Machine upgrade and experiment protection

Well known, that machine and experiments have to some extent conflicting requirements, see opening talk, Steve Myers, 1st Collider experiments interface workshop 30 Nov 2012

Machine upgrade, more aperture
increased intensity, energy, luminosity

↔

Experiments inner detectors close to the beam
safe stable operation, low backgrounds

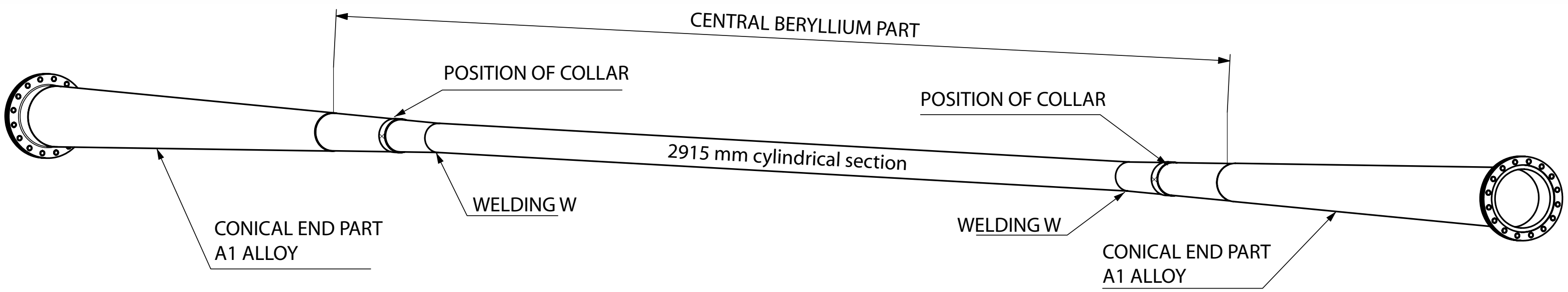
3000 fb-1 in each IP 1 and 5 with luminosity leveling and optimal conditions or at least well tolerable, stable, safe running conditions for all experiments

Based on the work for the HL-LHC in collaboration between several work packages and the experiments :
WP1 management incl. coordination WG, WP2 Accelerator physics (aperture needs for optics),
WP4 Crab cavities, WP5 Collimation, WP7 machine protection, WP8 collider experiment interface
WP10 energy deposition, WP 13 beam diagnostics ...

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.)**

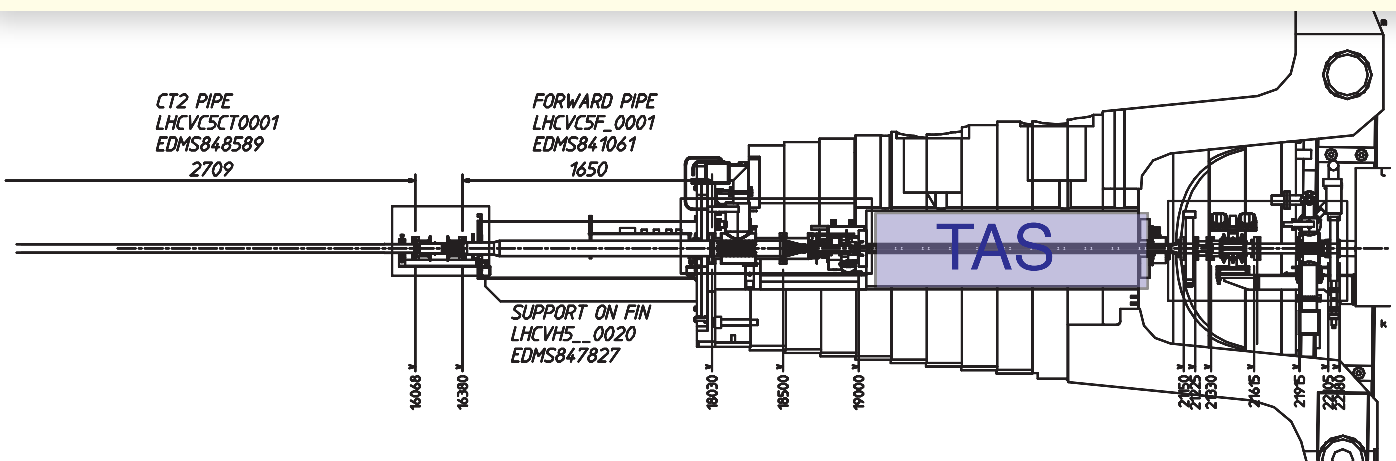
30% reduction from 29 mm to 21.7 mm inner radius for CMS and 23.5 mm for ATLAS



CMS
lhcvc5c_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

Layout changes by the machine, LS3

Reduction of β^* to 15 cm (round) or 7.5 cm / 30 cm (flat)

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

TAS radius increased by nearly 2× to r = 30 mm

Crab cavities after D2, D2 moved closer to IP

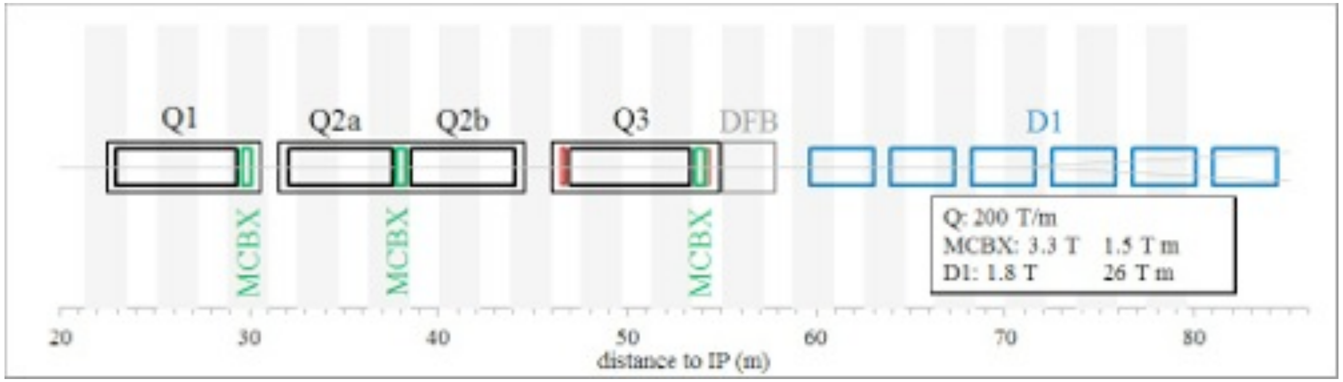
potential advantage in β^* levelling, i.e. starting the fill at increased β^*

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)

Triplet and D1

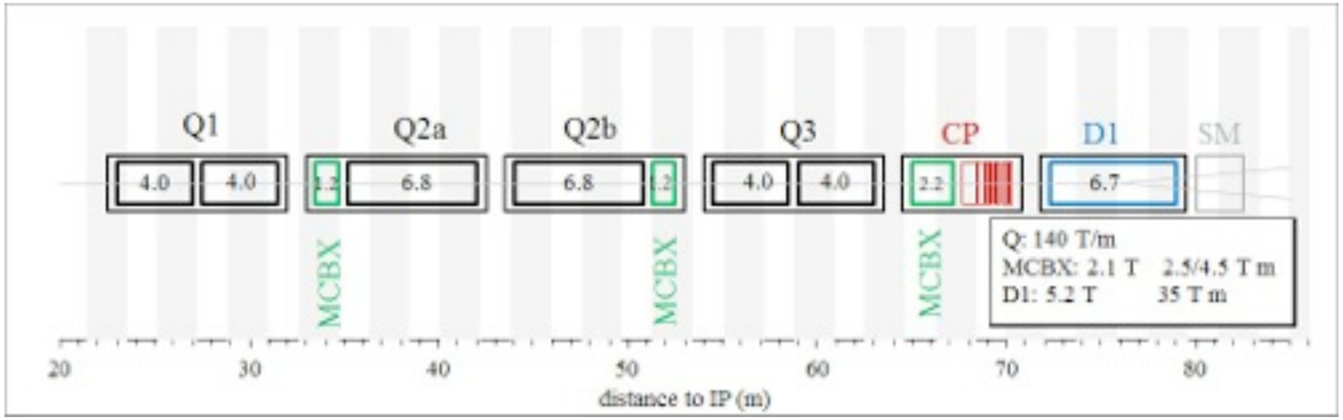
https://espace.cern.ch/HiLumi/WP3/SitePages/Home.aspx



LHC

inner coil

diameter 70 mm



HL-LHC

inner coil

diameter 150 mm

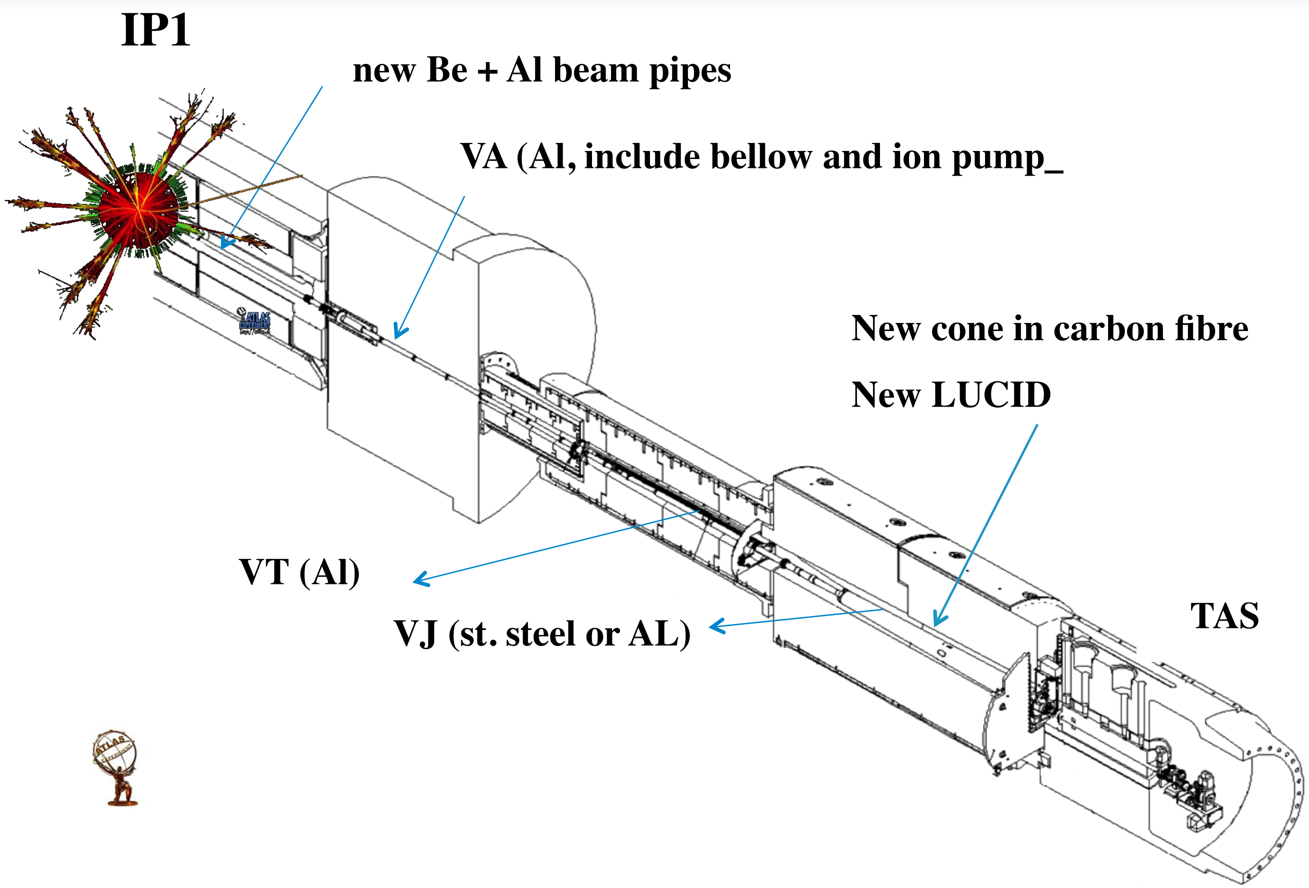
Detailed simulations

Done in close collaboration with the experiments

Contact persons for ATLAS and CMS

ATLAS : Beniamino Di Girolamo, Antonello Sbrizzi

CMS : Austin Ball, Anne Dabrowski



From Beniamino Di Girolamo, ATLAS simulation meeting, April 2013

Failure scenarios

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

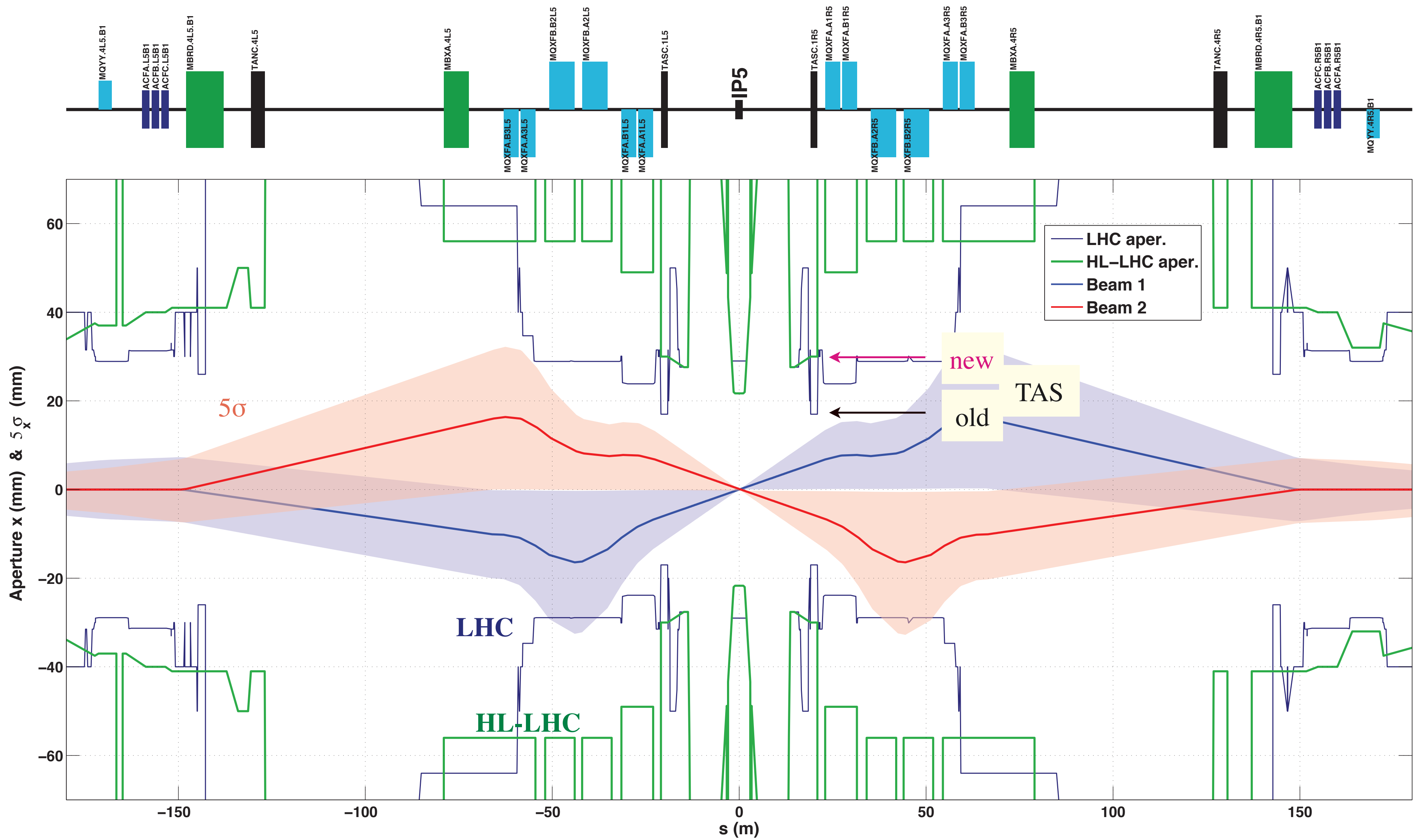
Most relevant in the context discussed here is top energy, fully squeezed, IP1 + 5

- Crab cavity failures - detailed simulations started and first results illustrated
- Asynchronous beam dump (beam 2 to CMS...)
- 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 ...

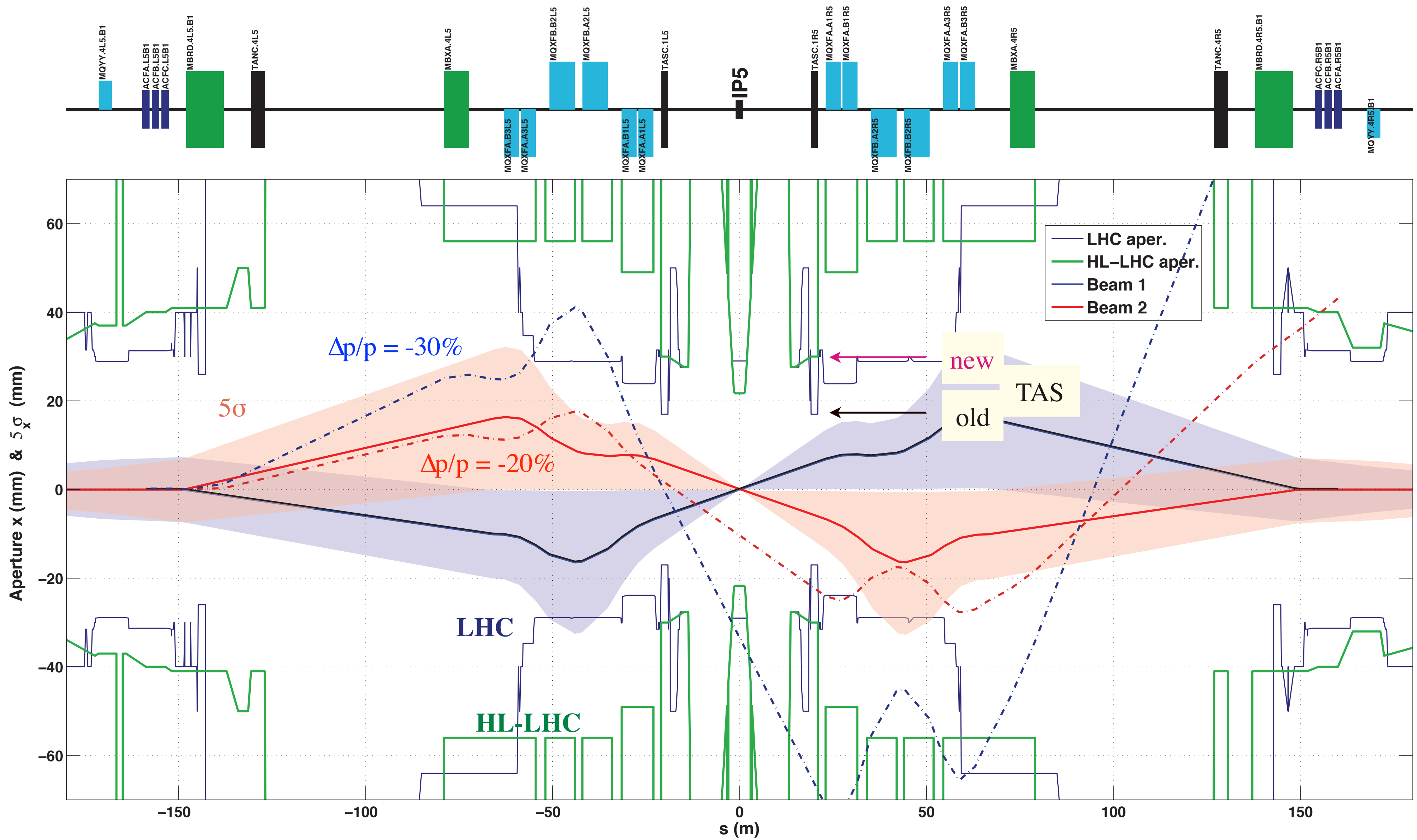
HL-LHC beam envelopes and apertures



5σ envelopes, β* = 15 cm

Based on studies and plots by Frederic Bouly

HL-LHC beam envelopes and apertures

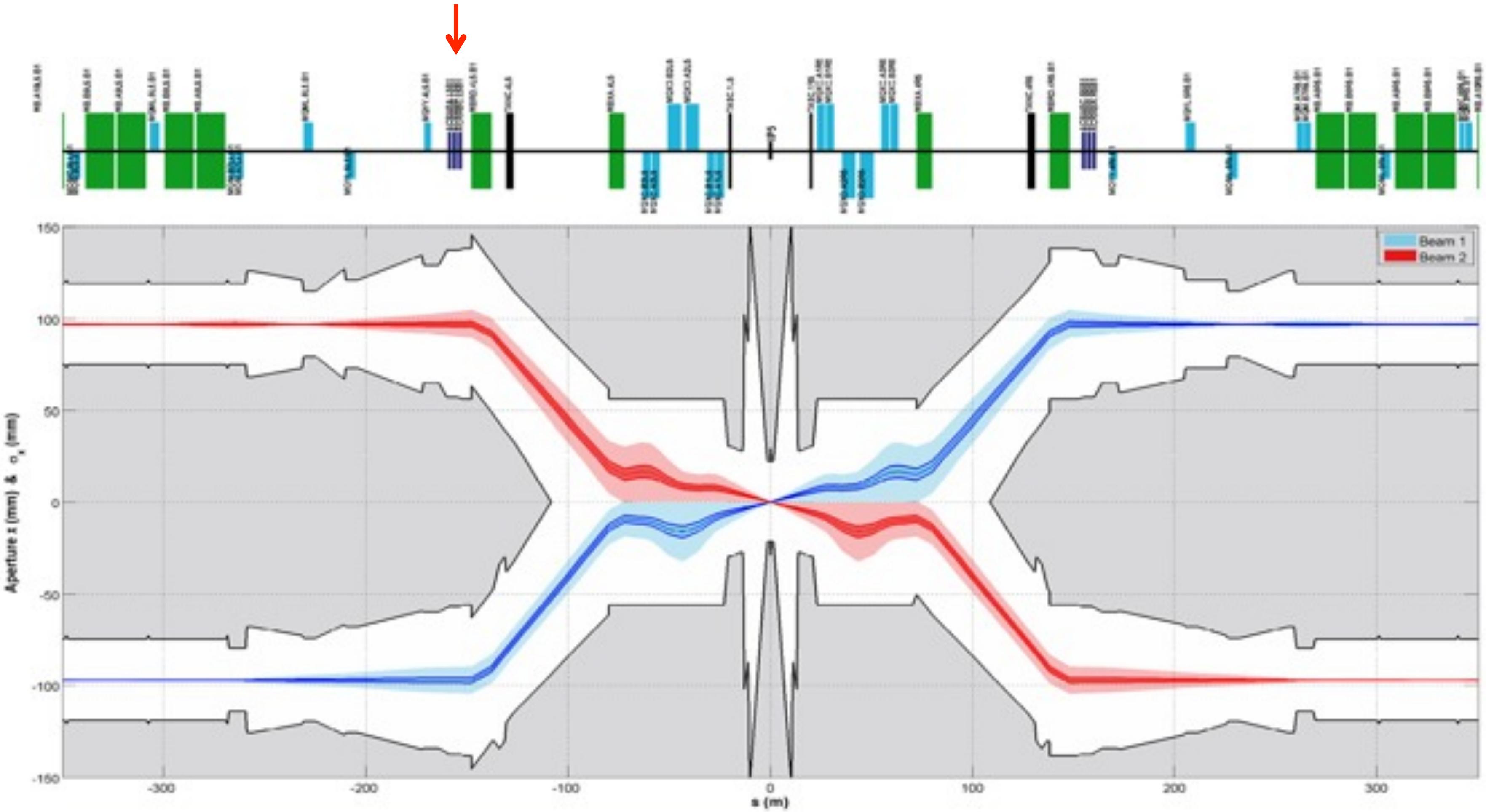


5σ envelopes, β* = 15 cm

Based on studies and plots by Frederic Bouly

Crab cavity failure simulation (1/3)

- **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˚



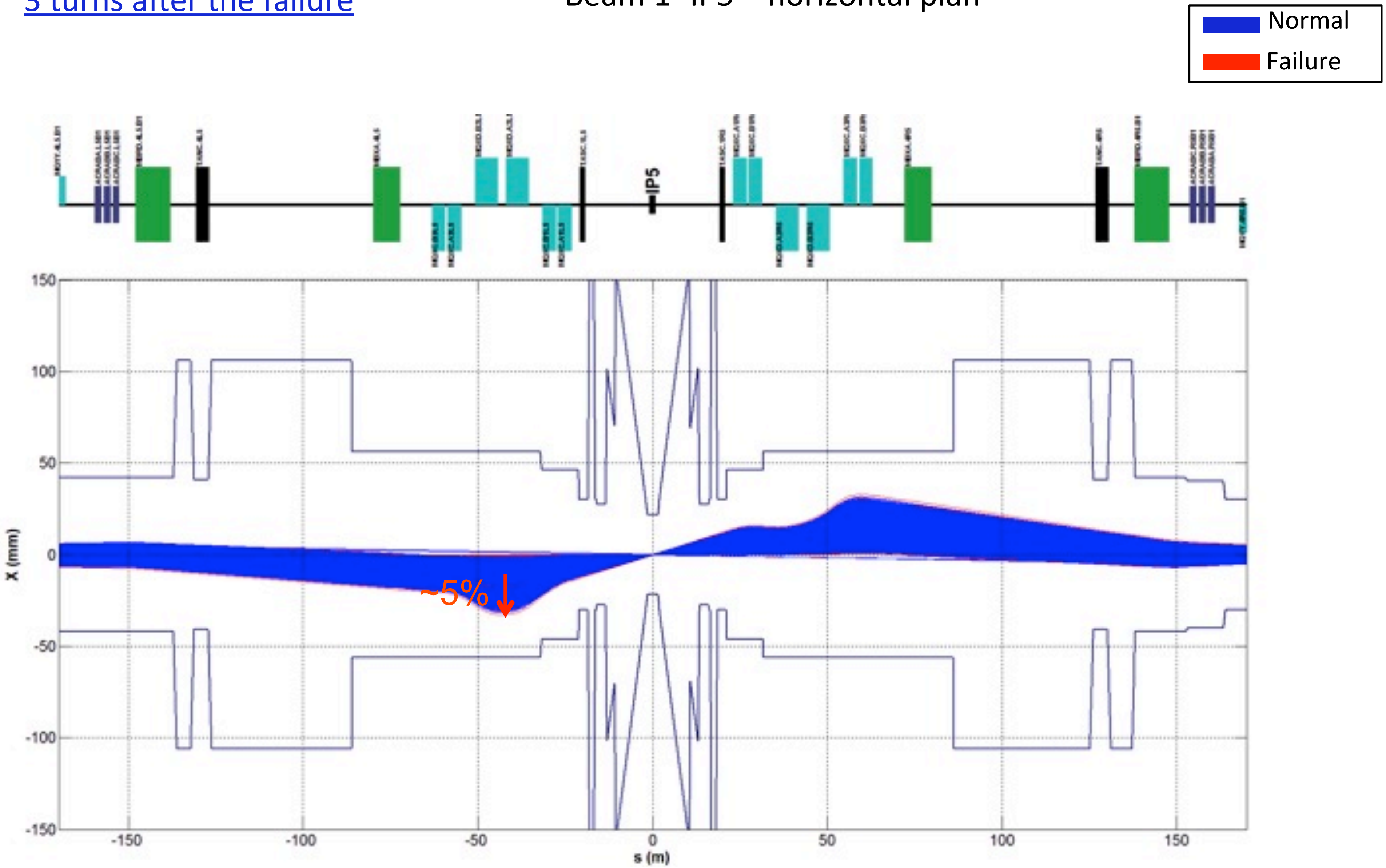
- NB : no losses observed for the core distribution - only the results for the halo distribution are presented

Frederic Bouly + B.Y. Rendon, tracking with SIXTRACK

Crab cavity failure simulation (2/3)

3 turns after the failure

Beam 1- IP5 – horizontal plan

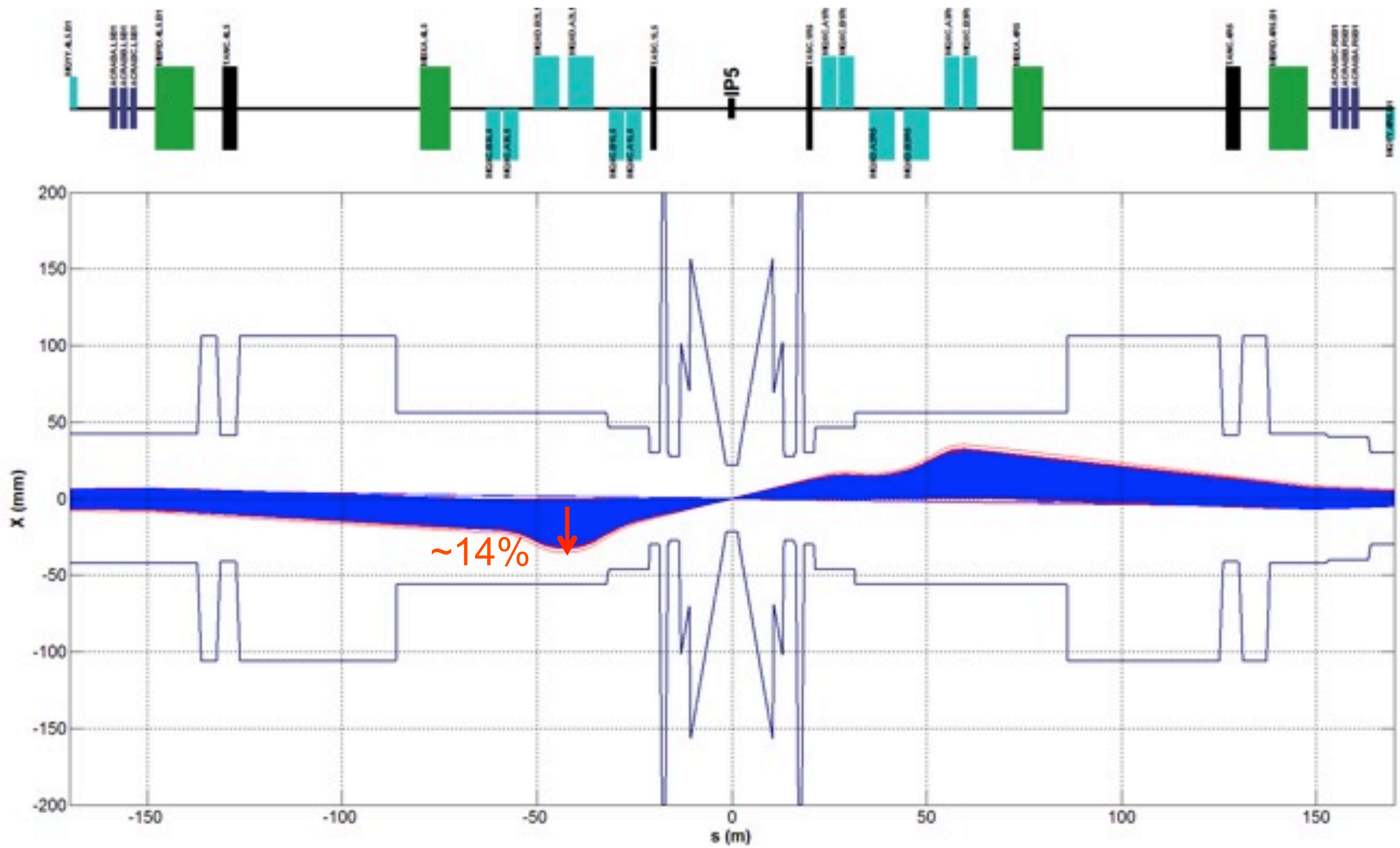


Frederic Bouly

Crab cavity failure simulation (3/3)

5 turns after the failure

Beam 1- IP5 – horizontal plan



First results rather encouraging:
fast but still manageable growth times
protected by collimator system

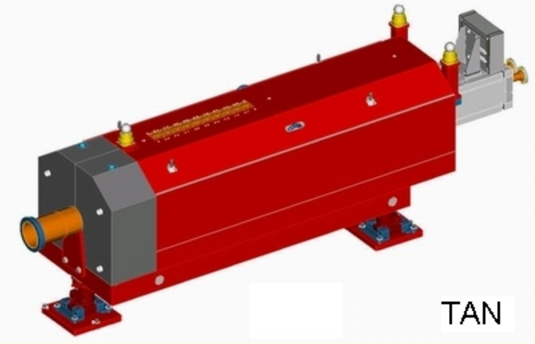
TAN

TAN absorber for neutral collision debries (n, γ) in front of D2

in IP1 and IP5 minimal TAN or shielding or TCLs also planned for IP8

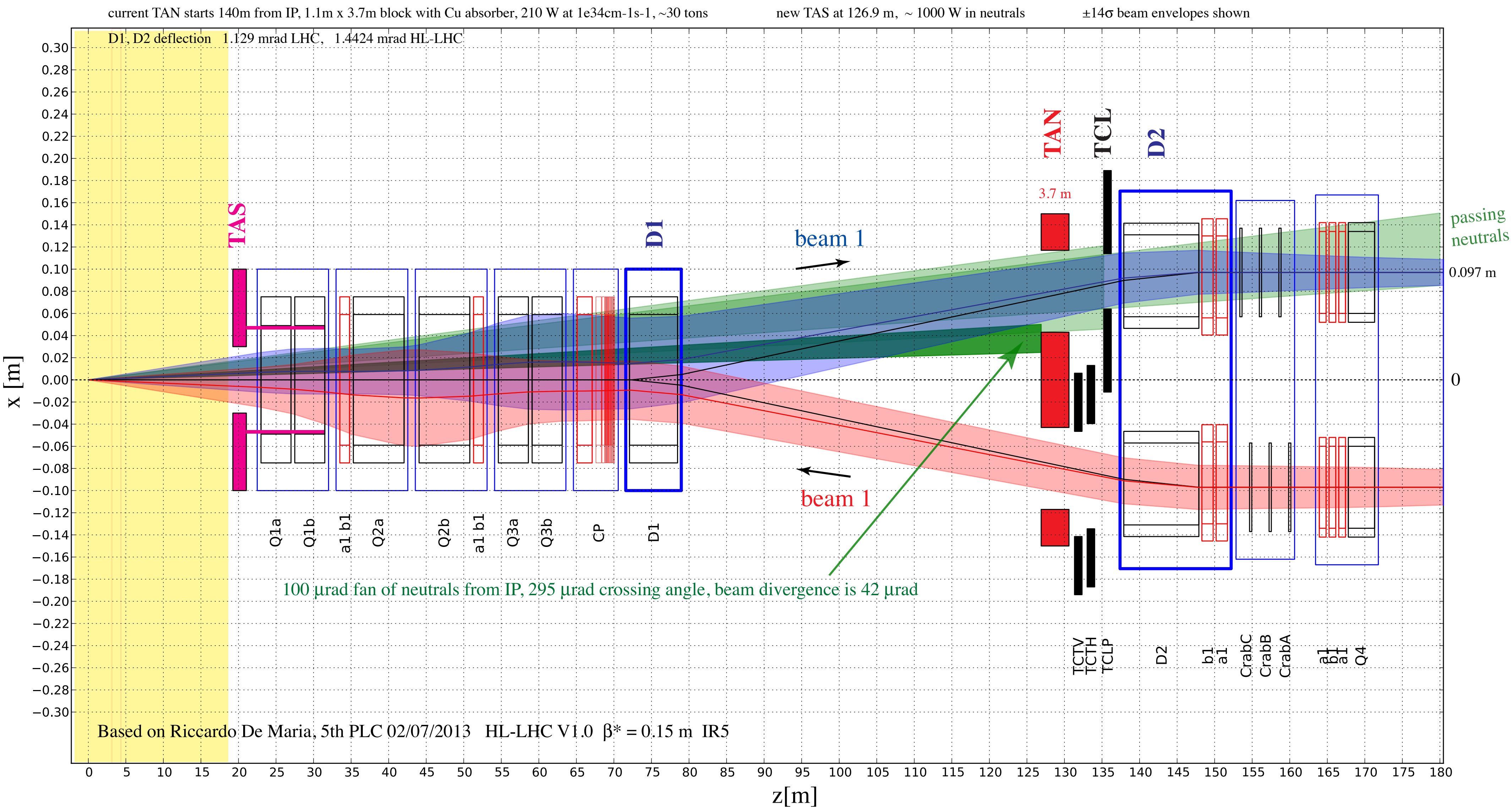
LHC → HL-LHC, LS3

- **changes in geometry, D2 closer to IP,** move TAN 13 m to IP
- **2× larger crossing angle (142.5 → 295 μrad)**
- **larger beams at TAN (increased β-functions), keep n1 > 7**
- **increased energy deposition (200 W → 1000 W)**



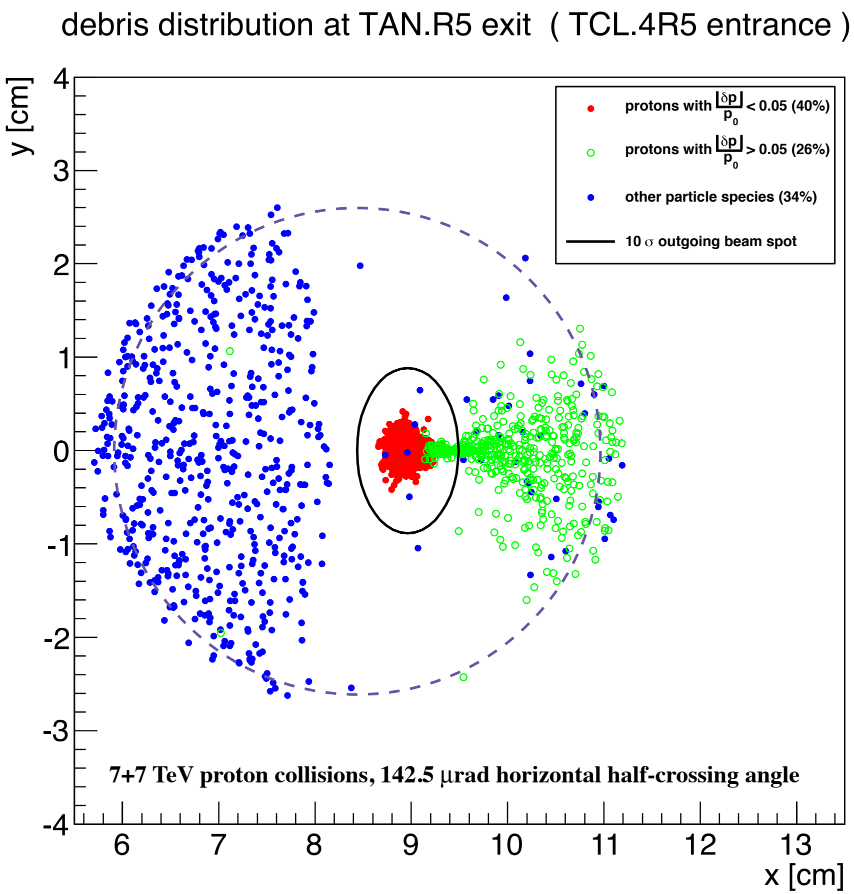
TAN redesign needed

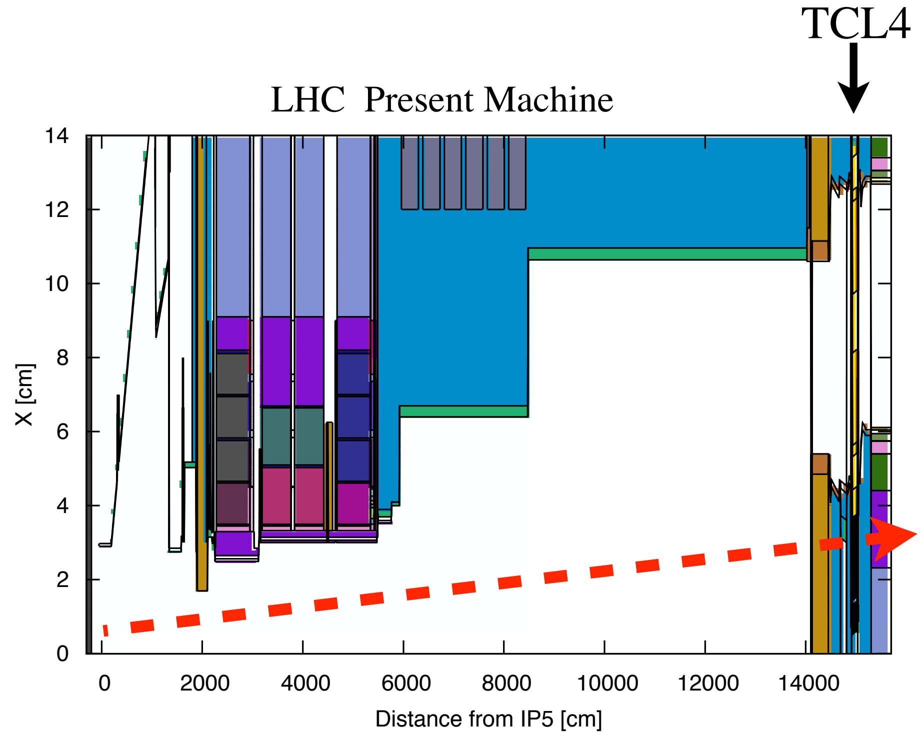
Geometry


current TAN starts 140m from IP, 1.1m x 3.7m block with Cu absorber, 210 W at 1e34cm-1s-1, ~30 tons
new TAS at 126.9 m, ~ 1000 W in neutrals
±14σ beam envelopes shown
D1, D2 deflection 1.129 mrad LHC, 1.4424 mrad HL-LHC
TAS
D1
beam 1
TAN
3.7 m
TCL
D2
passing neutrals
0.097 m
0
beam 1
Q1a
Q1b
a1 b1
Q2a
Q2b
a1 b1
Q3a
Q3b
CP
D1
100 μrad fan of neutrals from IP, 295 μrad crossing angle, beam divergence is 42 μrad
TCTV
TCTH
TCLP
D2
b1
a1
CrabC
CrabB
CrabA
a1
b1
a1
Q4
x [m]
z[m]
Based on Riccardo De Maria, 5th PLC 02/07/2013 HL-LHC V1.0 β* = 0.15 m IR5

Simulations, LHC, present TAN

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





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

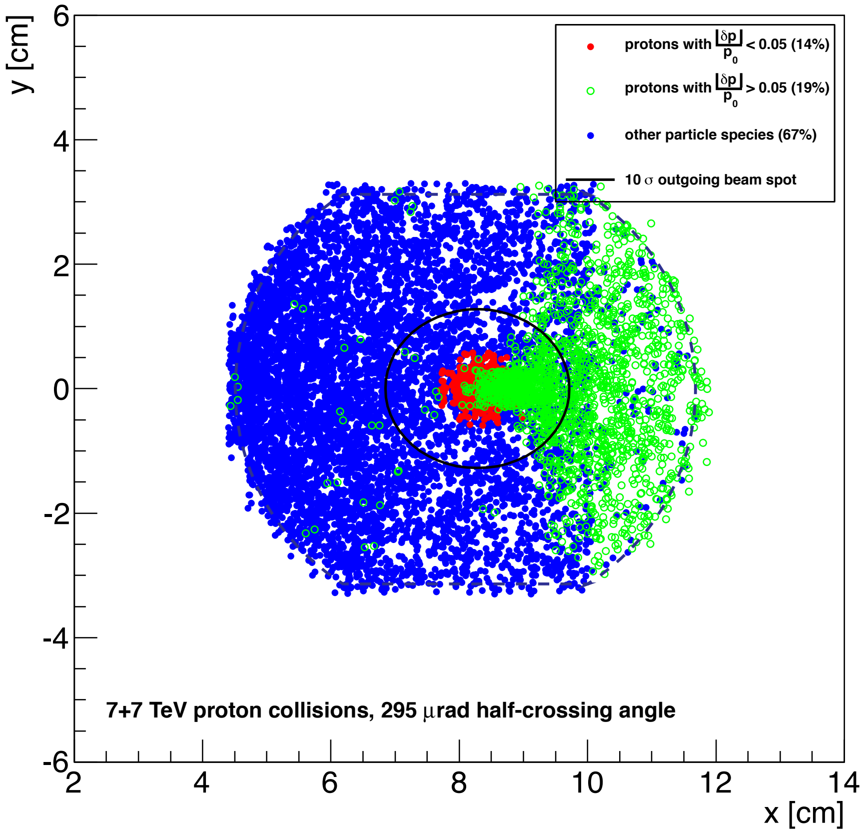
At TAN entrance, the offset due to crossing angle is ~ 142.5μrad × 141 m ≃ 2.1 cm
⇒ neutrals flying along the crossing angle well within TAN acceptance

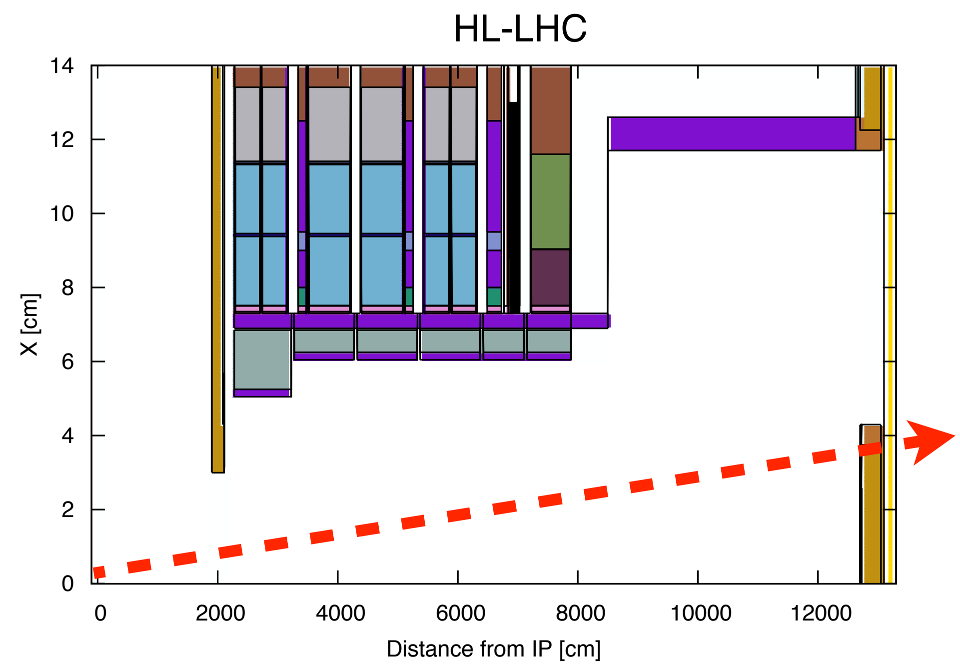
TAN aperture radius 26 mm, sep 160 mm

Simulations, HL-LHC, TAN

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

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





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

At TAN entrance, the offset due to crossing angle is ~ 295 μrad × 126 m ≃ 3.7 cm
⇒ neutrals flying along the crossing angle close to edge of TAN acceptance

TAN aperture rectellipse 37/32 mm, sep 160 mm

the currently proposed HL-LHC TAN aperture appears to me as rather generous

relies on TCL to protect D2 and leaves an increased fraction of collision debris going into

matching section and dispersion suppressor -- to be followed up

Instrumentation, Beam Loss Monitors

WP 13 beam diagnostics, Rhodri Jones, Bernd Dehning et al.

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 debries

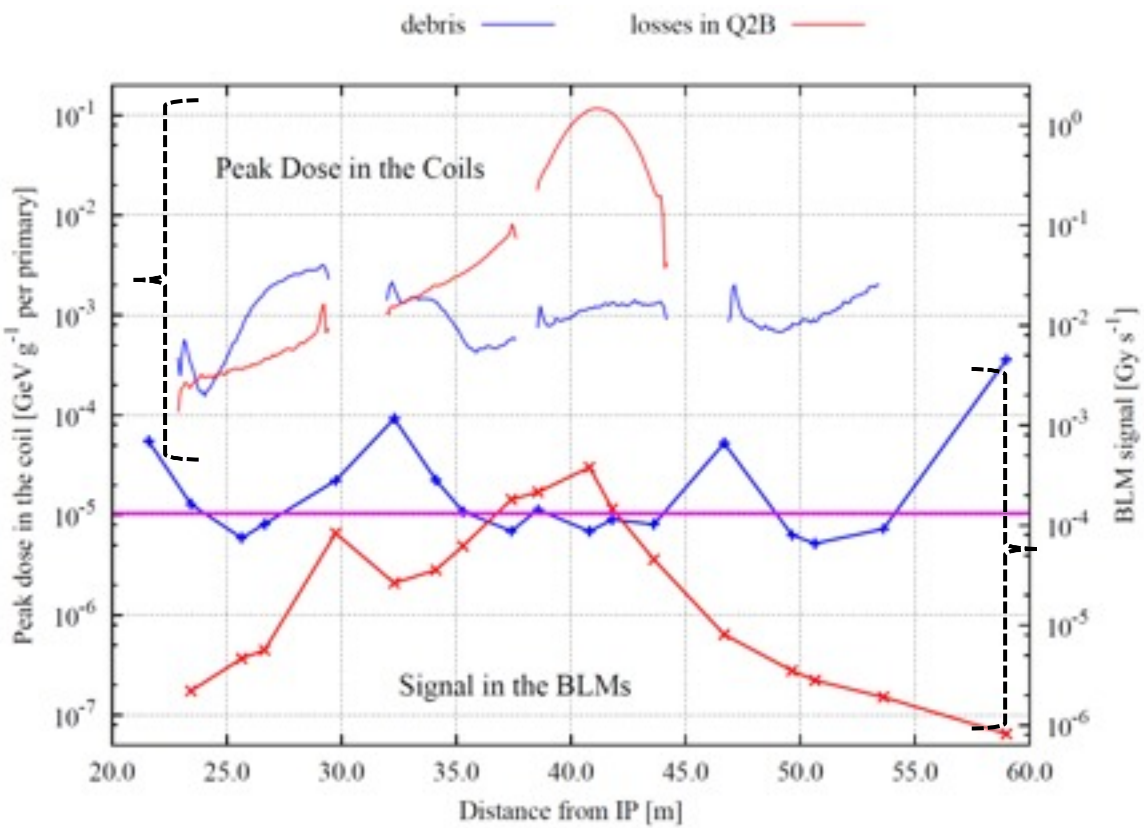
crucial for experiments to have their own monitoring/protection, BCMs

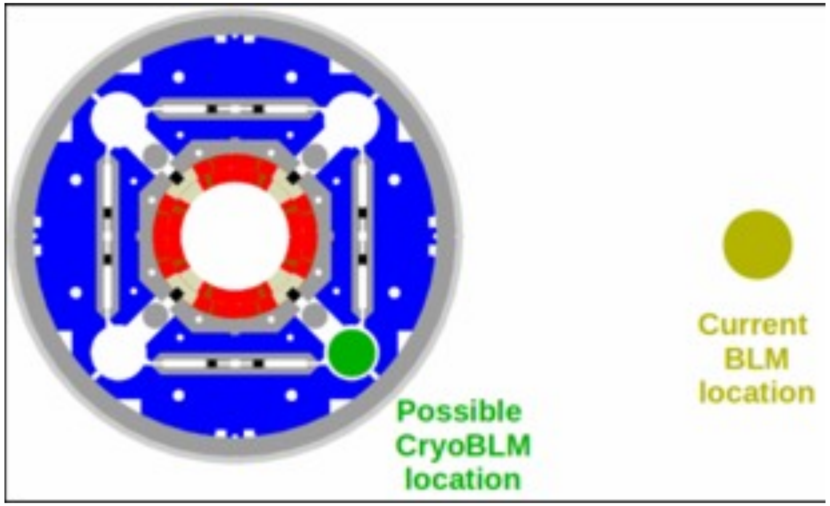
Summary

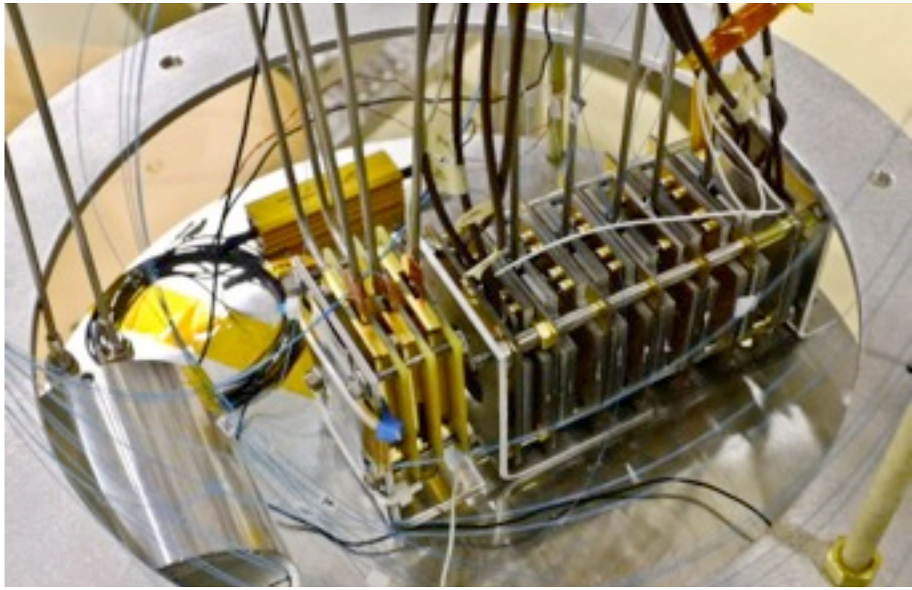
- The high-luminosity upgrade implies a major redesign of the layout around IP1 and IP5
- Machine aperture will nearly double around the high luminosity interaction regions resulting in a significant reduction in passive protection (TAS, TAN)
- We are in the process of critically reviewing tolerances and apertures to minimize the loss in passive protection in close collaboration between the HL-HLC work packages and experiments
- We rely on active protection based on beam loss monitoring by the machine + experiments + fast beam dump
- A list of potentially dangerous failure scenarios has been established, and is studied by detailed simulations

Backup

Steady state signal and collision debris contamination





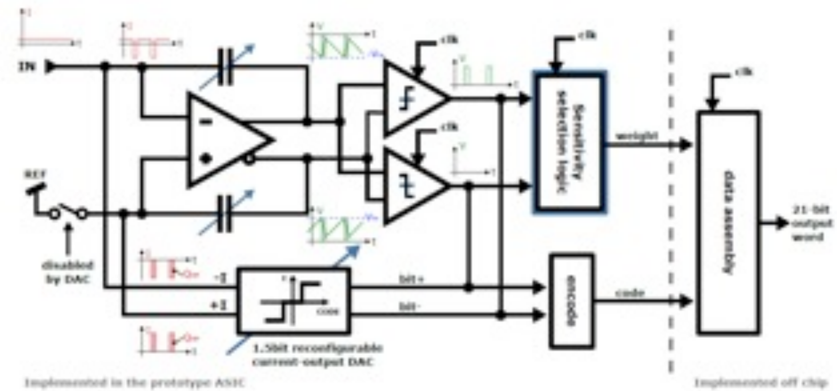


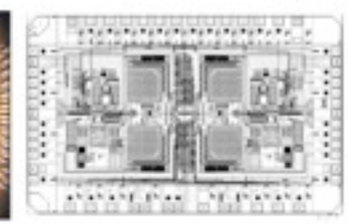
- Development of a sensor to be placed in the cold mass of the triplet magnets (2 Kelvin, 1 Tesla)

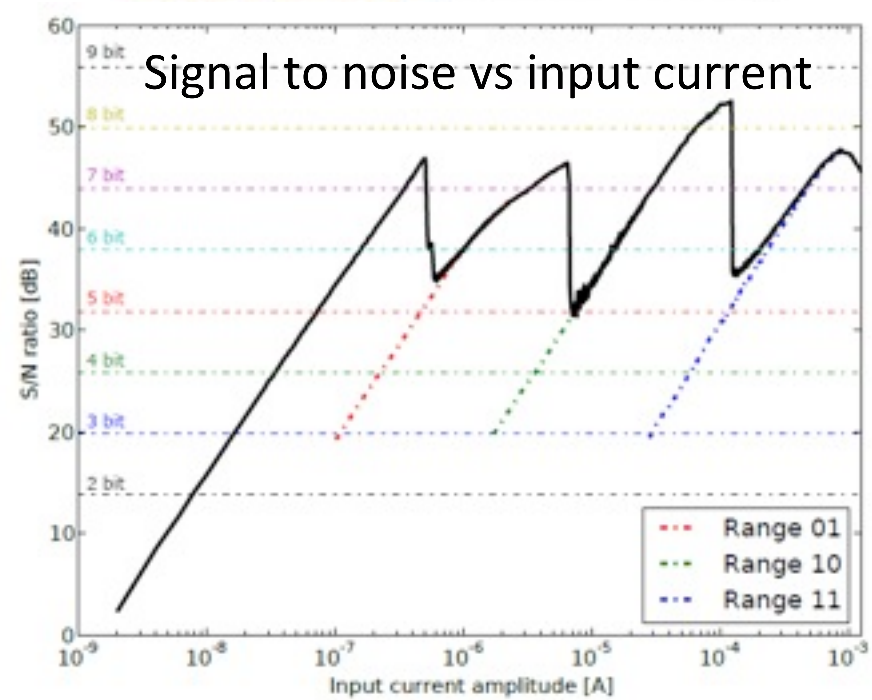
Beam loss acquisition system upgrade for HL-LHC

- Front end electronic:
  - Development of a radiation tolerant integrated circuit to overcome cable noise limitations for threshold settings

- Back end electronic:
  - Development of a FPGA VME carrier card to increase system availability and overcome FPGA limitations for threshold logic implementations







present TAN, designed by LBNL

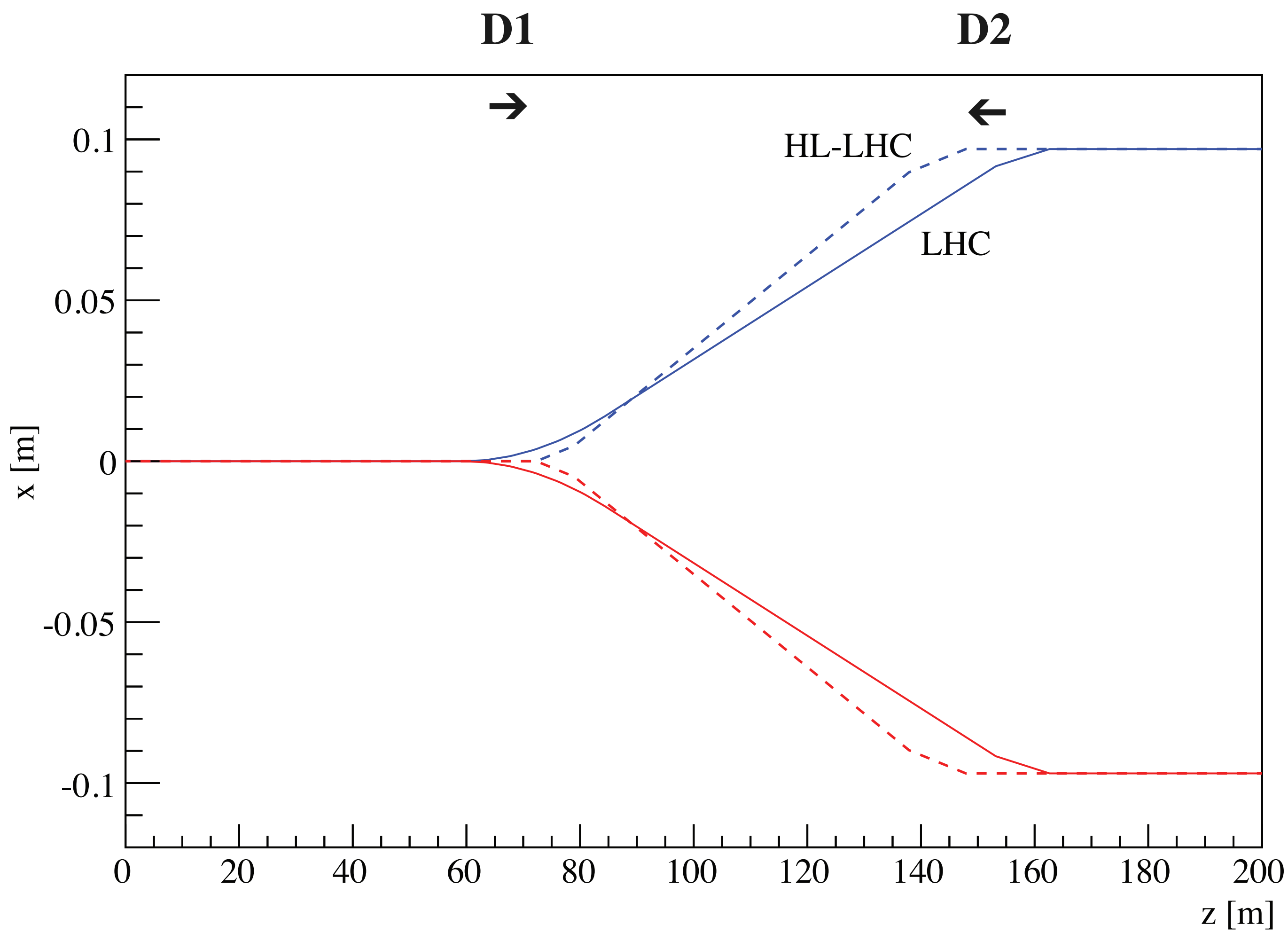
Functional Specification **LHC IP1/IP5 NEUTRAL BEAM ABSORBERS (TAN)**

Egon Hoyer, William Elliott, William Turner / LBNL, [EDMS 108093] from 2002

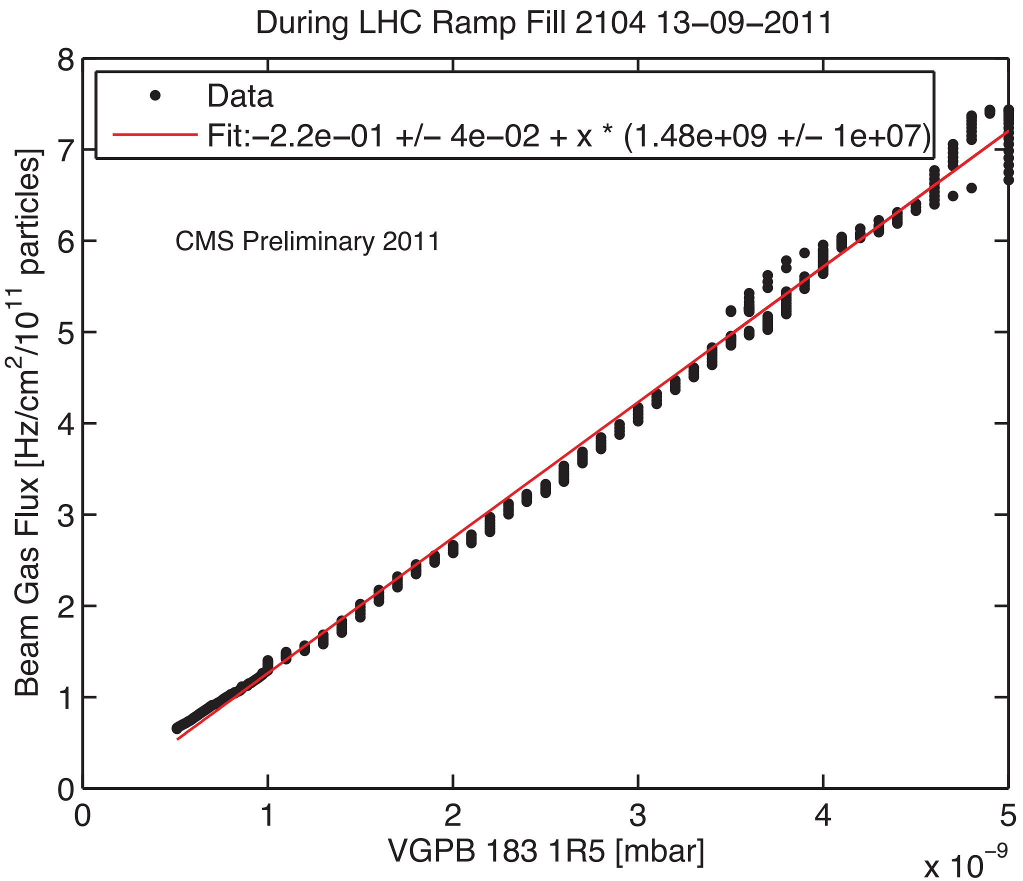
1.1m x 3.7m block with Cu absorber, 210 W at 1e34cm-1s-1

position, starts at 140 m from IP

Two beam separation, MAD-X survey



Beam-gas background



Courtesy Anne Dabrowski / CMS