LHC Luminosity Upgrades Using Quadrupoles

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October 17, 2006

Outline

- **The options for luminosity upgrades using modified or additional quadrupoles**
  - We are not talking about dipoles(except a bit)
  - We are not talking about increases in beam current
- **The challenges**
  - For the experiments
  - For the collider & magnets
- **Some issues and possibilities**
- **The next steps in R&D**
- **Conclusions**

Options

- **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 quadrupoles in front of the existing, modified inner triplet**
- **All of these options can, by themselves, increase the luminosity by about a factor of 1.5 to 2**

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

Larger-Aperture Triplet

- **Advantages**
  - Preserves present or similar optics
  - Larger aperture and/or stronger, allowing more shielding and smaller β*
  - If one uses Nb3Sn, the increased temperature margin will permit a significant increase in luminosity, > factor 3
  - **Preserves the decoupling of detector and LHC spaces**
- **Disadvantages**
  - Potentially fatal heating from debris. Must understand the debris effects
    - Requires the success of Nb3Sn magnet R&D
  - Decrease in β* is factor of two, but increase in luminosity due to β* is less
  - Larger βmax, resulting in large chromaticity that may be difficult to compensate.
    - This is worse if magnets are longer (i.e. NbTi).

Magnet Challenges (1)

- **The requirements for quadrupoles that significantly increase luminosity appear feasible but not easy**
  - Gradient requirement is not much greater than the present quads, but increased aperture makes the peak field high
  - Heating due to the interaction debris must be removed
  - **Nb3Sn has greater temperature margin and higher field capability**
- **R&D is progressing on Nb3Sn quadrupoles**
  - In the U.S. DOE labs (LARP)
  - In Europe (CARE/NED)
  - In Japan (Nb3AL?)

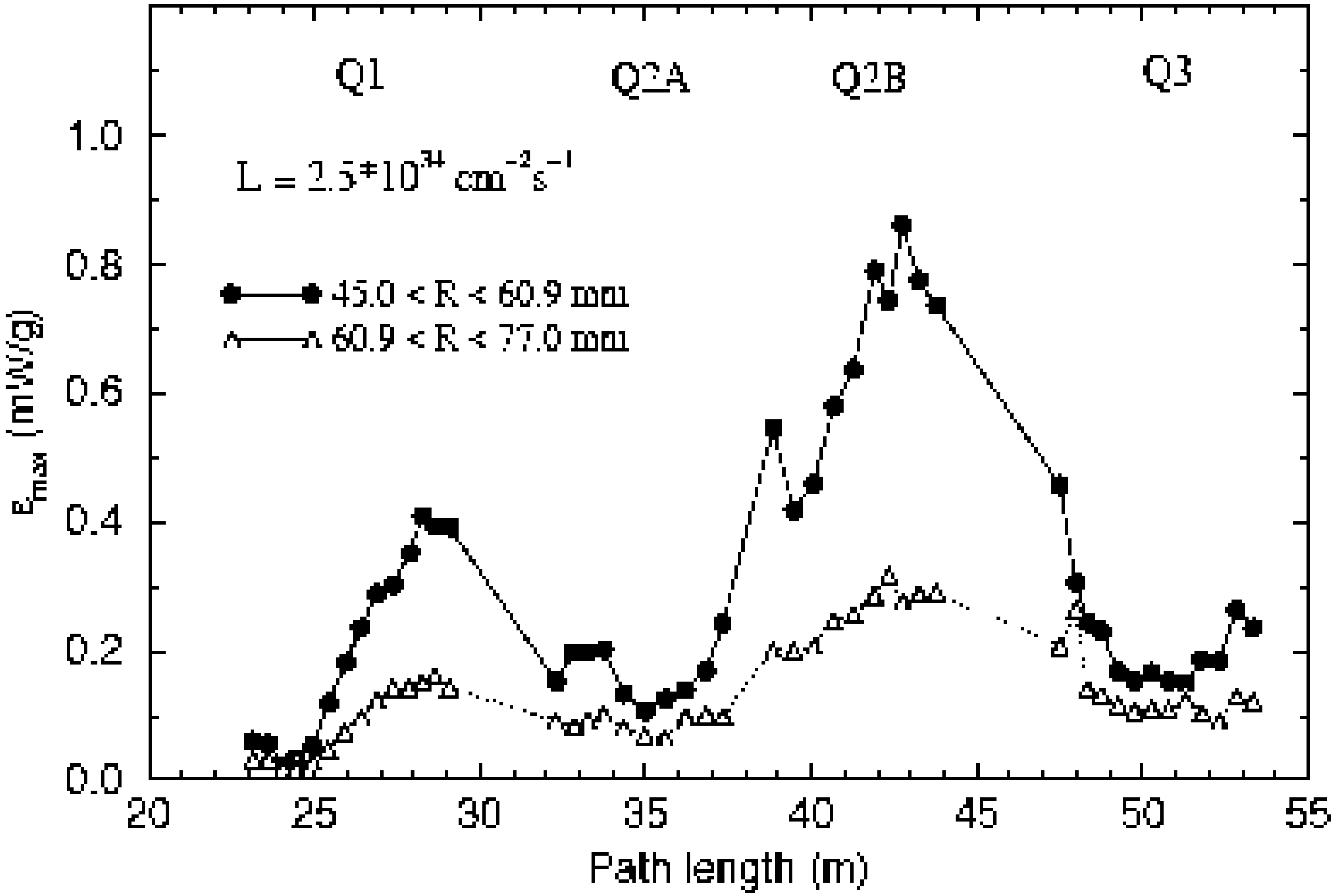
Nb3Sn or NbTi?

- **Which technology?**
- **The answer is------It depends!**
- **If the goal is to reach nominal or slightly more**
  - NbTi is probably adequate, but some increases might be possible without any magnet changes at all.

- **If the goal is to increase luminosity by factor of 2 or more**
  - Nb3Sn (or Nb3Al or HTS or MgB2) will be necessary
  - The most important (but not the only) factor is heating from interaction debris

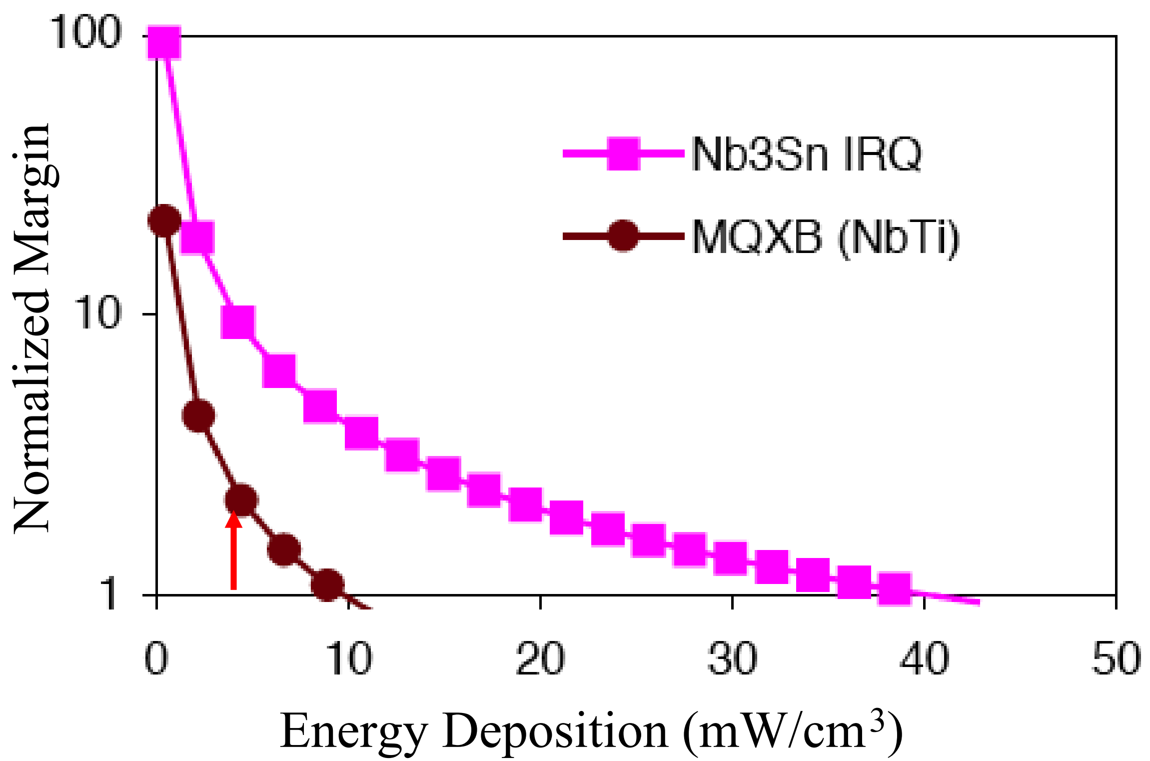
Beam Losses in Inner Triplet

From N. Mokhov



Temperature Margin

From A. Zlobin

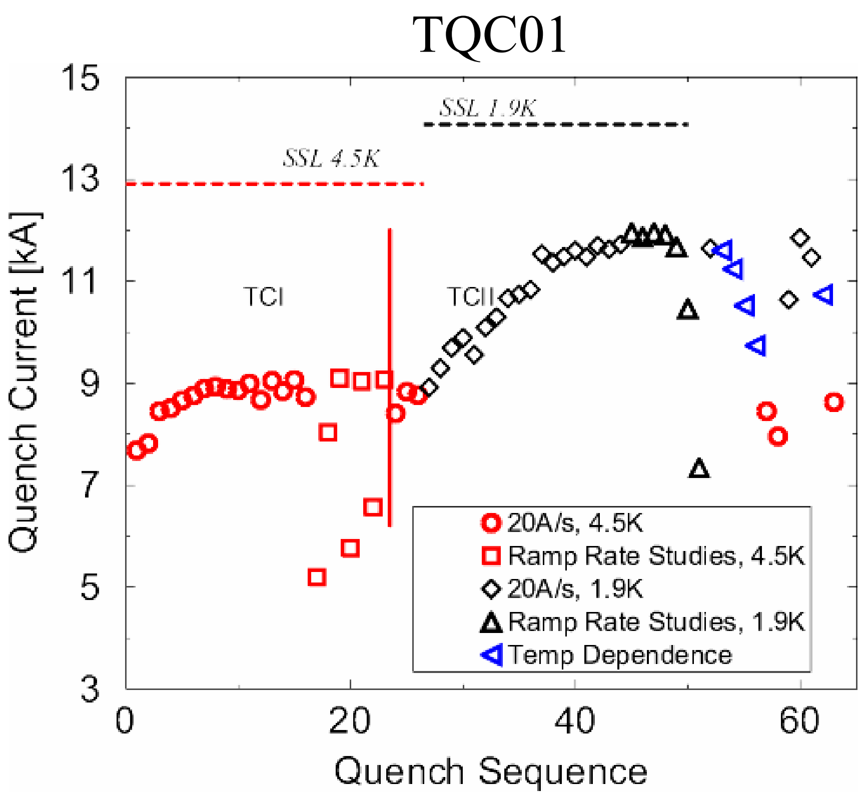


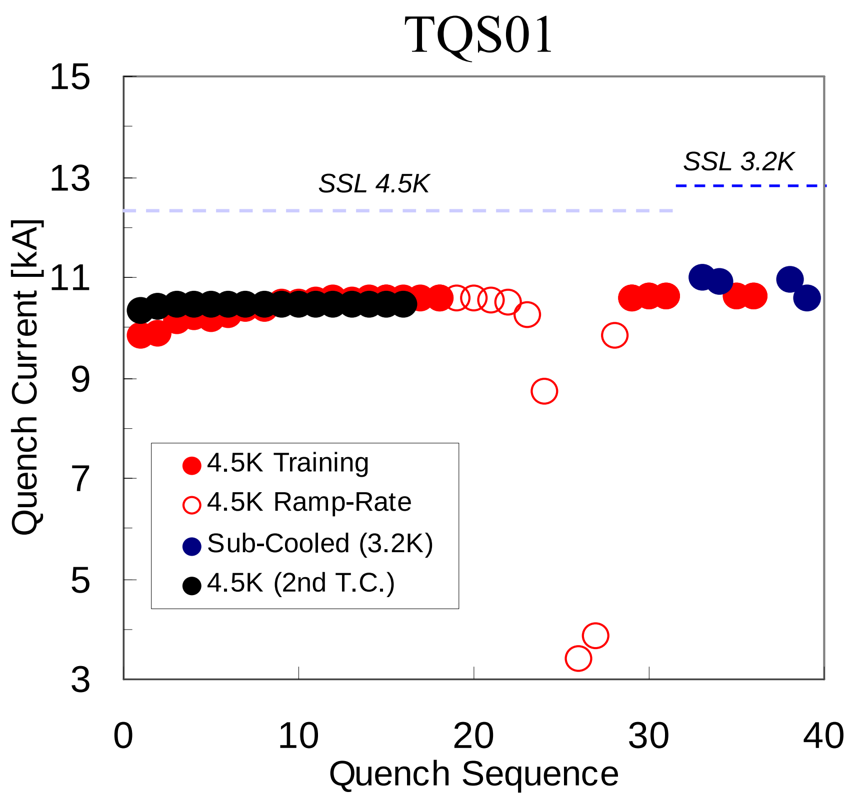
- **Based on realistic construction models at 1 x 10^{34}**
  - I.e. Potted Nb3Sn coils; st.st collars; iron yoke

U.S.-LARP Nb3Sn R&D

- **Initial goals(TQ) of the LARP R&D:**
  – Gradient ≥ 200 T/m
  – Aperture ≥ 90 mm
  – Radiation resistant
  – Long prototype (L ≥ 4 m) by 2009
- **Eventual goals(HQ):**
  – Peak field ≥ 15 T
  – Aperture ≥ 100 mm
  – (G ≥ 250 T/m @ d ≥ 100 mm)
- **Presently two designs are being pursued**
  – Collared coil
  – Bladder & Key
- **Initial models of each have been built and tested**

LARP Nb3Sn Magnet R&D





- **Both magnets achieved gradients close to 200 T/m (TQ objective), but improvement is necessary.**

Gaining Small Factors (1)

- **There are a number of options that do not involve major modifications or new magnets**
  - Increase the bunch spacing
    - This by itself increases the luminosity
    - Decreases electron cloud and long-range beam-beam effects
  - Decrease the collision angle
    - This may be possible if the current is low or if we go to fewer bunches
  - Remove the beam-tube liner in the inner triplet
    - This could be effective if physical aperture is a limit to β^*
    - Fewer bunches moderate the electron cloud effects
  - There are surely others

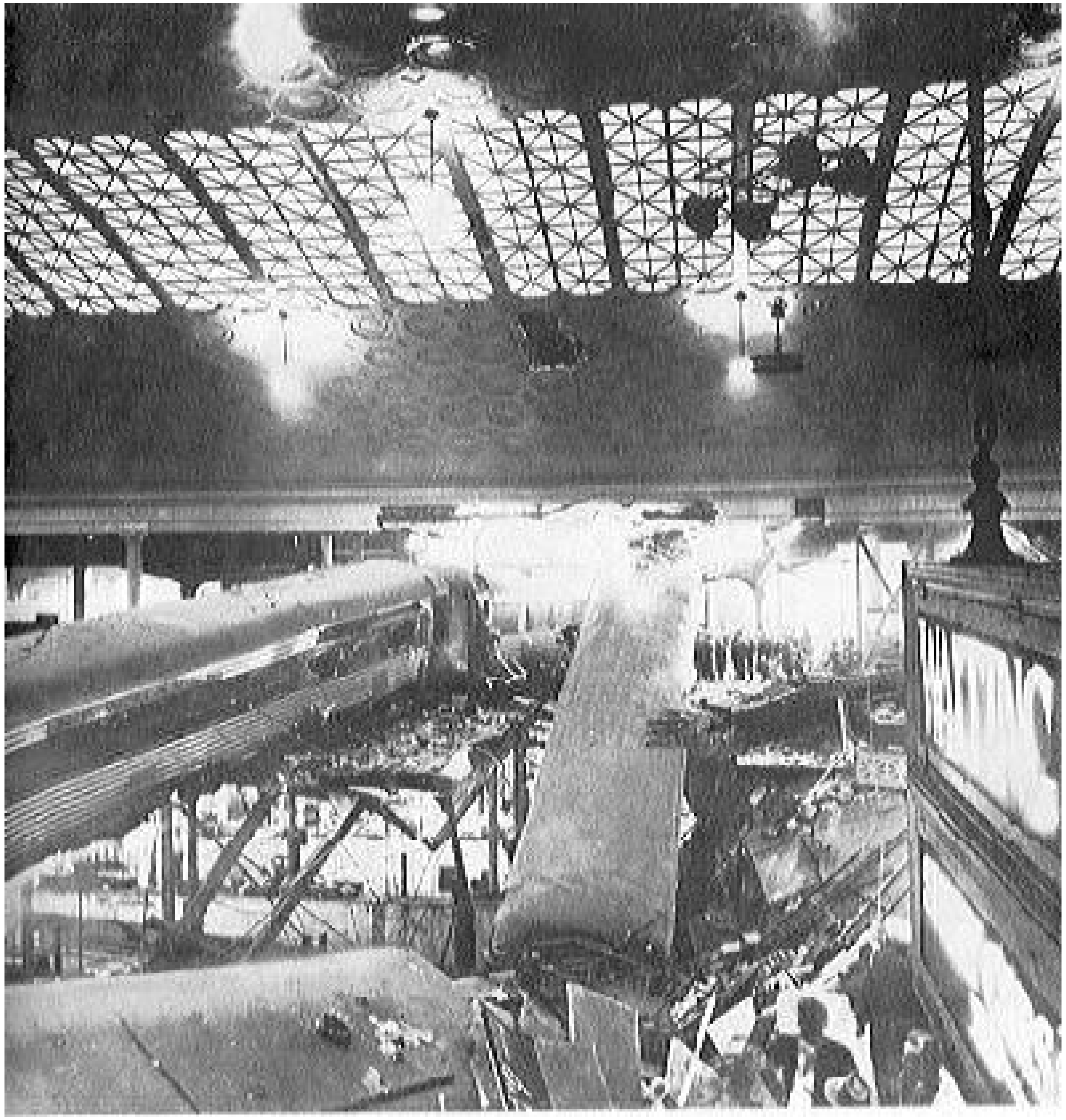
Gaining Small Factors (2)

- **Can the efficiency for data-taking be increased?**
  - The integrated luminosity per year is projected to be between 60 - 100 fb^{-1}
  - At a peak luminosity of $1x10^{34}$, 100 fb^{-1} /yr corresponds to ~1.6 $x10^{7}$ s/yr, which would be phenomenal performance
    - Fermilab, for example, regularly attains ≥ 1 x 10^{7} s/yr of data taking, but not much more

Moving the Triplet Closer

- **An upgraded triplet, similar to the previous example, is moved closer to the IP**
  - There is improvement for each meter that the triplet is closer, down to ~ 13 m from the IP
- **Advantages**
  - βmax is smaller, has less effect on chromaticity and aperture can be smaller
- **Disadvantages**
  - Potentially more heating from debris
    - Quads are long and strong, and therefore see lots of debris
    - Requires the success of Nb3Sn R&D
  - Impinges (somewhat) on the detectors
  - May require a "thin-quad" design depending on how close to the IP
  - Small-aperture TAS is also closer, generating more albedo; one may be able to redesign the TAS if the magnet aperture is greater
  - **May require a new support structure for magnets and shielding**

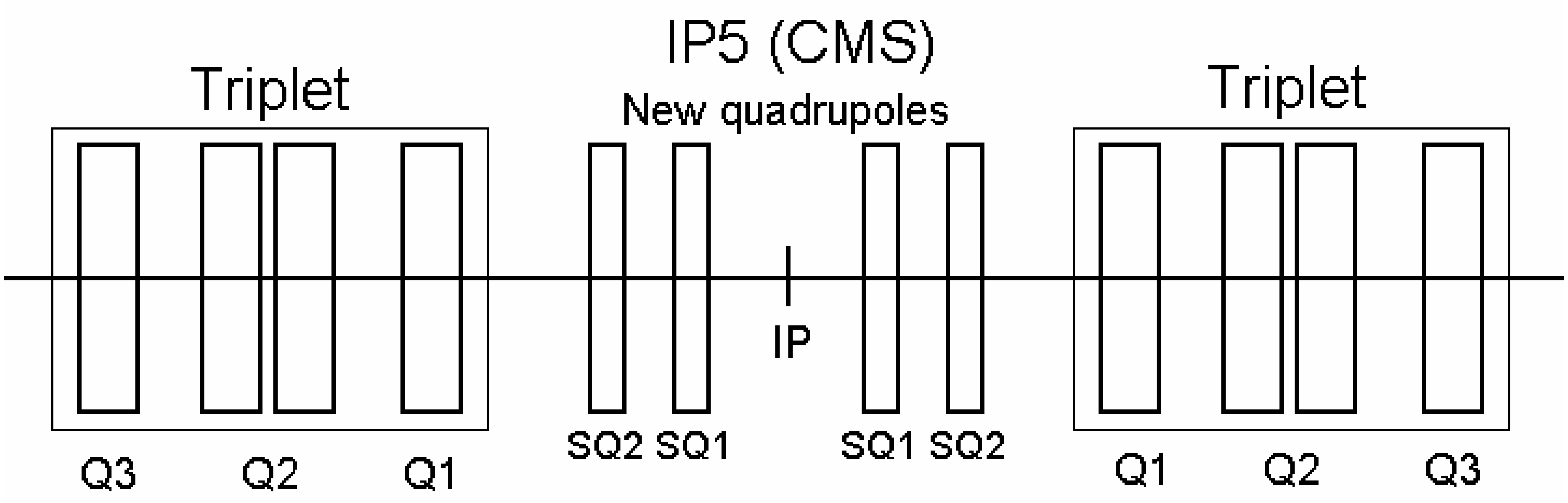
Pay Attention to the Support Structure



Quads in Front of Triplet

- **A doublet is inserted between the triplet and the IP, starting about 12 m from the IP - "Q0"**
- **Advantages**
  - βmax 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**
  - Will require the success of the Nb3Sn R&D
  - Impinges on the detectors
  - Requires a "thin-quad" design
  - Requires a TAS, but may be simple and large aperture.
  - Requires a new support system for magnets and shielding

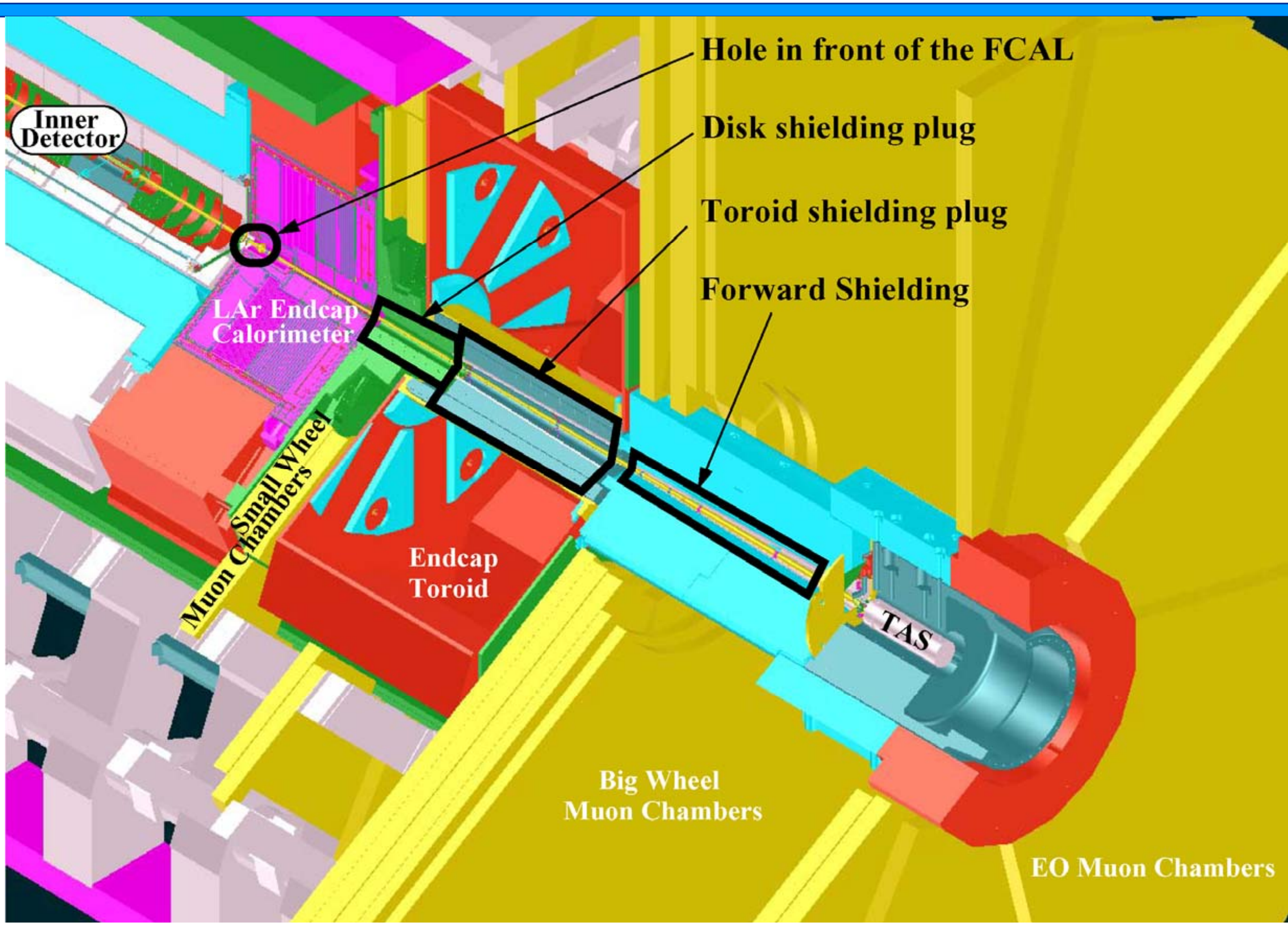
Quads in Front of Triplet



Q0

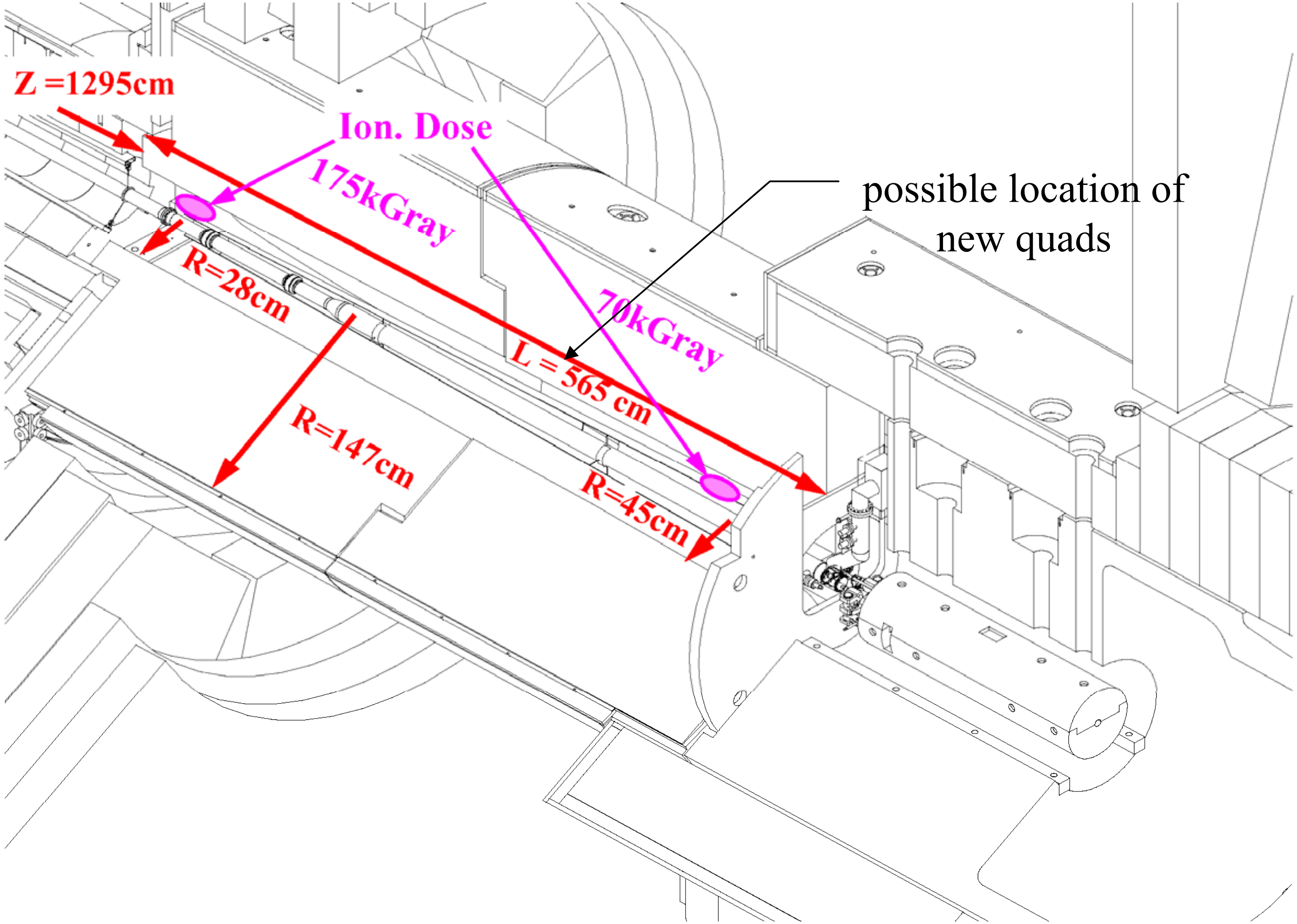
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

ATLAS

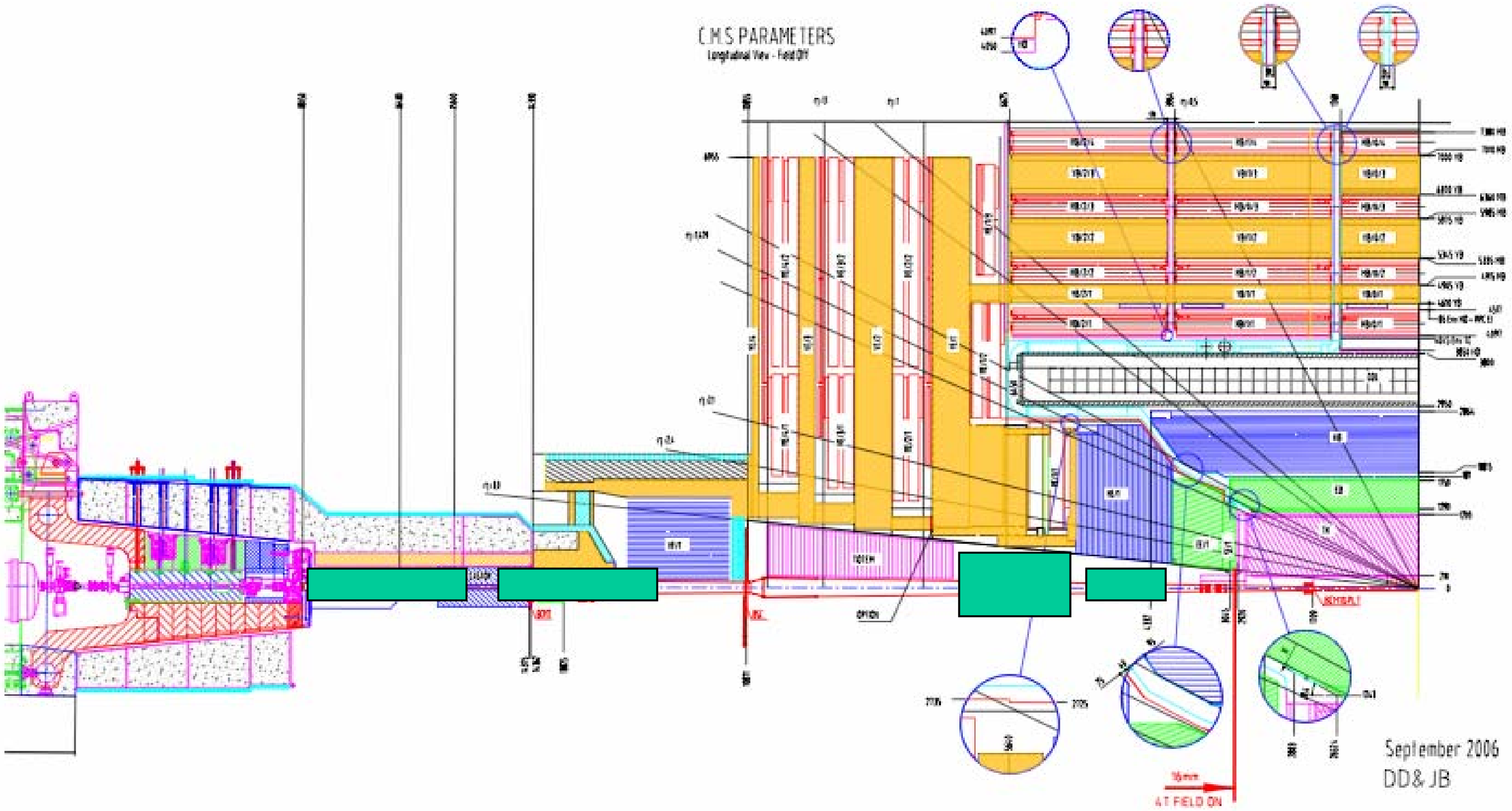


Hole in front of the FCAL
Disk shielding plug
Toroid shielding plug
Forward Shielding
Inner Detector
LAr Endcap Calorimeter
Small Wheel Muon Chambers
Endcap Toroid
TAS
Big Wheel Muon Chambers
EO Muon Chambers

Location of Forward Quads in ATLAS



CMS



C.M.S PARAMETERS
Longitudinal View - Field Off
September 2006
DD& JB
AT FIELD ON

Magnet Challenges (2)

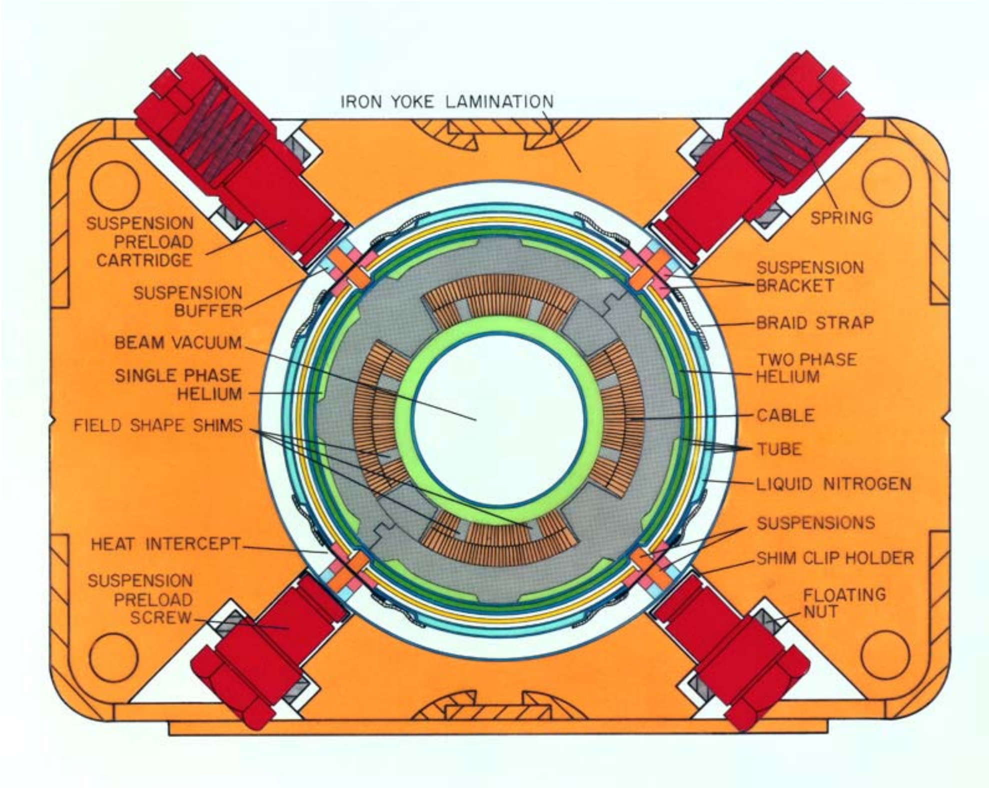
- **Close-in magnets are probably not a major magnet challenge for the quadrupole plans considered, provided that the Nb3Sn R&D is successful**
  - This may not be true for very close-in dipoles, particularly for CMS
  - Not only field strength, but also forces and torques, and the disturbance of the analysis field
  - Pay attention to the interaction of unshielded magnets with neighboring iron?
  - Do we want very large aperture for close-in quads? What about dense shielding coexisting with cryogenics and cryostat?

Some Issues

- **Lots of mechanical issues**
  - Have to support the quads in the forward position.
  - Quads have to permit opening of the detector
    - I.e. Outer diameter less than ~ 45 - 50 cm
      - This seems possible, but there will be minimal iron to reduce fringe field and interaction with surrounding steel
  - Have to remove heat due to interaction debris
  - What about pipes & valves? Need details

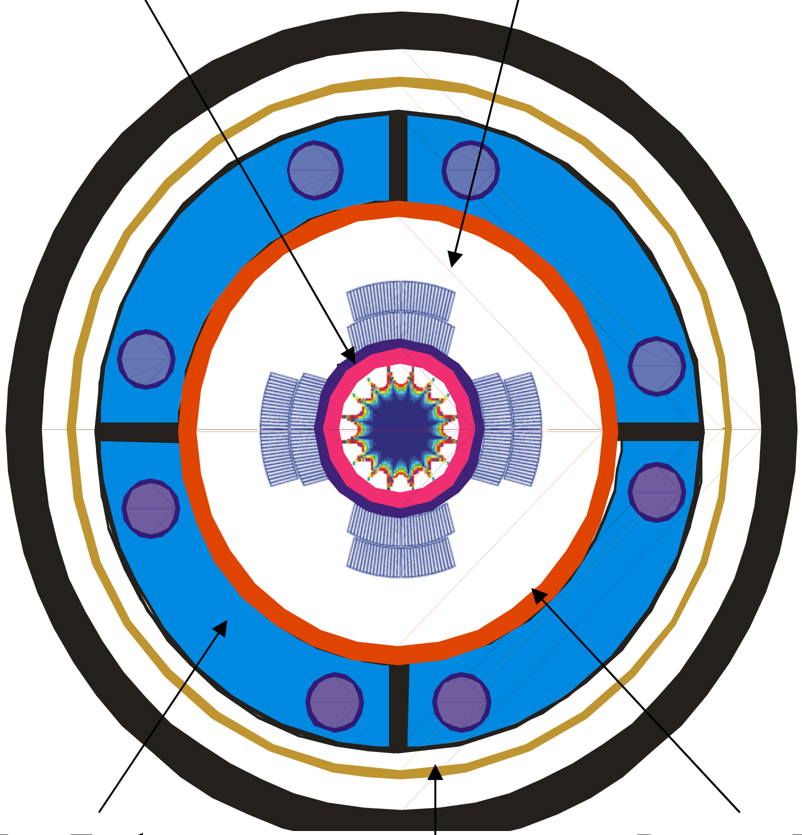
Coaxial Cooling

- **Coaxial cooling design based on Tevatron**
- **Tevatron quadrupole**
  - ~100 T/m with old-style NbTi. New NbTi could reach 150 T/m
  - 77 mm coil aperture is more than adequate
  - Heat transfer and cooling must be redesigned
  - Outer diameter of cryostat is 20 cm



Coaxial Cooling for Q0

- **Coil aperture = 70 mm**
  - 10 mm liner
  - 45 mm physical aperture
- **Outer diameter=300 mm**
  - 20 mm coil thickness
  - 20 mm collar thickness
  - 20 mm vacuum space including intermediate thermal shield
  - 40 mm low-pressure helium
- **Pressure-vessel cylinder**
  - laminated from copper and stainless bimetallic sheets



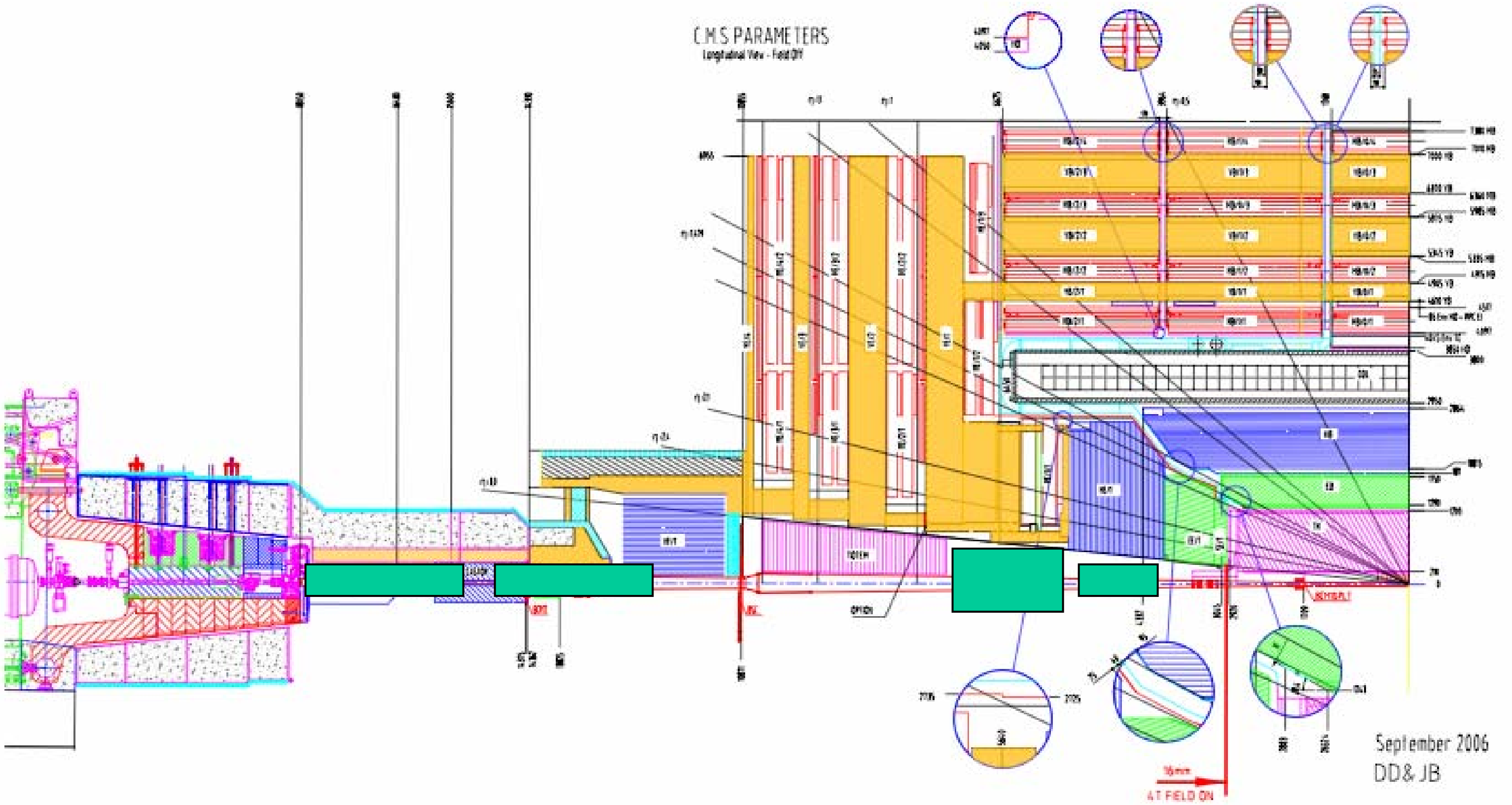
From G. Kirby

Material for Special Pressure Vessel Tube

Close-in Dipole

- **Dipole begins as close as possible to IP ~ 3.5 m**
  - It is in a strong magnetic field, especially in CMS
    - Forces, torques, field disturbance, quench forces...
  - 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.

CMS



Next Steps in the R&D

- **A list of R&D topics**
  - **Continue & expand Nb3Sn magnet R&D**
    - Model quads
    - Long quadrupoles
  - **More Nb3Sn magnet R&D**
  - Even more aggressive Nb3Sn magnet R&D
  - What else?
    - Much more work on energy deposition & cooling
    - Support structure, alignment techniques, etc.
    - Etc.
  - Lots of detector R&D

CONCLUSIONS

- **The magnets themselves are not impossible**
  - However, they rely on the success of Nb3Sn R&D
- **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 should begin the R&D soon. We need to define some boundaries.
- **We need to establish regular and useful lines of communication among, AT, AB, LARP and the experiments. We need to do this soon!**
- **There is a need for more magnet R&D in more places**