Power and Grounding for ESS instruments
(and a little bit on shielding)

Scott Kolya
19 Sept 2016

Everybody knows the problem...

Almost everyone working with instrumentation in a large facility will have come across some electromagnetic compatibility issues, typically signal noise.

There is a widespread consensus that planning ahead to prevent problems is much less costly than fixing up later. Some problems are not so easy to diagnose and fix. However, very often situations arise over time as facilities change or expand, and it is sometimes difficult or impossible to see a clear path from the outset.

There is a standing joke in the EMC community

“*ask two EMC consultants the same question and you will get three different answers*”

The theory is easy, but the practice is hard, or rather, while Maxwell’s equations are simple enough, precise calculations or simulations on real world system are impossibly complicated. Most often rely on generalized rules. **Different parts of the spectrum will interact with you very differently.**

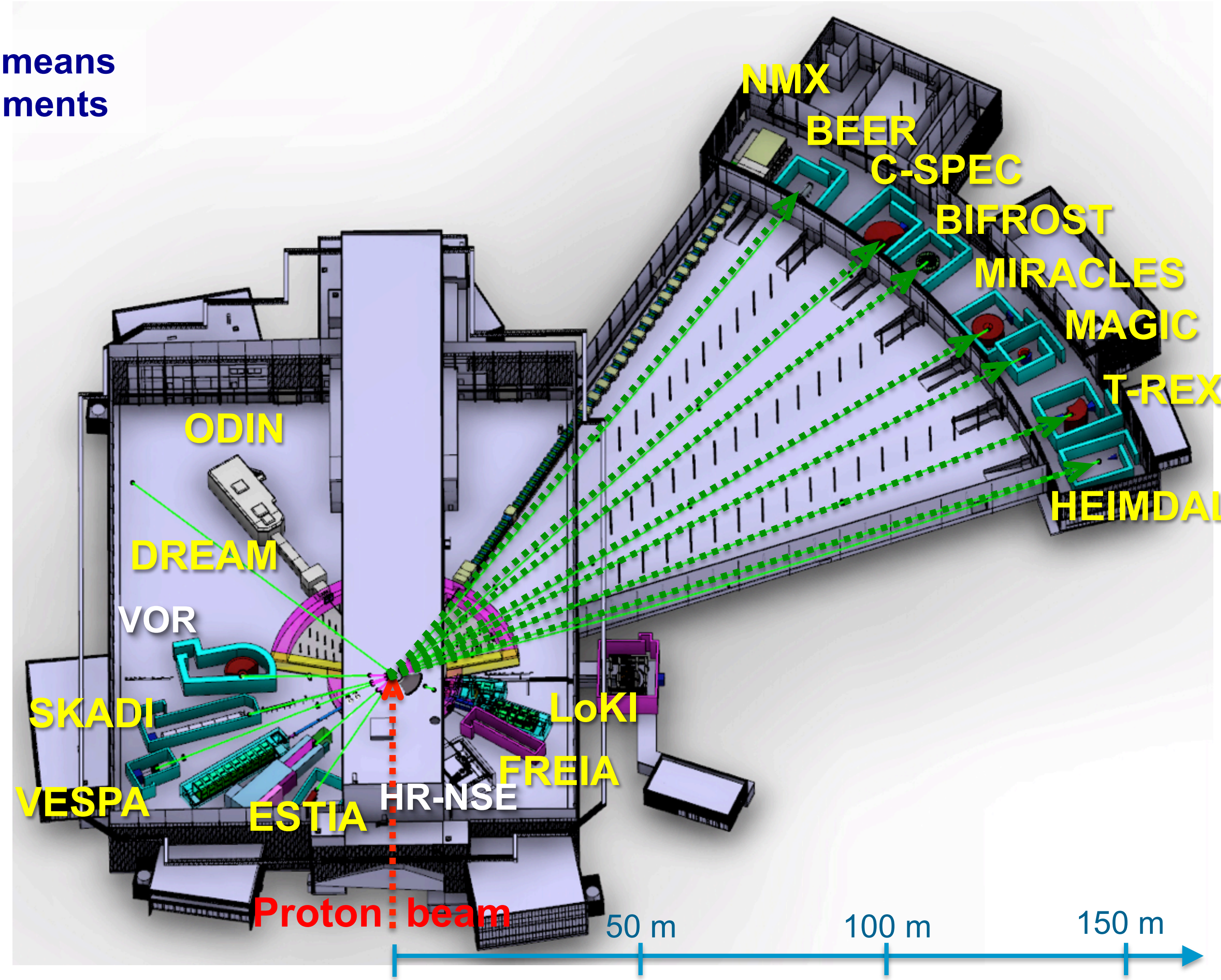
If you get it wrong the results can be catastrophic!!!

NASA-RP-1374
“Electronic Systems Failures and Anomalies Attributed to Electromagnetic Interference”

ESS.... *an Opportunity and a Challenge*...

ESS.... *an Opportunity and a Challenge...*

Long Pulse means
Long Instruments



Instrument Power and Ground Team

Team:
Thomas Gahl
Frithiof Jensen
Markus Larsson
Markus Olsson
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Scott Kolya

Advice:
Stuart Birch (RAL/ESS)
Andrew Thomson (Diamond)
Keith Armstrong
(Cherry Clough Consultants)

Provide basic guidance and rules for power and grounding to both minimize electrical interference between instruments (and construction work) and provide a sound basis for the internal instrument electrical design.

- **Isolate instrument connections**
- **Split instruments into independent power and ground zones.**
- **Provide guidance for grounding connections within zones.**

Document
Project
Date
Revision
State

Guidelines for Instrument Power and Grounding
Scott Kolya for ESS Instrument Power and Grounding Team
(Thomas Gahl, Frithiof Jensen, Scott Kolya, Markus Larsson, Markus Olsson, Harald Schneider)

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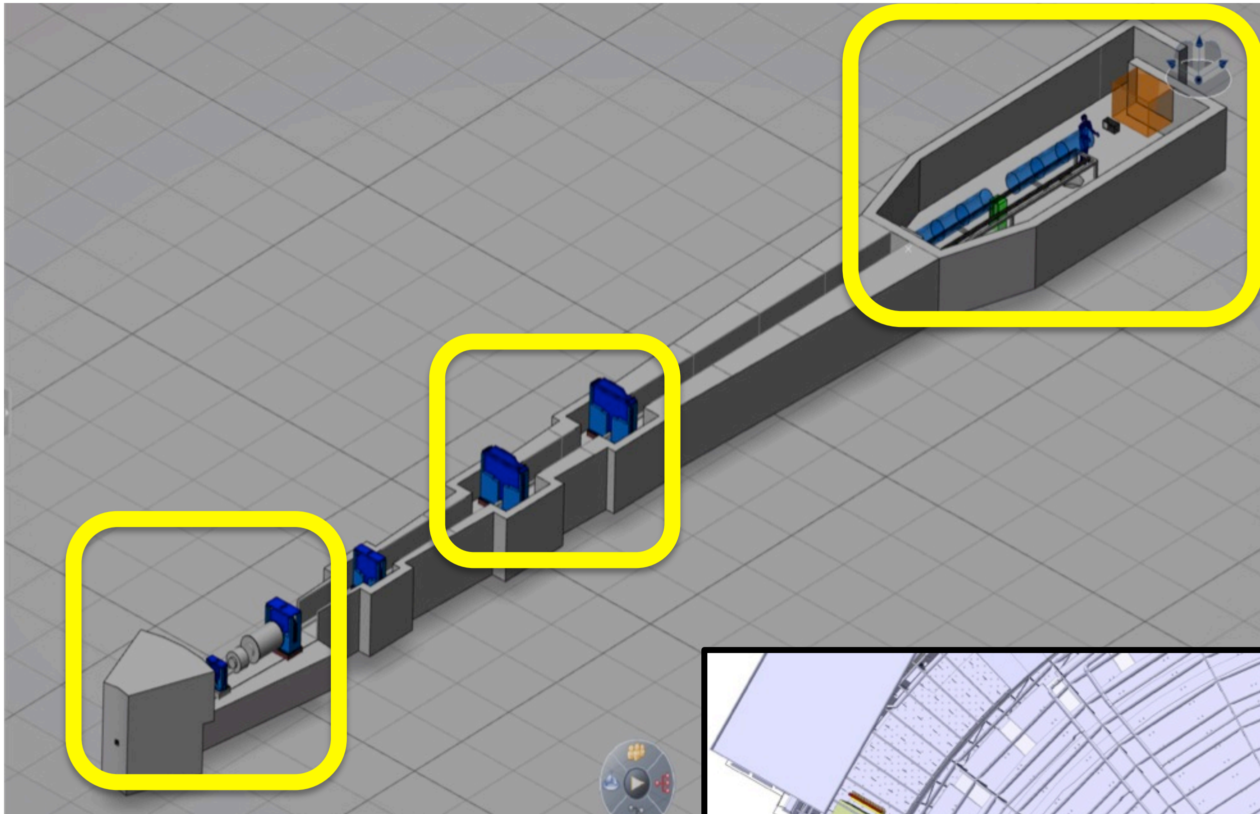
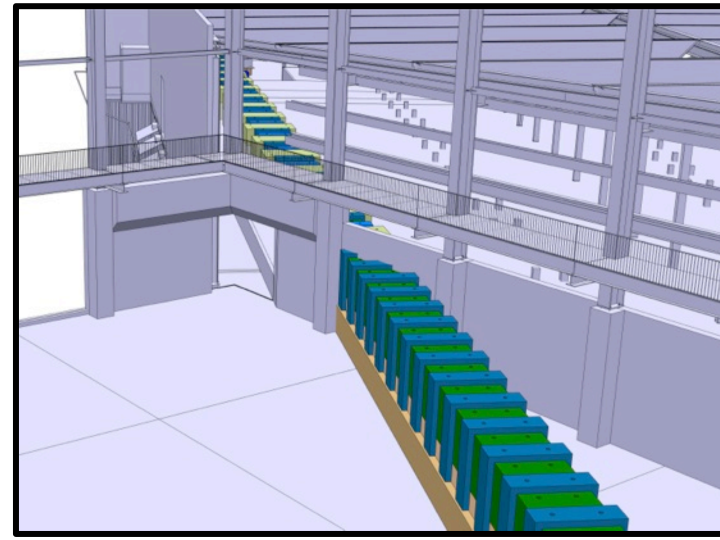
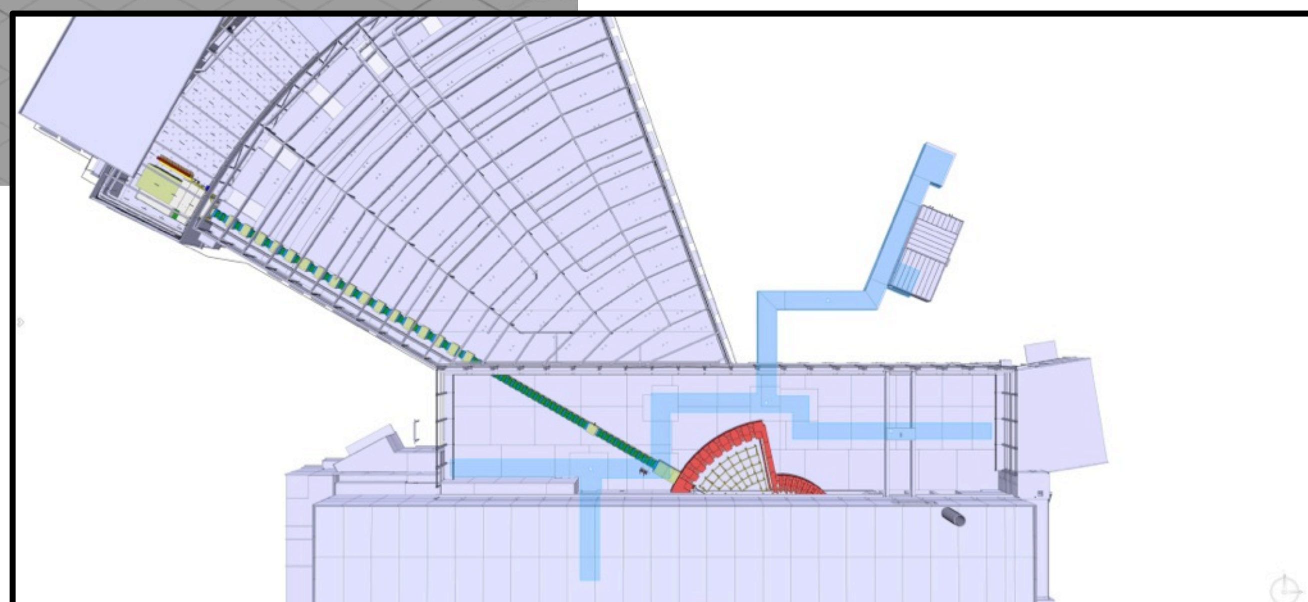
Approver	Shane Kennedy	ESS Technical Director

Distribution: ESS Instrument Teams
In-Kind Partners
Contractors participating in Instrument Construction

Instrument Zones





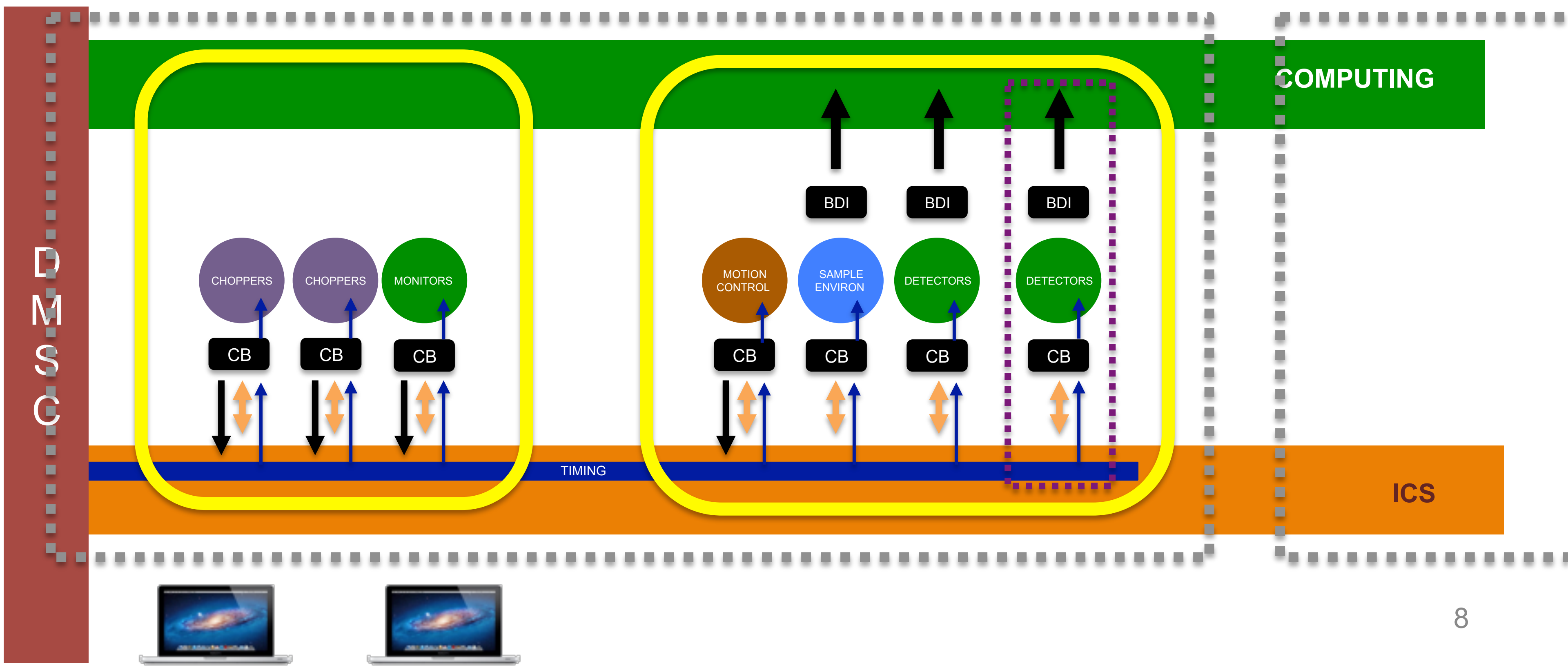


An aside... Instrument Control & Readout

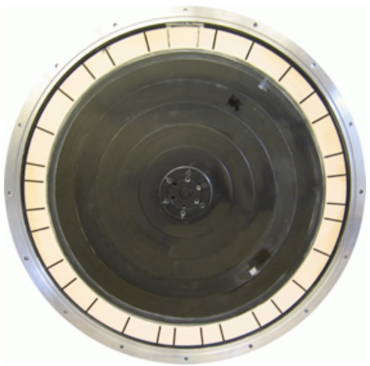
An instrument is a collection of independent subsystems connected only through ICS and DMSC. Each detector technology on an instrument will be readout as one or more subsystems.

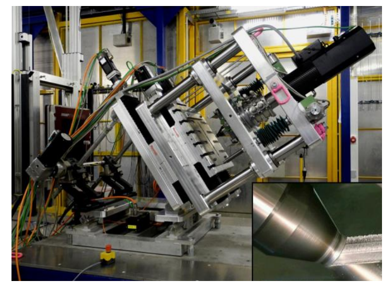
There are two ways data can get to the DMSC

- Via the ICS (controls) network, limited to ~100Mbits/sec
- Through a high speed dedicated interface (the Bulk Data Interface, BDI) up to 100Gbits/sec



Aside II Event mode, timestamping, and all that..





Timestamp
Top Dead Centre

Transitional Timestamp
Significant Variable Change

Timestamp Neutron
Candidate Data

Interpolate
Openings

Calculate Value
at any time

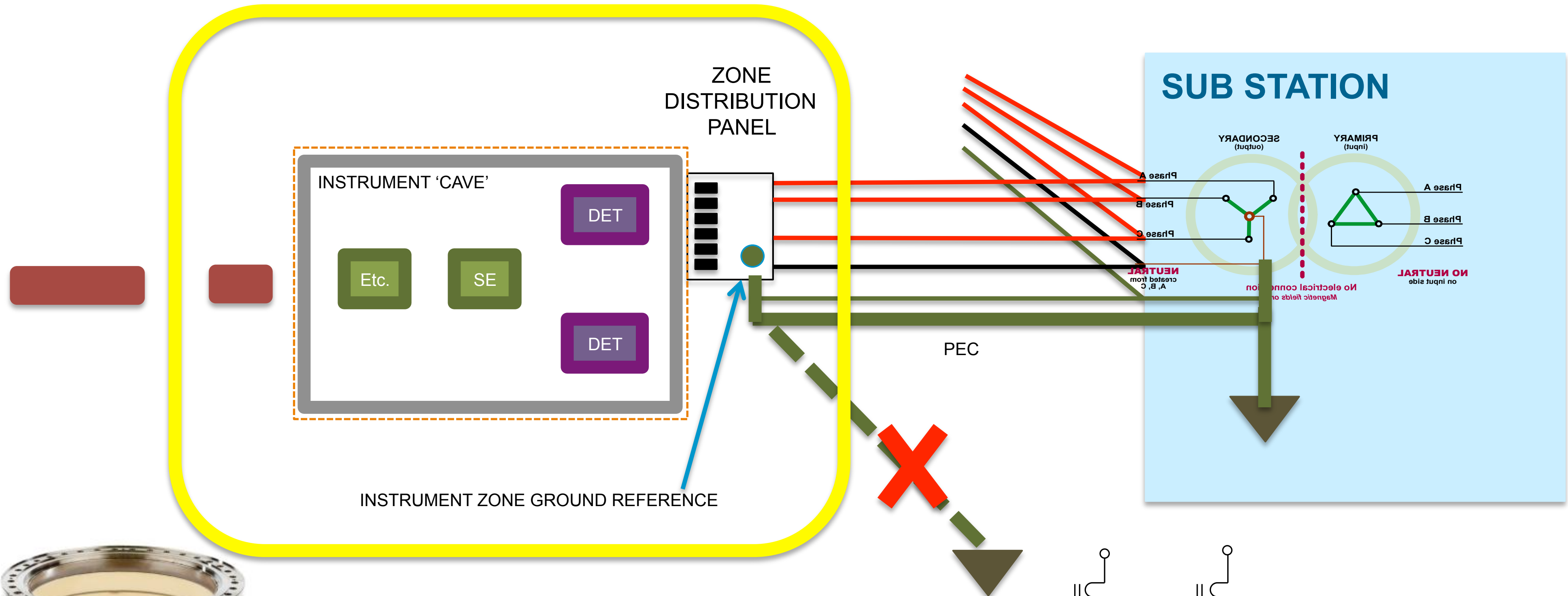
Neutron Candidate with
Time and Position

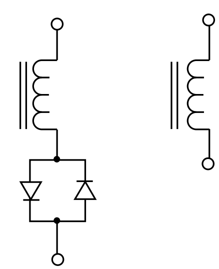
Periodically Record
Phase Error

Periodically Record
Process Variable

....Best possible flexibility, providing you have the data bandwidth

Main Instrument Zone Power





The Instrument Cave Zone must not be bridged to other zones unintentionally. For example, the beam guide should not provide an electrical path that connects multiple zones.

Power distribution direct from substations

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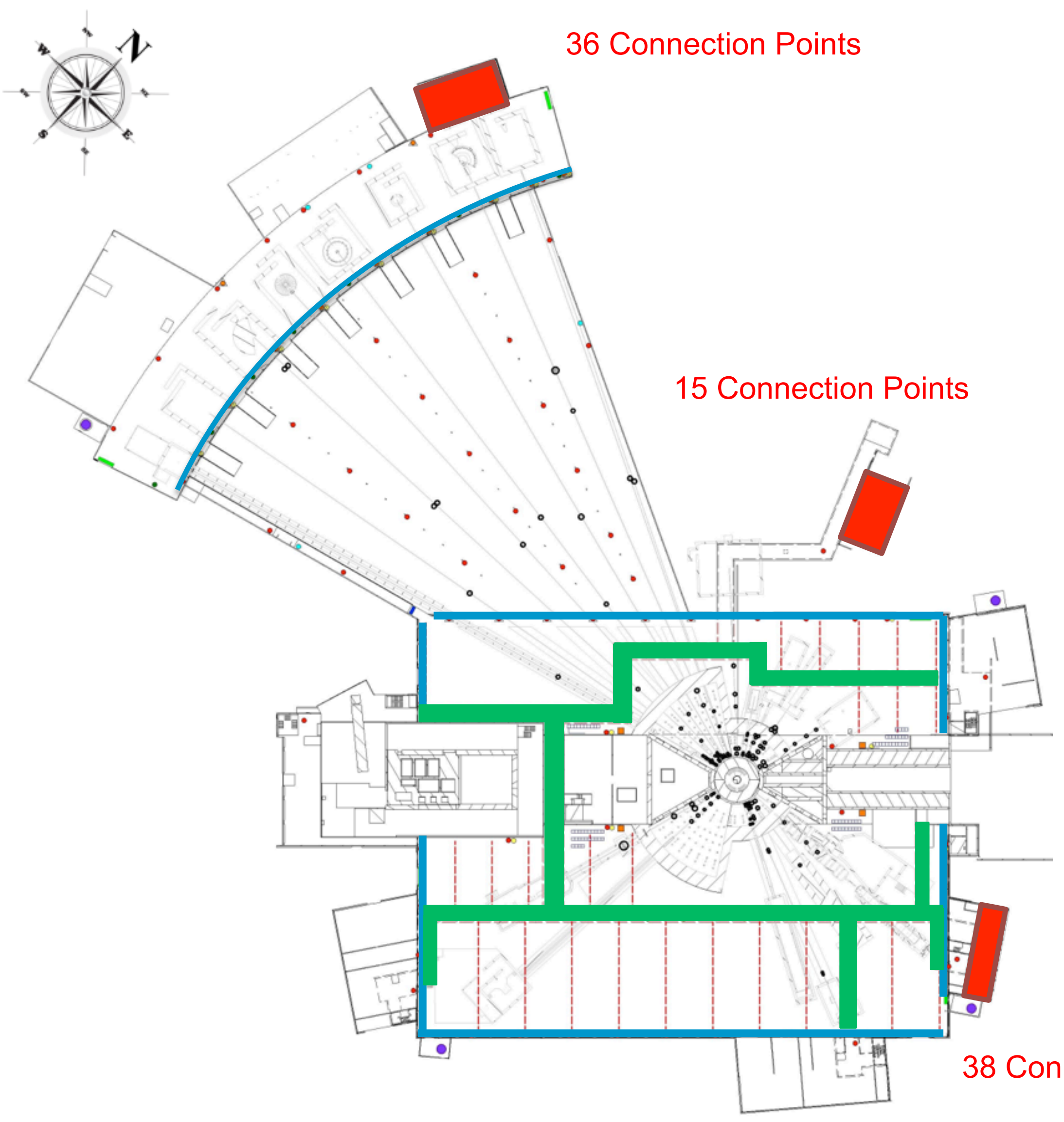
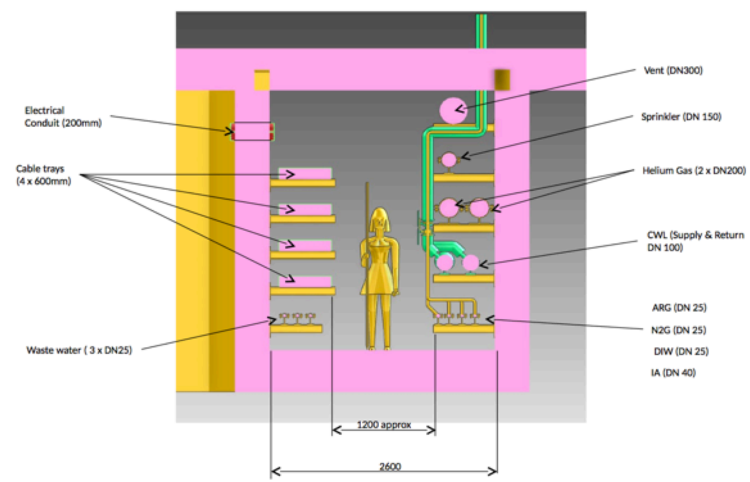
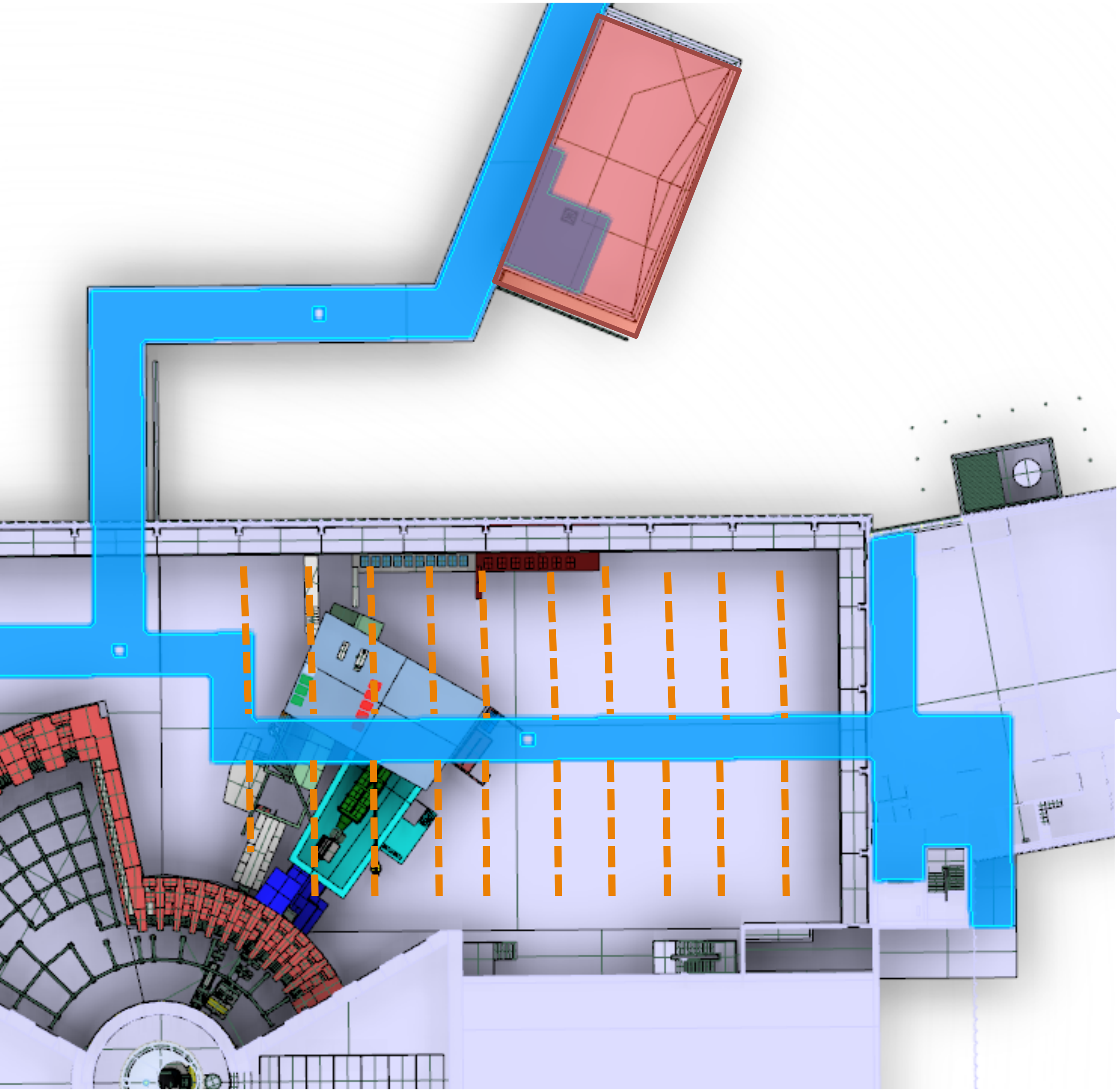
SOURCE



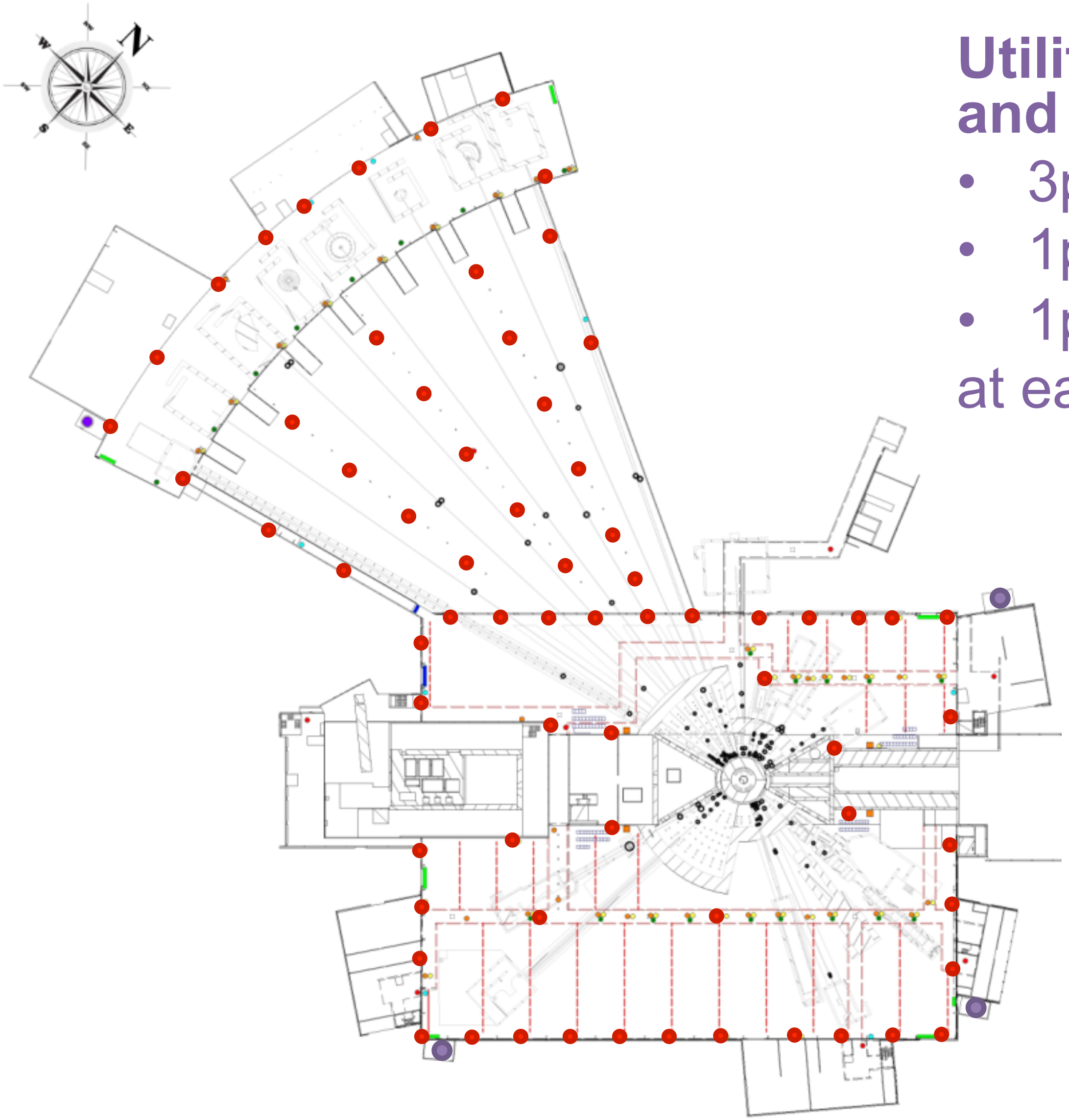
- **Walls/pillars**
- **Gallery (tunnels)**
- **Conduits (underground tubes from gallery)**



Example, FREIA, LoKI



Avoid ‘unauthorized plugging’



Utilities power for installation and maintenance:

- 3pcs. 16A 1-phase outlets
- 1pcs. 16A 3-phase outlet
- 1pcs. 32A 3-phase outlet

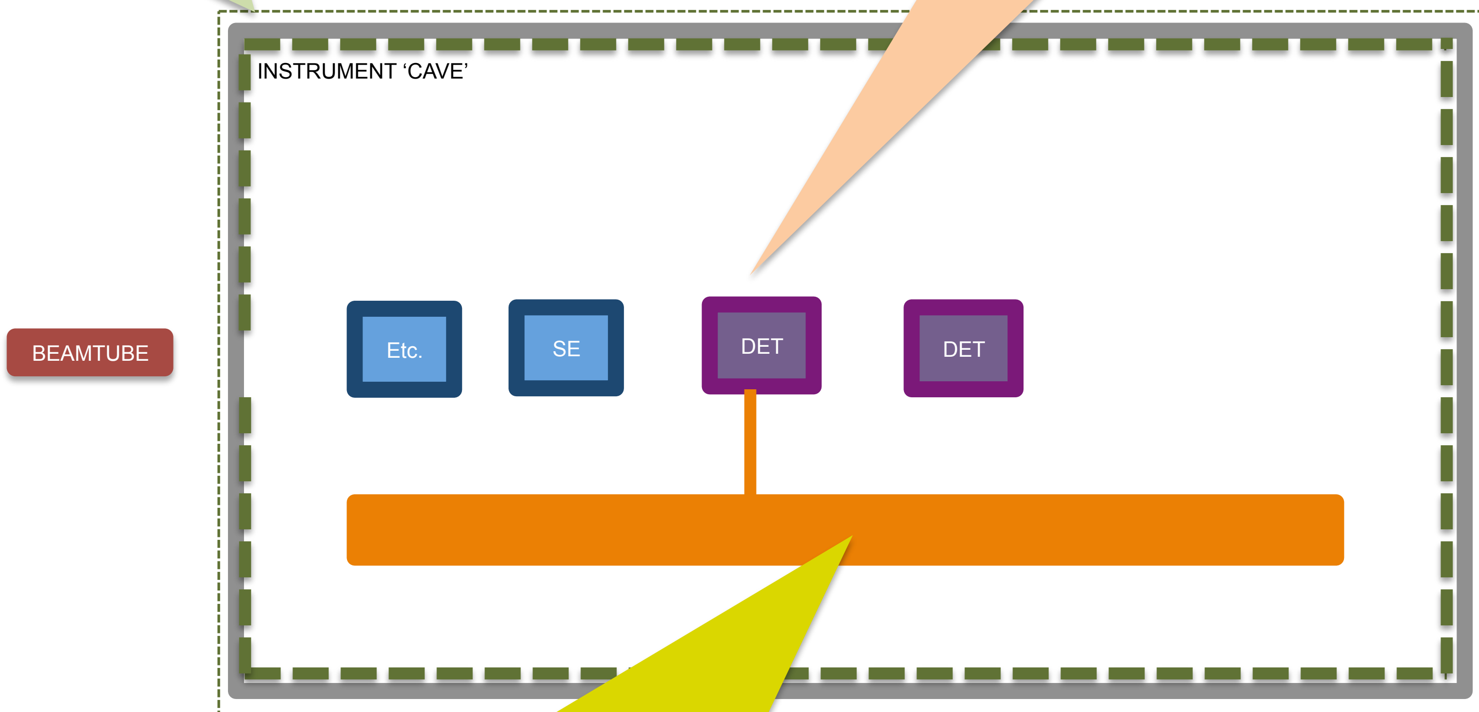
at each location

Instrument Grounding

Shown for an instrument cave but similar for other zones (except bunker)

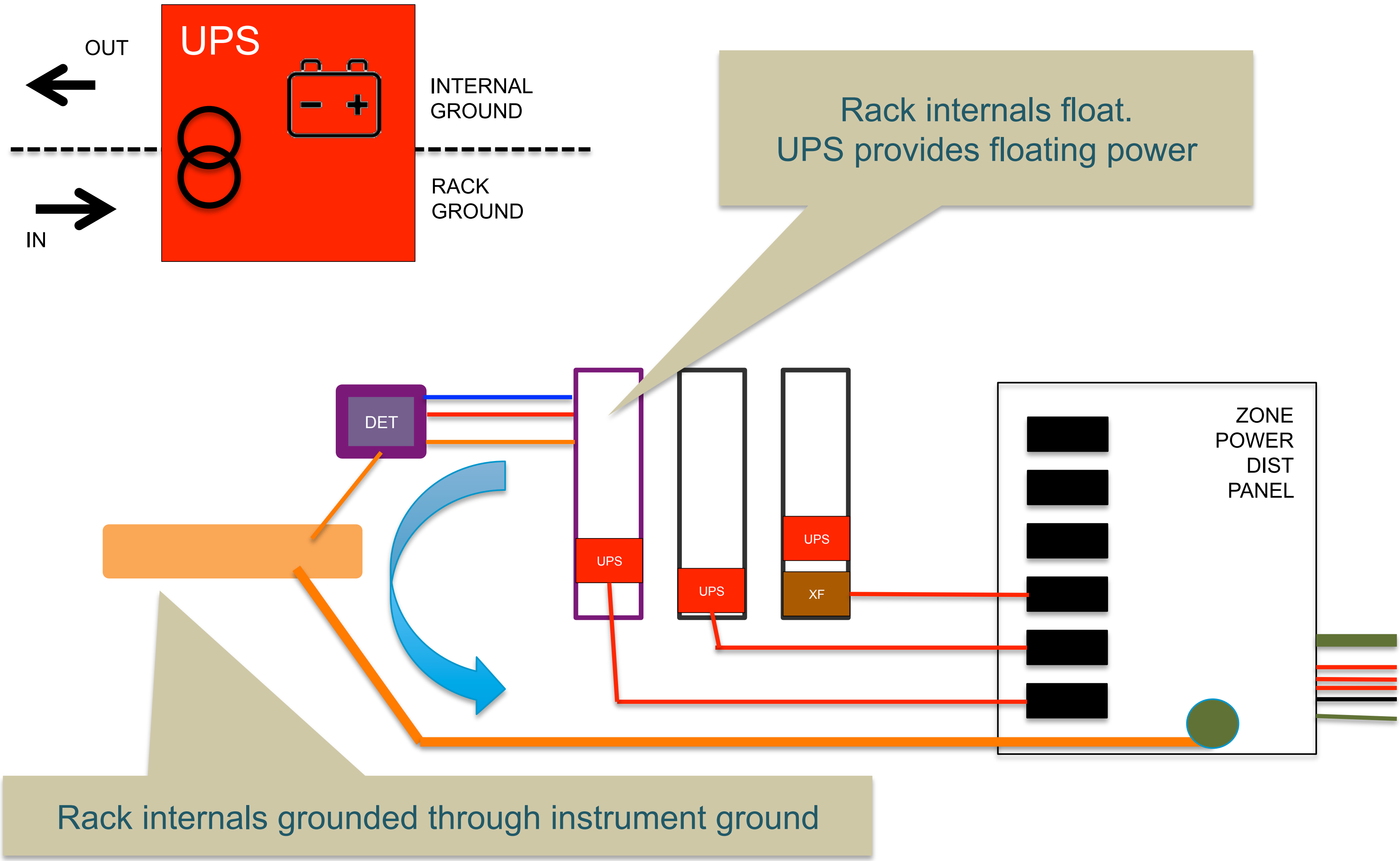
Shield Ground is general purpose ground. Connect everywhere. Radiological shielding is often in steel cans that can (indeed must!) be grounded)

Signal Ground is for electrically sensitive equipment. Selectively connect.



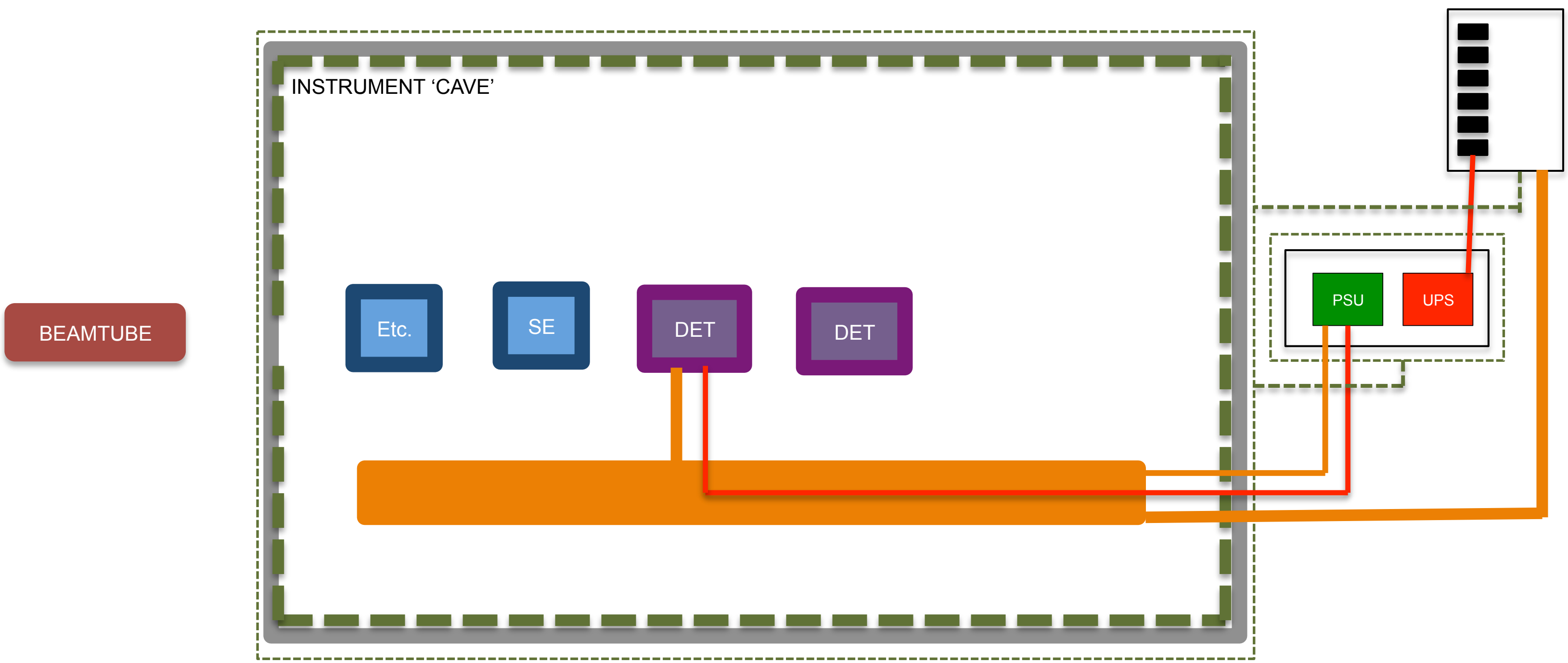
Grounding Structures (bus bars, etc.) as required

Grounding Path for Sensitive Equipment (if you really really need that)



Small Signal Quiet Implementation

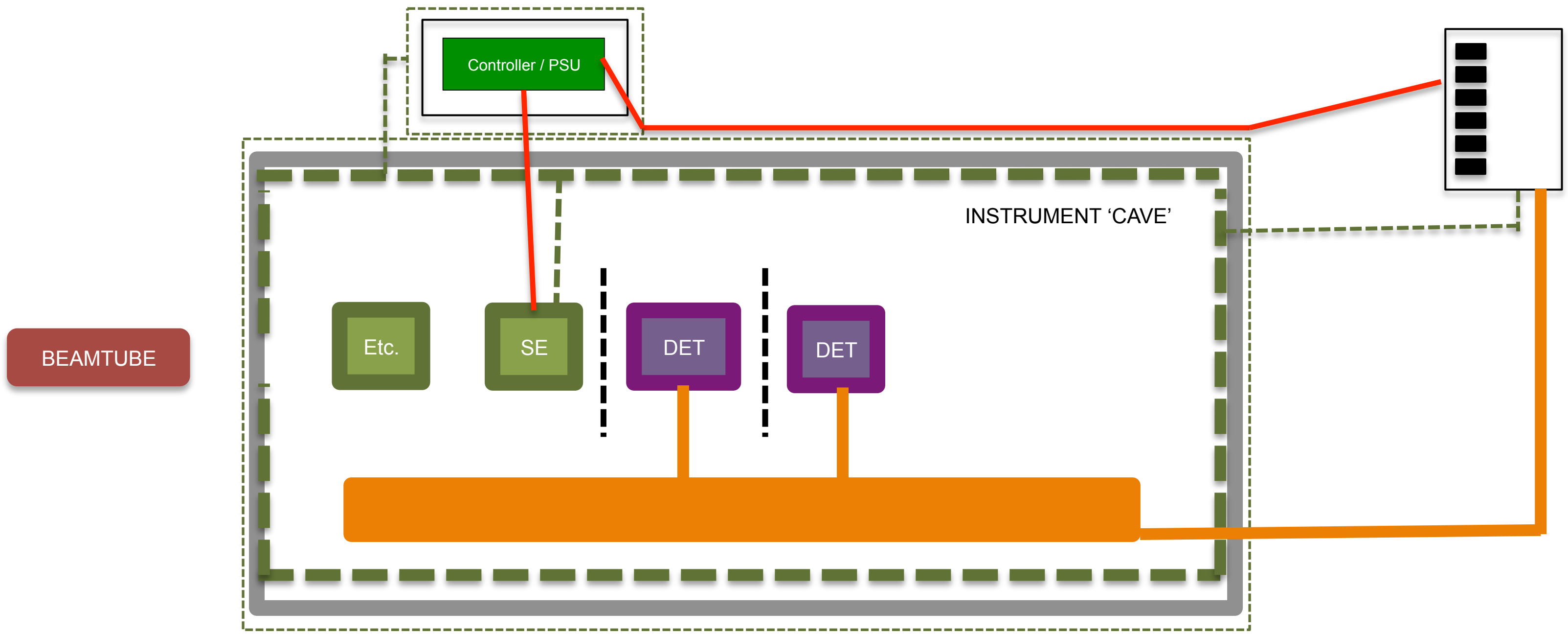
As shown on the last slide, rack internals are grounded through their connection to the instrument. This may be on some grounding structure (eg copper bar) rather than the actual subsystem itself. The rack frame is connected to shield ground, and the rack itself needs to be placed close to the outer shield of the cave structure.



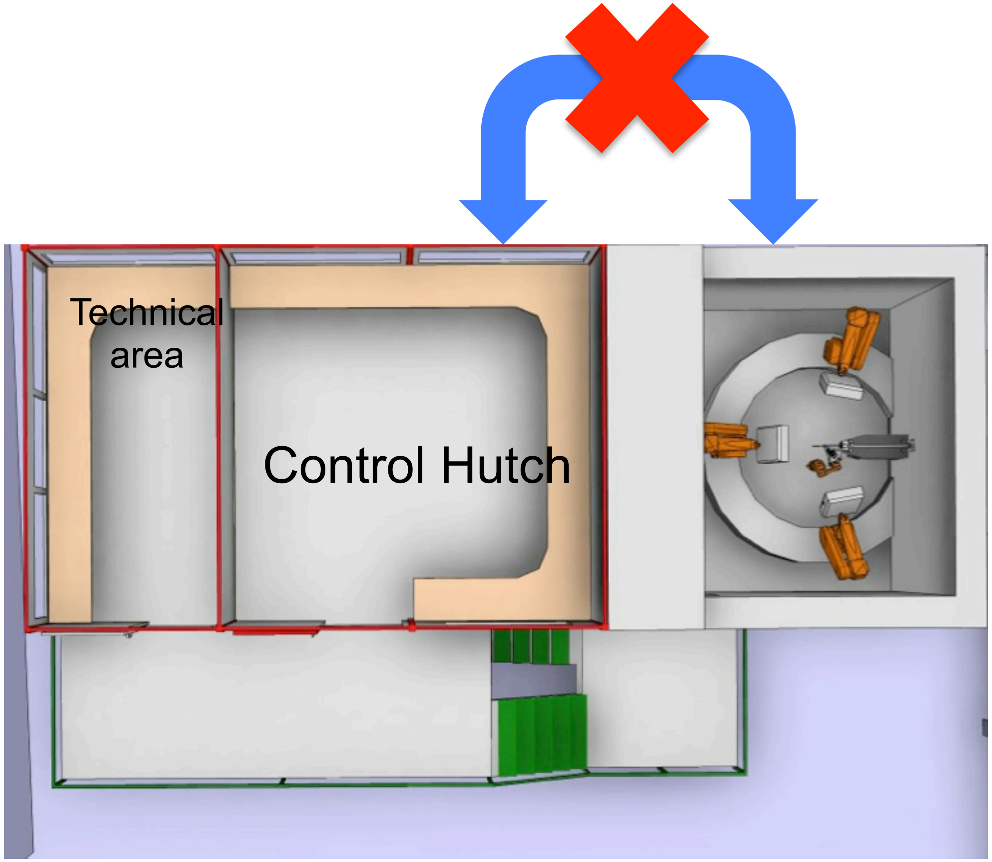
Noisy Drive System
(if you really really have to have that!)

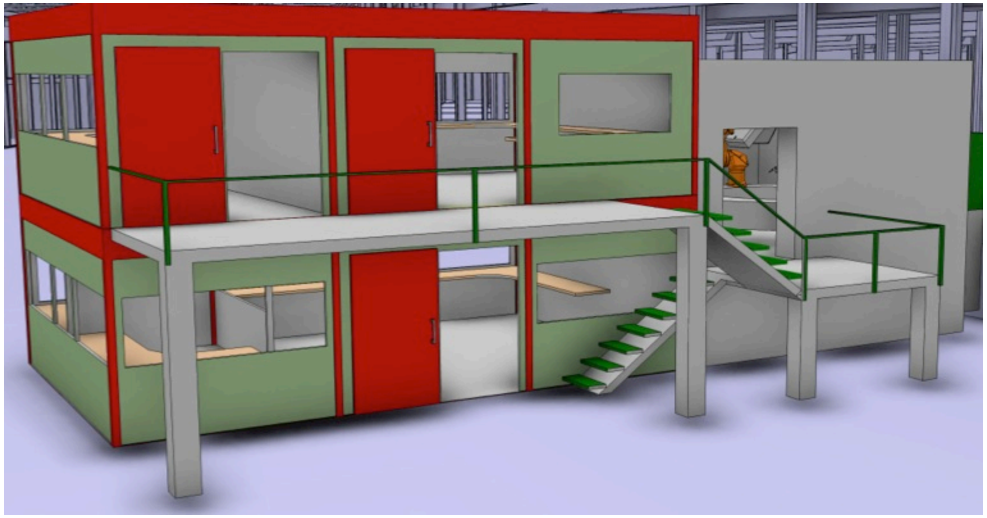
In cases where we expect some current into neutral/ground we isolate from the signal ground. All such are connections to the shield ground. This is a mesh type ground within this zone (but only this zone).

Accordingly it is very important that sensitive systems (such as detectors) can isolate their grounding from adjacent equipment. As best practice, you should aim to be able to isolate each internal module from its neighbours, and provide only one well defined grounding point for each module.

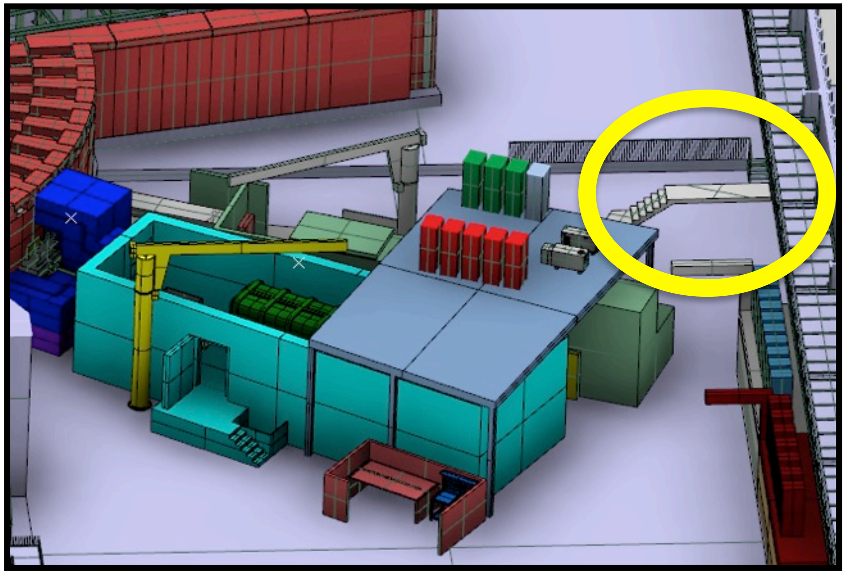


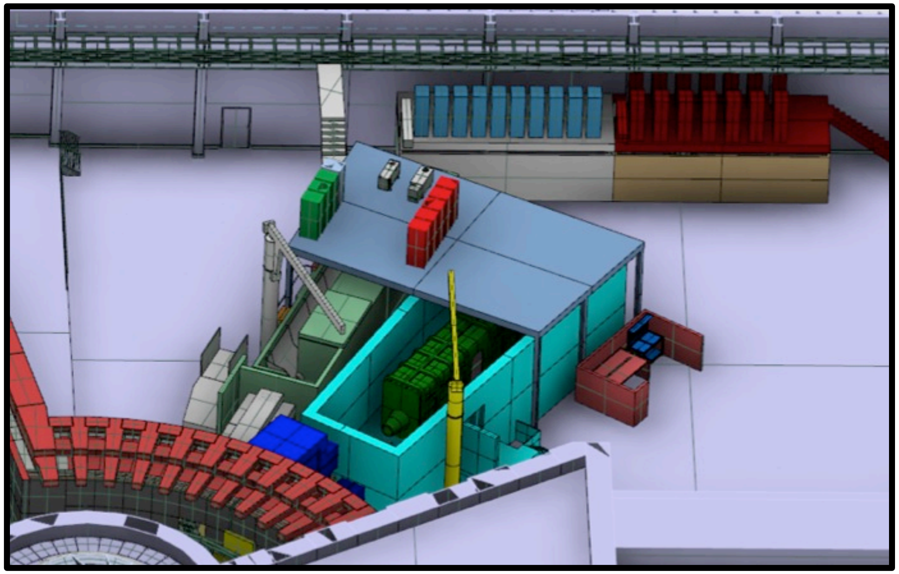
What needs to be in your Zone?

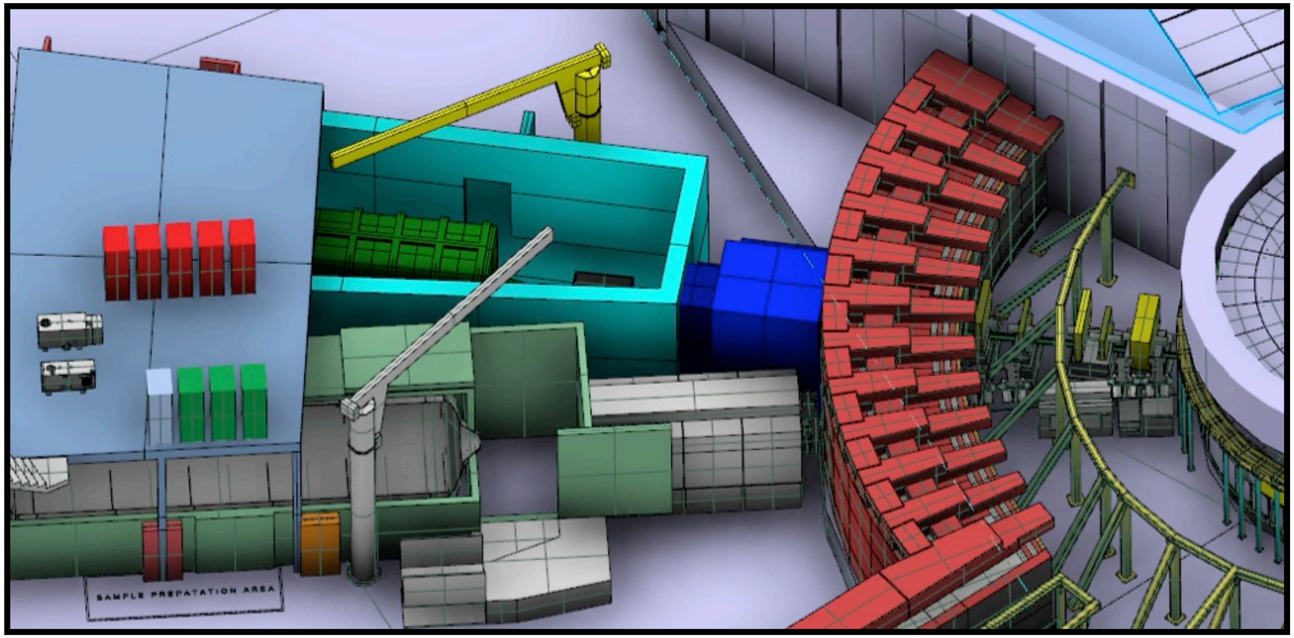




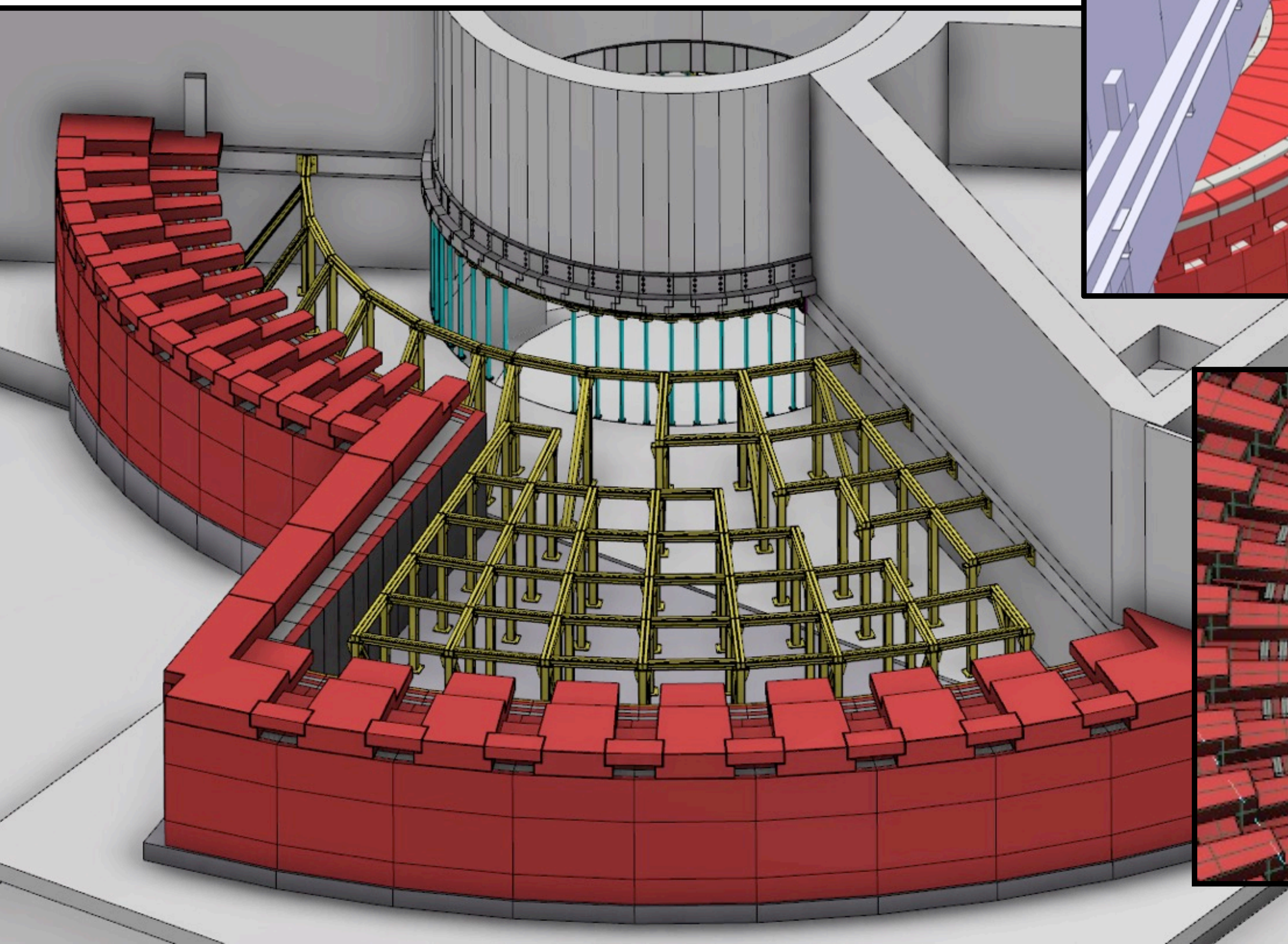
Sharing, not impossible, but discouraged...

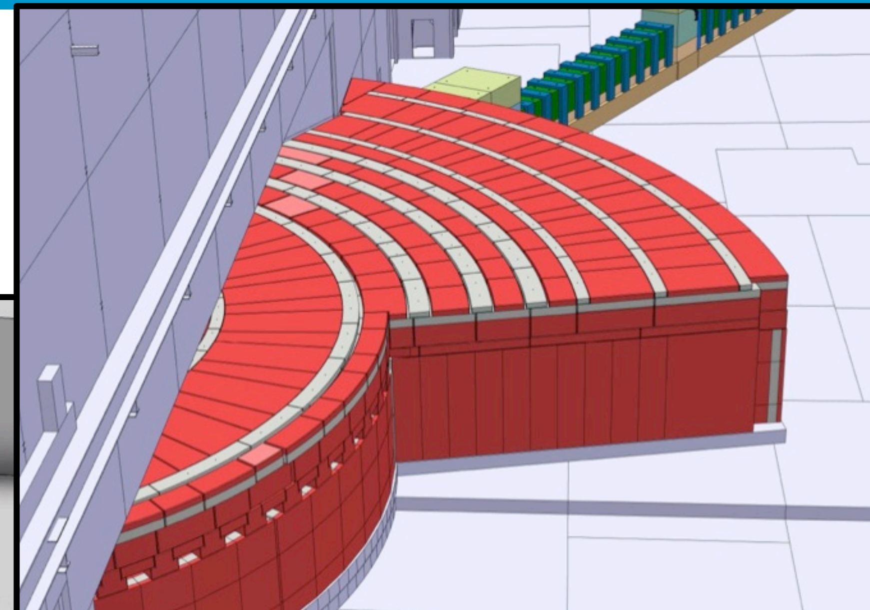


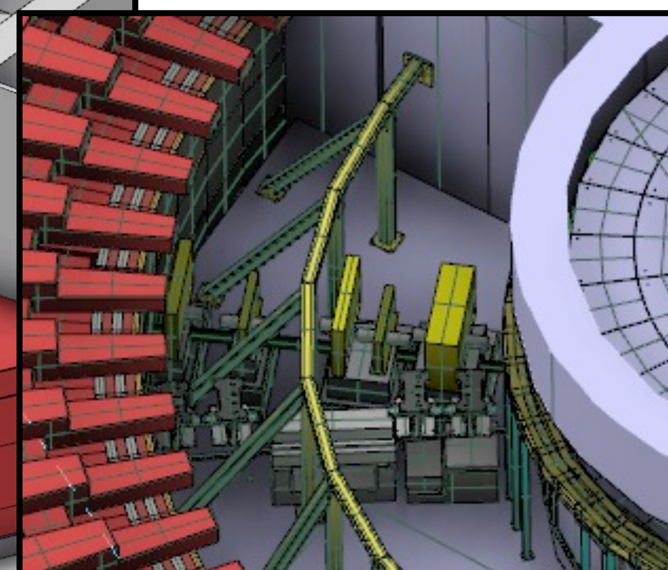




... except in the Bunker, unified zone(s).







How about shielding?

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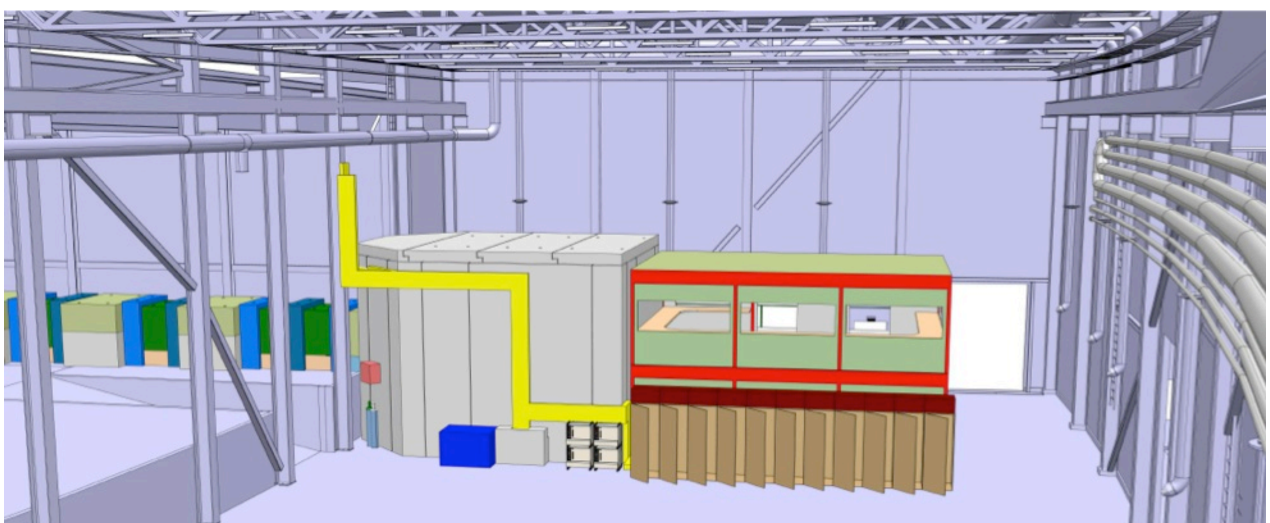
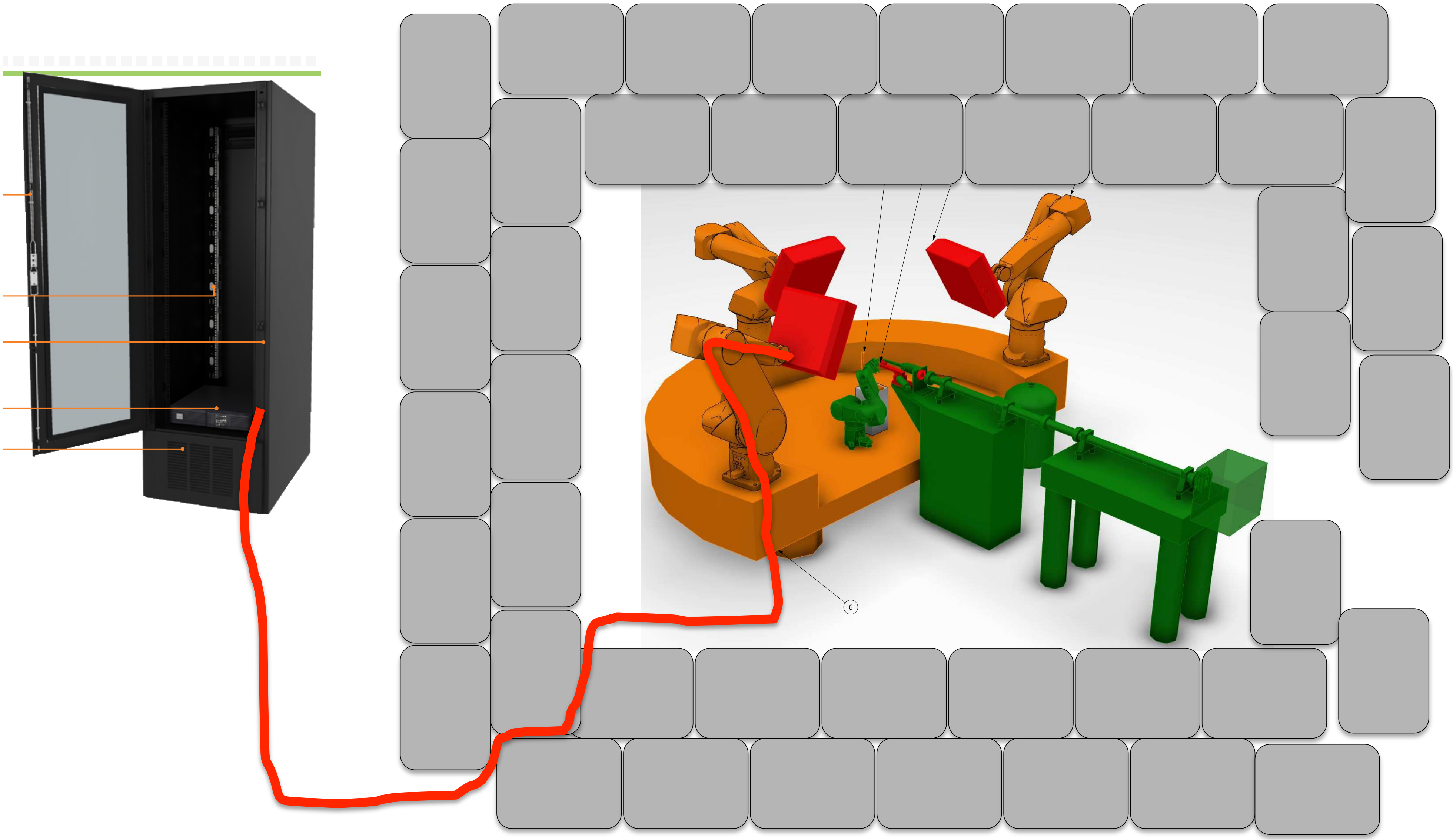
Won’t have a Faraday cage around the cave, racks typically next to or on top.

No budget or space for EMC shielded cabins etc.

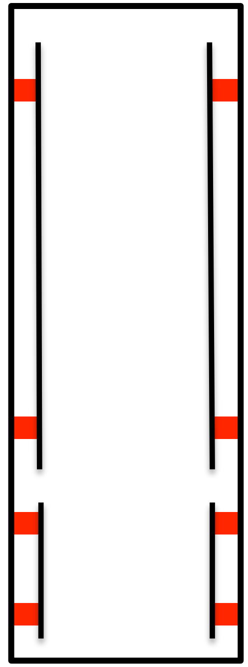


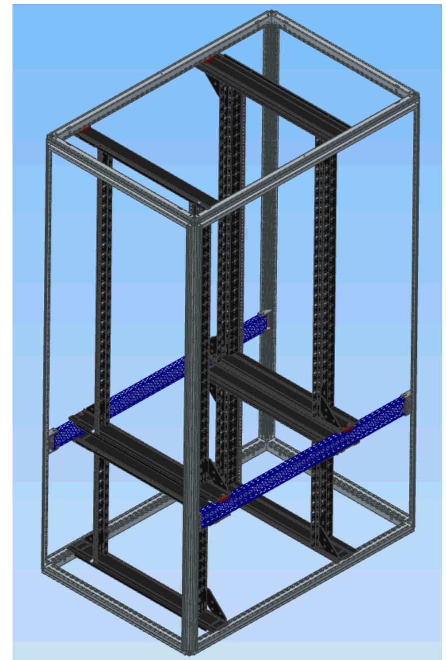
Connections into the Instrument (Detectors)

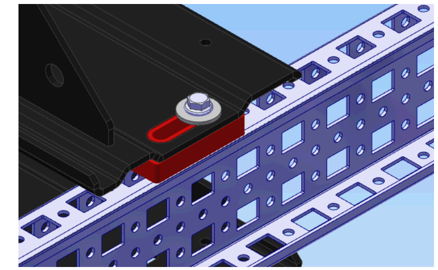


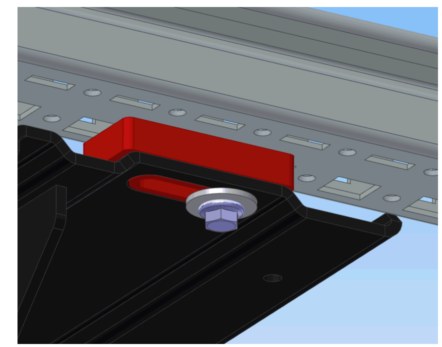
Special care with Racks

ESS Detector Group are prototyping racks with custom grounding, in both normal and 'EMC enhanced' versions (Verotec, Rittal, Pentair/ Schroff)

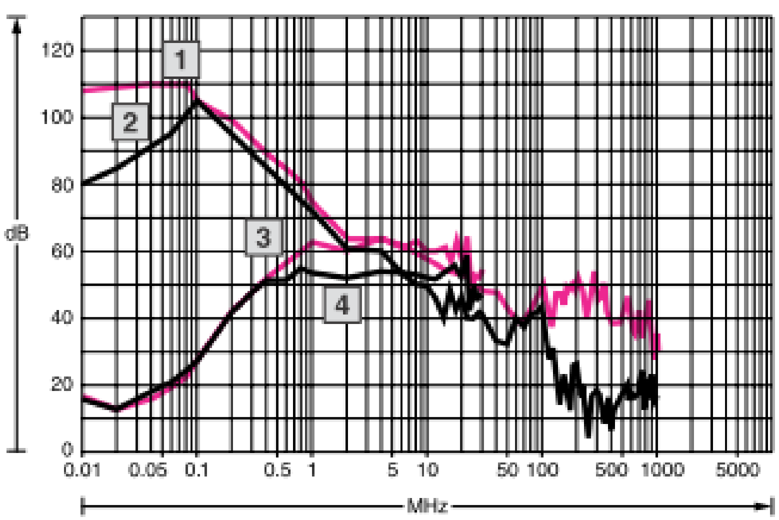








EMC baying systems TS 8



MHz = frequency
dB = RF attenuation

1 E field = Electrical field [V/m] EMC enclosures

2 E field standard enclosures

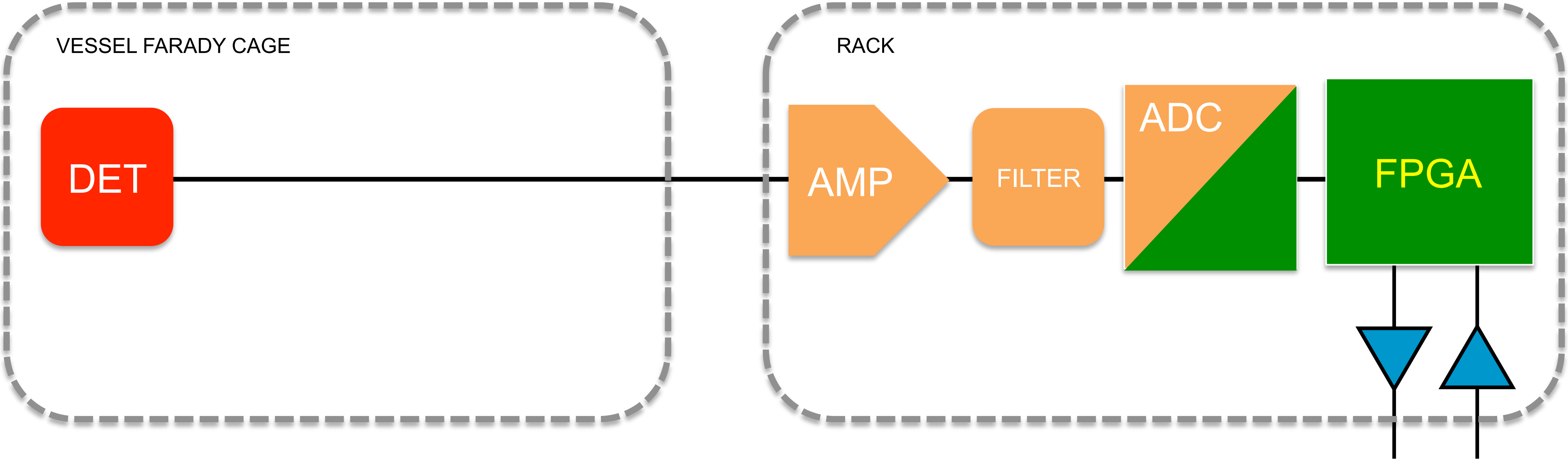
3 H field = Magnetic field [A/m] EMC enclosures

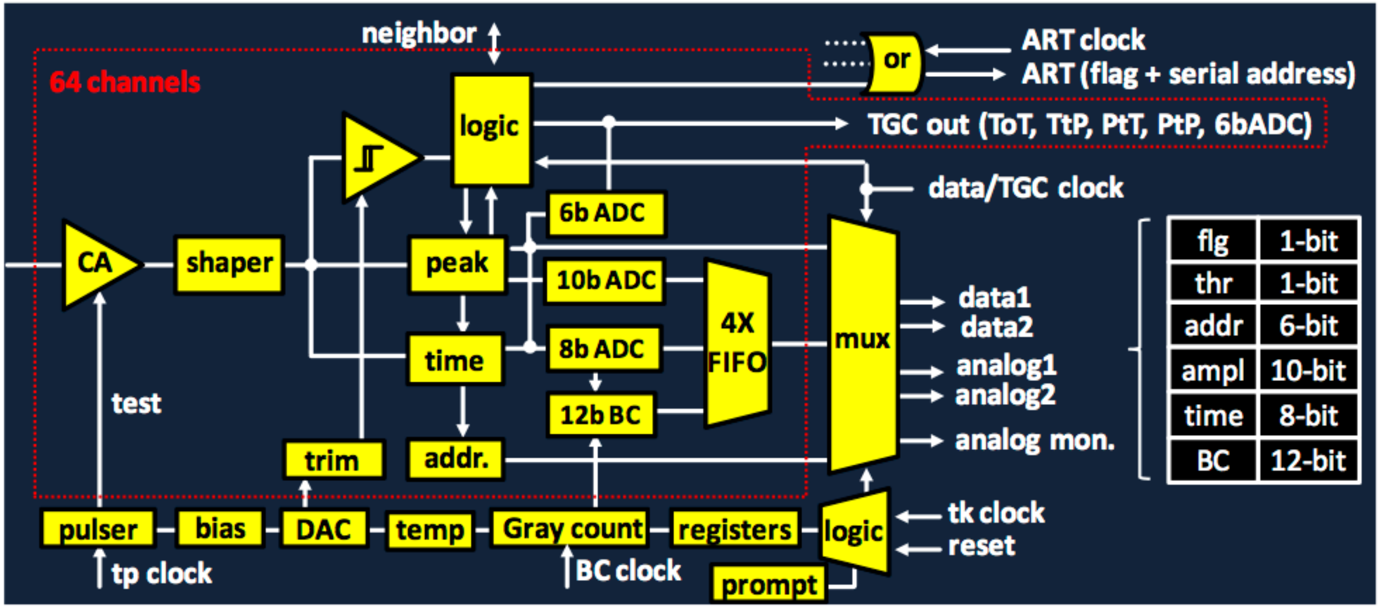
4 H field standard enclosures

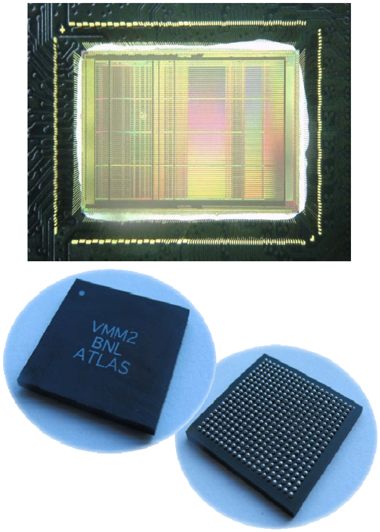
The diagram shows the shielding effectiveness in the frequency range from 0.01 MHz to 1000MHz.

Signals are not a problem !!!!!

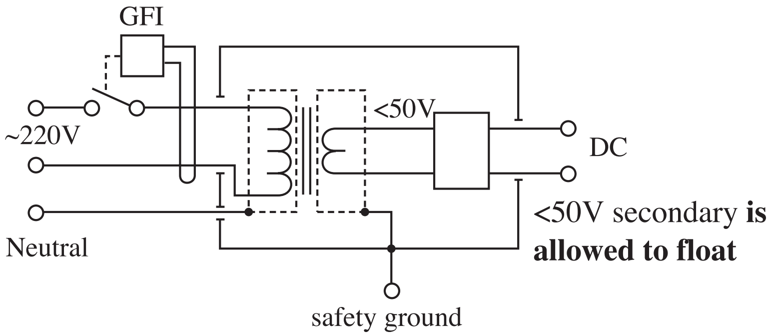
EUROPEAN SPALLATION SOURCE



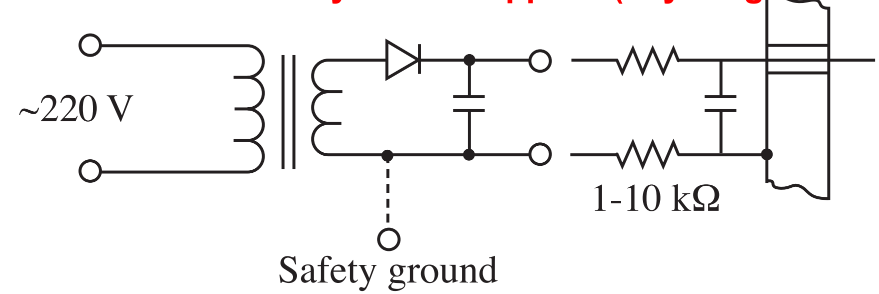


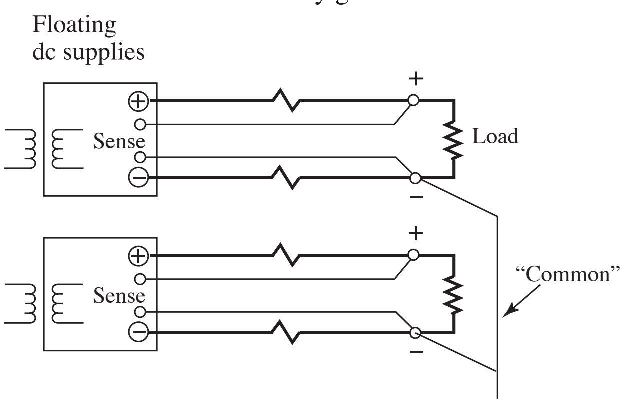


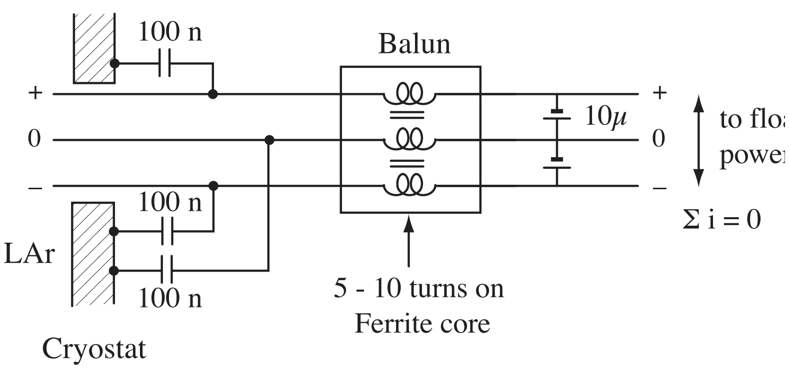
Power supplies can be problematic



Special care with safety on HV supplies (anything over 50V)







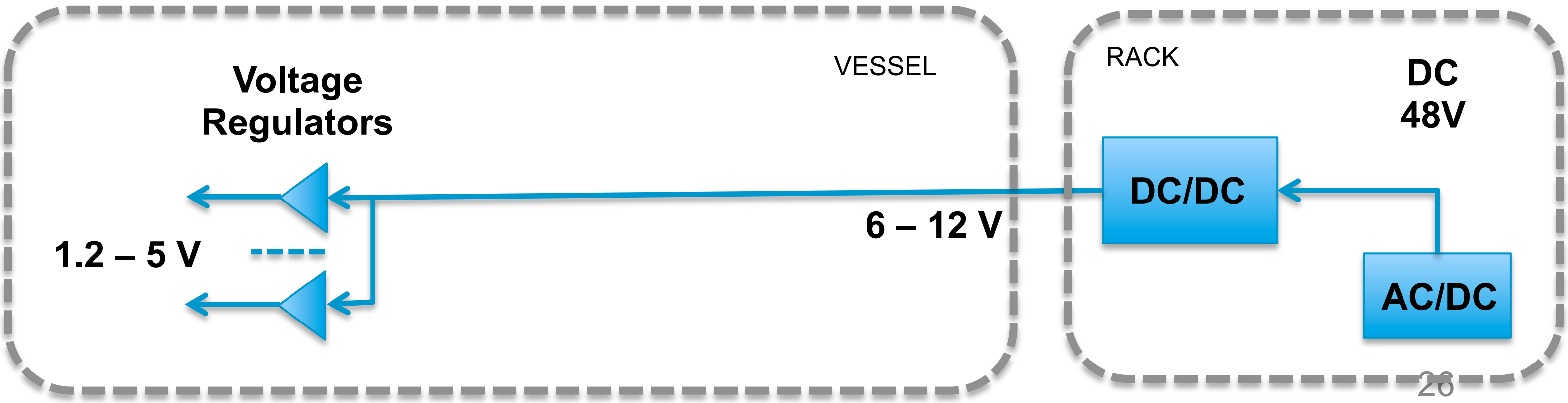
Cable/conduit shielding connections require careful planning.

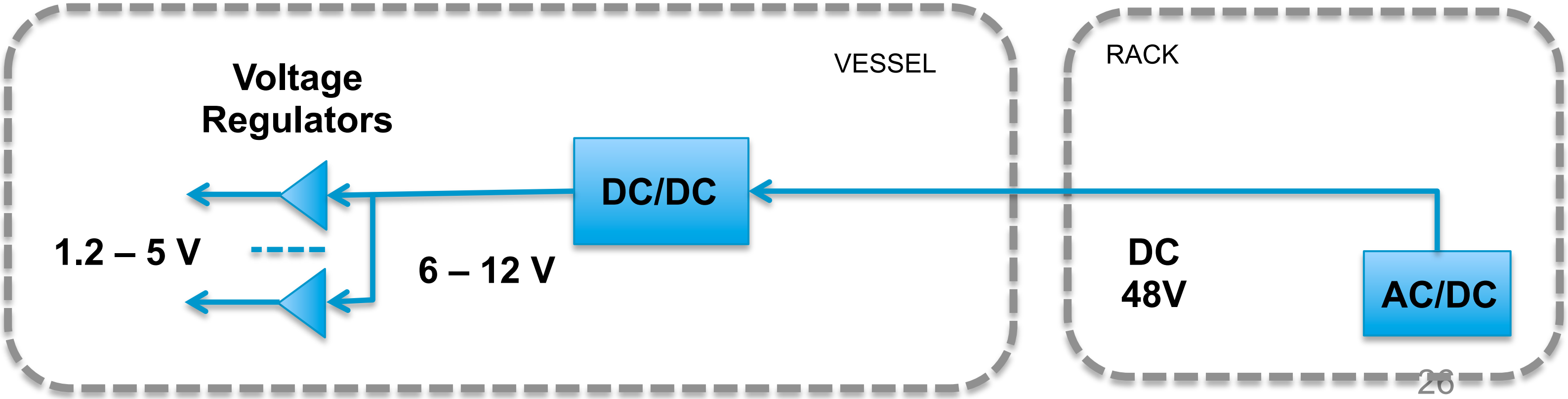
ESS guidelines needed soon

From "SHIELDING AND GROUNDING IN LARGE DETECTORS"

Veljko Radeka Brookhaven National Laboratory

Sometimes best to break the rules...





You might get better noise immunity if you put your (noisy!!) DC-DC inside your vessel

Are compliance standards useful?

EUROPEAN SPALLATION SOURCE

CISPR standards [edit]

CISPR standards generally only relate to EMC emission test methods and limits.

Is acronym of Comité International Spécial des Perturbations Radio [1]

- CISPR 11, Industrial, scientific and medical (ISM) radio-frequency equipment - Electromagnetic disturbance characteristics - Limits and methods of measurement
- CISPR 12, Vehicles, boats and internal combustion engine driven devices - Radio disturbance characteristics - Limits and methods of measurement f… except those installed in the vehicle/b… in adjacent vehicles/boats/devices.
- CISPR 14-1, Electromagnetic compat… for household appliances, electric tools and similar apparatus - Part 1
- CISPR 14-2, Electromagnetic compat… household appliances, electric tools and similar apparatus - Part 2 … duct
- CISPR 15, Limits and methods of me… ance characteristics of electrical lighting and similar equipment
- CISPR 16-1, Specification for radio di… surement apparatus and methods - Part 1: Radio disturbance … easu
- CISPR 16-2, Specification for radio di… rement apparatus and methods - Part 2: Methods of measu… ance
- CISPR 16-3, Specification for radio di… nent apparatus and methods - Part 3: Reports and recon… ISP
- CISPR 16-4, Part 4-1: Uncertainties, … rtainties in standardized EMC tests
- CISPR 22, Information technology eq… tics - Limits and methods of measurement
- CISPR 24, Information technology eq… ty c… and methods of measurement.
- CISPR 25, Vehicles, boats and inte… ngine… characteristics - Limits and methods of measu… otec… of on-board receivers
- CISPR 32, Electromagnetic compatib… equipme… ements

ISO standards [edit]

The following are ISO standards on automotive EMC…

- ISO 11451-1, Road vehicles - Vehicle te… agnetic energy - Part 1: General and definitions
- ISO 11451-2, Road vehicles - Vehic… tic energy - Part 2: Off-vehicle radiation source
- ISO 11451-3, Road vehicles - V… ctrical disturbances from narrowban… energy - Part 3: On-board transmitter simulation
- ISO 11451-4, Road vehicles… or electrical disturbances from narrowband radia… rgy - Part 4: Bulk current injection (BCI)
- ISO 11452, Road vehicle… ces by narrowband radiated electromagnetic energy - Com…
- ISO 13766, Earthmovi… romagnetic Compatibility
- ISO 14982, Agricu… achinery—Electromagnetic compatibility—Test methods and acceptance…

European standards … ing imm… ectrical emissions

- EN 50 082 part1 European … andard, part1: D… ercial and light industry … t, replaced by EN6…
- EN 50 082 part2 European … andard, part2: indu… nt, replaced by EN6…
- EN 50 093 European, imm… dips in the power su…)
- EN 55 020 European, imm… dio interference of broa…
- EN 55 024 European immu… nents for information techn… nt
- EN 55 101 older draft of im… rements for information tech… nt, replace… 024
- EN 50 081 part1 European… ssion standard, part1: Domesti… nd light… ironme…
- EN 50 081 part2 European… quirements for information techno… repl… 1000-6…

European standards concer… ted electrical emissions [edit]

- EN 50 081 part1 European Generic e… part1: Domestic, commercial and light industry environment, rep…
- EN 50 081 part2 European Generic e… part2: industrial environment, replaced by EN61000-6-4
- EN 55 011 European limits and metho… nt of radio disturbance characteristics for scientific and medical equip…
- EN 55 013 European limits and metho… nt of radio disturbance characteristics of broadcast receivers
- EN 55 014 European limits and methods of measurement of radio disturbance characteristics of household appliances and power tools, replaced by EN5501… part is covered by EN55014-2
- EN 55 015 European limits and methods of measurement of radio disturbance characteristics of fluorescent lamps
- EN 55 022 European limits and methods of measurement of radio disturbance characteristics of information technology equipment
- EN 60 555 part 2 and 3 Disturbances of power supply network (part 2) and power fluctuations (part 3) caused by of household appliances and power tools, re… EN61000-3-2 and EN61000-3-3
- EN 13309 Construction Machinery - Electromagnetic compatibility of machines with internal electrical power supplies
- VDE 0875 German EMC directive for broadband interference generated by household appliances
- VDE 0871 German EMC directive for broadband and narrowband interference generated by information technology equipment

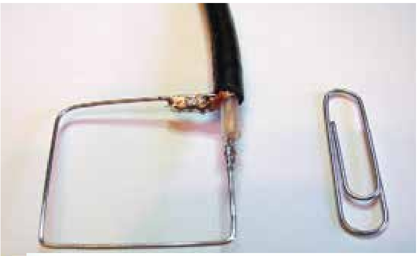
IEC standa…

The IEC standard… tly part of the IEC 61000 family. Below are some examples.

- IEC/TR EN 610… netic compatibility (EMC) - Part 1: General - Section 1: Application and interpreta… l definitions and terms
- IEC/TR EN 6100… tic compatibility (EMC) - Part 2: Environment - Section 1: Description of the … romagnetic environment for low-frequency conducted disturba… n public power supply systems
- IEC/TR EN 61000-2-… mpatibility (EMC) - Part 2: Environment - Section 3: Description … adiated and non-network-frequency-related conducted phenomena
- IEC EN 61000-3-2, Electro… MC) - Part 3-2 - Limits - Limits for harmonic c… nt input current ≤ 16 A per phase)
- IEC EN 61000-3-4, Electroma… art 3-4: Limits - Limitation of e… n low-voltage power supply systems for equipment with rated current greater than 16 A
- IEC/TS EN 61000-3-5, Electromagnetic… uctuations and flicker in low-voltage power supply systems for equipment with rated current greater than 16 A
- IEC EN 61000-4-2, Electromagnetic compatibility (EMC… techniques - Electrostatic discharge immunity test
- IEC EN 61000-4-3, Electromagnetic compatibility (EMC)- Part 4-3: Testing and measurement techniques - Radiated, radio-frequency, electromagnetic field immunity test
- IEC EN 61000-4-4, Electromagnetic compatibility (EMC) - Part 4-4: Testing and measurement techniques - Electrical fast transient/burst immunity test
- IEC EN 61000-4-5, Electromagnetic compatibility (EMC) - Part 4-5: Testing and measurement techniques - Surge immunity test
- IEC EN 61000-4-6, Electromagnetic compatibility (EMC) - Part 4-6: Testing and measurement techniques - Immunity to conducted disturbances, induced by radio-frequency fields
- IEC EN 61000-4-7, Electromagnetic compatibility (EMC) - Part 4-7: Testing and measurement techniques - General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto
- IEC EN 61000-4-8, Electromagnetic compatibility (EMC) - Part 4-8: Testing and measurement techniques - Power frequency magnetic field immunity test
- IEC EN 61000-4-9, Electromagnetic compatibility (EMC) - Part 4-9: Testing and measurement techniques - Pulse magnetic field immunity test
- IEC EN 61000-4-11, Electromagnetic compatibility (EMC) - Part 4-11: Testing and measurement techniques - Voltage dips, short interruptions and voltage variations immunity tests

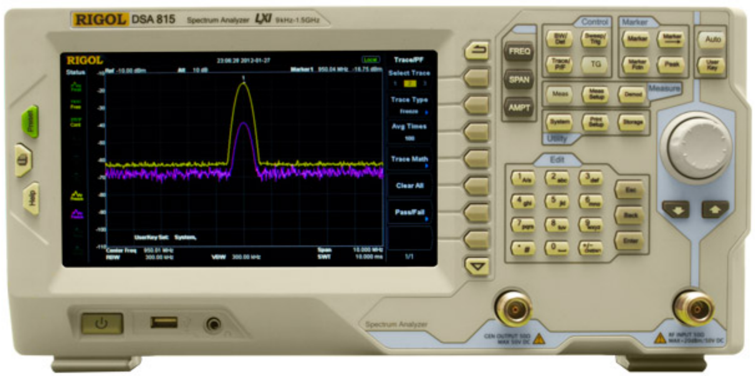
NO

Simple qualitative tests very useful

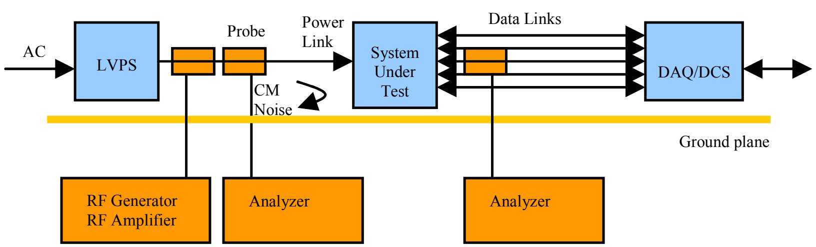


Near field probes, homemade above (Keith Armstrong)

Spectrum analysers, mobile useful, tracking generator can be used for noise injection



Simple bench tests can identify problems early in the prototyping cycle



Conclusion

- ESS is moving into the detailed design phase for instruments and mustn't waste the opportunity to design around a coherent EMC plan.
- Macro level guidelines exist, and the interfaces to Conventional Facilities are set, and not easy to change. Wherever possible we have taken decisions that give us the greatest flexibility.
- We now need detailed guidelines for the implantations within the instrument zones themselves. It is hardware to generalize here, and we will want to learn from best practice elsewhere.