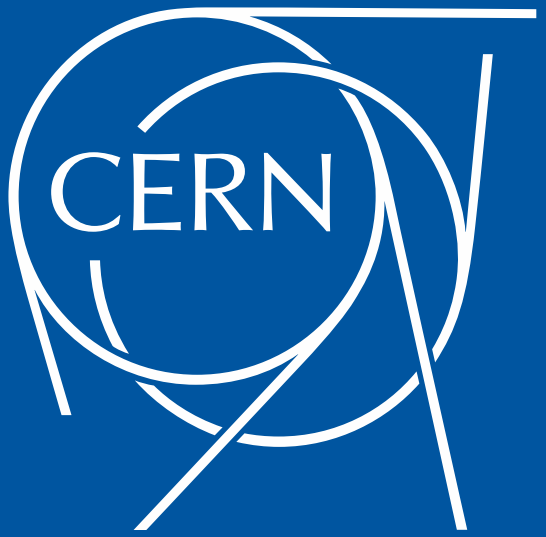
CERN

OLAV IV

LHC insulation vacuum system: consolidation activities and leaks follow-up during the first LHC long shutdown

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on behalf of all contributors to LHC insulation vacuum
(TE/VSC, AL4030 and ICIT)

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- Introduction to LS1
- LS1 activities for insulation vacuum (IV)
- LHC insulation vacuum system overview
- Leak test support
- Insulation Vacuum (IV) consolidation
- ‘Cold’ Beam Vacuum (BV) consolidation
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- Examples of leaks (LS1)
- Summary

Introduction to LS1

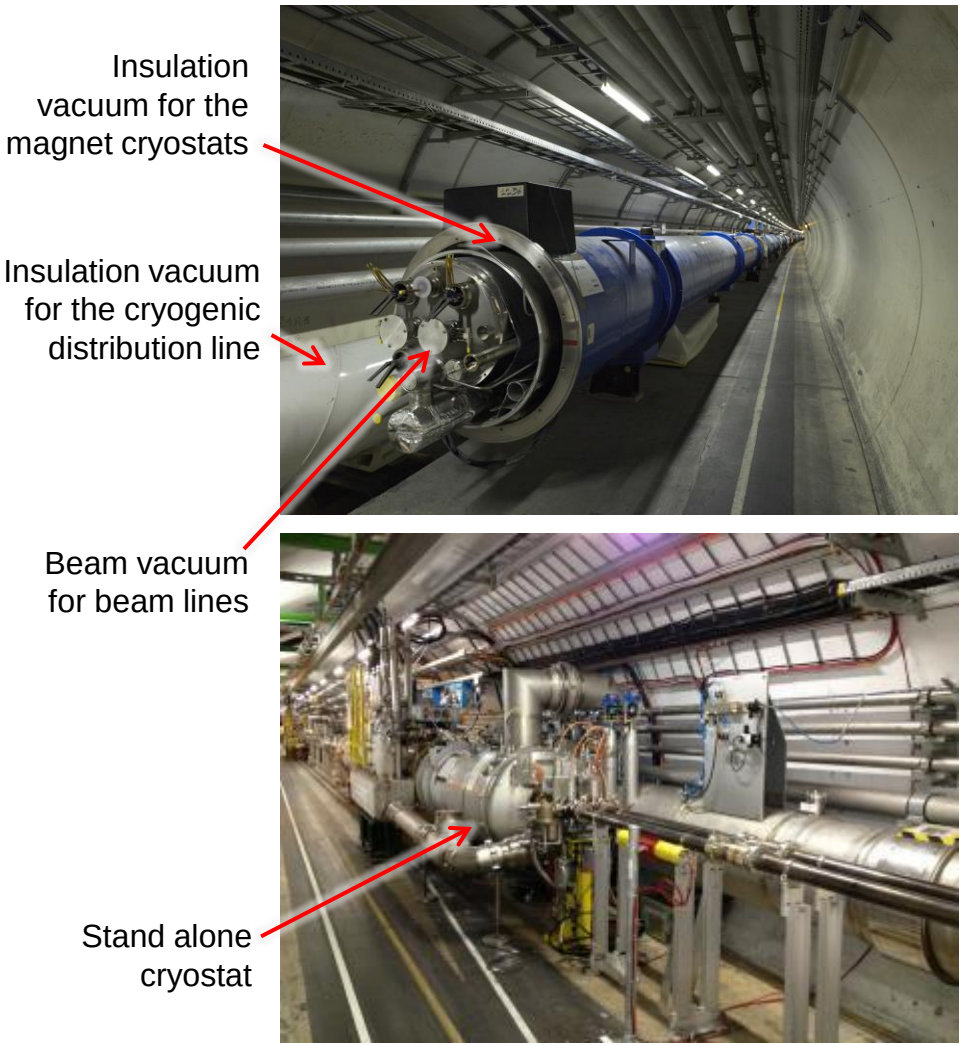
- LS1: ~ 2 year-break from operation
- Main priorities of LS1 for LHC:
  - Activities linked to incident Sept. 2008:
    - Consolidation of 13 kA supeconducting splices and repair of defectuous interconnects (powering at 7 TeV)
    - Installation of remaining pressure relief devices DN200
  - Bring all necessary equipment up to the level needed for 7TeV/beam
  - Repair of He leaks
- Others (related to IV):
  - IV and ‘cold’ BV consolidation
  - Maintenance

LS1 activities for IV

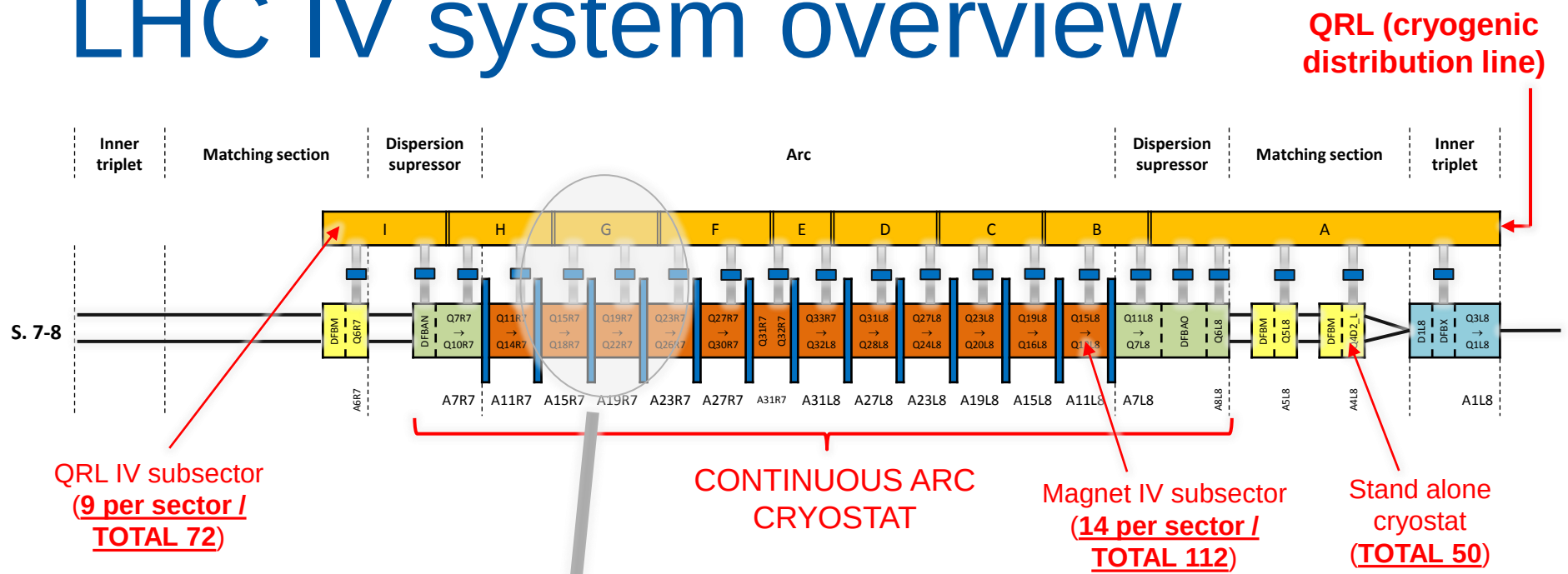
LEAK TEST (1) >80K; (2) 5 bar → VENT *IV*	**Leak test support**	*Splice consolidation*			**PUMP *IV* → LT (PRESS. TEST)**
		Special interventions	Cryomagnets, connection cryostats, diodes, Y lines, triplet braids…		
		DFBA	Splices and flexibles		
	IV consolidation	*Localisation of known leaks*			
		Final safety valve configuration	Flap valves and spring loaded valves		
		Improvements	New by-passes, turbos, p/o ports		
		Maintenance	Pumps, O-ring exchange		
VENT *BV* → RF BALL	**'Cold' BV consolidation**	*PIMs*		**PUMP & LT *BV***	
		New protection devices	Protective shells; rupture disks and non-return valves		
		Interconnection QC	Integrity of bellows		

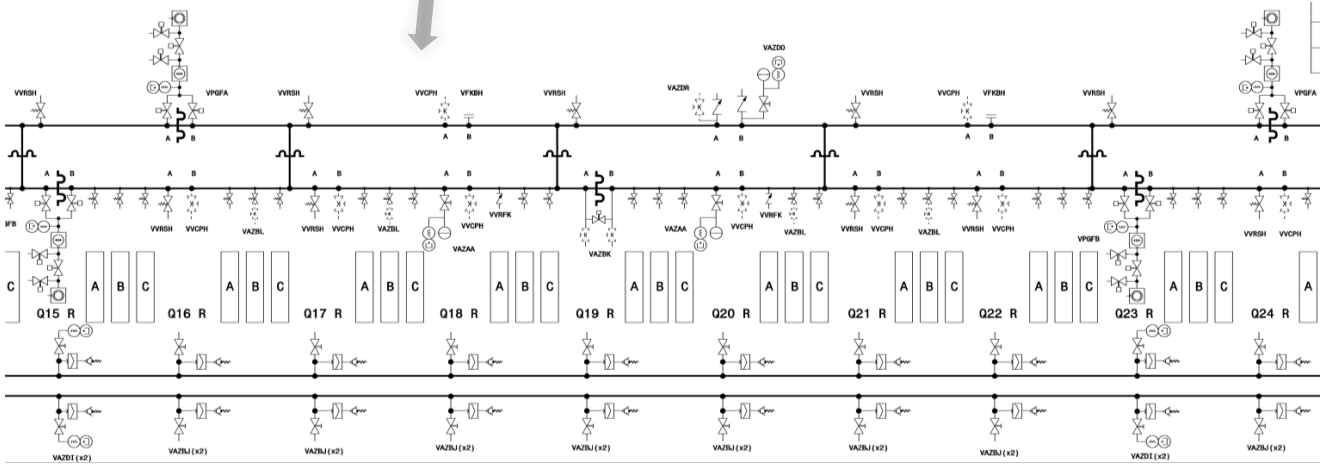
LHC IV system overview

Characteristic	Quantity for LHC machine & distribution line (QRL)
Insulation vacuum system length	**22,4 km & 25 km**
Welds	**~ 250 000 (90 000 in-situ)**
Weld length	**~ 100 000 m**
Elastomer joints	**~ 18000**
Elastomer joint length	**~ 22 000 m**
Multi-layer insulation	**~ 9 000 000 m^2 or 200 m^2/m of cryostat**
Vacuum subsectors	**234**
Vacuum subsector length	**214 m (machine) & 428 m (QRL)**
Vacuum subsector volume	**~ 80 m^3**
Fixed turbo pumps	**178**
Nominal turbo pumping speed	**0,25 l/s/m of cryostat**
Fixed vacuum gauges	**974**
Mobile turbo pumping groups	**36**
Mobile primary pumping groups	**36**



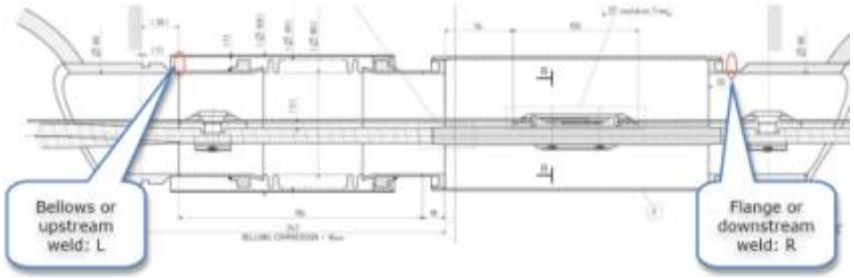
LHC IV system overview





Leak test support

Activity	Concept	Number of welds	Leak tests foreseen	Leak tests done	Leaks found	% leaks LS1	% leaks install.
Splice consolidation	M test	~11000	~5100	~3600	14	0.18	0.24
	W test		~1700	~800	15	1.75	2.4
DN200		~600	~600	~330	4	1.2	



Leak test support

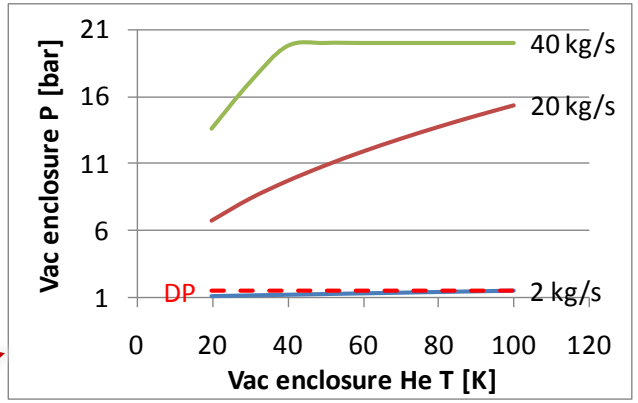
Activity	Leak tests foreseen for LS1	Leak tests foreseen and done in LS1	Leak tests <u>not</u> planned	Leaks found	% leaks LS1
Special interventions	~610	~500	~200… SO FAR	8	1.1 %
DFBAs	~320	~500	-	4	0.8 %

- Many different tools for many different positions to leak test

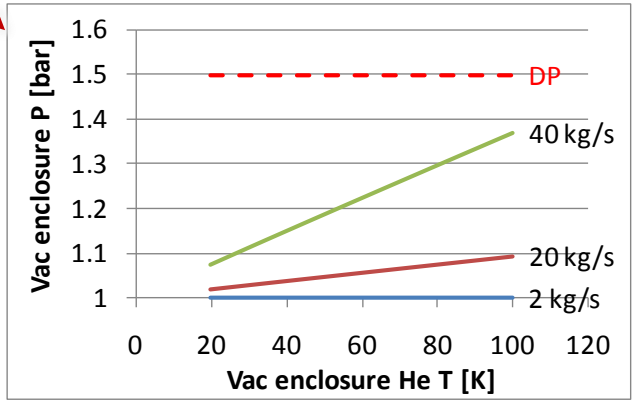
IV consolidation

- Improvements
  - Redundancy in configuration
    - Add simple by-passes (already included in 5 arcs)
    - Foresee 16 additional turbos at QRL extremities
  - Flexibility in configuration by means of new p/o ports
    - Leak test pre-localisation method
    - Chance of backup pumping through mobile groups
- Safety valve configuration → New protection scheme based on redefinition of MCI
  - MCI with magnets at nominal current and breach opening of 120 cm2 ⇒ max. flow of 30 Kg/s at 90K
    - Protection of the LHC insulation vacuum enclosure
  - MCI with access authorization of personnel (powering phase I) ⇒ max. flow of 1 Kg/s at 90K
    - Protection of the LHC insulation vacuum enclosure
    - Protection of personnel against 'He jam':
      - Avoid multiple He jams ⇒ 1 valve without spring per vac. subsector
      - Location of valve: as far as possible from potential intervention areas
      - Limit zones with relief points

Configuration Sept 2008: 2 DN90



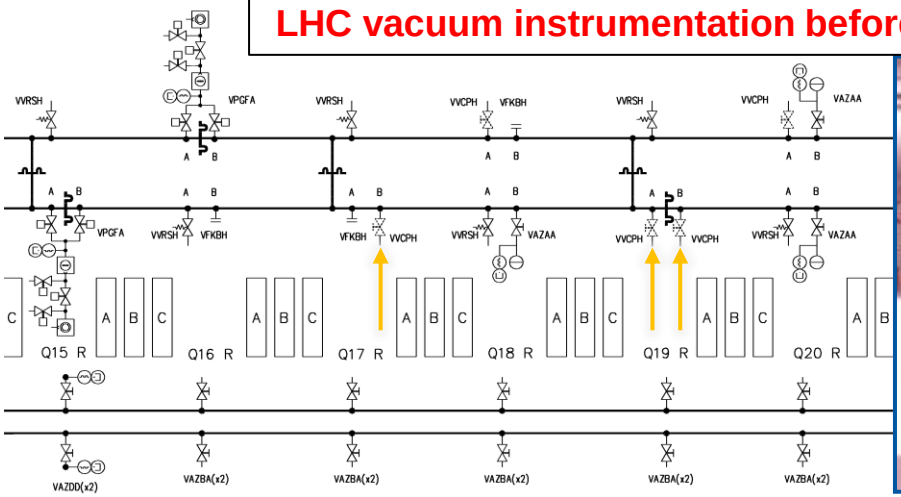
Protection on consolidated sub-sectors: 12 DN200, 2 DN90



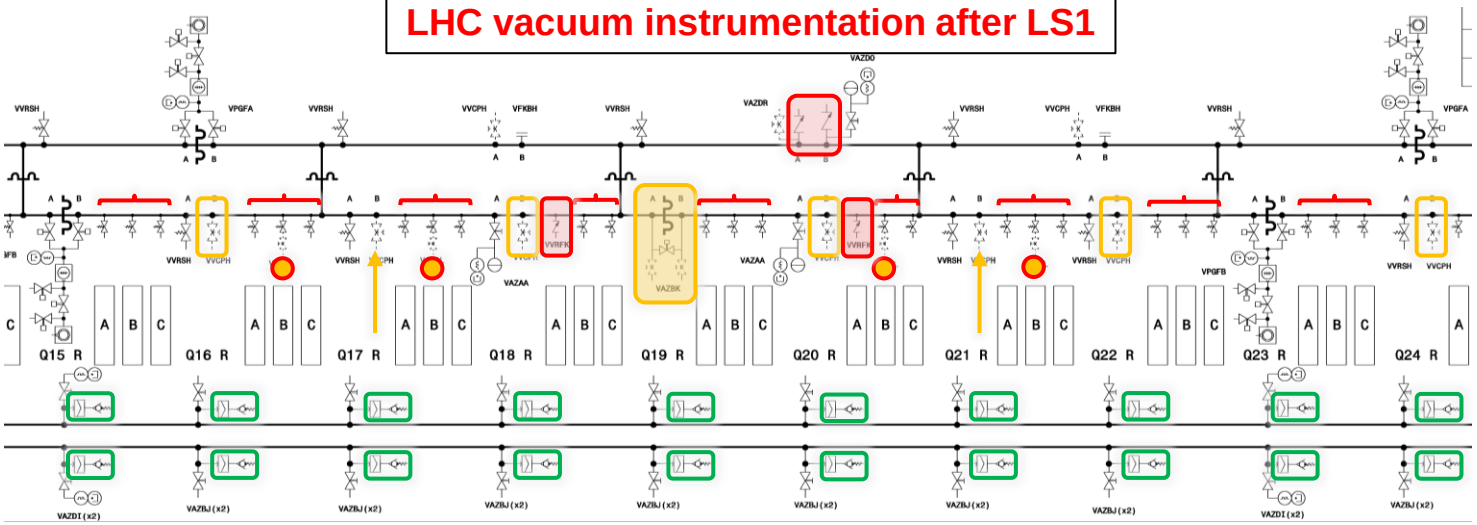
(DP: Design Pressure)

IV consolidation

LHC vacuum instrumentation before incident in 2008



LHC vacuum instrumentation after LS1



Spring loaded valve with p/o port

By-pass

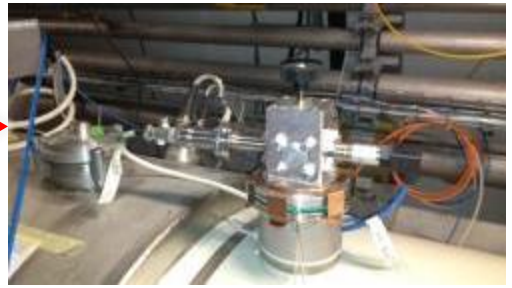
New p/o port

Self closing valve

Spring loaded valves

IV consolidation

Activity	Concept	New	Existing	% Done
Improvements	Turbos	16	178	100%
	By-passes	21	35	100%
	P/o ports	~400	~400	100%
Safety valve configuration	Flap valves DN200	120	-	95%
	Flap valves DN160	27	-	100%
	Gravity loaded valves DN90	144	-	100%
	SV with spring DN200	~620	~800	90%
	SV with spring DN160	6	67	100%
	SV with spring DN100	4	19	100%
	Reclamping	~700	-	100%

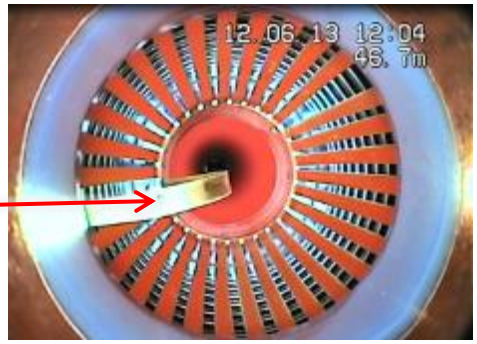


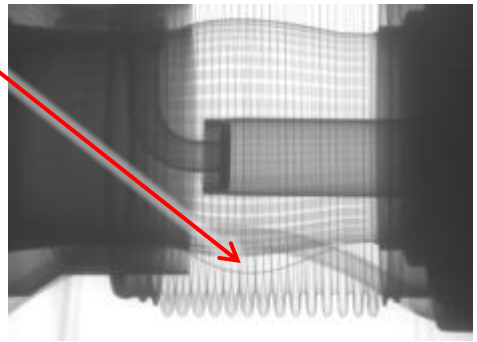
Activity	Item	Intervened	Existing	% Done
O-ring replacement	Seals DN100	~1200	~3500 (control)	85%
	Seals DN63	~200	~800 (control)	95%
Maintenance (fix groups)	Turbo	130	178	75%
	Prim. pump	42 (foreseen)	178	95%

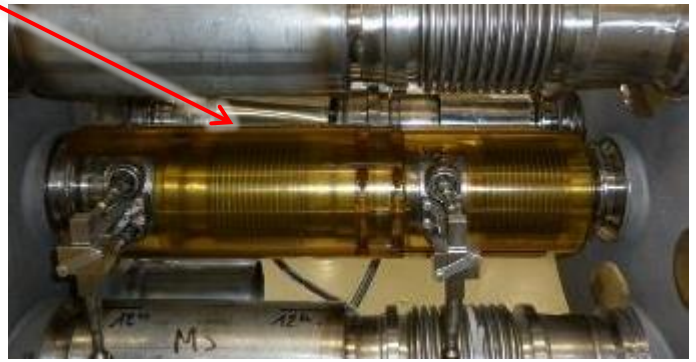
‘Cold’ BV consolidation

Activity	Number consolidated	Existing	% consolidated	Units with deformed fingers
PIMs	130	~3500	3,7%	4

Concept	Activity	Number	% done
New protection devices	Rupture disks and non-return valves	816	100%
	Half shells (temporary prot.)	~1700 ICs (~12000 pos.)	~70%



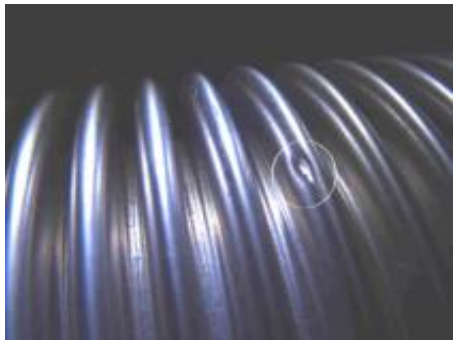




‘Cold’ BV consolidation

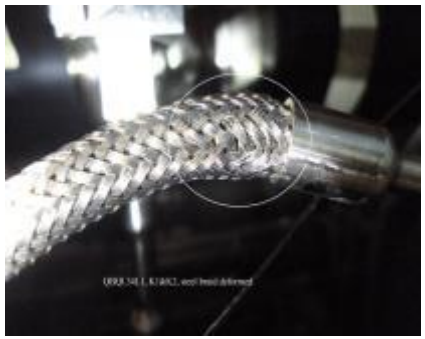
Concept	Activity	Bellows with shocks present during LS1	Consolidated during LS1 due to shock	% consolidated over bellows with shocks
Interconnection QC	PIM bellows	118	21	17,8 %
	Beam screen bellows	69	3	4.3 %

(*) NOTE: quality controls also include other components (flexibles, tubes, etc.)



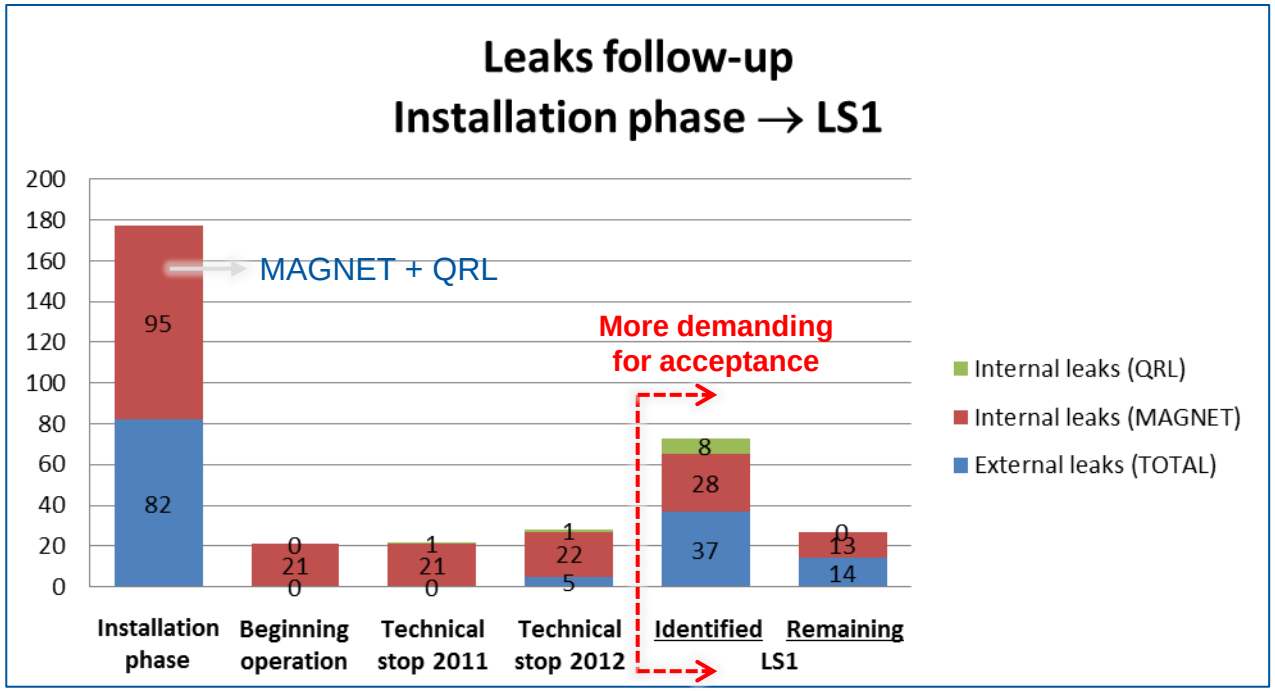
Bellows replaced

86 NCs opened after inspection in 7out of 8 sectors



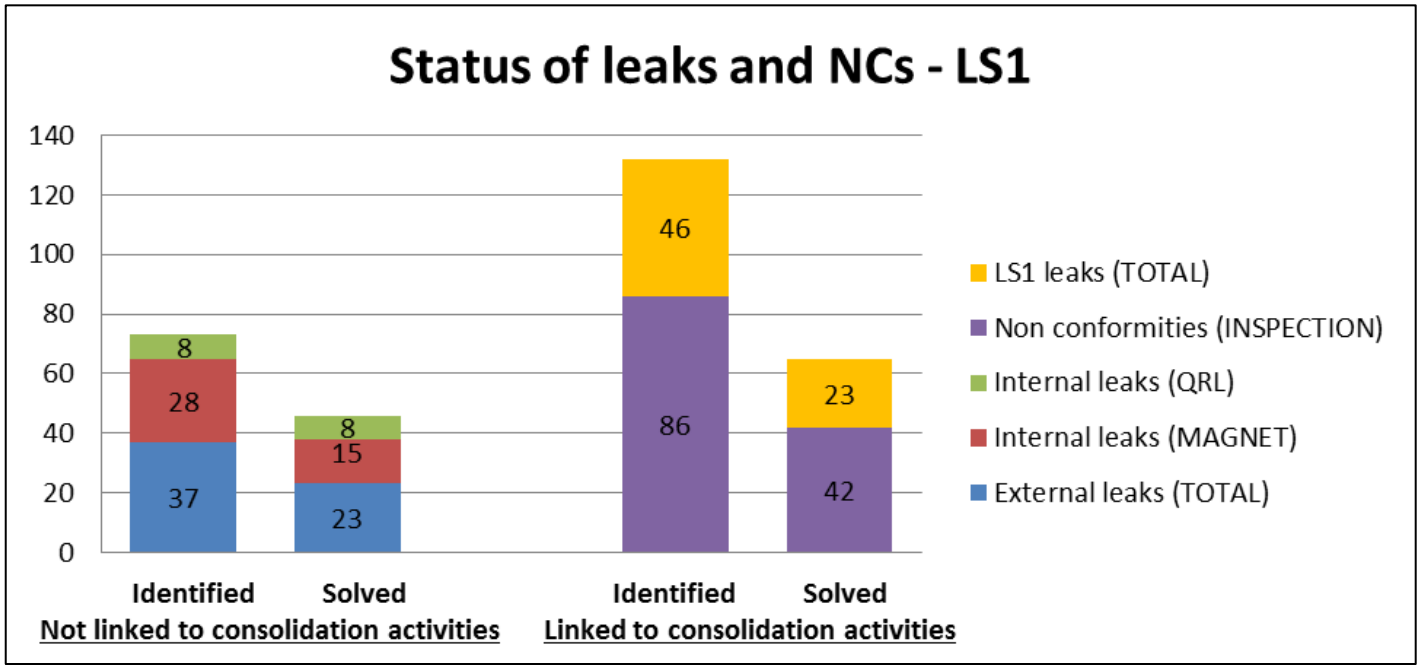
Convolution blocked – bellows not replaced

Leaks follow-up



- LS1 leaks identified before start of consolidation activities, and therefore, not linked to them
- Acceptable leak levels during LS1 more demanding than during installation phase

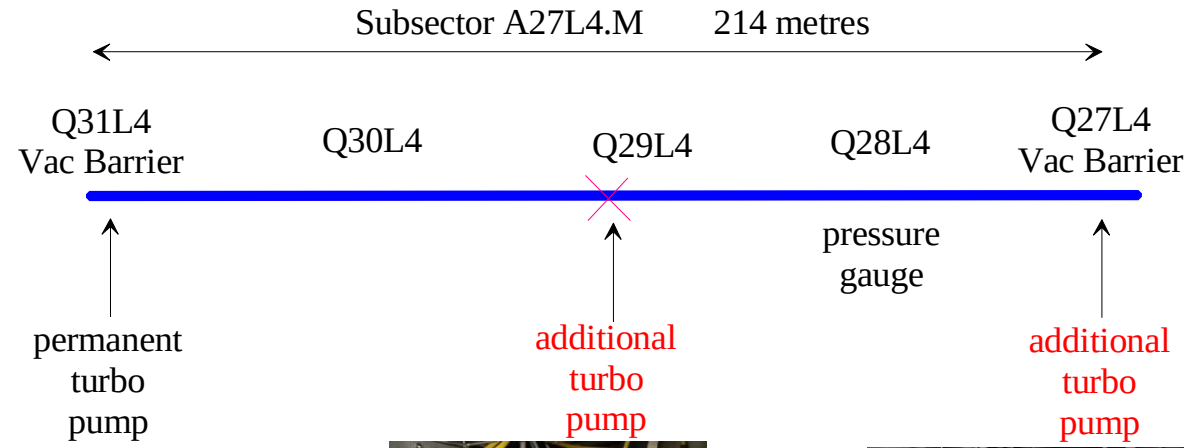
Status of leaks

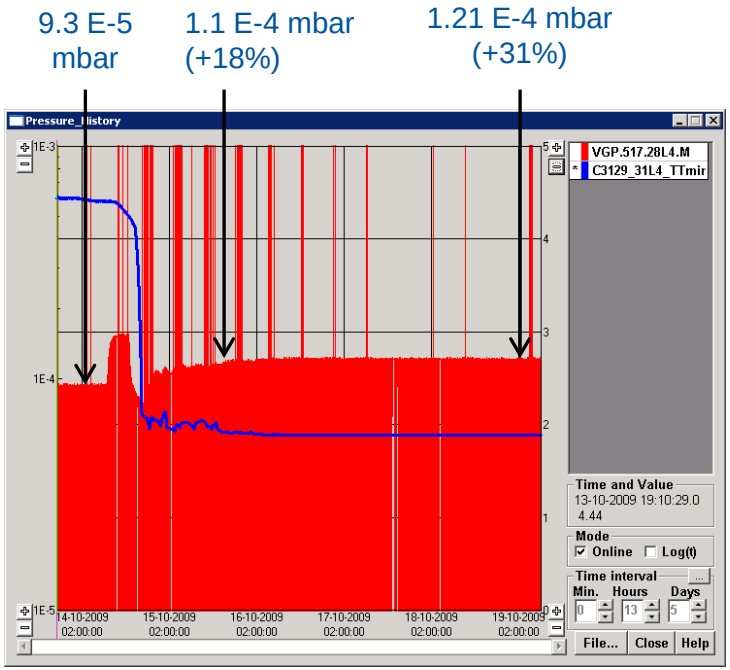


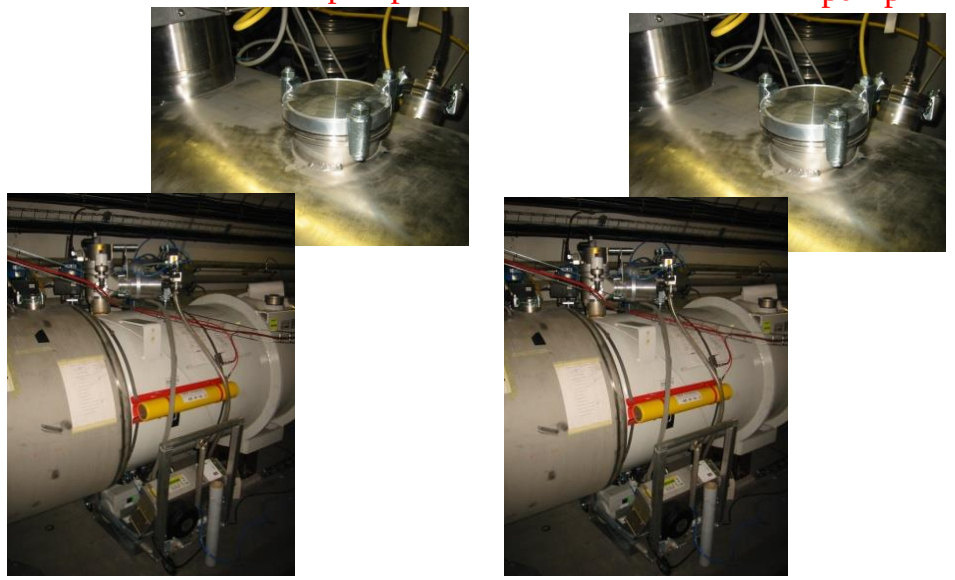
- Leak tests linked to consolidation activities have been done for **6** out 8 sectors
- Inspection procedures linked to consolidation activities have been done for **7** out of 8 sectors

Known leak: s. 3-4

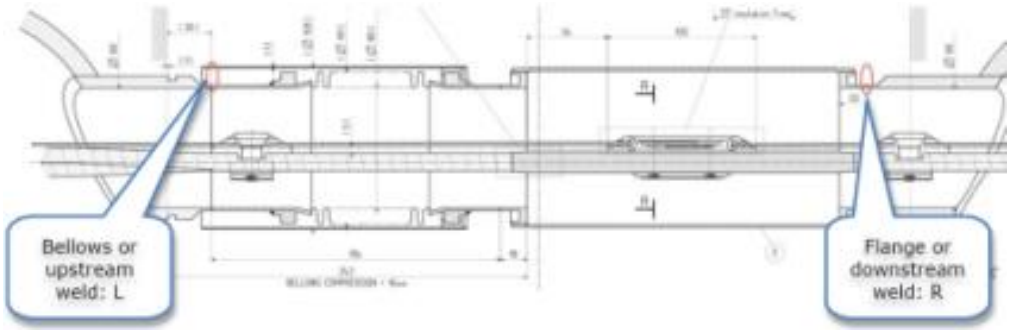
With 2 additional turbos, equilibrium pressure was
~ 5e-4 mbar max (Q28)
~ 5e-5 mbar at turbos





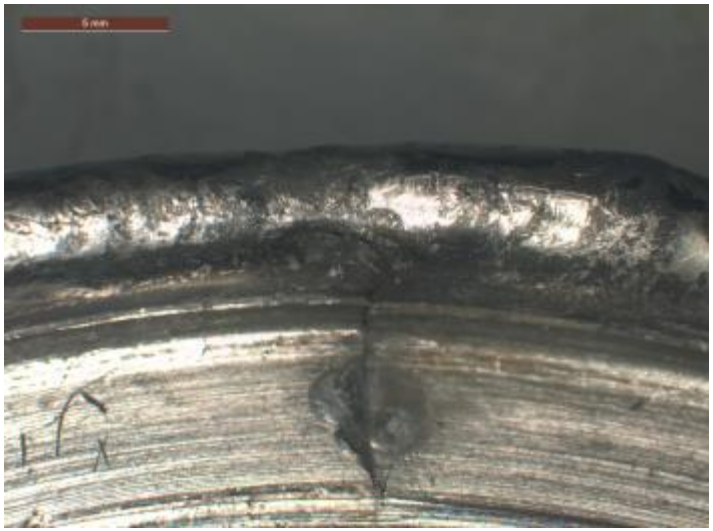


Known leak: s. 3-4

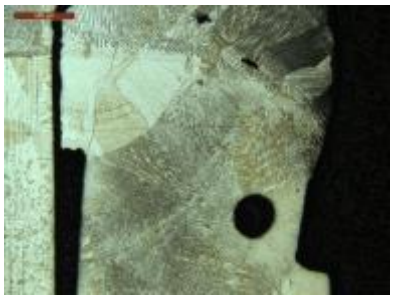


Error in strategy and Quality Control!!!

Leak location (inner surface; before cutting)



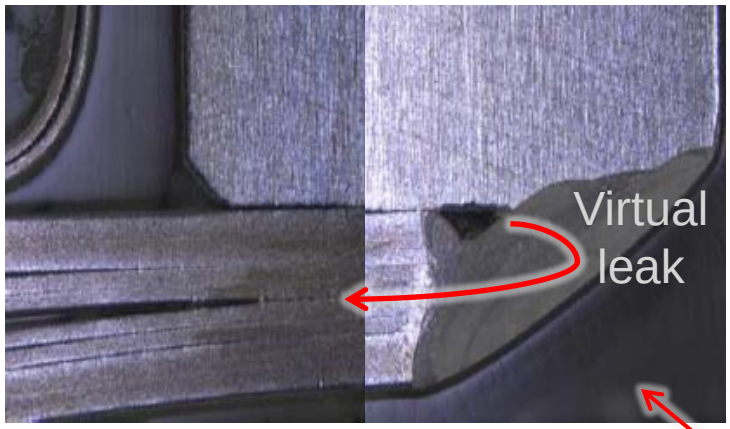
Details: crack, lack of fusion, segregation, cold drops



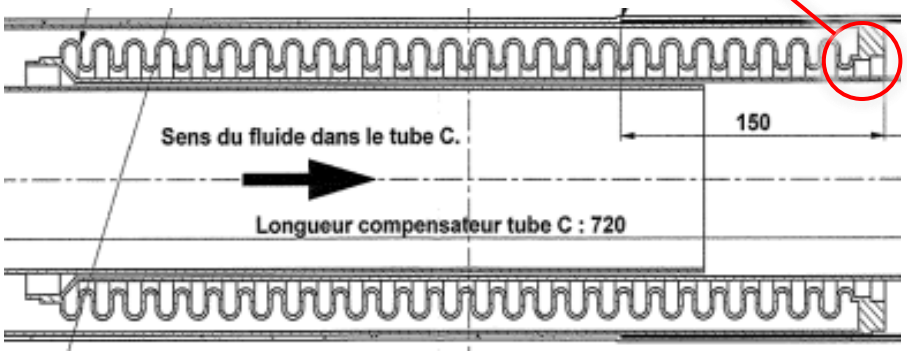
Detail inner surface: Porosity

Known leak: s. 4-5

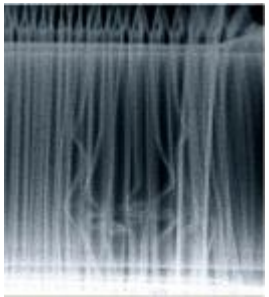
- QRL, lines C & D (internal leak)



Failure process: filling of the inter-layer space with time (3-4 years of operation) ⇒ Pressure increase of the inter-layer space during warm-up leading to the compensator collapse

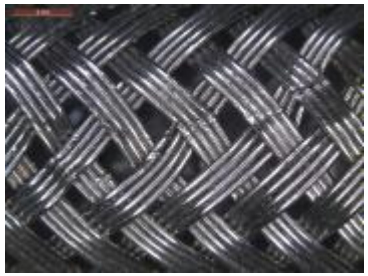


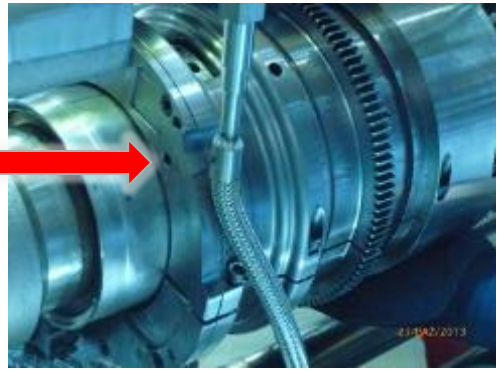
Compensator damaged: DN100 multiply (4 plies of 0.3 mm)

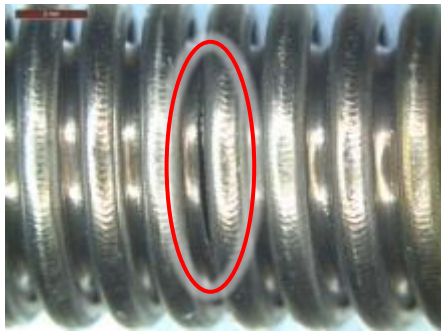


Leaks during LS1: example #1

- k flexibles (internal leak)







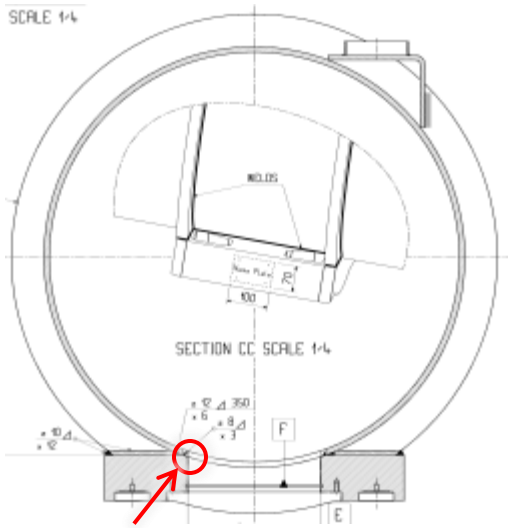
SHOCK

FATIGUE CRACK

k flexibles exposed to mechanical activities in interconnections ⇒ need for improvement of mechanical interventions and quality control?

Leaks during LS1: example #2

- Leaks on feet (external leak; 2 types)



Vacuum weld

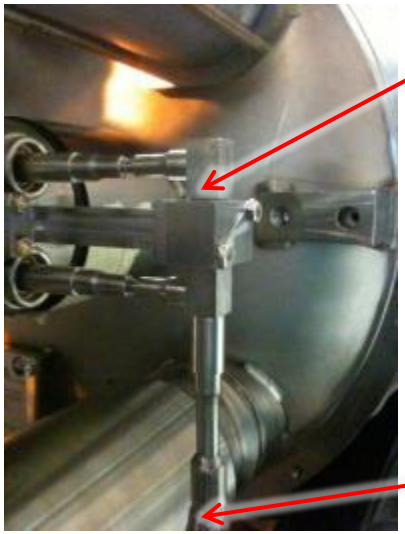
Type 1: continuous weld

Pump-out of volume in-between

Type 2: non continuous weld

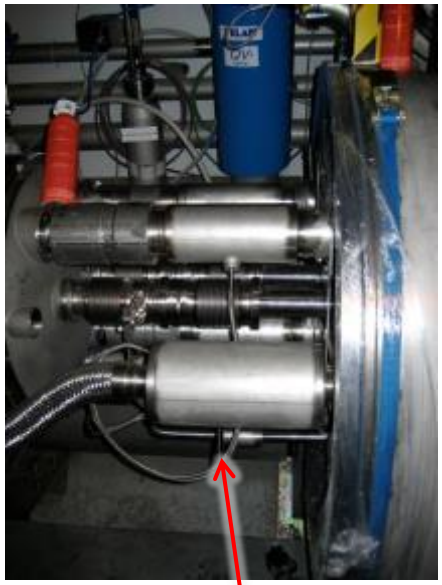
No accessibility to vacuum weld ⇒ pump-out or isolate space between enclosure and support structure

Other leaks



k collector

k flexible



M/N flexible

Jumper (weld/material)

W bellows (flat seal)

Connector feedthrough

Summary

- Consolidation activites are ongoing and with good timing
- Quality of final product has improved and leaks decreased
- Right leak test methodology has led to identification of all leaks; many of them already solved
- LS1 is allowing to deepen in machine knowledge and leak types

Thanks…