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

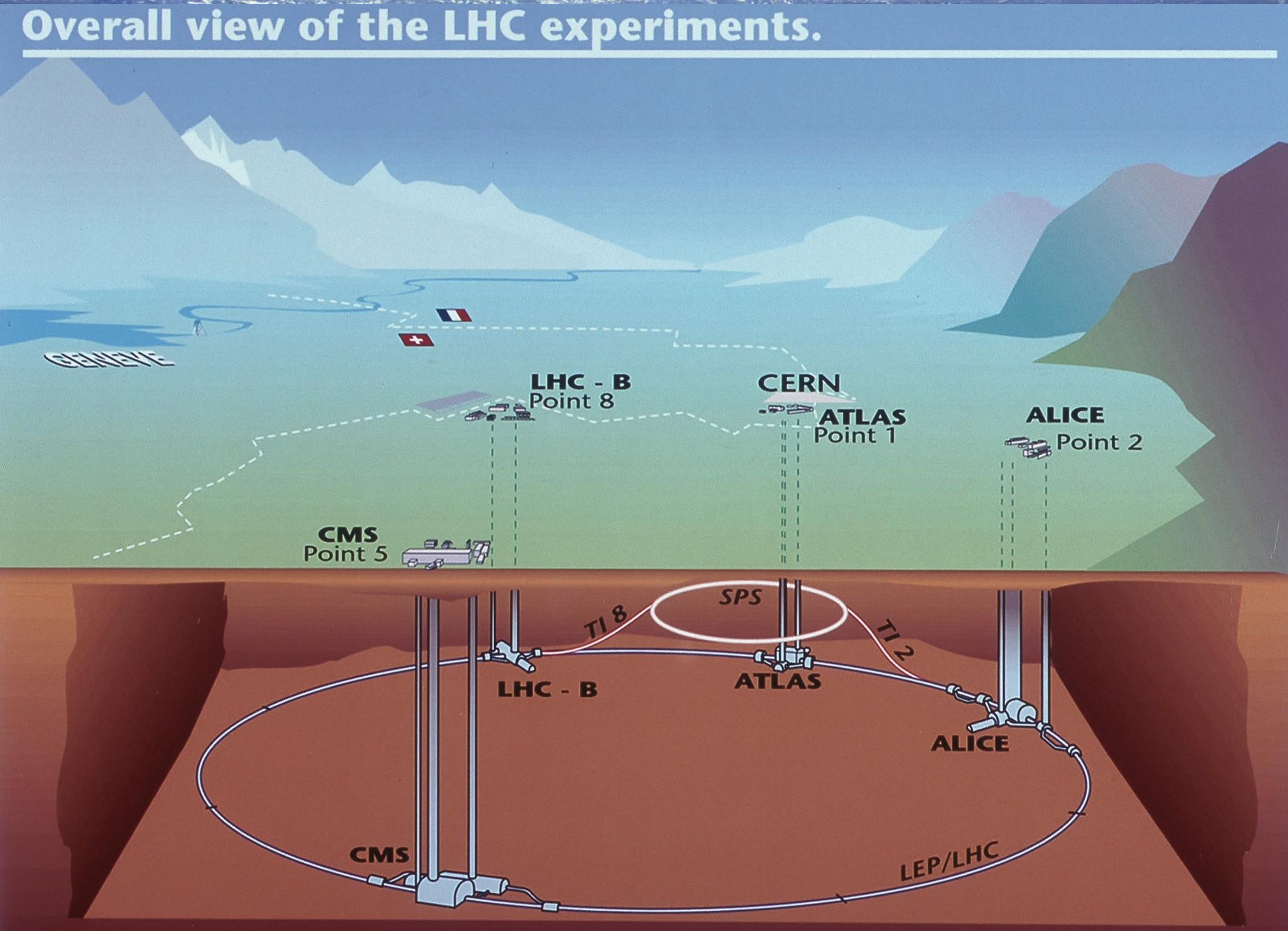
Member States: Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Israel, Italy, Netherlands, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland and United Kingdom

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; European Union, JINR and UNESCO



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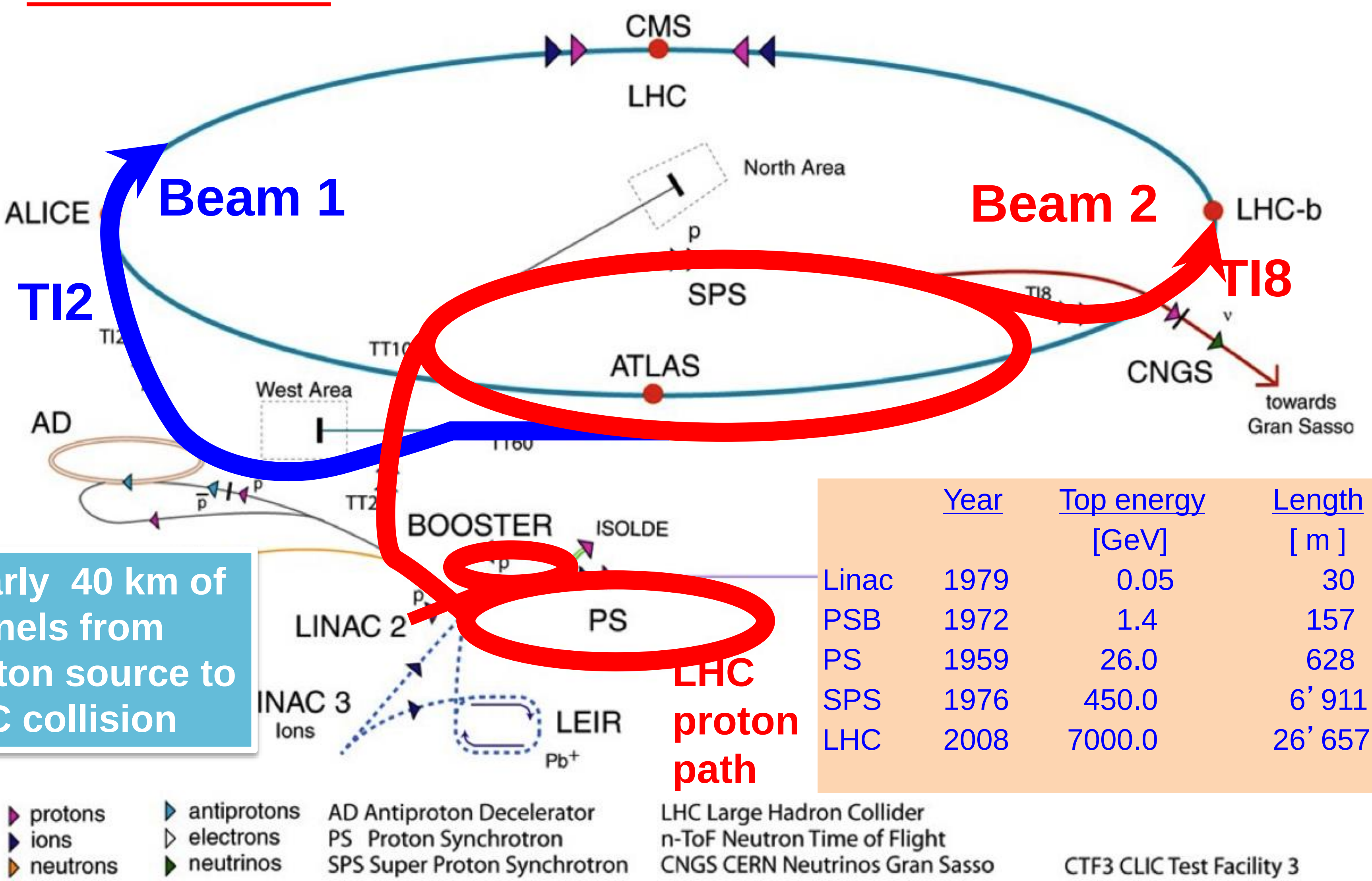
ALICE

C!

.5 TeV

Introduction: LHC is NOT a Standalone Machine:

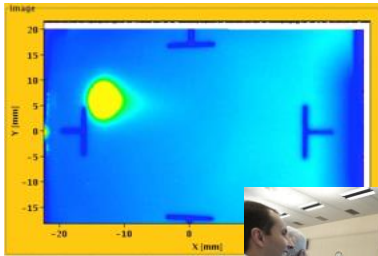


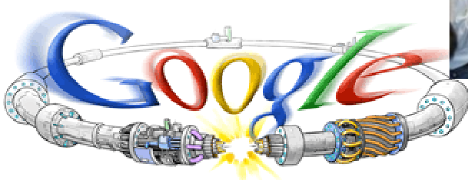
Nearly 40 km of tunnels from proton source to LHC collision

	Year	Top energy [GeV]	Length [m]
Linac	1979	0.05	30
PSB	1972	1.4	157
PS	1959	26.0	628
SPS	1976	450.0	6’911
LHC	2008	7000.0	26’657

LHC RUN-I Timeline

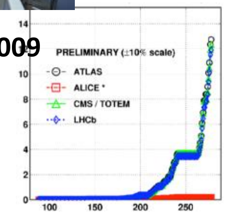
August 2008
First injection test





September 10, 2008
First beams around

November 29, 2009
Beam back



April 2010
Squeeze to 3.5 m

October 14 2010
1e32
248 bunches

June 28 2011
1380 bunches (50ns)

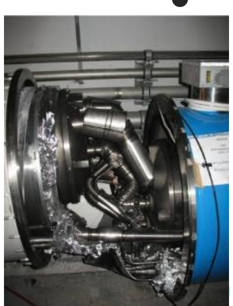
1380

6 June, 2012
L_{max} = 6.8e33

4 July, 2012
Higgs discovery

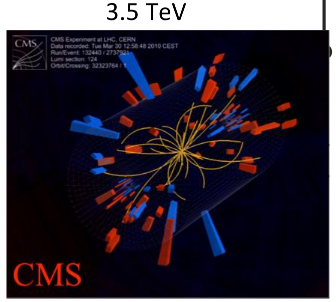
End of RunI
23.3fb^{-1}

2008 | 2009 | 2010 | 2011 | 2012

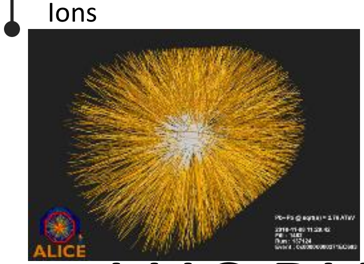


September 19, 2008
'Incident'
Accidental release of 600 MJ stored in one sector of LHC dipole magnets

March 30, 2010
First collisions at 3.5 TeV



November 2010
Ions

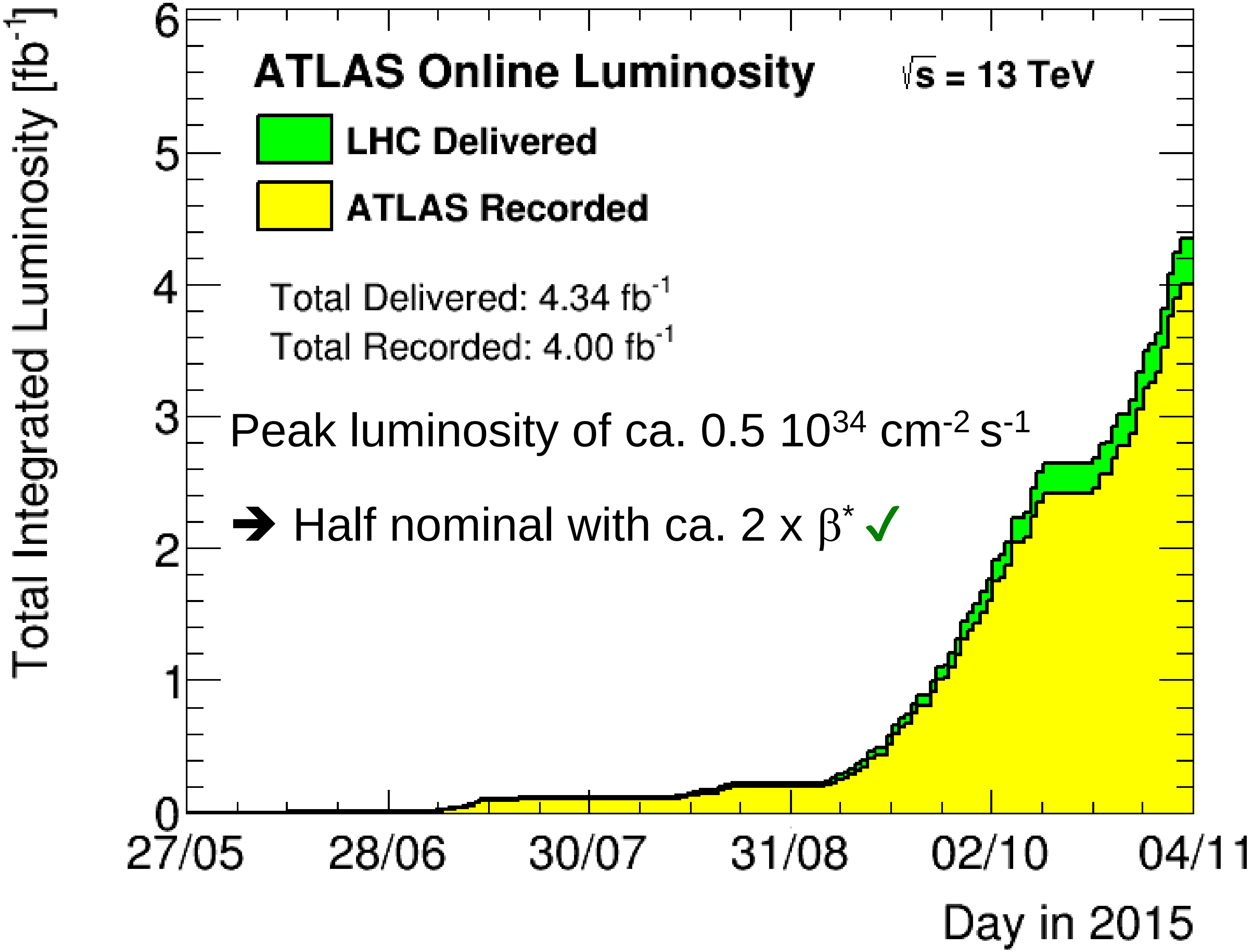


18 June, 2012
6.6 fb^{-1}
to ATLAS & CMS

LS1 Consolidation: 2013 & 2014

Performance ramp up in 2015

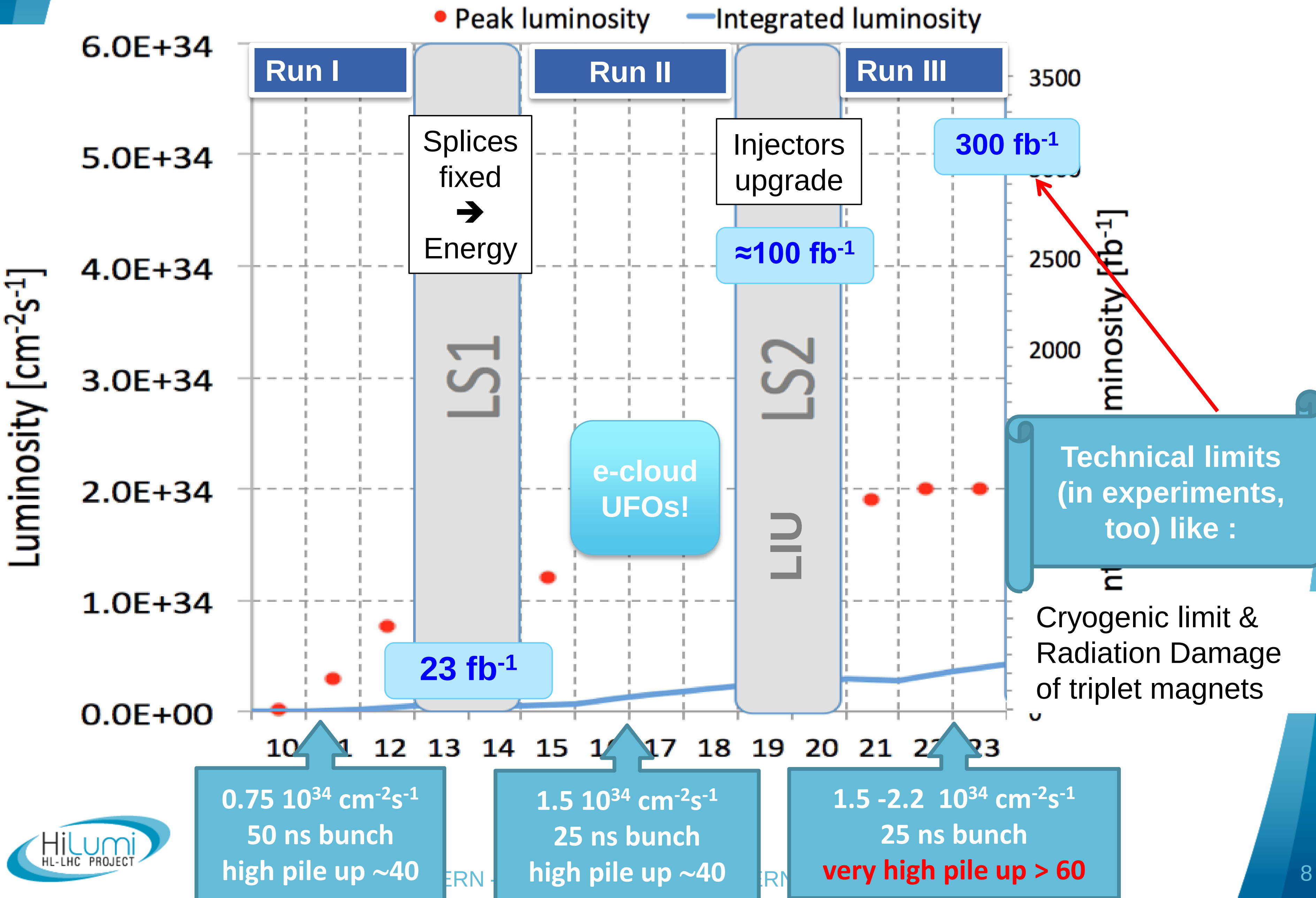
ATLAS Data



Peak luminosity of ca. 0.5 10^{34} cm^{-2} s^{-1}

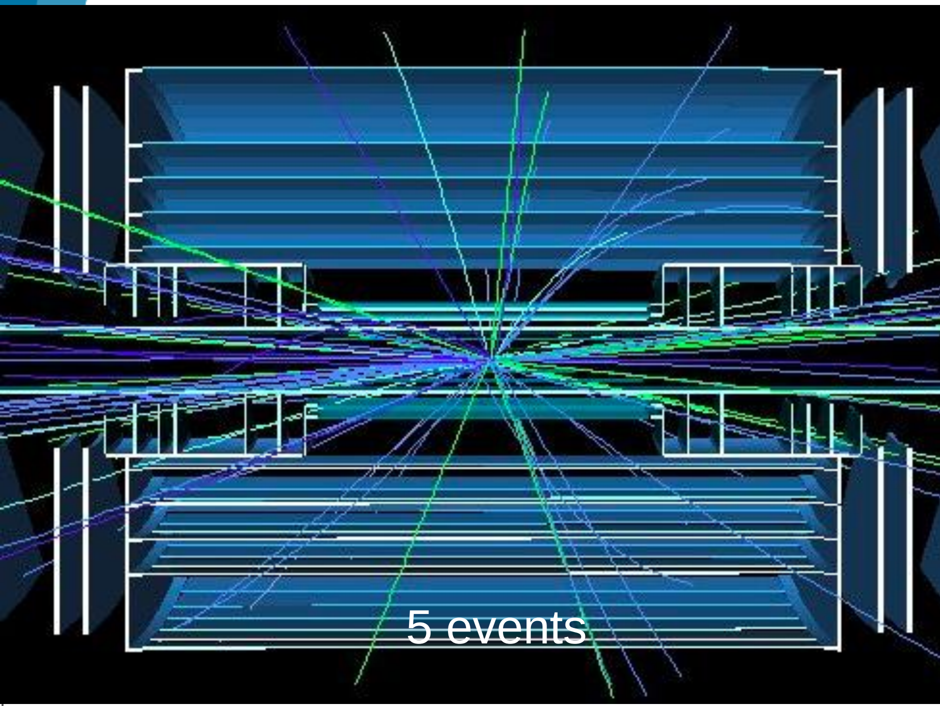
➔ Half nominal with ca. 2 x β^* ✓

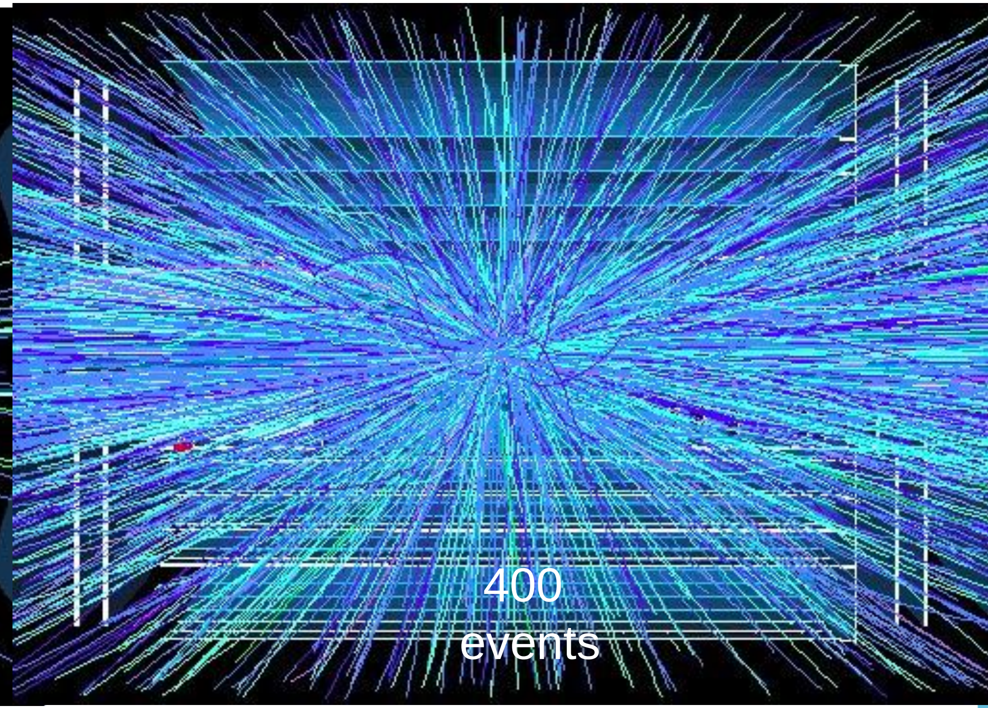
Performance Projections up to HL-LHC:



HiLumi HL-LHC PROJECT

Goal of High Luminosity LHC (HL-LHC):





implying an integrated luminosity of **250 fb^{-1} per year**,

design oper. for μ δ **140** (➔ peak luminosity **5 10^{34} cm^{-2} s^{-1}**)

➔ Operation with levelled luminosity!

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

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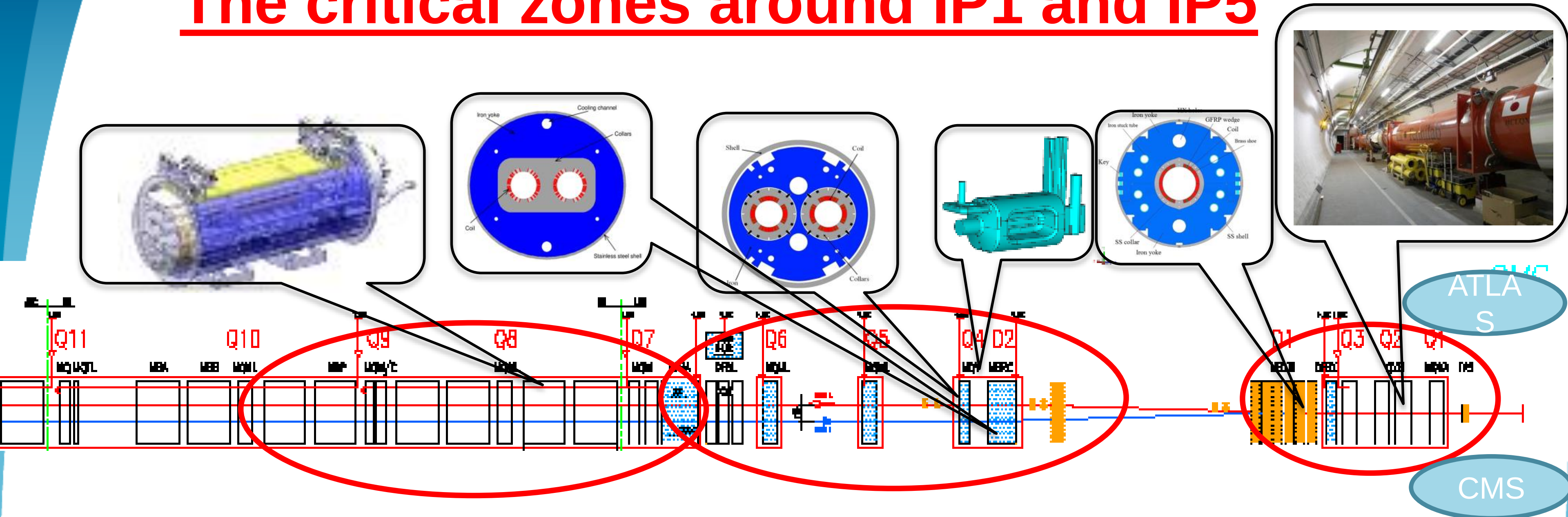
The critical zones around IP1 and IP5



3. For collimation we also need to change the DS in the continuous cryostat: 11T Nb_3Sn dipole

2. We also need to modify a large part of the matching section e.g. Crab Cavities & D1, D2, Q4 & corrector

1. New triplet Nb_3Sn 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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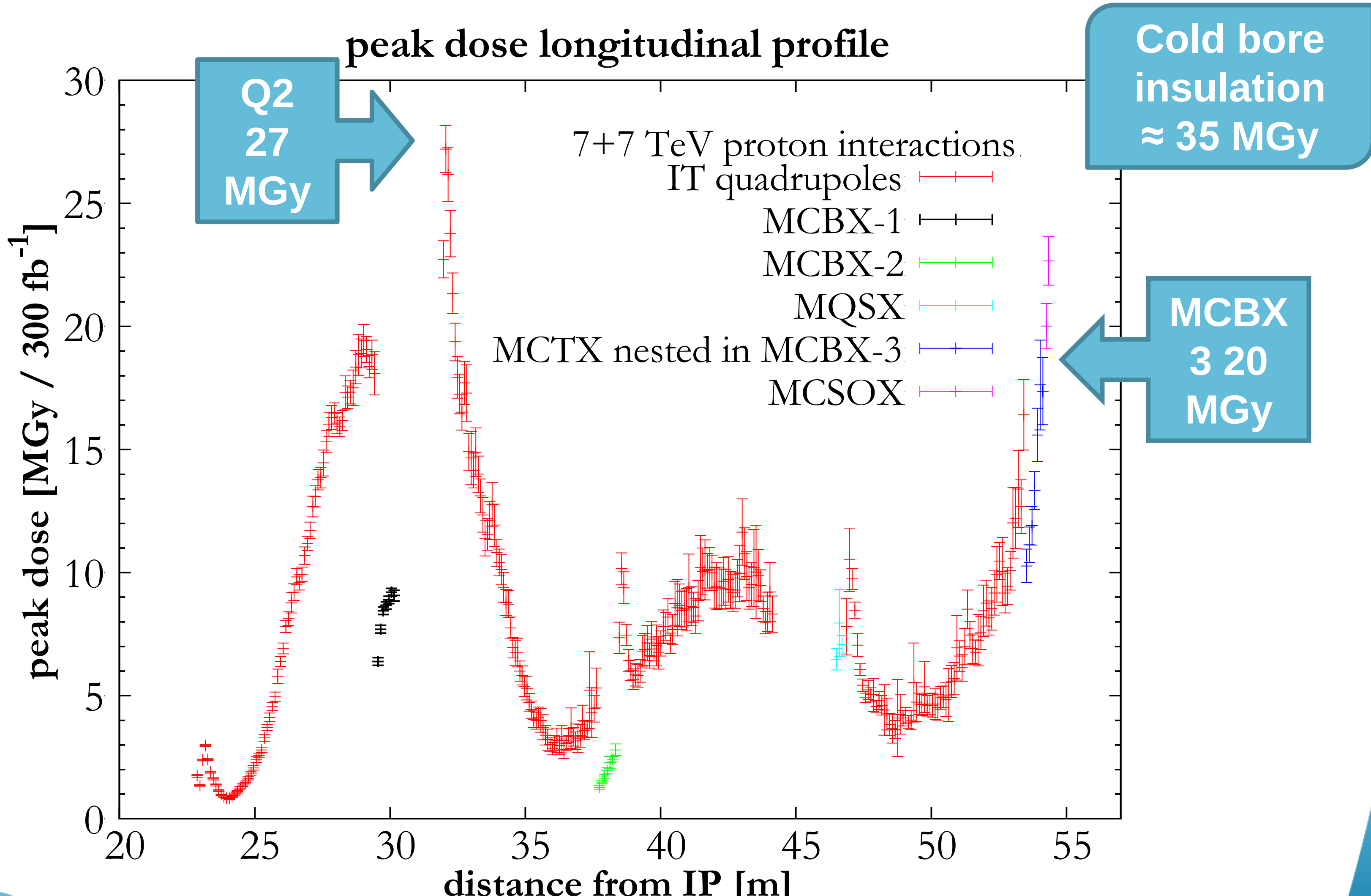
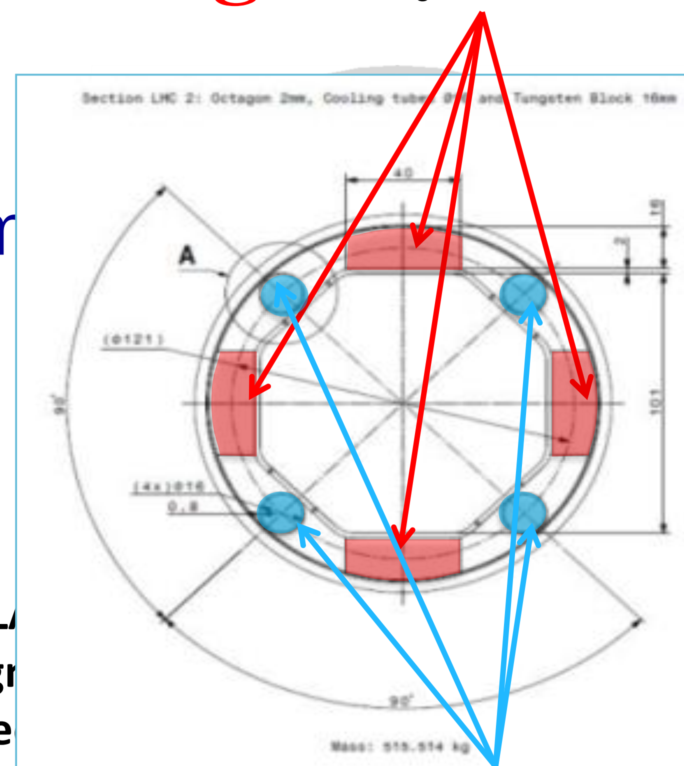
HL-LHC technical bottleneck: Radiation damage to triplet magnets at 300 fb^{-1}



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!!!!!



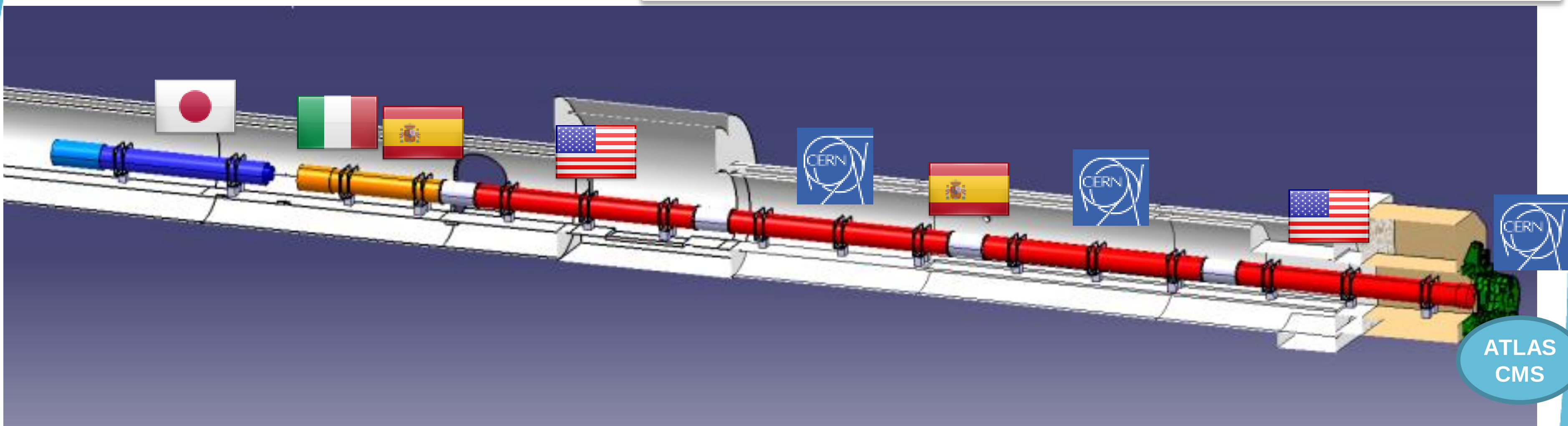
US-L
magr
Base
technology

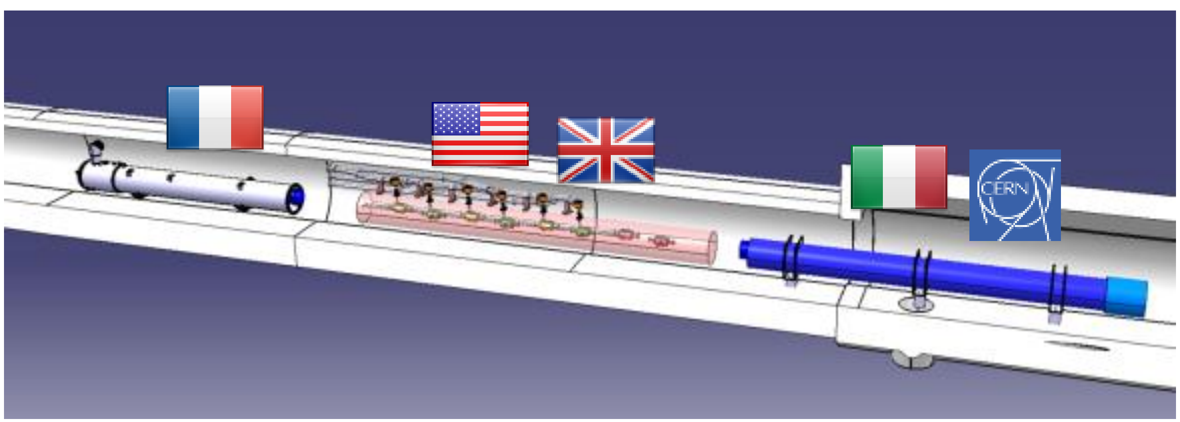
- Requires larger aperture!
- New magnet technology
- 70mm at 210 T/m ➔150mm diameter 140 T/m

8T peak field at coils ➔ 12T field at coils (Nb_3Sn)!!!

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**

CC : R&D, Design and in-kind **USA**

CC : R&D and Design **UK**

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} p /beam

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

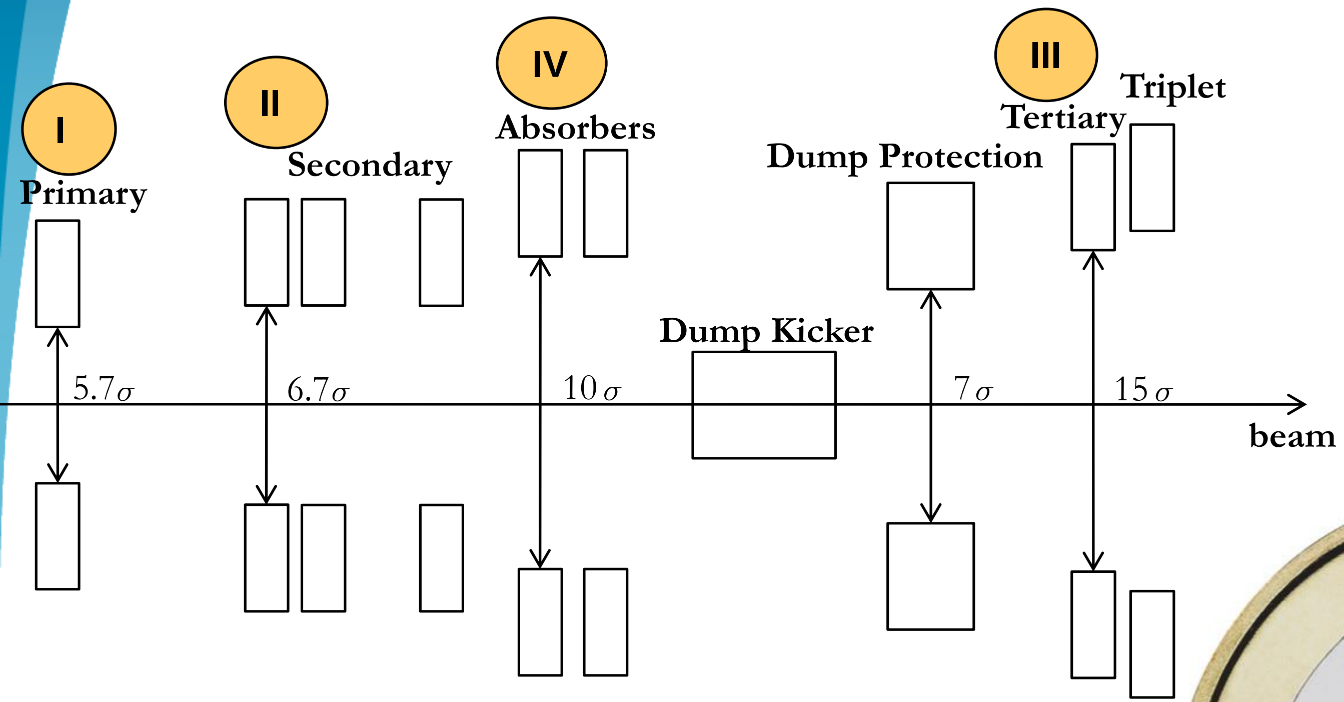
(compared to 20% to 30% in other superconducting rings)

➔ requires collimation during all operation stages!

➔ requires good optic and orbit control! ➔ Which we have demonstrated during RunI

➔ HL-LHC luminosity implies higher leakage from IP & requires additional collimators

HL-LHC Challenges: Collimation

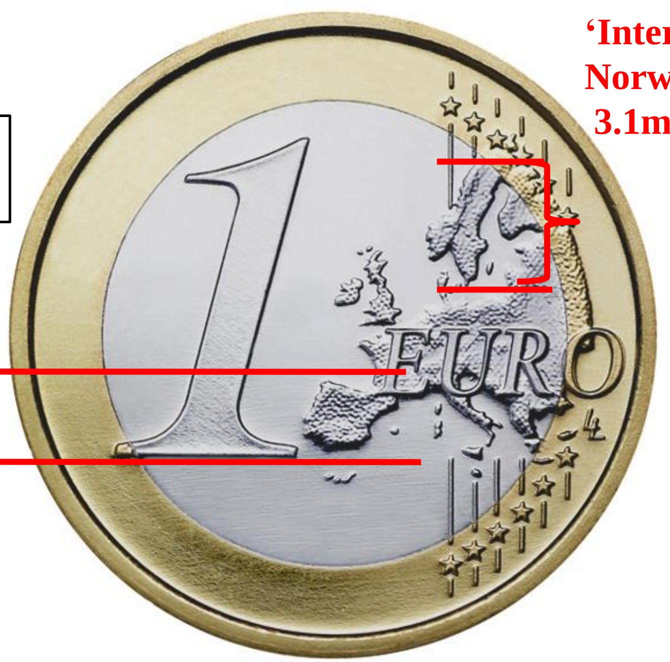


1 σ (450GeV) ≈ 1mm

1 σ (4TeV) ≈ 0.35mm

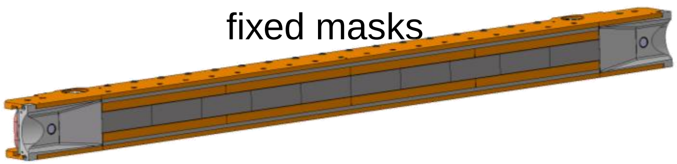
1 σ (6.5TeV) ≈ 0.25mm

Collimator type	N_i	Collimator type	N_i
TCP IR3	8 σ	TCDQ IR6	8 σ
TCSG IR3	9.3 σ	TCSG IR6	7 σ
TCLA IR3	10 σ	TCLI IR2/IR8	6.8 σ
TCP IR7	5.7 σ	TCT IR2/IR8	25 σ
TCSG IR7	6.7σ	TCT IR1/IR5	15 σ
TCLA IR7	10 σ	TCL IR1	20 σ



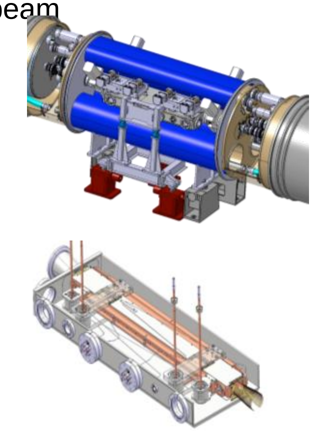
Baseline upgrades

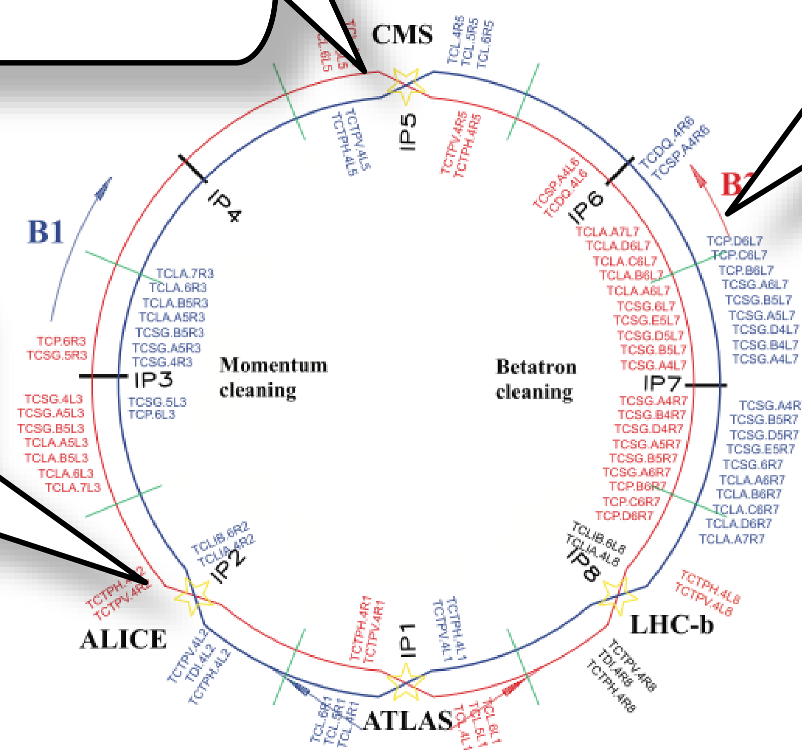
Completely new layouts
Novel materials.
IR1+IR5, <u>per beam</u>:
- 4 tertiary collimators
- 3 physics debris collimators
- fixed masks



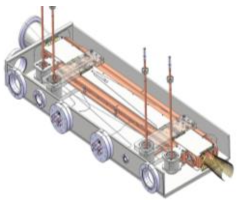
56 new collimators to be produced by LS3 in the present baseline!

Cleaning: DS coll. + 11T dipoles, 2 units per beam

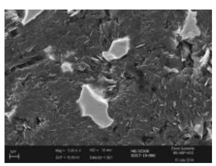


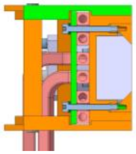


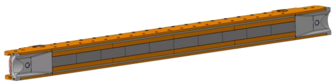
Ion physics debris: DS collimation



Low-impedance, high robustness secondary collimators







S. Redaelli,
Chamonix 2016, 28-01-2016

The magnets in IR3 and IR7

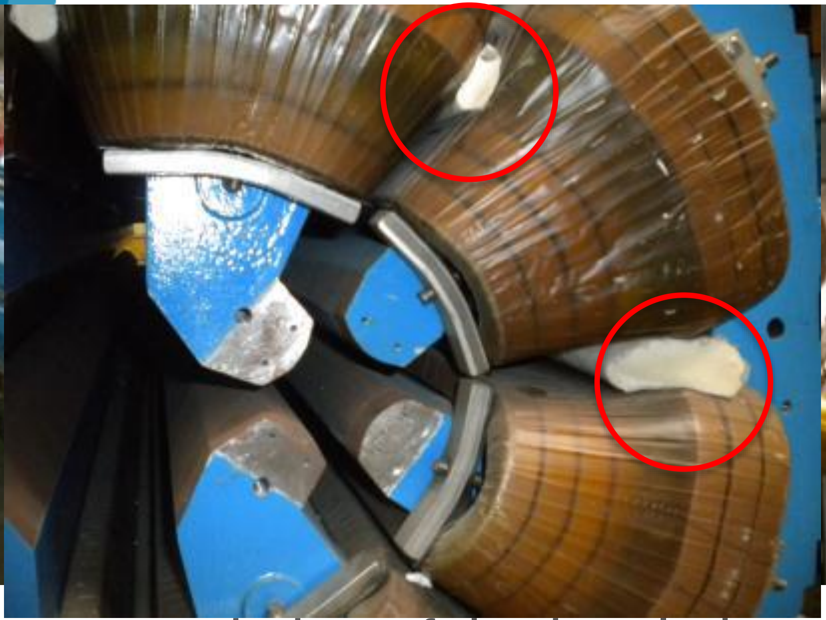
MQW

- 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

Point 3 and 7 coil magnet damage estimation with shielding

green arrow shielding installed LS1

yellow arrow shielding foreseen for LS2

IP 3

IP 3	Dose [MGy] for integrated luminosity 150 fb^-1		Dose [MGy] for integrated luminosity 350 fb^-1		Dose [MGy] for integrated luminosity 3000 fb^-1	
	R	L	R	L	R	L
MQWA.A4	0	0	0	0	2	4
MQWA.B4	0	0	0	0	2	4
MQWB.4	0	0	0	1	2	4
MQWA.C4	0	0	0	1	3	6
MQWA.D4	0	1	1	2	7	14
MQWA.E4	[illegible]	3	2	5	13	24
MQWA.A5	[illegible]	2	2	3	8	15
MQWA.B5	[illegible]	3	2	4	10	19
MQWB.5	[illegible]	7	5	10	24	45
MQWA.C5	[illegible]	15	11	22	57	106
MQWA.D5	[illegible]	4	3	5	14	25
MQWA.E5	[illegible]	7	5	10	25	47
MBW.A6	2	4	3	6	15	27
MBW.B6	2	5	3	7	17	31
MBW.C6	3	7	5	9	24	44

MQW	MBW
From 10 to 20 MGy	From 40 to 60 MGy
From 20 to 50 MGy	From 60 to 80 Mgy
Larger than 50 MGy	Larger than 80 MGy

IP 7

IP 7	Dose [MGy] for integrated luminosity 150 fb^-1		Dose [MGy] for integrated luminosity 350 fb^-1		Dose [MGy] for integrated luminosity 3000 fb^-1	
	R	L	R	L	R	L
MQWA.A4	1	1	1	2	10	15
MQWA.B4	0	1	1	3	9	22
MQWB.4	1	2	1	3	6	14
MQWA.C4	6	6	9	9	41	41
MQWA.D4	2	2	4	4	24	24
MQWA.E4	1	2	2	5	19	39
MQWA.A5	3	3	4	4	20	20
MQWA.B5	4	4	6	6	29	29
MQWB.5	4	4	6	6	29	29
MQWA.C5	2	5	3	7	11	28
MQWA.D5	3	5	6	8	34	49
MQWA.E5	14	5	32	11	278	93
MBW.A6	7	5	16	12	138	99
MBW.B6	12	6	29	14	247	123

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Point 3 and 7 coil magnet damage estimation with shielding

green arrow shielding installed LS1

yellow arrow shielding foreseen for LS2

IP 3

	Dose [MGy] for integrated luminosity 150 fb^-1		Dose [MGy] for integrated luminosity 350 fb^-1		Dose [MGy] for integrated luminosity 3000 fb^-1	
	R	L	R	L	R	L
MQWA.A4	0	0	0	0	2	4
MQWA.B4	0	0	0	0	2	4
MQWB.4	0	0	0	1	2	4
MQWA.C4	0	0	0	1	3	6
MQWA.D4	0	1	1	2	7	14
MQWA.E4	[illegible]	3	2	5	13	24
MQWA.A5	[illegible]	2	2	3	8	15
MQWA.B5	[illegible]	3	2	4	10	19
MQWB.5	[illegible]	7	5	10	24	45
MQWA.C5	[illegible]	15	11	22	57	106
MQWA.D5	[illegible]	4	3	5	14	25
MQWA.E5	[illegible]	7	5	10	25	47
MBW.A6	2	4	3	6	15	27
MBW.B6	2	5	3	7	17	31
MBW.C6	[illegible]	7	5	9	24	44

MQW	MBW
From 10 to 20 MGy	From 40 to 60 MGy
From 20 to 50 MGy	From 60 to 80 Mgy
Larger than 50 MGy	Larger than 80 MGy

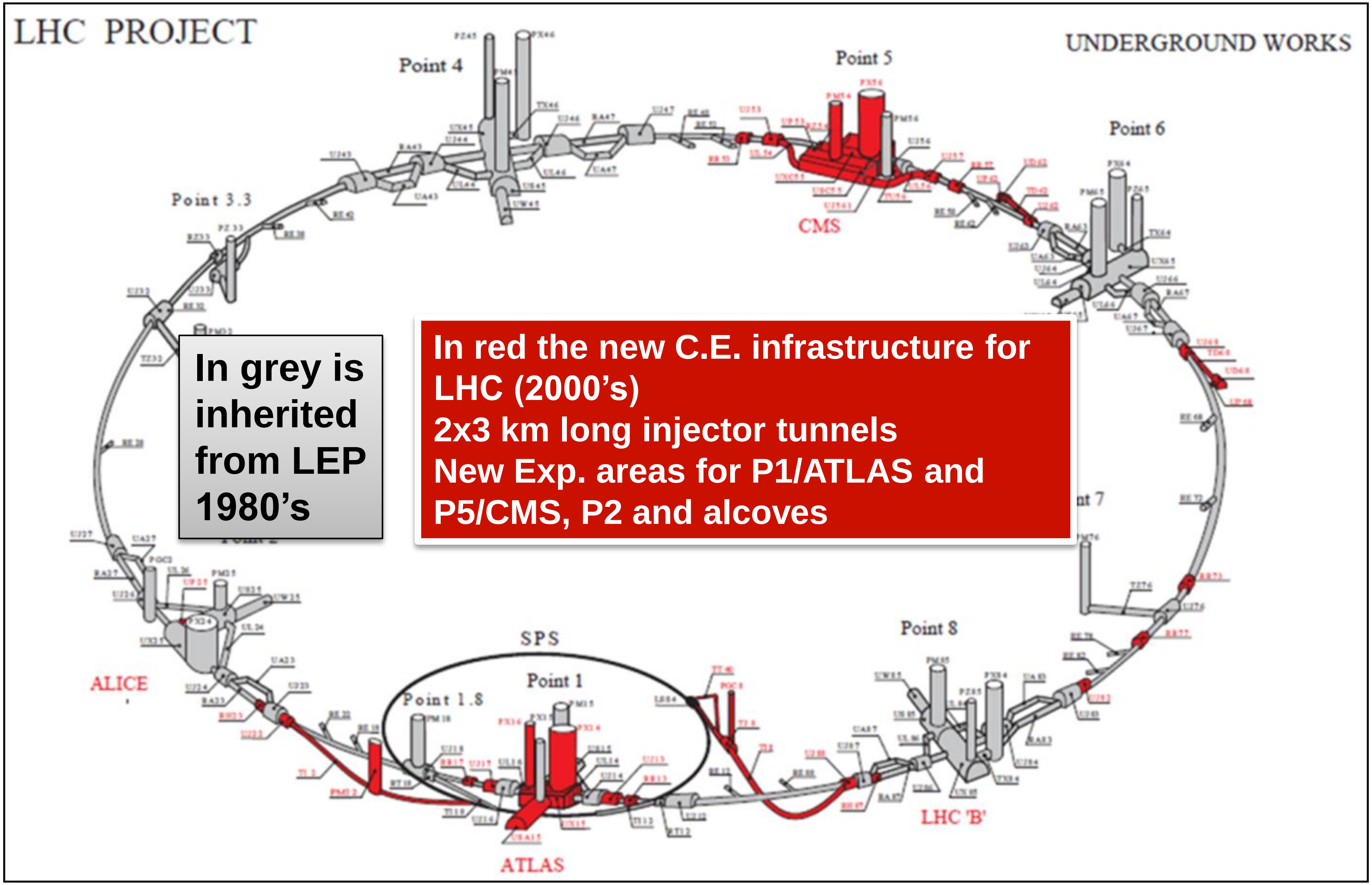
Connected in series with the other in new Q5 configuration

IP 7

	Dose [MGy] for integrated luminosity 150 fb^-1		Dose [MGy] for integrated luminosity 350 fb^-1		Dose [MGy] for integrated luminosity 3000 fb^-1	
	R	L	R	L	R	L
MQWA.A4	1	1	1	2	10	15
MQWA.B4	0	1	1	3	9	22
MQWB.4	1	2	1	3	6	14
MQWA.C4	6	6	9	9	41	41
MQWA.D4	2	2	4	4	24	24
MQWA.E4	1	2	2	5	19	39
MQWA.A5	3	3	4	4	20	20
MQWA.B5	4	4	6	6	29	29
MQWB.5	4	4	6	6	29	29
MQWA.C5	2	5	3	7	11	28
MQWA.D5	3	5	6	8	34	49
Replaced by absorber						
MBW.A6	7	5	16	12	138	99
MBW.B6	12	6	29	14	247	123

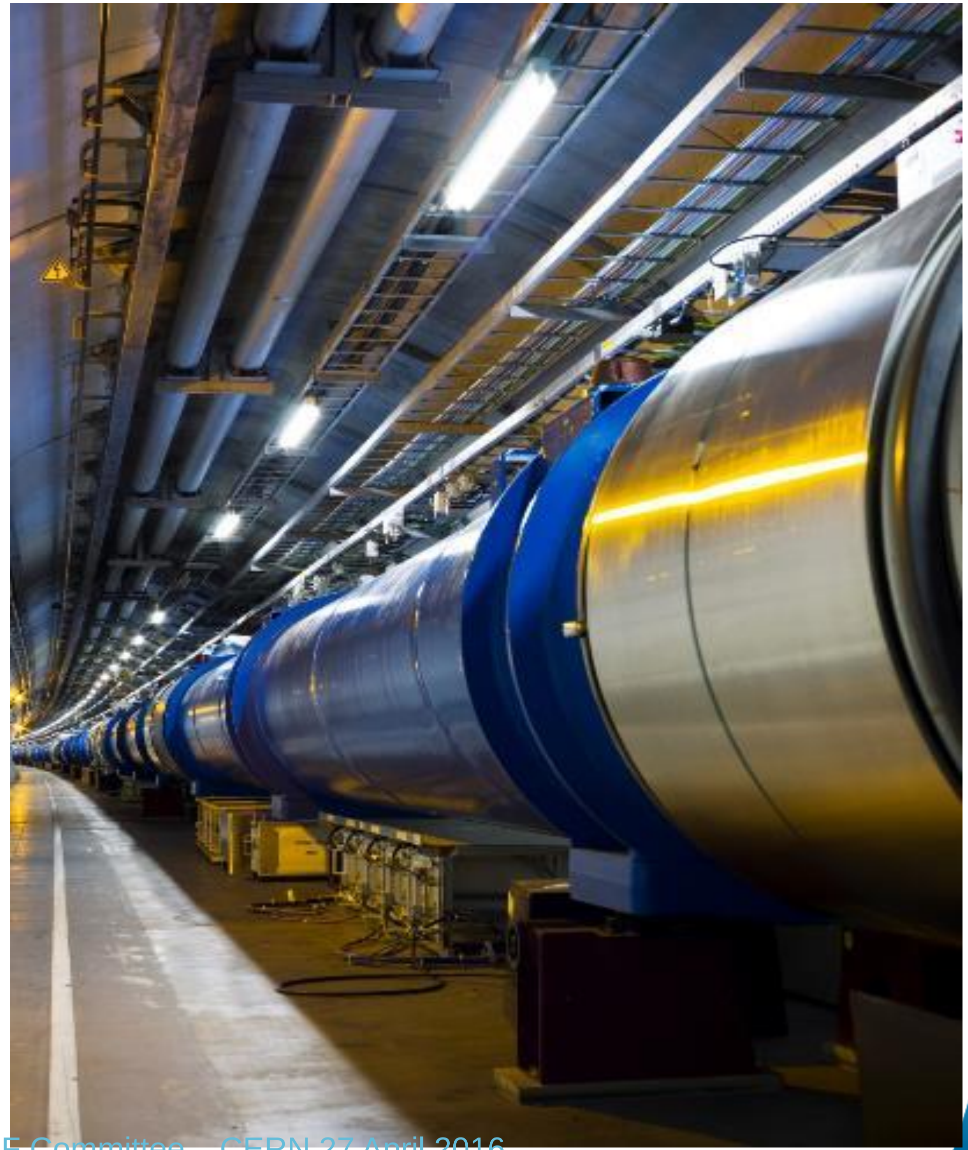
New Schedule: → HL-LHC CE during LS2

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

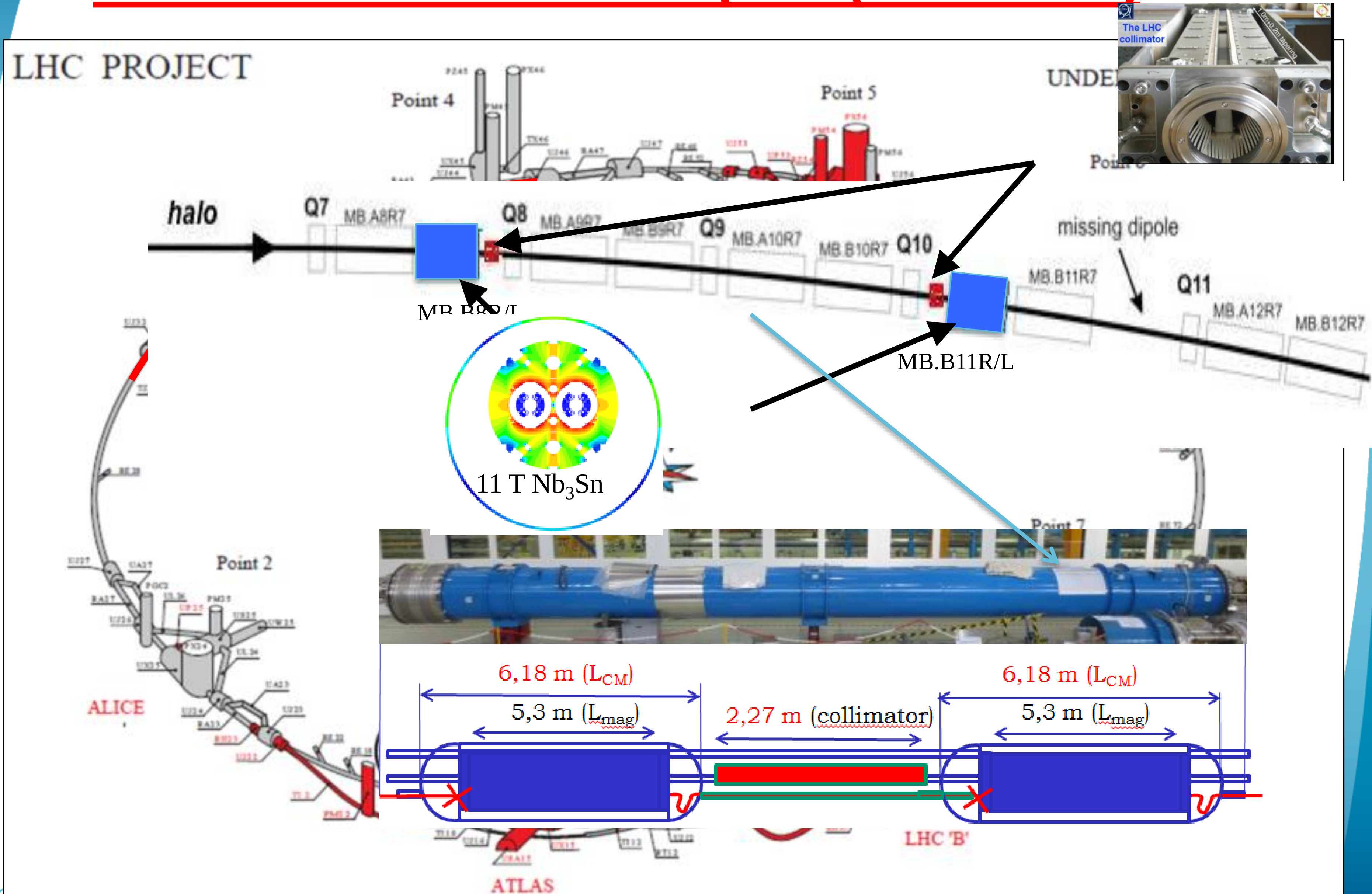


LHC: the largest instrument based on 18 km of superconducting dipole…

- 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!