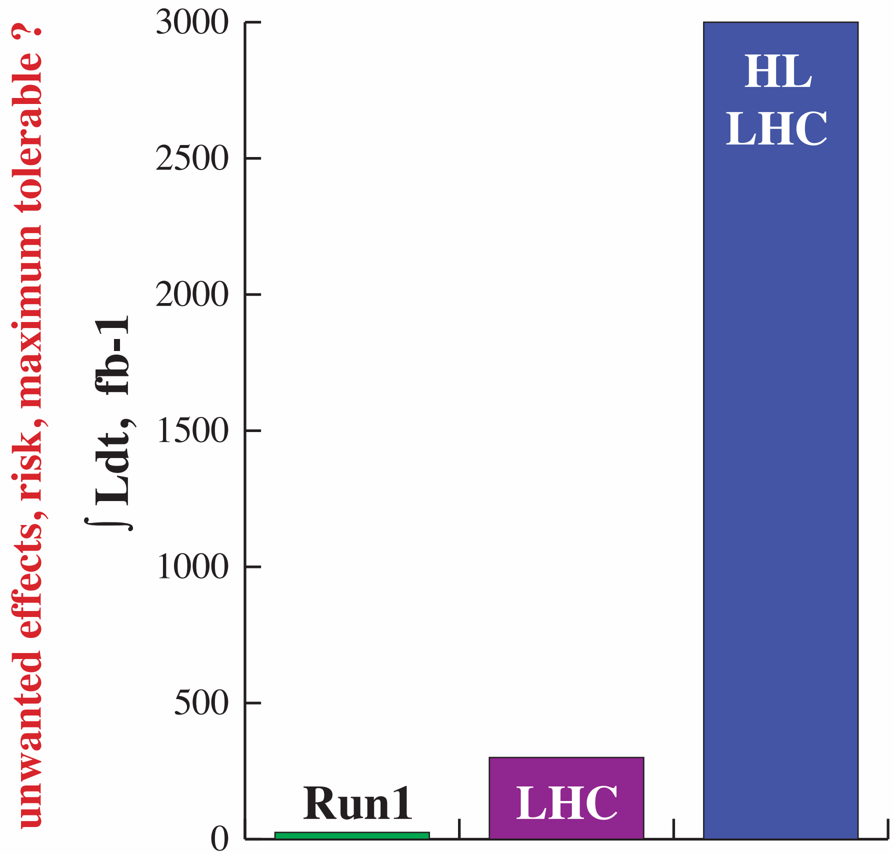
Overview of aperture, risks, losses, collimation and background

principles and main trends more quantitative, and concrete cases in next talks



HL-LHC : will give a lot more

- **integrated luminosity ✔**
- **radiation (✔)**

what about

- **background ?**
- **risk of damage ?**

Have to make sure we remain well balanced for what the experiments need and in particular that risks remain within tolerable limits

Based on work in the Collider-Experiments Interface WP8 in close collaboration with other WPs Accelerator Physics, Collimation, Crab cavities, Machine Protection, Energy Deposition, Integration and the LHC Background Study group + in collaboration with experiments

Introduction

well known that machine and experiments have to some extend conflicting requirements

Experiments : vertex detectors as close as possible to beam,

high luminosity safe stable operation and tolerable backgrounds

Machine : lower beta* and higher intensity - need for larger aperture next to experiments,

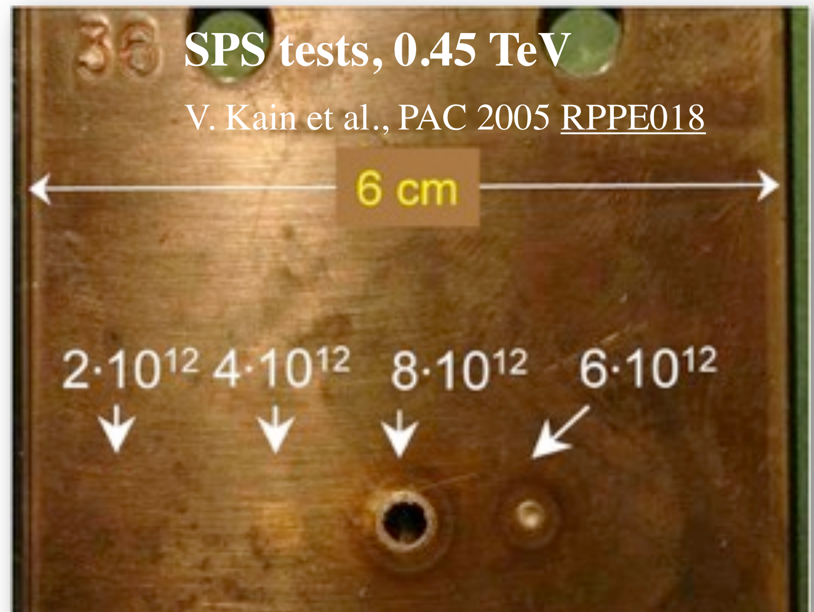
increased risk for damage and backgrounds

Also known

- SPS was **damaged several times** by accidental beam loss
- LHC by orders of magnitude **more dangerous** and **much longer** time scale for repairs
- we already had some scary events in the LHC Run I

async. beam dump with heavy loss into ALICE

RF-finger sticking into the beam-pipe next to CMS



LHC beams 15× more energy and reduced beam cross section

$8.e12 \; / \; 15^2 = \mathbf{3.5 \times 10^{10}}$

Risks, rough scaling from RUN I

as motivation for detailed study - not as definite numbers

- LHC **RUN II**, ~ 4× more dangerous

  ~ nearly 2 in beam energy / over 2 in energy density, ~2 #bunches, 3.2e14/beam

  smaller central beam pipes — but still larger than TAS radius.

- **HL-LHC** : ~ 2-3× more dangerous (6.e14/beam, lower emittance..) in general,

  interaction regions : lower β^*, new failure scenarios, ~ 3× more exposed

  longer running ~ 8y/3y

Together, risk to damage the more exposed central detectors, compared to RUN I :

$4 \times 2.5 \times 3 \times 8/3 = 80$ **~ two orders of magnitude**, similar to $\int L\, dt$ increase

Short term losses in detector region :

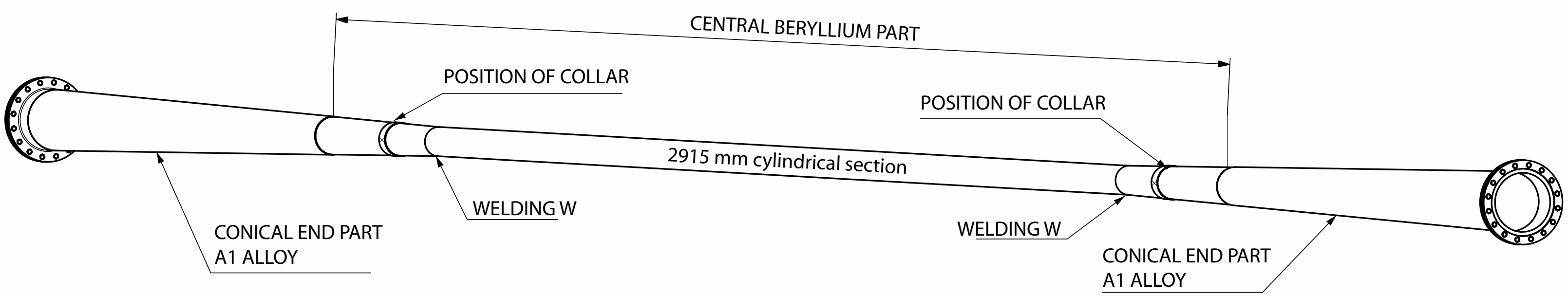
Roughly $O(10^9)$ charges cm^{-2} or $O(10^{-6})$ of full beam sufficient damage detectors

More in next talks

Inner beam pipes

New inner Be beam pipes in IP1 and IP5, implemented in LS1

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



CMS
lhcvc5c_0028-vAA

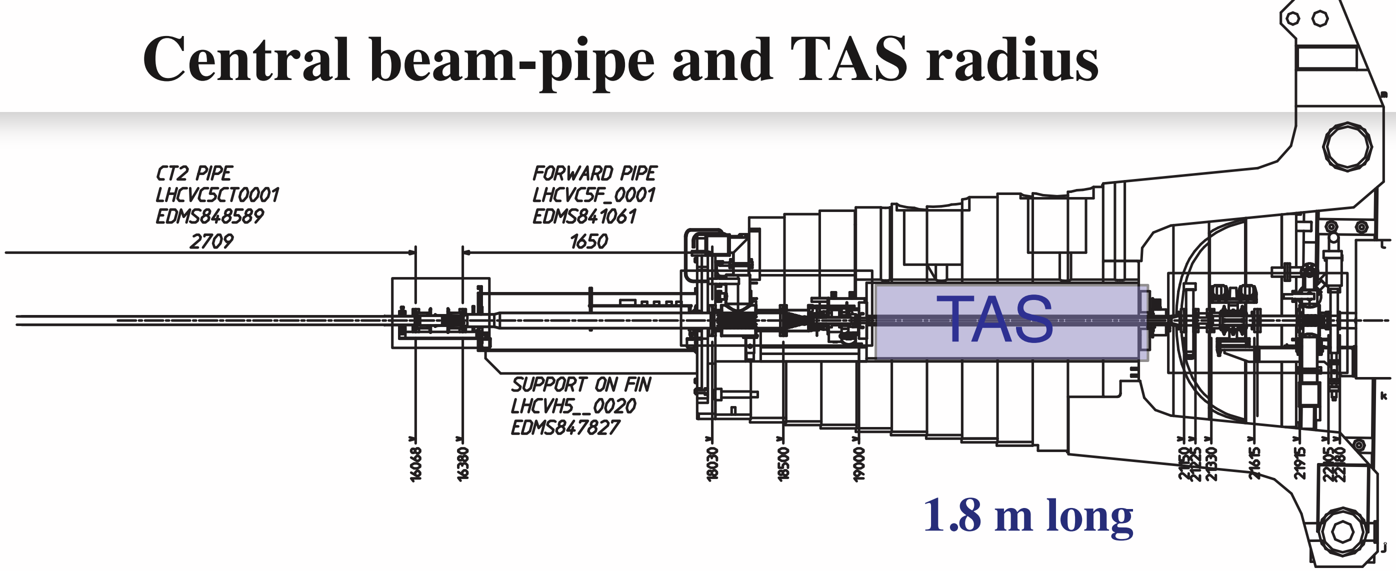
Initially approved for LHC, saying will have to confirm and in needed modify for HL-LHC

Has been verified that compatible with HL-LHC in terms of beam aperture

new ~ 2 × larger aperture triplet and absorbers TAXS, TAXN

experiments more exposed to beam loss, increased backgrounds and risks

Central beam-pipe and TAS radius



1.8 m long

Cu absorber

19m from IP

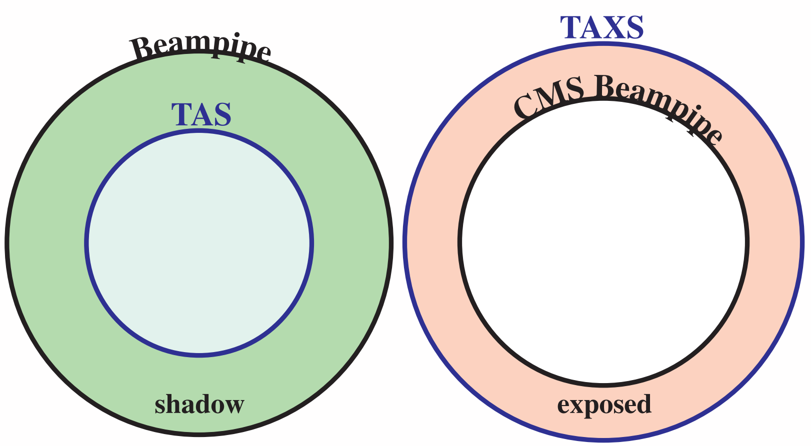
IP	original r_{min} mm	reduced r_{min} mm	Experiment	when
1	**29**	**23.5**	ATLAS	LS1
2	29	18.2	ALICE	LS2
5	**29**	**21.7**	CMS	LS1
8	30 (5)	30 (3.5)	LHCb (VELO closed)	LS2

LHC, TAS : **17 mm**

HL-LHC, TAXS ; **27 - 30 mm**

central beam-pipe not in shadow

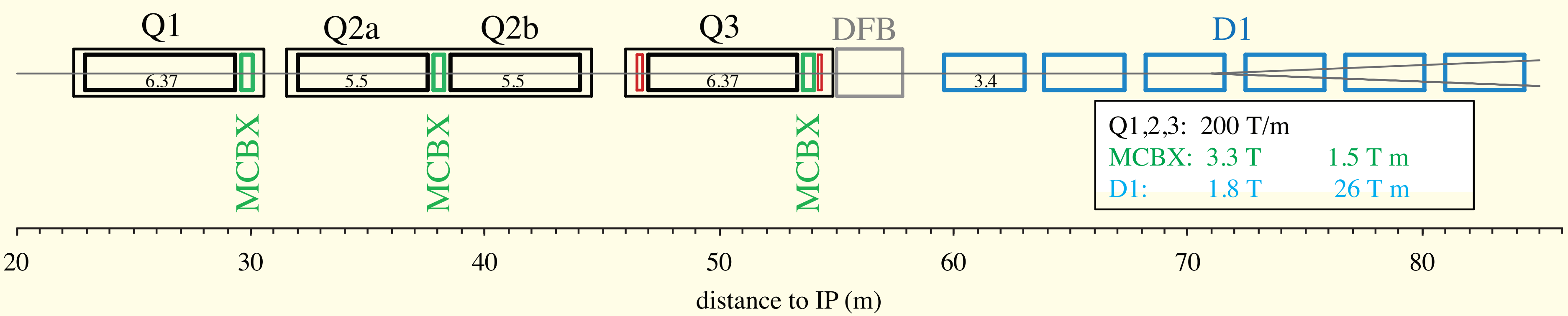
any more of TAS



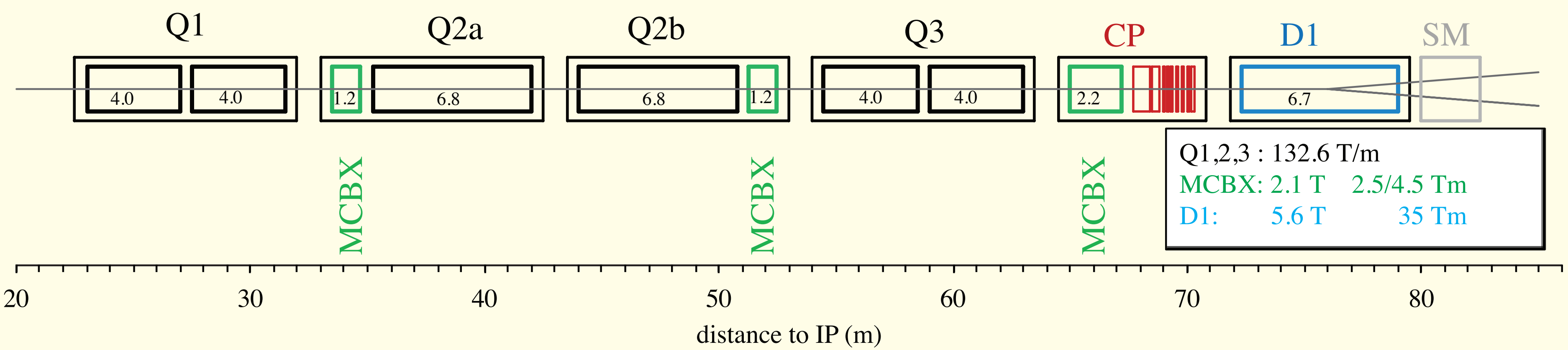
Layout changes, triplet Q1, Q2, Q3 and D1

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.)

Aperture

More luminosity : reduction of β* to 15 cm for round beams

Squeezing the beams at the IP

increases the beam size (and crossing angle) in the triplet

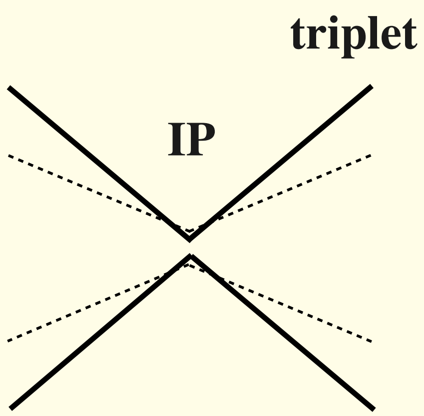
Beams largest in middle of Q2 at 44 m from IP

~ Linear increase of beam size from IP.

With need for beam screens and new internal tungsten shields

requires new, a bit over 2 × larger magnet triplet aperture

the inner coil diameter increases from 70 mm to 150 mm



TAS —> TAXS inner radius increased by nearly 2 × from 17 mm to 30 mm (60 mm in ∅)

to provide sufficient aperture down to beta* = 15 cm, for +/- 295 μrad crossing angle

and leave some margin for orbit and separation

increased matched to triplet aperture increase detailed aperture evaluation WP2 —>

Aperture update

Adding tolerances one by one in the next tables:

- Bare: no mechanical tolerances, perfect beam, perfect alignment
- Mech: mechanical tolerances in beam screen, perfect beam, perfect alignment
- Beam: mechanical tolerances in beam screen, imperfect beam (including triplet misalignments in orbit budget), perfect crab and perfect IP alignment
- Crab: mechanical tolerances in beam screen, imperfect beam (including triplet misalignments in orbit budget), crab misalignment, perfect IP alignment
- Offset: mechanical tolerances in beam screen, imperfect beam (including triplet misalignments in orbit budget), crab misalignment, IP misalignment

Aperture Round

	bare [σ]	mech[σ]	beam[σ]	crab[σ]	offset[σ]
TAXS		17.3	13.9	13.9	11.9
MQXFA.[AB]1	17.4	16.7	14.2	14.2	13.2
MQXFB.[AB][23]	12.8	12.4	10.5	10.4	9.4
MBXF	13.6	13.1	11.1	10.9	10.3
TAXN		17.3	14.7	14.2	12.7
MBRD	19.7	18.7	15.7	14.9	12.6
MCBRD	21.7	20.7	17.4	16.6	14.1
MCBYY	25	23.7	19.8	18.7	14.9
MQYY	26.3	25	20.9	19.7	15.7
TCLMB.5		28.6	23.9	23.9	20.2
MCBY[HV].5		29.6	24.7	24.5	20.6
MQY.5		30.6	25.6	25.4	21.4
TCLMC.6		29.2	23.9	23.9	21.2
MCBC[HV].6		30.3	24.7	24.7	24.7
MQML.6		30.2	24.6	24.6	21.8

β=15cm
Θ_c=±295 μrad
d_{sep}=±2 mm

Aperture Flat

	bare [σ]	mech[σ]	beam[σ]	crab[σ]	offset[σ]
TAXS		15.2	12.5	12.5	11.1
MQXFA.[AB]1	15.7	15.2	13	13	12.3
MQXFB.[AB][23]	12.5	12.1	10.4	10.4	9.7
MBXF	13	12.7	10.9	10.8	10.3
TAXN		14	11.9	11.6	10.6
MBRD	15.2	14.7	12.4	12.0	10.8
MCBRD	16.8	16.1	13.6	13.2	11.9
MCBYY	19.7	18.9	15.9	15.4	12.9
MQYY	20.2	19.4	16.3	15.8	13.4
TCLMB.5		20.6	17.1	17.1	14.5
MCBY[HV].5		21.4	17.8	17.6	15
MQY.5		21.7	18.1	18	15.3
TCLMC.6		20.7	16.8	16.8	14.9
MCBC[HV].6		21.4	17.4	17.4	17.4
MQML.6		21.7	17.7	17.7	15.7

β=30/7.5cm
Θ_c=±245 μrad
d_{sep}=±0.75 mm

Losses in the central detector region

Nominal beam very small at the interaction region

Aperture in number of sigma at the IP increases when beams are squeezed

Particles which can reach the inner detector region are the

secondary particles from showers :

- Charged particles with much reduced energy — over-focused
- Neutral particles — straight cone

Scaling of neutral particle flux, #neutrals / surface :

Roughly expect scaling with r^2

LHC/HL-LHC TAS, TAXS radius increase : (30 mm / 17 mm) ^ 2 ≈ 3 × increased flux

27, 29, 30 mm TAXS ? (in ∅ 54 mm, 58 mm or 60 mm)

(30/27)^2 23 % increase

(30/29)^2 7 % increase

not a major change in risk ; verify with simulations, watch out for hot spots — next talks

Failure scenarios for losses in the detector region

Important to understand, study and avoid as much as possible any fast failure modes

Should cover any dangerous scenarios — your ideas and suggestions are most welcome

According to our current knowledge, the main scenarios for very fast losses are :

- asynchronous beam dumps
- crab cavity failure modes

both studied in detail, more in following talks

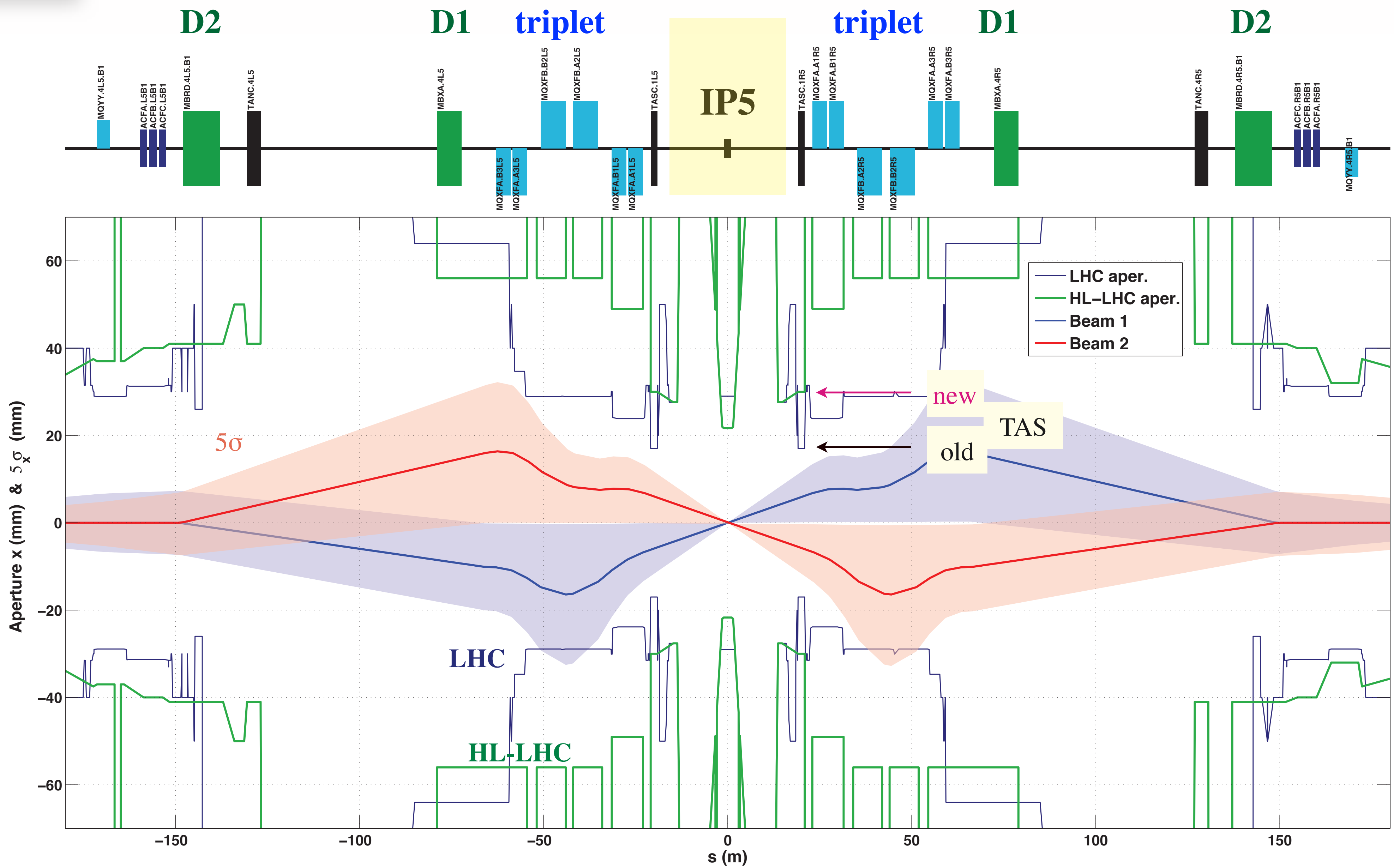
Other failure modes - magnet trips, UFOs:

to current knowledge not expected to lead to losses above damage levels before beam are dumped; still to be followed up ; extend studies to ALICE, LHCb

(my) concern : combined failure modes

- real life accidents often caused by combination of several factors
- what about : fast failure scenario + nonconformity like rf-finger which enhances local losses ? catastrophic events / reduced protection by damaged collimators

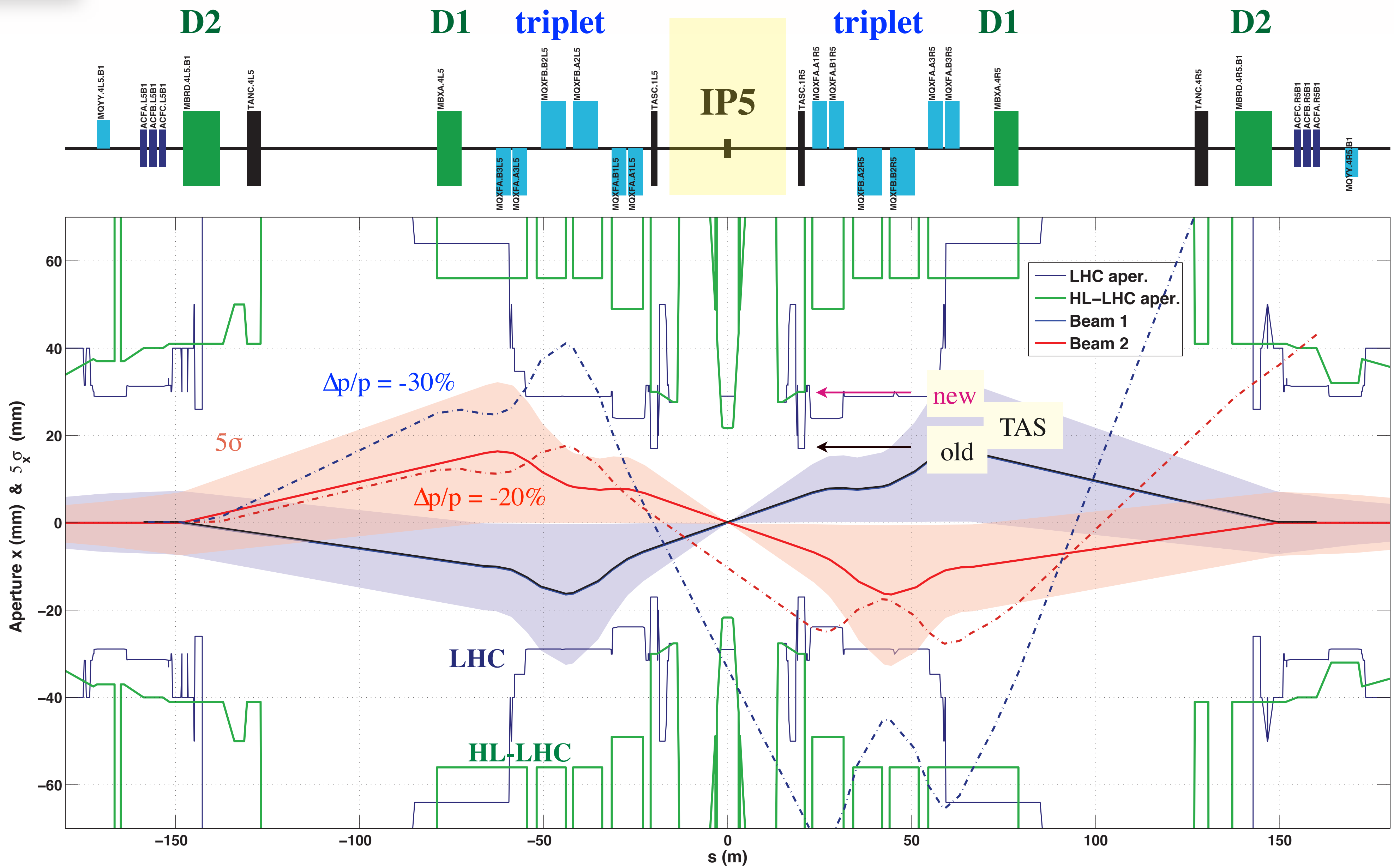
Schematic HL-LHC beam envelopes and apertures



Frederic Bouly et al. tupro021 IPAC’14

5σ envelopes, β* = 15 cm, 7 TeV / beam

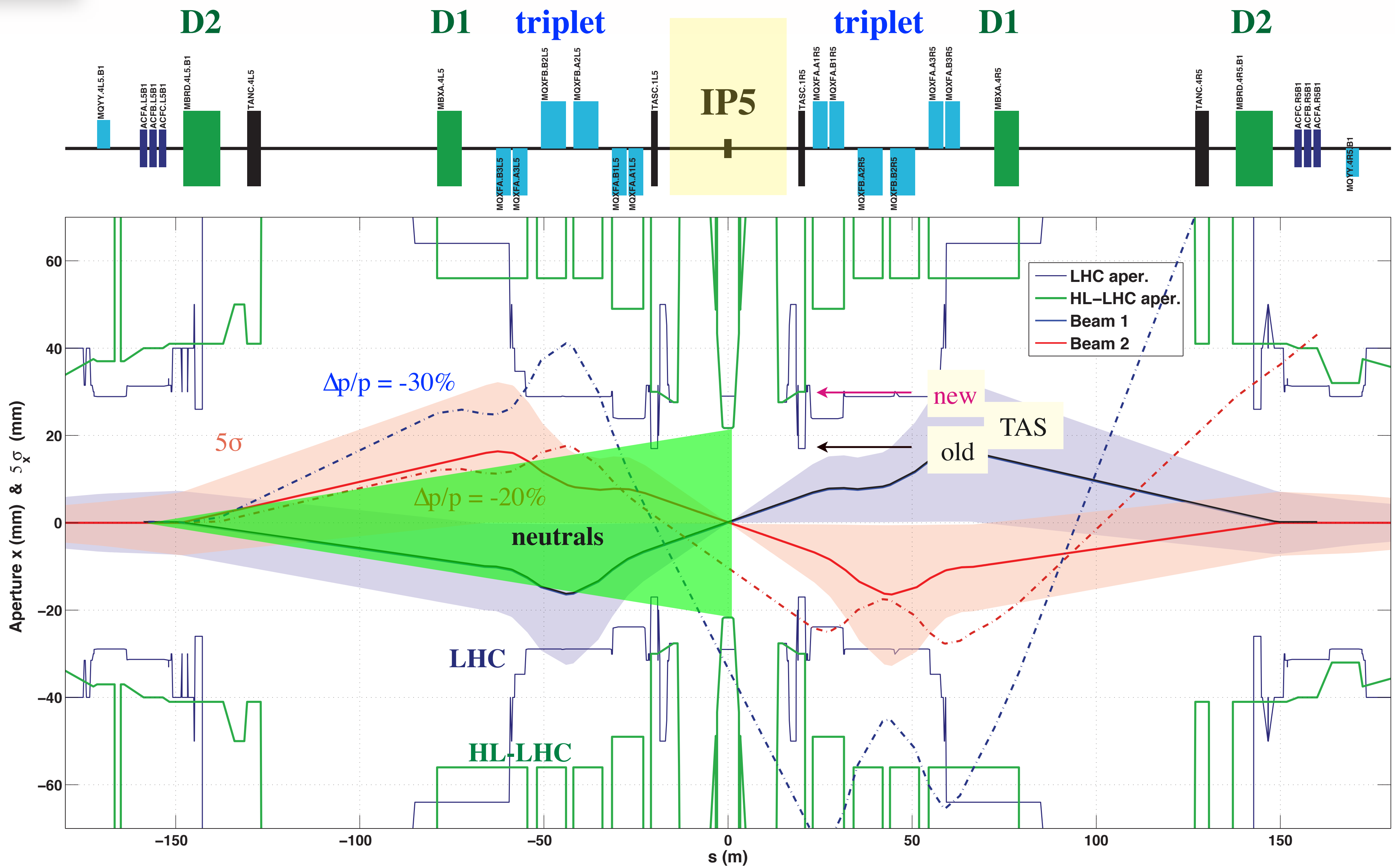
Schematic HL-LHC beam envelopes and apertures



Frederic Bouly et al. tupro021 IPAC’14

5σ envelopes, β* = 15 cm, 7 TeV / beam

Schematic HL-LHC beam envelopes and apertures



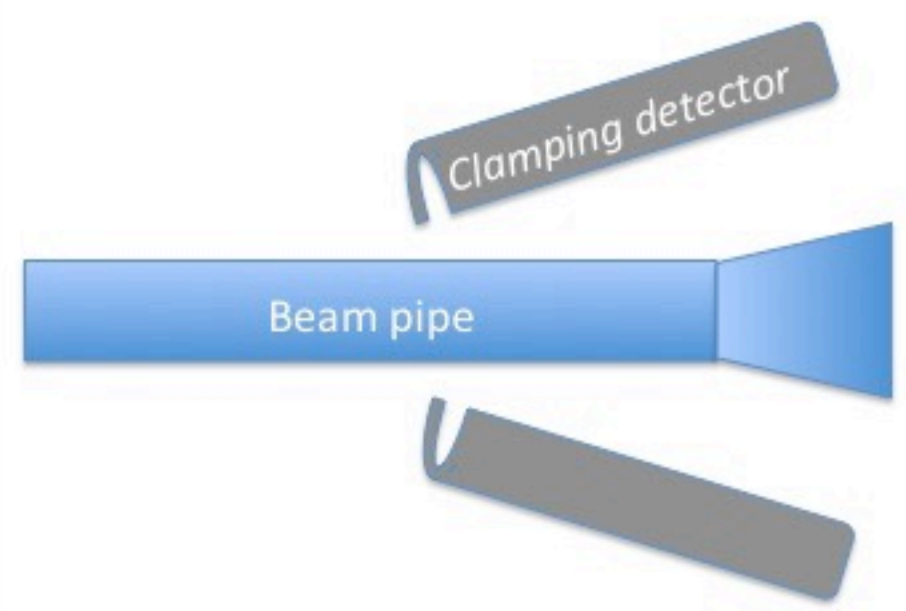
Frederic Bouly et al. tupro021 IPAC'14

5σ envelopes, β* = 15 cm, 7 TeV / beam

Practical considerations : flanches ; installation, removal

TAXS design and vacuum layout, WP8, Ilias Efthymiopoulos et al :
use of DN63 vacuum flanges imposes TAXS diameter ≤ 58 mm

Beam-pipe / geometry must be compatible with installation / removal of pixel detectors without creating holes in acceptance



What could be done for safety ? (1/2)

Controversial subject. Many parameters. Depends on running and failure scenario.
Safety measures are not always comfortable; should not compromise performance

- Collimation - more next talk Roderik Bruce

  increasing the margin between primary, TCDQ in case of asynch. beam dump, secondary collimators and tertiary collimators which protect triplet

  more, robust tertiary collimators

  halo cleaning, electron lens; study possibilities to adjust during the fill

- Mitigate (slow down) /avoid failures / detect quickly

  such as crab cavity trips — by design of hardware and control, described later by Kyrre et al.

- Limit TAXS / TAXN increase to what is needed for aperture

- Careful re-alignment of IRs — re-center beam pipes, in LS3

- Careful monitoring of beam induced backgrounds - may show first signs of non-conformities

What could be done for safety ? (2/2)

Optimize optics and running scenarios for safety

- The baseline scenario for luminosity leveling for HL-LHC is by leveling of β*
- during ramp/squeeze, beginning of fill we stay in the range of β* we already know down to β* ~ 40 cm, compatible with present TAS, at current crossing angle

- Really low β* ~ 15 cm only towards end of fills

- Optimize the phase advance between kickers and IRs to minimize losses

Experiments side :

- no further decrease in beam-pipe radius
- fast beam loss detection by experiments
- avoid structures which generate showers close to beam
- "beamloss hard" vertex detectors and electronics

Background

Comfortable signal to background ratios O(10^4) for ATLAS/CMS in Run1
(instead close to limits for pp, ALICE)

Dominated by beam gas ~ beam intensity × Pressure × beam energy (more secondaries)

Potential reasons for background increase compared to Run 1:

- heating, outgassing by synchrotron radiation; main step Run1 - Run2
- electron cloud, reduced bunch spacing and higher intensity; main step Run1 - Run2
- local heating from increased intensities
- more exposed central detectors
- changes in optics, phase advances, collimator settings

First experience in Run2 is good. No major issues. Changes in shape and moderate increase in backgrounds.

Important to monitor and understand in details; simulations very similar to failure cases, essential for testing / benchmarking simulations

Not expected to be a major limitation for HL-LHC ATLAS/CMS

Concluding remarks

Well known that the total beam power of the LHC and even more HL-LHC (700 MJ) is well above damage level (~3 orders of magnitude)

Safe running relies on excellent machine protection by fast beam loss detection and fast beam dump (within 3 turns)

Appears unavoidable that the passive protection of the inner detectors gets reduced

∅ 54 mm or 58 mm TAXS only marginally different in risk compared to 60 mm

What risk is acceptable ?

maybe a tiny risk of order once in 10 years to objects like collimator jaws might be acceptable but not for the triplet or inner detectors

- Good progress in detailed understanding and simulations (next talks)
- Potential to optimize the HL-LHC for safety without compromising performance

— to be further followed up