



CHIPP Board Meeting
Sursee June 25th to 26th, 2013



Swiss involvement / contribution to LHC machine

T. Pieloni
(CERN Accelerator Physics Group)
on behalf of the
EPFL Laboratory of Particle Accelerator Physics

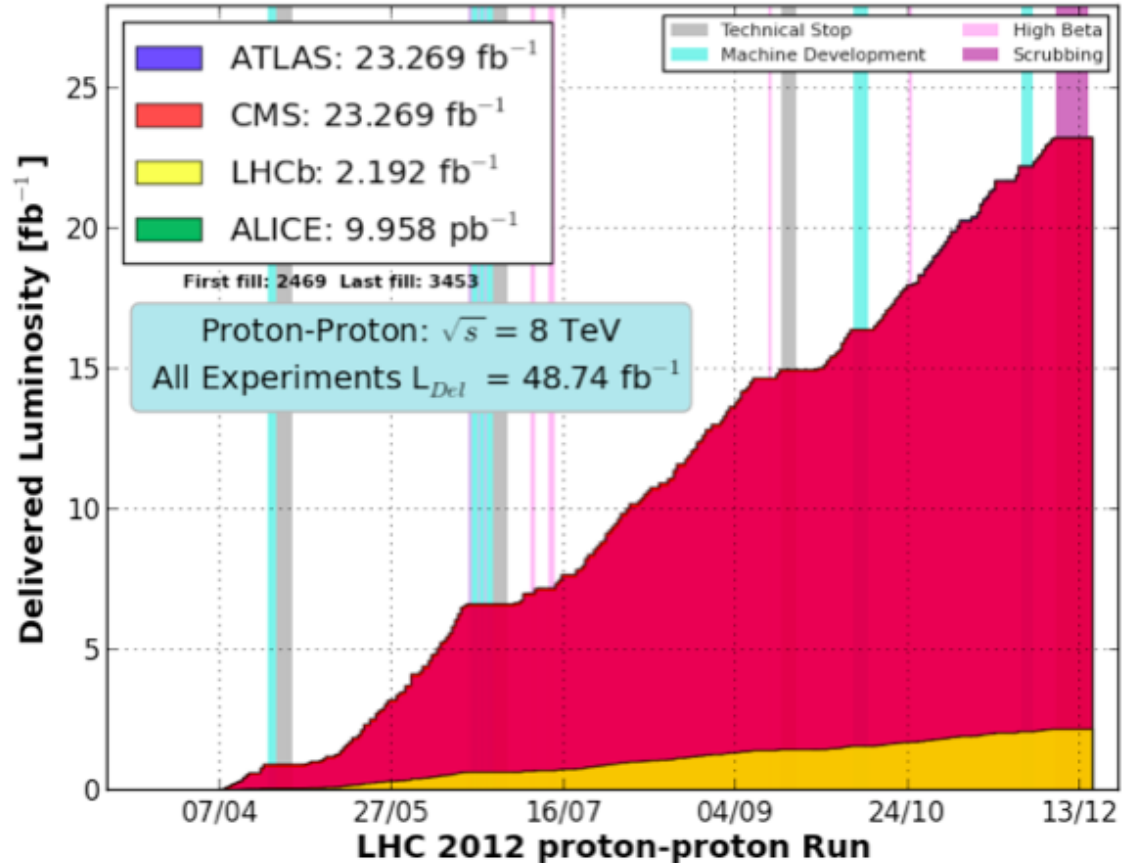


LHC Machine Performances



LHC Performance summary

Parameter	2010	2011	2012	Nominal
$N_p(10^{11} \text{ p/b})$	1.2	1.45	1.58	1.15
N_b	368	1380	1380	2808
Spacing (ns)	150	75/50	50	25
ϵ (μmrad)	2.4-4	1.9-2.4	2.2-2.5	3.75
β^* (m)	3.5	1.5-1	0.6	0.55
L ($10^{32} \text{ cm}^2 \text{ s}^{-1}$)	2	35	76	100



Courtesy A. Macpherson

Impressive performances, already at 70% designed luminosity!

High-lights on Swiss contributions to the LHC:

- LHC Contribution
 - Collimation (classical and bent crystal concept)
 - Impedance studies
 - Beam-beam interactions
 - Electron cloud effects
 - Leveling luminosity and stability issues
 - Energy deposition studies
 - Magnet design
 - Injectors studies
- HL-LHC contribution
 - Optics studies/solutions
 - Beam-beam interactions
 - Crab-cavities and colliding beams
- Computer facilities

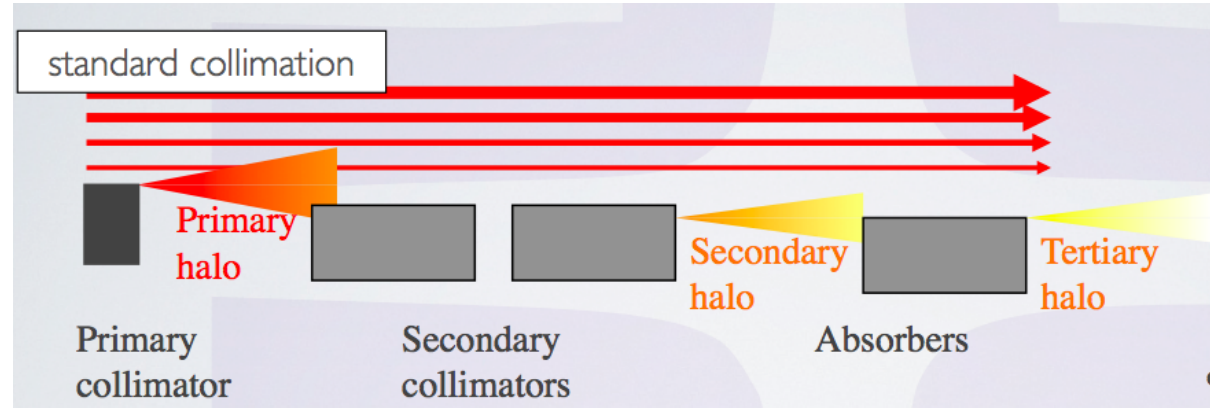
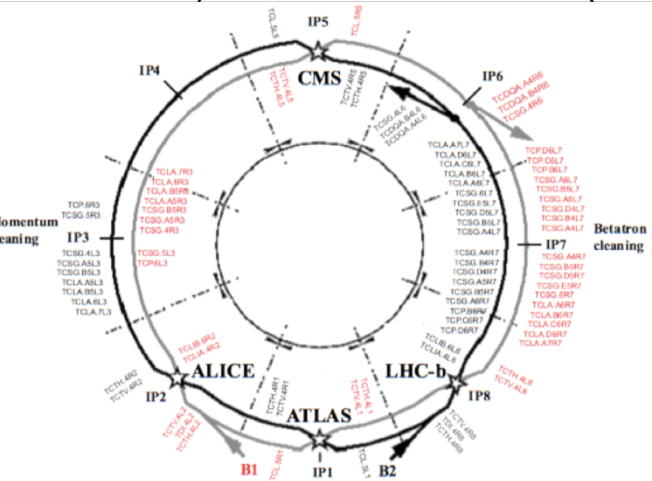
LHC collimation system



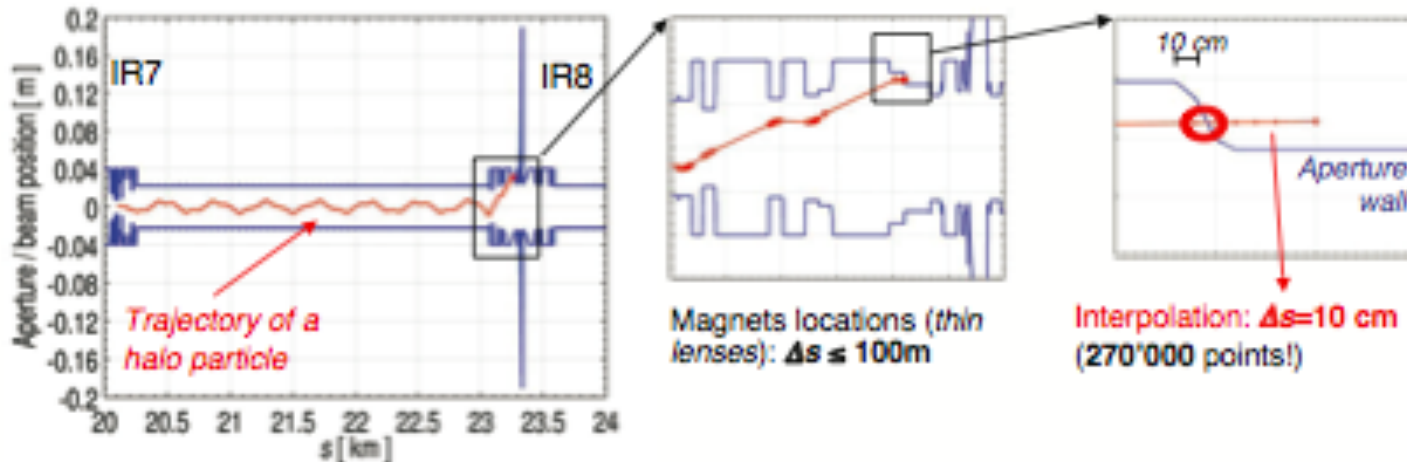
Losses on superconducting magnets unwanted: can provoke a quench
 System efficiency has to be better than 99.998% to avoid it!

Commissioning scenarios and tests for the LHC collimation system

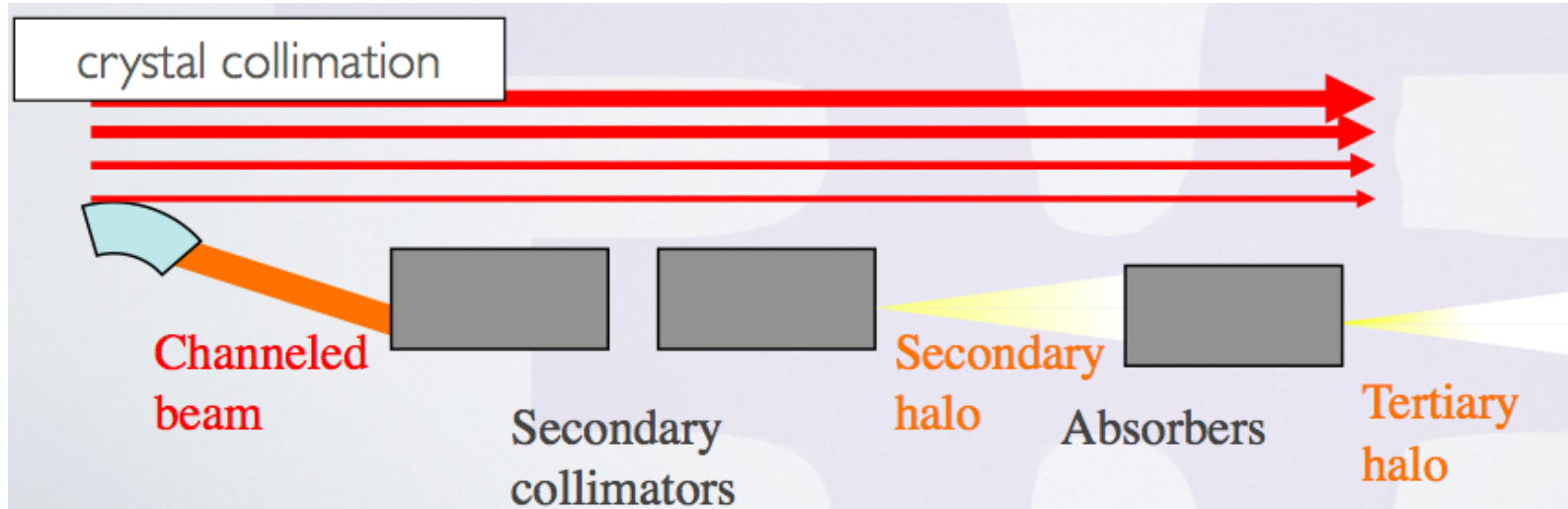
C. Bracco, EPFL PhD thesis n° 4271 (2009)



Studies of loss maps to optimize the system performances



LHC crystal collimation



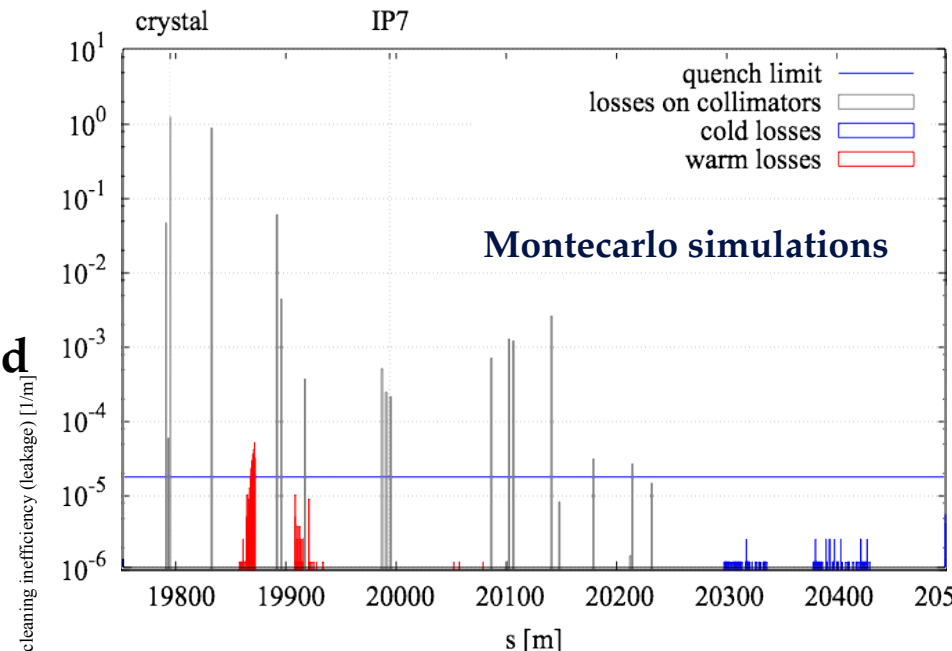
Use a bent crystal to drive the beam halo deep into a secondary collimator/absorber

- Collimation efficiency improved by factor 15
- “Standard” Collimators can be retracted

Performance evaluation of a crystal-enhanced collimation system for the LHC

V. Previtali, EPFL PhD thesis n° 4794 (2010)

P. J. Schoofs, EPFL PhD student



Beam Impedance:

traveling charges produce EM fields then scattered/reflected, depending on geometry and conductivity, by the surroundings. This acting back to beams can excite instabilities



The LHC Transverse Coupled-bunch Instability

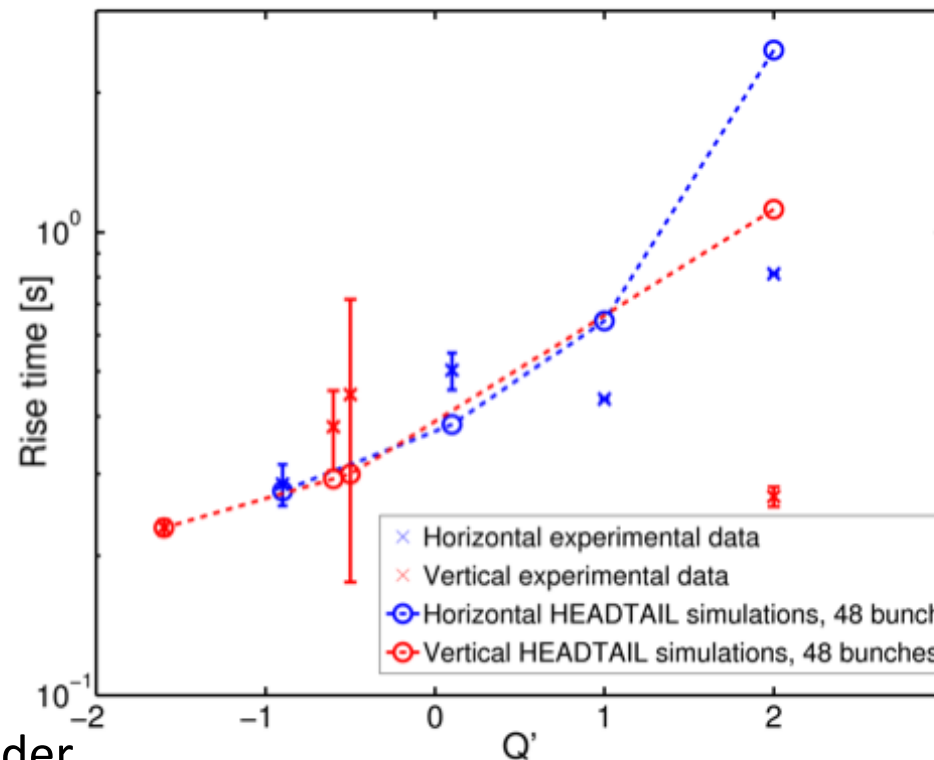
N. Mounet, EPFL PhD thesis n° 5305 (2012)

Low frequency transverse impedance of LHC collimator jaws

B. Salvant, EPFL PhD thesis n° 4585 (2010)

LHC transverse impedance is dominated by the collimators contribution.

Defines beam intensity limits



Impedance defines intensity limits of the collider.

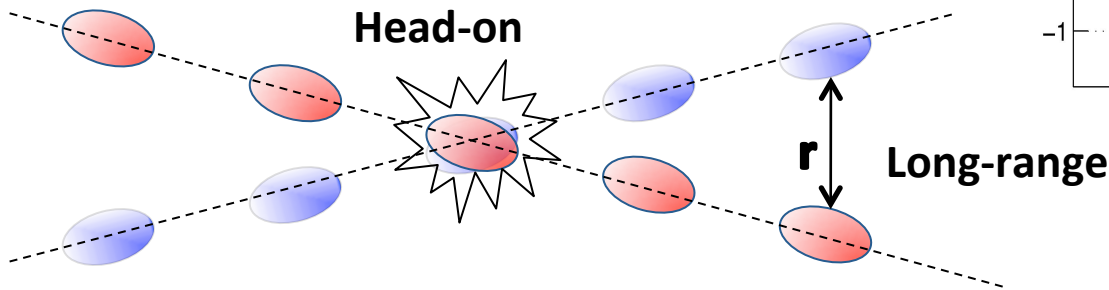
Drives transverse and/or longitudinal beam instabilities

Beam-beam interactions: EM interactions of beams when sharing a common beam pipe (Interaction regions)

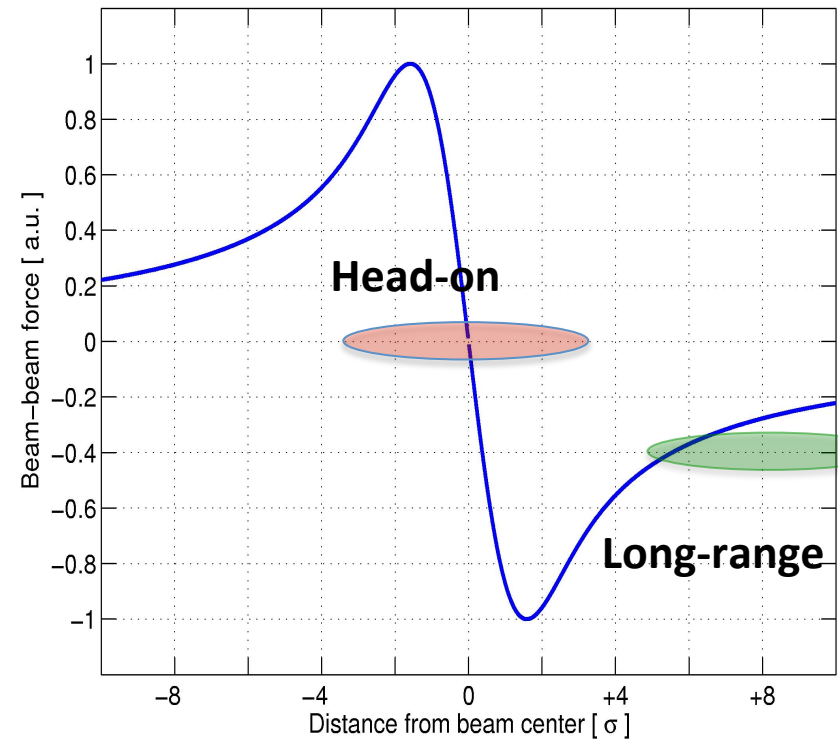
Unfortunately during a beam crossing most of the particles ... 99.999% (or more) are just distorted!

$$L \propto \frac{N_p^2}{\sigma_x \sigma_y} \cdot n_b \cdot f_{rev}$$

$$\xi_{x,y} = \frac{N r_0 \beta_{x,y}^*}{2\pi \gamma \sigma_{x,y} (\sigma_x + \sigma_y)}$$



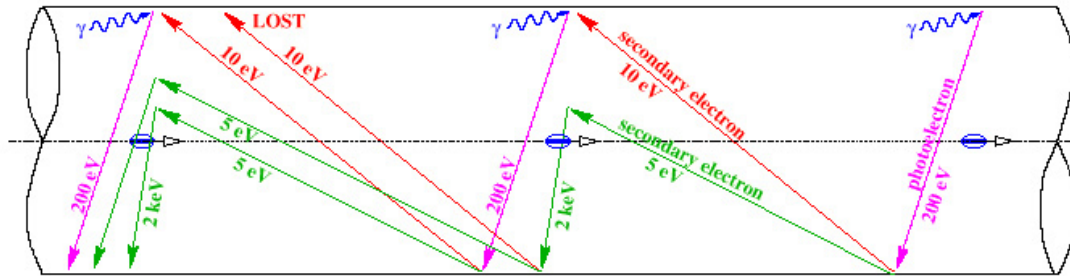
Strongest non-linearity



- 3 head-on collisions
- 120 long-range interactions

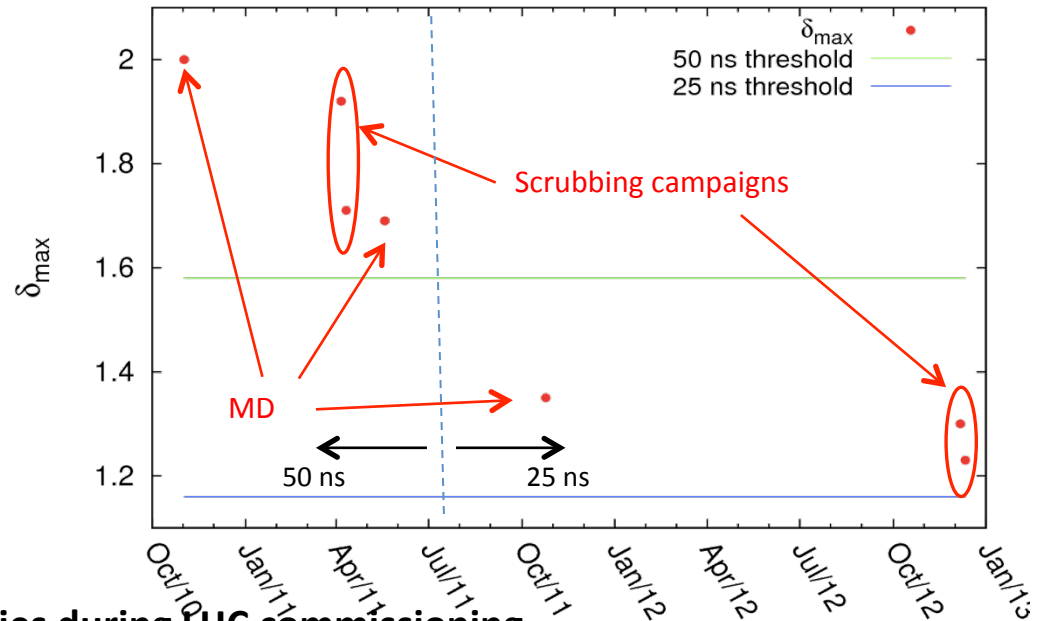
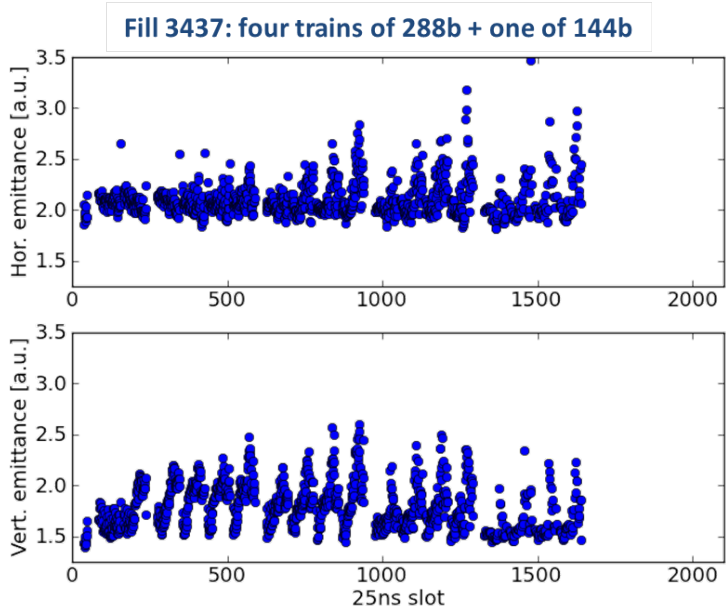
A Study of Beam-beam effects in hadron Colliders with a Large Number of Bunches

e^- cloud: limits the 25 ns operation



F. Ruggiero

2012 experiments to evaluate the scrubbing process in the LHC straight sections:
reduce the secondary emission yield to avoid build-up of electrons



E-cloud studies during LHC commissioning
 O. Dominguez Sanchez de la Blanca, EPFL PhD student

Electron-cloud will determine the future runs conditions 25 ns or 50 ns!

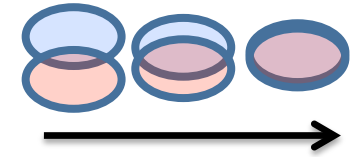
Beams Stability and Luminosity Levelling

New issues for accelerator physics from the LHC:

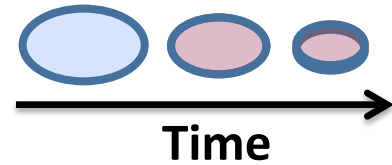
- **too High LUMINOSITY**
- **instability due to very high brightness beams (coherent instabilities present in most of the fills causing emittance growths & beam damps)**

Study of luminosity levelling scenarios for LHC and HiLumi LHC to guarantee beam stability (use beam-beam head-on Landau damping to avoid coherent instabilities)

Level with transverse offset



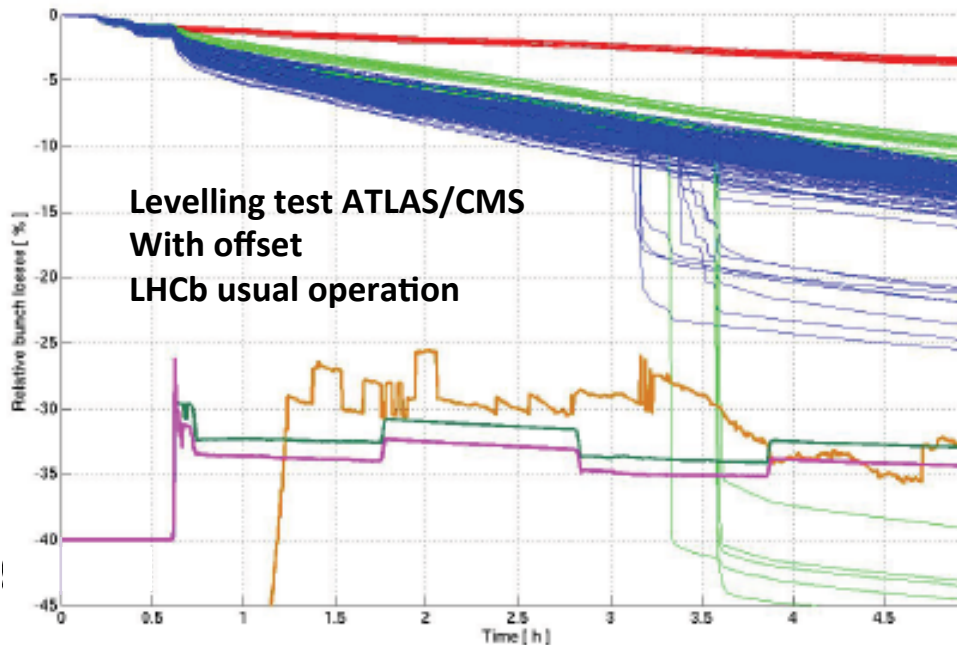
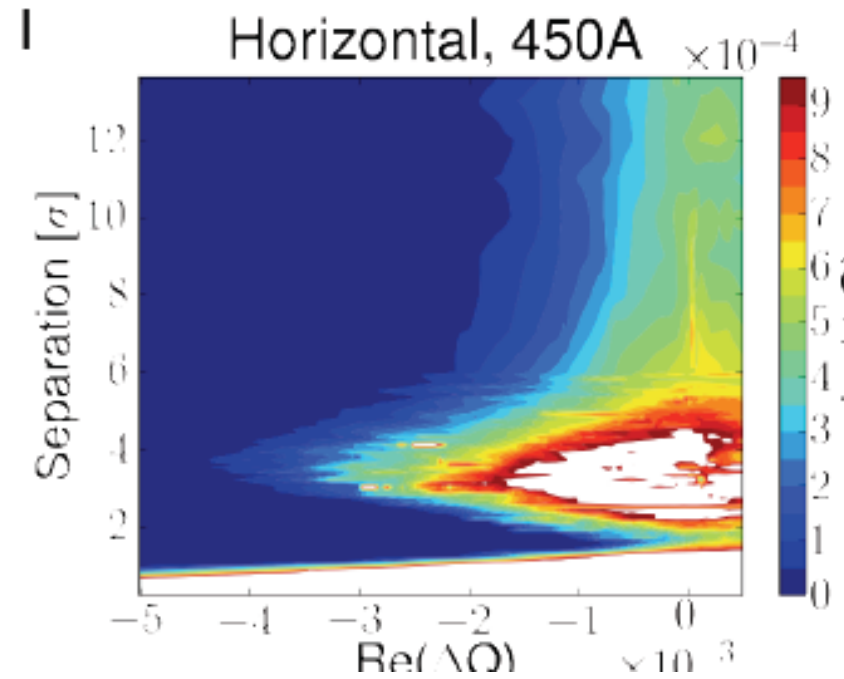
Level with transverse offset



Time

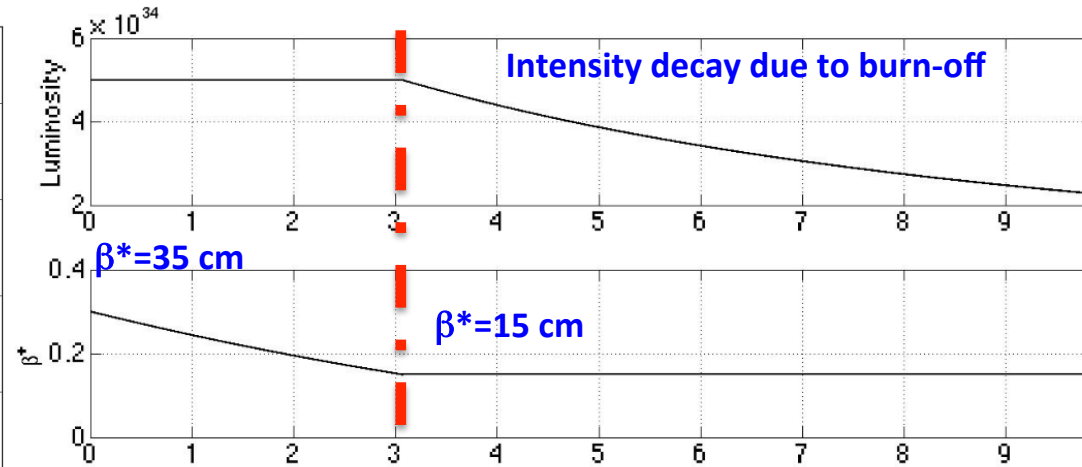
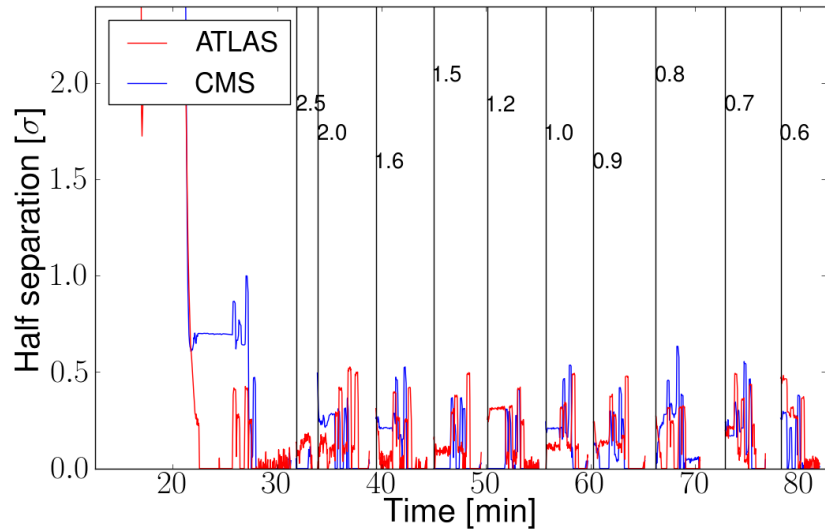
Stability of colliding Beams

X. Buffat, EPFL PhD student



β^* leveling and collide&squeeze for stability!

CERN-ATS-Note-2012-071 MD X. Buffat, W. Herr, T. Pieloni, S. Redaelli J. Wenninger



Example Lumi-leveling by β^* for HL-LHC scenario

Example of orbit offsets at β^* steps, LHC MD

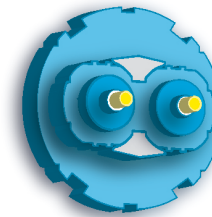
- a) Single bunch test
- b) Orbit reproducibility: 20 days later verification single bunches
- c) β^* and long-range: repeat above with 1 train of 48 bunches
- d) $\beta^* 9 \text{ m} \rightarrow 0.6 \text{ m}$: cover the full range

Development of an operational beta-star leveling scheme for the LHC

A. Gorzawski, EPFL PhD student



HiLumi LHC



High Luminosity LHC

Accelerator Physics - WP2

Objectives

Task 2.1. Coordination and Communication

- Coordinate and schedule work package tasks
- Monitor work progress and inform the project management and work package participants
- Manage the WP budget and use of resources
- Prepare internal and deliverable reports

Task 2.2. Optics and Layout

- Identify layout options for the Interaction Region (IR) upgrades.
- Identify optics solutions for the LHC upgrade.

Task 2.3. Particle Simulations

- Determine field quality tolerances for new magnetic elements for the LHC upgrade.
- Specify tolerances of the correction circuit settings.
- Evaluate the dynamic aperture.

Task 2.4. Intensity Limitations

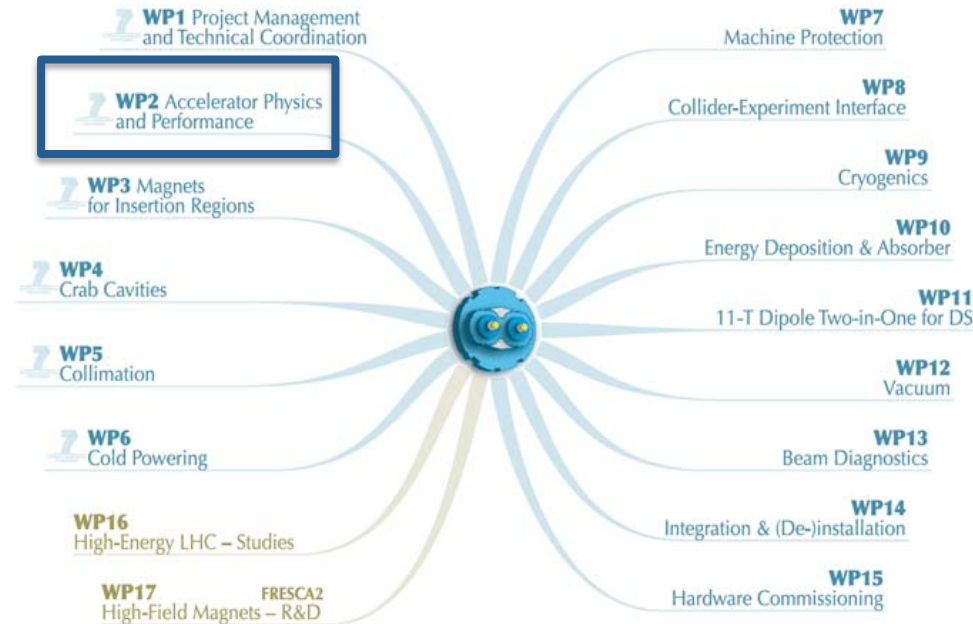
- Specify limits for maximum acceptable impedance of new components, and electron intensity limitations due to the machine impedance.
- Estimate impact of electron cloud effects.
- Estimate emittance growth rates from intrabeam scattering.

Task 2.5. Beam-Beam Effects

- Evaluate beam-beam effects for the LHC upgrade and identify minimum requirements for the beam separations in the Interaction Regions.
- Evaluate the limitations imposed by beam-beam interactions.

Task 2.6. Beam Parameter and Luminosity Optimization

- Identify relevant experience from LHC commissioning and operation.
- Determine optimum sets of machine and beam parameters based on the outcomes of Tasks 2.2, 2.3, 2.4 and 2.5, and the operational experience of the LHC.



ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

First involvements in LHC Upgrades before HiLumi-Project

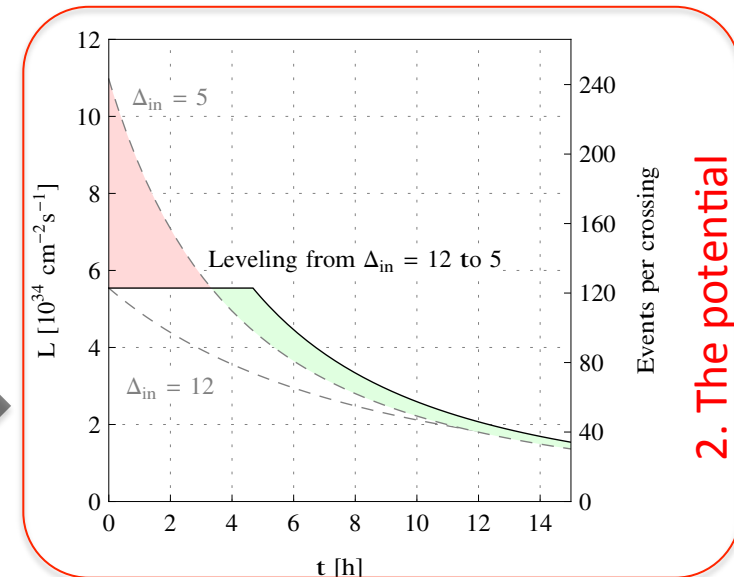
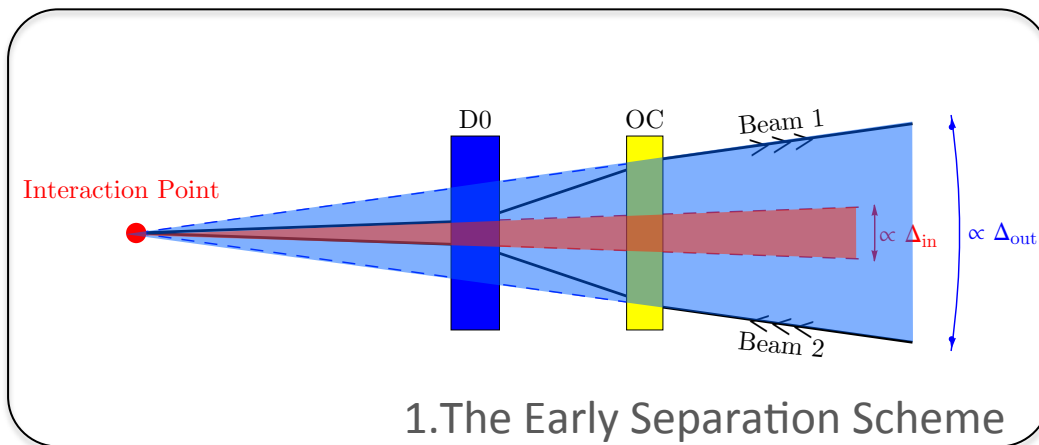
$$L = L_0 \frac{1}{\sqrt{1 + \frac{\sigma_{s1}^2 + \sigma_{s2}^2}{\sigma_{u1}^2 + \sigma_{u2}^2} (\tan \frac{\phi_u}{2})^2}}$$

LHC: 15-20%
HL-LHC: 70%

Local orbit bumps to alleviate the beam-beam long-range interactions and to mitigate the event multiplicity with luminosity leveling

An Early Separation Scheme for the LHC Luminosity Upgrade

G. Sterbini, EPFL PhD Thesis. 4574 (2010)

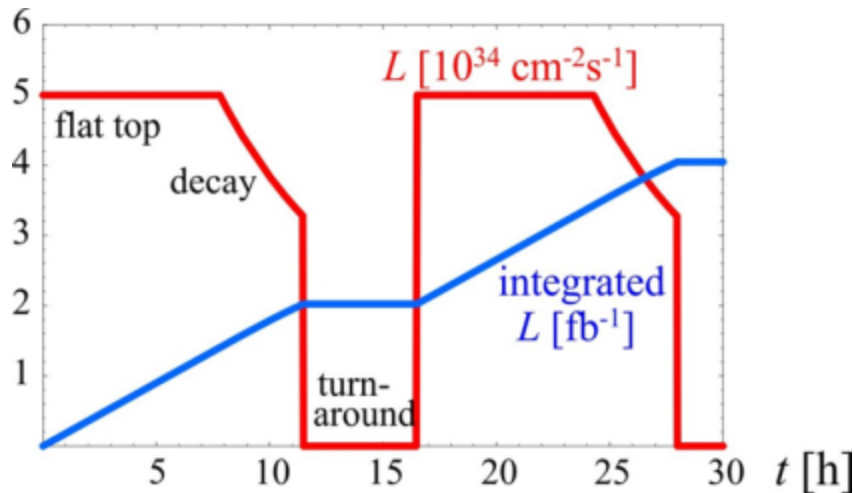


Several possible studies to define possible optics scenarios

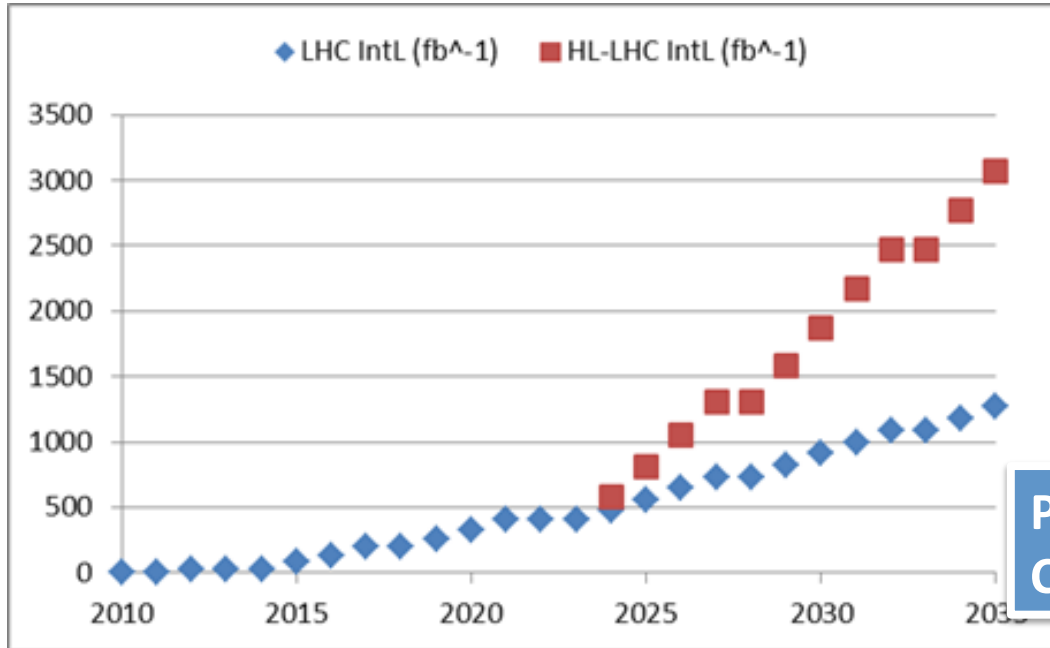
LHC interaction region upgrade

R. de Maria, EPFL PHD Thesis (2008)

Final goal : 3000 fb⁻¹ by 2030's...



5 10^{34} levelled lumi
(25 10^{34} virtual peak lumi)
140 pile up (average)
3 fb⁻¹ per day
60% of efficiency
250 fb⁻¹ /year
300 fb⁻¹/year as «ultimate»



FP- Full Performance upgrade (3000 fb⁻¹):

- crab cavities
- HB feedback system (SPS)
- Advanced collimation systems
- E-lens (?)

PIC-Performance Improving Consolidation Up-grade (~1000 fb⁻¹)

HL-LHC parameters and beam dynamics

‘Stretched’ Baseline Parameters following 2nd HL-LHC-LIU:

Parameter	nominal	25ns	50ns
N	1.15E+11	2.2E+11	3.5E+11
n_b	2808	2808	1404
beam current [A]	0.58	1.12	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	2.5	3.0
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
geom. reduction*	0.83	0.305	0.331
beam-beam / IP	3.10E-03	3.3E-03	4.7E-03
Peak Luminosity	1 10^{34}	7.4 10^{34}	8.5 10^{34}
Virtual Luminosity	1.2 10^{34}	24 10^{34}	26 10^{34}
Events/crossing	19 /28	207/140	476/140

Large ξ_{bb}

DA studies with Working Point optimization & Orbit effects

Large crossing angle requires compensation of geometrical factor by CRAB-CAVITIES

High pile-up needs robust strategy for leveling

Crab-Cavities and beam-beam

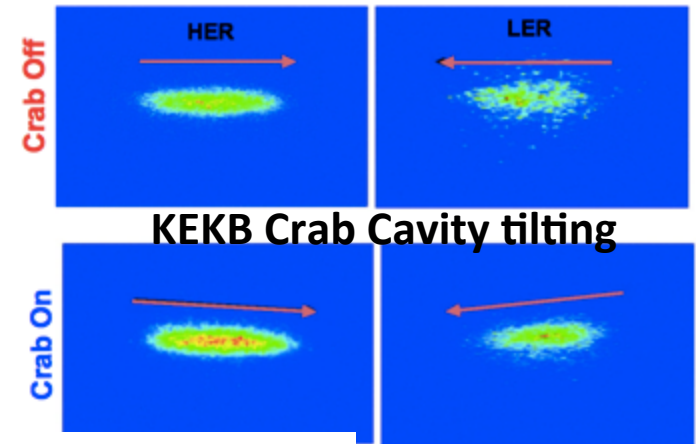
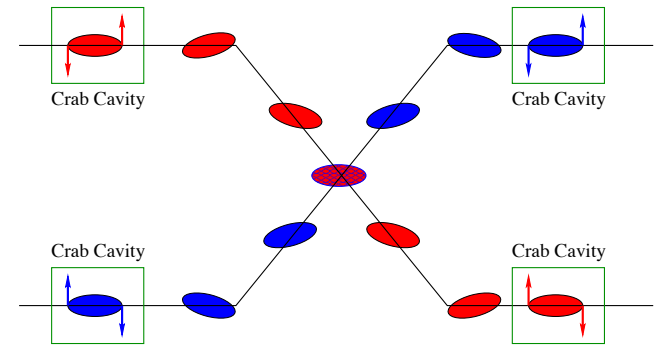
$$L = L_0 \frac{1}{\sqrt{1 + \frac{\sigma_{s1}^2 + \sigma_{s2}^2}{\sigma_{u1}^2 + \sigma_{u2}^2} \left(\tan \frac{\phi_u}{2}\right)^2}}$$

LHC: 15-20%
HL-LHC: 70%

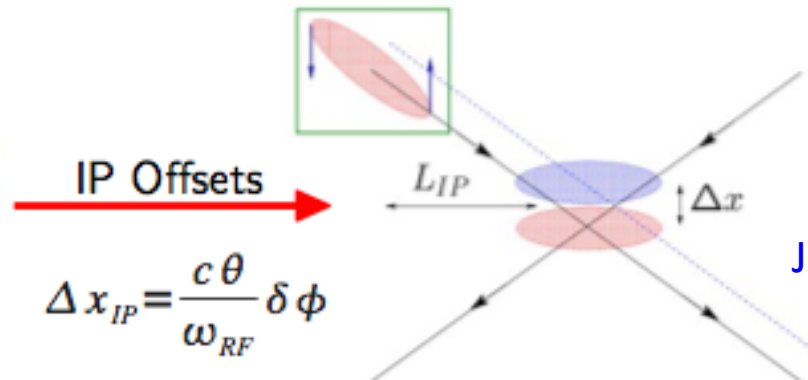
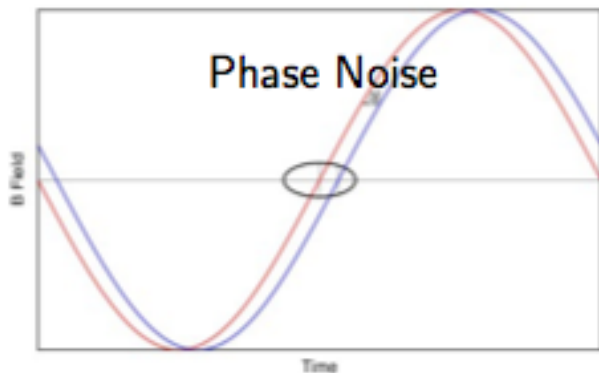
Crab Cavities and proton-proton collisions

- Study impact of crab cavities operation on p-p collisions
- Small offsets at IP can drive emittance growth and deteriorate lumi reach
- Evaluate failure scenarios and impact on colliding beams

LHC Crab Cavity schematic



KEKB Crab Cavity tilting



$$\Delta x_{IP} = \frac{c \theta}{\omega_{RF}} \delta \phi$$

**Strong-strong
beam-beam studies**
J. Barranco, EPFL post-
doctoral Fellow

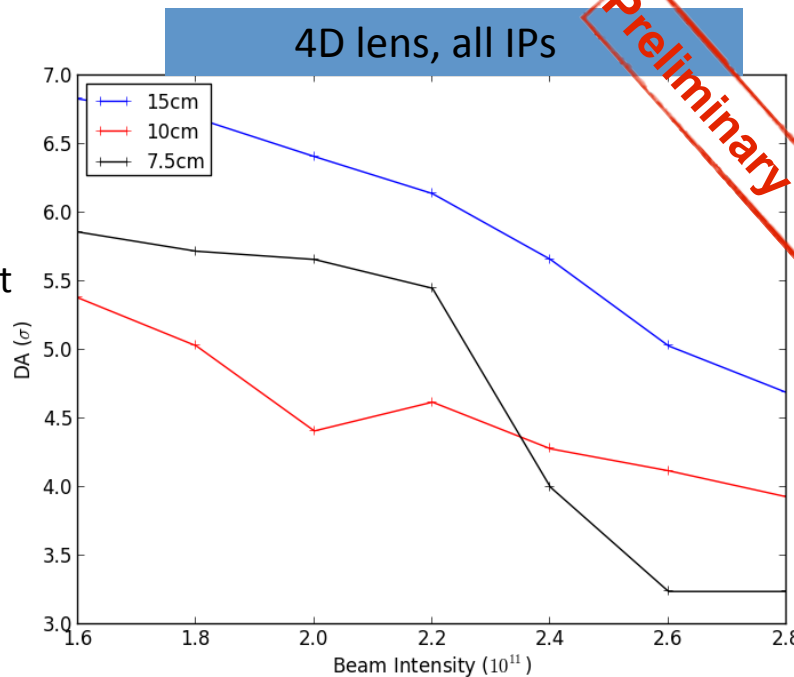
Simulations: single particle long term tracking to define onset of chaotic motion

- 6 HL-LHC optics
- 11 crossing angles (from 400 to 900urad)
- 17 XY plane angles
- 6 amplitude (2 to 12 sigma)
- 8 beam intensity (1.6E11 to 3E11)
- 60 seed
- 6 physics case (BB, Error, crab, noise source..)

	IR1	IR5	IR2/8
round 15cm	15cm	15cm	10m
round 10cm	10cm	10cm	10m
flat 7.5cm	7.5cm	30cm	10m
flat 5cm	5cm	20cm	10m
flat* 7.5cm	30cm	7.5cm	10m
flat* 5cm	20cm	5cm	10m

Close to **20Mjobs** to cover all possible cases! ...+ leveling scenarios + other IPS + ...?
 It's impossible to run such number of jobs on CERN Isf. **BOINC system** is the only way to go!
 EPFL is main sponsor of the LHC@Home project on BOINC platform!

Nominal X-ing angle:
 • 550urad @7.5cm flat
 • 720urad @10 cm
 • 590urad @15 cm



- Define operational scenarios:
- Choose optics layout
 - Working point
 - Crossing angles
 - Beam parameters
 - Calculate lumi performances
 - Decide lumi leveling scenario

Weak-strong beam-beam studies
 D. Banfi, EPFL post-doctoral Fellow



Not only people but computing infrastructures LHC@home and EPFL HPC

About SIXTRACK

SIXTRACK is a research project that uses Internet-connected computers to advance Accelerator Physics. Participate by downloading and running a free program on your computer.

SIXTRACK is based at CERN. You can run it under the LHC@home application. Read more about the:

- [SixTrack project](#)
- [SixTrack team](#)

Join SIXTRACK

- [Read our rules and policies](#)
- This project uses BOINC. If you're already running BOINC, select Attach to Project. If not, [download BOINC](#).
- When prompted, please enter:
<http://lhathomeclassic.cern.ch/sixtrack/>
- If you're running a command-line or pre-5.0 version of BOINC, [create an account](#) first.
- If you have any problems, [get help here](#).

Returning participants

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Sponsors



Computing status

Work	#	Users	#
Tasks ready to send	7	with recent credit	13,540
Tasks in progress	31,242	with credit	113,534
Workunits waiting for validation	2	registered in past 24 hours	117
Workunits waiting for assimilation	2	Computers	#
Workunits waiting for file deletion	1	with recent credit	20,454
Tasks waiting for file deletion	2	with credit	295,758
Transitioner backlog (hours)	0	registered in past 24 hours	112
		current GigaFLOPs	20,964

Tasks by application				
application	unsent	in progress	avg runtime of last 100 results in h (min-max)	users in last 24h
SixTrack	1	32,013	2.06 (0.01 - 13.08)	3,147

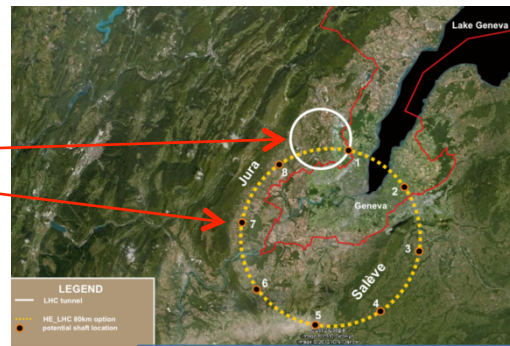
<http://lhathomeclassic.cern.ch/sixtrack/>

Summary

- Several contributions to the LHC over the past years with **12 PhD Thesis published between 2008 and 2013**
- Few studies showed, did not covered also **contribution to LHC injector chain and magnets design (2 PhD thesis)**
- Many studies on-going to push LHC performances after LS1 and to define HiLumi LHC scenarios (**14 PhD students working on various subjects**)
- **2 EPFL post-doctoral fellows via FP7 to HiLumi LHC** with responsibility to define HiLumi possible scenarios for colliding beams (HL-LHC optimization, crab-cavities dynamics, leveling scenarios...)
- Supports and provides **computing facilities** where needed LHC@home and HPC EPFL (BB studies impossible without!)
- ...looking also at future new machines!

pp machines beyond the LHC: HL-, HE- and VHE-LHC

	LHC	HL-LHC	HE-LHC	VHE-LHC
c.m. energy	14		33	100
Circumference (km)	26.7			80
Dipole field (T)	8.33			20
$N_b \cdot 10^{11}$ ppb	1.15	2.2	0.94	0.97
β^* (m)	0.55	0.15	0.35	1.1
ϵ_N (μm)	3.75	2.5	1.38	2.15
ϵ_s (eVs)	2.5		3.8	13.5
σ_s (cm)	7.6			
Current (A)	0.58	1.12	0.48	0.49
Stored energy per beam (GJ)	0.362	0.694	0.701	6.61
SR power per ring (kW)	3.6	7.3	96.2	$2.9 \cdot 10^3$
Arc heat load (W/m/aperture)	0.17	0.33	4.35	43.4
Energy loss per turn (keV)	6.5		201.3	$5.9 \cdot 10^3$
Luminosity ($\cdot 10^{34} \text{ cm}^{-2}\text{s}^{-1}$)	1.0	5.0 (lev.)	5.0	5.0



J. Osborne and C. Waaijer

→ ~18 times the LHC value!

→ Very high SR

→ unprecedented SR damping in hadron machines: Beam dynamics driver

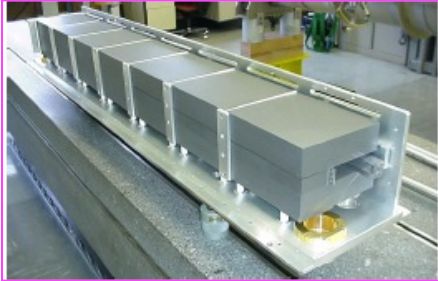
- 1) Luminosity performance studies (different scenarios, basic parameters, etc.)
- 2) e^- cloud studies

2013-2008 PhD Thesis:

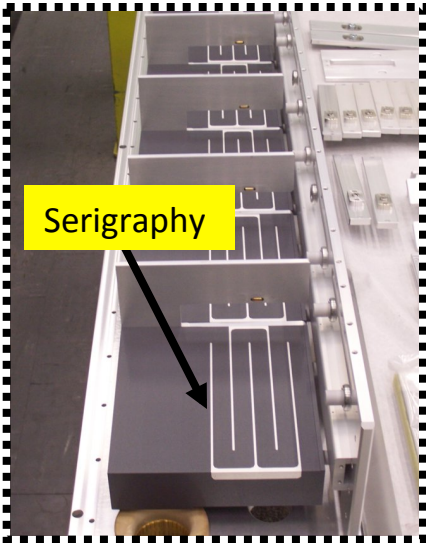
- **Electromagnetic Simulation of CERN Accelerator Components and Experimental Application,** [C. Zannini; L. Rivkin and G. Rumolo \(Dirs.\).](#)
- **Heat Transfer between the Superconducting Cables of the LHC Accelerator Magnets and the Superfluid Helium Bath.** [P. P. Granieri; L. Rivkin \(Dir.\).](#)
- **High Intensity Beam Issues in the CERN Proton Synchrotron.** [S. Aumon](#)
- **The LHC Transverse Coupled-Bunch Instability.** [N. Mounet; L. Rivkin and E. Métral \(Dirs.\)](#)
- **Cyclotron Designs for Ion Beam Therapy with Cyclinacs.** [Garonna; L. Rivkin and U. Amaldi \(Dirs.\).](#)
- **Study and Experimental Characterization of a Novel Photo Injector for the CLIC Drive Beam** [Ö. Mete; L. Rivkin and S. Döbert \(Dirs.\).](#)
- **Beam-Machine Interaction Studies for the Phase II LHC Collimation System.** [L. Lari; L. Rivkin \(Dir.\).](#)
- **Performance Evaluation of a Crystal-Enhanced Collimation System for the LHC.** [V. Previtali; L. Rivkin \(Dir.\).](#)
- **Impedance model of the CERN SPS and aspects of LHC single-bunch stability.** [B. Salvant; L. Rivkin and E. Métral \(Dirs.\).](#)
- **An early separation scheme for the LHC luminosity upgrade.** [G. Sterbini; L. Rivkin \(Dir.\).](#)
- **Commissioning scenarios and tests for the LHC collimation system.** [C. Bracco; L. Rivkin \(Dir.\).](#)
- **A finite element model of the LHC dipole cold mass with hysteretic, non-linear behavior and single turn description: towards the interpretation of magnet quenches.** [M. Pojer; L. Rivkin \(Dir.\).](#)
- **A study of beam-beam effects in hadron colliders with a large number of bunches.** [T. Pieloni; A. Bay and L. Rivkin \(Dirs.\).](#)
- **LHC interaction region upgrade.** [R. De Maria; L. Rivkin \(Dir.\).](#)

SPS kicker impedance model

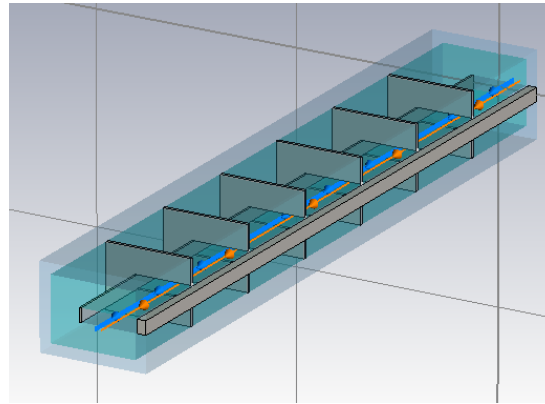
SPS kicker magnet



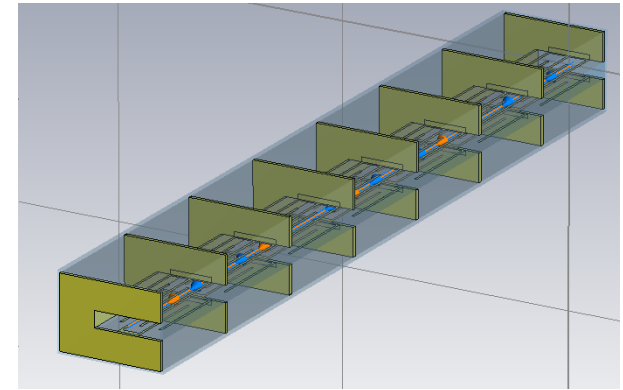
Serigraphy



SPS extraction kicker (MKE) without serigraphy

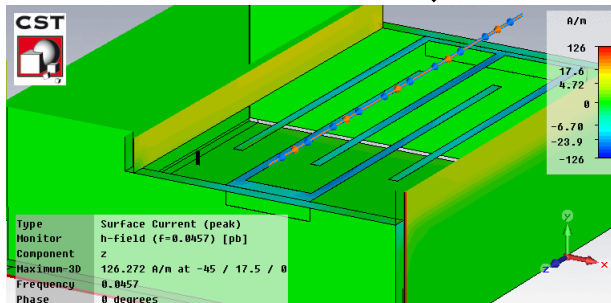
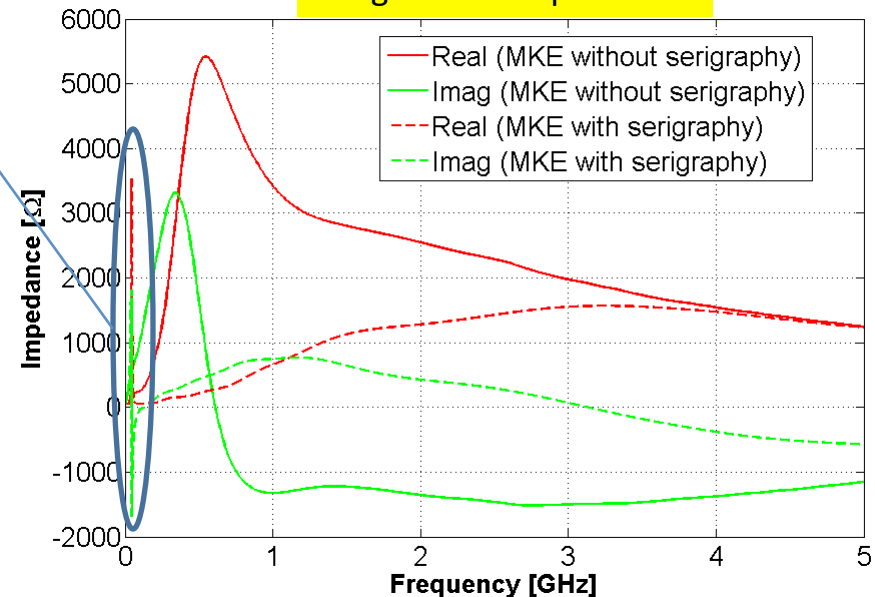


SPS extraction kicker (MKE) with serigraphy



Quarter wavelength resonance on the finger length

Longitudinal impedance

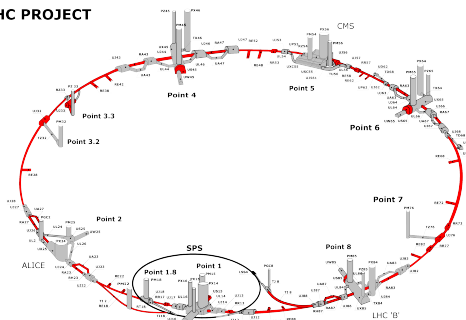


Thesis n. 5737
(2013)

Beam Machine Interaction studies for the Phase II LHC Collimation System

Luisella Lari

LHC PROJECT



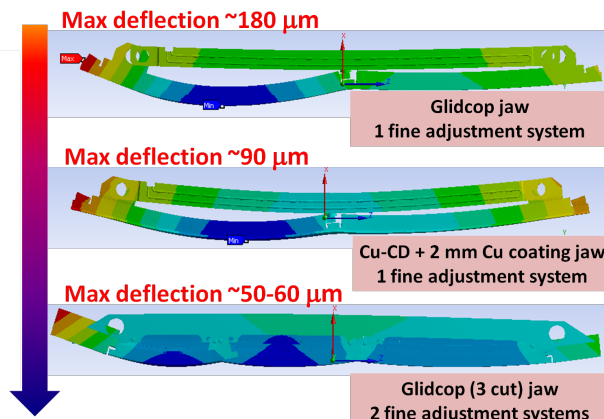
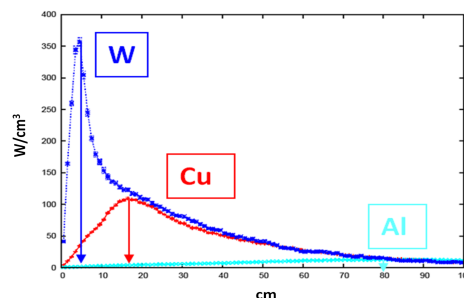
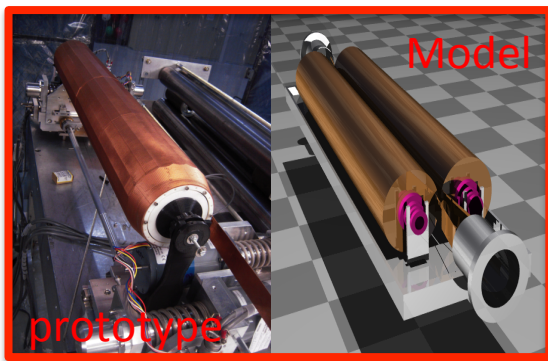
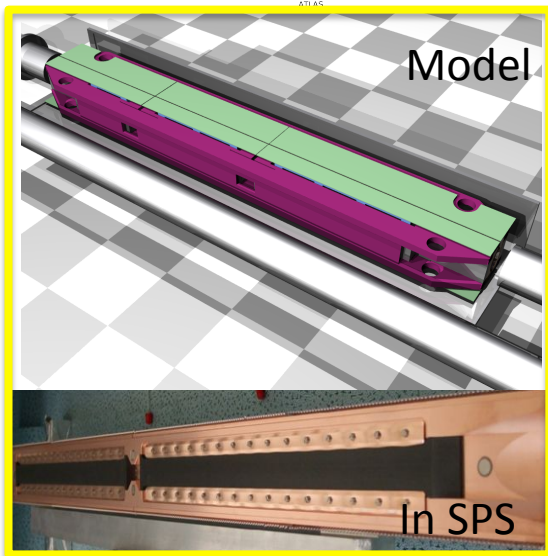
Main topics to which the PhD thesis was addressed:

<http://infoscience.epfl.ch/record/153492>

- Can the Ph2 collimators withstand the energy density deposition induced by the primary p+ losses?
- Which is the distribution of the thermal loads in the collimator components during the most destructive possible failure mode?
- How much is the influence of collimators on the residual ambient dose equivalent levels in the region in which they are installed?
- Which are the consequences of Ph2 on the adjacent equipments?
- How can we evaluate the degradation of the collimator materials due by radiation?

FLUKA model IR7

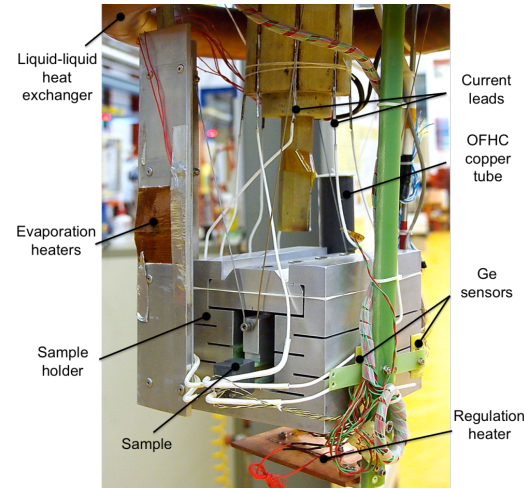
1.5 km



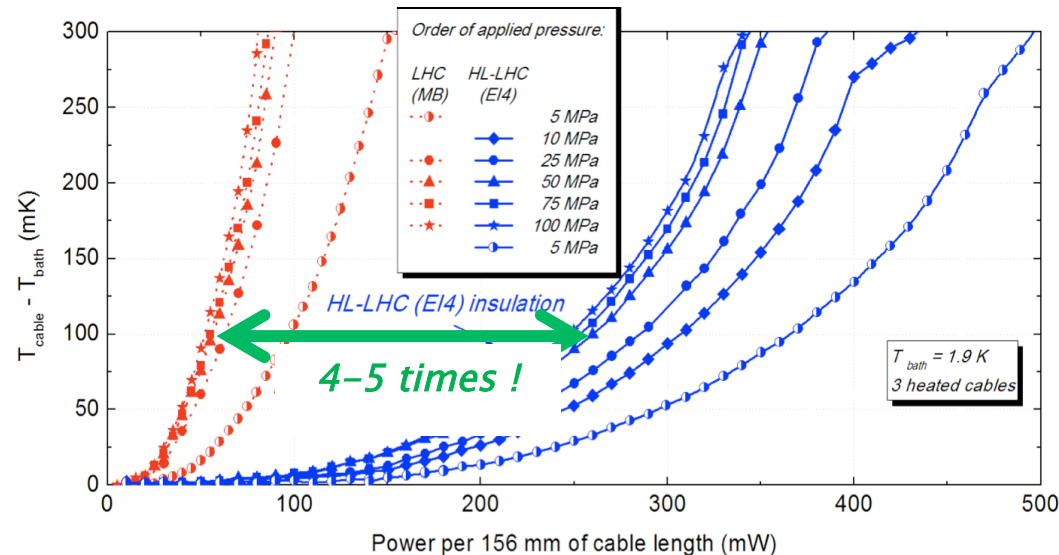
Heat Transfer between the Superconducting Cables of the LHC Accelerator Magnets and the Superfluid Helium Bath

Pier Paolo Granieri – thesis no. 5411 (2012)

- Experimental characterization of heat transfer in LHC SC coils operating in superfluid helium (He II)
- Development of a thermally enhanced insulation for HL-LHC
- Modeling of He II heat transfer through Nb-Ti cable insulation



- ▶ Fundamental investigation of He II heat transport laws in narrow channels
- ▶ Computation of LHC and HL-LHC magnets quench limits



HL-LHC Work-Package Structure

WP1 Project Management and Technical Coordination

WP7 Machine Protection

WP2 Accelerator Physics and Performance

WP8 Collider-Experiment Interface

WP3 Magnets for Insertion Regions

WP9 Cryogenics

WP4 Crab Cavities

WP10 Energy Deposition & Absorber

WP5 Collimation

WP11 11-T Dipole Two-in-One for DS

WP6 Cold Powering

WP12 Vacuum

WP16 High-Energy LHC – Studies

WP13 Beam Diagnostics

WP14 Integration & (De-)installation

WP17 FRESCA2 High-Field Magnets – R&D

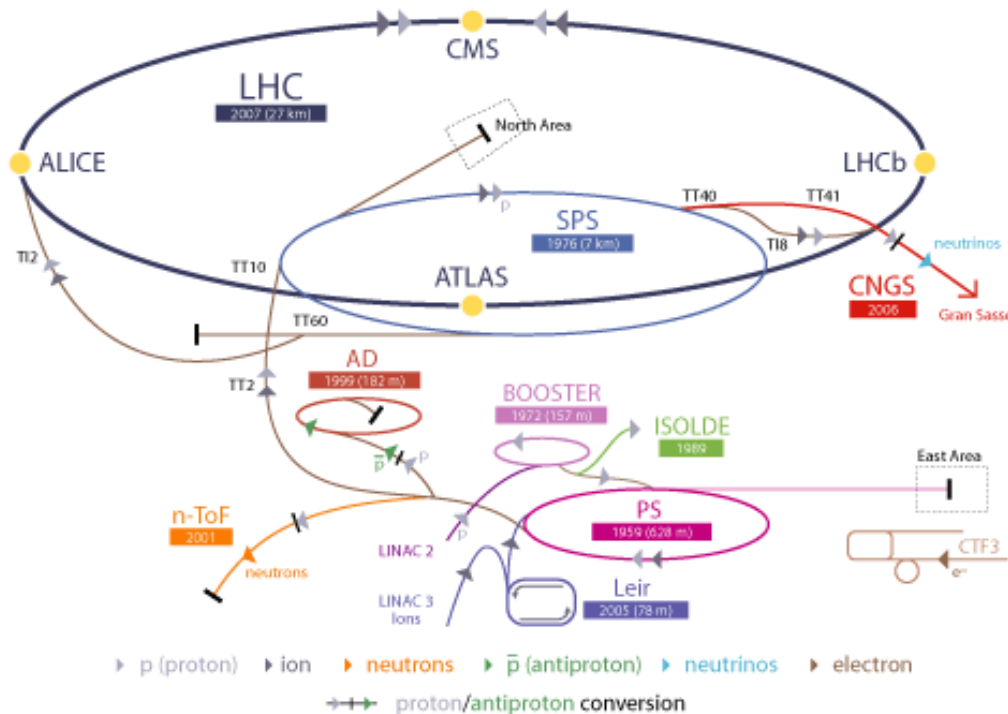
WP15 Hardware Commissioning

LHC Injector chain:

Injectors performances beyond LHC Design

Possible beam scenarios from injectors

CERN Accelerator Complex



	Number of bunches	Nb	Emit LHC (SPS) [um]
25 ns	2760	1.15e11	3.75 (2.8)
25 ns low emit (48 bunches/PS batch)	2320	1.15e11	1.9 (1.4)
50 ns	1380	1.6e11	2.3 (1.7)
50 ns low emit (24 bunches/PS batch)	1260	1.6e11	1.6 (1.2)

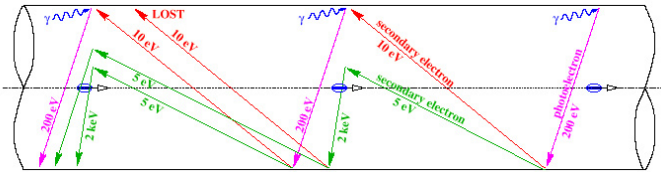
- After LS1 physics run
- LHC test-bench for HiLumi LHC studies
- Injectors up-grade

LHC Large Hadron Collider SPS Super Proton Synchrotron PS Proton Synchrotron
 AD Antiproton Decelerator CTF3 Clic Test Facility
 CNGS Cern Neutrinos to Gran Sasso ISOLDE Isotope Separator OnLine DEvice
 LEIR Low Energy Ion Ring LINAC LInear ACcelerator n-ToF Neutrons Time Of Flight

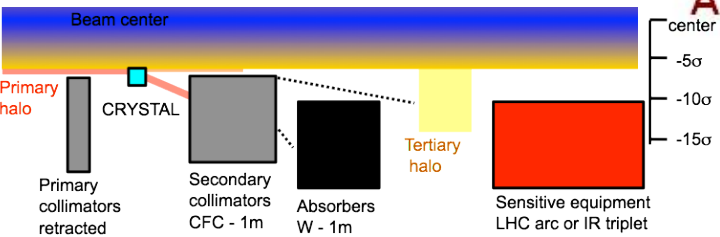
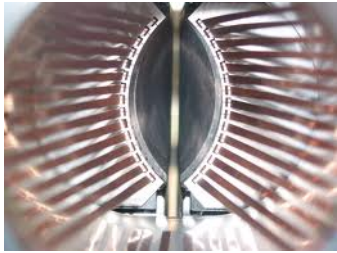
Injectors are a fundamental input to the big collider performances!

LHC and Swiss contribution to accelerator

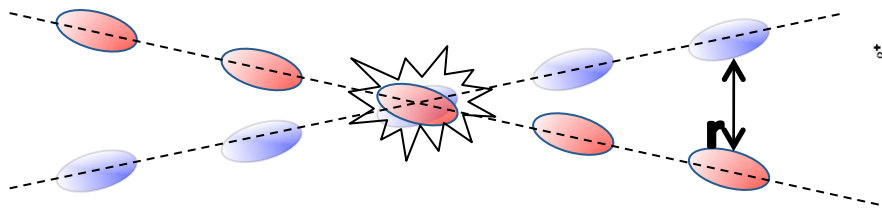
Electron cloud



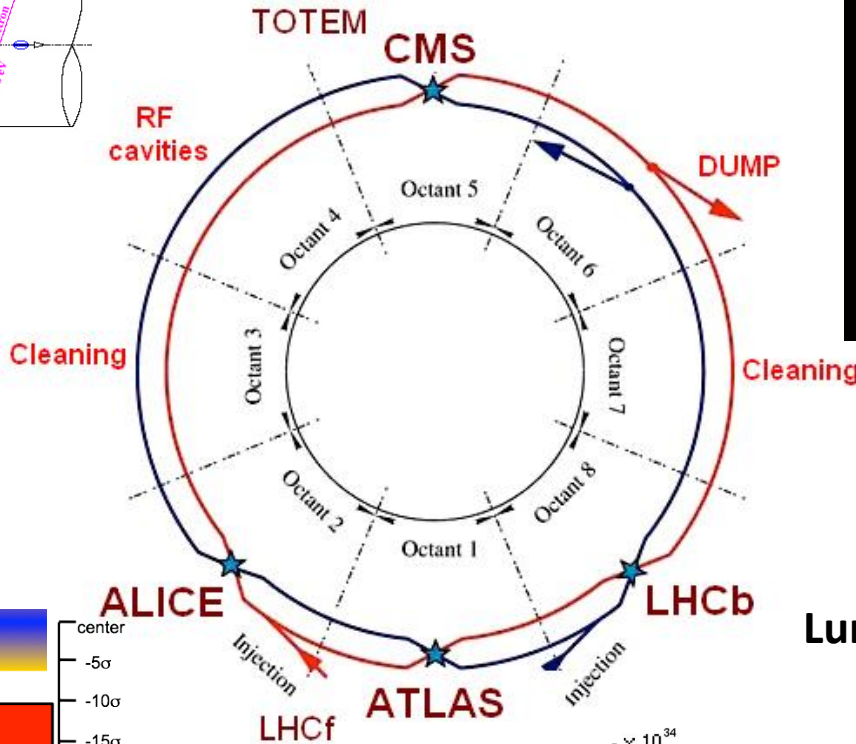
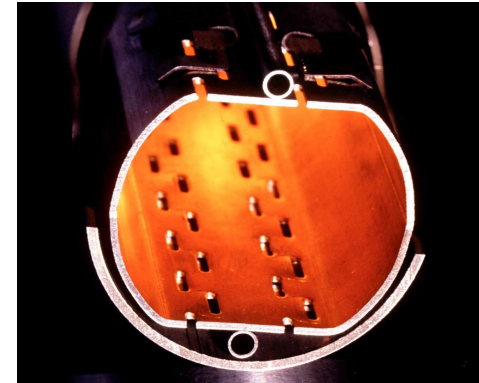
Collimation



Beam-Beam electro-magnetic interactions



Impedance



Lumi Leveling: techniques and scenarios

