# Report to the PAF WG on the status of the magnets in the existing accelerators

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# Outline

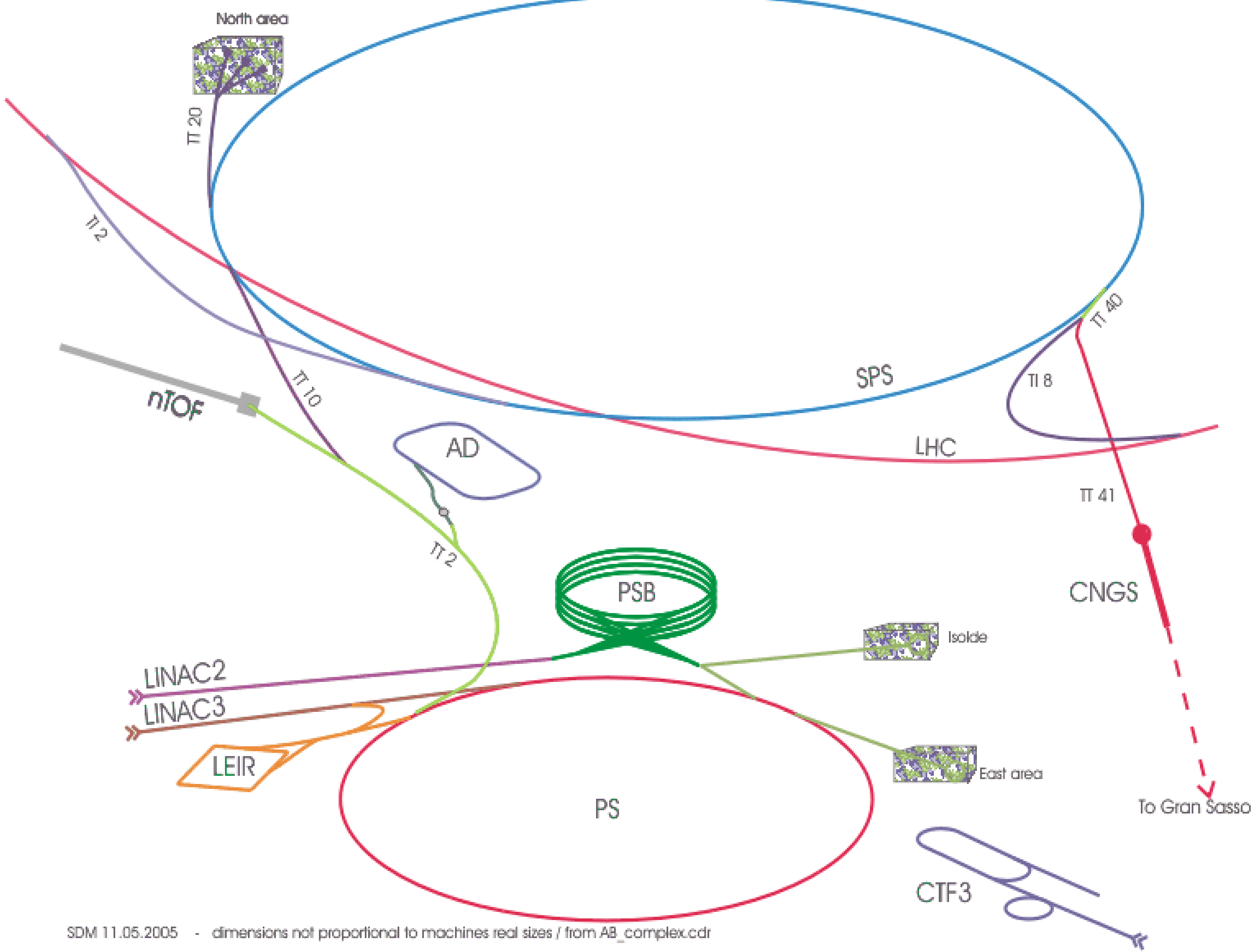
Accelerator Technology Division

- ➔ Introduction
- ➔ LINAC2
- ➔ BOOSTER
- ➔ PS MAIN RING MAGNETS
  - – Main Magnet consolidation program
  - – Auxiliary Magnets
- ➔ Risks of the magnets of the PS Complex
- ➔ SPS
  - – Problems
  - – Proposals
- ➔ Summary and Remarks

# Introduction

- ➔ AT-MEL (~50)
  - MI normal conducting magnets for CERN
  - ML SC magnets for LHC
  - MC SC correctors for LHC
  - PM SC magnet protection
  - CF SC current leads
  - EM Magnet design and electrical quality assurance (LHC)
- ➔ AT-MEL-MI (~14)
  - PS complex (PS, Booster…)
  - SPS complex (SPS, transfer lines, CNGS…)
  - LHC

- ➔ By the end of 05: ~4000 magnets in operation (~280/man)


North area
TT 20
TI 2
nTOF
TT 10
AD
TT 2
SPS
TT 40
TI 8
LHC
TT 41
CNGS
PSB
Isolde
LINAC2
LINAC3
LEIR
PS
East area
To Gran Sasso
CTF3
SDM 11.05.2005 - dimensions not proportional to machines real sizes / from AB_complex.cdr

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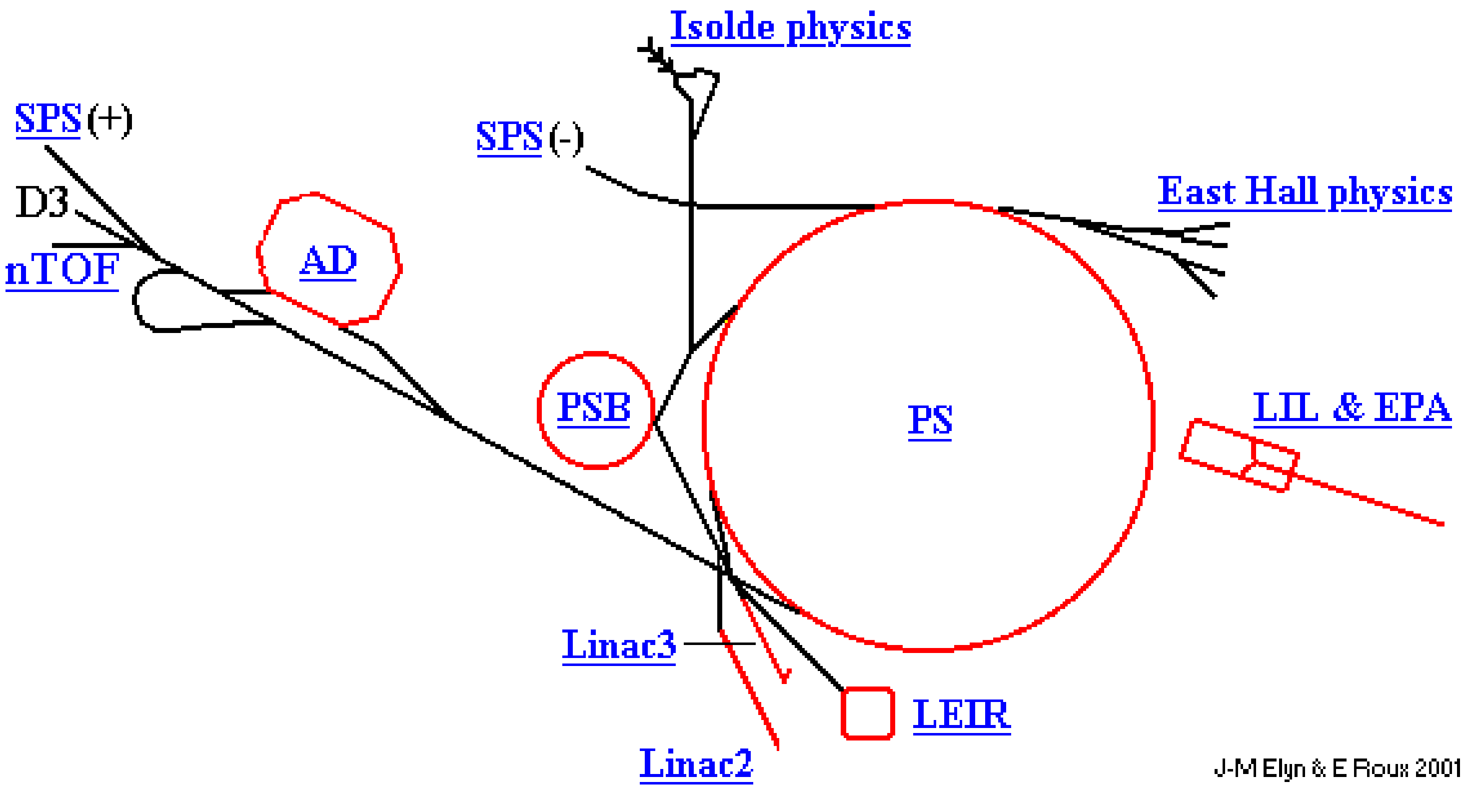
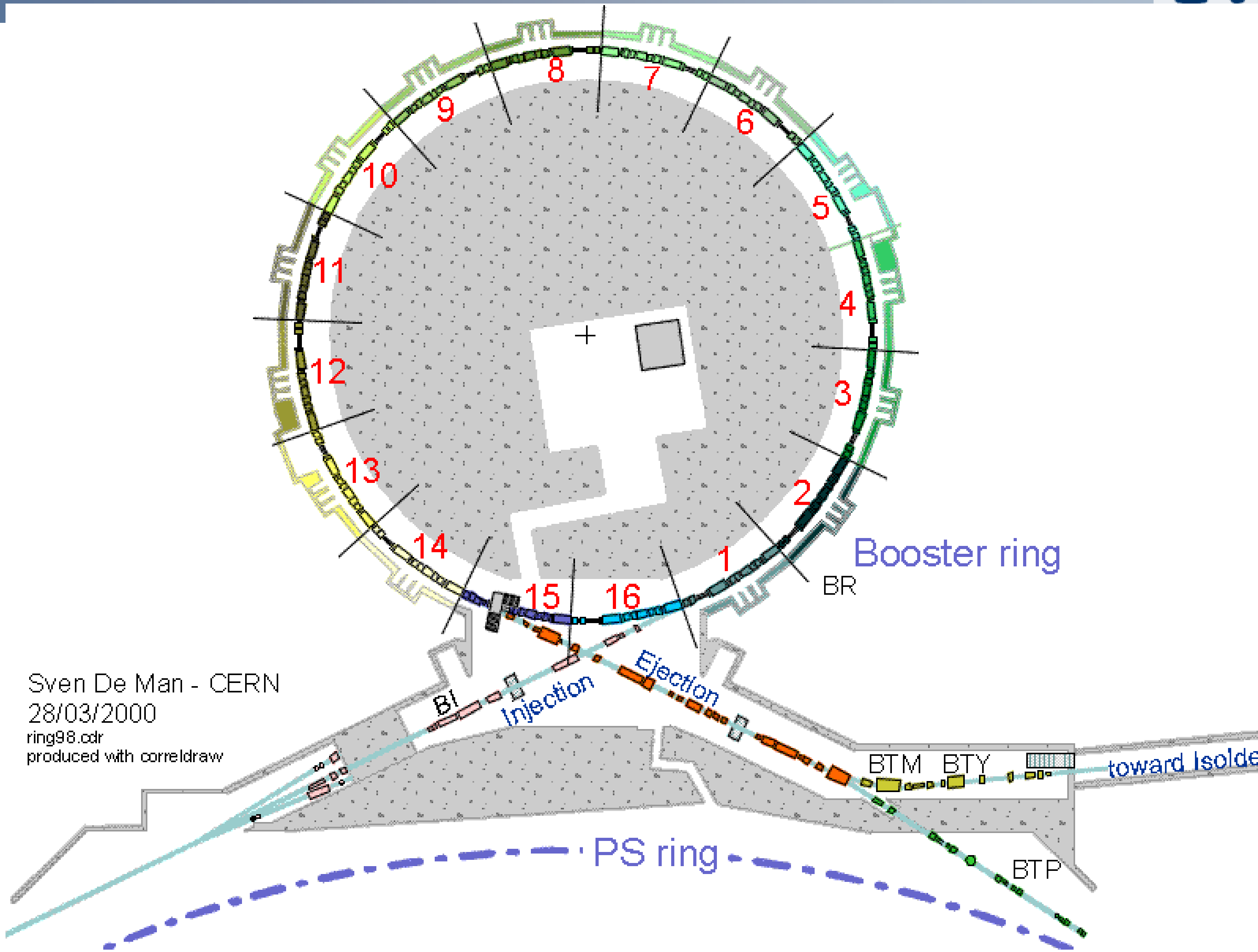


# LINAC2 Magnets

- ➔ LINAC2 started operation in 1978 providing 50 MeV protons.
- ➔ 102 magnets are installed.
- ➔ 4 bendings
- ➔ 2 solenoids + 1 spectrometer
- ➔ 95 quadrupoles
- ➔ Very few magnet failures:
  - a coil with a water leak in an IB1 (LT-BHZ30) magnet in the transfer line (fixed in 2004 & replacement coils for IB1 & IB2 under fabrication).
  - Bending magnets: 1 ground fault & 1 water leak
  - Quadrupoles & others: no problem
- ➔ Seems to be of no concern.

# Booster





8
7
9
6
10
5
11
4
12
3
13
2
14
1
15
16
Booster ring
BR
Sven De Man - CERN
28/03/2000
ring98.cdr
produced with correldraw
BI
Injection
Ejection
BTM
BTY
toward Isolde
PS ring
BTP

# PS BOOSTER Magnets



- The PS BOOSTER was put into operation in 1972.

- There are 4 rings stacked vertically with a common yoke housing the coils.
- In total there are 128 magnets installed.
- 32 bendings + 1 reference
- 48 quadrupoles
- Dipoles:
  - 14 type 1 / 2 type 2
  - 2 type 5 / 1 type 6
- Multipoles:
  - 4 type A / 4 type B (new 1976)
  - 12 type 1A / 4 type 2A (old 1970)
  - 4 type 2B (old 1970)

# PS BOOSTER Magnets



- The main problem encountered was the ageing of the rubber water hoses and seals causing water leaks.
- Water leaks:

  - Many stops in 1998 & 1999 to repair leaks on seals of flexible hoses.

  - All hoses and seals have been replaced in the 4 following shutdowns.

  - No leaks thereafter except in 2004 after the installation of 21 non-conform hoses (replaced during start-up).

  - 1 water collector leaking due to Cu erosion on QDE42 in 2003.

  - 1 water collector leaking on BHZ162 in 2005.
- We plan for an inspection in the next shutdown 2005-06 and replace hoses where necessary.
- There is a reasonable number of spare magnets and coils.

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- ➔ 100 combined function magnets
  - – Equipped with pole face windings and figure of eight coils
- ➔ 146 auxiliary magnets
  - – 60 corrections dipoles
  - – 34 quadrupoles
  - – 36 sextupoles
  - – 9 octupoles
  - – 7 bumpers

# A Main Unit today
## (PFW and fig. 8 coils removed)

# A Main Unit ~45 years ago


→ See the difference in manpower

→ and the absence of the figure of eight coils and the PFW

# PS main magnet consolidation



During the routine HV test before the 2003 start-up the coil insulation in 2 PS main magnets was destroyed by breakdown.

An overall inspection of the 45 years old PS main magnets showed heavy degradation induced by radiation and in particular:

- ➔ On many magnets the coil insulation was deteriorated and over larger areas no more adhering to the Al-conductor
- ➔ Insufficient spare coils with good insulation existed
- ➔ The cable insulation of the pole face winding was falling apart when touched

# Selection criteria

# PS main magnet consolidation

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Therefore, in summer 2003 it was decided to launch the PS Magnet Consolidation Project split into two phases :

➔ Phase I for 2003-2006: Refurbishment of the weakest 40 PS Main Magnets

➔ Phase II in 2006-2013: Refurbishment of the remaining 60 PS Main Magnets (still to be funded).

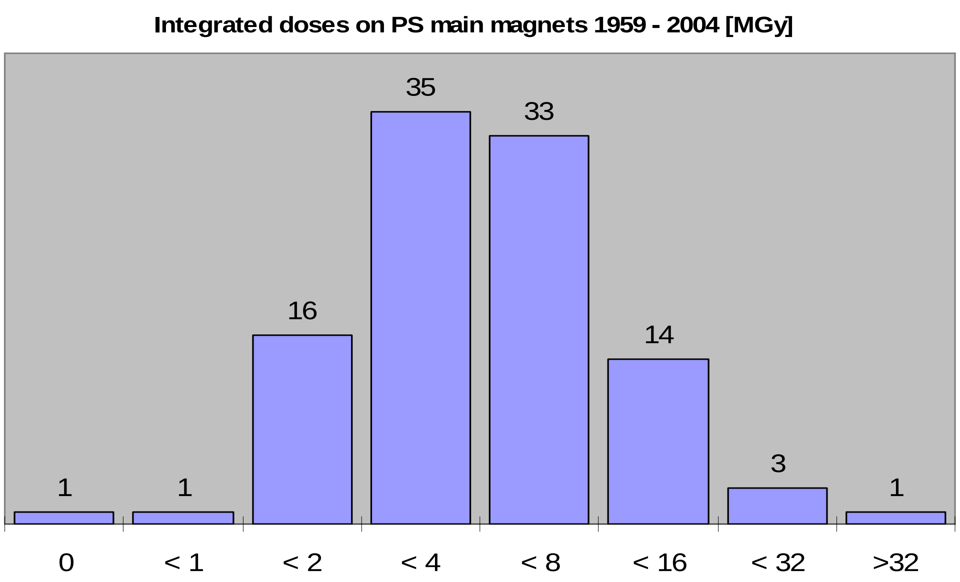
The split has the following reasons:

- ➔ Budget: The total amount of 20 MCHF was not available, whereas the amount needed for the first phase of about 7 MCHF could be allocated.
- ➔ Personnel: The strain on the personnel involved in LHC, CNGS & other project under full construction (magnets, vacuum, transport, survey) would have been too high for doing all magnets in 2003-2006.
- ➔ PS as LHC Injector: We believe that after phase I the risk of frequent PS stops due to magnet failures would be sufficiently reduced.
- ➔ Thus the refurbishment of the remaining magnets could be stretched over a longer period.

# Selection criteria

100 main magnet units are installed in the PS tunnel, 91 of them are still in original state (72 even on original position). The following criteria have been applied to find out the weakest magnets:

- ➔ The total integrated dose received between 1959 and 2004.
- ➔ The actual radioactivity.
- ➔ State of the electrical insulation of the main coils.
- ➔ State of the PFW cable insulation.
- ➔ Voltage seen by the main coils during operation.
- ➔ Foreseen PD testing had to be skipped since it was found to be too time consuming.



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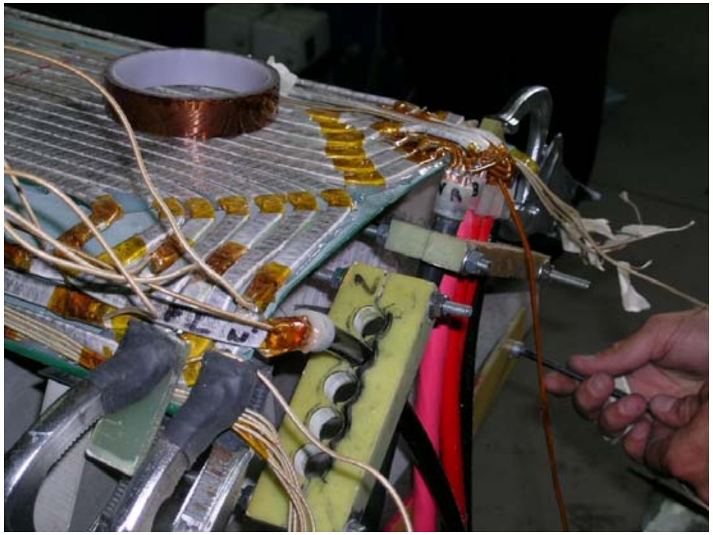
All components to complete 60 magnets have been ordered. New main coils and Pole Face Windings (PFW) are actually in production.

- 232 new main coils (pancakes) are in production at BINP/Novosibirsk.
- Coil prototype has arrived at CERN in December 2004 and was tested successfully.
- Series coil delivery has been delayed by over 4 months and started only in June 2005.
- As a consequence we can only refurbish 24 main magnets instead of the 40 planned.

# New magnet components

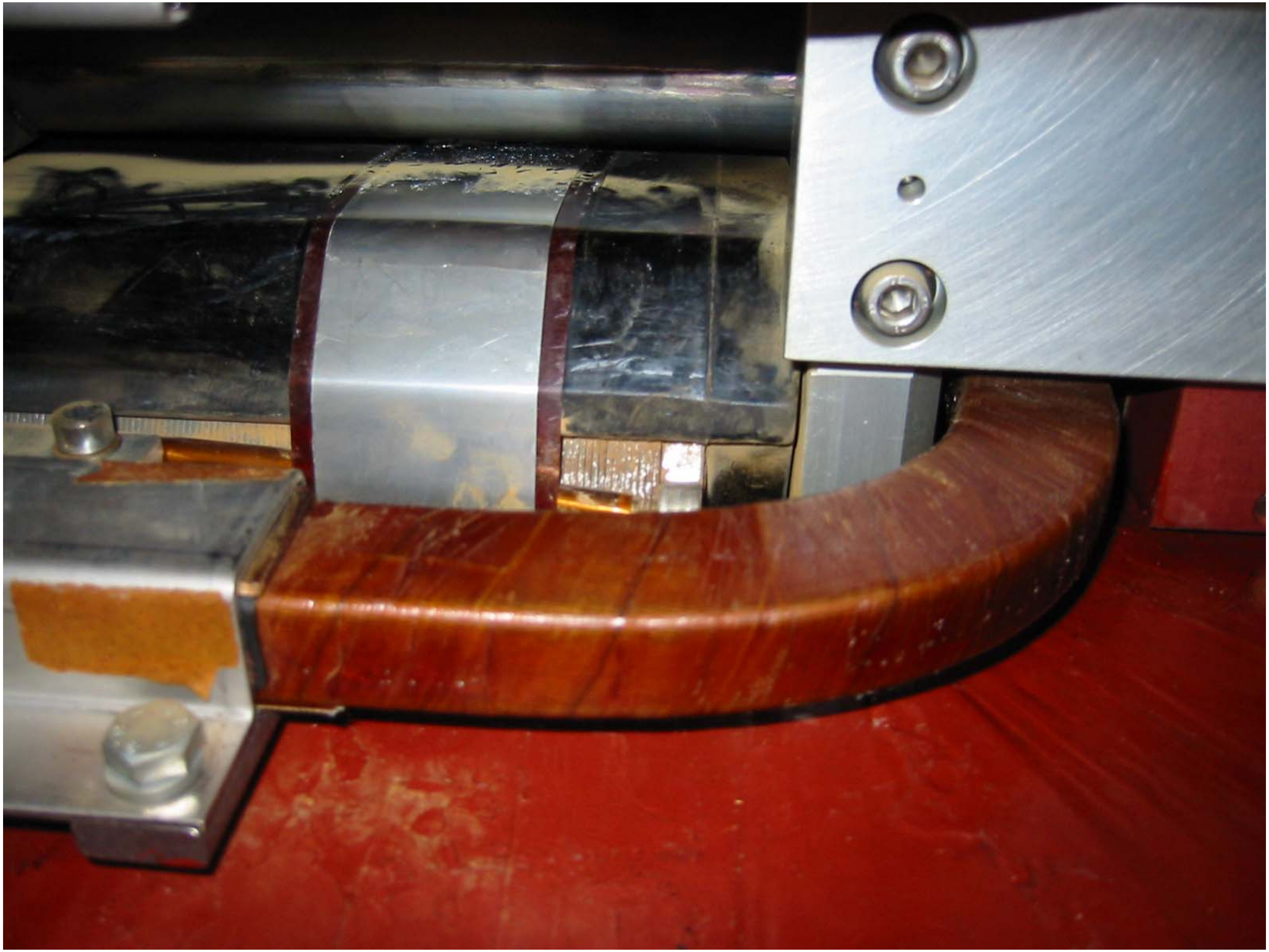
- 240 new Pole Face Windings are in production at SIGMAPHI/ France.
- PFW prototype has arrived at CERN in December 2004 (not conform to specification).
- Series PFW delivery delayed by 4 months to end of May 2005.
- The delays are due to the complexity of the PFW and that SIGAMPHI has underestimated the workload.
- By July the nominal rate of 8 per week was achieved.



# Problems with main magnet yokes

- Already in 1978 a heavy degrading of glue due to radiation was found that should keep together the 1.5 mm thick steel laminations of the 10 blocks forming the yoke.
- The remedy applied was :
  - Exterior blocks #1 + #10: use of tie rods pressing the laminations.
  - Gaps between all other blocks except #5 to #6: insertion of shims to compress the steel laminations.
  - Gap between #5 to #6: insertion of shims to compress the steel laminations impossible because of the passage of the conductor for the figure of eight coil.

# Problems with main magnet yokes



# Problems with main magnet yokes

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- When we disassembled the first PS main magnets in May 2005, we discovered that the degradation of the glue had further advanced. As a consequence loose lamination under the effect of the pulsed field did open up in the gap between blocks #5 & #6  where they cannot be constrained by shims.
- Without repair this effect would have damaged the insulation of the figure of eight coil and led to a short circuit.
- To solve this problem we apply  a new gluing in situ of the loose lamination sheets facing this gap and bolt them in addition with a 40 mm long M8 screw.
- A test with 30 kcycles at full field has shown that this method is successful.

# Conclusion PS main magnet refurbishment

- Serious delays in the coil production at BINP and PFW production have unfortunately reduced the number of refurbished units.
- Without further delays, 24 magnets are now foreseen to be refurbished in 2005 instead of the 40 planned.
- The refurbishment of the first magnet has started week 31 & will be finished week 33.
- The number of refurbished magnet could be increased by extending their installation into the begin of 2006 (approx. 1.5 units per additional week).
- No major risk for the start-up in 2006 identified.

# Risk expectation for PS Operation w.r.t. the PS main magnet system



2003:

- ➔ During the routine HV test before the 2003 start-up the coil insulation in 2 PS main magnets was destroyed by breakdown. Magnets replaced by spare units.

2004:

- ➔ Main unit #31 with a broken tie rod (compressing the loose laminations of 1 block) replaced by spare unit during shutdown 2002-2004.
- ➔ No failure occurred during operation.

2006:

- ➔ We have chosen the 24 weakest magnets for the refurbishment campaign.
- ➔ Therefore, the risk of magnet failure in 2006 should be much lower than in the past.

FUTURE:

- With 4 spare magnets we could refurbish a total of 8 units per year up to a total of 50 PS main magnets: Phase 1 of refurbishment project ending in 2009.
  - 4 units refurbished during shutdown and re-installed together with the 4 spares.
  - 4 units refurbished during PS operation leaving for this period no operational spares.
- For the renovation of the remaining 50 PS main magnets the Phase 2 of refurbishment project has to be approved with a budget of x MCHF.
  - This will extend the refurbishment period over another 8 years from 2010 to 2017.

FUTURE:

- ➔ With the construction of 4 new spare units (important effort) this could be reduced to a refurbishment period extending over about only 6 years from 2007 to 2012 provided that:
  - Additional human resources (1 Engineer + 1 Technician) will be made available in 2006.
  - Budget will be allocated.
  - A new workshop (35 t crane needed) for assembling and aligning the magnets can be created in the PS hall.

- ➔ In Conclusion: Provided we get the man power (after the LHC start) and the money, we can keep the PS magnets alive. However, interruptions as in the past will be unavoidable.
- ➔ Remark: SC machines of present design could not withstand the radiation, I believe.

# Risk expectation for PS Operation w.r.t. the PS auxiliary magnet system

- ➔ The 146 auxiliary magnets have been regularly refurbished during the annual shutdown.
- ➔ Spare units exist.
- ➔ No important magnet failures during operation.
- ➔ Therefore, we do not expect any serious risk jeopardizing the PS operation.

# SPS

→ **Appendix VIII and the conclusions recommend:**

→ A strategic reserve of about 5 Mio CHF, to be kept somewhere at CERN which would cover catastrophic events such as for example:

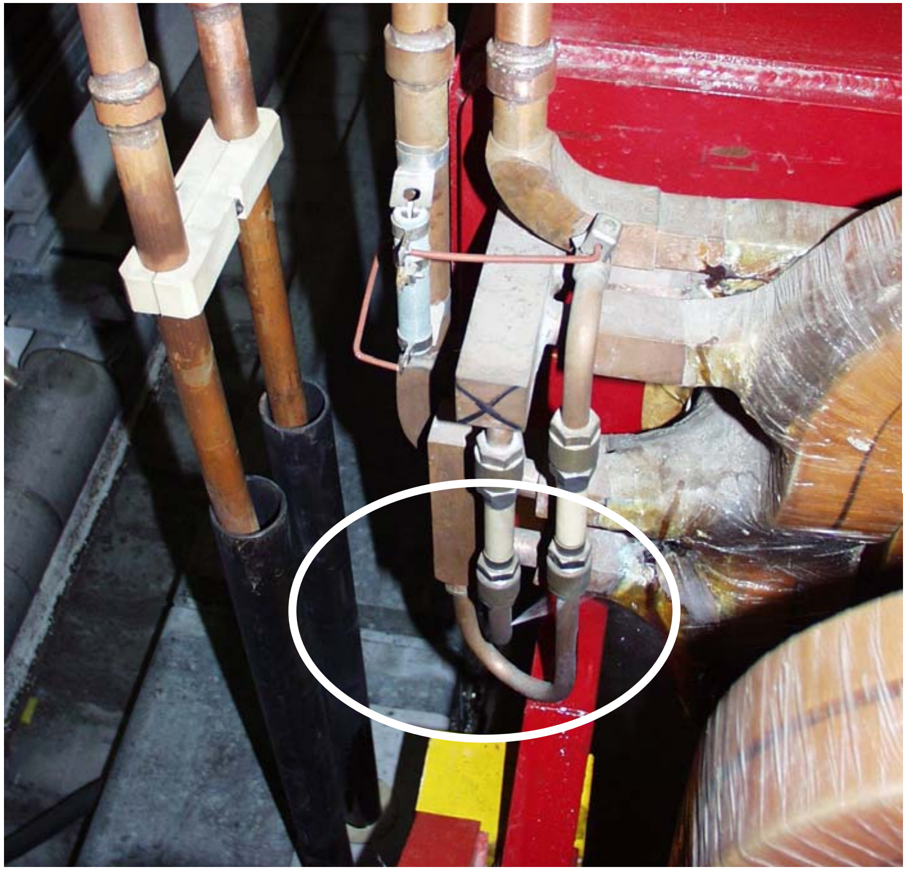
- x The thin-walled copper pipes in the manifolds of the Main Dipoles get eroded by the demineralized. water and a big series of MBs have to be dismounted and repaired.
- x The cooling duct in water cooled cables, made of low quality copper, gets eroded and perforated so that a series of water cooled cables have to be changed.
- x Bigger series of MB -coils could break if one , what will be probably the case, runs the magnets on higher temperatures in the future.
- x Killing a series of magnets with the beam. (With the present rate of change, reserves of MBB magnets will run out in 5 years). Ten new spare magnets including tools will cost around 1,5 Mio CHF.
- x Breakdown on highly radioactive Splitter magnets due to hidden corrosion. To fabricate a single MSSB - splitter magnet will cost in order of 1 Mio CHF.

# Recently re-discovered problems:



- vacuum leaks due to corrosion in TDC2 splitter area killed a collimator device, the collimator was exchanged. The splitters are attacked by acid, but are still air tight;
- several water leaks (not repairable) on MBA/MBB dipole manifold, presumably because erosion.

- Water leak on MBB No. 025 in position 5127 of the SPS. The leak is located on a U shaped standard copper tube and is probably due to erosion. This kind of leak is not repairable (copper tube probably completely eroded and impossible to replace with damaging the coil insulation when brazing a new one)



Marked rate increase in 2004

# Water leak problem

- ➔ In total 7 water leaks the copper tube manifold of the main dipoles MBB have shown up for the 1st time in 2004.
- ➔ A repair in situ is impossible because of the insufficient access.
- ➔ This could become a series problem for the SPS as it concerns 744 dipoles.
- ➔ We could NOT find diagnostics tools to evaluate the amplitude of this erosion problem. Cutting tubes longitudinally revealed that there are many tiny craters especially in the bend parts. ➔ Will be impossible to diagnose this from the outside !
- ➔ A removal of about 1 magnet from the ring, the repair in the lab, followed by transport and reinstallation takes about 2.5 days or for 774 magnets about eight years, if carried out sequentially.

# Water leak problem



- Even a partial consolidation (based on what?) could only be done during a long shut-down.
  - However, we cannot do this with our current manpower.
  - Impact on the SPS: Operation will be interrupted by at least 16h per MBB water leak.
  - For faults occurring during nights or weekends we have to get the replacement teams started. No piquet service possible.
- After the repair of 7 MBB (replacement in the lab of the leaking manifolds) a high voltage test revealed that the leakage current is about 300 times higher than normal. This is certainly due to the water having penetrated the coil insulation. Experience has shown that drying is not successful. Therefore, the 7 MBB shall be opened (if we get the operation budget for this), the coils be replaced by spare coils (this will reduce our stock from 16 to 9 sets, so consequently a new coil production has to get started with the same problem on P+M).

# Spare dipole coils

- **Situation of spare MBB coils:**
  - Good coils 16
  - Usable coils but not in good state, therefore candidates for refurbishment via burning off the insulation: 6 (+7 repl.)
  - However, our contract with TESLA for burning off the insulation has run out. And the shop looks ugly/dangerous.
  - Total price for burning off the insulation: 13 x 50 = 650 KCHF
  - Total price for new coils in EU: 13 x 80 = 1040 KCHF
- **Situation of spare MBA coils:**
  - 14 spare MBA coil sets

# Other consolidation needs to be covered within 5 years



- ➔ restart MBB & QD/QF coil reconditionning (contract for 30 coils)
- ➔ start MDSH/MDSV/MDH/MDV overhauling program (150 magnets)
- ➔ renovation of thermoswitches of sextupoles/octupoles in SPS (100 magnets)
- ➔ carry on with QTL quadrupole reconstruction (6 magnets /year over 5y)
- ➔ define in partnership with AB/CO: magnet interlock renovation for SPS (urgent), North Exp Area (critical), delta-I bus-bars differential current transducer interlock has no spare , no docs (critical),

# Other consolidation needs to be covered within 5 years

- define in partnership with AB/RF: B-train field probes for reference magnets of the SPS (either useless or critical?)
- define in partnership with AB/PO: renovation of Test of SPS busbar system
- define in partnership with TS/CV and start maintenance program for SPS waterhoses (1500 hoses within 5 years, should start in 2006)
- define and re-start maintenance program: tightening of electrical connections and exchange of water-connection gaskets (routine maintenance progressively abandoned from 1998)

# Summary on the SPS

- Looking into the logbook:
- It's a bit like going to work in the morning
  - With a car that breaks down every morning for ½ h
  - Can be fixed temporarily
  - And is taken once a year to the normal inspection.
- Yes, it still works.
- But:
  - Downtime (16 h/ water leak)
  - Radiation dose
  - Few people and low budget
  - And the progressing degradation are a big concern.

# Summary

- Radiation, time and the lack of preventive maintenance take its toll on the magnets.
- The degradation of the PS main units is worst but taken care of.
- Low energy machines and /or low intensity machines are more or less fine.
- The SPS (including the experimental lines) seems to be victim of an accelerated degradation, as predicted 10 years ago.
- After the LHC installation AT may have people to attack the SPS problems.
- Higher beam intensities (CNGS) will make it all worse.
- My prophecy: We will survive still some years (5??) with increasing dead times and peoples exposure to radiation unless we invest time and money. Thereafter we will need more people, simply to keep the radiation dose within legal limits.

# A final word on the LHC

- ➔ The MBW in 7 will see (without additional protection) 100MG/year (i.e. die after ~1 month!).
- ➔ The exchange of the MBW and of MQW is planned to take ~weeks due to radiation limits. Nevertheless MEL-MI has not enough people to share the radiation within legal limits.

- ➔ If you think of new machines, think also of new ways to exchange magnets and to make them more radiation, erosion and corrosion resistant! This will cost much extra money and may be very, very difficult for SC magnets.