

# WiNeRT: Towards Neural Ray Tracing for Wireless Channel Modelling and Differentiable Simulations

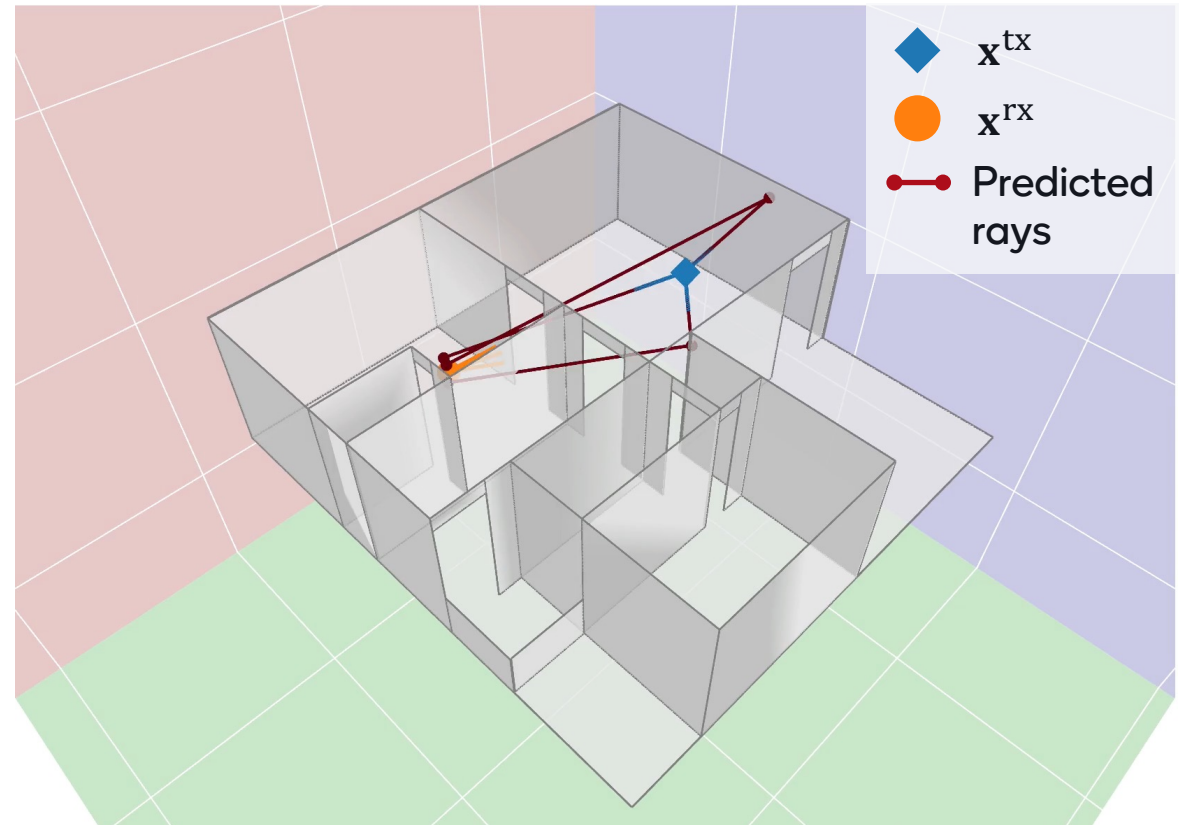
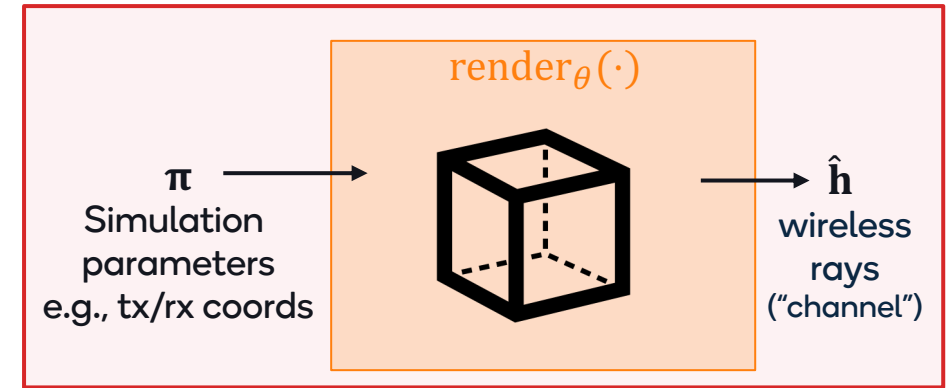
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<sup>†</sup> Qualcomm AI Research is an initiative of Qualcomm Technologies, Inc

# Tl;dr. WiNeRT = Wireless Neural Ray Tracer

- Neural Data-driven Differentiable Ray Tracer
- Motivation: Benefits over classical ray tracers e.g.,
  - Differentiability
  - Faster Simulation times
- Approach: NeRF<sup>1</sup>-like. Combination of:
  - Incidence-dependent MLP evaluations at spatial co-ordinates
  - Classical rendering (wireless ray tracing)
- Results
  - Evaluated on simulated data (Insite<sup>2</sup>/Pylayers<sup>3</sup>)
  - Avg. delay MAE: 0.82 – 1.8 ns
  - Bonus: 6-22X faster than simulators, Generalization, Positioning via Inverse Rendering

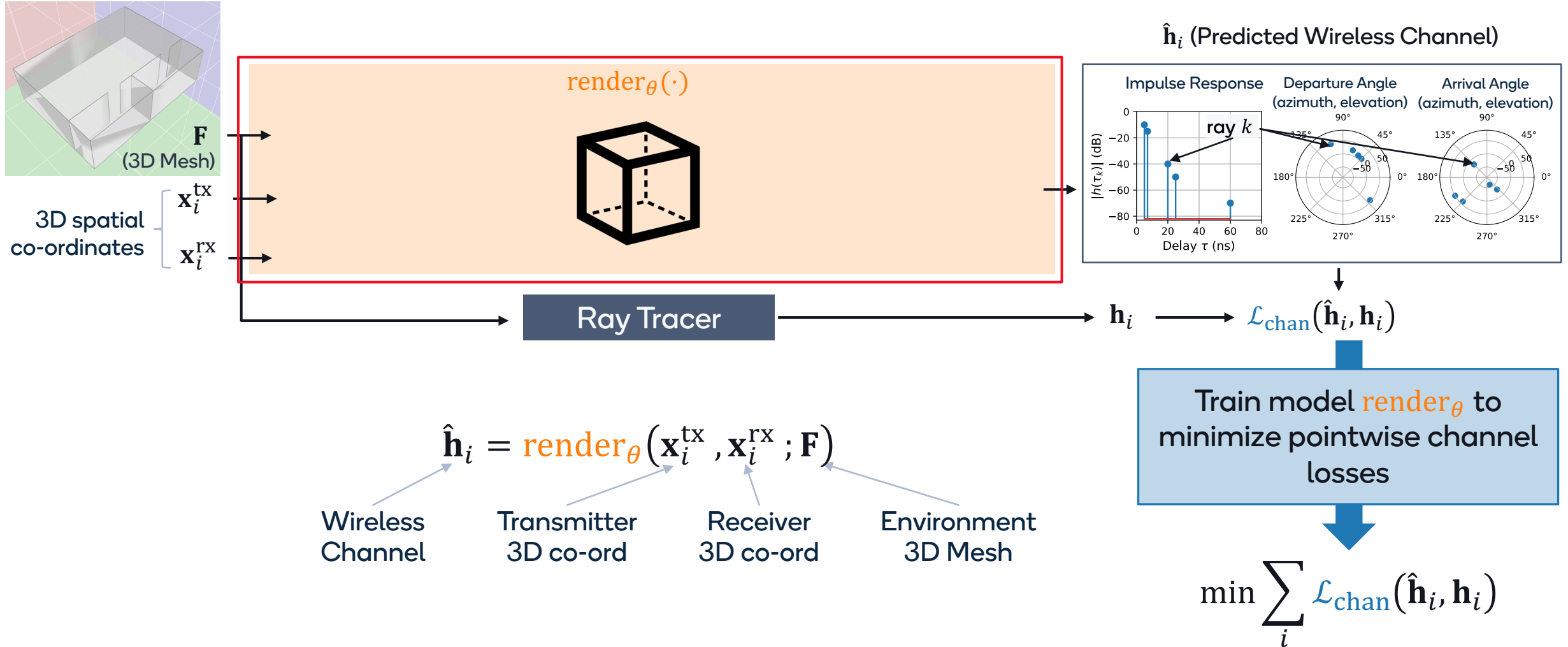


[1] Mildenhall et al., "Nerf: Representing scenes as neural radiance fields for view synthesis." ECCV '20

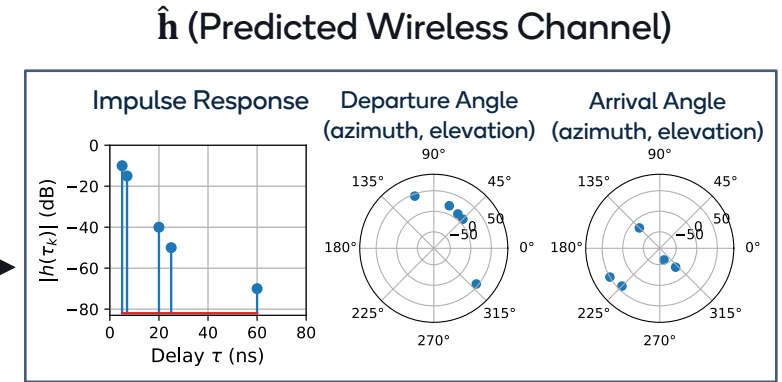
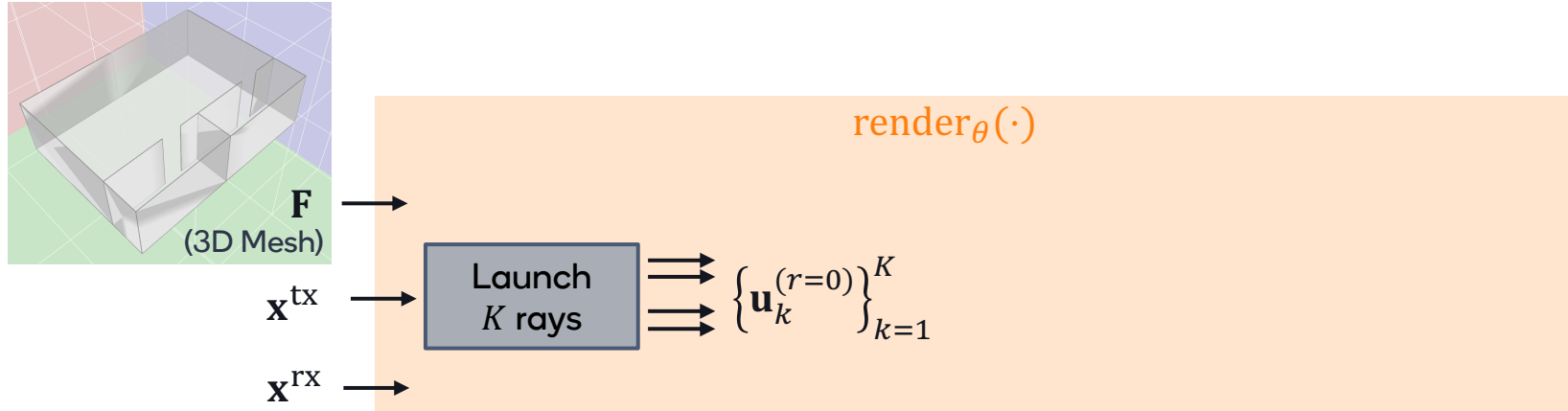
[2] Remcom Wireless InSite with Ray Tracer X3D

[3] Amiot et al., "Pylayers: An open source dynamic simulator for indoor propagation and localization." ICC '13

# Problem Statement: Surrogate Neural Ray Tracing

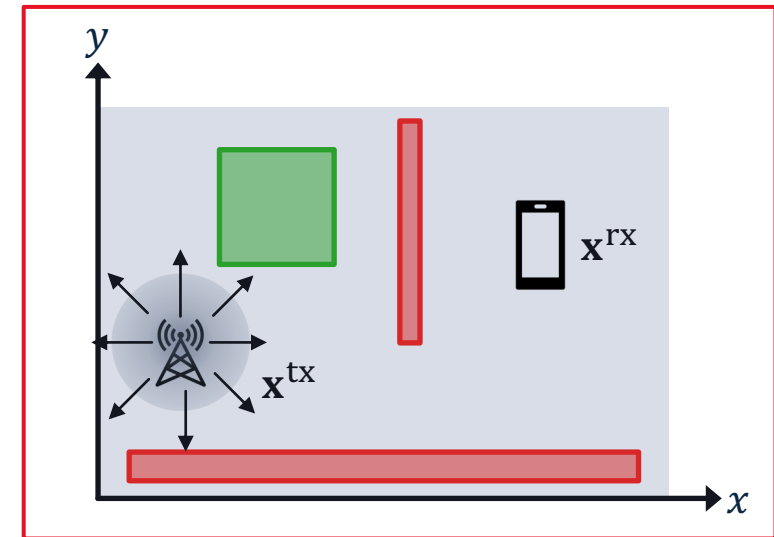


# WiNeRT: Approach (1/4)

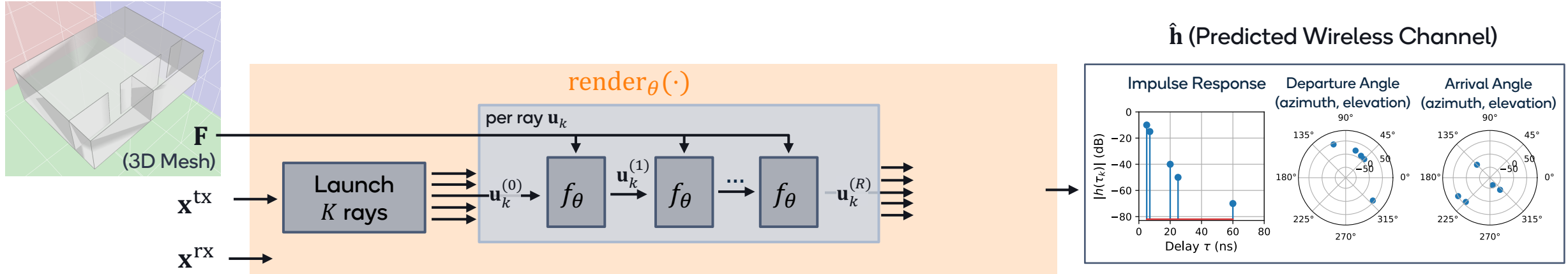


## • Step 1: Ray Launching

- Launch  $K$  rays  $\{\mathbf{u}_k^{(r=0)}\}$  uniformly in all directions
  - $K \approx 10K$  (vertices of ico-sphere, with 5 divisions)
- Ray  $\mathbf{u}_k^{(r)}$  contains geometric, wireless, and state attributes
  - E.g., Origin, direction, Gain  $a_k$ , Delay  $\tau_k$  (time-of-flight)

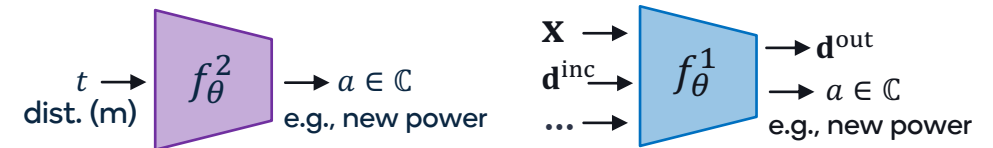
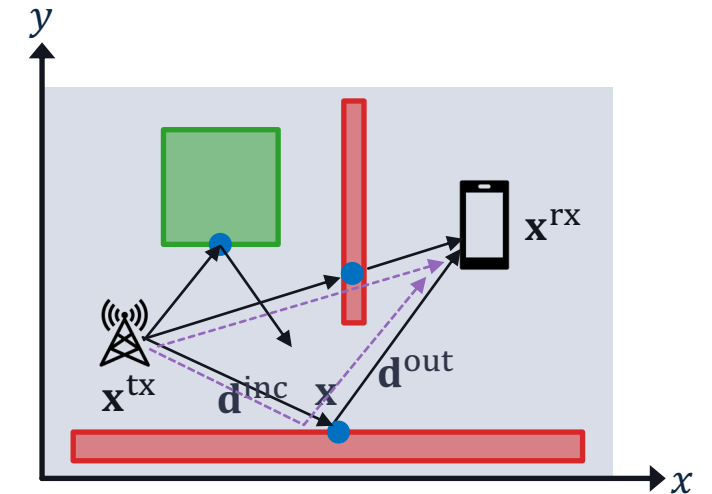


# WiNeRT: Approach (2/4)

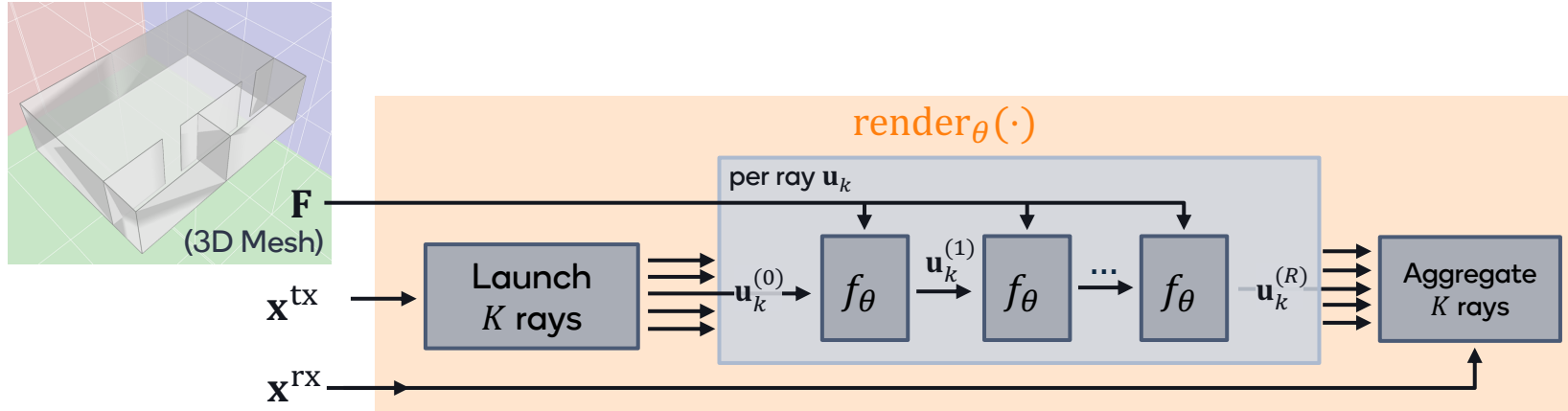


- Step 2: Ray Marching

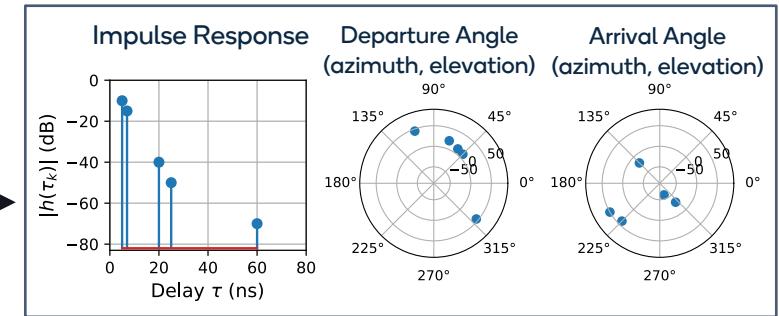
- Core Idea:  $f_\theta$  updates the ray attributes as it interacts (reflects/transmits) with surfaces in the environment
- Leverage simple ReLU MLP  $f_\theta^1$  to learn ray-surface interactions
  - Independently evaluate MLP for each ray  $\mathbf{u}_k^{(r)}$  at each step  $r$
- Finally apply distance-dependent free-space path loss  $f_\theta^2$



# WiNeRT: Approach (3/4)



$\hat{\mathbf{h}}$  (Predicted Wireless Channel)



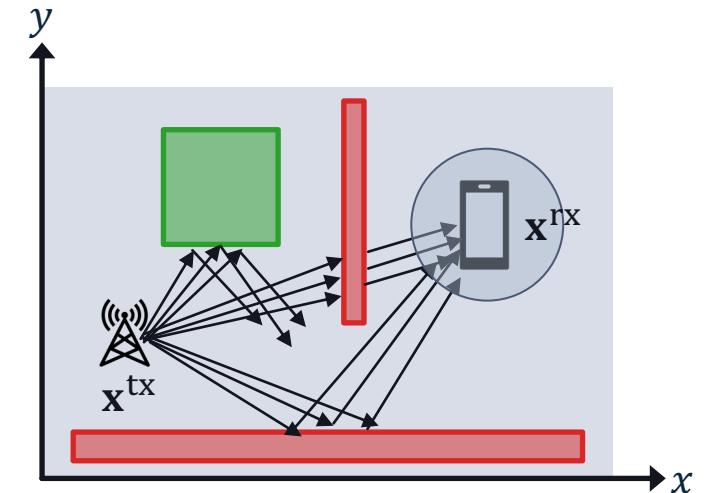
## • Step 3: Reception and Aggregation

### ◦ Which rays are received?

- Model fixed-size reception sphere centered at  $\mathbf{x}^{rx}$  and find subset of rays that impinge on sphere surface

### ◦ Dealing with double counting

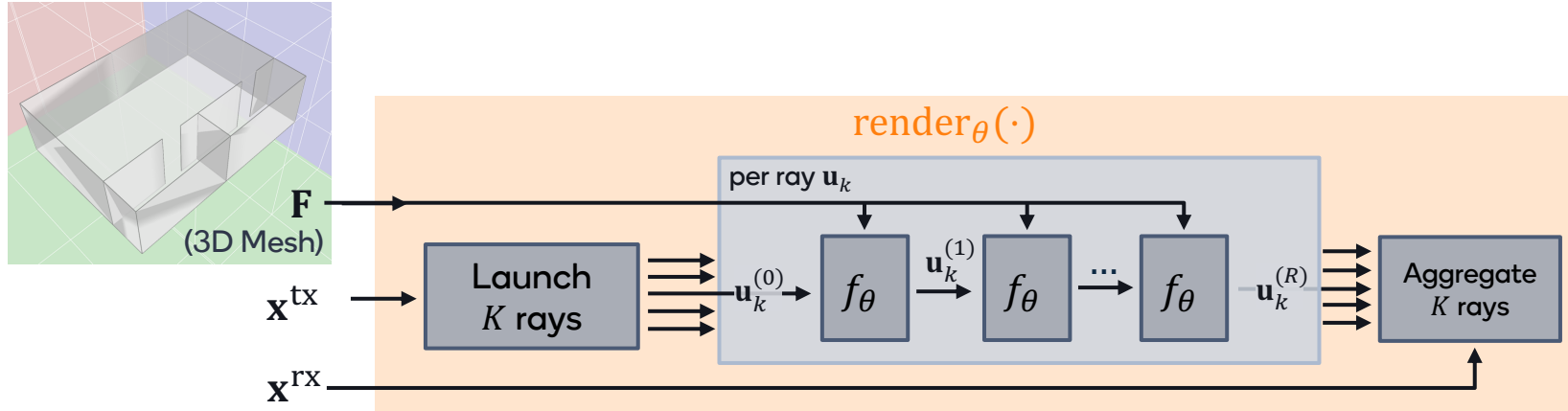
- Ray abstracts a spherical wavefront
- Fermat's principle of least time: consider the shortest ray



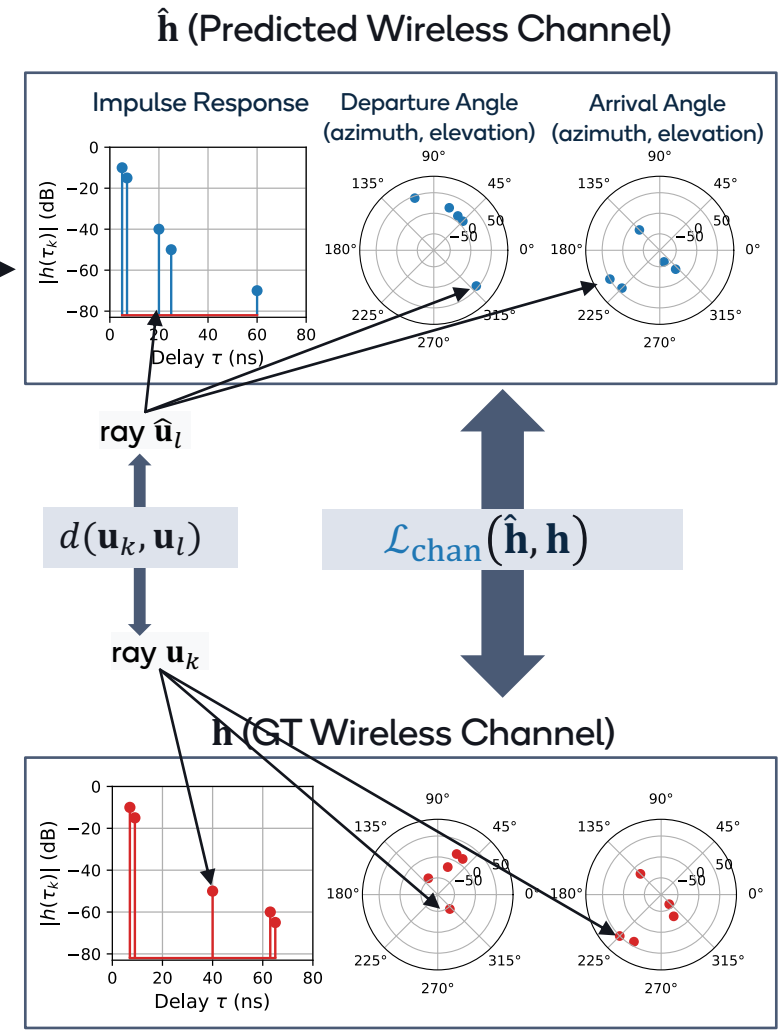
# WiNeRT: Approach (4/4)

$$\min \sum_i \mathcal{L}_{\text{chan}}(\hat{\mathbf{h}}_i, \mathbf{h}_i)$$

$$\hat{\mathbf{h}}_i = \text{render}_{\theta}(\mathbf{x}_i^{\text{tx}}, \mathbf{x}_i^{\text{rx}}; \mathbf{F})$$

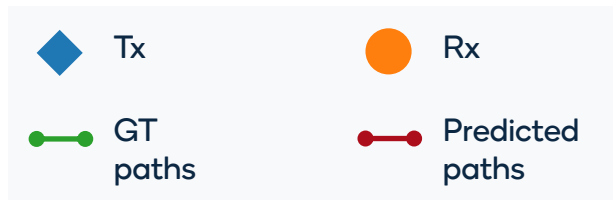
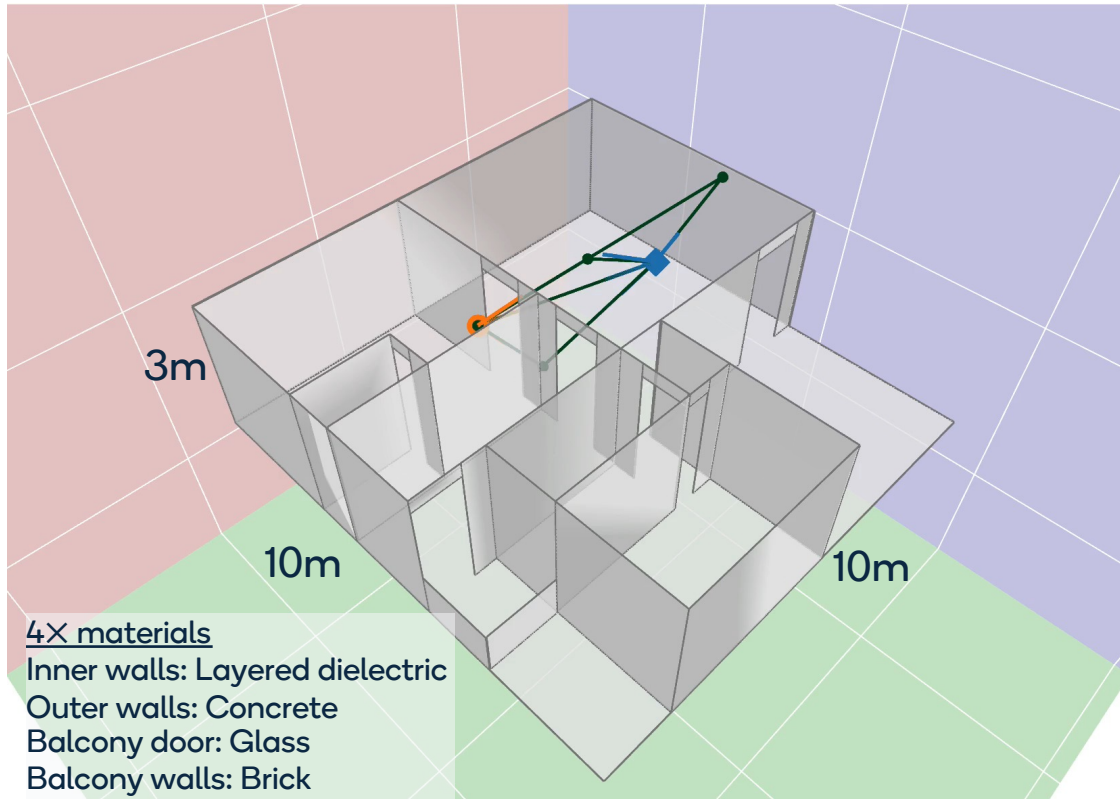


- Step 4: (Training) Loss evaluation
  - Comparing two time-angle impulse responses
  - Set-based loss over sets of rays
    - $\mathcal{L}_{\text{chan}}(\mathbf{h}, \hat{\mathbf{h}}) = \sum_k d(\mathbf{u}_k, \hat{\mathbf{u}}_{\Pi(k)})$
    - $\Pi$ : Angle-of-departure based association
  - Comparing two wireless rays  $d(\mathbf{u}_k, \mathbf{u}_l)$ 
    - MSE over individual attributes
    - Tricks: normalization, cartesian representation of angles, ...

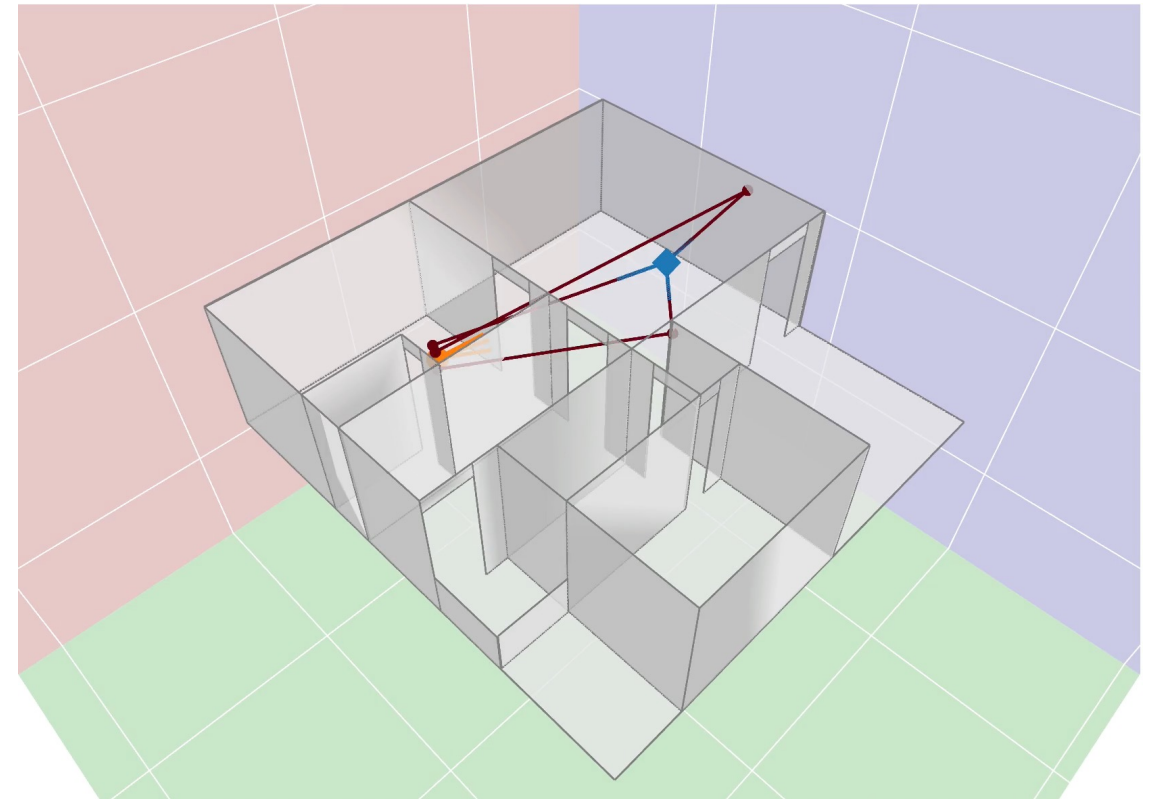


# Results: Overall

## Wireless Insite Ray-tracer (Ground truth)



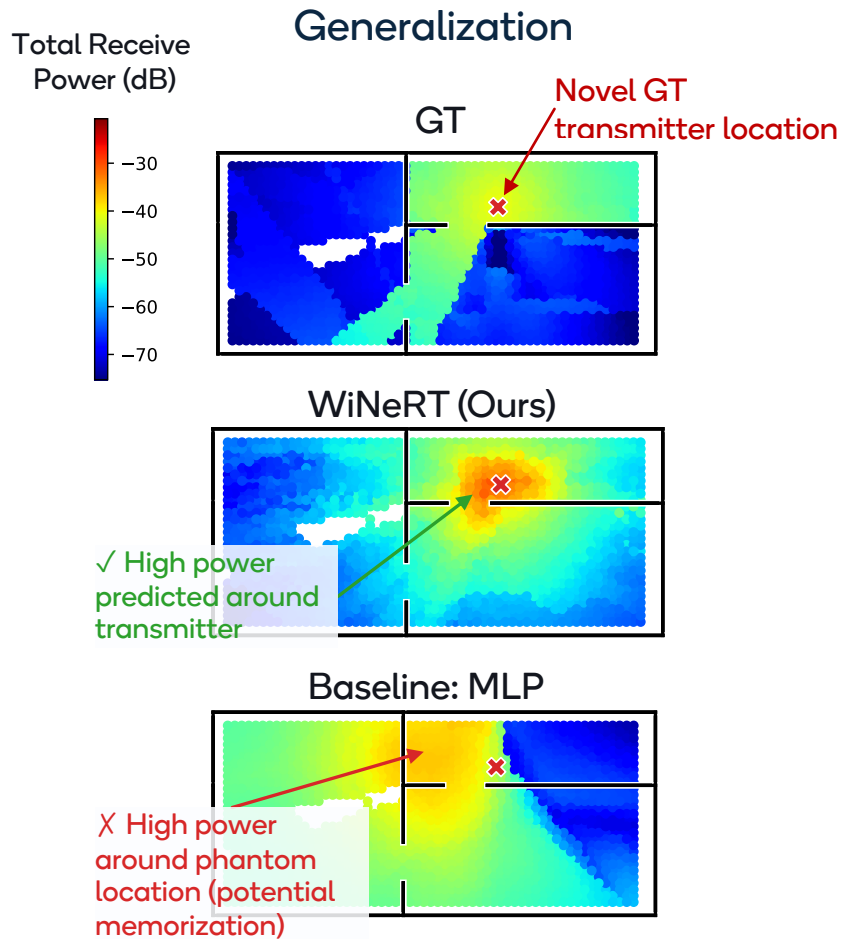
## WiNeRT (Predictions)



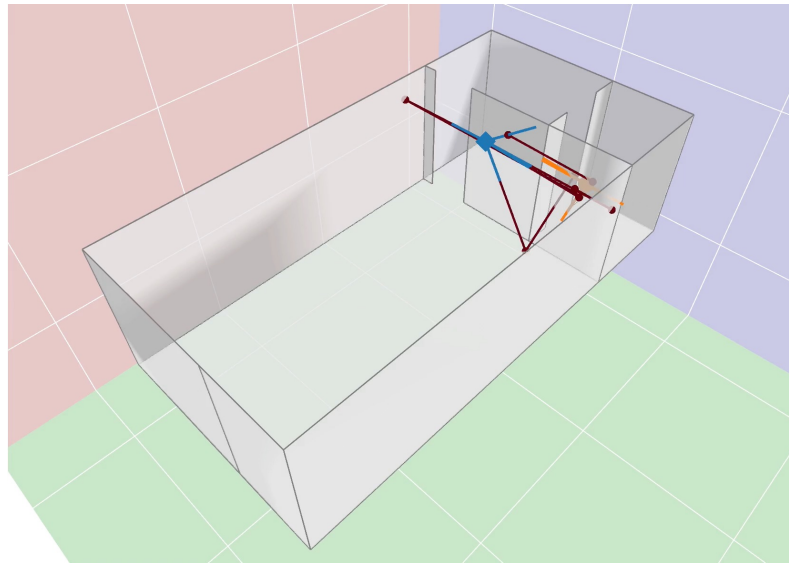
MAE – Average Delay	1.55 ns
MAE - RSRP	-106.74 dB
MAE – LOS ToF	3.97 ns
Hungarian distance	0.24



# Results: Additional Analysis

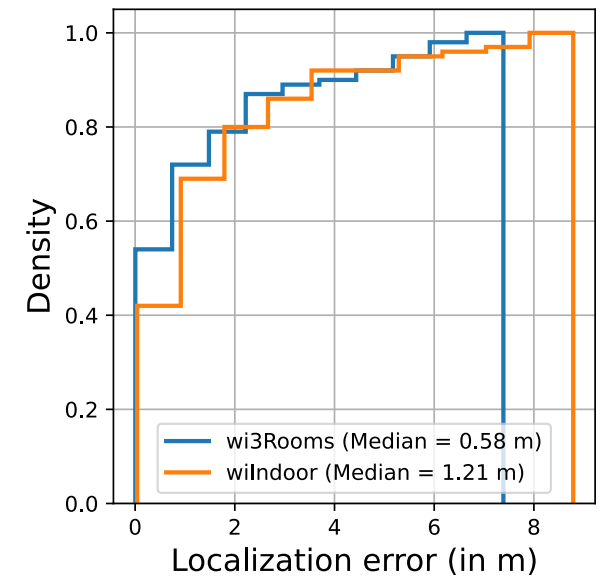


New re-configured Floormaps at test-time  
(Train on floor F, Simulate on F')



Inverse Rendering Application:  
Localization

$$\nabla_{\mathbf{x}^{\text{rx}}} \mathcal{L}(\text{render}_{\theta}(\mathbf{x}^{\text{rx}}, \dots), \mathbf{h}^{\text{target}})$$



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3-May (Wednesday)  
4.30pm – 6.30pm CAT

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