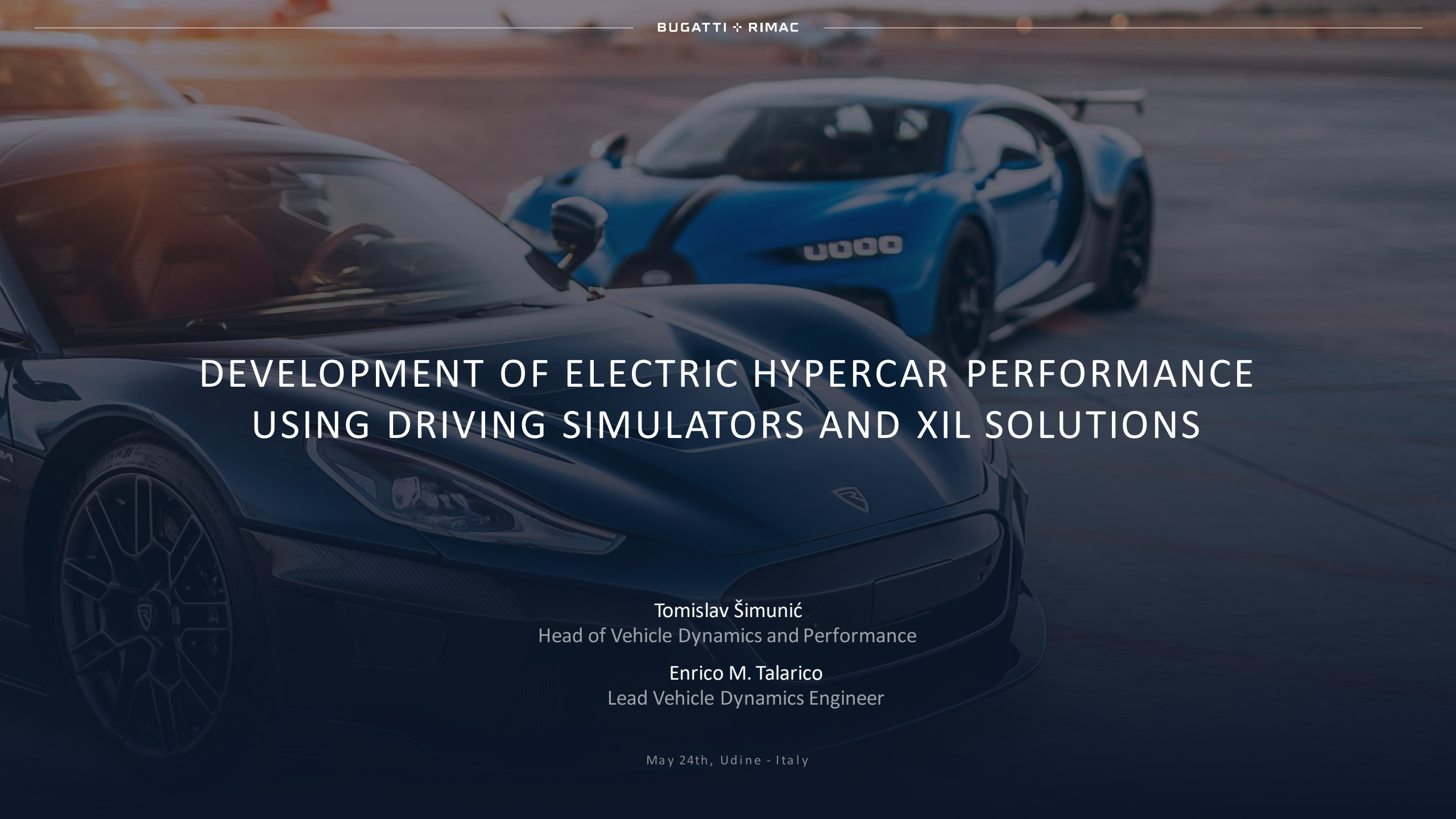


DEVELOPMENT OF ELECTRIC HYPERCAR PERFORMANCE USING DRIVING SIMULATORS AND XIL SOLUTIONS

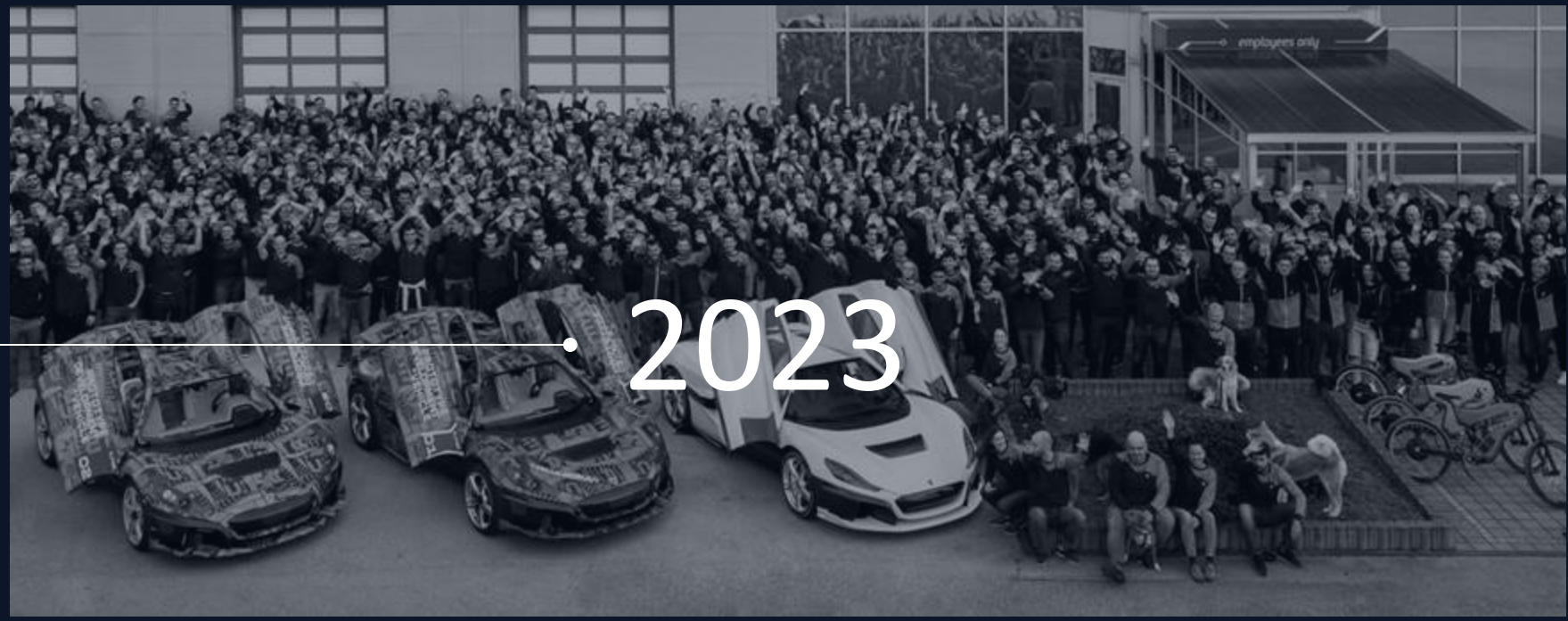
Tomislav Šimunić
Head of Vehicle Dynamics and Performance

Enrico M. Talarico
Lead Vehicle Dynamics Engineer

May 24th, Udine - Italy

RIMAC GROUP

2010



2023

GARAGE

2000+ PEOPLE STRONG TEAM

RIMAC TECHNOLOGY

RIMAC 0.0

2011-2015

Prototype projects

Focus on survival

RIMAC 1.0

2016-2020

Low volume projects

Focus on fundraising, growth

RIMAC 2.0

2020 >>>>

High volume projects

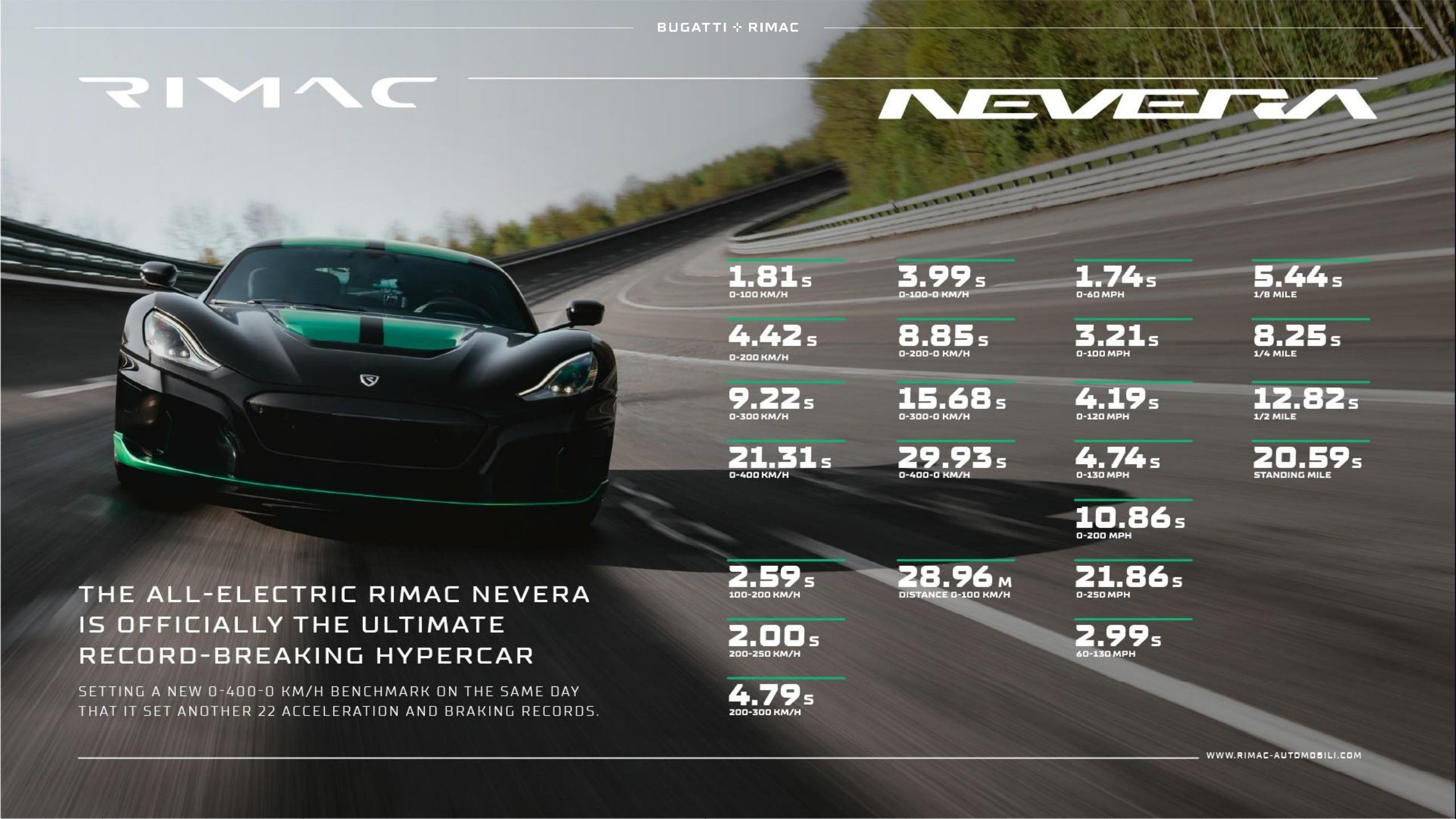
Focus on industrialization, automation

RIMAC AUTOMOBILI MODELS

	Rimac Concept_One	Rimac Nevera
Development start	2011	2017
Core Development team	15 engineers	80 engineers
Volume	8	150
Homologation	Single-type approval	Globally homologated

RIMAC

NEVERA



1.81 S 0-100 KM/H	3.99 S 0-100-0 KM/H	1.74 S 0-60 MPH	5.44 S 1/8 MILE
4.42 S 0-200 KM/H	8.85 S 0-200-0 KM/H	3.21 S 0-100 MPH	8.25 S 1/4 MILE
9.22 S 0-300 KM/H	15.68 S 0-300-0 KM/H	4.19 S 0-120 MPH	12.82 S 1/2 MILE
21.31 S 0-400 KM/H	29.93 S 0-400-0 KM/H	4.74 S 0-130 MPH	20.59 S STANDING MILE
		10.86 S 0-200 MPH	
2.59 S 100-200 KM/H	28.96 M DISTANCE 0-100 KM/H	21.86 S 0-250 MPH	
2.00 S 200-250 KM/H		2.99 S 60-130 MPH	
4.79 S 200-300 KM/H			

THE ALL-ELECTRIC RIMAC NEVERA IS OFFICIALLY THE ULTIMATE RECORD-BREAKING HYPERCAR

SETTING A NEW 0-400-0 KM/H BENCHMARK ON THE SAME DAY THAT IT SET ANOTHER 22 ACCELERATION AND BRAKING RECORDS.

MAKING OF BUGATTI RIMAC

COMBINING THE MOST ICONIC HYPERCAR BRAND WITH THE BEST EV TECHNOLOGY

BUGATTI AUTOMOBILES

CREATION OF A NEW SEGMENT IN THE AUTOMOTIVE INDUSTRY

SETTING NEW BENCHMARKS FOR THE BEST OF THE BEST

110 YEAR HISTORY

+

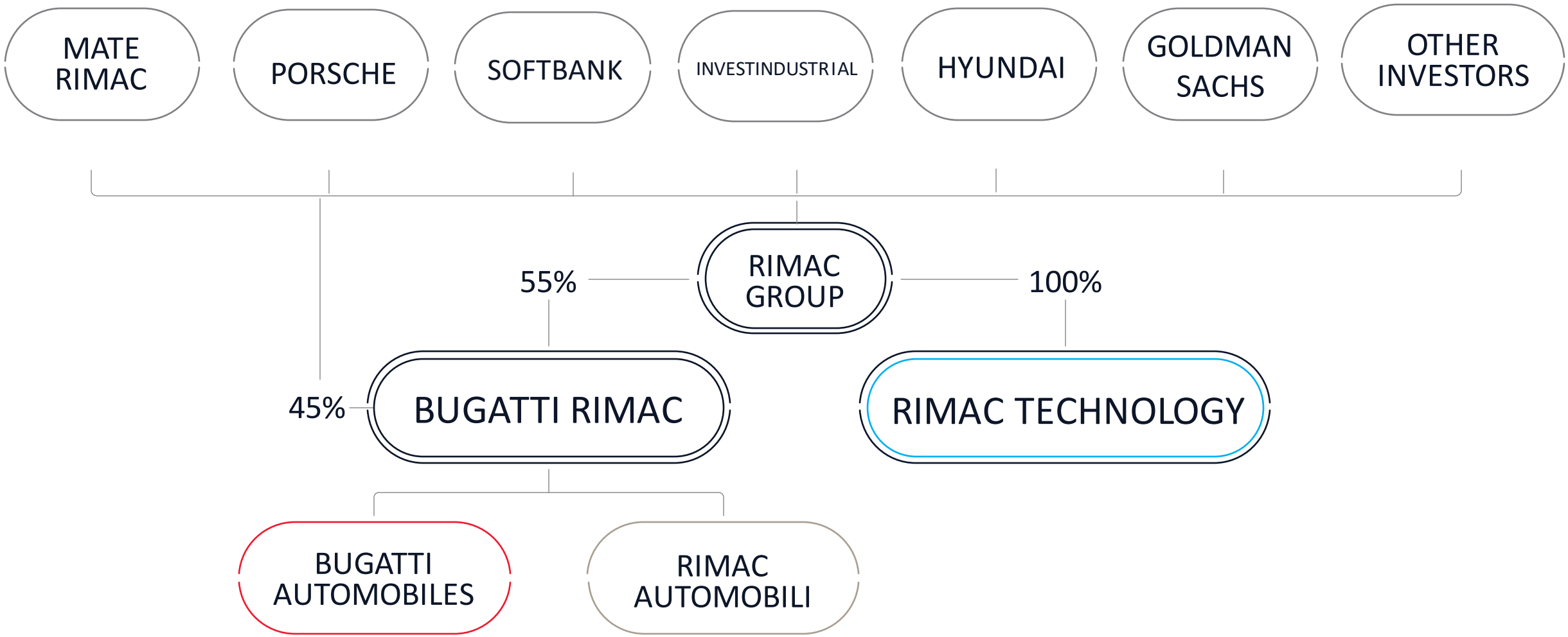
RIMAC AUTOMOBILI

FIRST ALL-ELECTRIC HYPERCAR

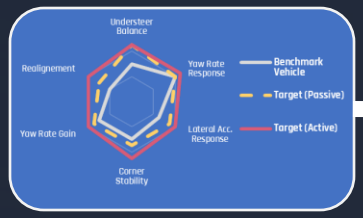
WORLD'S FASTEST ACCELERATING HYPERCAR 1,900+hp EV PLATFORM

TECHNOLOGY PARTNER TO GLOBAL AUTOMOTIVE MANUFACTURERS

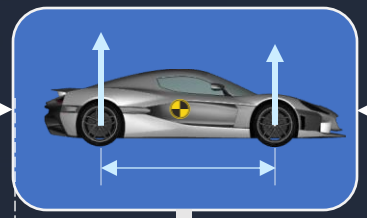
SHAREHOLDER STRUCTURE



VEHICLE DYNAMICS DEVELOPMENT PROCESS



BENCHMARKING/
TARGET SETTINGS



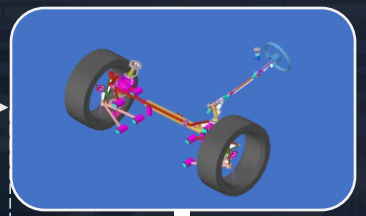
CONCEPT
DEFINITION

DRIVING SIMULATOR

VEHICLE
PROTOTYPE

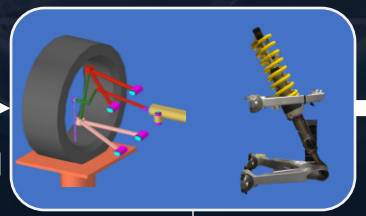
VEHICLE SIGN-OFF

CASCADING ON
SYSTEMS

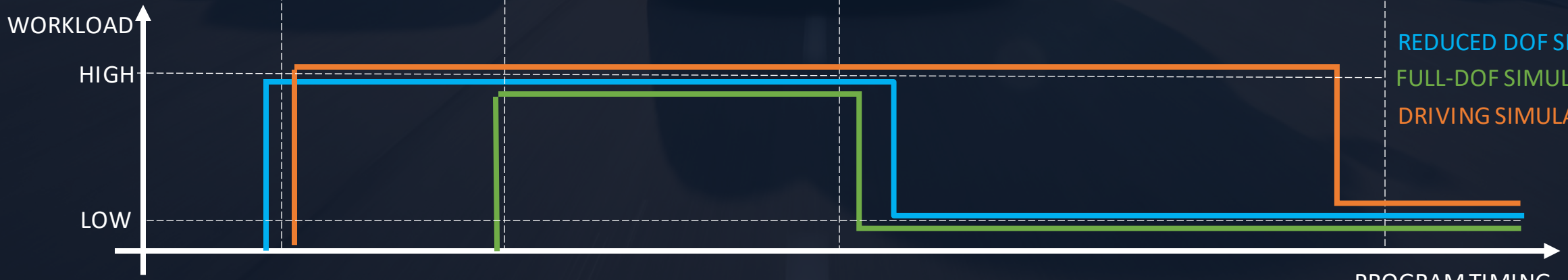


SYSTEMS BENCH
TESTING

CASCADING ON
COMPONENTS



PROTOTYPING
COMPONENTS



DEVELOPMENT OF TARGET SETTINGS – VEHICLE HANDLING D.N.A

PRODUCT DEFINITION / HIGH LEVEL TARGETS

- Benchmark in acceleration performance (defined 0-100, 0-200 kmph . . .)
- Road, not a track car. Comfortable for street use.
- Driver focused, enjoyable, fun-to-drive without artificial, 'digital' feeling, but natural, 'analog' feeling
- **Accessible vehicle limit performance to customers; ability to drift**

BENCHMARKING / VEHICLE POSITIONING SUBJECTIVE-OBJECTIVE TARGET DEFINITION

SUBJECTIVE EVALUATION ⟷ CORRELATION METHODOLOGY → OBJECTIVE CORRELATION

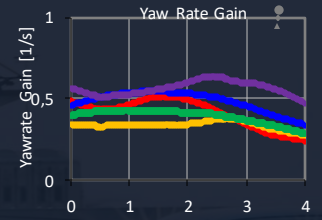
Handling Balance

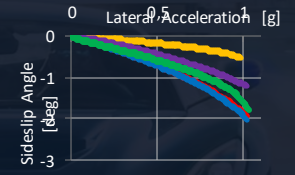
Agility (on-center response)

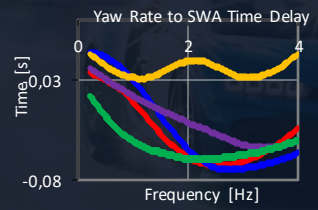
Stability (cornering)

Yaw Damping

Realignment







VEHICLE HANDLING TARGETS DEFINITION

	Characteristic	Unit	Passive	Active
Steady State Cornering	Maximum Lateral Acceleration	g	---	---
	Steering Wheel Gradient (0.05 to 0.4 g)	°/g	---	---
	Steering Wheel Gradient (0.85*ay_max)	°/g	---	---
	End of linear range of understeer curve	g	---	---
	Understeer Gradient (linear)	°/g	---	---
	Side Slip Angle Gradient (linear)	°/g	---	---
	End of linear range Side Slip Angle	g	---	---
	Side Slip Angle Gradient at 0.85*ay	°/g	---	---
	Steering Wheel Torque Gradient at 0.1g	Nm/g	---	---
	Maximum Steering Wheel Torque	Nm	---	---
	Lateral Acceleration at Maximum SWT	g	---	---
	Downfall Gradient between Ay_max and SWT_max	Nm/g	---	---
	Yaw Rate/SWA Steady State Gain	1/s	---	---
	Yaw Rate/SWA - Max/Steady State Gain Ratio	-	---	---
Frequency Response	Frequency @ Max YawRate/SWA Gain	Hz	---	---
	Delay Yaw Rate/SWA @ 1 Hz	ms	---	---
	Delay Yaw Rate/SWA @ 2 Hz	ms	---	---
	Delay Yaw Rate/SWA @ 3 Hz	ms	---	---
	Lateral Acceleration/SWA Steady State Gain	g/°	---	---
	Minimum Gain ay/SWA Frequency	Hz	---	---
	Delay Lateral Acceleration/Yaw Rate @ 1 Hz	ms	---	---
	Delay Lateral Acceleration/Yaw Rate @ 2 Hz	ms	---	---
	Delay Lateral Acceleration/Yaw Rate @ 3 Hz	ms	---	---

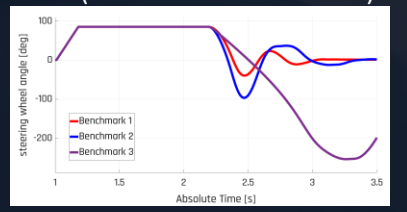
EXAMPLE: ABILITY TO DRIFT

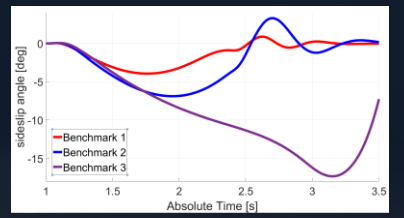
DEFINE VEHICLE HANDLING CHARACTERISTICS TO QUANTIFY 'ABILITY TO DRIFT' IN CHASSIS DESIGN

Realignment

Realignment is subjective vehicle handling characteristic defines driver controllability of vehicle yaw rate and side slip on the limit.

Steering release after limit steering step maneuver (without active controls)





Characteristics	Unit	Target
Release Phase		
Max. of Steering Wheel Velocity after release	deg/s	---
Residual Steering Wheel Angle	deg	---
Peaks		
First peak of steering wheel angle	deg	---
Second peak of steering wheel angle	deg	---
First peak of yaw rate	deg/g	---
Second peak of yaw rate	deg/g	---
First peak of Side Slip Angle	deg	---
Second peak of Side Slip Angle	deg	---
Peak Ratios (2nd/1st peak [1], <0: no change in sign)		
Steering wheel angle	-	---
Lateral acceleration	-	---
Side Slip Angle	-	---
Delays between First Peaks		
Yaw rate to steering wheel angle	ms	---
Side slip angle to steering wheel angle	ms	---
Delays between Second Peaks		
Yaw rate to steering wheel angle	ms	---
Side Slip angle to steering wheel angle	ms	---

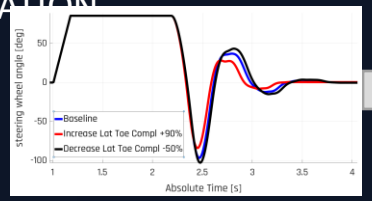
CASCADING THE TARGETS TO SYSTEMS - EXAMPLE

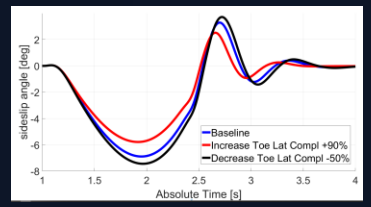
Characteristics	Unit	Target
Release Phase		
Max. of Steering Wheel Velocity after release	deg/s	---
Residual Steering Wheel Angle	deg	---
Peaks		
First peak of steering wheel angle	deg	---
Second peak of steering wheel angle	deg	---
First peak of yaw rate	deg/g	---
Second peak of yaw rate	deg/g	---
First peak of Side Slip Angle	deg	---
Second peak of Side Slip Angle	deg	---
Peak Ratios (2nd/1st peak [1], <0 : no change in sign)		
Steering wheel angle	-	---
Lateral acceleration	-	---
Side Slip Angle	-	---
Delays between First Peaks		
Yaw rate to steering wheel angle	ms	---
Side slip angle to steering wheel angle	ms	---
Delays between Second Peaks		
Yaw rate to steering wheel angle	ms	---
Side Slip angle to steering wheel angle	ms	---

Subjetive Target: Yaw rate and lateral acceleration are in phase with steering wheel with minimized overshoot of all three signals.

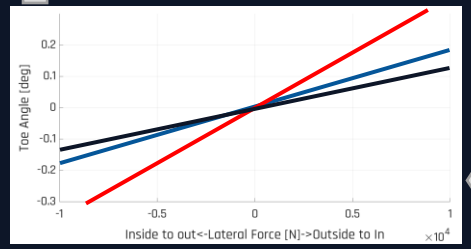
VEHICLE TARGET SETTING – EXAMPLE: REALIGNEMENT

OFF-LINE VEHICLE SIMULATIONS AND OPTIMIZATION





DRIVER IN THE LOOP



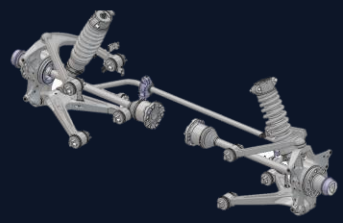
KnC TUNING REAR TOE COMPLIANCE

VIRTUAL DEVELOPMENT LOOPS TO REACH OBJECTIVE + SUBJECTIVE TARGETS

KnC CHARACTERISTICS TO REACH VEHICLE HANDLING TARGETS

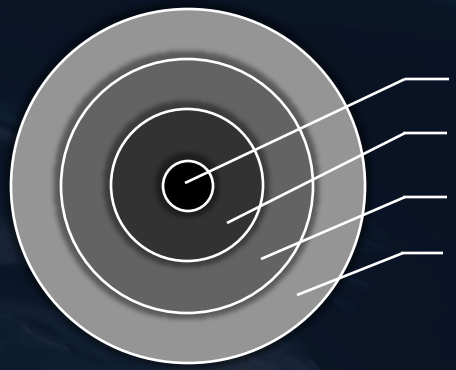
NOT FEASIBLE

CONFIRMED



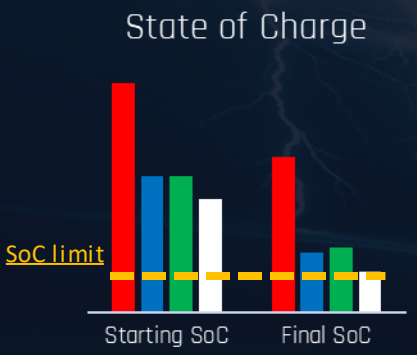
START OF KnC PHYSICAL DEVELOPMENT

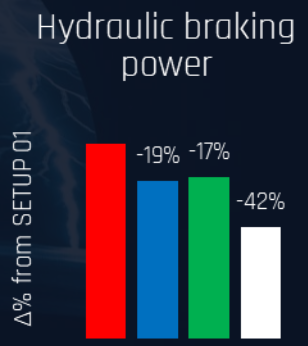
TEST CASE 1 – ENERGY MANAGEMENT USING SIL/DIL

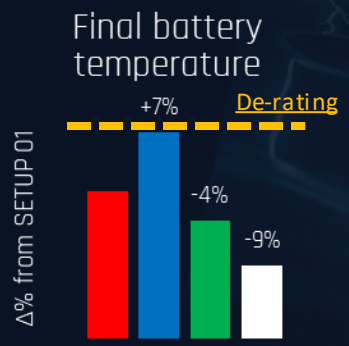


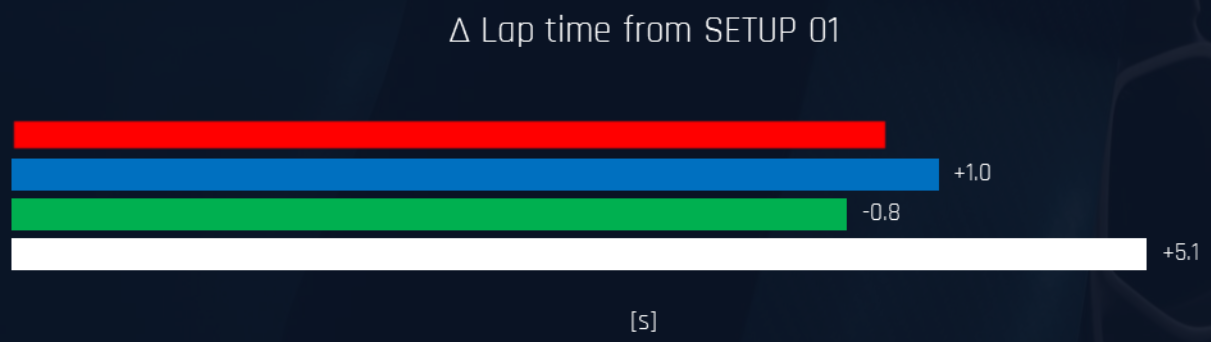
- Performance optimization
- Brake efficiency improvement
- Battery management
- Vehicle preparation before testing

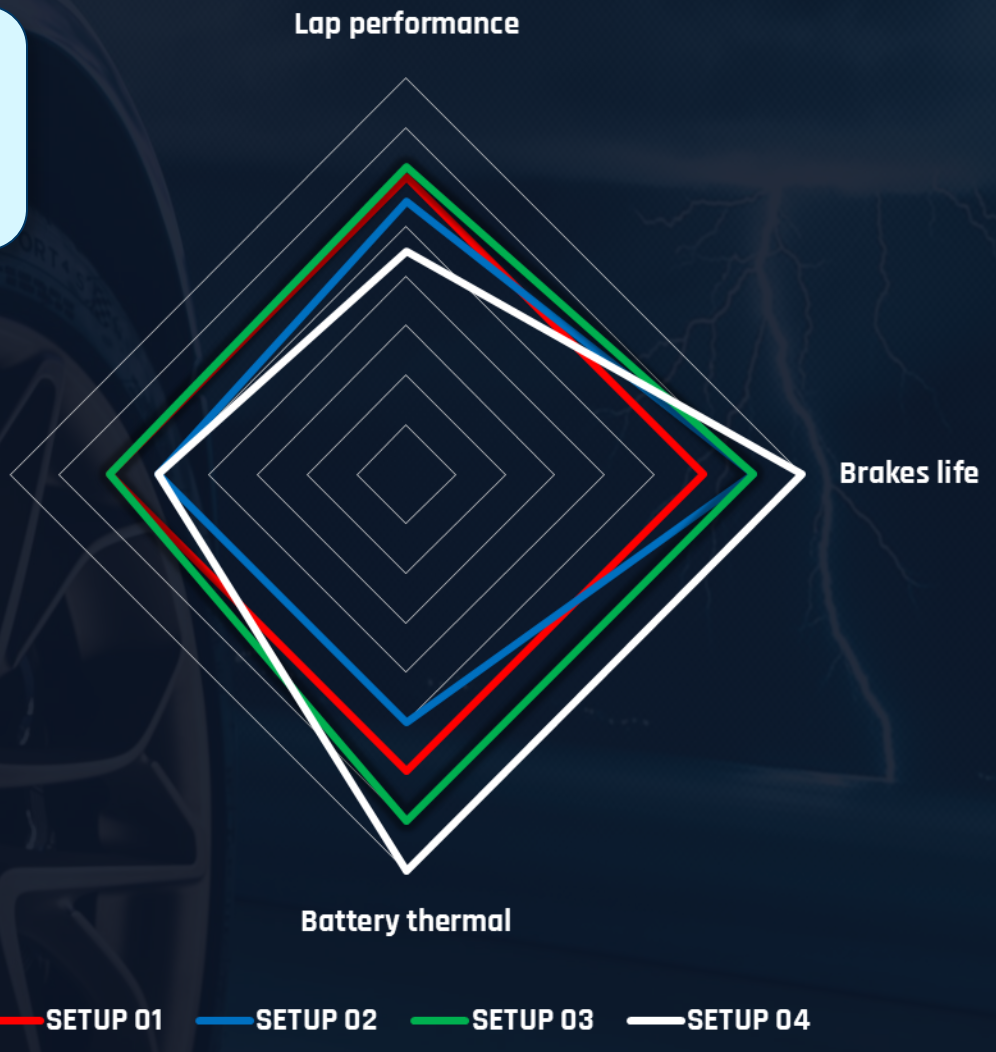
SETUP 03 chosen as best energy management strategy: optimal performance and better battery and brake behavior.







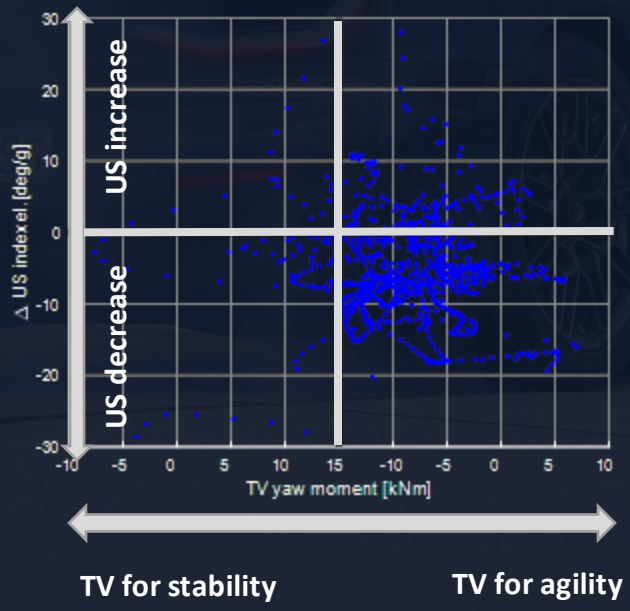


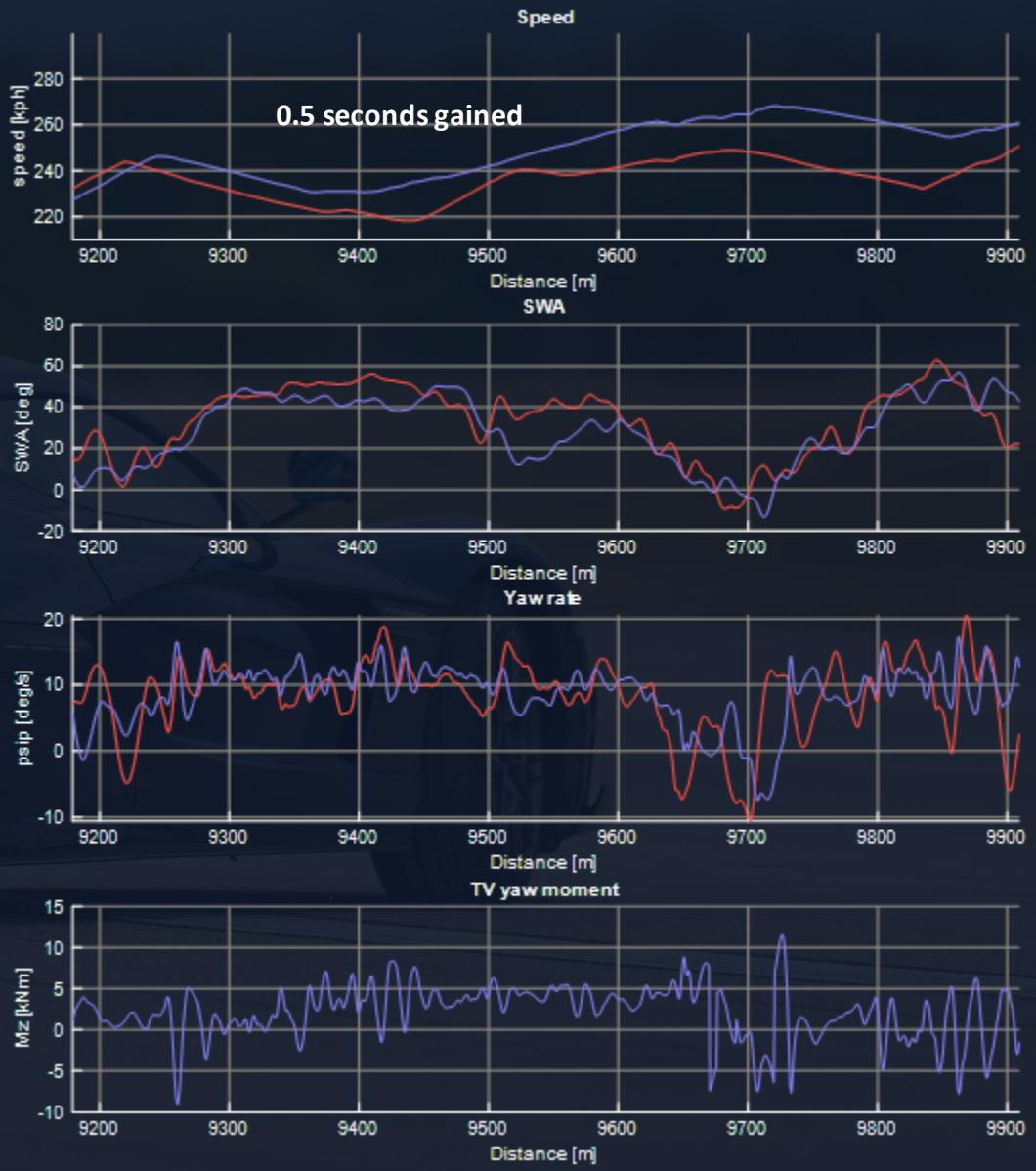


TEST CASE 2 – TORQUE VECTORING TUNING – BERGWERK TO KESSELCHEN @ NORDSCHLEIFE

4-wheel torque vectoring has been tuned to reduce understeer and increase the agility of the car in this particular corner of Nordschleife:

- Yaw moment induced to increase agility, reduced when stability is needed
- Understeer and yaw rate increased or decreased accordingly
- Time gained: 0.5 s





TEST CASE 3 – TELEMETRY ANALYSIS FOR DRIVER COACHING

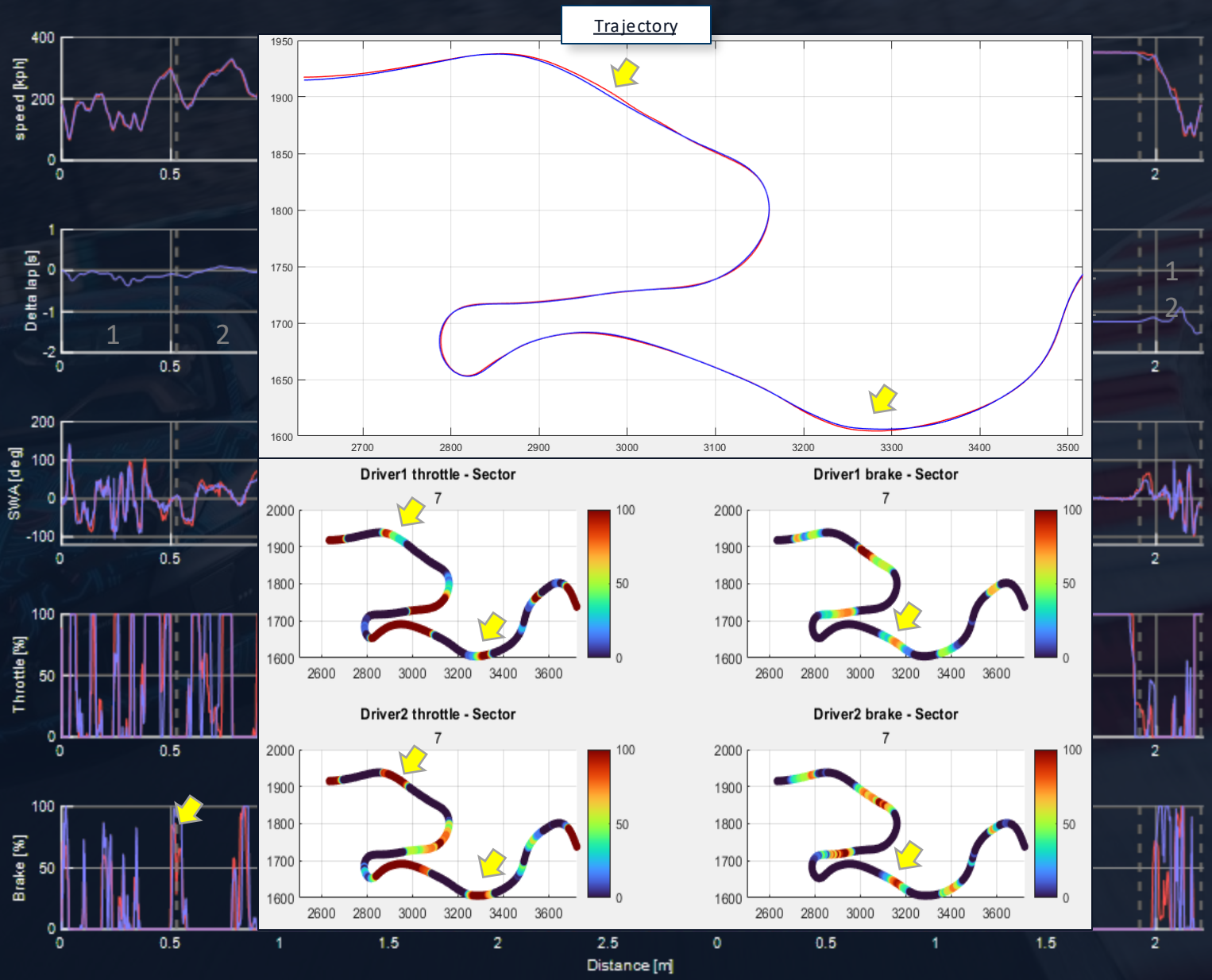
	Δ (Driver 2 – Driver 1) [s]
Sector1	-0.19
Sector2	0.09
Sector3	0.39
Sector4	-0.13
Sector5	0.23
Sector6	-0.16
Sector7	-1.04
Sector8	-0.29
Sector9	0.14
Sector10	-0.36
Sector11	-0.01
Sector12	-0.28
Total	-1.61

This test case shows a comparison between two different drivers in a lap @Nordschleife.

Track is divided into sectors to isolate different sections and analyze them.

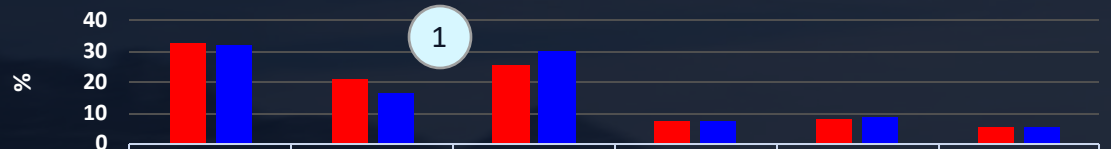
Driver 2 average pressure on the brake is higher.

Driver 2 main advantage built in sector 7 due to better Hohe act section but also a snap by Driver 1 at Klosteral



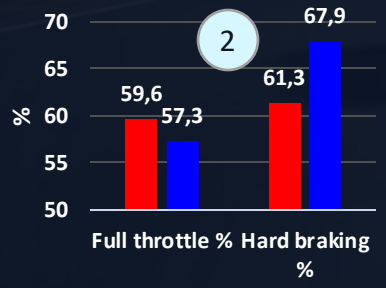
TEST CASE 3 – TELEMETRY ANALYSIS FOR DRIVER COACHING

Driving regions distribution

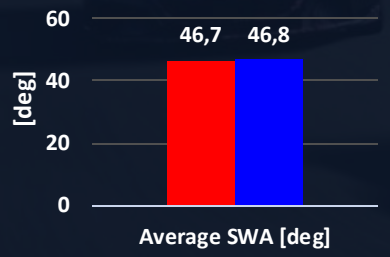


	Power in turn %	Brake in turn %	Pure lateral %	Pure power %	Pure brake %	Straight %
Driver 1	32,6	21,3	25,5	7,2	8,1	5,2
Driver 2	31,9	16,7	30,1	7,2	8,6	5,4

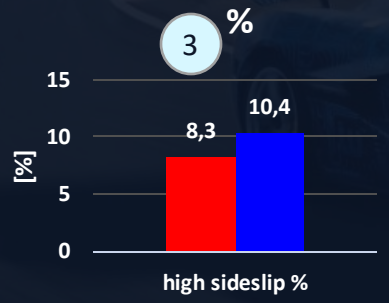
Pedals usage



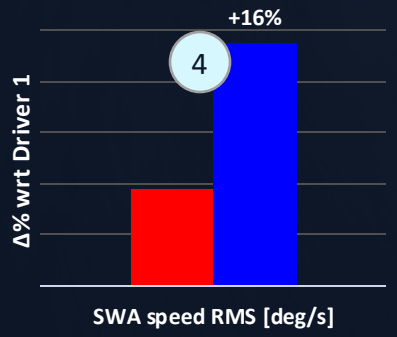
Corners average SWA



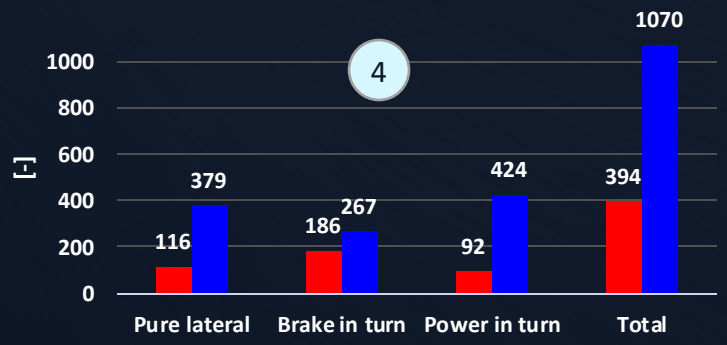
Corners high sideslip

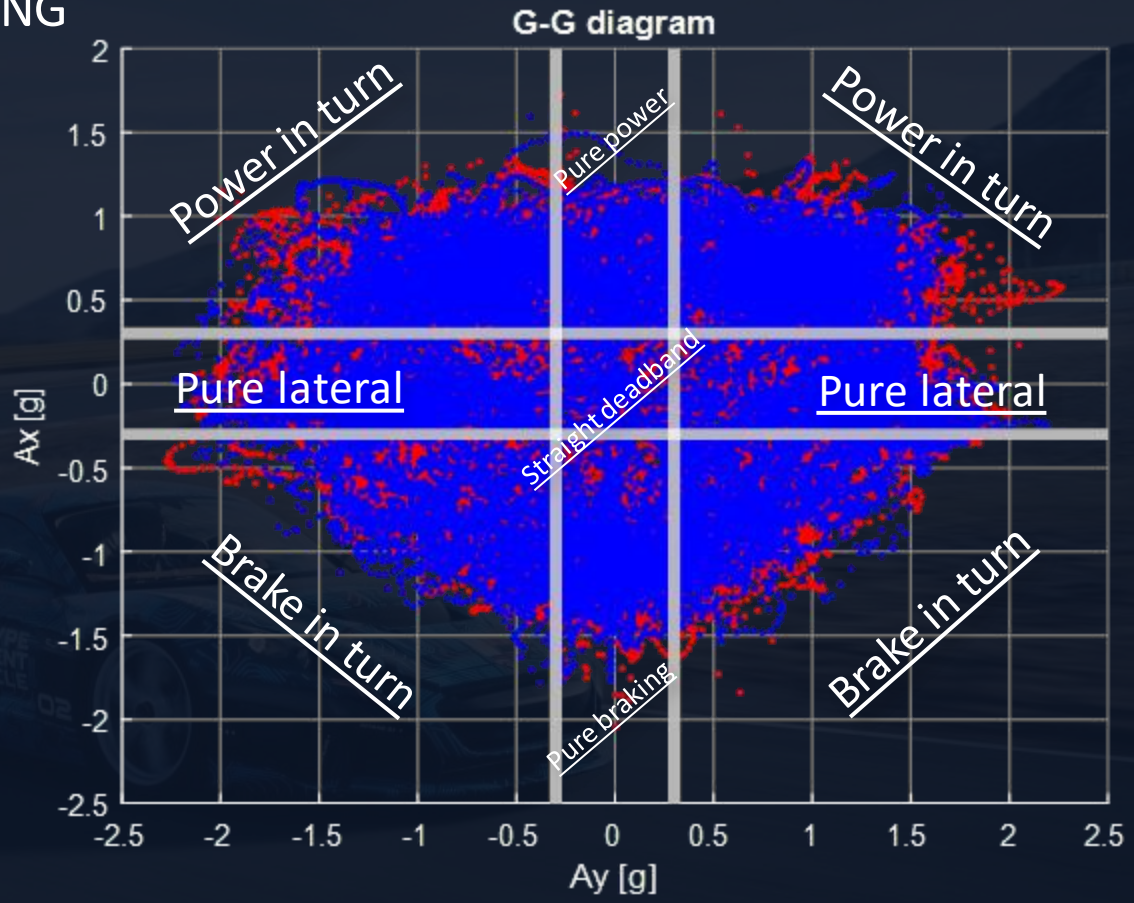


SWA speed RMS



SWA corrections index





- Driver 2 uses less trail braking than Driver 1, exploiting full t vehicle lateral performance.
- Driver 2 is more aggressive on the brake pedal, while Driver 1 spend slightly more time at full throttle. This witnesses a different approach for corner managing.
- Driver 2 has a higher % of time spent at high sideslip angle during the corner, keeping rear axle at the limit.
- Driver 2 is correcting the steering wheel at a higher rate. This is coupled with higher correction index, especially in pure lateral and power in turn.
- Telemetry and KPIs are then used to analyze performance but also to coach drivers.

RIMAC NEVERA – MEDIA IMPRESSIONS

Bloomberg

IT GOES FASTER THAN ANY OTHER PRODUCTION CAR YET IS ENGINEERED TO HANDLE LIKE A FRIENDLY CONVERSATION. ITS ASPHYXIA-INDUCING GOOD LOOKS DON'T COMPROMISE ON COMFORT FOR DAILY DRIVING. AND IT'S GOT EXCEPTIONAL BUILD QUALITY AND CRAFTSMANSHIP AMONG CADRES OF OTHER ELECTRIC VEHICLES THAT DON'T.

evo

ALL THAT WORK HAS PAID OFF, MAGNIFICENTLY, BECAUSE FROM THE WAY IT STOPS, TO THE WAY IT STEERS, TO THE WAY IT GOES AROUND THE CORNERS, AND, YES, TO THE ABSOLUTELY RIDICULOUS WAY IN WHICH IT ACCELERATES BETWEEN THOSE CORNERS, THE RIMAC NEVERA DRIVES LIKE NO OTHER ROAD CAR T HERE HAS EVER BEEN.

ars TECHNICA

THEY SAY THAT EVS LACK EMOTION. WELL, THE RIMAC NEVERA IS ABOUT TO CHANGE ALL OF THAT.

THE WALL STREET JOURNAL.

RIMAC'S FEAT OF TECHNICAL BOOT-STRAPPING MAKES THE NEVERA UNIQUELY EVOCATIVE, UNLIKE THE STERILE NARRATIVES OF CORPORATE HYPERCARS.

ROAD & TRACK

NEVERA. TOTAL GAME-CHANGER.

CAR and DRIVER

THE NEVERA IS EVERY BIT THE MOONSHOT YOU'D HOPE GIVEN THE PRICE OF 2 MILLION EUROS AND YET, IT DOESN'T FEEL LIKE A SCIENCE PROJECT. THE OUTRAGEOUS OUTPUT AND IMPRESSIVE CUSTOMIZABILITY MAKE ITS ELECTRIC POWERTRAIN AS FASCINATING AS ITS MOST POTENT INTERNAL-COMBUSTION COUNTERPART. THE NEVERA MAKES US OPTIMISTIC ABOUT THE FUTURE OF ULTRAHIGH PERFORMANCE.

POPULAR SCIENCE

EVEN AT THIS PRE-PRODUCTION STAGE, THE NEVERA IS GENUINELY NEXT LEVEL. THE NEVERA FEELS LIKE THE FUTURE OF ELECTRIC DRIVING.

motor1.com

THE 1,914-HORSEPOWER NEVERA HYPERCAR WILL REDEFINE YOUR DEFINITION OF QUICK.

AND EVEN FOR A HEFTY 4,740-POUND VEHICLE, THE NEVERA MOVES WITH EXCEPTIONAL GRACE. BODY CONTROL IS FLUID, CORNERING IS DEAD FLAT, AND THE GRIP IS UNBELIEVABLE.

TOP GEAR (SERIES 33) - CHRIS HARRIS ABOUT RIMAC NEVERA

BUGATTI + RIMAC

THANK YOU FOR YOUR ATTENTION

LOOKING FORWARD FOR YOUR QUESTIONS

For any additional information you might need, feel free to contact me.

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