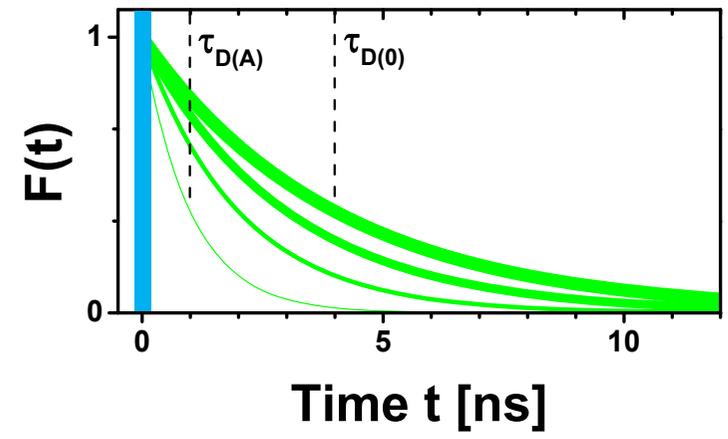
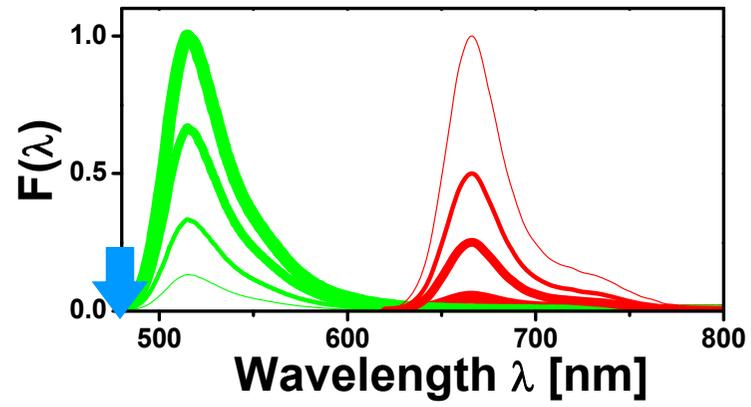
- Dynamic exchange

time-resolved detection (ps-ms/ min)	kinetic exchange networks
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**A N-dimensional vector with all observables characterizes each protein state**



# Förster Resonance Energy Transfer + FRET indicators



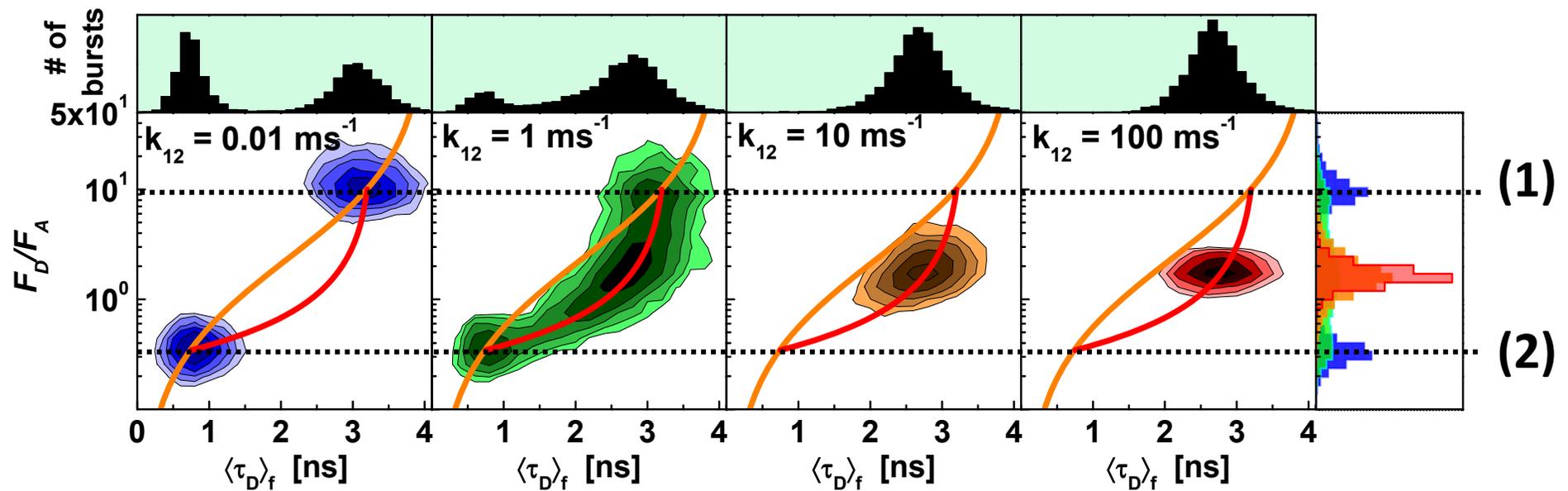
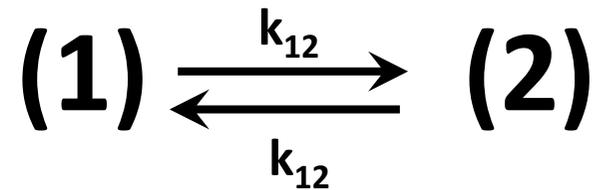
## FRET indicators

$$E = \frac{F_A}{\gamma F_D + F_A}$$

$$E = 1 - \frac{\tau_{D(A)}}{\tau_{D(0)}}$$

4

# Dynamic exchange between two states



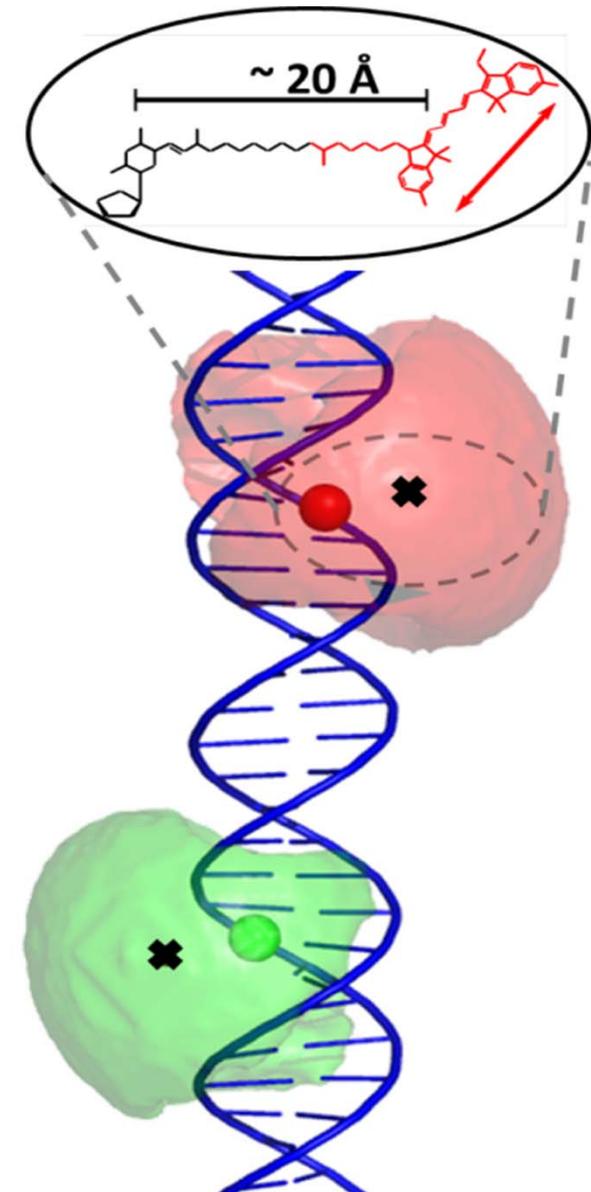
- Fluorescence lifetimes: states (1,2)
- Dynamic photon distribution analysis (dynPDA): states (1,2) + rate constants  $k_{12}$  (relax. disp.)

# Quantitative high-precision FRET (hpFRET) analysis

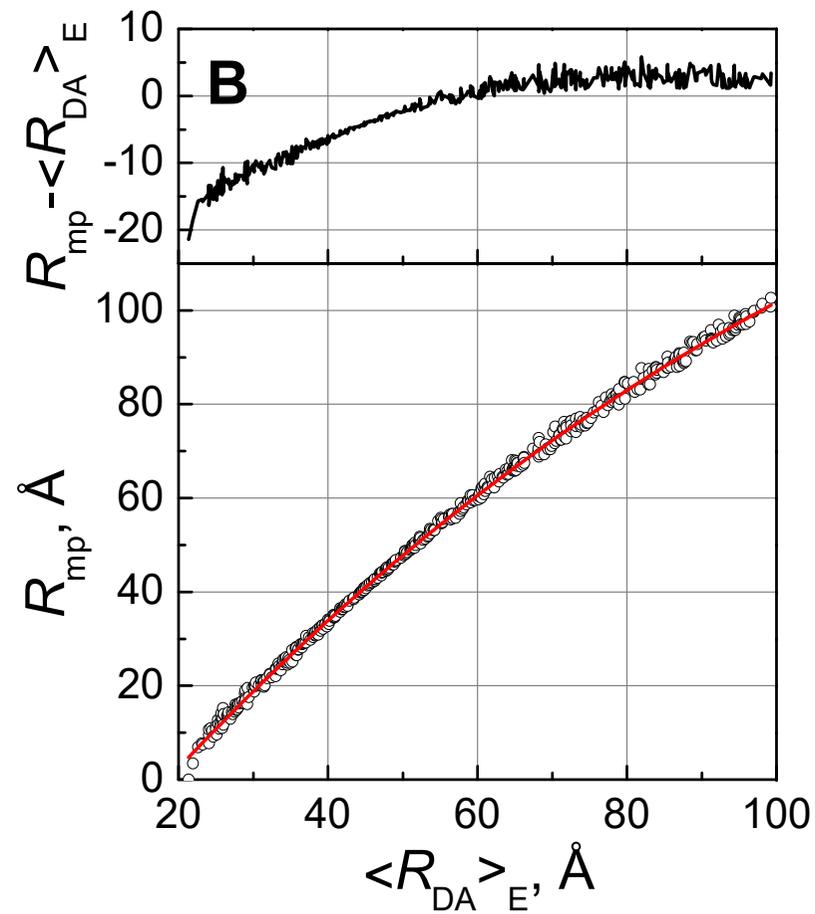
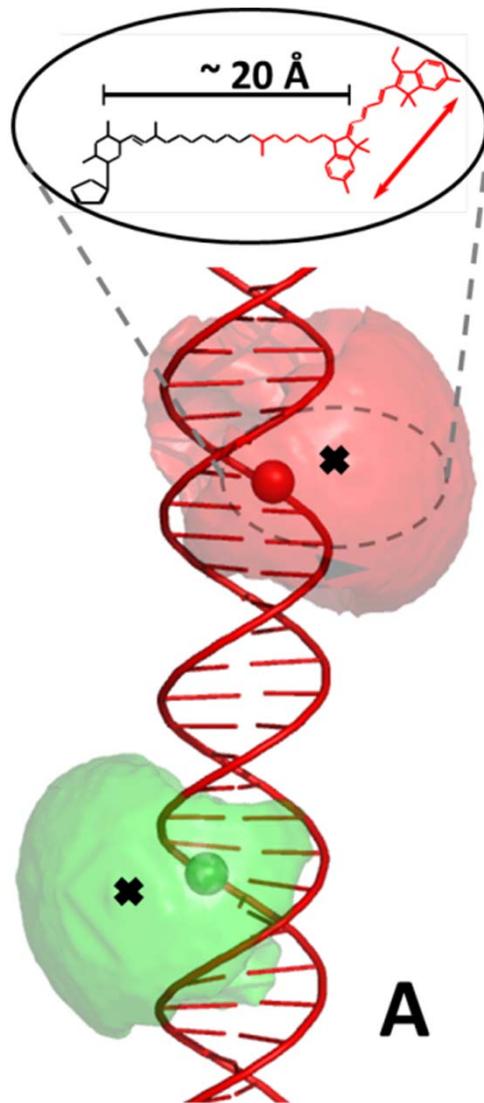
- Multiparameter Fluorescence Detection (MFD)
- Detect dynamic averaging
- Rigorous error analysis
- Dye properties: **Accessible volume (AV) simulations**
- Hybrid approach: **Combination with computer simulations**

## Structural models in data bases (wwPDB)

- Precision
- Accuracy
- Confidence levels
- **Dynamic / heterogeneous systems:**  
Use Single-molecule advantage:
  - multiple structures in parallel
  - kinetics: no need for synchronization
- Kinetics: reaction pathways
- Solution conditions, room temperature
- Large systems possible
- Combination with microscopy: *in vivo* option

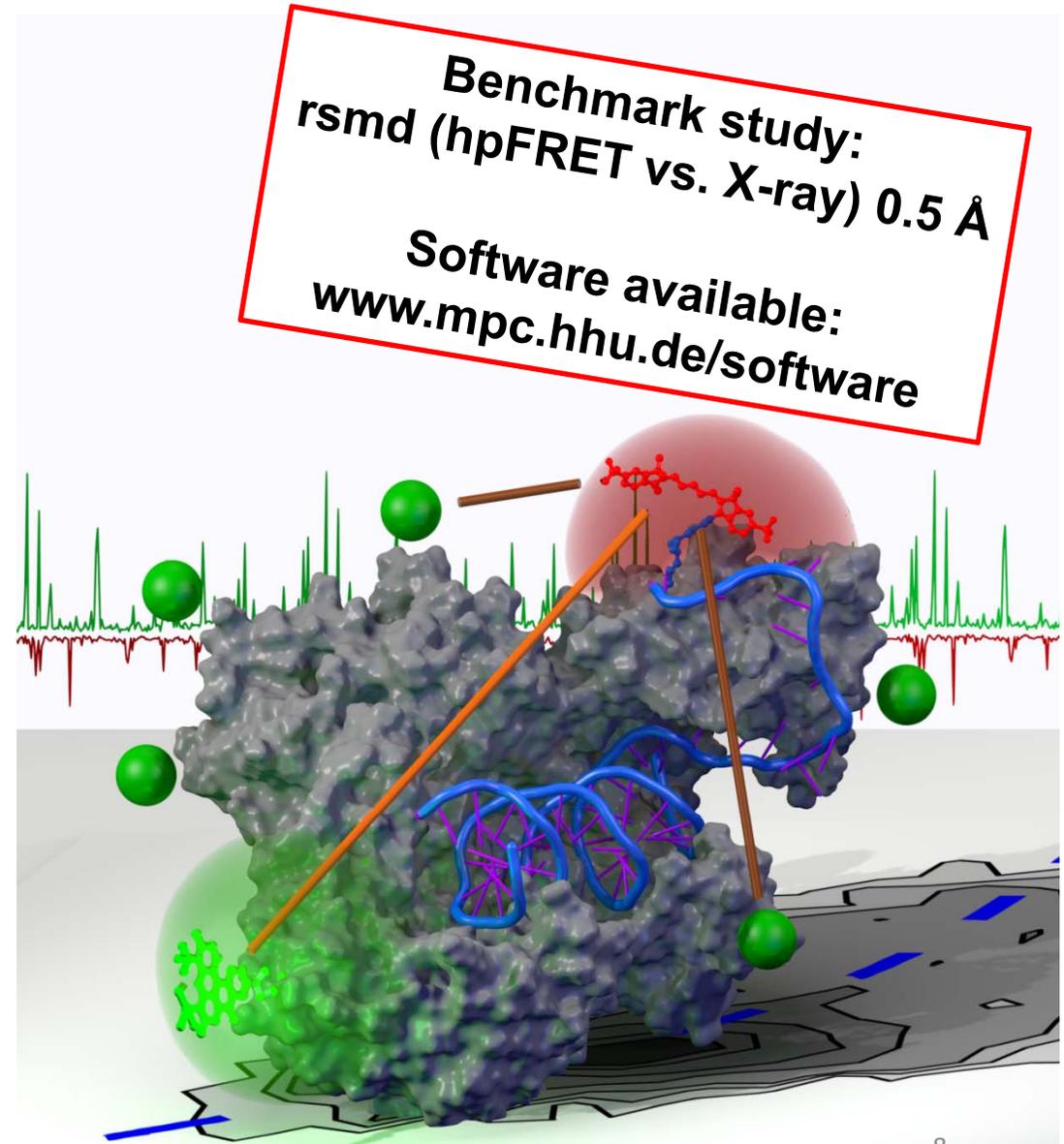
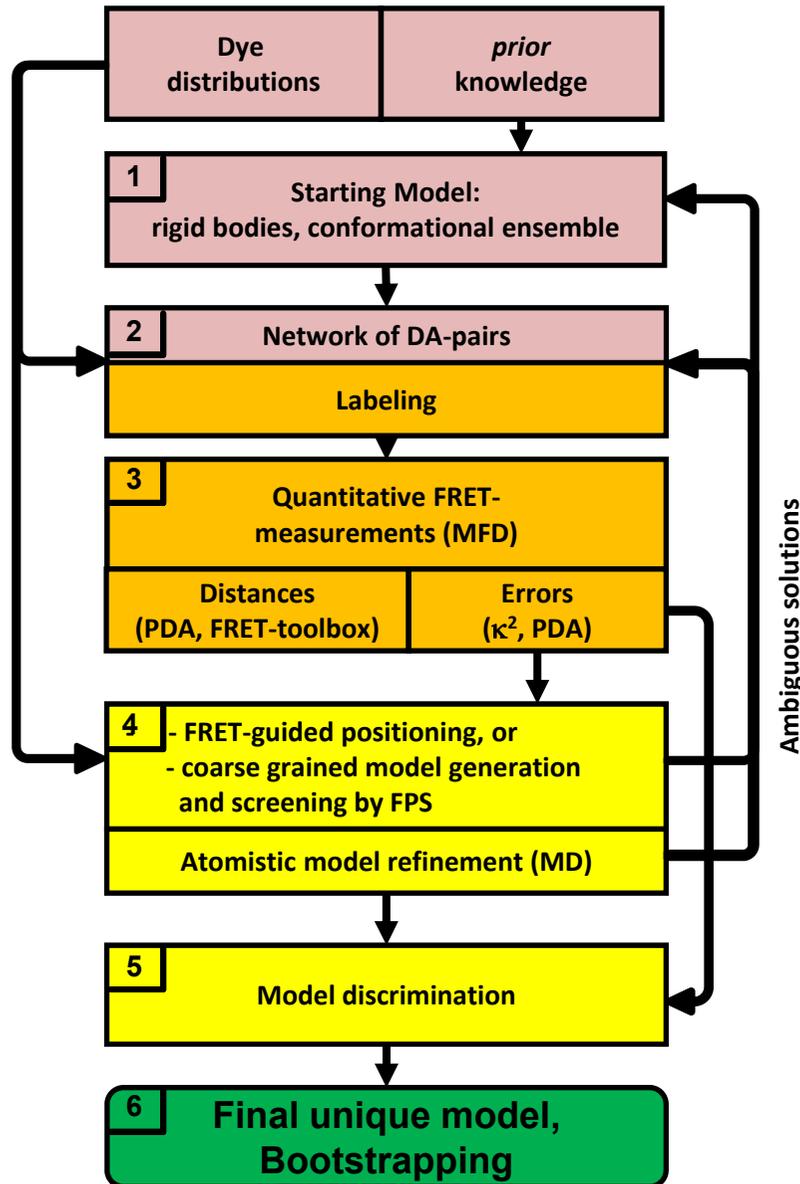


# Dye models: Dye distance distributions or mean positions



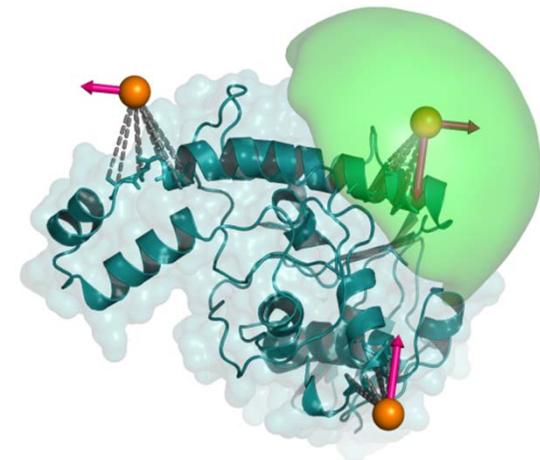
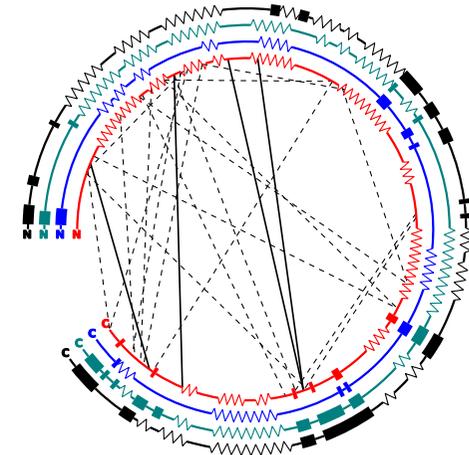
$R_{mp}$  approximation for short  
distances up to 30 % error

# High-precision FRET (hpFRET): 6 steps to FRET-restrained structural biology



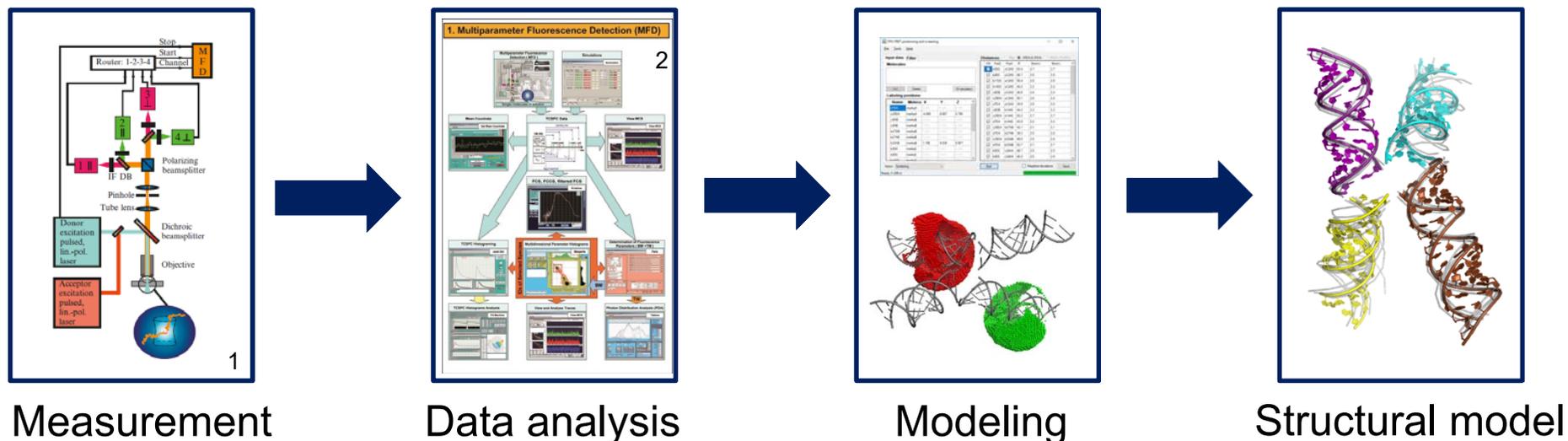
# Next generation of FRET toolkit: FPS 2.0 (Poster 56)

- 1. Finding most informative FRET-pairs:**  
FRET networks for least experimental work
- 2. FRET-restrained optimization of structural models:**  
Beyond rigid body docking and simple model selection  
-> Targeted structural sampling by FRET guiding
- 3. Estimation of accuracy:**  
Can we trust the FRET-restrained structural model?  
-> a crossvalidation approach analog to X-ray:  $R_{\text{free}}$
- 4. Archiving of the I/H models to share information:**  
Generation of documentation: Fluorescence dictionary



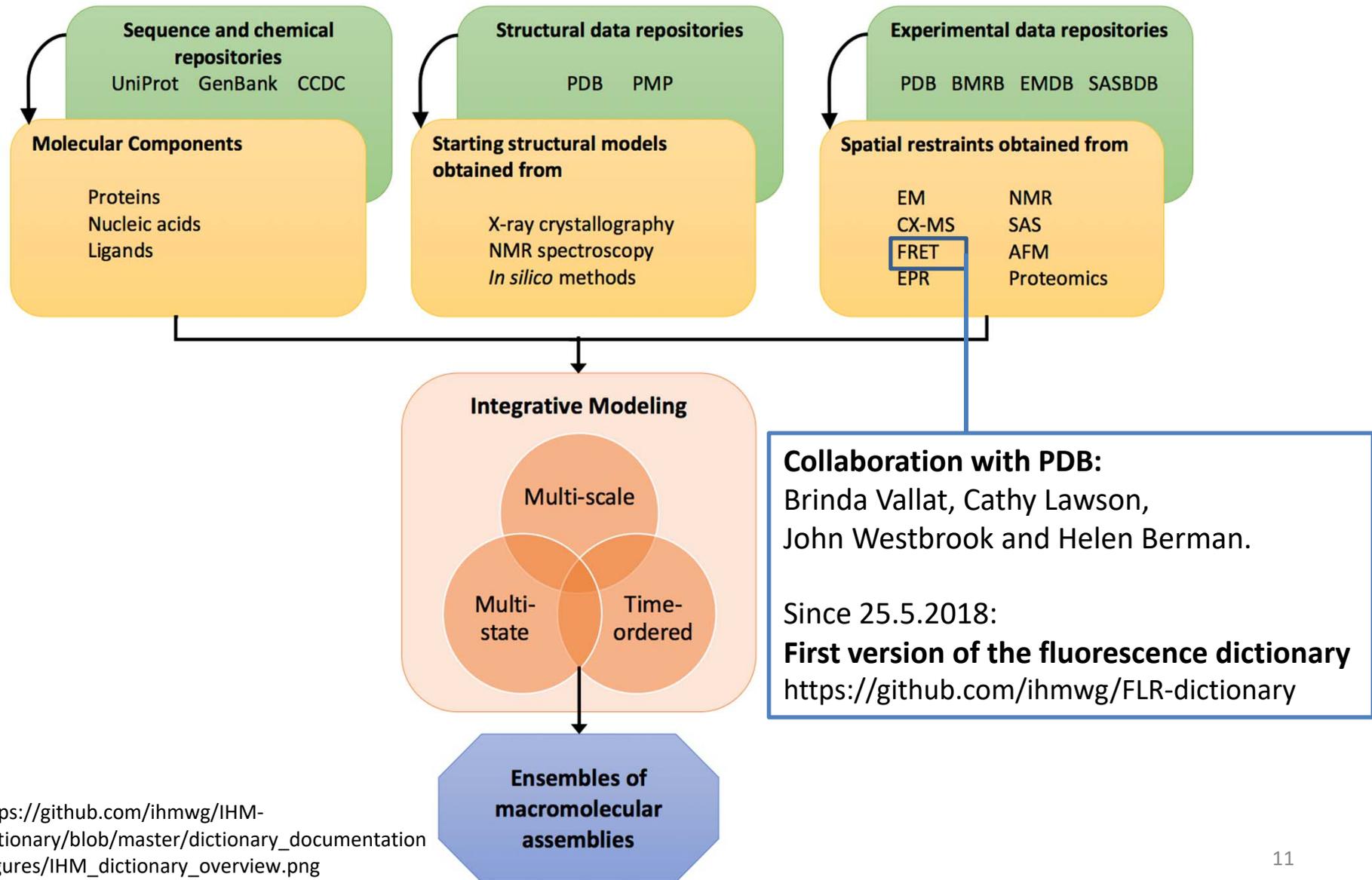
-> deposition in PDB-Dev

# PDB-Dev: New archive of structural models obtained through integrative/hybrid (I/H) methods



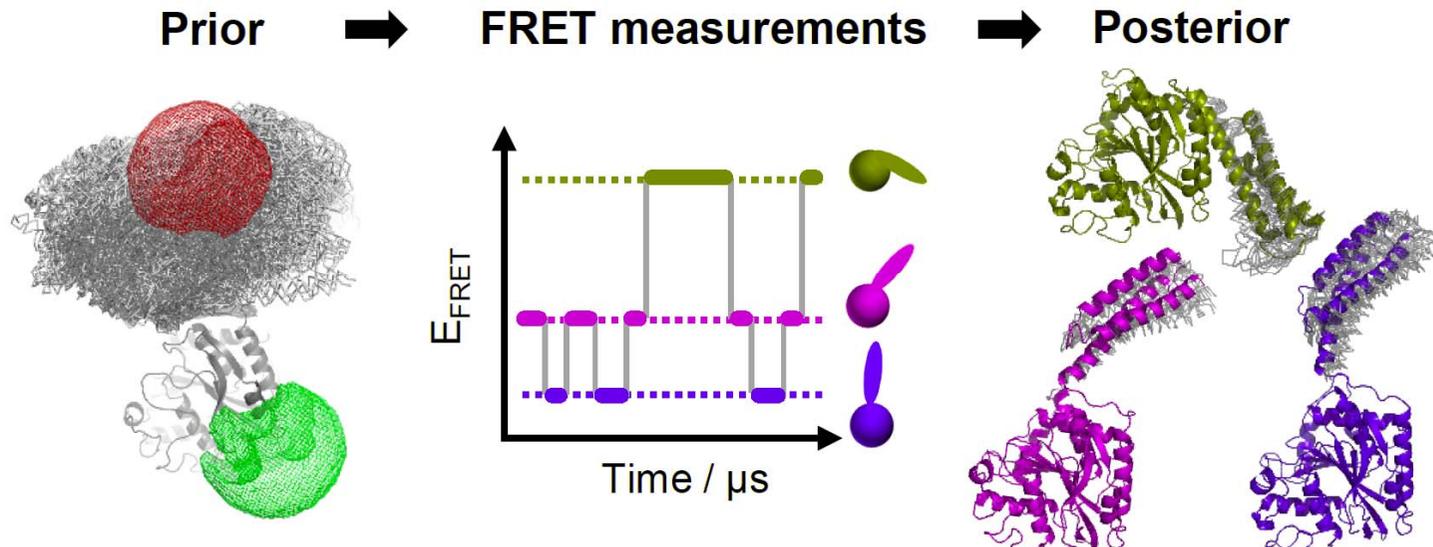
- Quality assessment + making the structural model available to the public
- Molecular structure information is important e.g.
  - in structure-based studies
  - in structure-based drug development

# PDB-Dev: New archive of structural models obtained through integrative/hybrid (I/H) methods



[https://github.com/ihmwg/IHM-dictionary/blob/master/dictionary\\_documentation/figures/IHM\\_dictionary\\_overview.png](https://github.com/ihmwg/IHM-dictionary/blob/master/dictionary_documentation/figures/IHM_dictionary_overview.png)

# Exploring the capabilities of hybrid-FRET modeling: An *in silico* experiment:



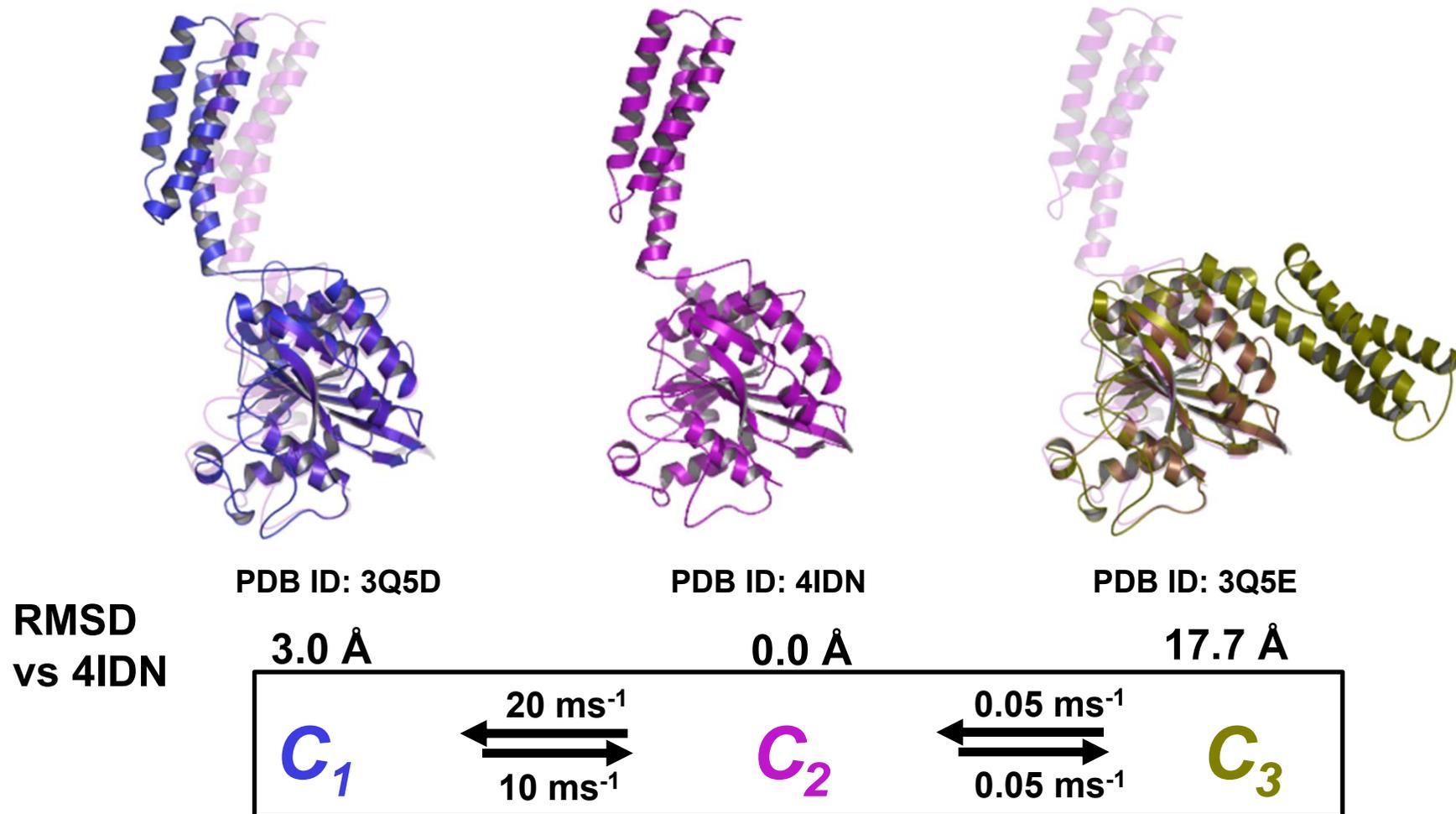
**Mykola Dimura\***, **Thomas-O. Peulen\***, **Christian A. Hanke**, Aiswaria Prakash, Holger Gohlke, Claus A.M. Seidel

Open Access: **Curr. Opinion in Structural Biology** 40, p163–185 (2016).

All obtained structural models, additional detailed information on the applied procedures and the simulated sm FRET data are deposited in the **Model Archive with the DOI:**

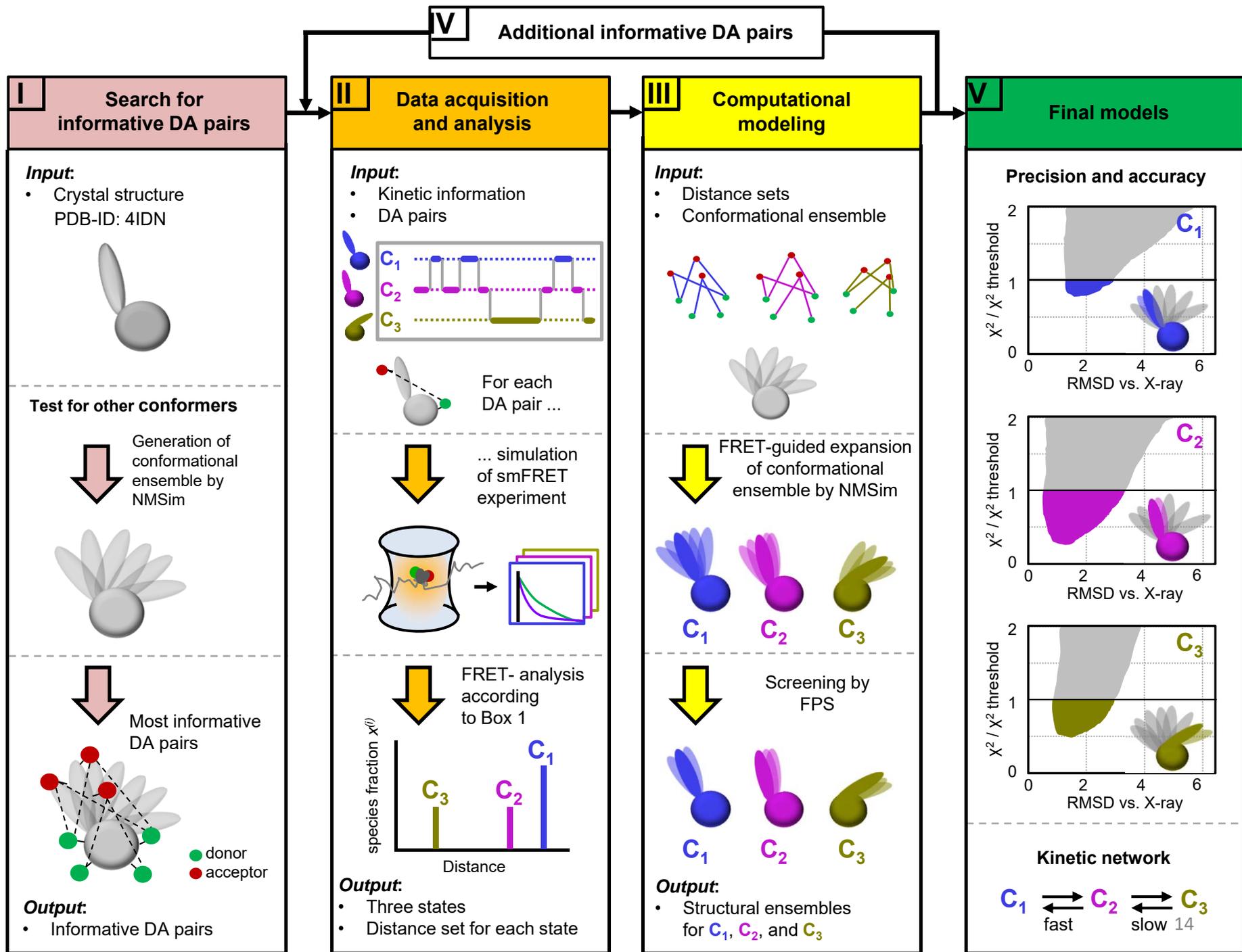
**10.5452/ma-a2hbq.**

# Exploring the capabilities of hybrid-FRET modeling: An *in silico* experiment:



Curr. Opinion in Structural Biology  
40, p163–185 (2016)

- Number of other states
- Kinetic connectivity
- Structural architecture knowing only C<sub>2</sub><sup>13</sup>

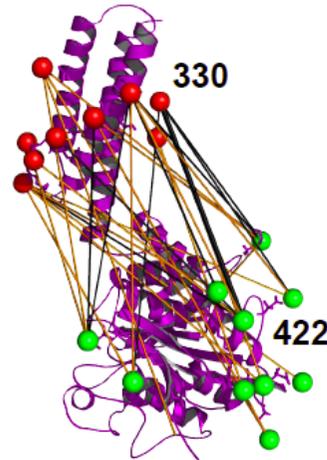


# hybrid-FRET modeling on rails: Analysis of in silico experiments

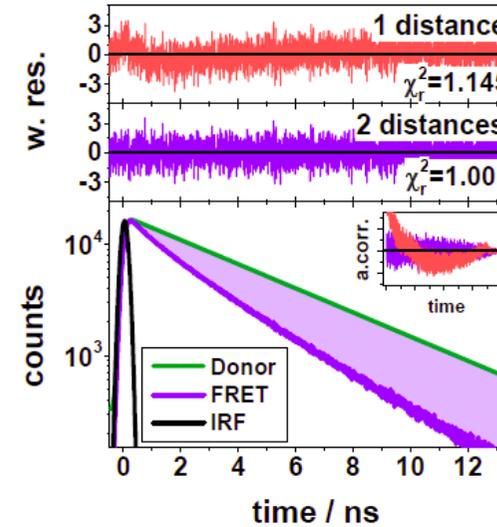
(a) *Distance network*

aa(D)-aa(A)

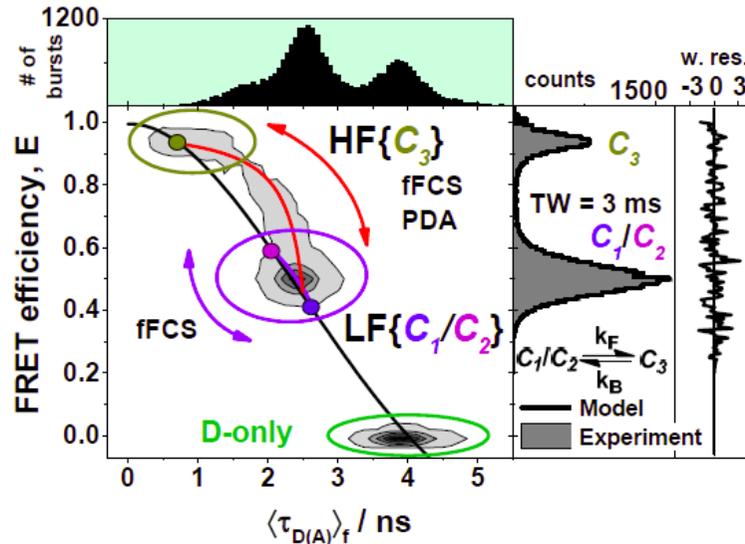
Iteration 1	Iteration 2	
205-430	334-411	205-392
330-422	58-368	318-411
330-368	205-426	61-392
42-430	42-392	39-411
205-368	330-430	61-426
334-430	54-364	64-411
39-368	318-430	205-334
318-368	42-403	35-392
330-411	39-430	58-411
42-426	330-418	



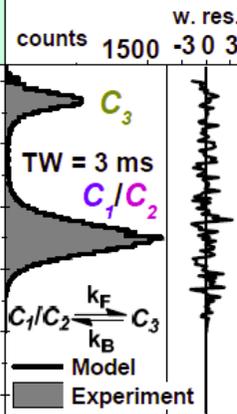
(d) *sub-ensemble TCSPC of LF*



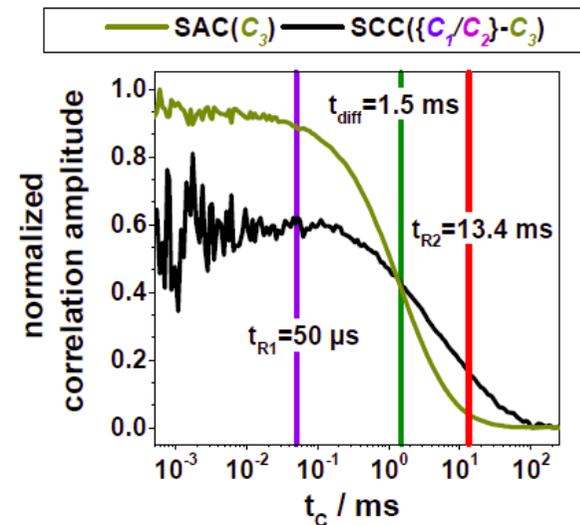
(b) *MFD*



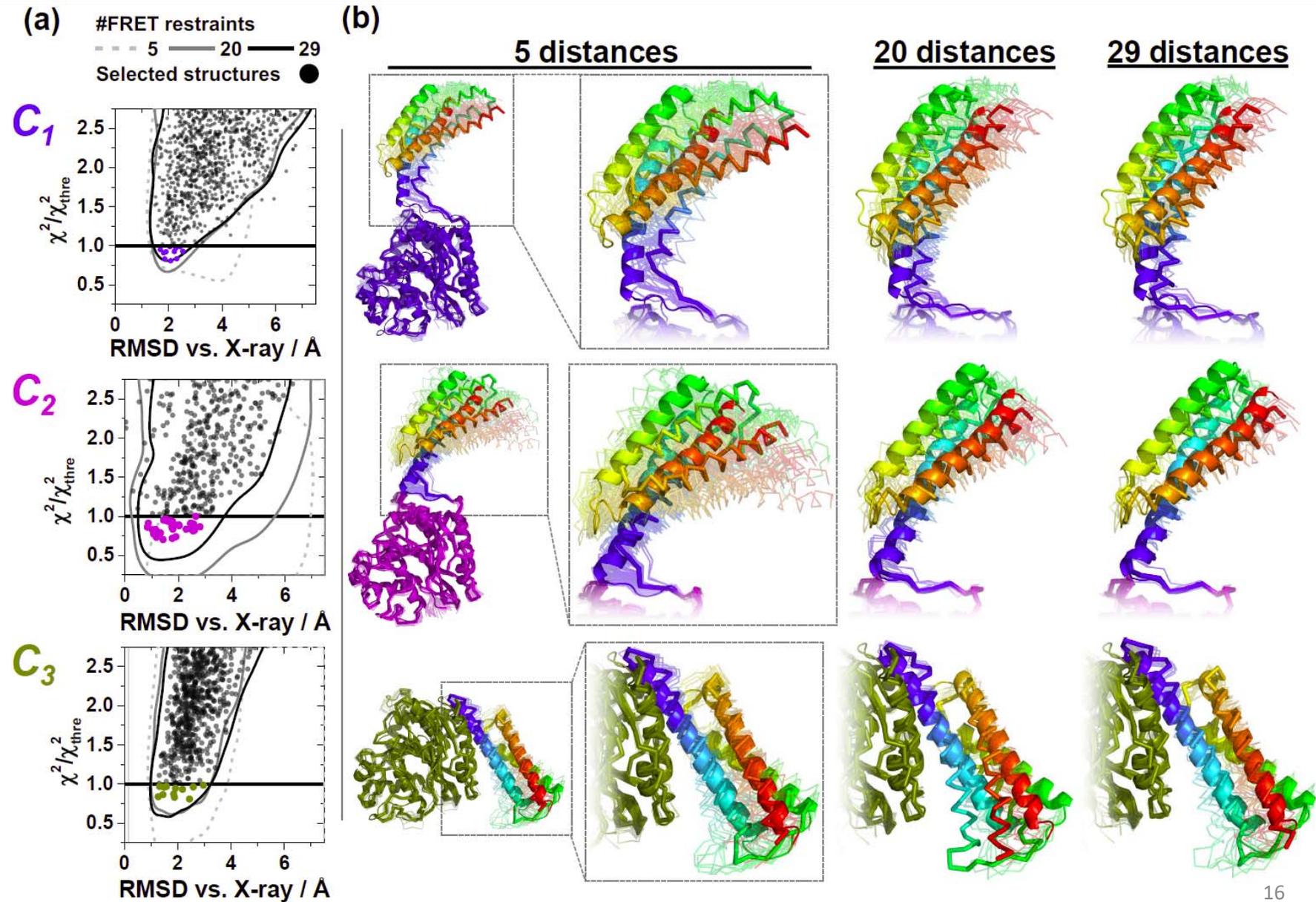
(c) *PDA*



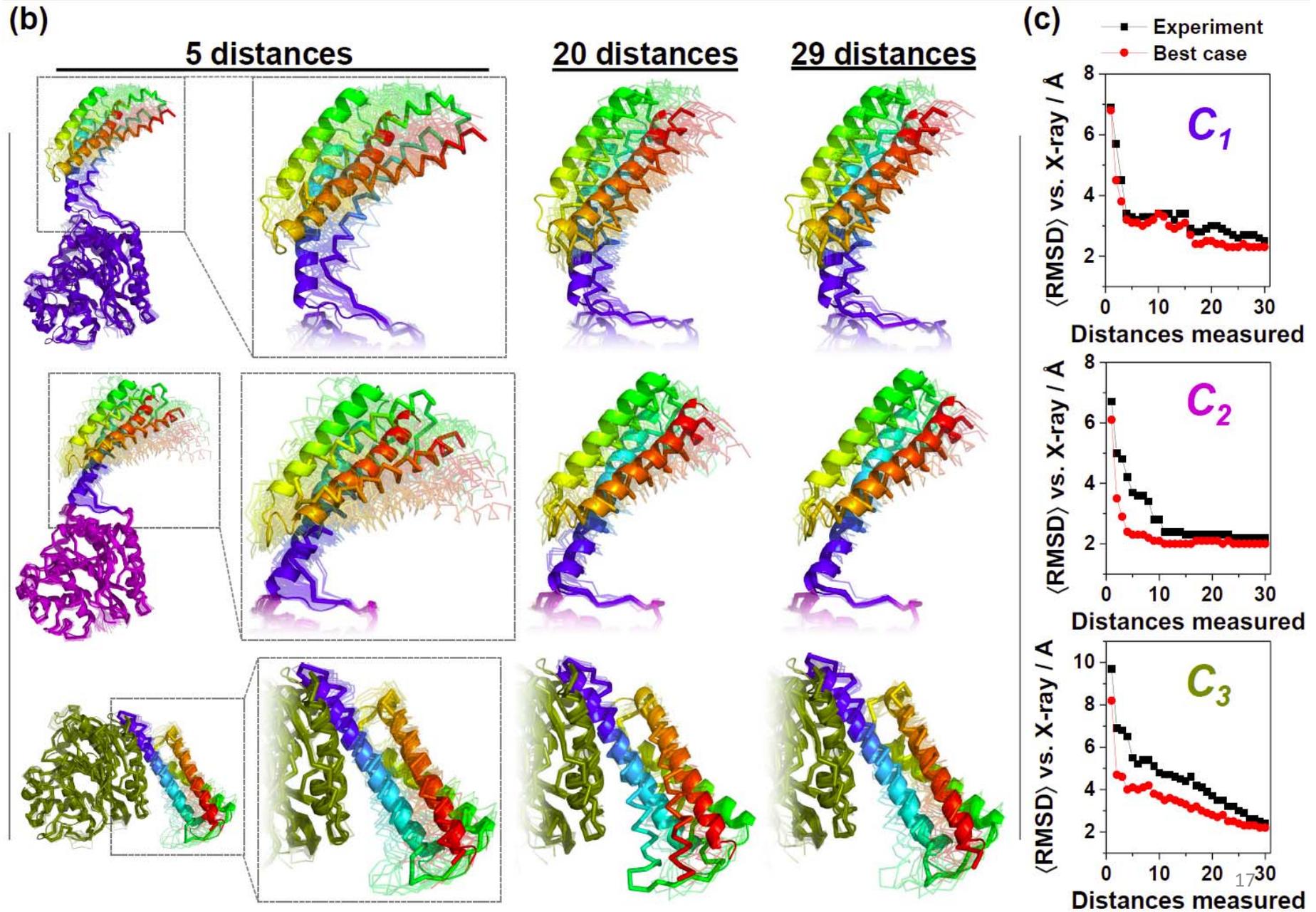
(e) *filtered FCS*



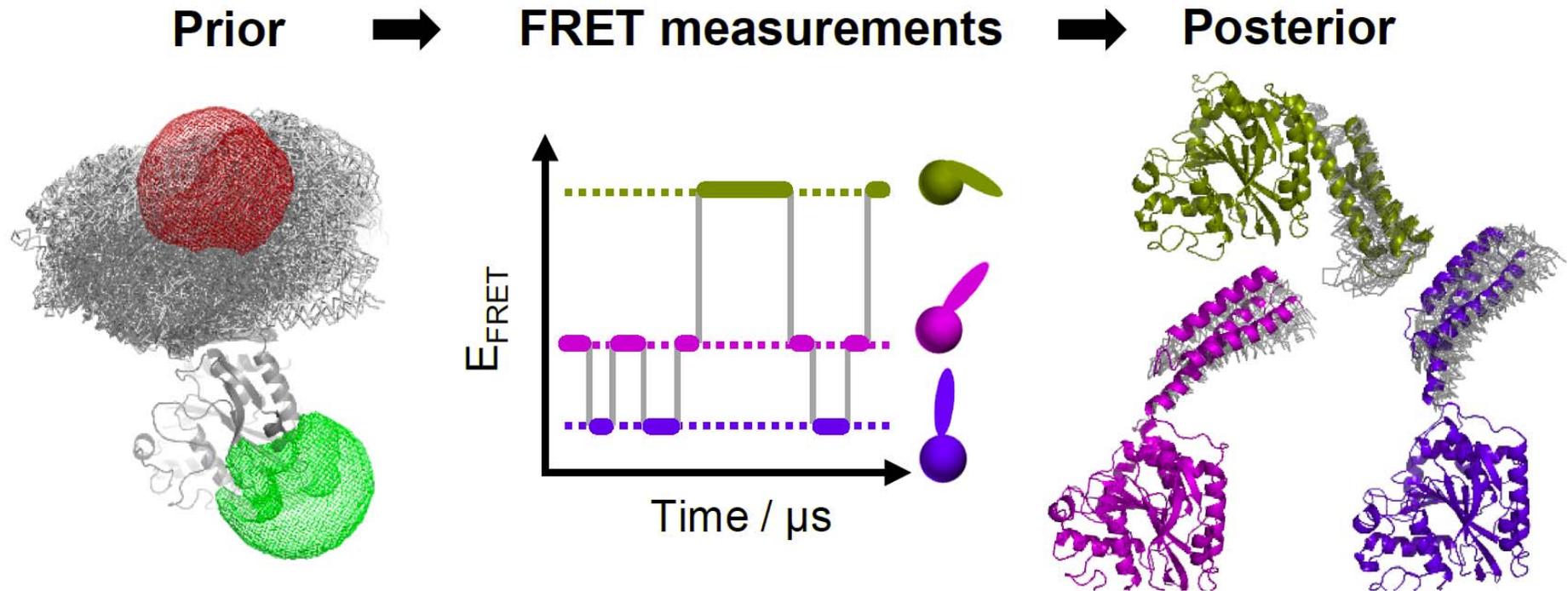
# hybrid-FRET modeling on rails: Precision and accuracy



# hybrid-FRET modeling on rails: How many distances are needed



# Outlook: hybrid-FRET modeling on rails



- Hybrid-FRET on rails automates FRET-based integrative structural modeling
- Automated experiment design assures highest structural quality with minimal effort
- Three protein conformers exchanging at 30  $\mu\text{s}$  and 10 ms resolved in a simulated test
- All three conformers recovered with 1 - 3 Å RMSD accuracy versus target
- Hybrid-FRET modeling captures the architecture of molecular machines in living cells

## Fluorescence-Tools help you to perform exact simulation and analysis

<https://github.com/Fluorescence-Tools>

**LabelLib:** (Python and C++)

Library for coarse-grained simulations of probes flexibly coupled to biomolecules

<https://github.com/Fluorescence-Tools/LabelLib>

**ChiSurf:** (Python)

Global analysis platform for fluorescence data

<https://github.com/Fluorescence-Tools/ChiSurf>

**and more tools**

## FRET-assisted categories in CASP-13

FRET measurements are a label-based technique, where the distance between a donor dye and an acceptor dye are measured. The donor and acceptor dyes are flexibly coupled to specific protein residues. Suggestions on how to process the FRET data:

[http://predictioncenter.org/casp13/doc/FRET\\_CASP13\\_AGSeidel.pdf](http://predictioncenter.org/casp13/doc/FRET_CASP13_AGSeidel.pdf)

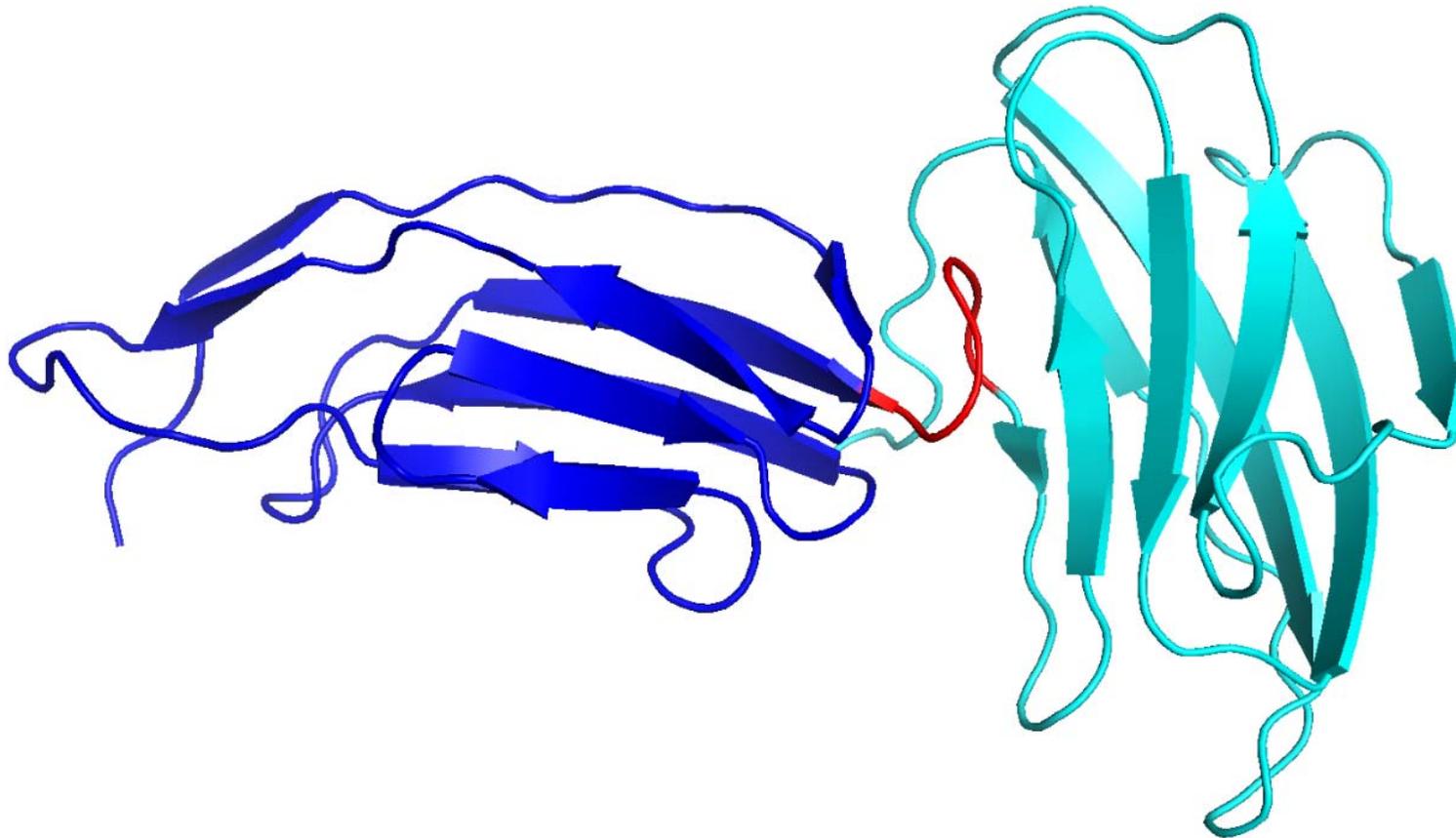
Using FRET data for structural modeling

Table of contents:

- \* FRET pair selection for FRET measurements (p. 2)
- \* Sequences of variants (p. 3-4)
- \* Network of donor-acceptor pairs (p. 5)
- \* Dyes used in the FRET measurements (p. 6)
- \* Labeling of variants (p. 7)
- \* What will be provided (p. 8)
- \* Using FRET data for structural modeling (p. 9)

# Casp13-target: Carbohydrate binding module 56 (CBM56) from $\beta$ -1,3-glucanase of *Bacillus circulans*

---



(domain 1):

aa 1 – 83

NVPVTGVTVNPTTAQVEVGQSVQLN  
ASVAPSNATNKQVTWSVSGSSIASVS  
PNGLVTGLAQGTTT VTATTADGNKA  
ASATITV-

(linker):

aa 84 – 89

APAPST-

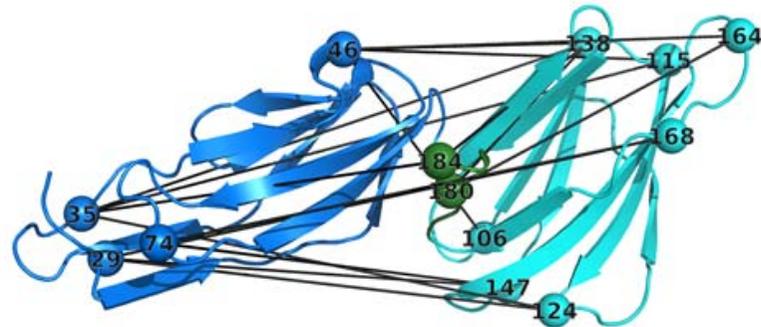
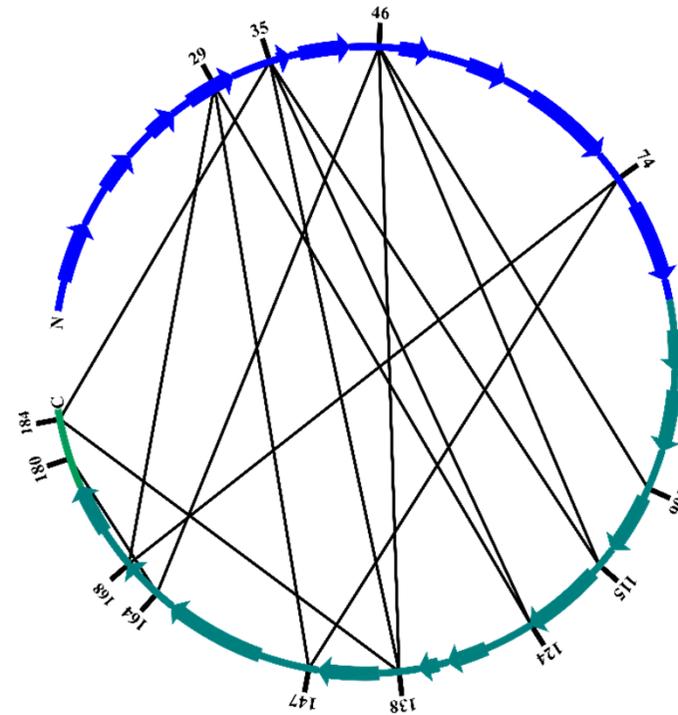
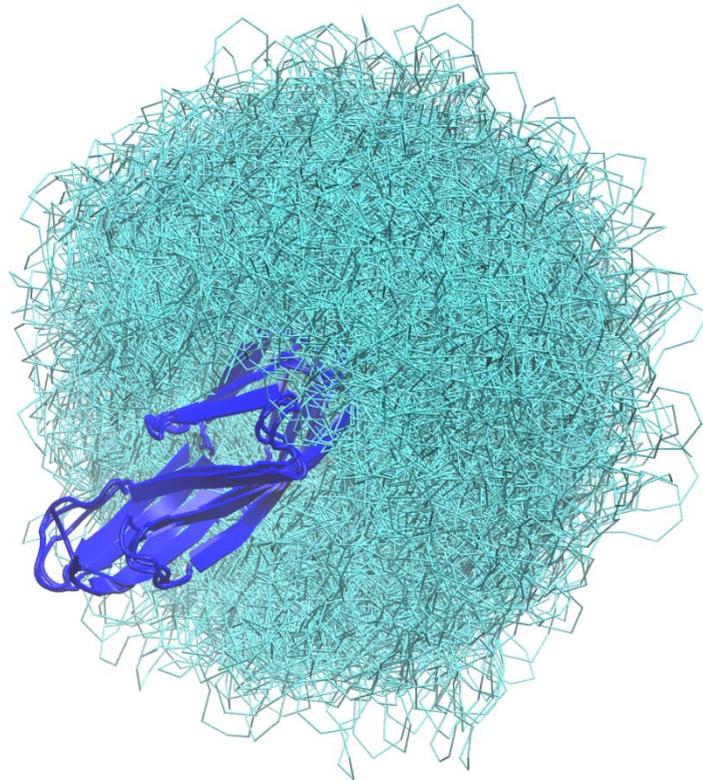
(domain 2):

aa 90 – 184:

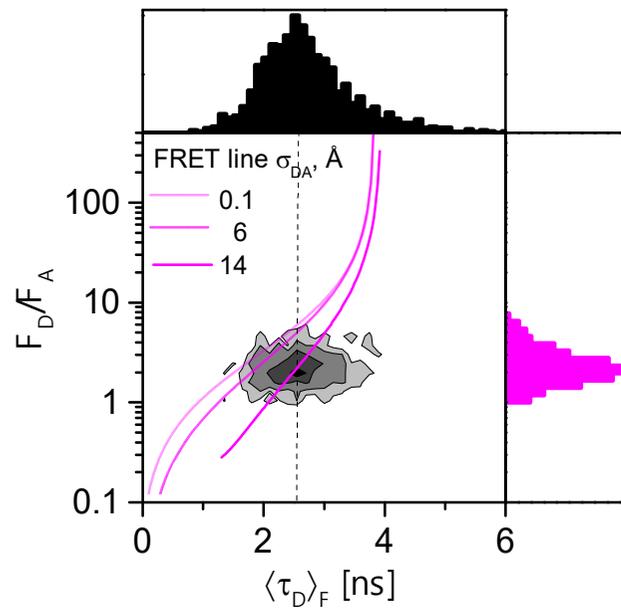
VIVIGDEVKGLKKIGDDLLFYVNGATFADLH  
YKVNNGGQLNVAMAPTGNNGNYTYPVHN  
LKHGDTVEYFFTYPGQGALDTPWQTYV  
HGVTQGTPE

# Prior and FRET-network for CBM56

---



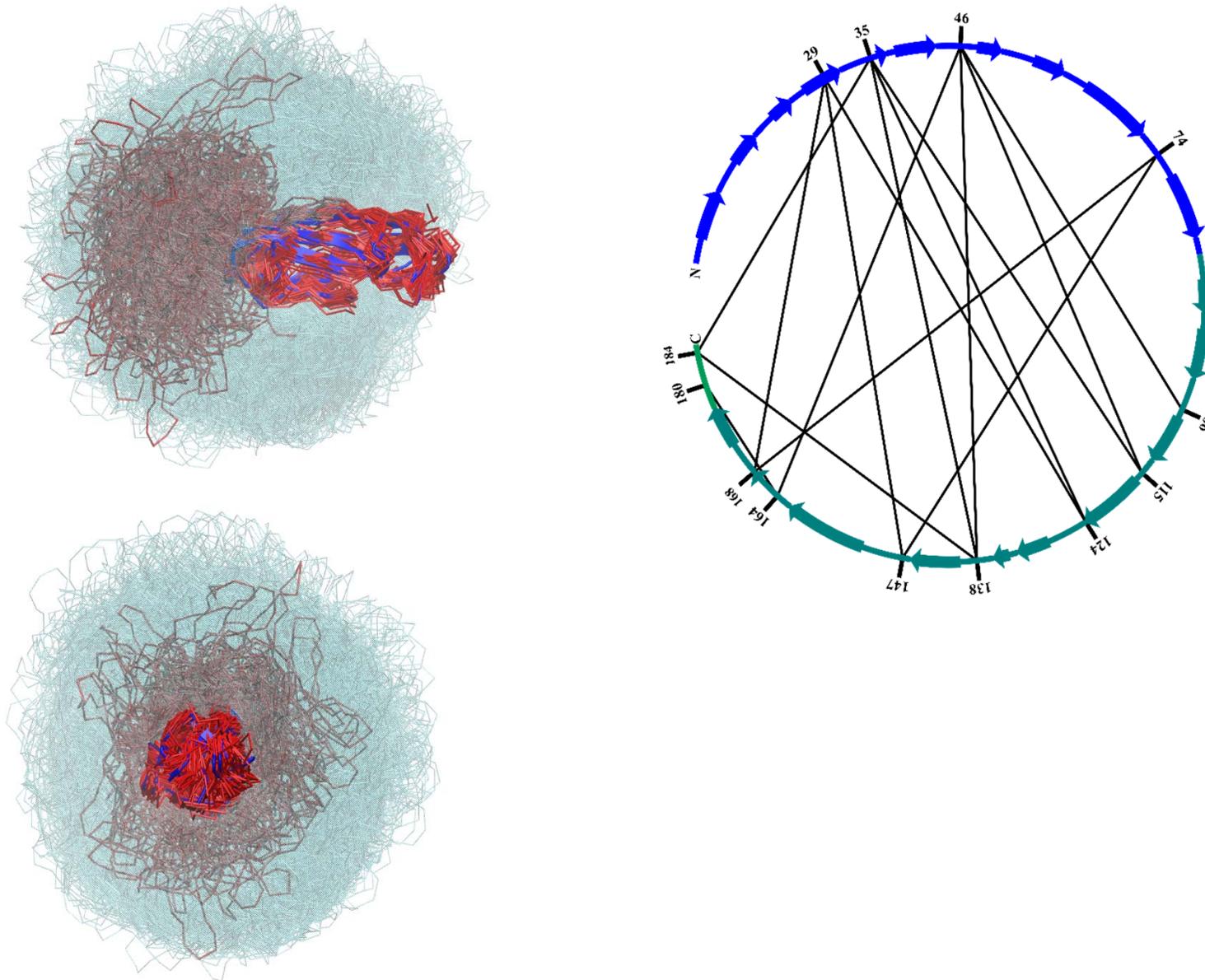
# First results: sm-FRET analysis for CBM56



Variant (mutations introduced for labeling)	Labeling successful	Dynamic shift visible?
1 (A29C, D168C)	OK	yes, large
2 (N35C, T115C)	OK	yes, large-medium
3 (A29C, N147C)	OK	yes, medium
4 (S46C, T115C)	OK	yes, large-medium
5 (S46C, D106C)	did not work yet	-
6 (N35C, N124C)	OK	medium-small
7 (N74C, D168C)	OK	large
8 (N35C, N138C)	OK	large
9 (A29C, N124C)	OK	medium-large
10 (S46C, Q164C)	did not work yet	-
11 (S46C, N138C)	OK	medium-large
12 (N74C, N147C)	OK	medium
13 (N138C, E184C)	OK	yes (slow)
14 (Q164C, Q180C)	OK	yes (slow)

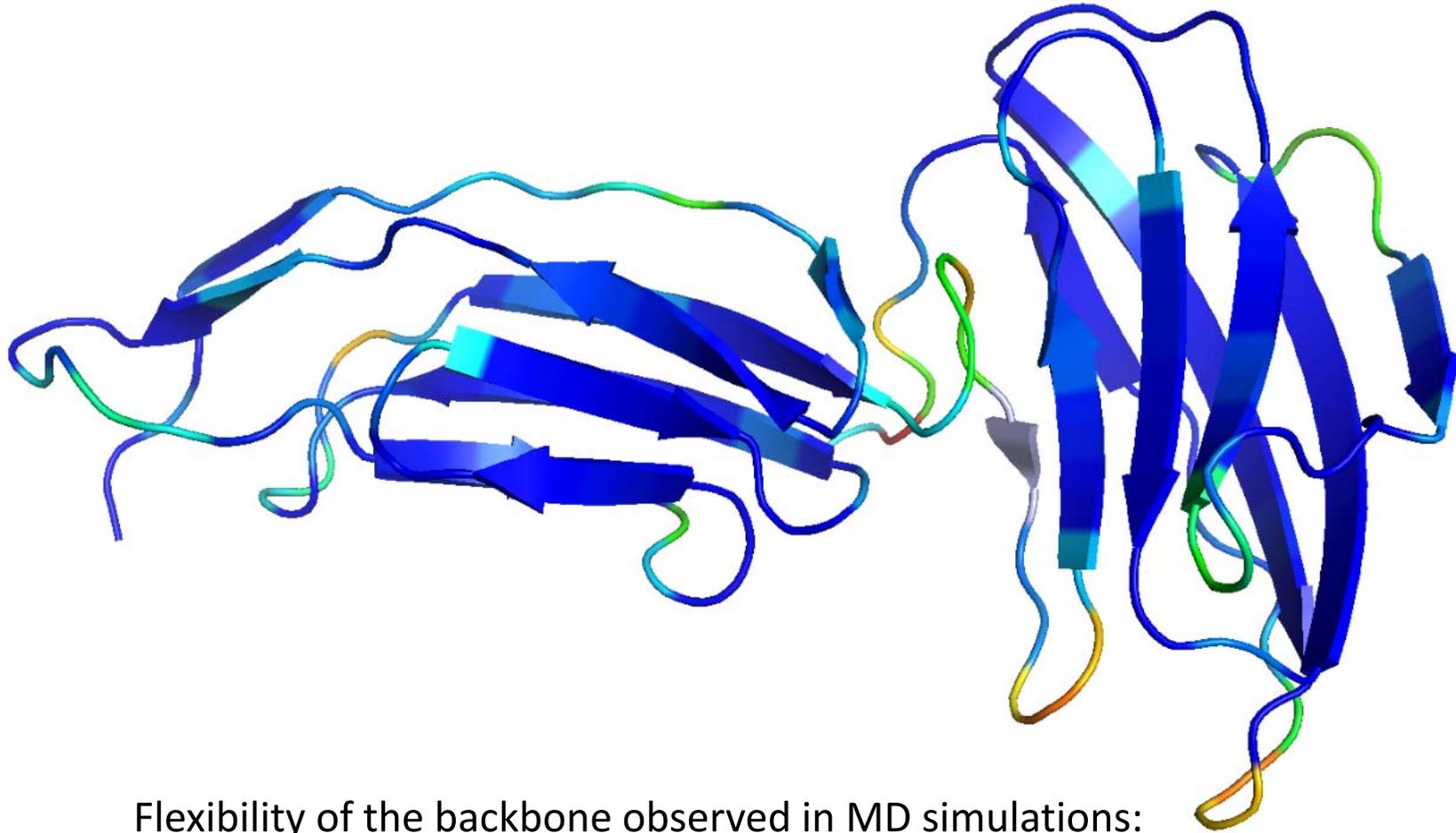
# Prior and FRET-network for CBM56

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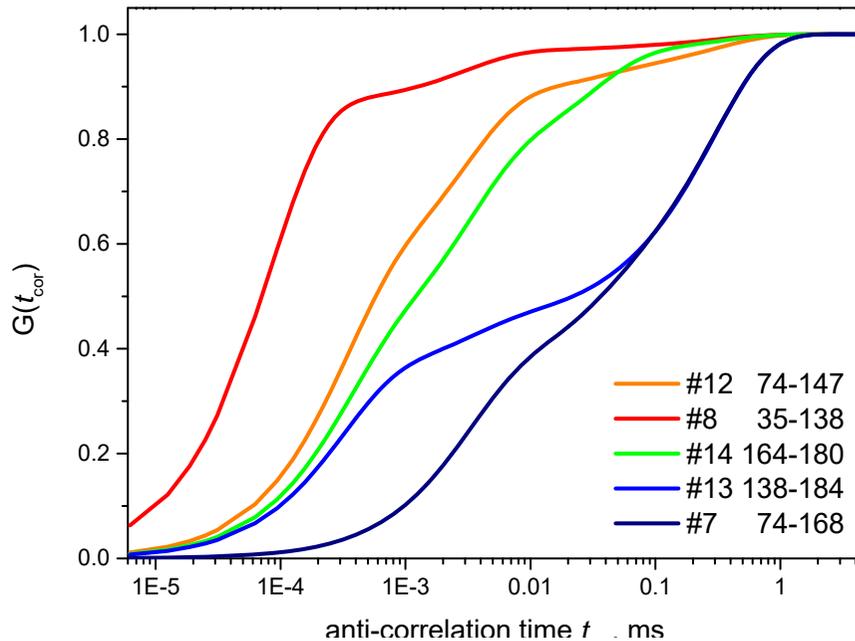
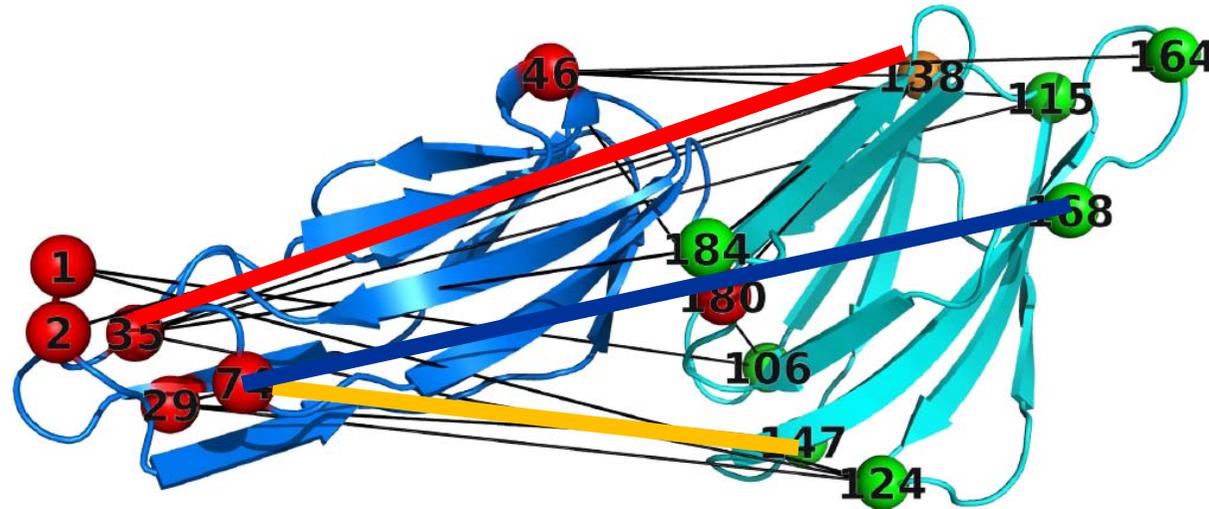
# Local flexibility of CBM56

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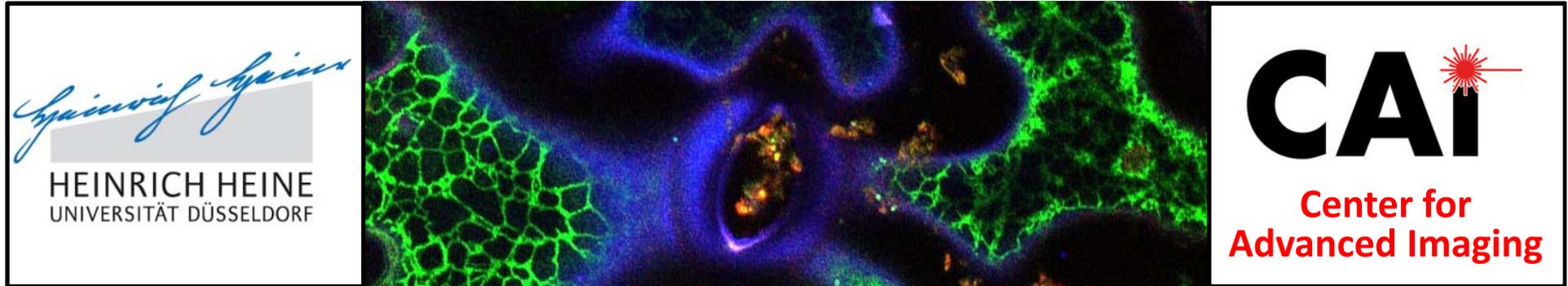
blue – cyan – green – yellow – orange – red  
rigid flexible

# Local and Global flexibility of CBM56



Spectrum of relaxation times of conformational dynamics obtained by filtered FCS

# Acknowledgements



## Seidel group:

M. Dimura, A. Larbig, B. Reschke, Jakub Kubiak, T. Peulen,

## Gohlke group:

D. Mulnaes

**Support:** DFG, BMBF and ERC

**- Jobs offers:**

open Ph.D. and PostDoc positions

**- NEW !!! Soft- and Hardware:**

[www.mpc.hhu.de/software](http://www.mpc.hhu.de/software)



European Research Council

Established by the European Commission

hybridFRET :ERC Advanced Grant<sup>27</sup> 2014