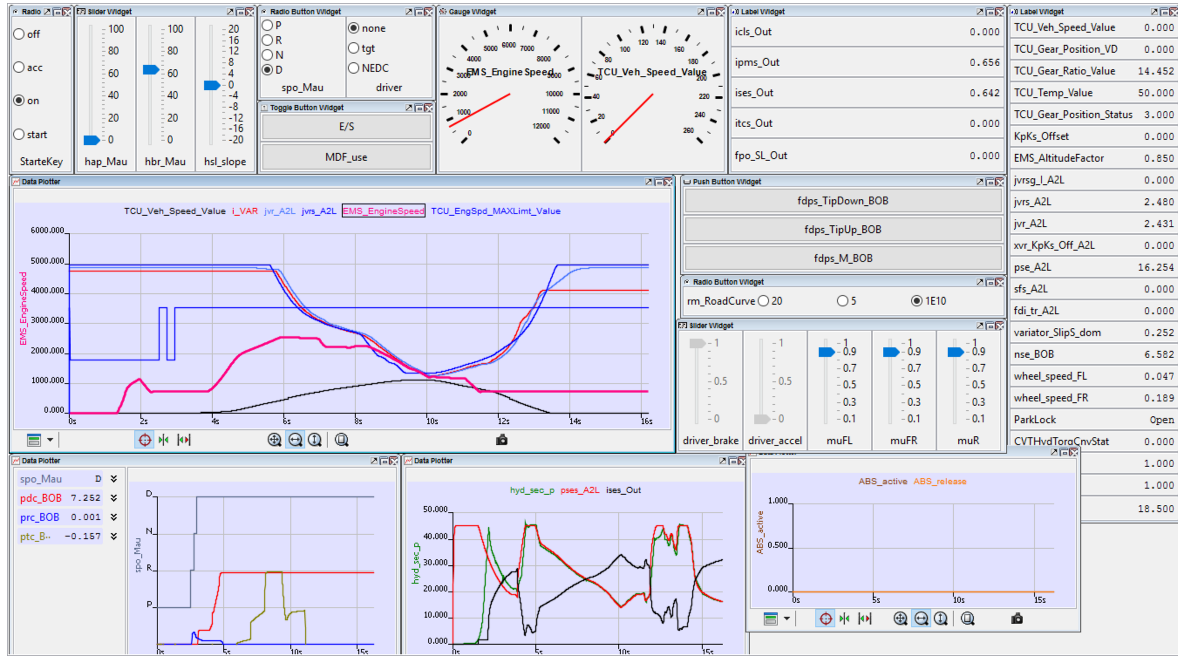


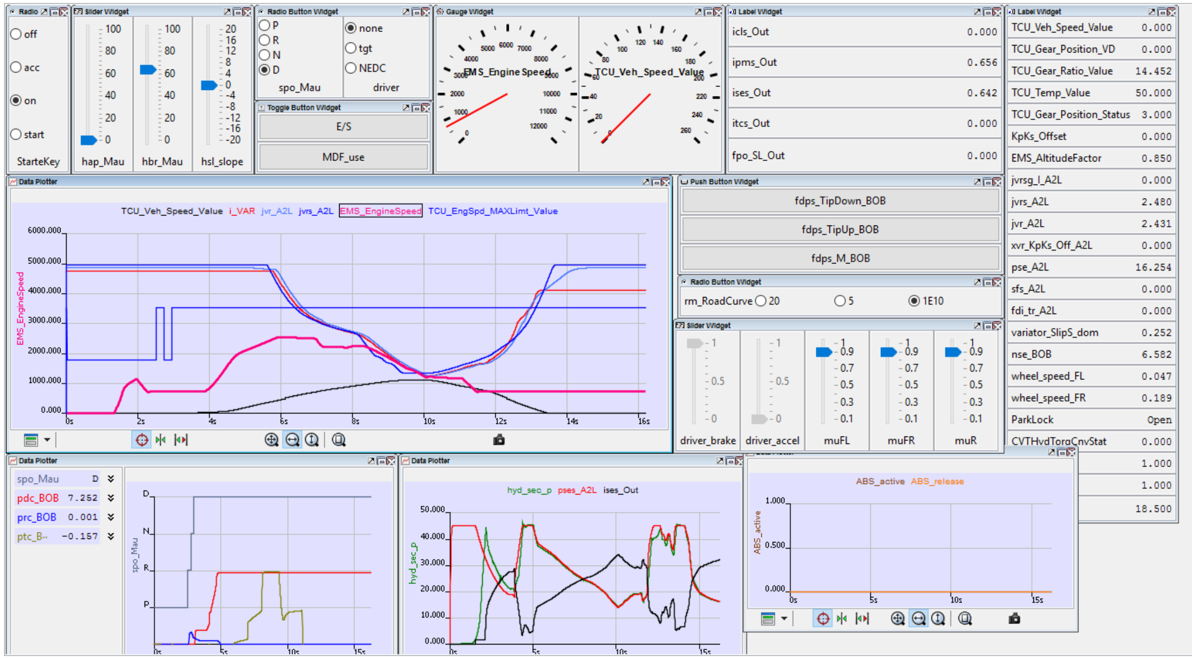
CVT control software testing

Lionel Belmon, Liu Fei – Global Crown Technology, Beijing

Zeng Weihua - Jianglu Rongda, Changsha

议程

1. Motivation
2. Vehicle plant modeling
3. TCU embedded software
4. Simulation validation
5. TCU Testing


StarteKey
hap_Mau
hbr_Mau
hsl_slope
spo_Mau
driver
E/S
MDF_use
EMS_Engine Speed
TCU_Veh_Speed_Value
icls_Out 0.000
ipms_Out 0.656
ises_Out 0.642
itcs_Out 0.000
fpo_SL_Out 0.000
TCU_Veh_Speed_Value 0.000
TCU_Gear_Position_VD 0.000
TCU_Gear_Ratio_Value 14.452
TCU_Temp_Value 50.000
TCU_Gear_Position_Status 3.000
KpKs_Offset 0.000
EMS_AltitudeFactor 0.850
jvrsg_I_A2L 0.000
jvrs_A2L 2.480
jvr_A2L 2.431
xvr_KpKs_Off_A2L 0.000
pse_A2L 16.254
sfs_A2L 0.000
fdi_tr_A2L 0.000
variator_SlipS_dom 0.252
nse_BOB 6.582
wheel_speed_FL 0.047
wheel_speed_FR 0.189
ParkLock Open
fdps_TipDown_BOB
fdps_TipUp_BOB
fdps_M_BOB
rm_RoadCurve
driver_brake
driver_accel
muFL
muFR
muR
TCU_Veh_Speed_Value i_VAR jvr_A2L jvrs_A2L EMS_EngineSpeed TCU_EngSpd_MAXLimt_Value
hyd_sec_p pses_A2L ises_Out
ABS_active ABS_release

Motivation

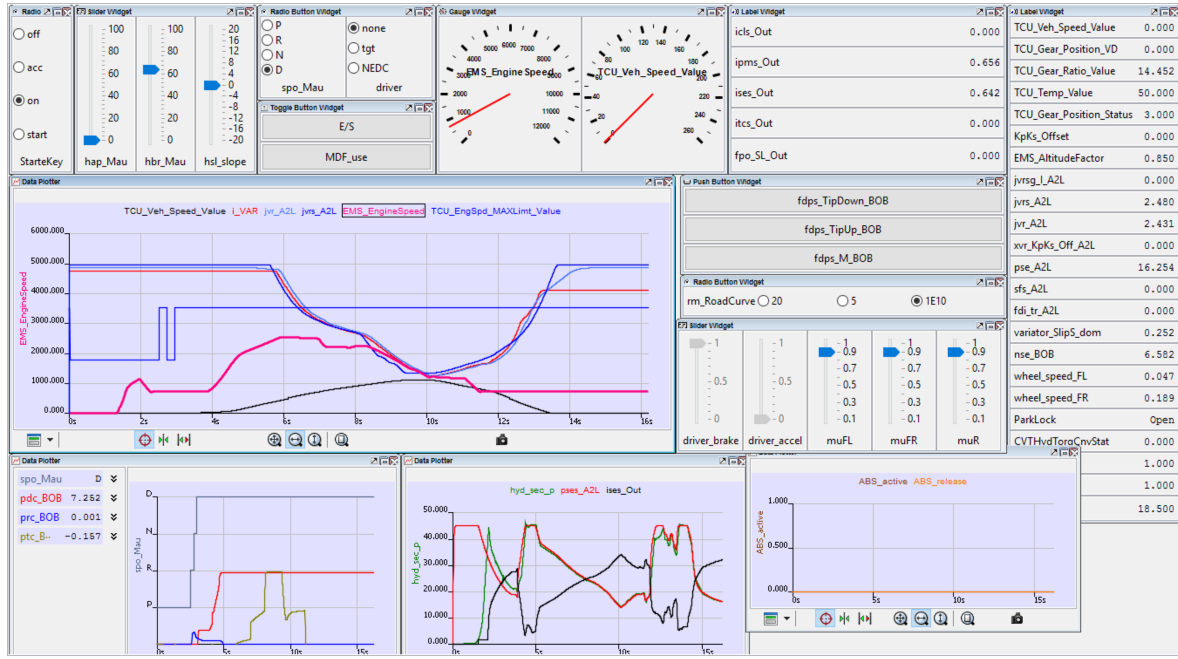
Motivation and objectives

Develop and test TCU control software

High quality vehicle model
Realistic simulation

Interaction road - vehicle - hydraulics - TCU

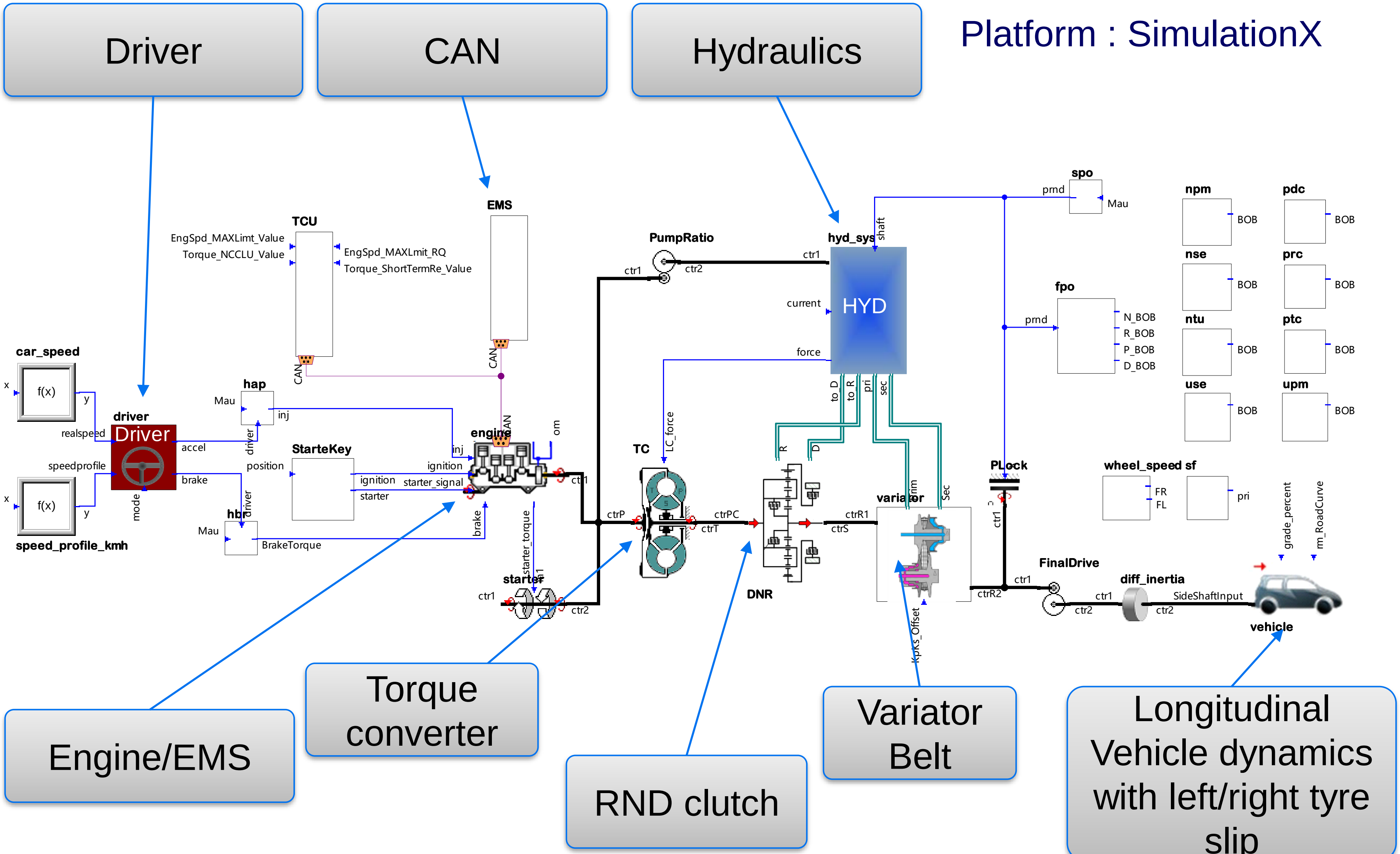
Cover large number of test cases



Vehicle plant model

Vehicle model overview

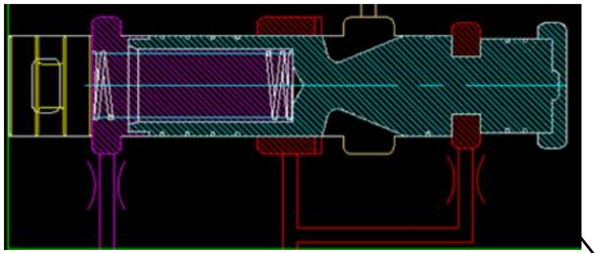
Platform : SimulationX



Hydraulic module

Torque converter lock-up

RND clutches

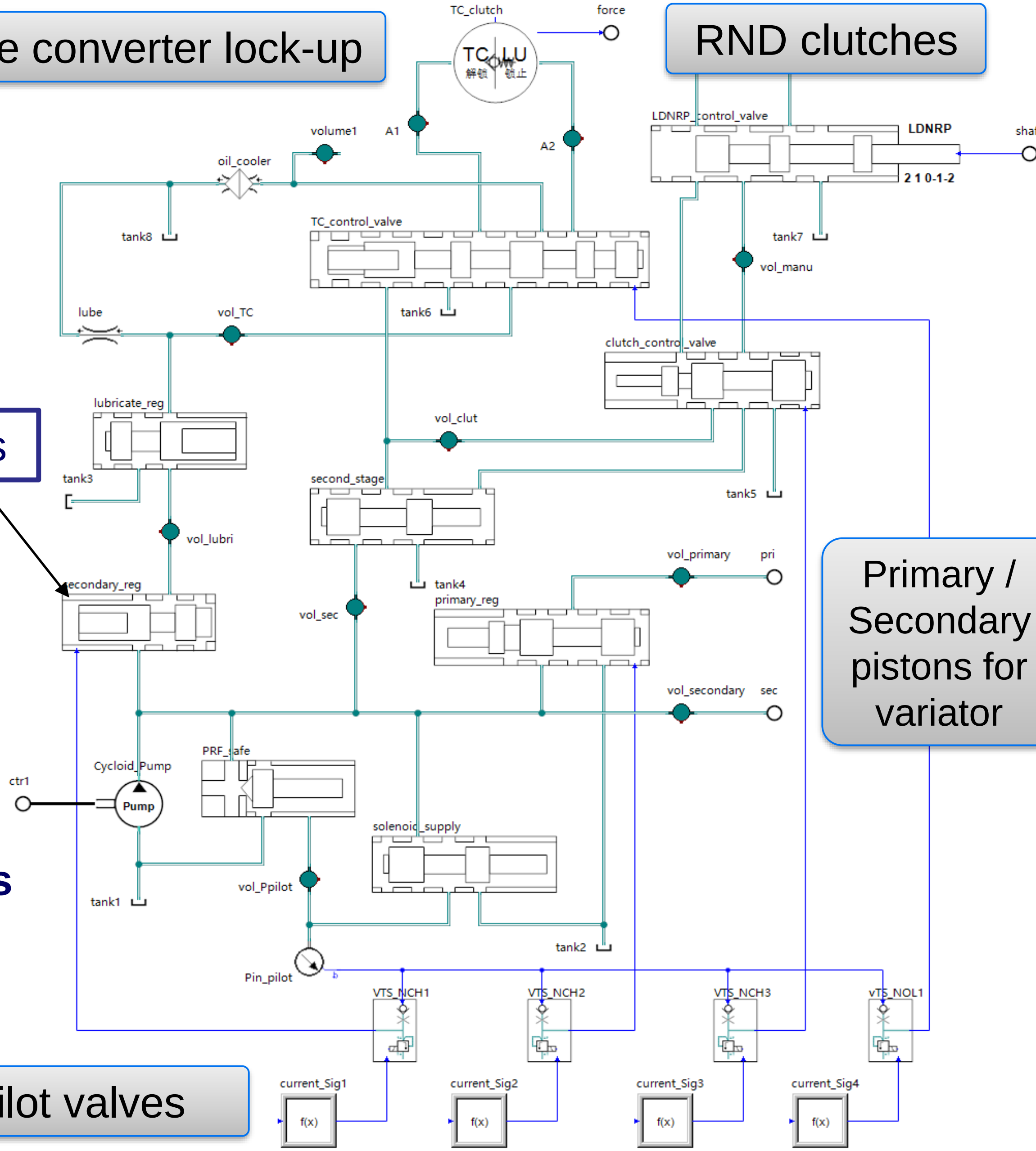


Extraction of CAD parameters

Main flow pressure dynamics

Spool valves characteristics

Solenoid valve - pilot pressures



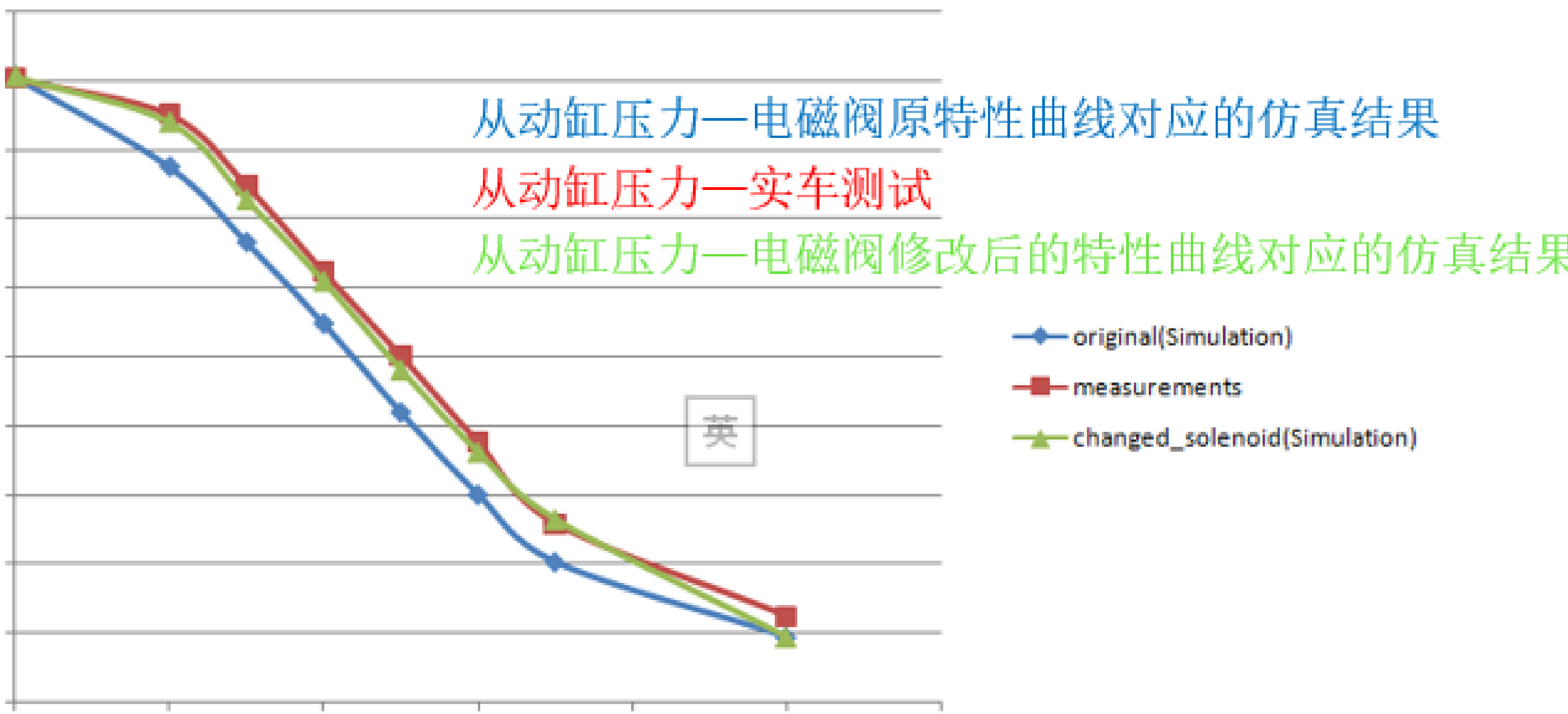
Primary / Secondary pistons for variator

Solenoid pilot valves

Hydraulic Unit tests and validation

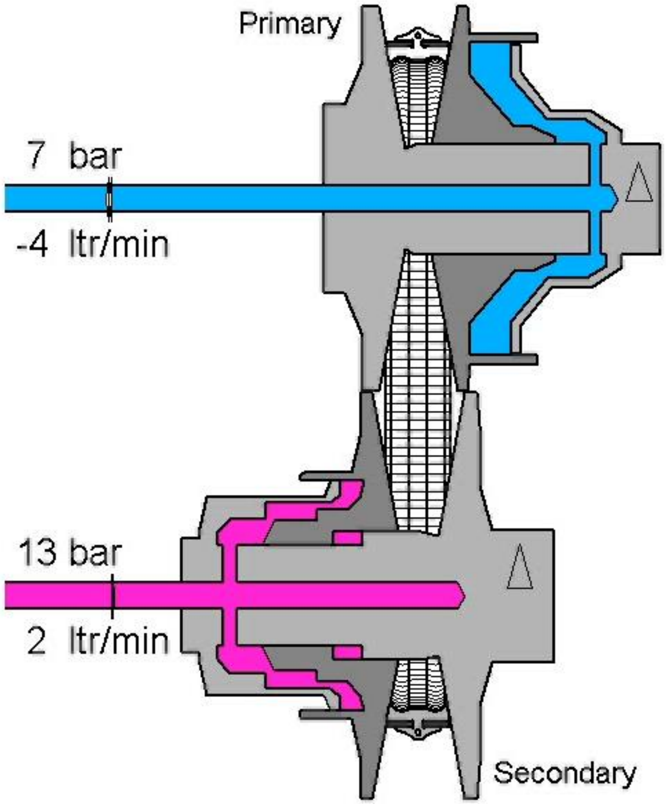
Adjustment of solenoid characteristics

Primary cylinder pressure



Solenoid current

Variator belt model concept



Variator ratio change by controlling primary/secondary pressure

$$\frac{di}{dt} = K_i n_{pri} (F_{pri} - F^*_{pri})$$

Actual force

steady-state force required

$$P_{\sec mx} = \frac{T_{pri} \beta \cos\alpha}{2\mu_{\sec} R_{pri} A_{\sec}}$$

Max torque limit depends on pressure !

Real-time simulation

Adjustment of hydraulic volumes and mechanical stiffness

Fixed-step solver – 0.5 ms

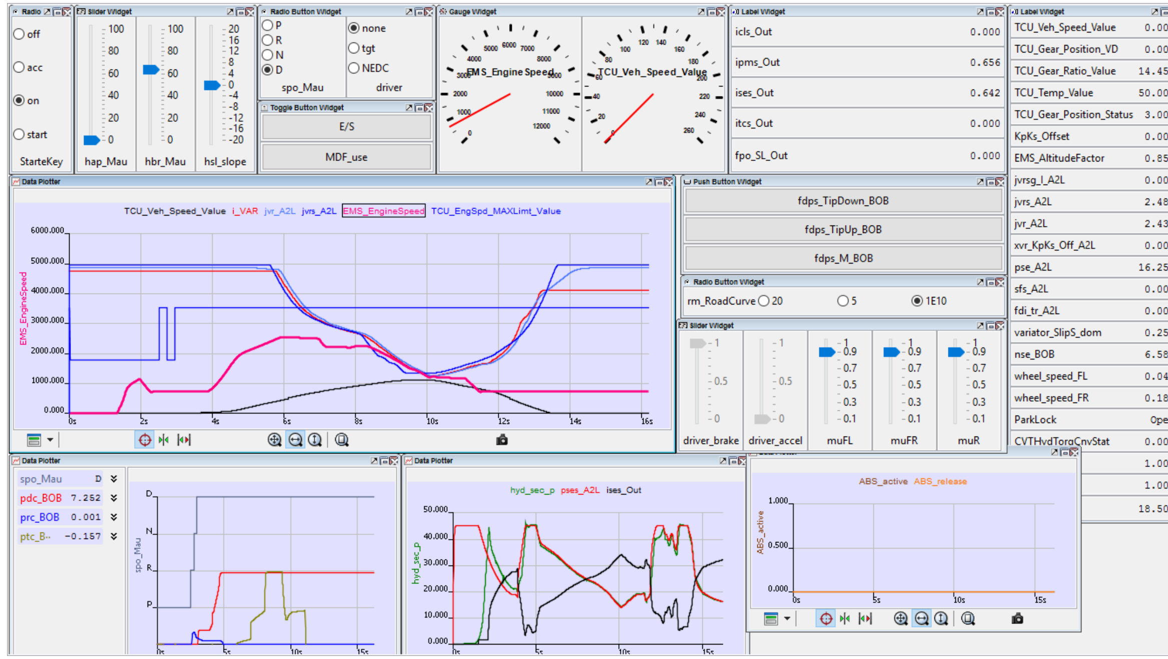
~80 ODE state variables

~200 inputs/outputs variables (CAN, sensors, actuators)

Code generation from SimulationX **to FMU cosimulation**

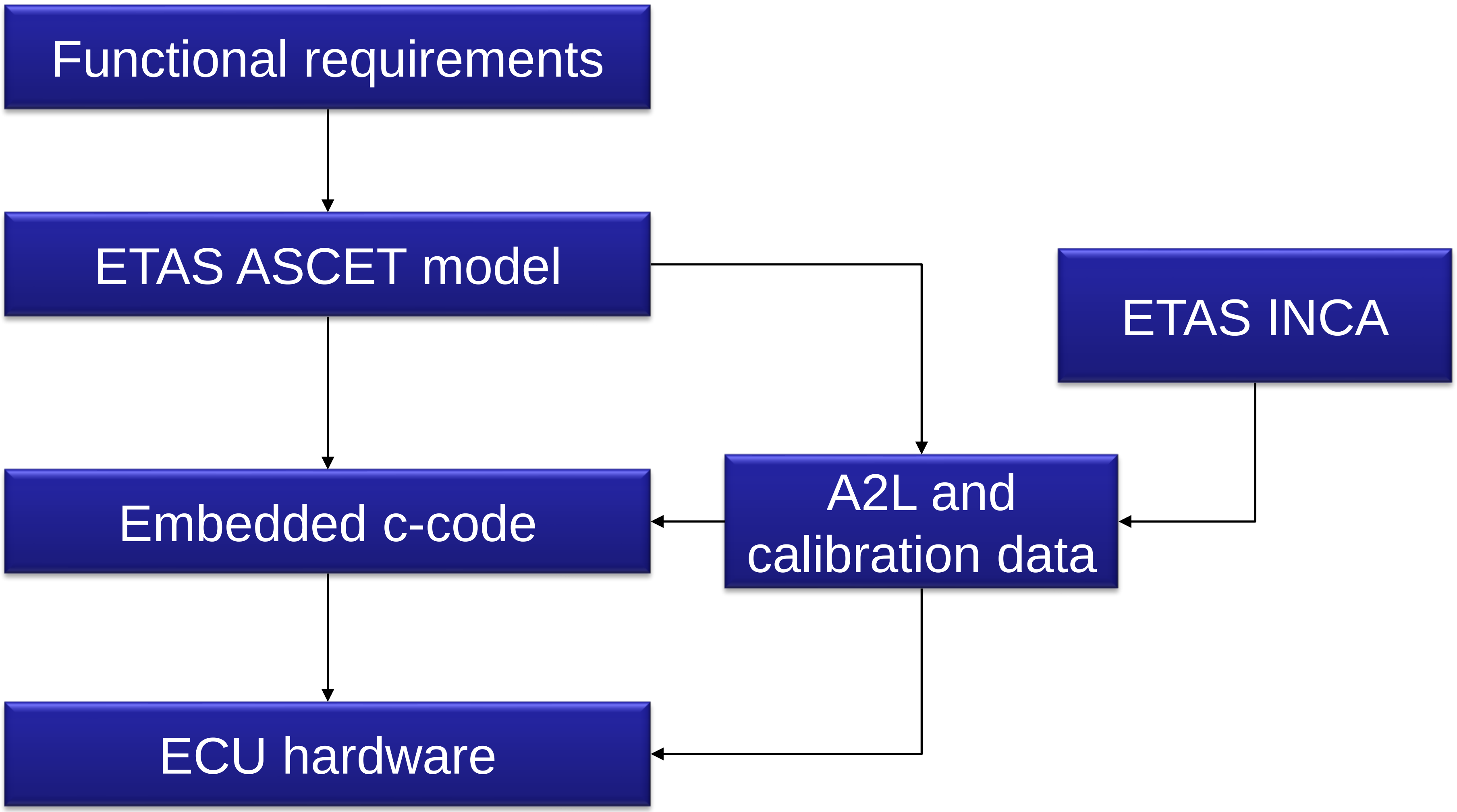
Execution in QTronic Silver

Simulated time: 98.38s; Actual time spent computing: 18.62s; Speedup factor: 5.28

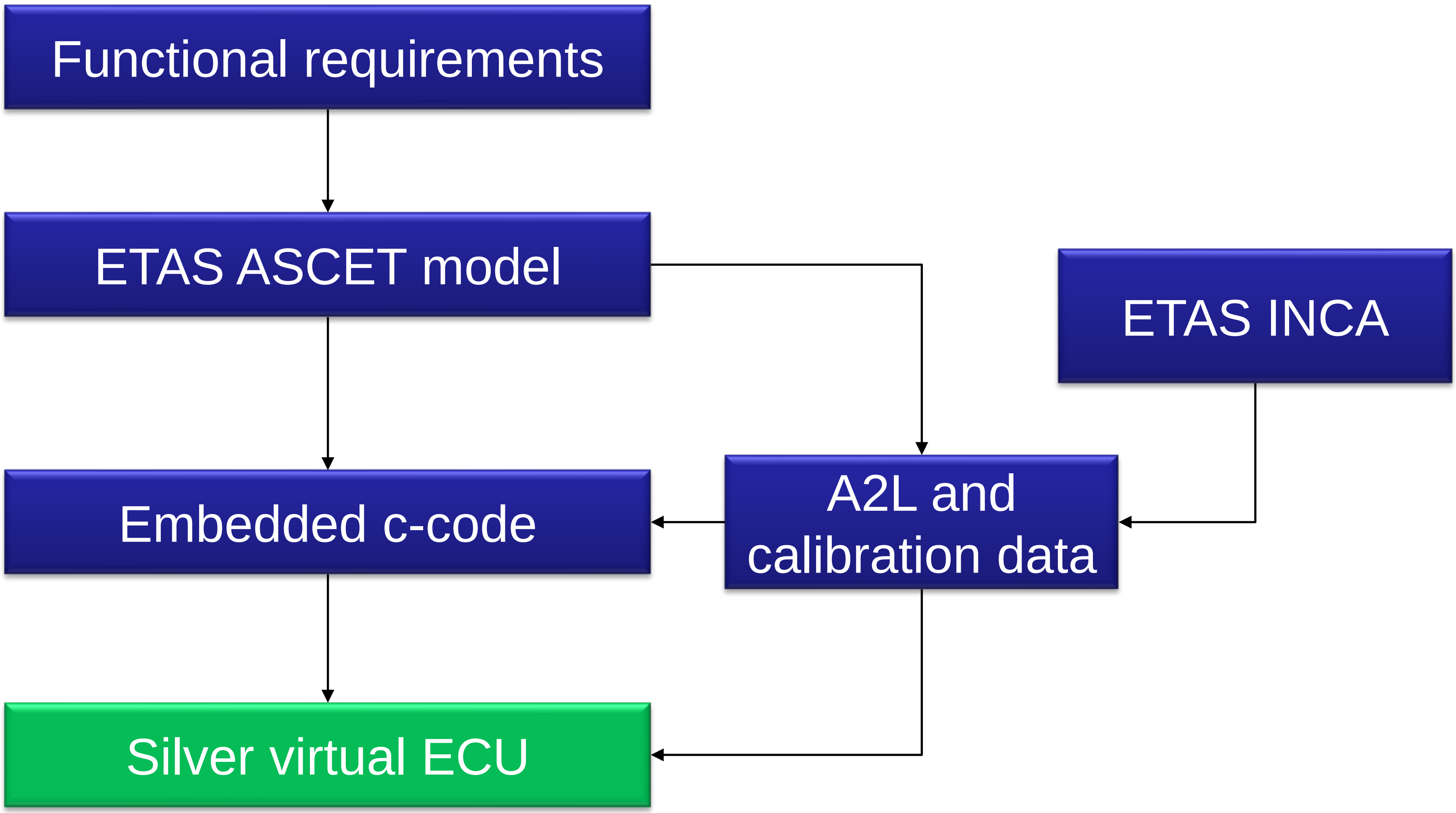


TCU embedded software

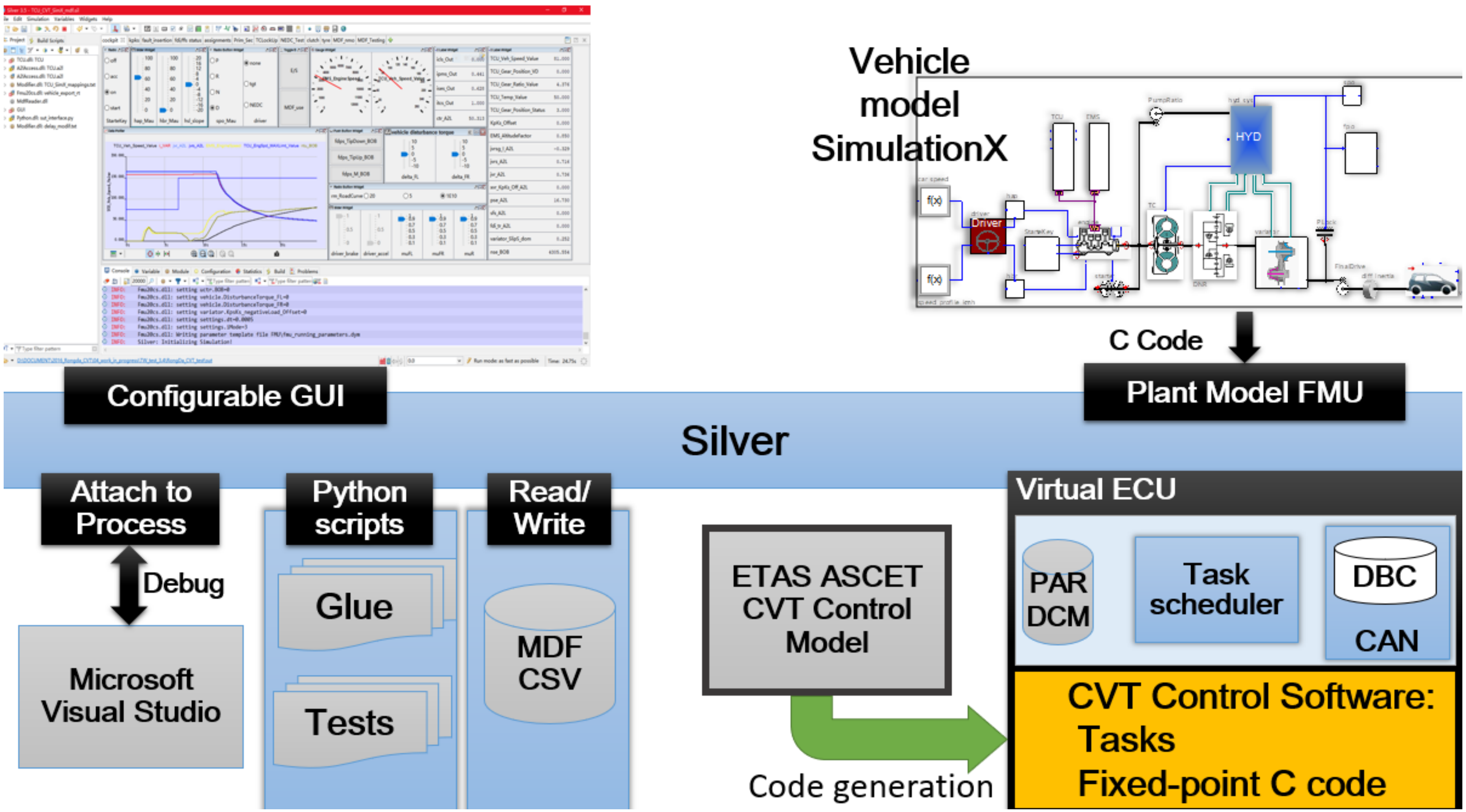
TCU software generation process

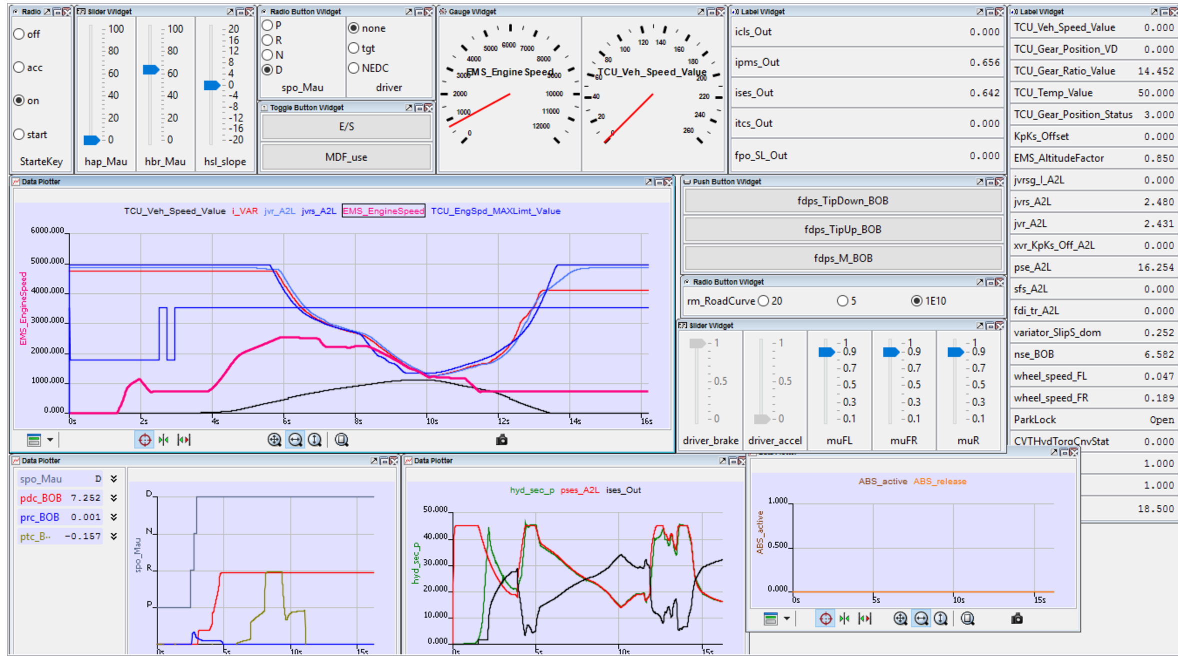


Virtual TCU with Silver



Virtual TCU platform





Validation of vehicle simulation

Test cases for simulation validation

~20 test drive cases to test various model characteristics :

10% pedal acceleration – coasting
30% pedal acceleration – coasting
…

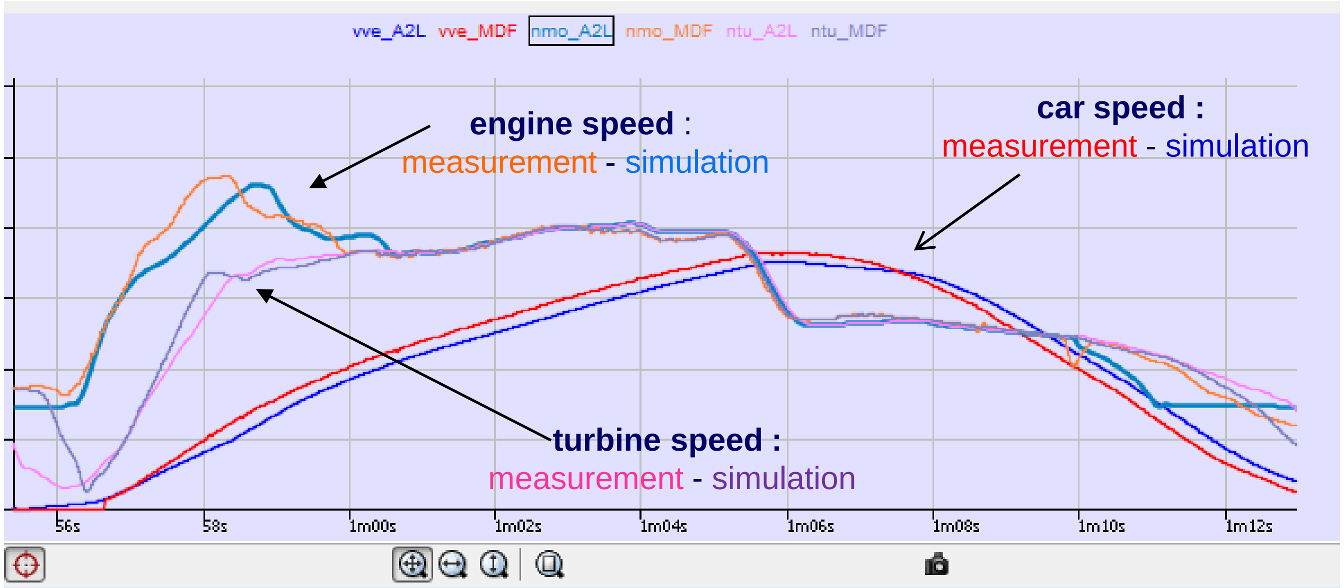
Lever position changes : N-R-N-D-N-R-P-R-N…

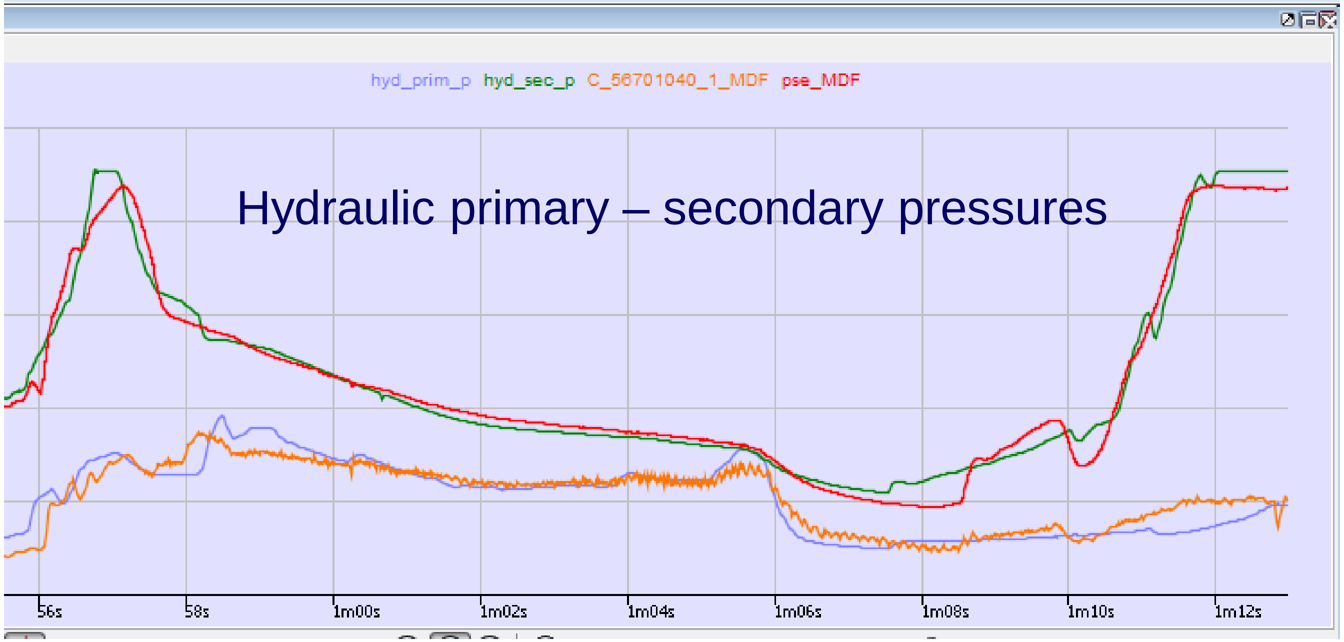
Heavy braking with ABS

Tip-in , Tip-off

…

Example of test drive validation





TCU embedded software testing

Test requirements

Usual test drive cases

NEDC, 100km/h acceleration…

Calibration parameters

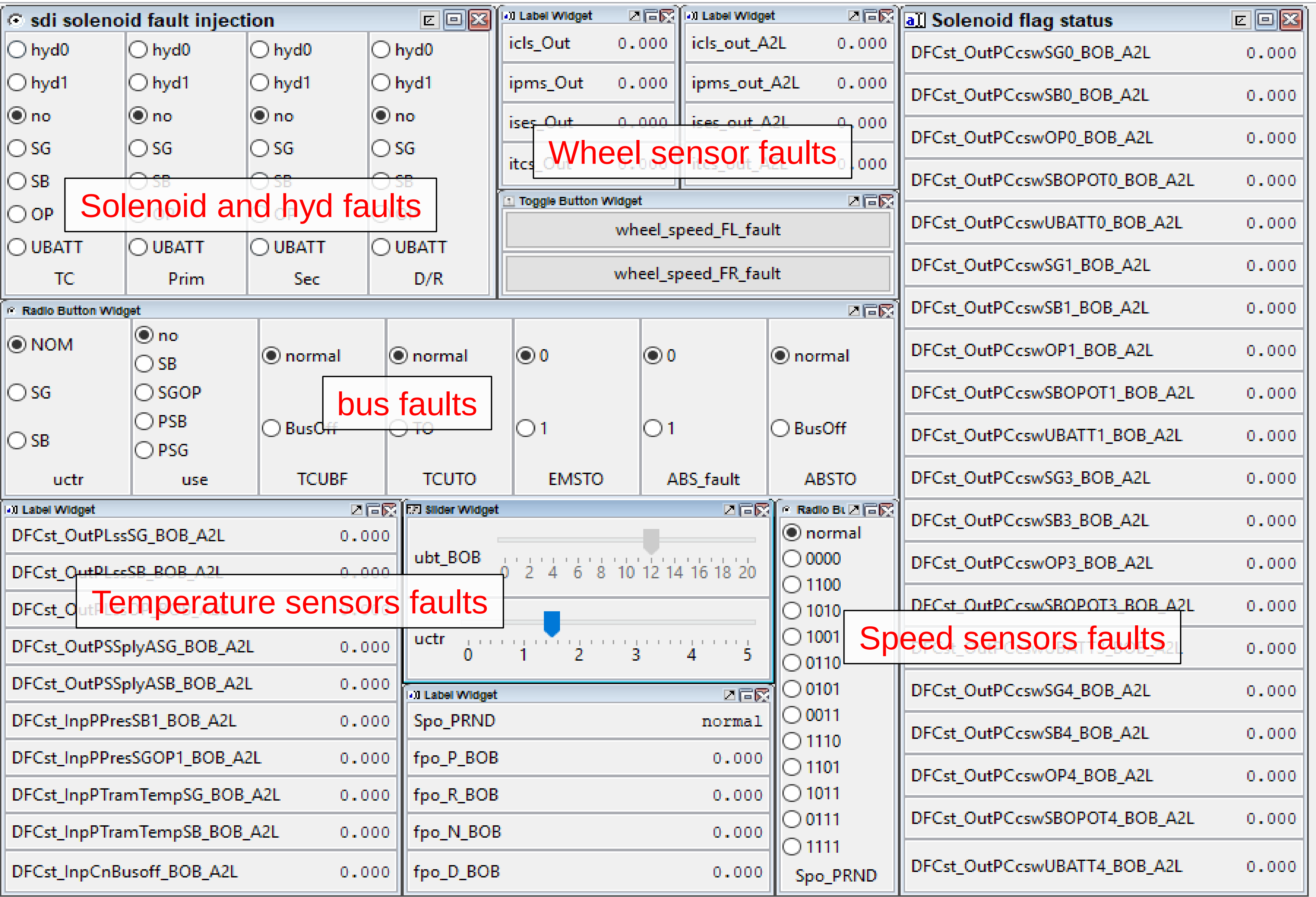
Software functions activation/deactivation

Various environment conditions :

- slope, snow/water…

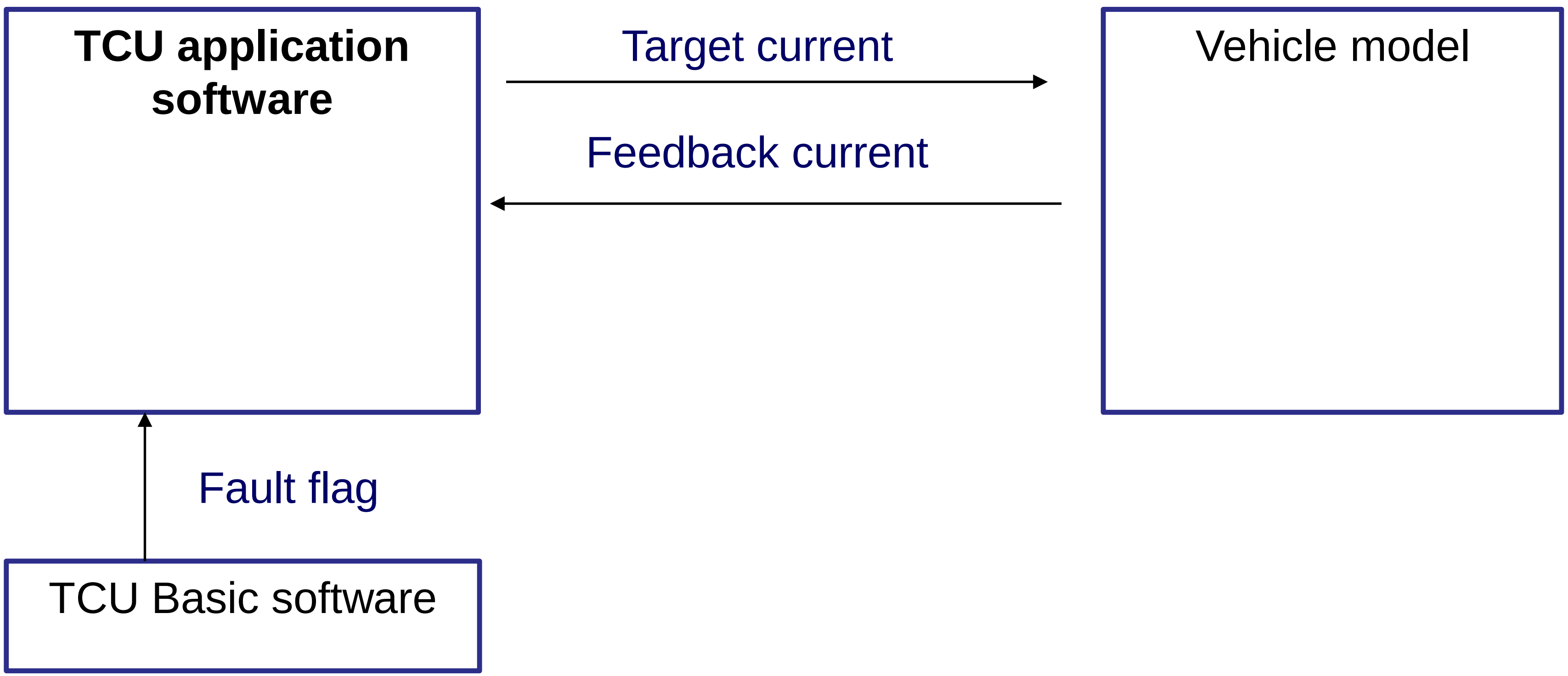
Fault monitoring and reaction

Fault insertion



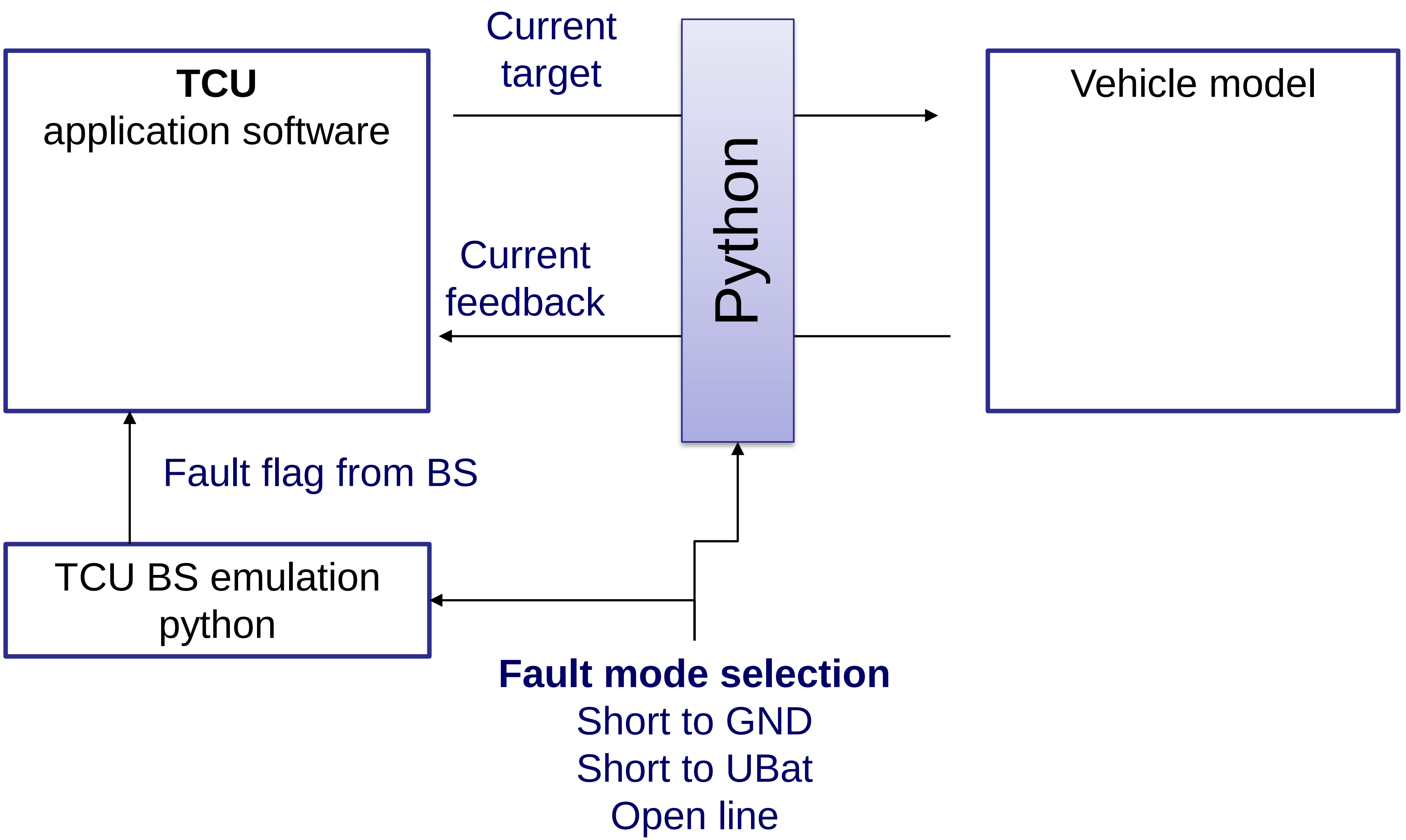
Fault insertion – how it works

Example on solenoid valve fault



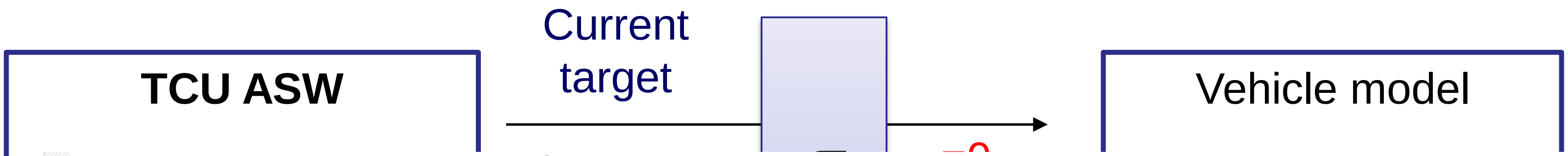
Fault insertion – how it works

Example on solenoid valve fault



Fault insertion – how it works

Example on solenoid valve fault



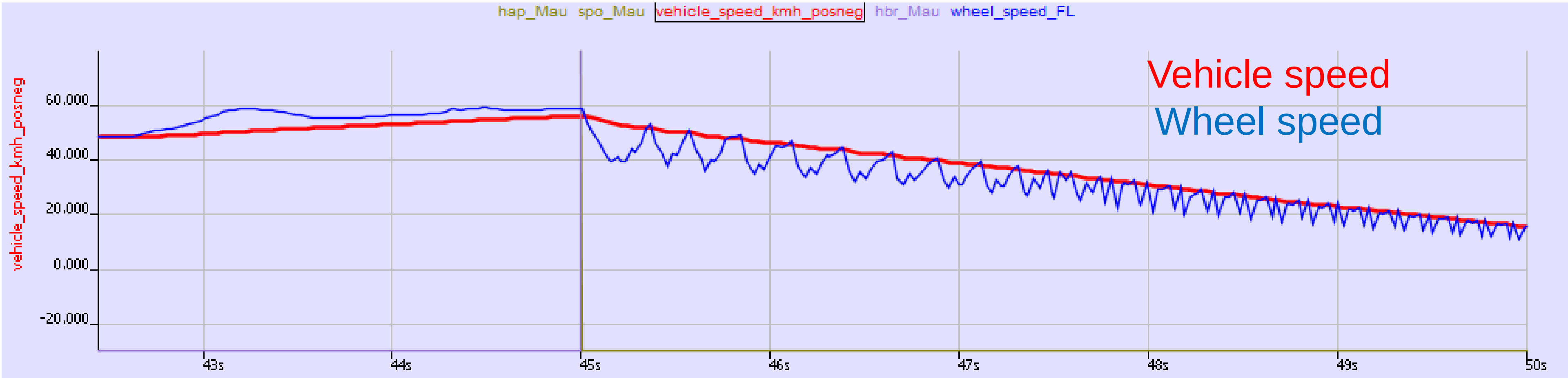

```
fault_sdi_tcsl_BOB = Chooser(
    # tw must be a WeaverConnection instance
    tw,
    # SiL/HiL Variable instance, or None if none
    Variable('fault_sdi_tcsl_BOB'),
    # instrument name shown by TestWeaver; if None use Variable name
    'fault_sdi_tcsl_BOB',
    # instrument unit shown by TestWeaver
    '',
    # instrument description shown by TestWeaver
    '',
    # partition definition
    # min and max, or value; name of partition; optional: severity/occurrence rate, comment
    [[-2,   'hyd0',  Occurrence.FaultLow, 'hyd0'],
     [-1,   'hyd1',  Occurrence.FaultLow, 'hyd1'],
     [0,    'no',    Occurrence.OK,       '0'   ],
     [2**1, 'SG',    Occurrence.FaultLow, 'bit1'],
     [2**2, 'SB',    Occurrence.FaultLow, 'bit2'],
     [2**3, 'OP',    Occurrence.FaultLow, 'bit3'],
     [2**6, 'UBATT', Occurrence.FaultLow, 'bit6']],
    # type of the instrument: Default, Real, Integer, String
    Type.Integer
)
```

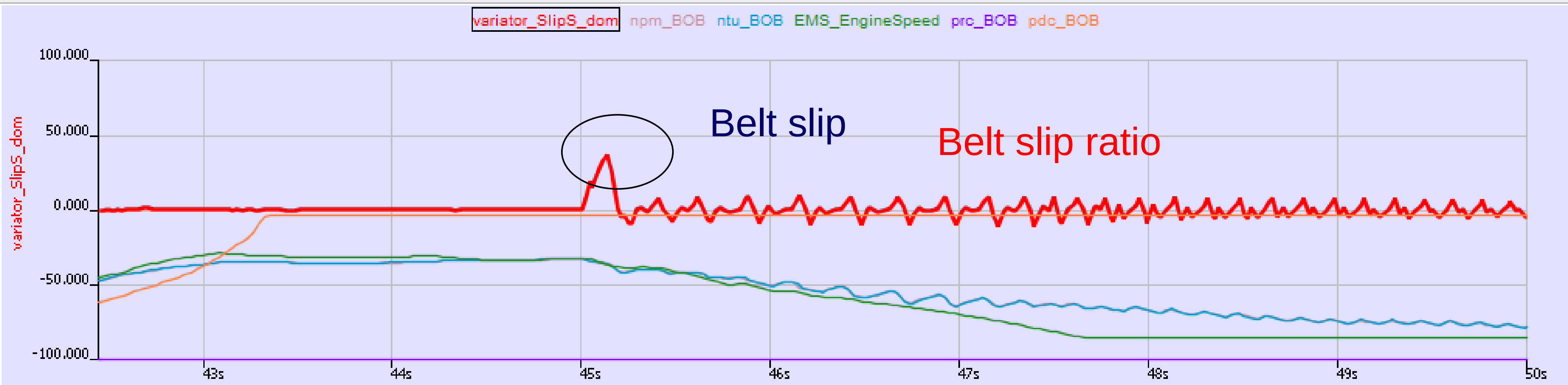
Use of QTronic TestWeaver

- Formal requirements monitoring
- Hand written test scripts
- Automatic test cases generation
- Automatic test report generation

ABS simulation example

Clutch locked + Strong braking → Wheel block → **strong engine deceleration** → Transmission torque exceeded → belt Slip !



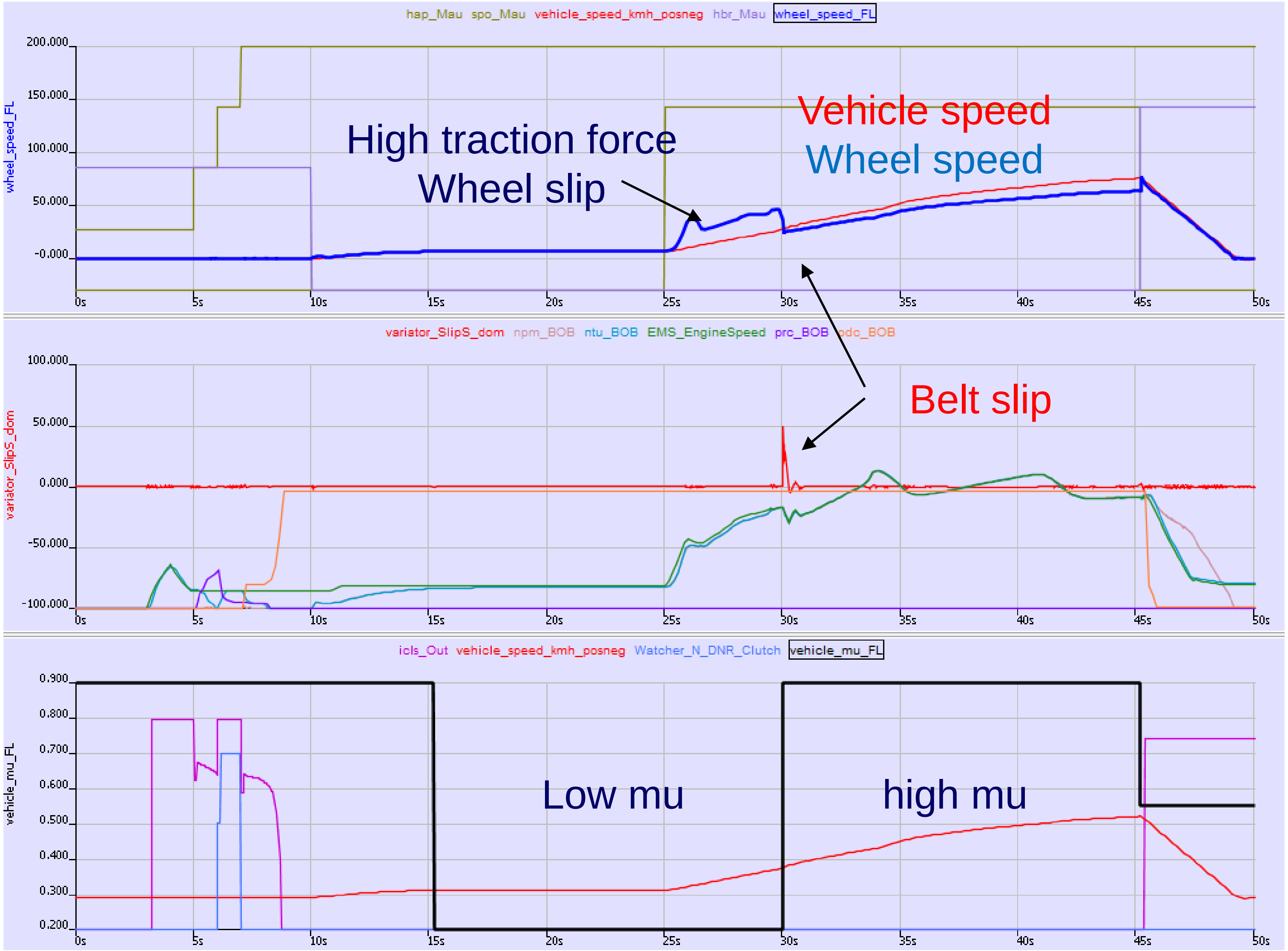


→ Belt slips are reported automatically in TestWeaver reports

Test case generation

QTronic TestWeaver automatically generates drive sequences

Example of Belt Slip found by TestWeaver



Code coverage with CTC++

MC/DC coverage

```
                362     fve_StandStill__F01_15_STANDSTILL_IMPL_p01_15_StandStill
                363        = jvr__F01_15_STANDSTILL_IMPL_p01_15_StandStill >= _jvru_StandStill_buff
                364        && jvrs__F01_15_STANDSTILL_IMPL_p01_15_StandStill >= _jvru_StandStill_buff
                365        && vve__F01_15_STANDSTILL_IMPL_p01_15_StandStill < _vveu_StandStill_C
                366        && hap__F01_15_STANDSTILL_IMPL_p01_15_StandStill < _hapu_StandStill_C
123000 137137   367        && npm__F01_15_STANDSTILL_IMPL_p01_15_StandStill < _npmu_StandStill_C && _fbp_StandStil
123000          367      1: T && T && T && T && T && T
             0  367      2: T && T && T && T && T && F
             0  367      3: T && T && T && T && F && _
          3772  367      4: T && T && T && F && _ && _
         59469  367      5: T && T && F && _ && _ && _
           115  367      6: T && F && _ && _ && _ && _
         73781  367      7: F && _ && _ && _ && _ && _
```

Conclusion

Realistic simulation – complex scenarios

Vehicle model + TCU + calibration :

validated simulation , reproduce very well the actual execution of TCU in the real vehicle

Fault insertion and validation of TCU fault management

Automatic **generation** and **evaluation** of test cases

TestWeaver + requirements modeling

Very efficient support for TCU development and testing !

谢谢！

Thank you ！

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