Impact on ATLAS and CMS

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On behalf of the ATLAS and CMS collaborations

Thanks to:
LBS working group (H. Burkhardt, A. Santamaria, K. Sjobaek)
Beam Collimation team (R. Bruce, R. Kwee-Hinzmann)
FLUKA team (F. Cerutti, A. Tsiganis)

Introduction

- HL-LHC target: 250/fb integrated luminosity per year (~10 x LHC!)
  - The accelerator optics will be redesigned, the layout of the insertion regions will be different, the magnet apertures in the proximity of the experiments will increase.

- Is there a risk of serious damages to the detectors in case of beam failures? What is the expectation on machine induced background?
  - Background and Protection issues are addressed in collaboration between experiments and machine experts (LBS working group).

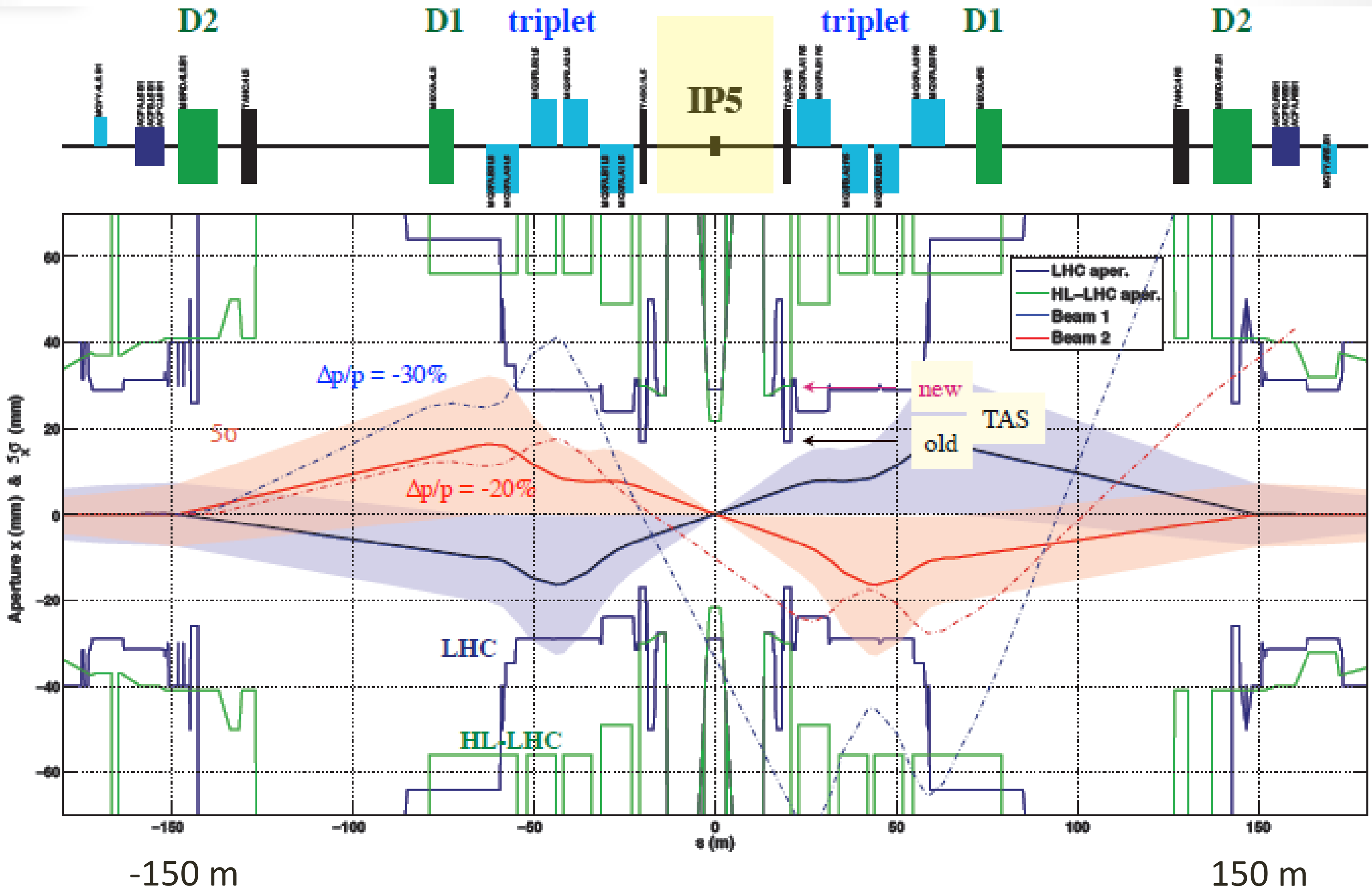
- Content:
  - General Considerations on HL-LHC beam failures (talk of R.Bruce).
  - Simulations of the impact on the experiments.
  - Machine Induced Background studies.

HL-LHC beam failures: considerations

- Superconducting D1
  - Good for protection (slower reactions) but worst for vacuum.
- β leveling
  - Good for protection (TCT more open at beginning of operations).
- Crab cavities
  - Realistic scenarios below the damage threshold in pixels.
- Asynchronous beam dump
  - Realistic scenario: 1-3 times/year.
  - Largest impact expected at IP5 (simulations under production).

- The impact of beam failures on the experiments is expected to be larger due to the larger aperture of the inner triplet quadrupole absorber (TAS) from 34 to 60 mm in diameter.
  - What are the consequences for the protection of the experiments?

HL-LHC beam envelope and apertures

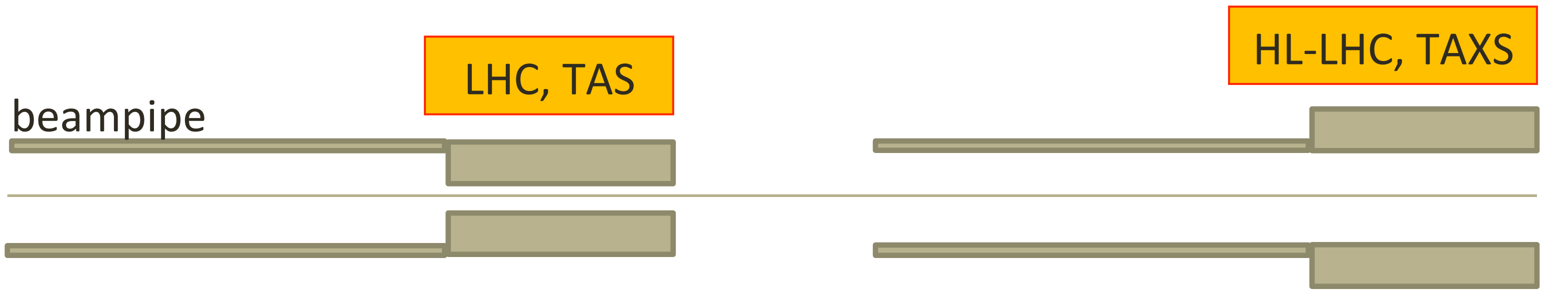


Frederic Bouly et al. tupro021 IPAC'14

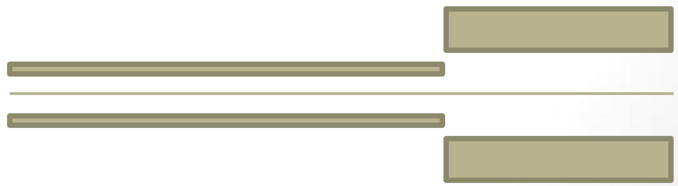
5σ envelopes, β* = 15 cm

Beam pipe and the TAS

- The beam pipe will not be anymore in the shadow of the TAS at HL-LHC.
  - The beam will be much more focused at the IP, it is hard to imagine any scenario in which the beam could hit directly the experiments.
  - What about protection from showers into the experiments? Simulations needed.



- Smaller beams at the IP opens the possibility to design smaller beam pipes
  - ATLAS has no plan to design a new beampipe.
  - New CMS beampipe is being designed.



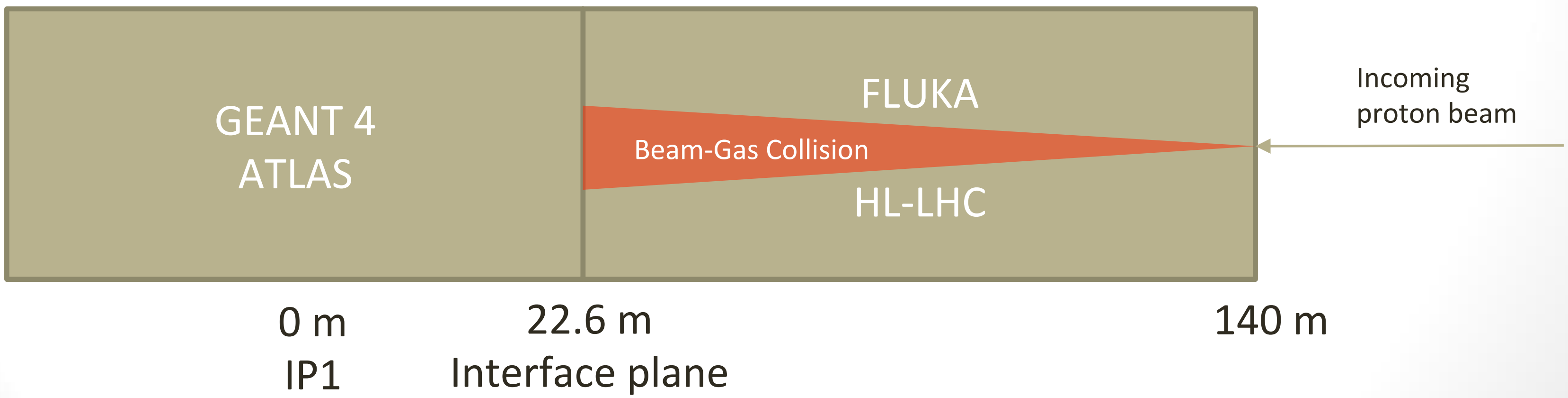
Damage to pixel detectors

- How close do we (can we) want to approach the beam? How to quantify the risk of damages? What is the maximum dose?
  - Hard to estimate because HL-LHC design evolves continuously (β^* now 20 cm) and the limits for damaging the pixel detector is not clearly established.
  - Damages are expected also at high instantaneous flux for which the integrated dose is below the maximum tolerated dose.

- Pixel Detectors have been tested in irradiation facilities
  - ATLAS: no damages at 1e10 MIPs/cm^2 [NIM A, 565 (2006) 50-54]
  - CMS: no damages at 5e9 MIPs/cm^2 [CMS-DN-2013/11]
  - Tests on phase 2 technology with higher intensity beams are needed.
  - Interesting possibility to use HiRadMat Facility at CERN SPS is under discussion.

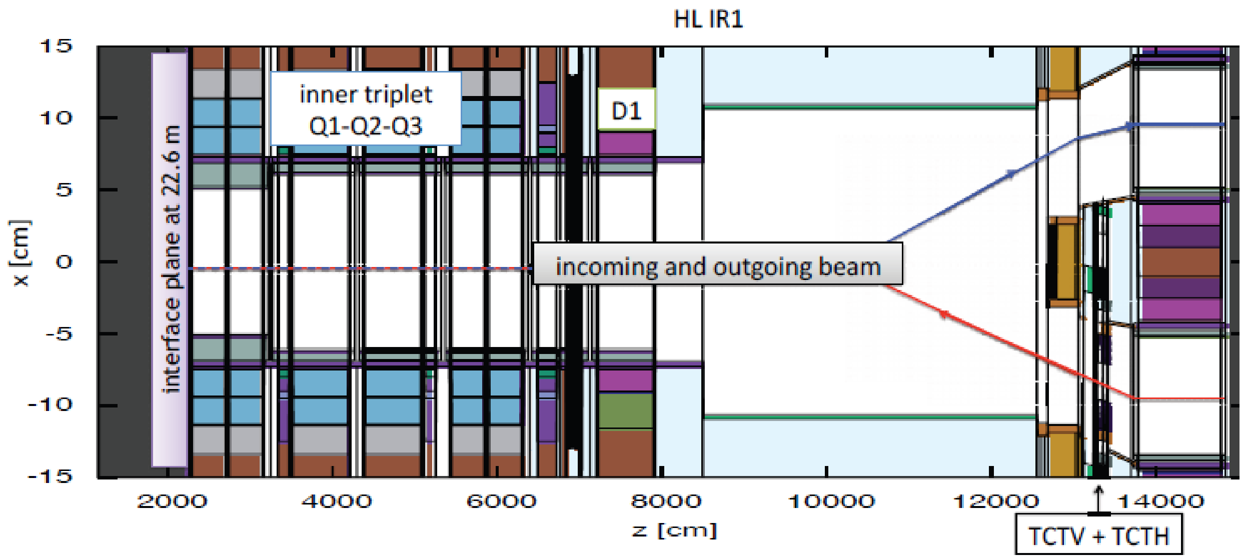
Simulation of beam failures in ATLAS

- Simulations of beam failure scenarios are under production
  - A first estimate is obtained from the simulation of beam-gas interactions.
  - Beam-gas interactions are simulated with FLUKA till the cavern entrance (22.6 m) where particles are scored for further tracking in ATLAS with GEANT4.
  - The average dose maps (R,Z) per beam-gas interaction are calculated for different TAS aperture between 34 and 60 mm.



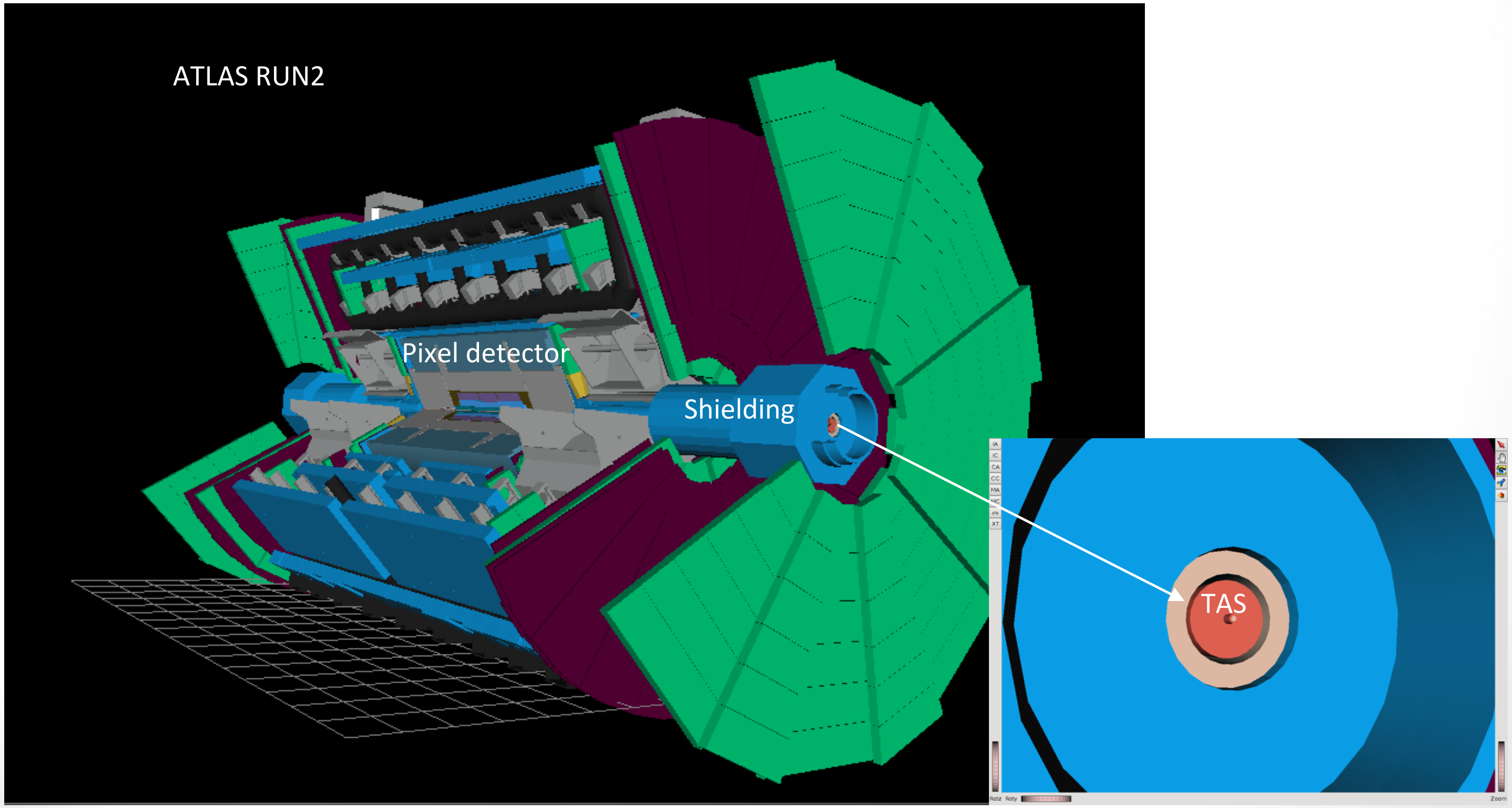
HL-LHC layout in FLUKA

- HL-LHC Layout 2013
  - HL-LHC IR1 B2 7 TeV beam, start-up machine.
  - β^* = 0.15m, optics version HL-LHC 1.0 (baseline now 0.2m).
  - nominal collimator settings - TCTs at 8.3σ (baseline now 10.9 σ).
  - TCTs assumed to be located 131.8/133.5 m from the IP (likely change of ~tens of cm).
  - TAN aperture (elliptical, with H and V semi-axes of 4.1 cm and 3.7cm) is not the final one.
  - TAN vacuum chambers for both beams are parallel (which will not be the case).
  - Concrete shielding blocks (JSCA) currently installed between D1 and TAN are not included.

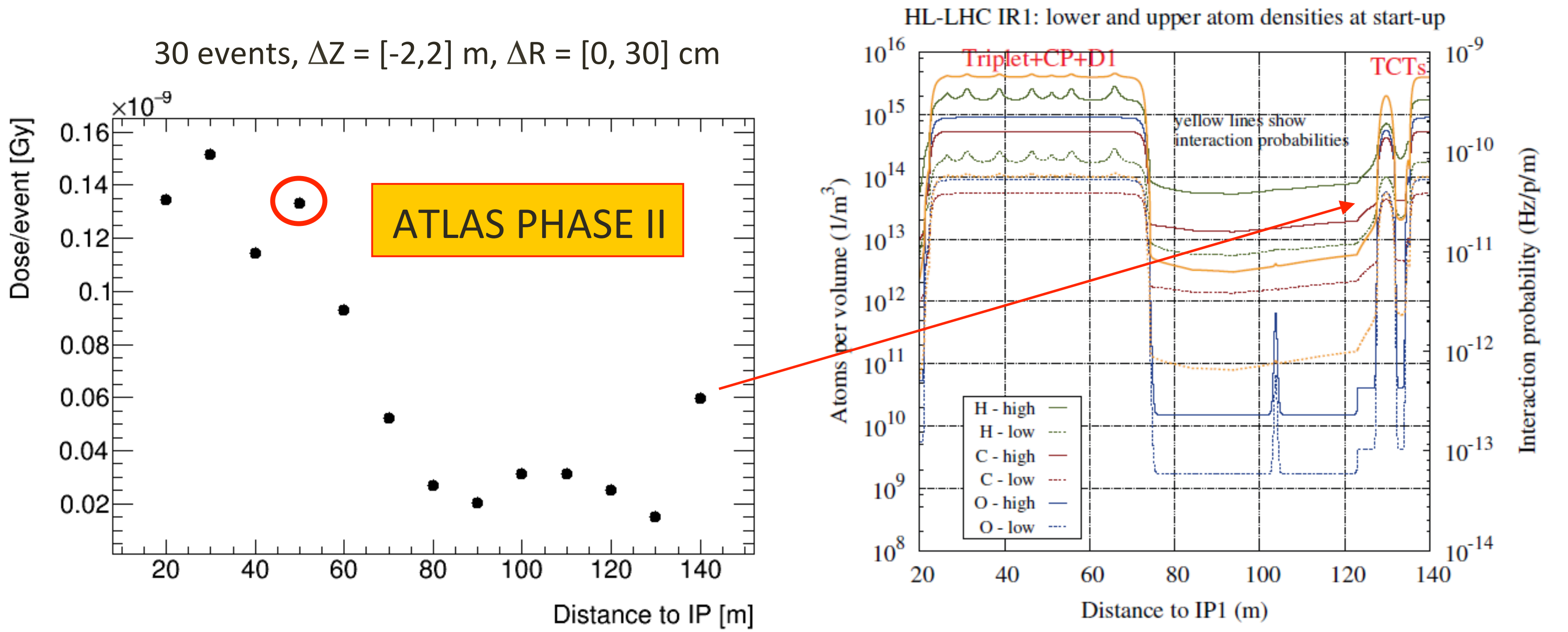


ATLAS geometry

- Simplified geometry for this study: beampipe + shielding + IDs.
- The TAS is a copper cylinder placed inside the ATLAS shielding system
  - Dimensions: 1.9 m long, R = [17 mm, 250 mm]), Z = 19.04 m



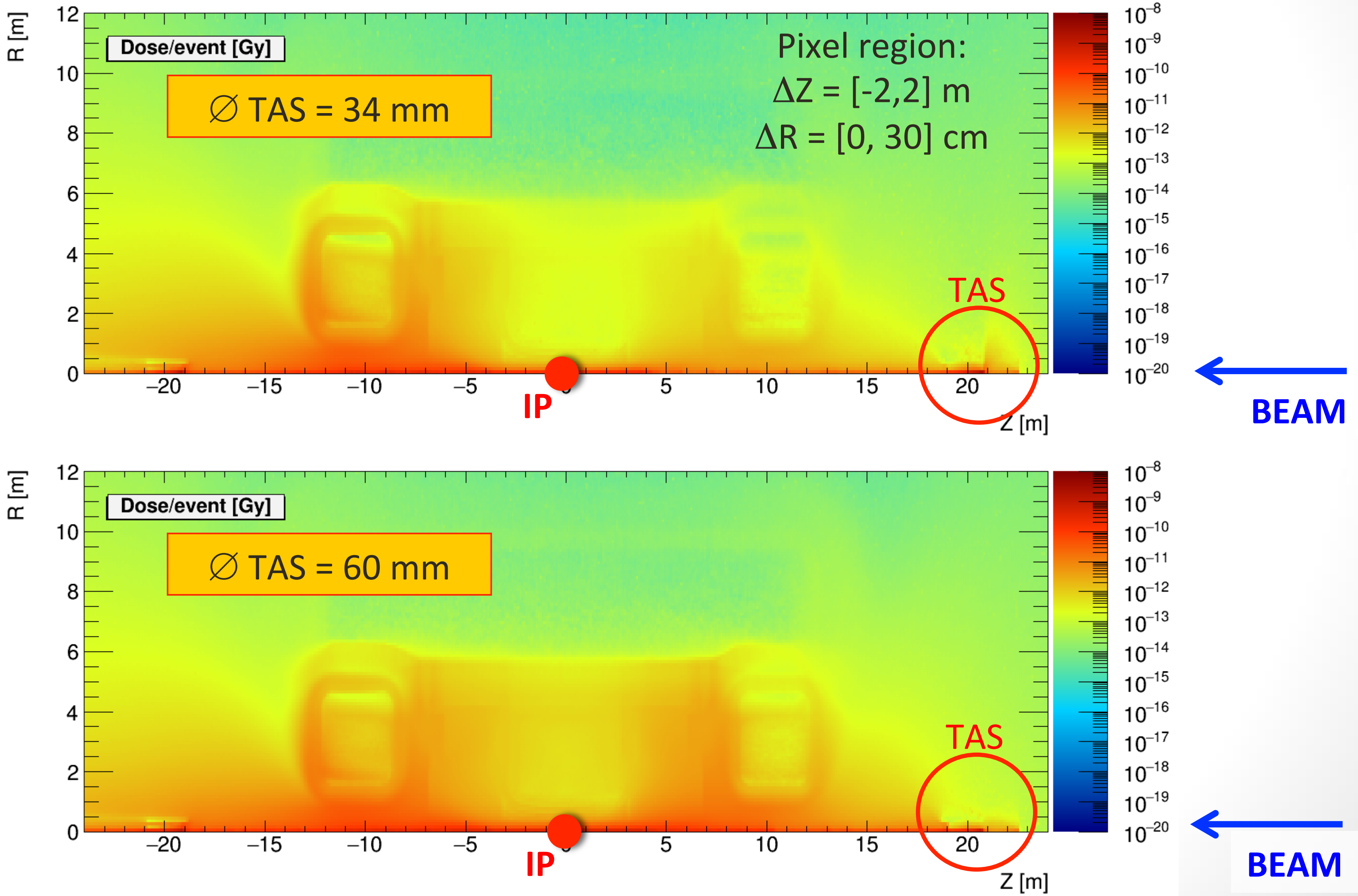
Dose Vs $Z_{Beam\text{-}Gas}$



- The region around Z = 50 m is one of the contributing most.
- Increase at 140 m due to higher local density of gas molecules.

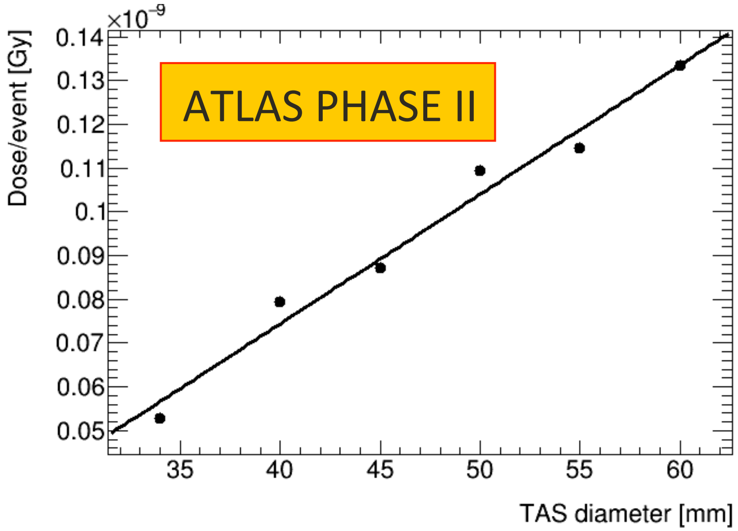
Dose maps

300 events, $\Delta Z = \Delta R = 10$ cm, HL-LHC Beam-Gas collision originating @ $Z_{BG} = [50, 60]$ m



Dose Vs TAS diameter

300 events, ΔZ = [-2,2] m, ΔR = [0, 30] cm, HL-LHC Beam-Gas collision originating @ Z_{BG} = [50, 60] m



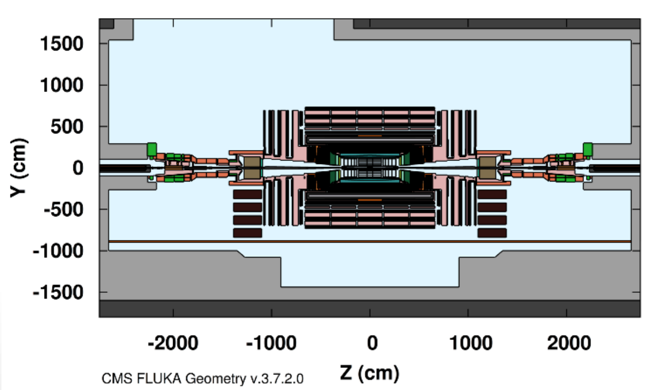
- The dose in the pixel region increases linearly with the TAS diameter.
  - Factor 2-3 increase opening the TAS from 34 to 60 mm.

- Assuming a damage threshold of 10^{10} MIPs/cm^2 and dE/dx = 3.9 MeV/cm/MIP, the maximum number of protons which can be lost is N = 27/Dose[Gy]
  - By opening the TAS, N decrease from 5e11 to 2e11 (huge losses, unlikely).

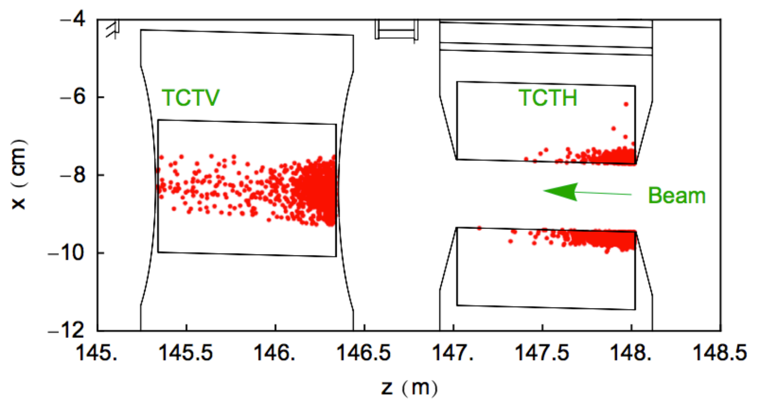
Simulation of beam failure in CMS

- Simulation steps:
  - SIXTRACK simulation of the beam failure scenario
  - FLUKA simulation of particle showers in the straight section
  - Store hit distributions at the entrance of the cavern
  - FLUKA simulation of particle showers in the experiment
- Simulations of beam failure scenarios are under production
  - For a first estimate: beam-halo hit distributions from TCT were used

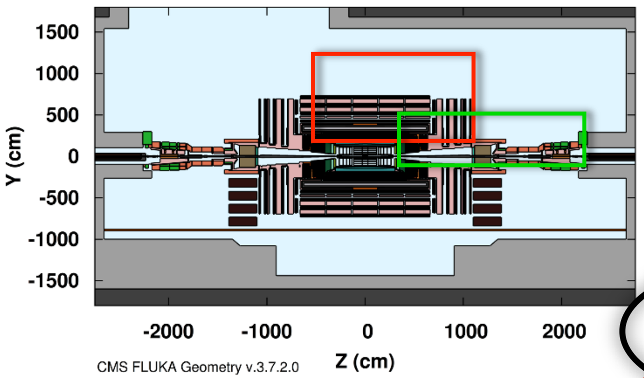
CMS

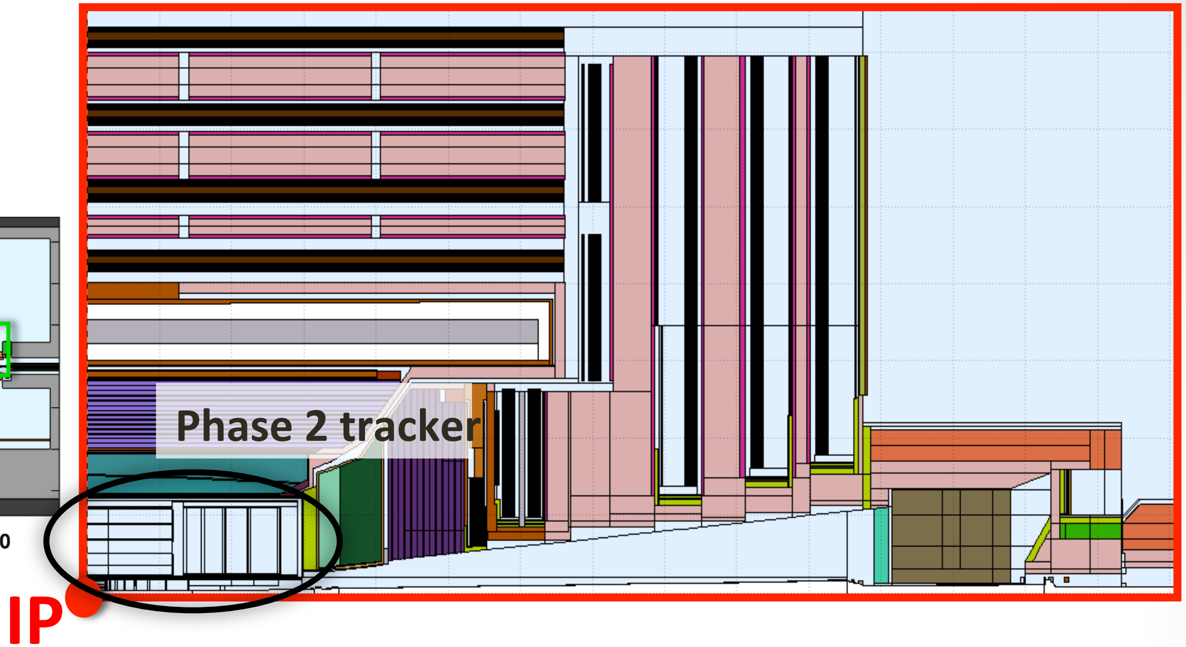


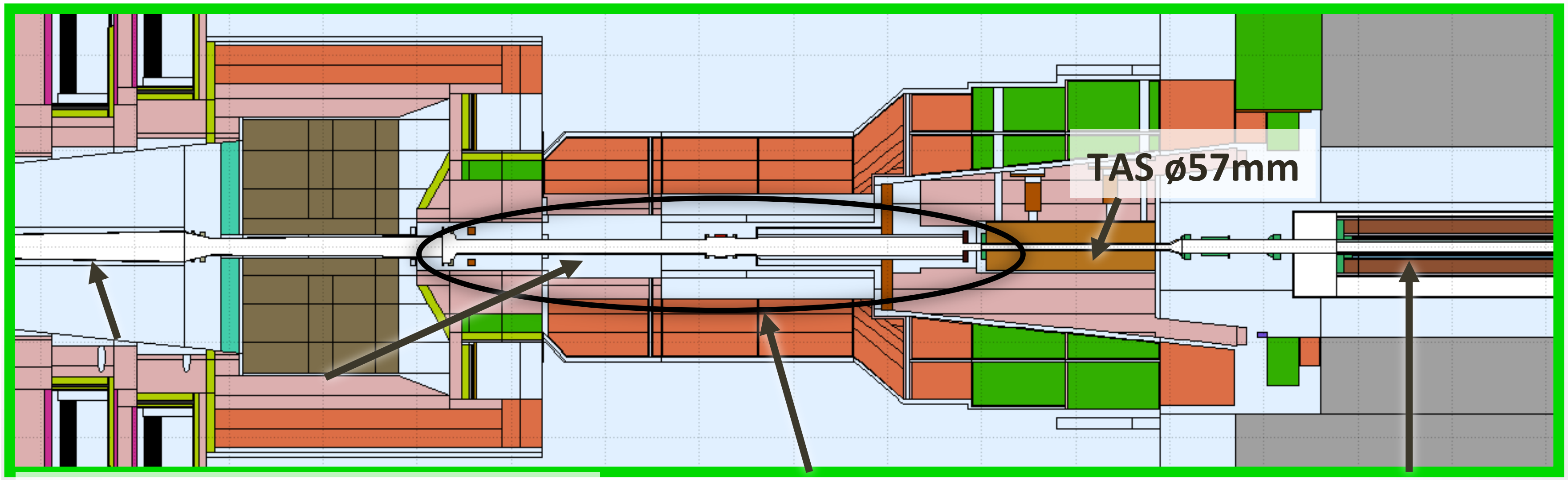
Example of hit distribution on TCTs from beam halo
[R. Bruce et al., NIM A 729 (2013) 825]



CMS







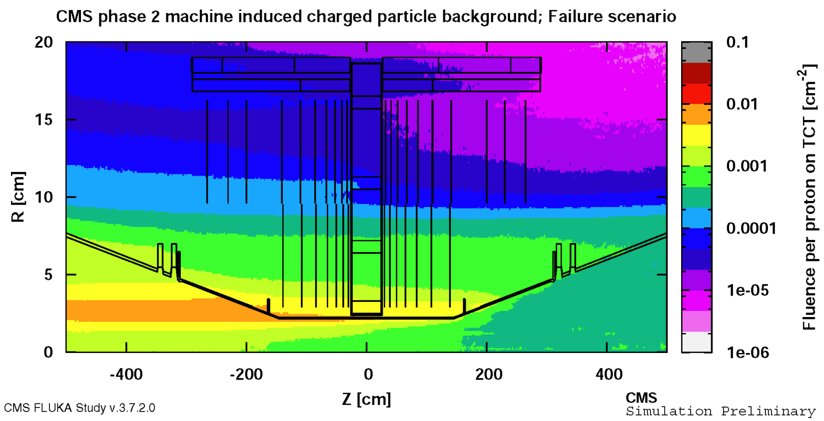
TP beam pipe:
Like Run 2, but Al & 150% thick

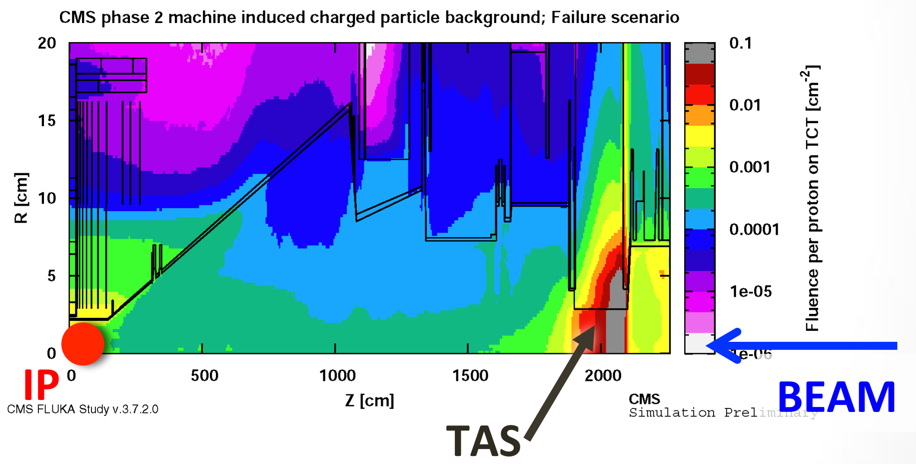
Increased aperture

HL-LHC quadrupole

Impact of beam failures in CMS

- Particles hitting the pixel detector are created mostly in the beam pipe
  - Particles from machine induced background are almost parallel to the beampipe -> beampipe acts as thick material for them.





- Peak energy density in the downstream end of barrel layer.
- Pixel damage threshold reached for 2.58 10^{11} protons on the TCT (huge loss, unlikely).

Machine induced background

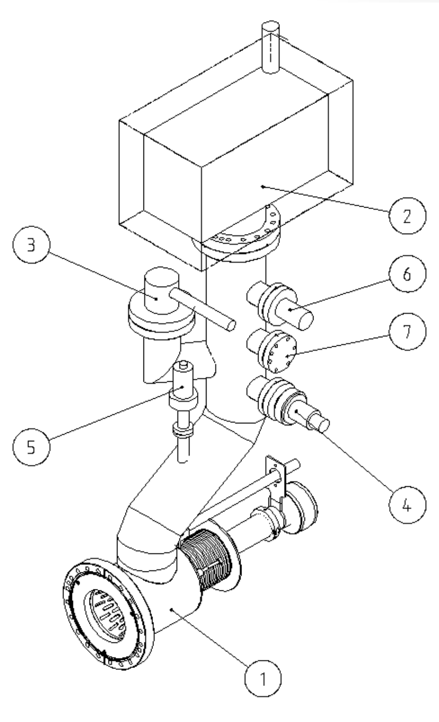
- Machine induced background will be larger at HL-LHC:
  - Background increases more than luminosity due to collimation hierarchy.
  - Vacuum will be worst at startup -> larger local beam gas.
  - After scrubbing, vacuum expected at same level.

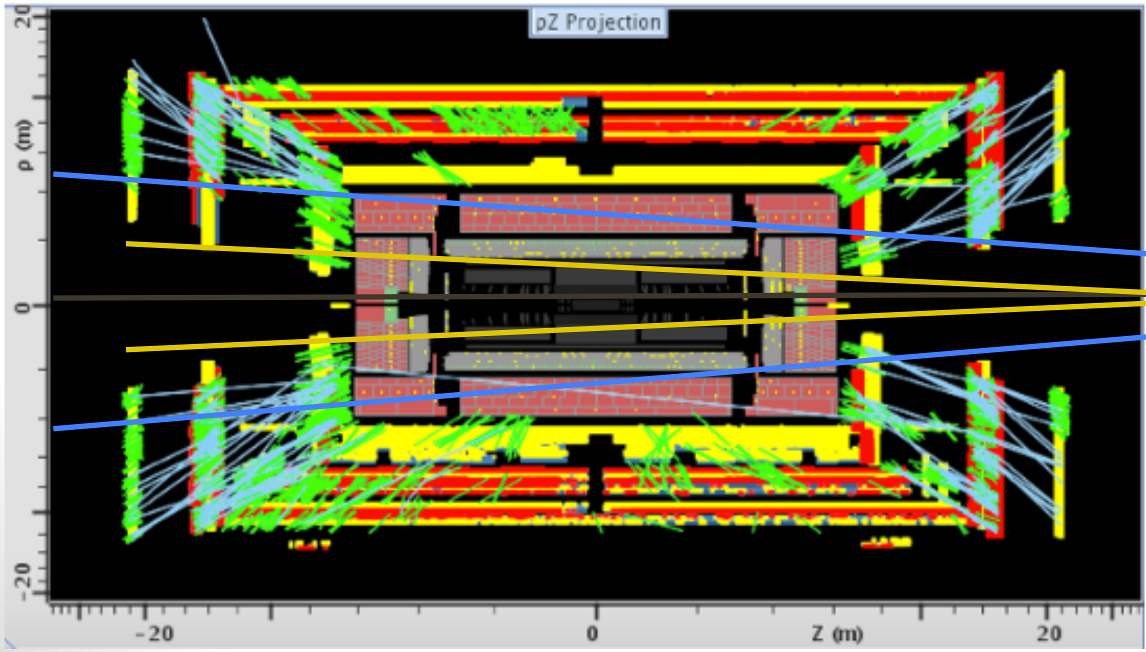
- Lesson learned at LHC
  - 2015 -> 2016: factor 10 more halo background due to closing TCT collimators from 13.7 to 9 sigma (to allow β^* = 40 cm)
  - Still dominated by beam gas (ATLAS results under approval)

- Machine development runs:
  - Pressure bump (next slides)
  - Loss maps (ATLAS results under approval)

MD runs 2016, ATLAS: pressure bumps

- Local increase of gas pressure in the LHC beam pipe
  - Distances from IP1: 19 m, 58 m, 150 m.
- Gas pressure monitored by gauges.
- ATLAS activity monitored to study machine induced background as a function of the distance from the IP.





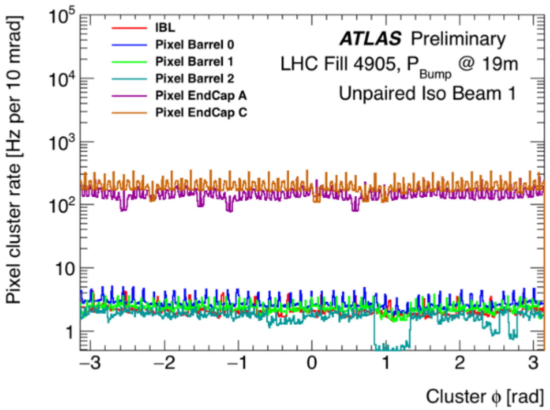
① Beam pipe

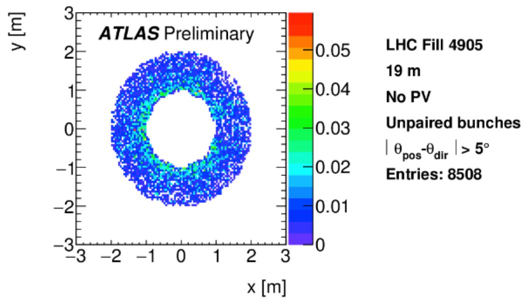
④ Pressure monitor

Result of pressure bumps in ATLAS

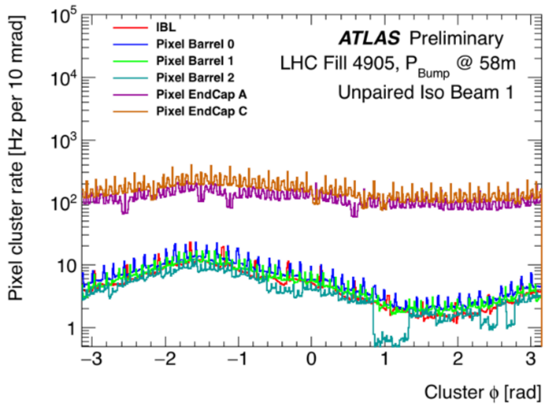
- The pixel φ asymmetry indicates the effect of the beam optics.
- The activity in the calorimeter increases with the distance from the IP.

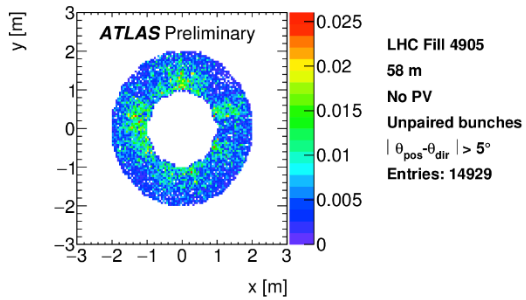
19 m



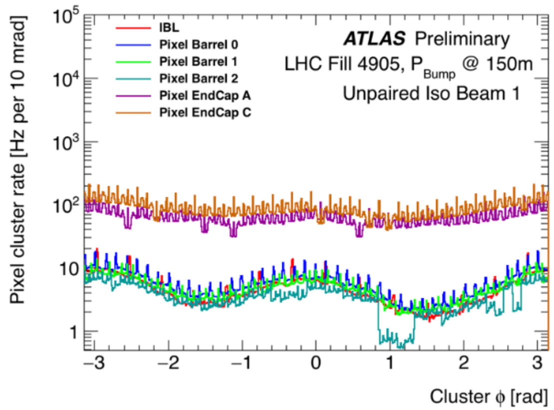


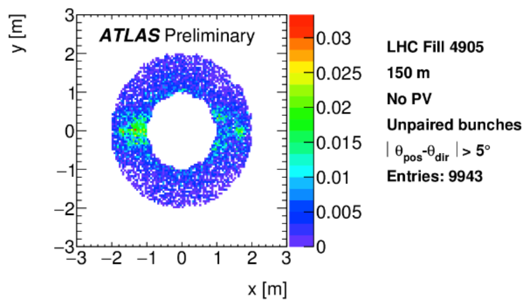
58 m



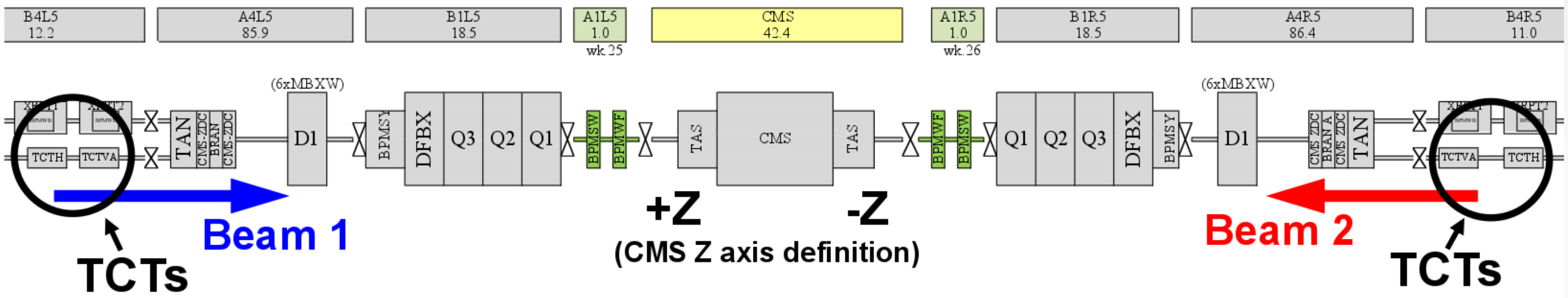


158 m

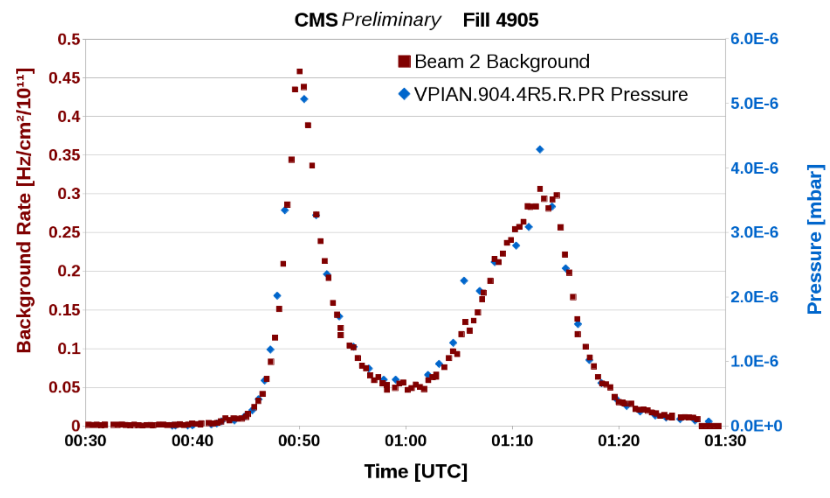


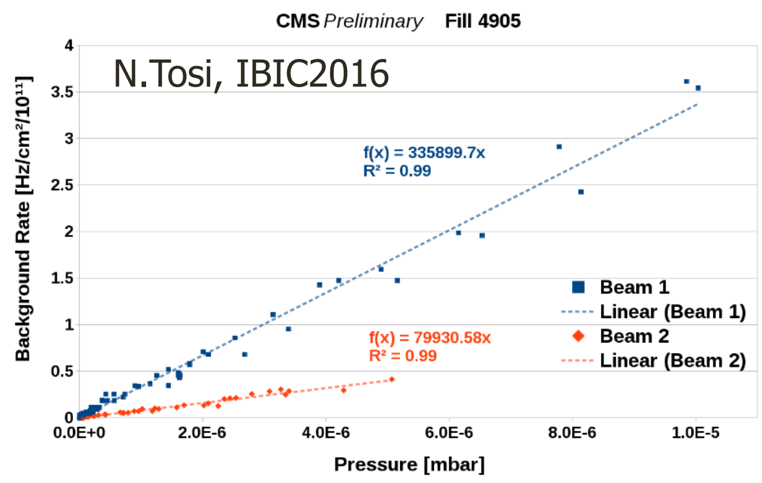


MD runs 2016, CMS: pressure scans



- Beam pipe vacuum degraded by heating a getter at +/-148 m from IP5.
- Machine induced background was monitored in CMS with BHM, a Cherenkov detector installed at 20 m from IP and a radius of 1.8 m.

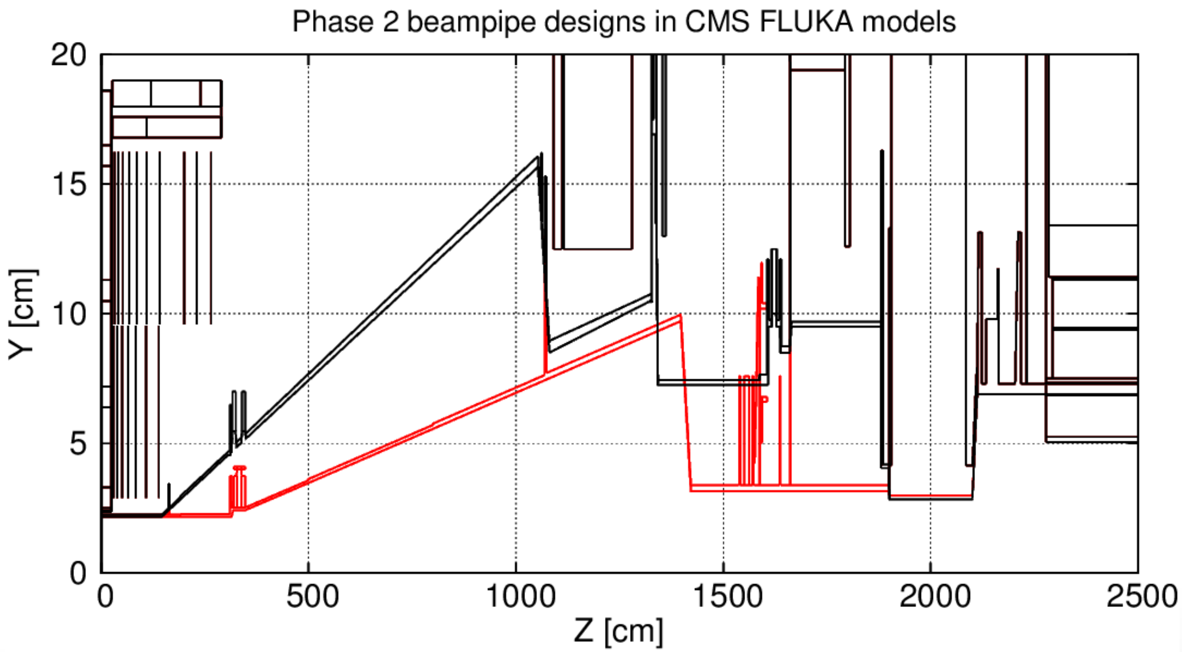




CMS Phase 2 beam pipe

- Phase 2 beam pipe design still be being studied and optimized.
  - Central beam pipe replaced to facilitate one long η-cone, which is desirable compared to various cones with transitions in order to reduce background.
  - Vacuum equipment now behind behind the TAS: it is shielded by the TAS, no problems for machine induced background.
  - Simulation results are being worked on.

Geometry outline of Techncial Proposal [Black] and Alternative [Red]



Summary

- HL-LHC will expose the experiments to a larger machine induce background and to a higher risk of damages in case of beam failures.
  - Major accidents could be very expensive in time and material.
  - It's hard to estimate the risk because the HL-LHC layout evolves and the damage threshold is not well known (new irradiation tests needed).
  - Particles fluxes to the experiments in case of beam accidents are estimated with generic background simulations: results below damage threshold.

- Machine induced background at LHC
  - Beam-gas dominating compared to beam-halo.
  - The farther the origin of beam-gas, the larger the impact at large radii.