REVIEW OF THE CRYOGENIC BY-PASS FOR THE LHC DS COLLIMATORS

ELECTRICAL CIRCUIT MODIFICATION, INCLUDING OPERATIONAL CONSIDERATIONS

PRESENTED BY A. SIEMKO

WITH INPUTS AND CONTRIBUTIONS FROM:
R. PRINCIPE, R. DENZ AND S. RUSSENSCHUCK

GENERAL ELECTRICAL CONSIDERATIONS

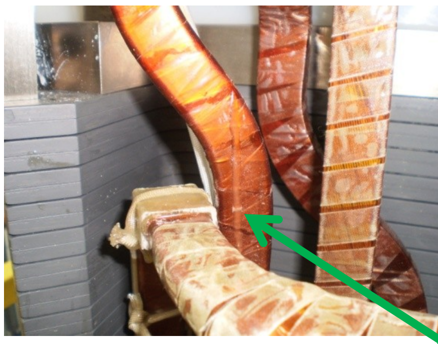
- **From the electrical point of view:**
  - The cryogenic by-pass represents an additional segment of the busbars added to the magnet circuits
  - The cryogenic by-pass creates an electrical singularity in magnet circuits
  - Electrical integrity of the main magnet circuits and the spool magnet circuits in point 3 is affected
  - Electrical modifications can impact on operations

RISK ANALYSIS DURING THE DESIGN PHASE

- Analysis of the 13 kA busbar circuit vs.:
  - Electrical continuity resistive (Cu and SnAg)
  - Electrical continuity (s.c. cable and wire splices)
  - Insulation
  - Robust and simple solutions, stable in time
  - Criticity and sensibility
  - Mechanical issues (Lorentz forces)

- See also: The Risk Analysis of the LHC 13 kA circuits, available at EDMS 1139345
- Continuous exchange of information between the TE-MSC and EN-MME on electrical issues since the very beginning of the cryogenic by-pass project

LESSONS LEARNT WERE TAKEN INTO ACCOUNT
FEW EXAMPLES (MANY OTHERS AVAILABLE)

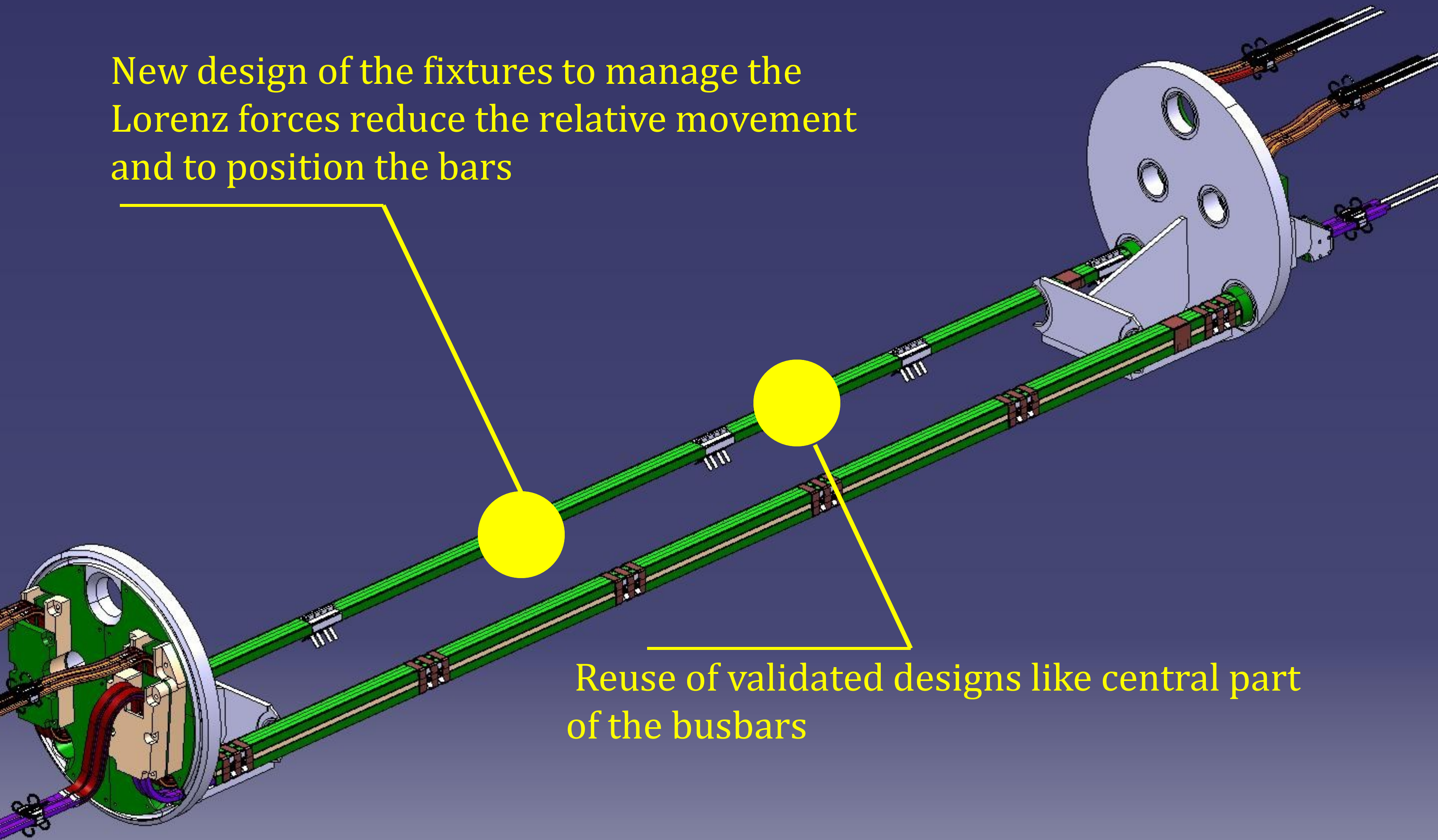


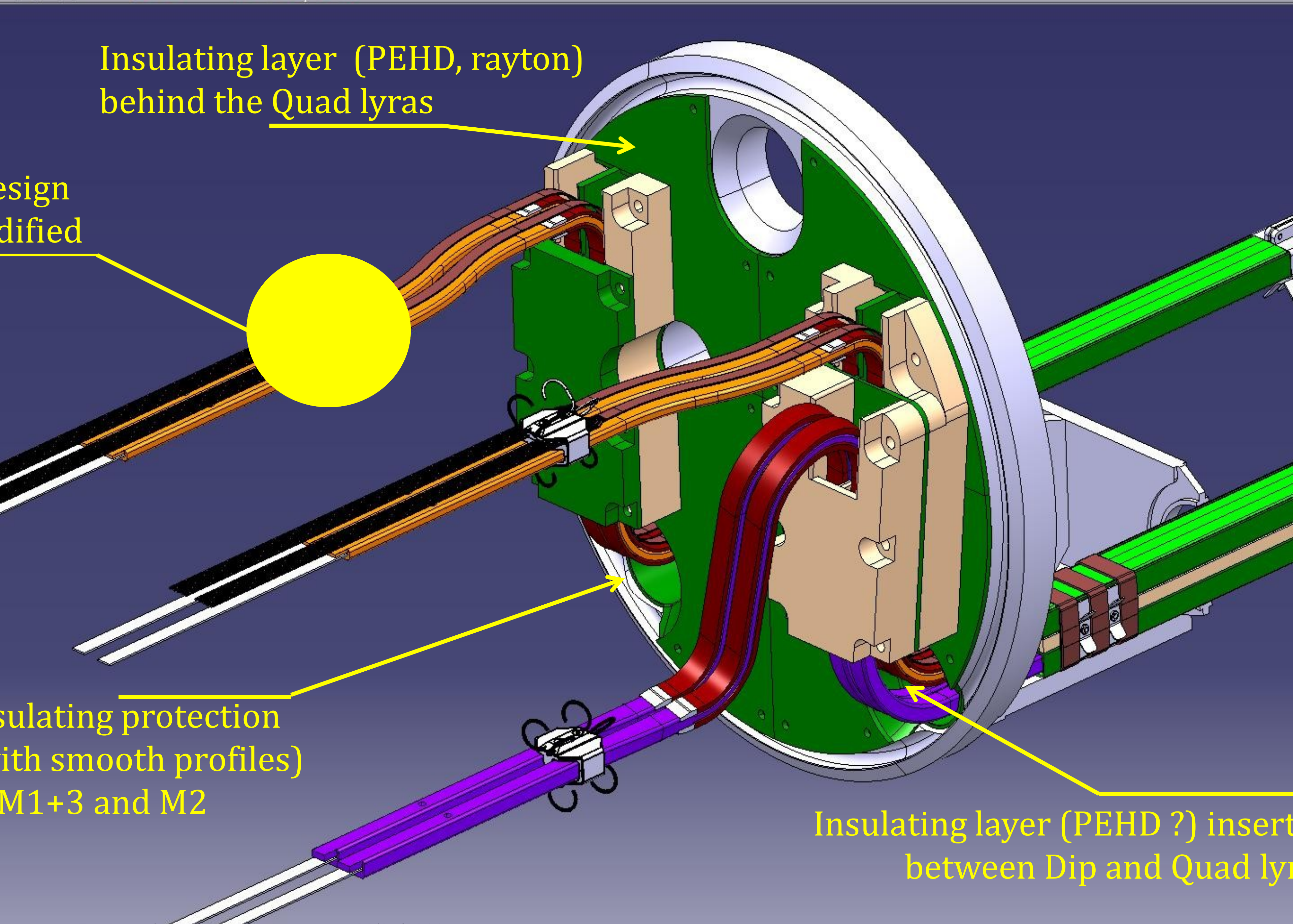
Bus bar routing in the SSS

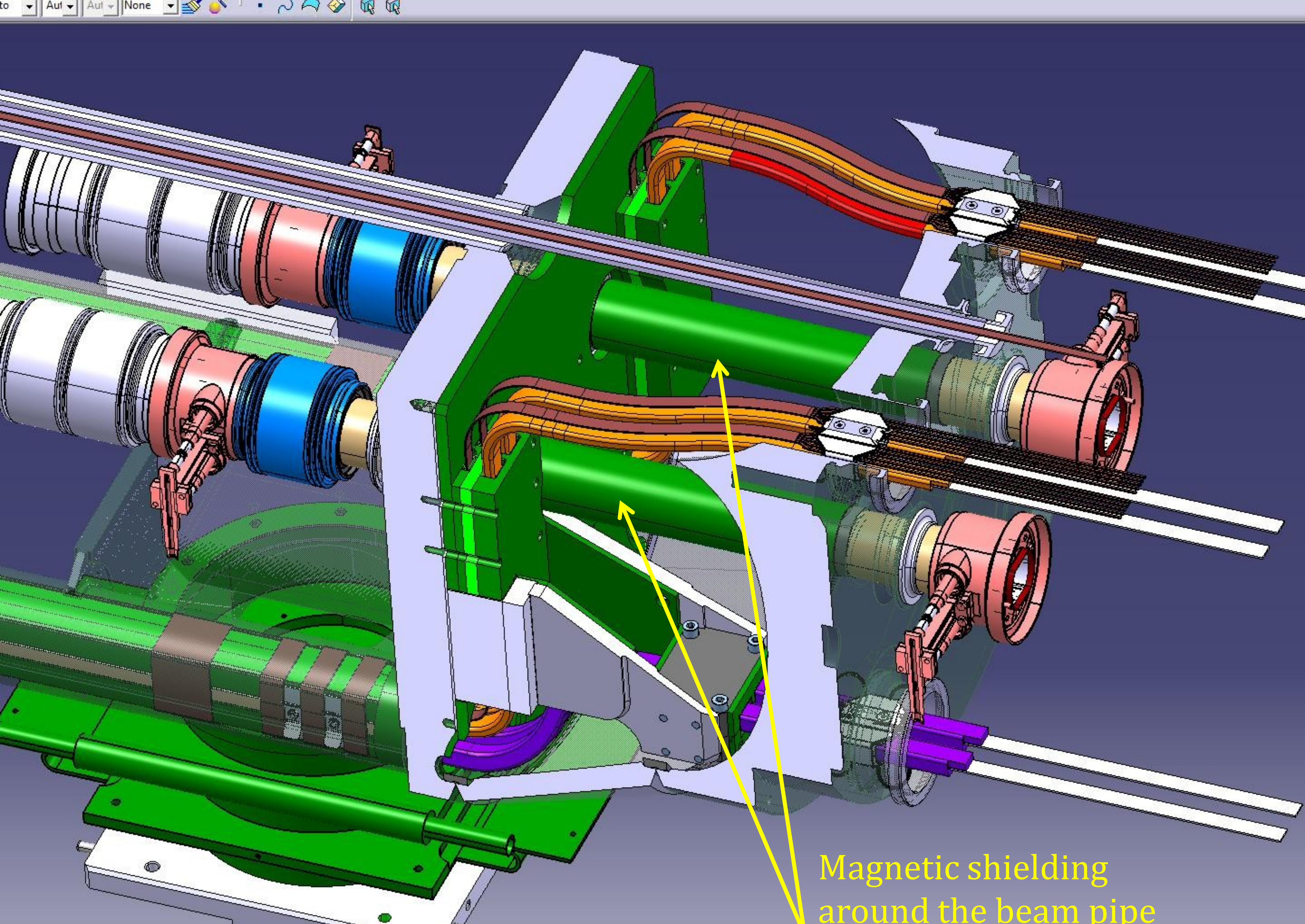
Dipole line MQ double lyra
Kapton damaged

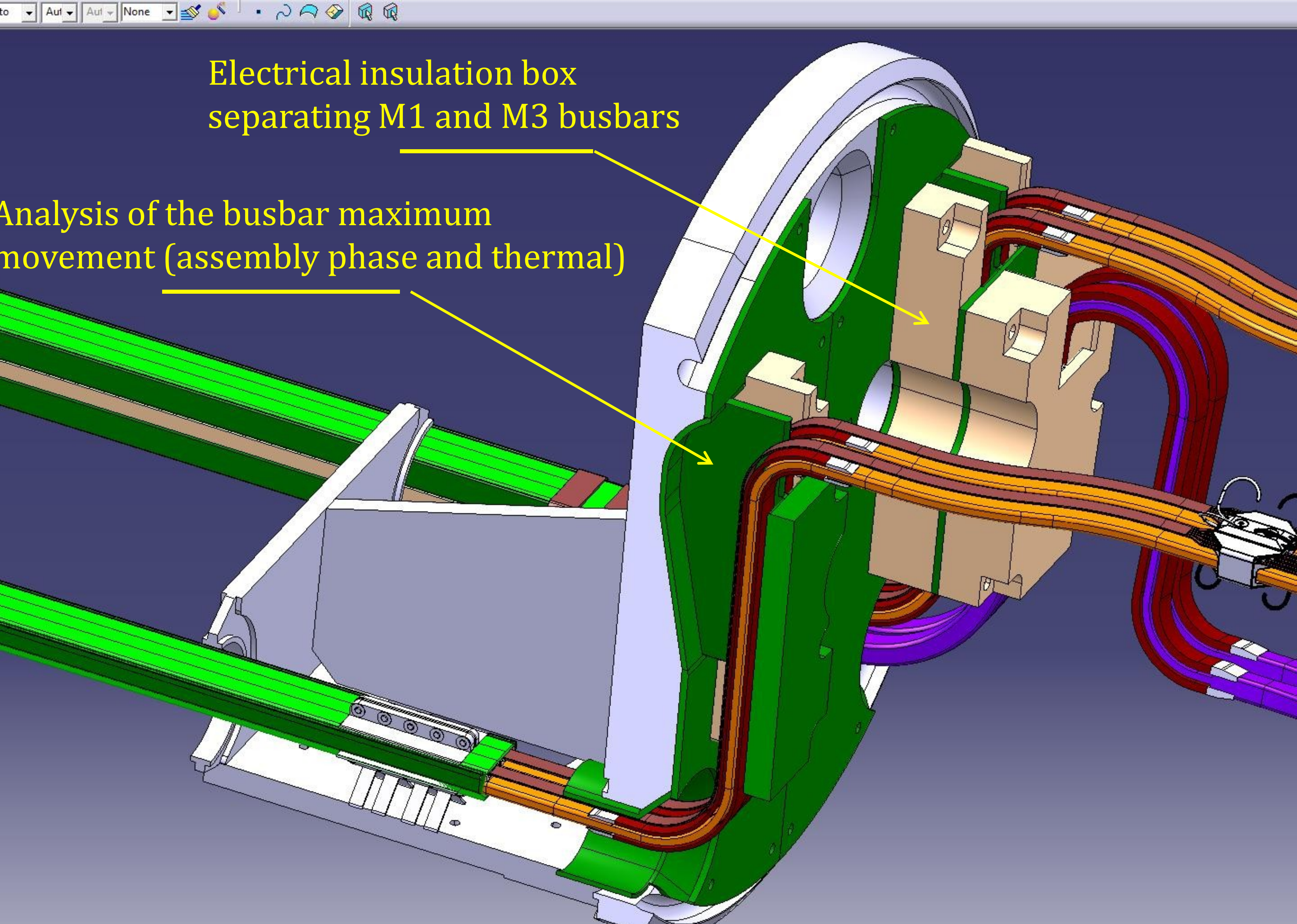
RISK ANALYSIS
DESIGN PHASE: THE CHECK LIST

- Check the DESIGN CONSISTENCY
    - construction process compromising the quality of the circuit (continuity resistive or supra, quality of insulation in the long term)
    - i.e. quality of the electric joint in the classical interconnection
    - i.e. quality of the contact in the splice of the SSS quadrupoles (examples and pics available by tomorrow)
- Avoid COMPLEX ROUTING
    - busbar partially filled in SnAg, continuity of the resistive circuit
    - i.e. see coil connections in the SSS quadrupole magnets, some parts manually filled badly compromising the soldering process (pics available by tomorrow).
- Polyimide exposed to friction (insulation concerns)
- Busbars locally positioned with INADEQUATE COMPONENTS
    - Shape and material (sharp angles, G11, examples)
    - Assembly (examples)
- Standard components to be improved (spider, supports in the pipe M1+3 and M2).
- Adequate dimensioning and positioning of the components to compensate the Lorentz forces (mainly M1+3).
- Electromagnetic field interactions: busbars in the vicinity of the vacuum pipe (calculation required to estimate the influence on the beam).
- Busbar movements (single bar) vs. the cryobypass structure
    - assembly phase (compression, extension, possible conflicts)
    - thermal and magnetic cycles
- Relative movements between busbars

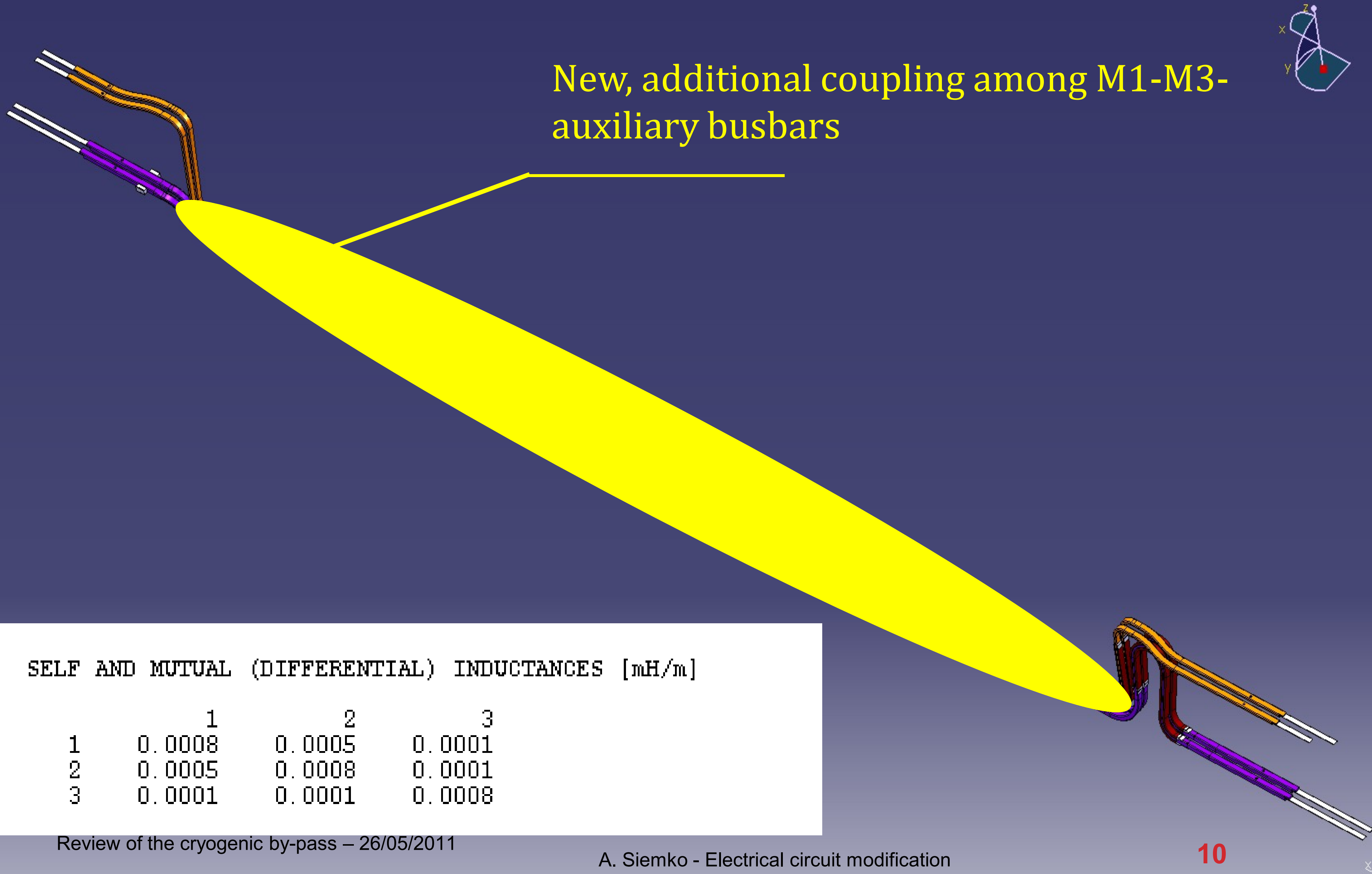

New design of the fixtures to manage the Lorenz forces reduce the relative movement and to position the bars
Reuse of validated designs like central part of the busbars


Insulating layer (PEHD, rayton)
behind the Quad lyras
esign
dified
sulating protection
ith smooth profiles)
M1+3 and M2
Insulating layer (PEHD ?) insert
between Dip and Quad lyr


Magnetic shielding
around the beam pipe


Electrical insulation box
separating M1 and M3 busbars
Analysis of the busbar maximum
movement (assembly phase and thermal)

PROTECTION ISSUE: ELECTRO-MAGNETIC COUPLING BETWEEN BUS-BARS



SELF AND MUTUAL (DIFFERENTIAL) INDUCTANCES [mH/m]

	1	2	3
1	0.0008	0.0005	0.0001
2	0.0005	0.0008	0.0001
3	0.0001	0.0001	0.0008

PROTECTION ISSUE: ELECTRO-MAGNETIC COUPLING BETWEEN BUS-BARS

- **Cross-talk between superconducting circuits due to inductive and capacitive coupling**
  - Only an issue during fast current discharges with some 100 As-1
  - Estimates indicate that over the concerned bus-bar length ca 180 V apparent voltage may be induced
    - nQPS nominal threshold for splice protection will be U_{TH} = 300 V with 10 seconds reaction time permitted

- **Two cases to be considered:**
  - M1 versus M3
  - and spools versus M1/M3

PROTECTION ISSUE: ELECTRO-MAGNETIC COUPLING BETWEEN BUS-BARS

- **Case1: M1 and M3**
  - Potential trigger of nQPS (splice protection only) systems during fast discharges
    - Concerned systems do no activate quench heaters
    - Global circuit protection will initiate fast circuit discharge if any of the main circuits is triggering -> no issue for LHC exploitation

- **Case 2: M1/M3 and spools**
  - Between M1/M3 and spools
    - A trip of a spool piece circuit must not cause a fast discharge of one of the main circuits
    - Spool piece bus-bars are currently routed close to M1 and M2
    - So far no major problems observed but no guarantee for the new case (needs to be verified experimentally)
- **Eventual coupling effects could be mitigated /ruled out by additional instrumentation**

PROTECTION ISSUE: REVISED PROTECTION SCHEME

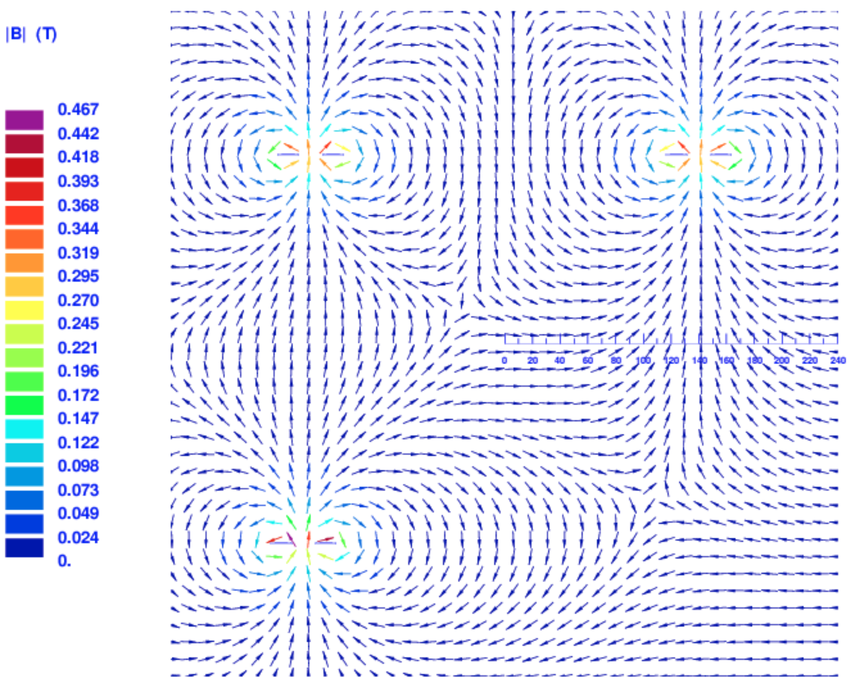
- **In principle the protection of the new bus-bar segments and splices could be assured by the existing protection units but …**
  - Neighboring QPS locations have to be modified introducing a singularity in the QPS protection scheme
    - By this the protection of the original segment will be weakened
  - No possibility other than raising thresholds to overcome problems related to cross-talk or other EMC related perturbations (e.g. collimator operation …)
    - Change of thresholds not recommended for LHC running with nominal powering parameters
  - No separate protection or diagnostics for the newly installed components
    - New type of cryostat etc. -> enhanced diagnostic capabilities desired

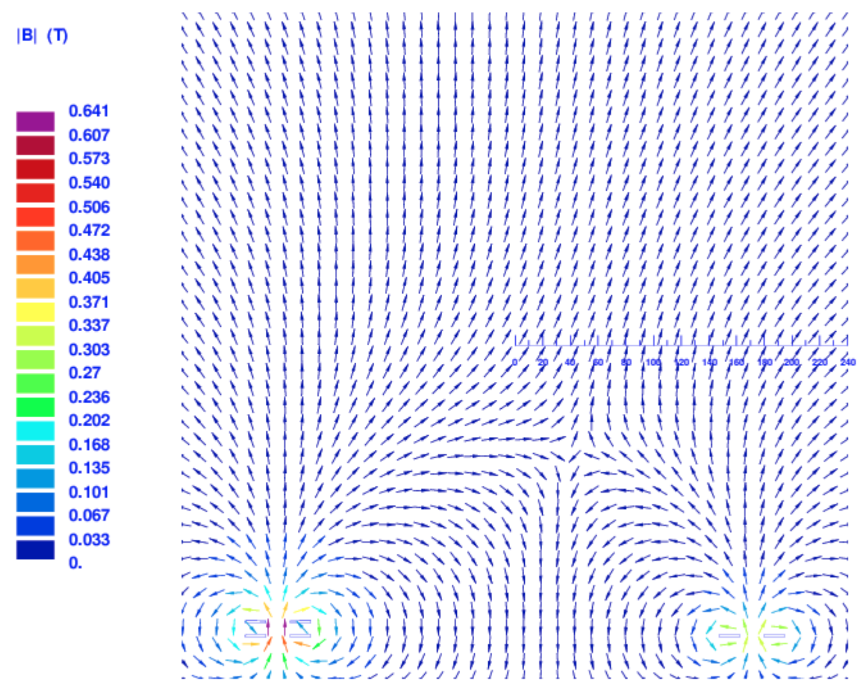
PROTECTION ISSUE: REVISED PROTECTION SCHEME

- **Implement dedicated protection module allowing decoupling and supervision of the busbars and interconnections routed through the new cryostats**
- **Add two redundant twisted pairs per interconnection in lines M1, M2 and M3**
  - 12 x 2 twisted pairs per QTC → design is critical for the overall electrical integrity and protection efficiency
    - One or two IFS boxes required depending on integration
- **Additional taps can be used as well for the quality assurance and electrical tests @ warm**
- **No additional taps required for spool piece bus-bars protection**
  - Nevertheless very useful for diagnostics -> implementation to be considered

FIELD ERRORS: POSSIBLE IMPACT ON OPERAIONS

- **Detailed calculations were performed by S. Russenschuck**





FIELD ERRORS: POSSIBLE IMPACT ON OPERAIONS

- **Field components in standard interconnection region and in the new cryogenic by-pass**

```
NORMAL FIELD COMPONENTS:
B 1:  0.22849E-02  B 2:  0.74295E-03  B 3: -0.48616E-04
B 4: -0.27817E-04  B 5: -0.61013E-06  B 6:  0.45445E-06
B 7:  0.49548E-07  B 8: -0.45943E-08  B 9: -0.11537E-0
B10: -0.37094E-11  B11:  0.17816E-10  B12:  0.12135E-1
B13: -0.19015E-12  B14: -0.29327E-13  B15:  0.98494E-1
B16:  0.46872E-15  B17:  0.13197E-16  B18: -0.66434E-1
B19: -0.99358E-18  B20: -0.48134E-18  B

SKEW FIELD COMPONENTS:
A 1:  0.22657E-02  A 2: -0.58182E-03  A 3: -0.15791E-0
A 4:  0.23547E-05  A 5:  0.37041E-05  A 6:  0.24671E-0
A 7: -0.50549E-07  A 8: -0.80281E-08  A 9:  0.28893E-0
A10:  0.14971E-09  A11:  0.54096E-11  A12: -0.19416E-1
A13: -0.20276E-12  A14:  0.15980E-13  A15:  0.38504E-1
A16: -0.31035E-17  A17: -0.54582E-16  A18: -0.19713E-1
A19:  0.87691E-18  A20:  0.34596E-19  A
ersion 1.29/04 of HIGZ started
```

```
NORMAL FIELD COMPONENTS:
B 1:  0.19987E-02  B 2:  0.15423E-03  B 3:  0.32110E-05
B 4: -0.37316E-05  B 5: -0.86987E-07  B 6:  0.18056E-07
B 7:  0.19352E-08  B 8: -0.18691E-10  B 9: -0.16833E-10
B10: -0.65085E-12  B11:  0.81626E-13  B12:  0.98508E-14
B13:  0.39498E-14  B14: -0.54684E-14  B15: -0.28677E-14
B16:  0.71349E-14  B17:  0.55968E-15  B18: -0.33440E-14
B19: -0.21930E-14  B20: -0.58450E-14  B

SKEW FIELD COMPONENTS:
A 1:  0.47627E-03  A 2:  0.25842E-04  A 3:  0.34441E-04
A 4:  0.43479E-06  A 5: -0.29010E-06  A 6: -0.15038E-07
A 7:  0.87934E-09  A 8:  0.19731E-09  A 9:  0.31698E-11
A10: -0.12383E-11  A11: -0.79961E-13  A12:  0.45246E-14
A13: -0.17336E-14  A14: -0.73177E-15  A15:  0.41094E-15
A16:  0.58222E-14  A17:  0.13547E-14  A18: -0.42023E-14
A19: -0.51578E-14  A20:  0.59711E-15  A
Version 1.29/04 of HIGZ started
```

- **No issue for the field quality, if we consider the length of this cryostat with respect to the length of all standard interconnection.**

OTHER OPERATIONAL CONSIDERATIONS

- **Risks for operation start-up**
  - The new cryogenic by-pass introduces significant modification to the main and spool LHC magnet circuits around point 3
  - Additional QPS hardware to be installed, integrated and tested
  - New cabling

- **Risks for operation**
  - More hardware in the tunnel impacts always on reliability & maintenance
  - Increased coupling between busbars in conjunction with existing and new noise sources can cause additional, spurious trips impacting on the machine integrated luminosity

CONCLUSIONS

- **The new cryogenic by-pass introduces an electrical singularity to several magnet circuits in point 3**
  - Protection issue can be mitigated by implementing dedicated protection module allowing decoupling and supervision of the busbars and interconnections routed through the new cryogenic by-pass
- **Lessons learnt during the LHC project were taken into account in the electrical design principles of the new cryogenic by-pass**
  - reuse of validated designs like central part of the busbars
  - Improved design of all known weak points like: lyres, interfaces and transitions, fixtures, etc.
- **Electrical modifications of circuits introduced by the new cryogenic by-pass seem to be of no major operation concern**