The powering scheme of the CMS Silicon Strip Tracker

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B1 61302 leaving Boston towards Sleaford, March 30th 1965

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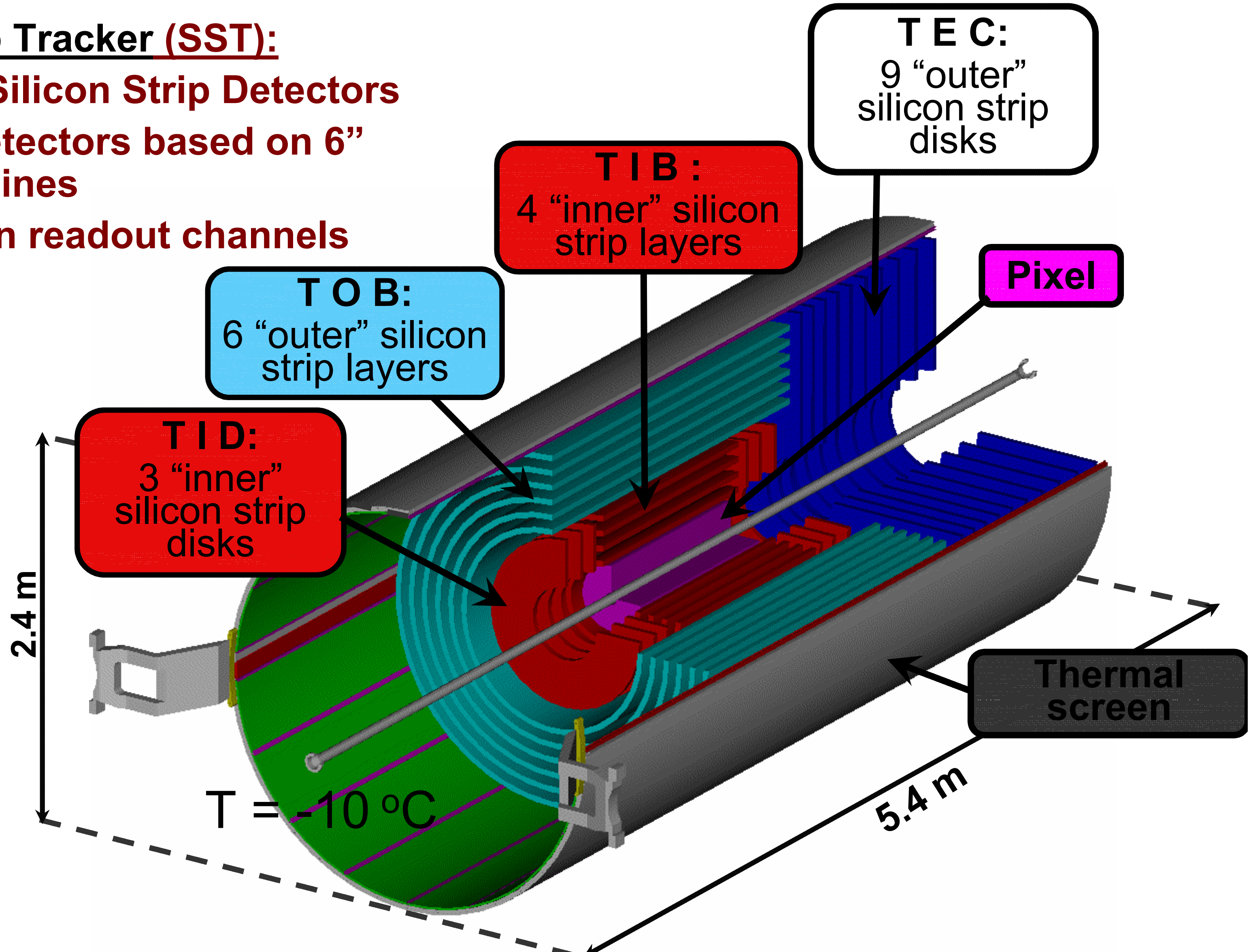
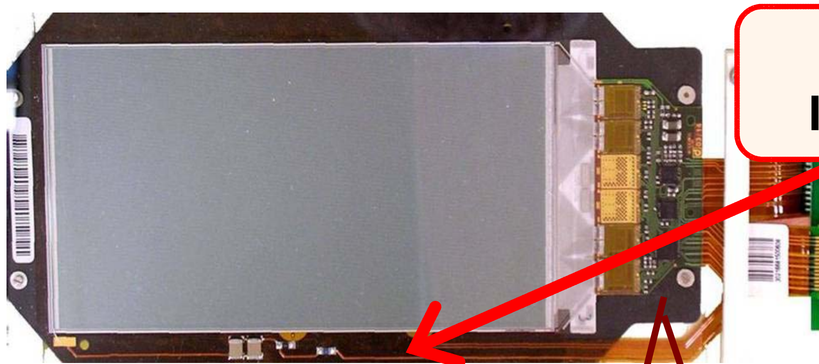
The CMS Central Tracker

Silicon Strip Tracker (SST):

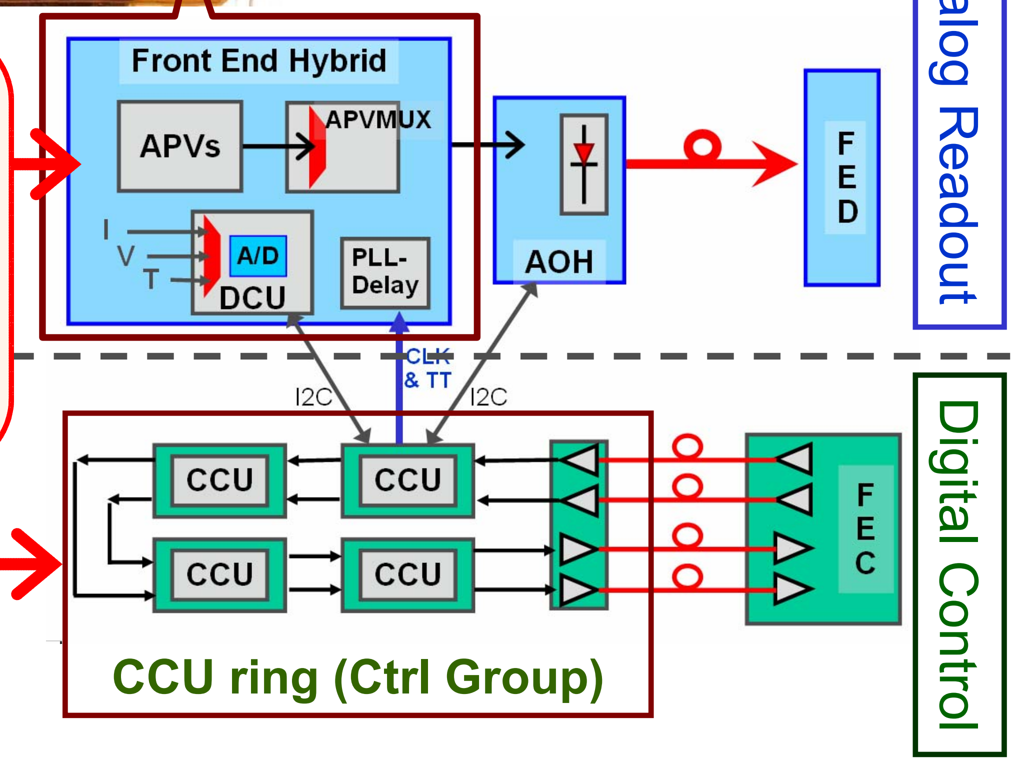
- **210 m^2 of Silicon Strip Detectors**
- **~ 15000 detectors based on 6" industrial lines**
- **~ 10 million readout channels**



Module Power Requirements



HV bias: 0 – 600 V
I_{LEAK} ~ 0.1 ÷ 500 μA



+2.5 V and +1.25 V

Tot FE Hybrid consumption (± 20 %):

4 APV:	6 APV:
1.6 W	2.4 W
$I_{2.5}$ ~ 510 mA	$I_{2.5}$ ~ 750 mA
$I_{1.25}$ ~ 260 mA	$I_{1.25}$ ~ 390 mA

+2.5 V
~ 5 W

Power Groups

Silicon strip modules are conveniently grouped into **1944** "**detector power groups**" to share the power for the analog electronics and the sensors.

- Detectors in the same power group share also:
  - cooling services
  - control services
- Grouping criteria are:
  - the mechanics;
  - the density of channels.

Number of detector power groups:

TIB	368
TID	120
TOB	688
TEC	768
Total:	**1944**

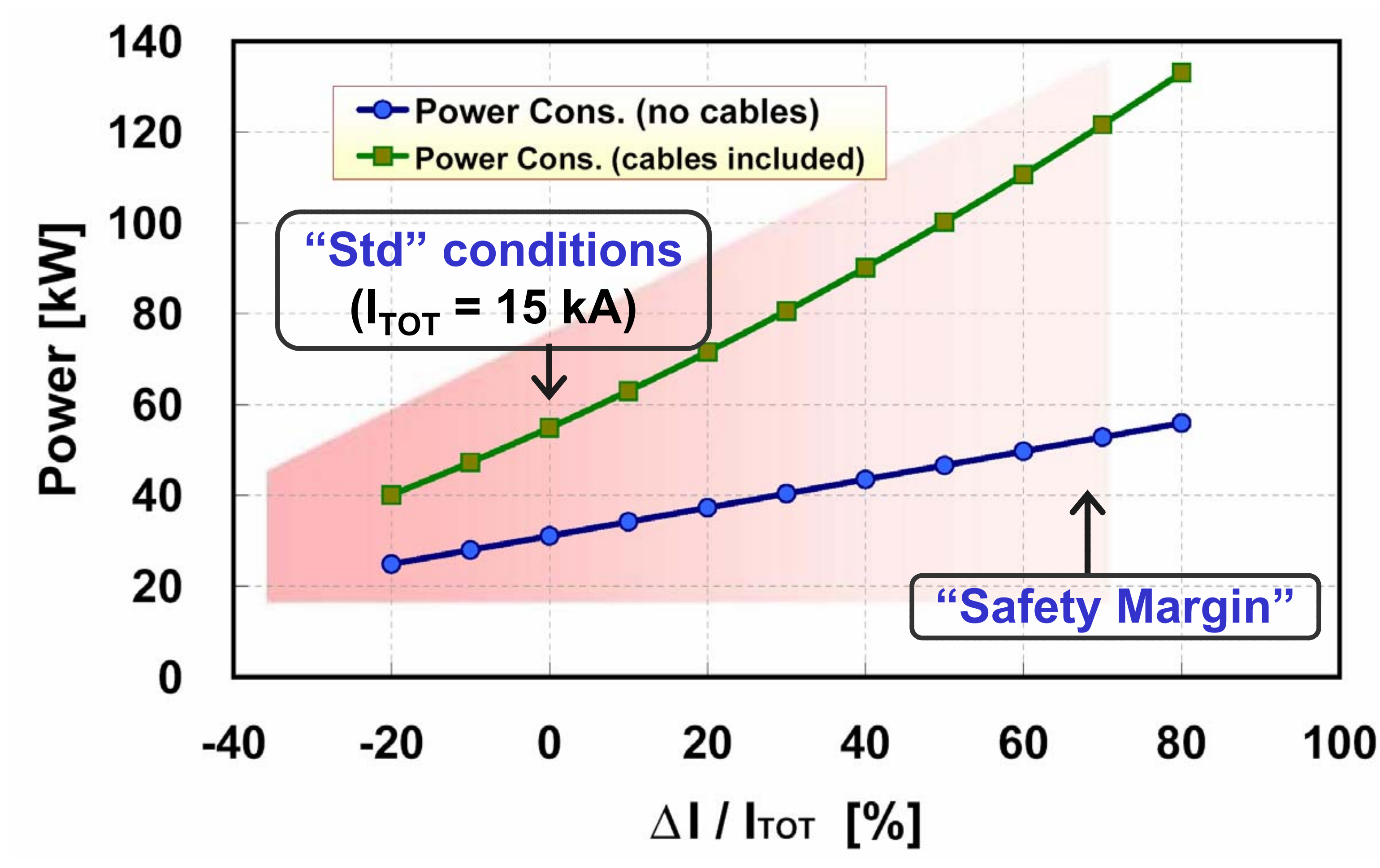
	n. APV	$I_{2.5}$ [A]	$I_{1.25}$ [A]	Pw [W]
Avg./group	37	5.2	2.4	16.0
Max/group	56	7.6	3.6	23.7
Min/group	12	1.6	0.8	4.9
Total	**72 784**	**10 066**	**4 731**	**31 079**

I_{TOT} ~ 15 kA

The digital control electronics requires a distinct powering system.

- Each one of the **352 CCU-rings** is powered by one power source.
- The total power consumption of CCU-rings is less than **2 kW**

Total Power Required



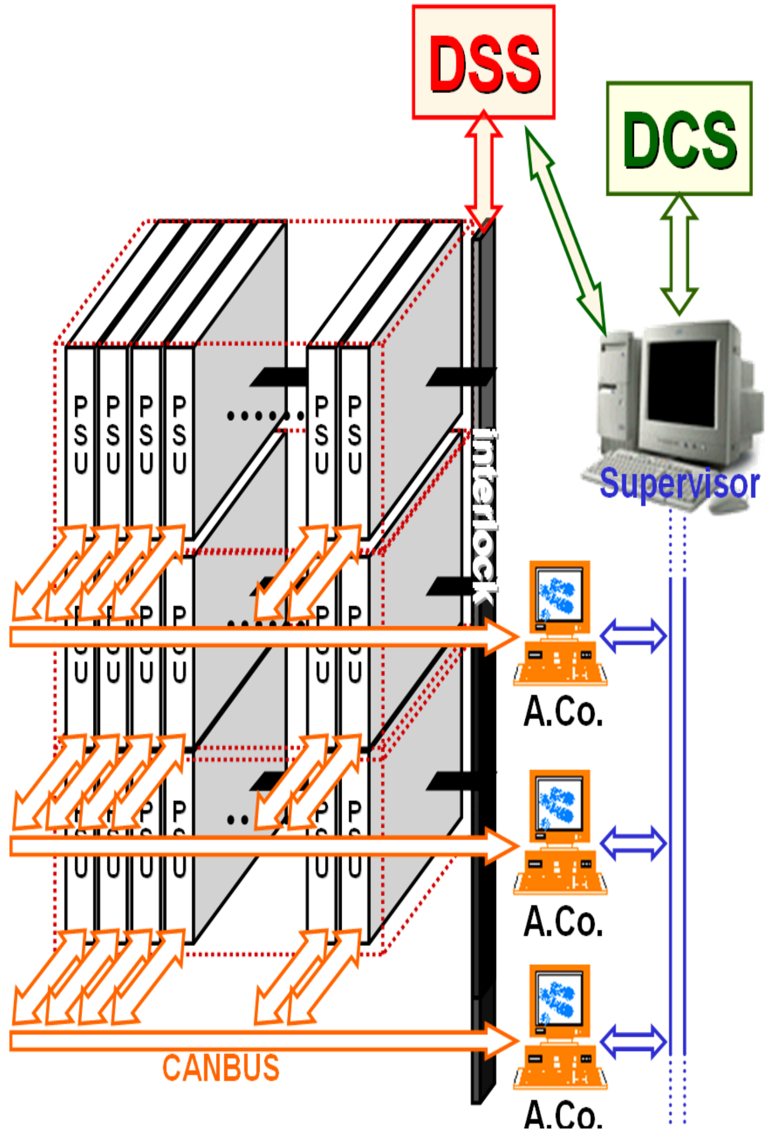
Key design considerations

The power supply project was initiated by the Florence CMS group according to the following guidelines:

- Modular system, based on:
  - Power Supply Units (**PSU**) for the detector groups equipped both with LV and HV regulators;
  - PSUs for the control groups (CCU-rings) integrated into the detector powering system;
- LV regulator outside the tracker volume
  - $\Rightarrow$ sense wires technique to be deployed
- Hard-wired safety systems

Power Supply System Scheme

– PSUs are powered by two independent +48V DC lines:
  - The **power (VP)** for PSU voltage regulators, provided by the 400 V/400 Hz facility of CMS ("Power Units");
  - The **service (VS)** for PSU control circuitry (easily backed-up for ~ 1 minute);
– PSUs are lodged in standard crates (19" X 6 U) and controlled by a set of external **Array Controllers** (A.Co.)
– A.Co. are interfaced to the "Detector Control System" (**DCS**) and to the "Detector Safety System" (**DSS**) via Supervisor units;
– Crates provide **Interlock** and **Reset** bus lines

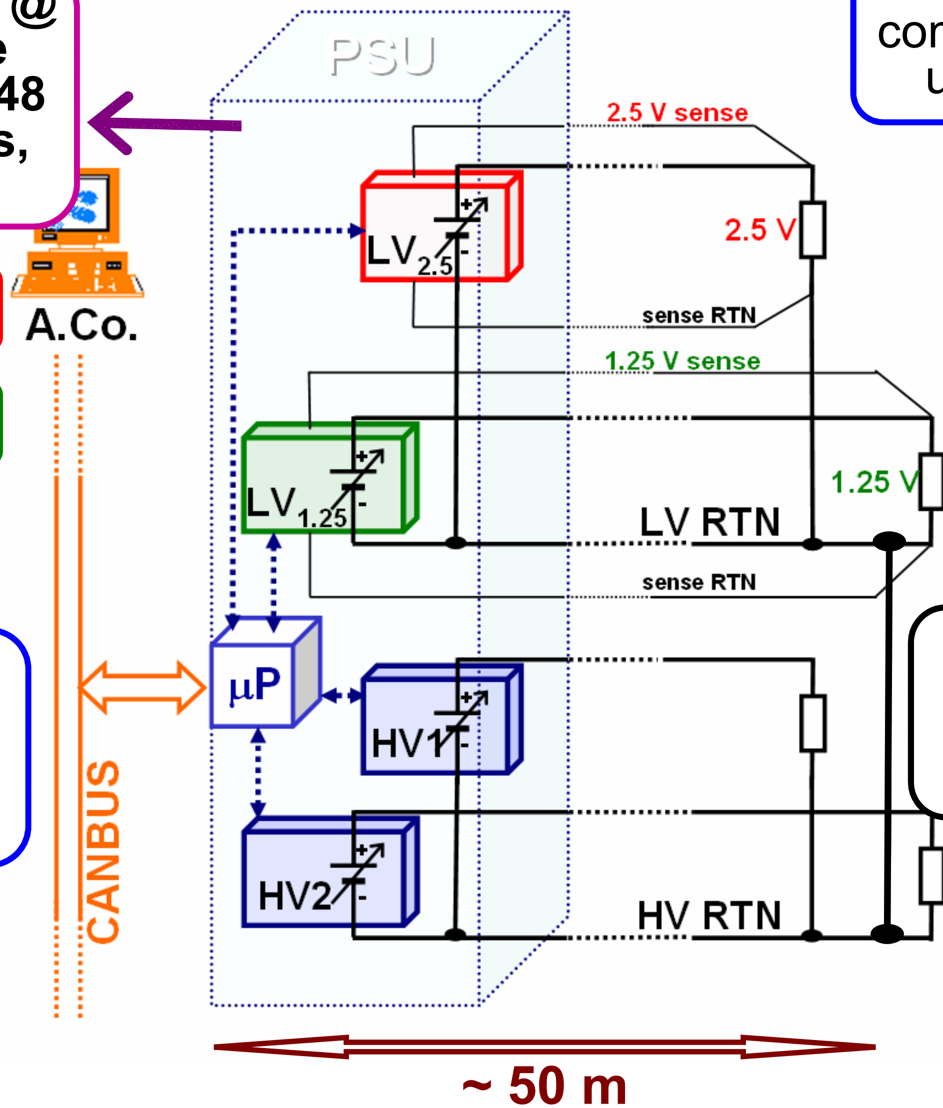


The PSU

~ 100 Ω isolation @ 5 MHz from the surroundings (+48 Vdc, other PSUs, etc...)

I_{MAX} = 13 A

I_{MAX} = 6 A



V_{DROP} compensated up to **4 V**

RTN lines are connected at the detector's side

On-board µP: controls and monitors the regulators.

Different reference voltages

Hardware PSU Safeties

Current Limiters:

– keep currents out of regulators within the Current Limit (CL) value (s/w settable)

– set the Over Current status (OC);

Low Voltage Comparators:

– set the Over Voltage status (OVV) whenever:

- the voltage difference of any sense wire pair is outside a fixed range (protects also against sense wires shorts and exchange);
- the voltage output at the connector of any voltage regulator is outside a fixed range;

Switch OFF

– Switch off all regulators whenever the OVV status lasts for more than the timeout period

Temperature Sensors:

– Inhibit all V regulators if T > 70 ^{o}C

Trip procedure:

The μP rumps regulators down if:

- OC lasts for more than ~1s
- OVV lasts for more than 10 ms

Alarms/Interlocks

Reset:

- the PSU ramps voltages down to zero. The reset may be addressed:
  - by the Array Controller;
  - by the manual Reset Button;
  - by the General Reset on the crate;
  - by the watch-dog circuit in case of μP failure.

Interlock:

- forces each PSU μP to ramp voltages down to zero;
- only when the interlock signal is removed the PSU can be used again.

48 Vdc failure:

- generated by the power distribution network
- triggers the fast ramp down of all voltages and protects from the 48V bounches.

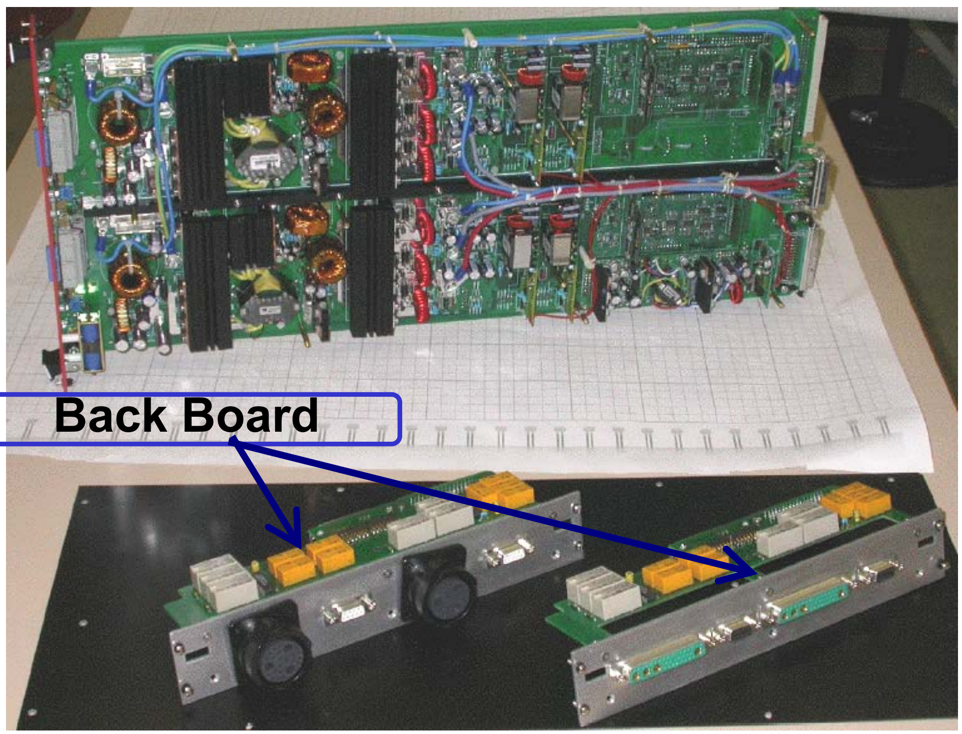
PS System implementation

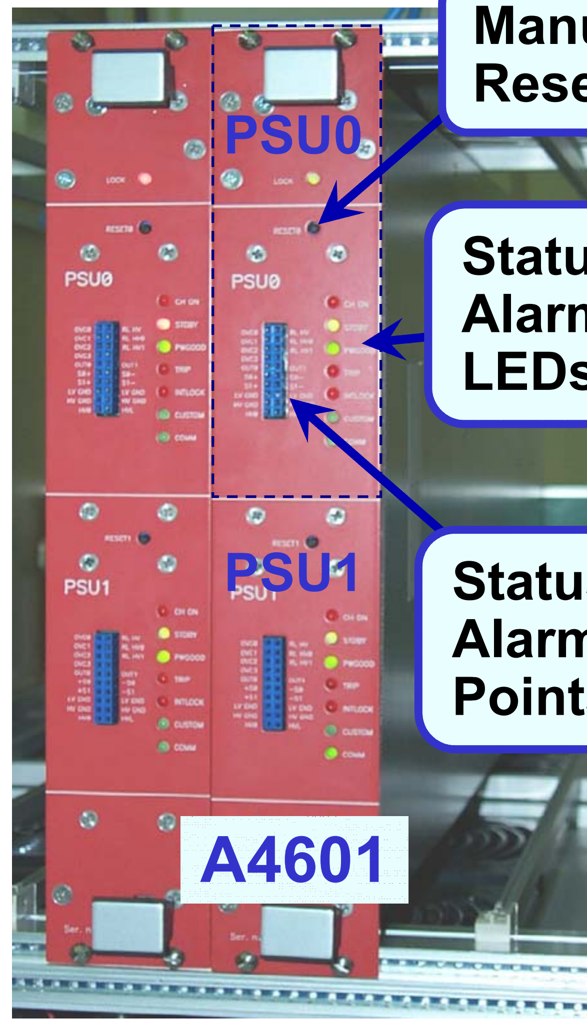
After going through the construction and the test of few PS prototypes the designed system has been successfully implemented using CAEN technology. In the following the description of the main parts.

The power supply system was approved by CMS and it is going to be supplied by CAEN S.p.A.

The Power Supply Module

Two PSUs are lodged inside one mechanical drawer (6U x 55 x 4.4 cm^2) to form the “Power Supply Modules” (PSM)

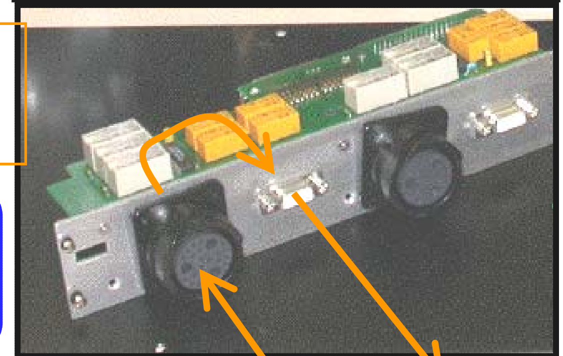




The Crates

Back Boards

(HV fanout, custom area)



Routing of T,H probes output (from inside the tracker)

to DSS

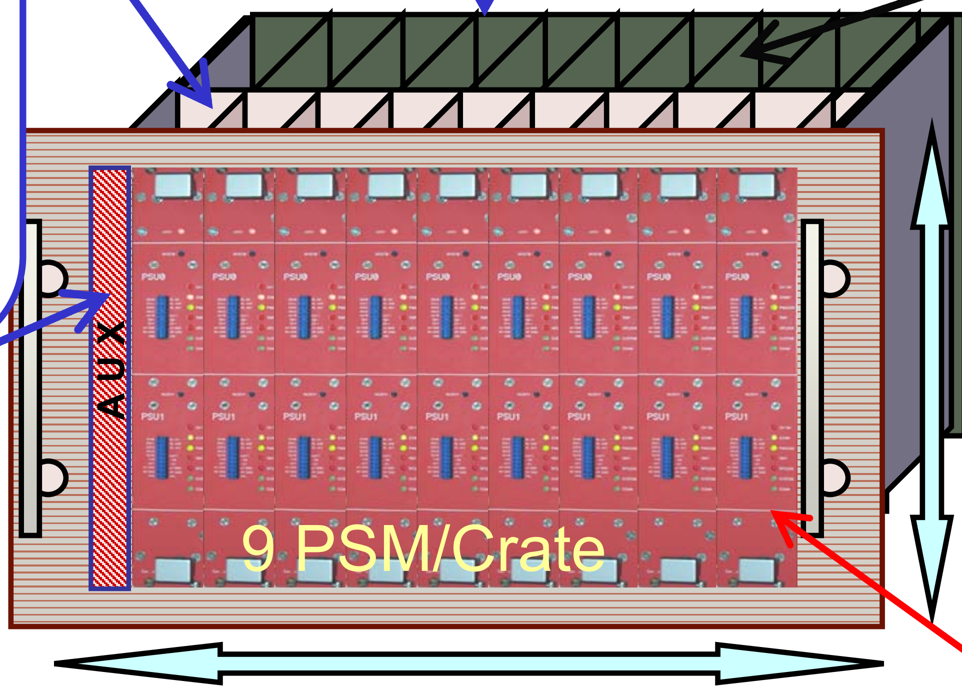
From T,H probes in the tracker

Back Plane 1

- Module Connectors
- Cu bars for +48 VP
- Cu bars for +48 VS
- CANBUS communication lines
- "General Reset" signal track
- 6 interlock lines
- +48 VP/VS signal tracks

Back Plane 2

(Cable Connectors)



6 U

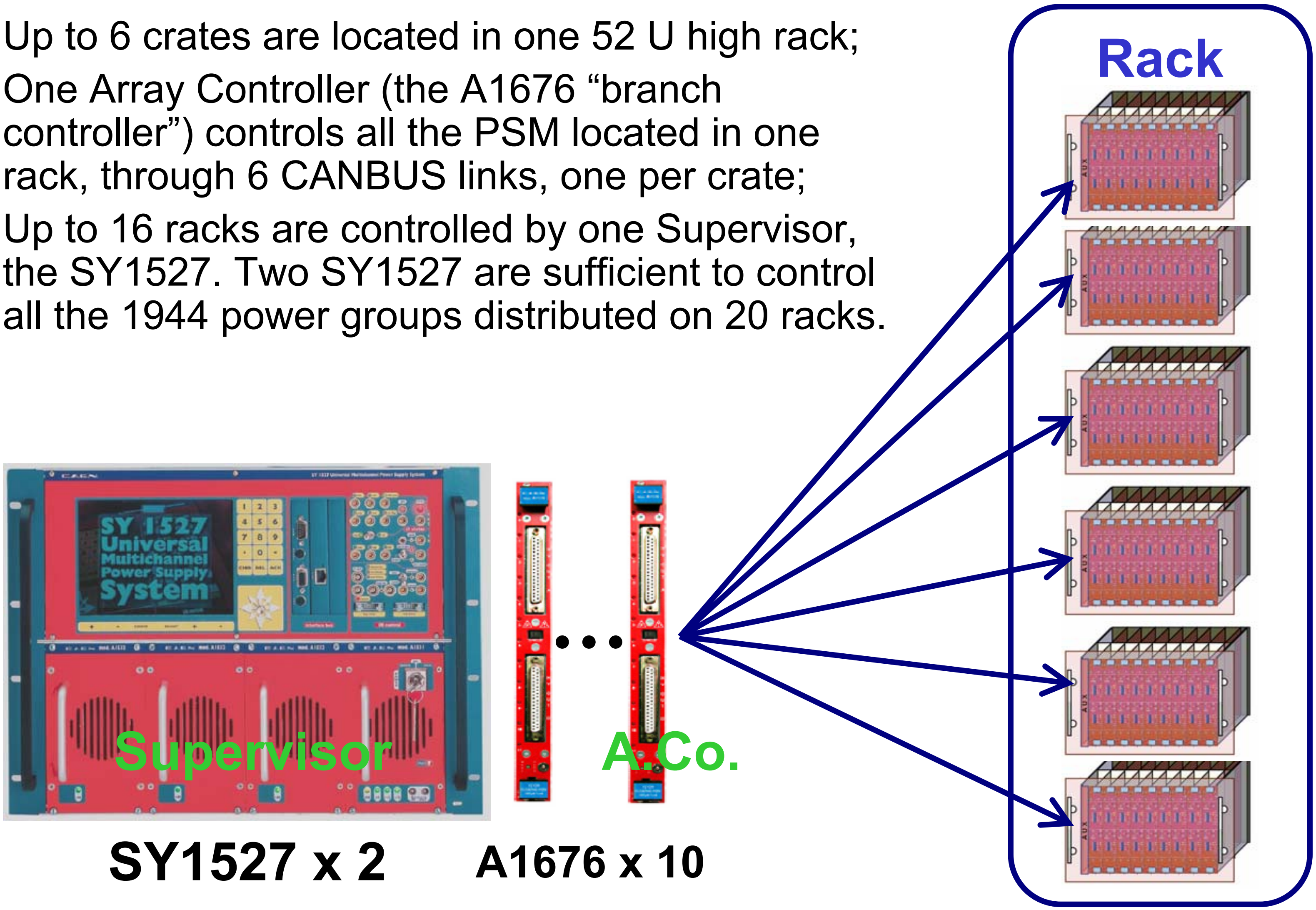
19''

Free Slot (available for custom purposes)

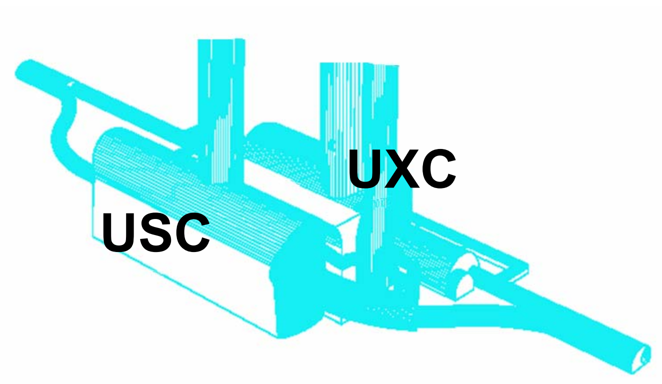
Each PSM is "hot" pluggable

The Control System

- Up to 6 crates are located in one 52 U high rack;
- One Array Controller (the A1676 “branch controller”) controls all the PSM located in one rack, through 6 CANBUS links, one per crate;
- Up to 16 racks are controlled by one Supervisor, the SY1527. Two SY1527 are sufficient to control all the 1944 power groups distributed on 20 racks.



Operational Environment



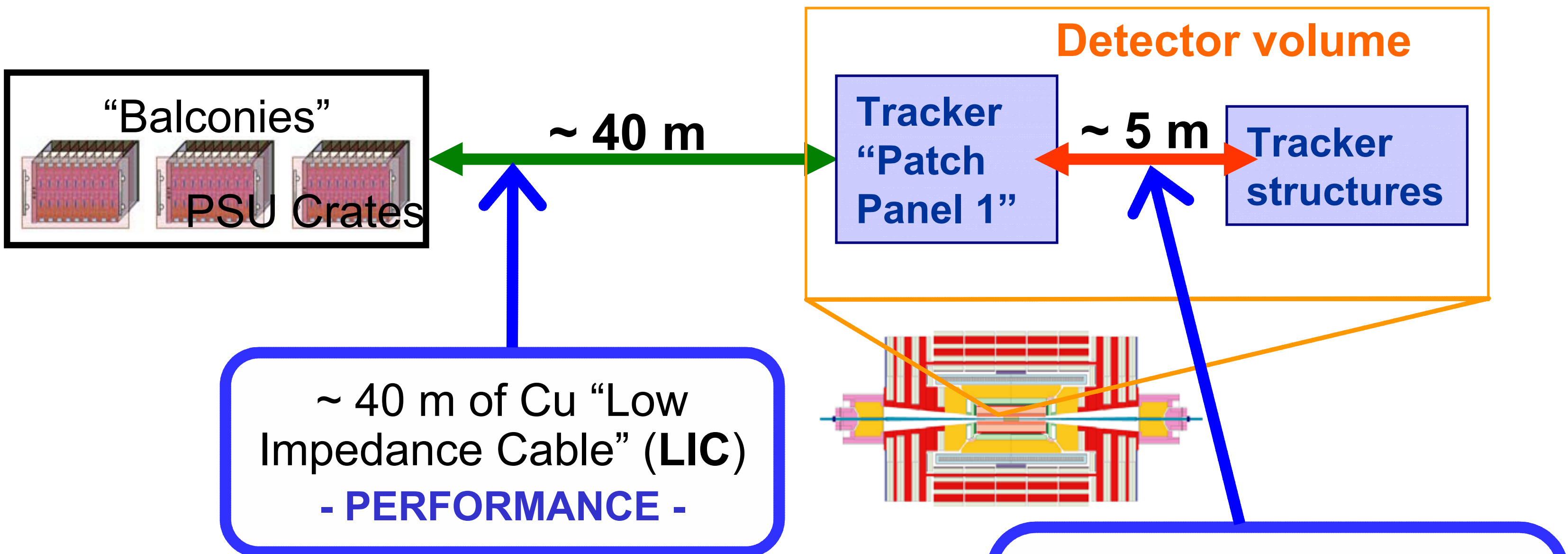
Two places for the SST PS System : the **Standard Environment** (SE) in the “Underground Service Cavern” (USC) and the **Hostile Env.** (HE) in the “Underground Exp. Cavern” (UXC) with **B < 1KG** and **~ 4 10^{10} n /cm^2** in 10 years at nominal LHC luminosity.

The developed PSMs **can be used either in SE or in HE by simply changing the DC-DC transformers,** mechanics and electronics remaining the same.

Experimental Tests done by CMS (M. Costa et al.) and CAEN experimenters on one PSM full size prototype have shown no relevant degradation of the conversion efficiency with B (H2 CERN facility) and no damages and irreversible faults under neutron irradiation at the Louvain-la-Neuve (UCL) facility.

CMS plans to locate PSMs and PUs in UXC, at ≈ 10 m from the beams interaction point, and Array Controllers and Supervisors ≈ 100 m apart, in USC.

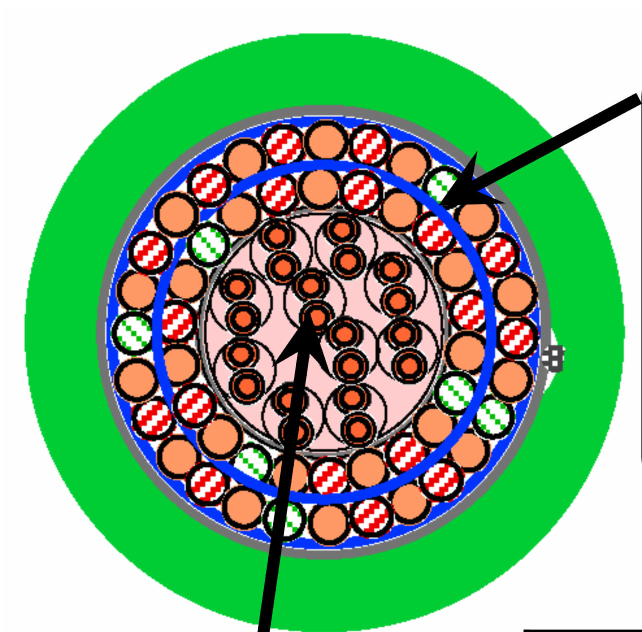
Routing of Power



~ 5 m of Aluminum "Multi Service Cable" (**MSC**)
- MATERIAL BUDGET -

- **The cable is part of the feedback loop of the regulator**
- **Both the stability and the transient response of the regulators depend on the quality of the cables.**
- **Rule of thumb: lower impedance better performances !**

Cu Low Impedance Cable



50 Cu 0.6 mm² enamelled power lines

- 2.5 V
- 1.25 V
- RTN

10 twp lines (HV, senses, H&T probes)

- Max use of material to bring power (~ 30 % of the section)
- The cable structure:
  - ⇒ **reduces the inductive coupling**
  - ⇒ **maximizes the distributed capacitance**
  - ⇒ matches the current load distribution:

$R_{1.25} \sim 2\ R_{2.5} \sim 3\ R_{RTN}$

CABLE CHARACTERIZATION	Cu LIC	Al MSC
R_{250} [mΩ/m]	1.7	9.3
R_{125} [mΩ/m]	4.5	14.0
R_{RTN} [mΩ/m]	1.3	5.8
Pw dissip. [mW/A²xm]	**2.5**	**11.5**
C_0 [nF/m]	6.7	0.174
L_0 [nH/m]	13	206.
Impedance: Z_0 [Ω]	**1.4**	**34.5**

Performance

The performance of PSU prototypes has been extensively tested (both in the LAB and during beam-tests) with close-to-final detector configurations, checking:

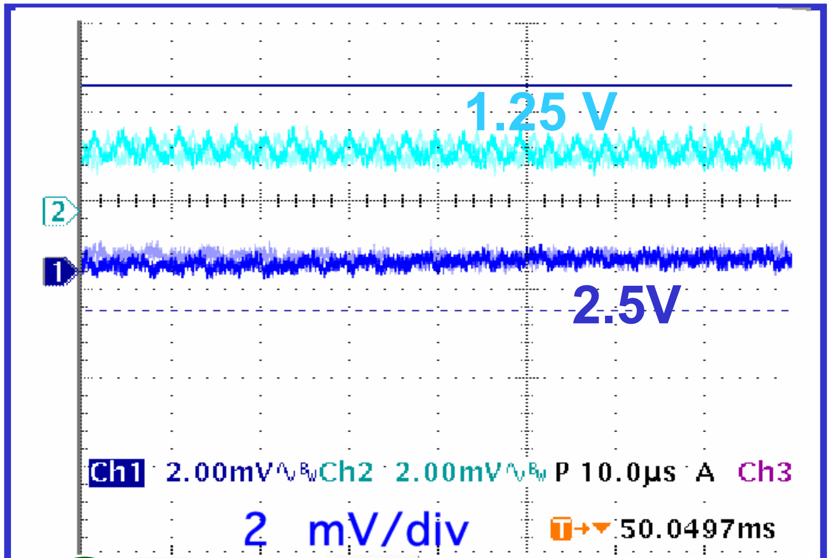
- Stability of operation
- Noise
- OVV and OC protections
- AC Isolation
- Efficiency
- Fast LV regulation (response to sudden current load variations)

Noise

Noisy regulators would directly impact the detector performance.

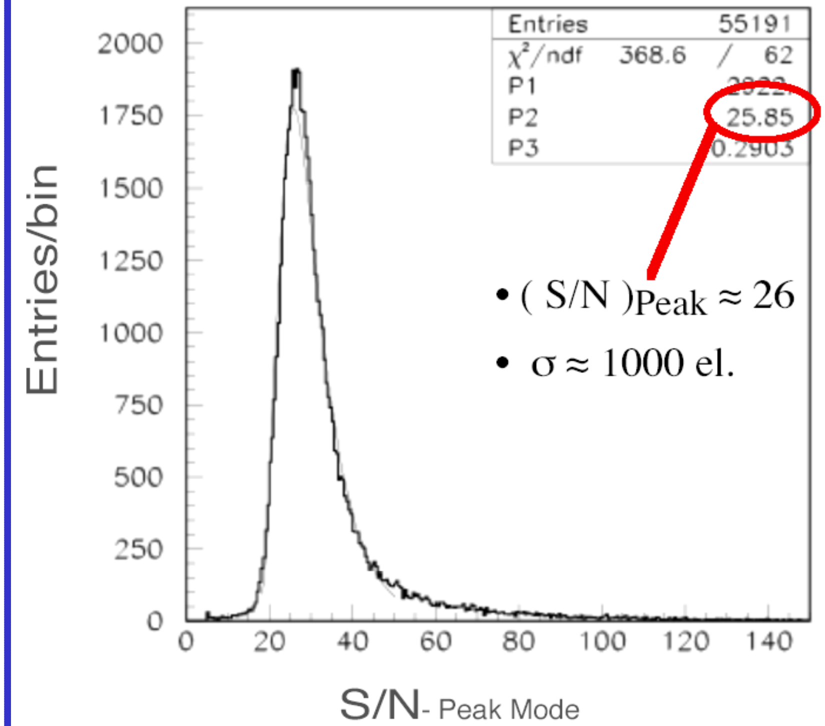
The noise on each regulator (20 MHz BW) is lower than:

- **LV: 10 mV peak-to-peak**
- **HV: 30 mV peak-to-peak**



@ 100m cable, C_{LOAD} = 350 µF

May 2003 CERN-X5 beam test



- TIB setup: 24 APVs
- 2003 PSU prototype
- 150 m long power-cable chain
- V_{bias}= 300 V

Fast LV Regulation

The voltage drop across the LV distribution lines may be considerable: the present PSUs are designed to compensate up to 4 V drop.

Special care is needed in order to prevent over-voltages affecting the powered electronics whenever an abrupt current consumption variation occurs:

- **the nonlinear sense circuit must react in a short time (< 0.5 ms)**

The performance is highly dependent on the quality of the power cables (resistance, impedance);

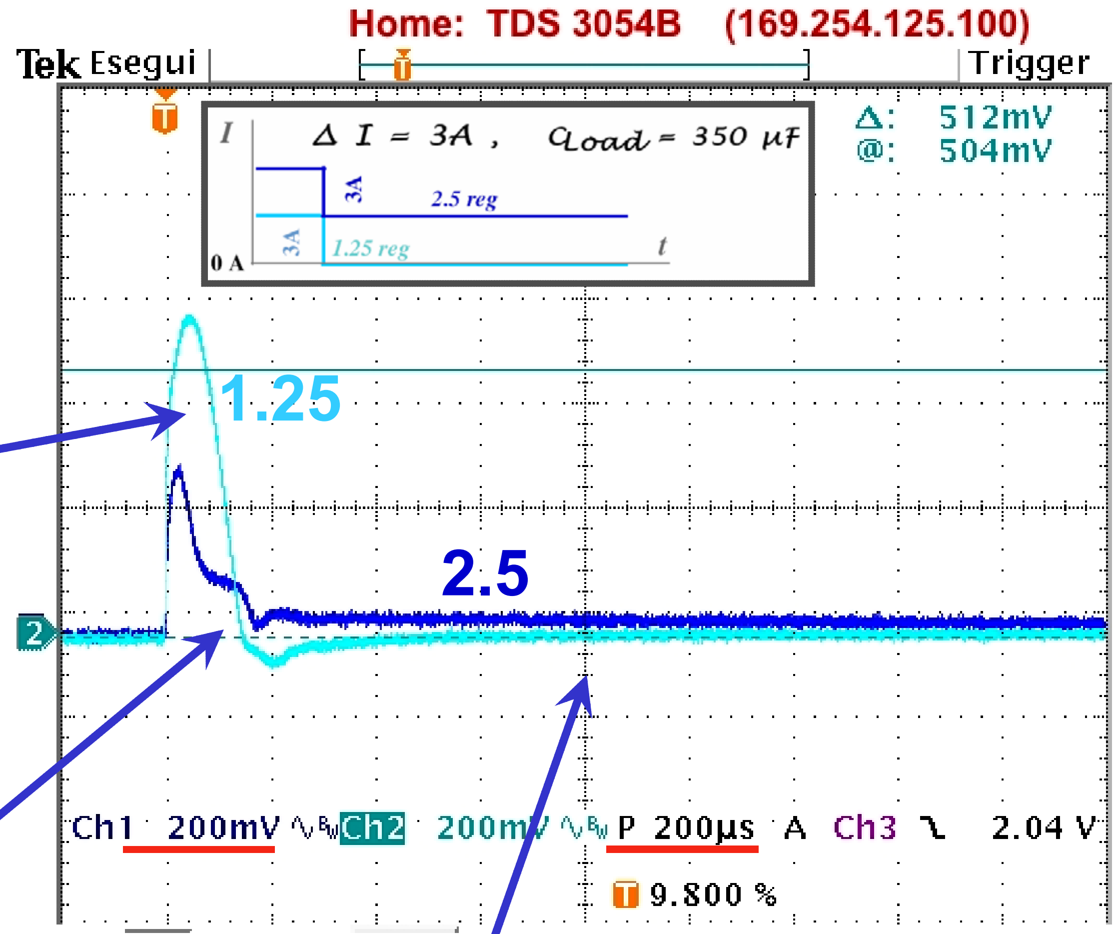
Several lab tests performed reproducing the typical power distribution to the detector groups.

Overshoot Tests

- Measured at the load's side, after an abrupt **ΔI = 3A** simultaneous variation on **both** the **1.25 V** and the **2.5 V** lines
- Simulates an uncontrolled APV reset of one entire power group (non-realistic case !)

Peaking value:

- Cable resistance
- Cable inductance
- Capacitive load
- PSU intervention

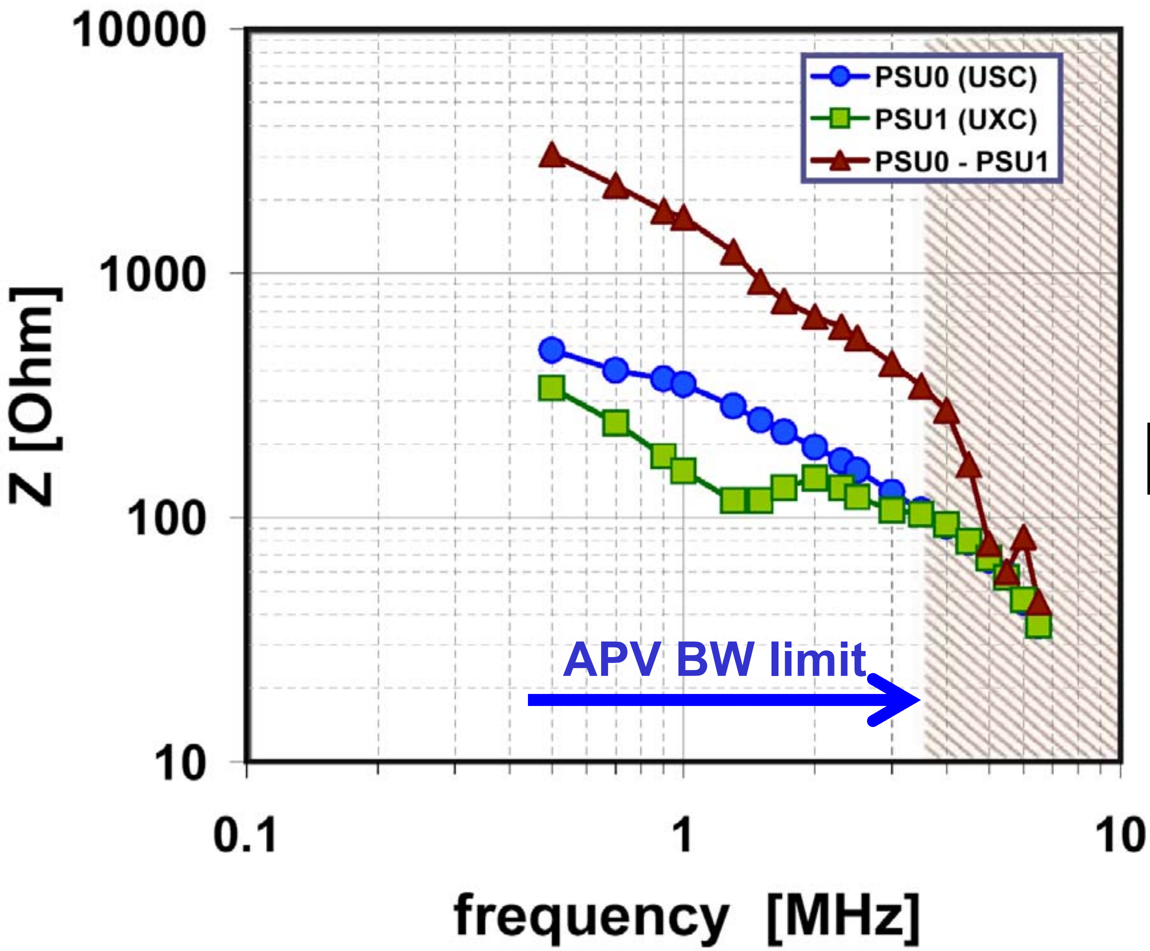


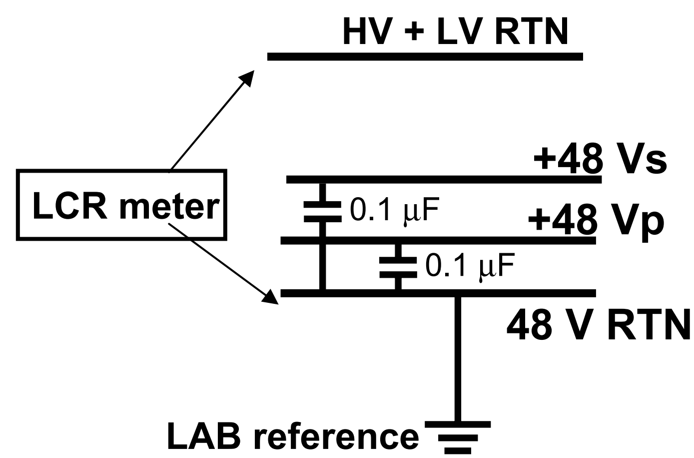
Fast PSU intervention

No oscillation after

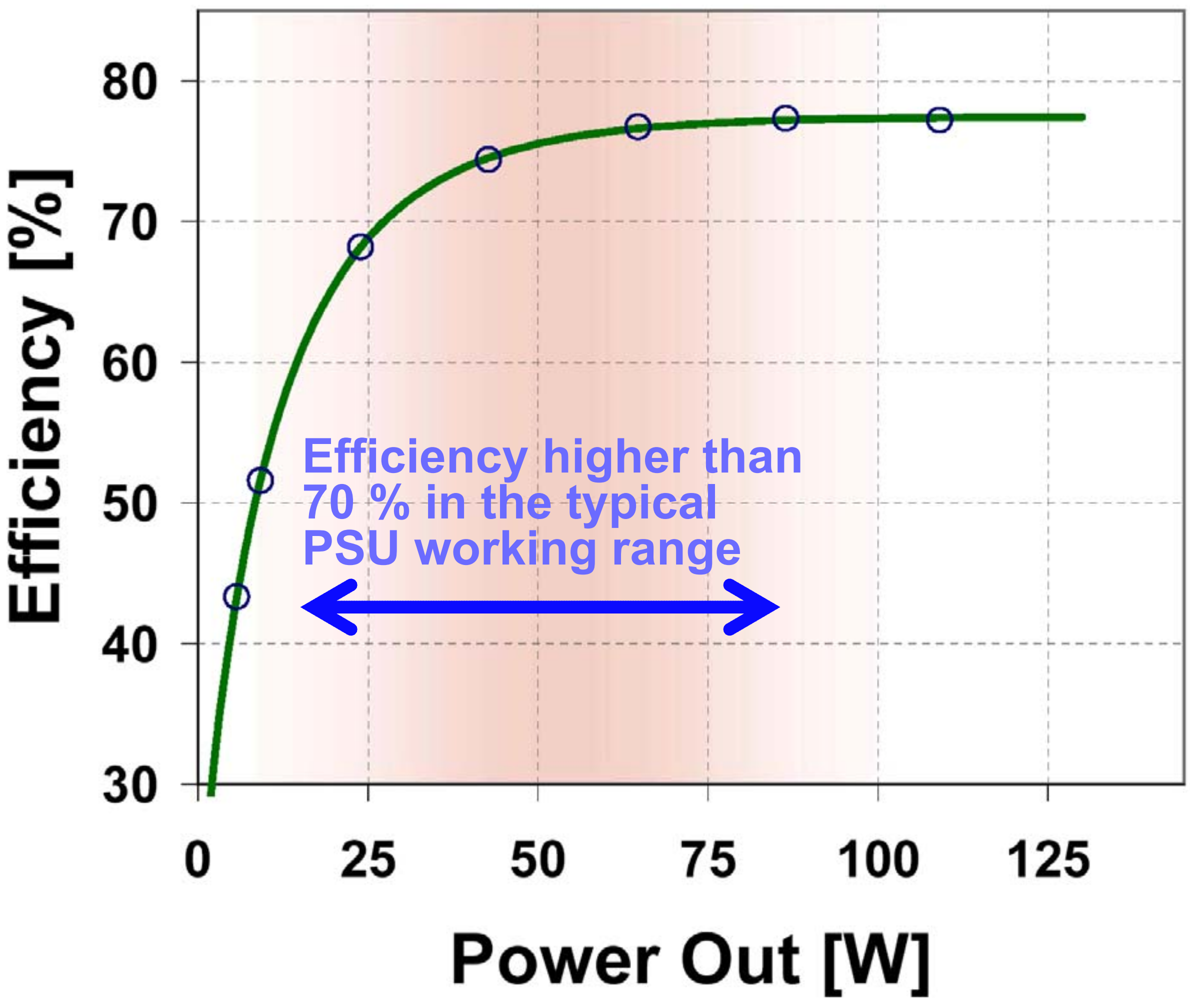
AC Isolation

Power channels are well isolated each other and from the +48 V system ("floating regulators") to avoid current loops flowing from one power group to the other





Efficiency



Tot. +48V Consumption

	STD [kW]	"Safety" [kW]
VP	**82**	**181**
Heat dissip. on racks	**44.6**	**61**

Conclusions

The powering scheme for the CMS SST is defined:

Partition of the SST into ~2000 groups of contiguous modules sharing power, cooling and control services;

Modular system of Power Supply Units featuring:

- complex channels with LV and HV regulators powering the detectors;
- good electrical isolation of the channels;
- full remote control;
- robust, hard-wired, safeguard system;

Cables routing power and services inside the detector:

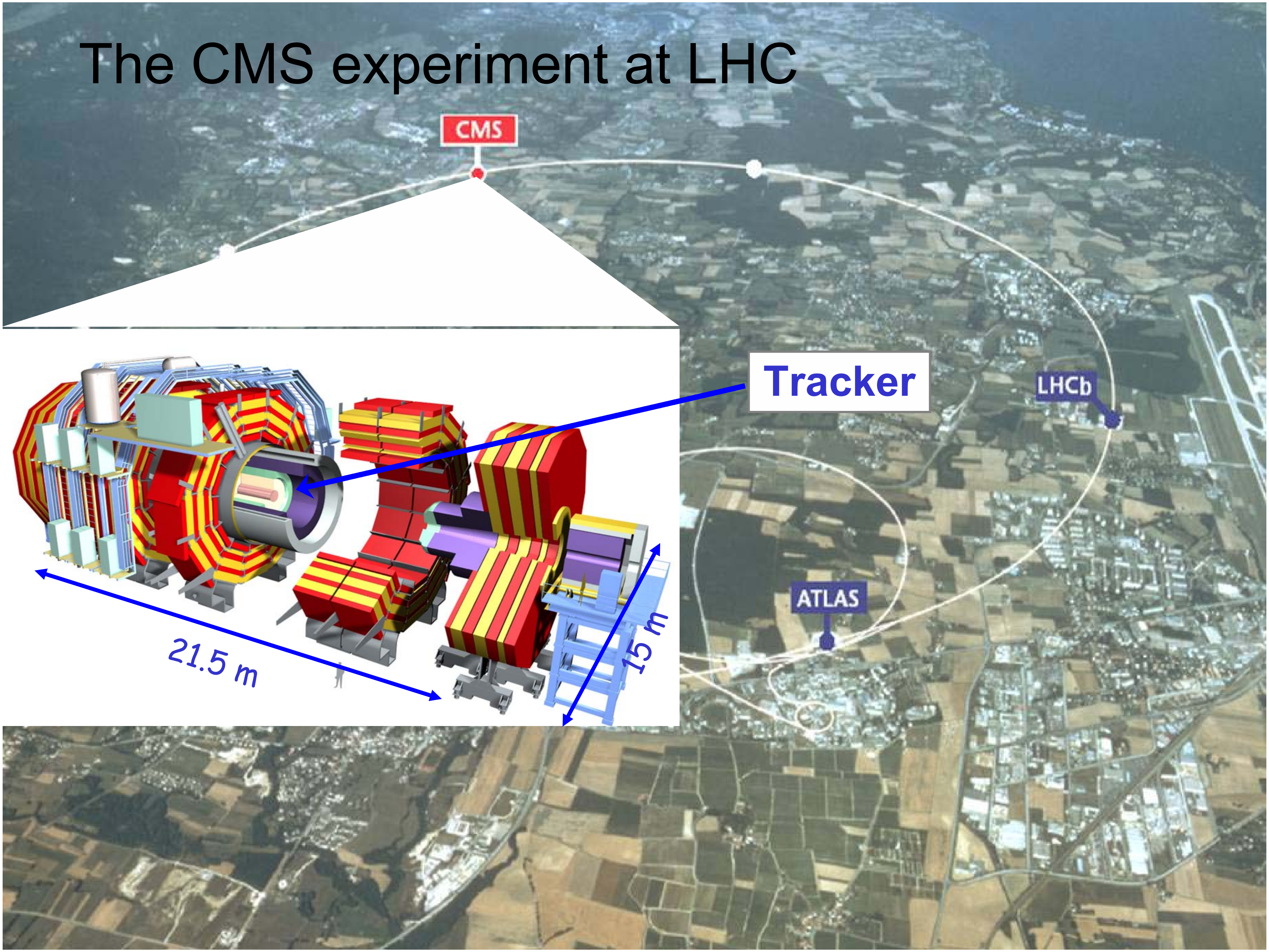
- New design Copper "LIC" cable outside the tracker volume
- Aluminum cables inside the tracker volume

Optimal system performance obtained with quasi-final detector setups both in extensive LAB tests and beam-tests:

- Good noise behavior
- Reliable and stable operation

Backup

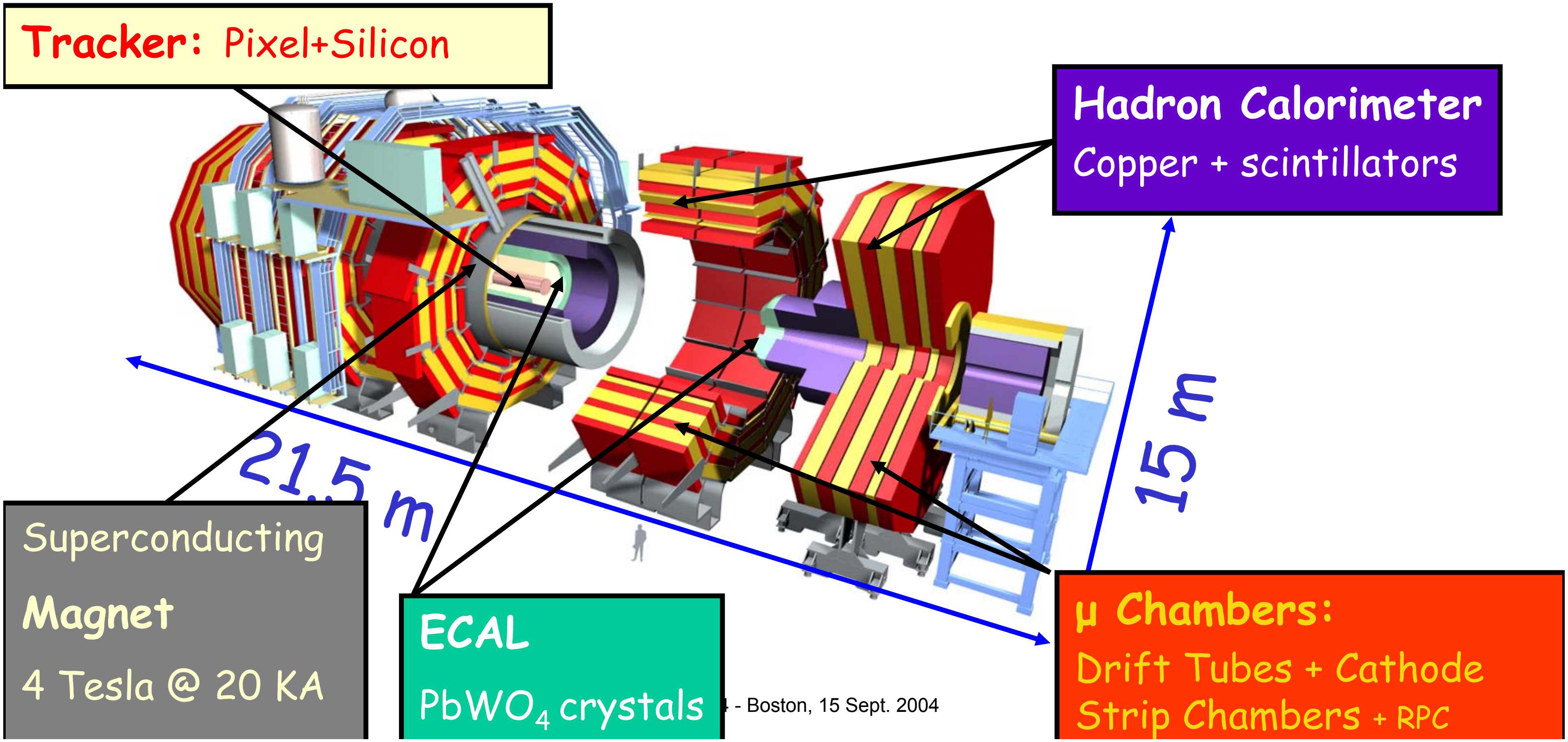
The CMS experiment at LHC



The CMS Detector (compact muon solenoid)

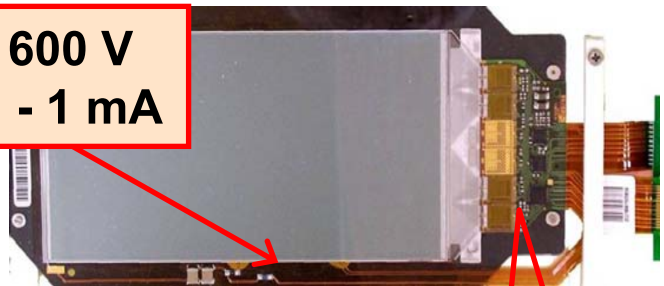
Precision measurement of muons, electrons, γ, jets in a wide energy range:

- Precision trackers in magnetic field (B = 4 T)
- Advanced electromagnetic and hadron calorimetry
- Full solid angle around the interaction point covered.



Module Power Requirements

HV bias: 0 – 600 V
I_{LEAK} ~ 0.1 μA - 1 mA

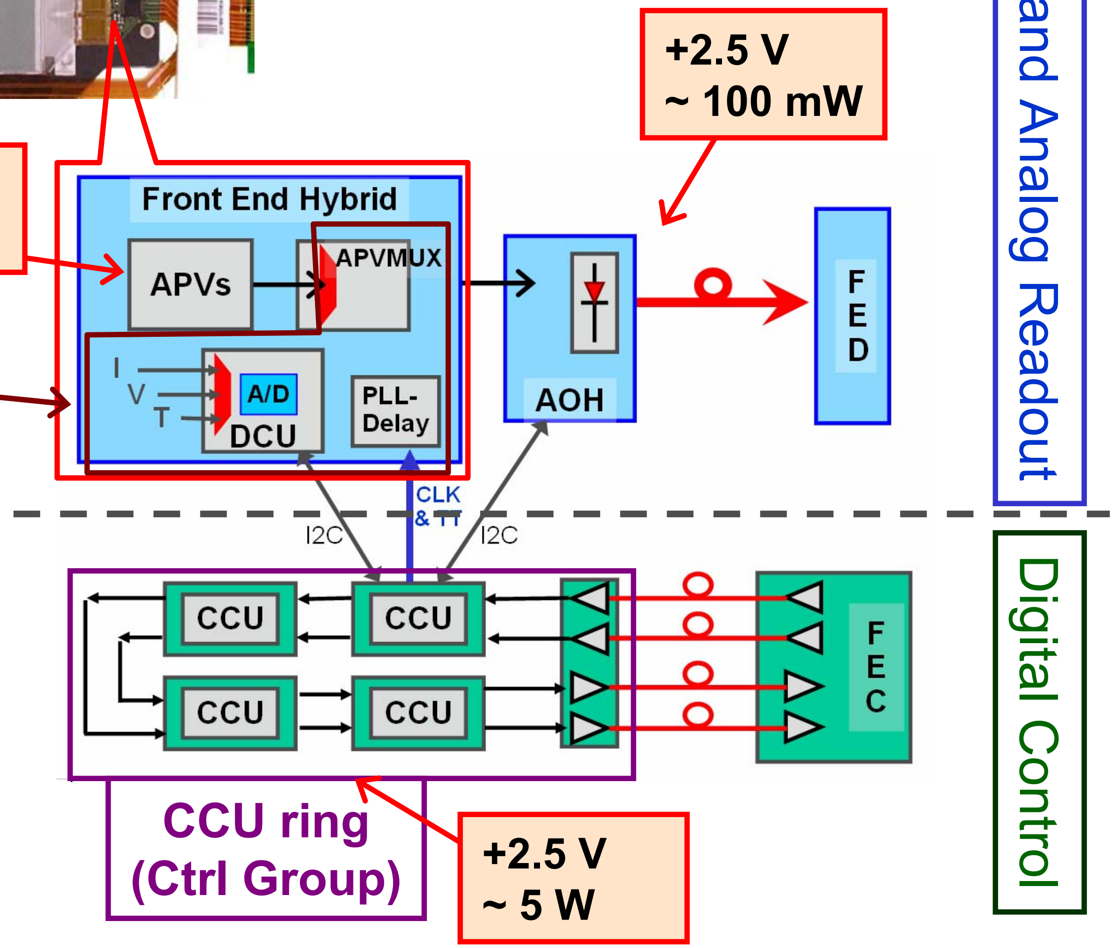


two pw lines: +2.5 V and +1.25 V
$I_{2.5}$ ~ 105 mA $I_{1.25}$ ~ 65 mA (± 20 %)

one pw line : +2.5 V
$I_{2.5}$ ~ 100 mA

Tot FE Hybrid consumption:

4 APV:	6 APV:
1.6 W	2.4 W
$I_{2.5}$ ~ 510 mA	$I_{2.5}$ ~ 750 mA
$I_{1.25}$ ~ 260 mA	$I_{1.25}$ ~ 390 mA

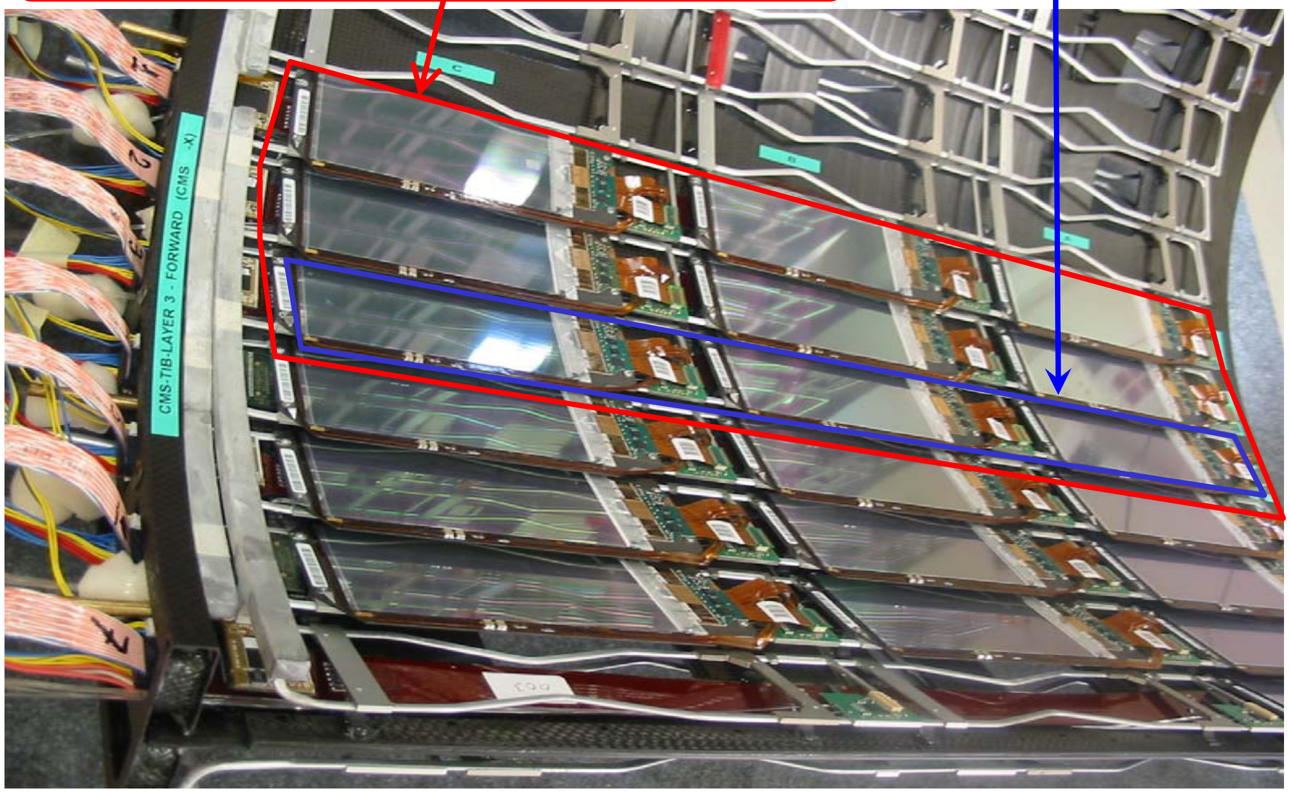


Grouping Examples

- **TIB**: 1 to 4 strings of 3 modules

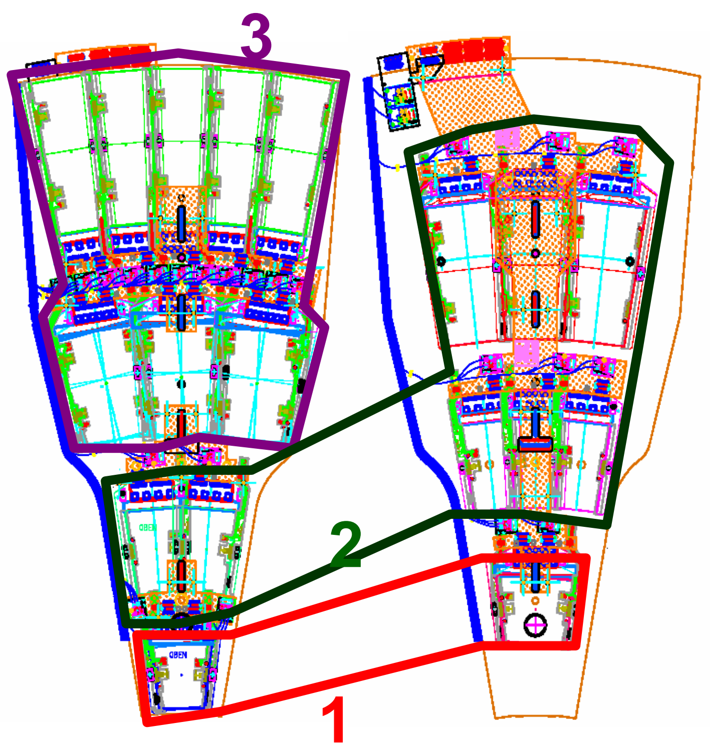
3-string power group (Inner TIB layer 3)

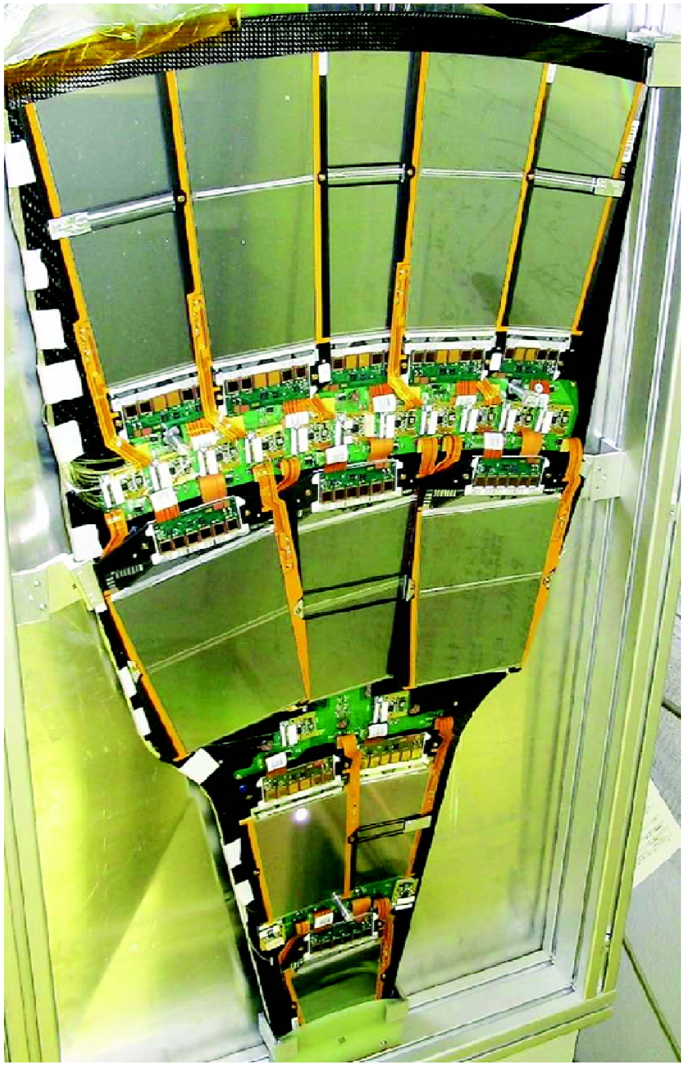
3-module strings

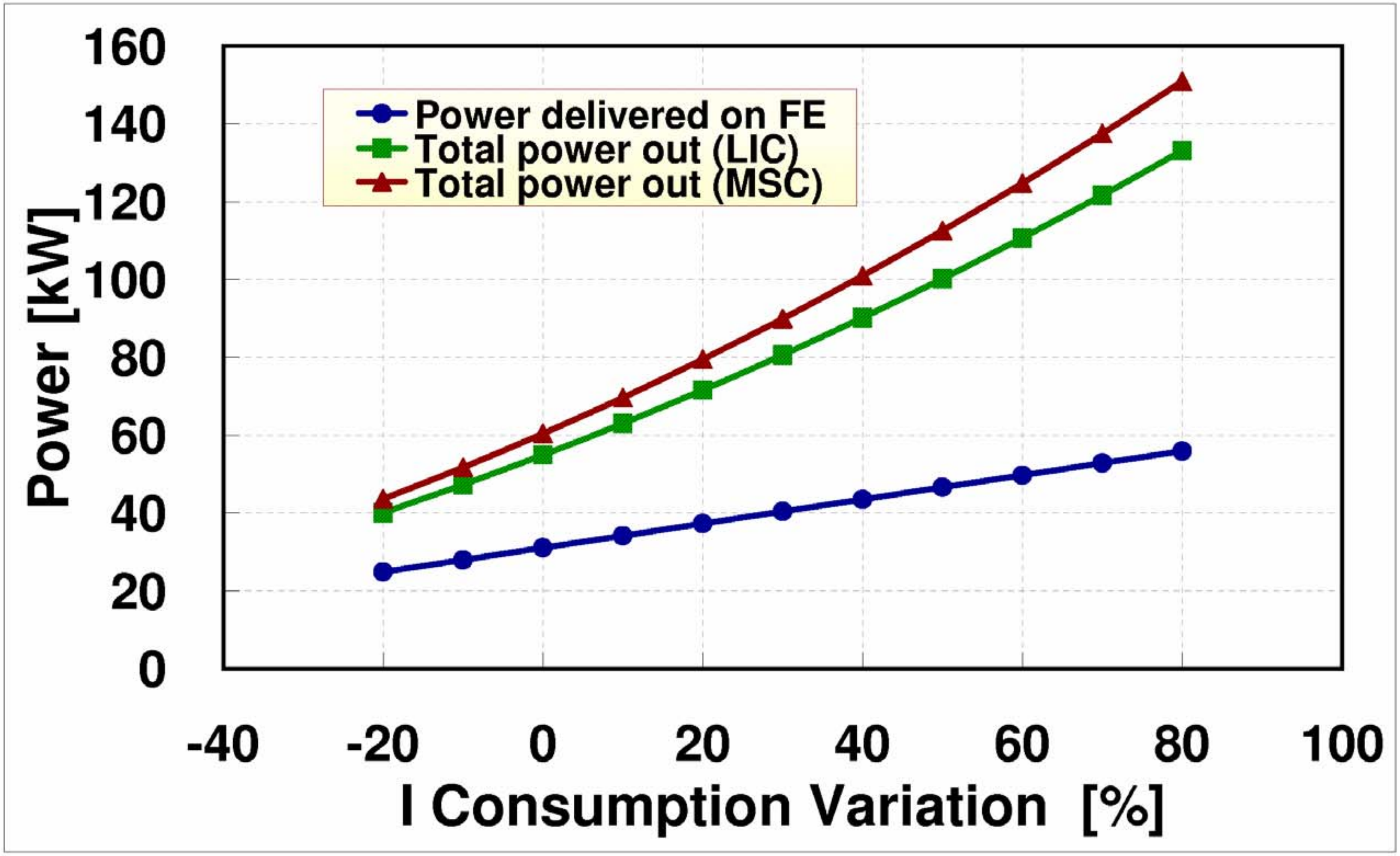


Groups and Tracker Mechanics

- **TEC**: 3 power groups for each petal
  2 x 9 Wheels x (8+8) petals







160
140
120
100
80
60
40
20
0
Power [kW]
Power delivered on FE
Total power out (LIC)
Total power out (MSC)
-40
-20
0
20
40
60
80
100
I Consumption Variation [%]

Power Supplies for the Control Rings

The CCU-Ring powering system is integrated into the detector powering system.

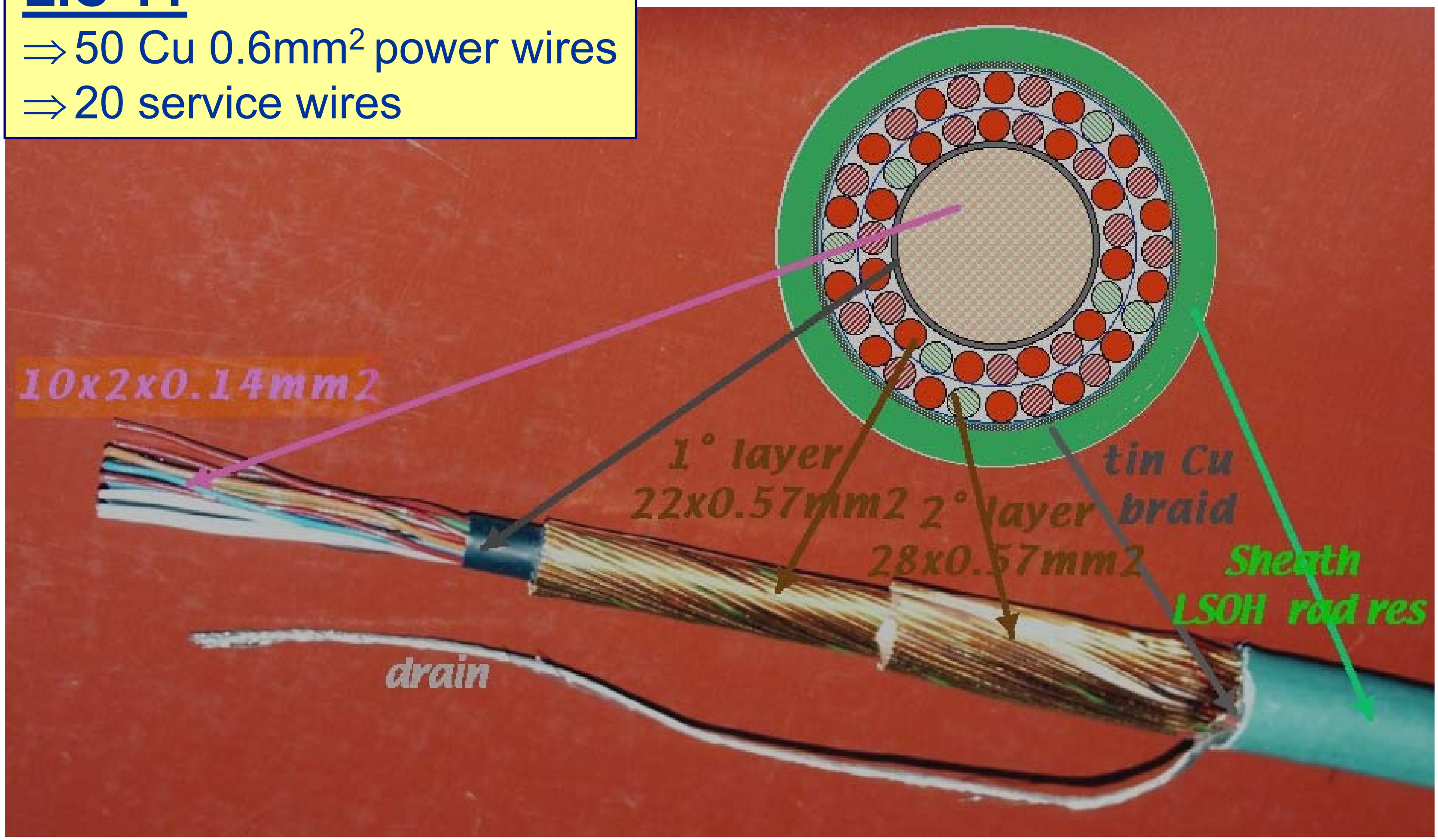
- Each PSU features one 2.5 V regulator;
- $I_{2.5}^{max}$ = 4 A per PSU;
- Up to 2 V voltage-drop compensation wirth sense wires technique;
- Four PSUs are hosted in one PSM and share one μP which is opto-isolated from the internal regulators;
- The CCU-Ring PSM and the Detector PSM are fully compatible and can lodge in the same crate;
- 88 PSM power the 352 Control-Rings;

Low Inductance Cable

LIC 11

⇒ 50 Cu 0.6mm^2 power wires

⇒ 20 service wires



Cable characterization

(2.5//1.25 vs RTN)

	Cu LIC	Al MSC	Cu cable
R_{250} [mΩ/m]	1.7	9.3	3.0
R_{125} [mΩ/m]	4.5	14.0	4.5
R_{RTN} [mΩ/m]	1.3	5.8	1.8
Power dissip. [mW/A^2xm]	2.5	11.5	3.6
C_0 [nF/m]	6.7	0.174	0.17
L_0 [nH/m]	13	206.	207
Impedance: Z_0 [Ω]	1.4	34.5	35

Cable Inductance

The cable is part of the feedback loop of the regulator

Both the stability and the transient response of the regulators depend on the quality of the cables.

Rule of thumb:

lower impedence ➔better performances !

Over Voltage Tests

- **CAEN PSU**
- **Sudden ΔI = 3A variation on both 1.25 and 2.5 lines**