WP2: on-detector power management

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CERN – PH-ESE

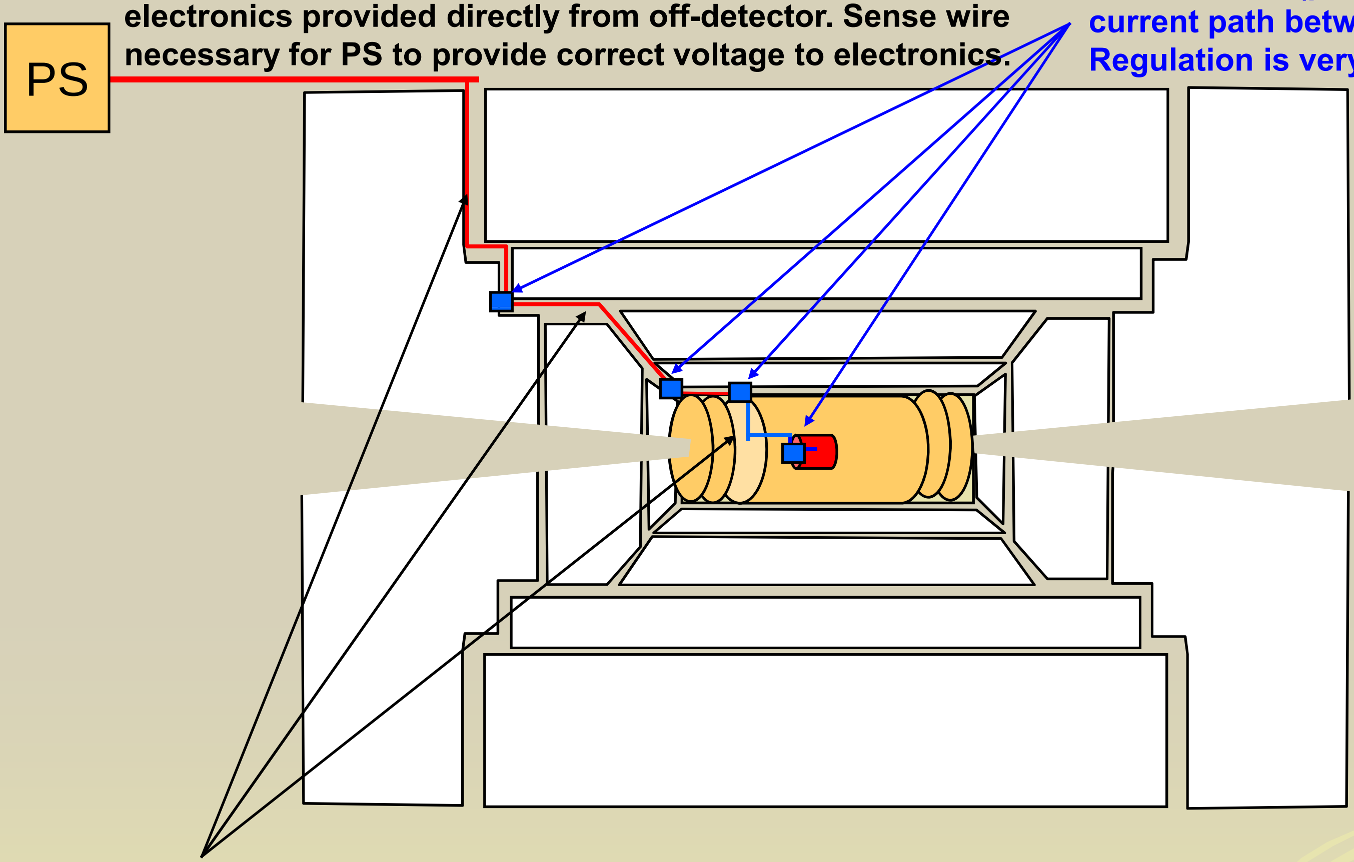
Outline

- Power distribution in LHC trackers
- Projection of power requirements in SLHC trackers
- Distributing power with on-detector switching converters: why and main challenges
- Framework and objectives of WP2
- Summary

Distributing power

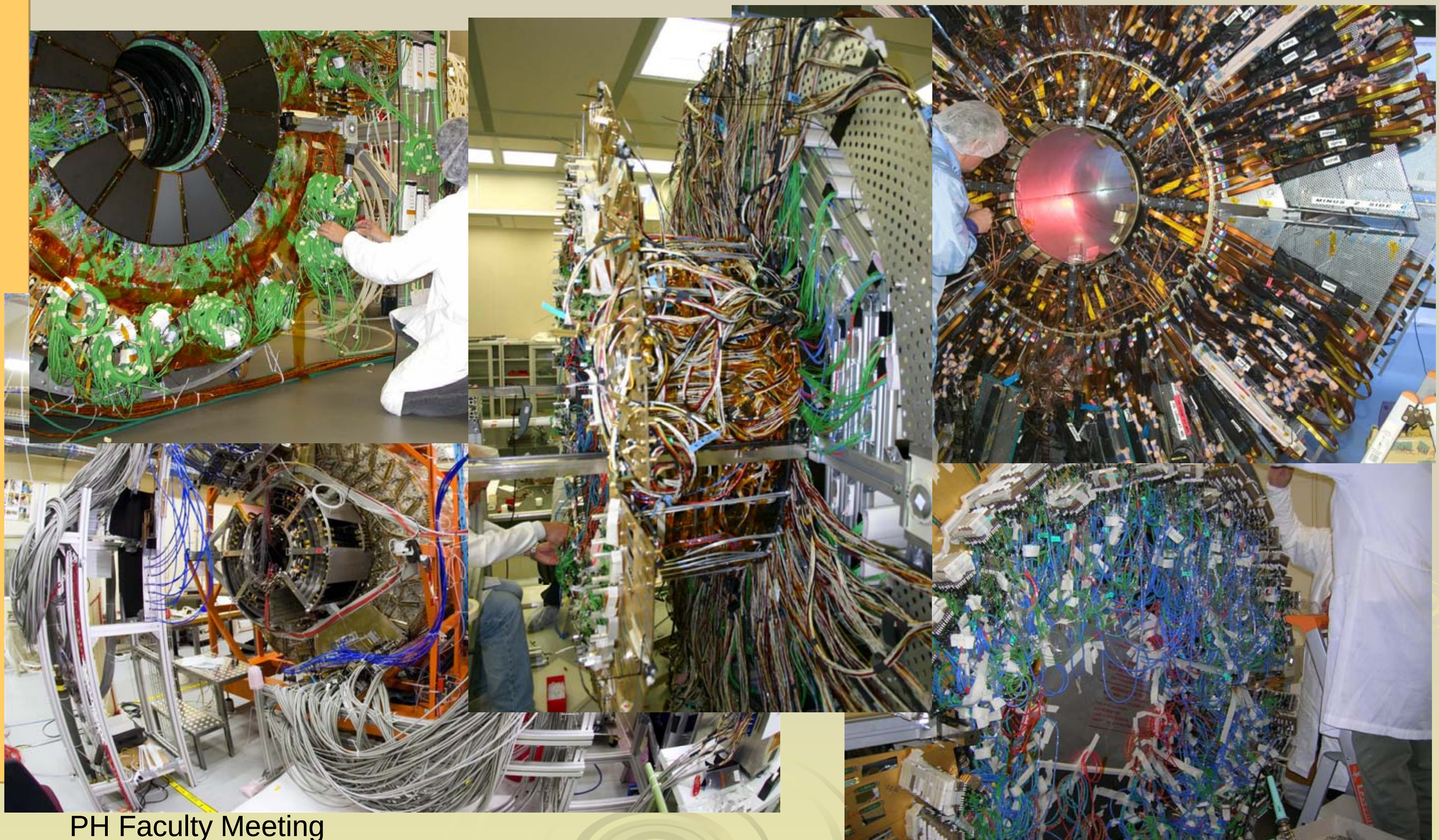
No on-detector conversion. Low-voltage (2.5-5V) required by electronics provided directly from off-detector. Sense wire necessary for PS to provide correct voltage to electronics.

Patch Panels (passive connectors ensuring current path between different cables. Regulation is very seldom used)



Current path from PS to module (or more seldom star of modules) and return. Cables get thinner approaching the collision point to be compatible with material budget.

Distributing power

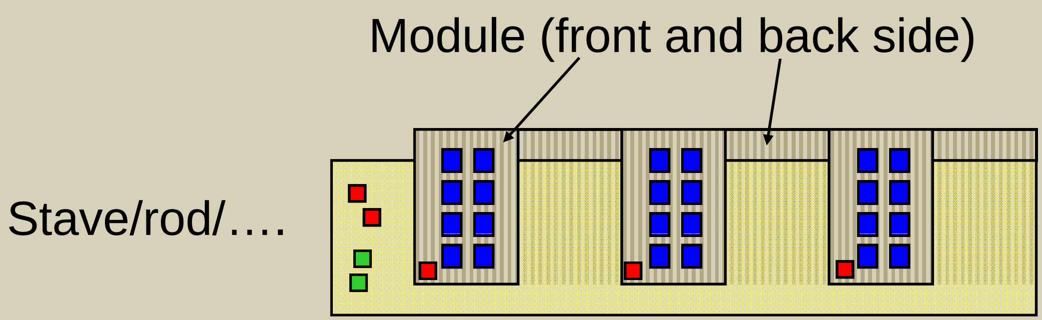


A few numbers

- The following are rough estimates to give orders of magnitude
- Total consumption in CMS tracker (strip + pixels, approximate numbers. Similar situation in ATLAS)
  - 33 kW active + 33 kW on cables (50% efficiency from PS output)
  - 16 kA
  - Considering only the efficiency from the tracker periphery (last patch-panel), it is about 70% - that is 14 kW on cables. With basic “average” assumptions (cable length 10m including return, all copper cables) this is equivalent to about 300Kg of copper in the tracker volume!
- How this scales to SLHC
  - More channels in tracker. Present estimate is an increase in current by factor 2-4. Let’s take 3x for this exercise: 48 kA. Let’s assume FE electronics operating at 1.2 V. Active power = 58 kW
    - Same cables as today: 300 kW lost on cables (1/2 of it inside the tracker). This means about 210 kW of power to be evacuated from the tracker – cooling power 4-5x with respect to present
    - Wishing to decrease the cooling requirements to 2x with respect to present (to a total of 100 kW), cable volume has to increase 3x => about 1 T of copper in the tracker
  - What about a different power distribution system?
  - Load current has to be minimized

Load in SLHC trackers

Projection based on today's view



Blue: **Chips in the readout chain (FE, mux, data concentrator, ….). Larger contributors to power consumption.**

- **130nm/90nm CMOS or BiCMOS**
  - **Analog: 1/3 of total current, maximum Vdd (1.5-1.2V), constant load**
  - **Digital: 2/3 of total current, minimum possible Vdd (1-0.8V), large load variations (3x) related to the presence of trigger signals**

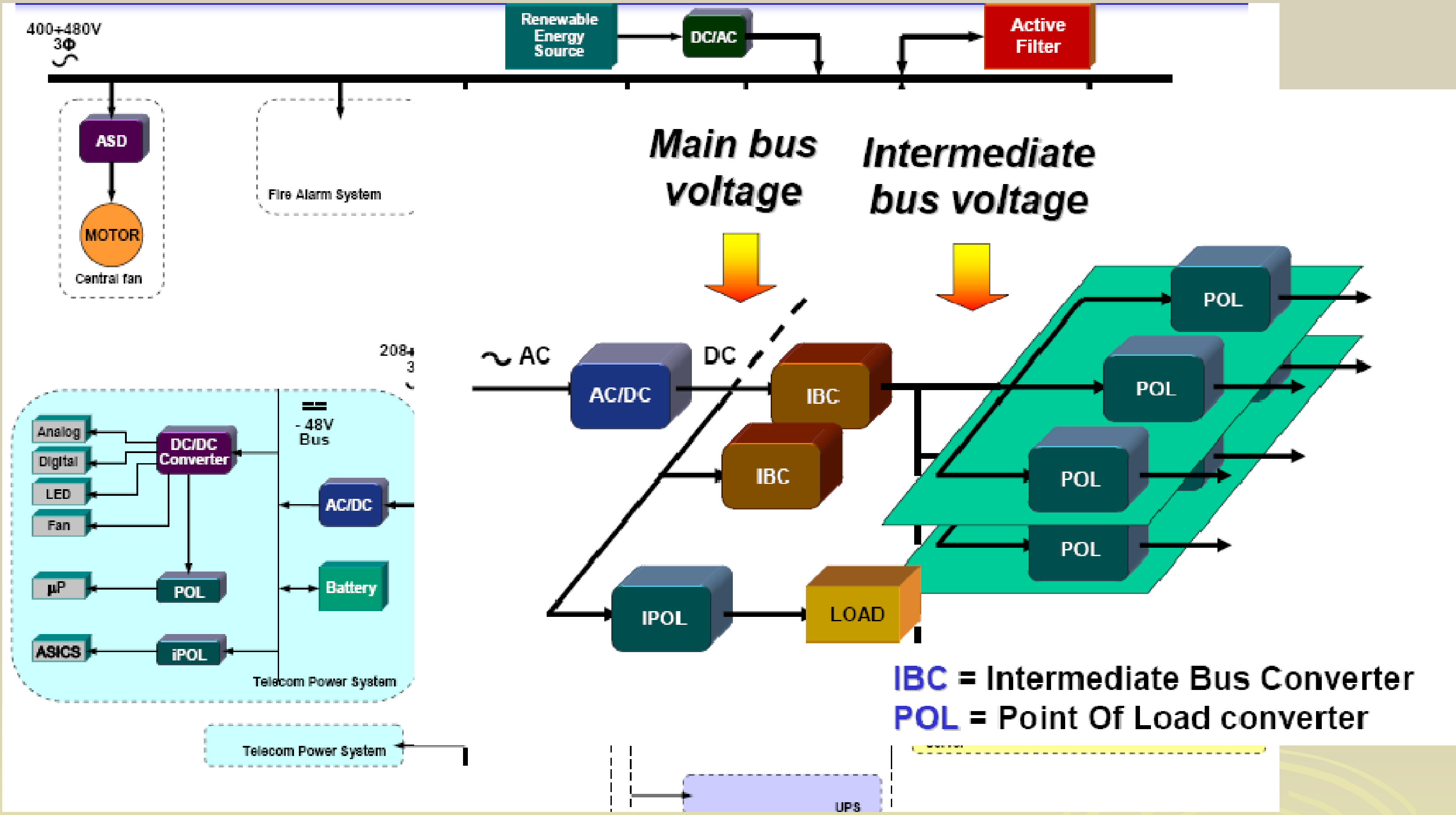
Red: **Chips in the control chain. Same technology as readout chain, mostly digital.**

Green: **Components used in optical data transmission. Some are ASICs (same technology as readout chain), others optical components (LED or VCSEL, PIN diode) requiring larger Vdd (2.5V).**

Load in LHC trackers: summary

- Several different voltages on stave/rod:
  - Optoelectronics components
  - Analog electronics on ASICs
  - Digital electronics on ASICs
- Main current consumption changes in relation to the presence of trigger signals
- To achieve high efficiency, the power distribution system shall be capable of delivering <u>the minimum required power at any time</u>

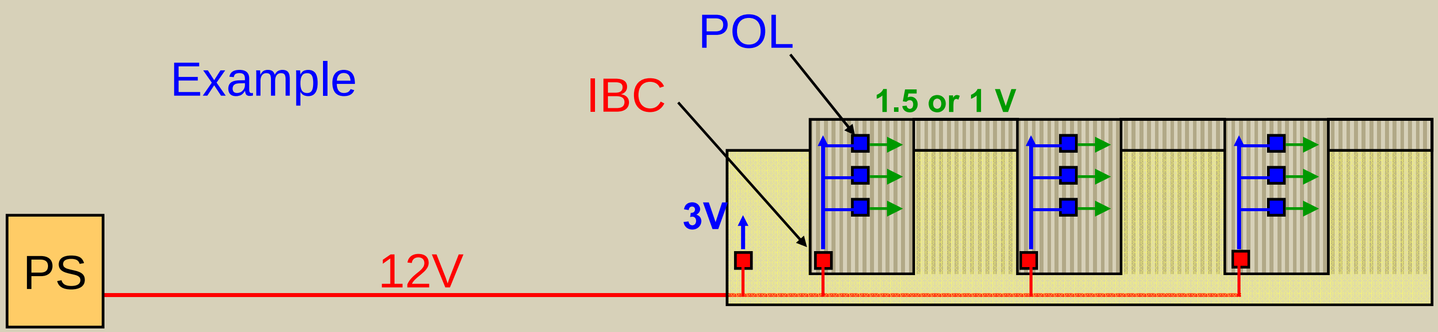
Power distribution in computers and telecom



Conversion is performed in several stages for high efficiency and modularity.
POL converters provide regulated power to the loads when needed.

How to apply this to SLHC

- Distribute power at higher voltage (for example 12V) to the stave/rod. Since P = I*V, same power can be transferred with much lower current.
- Convert locally (stave or module) to lower voltage, higher current.

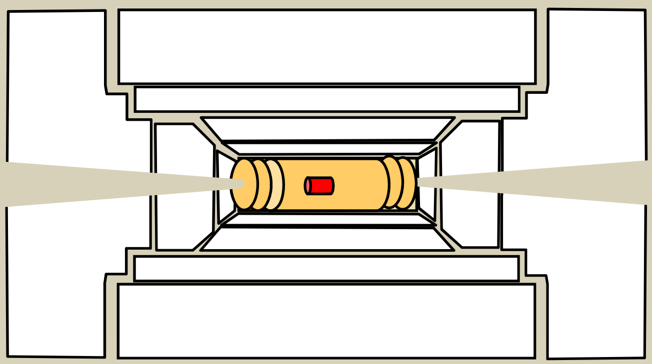


- Modularity
  - Each POL converter can be switched off/on independently at any time
  - Several different voltages can be distributed on-module from 1 power cable/stave
- Efficiency
  - Each "load" gets the appropriate current and voltage at any time, not more!
  - Cable volume can be reduced with respect to independent powering (LHC scheme):

Example **Module: 2A @ 1V + 1A @ 1.5V = 3.5W**
Stave: 20 modules = 70W
⇒ **About 7A on the 12V line (instead of 60A)**
Power wasted on cable: RI^2
=> Still 7x smaller for cable 10x smaller!

Challenges

- Converters to be placed inside the tracker volume



Magnetic field (up to 4T)

Radiation field (>10Mrd)

Environment sensitive to noise (EMI)

- That's why we need an R&D

Challenges: magnetic field

- Commercial transformers and converters use ferromagnetic compounds. These materials unfortunately can not be used in a 4T magnetic field…

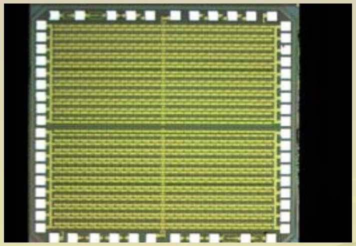
Material	Max. μ	Saturation B(T)
Coldrolled steel	2,000	2,1
Iron	5,000	2,15
Purified iron	180,000	2,15
4% Silicon-iron	30,000	2,0
45 Permalloy	25,000	1,0

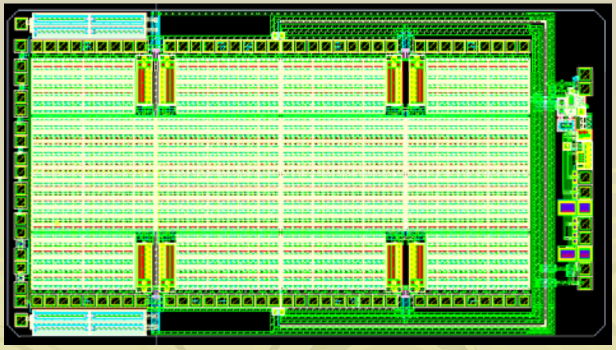
Material	Max. μ	Saturation B(T)
Hipernik	70,000	1,6
Monimax	35,000	1,5
Permendur	5,000	2,45
2V Permendur	4,500	2,4
Hiperco	10,000	2,42

- We are forced to use coreless (air-core) inductors. This has a big impact on the available inductance magnitude, hence on the design of the converter.
- Air-core inductors can also be manufactured in different configurations (planar, solenoidal, thoroidal, ….) and a choice should be made
- Alternative solutions not using inductors are base on switched capacitor topologies. These typically offer no regulation, and the integration of high-efficiency high-current converters is very difficult

Challenges: radiation field

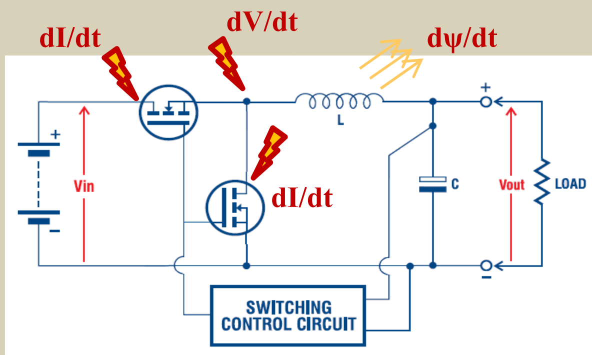
- The converter requires the use of a technology able to work up to at least 15-20V. Such technology is very different from the advanced low-voltage (1-2.5V) CMOS processes used for readout and control electronics, for which we know well the radiation performance.
- We need to find a suitable technology (typically developed for automotive applications) and develop radiation-tolerant design techniques enabling the converter to survive the SLHC radiation environment (more than 10Mrd).
- We have a good candidate now, in the 350nm node. Radiation tests give good results. This can be used in the first prototyping phase.
- For the final product, use of a more advanced technology (180 or 130nm node) would be extremely beneficial.

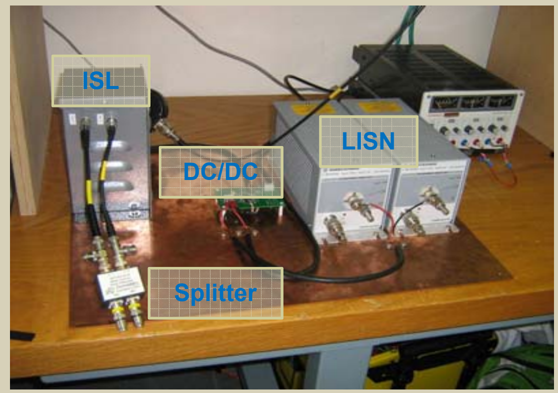




Challenges: EMI

- The detector performance is influenced by noise.
- Introducing switching converters inside the detector might add another source of noise. Switching implies swift variations of V and I, that can be capacitively (V) and inductively (I) induce noise within the detector system. The variation of magnetic field within the inductor can also matter.





- Sources of noise have to be understood and mastered. Techniques to minimize noise have to be exploited (for instance the choice of the converter topology, its layout, the pcb design, the position and size of the capacitors all have important influence on noise).
- This study has begun with the development and construction of a reference test bench enabling systematic measurements of conducted and radiated noise. The image to the right shows it.

Framework

- On-detector power management indicated as crucial common problem at ACES07 (joint ATLAS-CMS workshop) and at TWEPP07
- Activities aimed at proposing and validating solutions have started and are being coordinated:
  - ATLAS and (more recently) CMS both have Power Distribution working groups
  - A common Working Group has recently been formed (first meeting April 7 @ CERN)
  - A work package on this theme has been included in the approved “SLHC-PP” Preparatory Phase within EU FP7-Infrastructures programme (WP8). Participants are CERN, STFC (UK), University of Bonn (DE), AGH Cracow (PL), PSI (CH). Solutions based on both serial powering and the use of switched converters are included
    - Within this framework, CERN has committed to the study and prototyping of switched converters

Specific objectives of WP2

- DC-DC conversion (core activity, in line with commitment for SLHC-PP WP8)
  - Exploration of alternative conversion schemes to select the most suitable solution for SLHC applications
  - Development of prototypes (demonstrators)
  - Integration of prototypes in detector modules
- DC-DC conversion (extension within WP2)
  - Seek consultancy from experts in power electronics to get know-how. Power conversion requires very specialized electronics knowledge
  - Exploration of solutions based on piezoelectric transformers (transformers using piezoelectric effect to transfer energy from primary to secondary)
  - Survey of the available high-voltage CMOS technologies to prepare final integration phase in a few years time (to benefit from advances in technology). NB: the main issues are availability and radiation tolerance!
  - Optimize the design of the inductor (air-core)
- Linear Voltage regulation (extension within WP2)
  - Develop a design for a generic LDO regulator
- Time frame
  - 3 years

Conclusion

- Power distribution in SLHC trackers is such a unique engineering problem because of magnetic and radiation fields. It therefore requires specific development.
- Large consensus indicate power distribution requires a common and priority effort of HEP community
- Existing activities in this direction are coordinated via specific (ATLAS, CMS) and common Working Groups, and via the SLHC-PP effort
- WP2 is CERN contribution to address this issue. Its main focus is the study, development and integration of switching DC-DC converters.