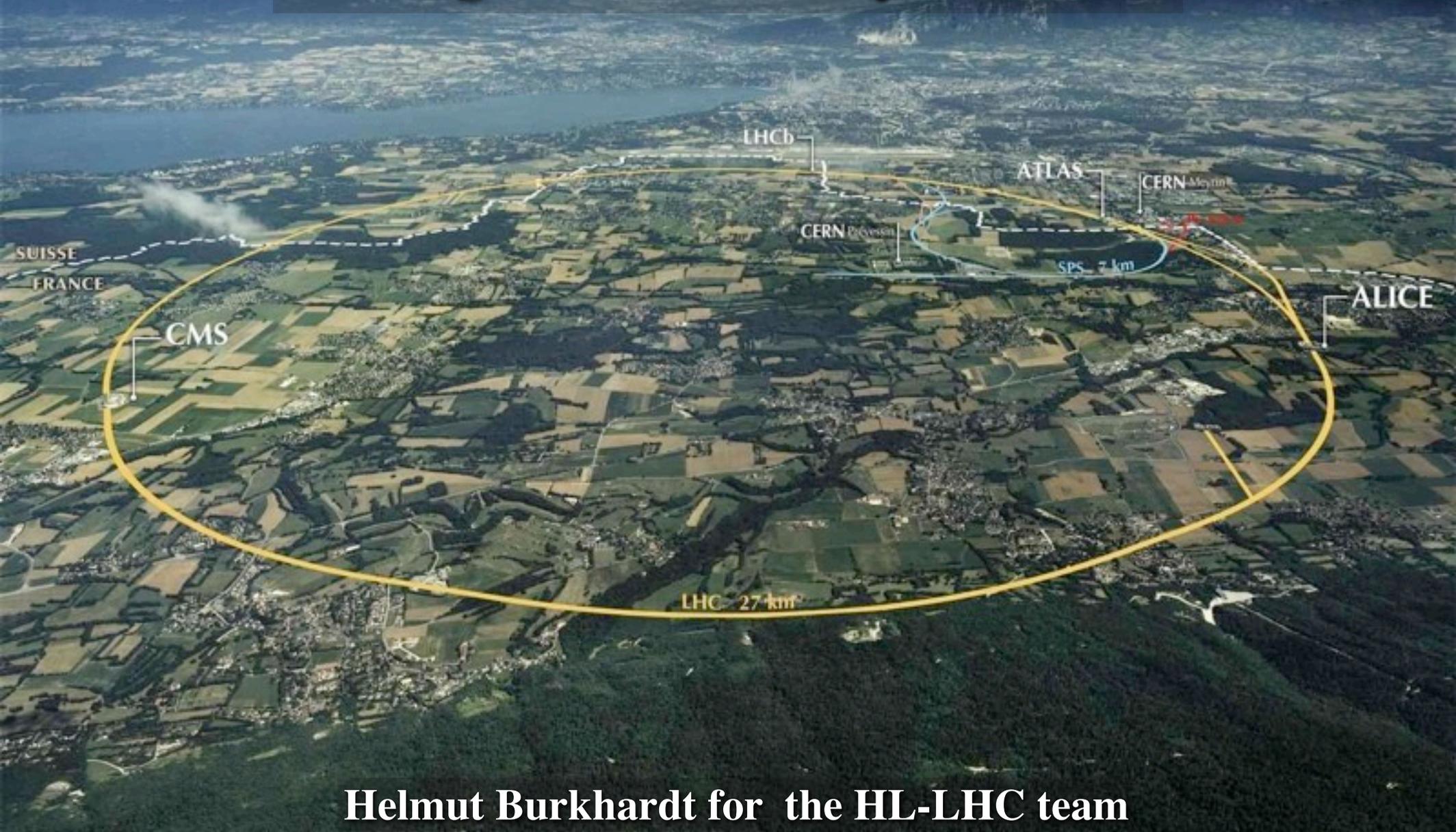


High-Luminosity LHC



Helmut Burkhardt for the HL-LHC team





- **LHC and HL-LHC**
- **timeline and expectations for future operation**
- **main changes on machine side**

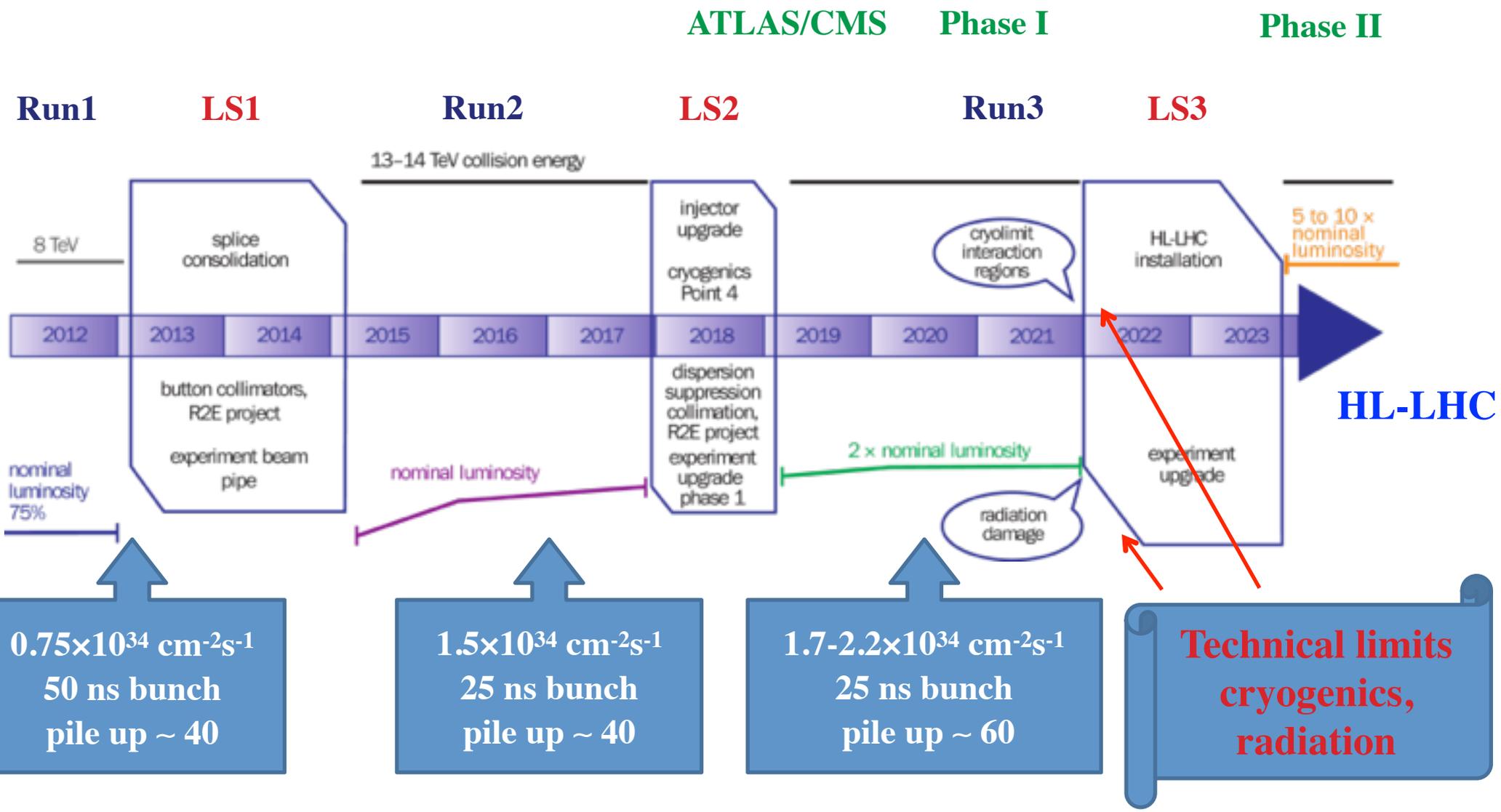
- **consequences for the experiments**
 - luminosity, pile-up, luminosity levelling**
 - layout changes in the interaction regions,**
 - implications for radiation and backgrounds**

Status and several slides from Lucio Rossi et al. as reported in the 2013
[3rd Annual Joint HiLumi LHC-LARP and HL-LHC kick-off meeting](#)
[11-15 November, Daresbury](#)

the [previous annual meeting](#) was here in Frascati 14-16 Nov 2012



The CERN 10 year plan and terminology



Experiments : consolidation / upgrades in all shutdowns

Most significant upgrades :

ALICE & LHCb in LS2

ATLAS and CMS in LS3



The main 2013-14 LHC consolidations

1695 Openings and final reclosures of the interconnections

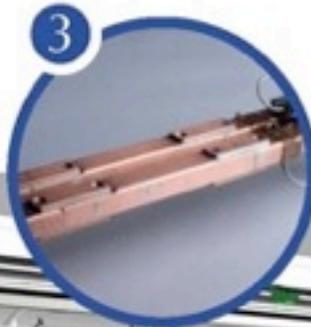
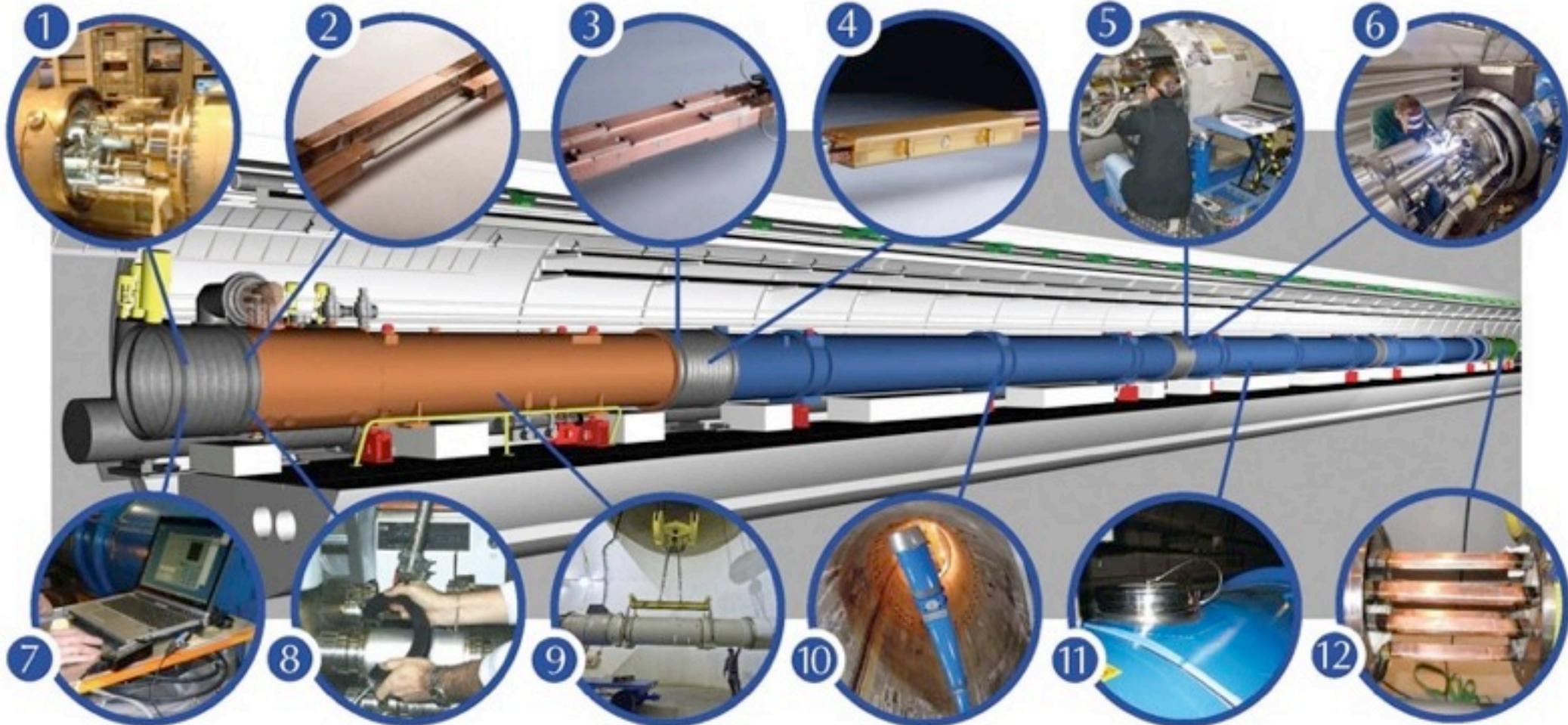
Complete reconstruction of 1500 of these splices

Consolidation of the 10170 13kA splices, installing 27 000 shunts

Installation of 5000 consolidated electrical insulation systems

300 000 electrical resistance measurements

10170 orbital welding of stainless steel lines



18 000 electrical Quality Assurance tests

10170 leak tightness tests

4 quadrupole magnets to be replaced

15 dipole magnets to be replaced

Installation of 612 pressure relief devices to bring the total to 1344

Consolidation of the 13 kA circuits in the 16 main electrical feed-boxes



Goal of High Luminosity LHC (HL-LHC)



initially fixed in November 2010

The main objective of HiLumi LHC Design Study is to determine a hardware configuration and a set of beam parameters that will allow the LHC to reach the following targets:

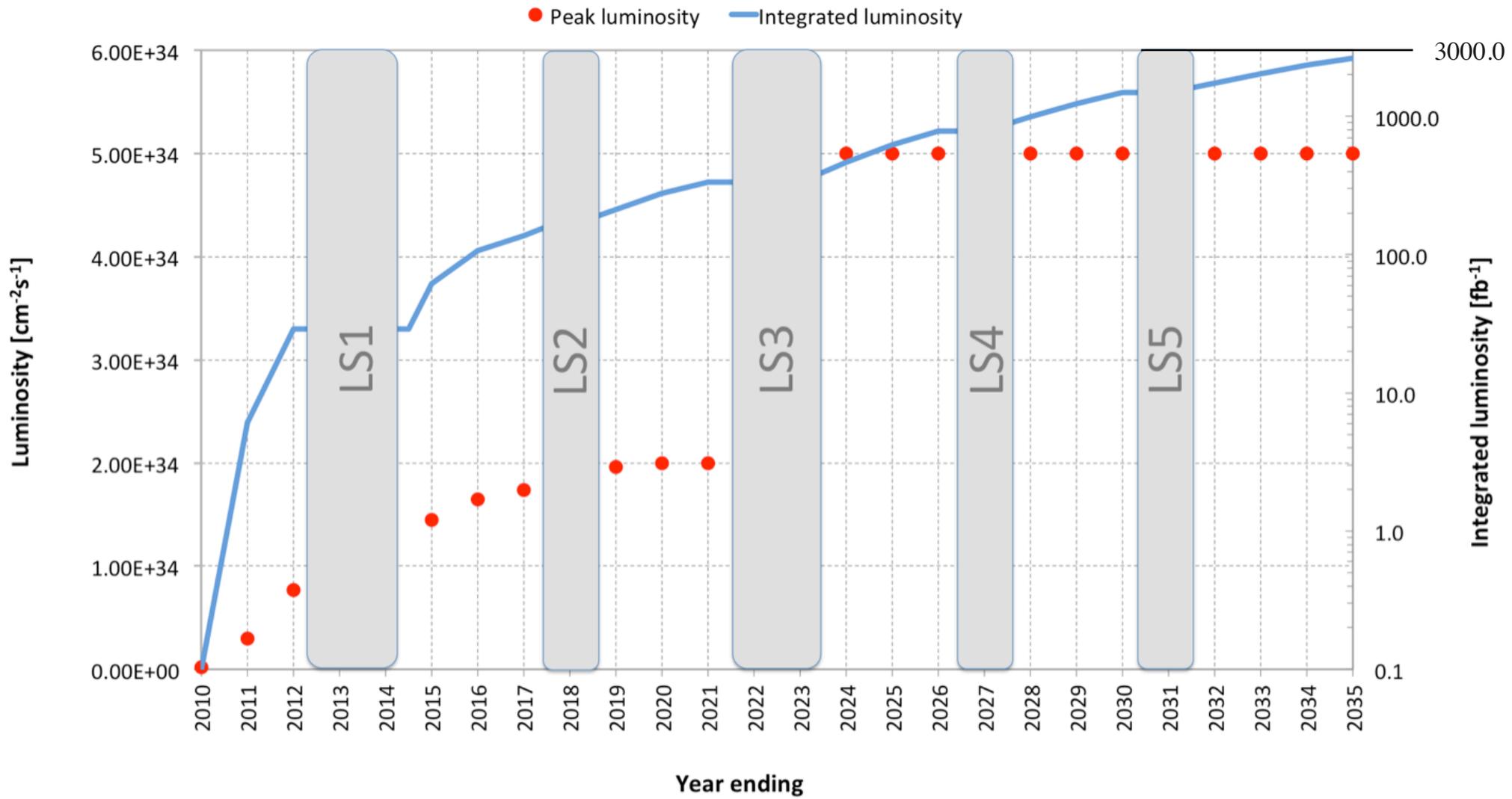
A peak luminosity of $5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ with levelling, allowing :

An integrated luminosity of 250 fb^{-1} per year, enabling the goal of 3000 fb^{-1} twelve years after the upgrade.

This luminosity is more than ten times the luminosity reach of the first 10 years of the LHC lifetime.

confirmed at the HL-LHC kick-off meeting 11 November 2013 in Daresbury

This goal would be reached in 2036



M. Lamont, [6th HL-LHC Coordination Group](#), Jul.2013



High Luminosity LHC Project, Work Packages



WP
Coordinators
Co-coordinators

Experiments directly involved

WP1 Project Management

Lucio Rossi, CERN
Oliver Brüning, CERN

WP2 Accelerator Physics

Gianluigi Arduini, CERN
Andy Wolski, UNILIV

WP3 Magnets

Ezio Todesco, CERN
Gianluca Sabbi, LBNL

WP4 Crab Cav. and RF

Erk Jensen, CERN
Graeme Burt, ULANC

WP5 Collimation

Stefano Redaelli, CERN
Robert Appleby, UNIMAN

WP6 Cold Powering

Amalia Ballarino, CERN
Francesco Broggi, INFN

WP7 Machine Protection

Daniel Wollmann, CERN
Jörg Wenninger, CERN

WP8 LHC-Exp. Interface

H. Burkhardt, I. Efthymiopoulos, CERN
A.Ball (CMS), **B. di Girolamo** (ATLAS)

WP9 Cryogenics

Laurent Taviani, CERN
Rob Van Weelden, CERN

WP10 Energy deposition

Francesco Cerutti, CERN
Nikolai Mokhov, FNAL

WP11 11T Dipole

Mikko Karppinen, CERN
Alexander Zlobin, FNAL

WP11 Vacuum

Roberto Kersevan, CERN
Mark Gallilee, CERN

WP13 Beam Diagnostics

Rhodri Jones, CERN
Hermann Schmickler, CERN

WP14 Beam Transfer

Jan Uythoven, CERN
Brennan Goddard, CERN

WP15 Integration

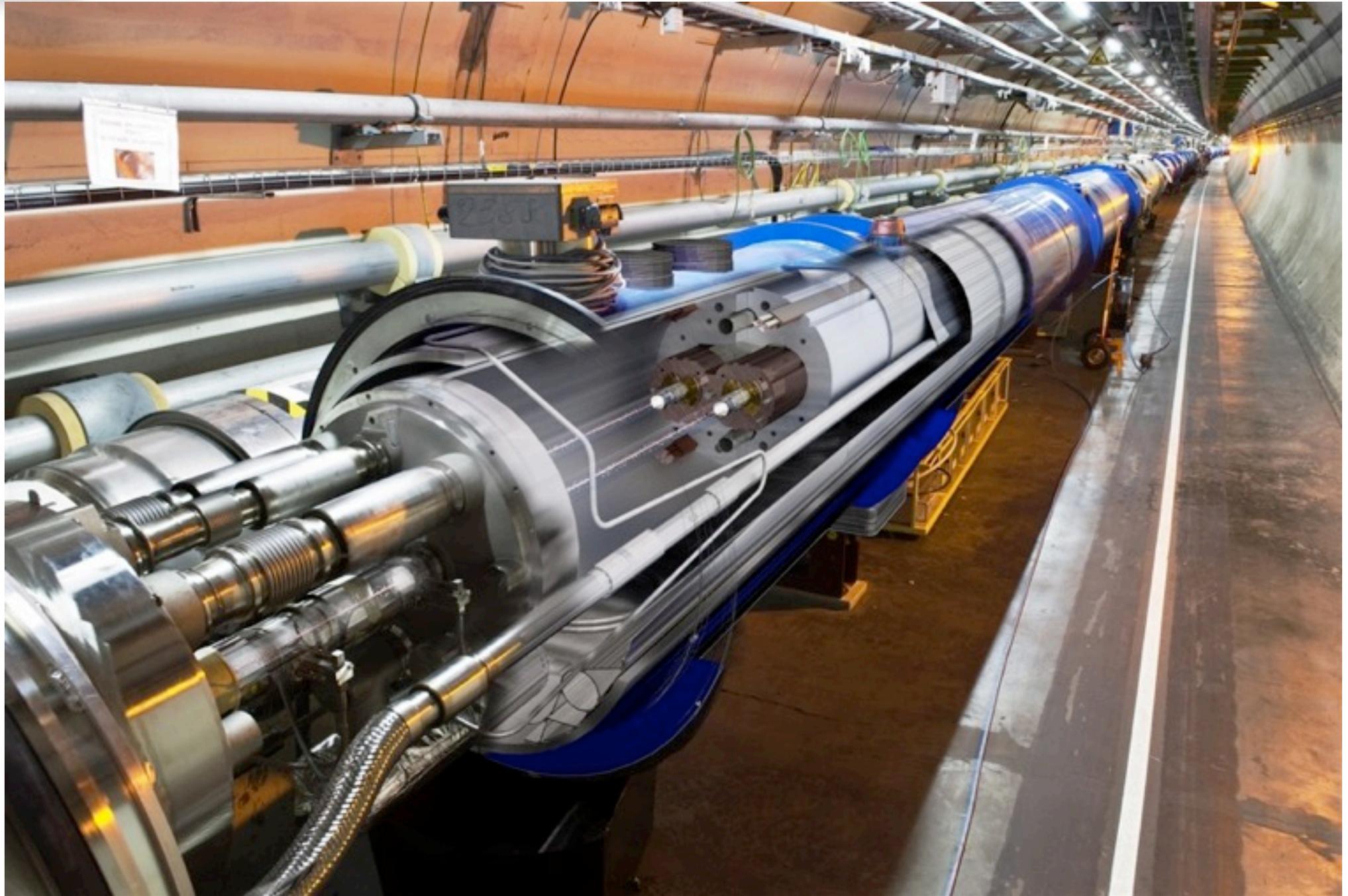
Sylvain Weisz, CERN
Paolo Fessia, CERN

WP16 Hardware Commissioning

Mirko Pojer, CERN

WP18 High Field Magnets, R&D

Gijs de Rijk, CERN
François Kircher, CEA

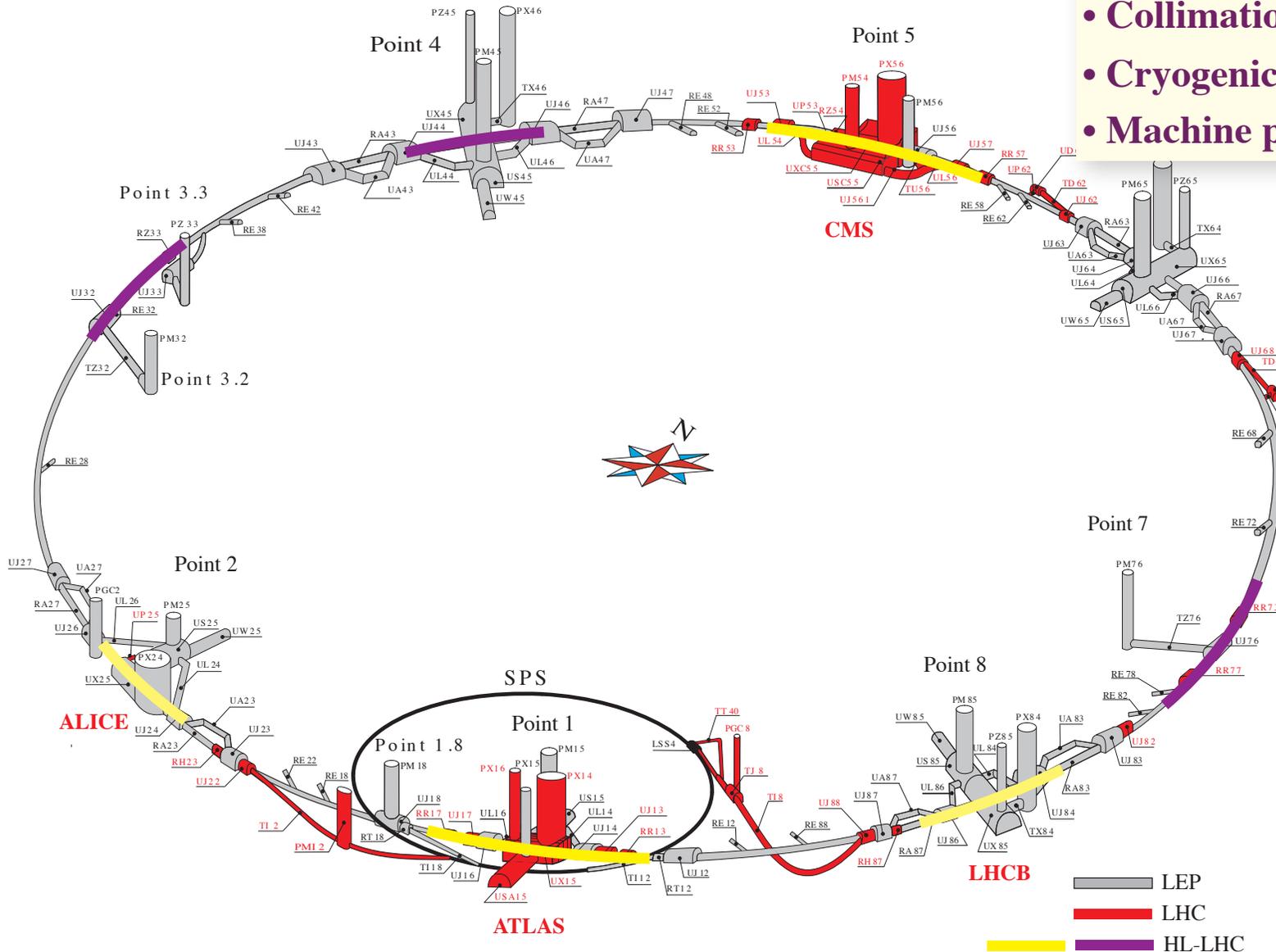


Major changes in more than 1.2 km of the LHC



- New IR-quads Nb₃Sn (inner triplets)
- New 11 T Nb₃Sn (short) dipoles

- Crab Cavities
- Harmonic RF, 200 or 800 MHz
- Cold powering
- Collimation upgrade
- Cryogenics upgrade
- Machine protection, ...



IP1,5
will change a lot

IP2,8
ALICE, LHCb
improved TDI
minimal TAN IP8



simple case : dispersion and slope $\beta' = 0$ by default at IP - relevant for experiments

beam size, r.m.s.	$\sigma(s) = \sqrt{\varepsilon \beta(s)}$
beam divergence, r.m.s.	$\theta(s) = \sqrt{\varepsilon / \beta(s)}$
product	$\varepsilon = \sigma(s) \theta(s)$

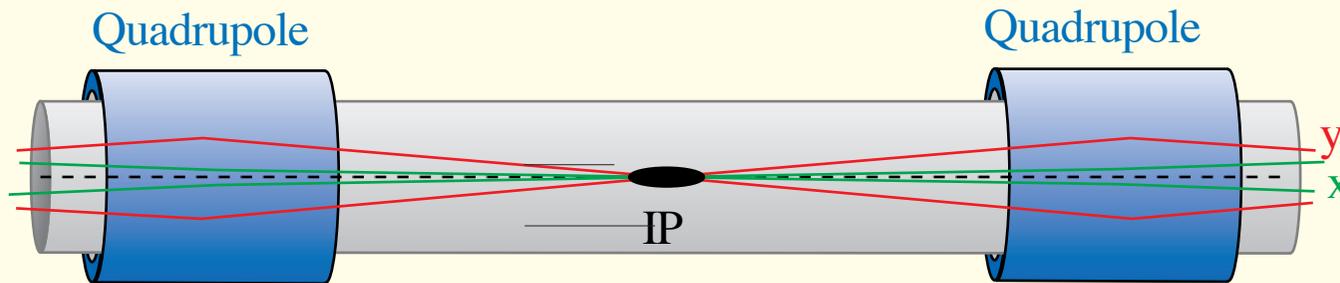
β - function : local machine quantity - focusing of lattice

Emittance ε : beam quantity - the average action

related to phase space density or kind of beam temperature

given by initial conditions (injected beam)

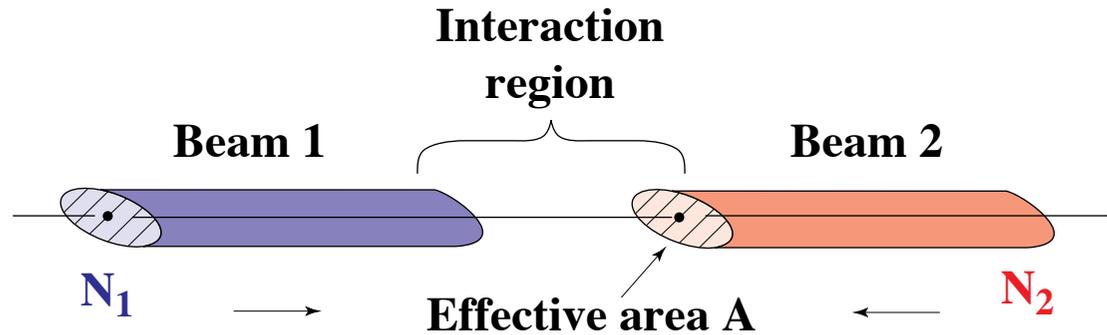
IP: squeeze β to a minimum, called β^* \Rightarrow maximum of divergence, **needs aperture**



LHC	$\varepsilon_N = \varepsilon \beta \gamma = 3.75 \mu\text{m}$,	$E_b = 7 \text{ TeV}$:	$\varepsilon = 0.503 \text{ nm}$,	$\beta^* = 0.55 \text{ m}$,	$\sigma^* = 16.63 \mu\text{m}$,	$\theta^* = 30 \mu\text{rad}$
HL-LHC	$2.50 \mu\text{m}$,		0.335 nm ,	0.15 m	$7.09 \mu\text{m}$,	$47 \mu\text{rad}$



$$L = \frac{N_1 N_2 n_b f_{\text{rev}}}{A_{\text{eff}}}$$



for head-on Gaussian bunches with rms sizes $\sigma_x \sigma_y$ $A_{\text{eff}} = 4 \pi \sigma_x \sigma_y$

From LHC to HL-LHC

N number of particles per bunch increased $2.0/1.15 = \times 1.91$

A_{eff} reduced emittance $3.75/2.5 = 1.5$, β^* $0.55/0.15 = 3.67$

together potentially $1.91^2 \times 1.5 \times 3.67 = 20 \times$ times more luminosity

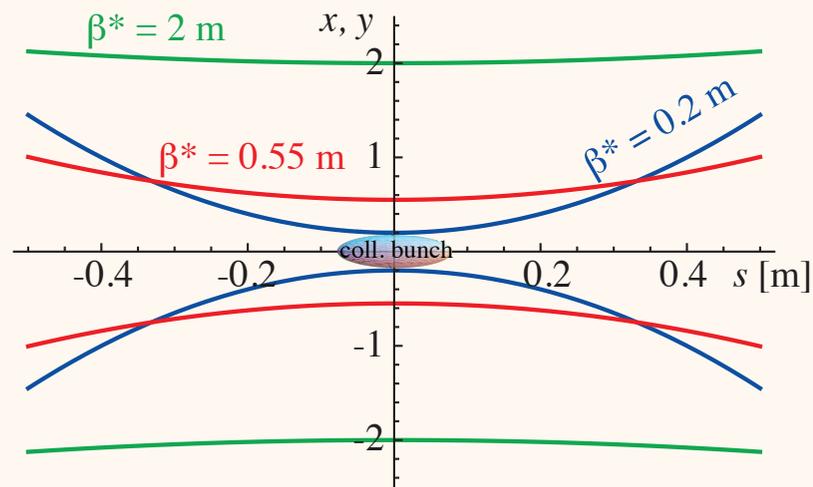


Hourglass effect. Relevant when β^* is decreased close to the bunch length σ_z . Define $r = \beta^* / \sigma_z$. Luminosity gets reduced. For round beams the factor is

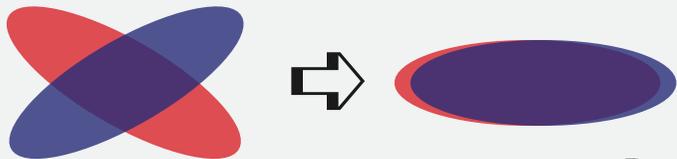
$$H(r) = \frac{1}{\sqrt{\pi}} \int_{-\infty}^{\infty} \frac{e^{-s^2}}{1 + s^2/r^2} ds = \sqrt{\pi} r e^{r^2} \text{Erfc}(r)$$

LHC design values
 $\sigma_z = 7.50 \text{ cm}$

β^* [m]	r	$H(r)$
1.0	13.33	0.9972
0.55	7.33	0.99095
0.15	2.0	0.9054



Crab crossing : relevant for large crossing angle θ_c or more precisely large Piwinski angles Φ . Use rf-cavities to rotate bunches by θ_c to get better overlap (higher lumi)

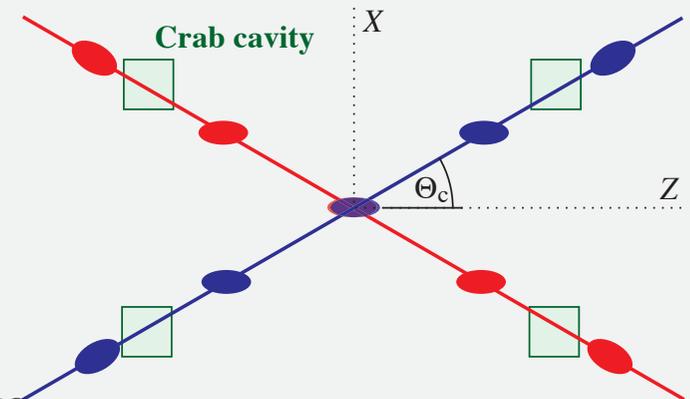


$$R_\theta = \frac{1}{\sqrt{1 + \Theta^2}}; \quad \Theta \equiv \frac{\theta_c \sigma_z}{2\sigma_x}$$

$R_\theta = 0.84$ or 20 % loss for nominal LHC
 $= 0.30$ or 70% loss HL-LHC

and less resonance excitation.

Tested at KEKB ; planned for LHC upgrade



Piwinski angle $\Phi = \frac{\sigma_z}{\sigma_x} \tan \theta_c$



Parameter table



Parameter	nominal	25ns	50ns
N_b	1.15E+11	2.2E+11	3.5E+11
n_b	2808	2808	1404
N_{tot}	3.2E+14	6.2E+14	4.9E+14
beam current [A]	0.58	1.11	0.89
x-ing angle [μ rad]	300	590	590
beam separation [σ]	9.9	12.5	11.4
β^* [m]	0.55	0.15	0.15
ϵ_n [μ m]	3.75	2.50	3
ϵ_L [eVs]	2.51	2.51	2.51
energy spread	1.20E-04	1.20E-04	1.20E-04
bunch length [m]	7.50E-02	7.50E-02	7.50E-02
IBS horizontal [h]	80 -> 106	18.5	17.2
IBS longitudinal [h]	61 -> 60	20.4	16.1
Piwinski parameter	0.68	3.12	2.85
Reduction factor 'R1*H1' at full crossing angle (no crabbing)	0.828	0.306	0.333
Hourglass reduction factor 'H0' at zero crossing angle (full crabbing)	0.991	0.905	0.905
beam-beam / IP without Crab Cavity	3.1E-03	3.3E-03	4.7E-03
beam-beam / IP with Crab cavity	3.8E-03	1.1E-02	1.4E-02
Peak Luminosity without levelling [$\text{cm}^{-2} \text{s}^{-1}$]	1.0E+34	7.4E+34	8.5E+34
Virtual Luminosity: $L_{peak} * H0 / R1 / H1$ [$\text{cm}^{-2} \text{s}^{-1}$]	1.2E+34	21.9E+34	23.1E+34
Events / crossing without levelling	19 -> 28	210	475
Levelled Luminosity [$\text{cm}^{-2} \text{s}^{-1}$]	-	5E+34	2.50E+34
Events / crossing (with leveling for HL-LHC)	*19 -> 28	140	140
Leveling time [h] (assuming no emittance growth)	-	9.0	18.3



HL-LHC pushed to rather hard limits in terms of radiation hardness and cryogenics

peak performance must be limited, level to $5 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$

aim is integrated, 3000 fb-1 total

Generally useful to allow for some margins :

aiming for 4000 - 5000 fb-1 for radiation hardness

$\sim 7.5 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$ peak (200 average pile-up)

integrating 250 pb-1 / y will be difficult, more like 350 pb-1/y appear un-realistic

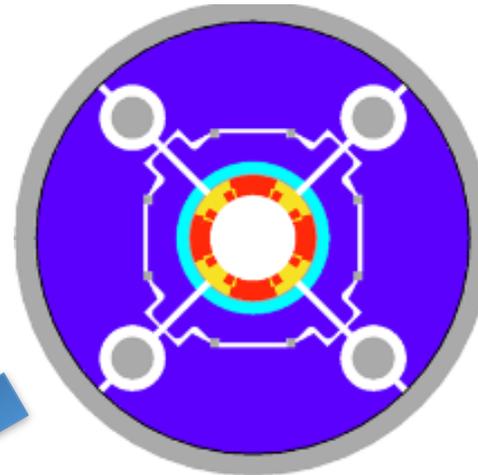
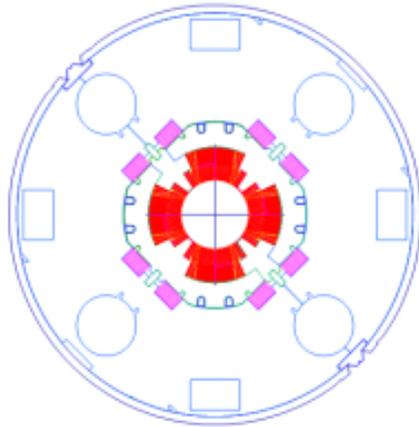


Fermilab

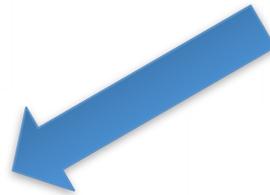
KEK
HIGH-ENERGY ACCELERATOR

Nb-Ti

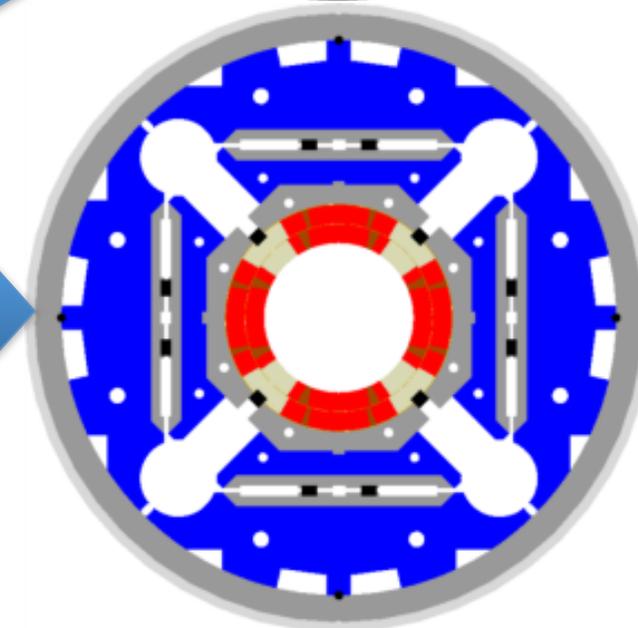
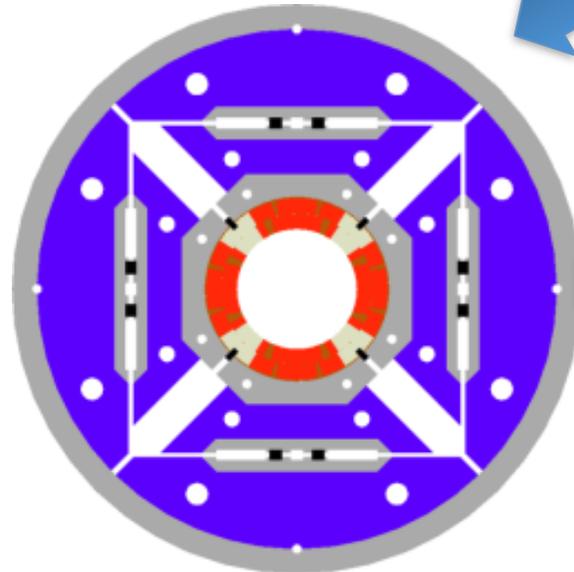
LHC (USA & JP, 5-6 m)
 $\varnothing 70$ mm, $B_{\text{peak}} \sim 8$ T
1992-2005



LARPTQS & LQ (4m)
 $\varnothing 90$ mm, $B_{\text{peak}} \sim 11$ T
2004-2010



LARP HQ
 $\varnothing 120$ mm,
 $B_{\text{peak}} \sim 12$ T
2008-2014



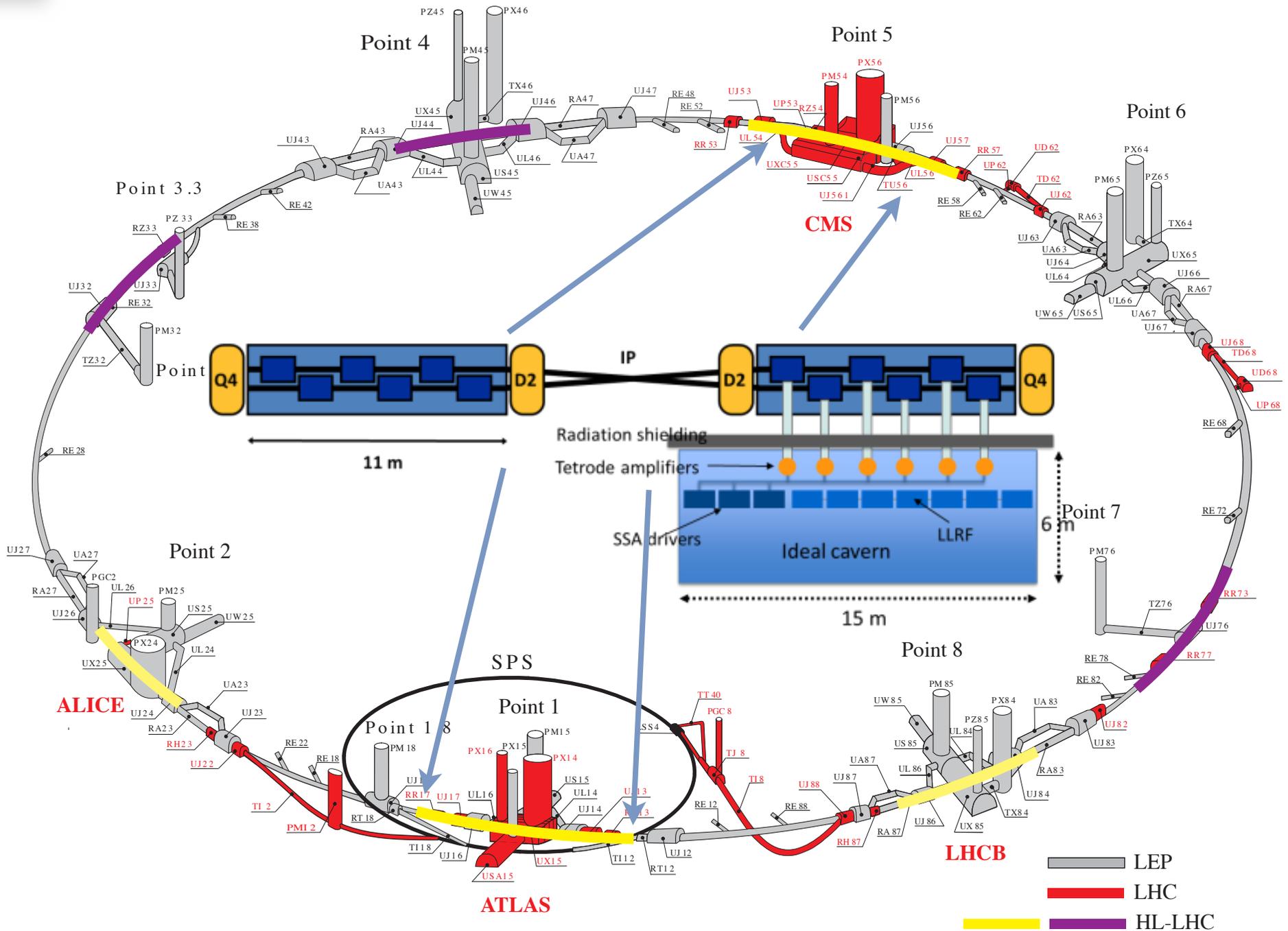
LARP & CERN
MQXF
 $\varnothing 150$ mm,
 $B_{\text{peak}} \sim 12.1$ T
2013-2020

Nb3Sn

high fields and radiation hardness

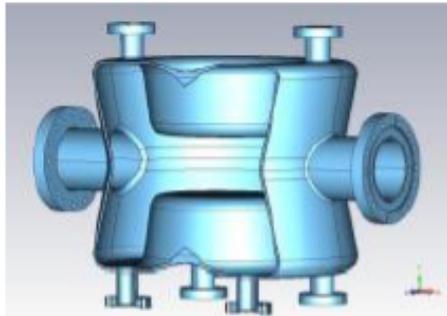


Crab cavities for local beam rotation





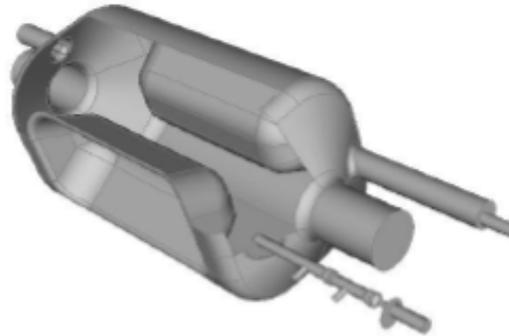
All Prototypes in Bulk Niobium (2011-12)



Double 1/4-wave



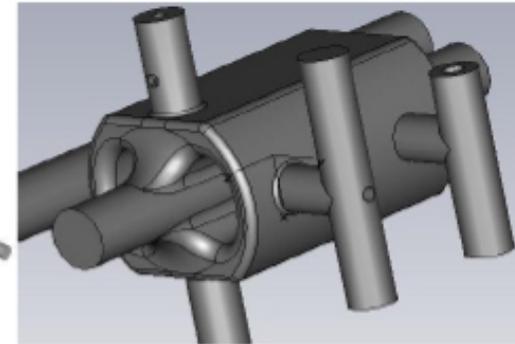
LARP-BNL



RF dipole



LARP-ODU-JLAB



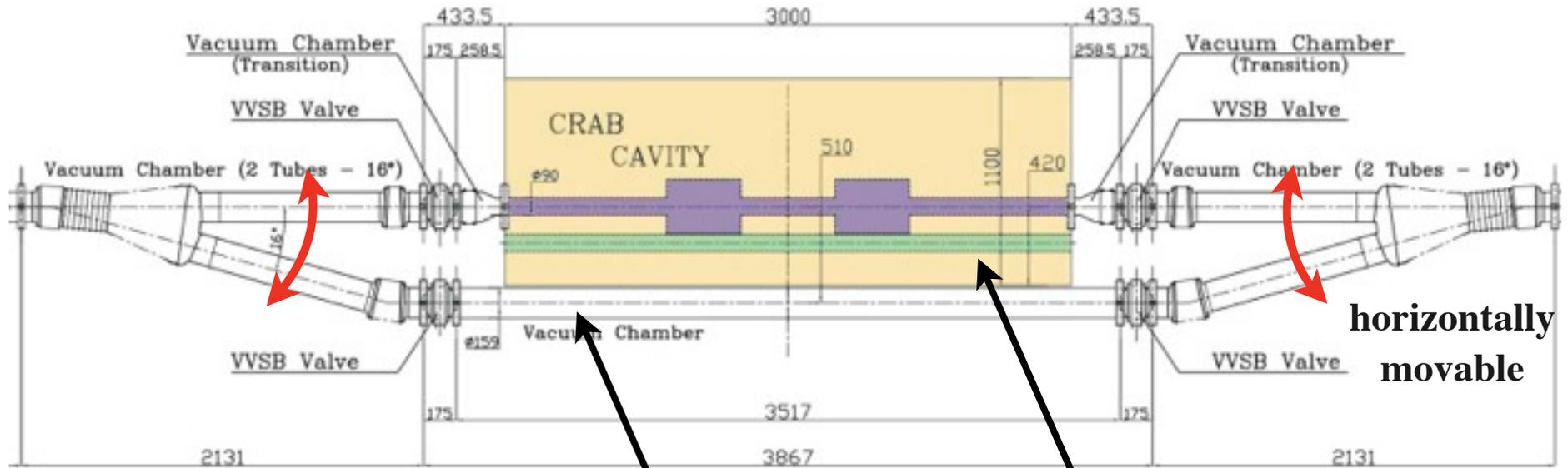
4-rod



UniLancaster-CI-CERN

Crab cavity tests, SPS

Preparation, for test with beam from 2016 - 2018



SPS Bypass

Dummy LHC Beam Pipe
to mimic LHC environment

horizontally
movable



Limit

peak luminosity to $5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$

pile-up $\mu < 140$

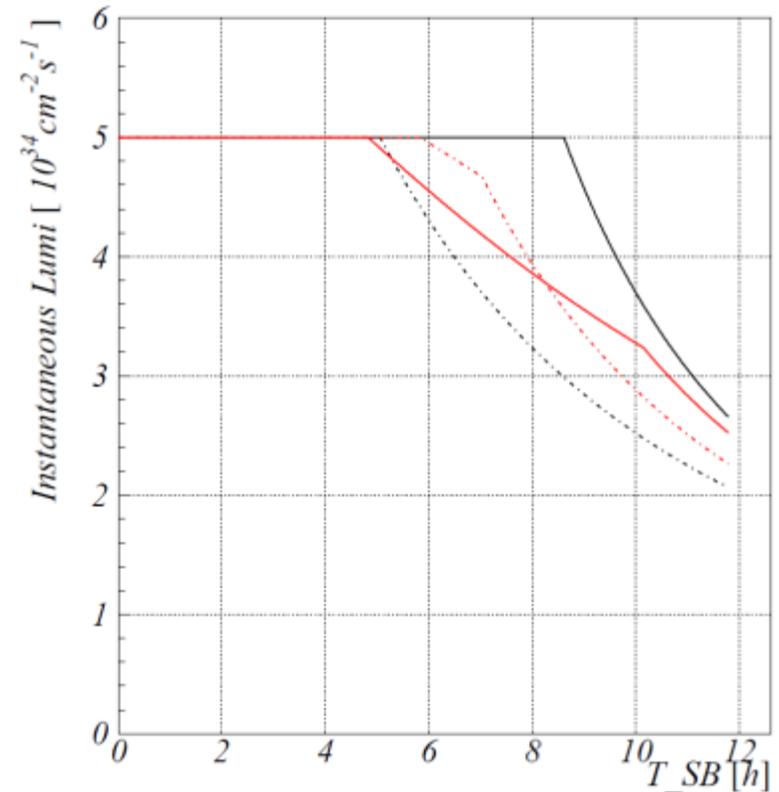
Many possibilities to reduce luminosity :

- Vary Crab angle (shorter overlap region)
- Parallel separation as already used for IP2,8

More difficult but with potential advantageous

- shaping of the longitudinal overlap “crab kissing”

- β^* -leveling potential advantage in β^* levelling, i.e. starting the fill at increased β^*
 reduces the beam size in the triplet and long-range beam-beam
 would allow for reduced crossing angle at constant separation in terms of sigma



→ more next slide



Event pile-up μ : # of visible inelastic proton-proton interactions / bunch crossing

HL-LHC design goals agreed with ATLAS / CMS :

“maximum average” $\mu < 140$ such that the maximum $\mu < 200$ $140 + 5 \sqrt{140} = 200$

In addition - to be able to distinguish collisions vertices longitudinally

rms bunch length $\sigma_z = 7.5$ cm, luminous overlap region $\sqrt{2}$ shorter, 5.3 cm

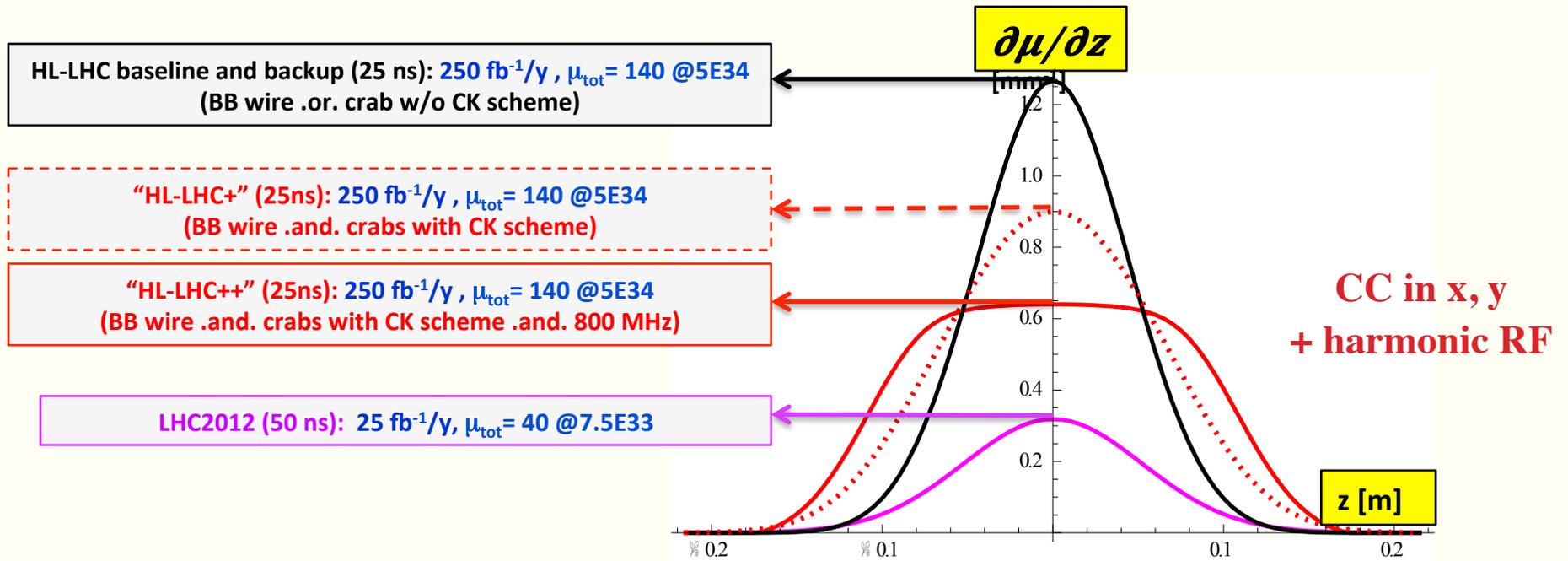
pile-up line density $\partial\mu/\partial z$

$\partial\mu/\partial z = \mu / (R \sigma_z \sqrt{\pi}) = 1.27 / \text{mm}$ at peak, with full crabbing, reduction factor R

ATLAS/CMS would like $< 0.7 / \text{mm}$ (< 1 mm including fluctuations)

would require special efforts (crab-kissing or 2x longer bunches by 200 MHz)

“maximum average” : highest luminosity, like towards beginning of fill, averaged over bunches





$\sigma_{tot} = \sigma_{in} + \sigma_{el}$ σ_{tot} relevant for lifetime by collisions (burn off)

σ_{el} measured with special high- β optics at low angle by /ATLAS-ALFA

Collision rate $\dot{N} = L \sigma$ $L = L_b n_b$

Divided by crossing rate $\mu = \frac{L \sigma}{n_b f_{rev}}$

The original LHC design

Assumed $\sigma_{in} = 60$ mb turned out to be much too small

$L_{tot} = 1.e34 cm^{-2}s^{-1}$, 2808 bunches, per bunch $L = 3.56e30 cm^{-2}s^{-1}$

$\dot{N} = L \sigma_{in} = 6.e8$ Hz, $\mu = 6.e8 / (2808 * 11245.5) = 19.0$

$f_{RF} = 400.79$ MHz

$h = 35640$

$f_{rev} = f_{RF} / h = 11245.5$ Hz

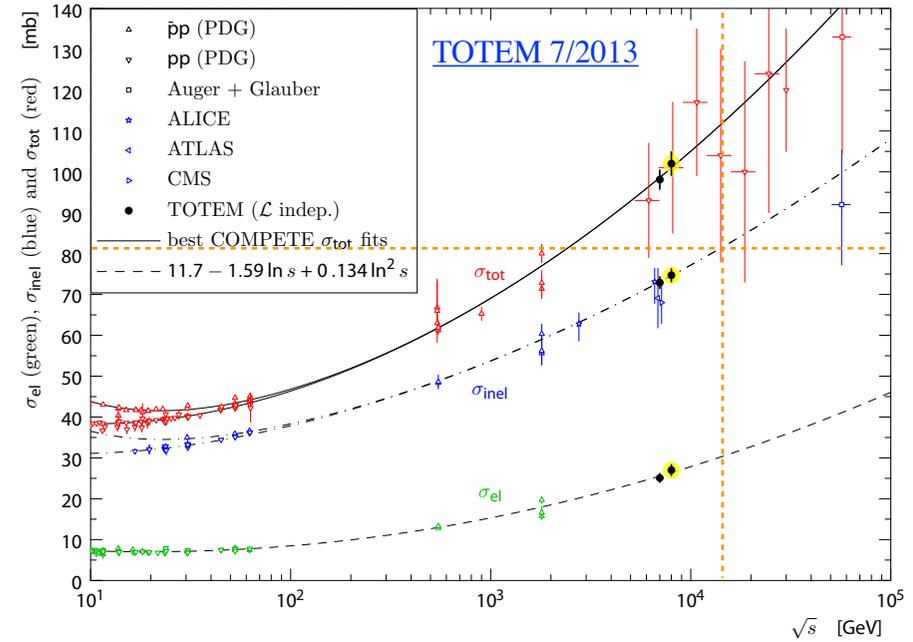
Conservative value used for HL-LHC estimates $\sigma_{in} = 85$ mb at $\sqrt{s} = 14$ TeV

$\mu = 26.9$ at design luminosity $1.e34 cm^{-2}s^{-1}$

HL-LHC at best 2760 colliding bunches

2508 with BCMS (bunch compression, merging and splitting)

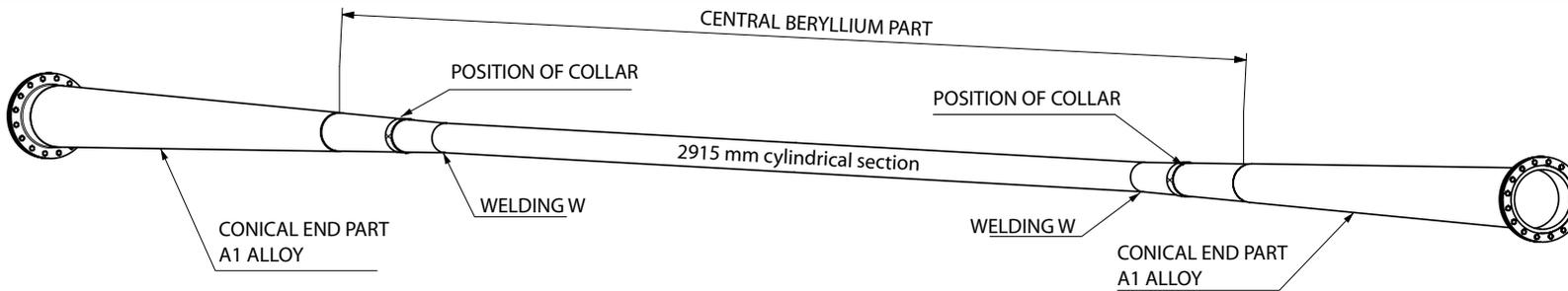
$L = 5.e34 cm^{-2}s^{-1}$, $n_b = 2760$, $\sigma_{in} = 85$ mb $\mu = 136.9 \approx 140$



Layout changes by the experiments, central beam pipes

new inner Be beam pipes in IP1 and IP5, implemented in LS1 (LEB, Mark Gallilee et al.)

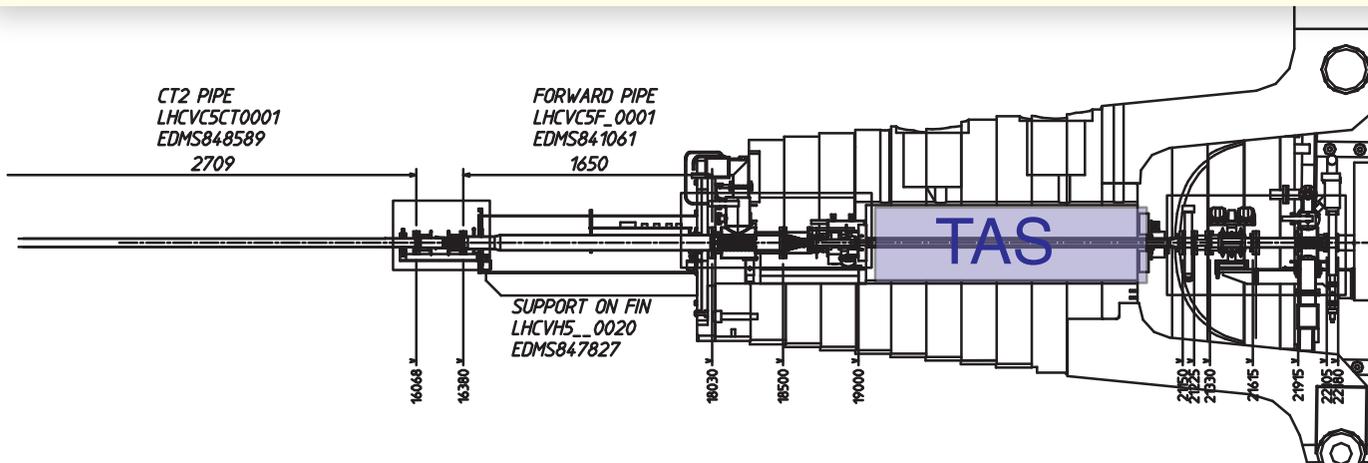
30% reduction from 29 mm to 21.7 mm inner radius for CMS and 23.5 mm for ATLAS



CMS
lhvc5c_0028-vAA

TAS : charged particle absorber and passive protection TAS, radius 17 mm

Including sagging, the reduced beam pipes remain in the shadow of the TAS after LS1



1.8 m long Cu absorber
19 m form IP



Reduction of β^* (to 15 cm for round beams)

increases the beam size and crossing angle in the triplet

Requires new, 2 × larger aperture triplet

the inner coil diameter increases from 70 mm to 150 mm

Crab cavities after D2, D2 moved 13 m closer to IP

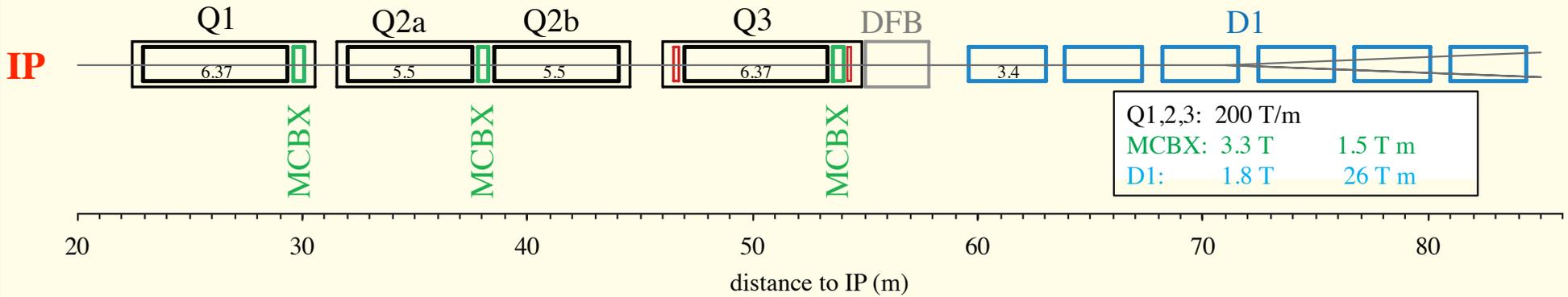
TAS radius increased by nearly 2 × from 17 mm to 30 mm

Idea by CMS A. Ball, W. Zeuer et al. : design an insertable TAS and start the conversion to the new geometry for the TAS already in LS2, see also slide 28

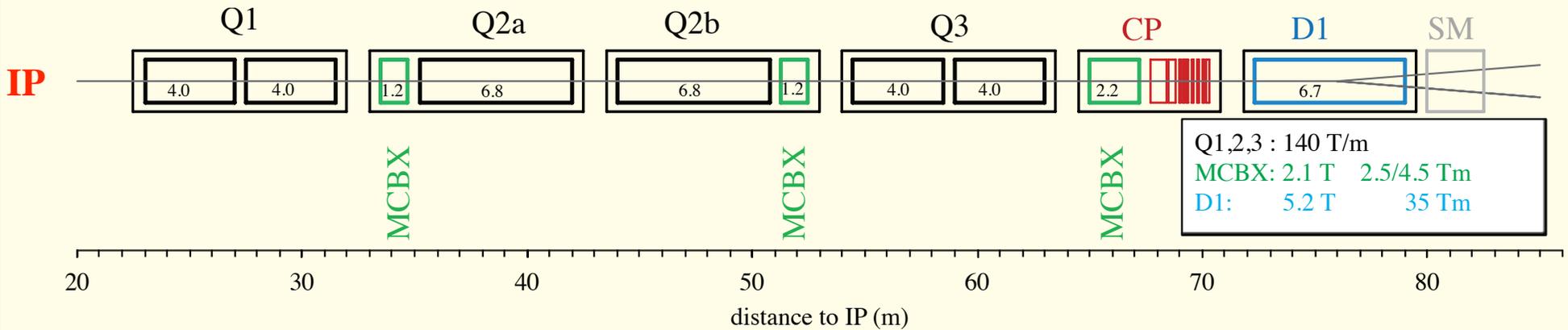


<https://espace.cern.ch/HiLumi/WP3/SitePages/Home.aspx>

present LHC, triplet inner coil diameter 70 mm



HL-LHC, triplet inner coil diameter 150 mm

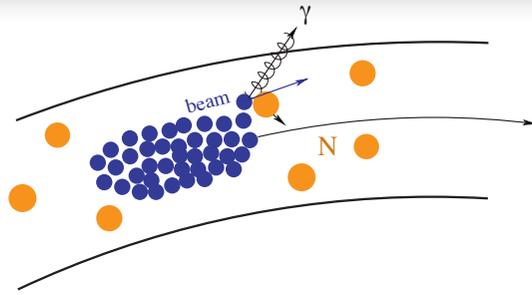


CP corrector package

SM service modules (cables..)

DFB distribution feed box

MCBX orbit correctors, used for crossing angle and parallel separation at IP (inj.)



1. Beam gas scattering on residual gas, always present; pressure and intensity dependent
most relevant: inelastic scattering, straight IR sections + beginning of arcs

2. Halo - losses by slow drift, on primary, secondary, tertiary collimators ; lifetime - collimation dependent

3. Collision related - only there when in collisions

“signal” if originating by collisions at the IP + backscatter and out of time afterglow
 non-colliding isolated bunches required for quantitative monitoring

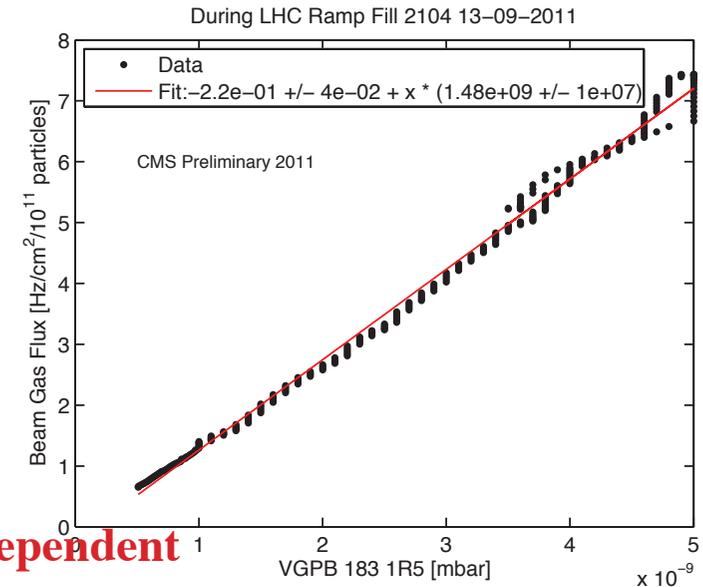
“collision - cross talk” background generated in collisions by other IPs

so far MIB mostly very low, thanks to excellent vacuum (and high pp collision rate)

HL-LHC : higher intensity & less protection for particles moving towards the IP

crucial step : higher energy, transition 50 ns to 25 ns right after LS1

possible issues with electron cloud (scrubbing, coating, bunch schemes with gaps)



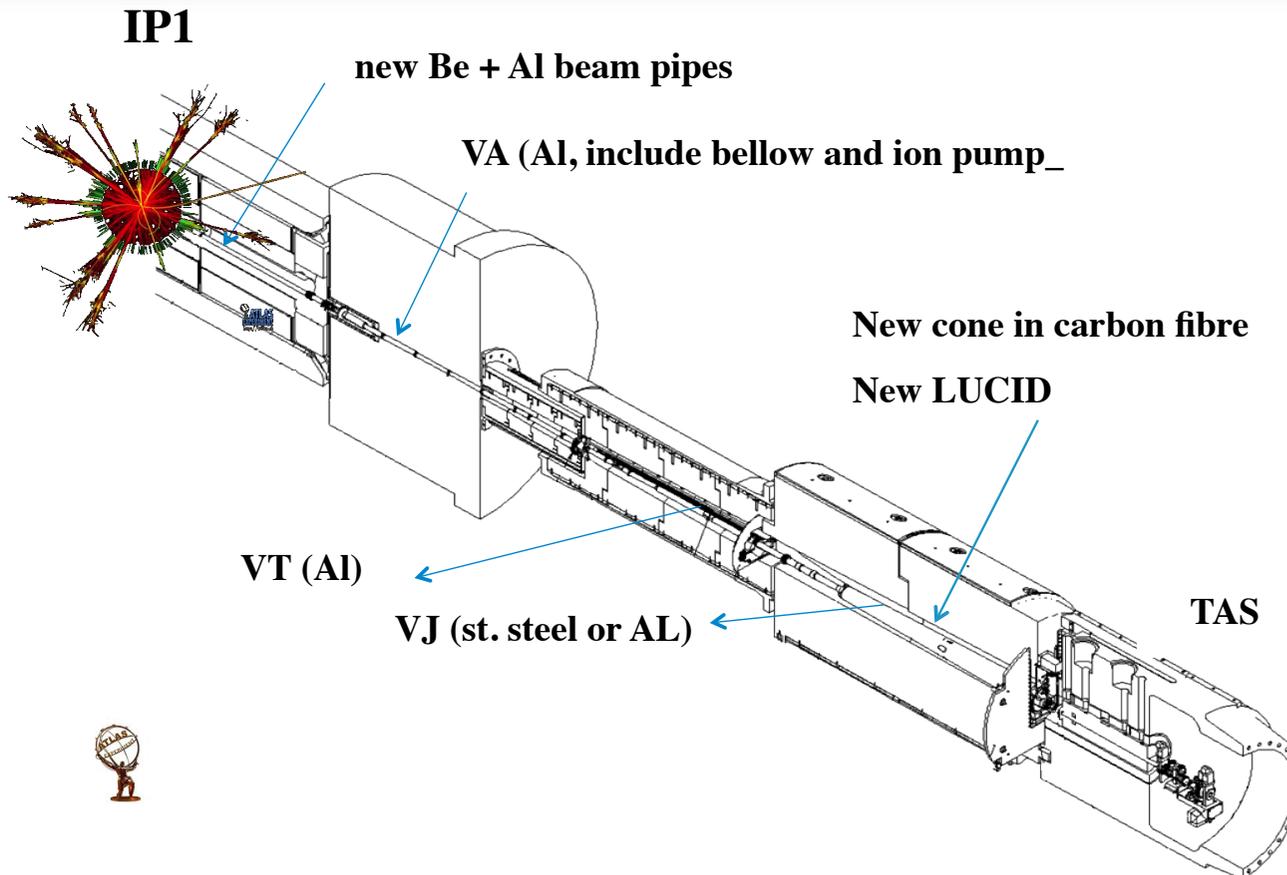


Close collaboration with the experiments in WP8 + LBS

Contact persons for

ATLAS : Beniamino Di Girolamo, Antonello Sbrizzi

CMS : Austin Ball, Anne Dabrowski



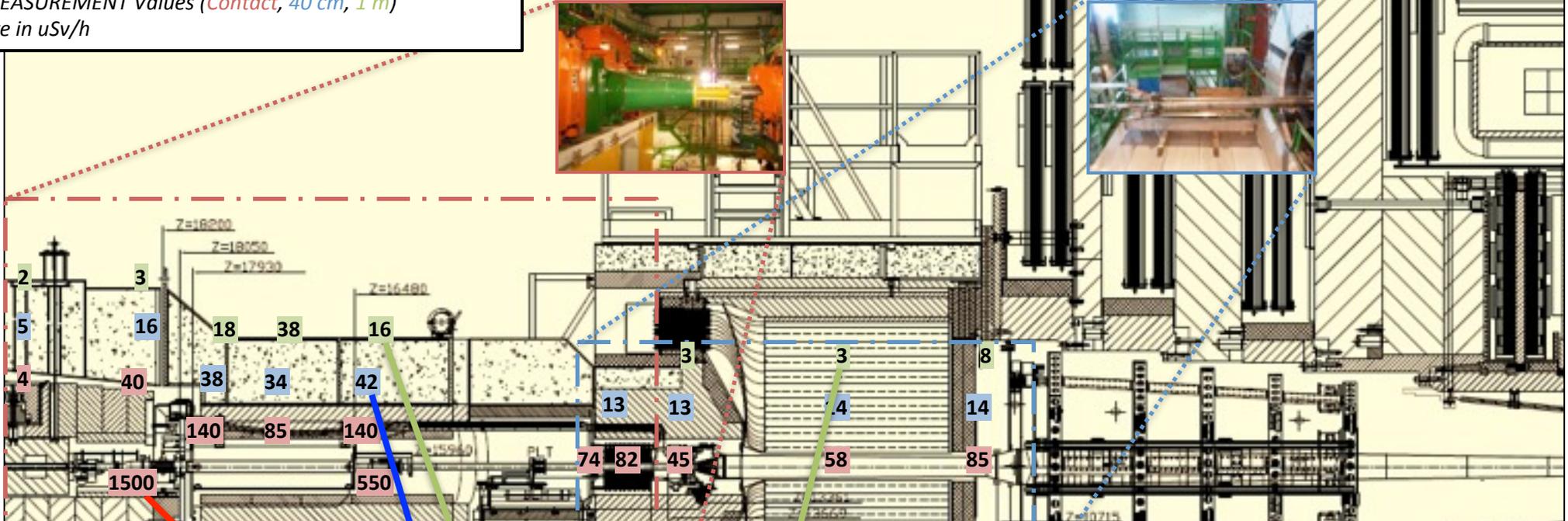
Anne Dabrowski CMS, [LBS#49](#), 21/10/2013

CMS – LS1 Radiation Dose Rate

MEASUREMENT Values (Contact, 40 cm, 1 m)
are in $\mu\text{Sv/h}$

20 Feb 2013 Rotating Shielding Open
DGS/RP + CMS RPE

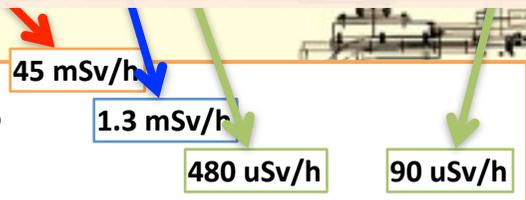
25 Feb 2013 Forward Detector on 2 risers
DGS/RP + CMS RPE



- Planning the intervention in the TAS needs to be done carefully.
- Should ideally happen at the end of LS2 (when activation rates are lower than in LS3)
- Consideration of a 2 volume TAS, with an inner cylinder (core) than can be removed at a later stage (W. Zeuner, A. Ball ECFA workshop)

CMS – LS4 Estimates

About 2 months cooling time
LS1/LS4 Scaling Factor of 30





WP7 - machine protection, Daniel Wollman, Markus Zerlauth, Jörg Wenninger et al.

Active machine protection : beam loss monitoring (BLM) + fast (within 3 turns) beam dump

Already proven to be essential and reliable for the present LHC

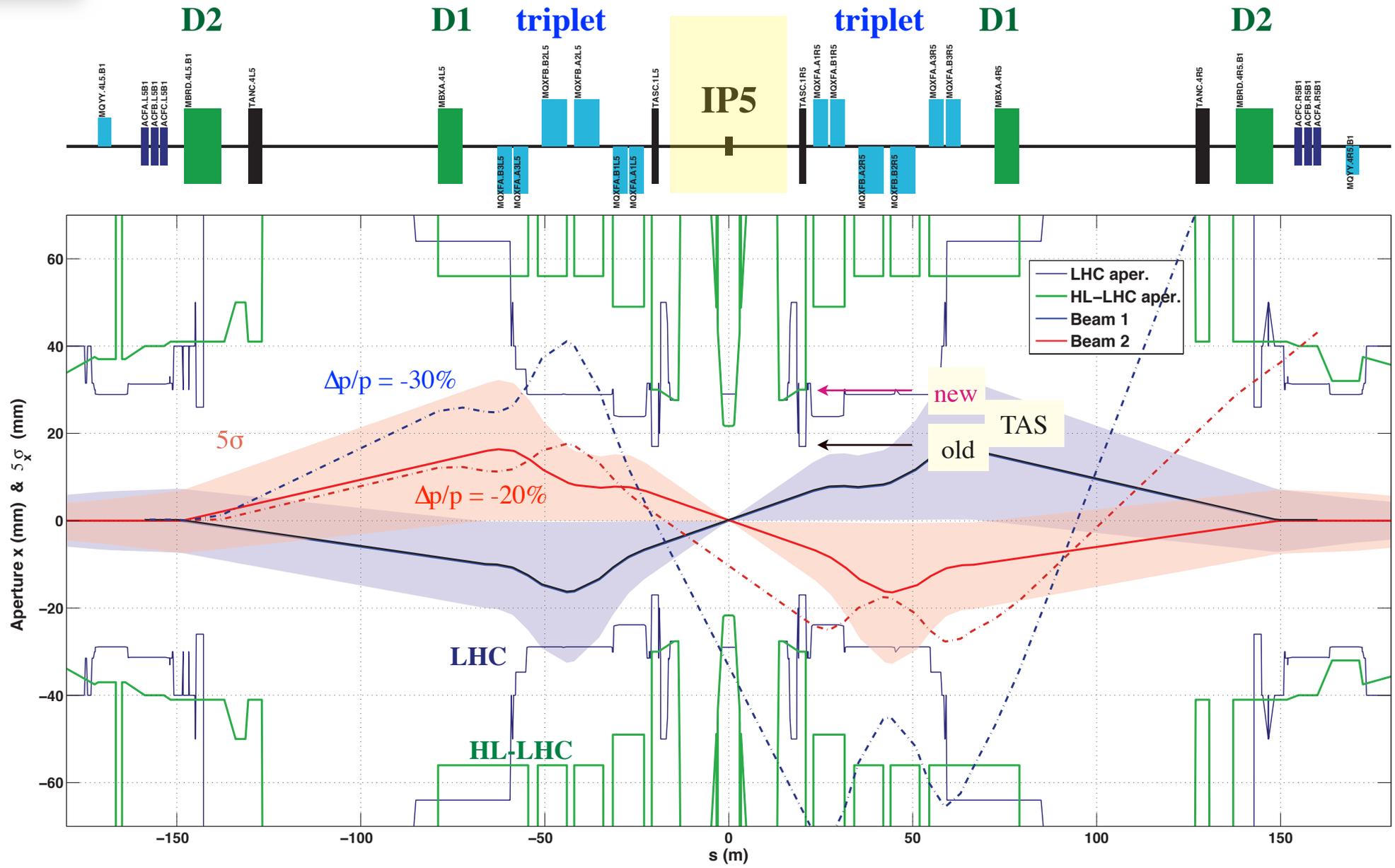
- even more important for the HL-LHC

Most relevant in the context discussed here is top energy, fully squeezed, IP1 + 5

- **Crab cavity failures - detailed simulations started and first results illustrated**
- **Asynchronous beam dump (beam 2 to CMS...)** extend study [L. Lari et al, IPAC13](#) to HL-LHC
- **UFO's or non-conformities (rf-fingers) resulting in showers with local production of off-momentum and neutral particles around the experiments**

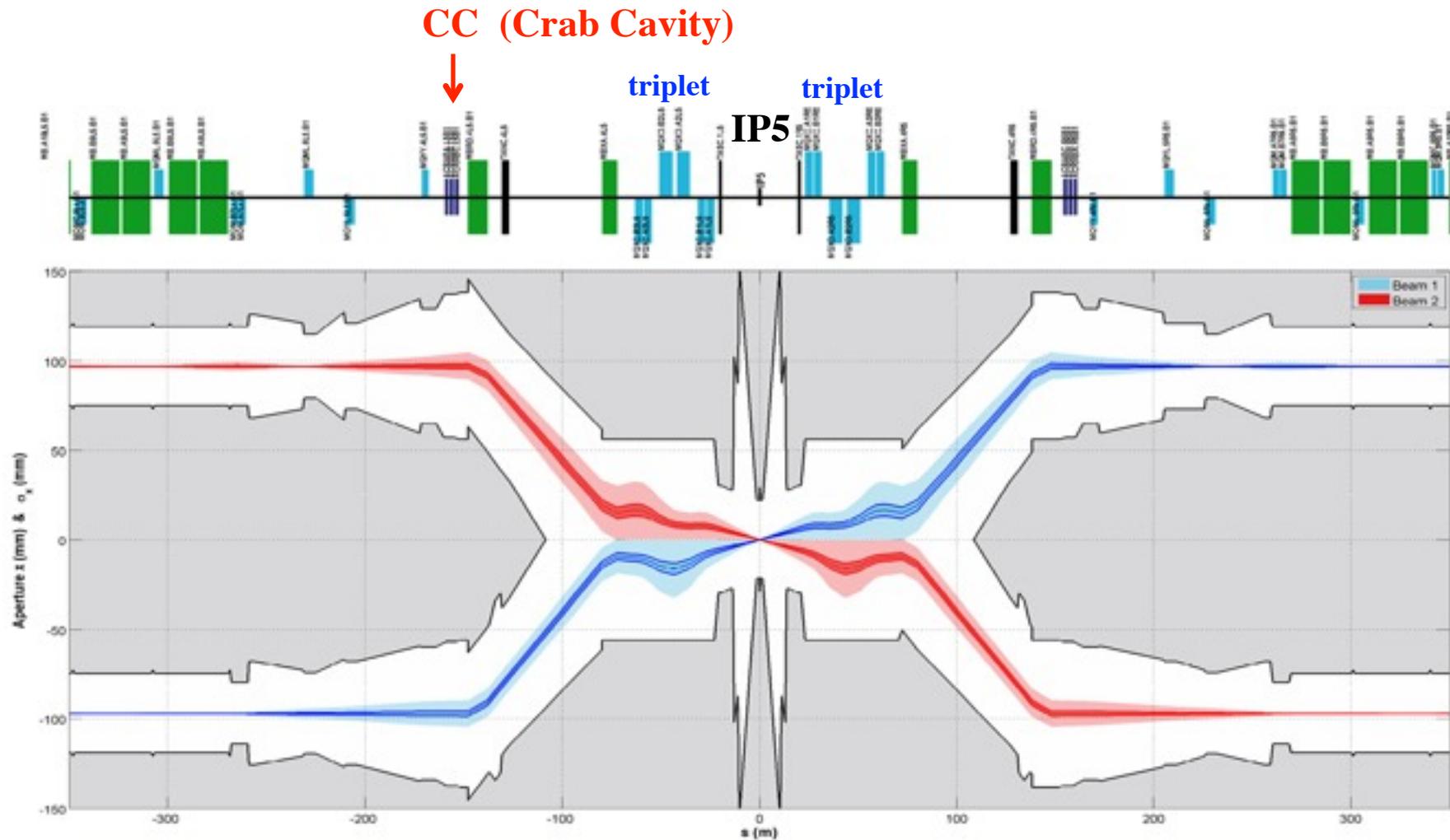
Scenarios which should not become more dangerous, still to be followed up :

- **D1 failures, will be superconducting which leaves more time to dump the beam**
- **Any new equipment, moving objects: it was decided to not use fast vacuum valves around the experiments**
- **+ injection, TDI, IP2 + IP8 ...**





Phase Failure of the first crab cavity at IP5 on the left side (Beam 1)
Failure in 1 turn : the phase of the cavity drops from 0° to 90°

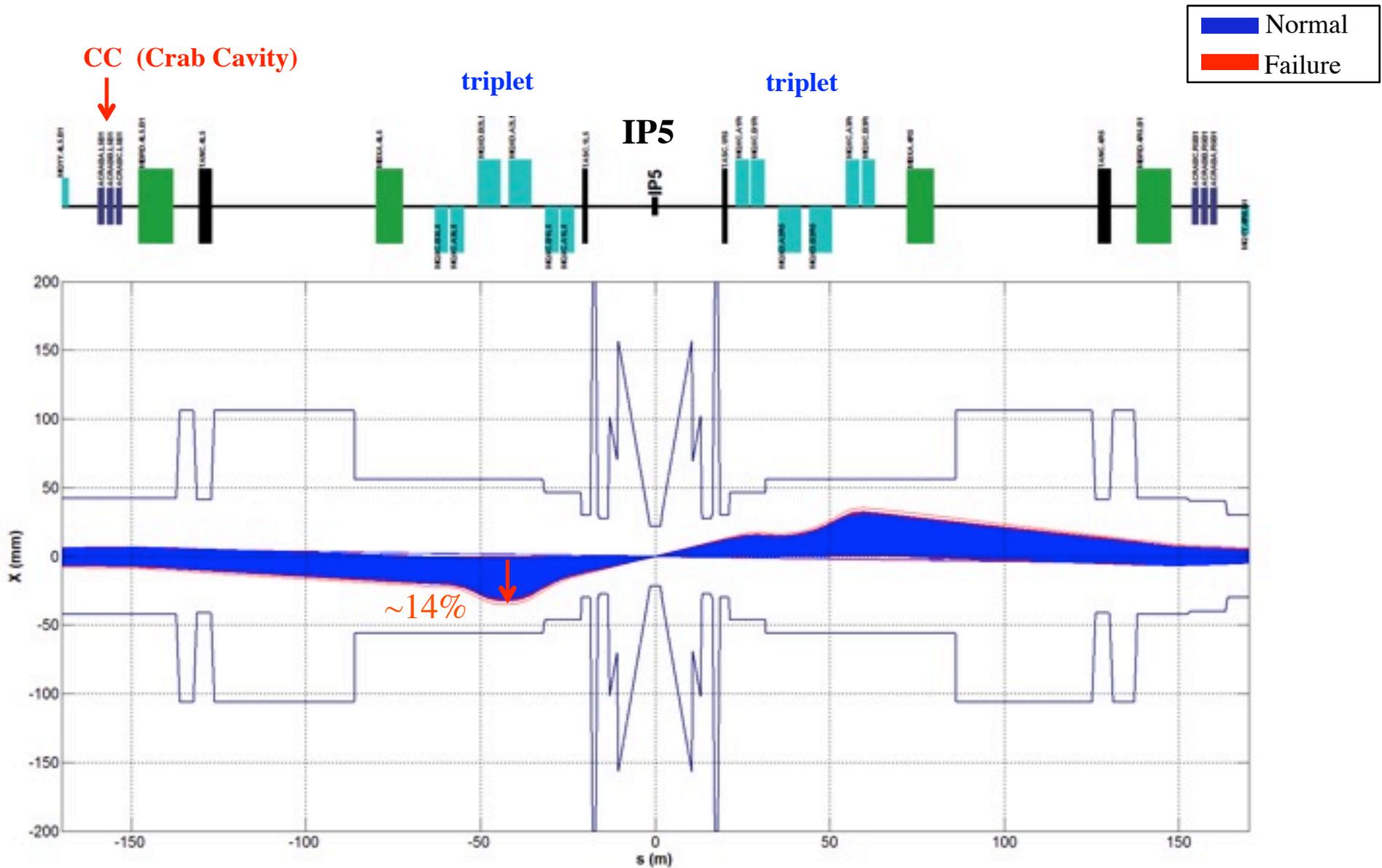


NB : no losses observed for the core distribution - only the results for the halo distribution are presented



5 turns after the failure

Beam 1 IP5 horizontal plane



First results rather encouraging:

fast but still manageable growth times protected by collimator system



**TAN absorber for neutral collision debris (n, γ) in front of D2
in IP1 and IP5** minimal TAN or shielding or TCLs also planned for IP8

LHC \rightarrow HL-LHC, LS3

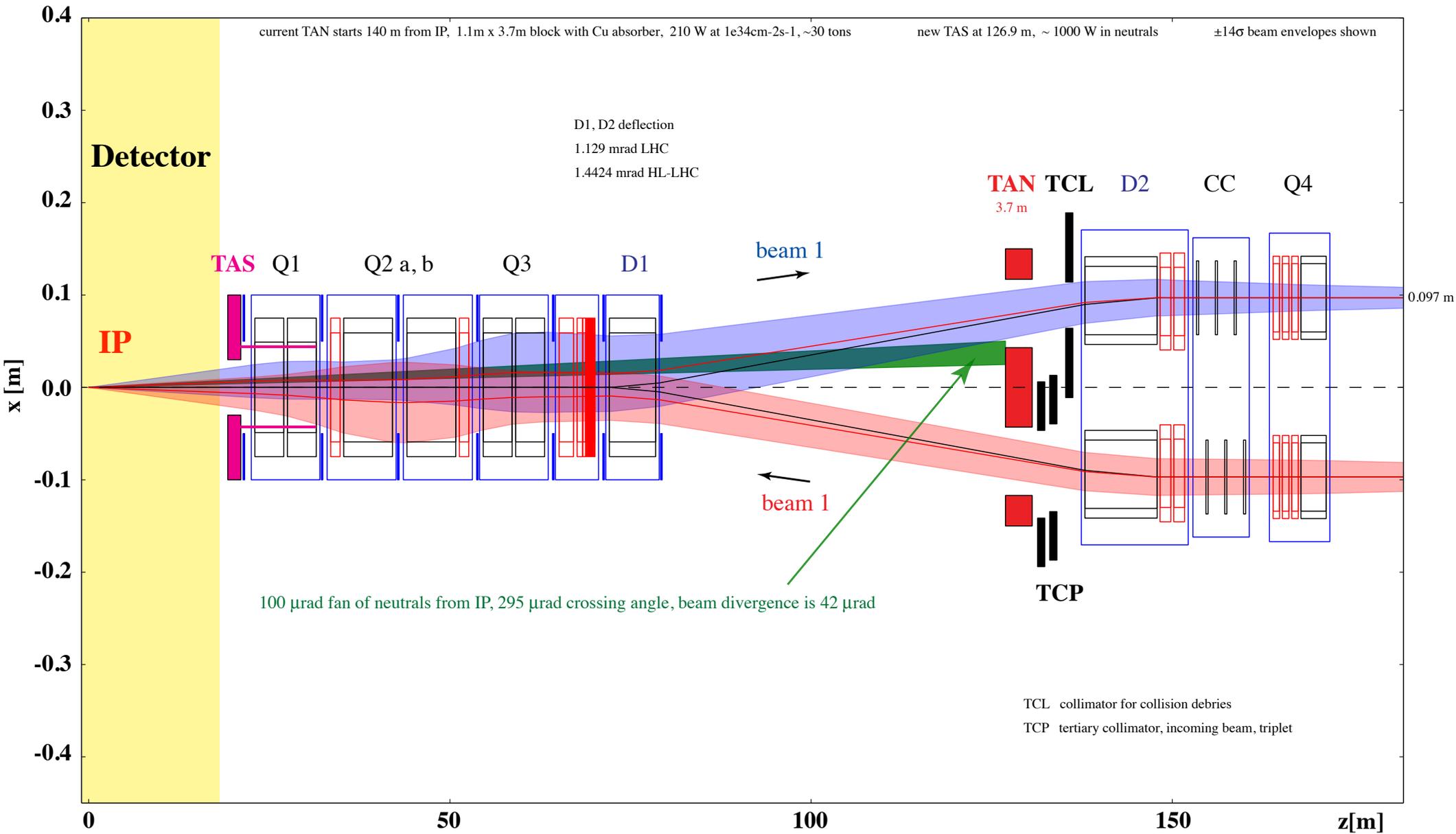
- **changes in geometry, D2 and TAN 13 m closer to IP**
- **2 \times larger crossing angle (142.5 \rightarrow 295 μ rad)**
- **larger beams at TAN (increased β -functions), keep $n1 > 7$**
- **increased energy deposition (200 W \rightarrow 1000 W)**

TAN redesign needed





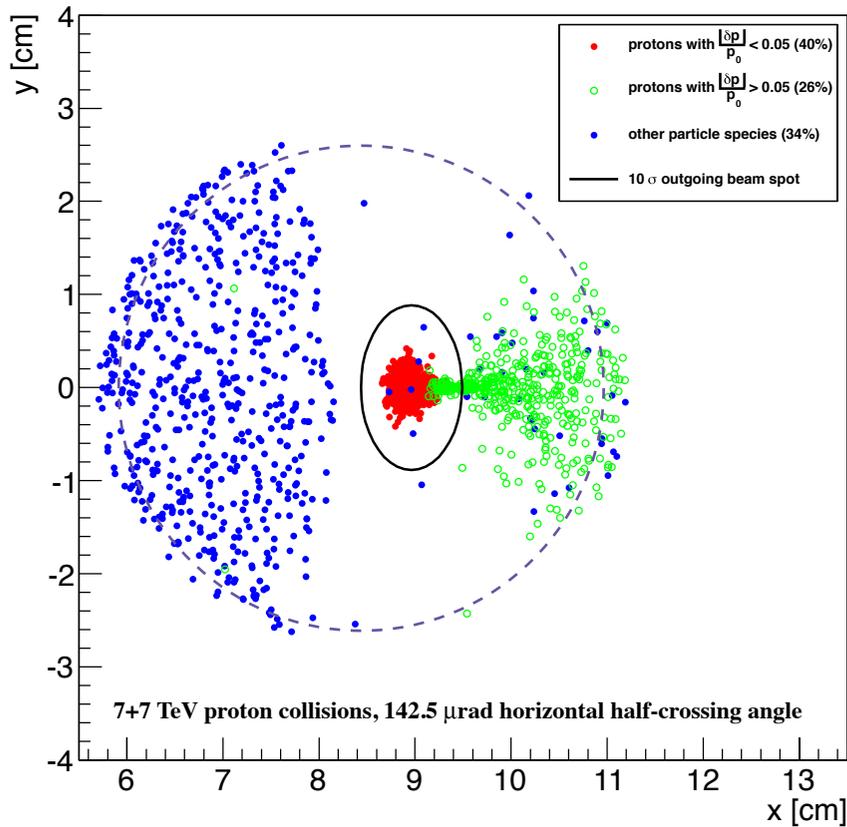
Schematic geometry up to 180 m from IP1, 5



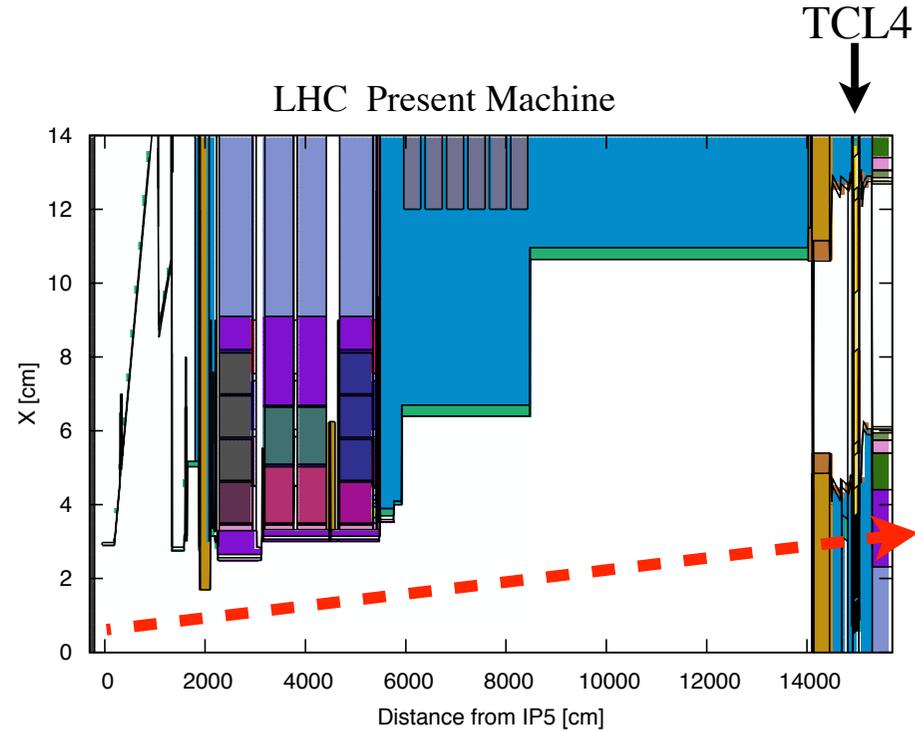


by Francesco Cerutti, Luigi Esposito / WP10, horizontal crossing angle (IP5)

debris distribution at TAN.R5 exit (TCL.4R5 entrance)



0.12 protons/collision (32.3% cleaned)
0.061 others/collision (98.5% cleaned)

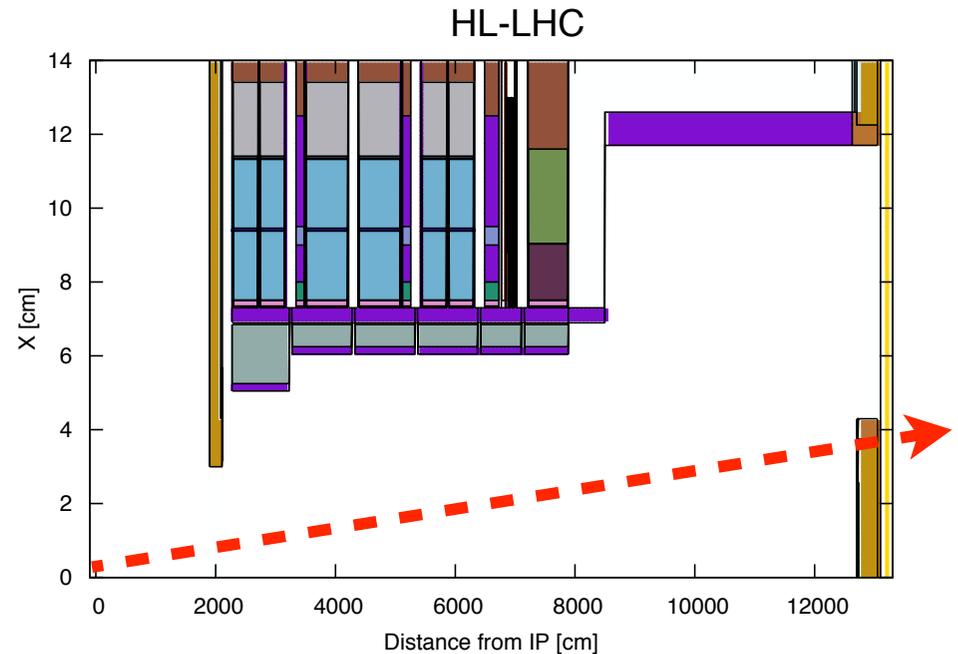
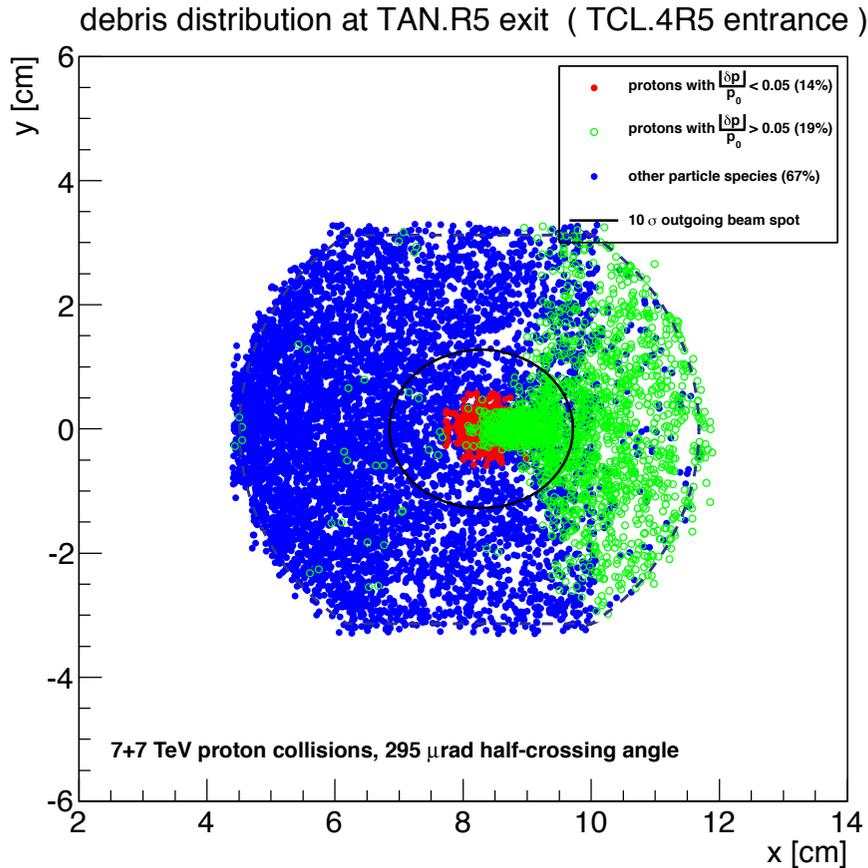


At TAN entrance, the offset due to crossing angle is $\sim 142.5 \mu\text{rad} \times 141 \text{ m} \approx 2.1 \text{ cm}$
 \Rightarrow neutrals flying along the crossing angle well within TAN acceptance

TAN aperture radius 26 mm, sep 160 mm



by Francesco Cerutti, Luigi Esposito / WP10, horizontal crossing angle (IP5)



At TAN entrance, the offset due to crossing angle is $\sim 295 \mu\text{rad} \times 126 \text{ m} \approx 3.7 \text{ cm}$
 \Rightarrow neutrals flying along the crossing angle close to edge of TAN acceptance

TAN aperture rectellipse 37/32 mm, sep 160 mm

0.17 protons/collision (28.4% cleaned*)
 0.35 others /collision (59.2% cleaned*)
 * by a TCL with horizontal aperture at that position

Satisfying all round/flat optics options using our original (generous) tolerances results in a rather large TAN aperture relies on TCL to protect D2 and leaves an increased fraction of collision debris going into Q5, Q6, Q7 matching section and dispersion suppressor -- currently reviewed by WP2, 5, 8, 10



HL-LHC

upgrades in collimation section, reduced noise

IRs : maintain BLMs external to cryostat

add cryogenic BLMs monitors in triplet (6 per magnet) to monitor more directly losses at the coils and be able to dump before quenching

note :

detecting abnormal beam losses close to experiments more difficult in HL-LHC

increased triplet size and increased level of collision debris

crucial for experiments to have their own monitoring/protection, BCMs



Concluding remarks



The LHC already reached close to design luminosity and can soon be expected to go beyond the originally very daring $10^{34} \text{ cm}^{-2}\text{s}^{-1}$ (pushed up from $1.e33$ to $1.e34$ by C. Rubbia to compete with SSC)

Towards the end of this decade we will reach rather hard limits in terms of radiation lifetime and cryogenics and would anyway have to rebuild the insertions to continue

After continued R&D, the HL-LHC has just started this month as a real project, aiming at 10 fold increase in integrated luminosity assuring the role of the LHC as flag-ship HEP machine until at least 2030

**Many interesting challenges, both on the machine and experiments side
(as we will see in the next talks)**

Reserve



High Luminosity LHC Project



PROJECT COORDINATION OFFICE

Project Coordinator: Lucio Rossi, CERN

Deputy Project Coordinator: Oliver Brüning, CERN

Technical Coordinator: Isabel Bejar Alonso, CERN

Project Safety Officer: Thomas Otto, CERN

Budget & Resource Management : Dorothee Duret, CERN

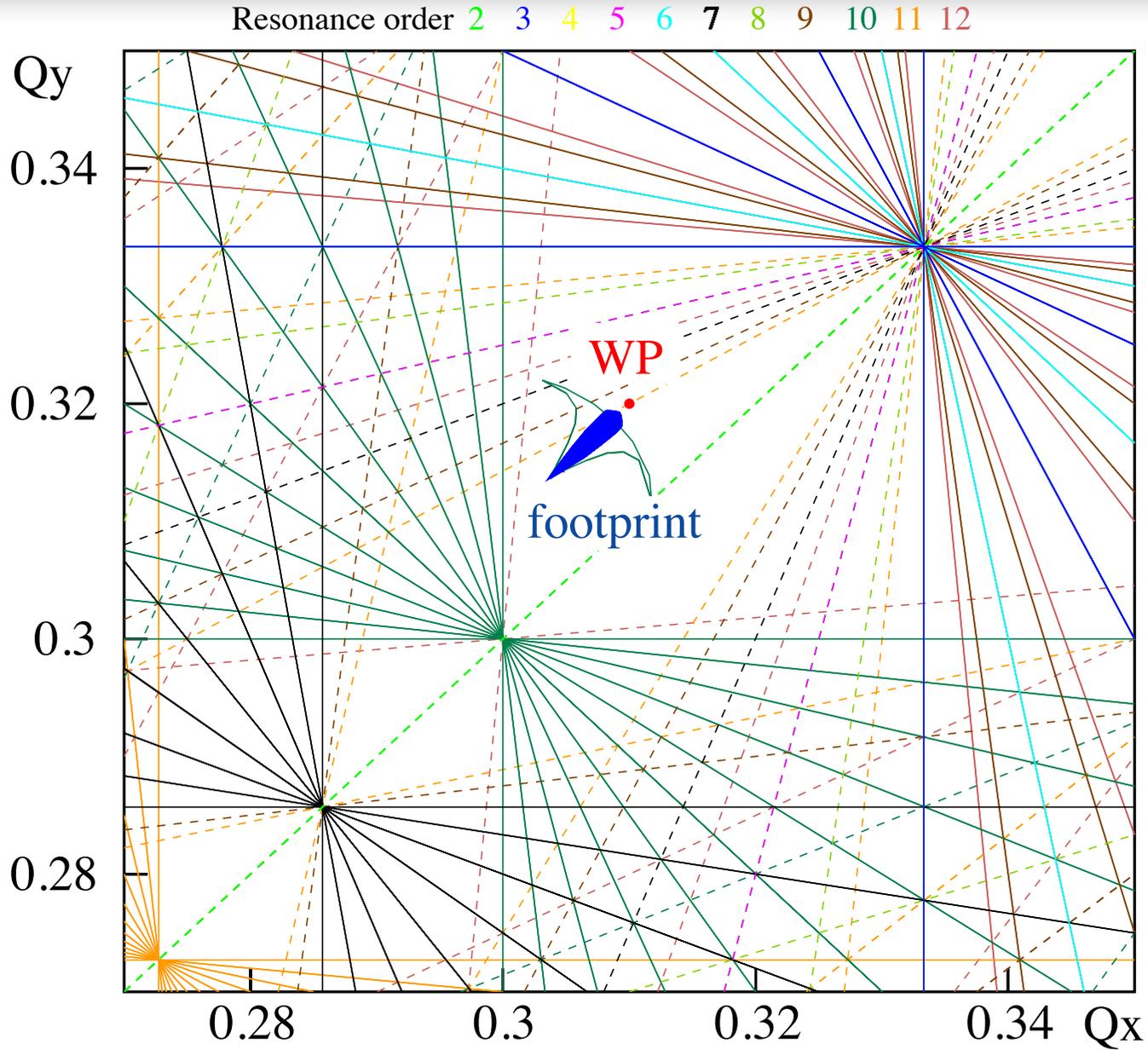
FP7 HiLumi LHC Administrative Manager: Svetlomir Stavrev, CERN

Dissimination & Outreach : Agnes Szeberenyi, CERN

Administrative Support: Cecile Noels & Julia Double, CERN



LHC tune working point



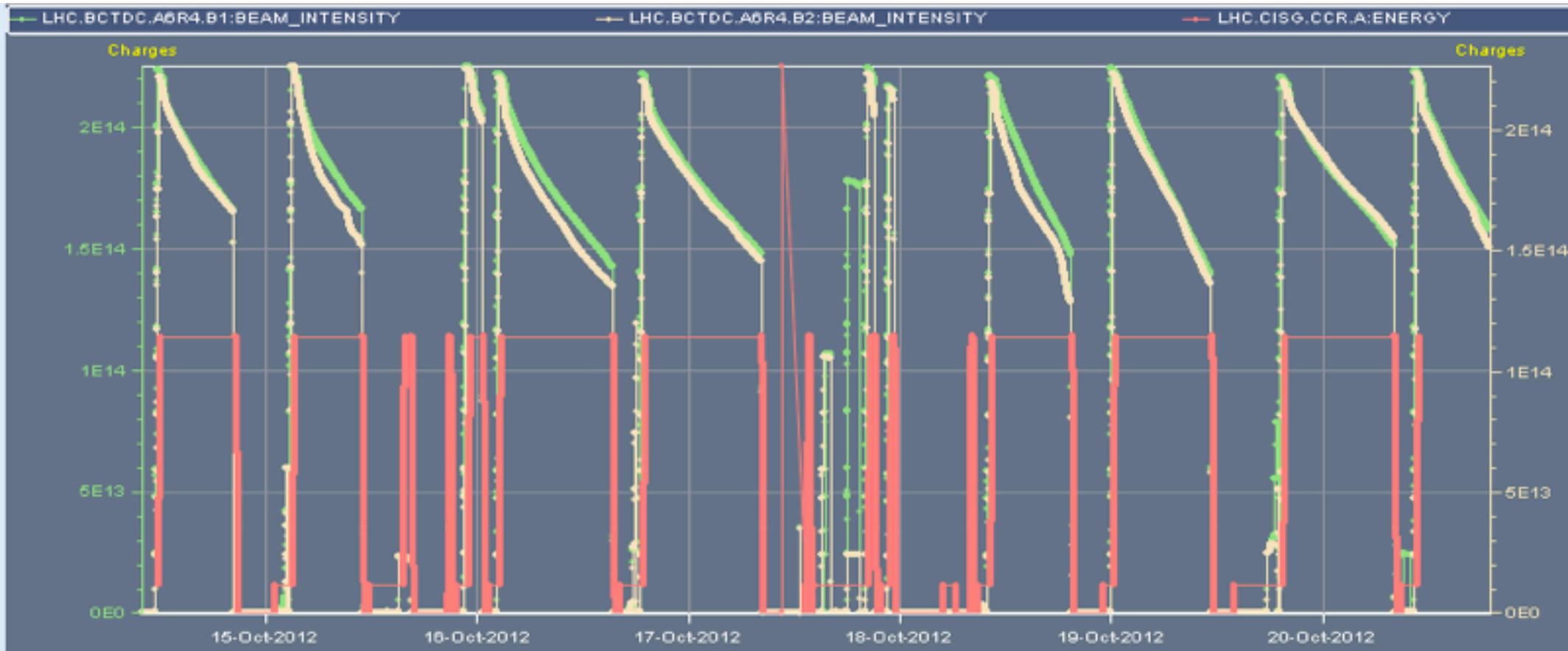
Beam-beam tune spread "footprint" of the LHC in the tune diagram.

Resonances up to 12th order are shown.

Sum resonances are shown with solid lines and difference resonances as dashed lines



Current LHC, Oct. 2012, 1.2 pb⁻¹





High Luminosity LHC Project, Work Packages



WP
Coordinators
Co-coordinators

WP1 Project Management

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Oliver Brüning, CERN

WP7 Machine Protection

Daniel Wollmann, CERN
Jörg Wenninger, CERN

WP13 Beam Diagnostics

Rhodri Jones, CERN
Hermann Schmickler, CERN

WP2 Accelerator Physics

Gianluigi Arduini, CERN
Andy Wolski, UNILIV

WP8 Machine Protection

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A.Ball (CMS), **B. di Girolamo** (ATLAS)

WP14 Beam Transfer

Jan Uythoven, CERN
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WP3 Magnets

Ezio Todesco, CERN
Gianluca Sabbi, LBNL

WP9 Cryogenics

Laurent Taviani, CERN
Rob Van Weelden, CERN

WP15 Integration

Sylvain Weisz, CERN
Paolo Fessia, CERN

WP4 Crab Cav. and RF

Erk Jensen, CERN
Graeme Burt, ULANC

WP10 Energy deposition

Francesco Cerutti, CERN
Nikolai Mokhov, FNAL

WP16 Hardware Commissioning

Mirko Pojer, CERN

WP5 Collimation

Stefano Redaelli, CERN
Robert Appleby, UNIMAN

WP11 11T Dipole

Mikko Karppinen, CERN
Alexander Zlobin, FNAL

WP18 High Field Magnets, R&D

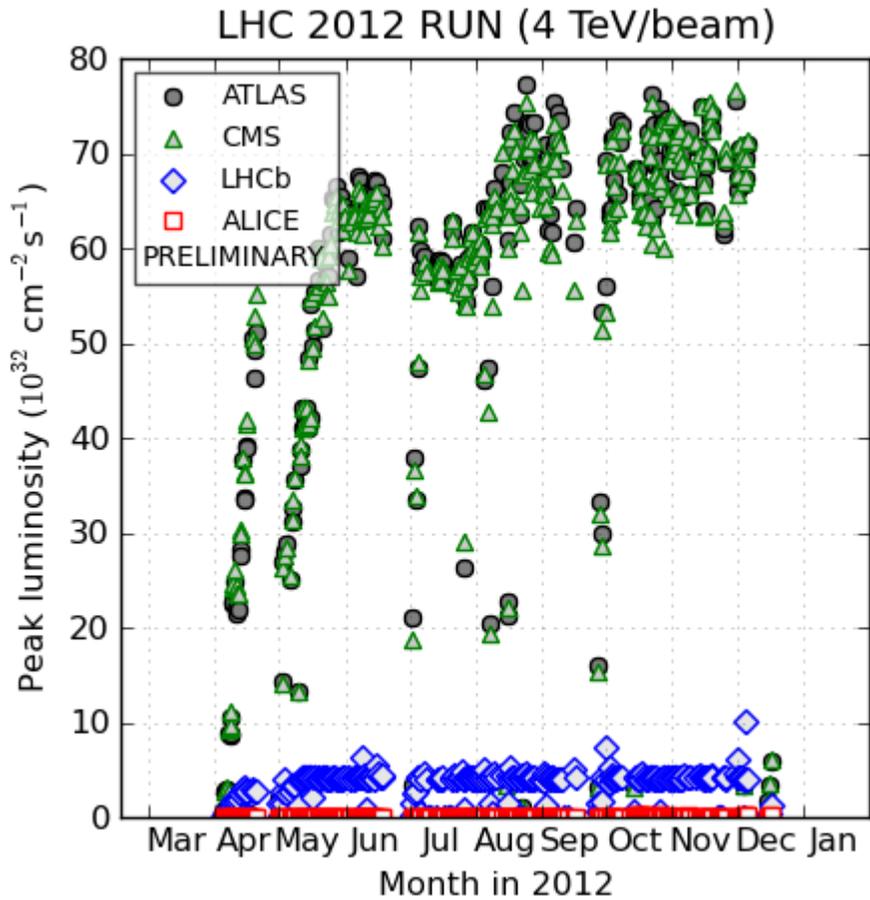
Gijs de Rijk, CERN
François Kircher, CEA

WP6 Cold Powering

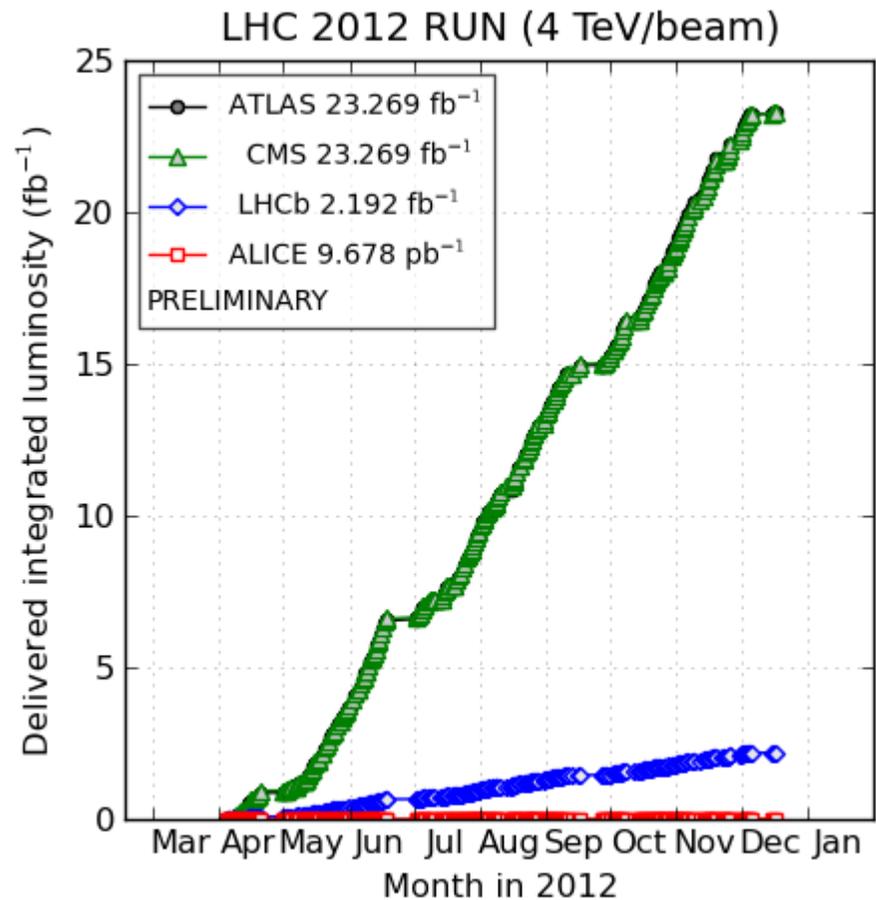
Amalia Ballarino, CERN
Francesco Broggi, INFN

WP11 Vacuum

Roberto Kersevan, CERN
Mark Gallilee, CERN



(generated 2013-01-29 18:28 including fill 3453)



(generated 2013-01-29 18:28 including fill 3453)

ALICE: 9.96 pb^{-1} ATLAS: 23.27 fb^{-1} CMS: 23.27 fb^{-1} LHCb: 2.19 fb^{-1}