



Fortezza da Basso • FLORENCE (Italy)



37<sup>TH</sup> INTERNATIONAL  
**NO - DIG**  
FLORENCE 2019

30<sup>th</sup> September • 2<sup>nd</sup> October 2019

## TUnIS Navigation E-PowerPipe

Precise Navigation of small Diameter Tunnelling Machines

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# Navigation of small Diameter Machines

## Key Questions



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### Statement:

Small Diameter Tunnelling Machines are now able to make long-distance drives of up to 1500m without intermediate shafts.

### Key Questions:

- How can we make sure that the machine will break through precisely at the designed exit point?
- How to make sure that the final product pipe will find itself exactly at the required position throughout the whole length of the drive?

# Navigation of small Diameter Machines

## Key Questions



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## Challenges

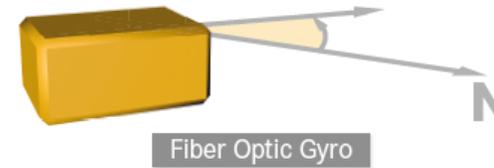
- Combination of long-distance and curved drives with small diameters (ID350)
- No line of sight at all inside the pipeline
- Very little space for navigation components inside the machine
- High advance rates expected (more than 500mm/min can be achieved)
- Small diameter machines react very sensitive to steering actions  
⇒ Operators need quick information about reaction of machine
- High accuracy requirements (Tolerances:  $\pm 10$ cm)



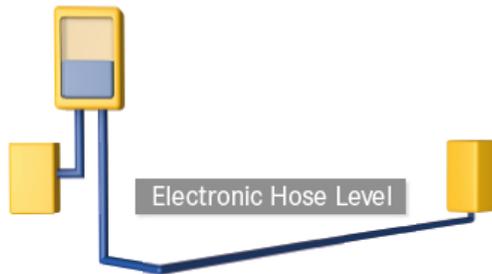
## ✔ SHORT STRAIGHT DRIVES



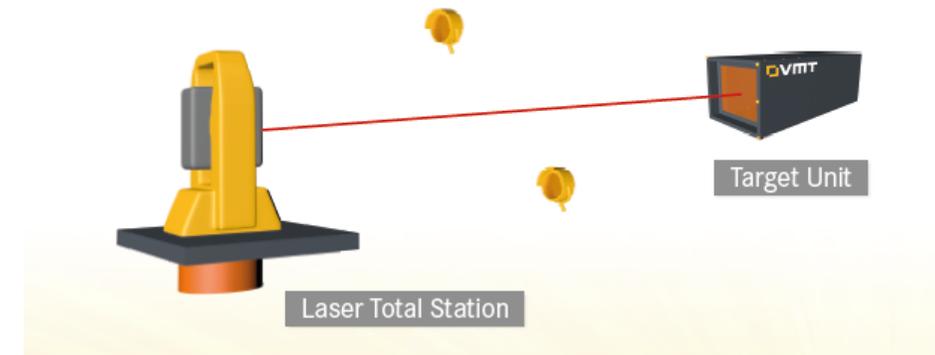
## ✔ EXTREME CURVES AND SMALL DIAMETERS



## ✔ GRADIENT SENSITIVE TUNNELS



## ✔ LONG DISTANCE AND CURVED DRIVES



# Navigation Technology for Microtunnelling Curved and long-distance drives



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## Gyro based Navigation System



- No space left for hose level
- Difficult to feed the hose line through the pipes
- Hose level too slow for high advance rates

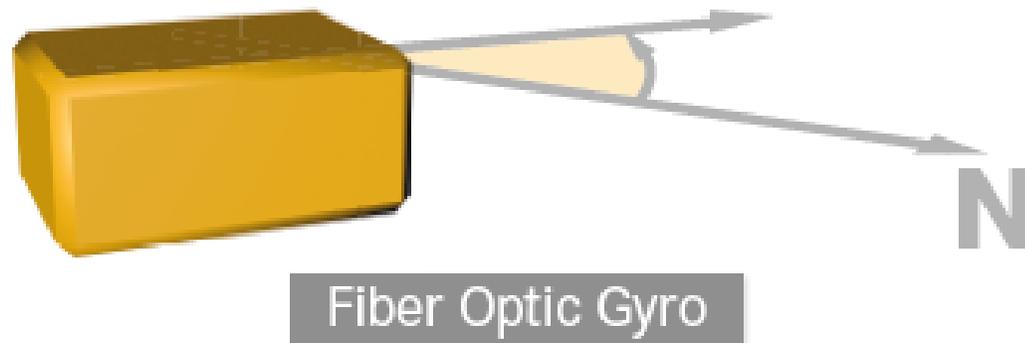
## Laser Tachymeter based Navigation System



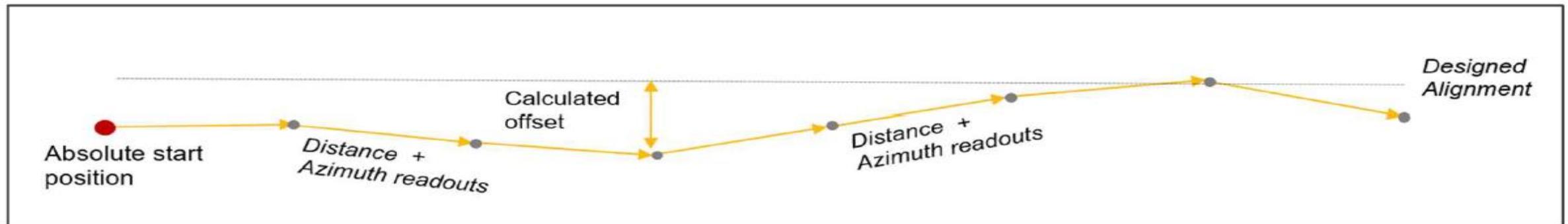
- Needs line of sight between the components
- Components need to be installed in the pipes

# Navigation Technology for Microtunnelling Curved and long-distance drives

## Gyro based Navigation System



- Uses the principle of “coupled navigation” to calculate the horizontal position
- Usually requires the electronic hose level to calculate the vertical position  
⇒ use internal inclinometer instead and use also principle of “coupled navigation”
- Requires calibration every ~50m
- Calibration = manual survey to confirm / correct the calculated machine position, by measuring from start shaft through the tunnel to the machine



# Navigation of small Diameter Machines Requirements and Checklist



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- Provide accurate and frequently updated machine tendencies to enable precise steering at high advance rates 
  - Modify navigation components so that they fit into the limited space of the machine 
  - No installations between machine and shaft possible 
- ⇒ use fibre optic Gyro MWDII in a modified housing

## Solution?

# Navigation of small Diameter Machines Requirements and Checklist - II



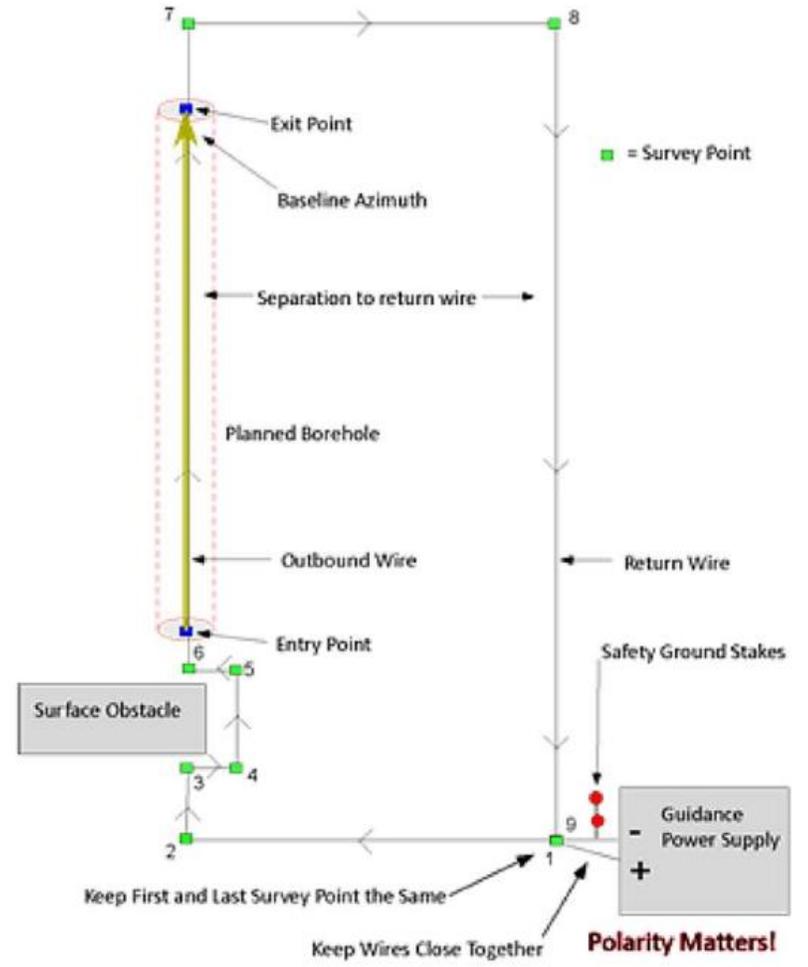
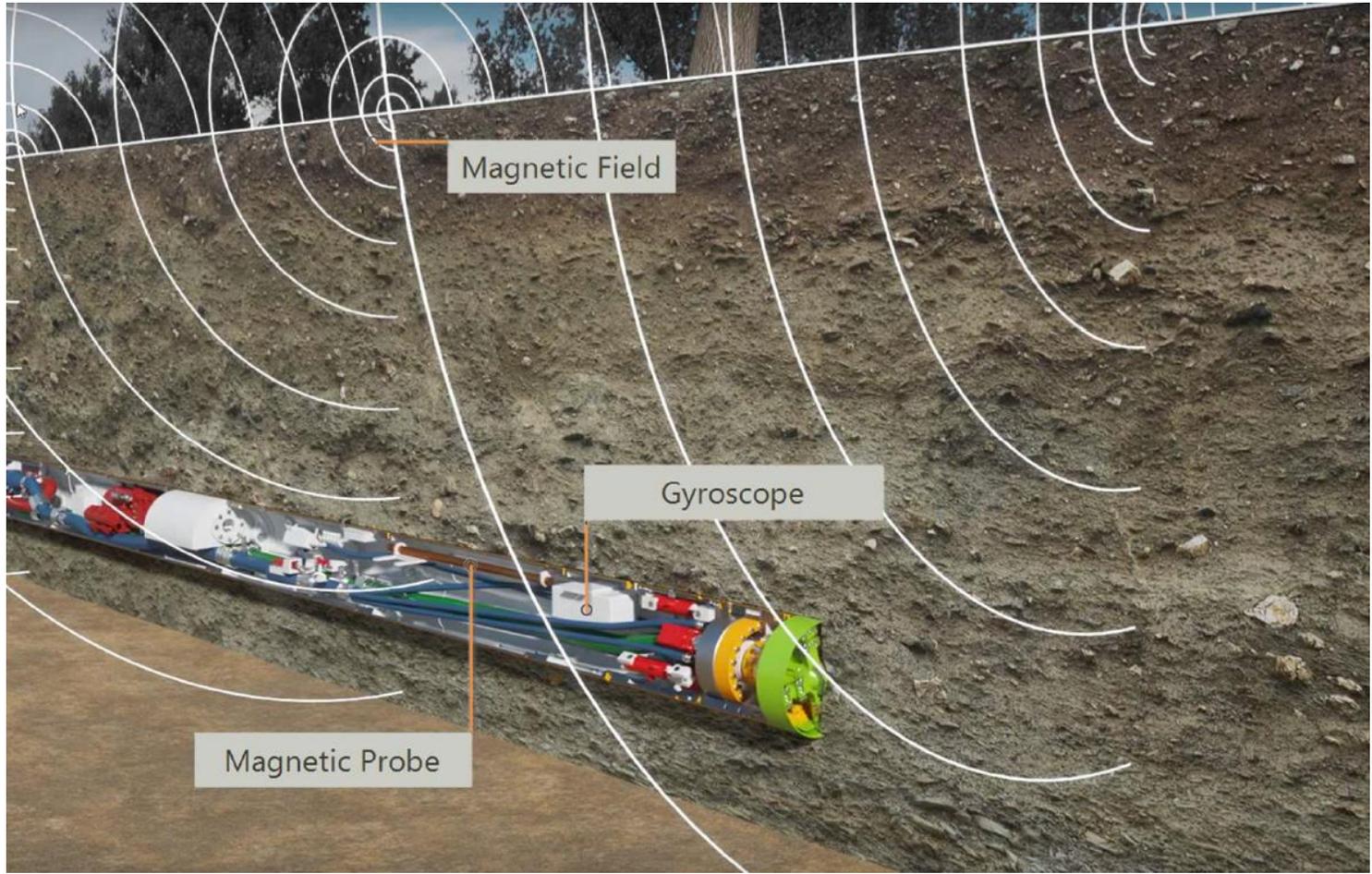
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- The advance process shall not be interrupted because of the navigation system 
- The position of the final product pipe must not exceed +/-10cm from design over the total length of the drive 
- To measure through the pipeline is not an option 
  - no line of sight
  - would require to interrupt advance process



Solution: use *Paratrack* to calibrate the gyro system

# Navigation of small Diameter Machines Paratrack

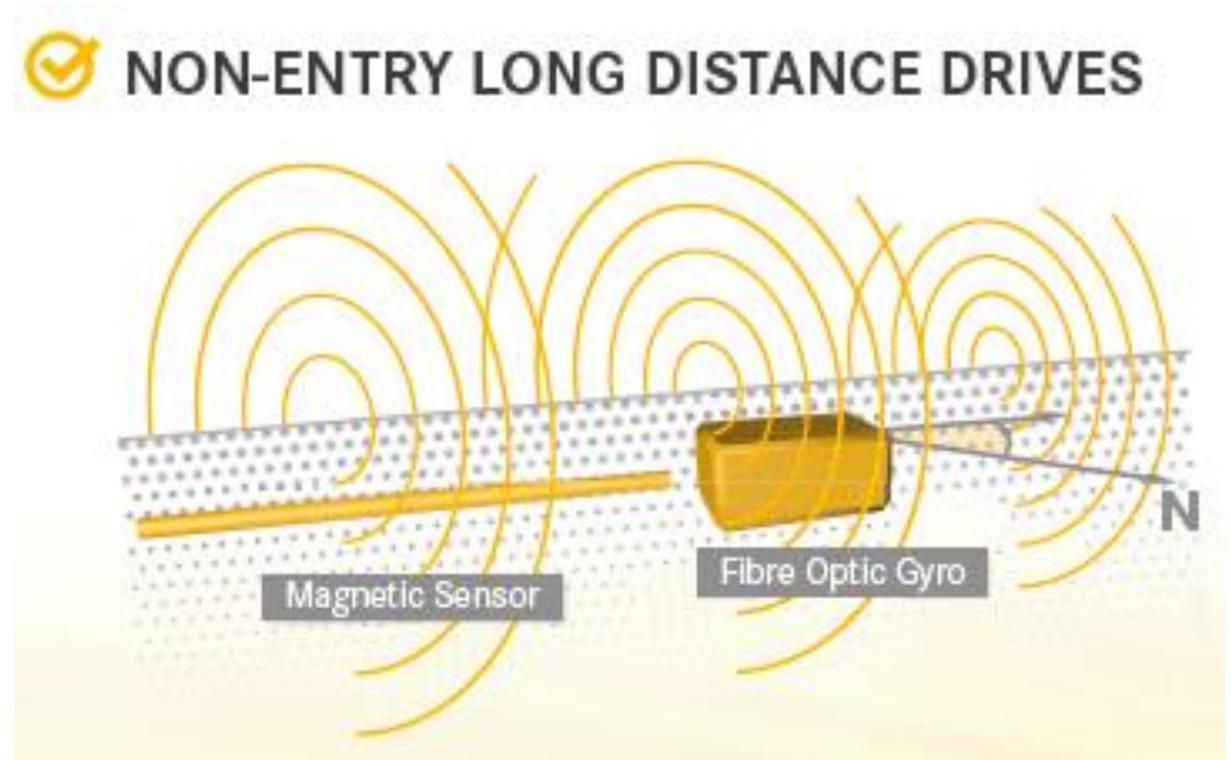


# Navigation of small Diameter Machines Requirements and Checklist - III



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- Make sure that the navigation system is fully automated and can easily be handled by the operator (no surveyor permanent on site)
- **Solution:**  
TUnIS Navigation E-PowerPipe combines Gyro and Paratrack and make both systems improve each other



# Navigation of small Diameter Machines System Comparison

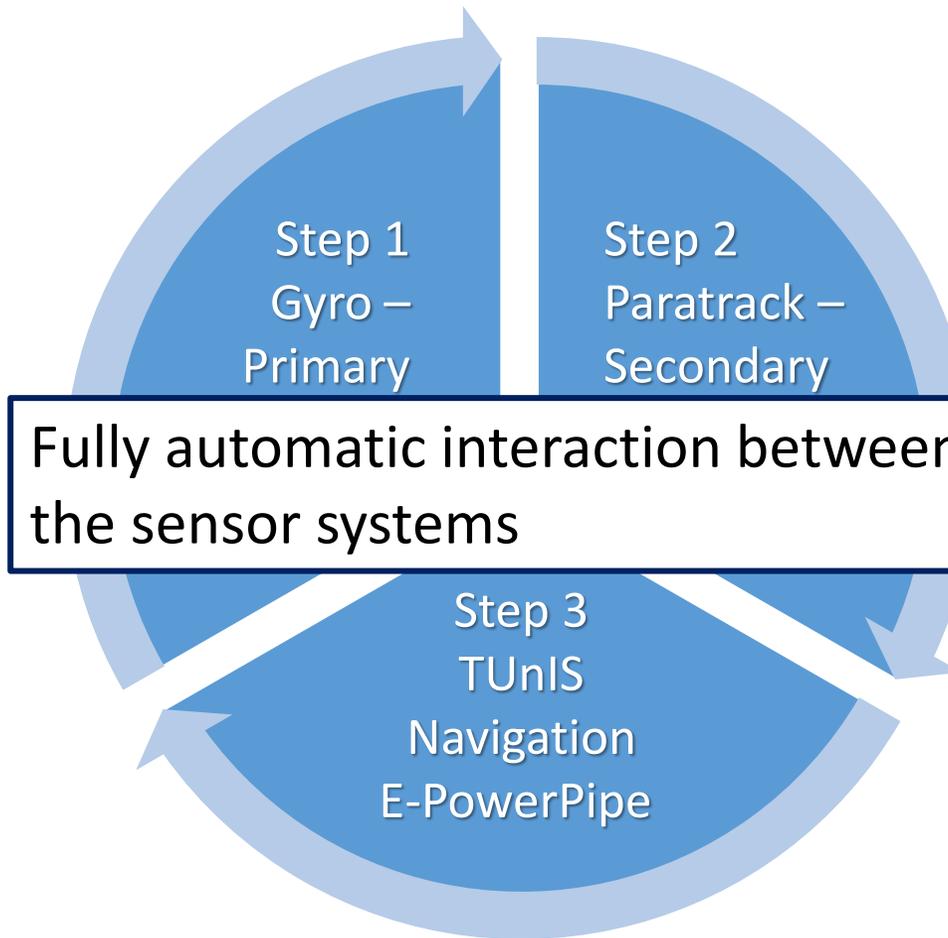


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| Gyro  |                                      | Paratrack                                     |  |
|---|--------------------------------------|---|--|
| Pros  | Cons                                 | Pros  | Cons   |
| Precise angles / tendencies                       | Frequent check measurements required | Provides reference to job-site survey network | Angles not accurate enough for steering                    |
| Quick update of calculated positions / tendencies | Electronic hose level cannot be used | Check measurement without entering pipes      | Update frequency for position / angles too slow            |
| Small dimensions                                  |                                      | Small dimensions                              | System accuracy depends on distance between probe and coil |

# TUnIS Navigation E-PowerPipe System Interaction

**Step 1**  
The Gyro calculates and displays the TBM position and TBM tendencies as a reference for the operator.  
The Gyro transfers chainage and azimuth to Paratrack in order to support the magnetic probe.



**Step 2**  
Paratrack takes chainage and azimuth to define its orientation inside the electro magnetic field. Based on the coordinates of the reference coil Paratrack determines the absolute position of the TBM.

**Step 3**  
TUnIS brings all information together and automatically calibrates the gyro position if necessary.

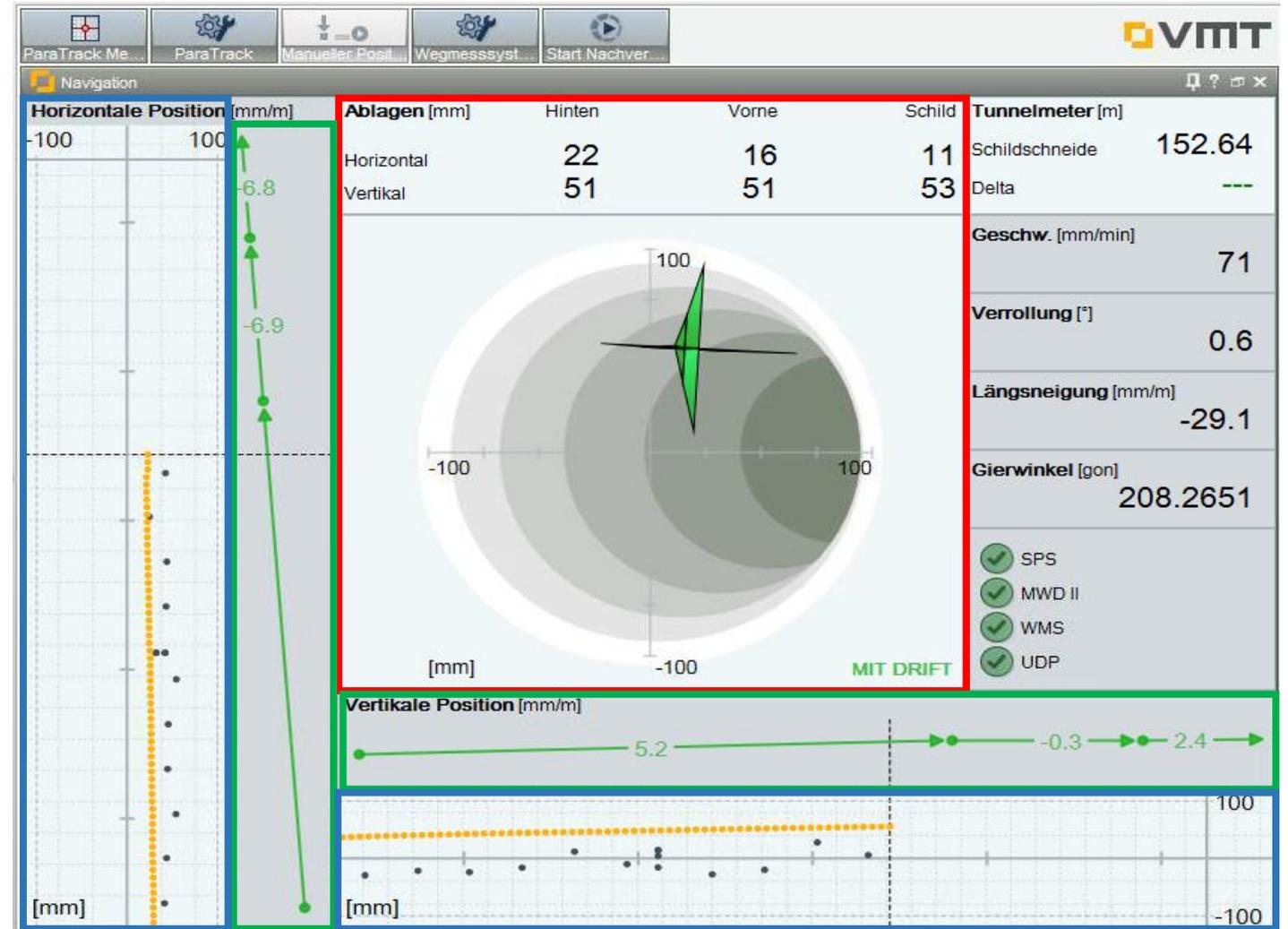
# TUnIS Navigation E-PowerPipe



Numerical and graphical TBM Position

Horizontal and vertical Tendencies

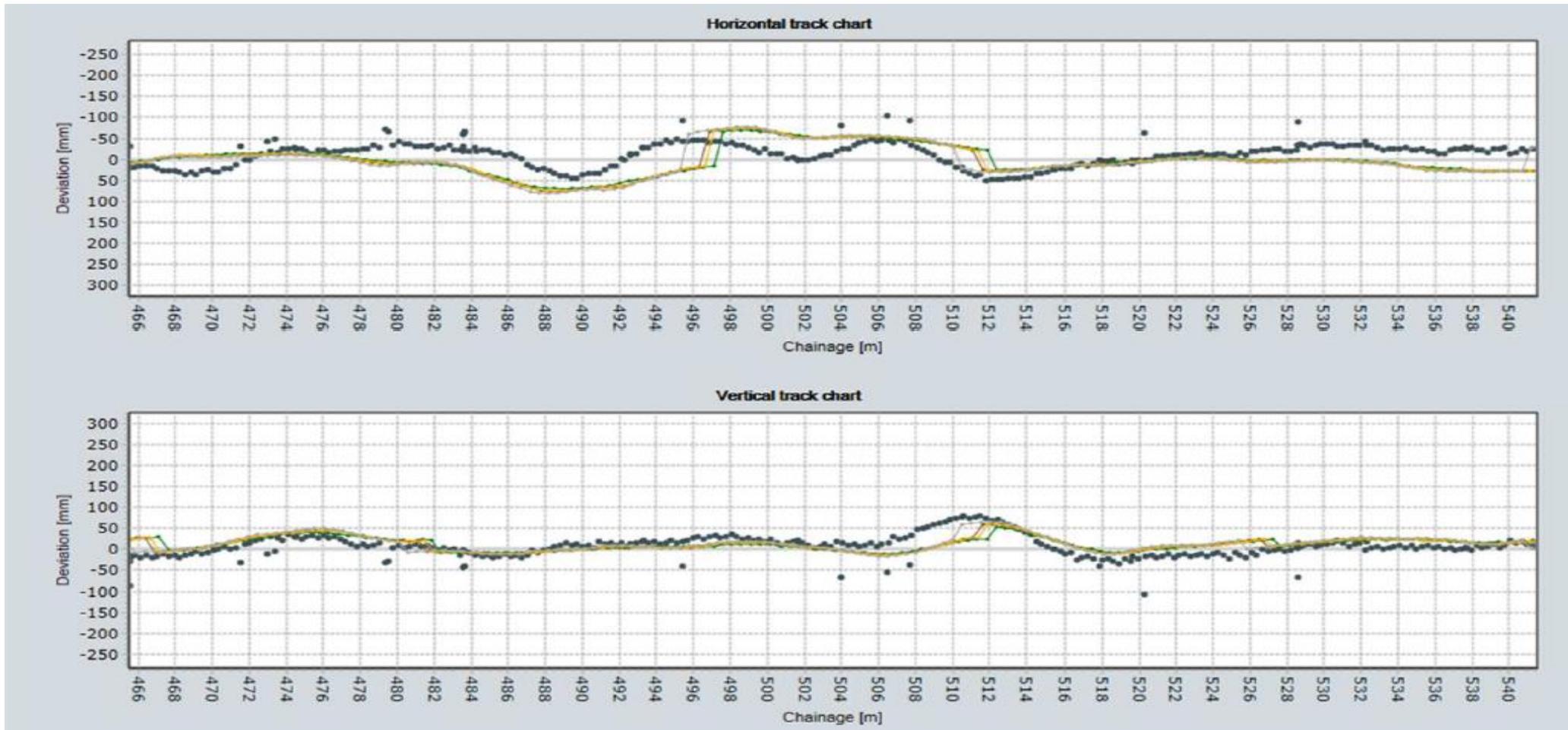
Trend Charts



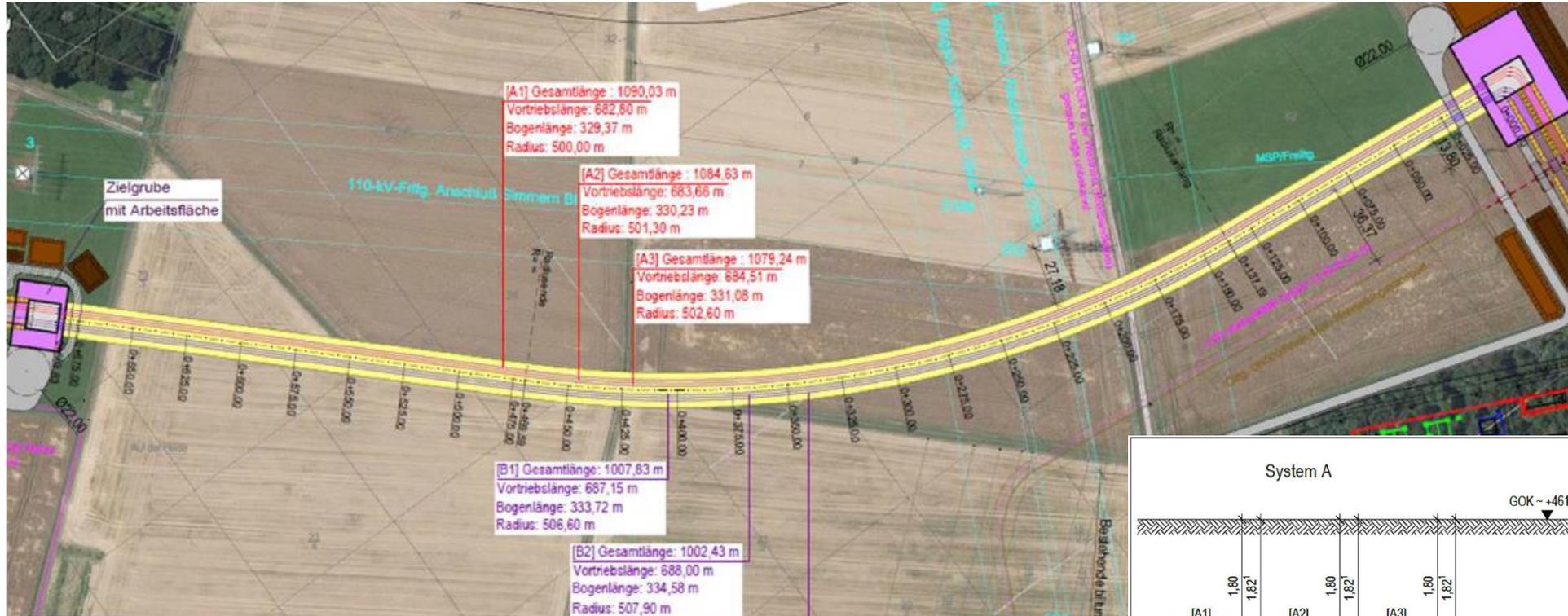
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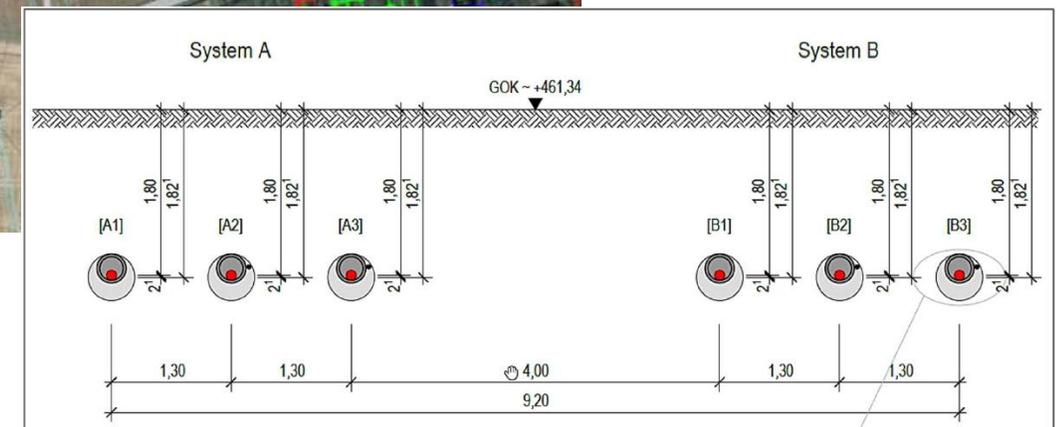
# TUnIS Navigation E-PowerPipe Project Review



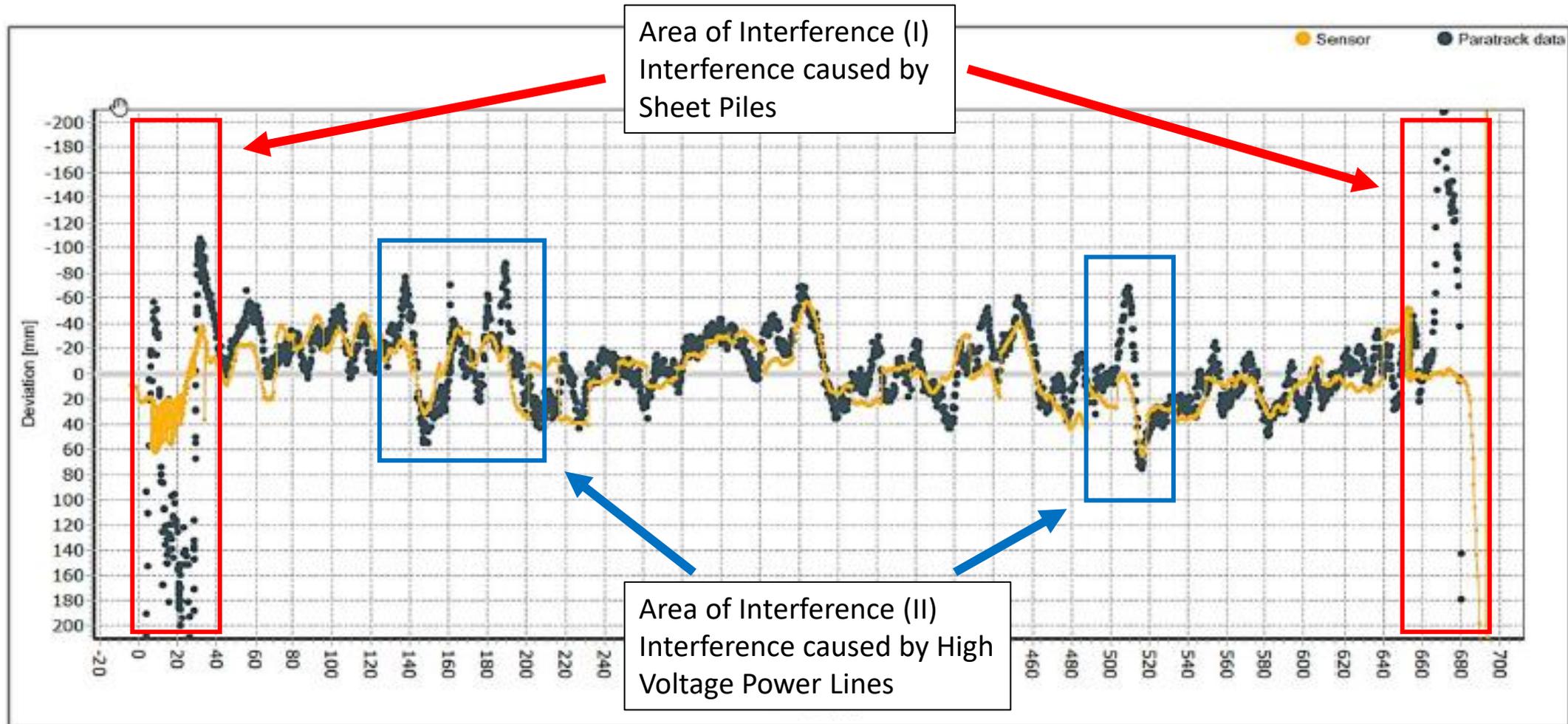
6 Drives with ~700m each

$R_{HOR} = 500m$

$R_{VER} = 25.000m$



# TUnIS Navigation E-PowerPipe Project Review



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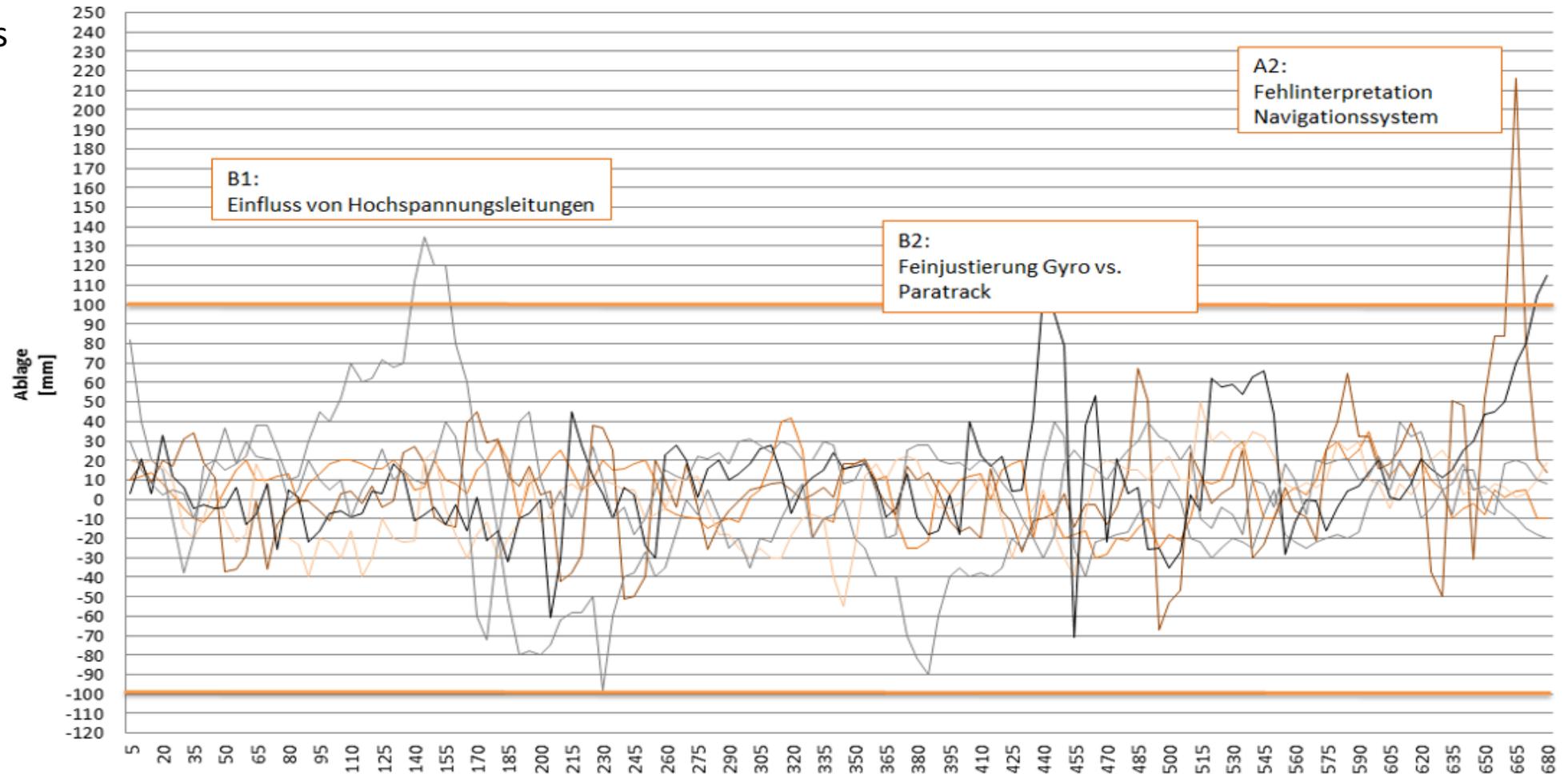
| Breakthrough Accuracy |          | TUnIS | absolute | △    |
|-----------------------|----------|-------|----------|------|
| Drive 1               | Hor [mm] | 0     | 0        | 0    |
|                       | Ver [mm] | +6    | +20      | +14  |
| Drive 2               | Hor [mm] | +21   | +110     | +89  |
|                       | Ver [mm] | +14   | +120     | +106 |
| Drive 3               | Hor [mm] | +11   | -23      | -34  |
|                       | Ver [mm] | +4    | +85      | +81  |
| Drive 4               | Hor [mm] | +20   | +50      | +30  |
|                       | Ver [mm] | +10   | +30      | +20  |
| Drive 5               | Hor [mm] | --    | --       | --   |
|                       | Ver [mm] | --    | --       | --   |
| Drive 6               | Hor [mm] | -10   | +58      | +68  |
|                       | Ver [mm] | +10   | +46      | +36  |

# TUnIS Navigation E-PowerPipe Project Review



## Horizontal Deviations

### Drives 1-6



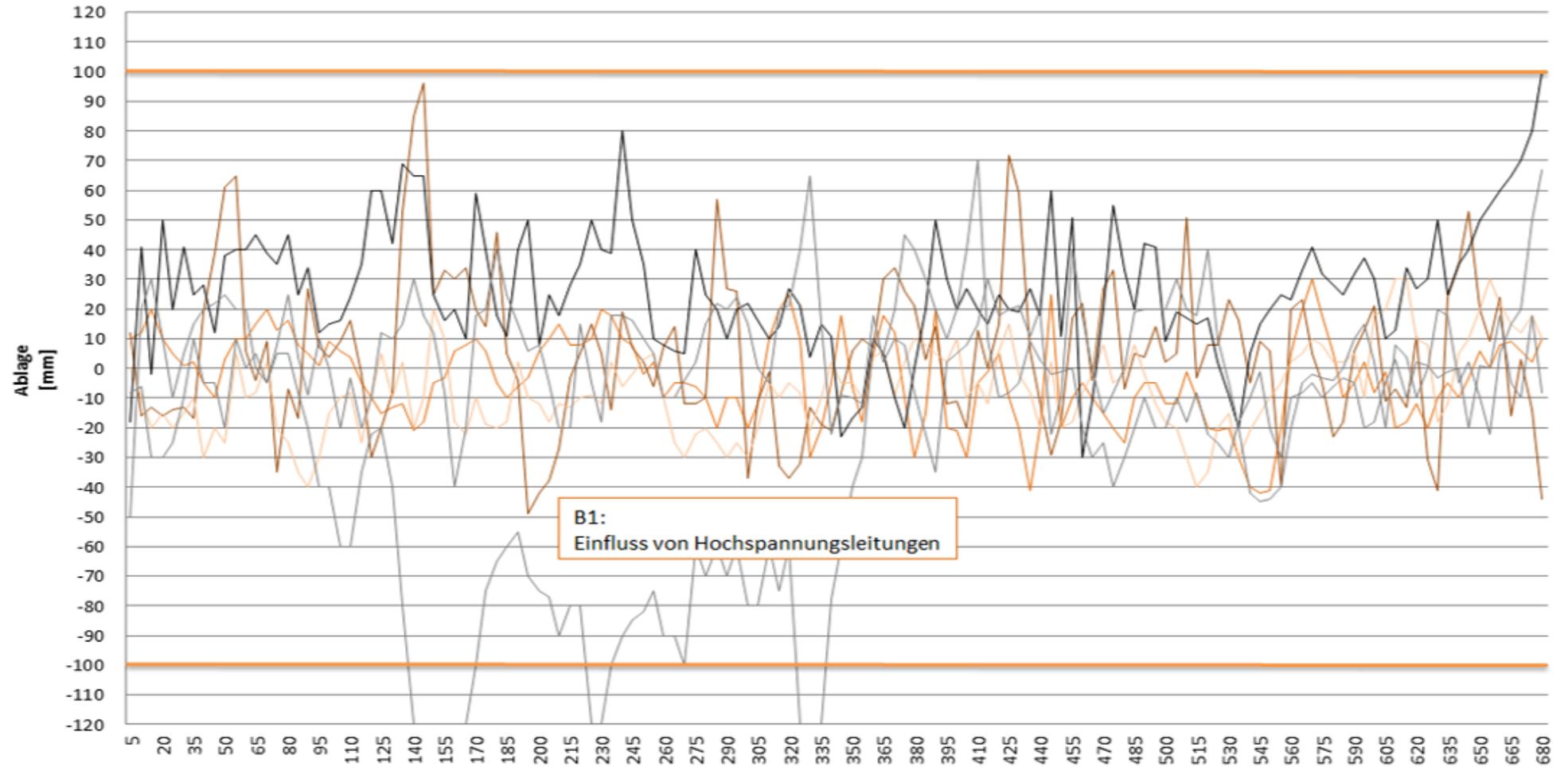
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Vertical Deviations

Drives 1-6

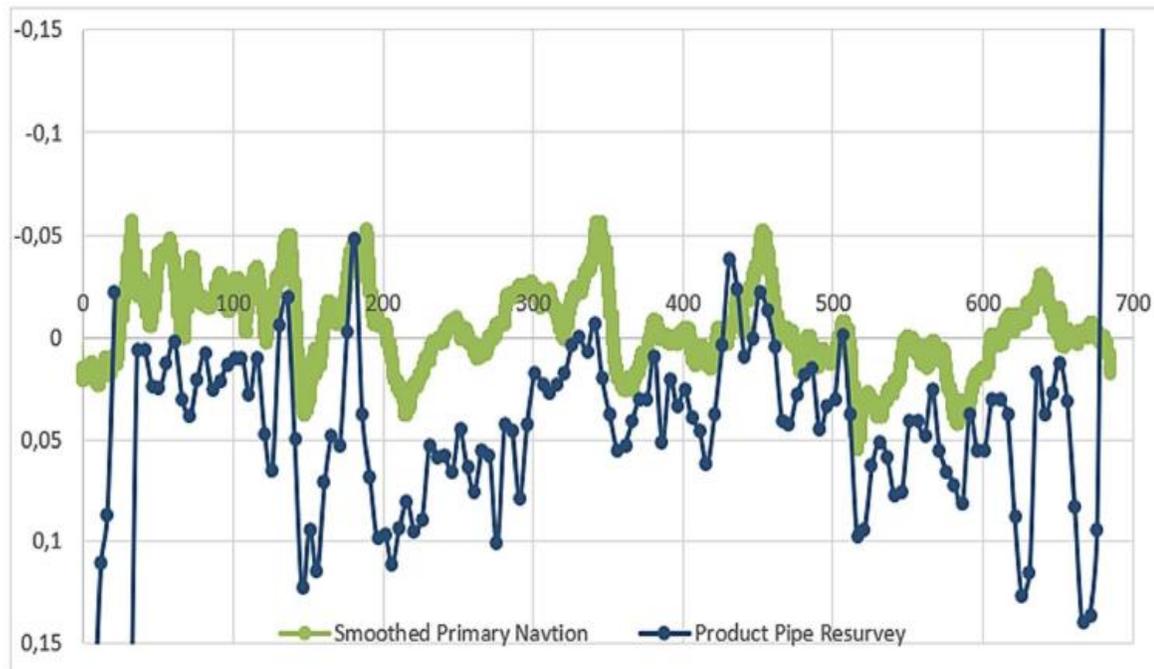


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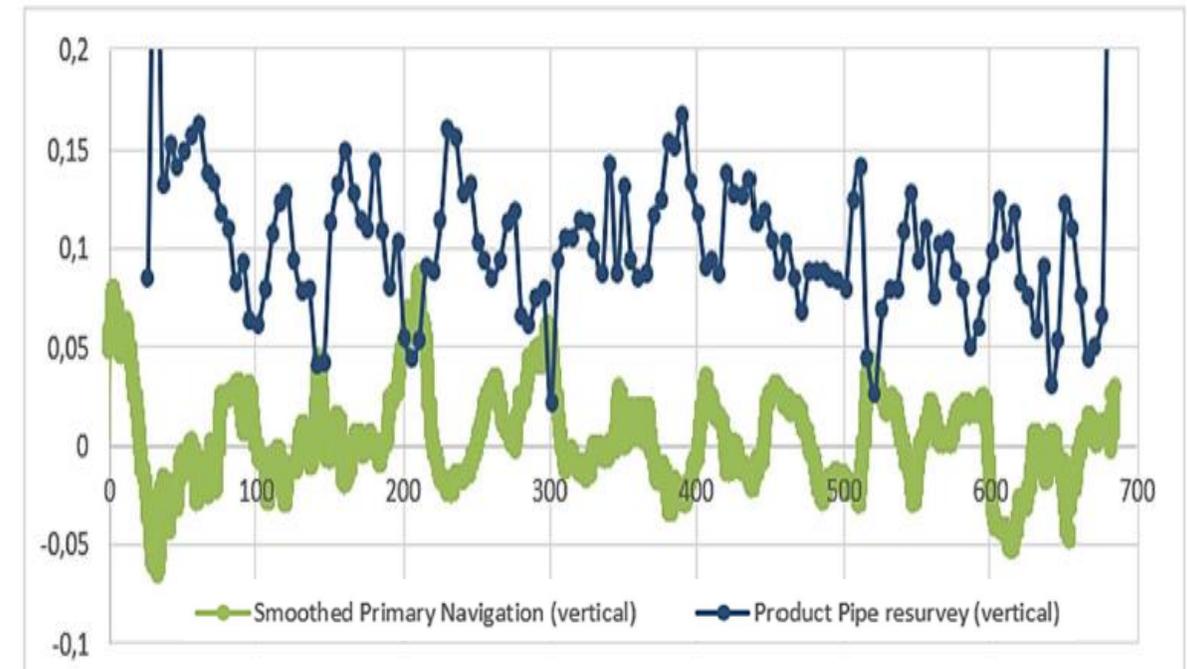


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## As-built of final Product Pipe



Horizontal



Vertical



## Lessons learned

- TUnIS Navigation E-PowerPipe is a tailor-made hybrid system for precise guidance of small diameter machines in shallow depth (max. 5-7m)
- the navigation software provides intelligent combination and management of 2 formerly separate systems thus allowing continuous operation without stopping for survey works
- The high frequency of the system calculations can cope with the high advance rates of the machine
- Areas where interference confuse the electro-magnetic field (sheet piles, high voltage powerlines above ground) can be bridged by relying on the gyro calculations only, but those areas must not be larger than 100m.



**Thank You For Your Attention !**

22/04/2019