

An Introduction to the High Luminosity LHC (HL-LHC) project

Oliver Brüning HL-LHC Deputy Project Leader

CERN: founded in 1954: 12 European States "Science for Peace". CERN is an Inter-governamental Organization Today: 21 Member States

~ 2300 staff

~ 1300 other paid personnel

~ 11500 scientific users

Member States: Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Israel, Italy, Netherlands, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland and United Kingdom
States in accession to Membership: Cyprus, Romania, Serbia
Associate Member States: Pakistan, Turkey
Applications for Membership or Associate Membership:
Brazil, Croatia, India, Lithuania, Russia, Slovenia, Ukraine
Observers to Council: India, Japan, Russia, United States of America; 2

European Union, JINR and UNESCO

Overall view of the LHC experiments.



Introduction: LHC is NOT a Standalone

Machine:







S1 Consolidation: 2013 & 2014

1st meeting of the CERN – TRIUMF Committee – CERN 27 April 2016

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25R7 / 27R7

Performance ramp up in 2015

ATLAS Data



Total Integrated Luminosity [fb⁻¹]



Performance Projections up to HL-LHC:



Goal of High Luminosity LHC (HL-LHC):



implying an integrated luminosity of 250 fb⁻¹ per year,

design oper. for $\mu \delta$ 140 (\rightarrow peak luminosity 5 10³⁴ cm⁻² s⁻¹

Operation with levelled luminosity!

→ 10x the luminosity reach of first 10 years of LHC operation!!



The critical zones around IP1 and IP5

3. For collimation we also need to change the DS in the continuous cryostat:11T Nb₃Sn dipole

uqu/c

2. We also need to modify a large part of the matching section e.g. Crab Cavities & D1, D2, Q4 & corrector New triplet Nb₃Sn required due to:
 Radiation damage
 Need for more aperture

Changing the triplet region is not enough for reaching the HL-LHC goal!

More than 1.2 km of LHC !! Plus technical infrastructure (e.g. Cryo and Powering)!!



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CMS

HL-LHC technical bottleneck:

Radiation damage to triplet magnets at 300 fb⁻¹



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HL-LHC technical bottleneck:

Radiation damage to triplet magnets

Need to replace existing triplet magnets with radiation hard system (shielding!) such that the new magnet coils receive a similar radiation dose @ 10 times higher integrated luminosity!!!!!

Requires larger aperture!



- New magnet technology
- → 70mm at 210 T/m → 150mm diameter 140 T/m 8T peak field at coils → 12T field at coils (Nb₃Sn)!!!

In-kind contributions and collaborations for design and prototypes

First approval as construction Project: Sept. 2013





Q1-Q3 : R&D, Design, Prototypes and in-kind **USA** D1 : R&D, Design, Prototypes and in-kind **JP** MCBX : Design and Prototype **ES** HO Correctors: Design and Prototypes **IT** Q4 : Design and Prototype **FR**

ril 2016

LHC Challenges: Beam Power

Unprecedented beam power:

Worry about beam losses:

Failure Scenarios -> Local beam Impact

- → Equipment damage
- ➔ Machine Protection
- Lifetime & Loss Spikes -> Distributed losses
 - ➔ Magnet Quench
 - → R2E and SEU
 - ➔ Machine efficiency

LHC Challenges: Quench Protection Magnet Quench:

→ beam abort → several hours of recovery

HL LHC beam intensity: $I > 1 A => > 7 \ 10^{14} \text{ p /beam}$

Quench level: $N_{lost} < 7 \ 10^8 \ m^{-1} \rightarrow < 10^{-6} \ N_{beam}!$

(compared to 20% to 30% in other superconducting rings)

- → requires collimation during all operation stages!
- → requires good optic and orbit control! → Which we have demonstrated demonstrated during Runi
 → HL-LHC luminosity implies higher leakage during Runi
 from IP & requires additional collimators

HL-LHC Challenges: Collimation





Baseline upgrades

LHC Collimation

Project



The magnets in IR3 and IR7



MQW

- Produced by Alstom-Canada
- Welded and bolted yoke
- 48 units in LHC IR3 and IR7
- 4 spares available

MBW

- Produced by BINP
- Welded and bolted yoke
- 20 units in LHC IR3 and IR7
- 3 spares available + 1 spare for the life test



Possible Failure modes



- Degradation of the insulation system due to radiation leading to inter turn short or shorts to ground
- Degradation of the mechanical shimming performed with ambient temperature cured resins

- Degradation of the insulation system due to radiation leading to inter turn short or shorts to ground
- Remark magnet build with no coil on the mid plane and therefore out from the expected zone of highest losses



IP 3	3 Dose [MGy] for integrated luminosity 150 fb^-1		/] for Dose [MG minosity integrated lui -1 350 fb^		IGy] for Dose [MGy] fo luminosity integrated lumino b^-1 3000 fb^-1		Point 3 and 7 coil				
	R	L	R	L	R	L					
MQWA.A4	0	0	0	0	2	4		agne	er da	mag	je
MQWA.B4	0	0	0	0	2	4					
MQWB.4	0	0	0	1	2	4	e	Stim	atior) WIT	n
MQWA.C4	0	0	0	1	3	6					
MQWA.D4	0	1	1	2	12	14		sh	ieldi	nd	
MOWA.A5		2	<u> </u>	<u>5</u> 3	8	15					
MQWA.B5		3	<u>~</u> 2	<u>5</u> 4	10	19	aree	n ar	OW S	shiel	dina
MQWB.5		7	5	10	24	45	9.00				
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MQWA.D5		4	<u>3</u>	<u>5</u>	<u>14</u>	<u>25</u>		mou			
MQWA.E5		7	<u>5</u>	<u>10</u>	<u>25</u>	<u>47</u>	vella	w ar	row	shiel	dina
MBW.A6		4	<u>3</u>	<u>6</u>	<u>15</u>	<u>27</u>	yciic			Sinci	ung
MBW.B6		5	<u>3</u>	<u>Z</u>	<u>17</u>	<u>31</u>	fo	rece	on fr	or I S	2
MBW.C6		7	<u>5</u>	<u>9</u> _	<u>24</u>	<u>44</u>					
MQW		MBW			IP 7 integrate			integrated luminosity integrated lu 350 fb^-1 3000 fb		l luminositv	
M					IP 7	integrate 150	o fb^-1	integrated 350 fi	b^-1	3000	fb^-1
M(From 10	to 20	From 40	to 60		IP 7	R	b fb^-1 L	R	b^-1 L	3000 R	<i>fb^-1</i> L
M(From 10 MGy	2w to 20	From 40 MGy	to 60		IP 7 MQWA.A4	150 R 1	2 fb^-1 L	Integrated 350 fi R 1	2	R 10) fb^-1 L 15
M(From 10 MGy From 20	to 20	From 40 MGy From 60) to 60) to 80		IP 7 MQWA.A4 MQWA.B4	Integrate 150 R 1 0	2 fb^-1 L 1 1	Integrated 350 fi R 1 1	L 2 3	R 10 9	fb^-1 L 15 22
MC From 10 MGy From 20 MGy	to 20 to 50	From 40 MGy From 60 Mgy) to 60) to 80		IP 7 MQWA.A4 MQWA.B4 MQWB.4	150 R 1 0 1	2 fb^-1 L 1 1 2	1 1 1 1 1	L 2 3 <u>3</u>	R 10 9 <u>6</u>	fb^-1 L 15 22 <u>14</u>
M(From 10 MGy From 20 MGy	to 20 to 50	From 40 MGy From 60 Mgy) to 60) to 80	=	IP 7 MQWA.A4 MQWA.B4 MQWB.4 MQWA.C4	Integrate 1 0 1 6	2 fb^-1 L 1 1 2 6	1 1 1 2 2 2	2 3 3 9	R 3000 R 10 9 <u>6</u> 41	fb^-1 L 15 22 14 41
From 10 MGy From 20 MGy Larger t	to 20 to 50 han 50	From 40 MGy From 60 Mgy) to 60) to 80 ;han 80	₿	IP 7 MQWA.A4 MQWA.B4 MQWB.4 MQWA.C4 MQWA.D4	1 0 1 6 2	2 fb^-1 L 1 1 2 6 2	1 1 1 <u>1</u> <u>1</u> <u>1</u> <u>1</u> <u>9</u> <u>4</u>	2 3 3 <u>3</u> 9 <u>4</u>	R 10 9 <u>6</u> 41 24	fb^-1 L 15 22 14 41 24
From 10 MGy From 20 MGy Larger th MGy	to 20 to 50 han 50	From 40 MGy From 60 Mgy Larger t MGy) to 60) to 80 :han 80		IP 7 MQWA.A4 MQWA.B4 MQWB.4 MQWA.C4 MQWA.C4 MQWA.E4	Integrate 1 0 1 6 2 1	2 fb^-1 L 1 1 2 6 2 2 2 2	1 1 1 1 9 4 2	2 3 3 9 4 5	R 10 9 <u>6</u> 41 24 19	fb^-1 L 15 22 14 41 24 39
MC From 10 MGy From 20 MGy Larger t MGy	to 20 to 50 han 50	From 40 MGy From 60 Mgy Larger t MGy) to 60) to 80 :han 80		IP 7 MQWA.A4 MQWA.B4 MQWB.4 MQWA.C4 MQWA.D4 MQWA.E4 MQWA.A5	R 1 0 1 6 2 1 3	2 fb^-1 L 1 1 2 6 2 2 3	1 1 1 <u>1</u> <u>9</u> <u>4</u> <u>2</u> <u>4</u>	2 3 3 <u>3</u> <u>9</u> <u>4</u> <u>5</u> <u>4</u>	R 10 9 <u>6</u> 41 24 19 20	fb^-1 L 15 22 14 41 24 39 20
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M(From 10 MGy From 20 MGy	to 20 to 50 han 50	From 40 MGy From 60 Mgy Larger t MGy) to 60) to 80 :han 80		IP 7 MQWA.A4 MQWA.B4 MQWB.4 MQWA.C4 MQWA.D4 MQWA.E4 MQWA.A5 MQWA.B5 MQWB.5	R 1 0 1 6 2 1 3 4 4	2 fb^-1 L 1 1 2 6 2 2 3 4 4	1 1 1 <u>1</u> <u>9</u> <u>4</u> <u>2</u> <u>4</u> <u>6</u> <u>6</u>	5 6 6 6 6	R 10 9 <u>6</u> 41 24 19 20 29 29	fb^-1 L 15 22 14 41 24 39 20 29 29 29
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MQWB.4	0	0	0	1	2	4	e	stim	atior) WI	th
MQWA.C4	0	0	0	1	3	6					
MQWA.D4	0	1	1	2	12	14		sh	ieldi	nd	
MOWA.A5		2	<u>~</u> 2	<u>5</u> 3	8	15		••••			
MQWA.B5		3	2	<u>-</u> 4	10	19	aree	n ar	row s	shiel	dina
MQWB.5		7	5	10	24	45	9.00				ang
MQWA.C5		15	11	22	57	106		inst	alled	I S1	
MQWA.D5	<u> </u>	4	<u>3</u>	<u>5</u>	<u>14</u>	<u>25</u>					
MQWA.E5		7	<u>5</u>	<u>10</u>	<u>25</u>	<u>47</u>	vello	w ar	row	shie	Idina
MBW.A6	2	4	<u>3</u>	<u>6</u>	<u>15</u>	<u>27</u>	ycno				ung
MBW.B6	2	5	<u>3</u>	<u>Z</u>	<u>17</u>	<u>31</u>	fc	rese	oon fo	or I S	52
MBW.C6		7	<u>5</u>	<u>9</u> _	<u>24</u>	<u>44</u>					
						Doce	[MGv] for	Doce [MGvitor	Dose	
MQ	QW	M	BW		IP 7	Dose integrate 150	[MGy] for ed luminosity) fb^-1	Dose [integrated 350 :	MGy] for luminosity fb^-1	Dose integrate 300	[MGy] for ed luminosity 0 fb^-1
M(From 10	QW to 20	MI From 40	BW to 60		IP 7	Dose integrate 150 R	[MGy] for ed luminosity 0 fb^-1 L	Dose [integrated 350 ; R	MGy] for luminosity fb^-1 L	Dose integrate 300 R	LMGy] for d luminosity 0 fb^-1 L
M(From 10 MGy)W to 20	MI From 40 MGy	BW to 60		IP 7	Dose integrate 150 R 1	[MGy] for ed luminosity 0 fb^-1 L 1	Dose [integrated 350 i R 1	MGy] for luminosity fb^-1 L 2	Dose integrate 300 R 10	lmGy] for d luminosity 0 fb^-1 L 15
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M(From 10 MGy From 20 MGy	2W to 20 to 50	MI From 40 MGy From 60 Mgy	BW to 60 to 80		IP 7 MQWA.A4 MQWA.B4 MQWB.4	Dose integrate 150 R 1 0 1	[MGy] for ed luminosity 0 fb^-1 L 1 1 2	Dose [integrated 350 : R 1 1 1 1	MGy] for luminosity fb^-1 L 2 3 <u>3</u>	Dose integrate 300 R 10 9 <u>6</u>	L [MGy] for d luminosity 0 fb^-1 L 15 22 <u>14</u>
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M() From 10 MGy From 20 MGy	2W to 20 to 50 han 50	MI From 40 MGy From 60 Mgy	BW to 60 to 80 han 80		IP 7 MQWA.A4 MQWA.B4 MQWB.4 MQWA.C4 MQWA.D4 MQWA.E4	Dose integrate 150 R 1 0 1 6 2 2 1	[MGy] for ed luminosity 0 fb^-1 1 1 2 6 2 2 2	Dose [integrated 350 : R 1 1 1 <u>1</u> 9 <u>4</u> 2	MGy] for uminosity fb^-1 2 3 3 <u>3</u> <u>9</u> <u>4</u> <u>5</u>	Dose integrate 300 R 10 9 6 41 24 24 19	[MGy] for ed luminosity 0 fb^-1 L 15 22 14 41 24 24 39
M(From 10 MGy From 20 MGy	W to 20 to 50 han 50	MI From 40 MGy From 60 Mgy Larger t MGy	BW to 60 to 80 han 80		IP 7 MQWA.A4 MQWA.B4 MQWB.4 MQWA.C4 MQWA.D4 MQWA.E4 MQWA.A5	Dose integrate 150 R 1 0 1 6 2 2 1 3	[MGy] for ed luminosity 0 fb^-1 1 1 2 6 2 2 2 3	Dose [integrated 350 i R 1 1 1 <u>1</u> 9 <u>4</u> 2 <u>4</u>	MGy] for luminosity fb^-1 2 3 3 <u>3</u> 9 4 5 <u>4</u>	Dose integrate 300 R 10 9 6 41 24 19 20	24 24 24 24 20 20
M(From 10 MGy From 20 MGy Larger th MGy	2W to 20 to 50 han 50	MI From 40 MGy From 60 Mgy Larger t MGy	BW to 60 to 80 han 80		IP 7 MQWA.A4 MQWA.B4 MQWB.4 MQWA.C4 MQWA.C4 MQWA.E4 MQWA.E4 MQWA.B5	Dose integrate 150 R 1 0 1 6 2 2 1 3 4	[MGy] for ed luminosity 0 fb^-1 1 1 2 6 2 2 2 3 4	Dose [integrated 350 : R 1 1 1 <u>1</u> 9 4 2 4 2 4 6	MGy] for luminosity fb^-1 2 3 3 3 9 4 5 4 5 4 6	Dose integrate 300 R 10 9 6 41 24 24 19 20 20	24 20 20 24 20 20 29
M(From 10 MGy From 20 MGy	2W to 20 to 50 han 50 nected i e other	MI From 40 MGy From 60 Mgy Larger t MGy	BW to 60 to 80 han 80 S with Q5		IP 7 MQWA.A4 MQWA.B4 MQWB.4 MQWA.C4 MQWA.D4 MQWA.E4 MQWA.E5 MQWB.5	Dose integrate 150 R 1 0 1 6 2 1 6 2 1 3 4 4 4	[MGy] for ed luminosity 0 fb^-1 1 1 2 6 2 2 3 4 4 4	Dose [integrated 350 i R 1 1 1 <u>1</u> 9 4 2 4 2 4 6 6 6	MGy] for luminosity fb^-1 2 3 3 <u>3</u> 9 4 5 4 <u>6</u> 6	Dose integrate 300 R 10 9 6 41 24 19 20 29 29 29	20 29 20 20 20 20 29 20 29 29
M(From 10 MGy From 20 MGy Larger the MGy	2W to 20 to 50 han 50 nected i e other	MI From 40 MGy From 60 Mgy Larger t MGy	BW to 60 to 80 han 80 s with Q5		IP 7 MQWA.A4 MQWA.B4 MQWB.4 MQWA.C4 MQWA.D4 MQWA.E4 MQWA.E5 MQWB.5 MQWB.5	Dose integrate 150 R 1 0 1 6 2 1 3 4 4 4 2	[MGy] for ed luminosity 0 fb^-1 1 1 2 6 2 2 3 4 4 4 5	Dose [integrated 350 ; R 1 1 1 9 4 2 4 2 4 6 6 3	MGy] for luminosity fb^-1 2 3 3 9 4 5 4 5 4 6 6 6 2	Dose integrate 300 R 10 9 6 41 24 19 20 29 29 29 11	Lingy for d luminosity 0 fb^-1 L 15 22 14 41 24 39 20 29 29 29 28
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M(From 10 MGy From 20 MGy Larger the MGy	2W to 20 to 50 han 50 hected i e other configu	MI From 40 MGy From 60 Mgy Larger t MGy	BW to 60 to 80 han 80 s with Q5		IP 7 MQWA.A4 MQWA.B4 MQWB.4 MQWA.C4 MQWA.D4 MQWA.E4 MQWA.E5 MQWB.5 MQWB.5 MQWA.C5 MQWA.D5	Dose integrate 150 R 1 0 1 6 2 1 3 4 4 4 2 3	[MGy] for ad luminosity 0 fb^-1 1 1 2 6 2 2 3 4 4 4 5 5 5 Replace	Dose [integrated 350 ; R 1 1 1 9 4 2 4 2 4 6 5 6 3 6 0 by ab	MGy] for luminosity fb^-1 2 3 3 9 4 5 4 5 4 6 6 6 7 8 8 Sorber	Dose integrate 300 R 10 9 41 24 19 20 29 29 29 11 34	<pre>[Ingy] for a luminosity 0 fb^-1 L 15 22 14 24 39 20 29 29 29 29 29 29 29 29 29 29 29 29 29</pre>
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New Schedule: -> HL-LHC CE during

LS2











LHC 27 km tunnel with 8 Points for Experimental Areas or accelerator services





LHC: the largest instrument based on 18 km of superconducting dipole...

- 27 km, p-p at 7+7 TeV
 3.5+3.5 2010/11, 4+4 in 2012,
 6.5+6.5 2015
- 1232 x 15 m Twin Dipoles
- Operational field 8.3 T @11.85 kA (9 T design)
- HEII cooling, 1.9 K with 3 km circuits (130 tonnes He inventory).
- Field homogeneity of 10⁻⁴, bending strength uniformity better then 10⁻³.
 Field quality control (geometric and SC effects) at 10⁻⁵.





DS collimators – 11 T Dipole (LS2 -2018)



Prototyping of cryogenics bypass @ CERN



Prototyping of the by-pass crystostat (QTC) for the installation of a warm collimator in the cold dispersion

Magnet: prototypes reached 11 T field in March 2013!

