Integrating LHC Upgrades With CMS

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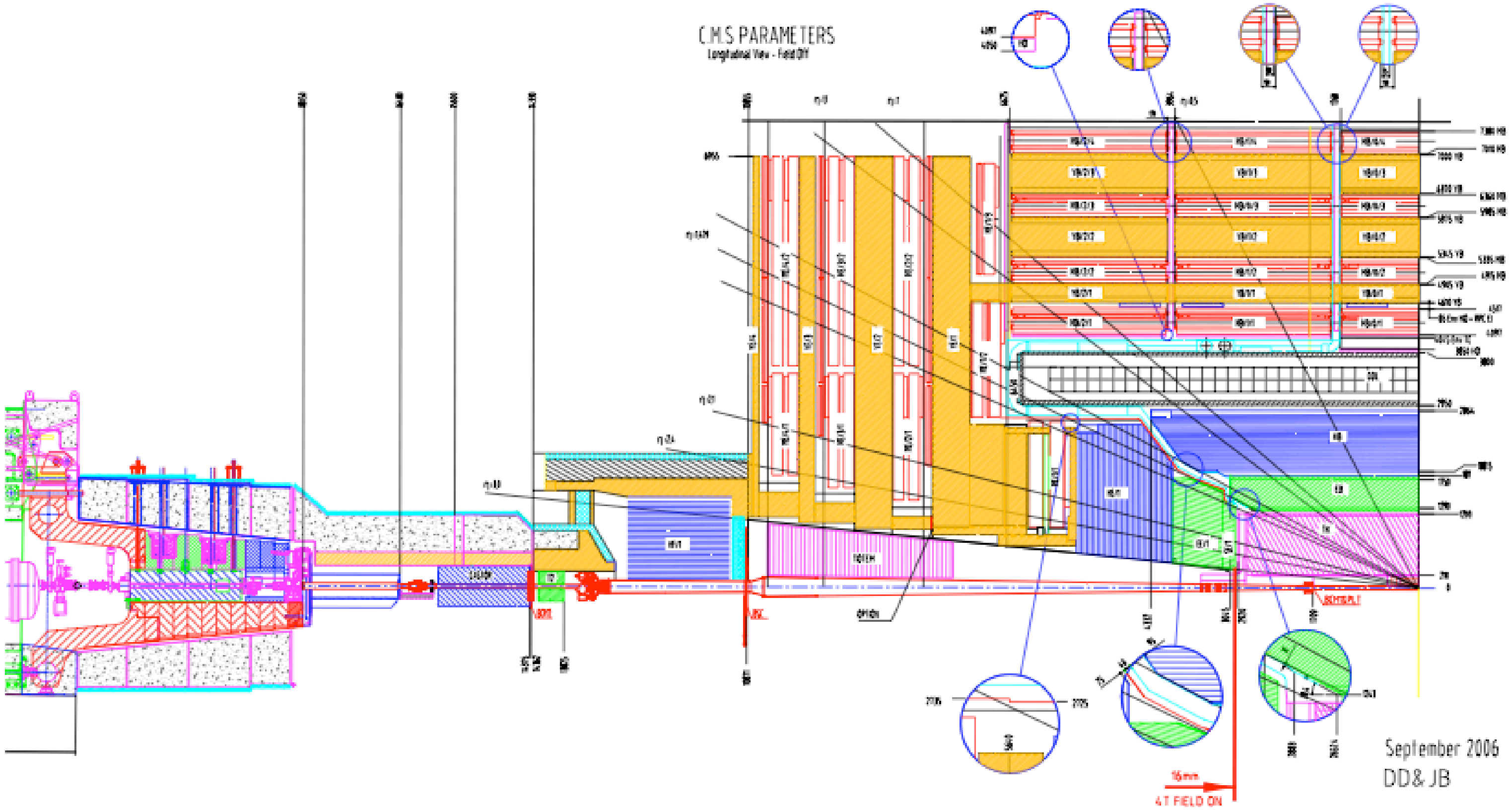
Outline

- **The options for luminosity upgrades using modified or additional insertion magnets**
  - The goal is to increase luminosity without increasing beam current.
- **The challenges**
  - For the experiments
  - For the collider & magnets
- **Some examples**
- **The next steps**
- **Conclusions**

Issues

- **There are two basic issues for the experiments**
  - Displacement, interference with, or elimination of parts of the detectors
  - Scattering and albedo of particles into the detectors
- **There are three basic issues for the LHC**
  - Developing and building magnets that reach the performance goals
    - Field strength & quality, aperture, radiation hardness, reliability...
  - Reducing or removing the heat deposited by the interaction debris
  - The effects on the parameters and performance of the LHC
- **There are two basic issues in common**
  - A design that permits the detectors to open for service or modifications
  - Implementing stable mechanical support and cryogenic and electrical services for the magnets

CMS


C.M.S PARAMETERS
Longitudinal View - Field Off
16mm
4 T FIELD ON
September 2006
DD& JB

Options Using Quadrupoles

- **Reproduce the present optics with stronger, and/or longer, and/or larger-aperture triplets**
- **Same as above with triplets moved closer to the interaction region**
- **Additional quadrupole(s) in front of the existing, modified inner triplet**
- **Any of these options can, by themselves, increase the luminosity by about a factor of up to 1.5**

Larger-Aperture Triplet

- **Advantages**
  - Preserves present or similar optics
  - Larger aperture and/or stronger, allowing more shielding and smaller β*
    - The triplet is the determining aperture of the LHC. Smaller β* leads to larger β_{max}, which strains the collimation system. Larger aperture provides some relief.
  - If one uses Nb_3Sn, the increased temperature margin will permit a significant increase in luminosity, > factor 5.
    - NbTi does not have the temperature margin to allow large luminosity increases
    - **Preserves the decoupling of detector and LHC spaces**
- **Disadvantages**
  - Potentially fatal heating from debris. Must understand the debris effects
    - Requires the success of Nb_3Sn magnet R&D for significant luminosity increase
  - Decrease in β* is up to a factor of two, but the resulting increase in luminosity is less due to crossing-angle and waist effects.
  - Larger β_{max}, resulting in large chromaticity that may be difficult to compensate. Correction is by sextupoles in the arcs.
    - This effect is worse if magnets are weaker and longer (i.e. NbTi).

Integrating Close-In Magnets with CMS

- **CMS: Important parameters**
  - The forward calorimeter is far away ~ 12m from the IP
  - The major source of background is the TAS, which is heavily shielded.
    - The beam tube is tapered, so it is not an important source of background.
    - The return yoke shields most of the muon system, so the shielding around the beam tube is minimal.
  - The solenoid is long (±6m) and strong (B_0=4T).
- **All very different from ATLAS**

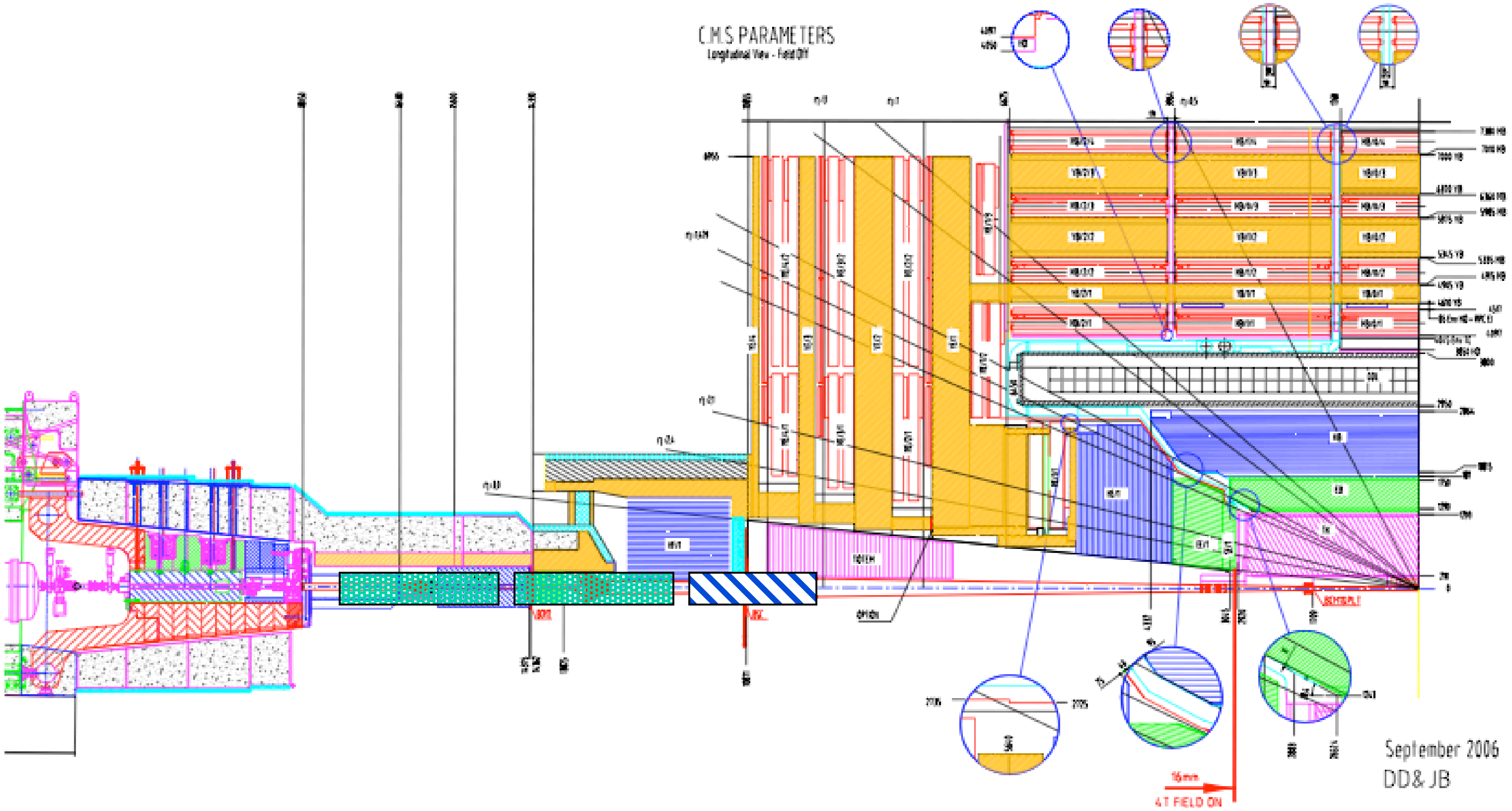
Effects of Close-In Magnets

- Putting in a D0 or Q0 will require major modifications to the CMS experiment.
  - Placing devices in front of forward calorimeter changes and perhaps destroys its effectiveness.
    - The forward cal (if any, in the upgraded configuration) could be moved closer to the IP, in front of the magnets.
      - This will increase background tracks in the central tracker.
      - A close forward cal may require an entirely different technology.
  - Close-in magnets will need close-in TAS, which may increase the background in the cavern.
  - The CMS solenoid has a strong fringe field at the magnet positions, particularly at the D0 location.
  - The magnet supports and services must permit opening the detector.

Quads in Front of Triplet

- **A doublet (or singlet) is inserted between the triplet and the IP, starting about 12 m from the IP - "Q0"**
- **Advantages**
  - β_{max} is smaller - magnet apertures of doublet & triplet may be smaller
    - Less effect on chromaticity
  - Less debris heating because quads are shorter and weaker - MAYBE
- **Disadvantages**
  - Impinges on the detectors; obstructs HF in CMS
  - Requires a "thin-quad" design. i.e. little or no steel
  - Requires a forward TAS, a severe source of background for detectors.
  - Requires a new support system for magnets and shielding

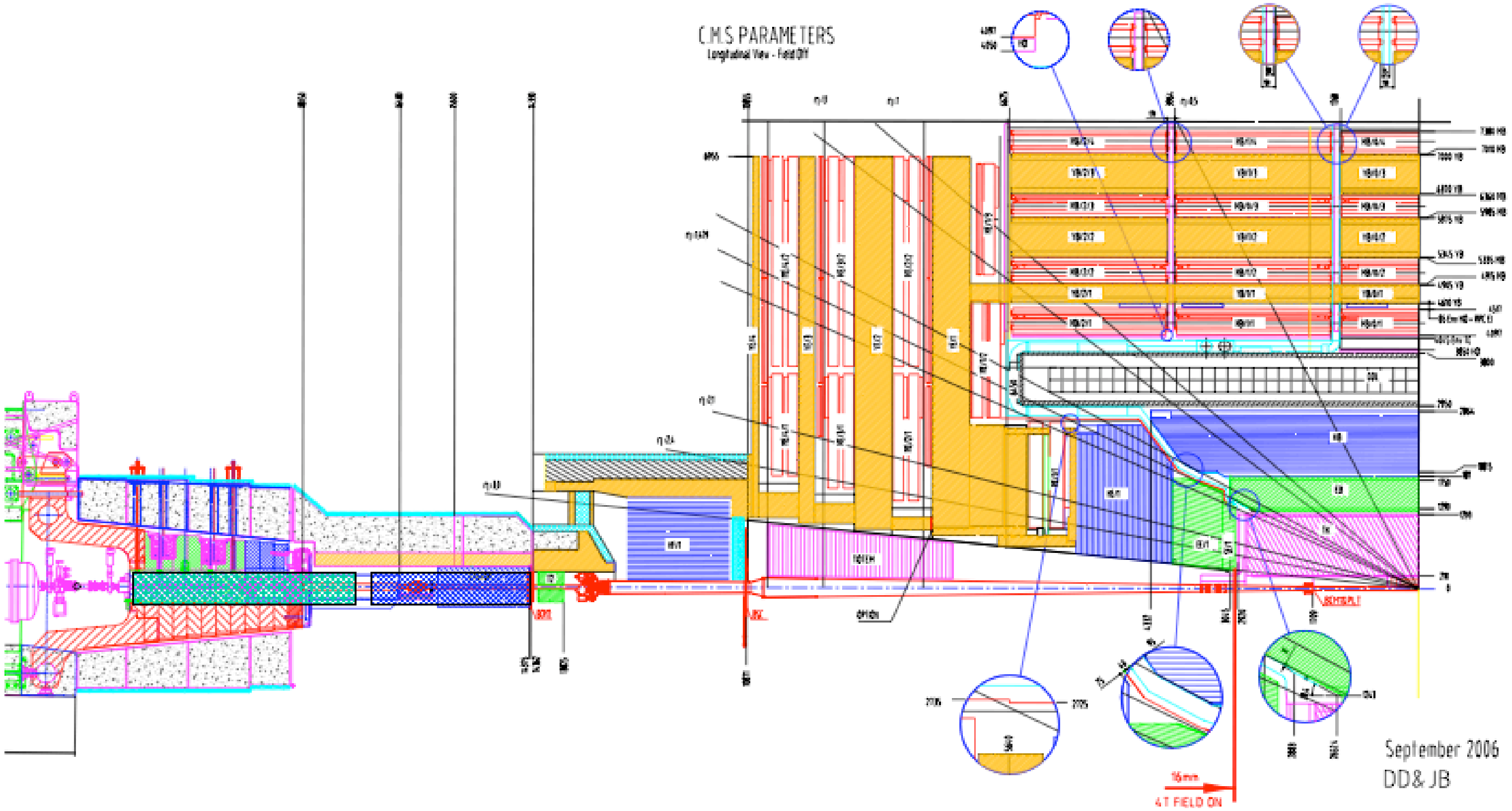
CMS with Q0 doublet



Problems with the Q0 Doublet

- **There are potential optical problems with this solution.**
  - It is possible that this arrangement will not match into the LHC
- **There are other solutions that may be better**
  - Adding a single quad in front of the triplet and rearranging the triplet is a possibility.
  - This solution also looks better for the experiments
- **However, the TAS and increased background is still an issue.**

CMS with Q0 Singlet



Options Using Close-In Dipoles

- **A close-in dipole would help reduce the crossing angle:**
  - Reduces geometric effects that limit advantages of small β*
  - Closeness to IP reduces the long-range beam-beam effects
- **A close-in dipole adds flexibility to upgrade possibilities**
  - A smaller crossing angle could make crab cavities easier to implement
  - A beam-splitting dipole might make possible new ways to level the luminosity without touching the quadrupole optics
    - Smoothly changing the crossing angle
    - Changing the bunch rotation with crab cavities
- **Hence, close-in dipoles deserve serious consideration**

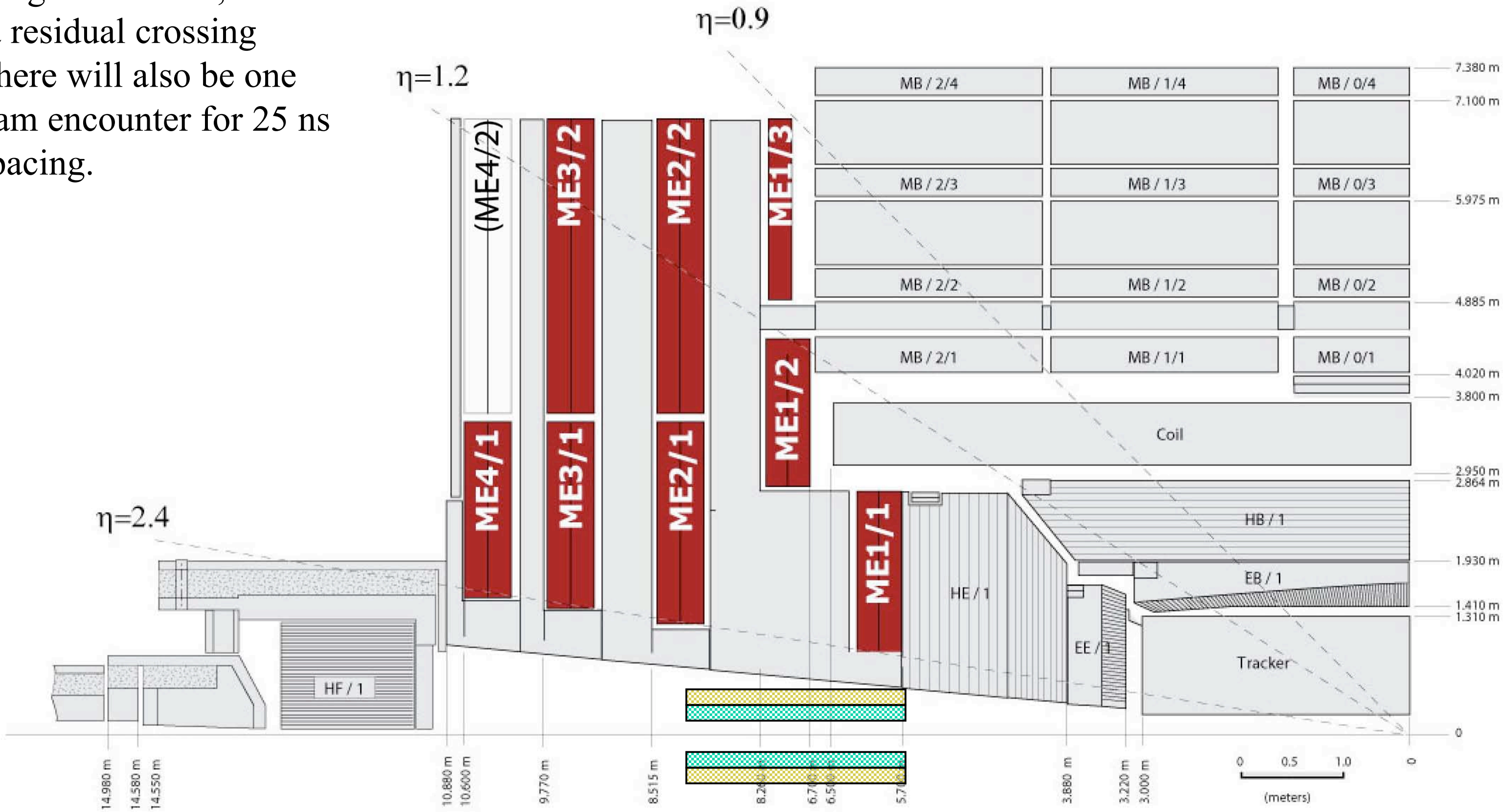
- **For various reasons, close-in dipoles are thought to be more difficult for CMS than for ATLAS.**

Close-in Dipole

- **Dipole begins as close as possible to IP**
- **It is in a strong magnetic field, especially in CMS**
    - Forces, torques, field disturbance, quench forces...
    - Even if the magnet can be supported, the ends may be crushed and need internal support.
  - Can it be made with a large aperture?
    - Yes. There appears to be room to make a 4T - 6T dipole with a 30 cm bore diameter (No outside iron)
  - What about the interaction debris?
    - It may not be so bad. Since it has large aperture, the cold mass is at low η (large angle), so flux is reduced.
  - What about albedo
    - Don't know. Large aperture increases magnetic albedo but may permit a large-aperture TAS.

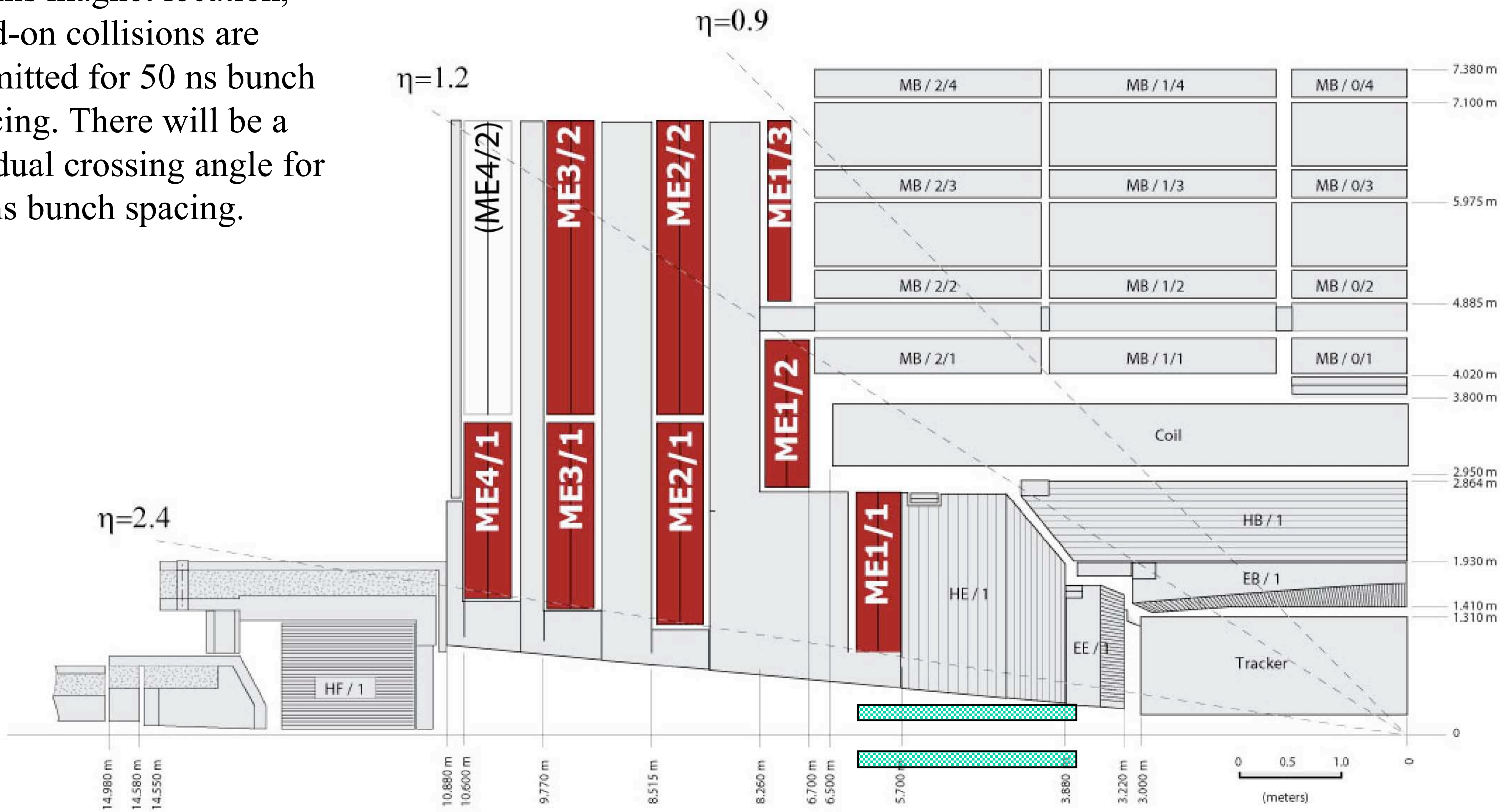
CMS with D0 - Dipole at 5.8 m

At this magnet location, there will be a residual crossing angle. There will also be one close beam encounter for 25 ns bunch spacing.

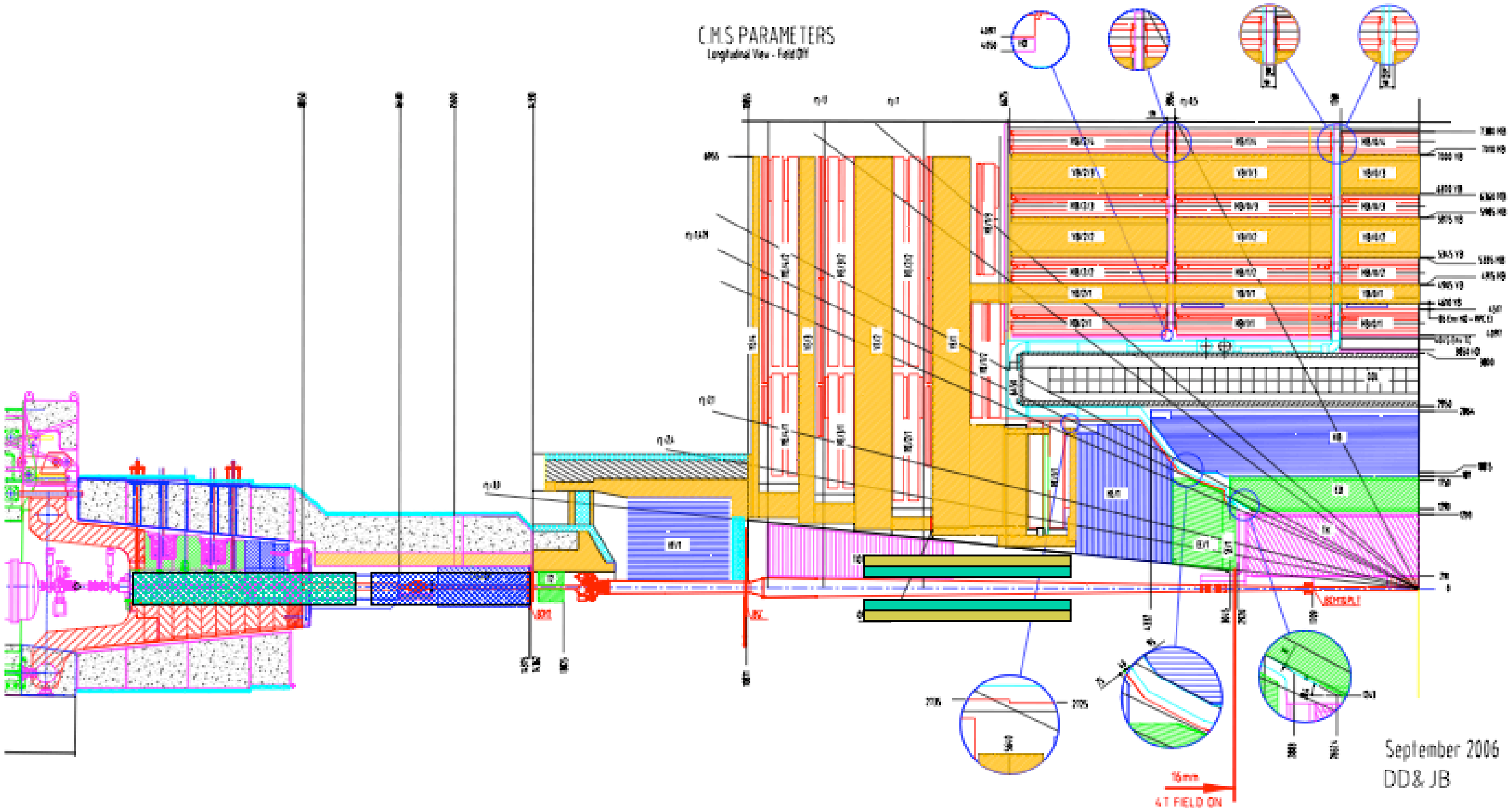


CMS with D0 - Dipole at 3.7 m

At this magnet location, head-on collisions are permitted for 50 ns bunch spacing. There will be a residual crossing angle for 25 ns bunch spacing.



CMS with D0 & Q0 Singlet



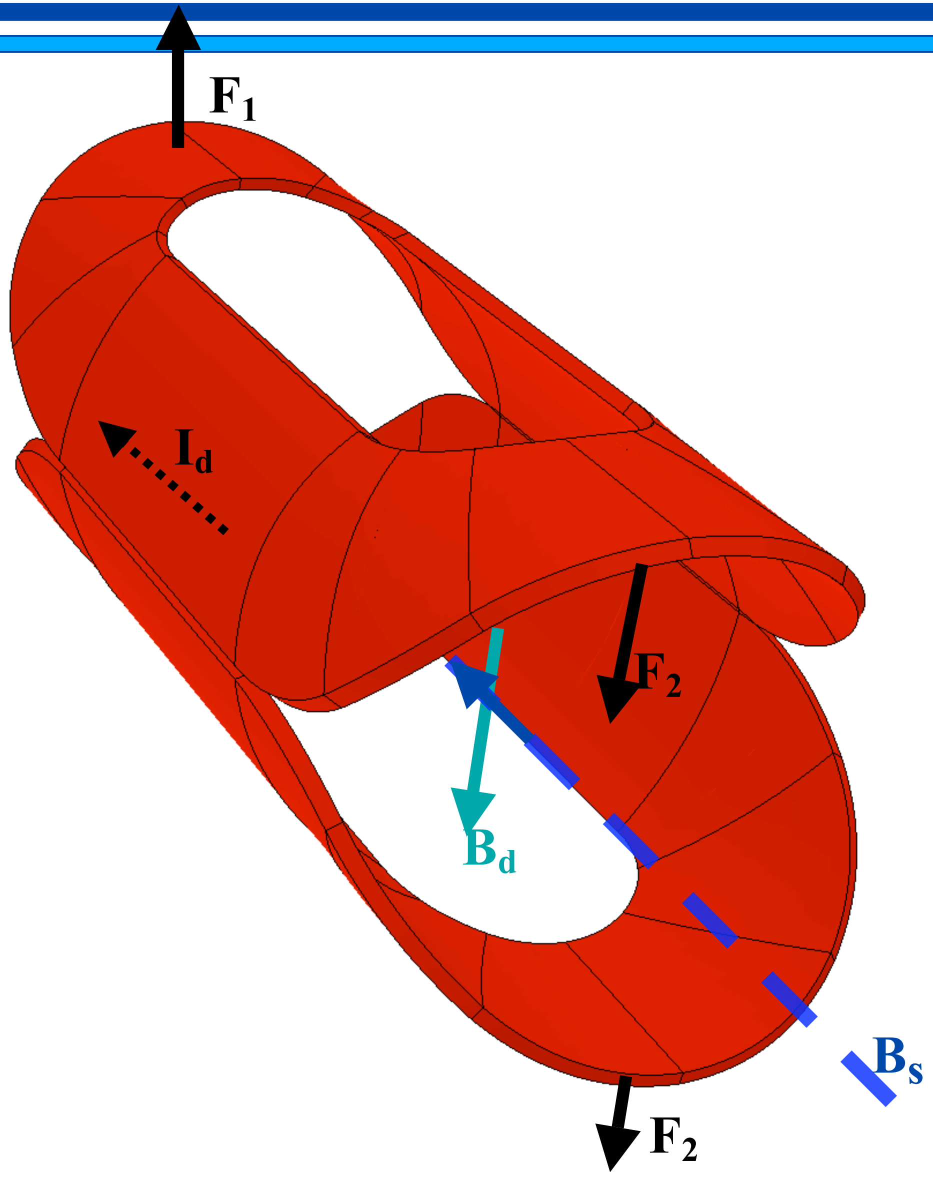
Magnet Challenges (1)

- **Removing the heat caused by the beam debris.**
  - Q0 will almost certainly require a closer TAS resulting in more background.
  - Very close-in dipoles (~3.5 m from IP) may be even more difficult.
    - Using a very large aperture D0 may reduce the beam-debris energy deposition. What is "large aperture"?. This requires study.
    - Perhaps the D0 dipole does not have to be so close to the IP.
      - How many long-range crossings are tolerable?
- **The issues of debris heating and detector backgrounds, and the accelerator issue of long-range crossings need much more study.**

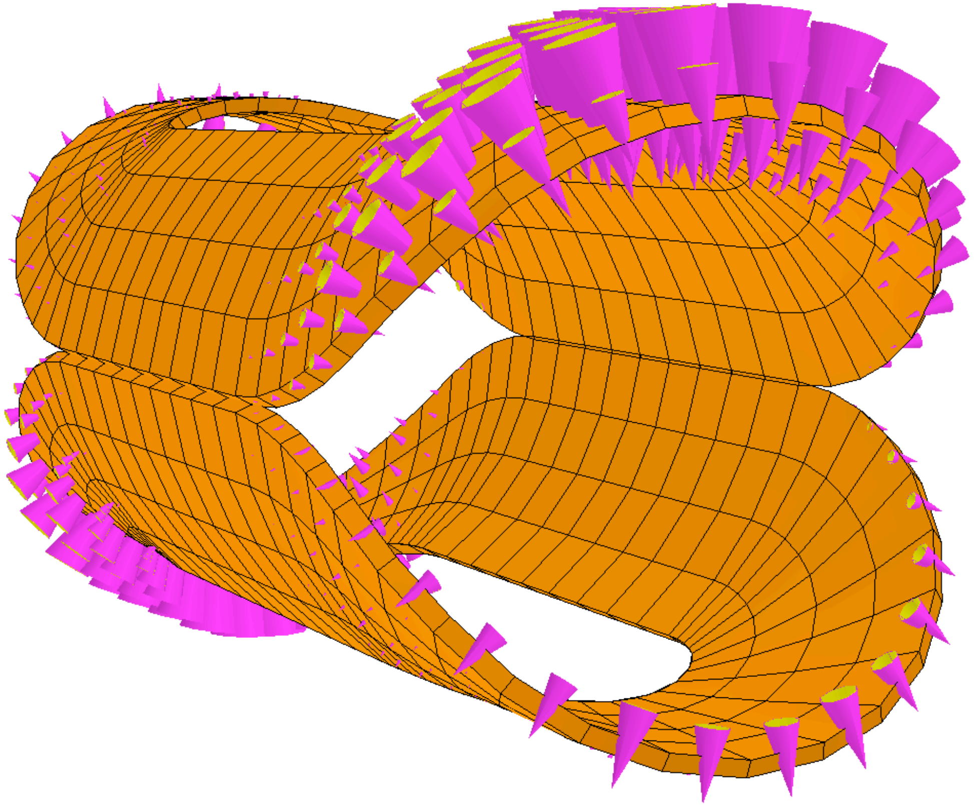
Magnet Challenges (2)

- **The solenoid is ±6 m long, $B_0 = 4$ T**
  - The field at the near end of D0 is ~2 T (This is a guess)
  - The solenoid field at the far end of the dipole is ~1 T (also a guess)
  - A 4 T dipole of 30 cm aperture requires 1500 kA-turns
- **Hence, at the near end F/L = 3000 kN/m**
  - Total force on near end ~ 100 tons
  - Total force on far end ~ 50 tons
  - Total torque on 2m long magnet = 1500 kN-m
  - Net force on the magnet is ~ 50 tons
  - These forces and torques vary as (dipole aperture)^2
- **These very large forces and torques have to be reacted.**
  - A cantilever is doubtful, so it must be supported against the inside walls of the solenoid cryostat or barrel calorimeter, or the forward muon system

Forces on D0 in CMS



Forces on D0 in CMS



Forces on D0 in CMS (2)

- **Crushing forces on the dipole magnet**
  - Force on each coil near end is ≈ 1500 kN/m (I.e. top & bottom coil)
  - Each 30 cm diameter coil near end has 450 kN ≈ 50 tons
- **This force will tend to crush the coils**
  - The end of a cos(θ) coil is not a good arch.
  - The coil ends need inside support with a tight-fitting cylinder
  - The cylinder will be about 1 to 2 cm thick
- **This makes the magnet more challenging**
  - Cooling at the ends, extra friction, etc.

- **Close-in magnets are a major magnet challenge for the early separation plan considered, even if Nb_3Sn R&D is successful**
  - In fact, with the additional forces, Nb3Sn might not work due to increased stress on the conductor!

Forces on D0 in CMS (3)

- **A solenoid surrounding the dipole could be used to cancel the interaction of the dipole and CMS solenoid.**
  - This transforms the transverse forces into longitudinal forces, which might be easier to handle.
    - Luckily, Fermilab engineers are (now) expert at analyzing longitudinal forces.
  - The transverse dimension of the magnet would be larger. It will no longer be “slim.”

Gaining Small Factors

- **There are a number of options that do not involve major modifications or new magnets**
  - Increase the bunch spacing
    - This by itself would increase the luminosity at constant beam current
    - Decreases electron cloud and (maybe) long-range beam-beam effects
    - The penalty is increased event multiplicity - **what is the limit**?
  - Decrease the collision angle without a D0.
    - This may be possible if the beam current is low or if we go to fewer bunches. Limited by long-range beam-beam.
  - Remove the beam-tube liner in the inner triplet
    - This could be effective if physical aperture is a limit to β^* (β_{max})
      - Fewer or weaker bunches would moderate the electron cloud effects, allowing the liner to be removed.
  - There are surely others

Next Steps in the R&D

- **A list of R&D topics**
  - **Continue & expand Nb3Sn magnet R&D**
    - **Especially large-aperture strong quads for the triplets**
  - Much more work on energy deposition & cooling
  - Support structure, alignment techniques, etc.
  - **Luminosity leveling**
    - **Very high luminosity profits from luminosity leveling.**
    - **Experiments we can do now on existing machines?**
  - **Crab cavities**
    - **The full effectiveness of the D0 may require crab cavities**
    - **Long-range crossings of stored beams, effects and fixes.**
      - **Experiments on existing colliders?**
  - **Lots of detector R&D**
    - **Especially shielding & background studies**

To Aide the R&D and Design

- **LARP is starting a new high-level task – JIRS**
  - Joint Interaction Region Studies
  - **Bring together connected tasks concerning interaction region changes related to the luminosity upgrade.**
- Improve efficiency and communication between tasks.
- Make better connections with CERN on concepts, designs and R&D.
- **Overall Leader – Sasha Zlobin**
  - Operating Margins: N. Mokhov
  - Accelerator Quality & Tracking: G. Robert - Demolaize
  - Optics & Layout: J. Johnstone
  - Magnet Feasibility Studies: P. Wanderer
- **The goal is to help CERN better define the magnet requirements.**
- **Close communication with CERN and the detectors is crucial.**

CONCLUSIONS

- **The magnets themselves are not impossible**
  - **But not easy**
- **The consequences for the detectors are potentially severe.**
  - **CMS & ATLAS need to get more involved.**
- **The solution lies in optimizing a complex set of parameters**
  - Useful luminosity, effect on the LHC performance and so forth.
  - Some of the problems are difficult. We need to define some boundaries.
- **We need to establish regular and useful lines of communication among, AT, AB, LARP and the detectors. We need to do this soon!**