



**PROTEAN**

Electric Automotive Technology



**PROTEAN**

# **Engineering the Highest Performance In-wheel Motor Ever Developed for Performance Road Car Applications – The Challenges and Solutions**

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**February 2026**

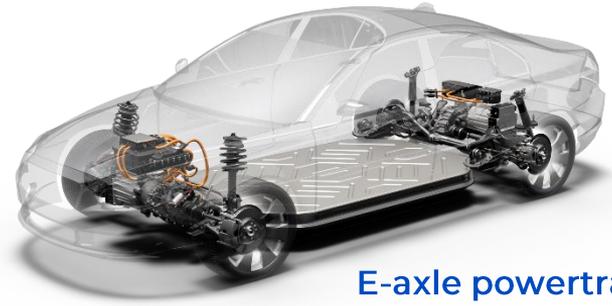
# High performance vehicles are benefitting from electric powertrains

Electric powertrains are powering improved high-performance vehicles:

- High, near instant torque from zero speed.
- Fast response rates.
- No gear changes.
- Distributed drive architectures.

**In-wheel motors (IWM's) make them even better:**

- Higher bandwidth, full torque range, fully independent wheel control without backlash enables better traction control and handling.
- New vehicle design improvements leading to lower mass and more optimal aerodynamics and mass distribution.



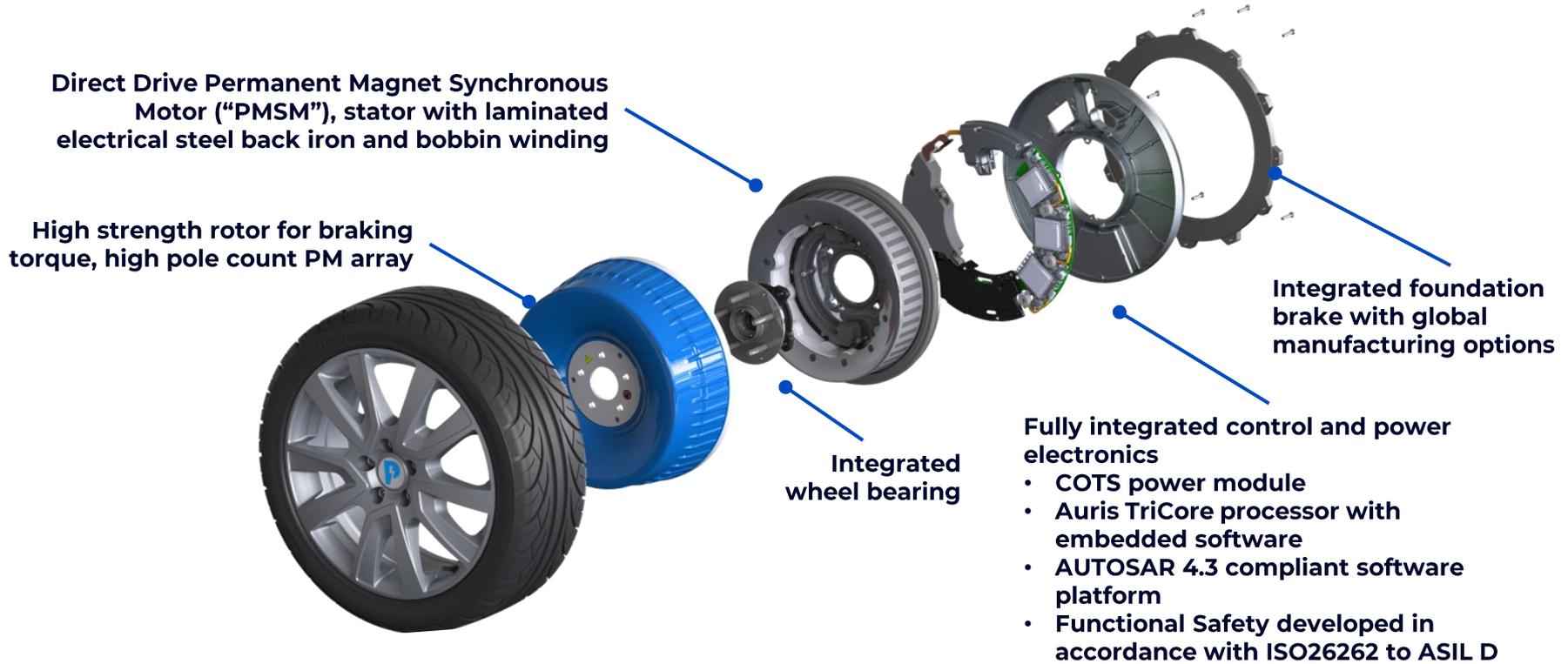
E-axle powertrain



IWM powertrain



# Protean's in-wheel motor system delivers power directly to the wheels



# Current Product Lineup

## Gen5 18" Lineup

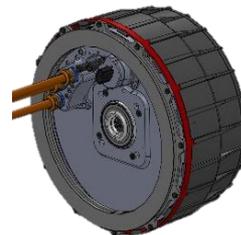


**Pd18 1500Nm, 103kW, 400V**  
Validated, fully integrated,  
fully PPAP'd and in  
production since 2023



**Pm18 1500Nm, 103kW, 800V**  
Motor based on Pd18  
**A-Samples Q3 2024**  
**Production customer**  
**dependant**

**Pi 800V SiC 440kW Inverter**  
Twinverter for dual motors.  
**A-Samples Q3 2024**  
**Production Q3 2026**



**Pm18 2500Nm, 220kW 800V**  
High performance motor  
**A-Samples available**  
**Q4 2024**  
**Production Q3 2026**



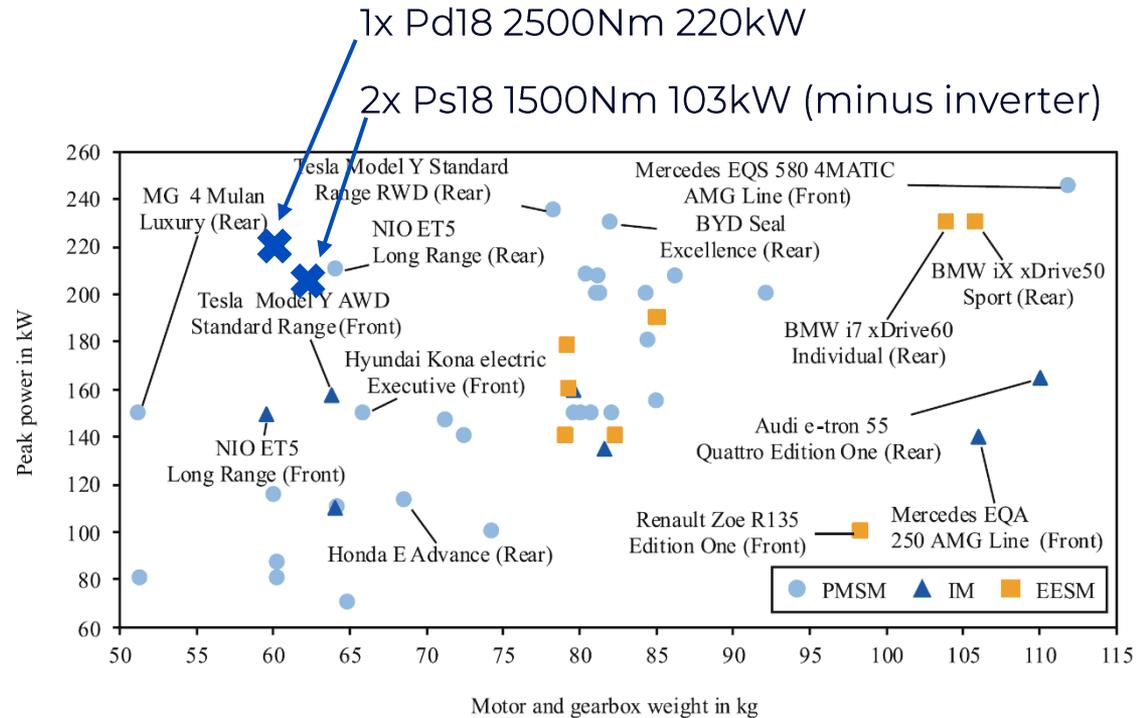
# Power Density

Existing motors provide a more favourable power to weight solution compared to existing e-axle solutions

- 20-50kg saving compared to existing technology

Further mass savings come at a vehicle level.

- Estimated 80kg can be saved from the body in white structure.



Drexler, D., Kampker, A., Born, H. et al. Advances in electric motors: a review and benchmarking of product design and manufacturing technologies. *Elektrotech. Inftech.* 142, 312–345 (2025).



# High Motor Speed Efficiency (Track Driving)



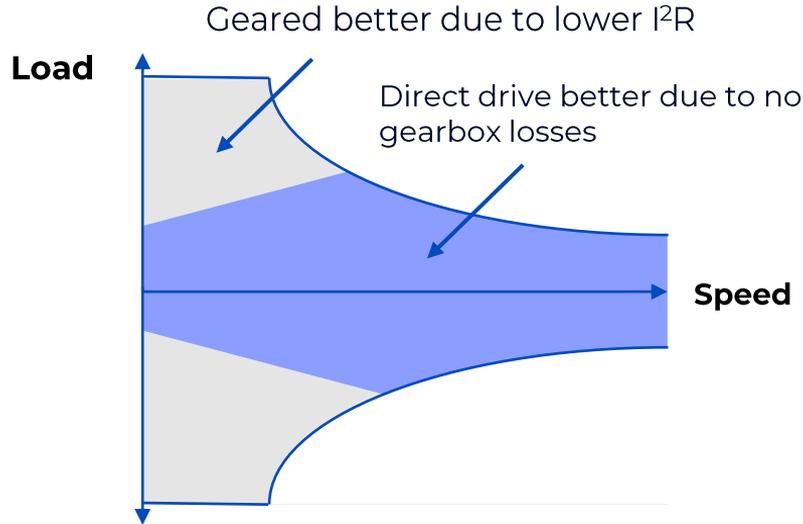
**Inverter Losses**

**Emachine Losses**

**Gearbox – become significant contributor at high speed, low load.**

**CVJ – small losses but present across whole range.**

**Bearing / Seal Losses**



**Inverter Losses**

**Emachine Losses**

**Bearing / Seal Losses**



# Cooling

High performance vehicles require high efficiency cooling

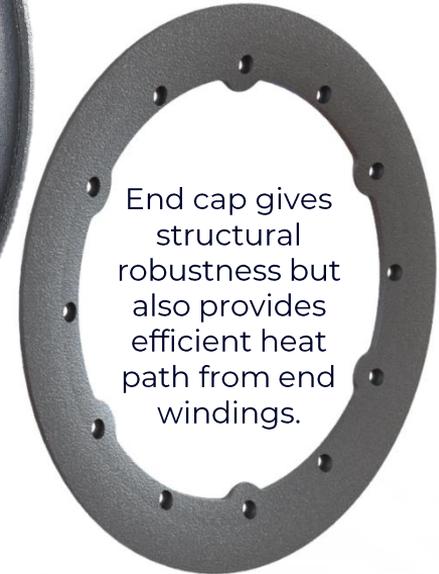
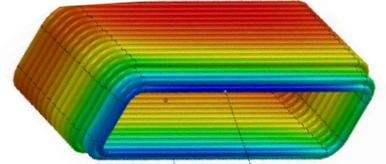
- Sustained track driving generates high temperatures in windings and back irons
- Even in highly efficient motor designs

Outer rotor design enables effective cooling of magnets and rotor back iron

- Magnet temperatures are not a problem

Stator requires effective cooling along its whole length to ensure consistent and even cooling

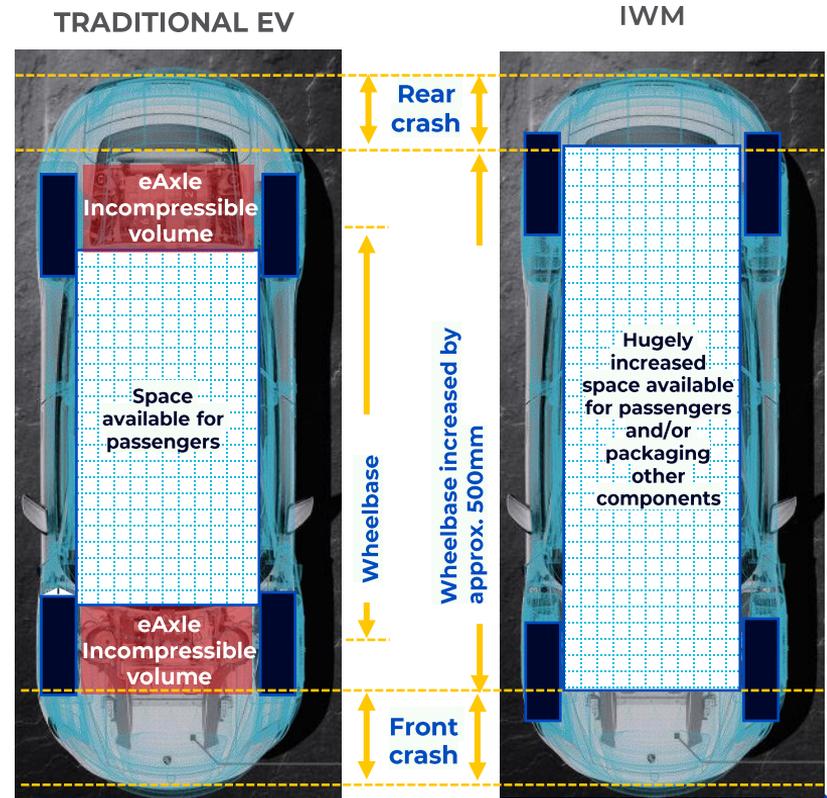
- Hottest area(s) will determine maximum performance



# IWM's offers new vehicle design freedom that improve the performance of high performance EV's

The Space Chassis concept, enabled by the elimination of the onboard powertrain, creates opportunities to improve performance:

- Reduced mass with the same interior space.
- Increase of wheel-base for high-speed stability.
- More freedom to distribute mass favourably.
- **Lower roofline with the same interior headroom.**
- **More freedom to design for low aero drag.**
- **Fewer constraints on the design of diffusers and other aerodynamic features to support traction.**
- Better efficiency, longer range.



# Adopting IWM's enables vehicle mass and aero advantages

Cab forward design allows smooth transition from windscreen to hood



E-axle



IWM

Diffuser design unencumbered by e-axle at rear

No driveshaft means long suspension is mounted without high top mount

Longer wheelbase, better battery packaging options, lower hood. All allow lower vehicle height with same comfort levels, resulting in ~14% lower frontal area.

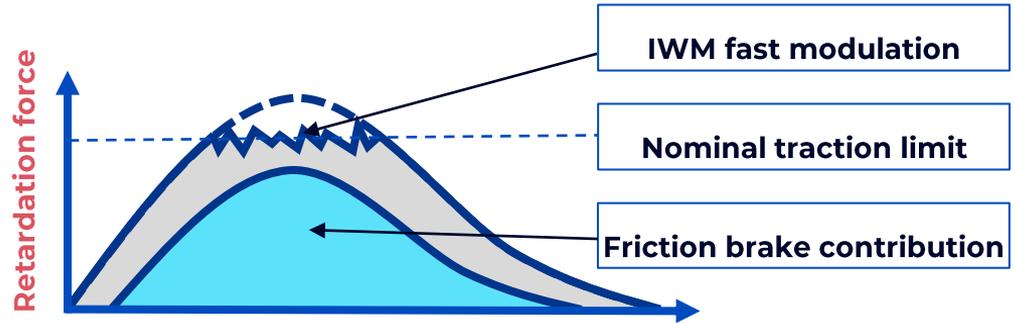
Smaller footprint and reduced mass (~80kg) for given space



# IWM's enable greater acceleration and deceleration

With high performance powertrains, acceleration and deceleration are limited by the ratio of the traction limit and the vehicle's inertia.

IWM's allow all driven tyres to operate closer to their traction limit at all times due to high bandwidth control and the ability to use positive and negative torque seamlessly and independently at each wheel.



**In testing in high  $\mu$  conditions, stopping distances were reduced by ~10% by utilizing the IWM for high bandwidth traction control compared to a conventional ABS system.**

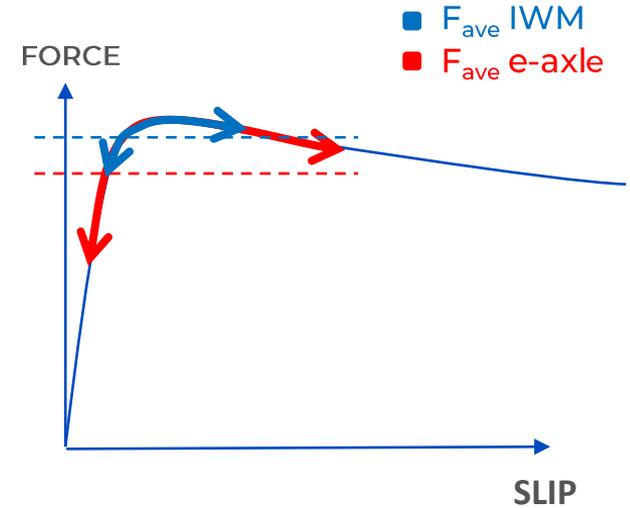


# The importance of good slip control

Tyres generate longitudinal and lateral forces via shear mechanisms in the rubber compound of the tyres. This results in the wheel moving slightly faster than the car. This slip ratio of the wheel should be carefully controlled to give the maximum force on the car.

The shape of this relationship is commonly modelled by the Pacejka Tyre model, but this is still very road surface (and tyre) specific so can vary significantly with time.

With limited control authority (slow actuators, twisty driveshafts, limited speed signal) the best that can be done is to oscillate above and below the peak. This gives control but is not in any way optimal.

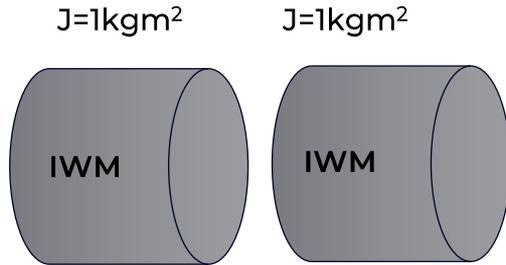


To get better slip limited force there are two factors:

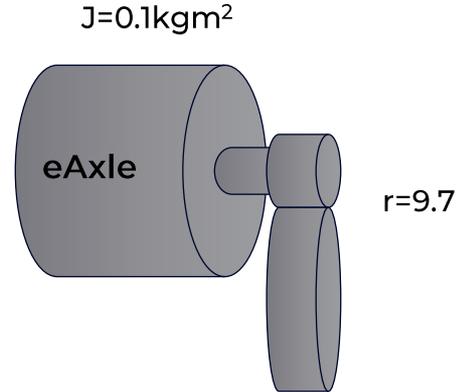
- 1) **Better control of slip.** Can be achieved with fast response and minimal system dynamics
- 2) **Better understanding of (changing) shape of curve.** Models need to be provided with accurate torque and speed estimates (available from IWM)



# Rotating inertia is important for acceleration



$$J_{\text{tot}} = J * r^2$$



**Note:** this extra 'equivalent mass' does not help with traction, it only reduces the acceleration.

	Referred inertia at wheel [kgm <sup>2</sup> ]	Equivalent vehicle mass [kg]	0-100kph for 1200kg vehicle [s]
2*IWM	2	~15	3.3
1*E-Axle	10	~75	3.5

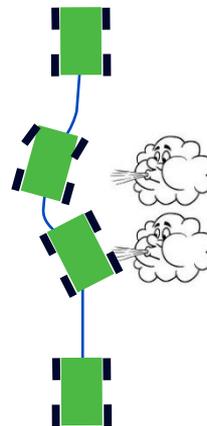


# IWM's enable better and more tunable lateral dynamics

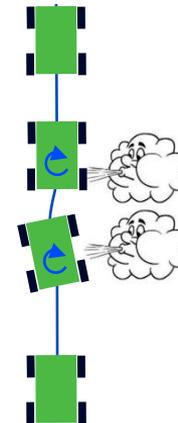
In sub-limit vehicle operation, torque vectoring (TV) can be used to:

- optimize over/under-steer characteristics when cornering
- increase vehicle stability at high speed by working against disturbances
- increase vehicle agility at low speed by working with steering input

In near limit vehicle operation torque vectoring makes optimal use of the differential traction available to enable faster, safer cornering, maintaining linearity.



**No TV. Driver responds to disturbance with steering input. Vehicle feels unstable at high speed.**



**TV, operating at order of magnitude higher bandwidth than driver, compensates for disturbance. Vehicle feels stable at high speed.**



# Protean's Brake Concept

Protean's brake solution is the highest performance currently available with in wheel motors.

## **Largest diameter disc possible**

- Larger diameter than standard discs possible

## **Effective removal of heat**

- Disc open to airflow
- Large surface area
- Vented options available

## **Standard caliper technology**

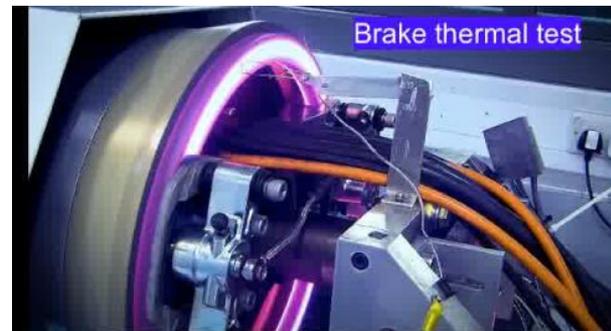
- Including EPB

## **No weight penalty**

- Identical mass to standard brake disc solutions

## **Easy brake pad servicing**

- Pads serviced without removal of motor



# The future of high performance EV's has arrived

Production of the first high performance car equipped with in-wheel motors is about to start.

It will benefit from the unique performance and handling opportunities that in-wheel motors enable.

**In-wheel motors make better high performance EV's.**





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# Questions

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