When Diffusion MRI Meets Diffusion Model: A Novel Deep Generative Model for Diffusion MRI Generation

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- **Goal of the paper:**

Generation of dMRI using machine learning to enhance image quality while reducing acquisition costs and scanning time

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propose a novel generative approach to perform high quality dMRI generation using deep diffusion models

- ***Diffusion model***

a forward diffusion stage, where Gaussian noise is added to input data progressively

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followed by a reverse diffusion stage aimed at gradually reverting the process to recover original input

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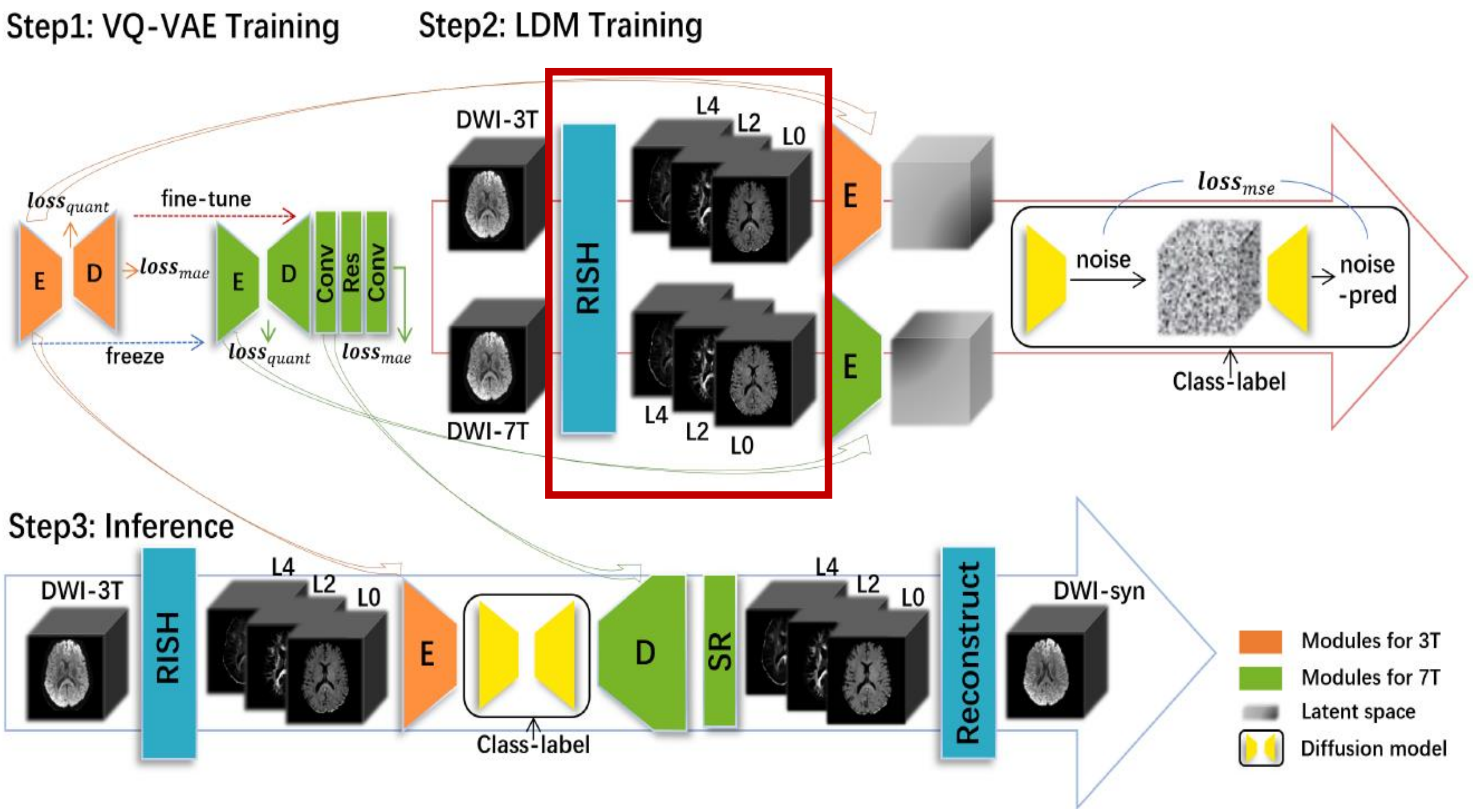
- **Model architecture**



Training Time

1. Computing ***Rotation Invariant Spherical Harmonic (RISH)*** features in different orders for a compact representation of input 3T and 7T dMRI

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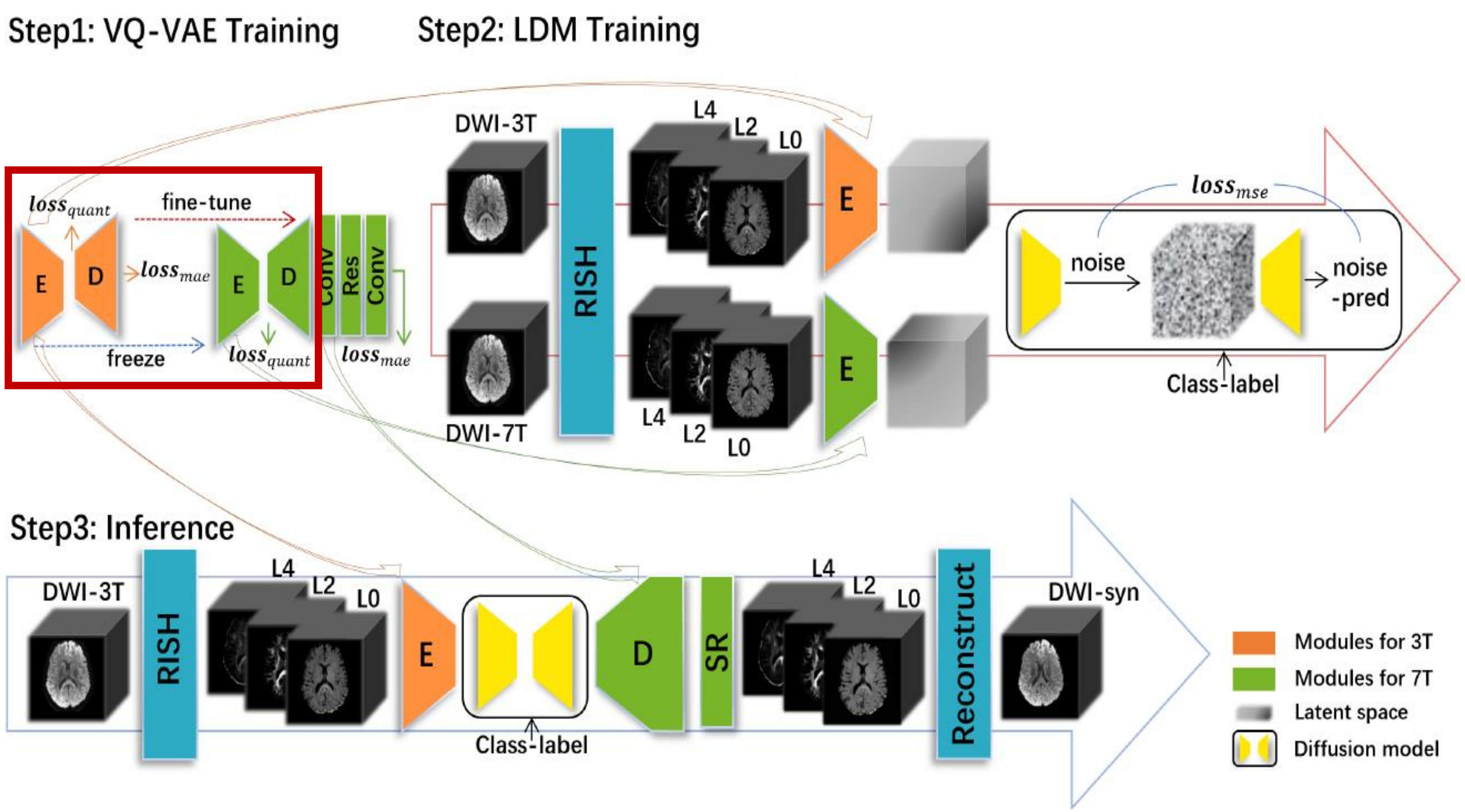

Training Time

1. Computing RISH features

2. Vector Quantised-Variational AutoEncoder (VQ-VAE)

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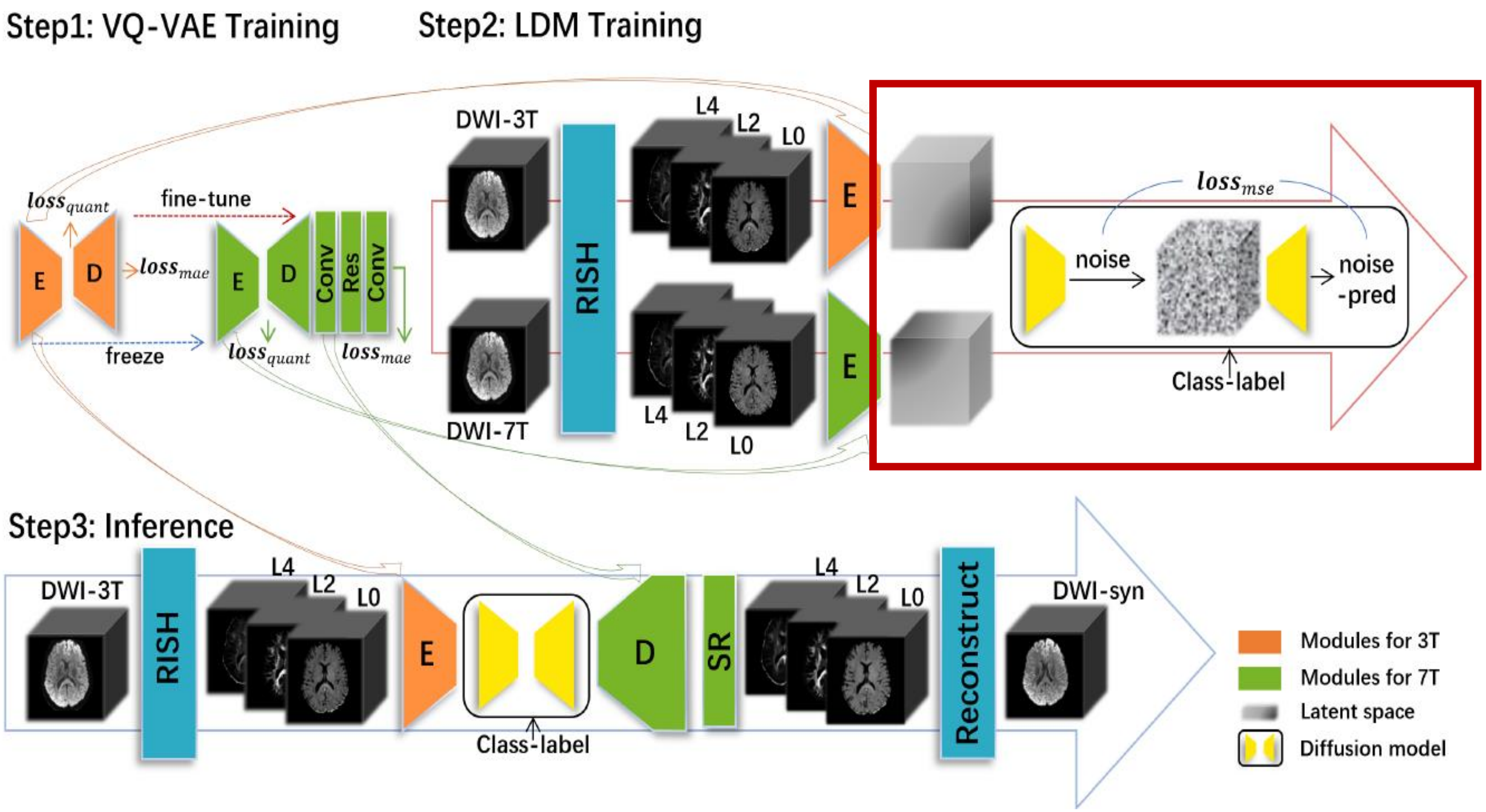

Training Time

1. Computing RISH features

2. Vector Quantised-Variational AutoEncoder (VQ-VAE)

3. VQ-VAE's encoder outputs used as inputs for diffusion model

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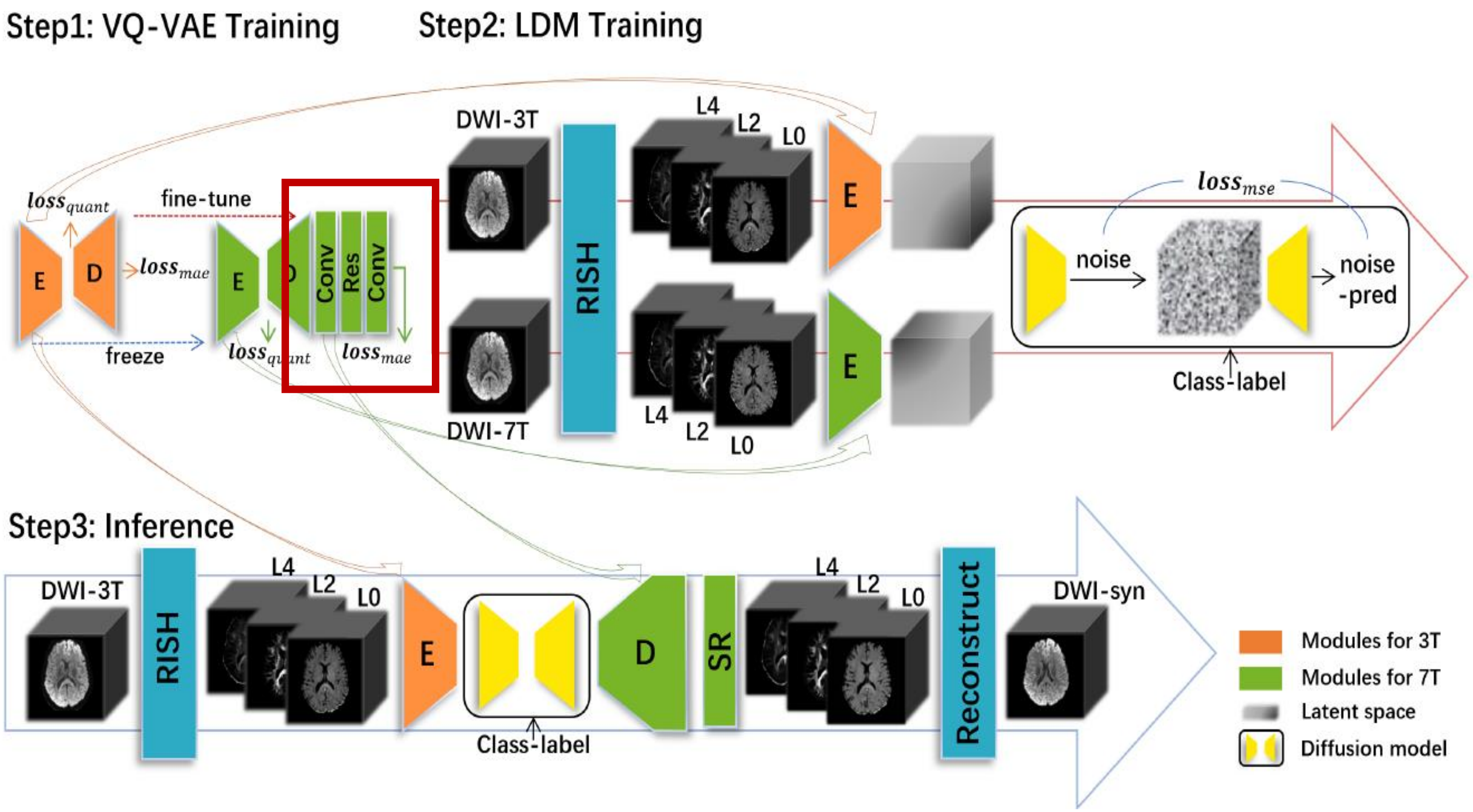

Training Time

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4. train the super-resolution module using the dataset generated by LDM

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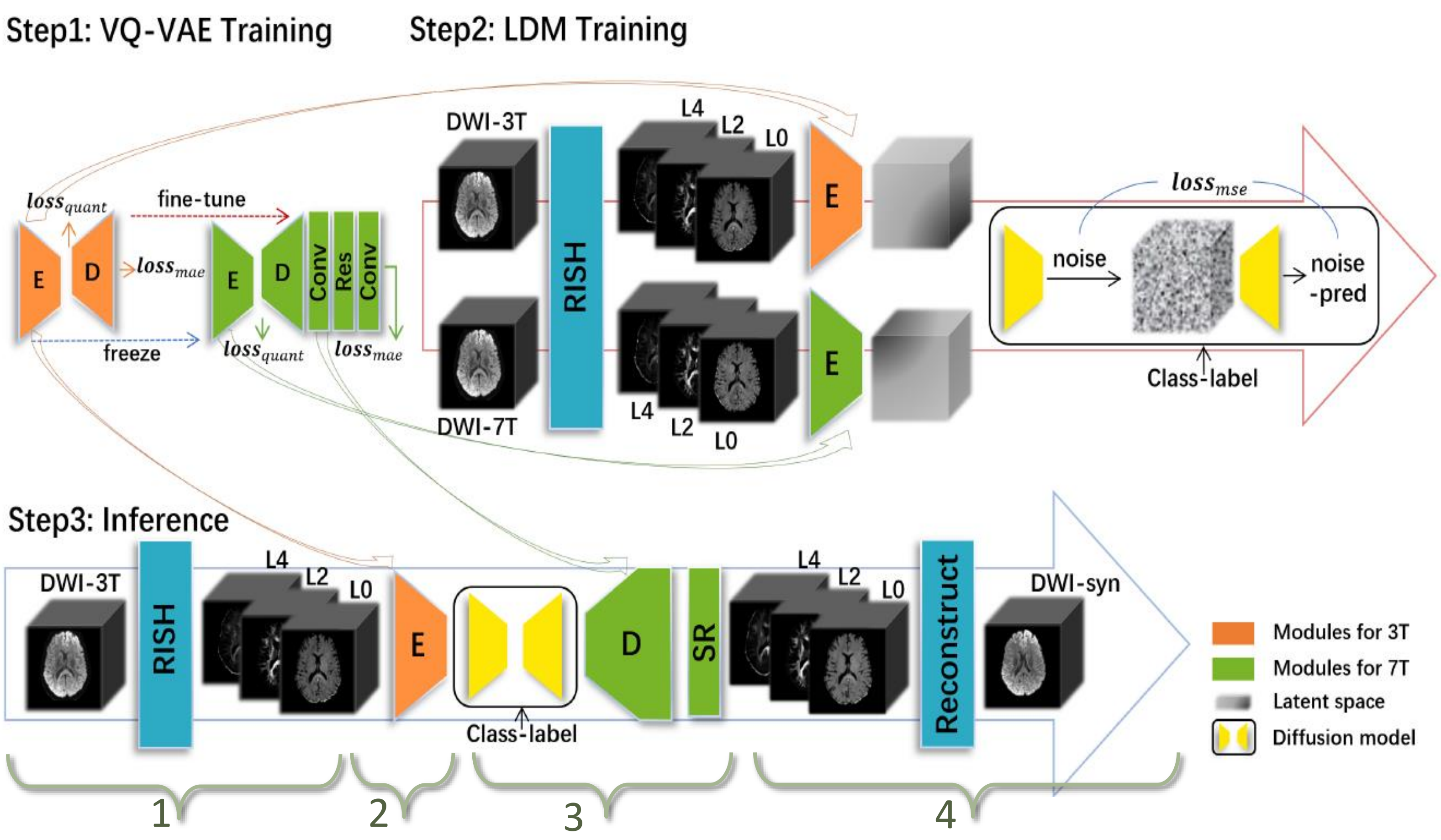

Inference Time

1. RISH features of 3T test data
2. Using 3T encoder to encode into latent space
3. Diffusion model followed by decoder and super resolution model
4. Generating 7T-like RISH features to reconstruct a high quality 7T dMRI

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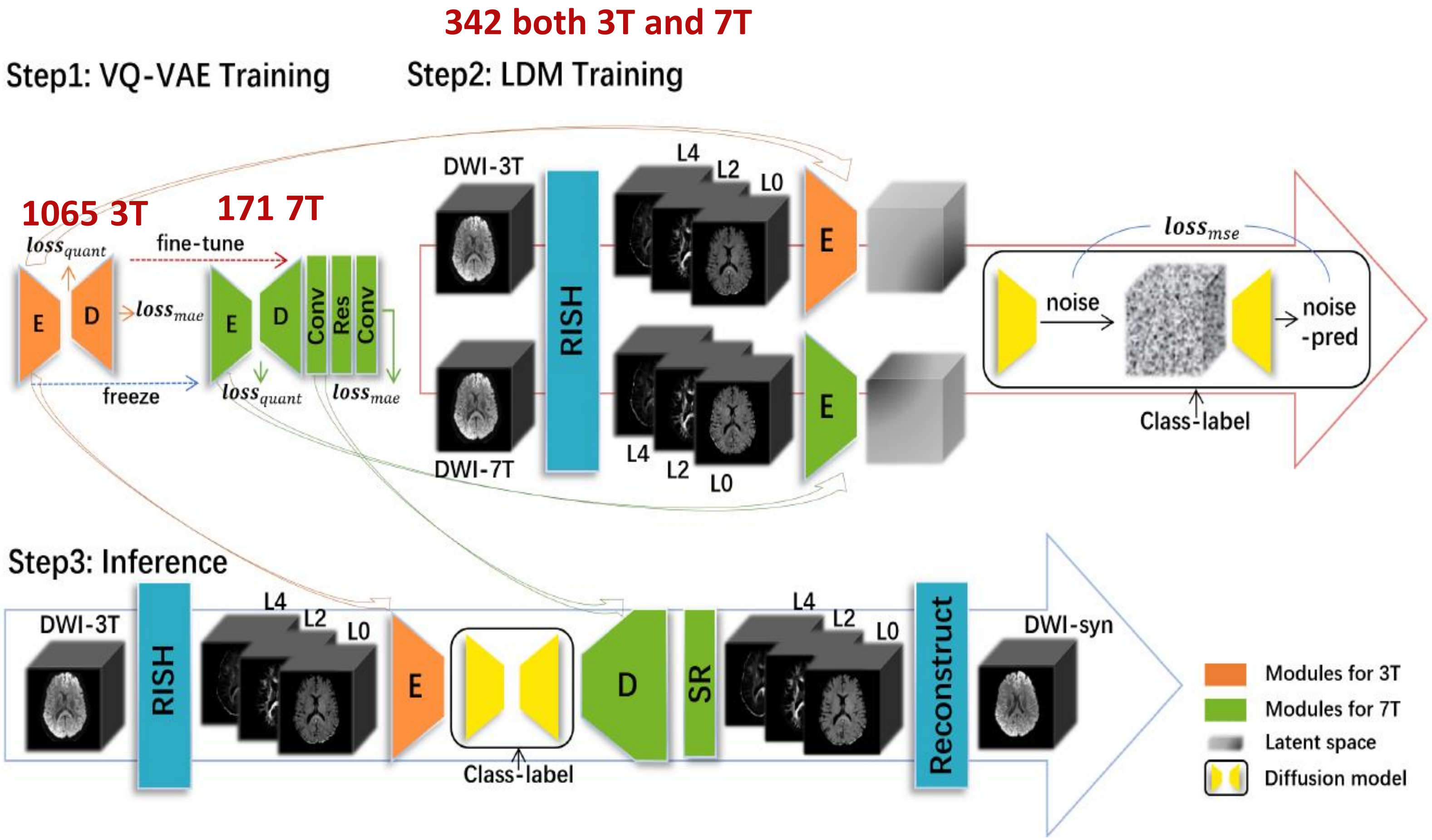
- **Dataset**



1065 subjects from Human Connectome Project (HCP) including:

- 171 subjects has both 3T and 7T data
894 subjects has only 3T data

- Every test set includes 17 test subjects

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- **Results**

Table 1. Comparison of NMSE and SSIM in RISH and FA across different methods.

NMSE↓:	RISH_L0	RISH_L2	RISH_L4	FA
CNN	0.126 ± 0.014	0.143 ± 0.011	0.495 ± 0.107	0.053 ± 0.007
GAN	0.129 ± 0.029	0.427 ± 0.051	1.652 ± 0.360	0.118 ± 0.009
Diffusion	$\mathbf{0.105 \pm 0.026}$	$\mathbf{0.102 \pm 0.017}$	$\mathbf{0.158 \pm 0.031}$	$\mathbf{0.044 \pm 0.008}$
SSIM↑:				
CNN	0.889 ± 0.008	0.959 ± 0.006	0.956 ± 0.016	0.958 ± 0.006
GAN	0.915 ± 0.012	0.893 ± 0.010	0.943 ± 0.004	0.902 ± 0.010
Diffusion	$\mathbf{0.922 \pm 0.009}$	$\mathbf{0.961 \pm 0.007}$	$\mathbf{0.967 \pm 0.002}$	$\mathbf{0.966 \pm 0.007}$

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- **Results**

CNN: a loss of contrast information between different regions **X**

GAN: fails to preserve some structural details in higher order RISH features **X**

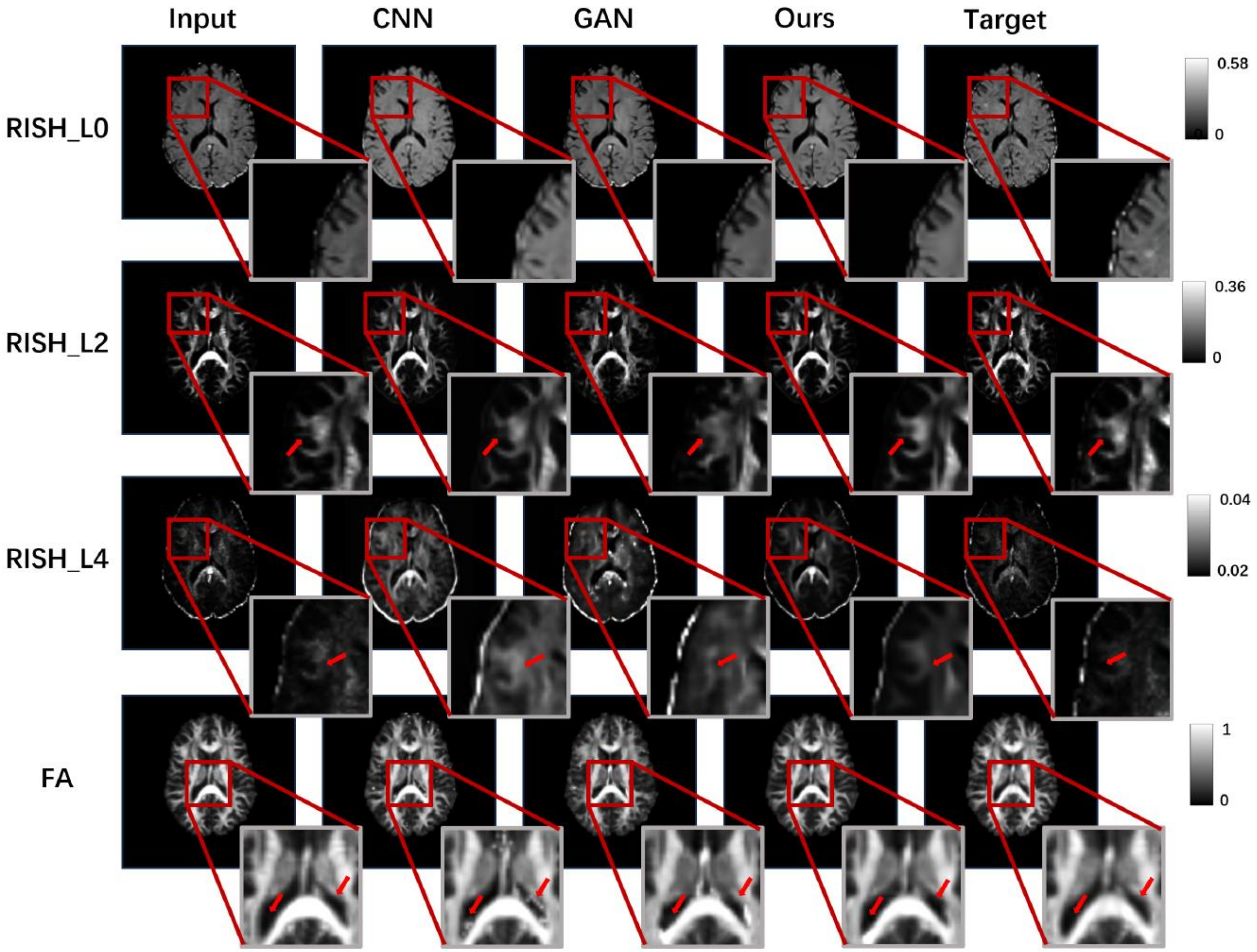

Fig. 2. Results for the RISH features and FA generated by different methods.

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- **Results**

1. Trained with 7T dataset without fine-tuning

2. Trained without super-resolution module, instead using a B-spline interpolation to upscale 3T to resolution of 7T

Table 2. Ablation study results

	Fine-tuning	Super-resolution	NMSE↓	SSIM↑
1.	-	-	0.046 ± 0.008	0.962 ± 0.008
2.	✓	-	0.044 ± 0.008	0.966 ± 0.007
	✓	✓	$\mathbf{0.042 \pm 0.004}$	$\mathbf{0.967 \pm 0.007}$

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- **Conclusion**

✓ The application of latent diffusion models to dMRI generation is new

✓ The integration of new feature extraction with the diffusion model in training is interesting

× Dependent on the availability of both 3T and 7T dMRI data for training

× High computational costs due to using diffusion model, VQ-VAE and super-resolution module

× Generalizability to other datasets

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Thank you