Status of Hardware for quench detection and circuit monitoring for HL-LHC

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Acknowledgements:
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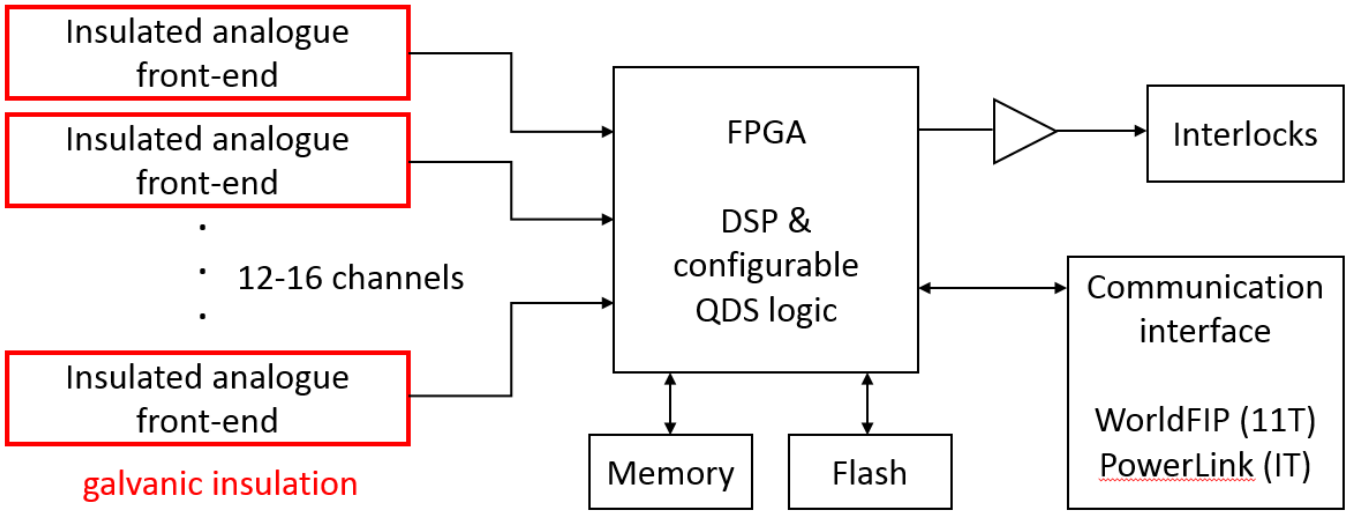
Topics

- uQDS concept
- uQDS components & specification
- Status of Digital Platform
- Status of frontend channel
- Application of uQDS to 11T magnet
- Results from 11T SM18 measurements

uQDS concept

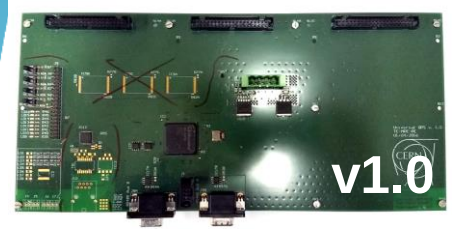


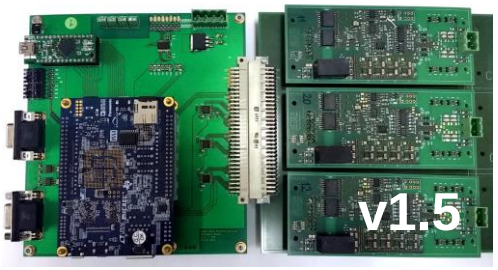
- Generic solution for various QDS tasks
- Multiple insulated front-end channels connected to one logic device performing the QDS task
- QDS function defined by FPGA configuration
- Front-ends flexible enough to cope with all required input signals ranges & resolutions

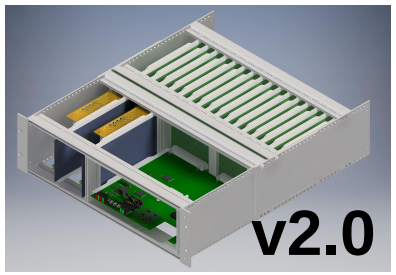
uQDS components

- **Digital platform** houses FPGA, interlocks and communication interface. Performs quench detection algorithms
- **Mid-plane** connects Front-end with Digital platform and power supplies
- **Frontend** amplifies signal, digitizes and provides galvanic insulation

Status of the digital platform







- First board with Microsemi IGLOO2 (M2GL060)
- Hosts up to 3 frontends
- Communication via RS485 (2.5Mbit)

➔ Proof of concept

- Intel Cyclone V dev. board on carrier
- Supports channel carrier with 6 frontends
- Communication via USB 2.0 and RS485

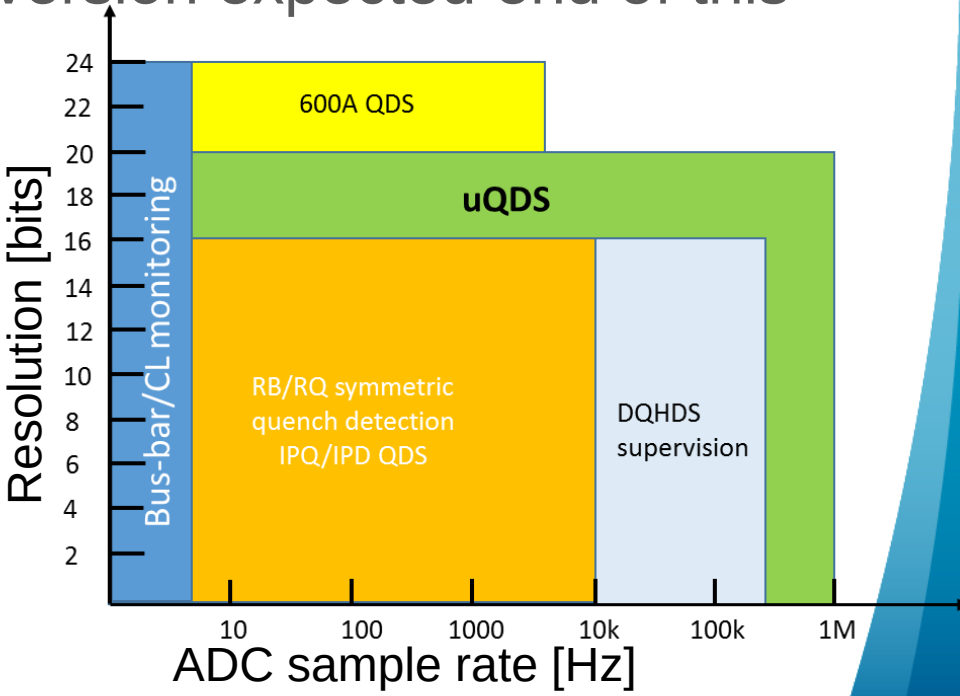
➔ Intermediate solution for SM18 and LHC tests

- Based on IGLOO2 (M2GL150)
- Supports up to 16 front-ends via mid-plane
- Communication via RS485, USB 2.0, USB 3.0 or WorldFIP

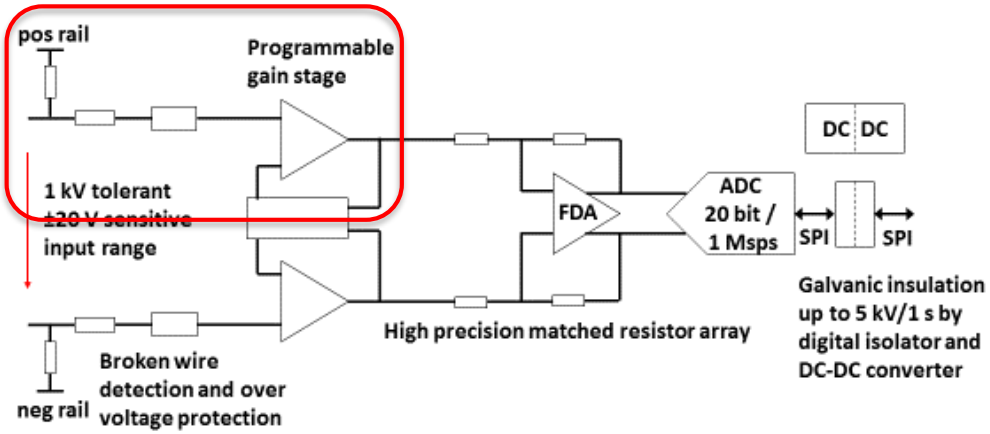
➔ First prototype for 11T QDS

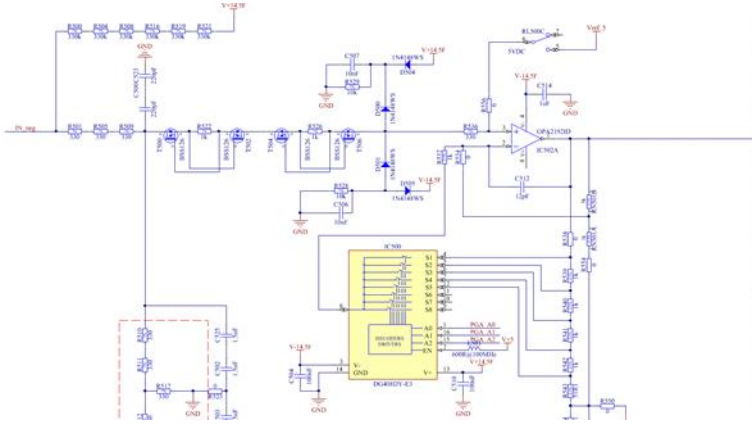
Front-end channel status

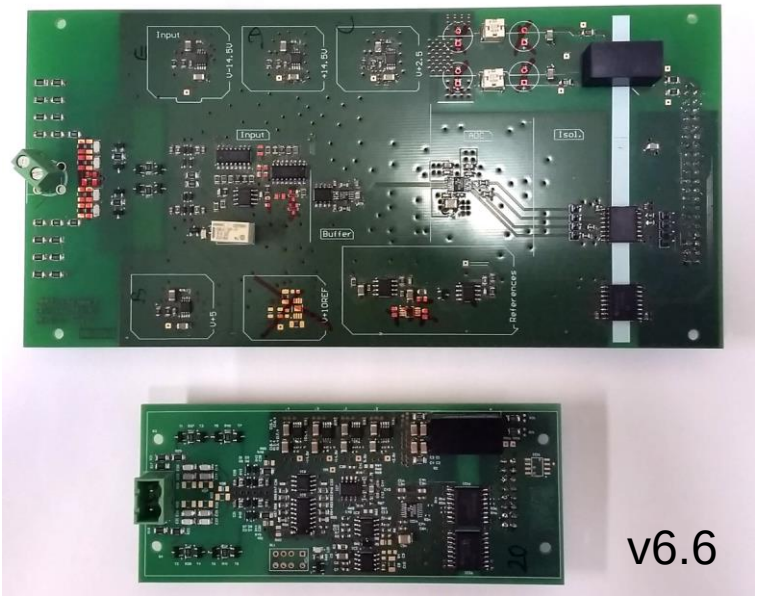
- Design/Prototyping process started already end of 2015
- Challenging design (20bit/1Msps), final verification by prototype testing only (Calculations/SPICE do not show noise…)
- Several prototypes built and evaluated in LHC and SM18
- First uQDSv2.0 compatible version expected end of this year
- Serves as universal QDS data acquisition channel
- Covers all existing quench detector requirements



Front-end channel specifications/design



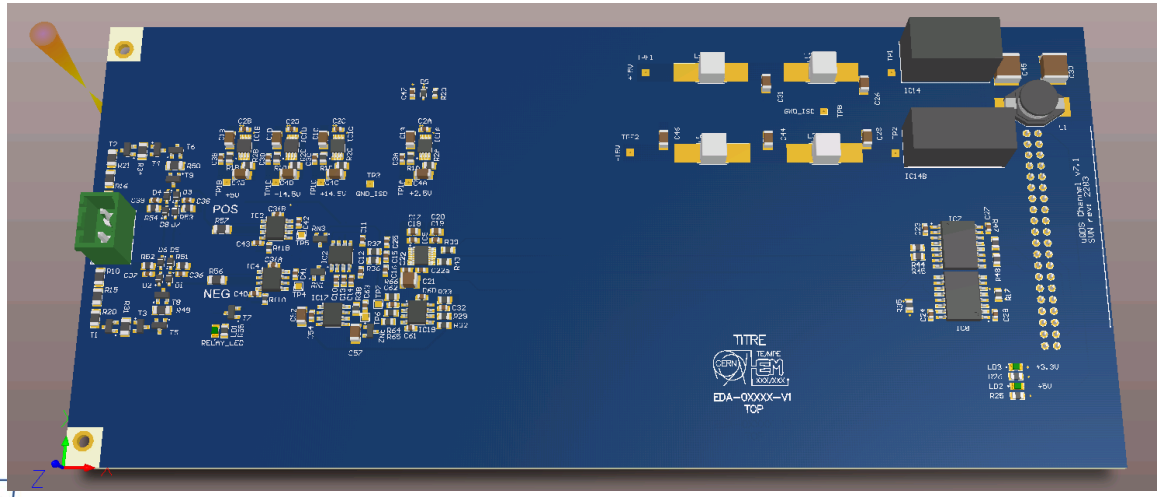




Parameter	Value
Resolution (20-bit ADC)	105nV/LSB .. 48uV/LSB
ADC speed	Up to 1Msp/s
Analogue bandwidth/ gain	150kHz @ G=1 140kHz @ G=9 84kHz @ G=45 12kHz @ G=450
Active input voltage range	+/-50mV .. 22.5V
Max differential input voltage	1kV/1s
Galvanic insulation	2.5kV/20min

Front-end channel outlook

- Generation 7 based on v5.6 circuit currently in prototype assembly
- Form factor increased again to euro card size (220 mm x 100 mm) to fit in uQDS v2.0 box and leave enough space for future options
- Optimization of DC-DC converter filtering
- Intensive high voltage stress testing upcoming

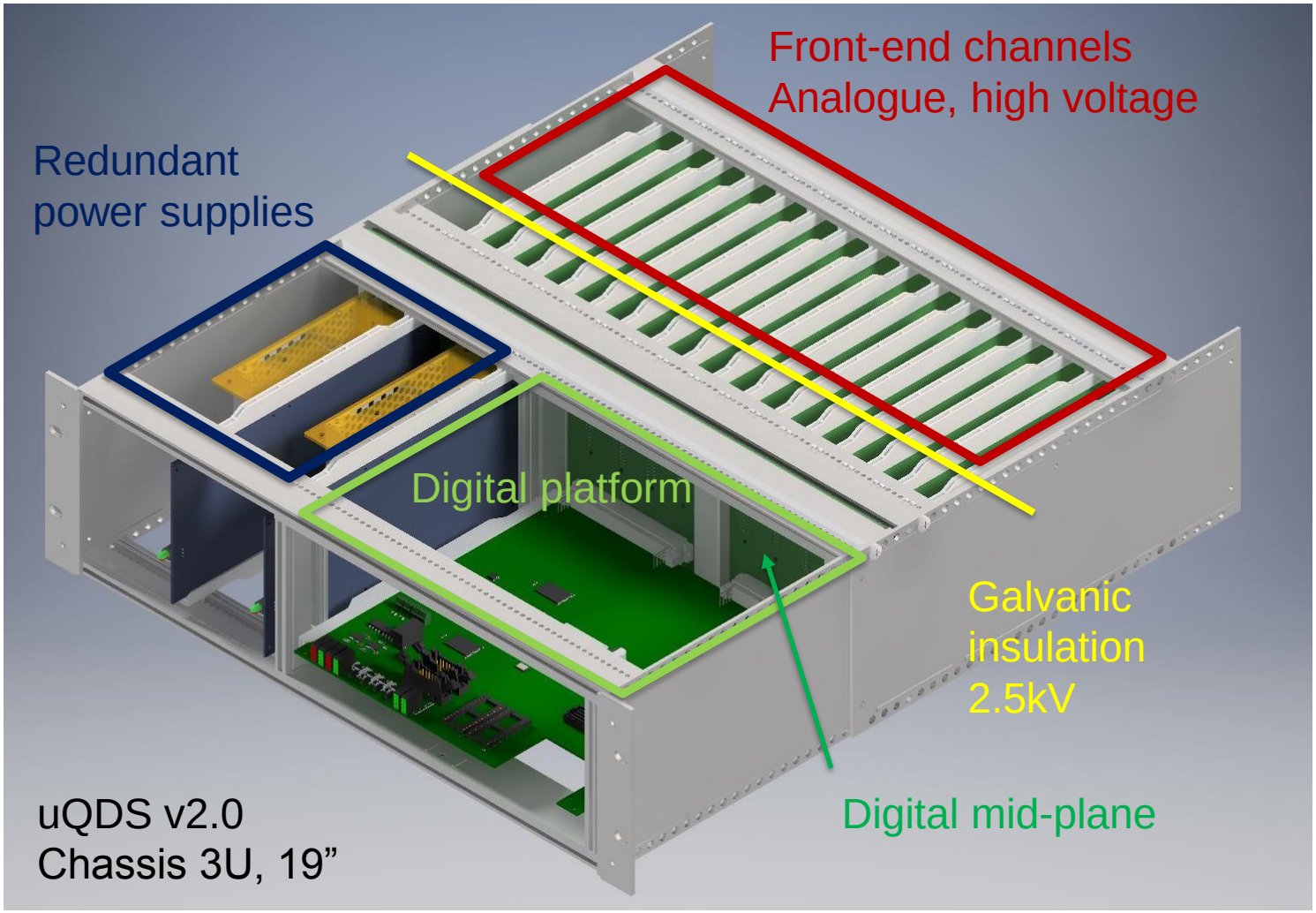


Specifications of uQDS box 2.0

- Up to 16 front-end channel interfaces
- Microsemi IGLOO2 FLASH FPGA for processing
- Four Interlocks, PhotoMOS based T_{open} <1ms
- Supports WorldFIP or future field bus via FMC extension slot
- Supports USB2.0 + USB3.0 for fast data read-out in test facilities
- Redundant power supplies
- Radiation tolerant up to RR73/RR77 environment (~1Gy/a, 50..100Gy TID)

➔ Preliminary specifications, final hardware will evolve to v2.x with optimized specifications

uQDS version 2.0, system overview



Application of uQDS to the 11T magnet

Application of uQDS to the 11T magnet

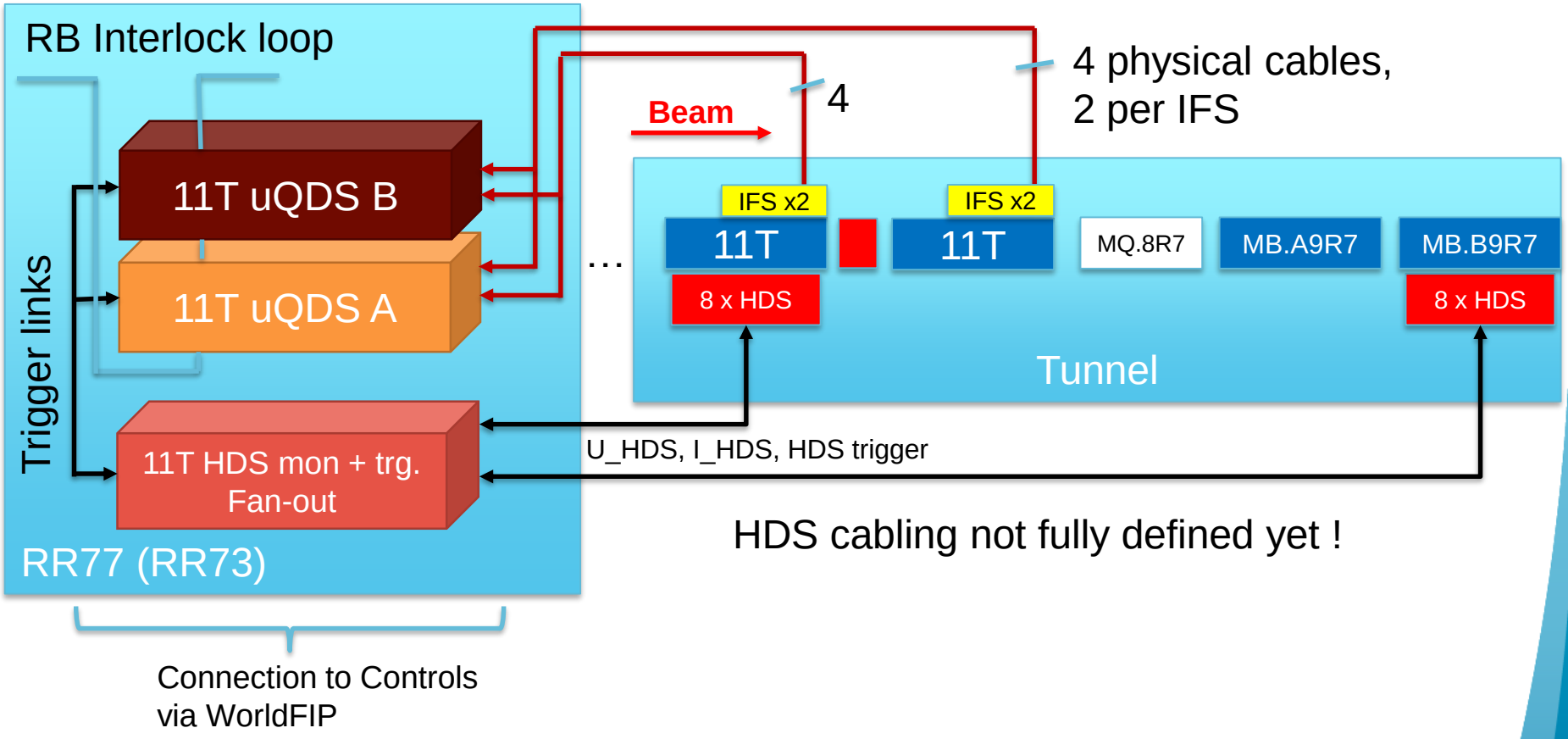
Requirements:

- Detect asymmetric and symmetric quenches
- Detect quenches of the interconnection bus-bar
- Cover all bus-bars in the magnet assembly
- Monitoring of the quench heaters
- Allow circuit current dependent settings

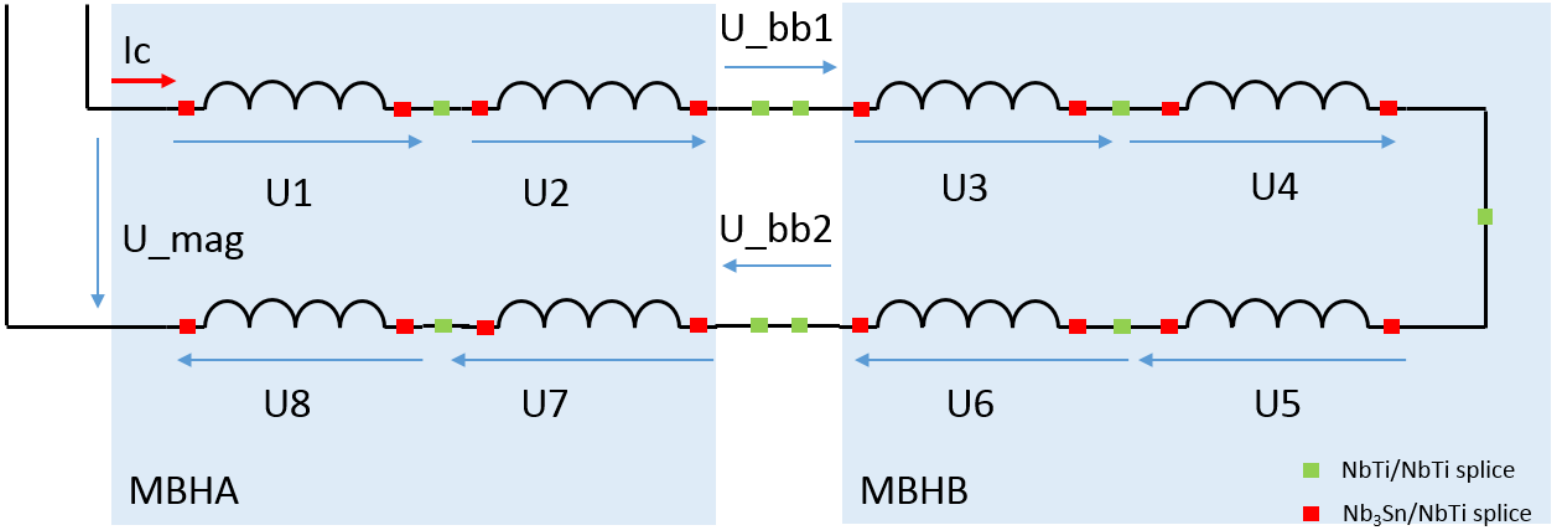
Integration boundaries:

- Quench detection crates will be located in the “RR” area ~75m away from the magnet
- Quench heaters will be located as close as possible to the magnet while monitoring resides in “RR” area

uQDS for 11T magnet: integration



11T instrumentation/channel distribution



- 8x pole voltages for asymmetric and symmetric quench detection
- 2x interconnection bus-bar for bus-bar protection
- 1x total magnet voltage
- 1x circuit current (for current dependent settings)

➔ 12 channels per QDS box

➔ Fully redundant scheme (Vtaps → cables → QDS boxes)

➔ All superconducting splices & bus-bars covered

11T Quench detection

- Comparisons between pole voltages used for quench detection
- Fast detection between neighbouring poles (SM18 saw good common mode rejection)
- Detection of symmetric quenches by comparing pole voltages further apart

➔ Exact algorithms to be defined ! (instrumentation should permit a wide range of detection schemes)

- To evade flux-jumps and other noise a time discrimination filter will be used
- Length of time discrimination filter can be set as a function of the circuit current (Susana's talk for the circuit review) → filter out flux-jumps at low currents

11T trigger & HDS controller

- Receive trigger from QDS box A and B
- Provide safe trigger fan-out
  (2 x uQDS to 16x DQHDS)
- Monitor quench heater voltage & current
  (uses 4x DQHSU card)

➔ Type test concerning cable length upcoming
(HDS diagnostics cables have to be extended from 1m (RB) → ~100m (11T))

Some results from SM18

SM18 measurements

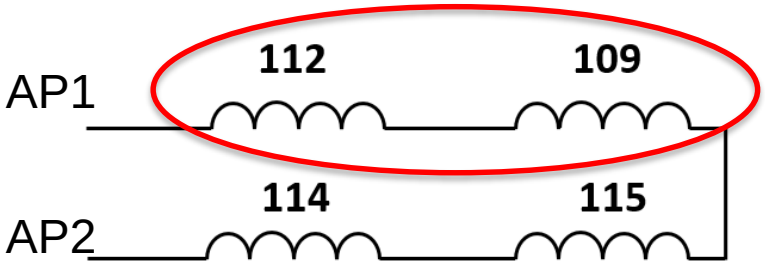
- Follow Nb3Sn magnet development by “testing” uQDS on the new magnets
- Study flux-jumps, quench precursors, oscillations etc.
- Estimate what level of filtering is necessary

➔ Lots of noise/fast transients present in measurements due to power converter (Thyristor based)

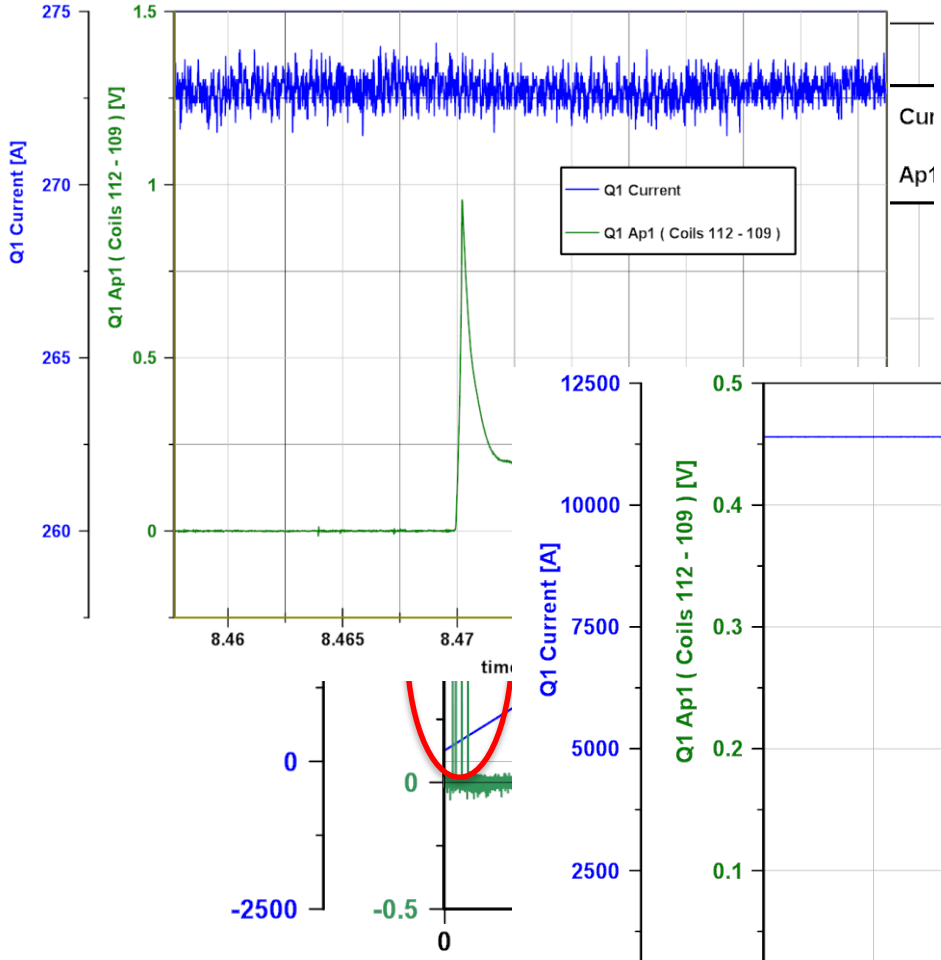
SM18 measurements

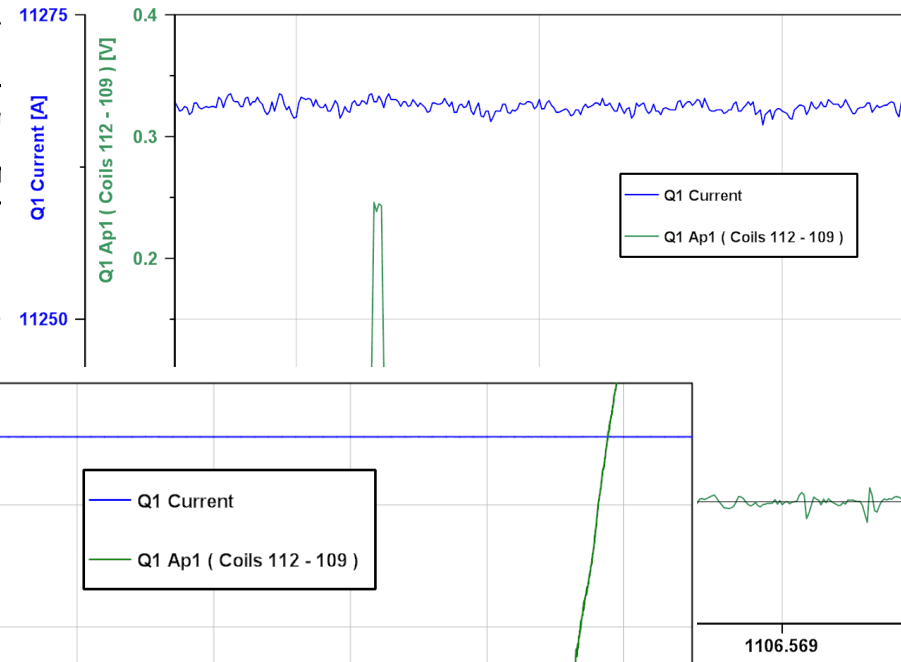
- Participated in test of 11T 2m model magnet (double aperture)
- Sampling rate of 500ksps, raw data transmitted via USB2.0
- Signal processing offline:
  - 10us width median filter
  - 50kHz 10th order Bessel low-pass
  - Decimation by 5
- Following plots show aperture 1 only (112 and 109) during first training ramp to ~11kA
- Model magnet constructed from non-final conductor

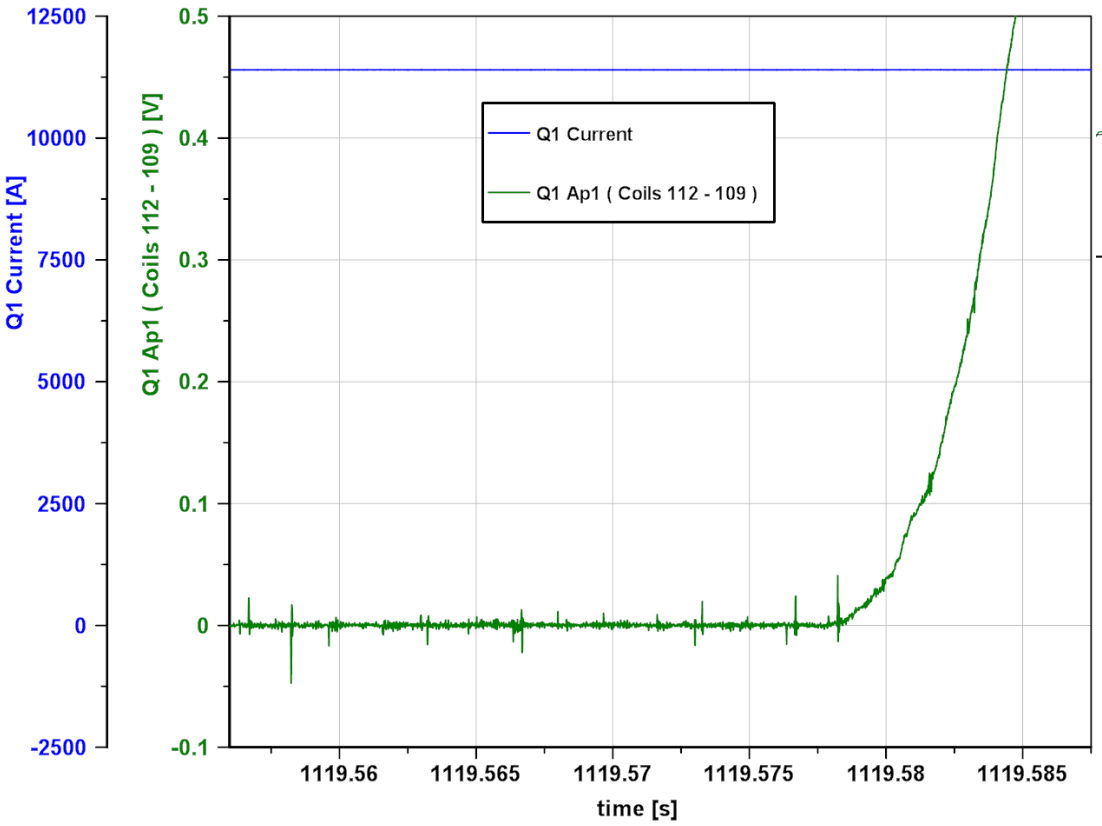
  ➔ Results not representative for final 11T magnet



SM18 measurements 11T prototype Nov 2017







2m model magnet made from non- final cable !

Conclusion/Outlook

- Development is progressing well
- Basic design of 11T QDS defined
- Instrumentation of 11T defined
- Integration studies ongoing, major points clear

- Version 2.0 of uQDS expected end of this year
- Final version for 11T QDS next year
- IT QDS on base of uQDS for 11T
- Looking forward to test final QDS on final 11T in SM18