

How to Monitor Beam: Beam Current Monitors

(for the Machine Protection Review)

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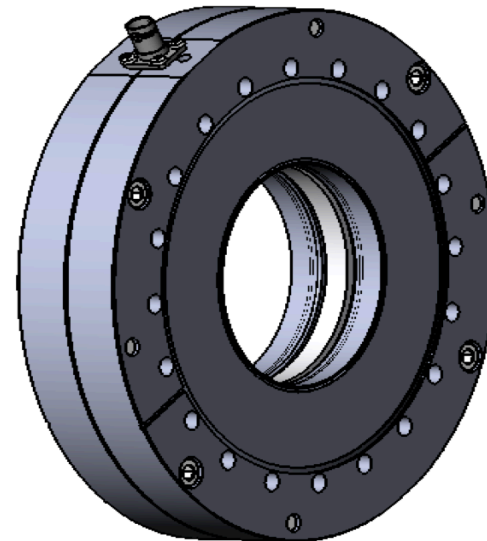
What can/cannot be measured with the BCMs?

- The ACCTs will be used to measure the beam current and charge. This includes:
 - Continuous measurement of the beam current (pulse + gap)
 - Average current over the pulse width
 - Pulse profile
 - The current will be integrated to calculate the per-pulse and cumulative charge.
- The ACCTs cannot measure:
 - DC or slowly-varying current
 - Bunch current
- The FCT can have a bandwidth of up to 2 GHz. It will be used to measure the pulse profile after the MEBT chopper.

Bergoz ACCT toroids

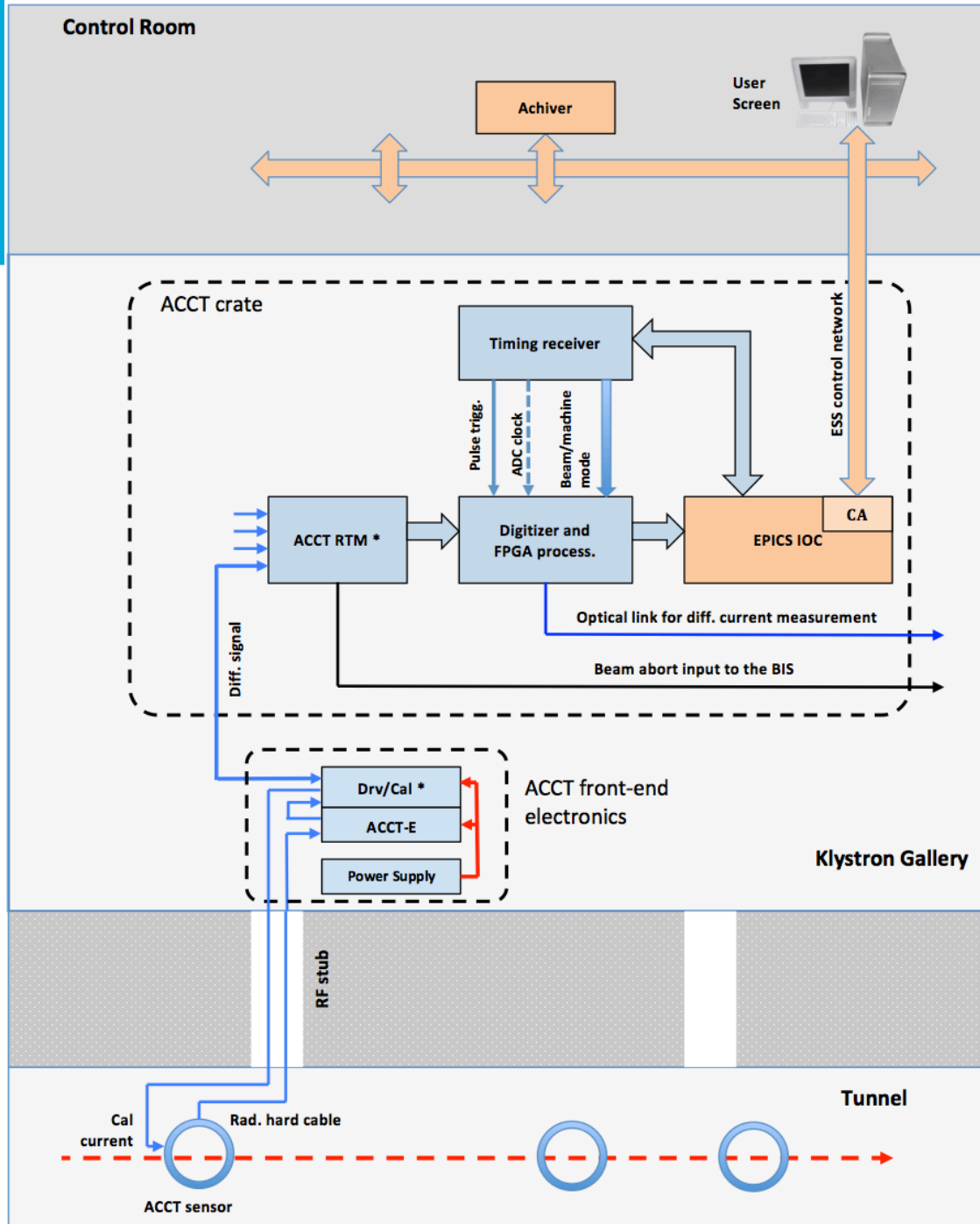
Based on the current design, the calibration cable needs to be terminated in 100 Ohm near the toroid.

With the current Bergoz design, the ceramic will be exposed to the beam (ex. after particles are deflected by quad). The ceramic may then break as a result of charge building up on it (happened two times at SNS as reported by Tom Shea). This can be prevented by putting a thin conductive plate in front of the ceramic leaving a little gap on one end so that it doesn't make a path for the image current.



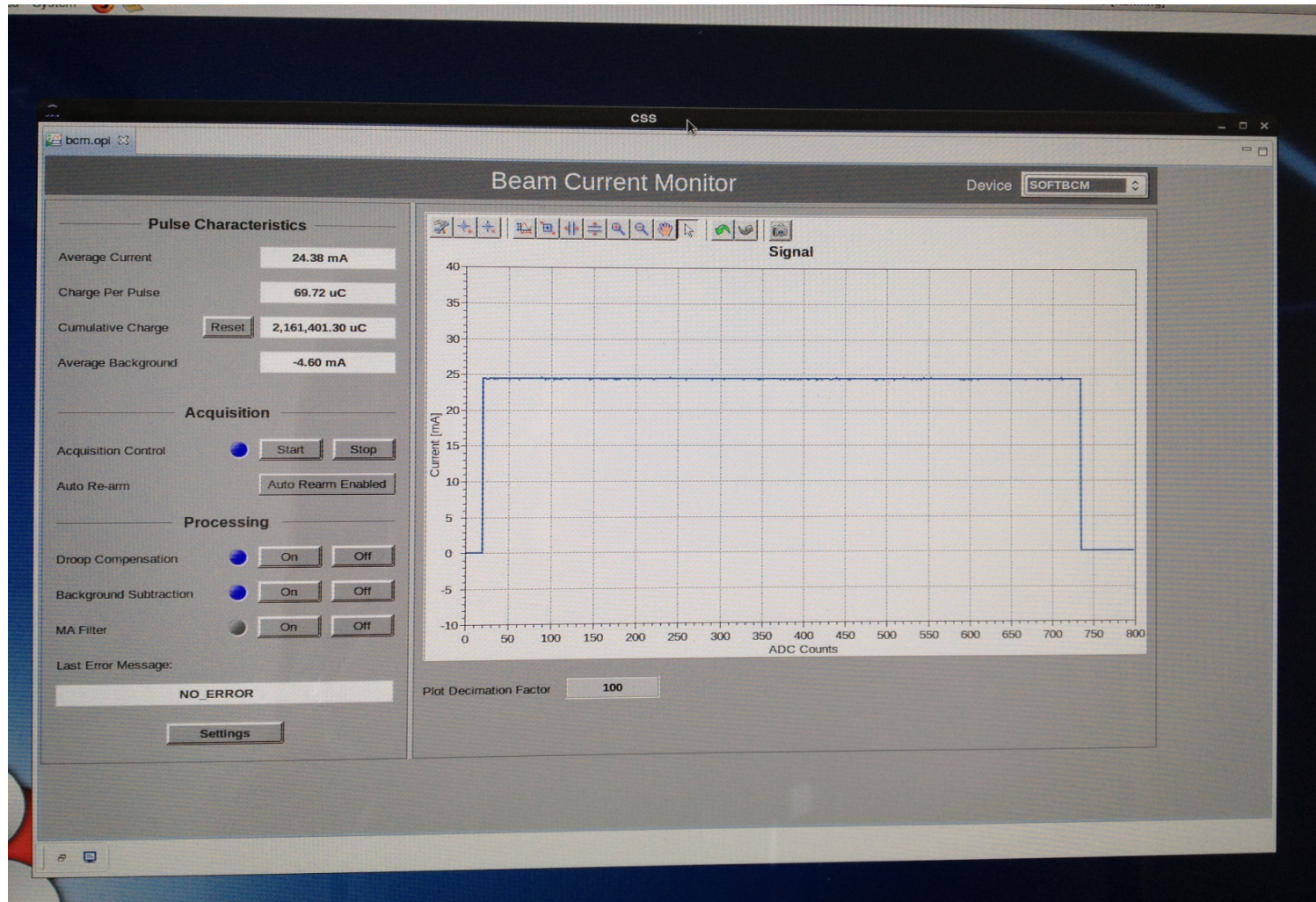
Examples of Bergoz in-air (left) and flanged (right) ACCT toroids. Both sensors include a calibration winding. The later also includes shielding and ceramic break.

Simplified BCM system layout (current plan)



* New development

Beam current and charge measurement with an ACCT

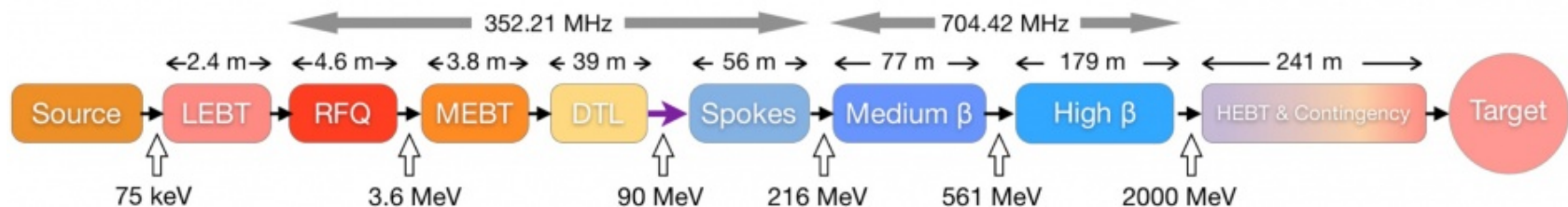


EPICS-integrated ACCT prototype showing pulse current, charge and profile

BCM no. and distribution (draft)

Section name	ACCT no.	FCT no.	Comments
LEBT	1	0	
RFQ and MEBT	1	1	Numbers updated based on the Bilbao scope dated Oct. 26 th 2015
DTL	5	0	ACCT integration in the inter-tanks
SPK	0	0	
MB	1	0	Integration into the 1 st MB LWU
HB	1	0	Integration into the 1 st HB LWU
HEBT	2	0	Integration into the 1 st HEBT LWU
DgLg	1	0	Integration into the 1 st DgLg LWU
A2T	2	0	
DmpL	2	0	
Total	16	1	

Optimus+_2013_10_31



Fault cases to be detected by the BCMs

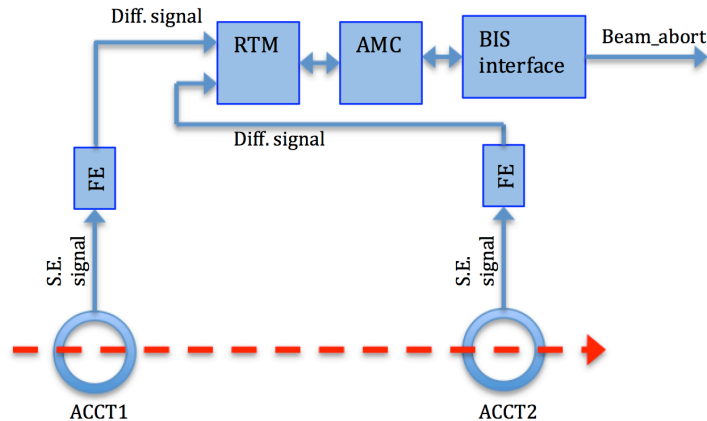
We foresee to use the BCM system to abort the beam if any of the following faults happen:

- Pulse duration exceeds its MPS threshold.
- Pulse current exceeds its MPS threshold.
- Pulse frequency exceeds its MPS threshold.
- Absolute current difference of an ACCT pair exceeds its MPS threshold.

Special blocks are foreseen in the firmware for the areas where a significant portion of the beam current will be lost by default (ex. RFQ and MEBT chopper).

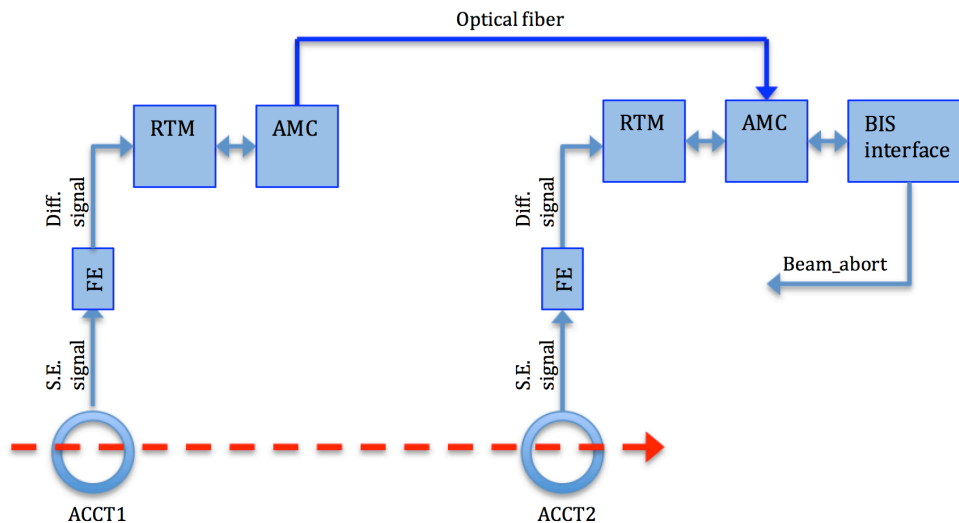
The BCM electronics will receive beam and machine mode information from the timing system. This includes pulse width/amplitude and beam destination. This information will then be used to correctly configure the electronics, and avoid generating false beam abort signals.

Differential current measurement with the ACCTs



Solution A - differential ACCT signal transmission over differential lines

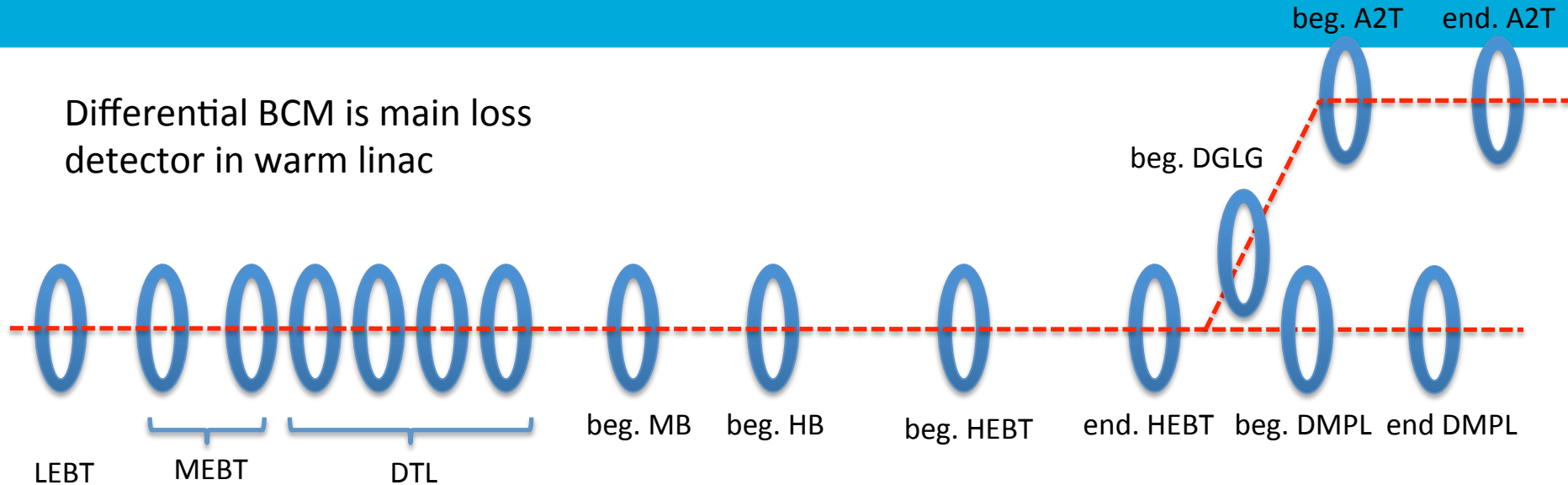
The implementation of the optical line needs significant effort. The idea is to start with the differential line (Solution A) that should be sufficient for the low-energy linac sections. The optical line can be added later if needed. The use of the optical line also depends to a large extent on final differential ACCT layout.



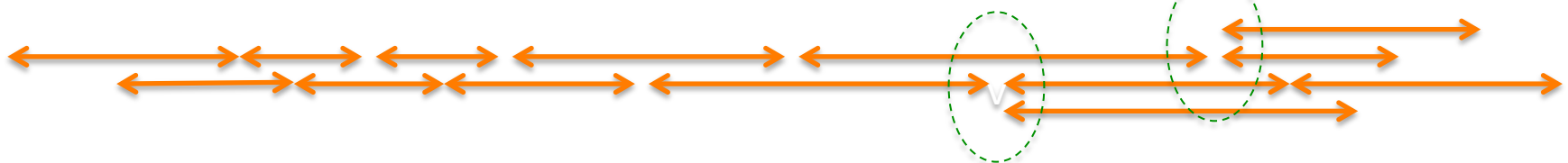
Solution B - differential ACCT signal transmission over optical fiber

BCM redundancy

Differential BCM is main loss detector in warm linac

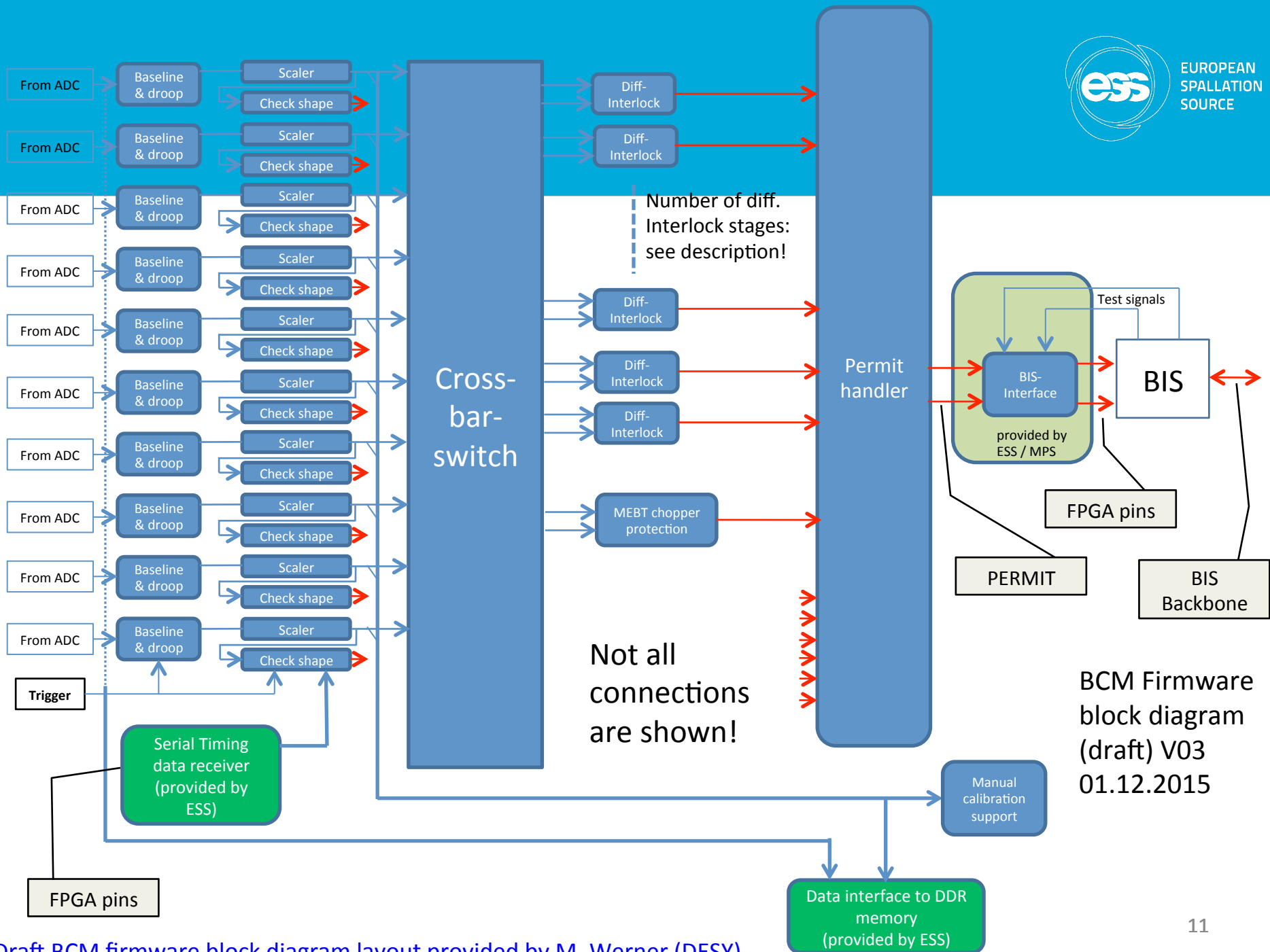


Configuration destination dependent



NB. Configuration to be refined by analysis. Also need to handle intermediate faraday cups/ beam stops (presumably by masks)

This particular layout could potentially be handled by 2 independent 8ch boards



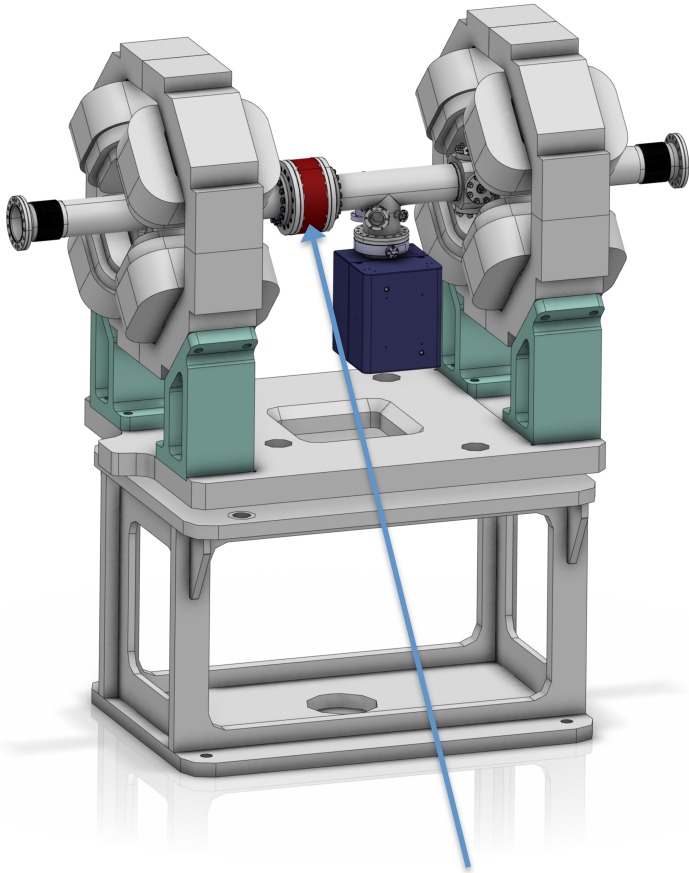
BCM Firmware block diagram (draft) V03
01.12.2015

Summary of the current status

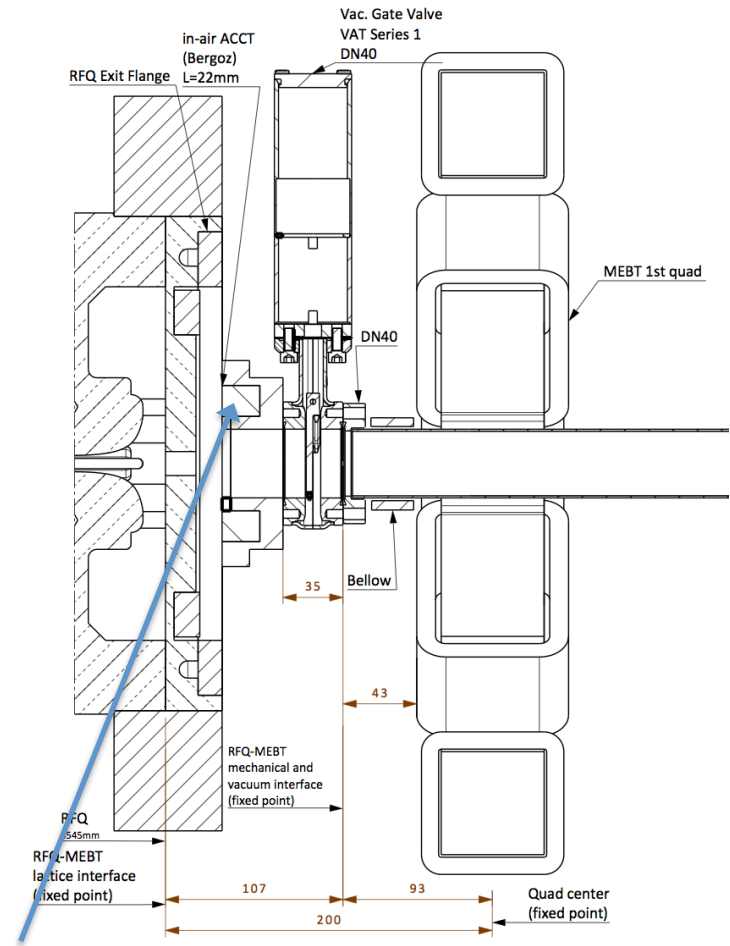
- A prototype BCM system consisting of a Bergoz ACCT and uTCA electronics has already been made and successfully tested. For this prototyped, Cosylab provided the firmware and ESS ICS provided the software.
- Draft BCM specifications are under discussion with the IK partners.
- Details of the FPGA code of the LEBT, MEBT and DTL BCMs are being discussed with M. Werner (DESY) and these are close to being finalized.
- Prototyping and implementation of part of the BCM analog electronics are being discussed with the Polish.
- Details of the protocol for beam/machine more data transfer to the BCM electronics are under discussion with the MPS group and the ICS.
- Commissioning of the LEBT ACCT is planned for Oct. 2016 in Catania. We have recently started with the procurement of part of the LEBT ACCT electronics.

- **Supporting slides...**

ACCT mechanical integration



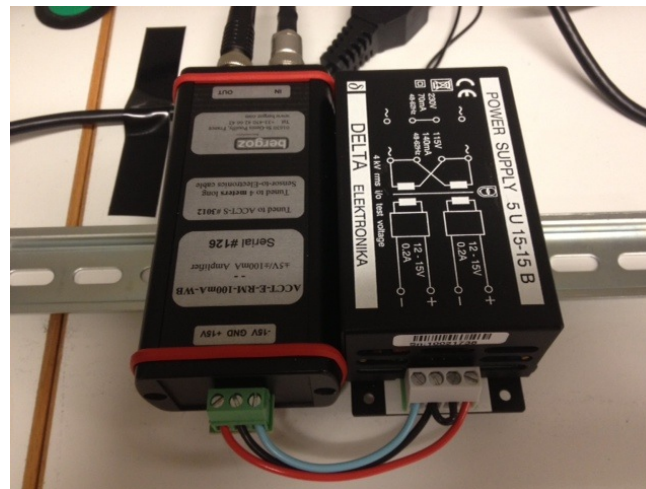
Layout of the elliptical LWU including one in-flange ACCT sensor



Layout of the RFQ end flange including one "in-air" toroid.

Bergoz front-end electronics

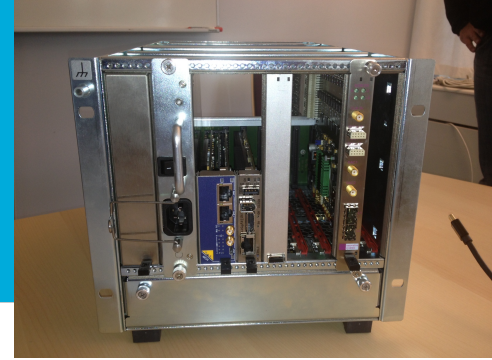
- The Bergoz front-end unit (i.e. ACCT-E-RM) converts the ACCT output current into a proportional voltage with a full-scale range of ± 10 V.
- It is important to connect the ACCT-E-RM output to high impedance.
- The ACCT-E-RM is supplied by a Bergoz ± 15 V power supply.
- Both the ACCT-E-RM and power supply are rail mount
- The front-end electronics should be installed in a small wall-mount box in the klystron gallery at the head of the RF stub.



Drv/Cal module

- The ACCT-E-RM output is fed into the Drv/Cal module that should sit next to the ACCT-E-RM and supplied by the same power supply.
- The Drv/Cal module will then convert the single-ended output of the ACCT-E-RM to differential and feed this signal into a CAT-8A cable that is terminated in 100 Ohm at both ends.
- The Drv/Cal module will also generate a calibration current pulse out of the digital calibration pulse from the ACCT RTM. The Drv/Cal module will then convert this pulse to have a fixed amplitude of 50 mA and feeds it into the ACCT calibration winding.
- The Drv/Cal module will be a new development. Circuit schematics has been received form M. Werner (DESY) based on an ESS-DESY MoU and technical annex.
- Preliminary discussions have started with the Polish institutes for prototyping and fabrication of the Drv/Cal module as Polish IKC.

AMC/RTM

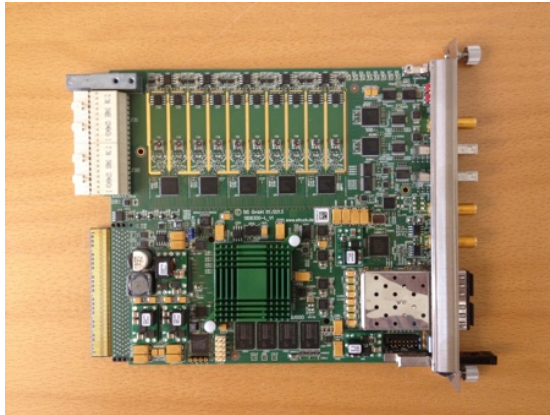


MTCA.4 demo crate with a Struck digitizer and RTM

Advantages of Solution A:

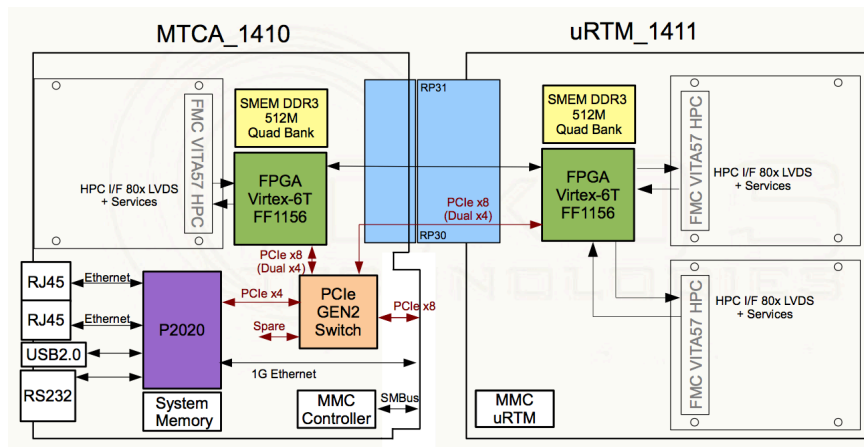
- Includes ACCT calibration
- Diff. drivers fits well with the receiver
- In-house RTM knowledge
- Already-existing, tested and verified AMC

Solution A – Struck (or similar) digitizer/FPGA AMC to be paired with a custom ACCT RTM:

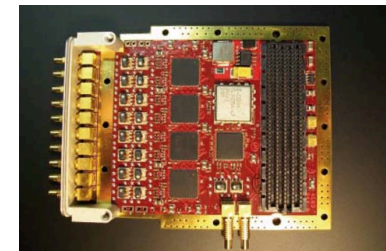


+ custom ACCT RTM

Solution B – IOxOS (or similar) FMC-carrier AMC with a COTS differential receiver FMC:

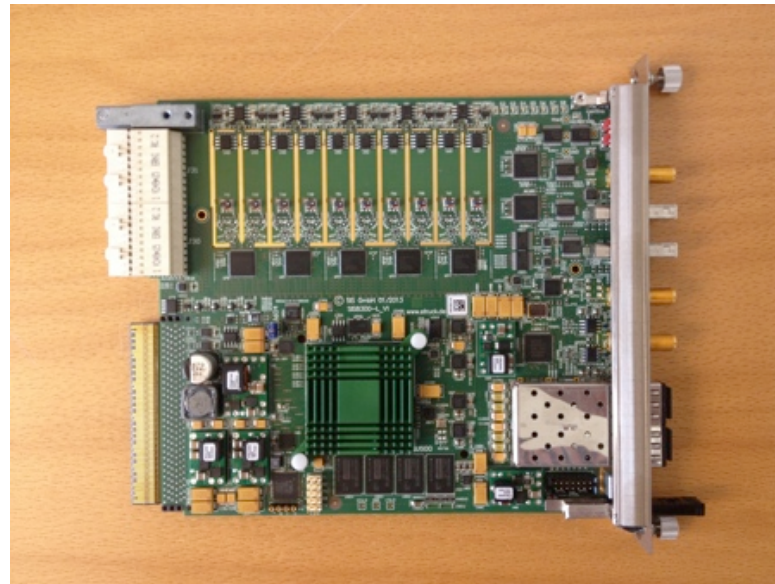


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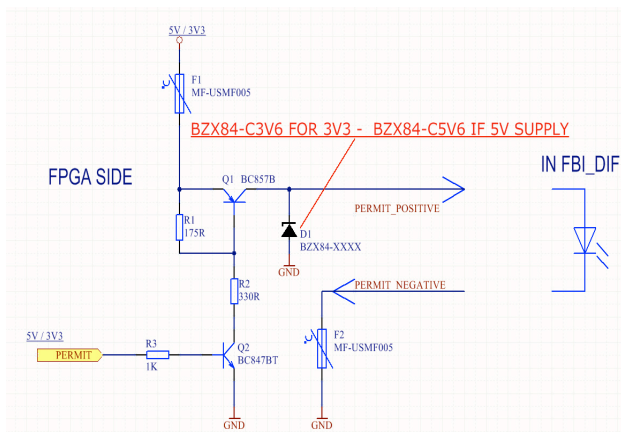
Struck SIS8300-L specifications

- Ten 16-bit/125 MSPS ADC input channels
- 4x4 Gbit (default) DDR3 memory
- Two Gigabit transmitter/receiver SFP slots
- Two dedicated user clock inputs (TCLKA and TCLKB)
- 8 bidirectional differential interfaces to the backplane bus
- Virtex 6 FPGA

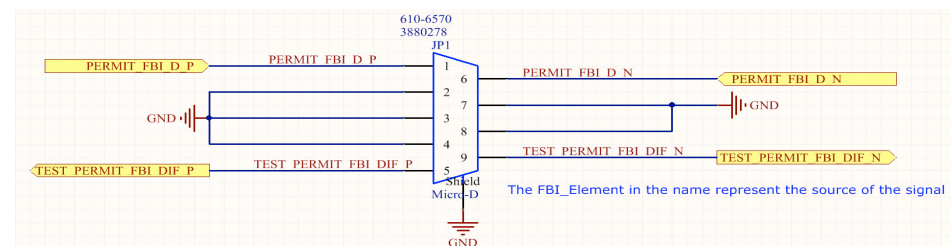
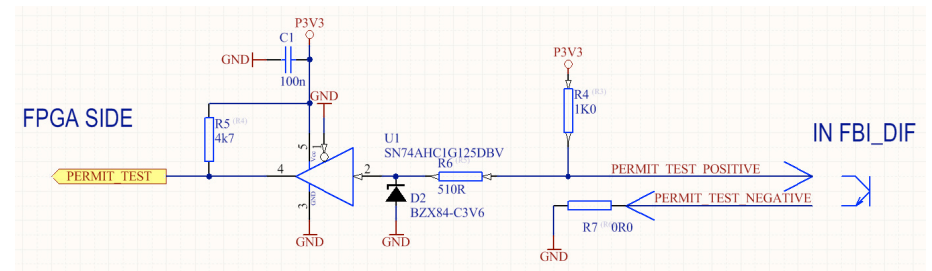


BIS interface

- Based on the ESS MPS requirements, the BIS interface should consist of a beam_permit interface that is driven by the ACCT FPGA and a permit_test interface driven by the BIS.
- With the ACCT RTM option, both the both beam_permit and permit_test interface circuits will be implemented on the RTM.
- There will be one or two (for redundancy) of these interfaces on the ACCT RTM. Aggregation will then be done at firmware level.
- With the FMC option, the interface circuits should be replaced by another FMC with similar electrical specifications (details TBD).

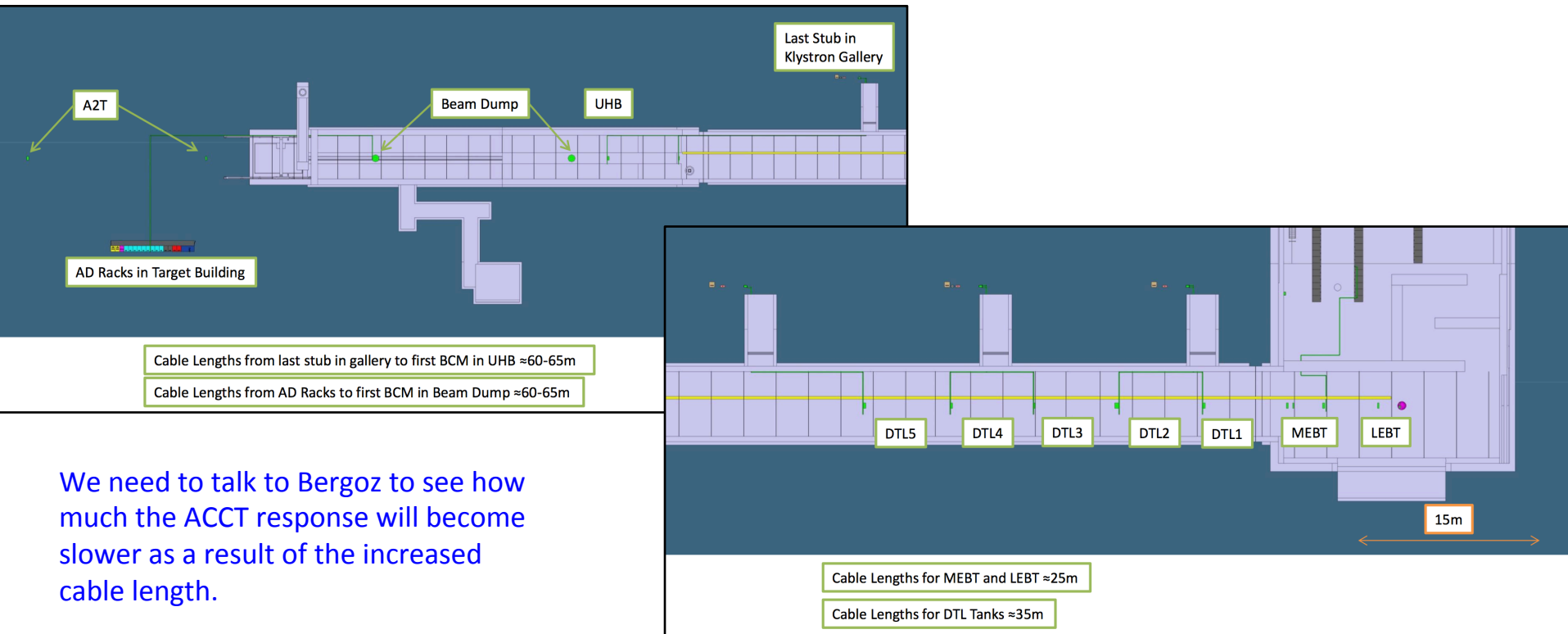


circuit schematics of the beam_permit and permit_test interfaces (source: ESS MPS group)



ACCT cabling

- Based on the Bergoz ACCT specifications, the ACCT-to-FE cable length should not be longer than 25 m. In areas where this will not be possible, the FE electronics can be slightly modified by the manufacturer to allow longer cable lengths at the expense of degrading the ACCT response time, rise time and bandwidth to some degree.
- The ACCT-FE cable length is expected to be about 25 m in the LEBT and MEBT sections. The length then increases to about 35 m in the DTL and 60-65 m in the high-energy end of the linac.



We need to talk to Bergoz to see how much the ACCT response will become slower as a result of the increased cable length.

Timing requirements for the electronics

- **Trigger/consistency check:**

Although the ACCT firmware will include a self-trigger mechanism that will trigger on the edge of the beam pulse, an external trigger will still be needed for the purpose of consistency check. The beam can then be stopped if the frequency of the trigger is not within the acceptable range, or if a beam pulse does not arrive shortly after each trigger.

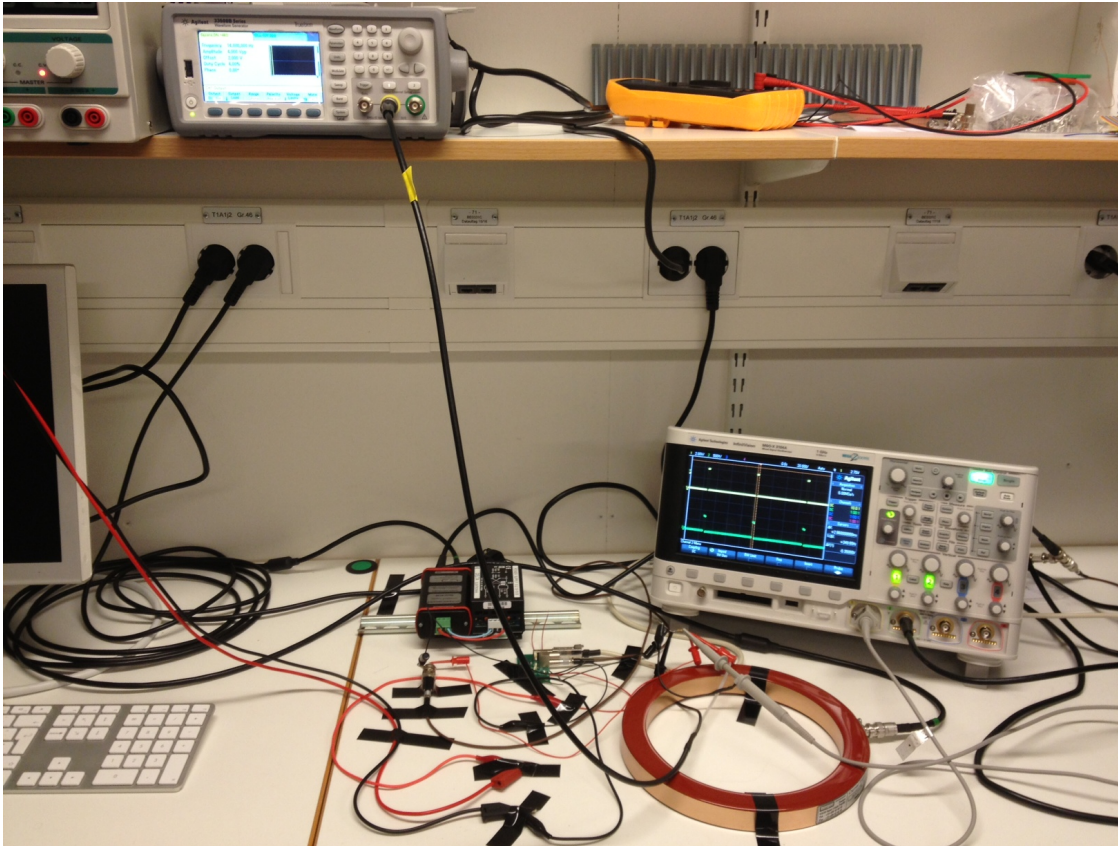
- **Beam/machine mode data:**

The beam/machine mode data need to be transferred to the ACCT readout electronics using the timing system. The ACCT readout electronics will know the expected pulse current/width from the beam mode and the expected beam destination from the machine mode. This information will then be used to correctly configure the electronics including the width of the averaging filters and the masking/unmasking of some interlocks.

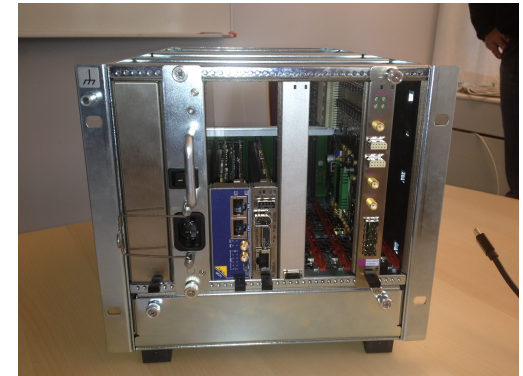
- **ADC clock:**

Although this is not strictly required, it is generally preferred that the ADC clock frequency be locked to RF. An external ADC clock of 88.0525 MHz ($\frac{1}{4}$ of the 352.21 MHz RF frequency) can be provided by the timing receiver module and transferred to the ACCT AMC through a dedicated clock line of backplane.

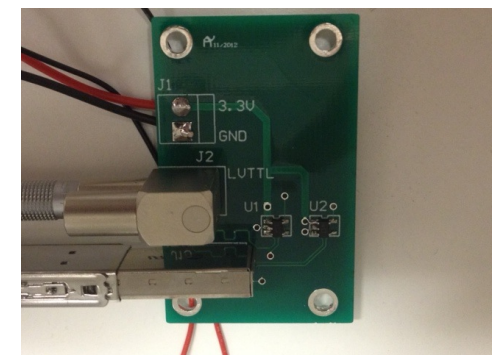
ACCT prototyping at ESS



ACCT test setup with a Bergoz toroid



MTCA.4 demo crate hosting a Struck digitizer card and RTM



**TTL - LVDS converter board
(trigger input for the digitizer)**