Vacuum & Cryogenics Controls @ CERN

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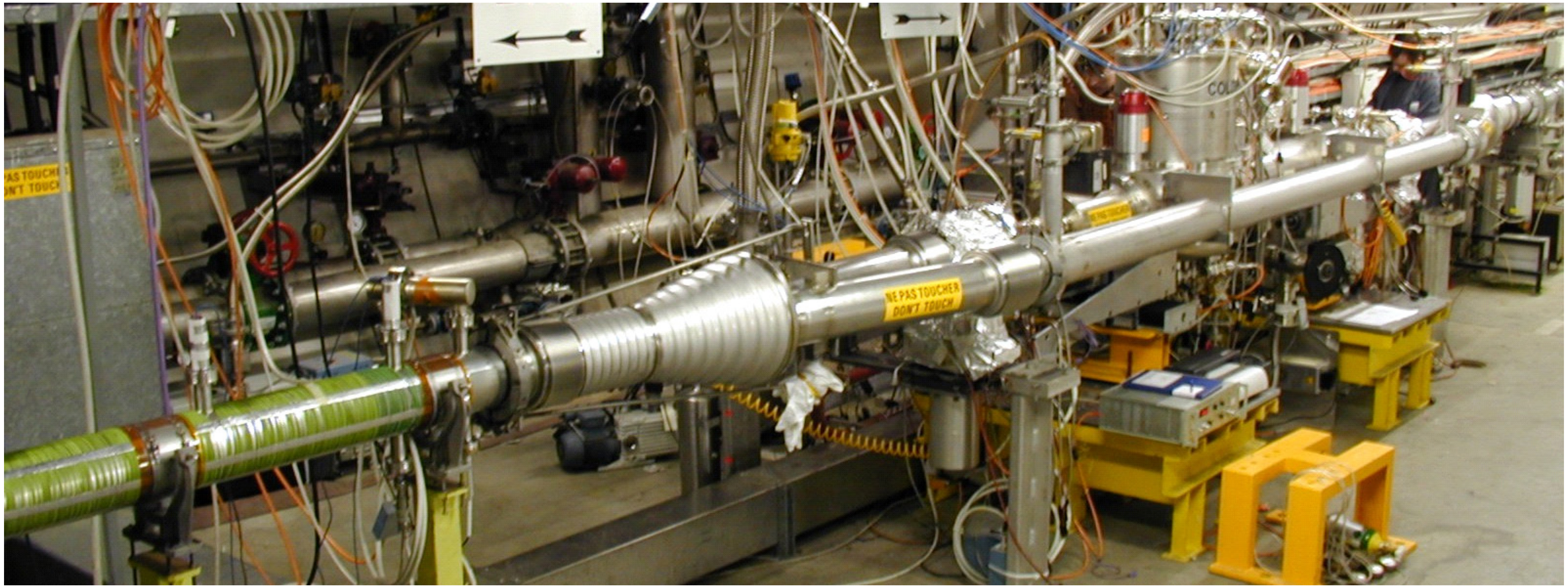
TE / VSC / ICM

TE – Technology Department

VSC – Vacuum, Surfaces & Coatings Group

ICM – Interlocks, Controls & Monitoring Section



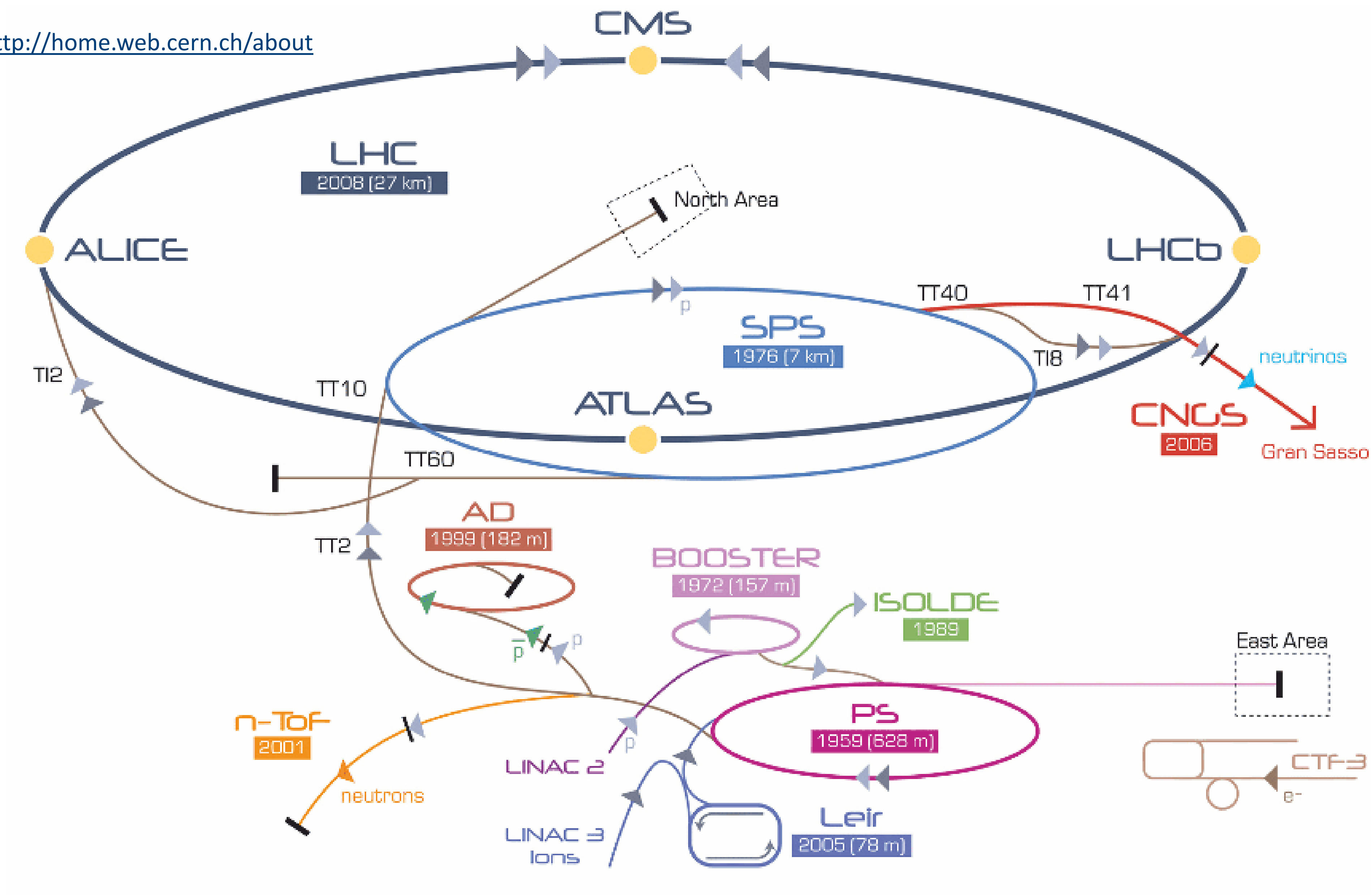
CERN 60 YEARS/ANS CERN

TE VSC Interlocks Controls Monitoring

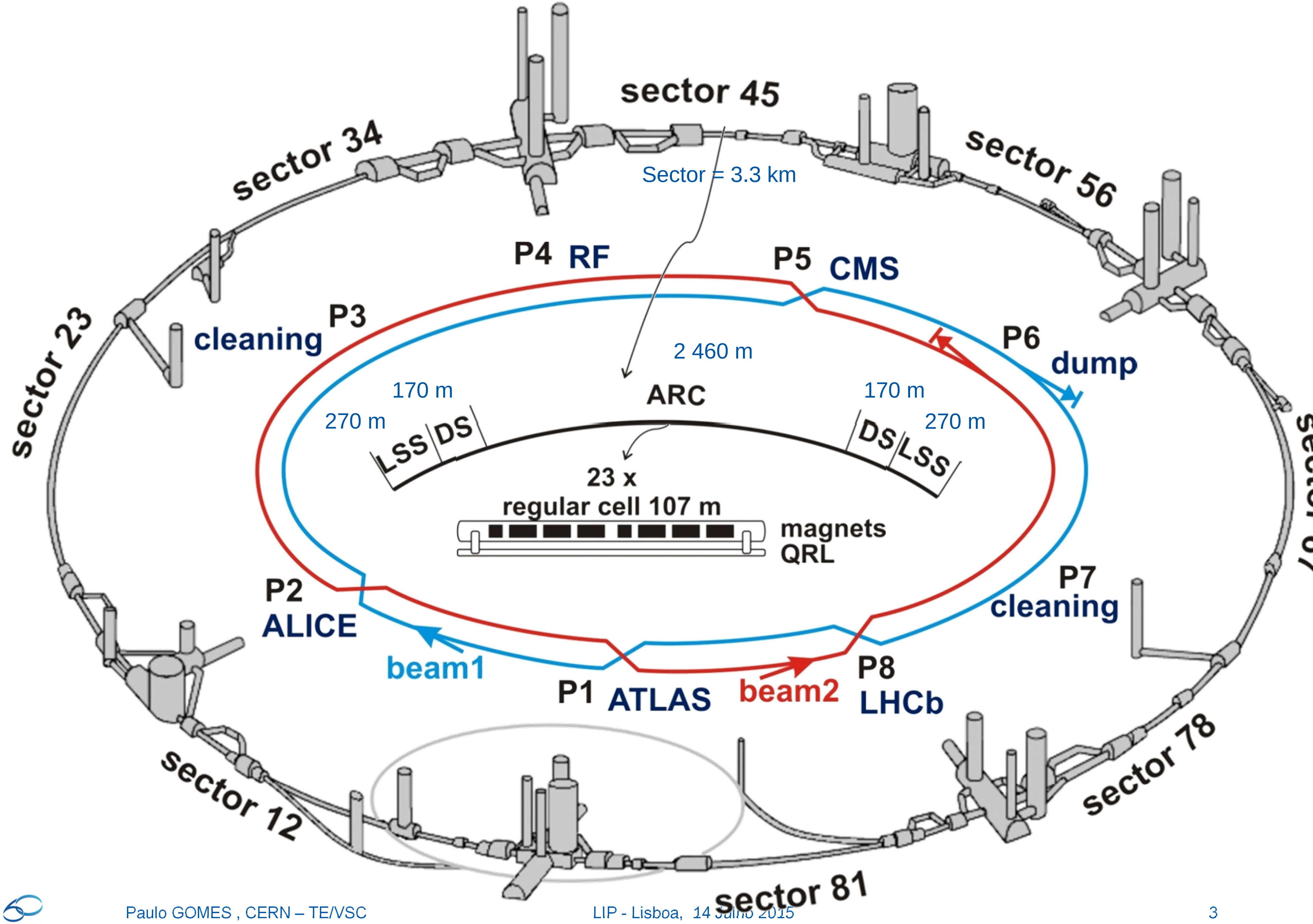
LIP LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTICULAS

CERN accelerators :
the LHC & its injectors

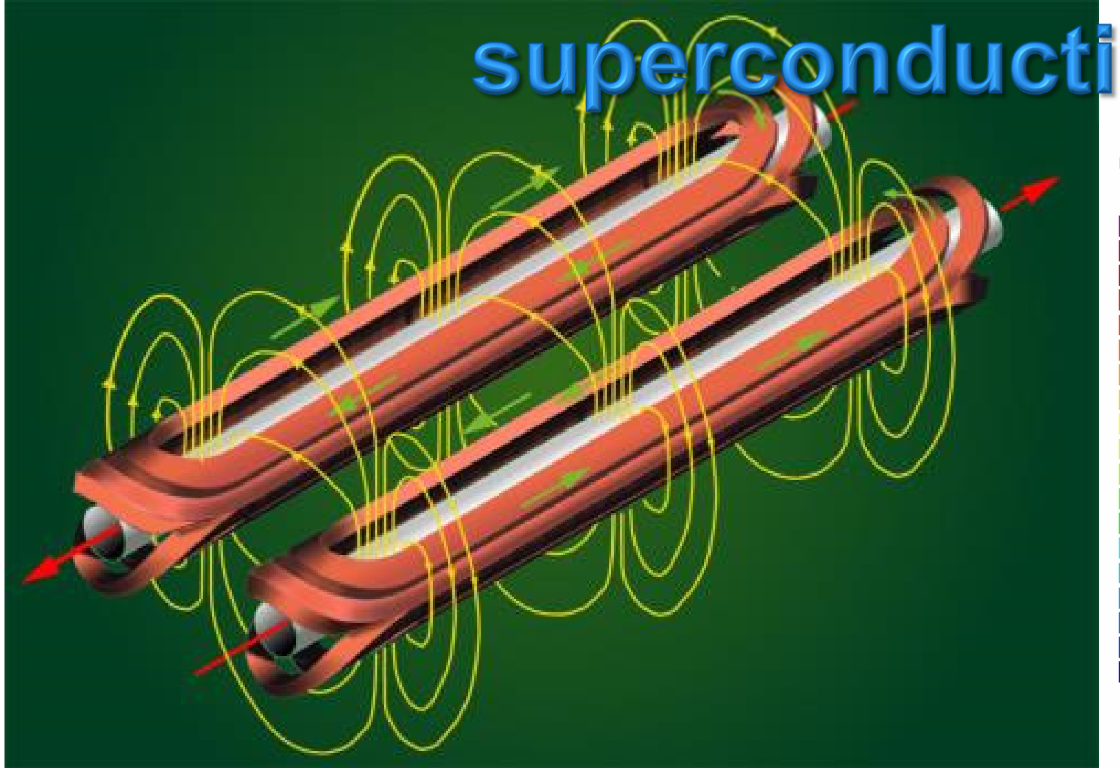
http://home.web.cern.ch/about

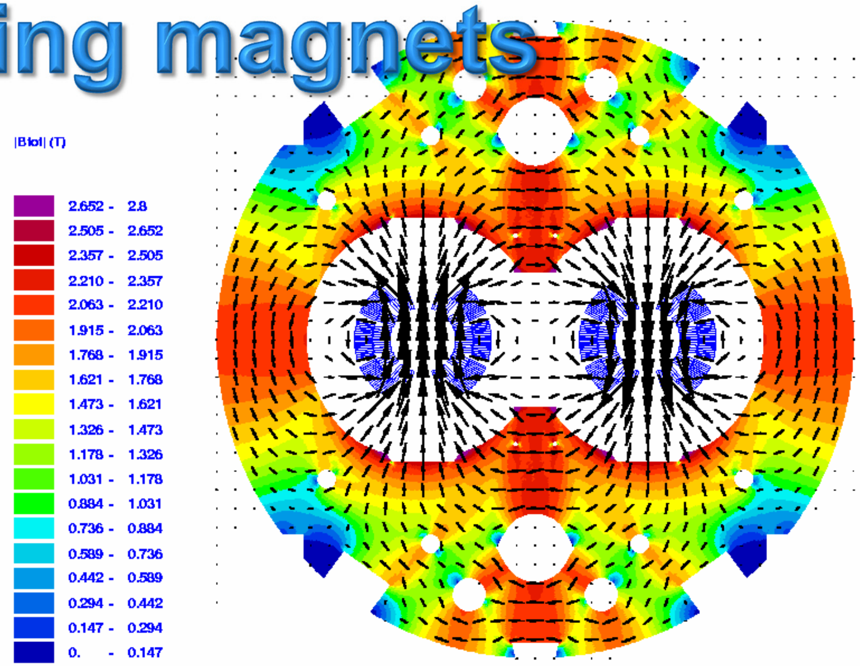


LHC : 27 km collider for protons (ions)
8 sectors of 3.3 km



superconducting magnets





energy per beam: 7 TeV

main dipoles field: 8 T

current: 12 kA

superconducting magnets

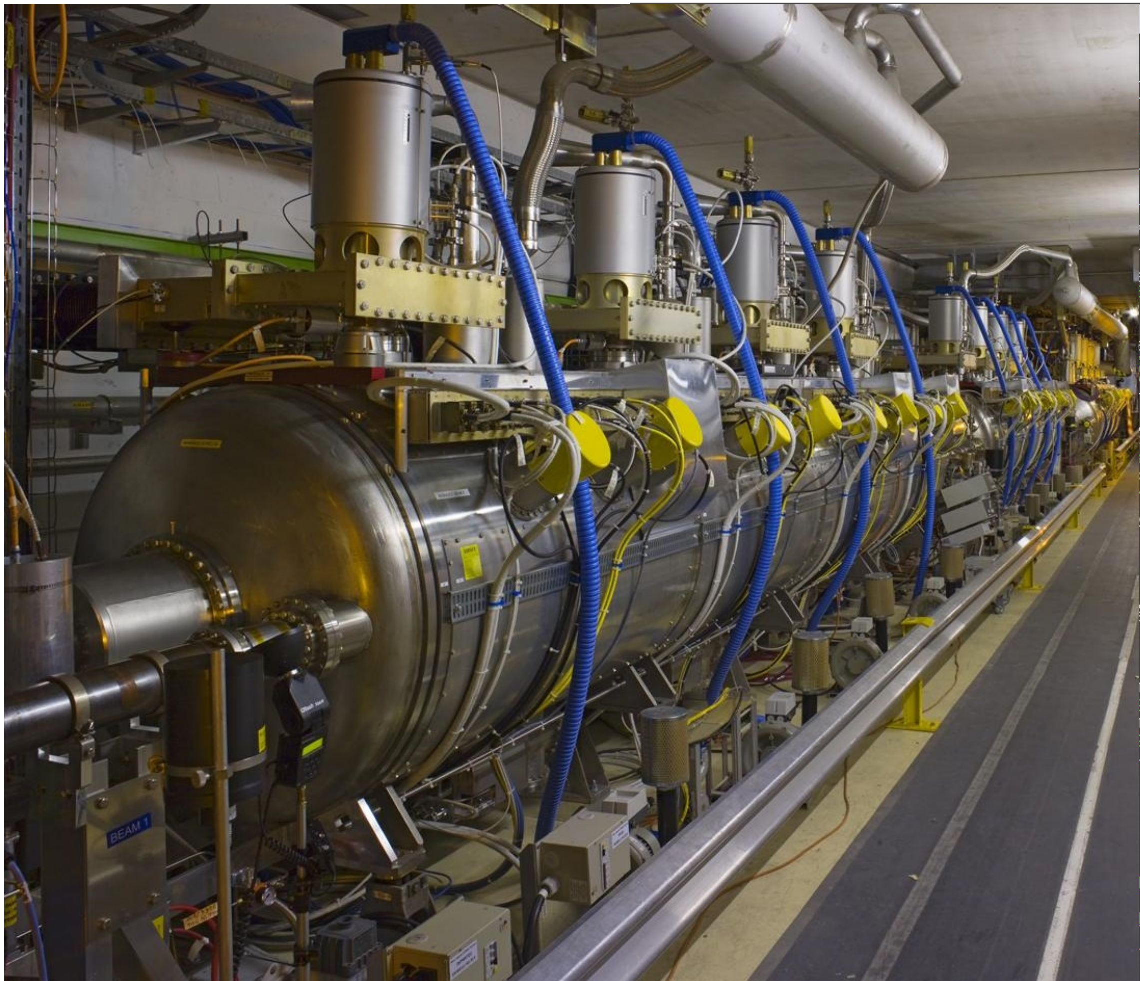
NbTi @ 1.9K

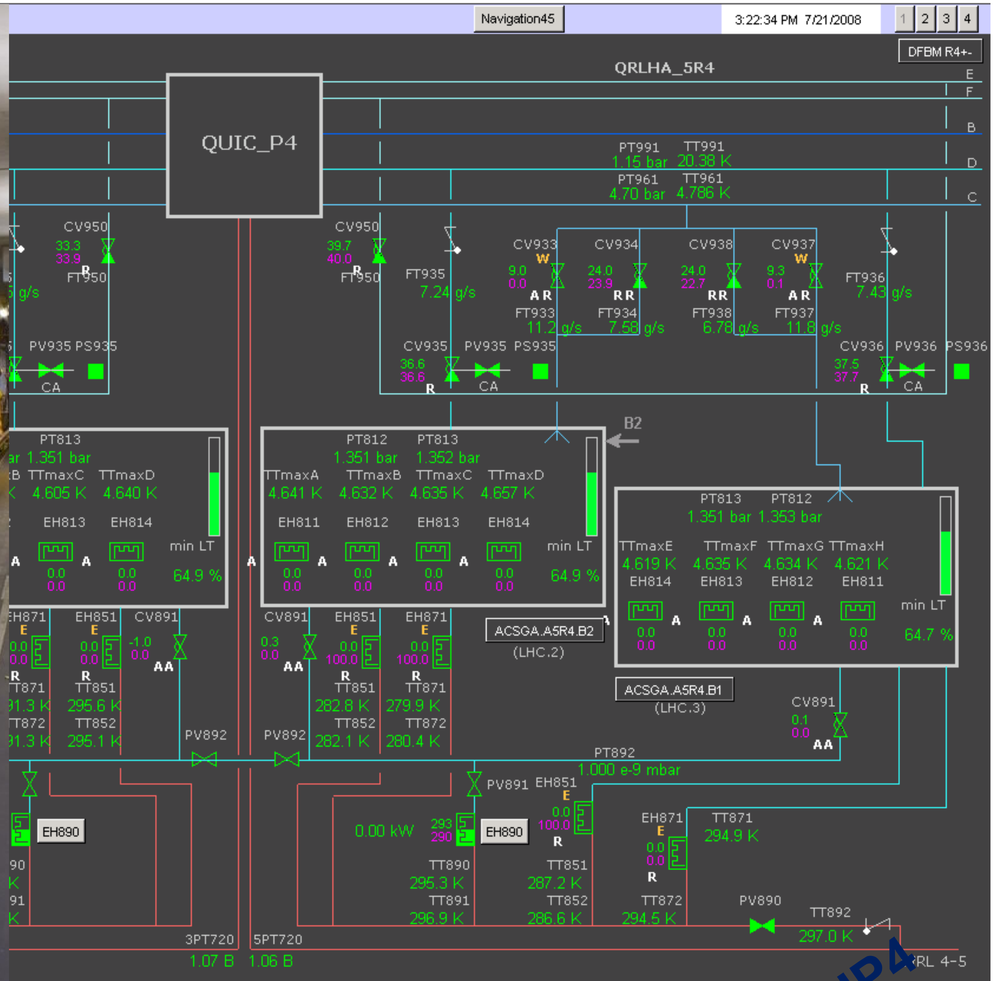
(1200 D + 400 Q)

http://home.web.cern.ch/about/engineering/pulling-together-superconducting-electromagnets

http://home.web.cern.ch/about/engineering/superconductivity

RF superconducting accelerator cavities



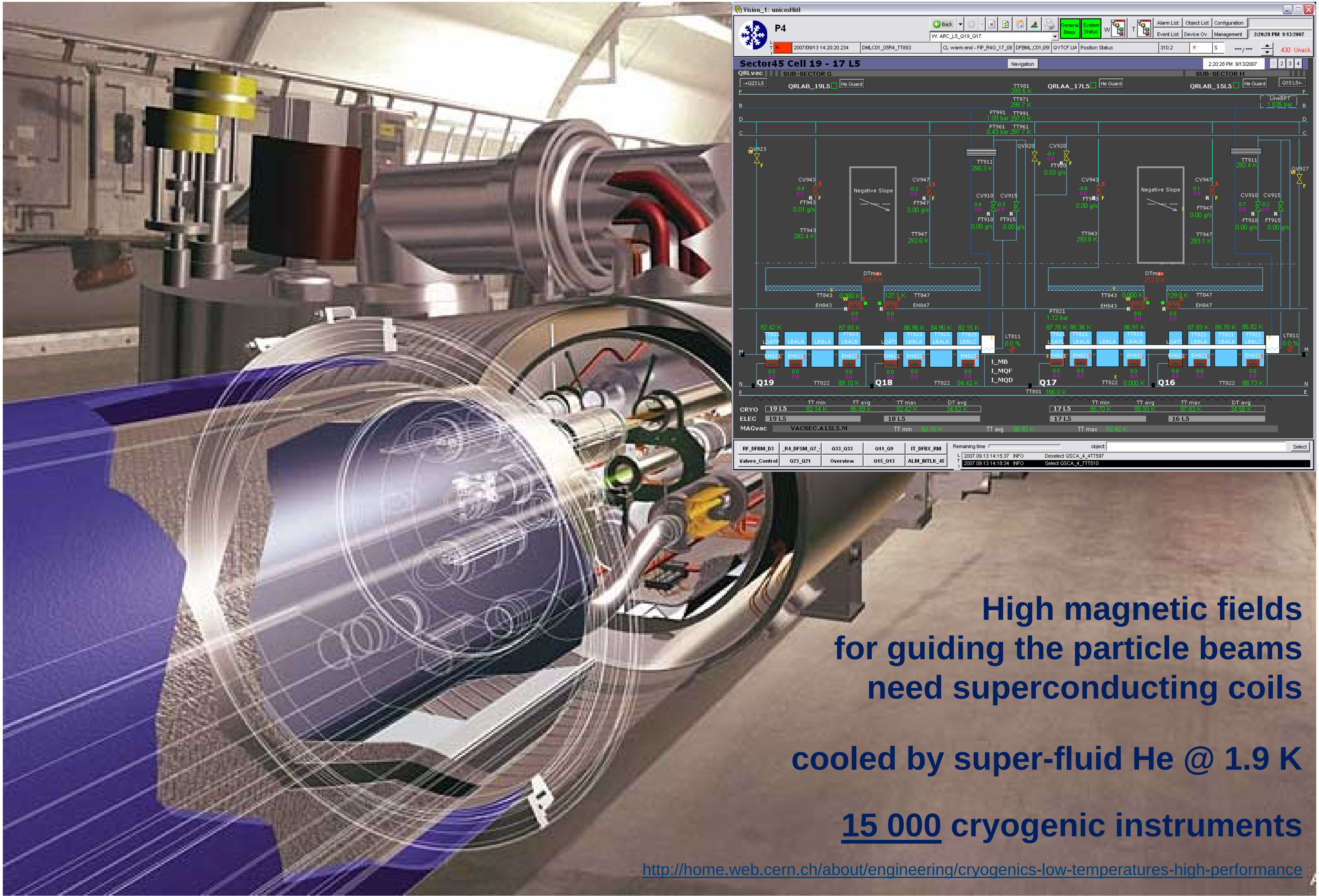


16 cavities @ 4.5 K

grouped on 4 modules, on IP4

http://home.web.cern.ch/about/engineering/radiofrequency-cavities

cryogenics @ LHC

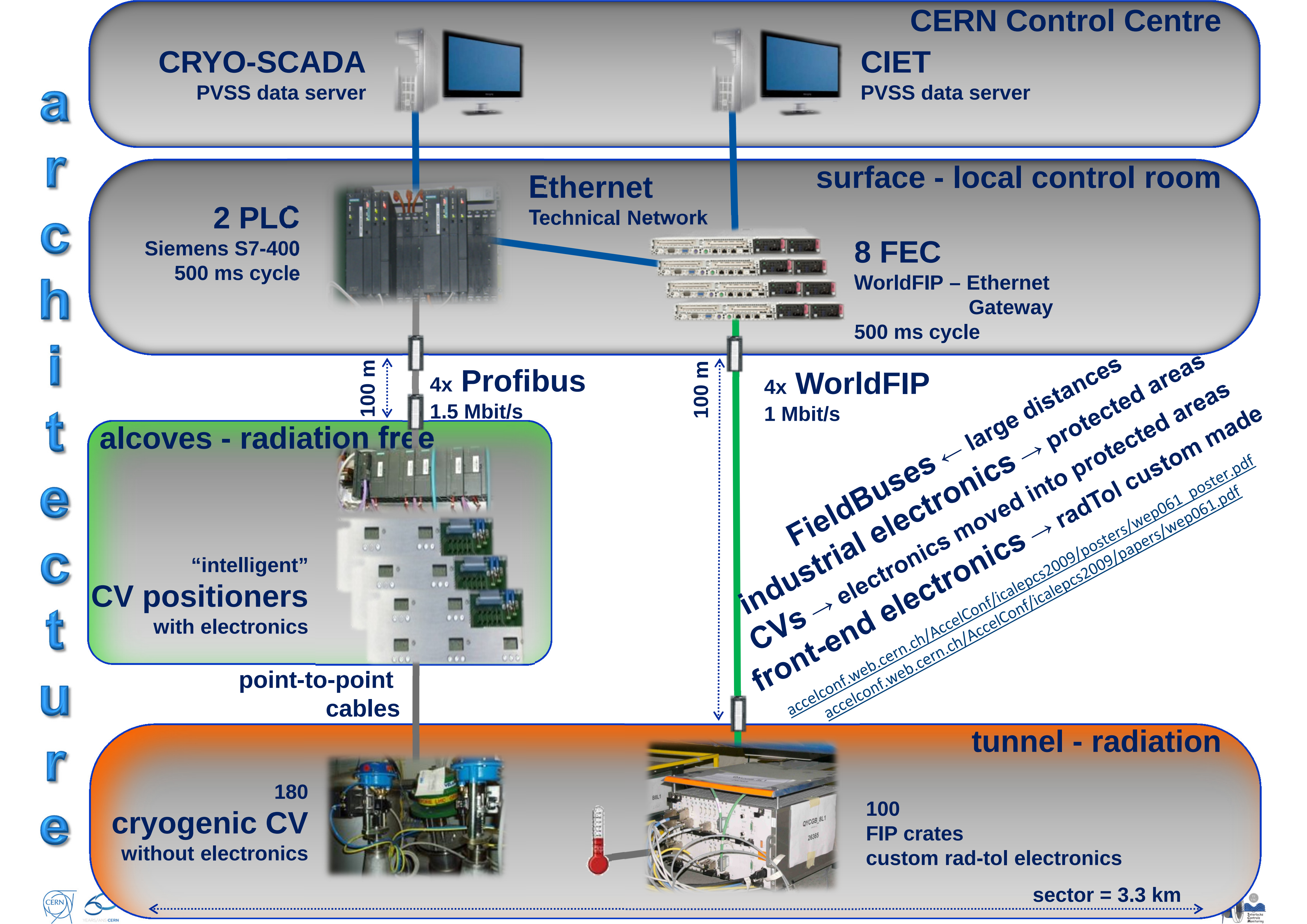


High magnetic fields
for guiding the particle beams
need superconducting coils

cooled by super-fluid He @ 1.9 K

<u>15 000</u> cryogenic instruments

http://home.web.cern.ch/about/engineering/cryogenics-low-temperatures-high-performance


architecture
CERN Control Centre
CRYO-SCADA
PVSS data server
CIET
PVSS data server
surface - local control room
2 PLC
Siemens S7-400
500 ms cycle
Ethernet
Technical Network
8 FEC
WorldFIP – Ethernet Gateway
500 ms cycle
100 m
4x Profibus
1.5 Mbit/s
100 m
4x WorldFIP
1 Mbit/s
alcoves - radiation free
"intelligent"
CV positioners
with electronics
point-to-point cables
FieldBuses ← large distances
industrial electronics → protected areas
CVs → electronics moved into protected areas
front-end electronics → radTol custom made
accelconf.web.cern.ch/AccelConf/icalepcs2009/posters/wep061_poster.pdf
accelconf.web.cern.ch/AccelConf/icalepcs2009/papers/wep061.pdf
tunnel - radiation
180
cryogenic CV
without electronics
100
FIP crates
custom rad-tol electronics
sector = 3.3 km

databases intensively used in cryo-controls

ICALEPCS 2011 poster : https://cernbox.cern.ch/public.php?service=files&t=8d49fd498d38f9fb0a7824ba93afc09a
ICALEPCS 2011 paper : http://accelconf.web.cern.ch/AccelConf/icalepcs2011/papers/mopkn024.pdf

17 000 instrumentation channels

800 FIP crates 900 cards

1 700 Profibus components

5 000 cable numbers

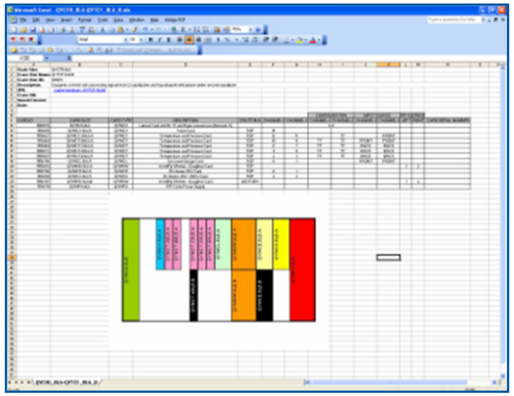
LHC Layout Database

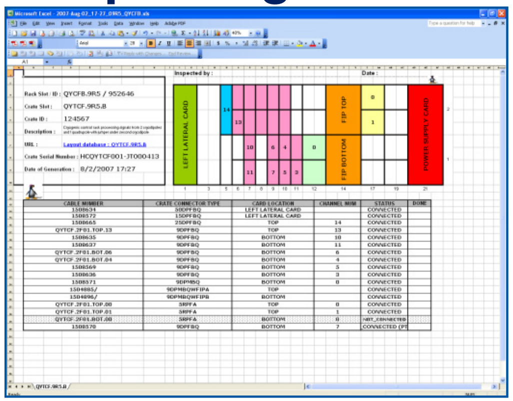
specification files for manufacturing FIP Crates

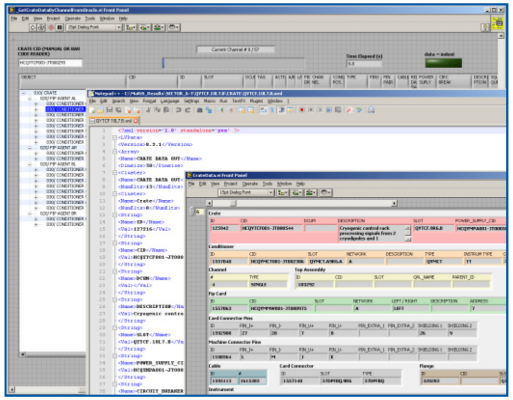
cabling files for connecting & inspecting cables

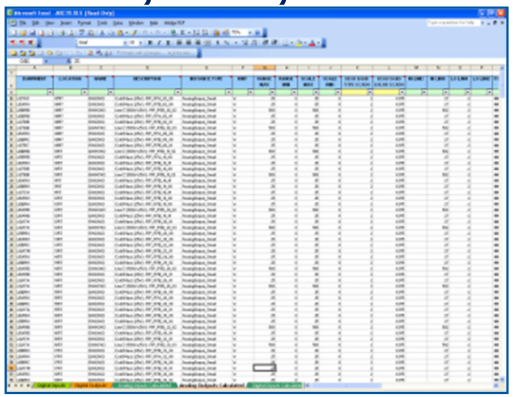
XML files for Mobile Test Bench

specifications for control software PLC , FEC, SCADA







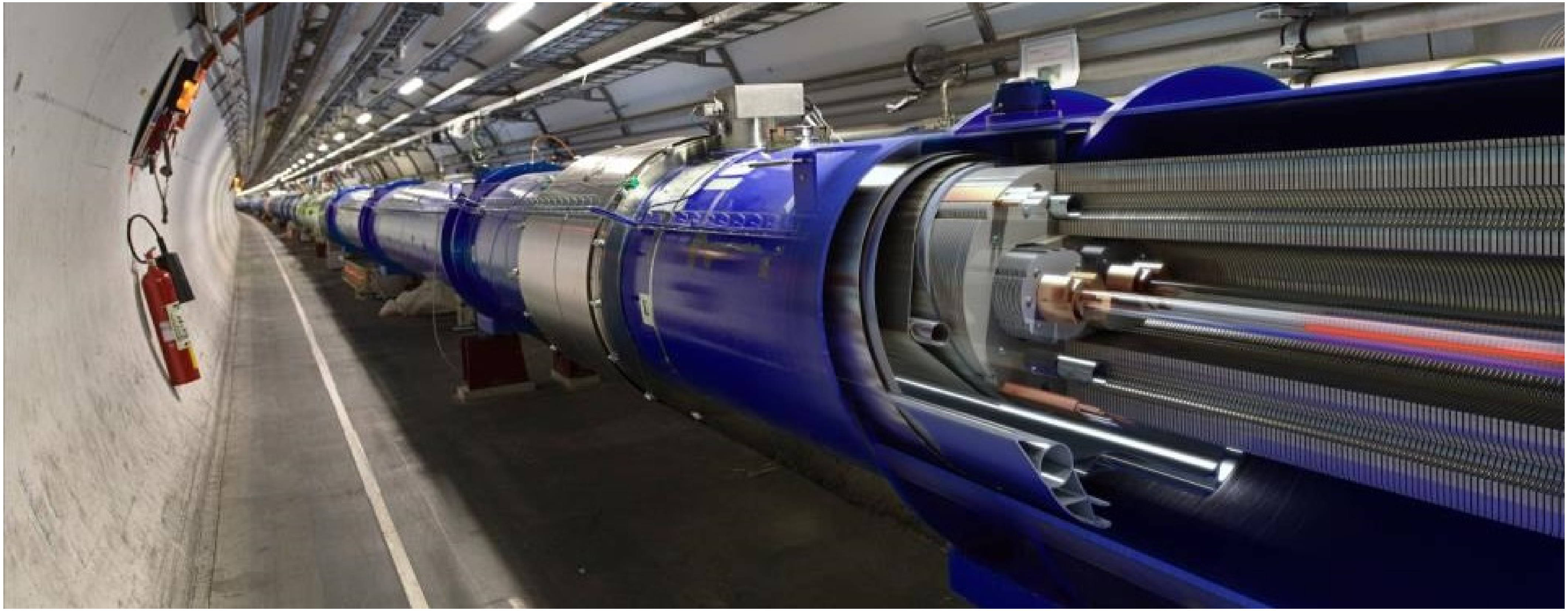


cryo people

vacuum for cryogenics (LHC)

To achieve high magnetic fields for accelerating and guiding the particle beams,
superconducting materials are needed
Bending magnets and accelerating RF cavities are operated at 1.9 and 4.5 K

Thermal insulation requires high-vacuum
Before cooling can start, insulation vacuum must be $< 10^{-1}$ mbar
Below 20 K, the cryo-pumping effect keeps the pressure around 10^{-7} mbar

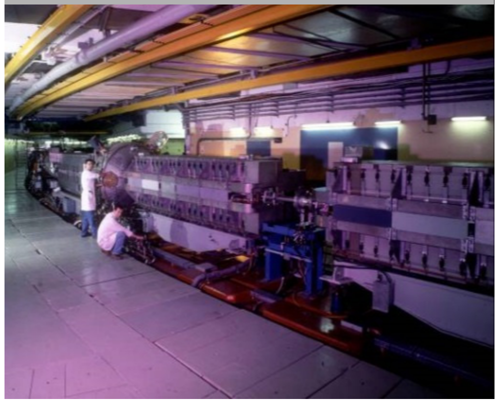


vacuum for beams

LINAC_2: 50 MeV

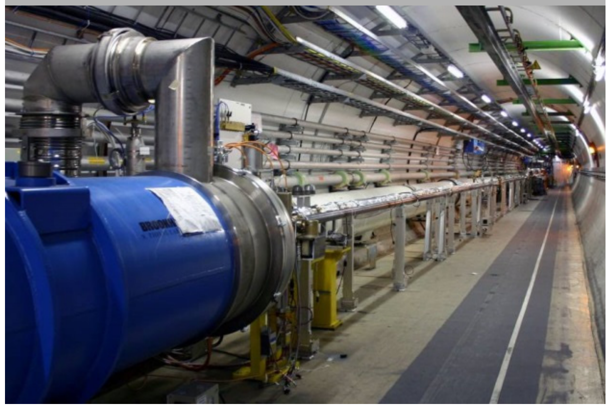
PS_Booster: 1.4 GeV

PS: 26 GeV



SPS: 450 GeV

LHC: 7 000 GeV

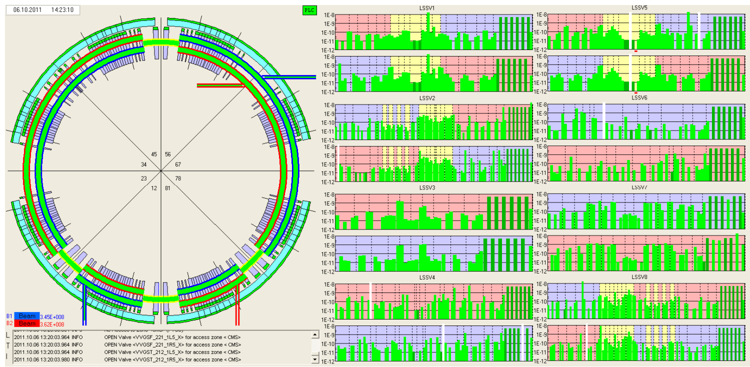


To avoid beam loss (100 h lifetime) and noise to the experiments
need to minimise interactions between beam and residual gases
therefore, beam pipes must be pumped to ultra-high vacuum

LHC : nominal beam vacuum ~ 10^{-12} mbar

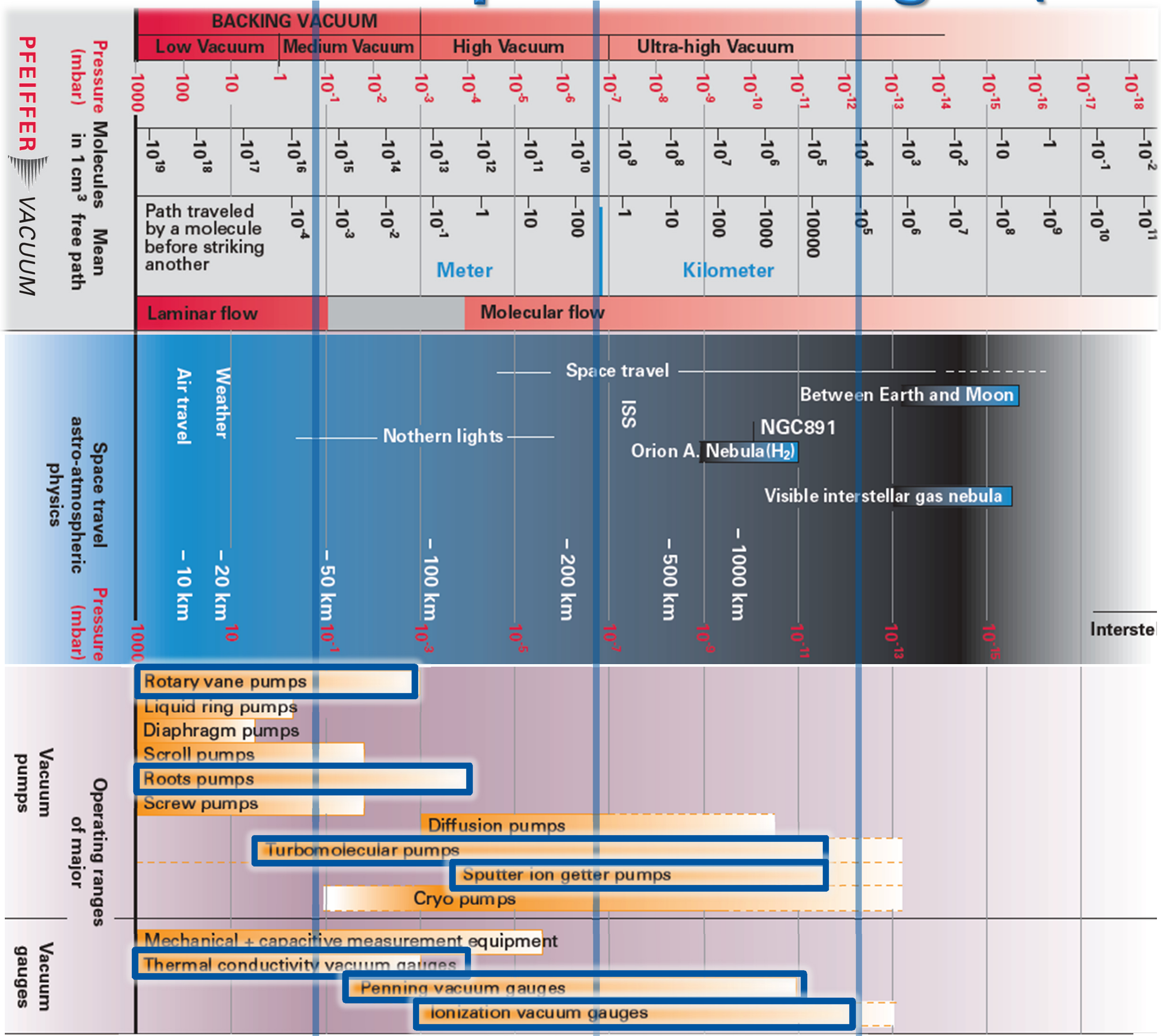
LHC : insulation and beam vacuum ~ 109 km [10^{-5} .. 10^{-12} mbar]

SPS, PS, PSB, L2, L3 : beam vacuum ~ 19 km [10^{-7} .. 10^{-9} mbar]



http://home.web.cern.ch/about/engineering/vacuum-empty-interplanetary-space

vacuum pressure ranges (15 decades)



LHC Insulation Vacuum

P < 10^{-1} mbar

VAC_OK for cool-down

@T < 20 K : cryo-pumping

P ~ 10^{-7} mbar

Beam Vacuum

P ~ 10^{-9} .. 10^{-12} mbar

primary /roughing pumps

10^{+3} .. 10^{-2} mbar

turbomolecular pumps

.. 10^{-11} mbar

sputter ion pumps

10^{-5}.. 10^{-11} mbar

pirani gauges

10^{+3} .. 10^{-4} mbar

Penning gauges

10^{-5} .. 10^{-11} mbar

Bayard-Alpert gauges

10^{-5} .. 10^{-12} mbar

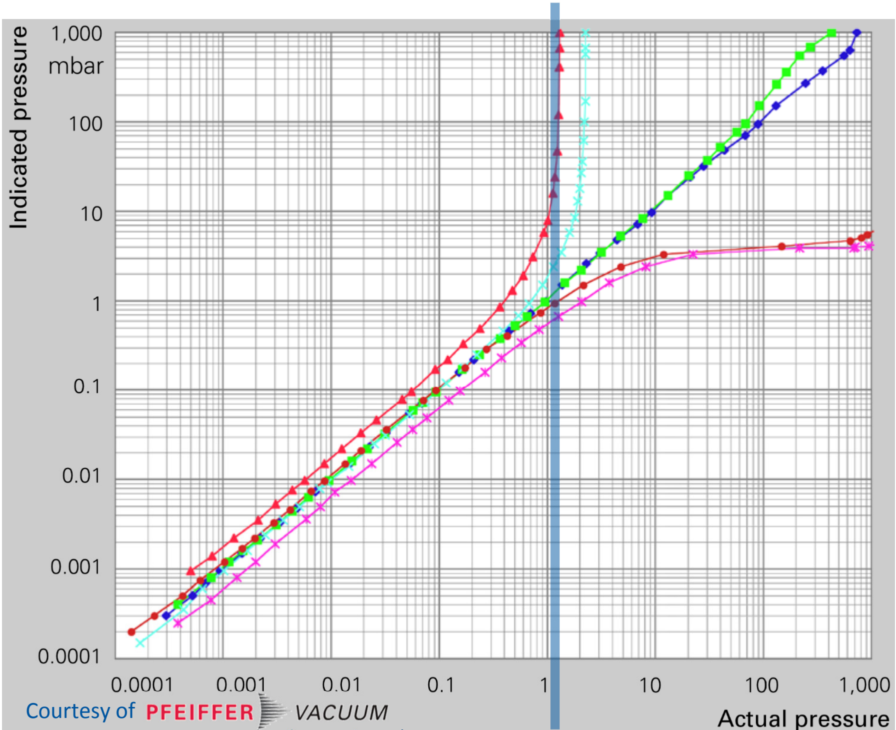
Courtesy of PFEIFFER VACUUM
www.pfeiffer-vacuum.com/know-how/

Pirani gauges (thermal conductivity)

Dependence of thermal condutivity on gas pressure
Resistor under vacuum is heated to constant temperature (~ 120 °C)
The necessary heating current is a measure of the pressure

1 bar .. 10^{-4} mbar

above 1 mbar : non-linear ; dependent on gas spiecies
Accuracy ~ 30%
Needs calibration, to compensate for cable length
Sensitive to ambient temperature



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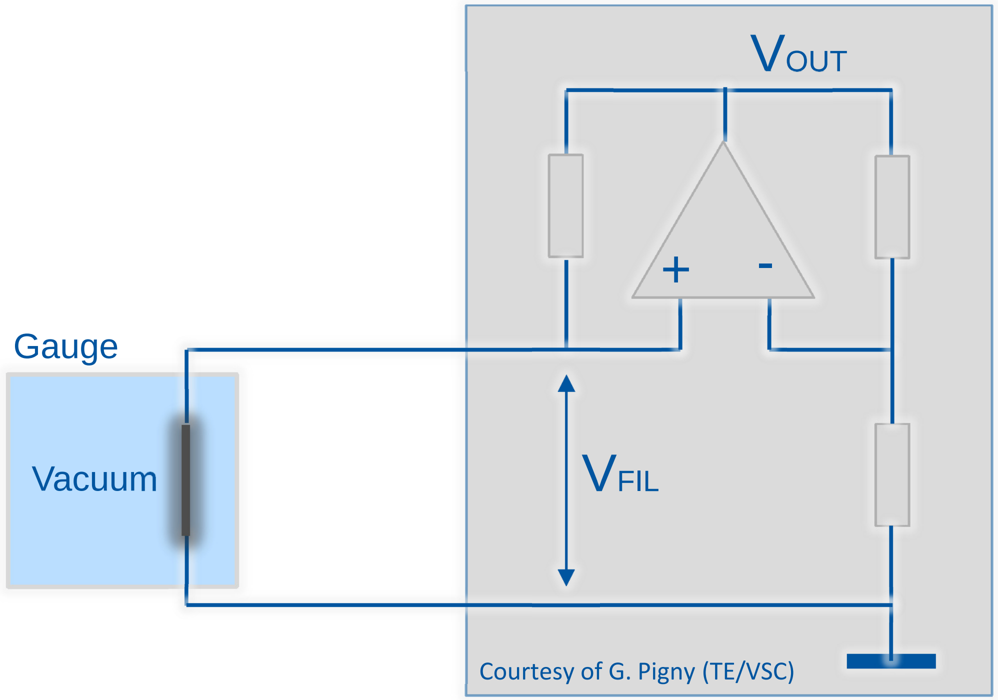
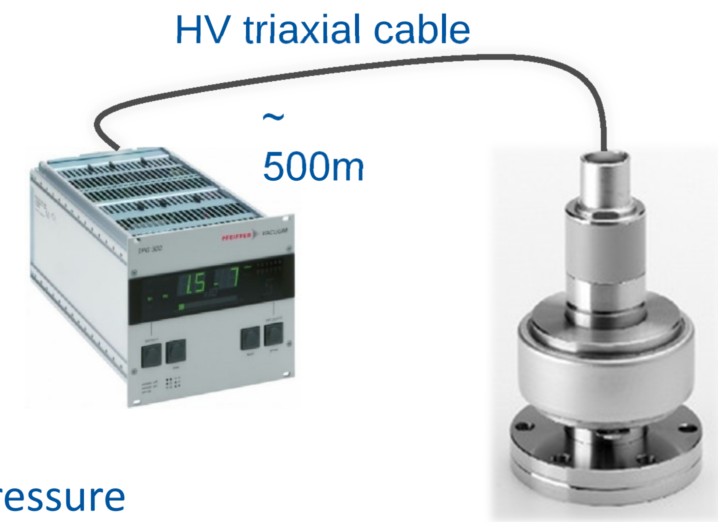
www.pfeiffer-vacuum.com/know-how/



Courtesy of G. Pigny (TE/VSC)

Penning gauges (cold cathode ionization)



Electrons are emitted from cathode, due to high electric field (3 kV)

Magnetic field (0.1 T) provokes longer oscillating paths to anode
increasing the probability of ionizing gas molecules

Ion current collected in cathode (1 uA .. 1 pA) is a measure of the pressure

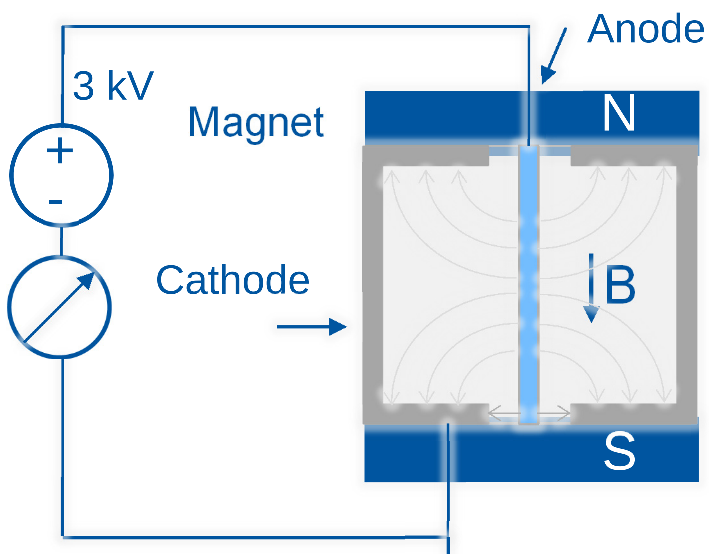
10^{-5} .. 10^{-11} mbar

Accuracy ~ 50%

At high pressure : current is unstable due to arcing
At low pressure : current extinguishes (zero reading)

Broken cable (zero reading) may simulate good vacuum

Poor isolation on HV cables & connectores :
leakage current simulates higher pressure reading



Courtesy of G. Pigny (TE/VSC)

Bayard-Alpert gauges (hot cathode ionization)

Electrons are emitted by the heated filament (no need for high electric field)

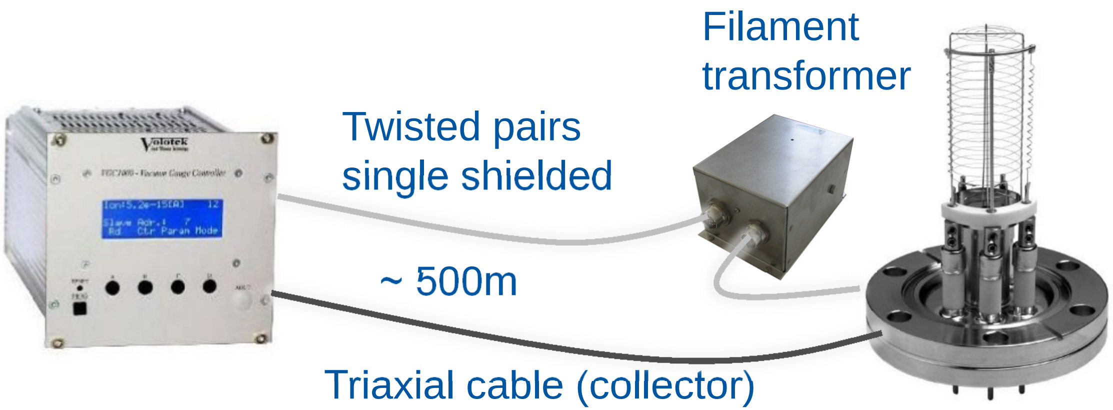
Electric field inside the grid (150 V) provokes longer oscillating paths
increasing the probability of ionizing gas molecules

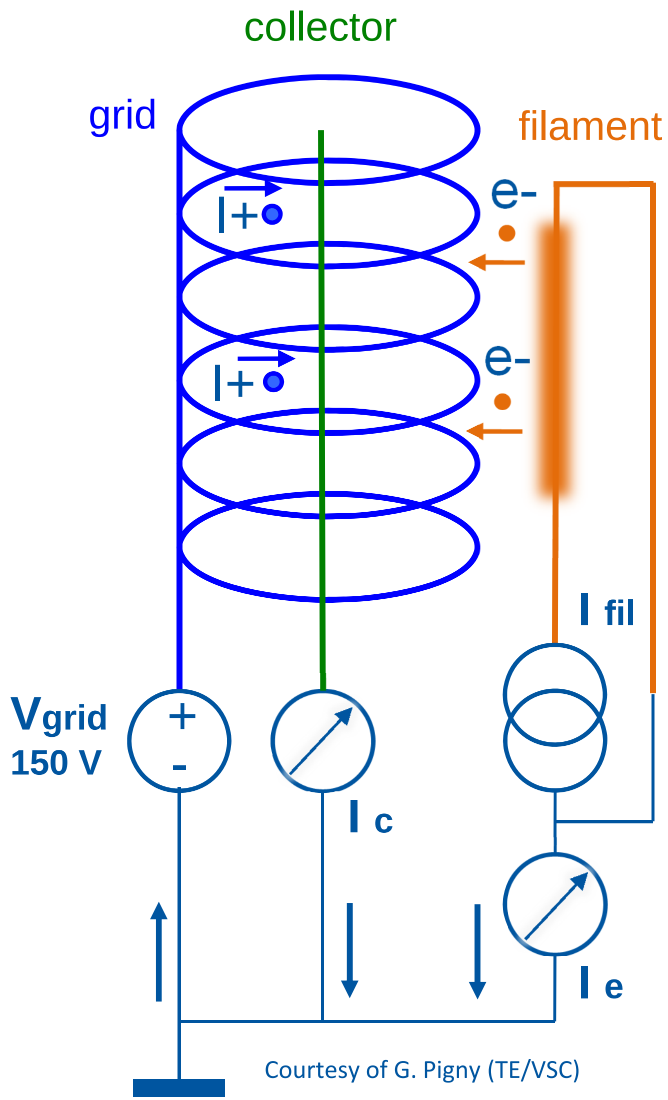
Ions are attracted to the collector

Ion current (1 uA .. 0.1 pA) is a measure of the pressure

10^{-5} .. 10^{-12} mbar

Accuracy ~ 10%
Needs callibration





Courtesy of G. Pigny (TE/VSC)

Primary (or roughing) pumps

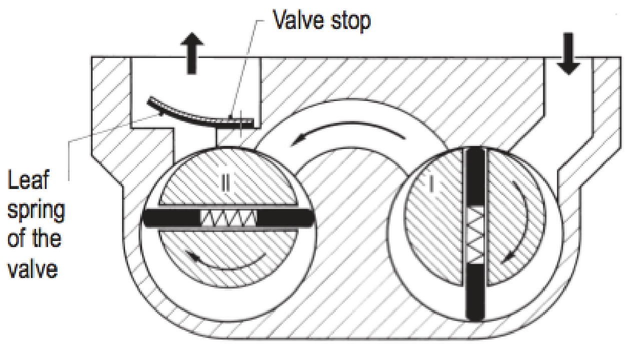
Used as the first stage of pumping from atmospheric pressure,
or as a backing pump for TurboMolecular pumps

wet pumps (ex. **Rotary vane**) : with oil as sealing, lubricant, and heat exchanger

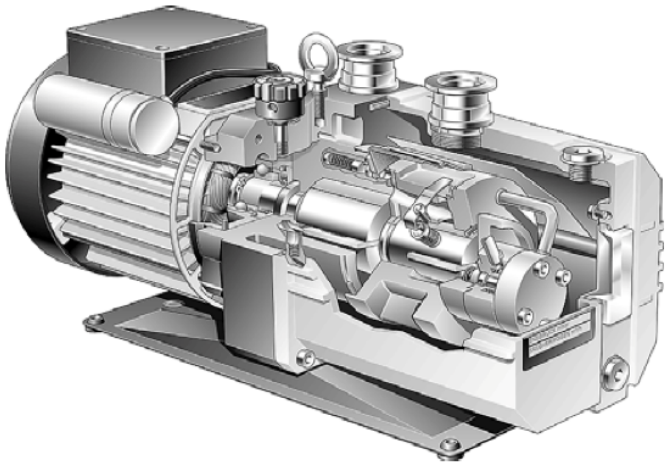
dry pumps (ex. **Roots**) : more clean

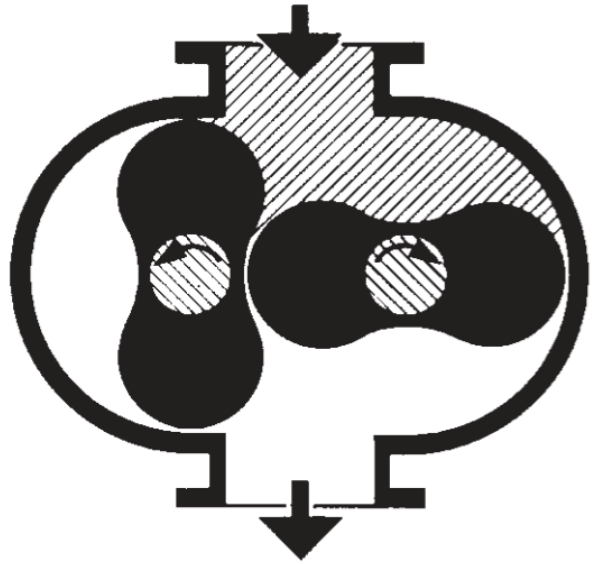
1 bar .. 10^{-2} / 10^{-4} mbar

pumping speed of a few m^3 /h



I High vacuum stage
II Second forevacuum stage





1 Intake flange
2 Rotors
3 Chamber
4 Exhaust flange
5 Casing

Courtesy of Oerlikon-Leybold
http://www.oerlikon.com/leyboldvacuum/en/documents/download-documents/

Turbo Molecular pumps

The rapid movement (30 000 - 70 000 rpm) of the turbine rotor kicks the gas molecules into the stator surfaces and then in the direction of the backing (exhaust) port

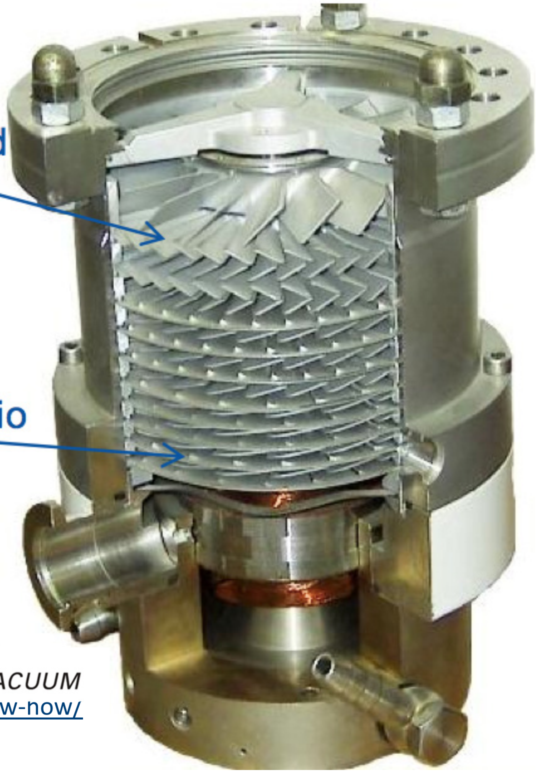
Used as the second stage, together with a rughing pump connected to the atmosphere

10^{-2} .. 10^{-11} mbar

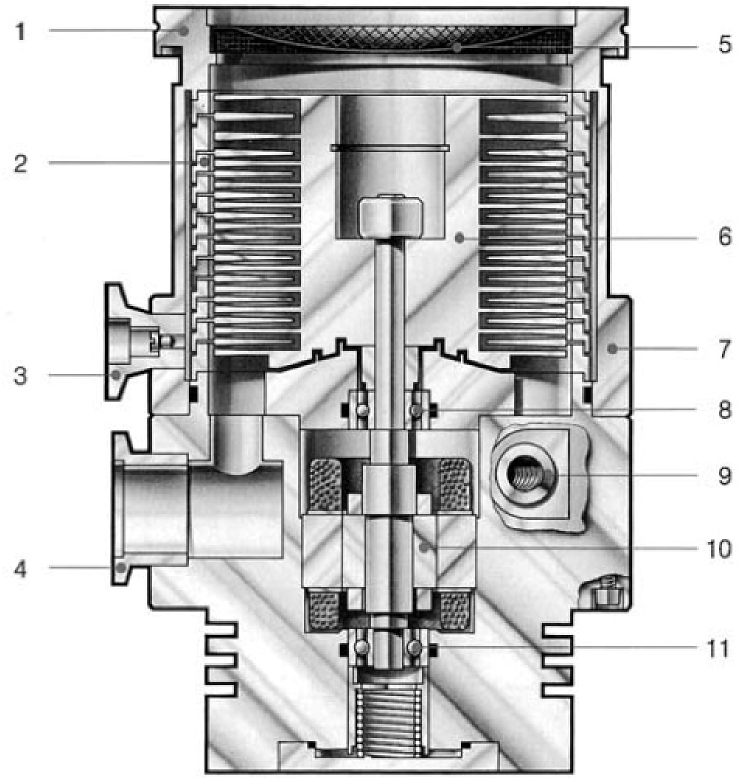
pumping speed of 10 .. 3 000   l /s

High pumping speed

High compression ratio



Courtesy of PFEIFFER VACUUM
www.pfeiffer-vacuum.com/know-now/



1 High vacuum inlet flange
2 Stator pack
3 Venting flange
4 Forevacuum flange
5 Splinter guard
6 Rotor
7 Pump casing
8 Ball bearings
9 Cooling water connection
10 3-phase motor
11 Ball bearings

Courtesy of Oerlikon-Leybold
http://www.oerlikon.com/leyboldvacuum/en/documents/download-documents/

Sputter ion pumps

Composed of several Penning cells

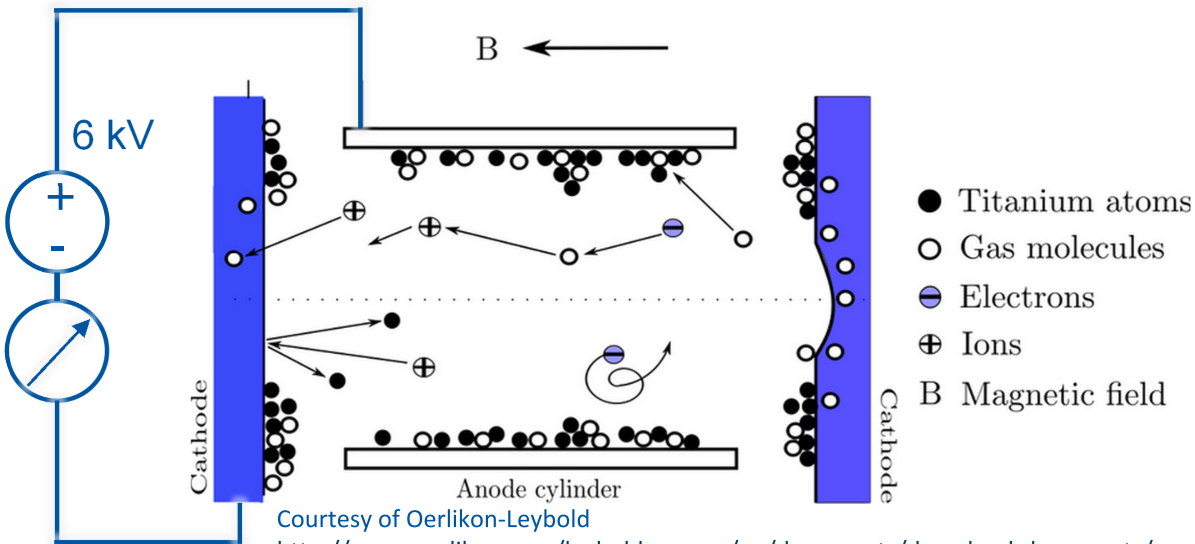
Electrons are emitted from cathode, due to high electric field (6 kV)

Magnetic field (0.2 T) provokes longer oscillating paths to anode increasing the probability of ionizing gas molecules

Ion current (10 mA .. 1 uA) is a measure of the pressure

Pumping : ions bombardment of the Ti cathodes
Sputtering & deposition of Ti => getter reactive gases
Ion implantation into the cathode => all type of ions

10^{-5} .. 10^{-11} mbar



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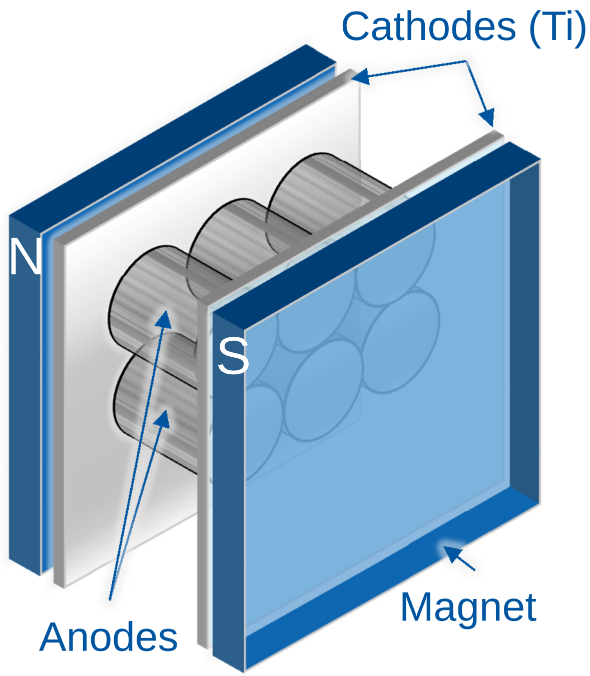
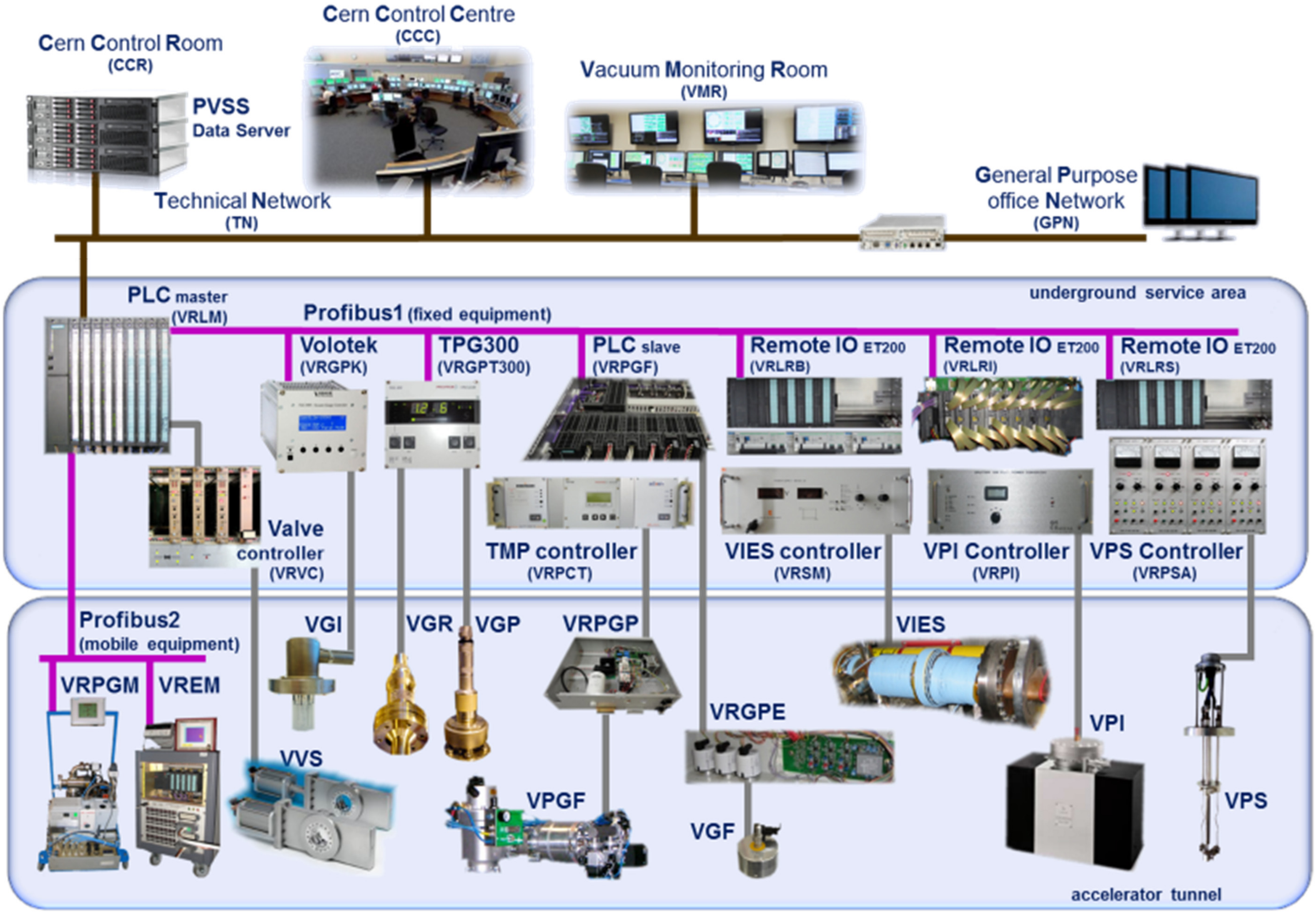


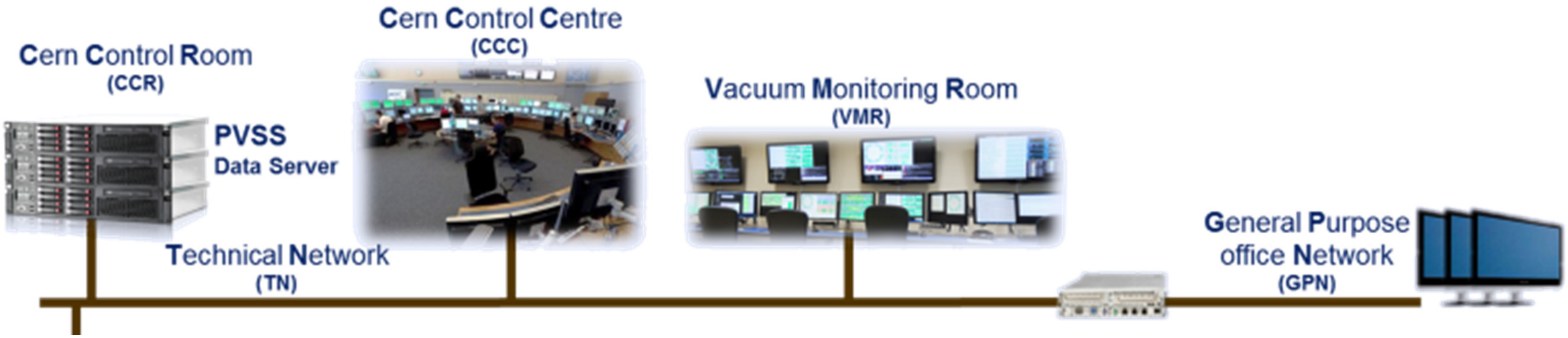
Courtesy of G. Pigny (TE/VSC)

vac controls architecture



ICALEPCS 2011 poster : http://accelconf.web.cern.ch/AccelConf/icalepcs2011/posters/mopms016_poster.pdf
ICALEPCS 2011 paper : http://accelconf.web.cern.ch/AccelConf/icalepcs2011/papers/mopms016.pdf

vac controls - on the surface



Since 2000, all accelerators have been upgraded to a PLC-based architecture

Master_**PLC**: Siemens S7-400

Human-Machine Interface (**SCADA**): Siemens WinCC-OA (former PVSS II, from ETM)

Small accelerators are controlled by a single PLC

Large accelerators have one PLC at each underground service area

(**CPS**: 5, **SPS**: 7, **LHC**: 28)

However, olny 1 SCADA Data-Server (DS) per accelerator

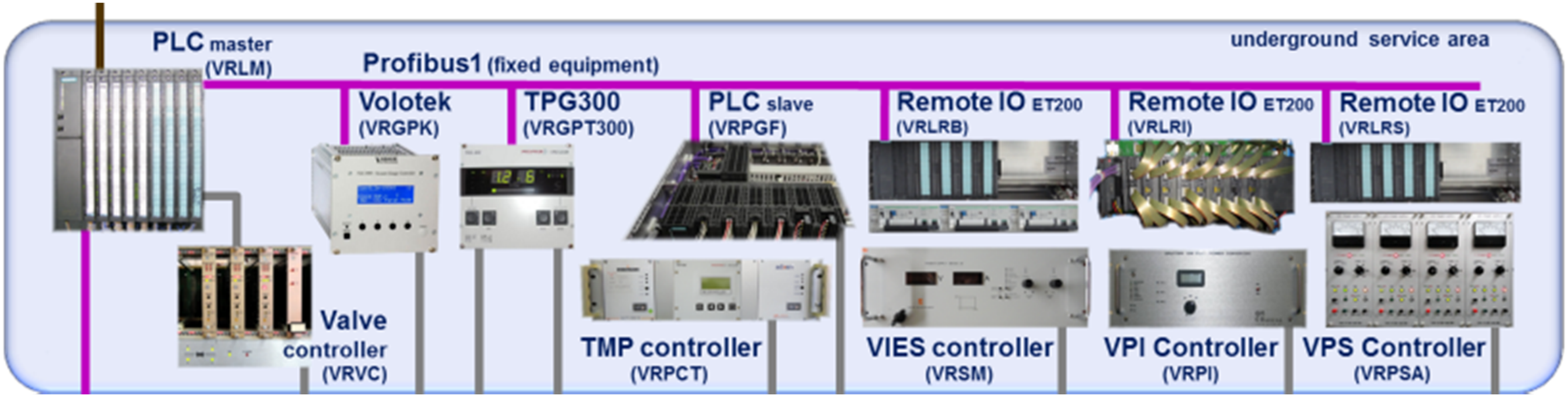
PLCs and DS communicate through Ethernet in a protected and restricted "Technical Network“

Consoles in the "Office Network" can only monitor the system evolution

vac controls - in underground service areas

Master_PLC, controllers, power supplies - kept in underground service areas
away from the radiation in accelerator tunnels

PLCs talk to field equipment (gauges and pumps) through controllers; the modern ones often :
are intelligent, with embarked microprocessor or FPGA
can communicate with the PLC via Profibus, minimising the complexity and price of cabling and allowing wider exchange of information & configuration



On Profibus, controllers for:
- **VGR** : TPG300, Thermal conductivity gauge (Pirani) : [1..10^{-4} mbar]
- **VGP** : TPG300, Cold cathode ionisation (Penning) gauge : [10^{-5}..10^{-11} mbar]
- **VGI** : Volotek, Hot cathode ionisation (Bayard Alpert) : [10^{-5}..10^{-12} mbar]
- **VIES** : power supplies for "anti-electron-cloud solenoids"
- **VPGF** : fixed pumping groups and their TMP controller , managed by a small Slave_PLC S7-300

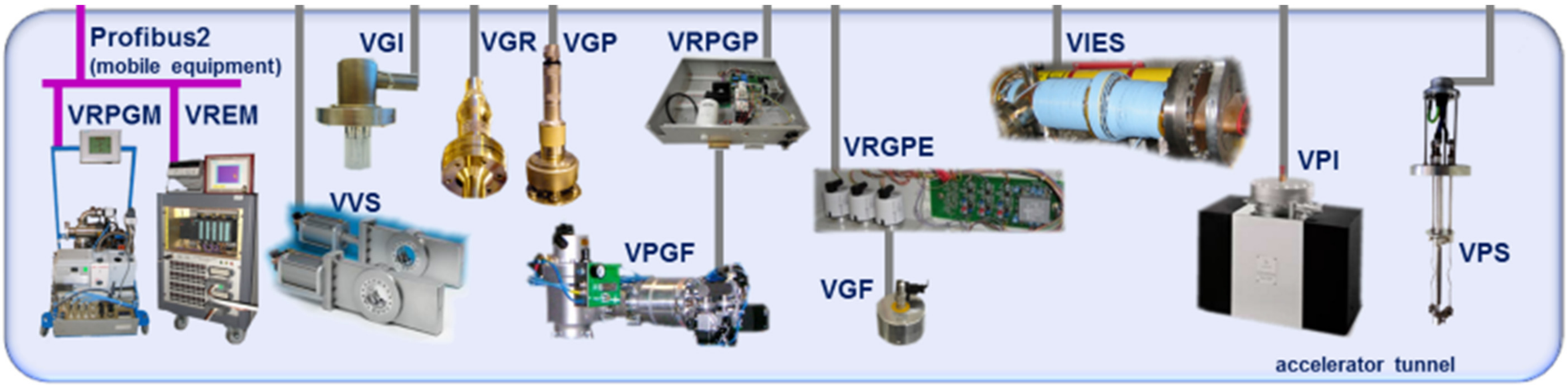
Not on Profibus:
- **VVS** : controllers on individual IO channels on the Master_PLC
- **VPI** : power supplies on remote-IO stations (Siemens-ET200)

vac controls - in the accelerator tunnel

VGF : "active" pair of VGR+VGP, with front-end electronics nearby
in tunnel zones where : radiation low, and far from a service area

VGR and **VGP** closer to the service areas; can be directly accessed by a “TPG”

Mobile Profibus : dynamic network for "mobile" equipment (when the accelerator is stopped)
VPGM : mobile pumping groups, with "Slave" PLC S7-200
VREM : mobile bake-out stations, with "Slave" PLC S7-300



vac instrument count for all accelerators

6 000+ vacuum instruments to be controlled and monitored

along **130 km** of vacuum chambers
pressure range **[10^{-4} .. 10^{-11} mbar]**

PLCs : **300+**

gauges : **3 000**

pumping groups : **250**
ion pumps : **2 700**

sector valves : **500**

	L2,L3, PSB,PS	SPS	LHC beam	LHC insul.	other facilities	total
length [km]	2	16	59	50	1	128
log (P [mb])	-7..-10	-7..-9	-8..-11	-5..-7	-4..-10	-4..-11
PLC master	5	8	28		3	44
PLC other	0	10	7		0	17
PLC slave	0	0	100		155	255
VGM	0	0	10	231	0	241
VGR	102	113	428	348	61	1052
VGP	122	128	649	364	66	1329
VGF	0	13	4	0	0	17
VGI	28	0	167	0	16	211
VPGF	7	3	14	179	51	254
VPI	370	1429	825	0	69	2693
VPS	48	0	0	0	0	48
VVS	76	87	305	39	13	520
VVF	0	11	0	0	0	11
VVW	0	5	0	0	0	5

LS1 consolidations (2013-14)

During LS1, vacuum control systems of PS & AD were renovated (**600+** new controllers)
propagating the PLC/SCADA architecture,
bringing the hardware & software to the level of the other machines, and thus enforcing standardization

	VGR/P	VGI	VPG	VPI	VPS	VPC	VVS	TOT
PS	86			156	117		13	**372**
AD	72	19	16	65	100	6	15	**293**

Furthermore, each accelerator received new sectors, new instruments, new features (**1 500+** new controllers)

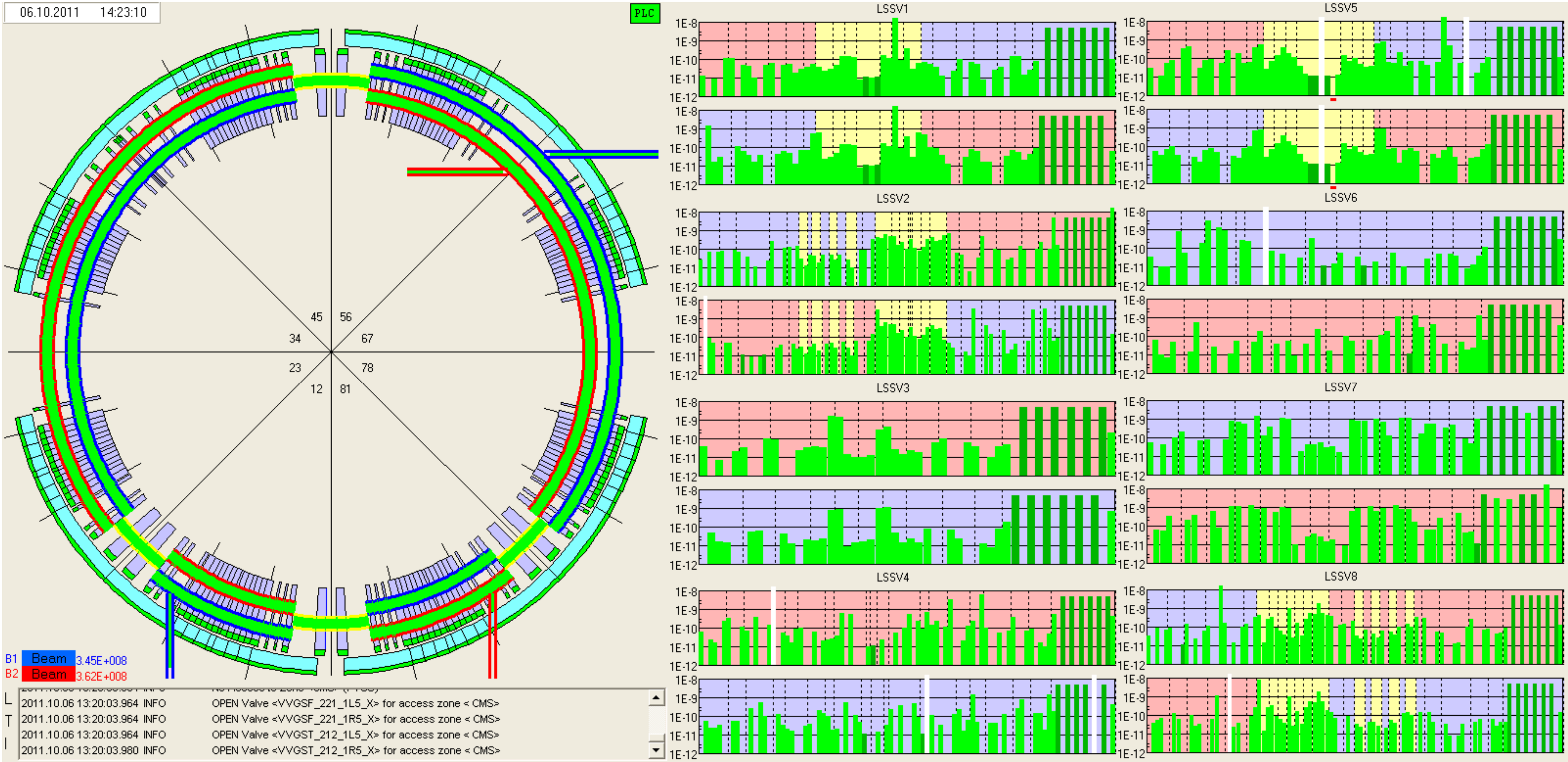
	New Instruments	New Cables	Damaged Cables
PS	372	365	21
AD	293	29	
CPS other	49	6	3
SPS	74	229	276
LHC	392	562	8
R2E LHC		480	
HIE-ISL	132	390	
L4	142	350	
NA62	102	200	
nTOF	19	60	
TOTAL	**1 575**	**2 671**	**308**

SCADA for vacuum

SCADA applications have been under significant evolution,

regarding their ergonomics, configurability and standardization :

- simplified &normalized presentation of information
- coherent functionalities & menus, across all machines
- automatic scripts, instead of fastidious manual actions
- enhanced tools, for data analysis and interventions



Quality Management

A QM Plan is progressively being put into place, concerning methods & tools :

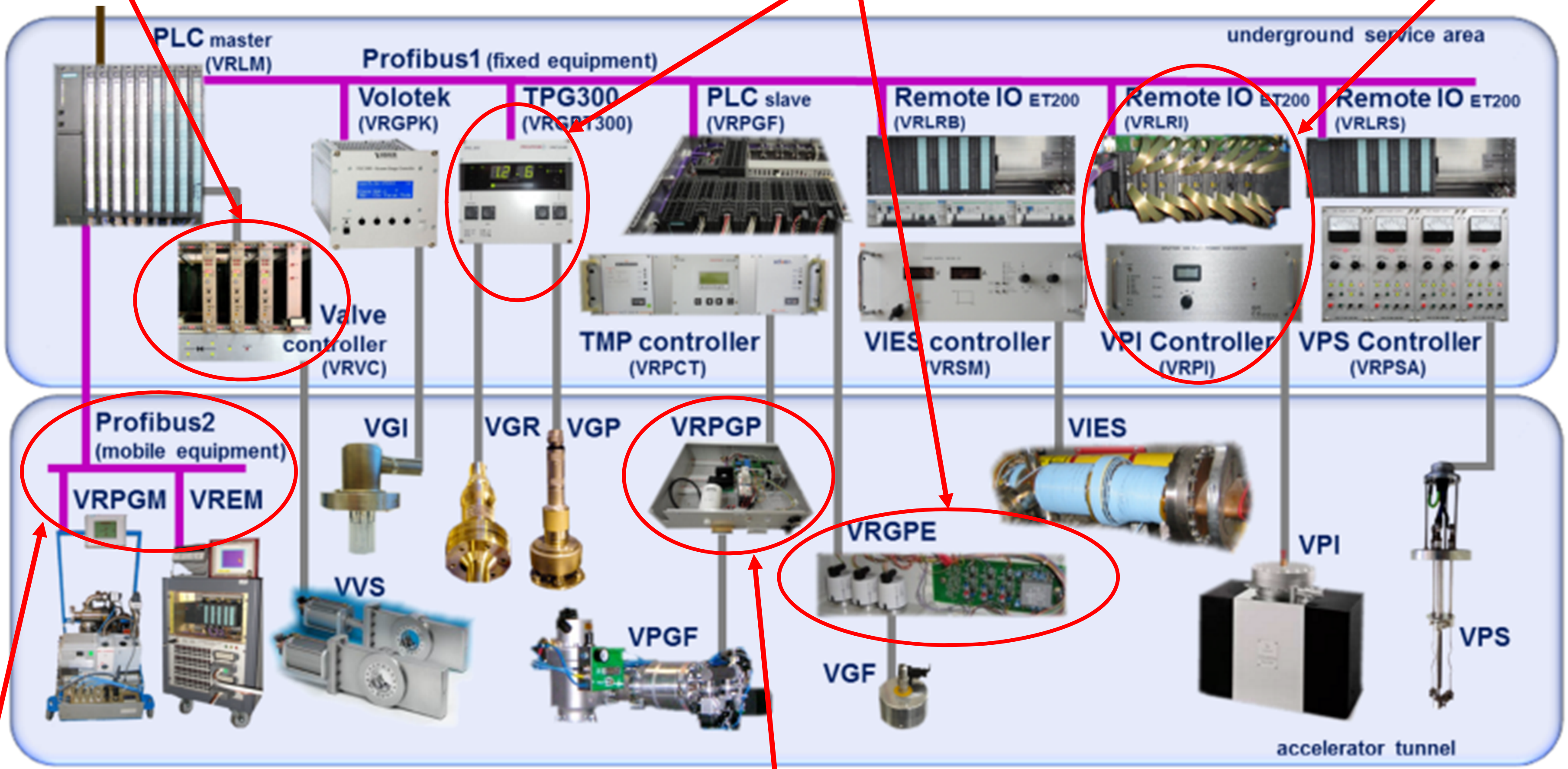
Naming: rules for coding equipment names, independently of machine
VTL: track problems, requests, repairs, and other actions
MTF: assign a unique "part-identifier" to each individual device; trace history
EDMS: centralise information on architectures, procedures & settings
Layout-DB: describe topology of control components

next hardware developments

New sector valve card
New Interlock crate
Standardise (PS, SPS, LHC)

New gauge controllers
LSS: Have an alternative design
ARC : Transmission 4-20mA

New Ion Pump controller
Switching mode PS + Profibus



Field bus for mobile ctrls
Evaluate a wireless solution

New turbo ctrl & local crate
Standardise types

vac people

LHC preparing to restart

https://youtu.be/xcMmiKnbFyY


EN CAS D'ALARME
Défense de descendre
Manque d'oxygene