

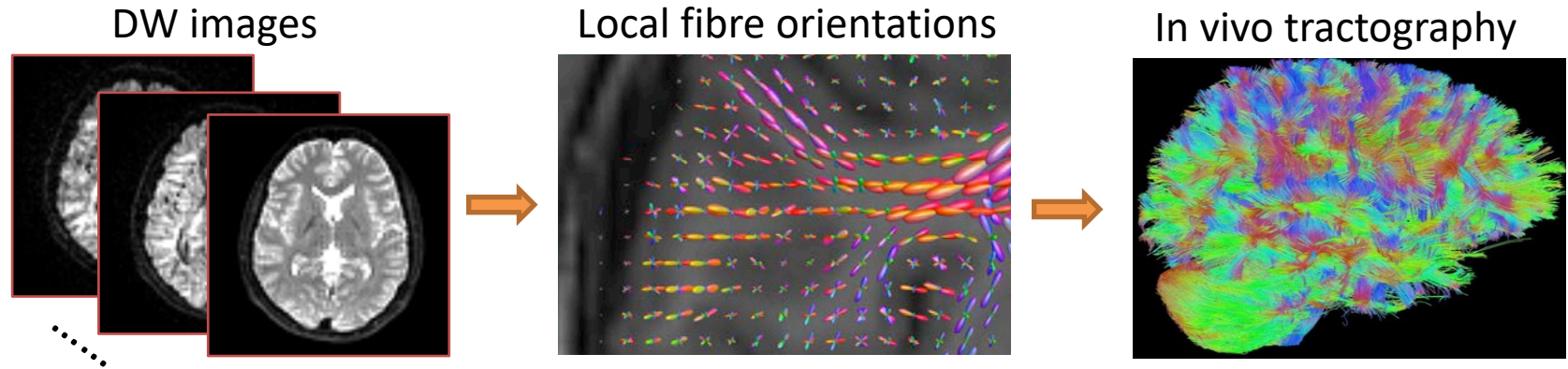
# Fibre Orientation Estimation with Deep Learning

TING GONG, PhD  
POST-ISMRM MIML WORKSHOP  
13 May 2022

# ● What is fibre orientation estimation & why

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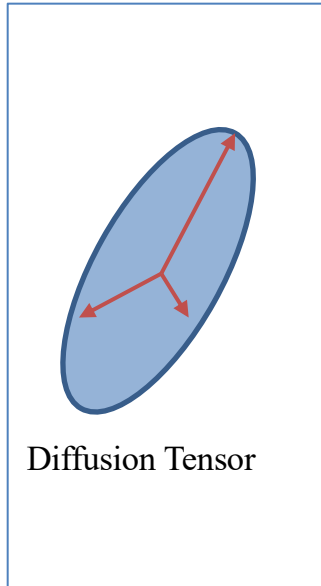
1



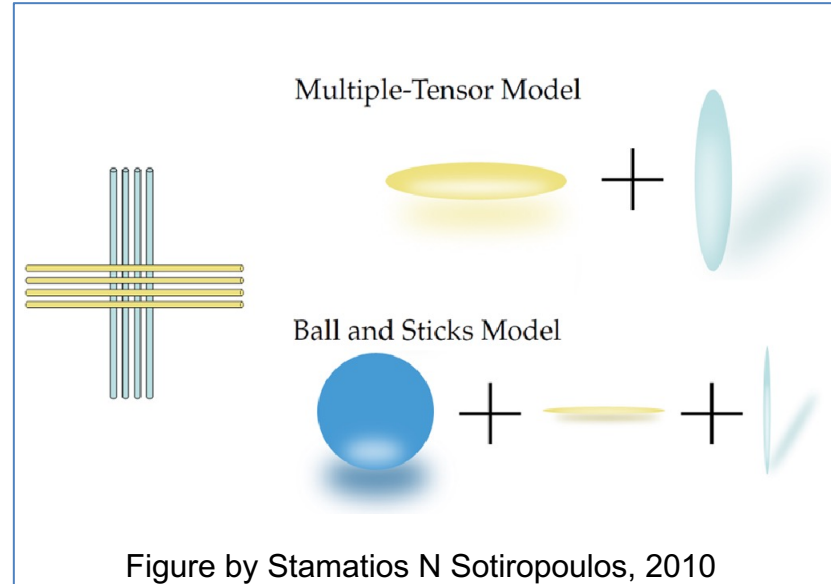
# ● From single orientation to fODF

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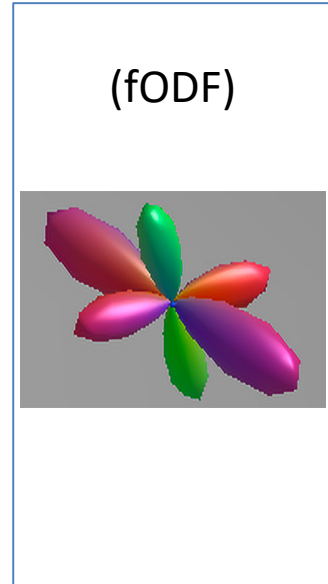
## Single Orientation



## Multiple Orientations



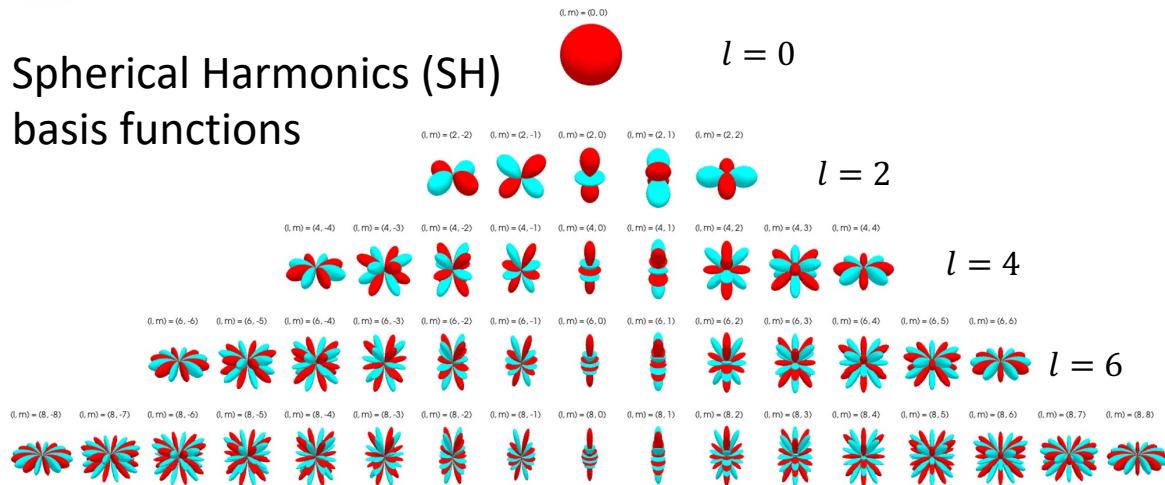
## Fibre Orientation Distribution function (fODF)



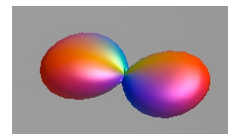
# How to estimate fODF conventionally

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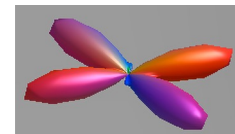
Spherical Harmonics (SH)  
basis functions



$$l_{max} = 4$$

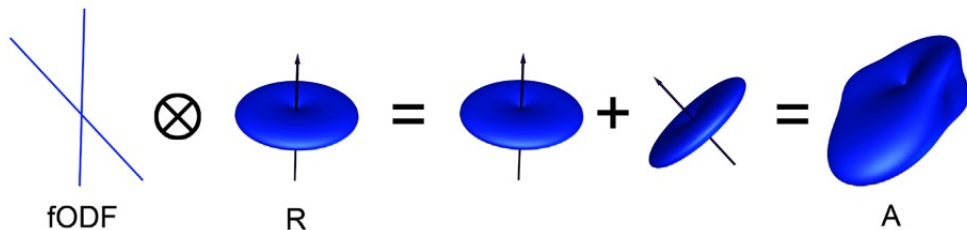


$$l_{max} = 8$$



Number of SH coefficients:

$$(l_{max} + 1)(l_{max} + 2)/2$$



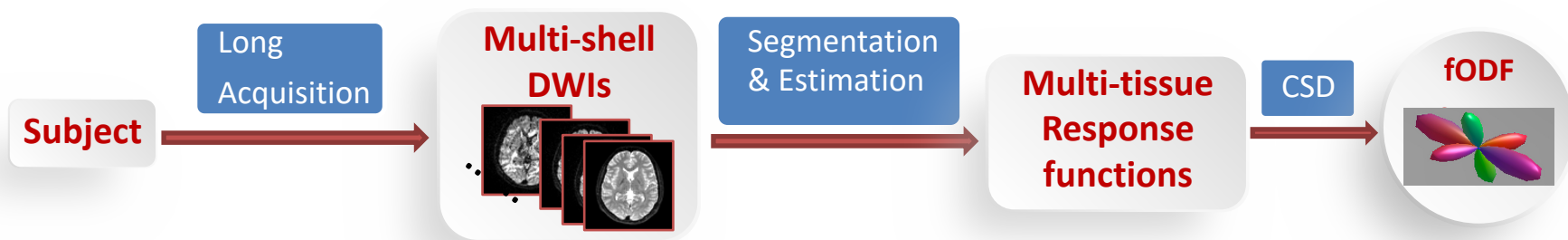
**Constrained Spherical Deconvolution  
(CSD)**

# ● State-of-art CSD approach & challenges

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4

1. Long acquisition time
2. Multiple processing steps



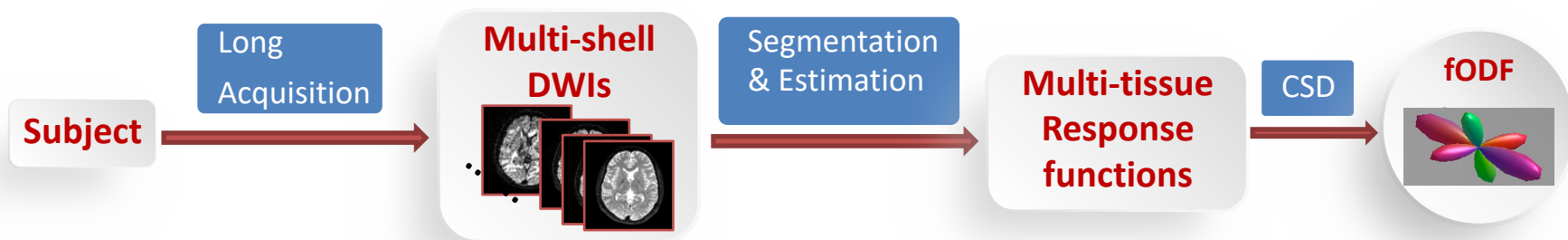
Pipeline of Multi-shell Multi-tissue (MSMT)-CSD

Jeurissen B, et al. NeuroImage, 2014

# ● How can DL help improve

5

- |   |   |  |
|---|---|--|
| <ol style="list-style-type: none"><li>1. Long acquisition time</li><li>2. Multiple processing steps</li></ol> | <b>DL</b><br> | <ol style="list-style-type: none"><li>1. Rapid acquisition with fewer DW measurements</li><li>2. End to end estimation</li></ol> |
|---|---|--|



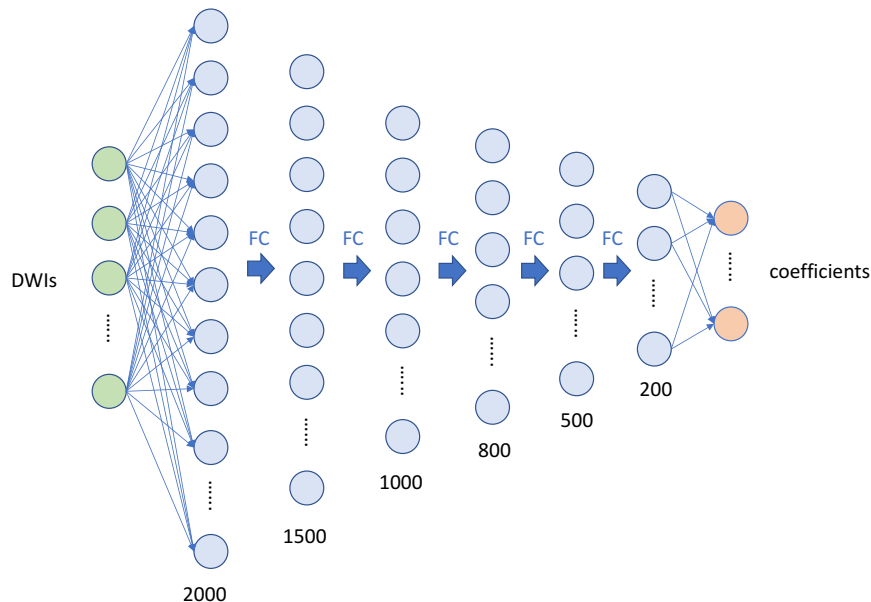
Pipeline of Multi-shell Multi-tissue (MSMT)-CSD

Jeurissen B, et al. NeuroImage, 2014

# ● An example of how DL works

6

➤ Multi-output regression task **per voxel**:  $f(d) = x$



**Architecture:** multi-layer perceptron (MLP)

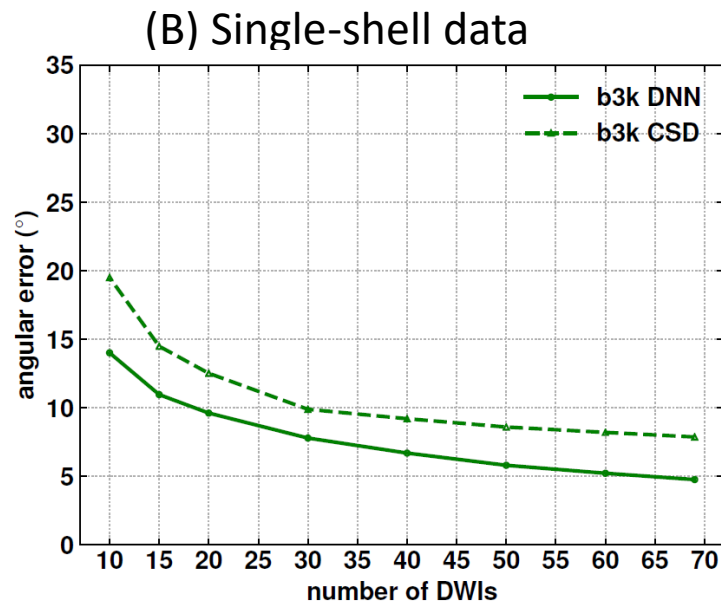
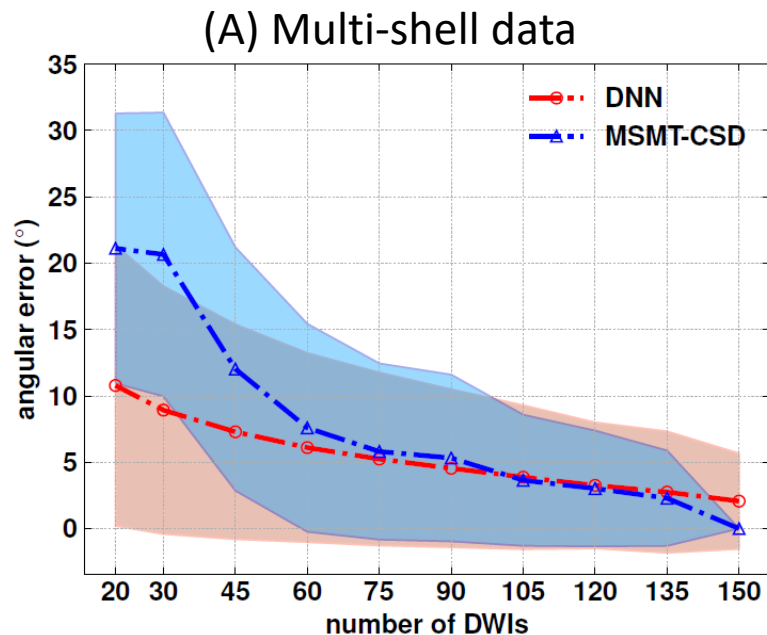
**Inputs:** undersampled DWI measurements

**Outputs:** 45 SH coefficients at  $l_{max}=8$

**Training labels** generated from MSMT-CSD with a rich sampled dataset

# Reduced angular error when under-sampling 7

- Evaluation reference: MSMT-CSD estimation from 150 measurements
- including 14  $b=0$ , 23  $b=1000$ , 45  $b=2000$ , and 68  $b=3000$  s/mm<sup>2</sup>





# ● Questions to consider with DL methods

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8

1. What is the right Input Information

- MLP [1][3][4]
- Patch-based CNN [2][5]

2. What to use as training labels

- MSMT-CSD [1-2][4-5]
- Simulation [2][4]
- Histology [3]

3. How to Handle protocol difference

- SH basis[2][3]
- Gradient resampling [4]
- fODF [5]

[1] Gong T, et al. *ISMRM*, 2018

[2] Lin Z and Gong T, et al. *Medical Physics*, 2019

[3] Nath V, et al. *MRI*, 2019

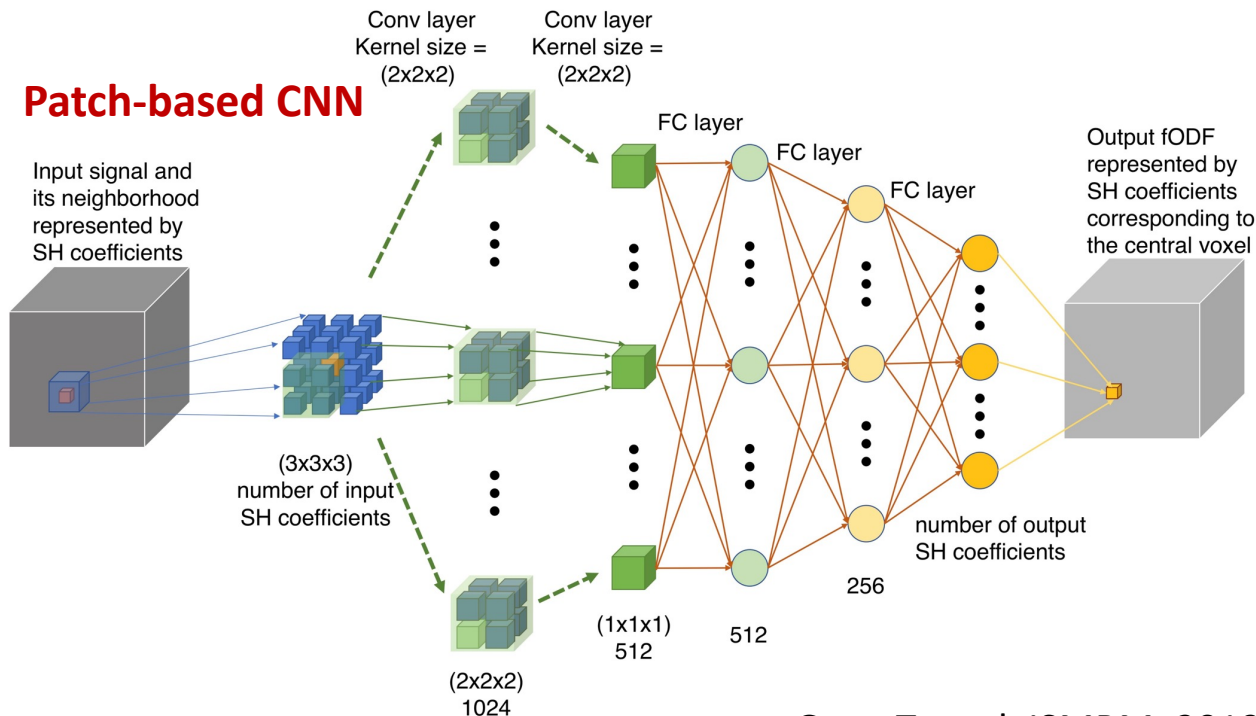
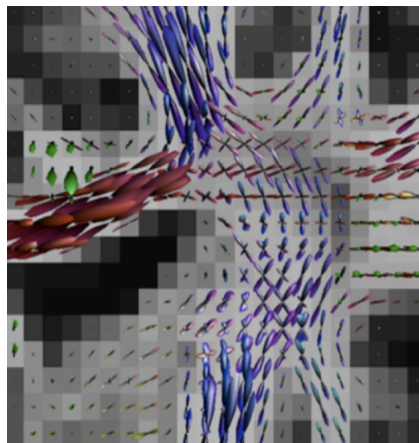
[4] Karimi D, et al. *Neuroimage*, 2021

[5] Zeng R, et al. *Medical Image Analysis*, 2022

# 1. What is the right input information

9

## ➤ Making use of spatial information

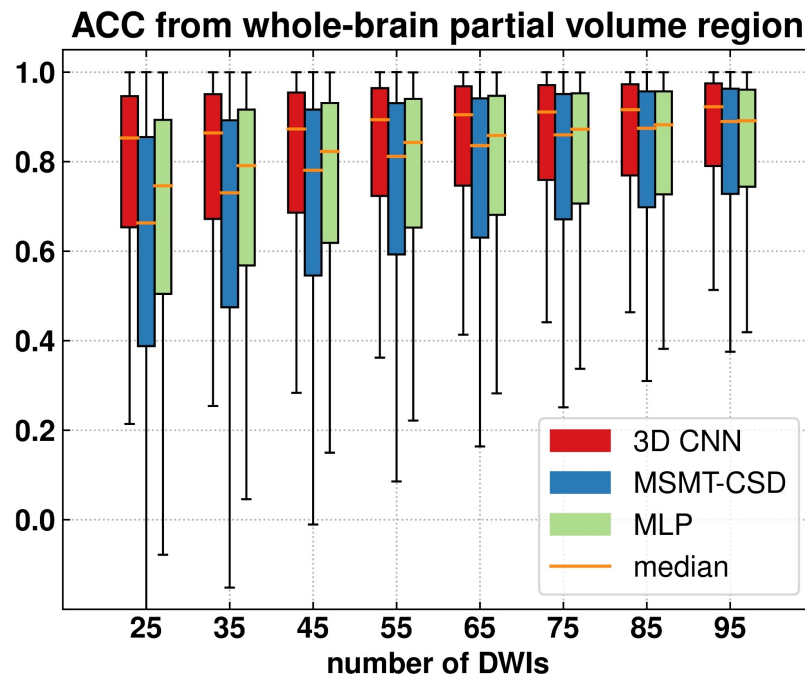
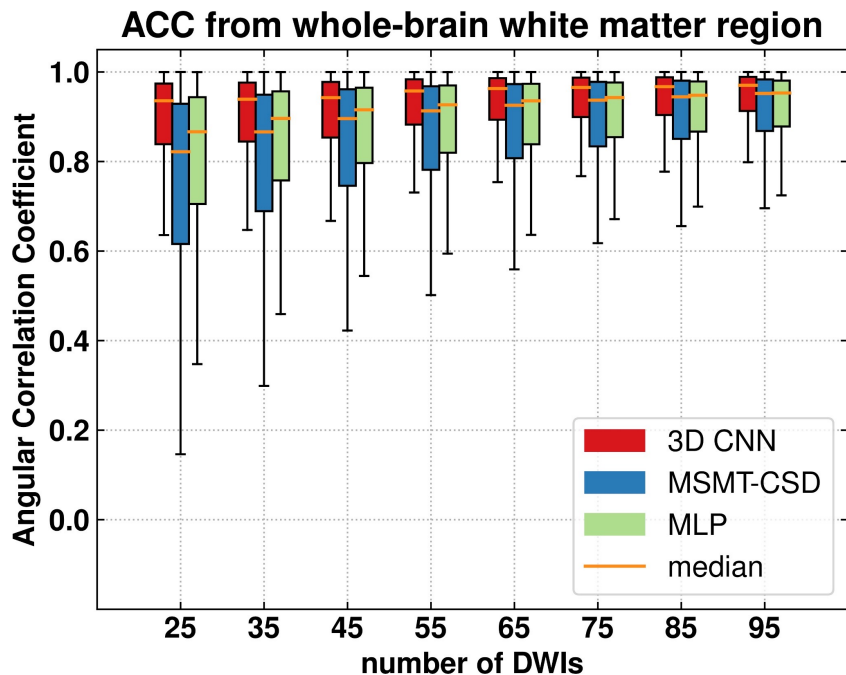


Gong T, et al. ISMRM, 2019

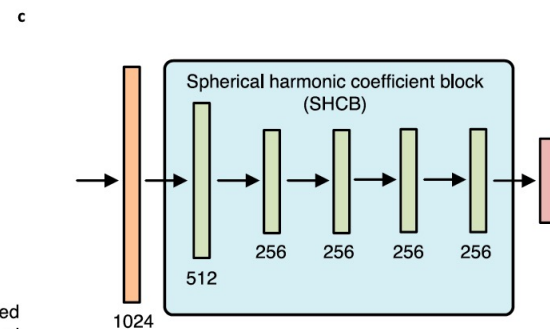
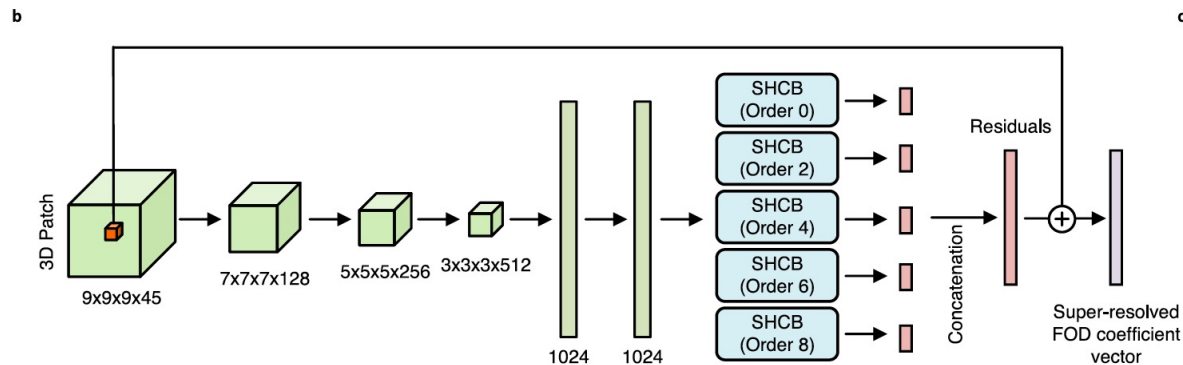
Lin Z and Gong T, et al. Medical Physics, 2019

# ● Improvement to MSMT-CSD & MLP

10



Gong T, et al. ISMRM, 2019  
Lin Z and Gong T, et al. Medical Physics, 2019



## 2. What to use as training labels

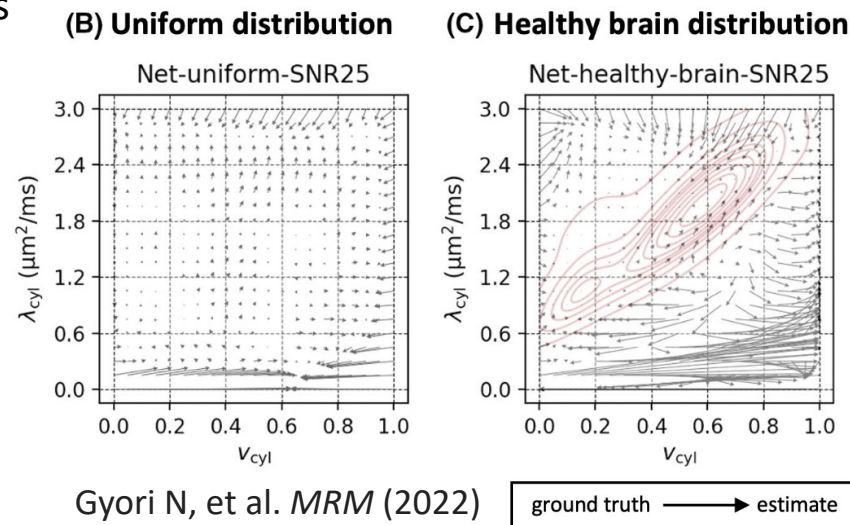
12

### ➤ MSMT-CSD estimation from rich-sampled in vivo data

- not always available
- training and evaluation bounded by the quality of estimation
- generalisation issue to pathological datasets

### ➤ Simulation

- distribution matters
- including brain structures



## 2. What to use as training labels

13

### ➤ MSMT-CSD estimation from rich-sampled in vivo data

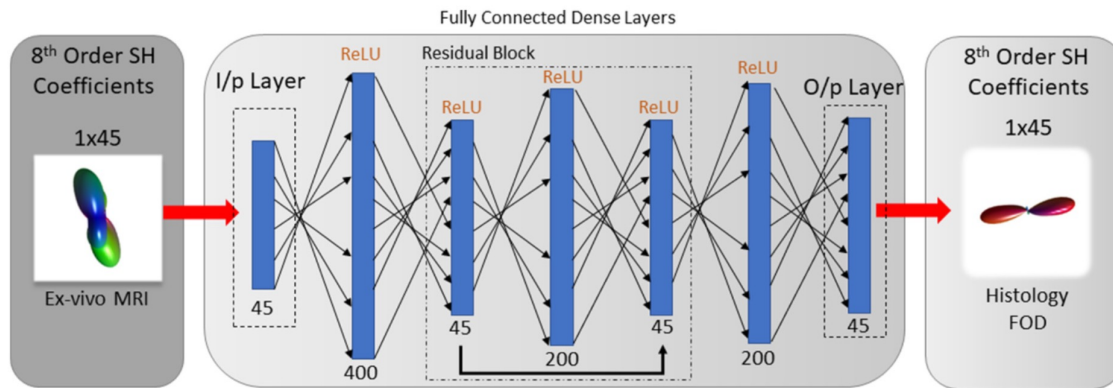
- not always available
- training and evaluation bounded by the quality of estimation
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### ➤ Simulation

- distribution matters
- including brain structures

### ➤ Histology

- hard to get
- gaps between in vivo and ex vivo
- gaps between MR signals and histology



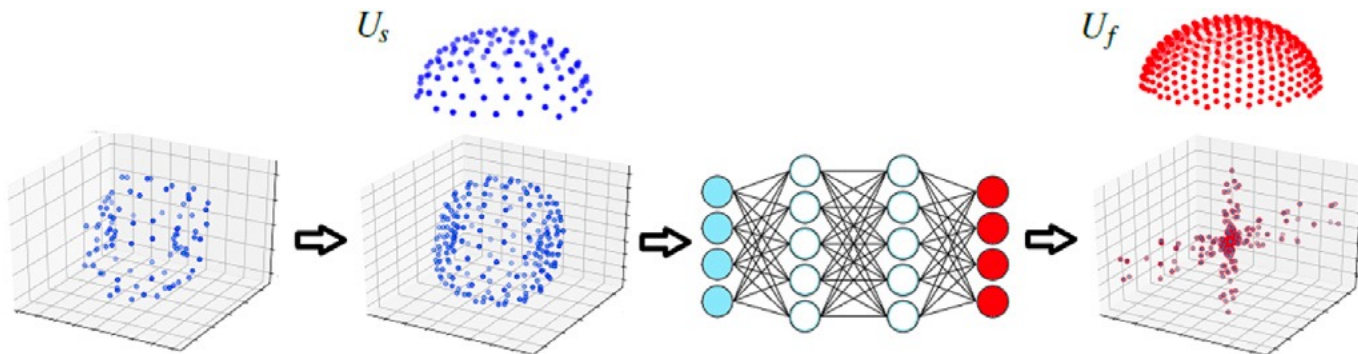
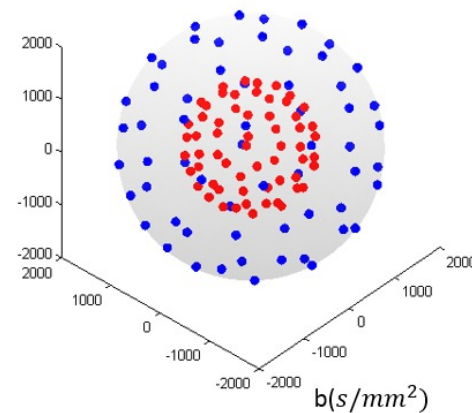
Nath V, et al. *MRI*, 2019

# 3. How to handle protocol differences

15

## ➤ Differences in gradient directions

- **Using SH basis**  
(Lin Z and Gong T, et al. *Medical Physics*, 2019; Nath V, et al. *MRI*, 2019)
- **Resampling gradient**  
(Karimi D, et al. *Neuroimage*, 2021)



# 3. How to handle protocol differences

16

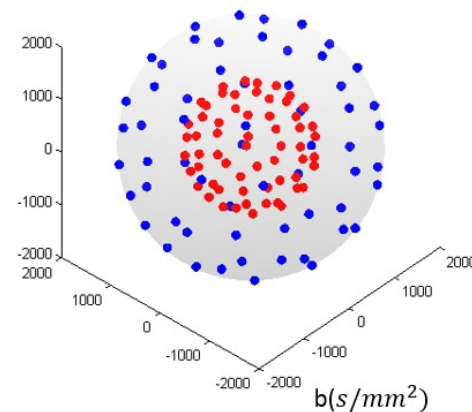
## ➤ Differences in gradient directions

- **Using SH basis**

(Lin Z and Gong T, et al. *Medical Physics*, 2019; Nath V, et al. *MRI*, 2019)

- **Resampling gradient**

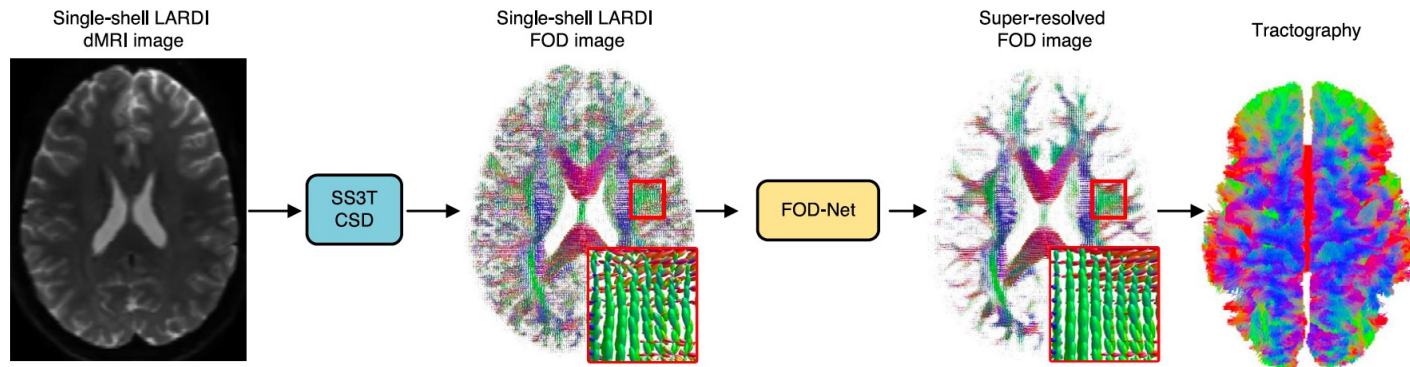
(Karimi D, et al. *Neuroimage*, 2021)



## ➤ Difference in b values

- **Using fODF**

(Zeng R, et al. *Medical Image Analysis*, 2022)





- DL based method can improve fODF estimation compared to the conventional method
- Choice of the Training dataset
- Protocol difference
- Generalizability issue