JÜLICH
FORSCHUNGSZENTRUM

PLCs for neutron instrument control

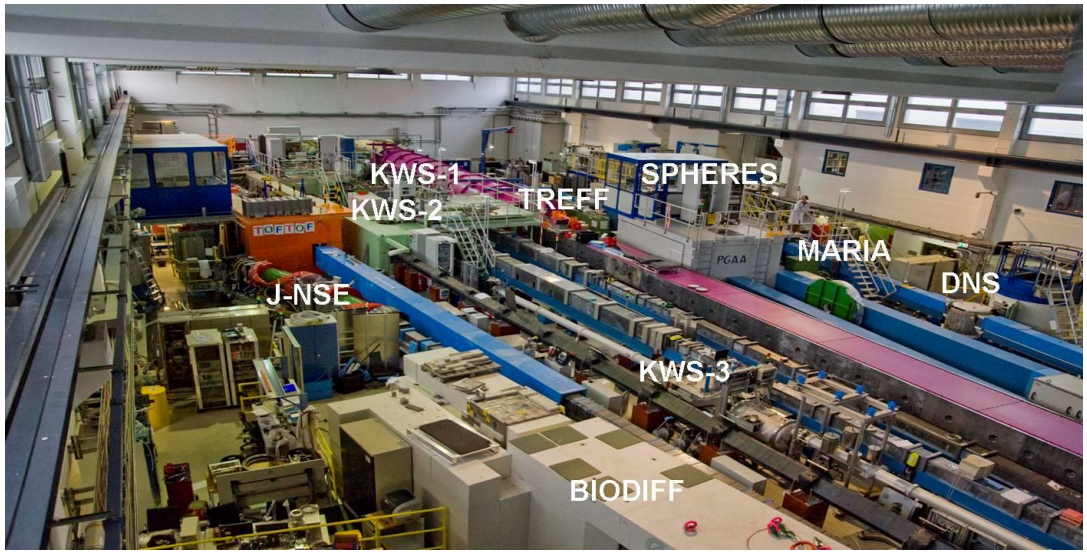
May 15th, 2018 | Harald Kleines

Jülich Centre for Neutron Science

- Forschungszentrum Jülich
  - Multi-disciplinary research institute, about 5800 employees
  - Research reactor FRJ-2 was switched off in 2006

⇒Foundation of the JCNS in 2006

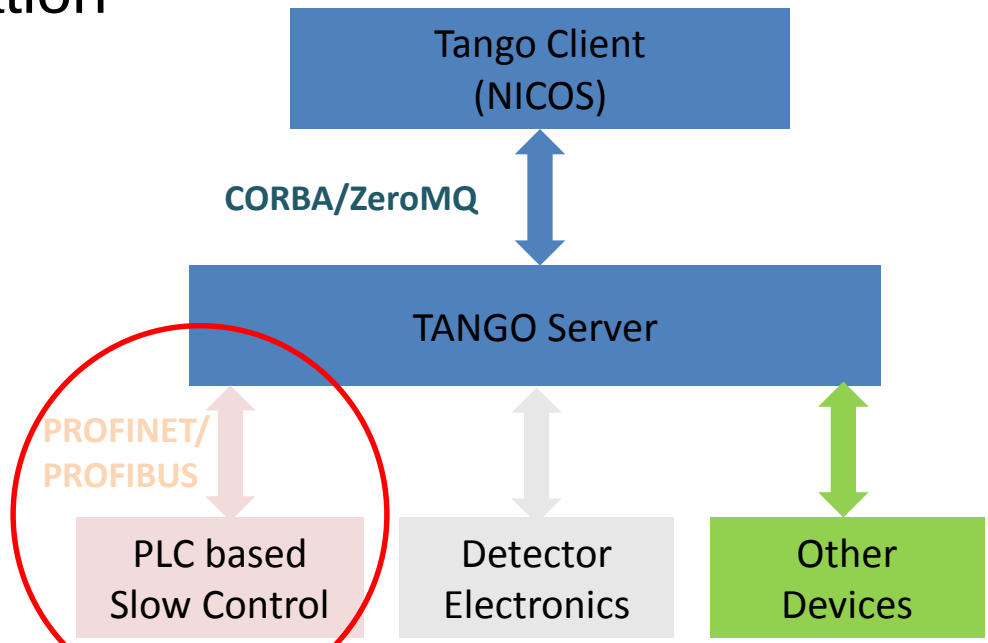
  - Central Divisions: JCNS-1, JCNS-2, (JCNS-3) in Jülich
  - Outstation at MLZ in Garching: 11 instruments at FRM-2
  - Outstation at ILL in Grenoble: 3 instruments in cooperation with CEA
  - Outstation at SNS in Oak Ridge: 1 instrument
  - Future activities: ESS (3+ Instruments) + High Brilliance Source



Control System Architecture of the JCNS Instruments

- Jülich-Munich Standard: Common framework for neutron instrument control defined by JCNS and TUM
- Ca. 1995 first implementation at instruments in Jülich
- Historical evolution from TACO to TANGO
- Slow Control at JCNS:
  - Extremely standardized
    - Architecture
    - Products
    - Communication Mechanisms

  ⇒ Reduction of efforts for development and maintenance, spare parts,…..



Architecture of the Control- and DAQ-Systems according to the Jülich-Münch Standard

Slow Control at JCNS Neutron Instruments

- Dominating task is **Motion Control**
  - Equipment: motor controllers, frequency converters, encoder interfaces,…….
  - Motors at JCNS:
    - Predominantly 2-phase stepper motors, only few 3-phase from Berger-Lahr (now Schneider Electric)
    - (Almost) no DC motors
    - No BLDCs
    - A few asynchronous AC motors (3-phase, 400 V)
    - Increasing number of synchronous AC servo motors
    - Only a few piezo motors: mechanics + electronics from vendor
- Additional Slow Control Tasks:
  - **Personal safety system**: IEC61508 SIL3 and ISO 13849 PLe
  - **Vaccum and cryogenic systems**: vacuum gauges, pump controllers, digitial + analog IOs,….
  - **Sample environment**: PID controllers, digital + analog IOs,…

Historical evolution of Motion Control at JCNS

- Originally: in-house developments of stepper motor drivers and controllers, encoder interfaces or frequency converters
  - Approach at LLB and ILL
- Later: modular 19“ board systems and other commercial products
  - Approach at ISIS, NIST,…
- Paradigm change (ca. 1995): Introduce industrial automation technology from manufacturing
  - Approach at PSI, HZG, ESS

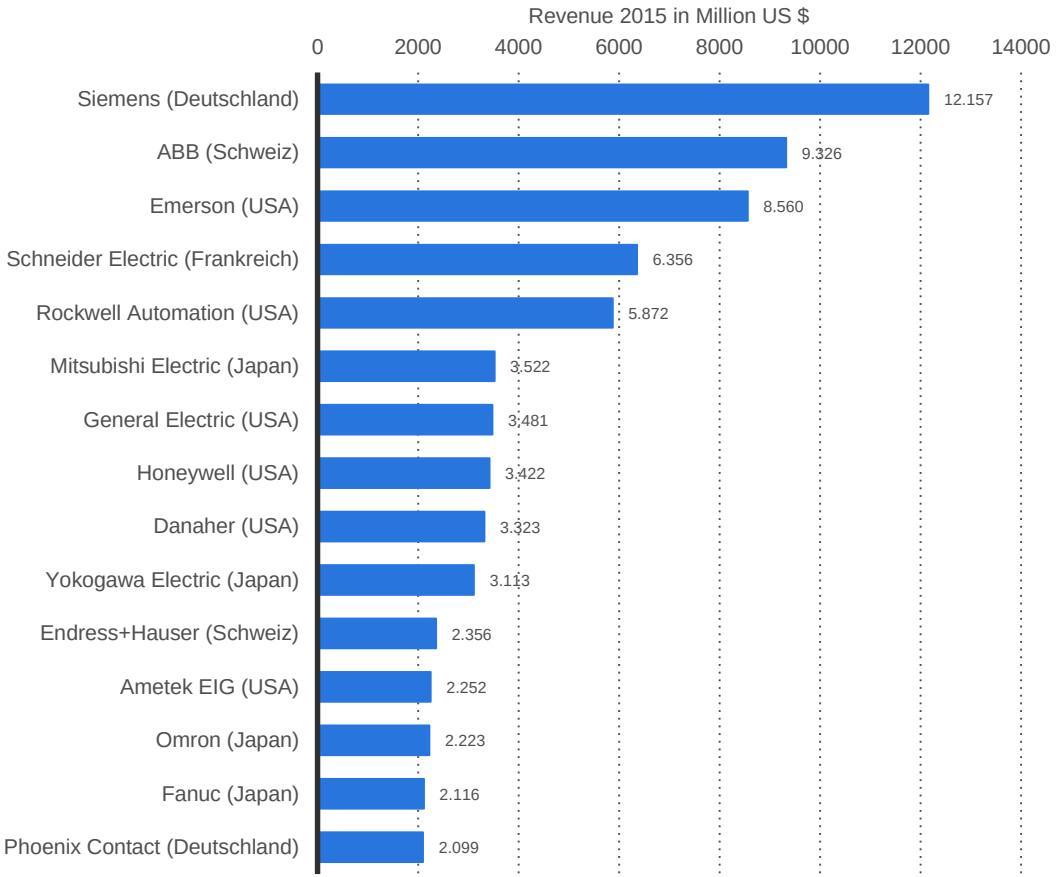
Industrial Automation technology

- Components/Systems:
  - Programmable Logic Controllers (PLCs)
  - Fieldbus systems
  - Decentral IO systems

⇒ **Common systems for motion, safety, vacuum,…..**

- Motivation:
  - Long term availability
  - Price
  - Robustness/Stability
  - Wide product range

Vendors in Automation



Beckhoff: ca. 600 Mio. $

- Extreme market segmentation
- Situation in Germany
  - Siemens absolute dominant (>60% market share)
  - Numerous medium sized vendors, especially for decentralized IO systems: Wago, Möller, Phoenix Contact, Weidmüller, Helmholz, Beckhoff, B&R,…..
- All required products offered by Siemens (quality, price,…)
- Already a de-facto standard in Jülich

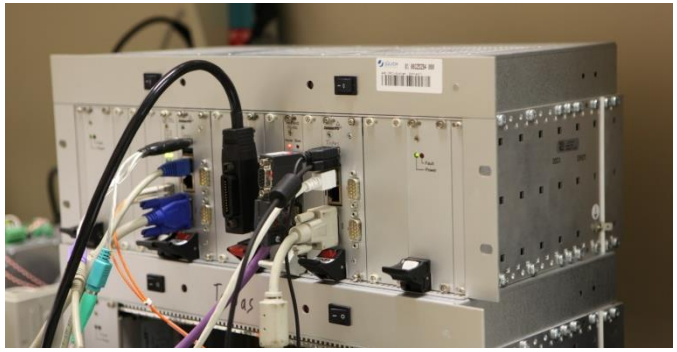
⇒ Decision for Siemens

  - Decision against high end systems Sinumerik und Simotion

  ⇒ S7-300 + ET200S

Communication Architecture

Server Computers (only CPCI)



PLC gives homogeneous view on axes, independent of controller type, encoder,..

PROFIBUS DP, PROFINET IO

PLCs + Op. Panels

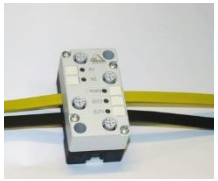
PROFIBUS DP, PROFINET, AS-Interface

Decentral Periphery

ET200S

ET200M

ET200pro



ASi

Decentral IO Systems in Protection class ≥ IP65

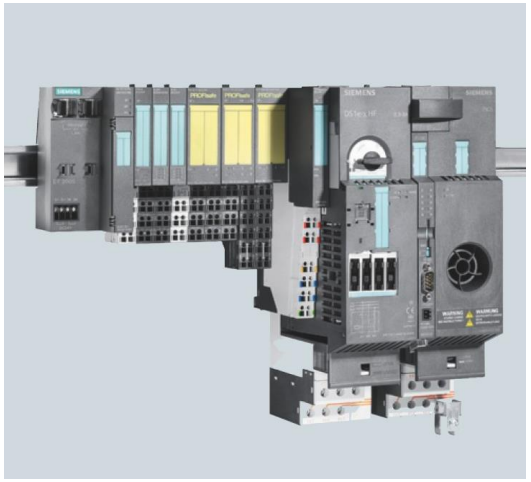
- Without cabinet in the field
- ASi-Module (IFM: Digital I/Os, pneumatic valves)

- Siemens ET200pro
  - PROFIBUS und PROFINET
  - Supports FESTO valve manifolds
  - Failsafe IO supported

- Festo CPX
  - PROFIBUS und PROFINET
  - Integrated valve manifolds

Decentral IO Systems for cabinets

- Siemens ET200S
  - IF modules for PROFIBUS + PROFINET
  - Digital + analog IOs
  - Motor controllers, encoder modules,…
  - Motor starters up to 5 kW



- Siemens ET200M
  - IF modules for PROFIBUS and PROFINET
  - S7-300 peripheral modules

- Integration of other vendors
  - Straight forward on base of GSD files

Stepper motor controllers

- **Almost exclusively used**

1STEP
-ET200S
-204 kHz
-Step/direction

Phytron 1STEP-Drive
-ET200S
-510 kHkz / 512 microsteps
-Integ. driver: 5A (peak) / 48V

- **Only a few axes (are being replaced)**

FM357
-S7-300
-4 axes trajectory control (NC)
-625 kHz oder Servo
- incremental + SSI encoders

Outdated!!

- **In Future**

Phytron
TM Step Drive
-ET200S P
-510 kHkz/
256 microsteps
-5A (peak) / 48V

TM PTO 4
- ET200MP
- 4 channel
- 1 MHz

External Stepper Motor Drivers

- Phytron 2-phase drivers

CCD+
-9A/70V
-1/20 Microstep
-Manual control
-Display

MR8+
-5A/48V
-1/20(512)Microstep

Outdated!!

MSD /MSD2 +
-17A (peak)
-140/120 V
-1/20 Microstep

MCD+
-9A/70V
-1/20(512) Microstep

Controllers for AC Motors

DS1-X

- ET200S
- Direct starter (also as soft starter) for 3 phase 400V
- Up to 5,5 KW

Sinamics S120

- Family of intelligent servo controllers
- Decentral (PROFINET + PROFIBUS)
- Distributed operation without PLC possible
- Dedicated engineering tool Startdrive integrated into TIA portal

- Many other optimized servo controller families available
- Easy integration of third party products via PROFIdrive standard

Encoder Readout

- Angle + linear-encoders from Heidenhain, Balluff, Renishaw, AMO,…
- Absolute, incremental (optical, inductive,….),
- Interfaces: SSI , EnDat (PB-Gateway), PROFIBUS, PROFINET, DRIVE-CliQ (only used for AC servo motors)
- ET200S modules 1SSI und 1Count (RS485 quadrature signals)
- Also a few resolvers (PROFIBUS Interface from AMCI) and potentiometers

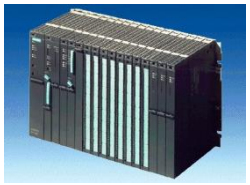
1SSI

1COUNT

Controllers (CPUs)

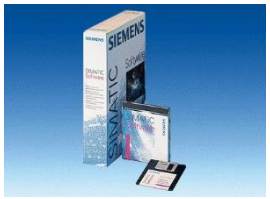
- Only Siemens products (very wide product range, common programming model)

High End: S7-400



ET200pro CPU

SoftSPS: WinAC

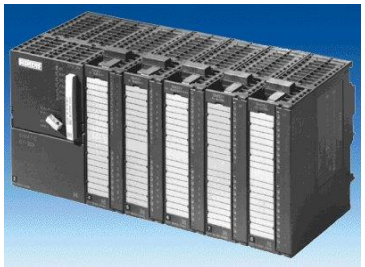


S7-mEC (Windows PC)

Simatic MP

- JCNS: exclusively S7-300 (CPU 315-2 PN/DP) and ET200S CPU (IM 151-7 CPU)
  - Single processor
  - Modular and scalable
  - Powerful Communication ⇒ decentral architecture

Mid Range: S7-300



Micro: ET200S CPU

Programming of Controllers

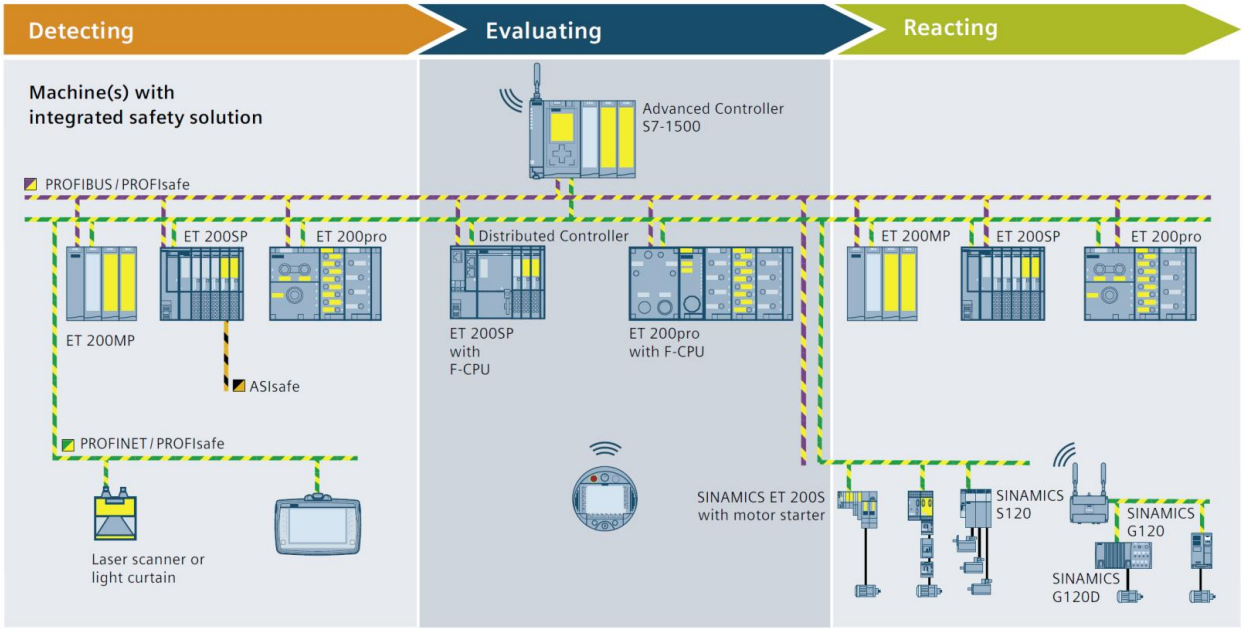
- Goal: all automation tasks shall be solved in the front-end and **not** in control system servers or application software
  - Separation between technology know how and “standard” SW development
  - Hardware specialties (like different motor controllers) are hidden
  - High complexity because of real time requirements and simultaneous handling of several devices and communication interfaces
- Development environment: Step7 / TIA Portal
  - Hardware configuration
  - Monitoring, debugging, SW loading
  - Programming:
    - KOP (ladder diagram) is not used at all
    - FUP (function plan) only used for safety applications
    - STL (statement list)
    - ST (structured text)
    - S7-Graph: graphical programming of sequencers (Petri-Nets)
  - Touchpanel: WinCC
    - Direct operation/visualisation of the PLC independent of control system computers
    - Internal PLC diagnostics

Recent Activities

- New PLC-Familiy S7-1500
  - Successor of S7-300
  - Decentral Periphery: ET200MP
    - Max. 30 Modules (12 with PROFIBUS)
  - SW-compatible low end family: S7-1200
    - Compact PLCs for around 200€

- Improved development environment: TIA-Portal
  - Programming changes required
  - JCNS SW framework was adapted successfully
- Integrated motion functionality based on PLCopen
  - Standardized function block interface
  - Independent of specific motor/controller type
- New decentral periphery System ET200SP
  - Hot swap of modules
  - Up to 64 modules (32 with PROFIBUS)

Safety: Siemens Safety Integrated

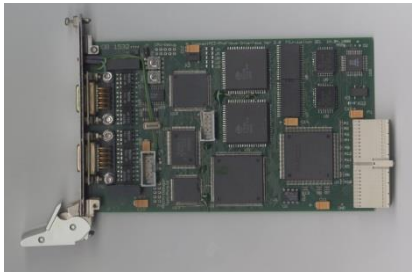


- Special failsafe CPUs (F-CPUs; S7-400 provides even high availability)
- Standard PROFIBUS/PROFINET hardware extended by application layer protocol to implement PROFIsafe
- Special failsafe peripheral modules can be mixed with standard peripheral modules
- Failsafe Program can coexist with standard program on the same CPU
- Engineering: Add-on to Step7/TIA Portal
- Up to IEC61508 SIL3 and ISO 13849 PLe

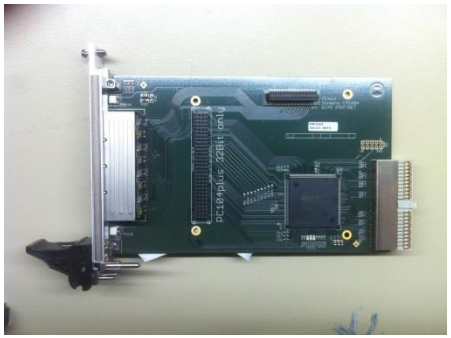
Communication with the control system

- Originally in house development of an PROFIBUS controller as CPCI module
  - with Linux device driver and configuration SW
- Now PROFINET: Development of PC104+ carrier
  - Mezzanine: Siemens CP1604
  - Configuration automatically by PLC configuration
  - Functionally similar to PROFIBUS

⇒ simply a new library under Linux and different function calls on the PLC side



PROFIBUS controller



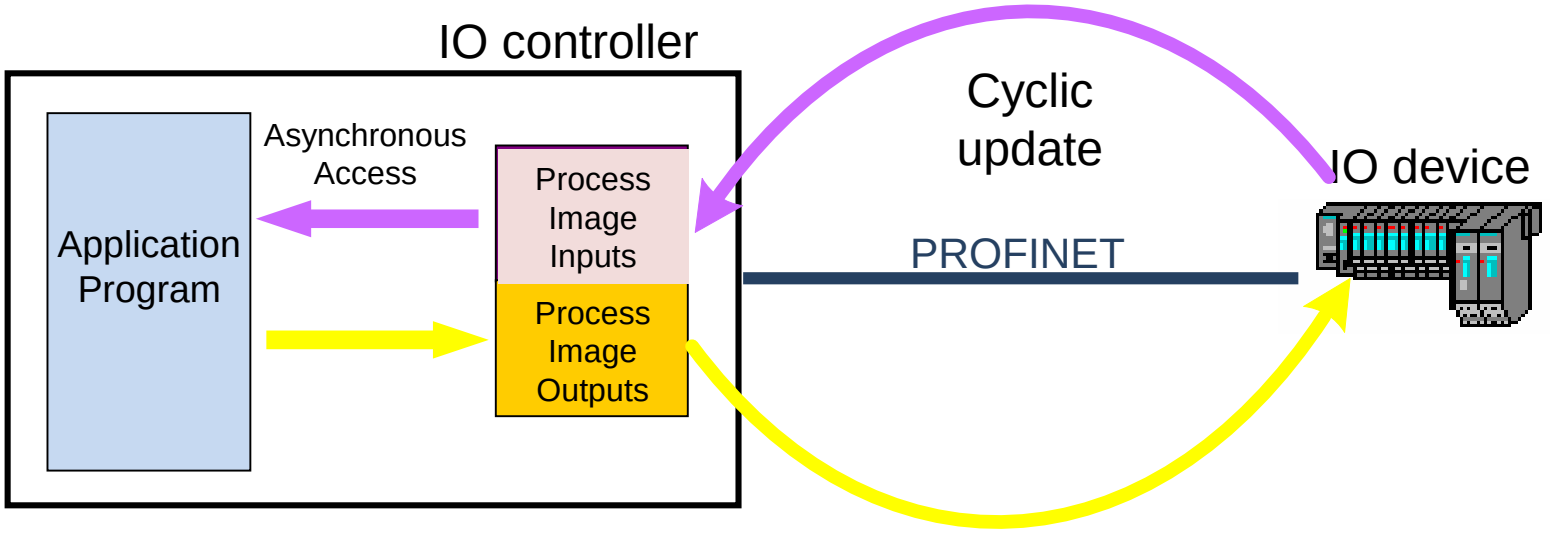
PC104+ Carrier

PROFINET Controller CP1604

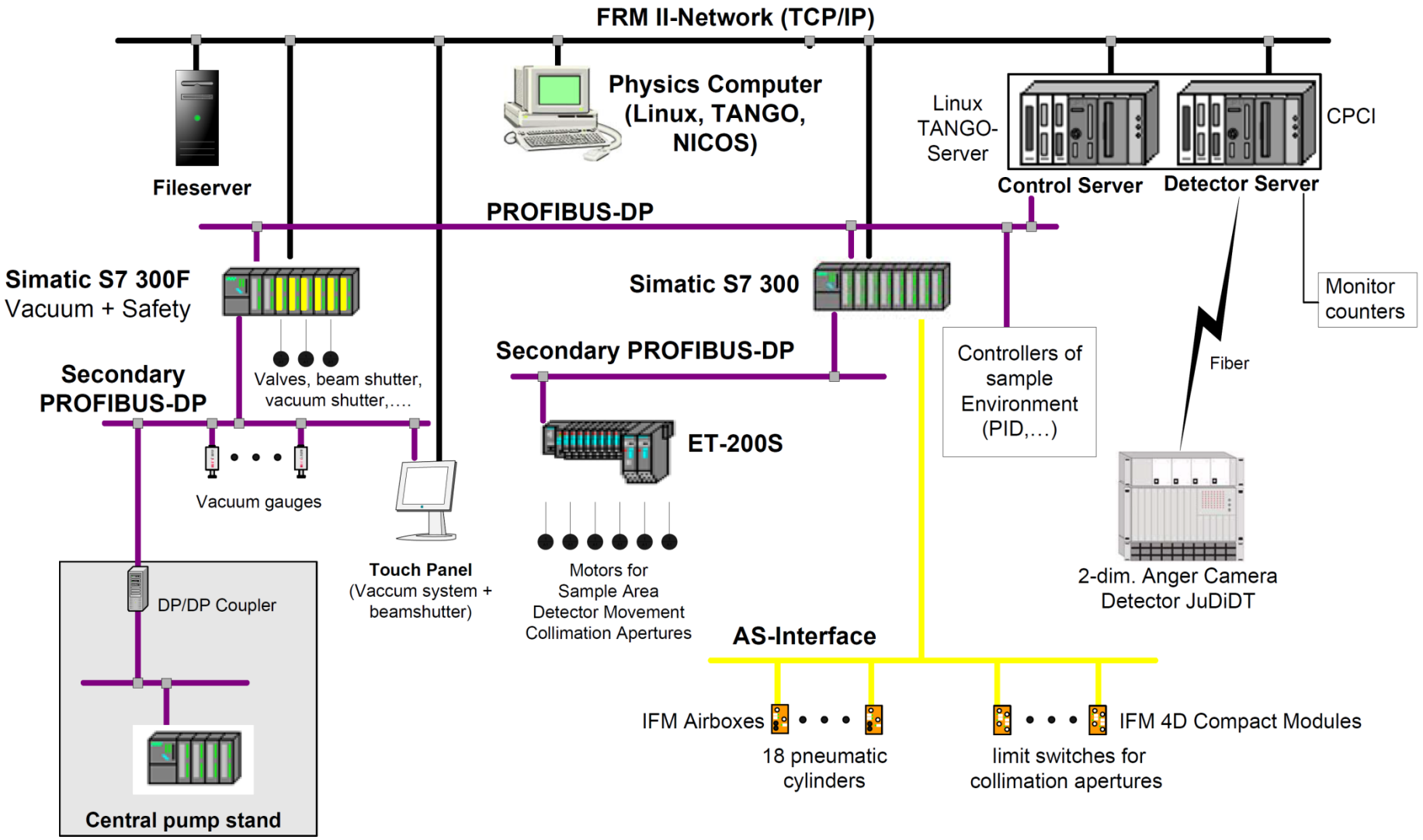
Application Protocol

- Abstract controller/axis modell (e.g for synchronized movement)
- Transactions for the execution of most commands
- Producer/Consumer model of PROFIBUS/PROFINET

⇒Fast communication by directly mapped areas (e.g. for positions)

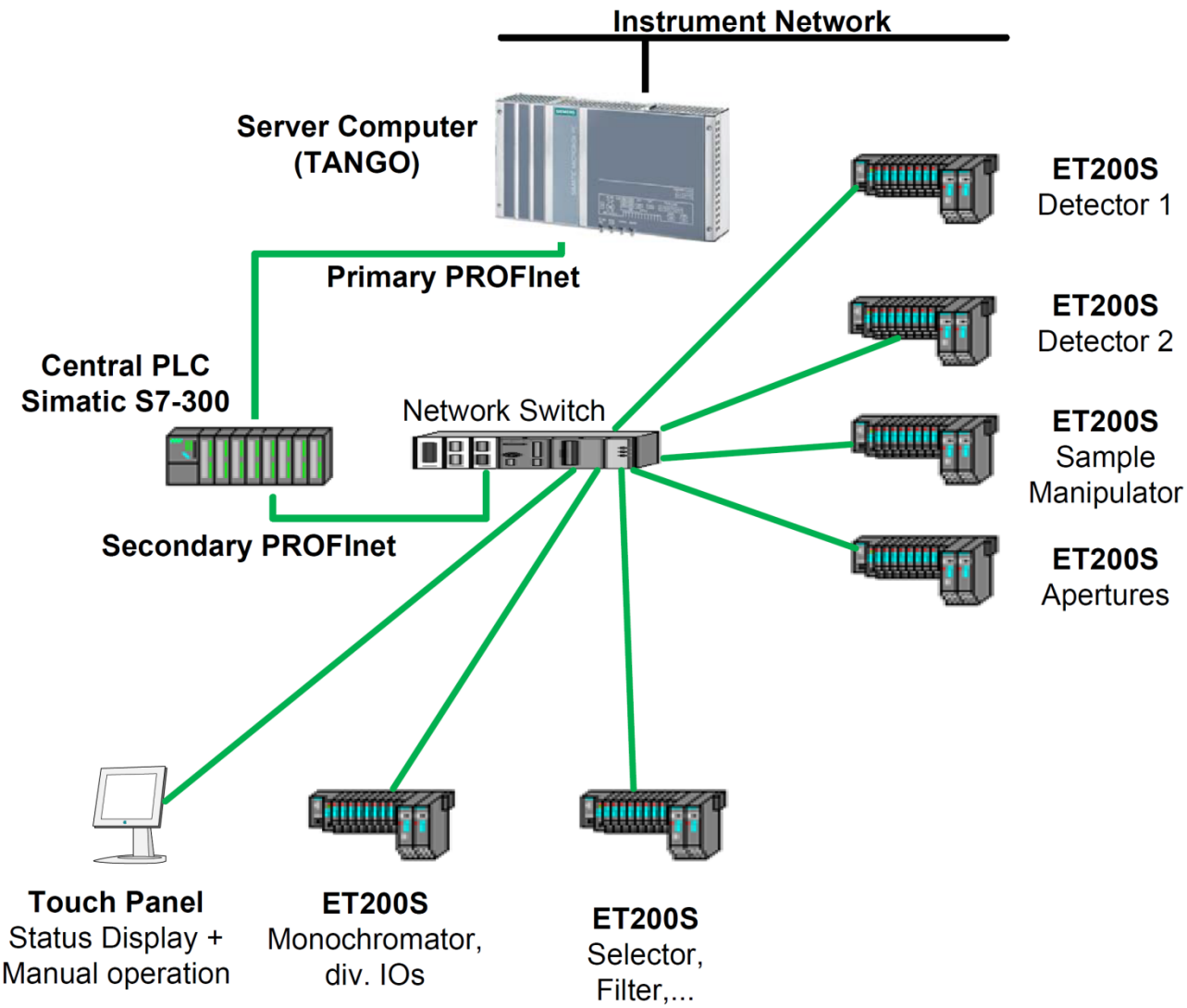


Example 1: Small Angle Instrument KWS1

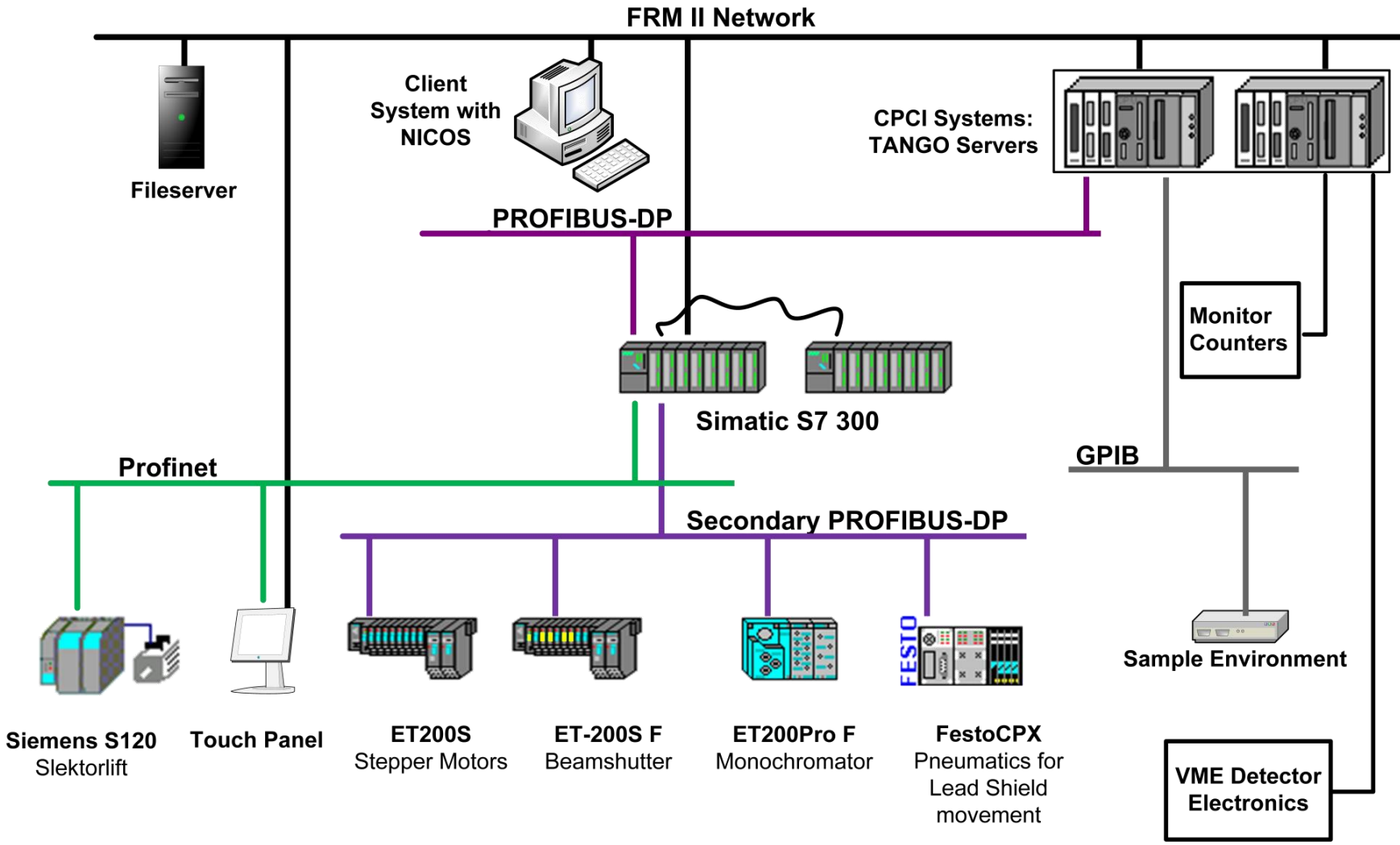


KWS1 Implementation

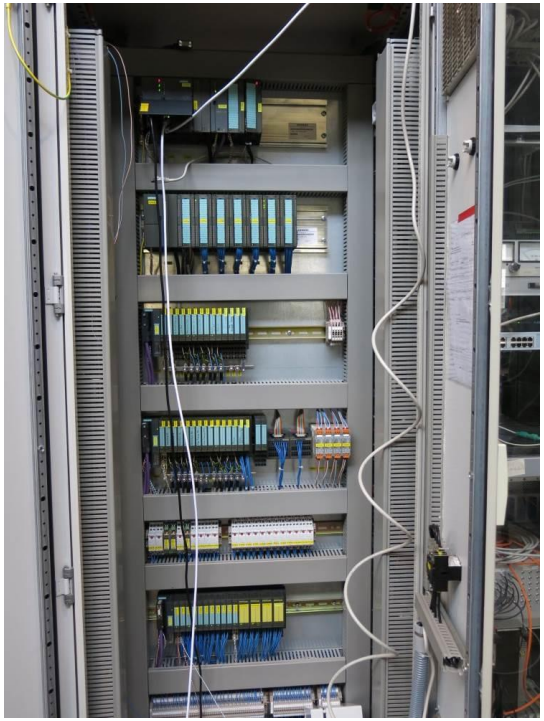
Example 2: Motion Subsystem of ANTARES



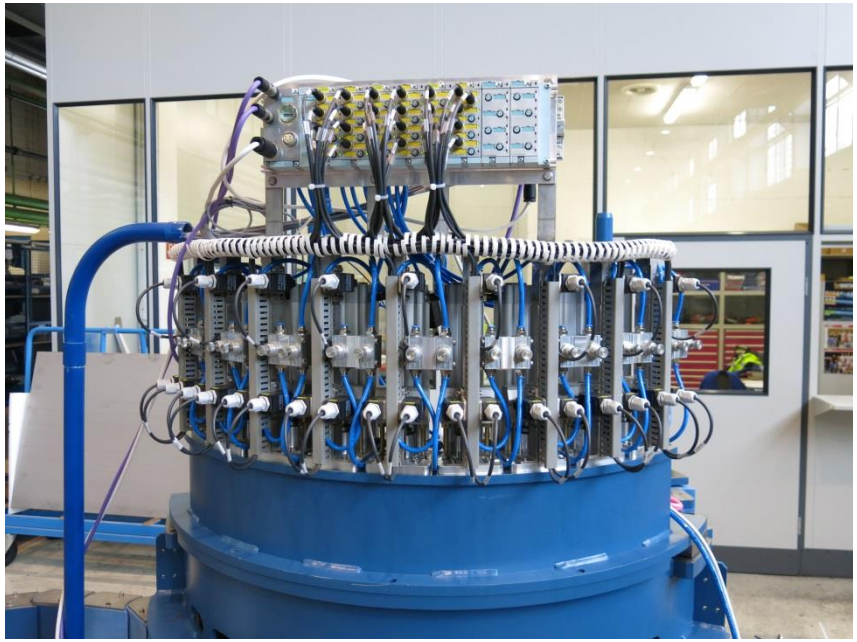
Example 3: TOF instrument DNS



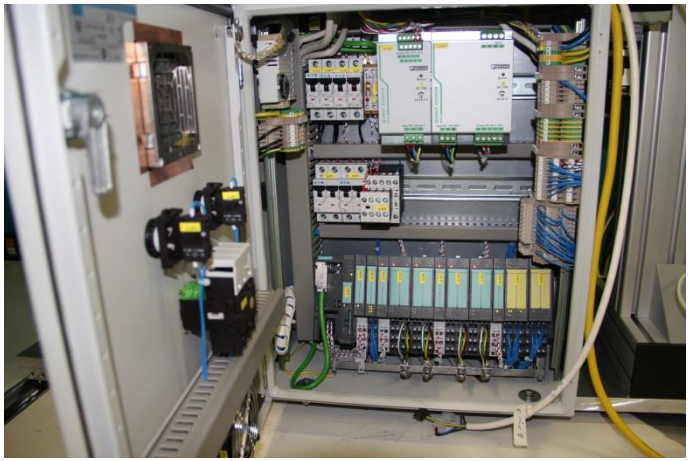
DNS Implementation I

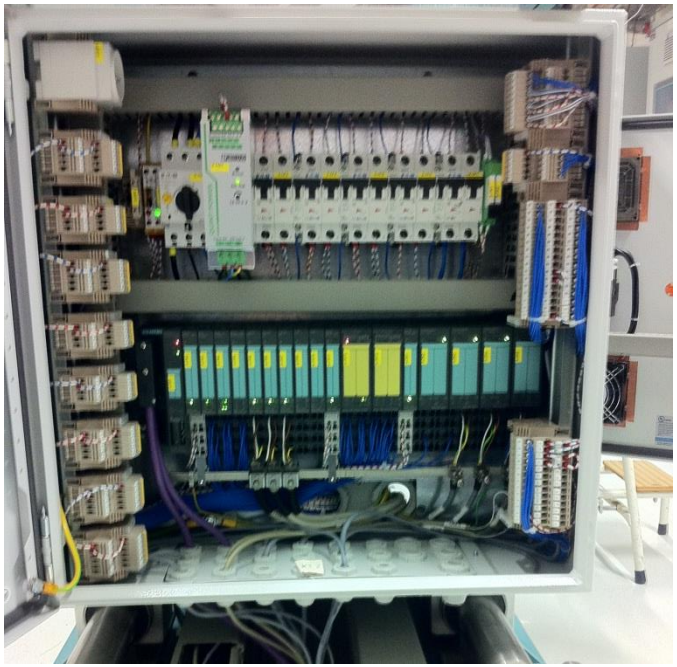


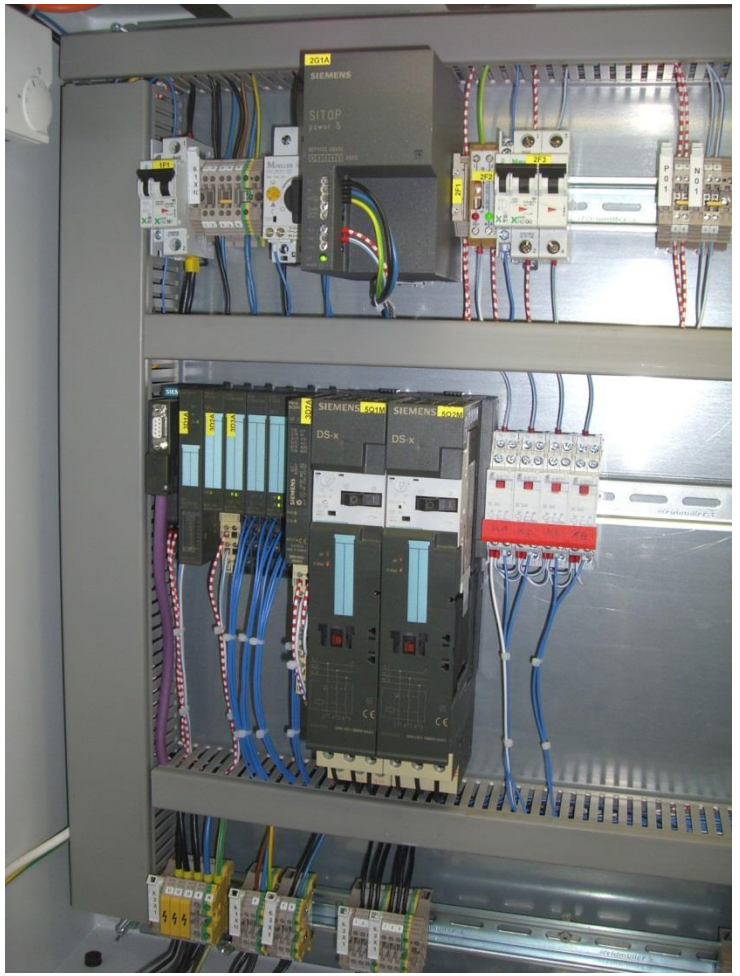
DNS Imlementation II



Examples of decentral cabinets







S7-1500 at the Spin Echo Instrument

Conclusions

- Successful concept for more than 20 years
  - Standardized software and hardware
  - Minor changes with S71500 and ET200SP
  - Arbitray mixing of PROFIBUS, PROFINET, S7-300, S7-1500, ET200S/SP/M/MP possible
- Decision for the de-facto industry standard:
  - Easy interfacing devices from other vendors
- ESS: S7-1500 for safety, vacuum, etc. but Beckhoff Ethercat modules for motion
  - Effort in working with new vendor required
  - First experiences show disadvantages regarding functionality, electro mechanical design, documentation, help system, diagnostics,…..