LHC Interaction Region Upgrades and the Machine-Experiment Interface

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Introduction

- Regular meetings between machine and experiment groups held during 2007 to discuss issues related to an upgrade of the LHC Interaction Regions at P1 and P5
  - For ATLAS
    - http://indico.cern.ch/categoryDisplay.py?categId=1450
  - For CMS
    - http://indico.cern.ch/categoryDisplay.py?categId=1462

LHC Upgrade Options

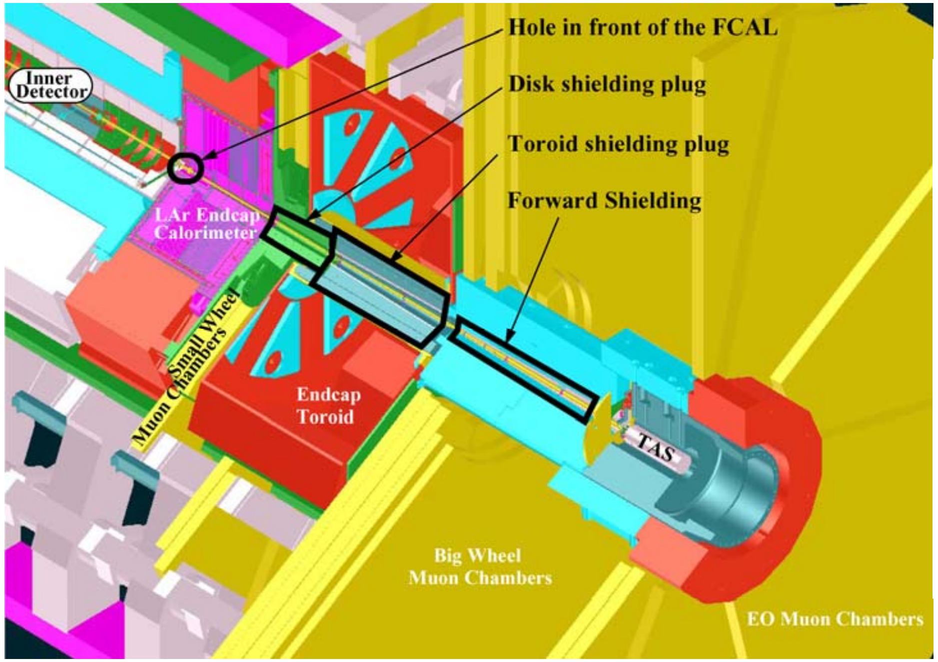
- Interaction region upgrade options considered in the working groups:
  - Baseline LHC optics with stronger, and/or larger aperture triplets.
  - Moving existing/modified inner triplets closer to IP.
  - Additional `thin' quadrupoles (Q0) between existing/modified inner triplets and IP.
  - A close–in dipole (D0).

General Machine-Experiment Issues

- For the experiments
  - Displacement, mechanical interference and/or removal of components of the particle detectors, particularly in the forward region.
  - Effect of fields of machine magnets on spectrometer magnets and *vice-versa*.
  - Scattering and albedo of particles into detectors from additional machine elements inside particle detectors, especially in the muon systems.
- For the machine
  - R&D and production of magnets with required performance (NbTi & Nb_3Sn).
  - Minimising and removing the heat deposited on magnets from products from the high-energy collisions.
- For the machine-experiment interface
  - An overall design that will enable the detectors to open for maintenance and modifications.
  - Implementation of stable mechanical supports and technical services (cryogenics, power) for the machine magnets within the particle detectors.

Integration in ATLAS

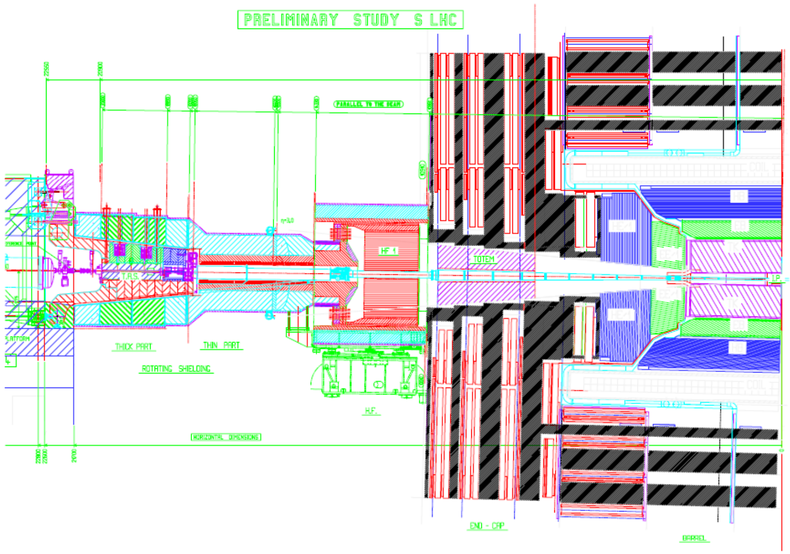
- Forward Calorimeter
  - Relatively close to IP1 so machine magnets can be installed on the non-IP side.
  - Removing it for servicing would require that the experimental beam pipe be of constant diameter.
    - But experimental beam pipe is major source of background.
- Radiation Shielding
    - The dense shielding around the experimental beam pipe could become an integrated magnet/shielding structure.
    - Decreasing the radiation shielding by inserting magnets has to be fully studied.



- Spectrometer solenoid is short and weak (2T), so small effect on Q0 and D0.

Integration in CMS

- Forward Calorimeter
  - Relatively far away from IP at 10 m. (front).
  - Machine elements cannot be installed in front.
- Collision background
  - As the experimental beam pipe is tapered, background is reduced.
  - The CMS solenoid return yoke shields most of the Muon System, so shielding around experimental beam pipe is minimal.

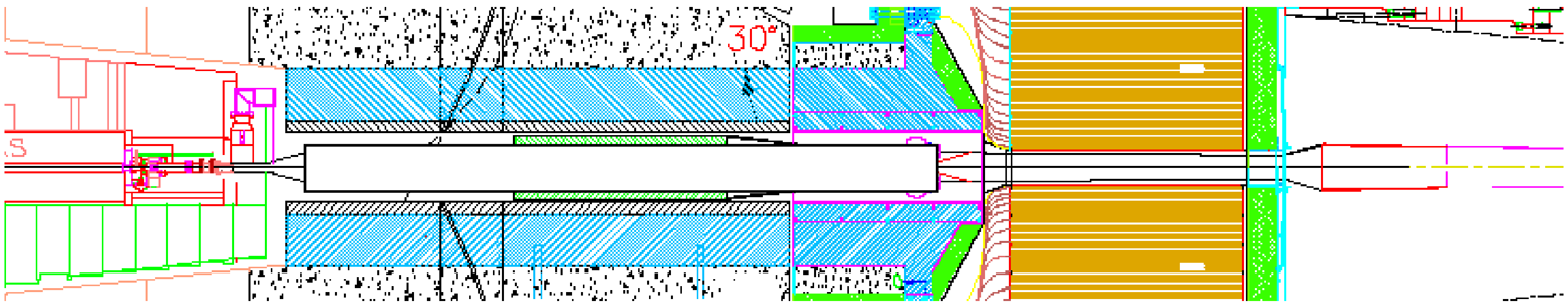


Integration in CMS

- Integrating the D0 and Q0 will require major modifications to the CMS detector.
  - Major change is that the Forward Calorimeter would need to be moved closer to the IP.
- The CMS solenoid is long (6 m) and strong (4T), and so the fringe field is important near the magnets, particularly D0.

CMS Experimental Beampipe

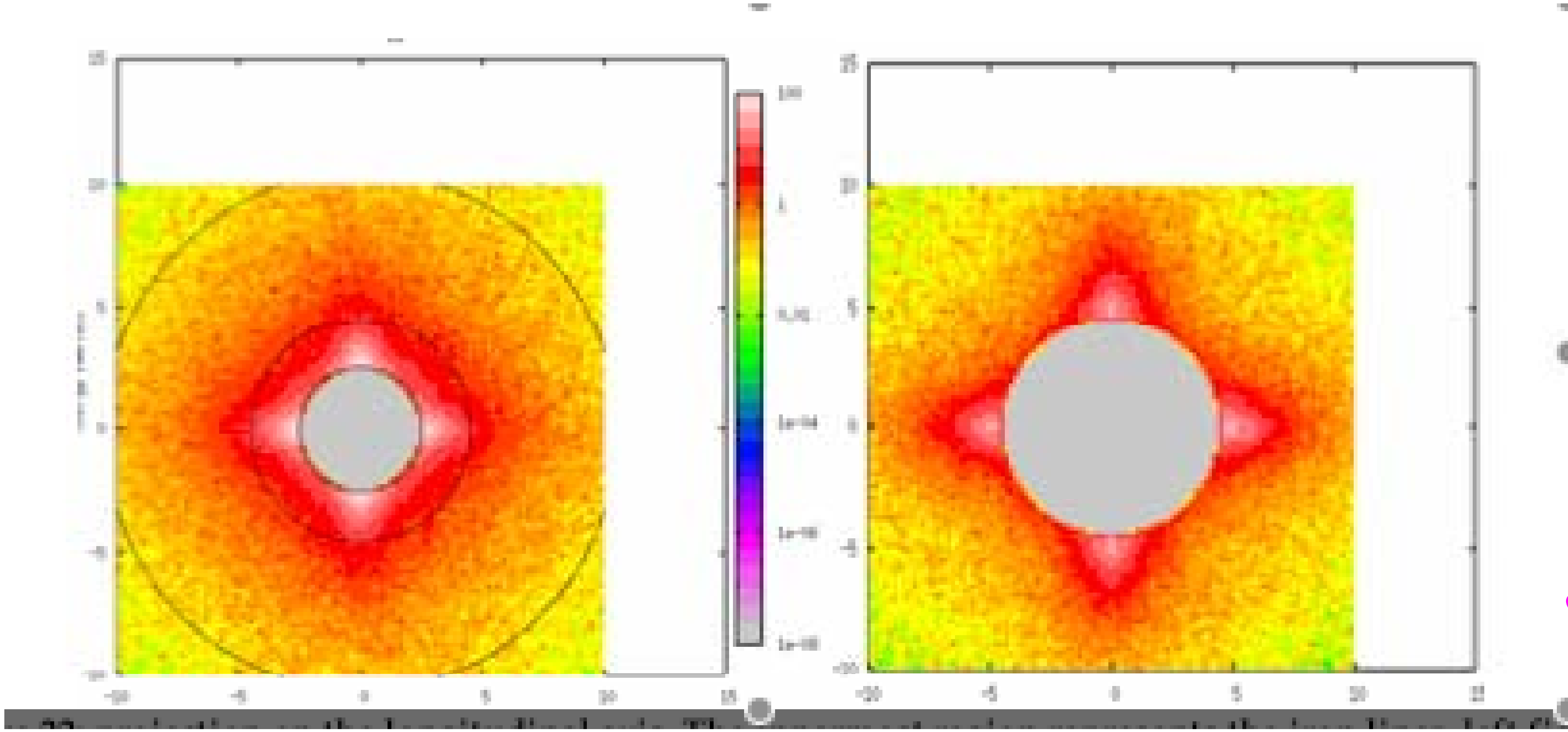
- CMS does not expect any change in the beampipe material.
  - Beryllium beam pipe around the IP and Stainless Steel elsewhere.
- Beampipe diameter set by the dynamic aperture of beam.
  - Current diameter at the IP is 58 mm
    - Q: Would this need to be modified for LHC upgrade?
  - Forward beam pipe diameter is 400 mm after Forward Calorimeter and thus in the calorimeter's shadow.



TAS Absorber

- Reduces heating of machine magnet coils by absorbing the energy of the beam debris from the IP and shadows the coils by reducing the number of particles hitting them.
- However, neutron production in the TAS absorbers will fill the cavern like a gas and are a major source of background in the muon chambers.
  - Care must be taken in the design of the new TAS(es)

Energy Deposition in Q0 Coils



Preliminary

Power deposition (W) with staggered aperture TAS and 10 mm Cu liner

TAS	Q01Lnr	Q01	Q02 lnr	Q02
1550	100	100	150	180

This is essentially the same as without a liner.

Lum = 10^{35}

Power in mW/cm^3

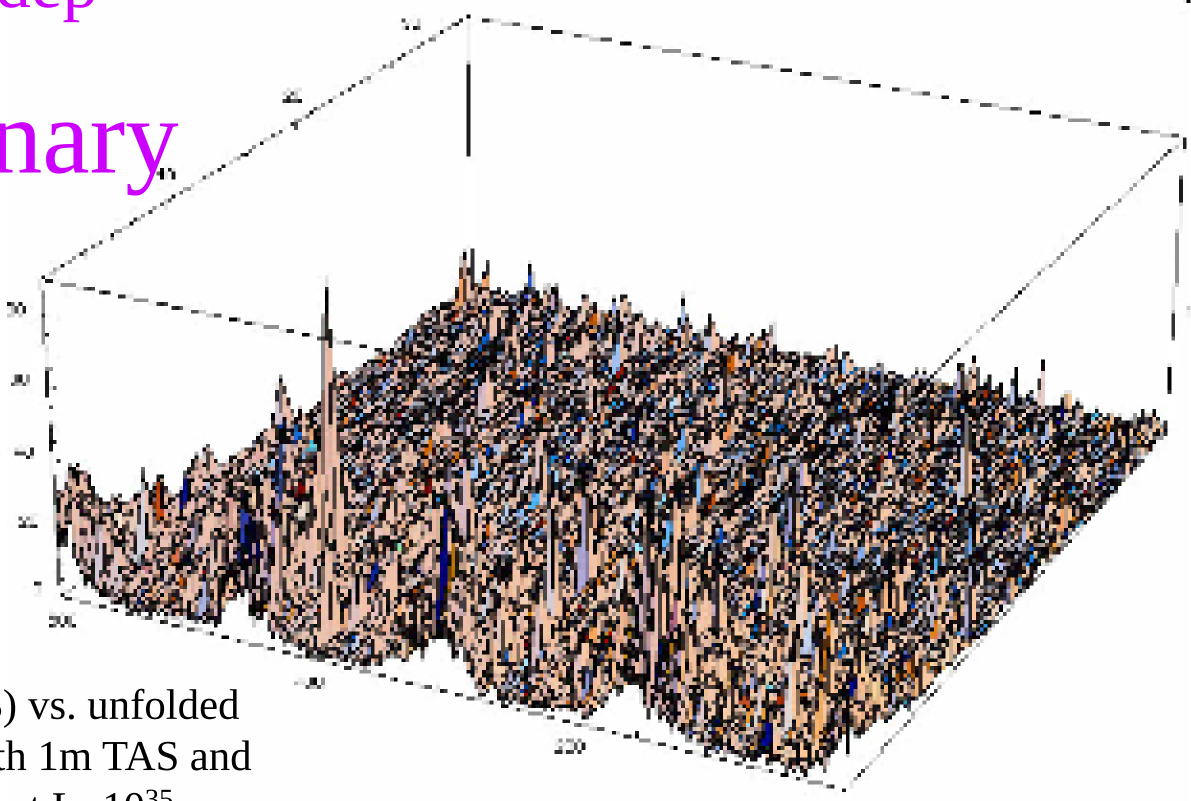
Courtesy of E. Wildner

Advantage of Liner

Q_{02} E_{dep}

Preliminary

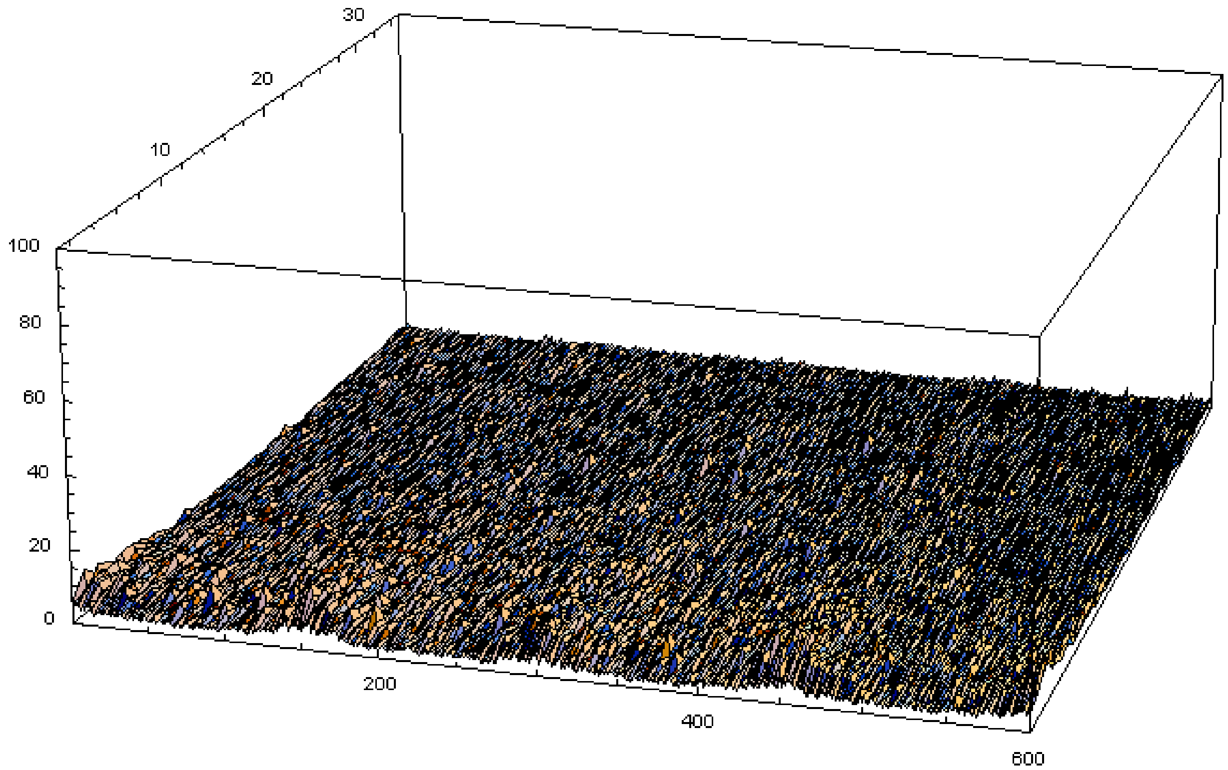
Liner evens out heat deposition



Power (mW/cm3) vs. unfolded angle & depth with 1m TAS and 1cm Cu liner at $L=10^{35}$

Courtesy of E. Wildner

Intermediate TAS between Q0a/Q0b



Power (mW/cm3) vs. unfolded angle & depth with 1m TAS and 1cm Cu liner at L=10^{35}

Q_{02} E_{dep}

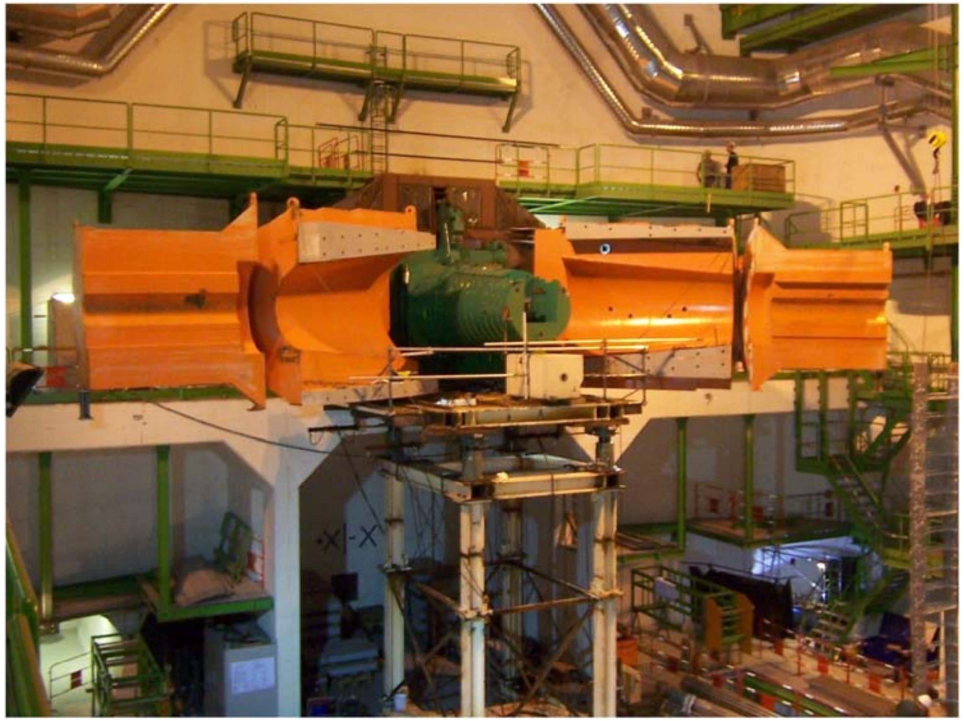
Preliminary

Adding a small TAS between the Q0 quadrupoles

Courtesy of E. Wildner

CMS Forward Shielding

- Located at the two ends of the UXC55 underground cavern.
- Designed to reduce the background radiation in the experimental area and in the CMS detector.
  - Radiation shielding along the beam line, especially around the TAS absorber protecting the inner triplets, is required to:
    - reduce the background rates in the CMS outer muon stations to acceptable levels, and
    - protect the electronics in the cavern.
- Construction.
  - Each Blockhouse weighs about 245 tonnes, each of the FINs weighs close to 60 tonnes, while the RS structures (steel, boron-loaded concrete and iron scrap) weigh 200 tonnes.



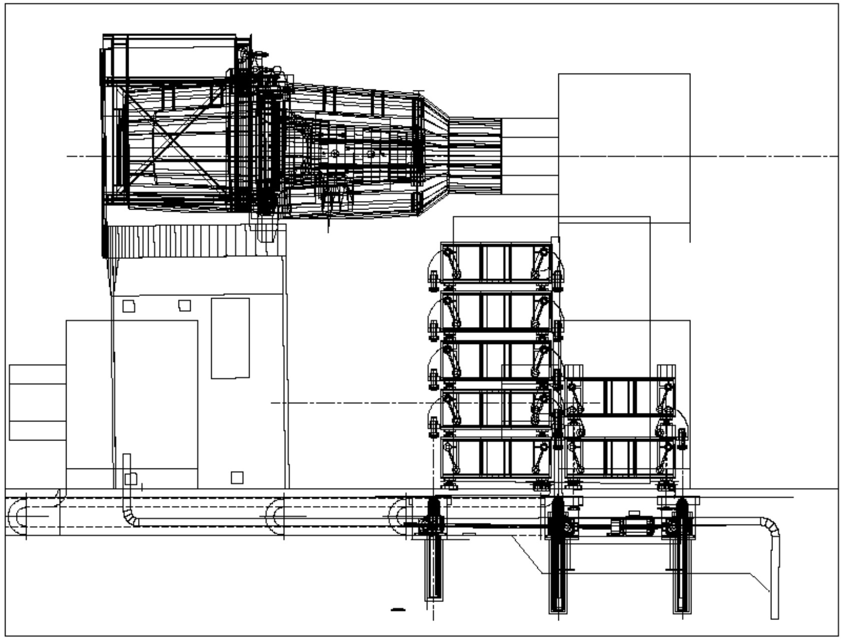
The Forward Shielding at Point 5 as installed in the CMS experimental cavern showing a Blockhouse (brown), a Fixed Iron Nose (green) and a Rotating Shielding in its open position (orange).

CMS Forward Shielding

- As a result, the radiation levels in the caverns are low (~1 Gy/yr) and CMS will be rather insensitive to machine-induced background such as upstream beam losses.
- Muons, which are the only particles that penetrate the shielding from the machine side, are estimated to arrive at CMS at a rate of $< 10\ \mu\ cm^{-2}\ s^{-1}$ from the machine side.

CMS Forward Shielding

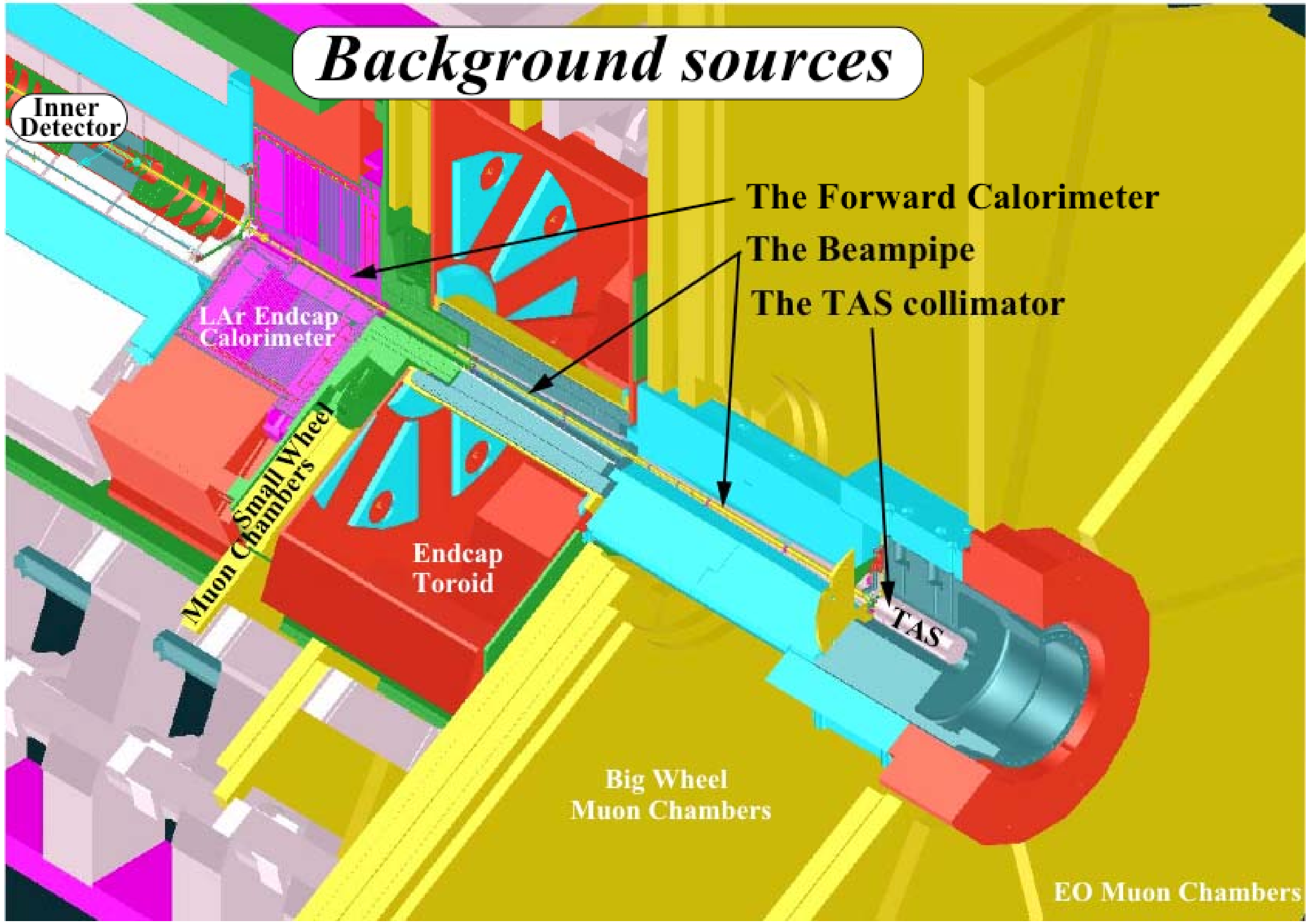
- Forward Shielding is near the limits of mechanical strength.
- New concept or supplementary system is thus needed.
  - Insertions for second set of jacks at each end built into UXC55 floor.
  - Would form basis of support for a supplementary structure closing around the existing Forward Shielding.
- Time needed to open and close CMS would increase significantly (~1 week per shutdown at present).



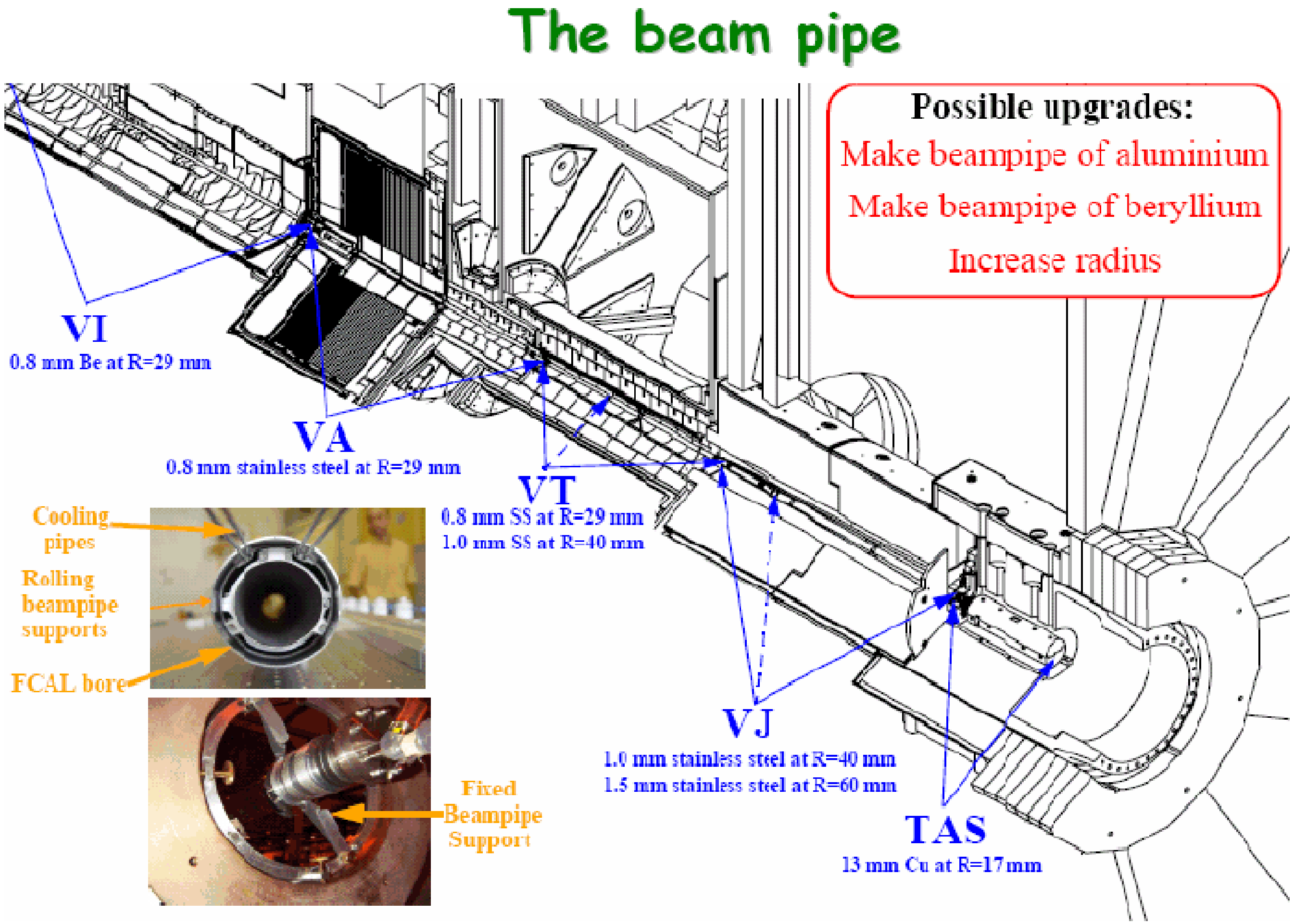
Magnet Challenges - D0 and Q0

- Potentially fatal heating from debris resulting from the high-energy collisions.
  - Not only the total heat load, but also the peak power deposition.
  - Heat must be removed.
- The development of Nb_3Sn magnets will be required for any significant luminosity increase.
  - Such magnets have higher temperature margins but further R&D is needed.

Background Sources in ATLAS



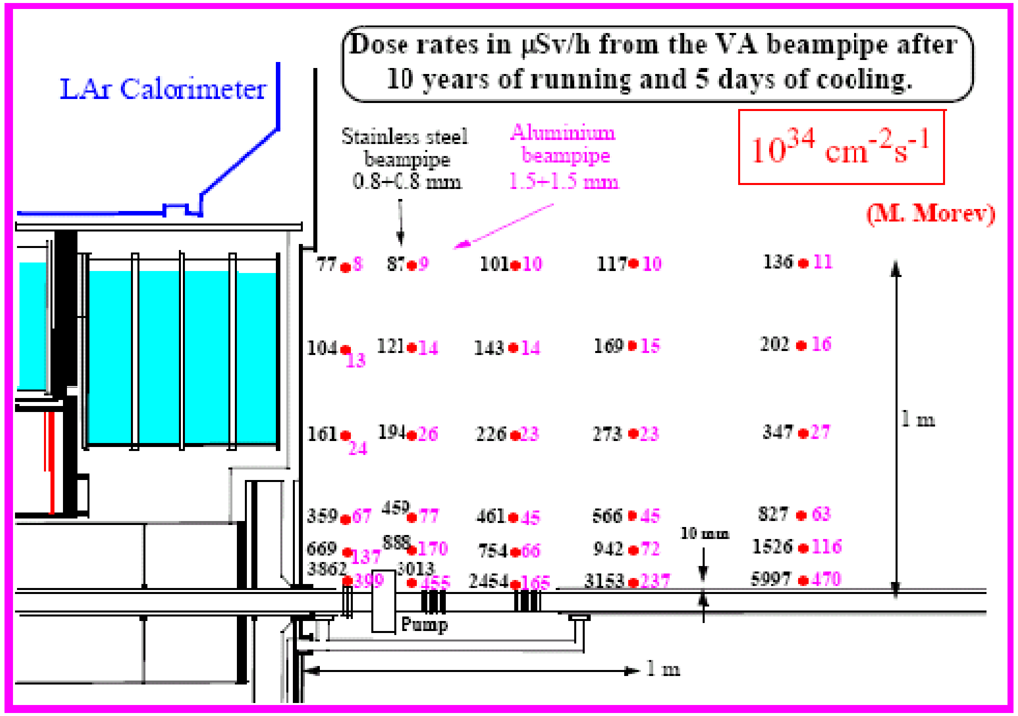
ATLAS Experimental Beampipe



ATLAS Experimental Beampipe

An aluminium beampipe

An aluminium beampipe has been proposed as an upgrade before running at 10^{34} cm^{-2}s^{-1} in order to reduce the activation. Bellows etc could be a problem.



For long running and cooling times the advantage of an Aluminium beampipe is smaller.

The ratio of the doserate from a steel and an aluminium beampipe with the same thickness.

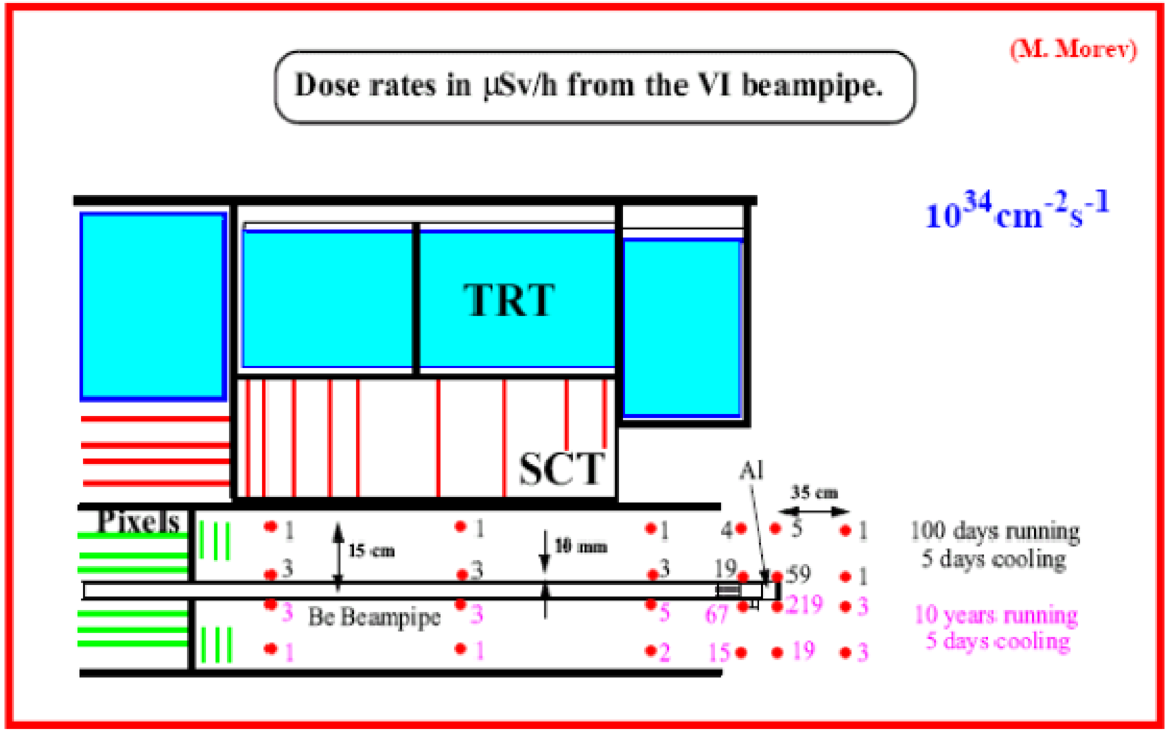
Cooling time	Running time			
	5000d	1000d	100d	30d
1 d:	9	13	23	23
5 d:	9	15	76	181
7 d:	8	14	68	164
30 d:	4	7	22	39

ATLAS Experimental Beampipe

A beryllium beampipe

At SLHC we will have to consider going to a beryllium beampipe.

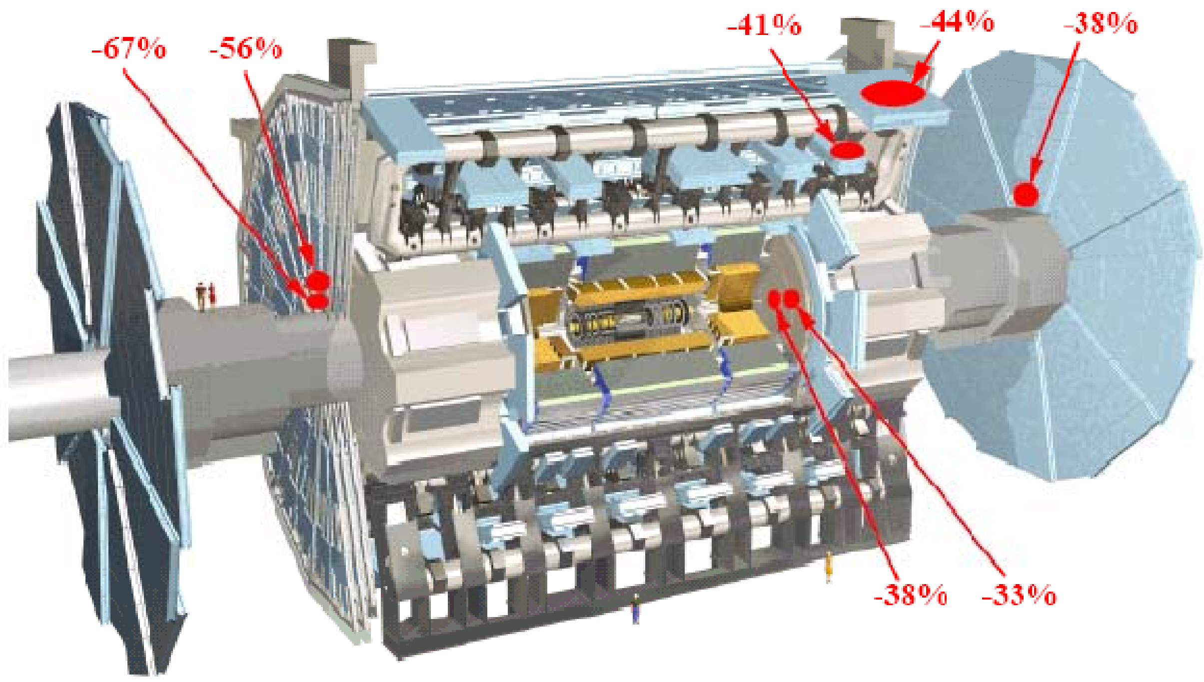
The activation of the beampipe will then not be an issue.



ATLAS Experimental Beampipe

A beryllium beampipe (cont.)

Decrease of the single background rate in the muon detector if the beampipe material is changed from stainless steel to beryllium.



Magnet Challenges – D0 and Q0

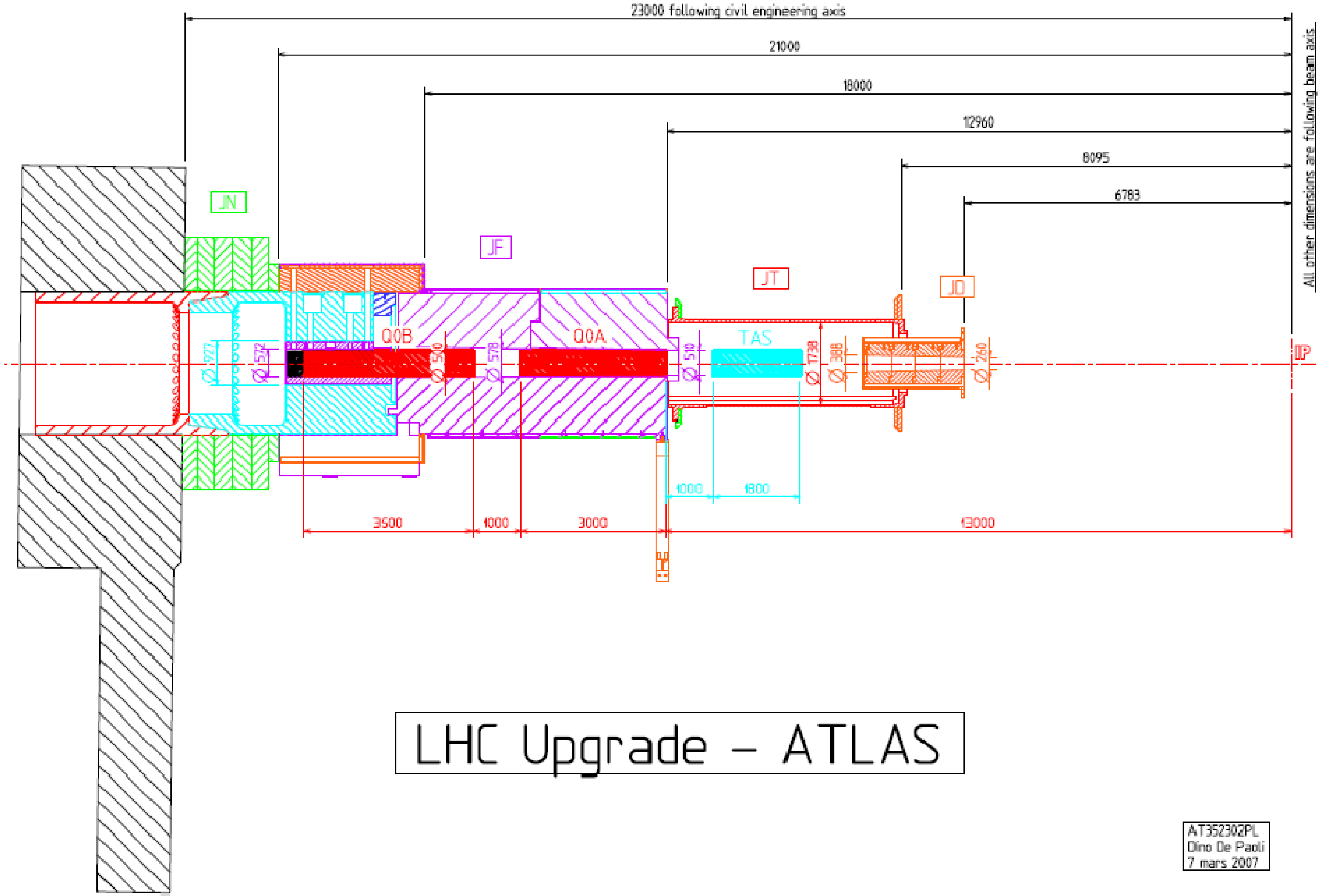
- Interaction of unshielded magnets with solenoidal fields of spectrometer magnets and the neighbouring iron.
  - Particularly in the case of CMS
- Integration of dense shielding with cryogenics and cryostat.

Close-in magnets remain a major challenge for the upgrade plans considered.

New Quadrupoles in Front of Inner Triplet

- A doublet or singlet (Q0) is inserted between the inner triplet and the IP
  - Starting not closer than 13 m. from IP
- Issues
  - Less heating from collision product debris as Q0 are shorter and weaker.
  - Integration with the detectors.
  - Requires a `thin-quad' design, i.e. minimise steel.
  - Requires a new TAS, which is a severe source of background for the particle detectors.
  - Requires a new mechanical support structure for the magnets and the shielding.

Integration in ATLAS



Close-in Dipole D0

- Front-face of dipole at 3.5 m. from IP.
- Located in a strong magnetic field, especially in CMS.
  - Issues related to forces, torques, field disturbance, quench forces.
  - Mechanical support structures.
- Maximise the D0 aperture.
  - Sufficient space for a 4T – 6T dipole with a 30 cm. bore diameter (no outside iron).
  - For a large aperture D0, the cold mass is at high angle, so flux is reduced.
  - Larger aperture increases magnetic albedo but may allow for large-aperture TAS.

Mechanical Issues

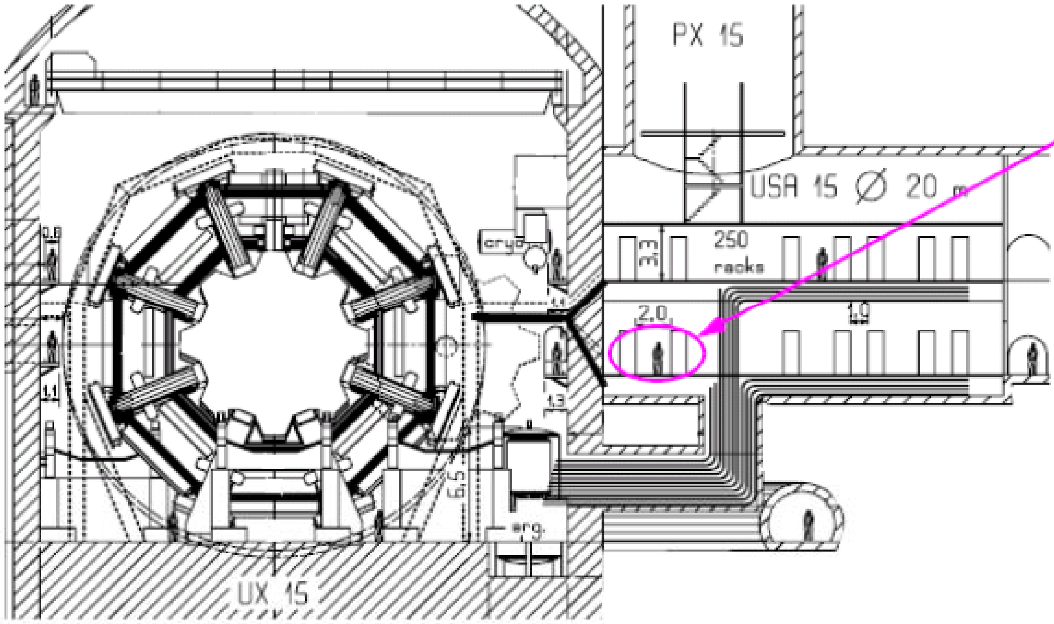
- Mechanical support structures need to be designed to support new machine magnets in the forward positions of the detectors.
- Integration of technical services (cryogenics, power) of the machine magnets in the particle detectors need to be studied further.

ATLAS Service Cavern

The counting room-high luminosity upgrade issues

The 2 m thick wall between the ATLAS cavern and the USA15 electronics cavern was designed such that USA15 could be designated as a simple controlled area (i.e. unlimited access with film badge).

The present limit for a simple controlled area is 25 μSv/h based on maximum does of 50 mSv per year. This is expected to be lowered to a maximum dose of 6 mSv per year.



Prediction for 10^{34} is < 4 μSv/h

USA15 would not be a simple controlled area at 10^{35} !

A strengthening of the wall could decrease the rate with a factor 2.

Machine-induced Background

- Impact of machine-induced background (beam-gas and beam halo) to experiments.
  - Measurement to be carried-out at the LHC to determine the background's spectrum.
  - Benchmark extensive simulation studies.
  - Only then could a good judgment be made on whether an increase could be tolerable.
- Question to be addressed now
  - Expectation for magnitude of machine-induced background relative to present estimates for the LHC,
    - Further increase beyond simple scaling with bunch intensity / beam current relative to present case?

Detector Maintenance in Higher Luminosity Environment

- The increased activation will seriously affect the maintenance of the detector.
  - Activation of detector and machine elements and restrictions arising for access scenarios.
  - e.g. cool-down of 10 hours at the CMS Tracker end-flange and 1 hour at the inner CMS ECAL Endcap to reach 5 mSv = 1year allowed dose.
- Remote handling might become mandatory in the design of the new particle detectors and should probably be developed for the existing ones.
- Probable increase in sensitivity to beam accidents.
  - Super Beam Condition Monitor needed

Installation and Commissioning

- Installation and commissioning of new particle detectors, machine elements (magnets and their supports/services), and other equipment (experimental beam pipes, radiation shielding) would need to be carefully planned.
  - All activities being carried out inside the experimental areas.
- Could/would all changes be done during a single shutdown?

The LHC Experimental Area Group at CERN

- The LHC Experimental Area Group (TS/LEA) is responsible for the technical co-ordination of the experimental areas of the LHC within the framework of the LHC Project and in close collaboration with the LHC experiments.
- The Group would provide the technical co-ordination for the work related to the upgrades of the experimental areas.
  - Co-ordinate the experimental area design and realisation for issues such as the integration of the LHC machine elements in the experimental areas and other machine-experiment interface matters.

Conclusions

- Integration of new machine magnets in the experimental areas and experiments is feasible but challenging.
- Next Steps
  - Studies on energy deposition, integration of magnet systems and services (cryogenics, power, cooling) and radiation shielding need to be continued.
  - Design of mechanical support structures need to be developed.
  - Alignment techniques should be considered.
  - Backscattering to particle detectors from additional machine elements need to the studied.
- Need to continue with regular discussion forums between the machine and experiment groups.