GPU TECHNOLOGY CONFERENCE

March 27, 2014

QUANERGY™

Today's LiDARs and GPUs Enable Ultra-accurate GPS-free Navigation with Affordable SLAM

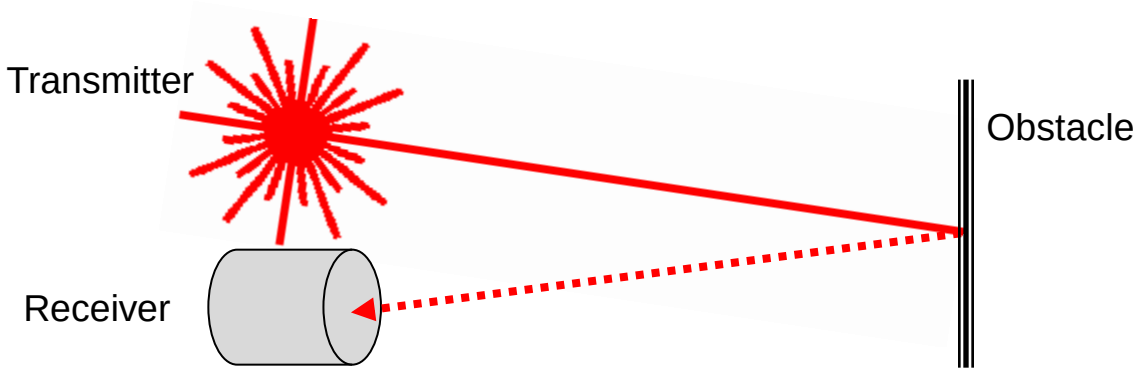
Louay Eldada
CEO, Co-Founder
Quanergy Systems, Inc.

New Paradigm in Automotive Safety & Navigation

- Recent technology advances resulted in low cost, high performance:
  - LiDARs
  - GPUs
  - IMUs
- These new components enable affordable ADAS and autonomous driving systems
- These advanced systems, installed on a network of vehicles, enable GPS-free navigation through SLAM

LiDAR: Light Detection And Ranging
IMU: Inertial Measurement Unit
ADAS: Advanced Driver Assistance Systems
SLAM: Simultaneous Localization and Mapping

Time of Flight LiDAR



- LiDAR stands for **Light Detection And Ranging**
- Measures **Time of Flight** (TOF), the round-trip travel time for a laser pulse reflected off obstacles
- Depth perception → **3D mapping**
- High-speed detection & processing → **real-time detection**
- Long **range**, high **accuracy**, works **day & night**, **rain or shine**
- Low-cost LiDARs benefit **Mapping** vehicles and **ADAS** today, **semi-autonomous** vehicles in the near future, and **fully autonomous** vehicles in the future

Levels of Automation for On-Road Vehicles

NHTSA Level	SAE Level	SAE Name	SAE Narrative Definition	Execution of Steering and Acceleration/ Deceleration	Monitoring of Driving Environment	Backup Performance of Dynamic Driving Task	System Capability (Driving Modes)
	Human driver monitors the driving environment						
0	**0**	**Non-Automated**	The full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	**1**	**Assisted**	The driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task	Human driver and system	Human driver	Human driver	Some Driving modes
2	**2**	**Partial Automation**	The driving mode-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task	System	Human driver	Human driver	Some Driving modes
	Automated driving system ("system") monitors the driving environment						
3	**3**	**Conditional Automation**	The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene	System	System	Human driver	Some Driving modes
4	**4**	**High Automation**	The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene	System	System	System	Some Driving modes
	5	**Full Automation**	The full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver	System	System	System	All driving modes

Source: Summary of SAE International's Draft Levels of Automation for On-Road Vehicles (July 2013)
NHTSA - National Highway Traffic Safety Administration
SAE - Society of Automotive Engineers

Why LiDAR

- LiDAR is the most reliable sensor for object detection
- LiDAR is more reliable than any existing sensing solution, including:
  - Radar (all types)
  - Video (all types, including IR)
  - Video + Radar
  - Video + Ultrasonic Sensors
  - Stereoscopic Cameras

LiDAR is the only acceptable technology for object detection in vehicles – technologies that detect 99 out of 100 objects would be acceptable if one accepts the consequences of failing to detect 1 out of 100 pedestrians or bikers

Brad Templeton, Robocars (& Google Car Consultant)

The Need for Low Cost LiDAR

Surveying

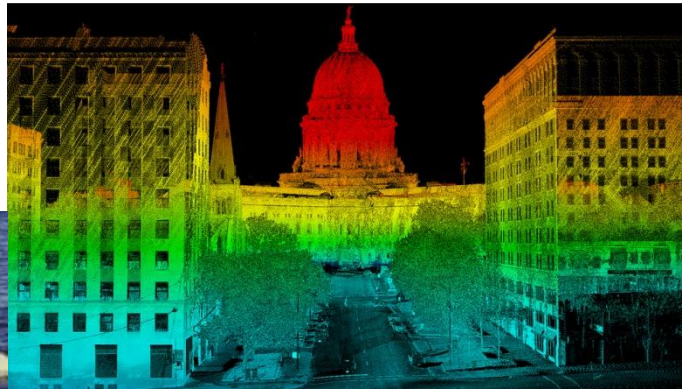
Automotive – Full Awareness

Safety – Monitoring, Security – Surveillance

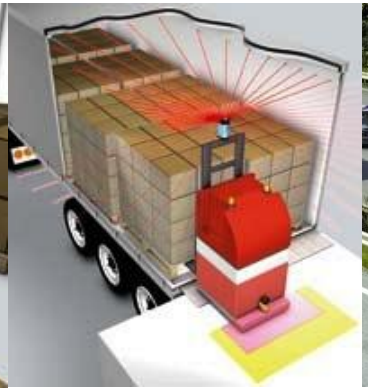
Military – Driverless Vehicles

LiDAR 3D sensors enable safety and efficiency in numerous applications unserved on mass scale due to cost, size, reliability

Maritime – Autonomous Vessels



Simultaneous Localization & Mapping



Industrial – Factory/Warehouse Automation

Automotive – Driver Assistance

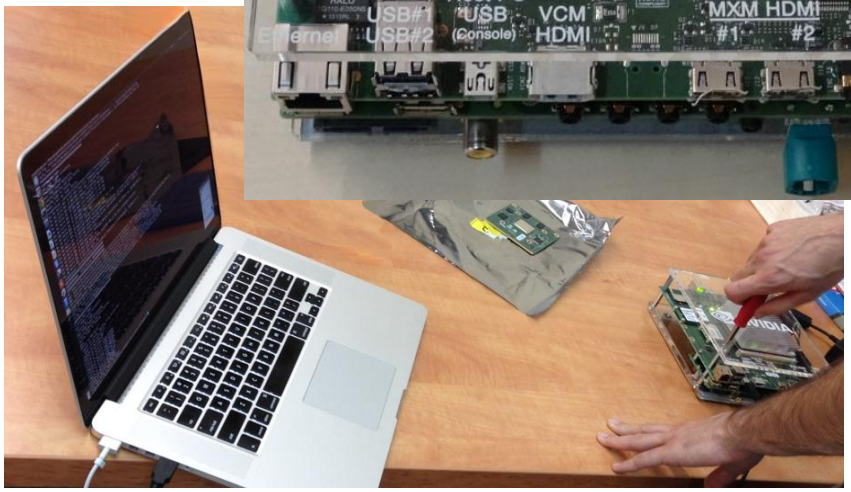
Automotive – Autonomous Driving

TEGRA K1 Based Automotive System

- Real-time object detection, tracking, identification and classification is important in ADAS and critical in Autonomous Vehicles
- Objects include vehicles, pedestrians, animals, road features (e.g., debris, speed bumps, potholes), infrastructure (e.g., bridges, curbs, street signs), etc.
- We are doing CUDA implementation of this capability on the Tegra K1 platform

Jetson TK1

- NVIDIA Jetson TK1 (Tegra K1 dev kit) was provided to Quanergy by Carlos Garcia-Sierra (thank you!)
- TK1 is computer-on-a-board with K1 processor, 2GB RAM, 16GB eMMC storage, and:
  - Half mini-PCIE slot
  - Gigabit Ethernet
  - SD card connector
  - HDMI port
  - Mic and Line jacks
  - 1 micro USB 2.0 port
  - 1 USB 3.0 port
  - SATA data port
  - 4MByte boot flash
  - Expansion port for UART, GPIO, DP/LVDS signals



- Jetson TK1 board has NVIDIA's ARM Cortex-A15 4-Plus-1 quad-core processor with Kepler graphics and 192 CUDA cores
- TK1 supports the CUDA 6.0 developer tool suite; it provides tools for app developers to take advantage of the Tegra K1 features, and for hardware makers to test the platform for chip selection

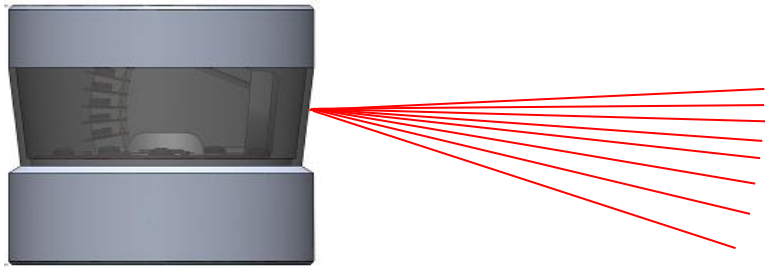
The Mark VIII: 8-Beam LiDAR

Designs focus simultaneously on cost, performance, size, and reliability

Gen 1: mechanical LiDAR (Mark VIII)

Gen 2: solid state LiDAR

19 Patents Pending



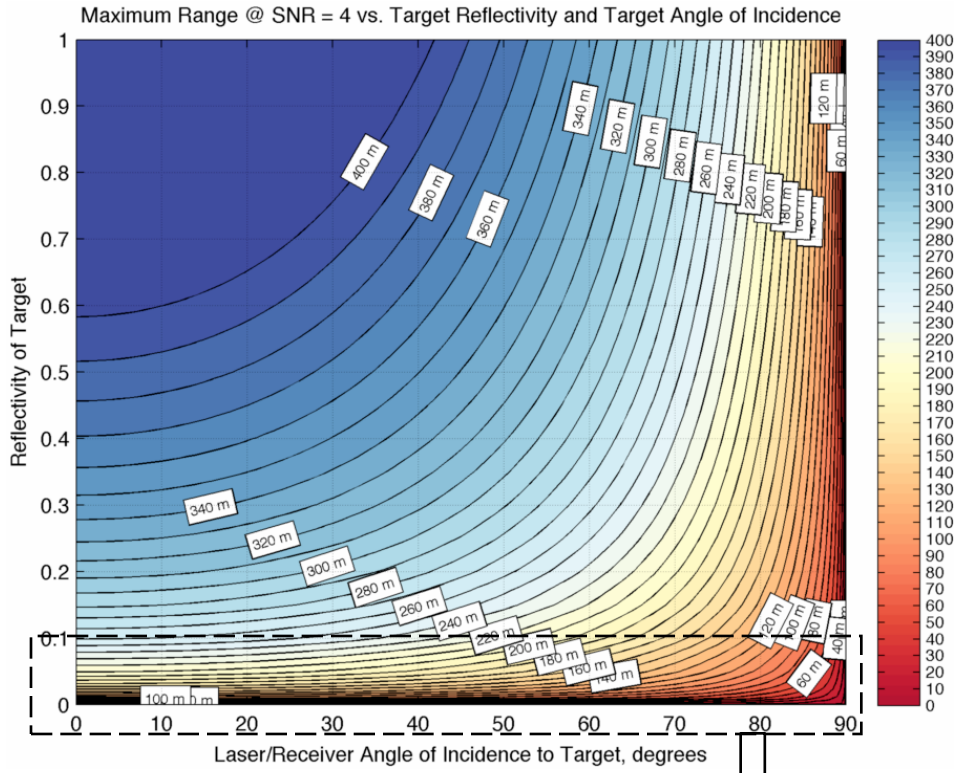
- Lasers that see farther are spaced closer to maintain resolution at distance
- Some beams are pointed skyward to prevent blind spots in the event of pitch or roll

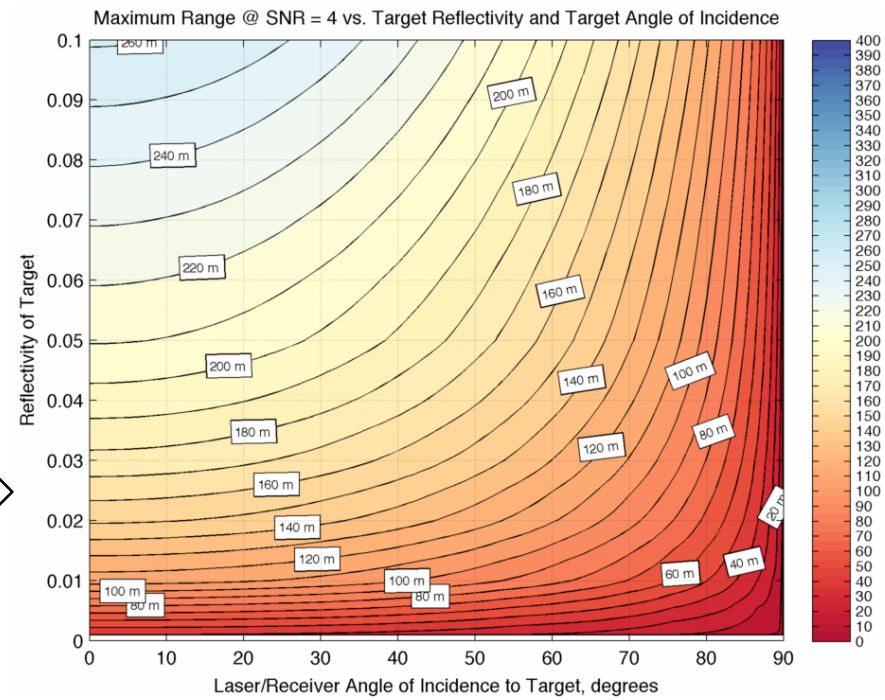
Mark VIII Specifications

Parameter	Specification
Laser Class	Class 1 (eye safe)
Laser Wavelength	905 nm
Measurement Technique	Time of Flight (TOF)
Measurement Range	300 m at 80% reflectivity, 100 m at 10% reflectivity
Range Accuracy	1.5 cm
Angular Resolution	0.1°
Spatial Resolution	17.5 cm at 100 m
Sensors	8 laser/detector pairs, 3-axis accelerometer
Field of View (FOV)	Horizontal: 360°, Vertical: 20° (+3°/-17°)
Frame Rate (Update Frequency)	10-30 Hz
Operating Temperature	-40°C to +85°C (-40°F to +185°F)
Storage Temperature	-40°C to +105°C (-40°F to +220°F)
Power	20 W
Operating Voltage	9-32 VDC
Weight	1 kg
Dimensions	3.5” diameter x 3” height
Shock	500 m/sec^2 amplitude, 11 msec duration
Vibration	5 Hz to 2000 Hz, 3 G_{rms}
Environmental Protection	IP69K – NEMA* rating for dust & water ingress protection
Functional Safety	ISO 26262 – Road Vehicle Functional Safety
Stress Resistance	AEC-Q100 – Critical Stress Test for Automotive ICs
Laser Safety	ANSI Z136.1 – American National Standard for Safe Use of Lasers
Laser Product Safety	IEC 60825 – European Standard for Safety of Laser Products
Military System Safety	MIL-STD-882E – System Safety (for Military Applications only)
Data Output Connection	1 Gbps Ethernet
UDP Packets**	Angle, Distance, Intensity, IMU, Status, Return Classification (solid vs. aerosol)

*NEMA: National Electrical Manufacturers Association **User Datagram Protocol

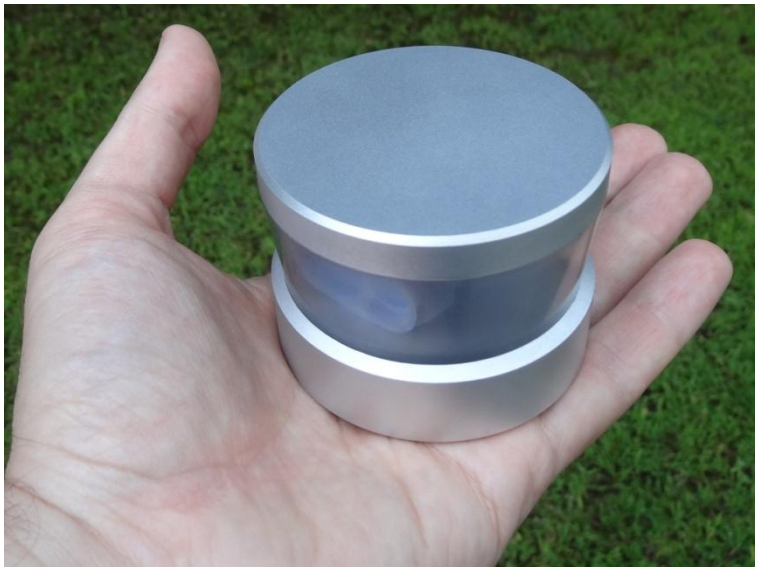
LiDAR Range
vs. Target Reflectivity & Incidence Angle

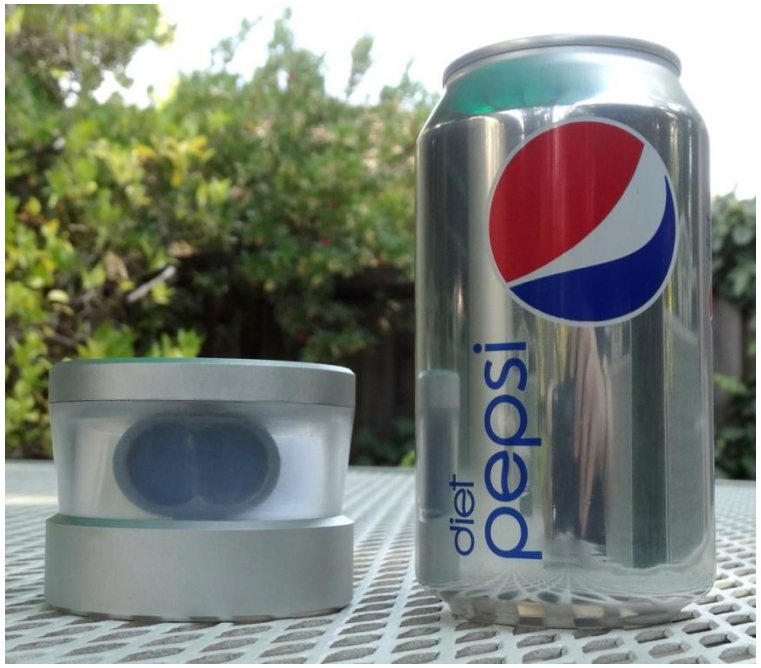




- For vehicles (0.8 reflectivity [standard in range reporting]), **range is >400m**
- For low reflectivity obstacles (0.1 reflectivity), **range is 250m**

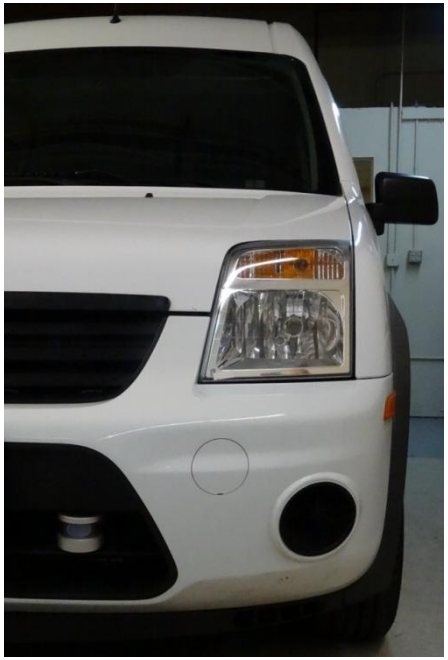
The Mark VIII 8-beam LiDAR





Compact size, easy to integrate discreetly in various vehicle types

Mark VIII LiDAR
Mounting in Van



Small form factor allows easy fit in various locations on a vehicle

Mark VIII LiDAR
Mounting in Sports Car

Small form factor allows easy fit in sports cars without impacting aesthetics or aerodynamics

ADAS Ecosystem

Cloud Based
Data Processing

Off-line Data Fusion
Cloud Computing

Online Map Data
Cloud Streaming

Telematics

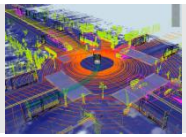
Cellular
Connectivity

Wi-Fi
Connectivity

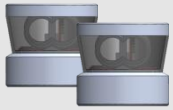
Map Data
Generation

Safety
Monitoring

On-Board
Data Parsing



Sensor
Layer



Point Cloud Fusion in the Cloud

LiDAR point cloud data is pre-processed in the system, then post-processed and fused in the cloud, creating a continuously updated 3D map for SLAM

Vehicle Side

- **Hardware:**
  - NVIDIA **Tegra K1** integrated CUDA **GPU** and **CPU** coprocessor
- **Software:**
  - Onboard software performing real time sensor data pre-processing, vehicle localization, sensor fusion (with GPS and IMU data), scene segmentation, object identification, tracking and classification, scenario analysis and preemptive safety modeling
  - Written in **C++** and employing extensions/customizations of the **PCL** (Point Cloud Library)

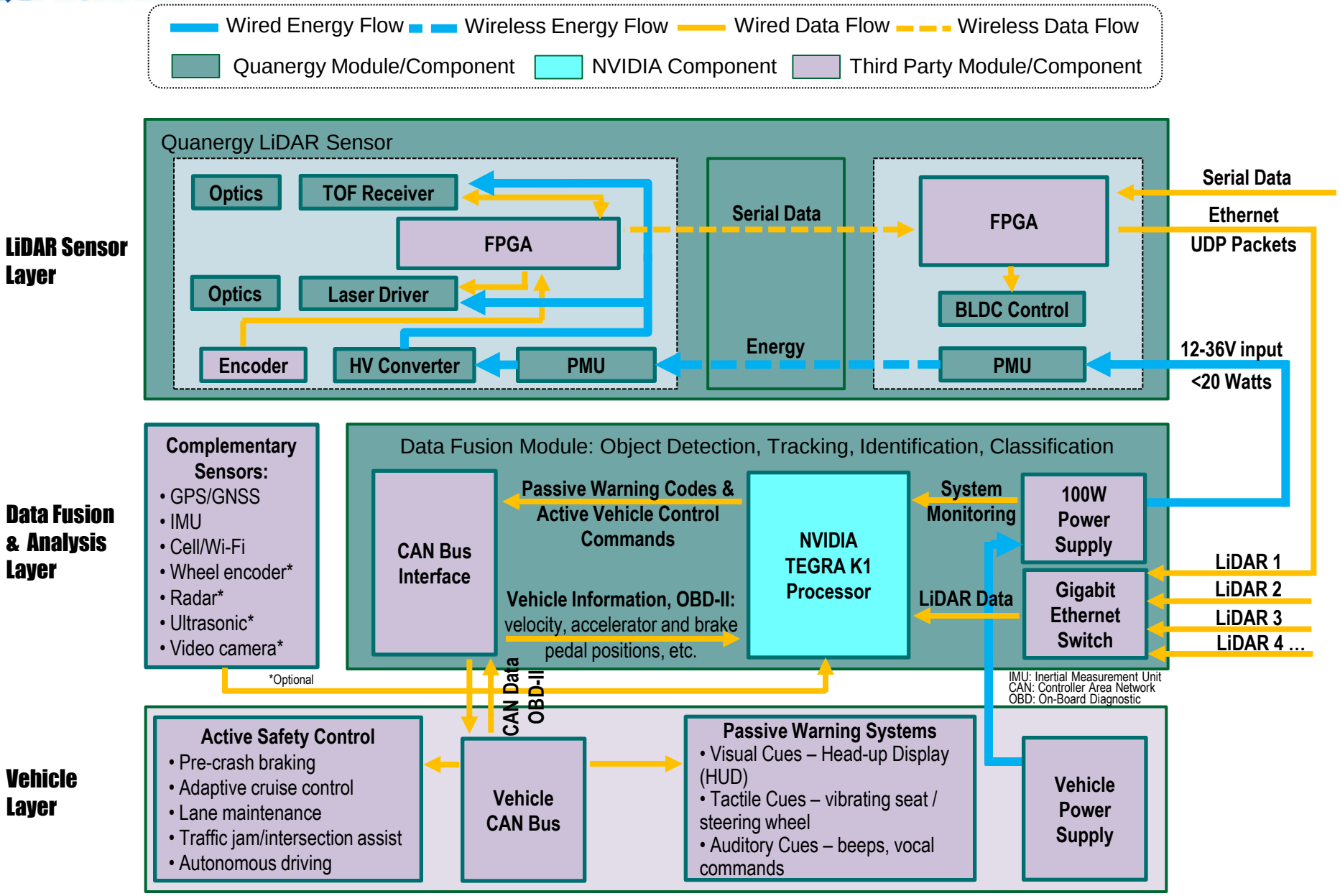
Server Side

- **Hardware:**
  - Scalable cloud storage and processing using a web service such as **AWS** (Amazon Web Services) and leveraging free data transfers between AWS modules
  - Expandable storage cluster using service such as Amazon **S3** for saving raw and processed data and serving data to both end users and internal processing routines
  - On-demand **HPC** (High Performance Compute) cluster such as Amazon **EC2** using NVIDIA CUDA **GPU**s for highly parallelized raw point cloud fusion, multi dataset co-registration, filtering, scene segmentation & classification, and dataset down-sampling
- **Software:**
  - Scalable **Hadoop** instance on cluster such as **EC2**
  - Customized **C++** fusion algorithms employing HPC **API** wrappers, **OpenCL**, and **PCL**
  - External-facing **API** for use of final 3D map

Quanergy ADAS Components

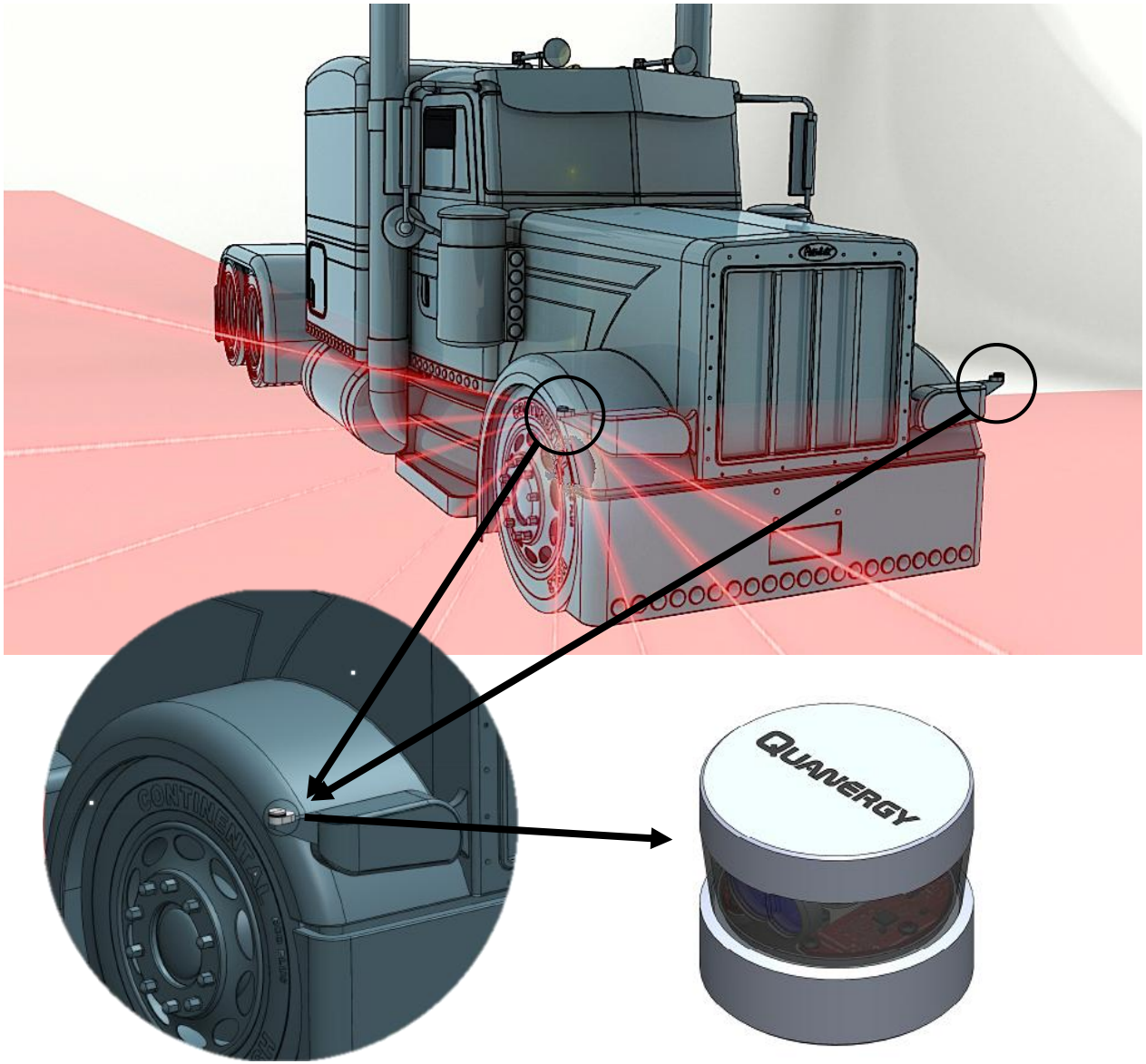
- **Sensor modules**
  - 8-beam Quanergy LiDAR (typically 1 or 2 units)
  - GNSS (Global Navigation Satellite System) receiver
  - IMU (Inertial Measurement Unit), includes accelerometer & gyroscope
  - Wheel encoder (optional)
  - Video camera (optional)
  - Ultrasonic sensors (optional)
  - RADAR (optional for long-haul vehicles)
- **Processing and communication modules**
  - TEGRA K1 processor
  - Ethernet controller
  - Cell modem
  - Wi-Fi controller
  - Data storage
  - HMI (Human Machine Interface) e.g., onboard display, audio, buzzer
- **Balance of System (BOS)**
  - Power supply
  - Enclosure
  - Cabling
  - Mounting hardware

ADAS System Schematic



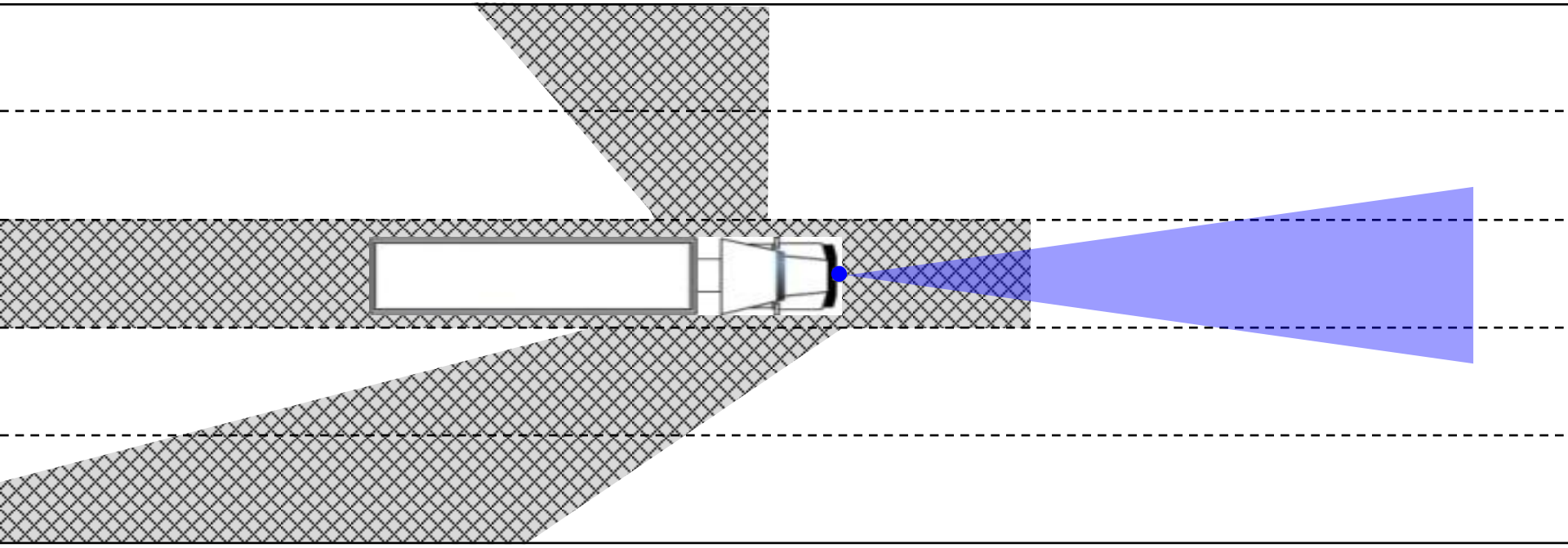
Quanergy LiDAR Use in Truck ADAS

- **1 or 2 LiDAR** sensors secured to vehicle (side or roof mount)
- LiDAR sends pulsed laser light in **360° swath**
- Data is relayed to a central processor for **data fusion**, **object recognition**, **scenario analysis** and **decision making**
- Passive ADAS: data is sent to **HMI** in cabin (audio, visual and/or tactile feedback)
- Active ADAS: system interfaces to **ECU** and takes action when driver does not react in time
- Autonomous Vehicle (AV): **AI** takes over, with driver or driverless



Conventional ADAS Sensors: Long Range Radar

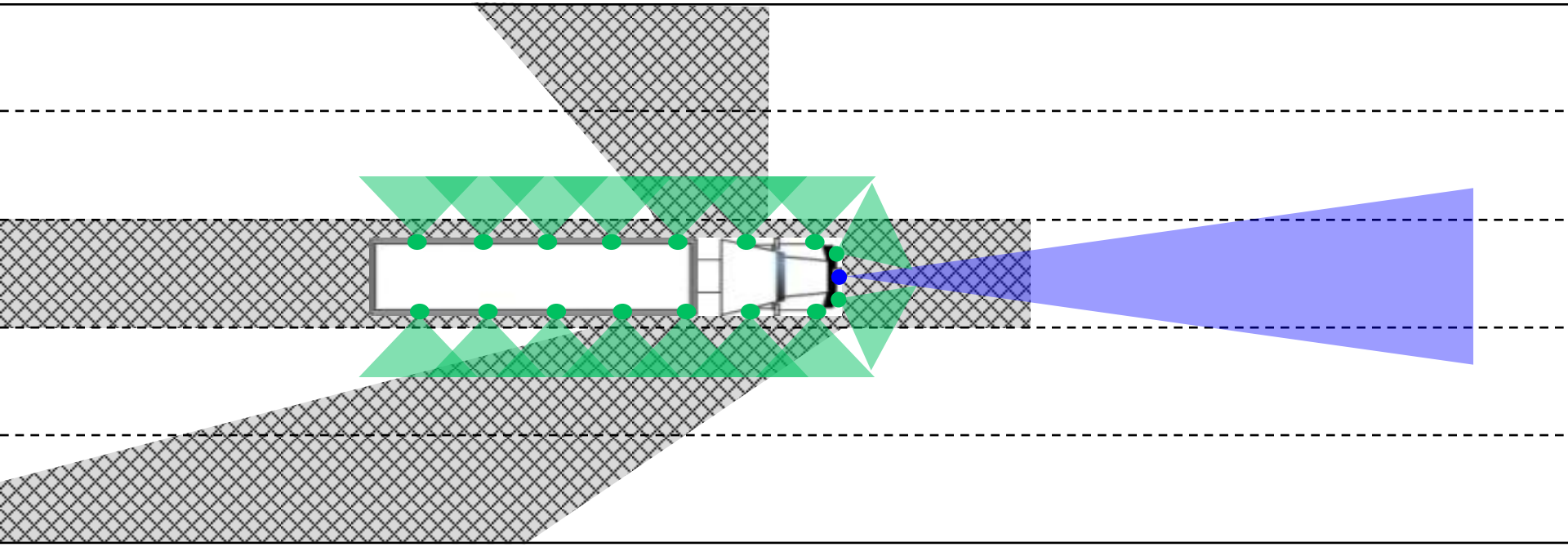
- Video camera
- Ultrasonic Sensor
- 50° RADAR Sensor
- 12° RADAR Sensor
- LiDAR Sensor
- Blind Spot



Forward looking long range radar:
Most ADAS solutions require a long range, forward looking radar for high speed collision warnings

Conventional ADAS Sensors: Ultrasonic Sensors

- Video camera
- Ultrasonic Sensor
- 50° RADAR Sensor
- 12° RADAR Sensor
- LiDAR Sensor
- Blind Spot

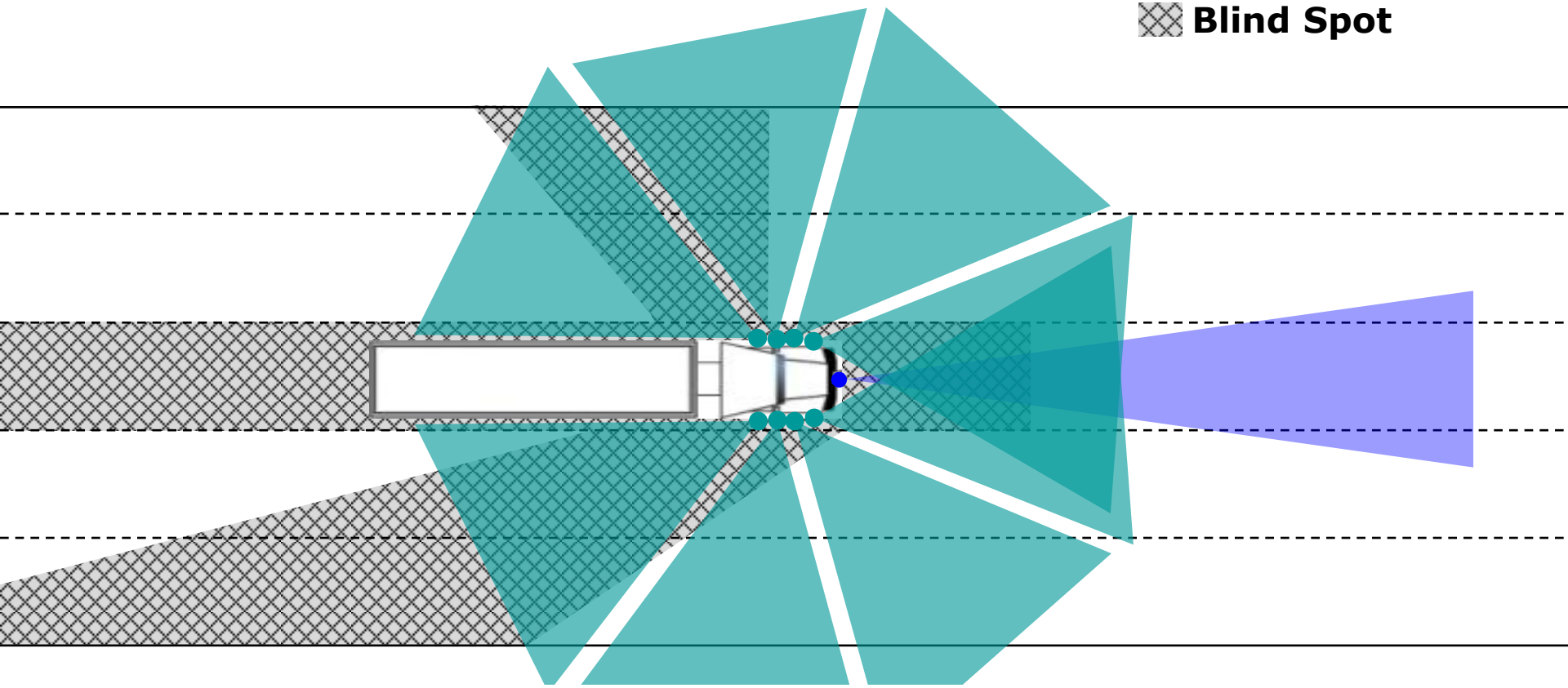


Ultrasonic Sensors – Impractical and poor performance:

- Impractical and expensive to mount so many sensors and to equip every trailer
- Sensors provide low quality data; a binary observation depending on presence of object, and short range

Conventional ADAS Sensors: Radar Sensors

- Video camera
- Ultrasonic Sensor
- 50° RADAR Sensor
- 12° RADAR Sensor
- LiDAR Sensor
- Blind Spot



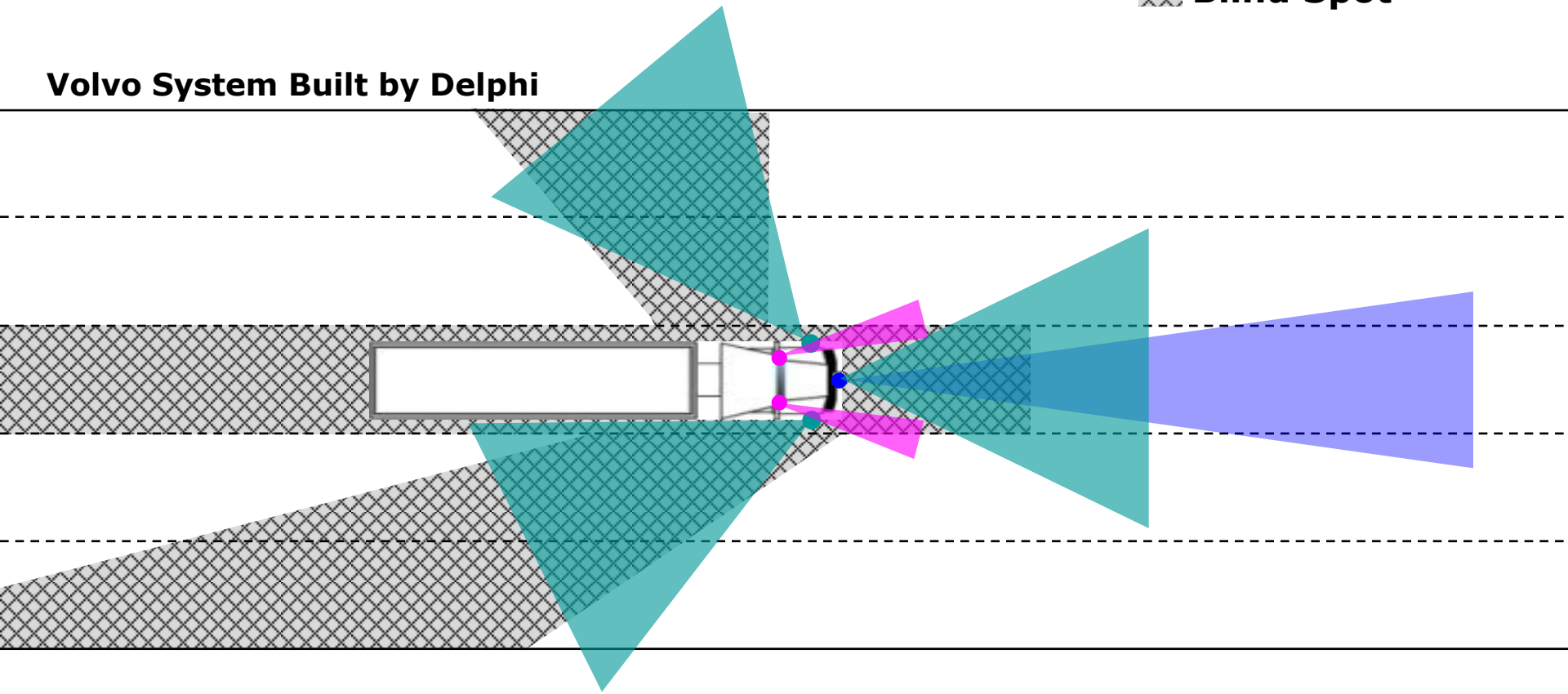
Radar Sensors – prohibitively expensive:

- Due to narrow field of view, 6-8 radar sensors are necessary to cover the area surrounding the vehicle
- Sensors provide medium quality data: capable of tracking stationary and moving objects; incapable of classifying objects, which can lead to false positive warnings and diminished driver trust

Typical Commercial ADAS

- Video camera
- Ultrasonic Sensor
- 50° RADAR Sensor
- 12° RADAR Sensor
- LiDAR Sensor
- Blind Spot

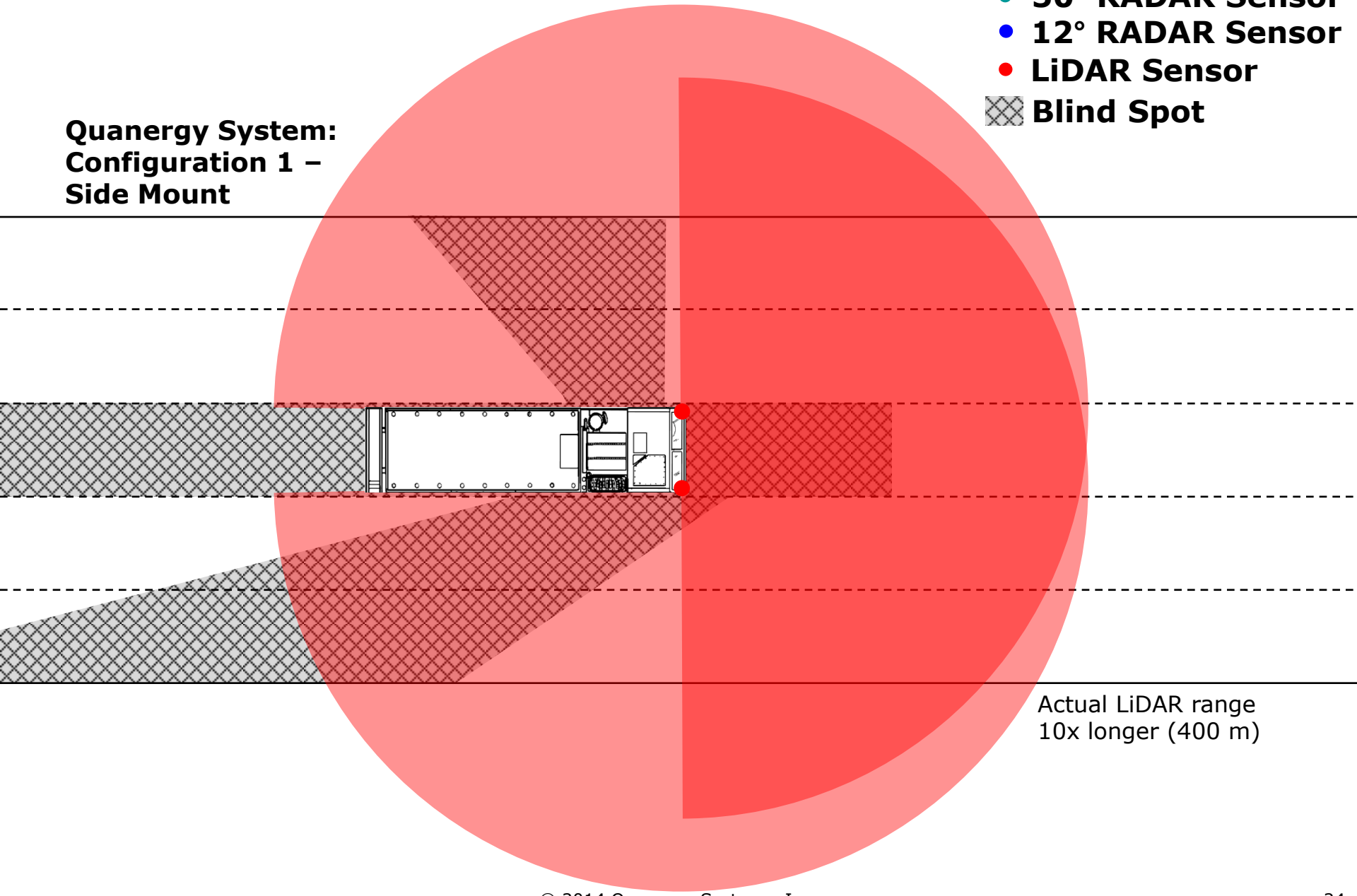
Volvo System Built by Delphi



Quanergy ADAS

- Video camera
- Ultrasonic Sensor
- 50° RADAR Sensor
- 12° RADAR Sensor
- LiDAR Sensor
- Blind Spot

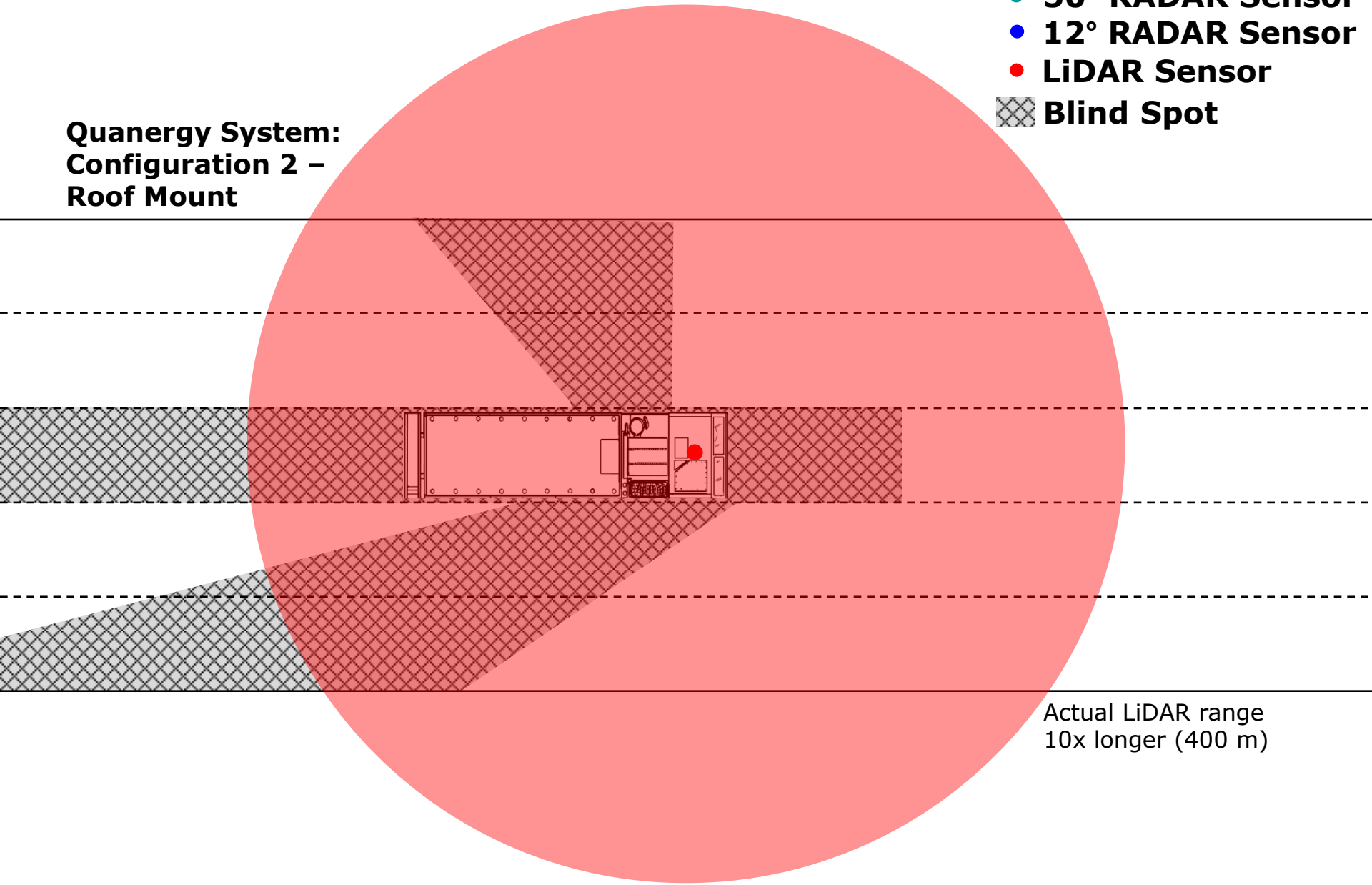
Quanergy System: Configuration 1 – Side Mount



Quanergy ADAS

- Video camera
- Ultrasonic Sensor
- 50° RADAR Sensor
- 12° RADAR Sensor
- LiDAR Sensor
- Blind Spot

Quanergy System: Configuration 2 – Roof Mount



Quanergy ADAS Safety Features

- Front Collision Warning
  - up to highway speeds, detection of moving & stationary objects
- Blind Spot Detection
  - comprehensive front and side coverage
- Cross Traffic Monitoring
  - for intersection crossings, tight turns, etc.
- Object Detection, Tracking, Identification, Classification
  - false alarms suppressed with high resolution under all conditions
- Lane Assistance
  - using robust road surface intensity readings, not video cameras
- Scene Capture
  - accurate capture of accident scenes, etc.

Features offered with 3D high-resolution mapping, 360° view, long range, and object recognition, at lower cost than today's video & radar systems

Autonomous Vehicles

US Army: 600,000 non-combat vehicles self-driving by 2015

Tesla: Rolling out semi-autonomous technologies by 2017

Nissan: “Commercial self-driving Nissan cars in 2020”

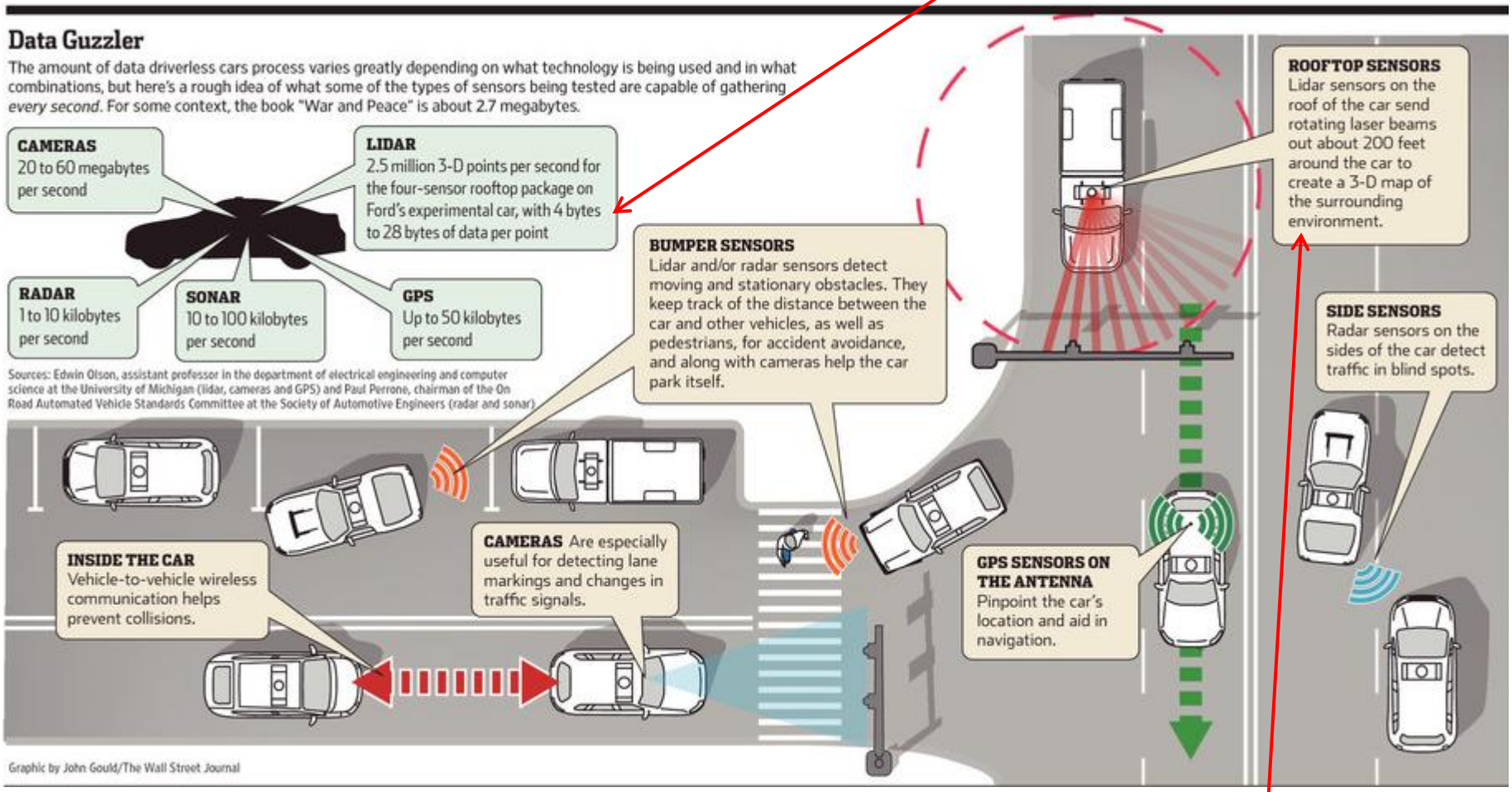
Mercedes: “Commercial fully autonomous Mercedes cars in 2020”

Google: Developing commercial self-driving car systems

Driverless Cars Are Data Guzzlers

Wall Street Journal – March 23, 2014

One 8-beam Quanergy LiDAR sensor: 864,000 3D points/sec, 144 bytes of data per point → 1 Gbps Ethernet
Each 32-beam LiDAR sensor on Ford: 625,000 3D points/sec, 28 bytes of data per point → 100 Mbps Ethernet

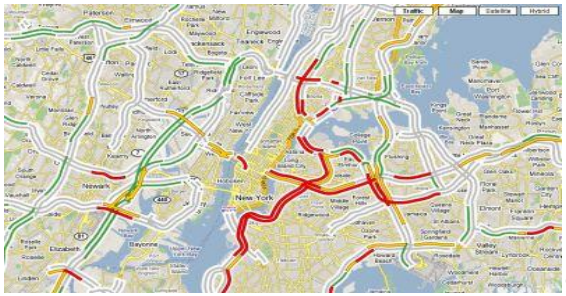


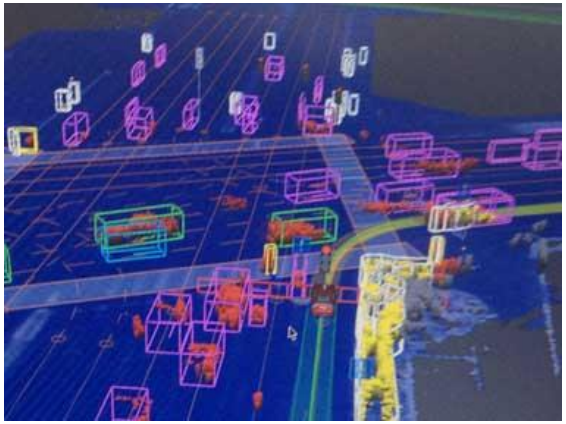
Quanergy LiDAR sensor range: 400 m (1333 ft)
LiDAR sensor on Ford experimental car: 70 m (200 ft)

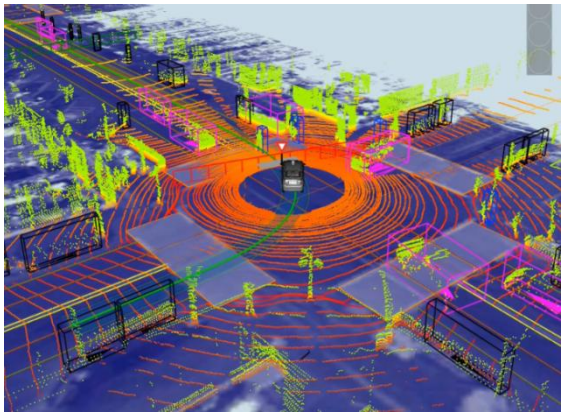
Benefits of Real Time 3D Map Data

Real time 3D maps deliver automatically:

- Actual local **weather** and **road quality** information
- Quantified **traffic observations** (speed, density, …)
- Lane-level **traffic flow** measurements
- cm-accurate location of **accidents**, **obstacles**, **debris**
- Lane-level **street maps**
- cm-accurate position of **infrastructure** (road signs, …)
- Full array of **LBS** (location based services)
- **Vehicle parameters** (speed, acceleration, braking patterns, gps coordinates, etc.) and accurate factual **accident recreation**
- Rich smart data needed for **autonomous vehicles**
- *And* the first **GPS-independent, cm-accurate localization** system on the planet


Google



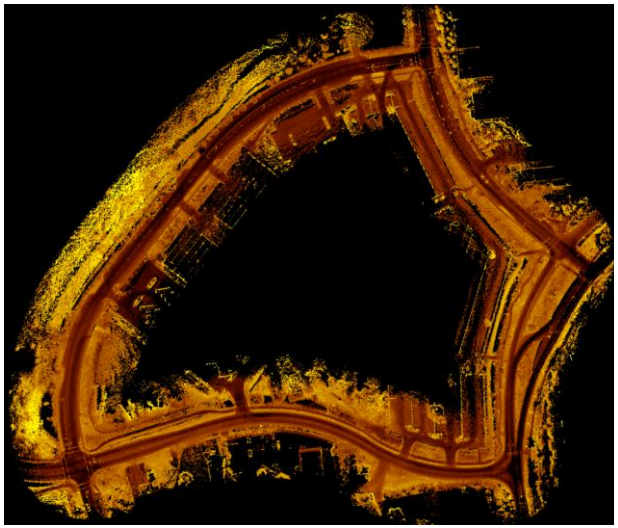


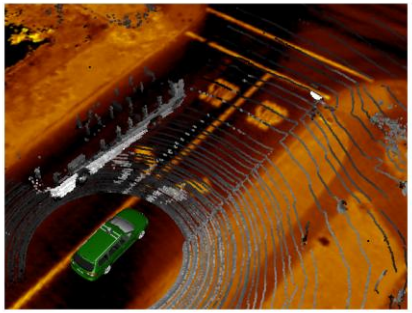
Centimeter-Accurate Localization with LIDAR

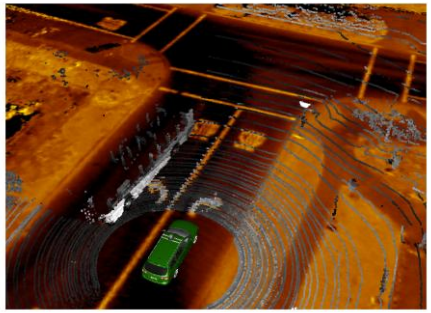
1. A centimeter-accurate, probabilistic 3D map is created from LIDAR, GPS, and IMU data using a computationally intensive simultaneous localization and mapping (SLAM) algorithm

2. The map is loaded into a LIDAR equipped system, which combines real-time LIDAR data with a computationally efficient, localization algorithm to determine its location within the map with high accuracy

3. The approach is robust even in dynamic environments







In Summary

- Today's mobile 3D mapping LiDARs are low cost and compact while delivering high performance and high reliability
- Advanced vehicular safety and navigation systems using LiDARs and GPUs with artificial intelligence deliver the most capable solution for real-time object detection, tracking, identification and classification
- Combining state of the art LiDARs and GPUs enables ultra-accurate GPS-free full-availability jam-proof centimeter-accurate navigation based on SLAM

Thank You

Louay Eldada
Quanergy Systems, Inc.
265 Sobrante Way, Ste M
Sunnyvale, CA 94086, USA
+1-512-965-6151
louay.eldada@quanergy.com
www.quanergy.com