When Cryptography Needs a Hand: Practical Post-Quantum Authentication for V2V Communications

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NDSS SYMPOSIUM/2024

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Vehicle-to-Vehicle (V2V) Communication

Direct wireless communication between vehicles for safety could prevent 600,000 car crashes every year[1]

[1] National Highway Transportation Safety Administration (NHTSA), “Federal Motor Vehicle Safety Standards; V2V Communications,” Notice of Proposed Rulemaking (NPRM) for FMVSS No. 150, V2V Communications; 88 FR 80685, Nov. 2023.

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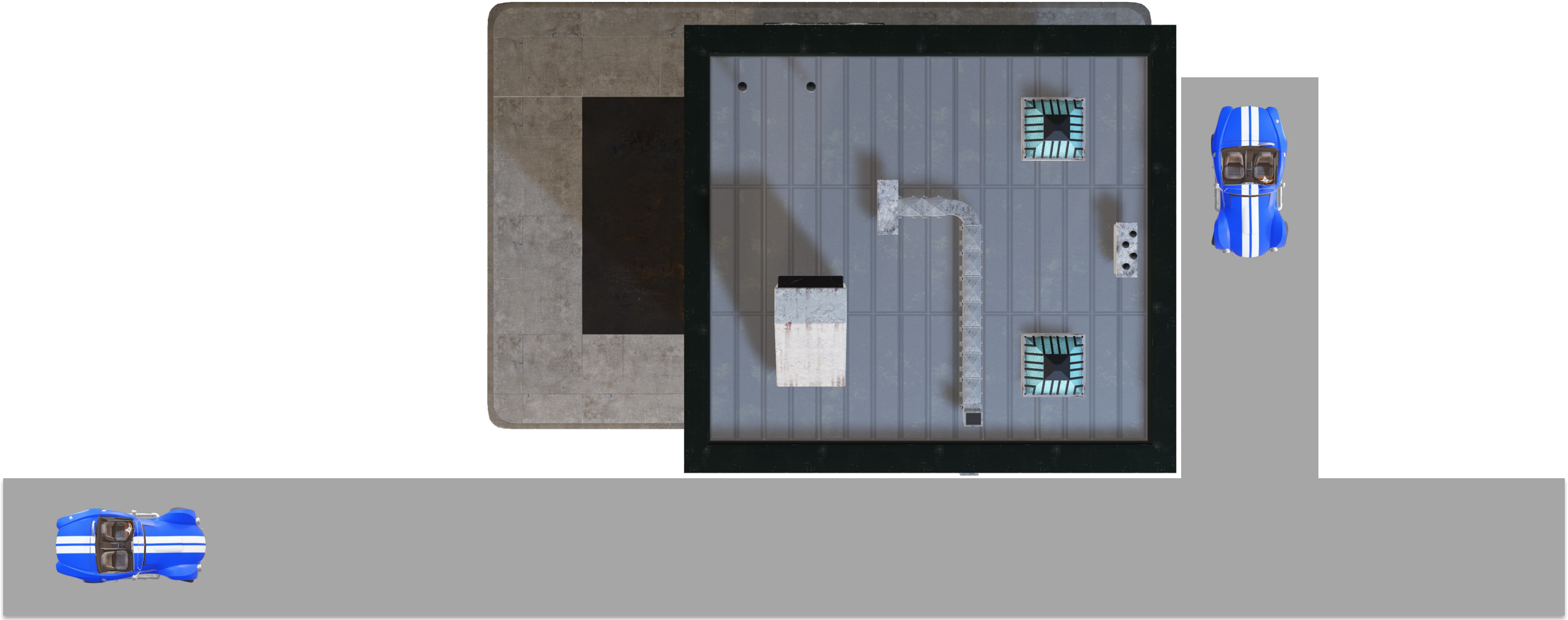

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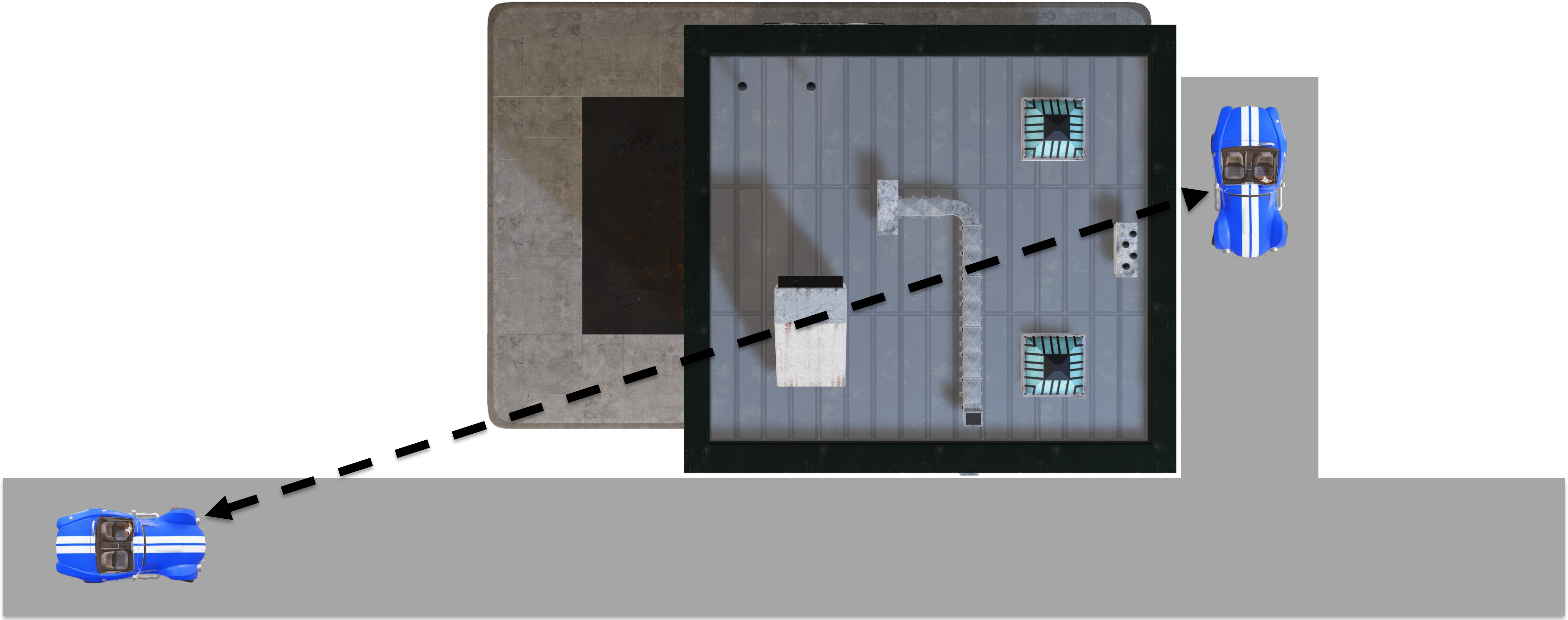

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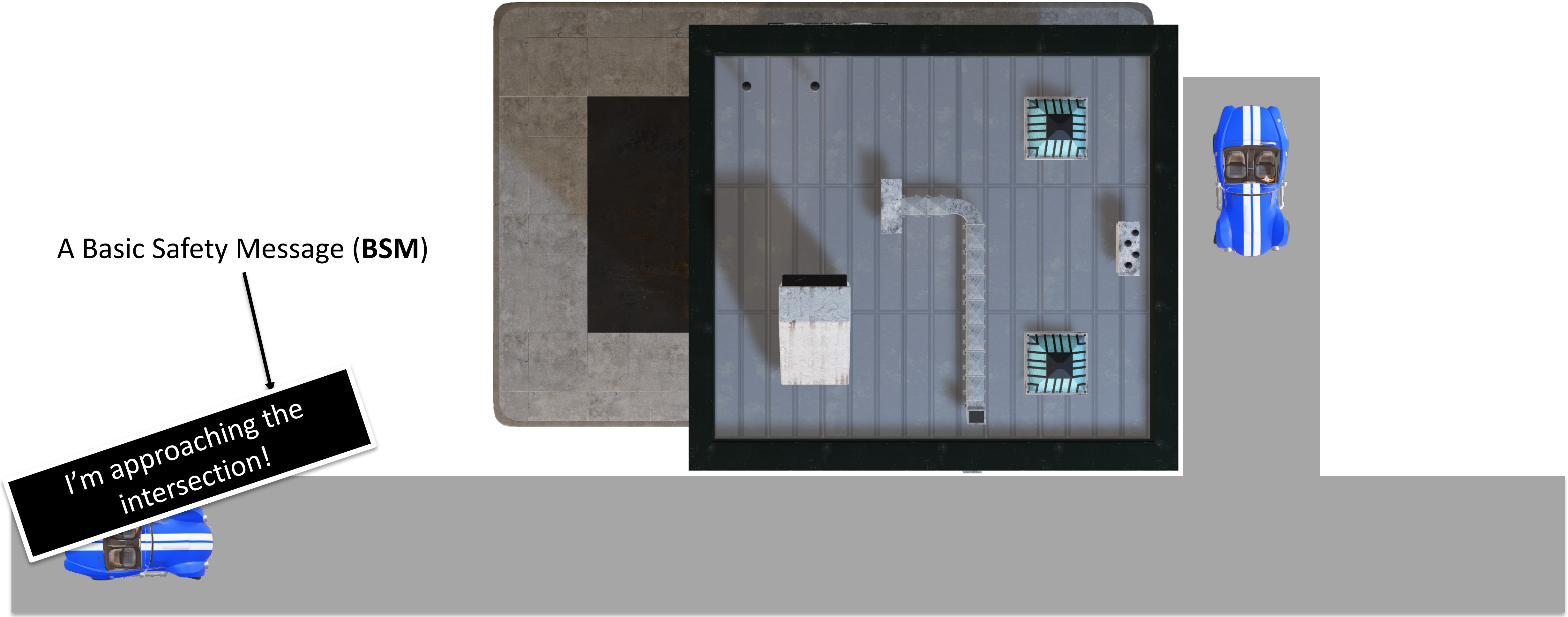

A Basic Safety Message (**BSM**)

I'm approaching the intersection!

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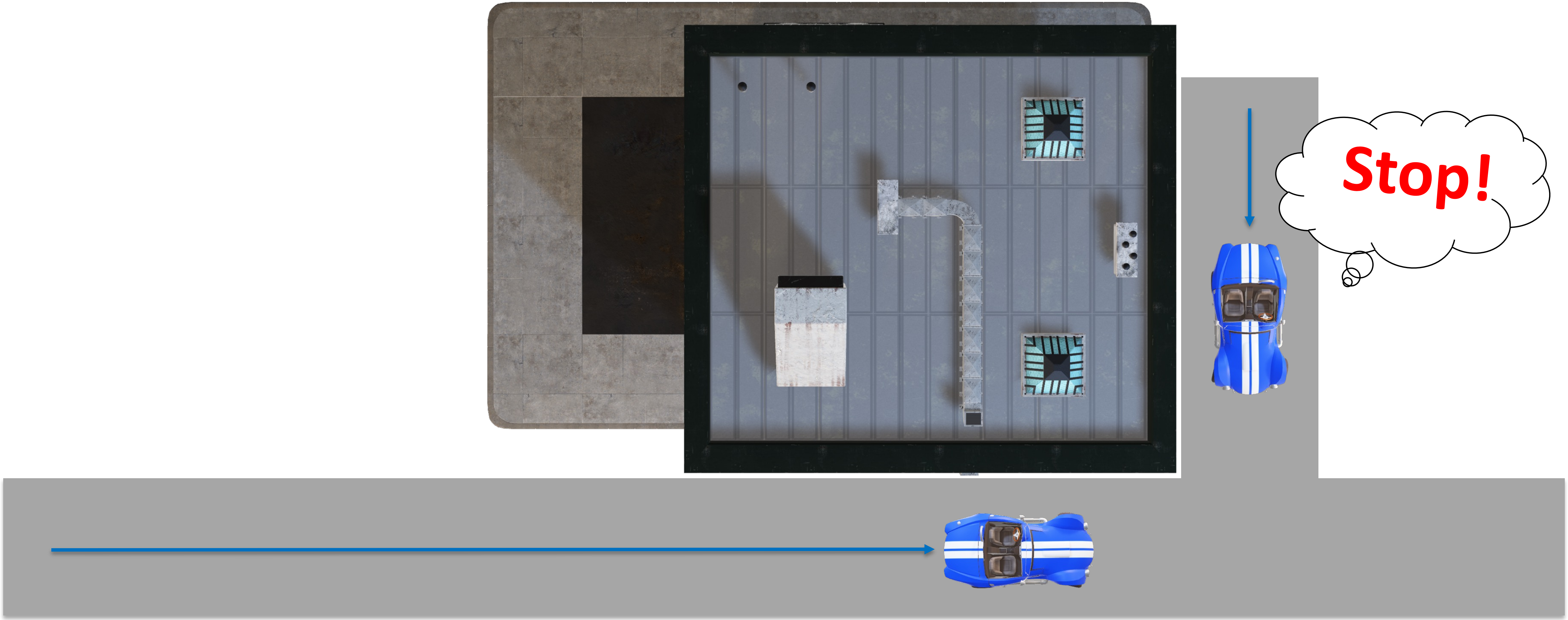

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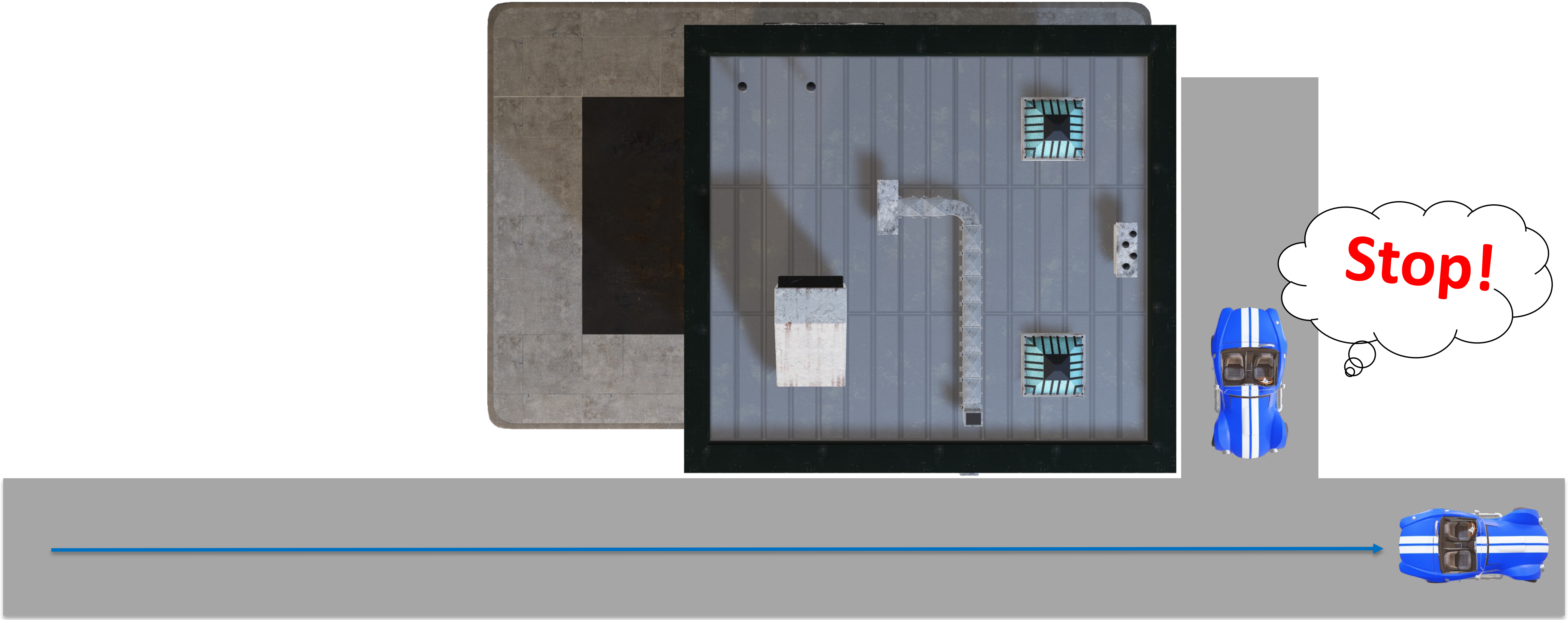

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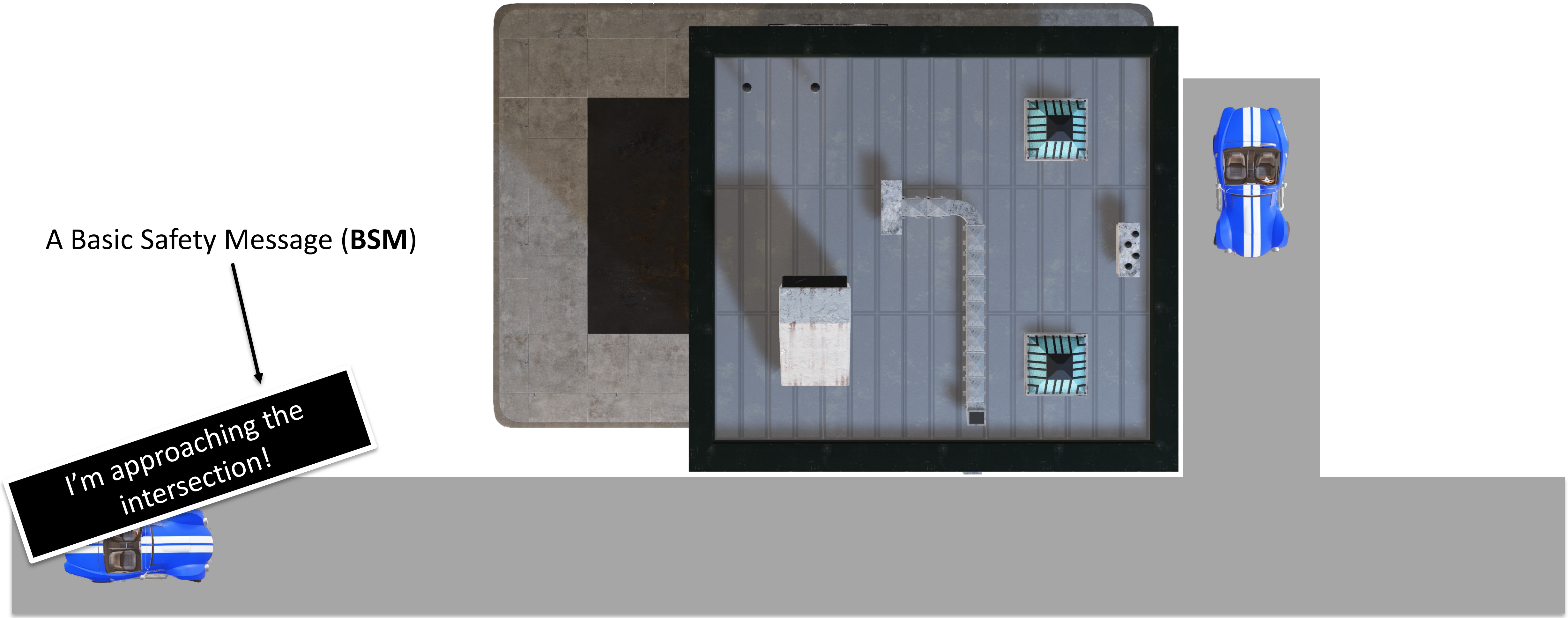

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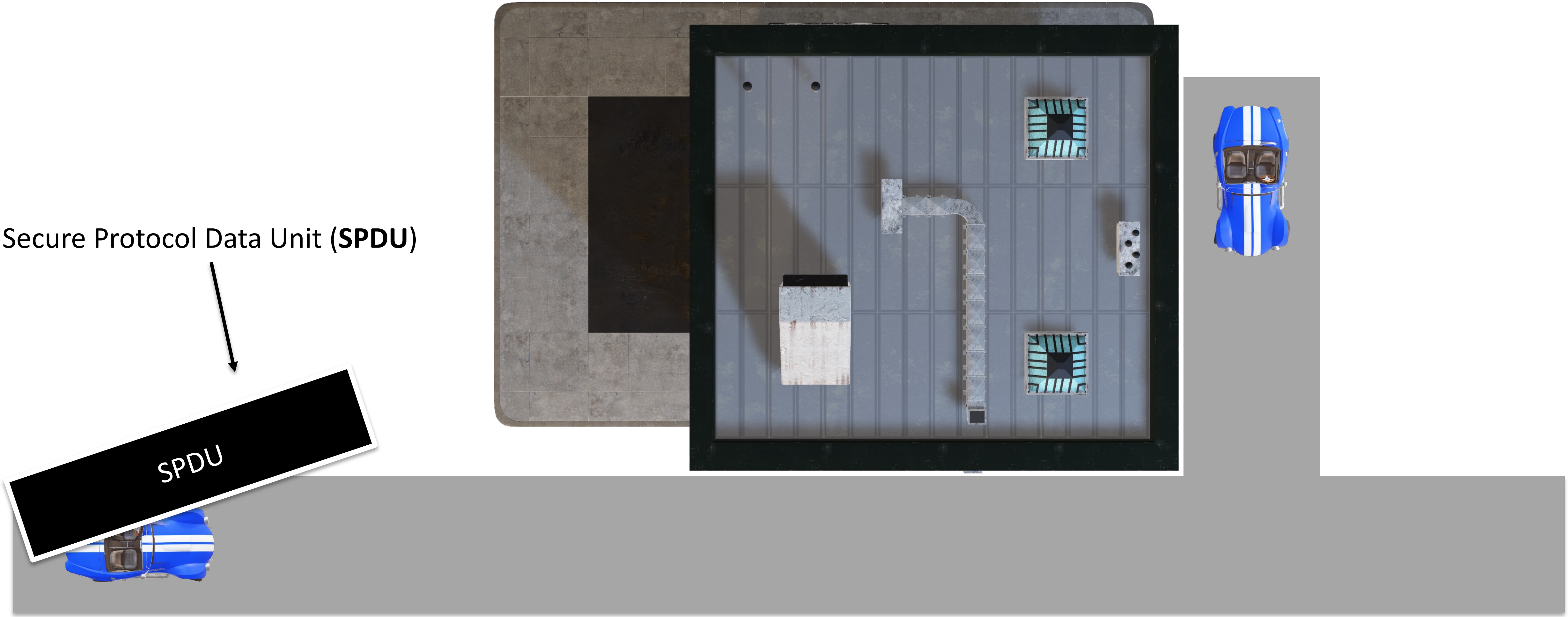

V2V Authentication

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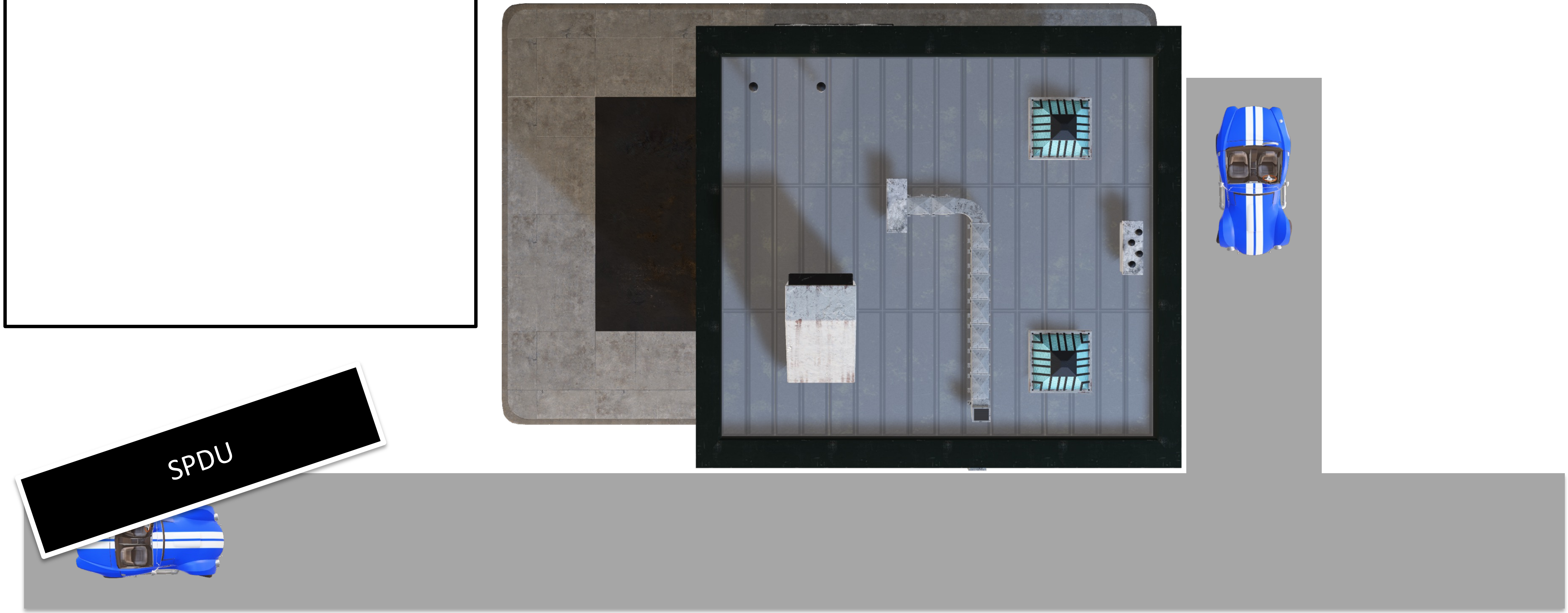

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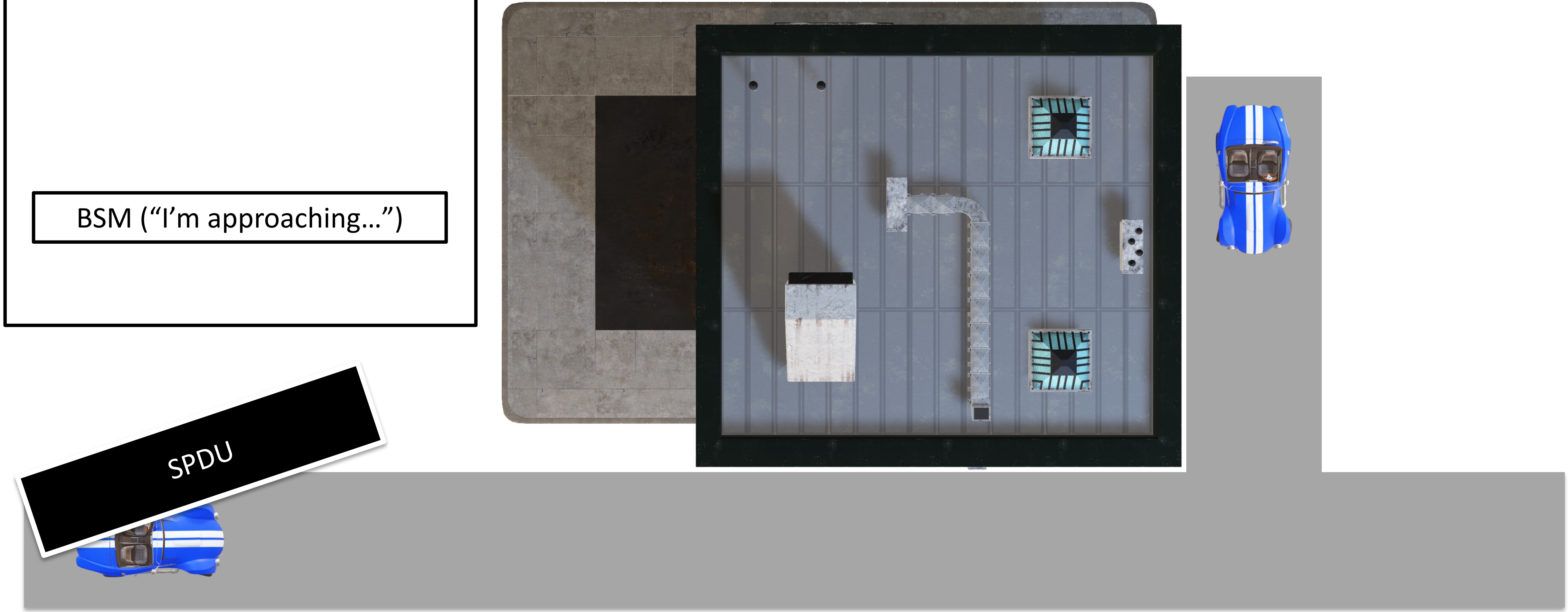

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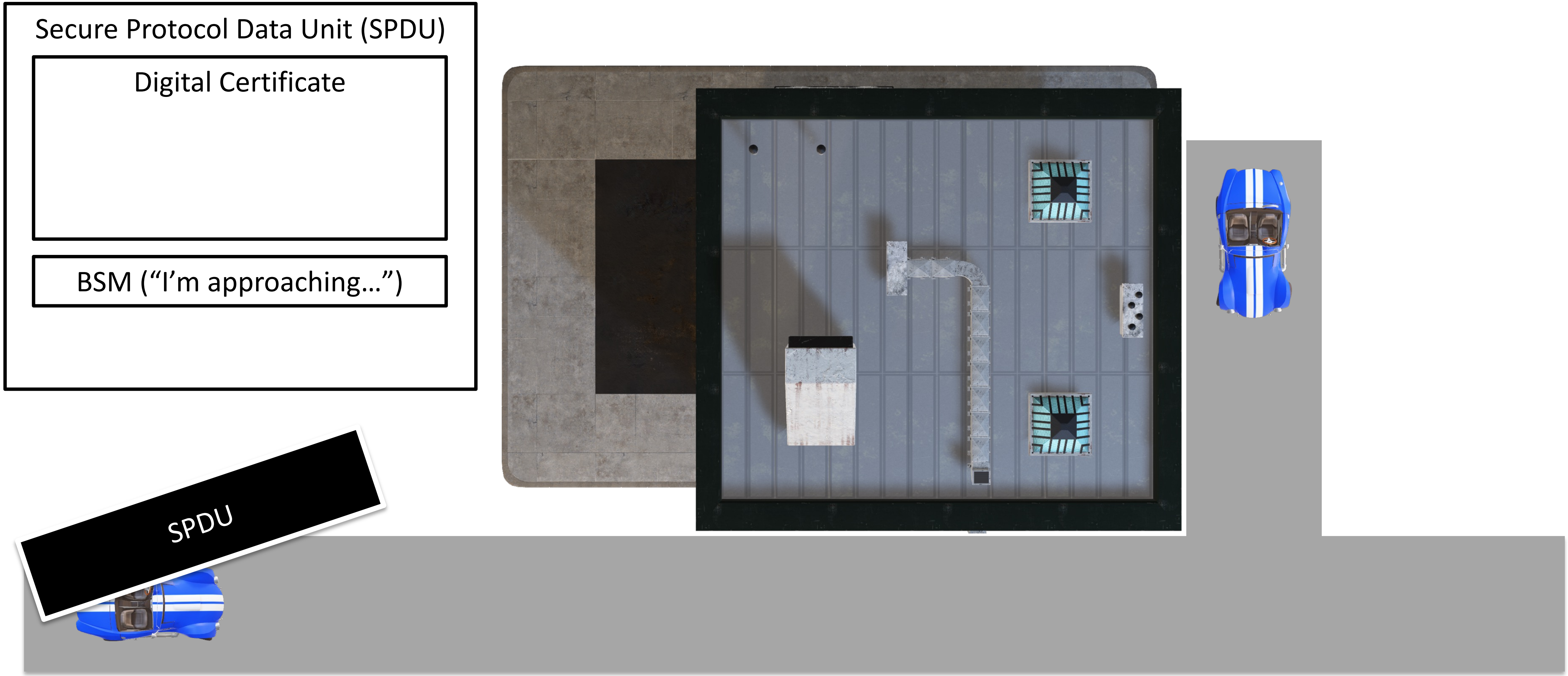

Secure Protocol Data Unit (SPDU)

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V2V Authentication

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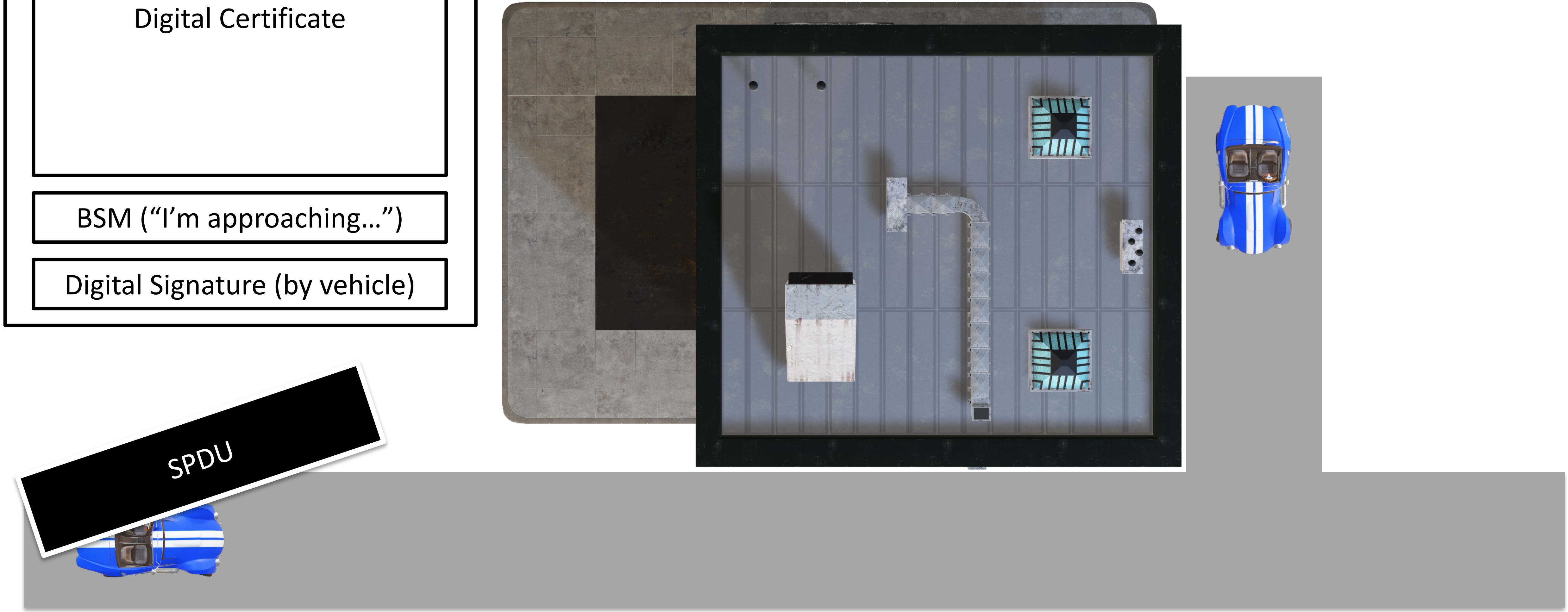

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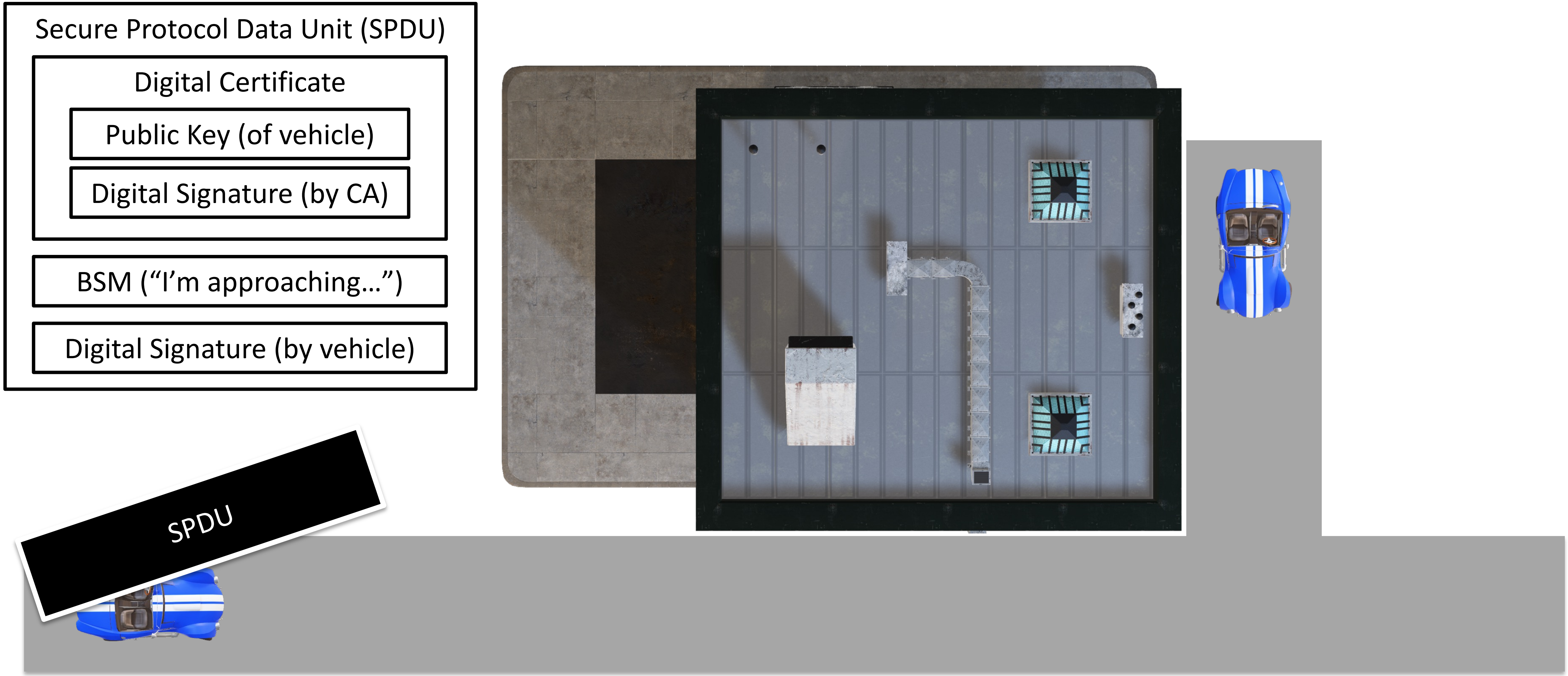

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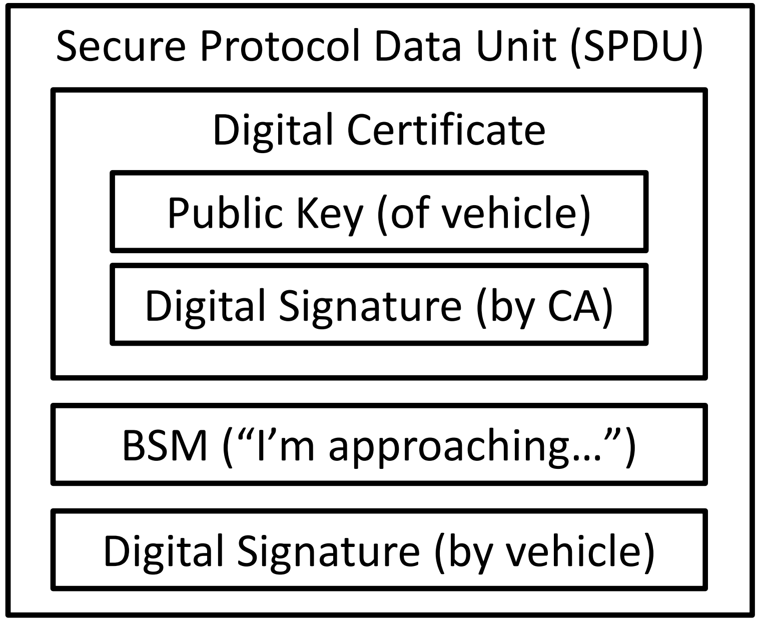

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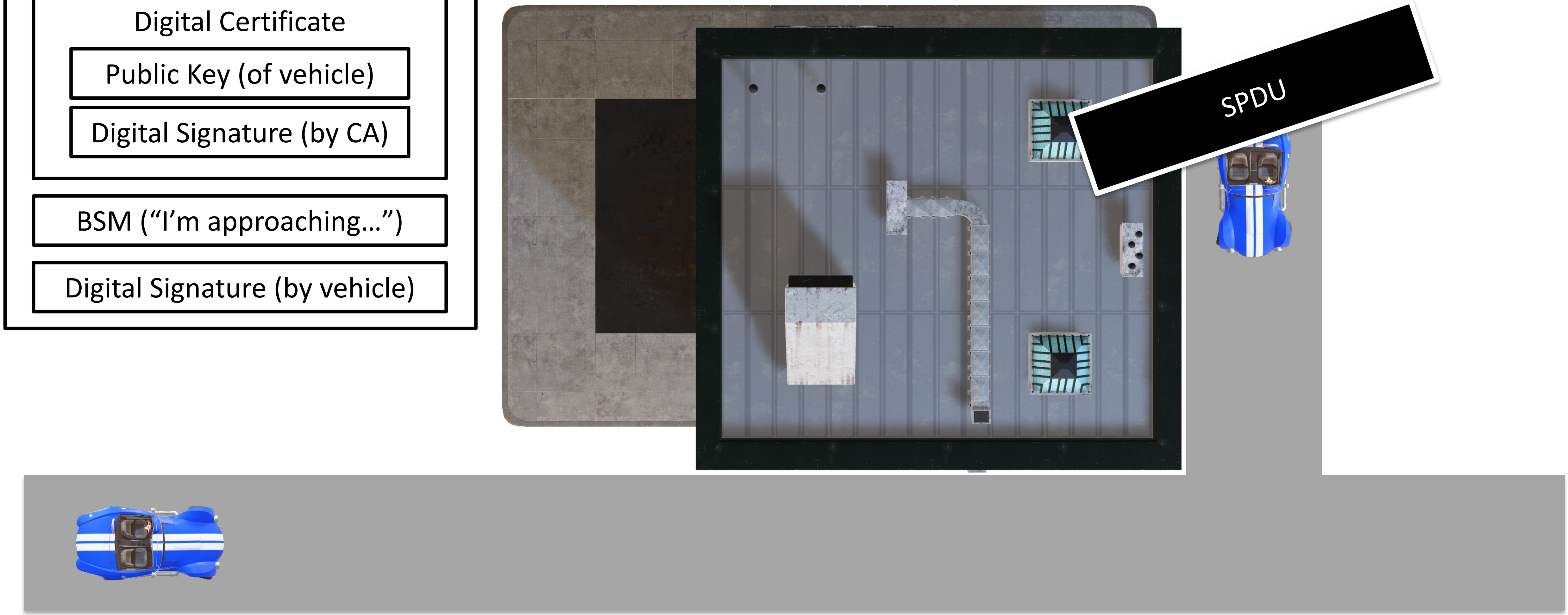

V2V Authentication

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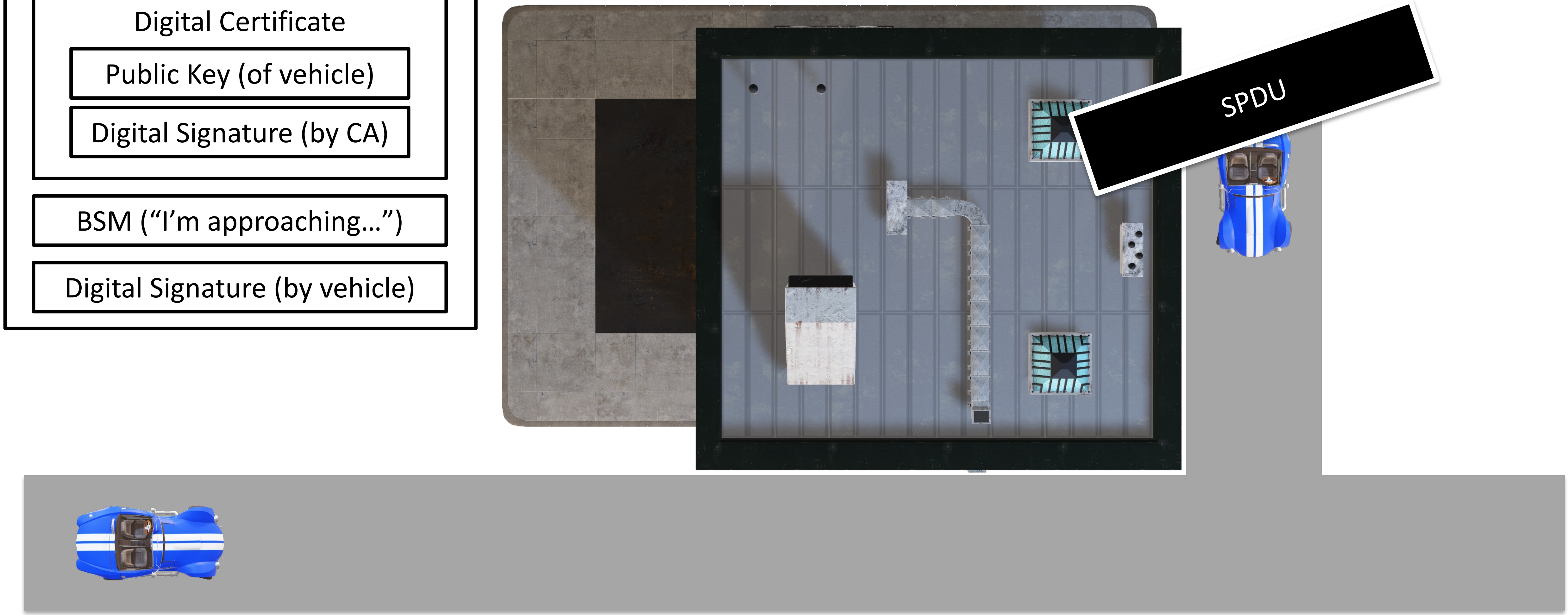

V2V Authentication

Certificate Valid?

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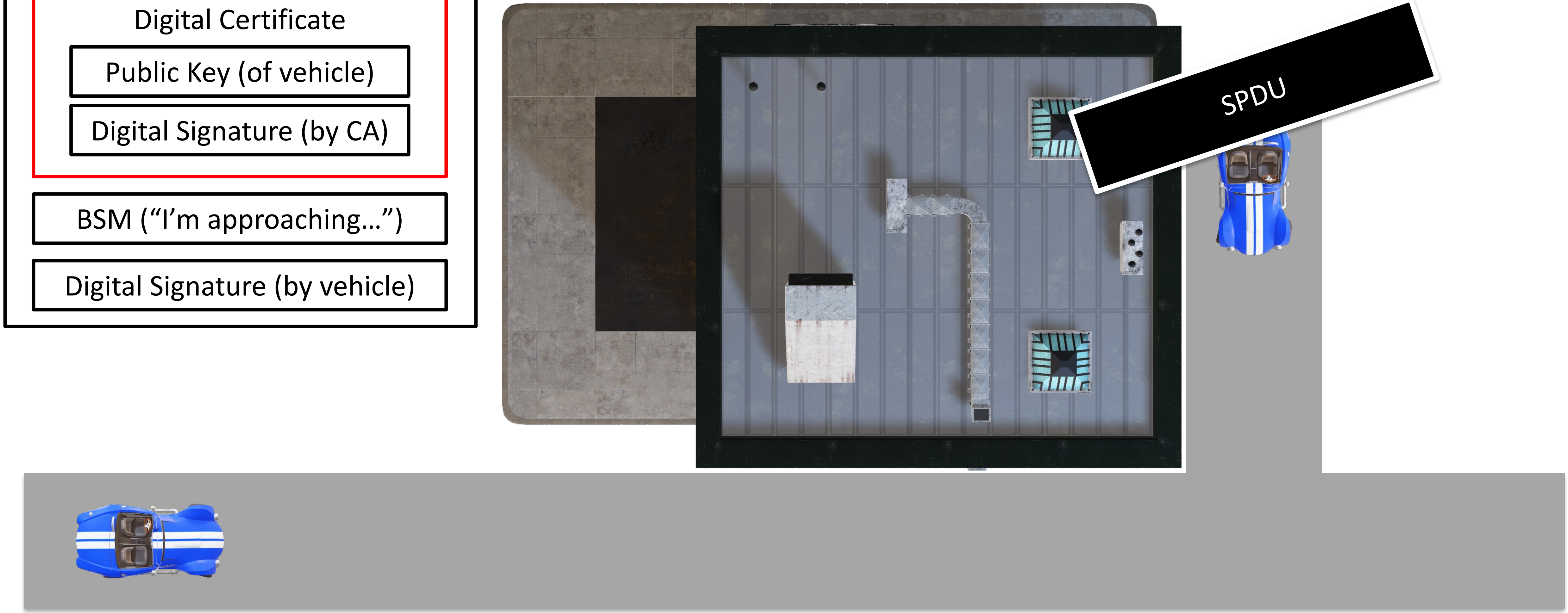

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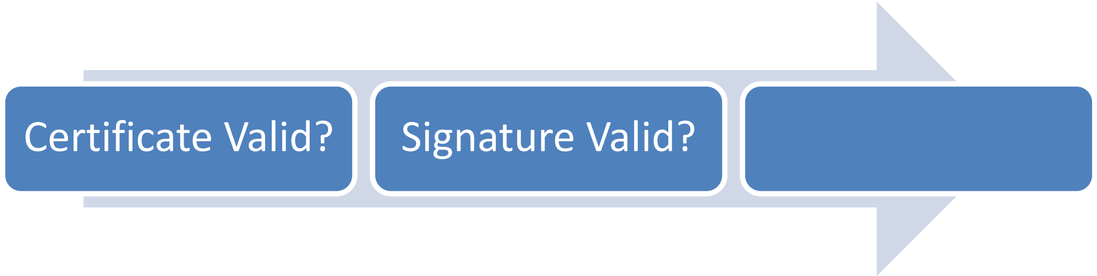

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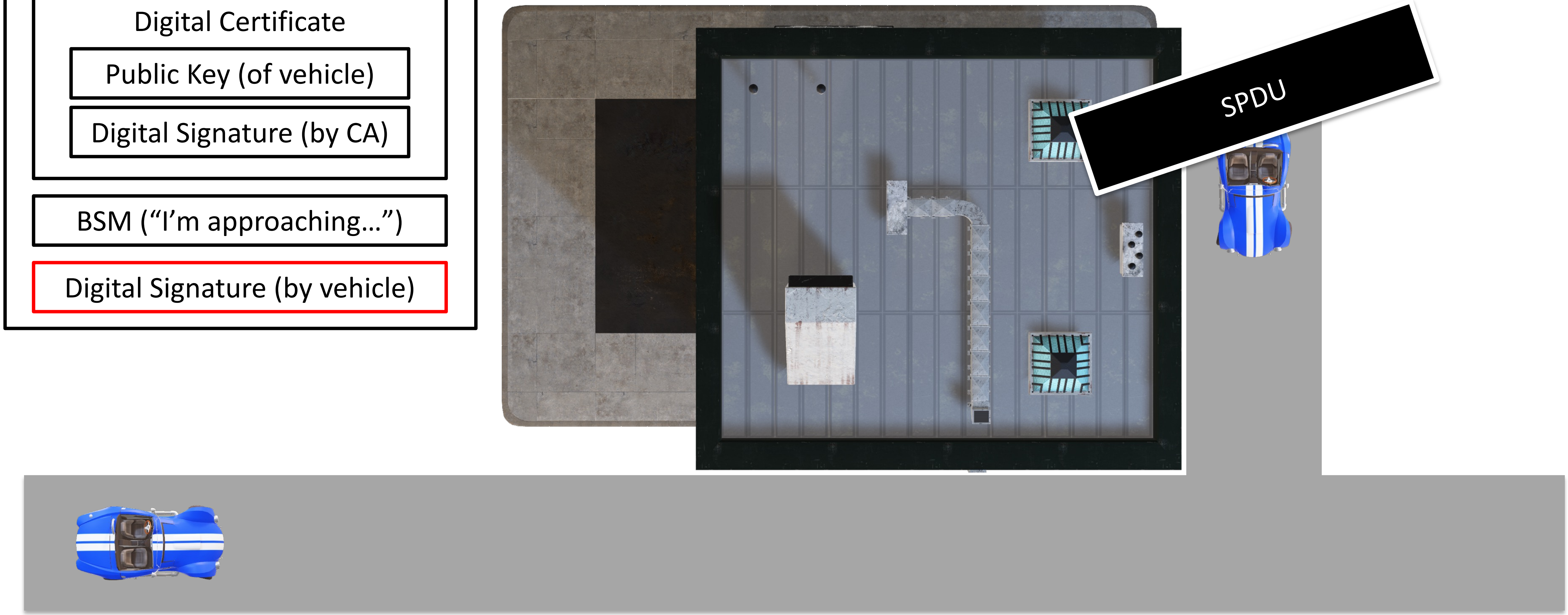

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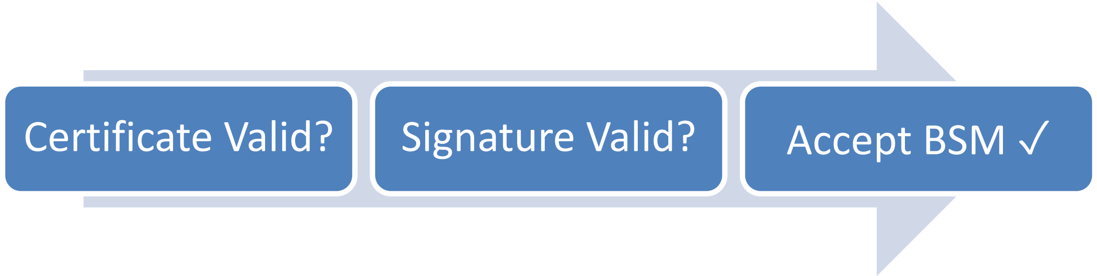
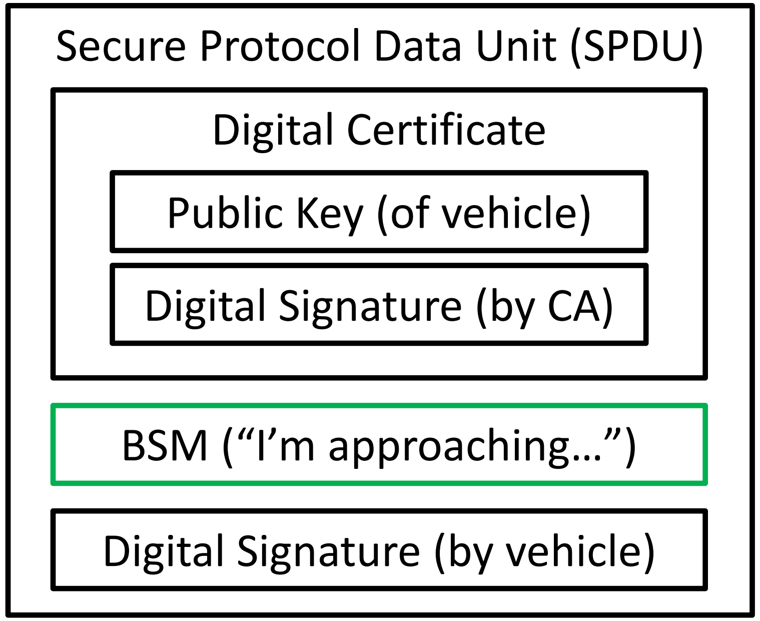


Certificate Valid?

Signature Valid?

Accept BSM ✓



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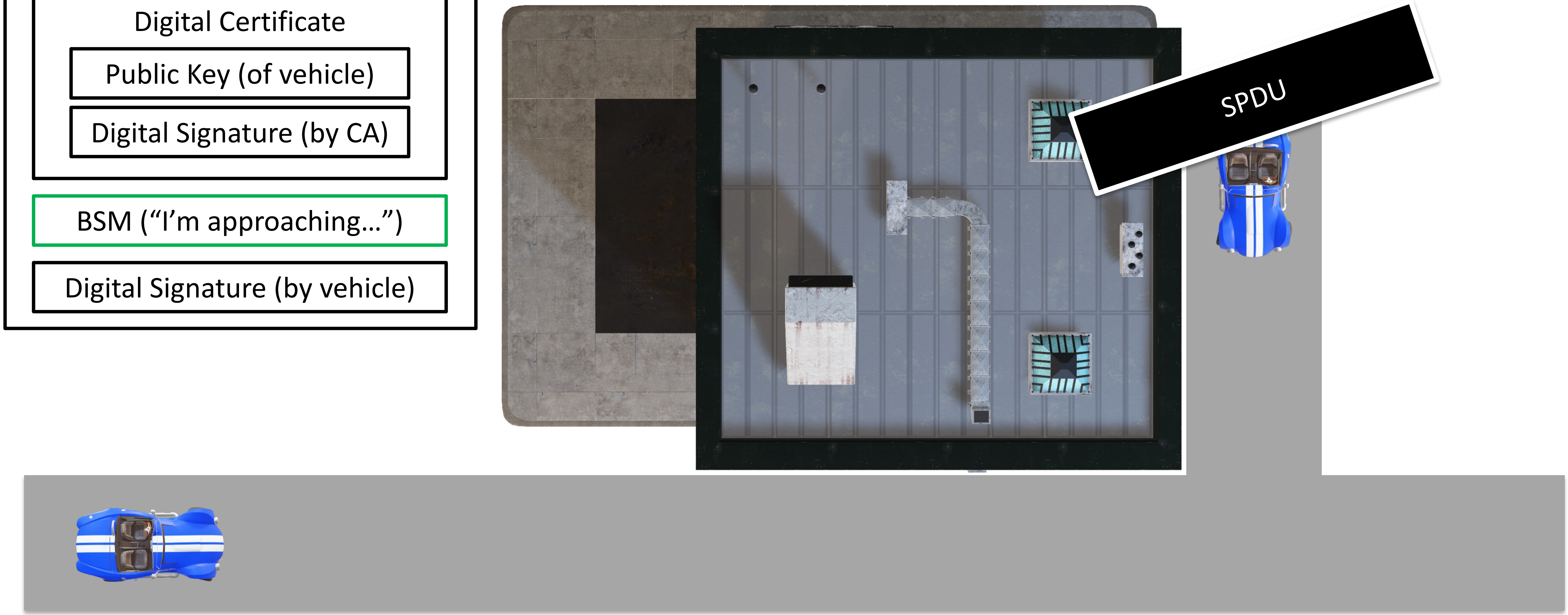

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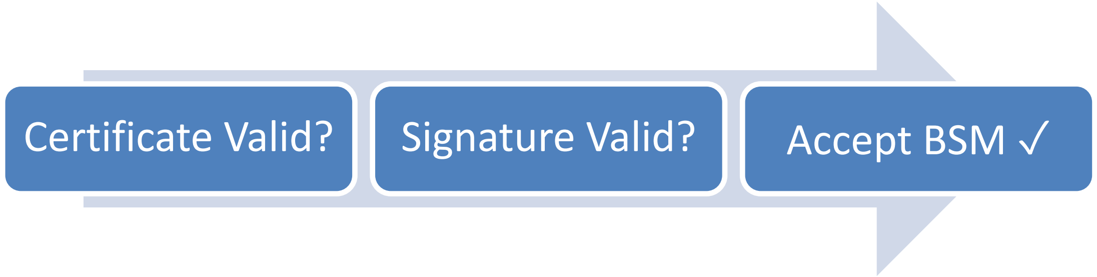

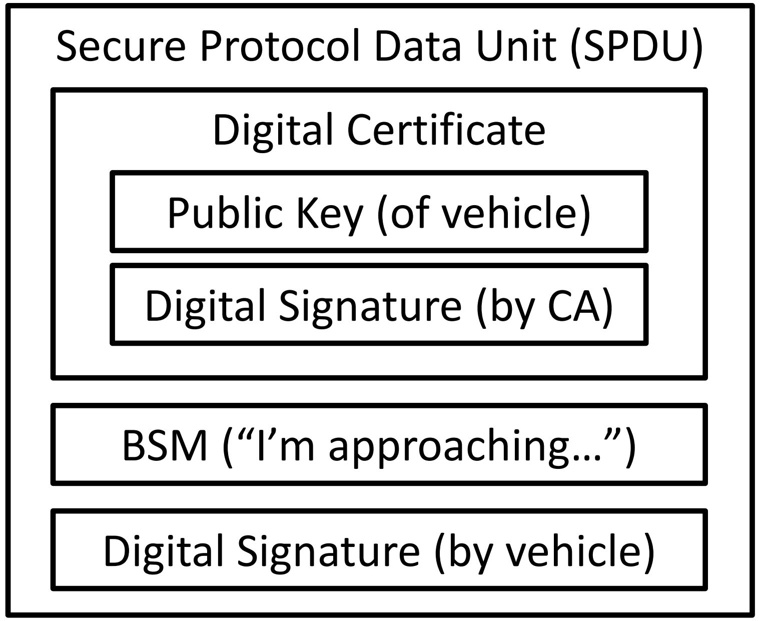
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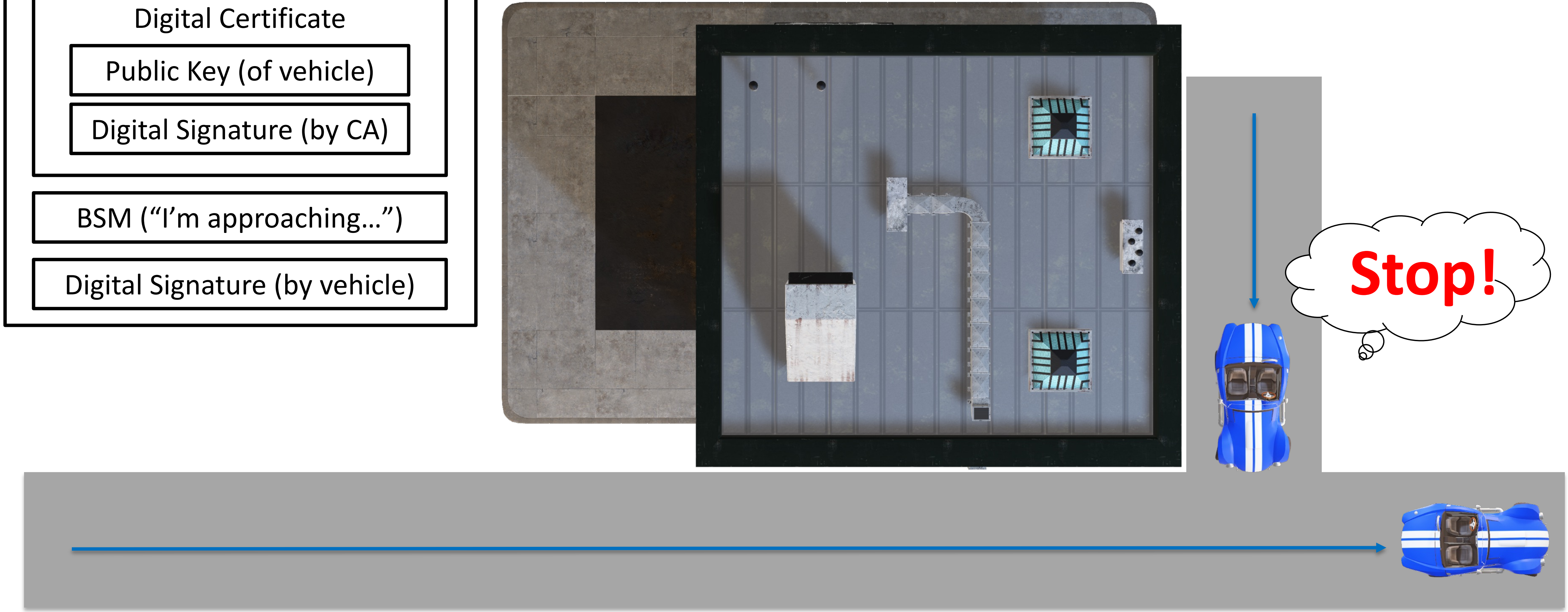

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Problem: V2V protocols cannot easily adopt these PQ signatures

Why Isn’t PQ “Plug-and-Play” in V2V?

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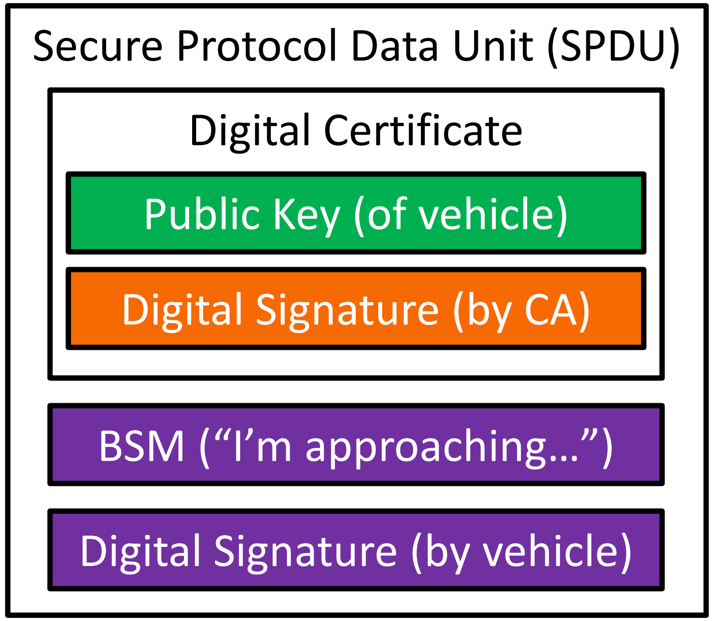

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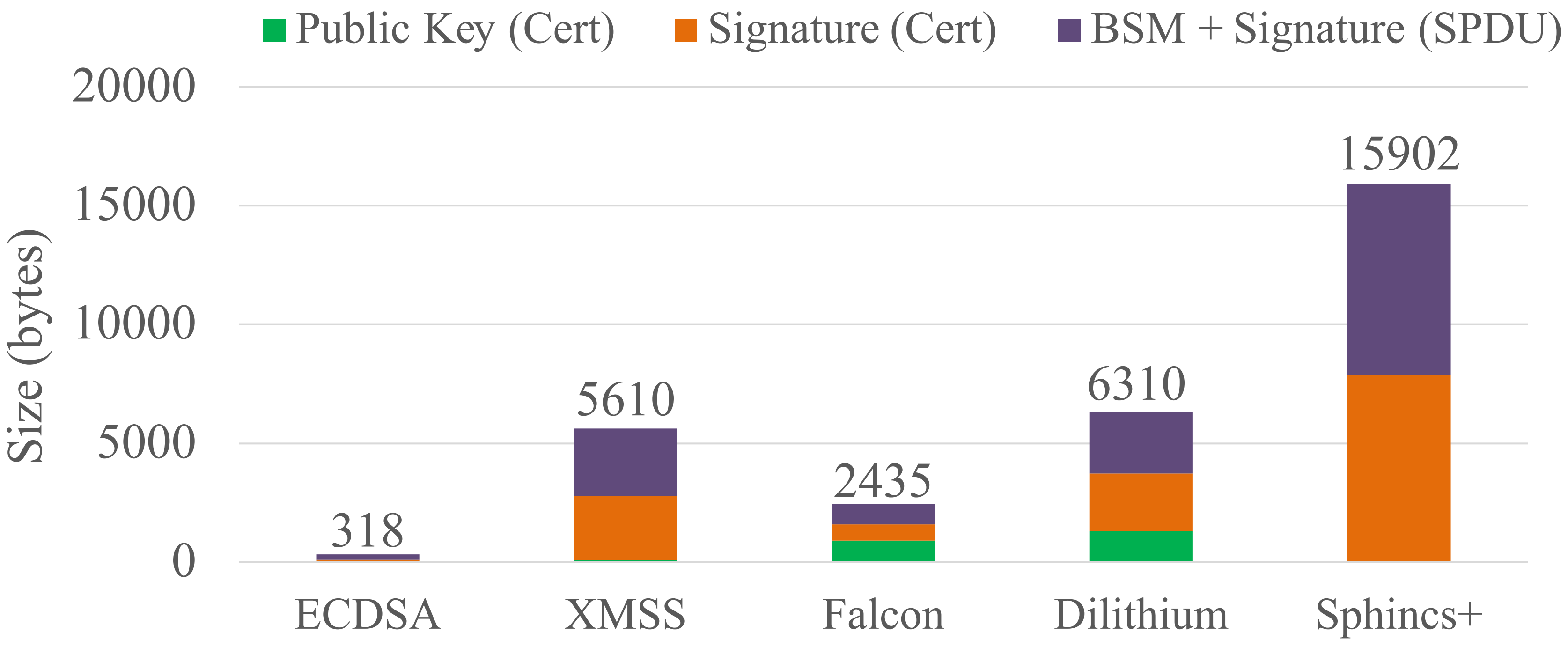

NIST-approved algorithms

PQ algorithms we consider for V2V

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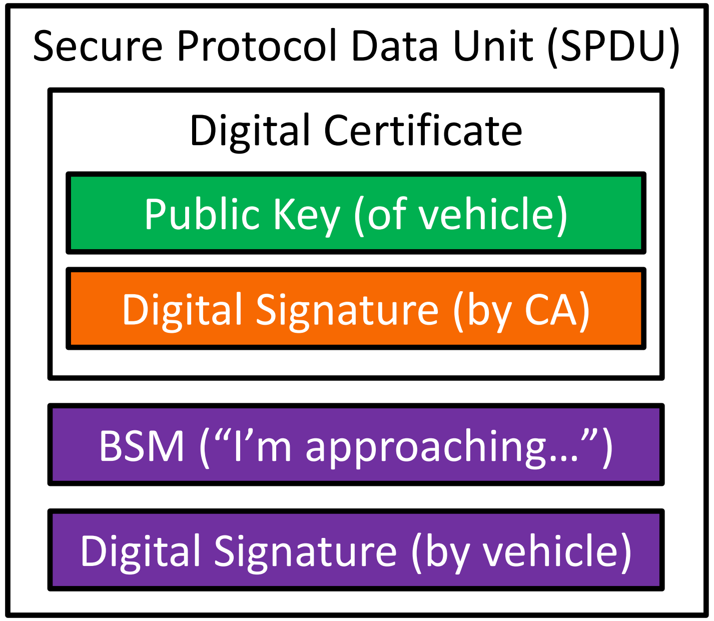

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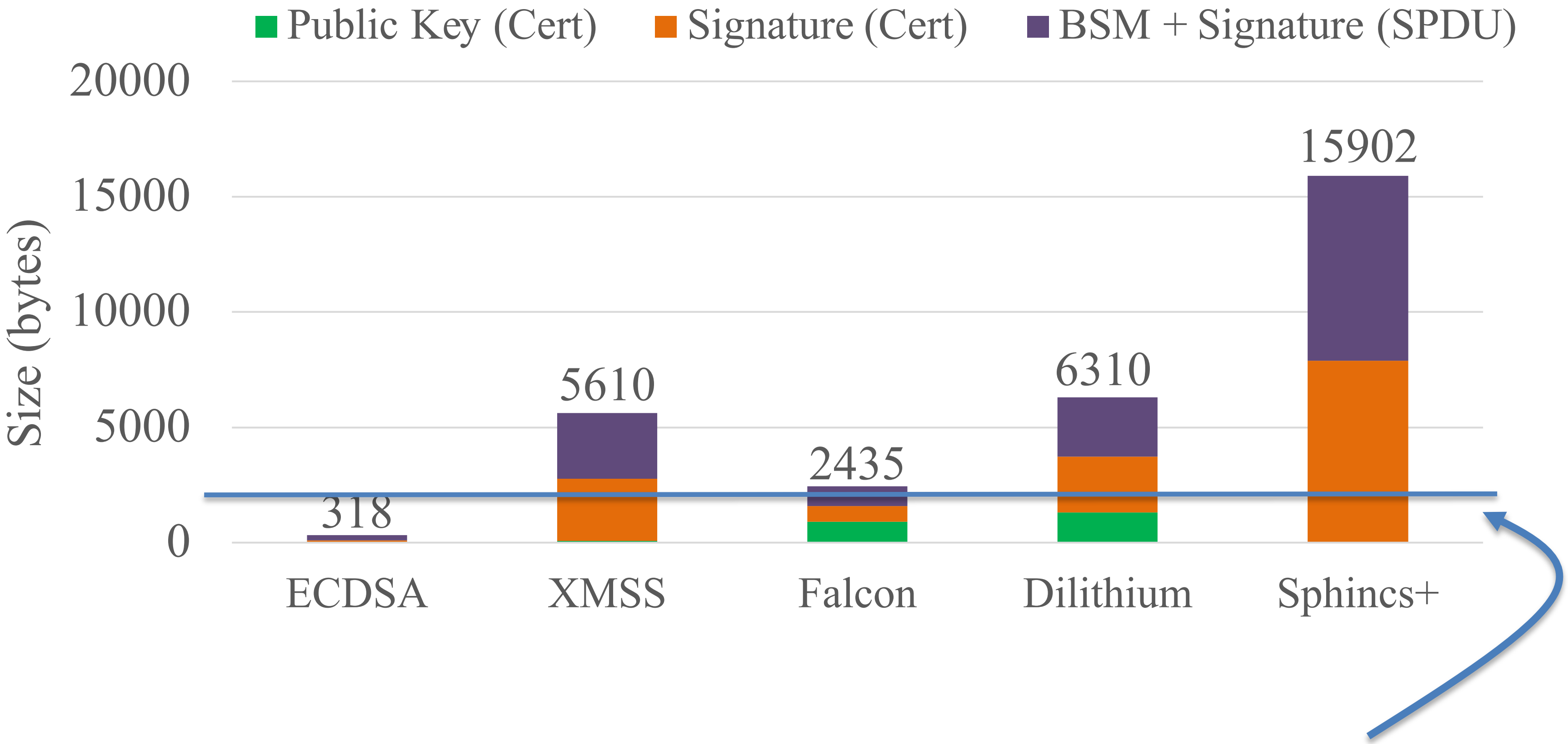
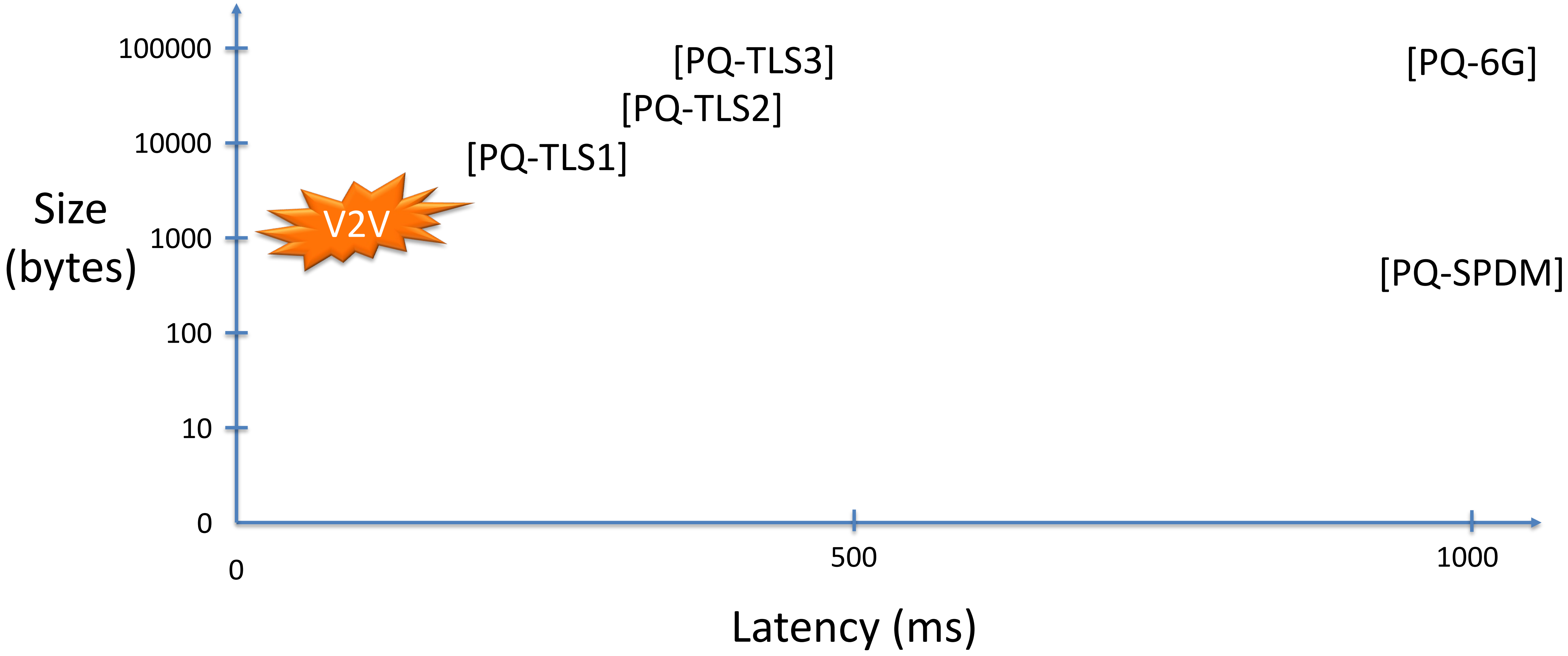


- ❑ Dedicated Short-Range Communication (DSRC) → 2,304-byte limit

V2V is (Uniquely) More Constrained



Our Contributions

Analyze quantum threat
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Identify V2V constraints for PQC

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Hybrid (PQ/EC) Authentication Protocol
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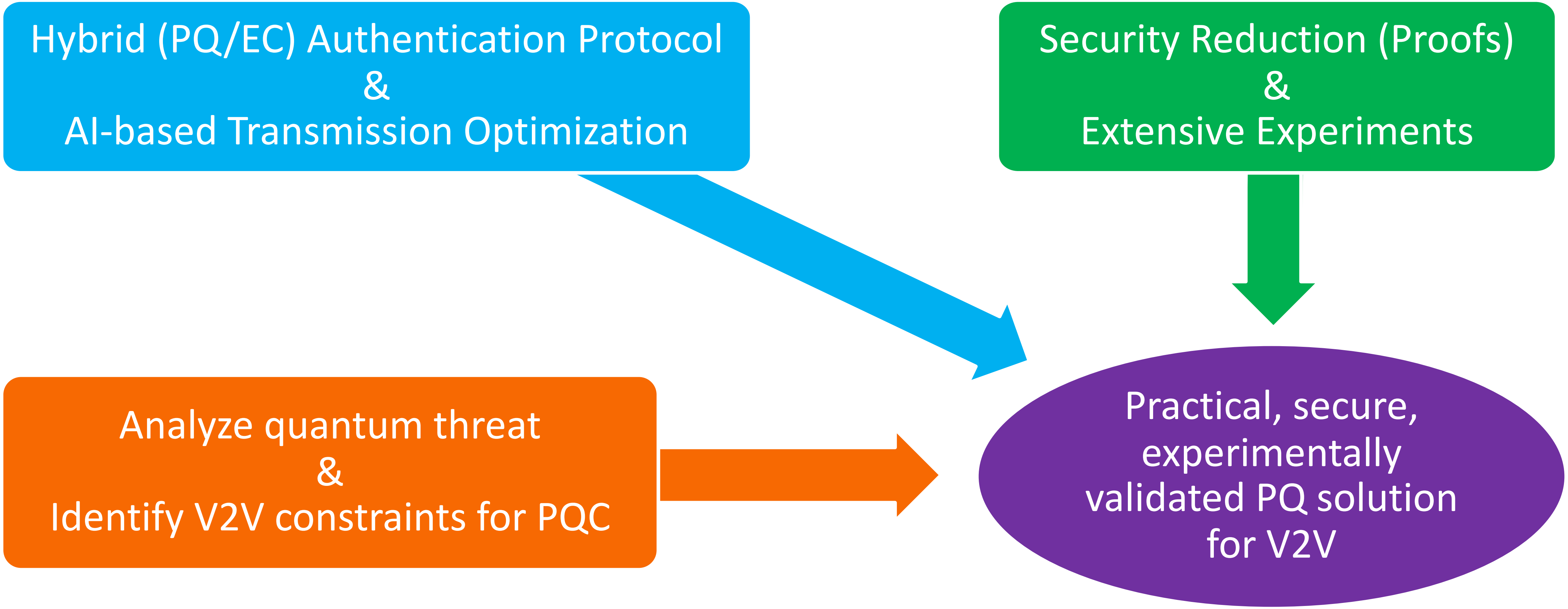

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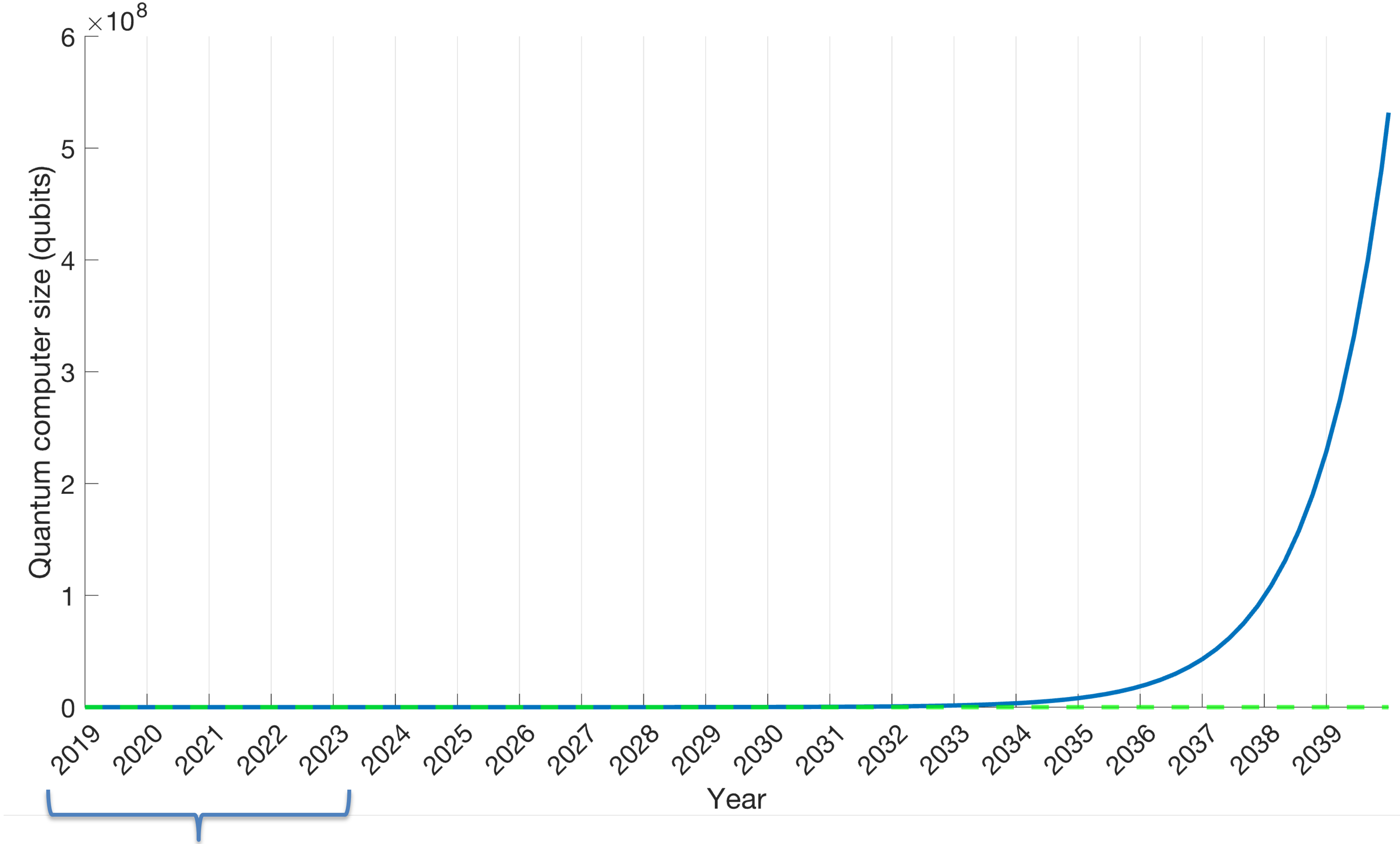
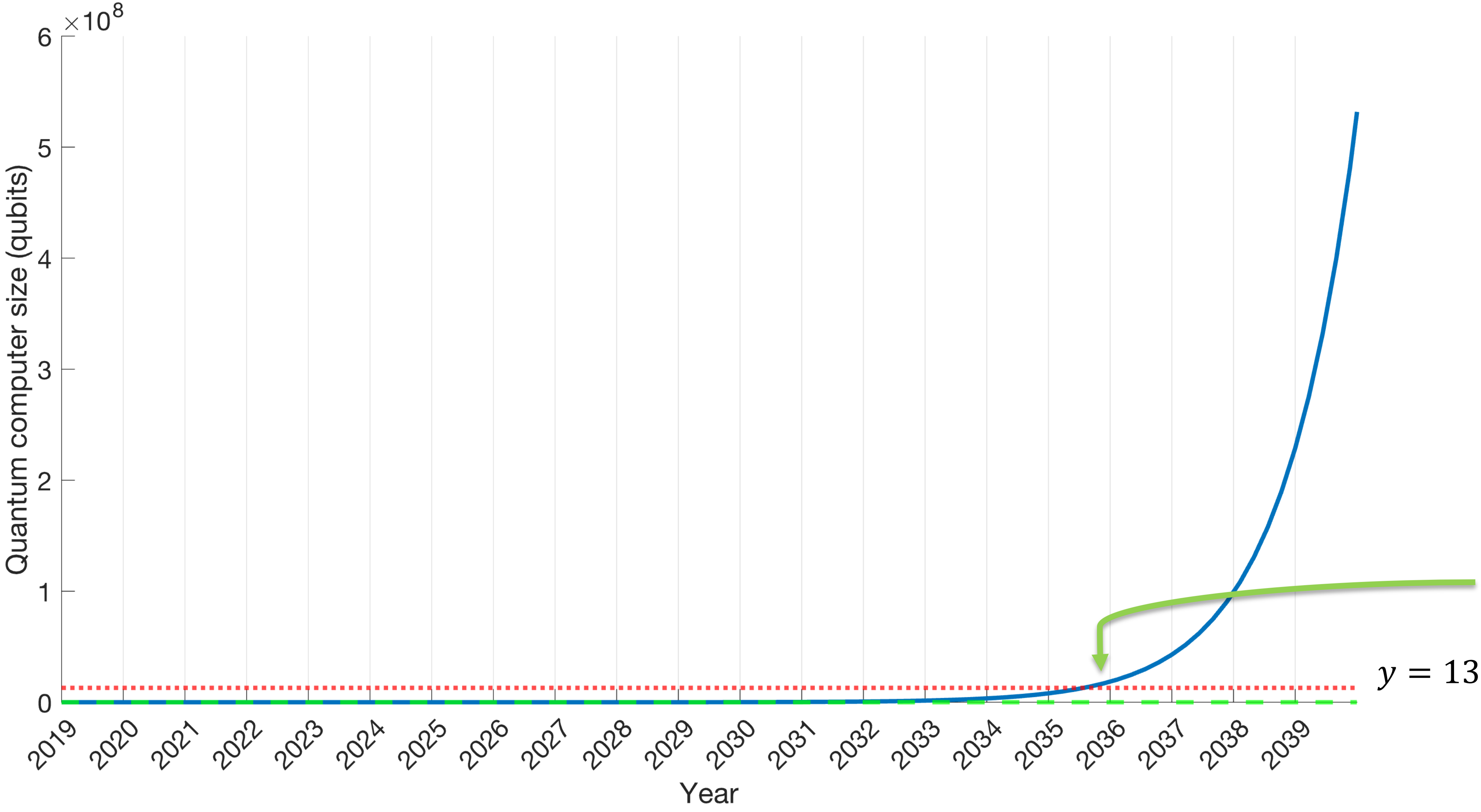
Practical, secure, experimentally validated PQ solution for V2V

How Much PQ Security Do We Need *Now*?

- ❑ Quantum computers (QCs) can’t break much (yet)

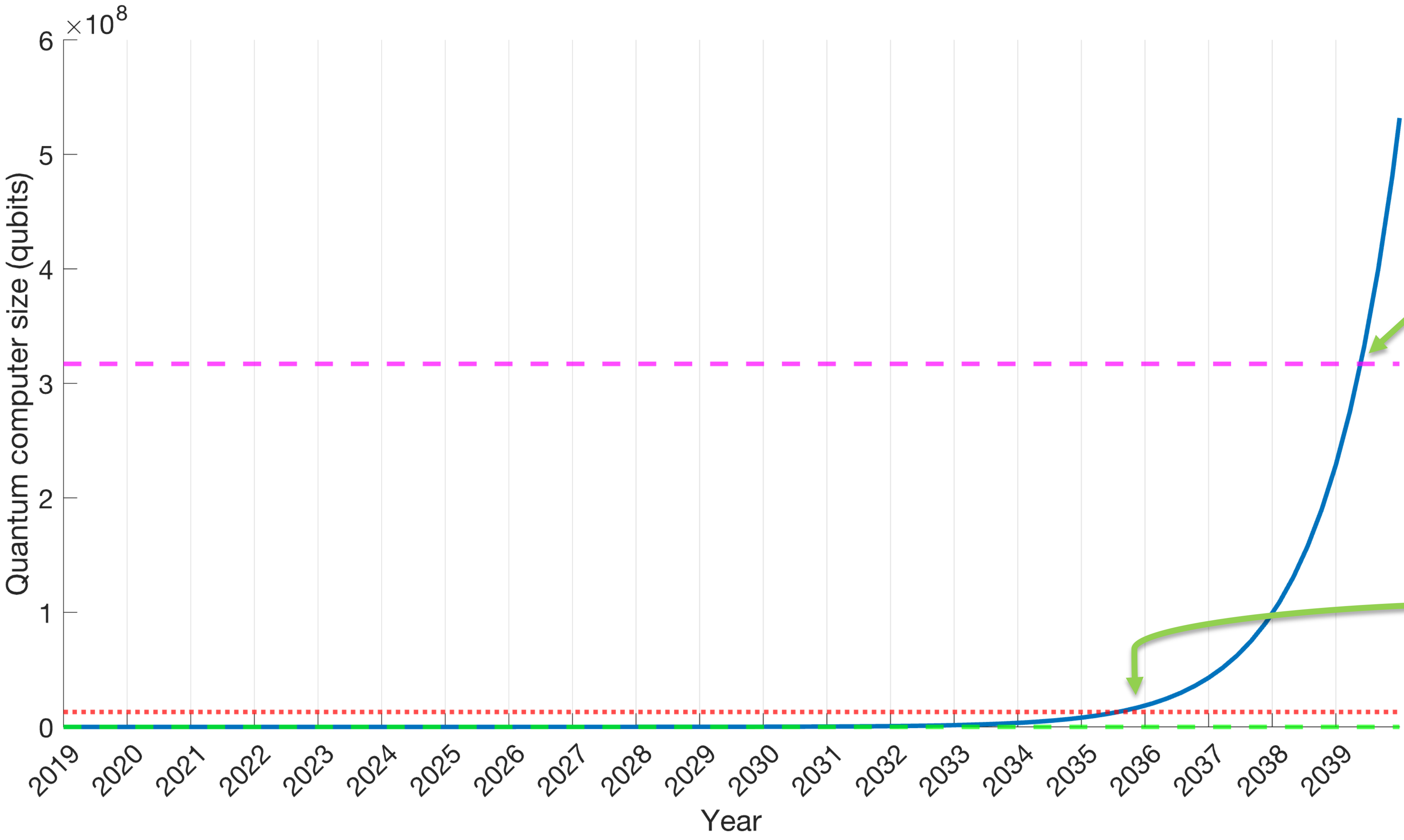


Extrapolation from 2019-2023 IBM data and forecast



Break ECDSA in one day ~2035

$y = 13{,}000{,}000$ qubits



Break ECDSA in one hour ~2039

$y = 317{,}000{,}000$ qubits

Break ECDSA in one day ~2035

$y = 13{,}000{,}000$ qubits

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Unlikely to have quantum threat before ~ 2035

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Today’s V2V wireless protocols and vehicle hardware need quantum resistance

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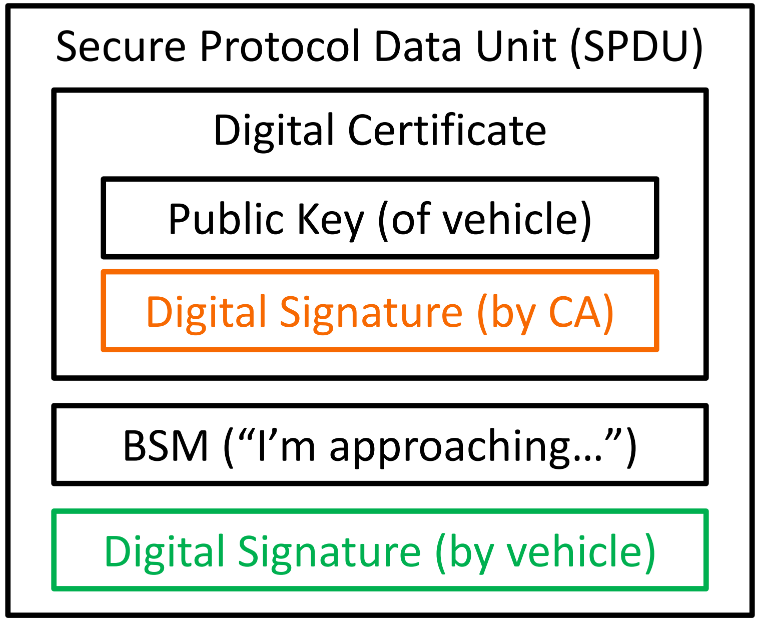

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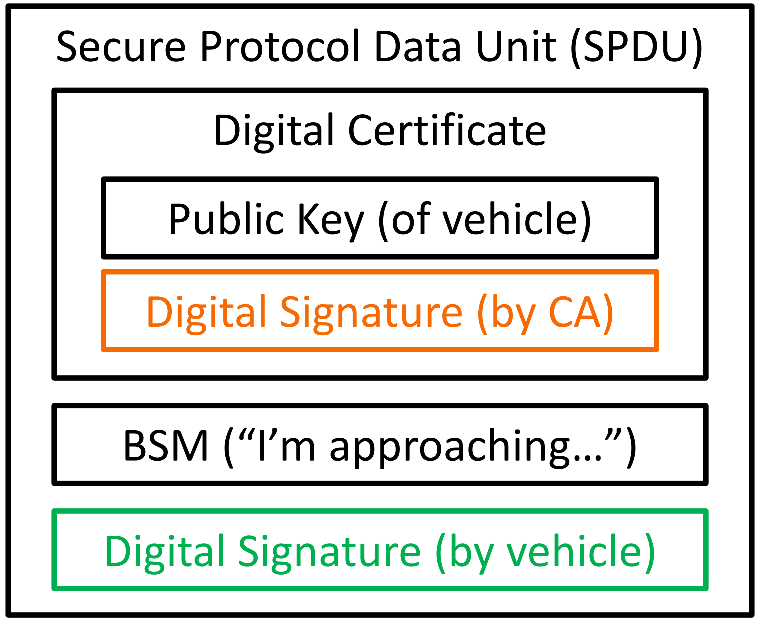
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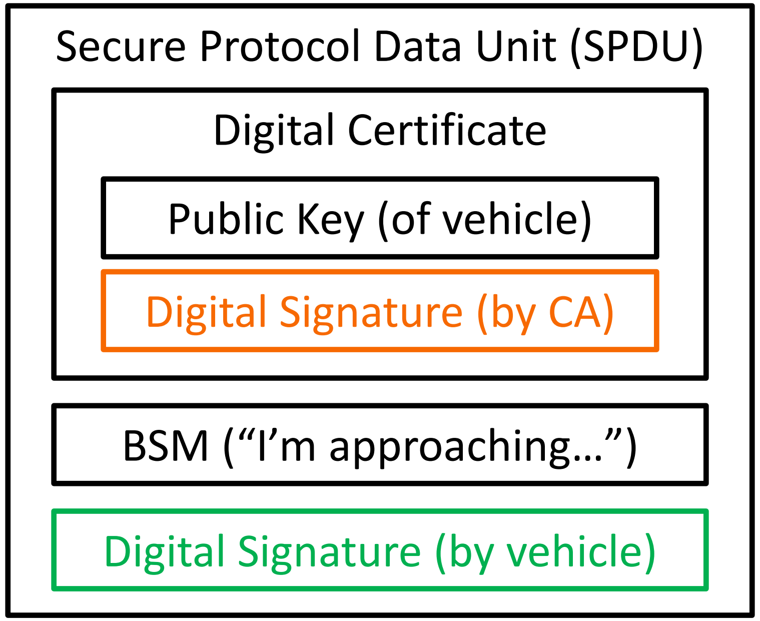
For the near future, focus on protecting certificates from quantum attacks in a hybrid solution for PQ V2V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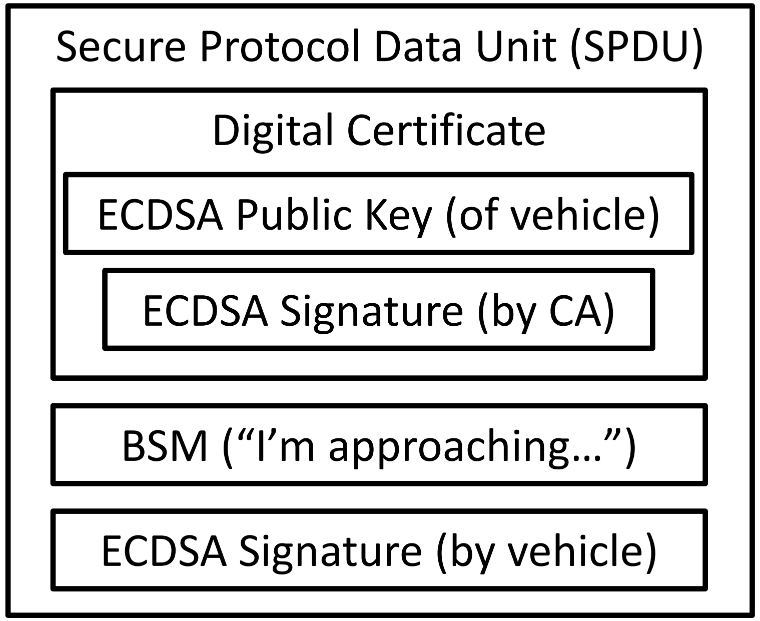

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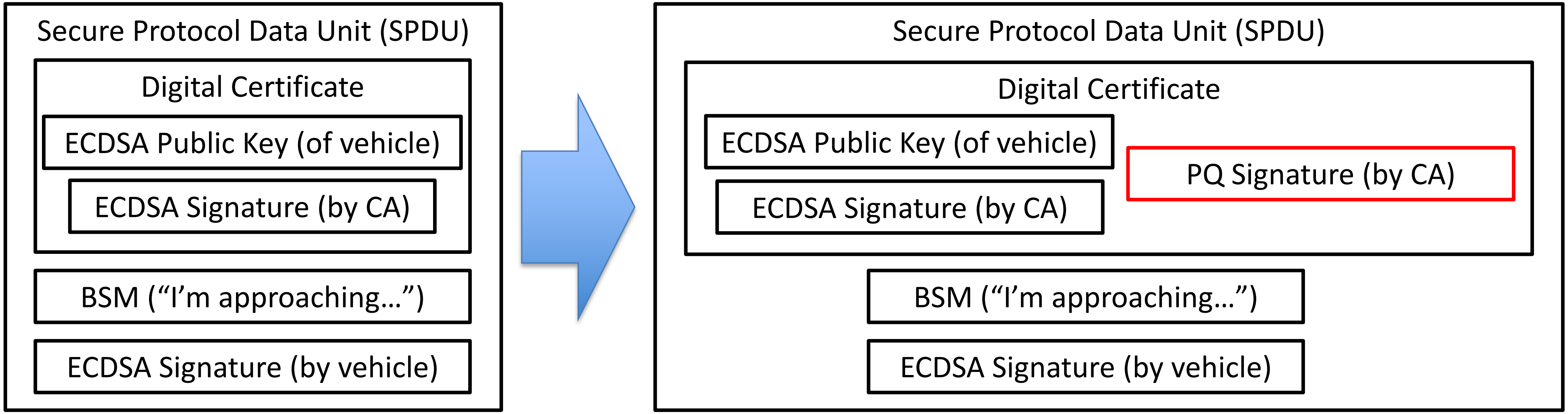
- Kickstart transition to PQ hardware and protocols
- Use PQ signature for certificate, keep EC signature for message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- Certificates are transmitted in every fifth SPDU
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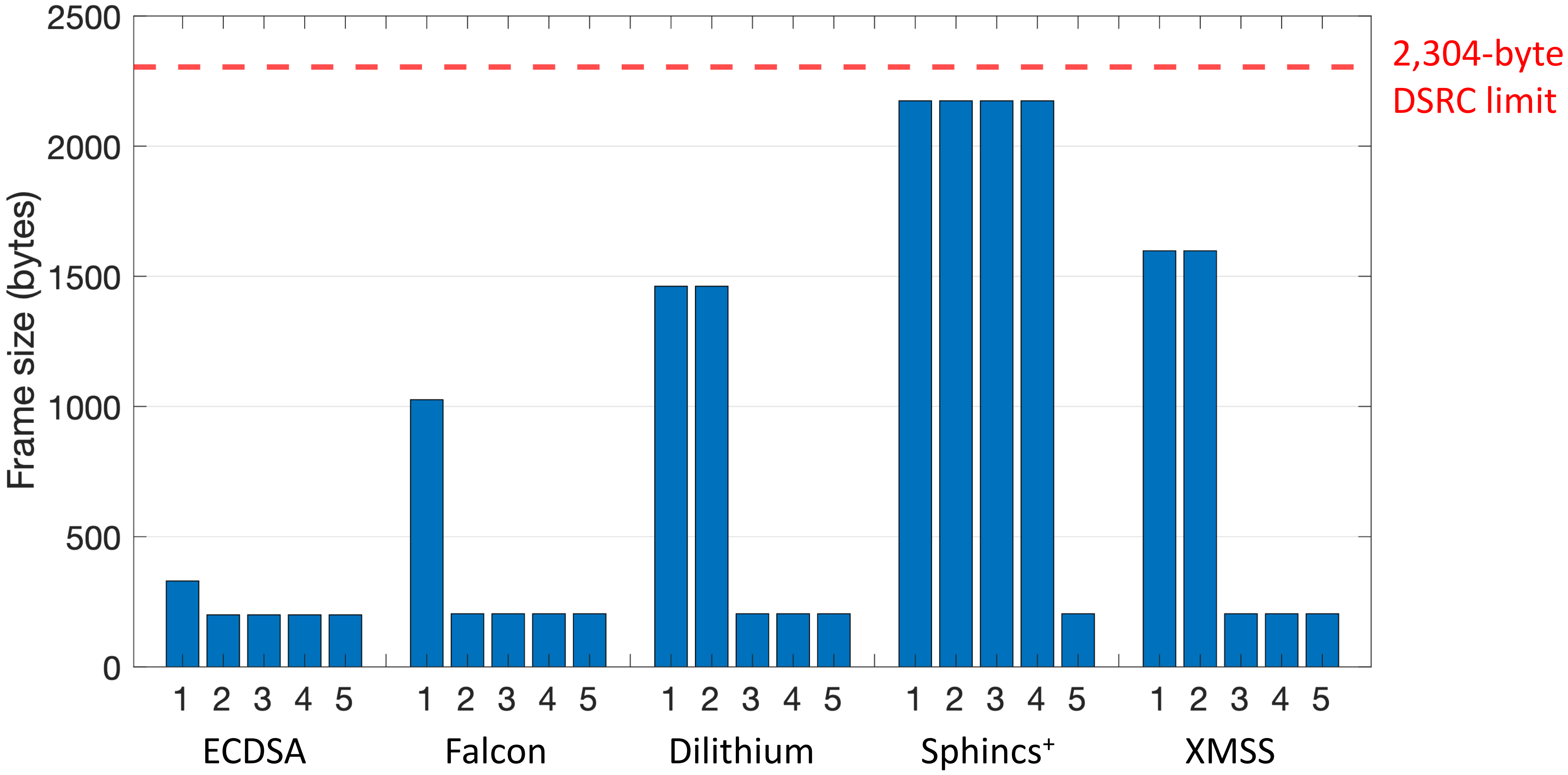
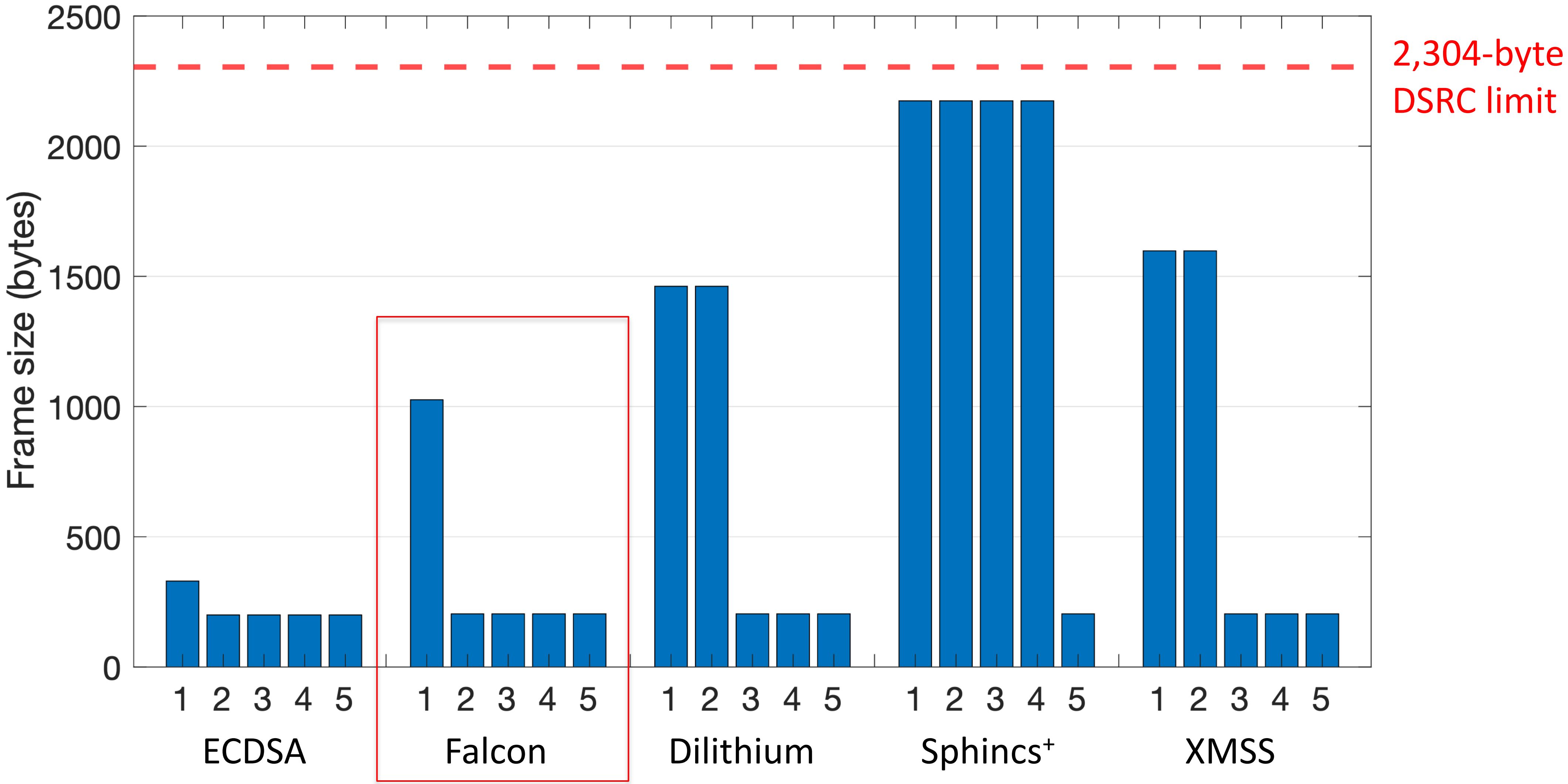
- Goal: Minimize message size



5-SPDU certificate cycle for ECDSA and selected PQ algorithms



5-SPDU certificate cycle for ECDSA and selected PQ algorithms

Larger Frames → Less Reliable

- Medium contention, hidden terminals in mobile network

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Problem: In high-density scenarios (100 vehicles/km), FLR is $+63\%$ when ECDSA replaced with *Partially Hybrid* design (using Falcon)

Source: https://bit.ly/3UPmBCG

Solution: Optimize Transmissions

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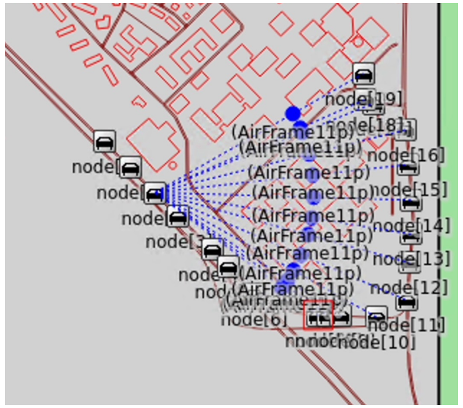
- Use distributed AI to dynamically adjust certificate interval
- Also optimize peer-to-peer certificate sharing protocol (P2PCD)

Experiments

- Extensive simulations in VEINS
  - Custom PQ-V2V module



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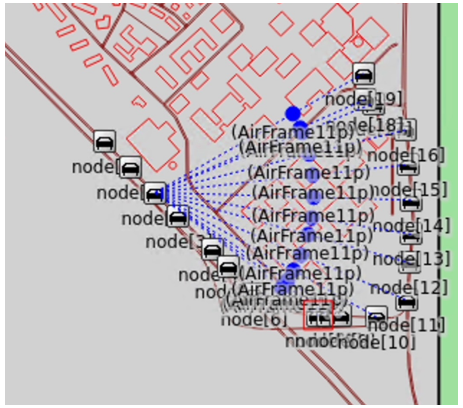

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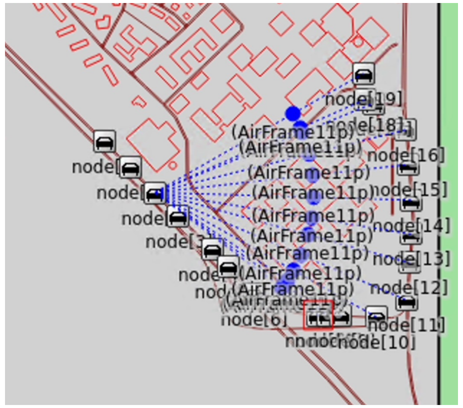

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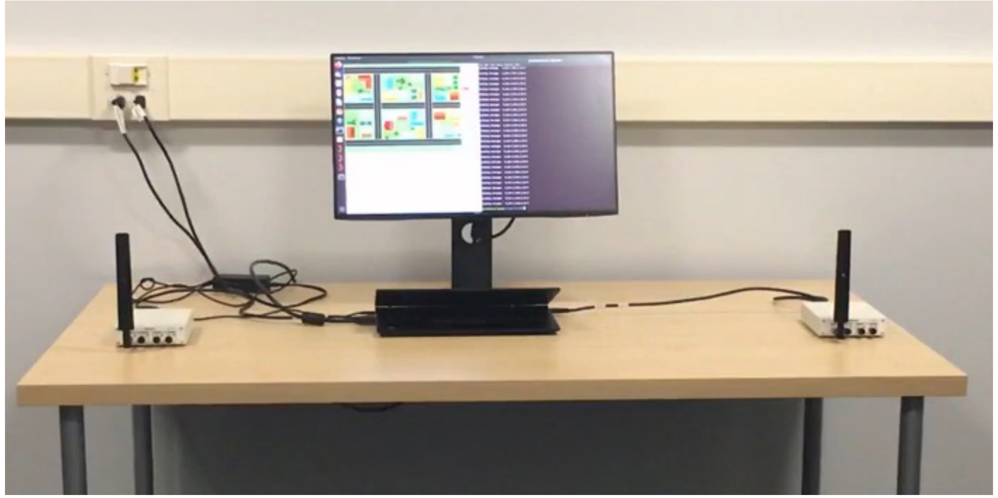
- ❑ USRP experiments in the lab and on real roadways
  - New testbed: *PQ-V2Verifier*



Experimental Results

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	Metric (vs. ECDSA)	Low-density (60 vehicles/km)	High-density (100 vehicles/km)
Partially Hybrid	Per-BSM delay	+0.66 ms	+0.67 ms
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	Δ FLR	+29%	+61%
Partially Hybrid w/ Spectrum Optimization	Δ FLR	+7.9%	+7.1%

Conclusions

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- ❑ Developed practical, hybrid authentication protocol
- ❑ Identified Falcon as best PQ algorithm for V2V
- ❑ Applied AI to optimize spectrum, improve reliability
- ❑ Validated through simulations and hardware experiments

Key Contributions

Forecast/assessment of quantum risk

Hybrid authentication protocol

Falcon is best PQ algorithm for V2V

AI to optimize spectrum, reliability

Simulations + hardware experiments

Thank You! Questions?

← Our paper

← Artifacts

Artifact Evaluated NDSS SYMPOSIUM
Available
Functional

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