AB/PO Equipment irradiation test in CNGS

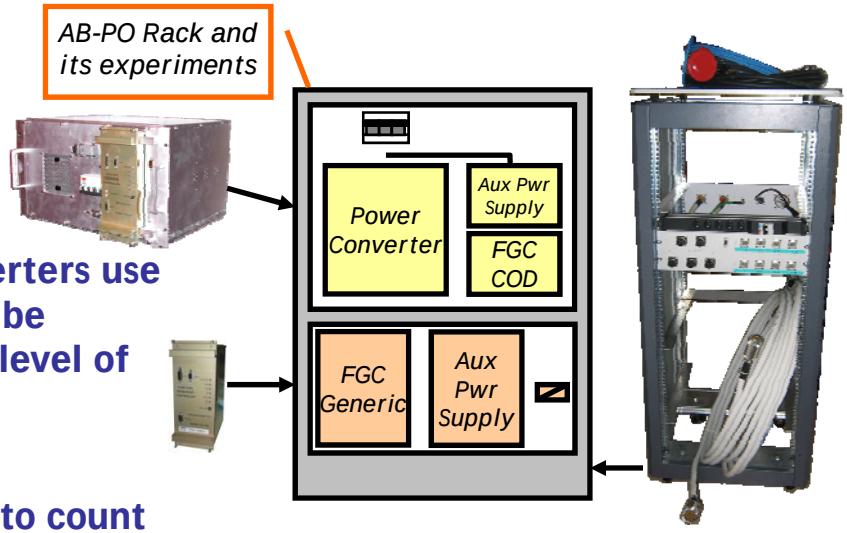
Phase 1: [2008-10-09…2008-10-09: Crash Event]
Phase 2 : [2008-10-20...2008-11-17: Shutdown]

AB-PO
CERN

Experiment description

a) FGC Generic

- **LHC Equipment tested:**
  FGC Generic
- **LHC Equipment concerned:**
  All LHC converters except LHC60A-08V converters use a FGC Generic. This FGC Generic is known to be sensitive at the level of its ADCs, then at the level of the current precision regulation.
- **CNGS Test goals:**
  A dedicated software is installed in this unit, to count the number of SEU, and to analyze how precision parts are affected, and to analyse memory and internal registers behaviour vs radiations.



2x AB-PO Experiments located in AB/PO Rack

b) LHC60A-08V

- **LHC Equipment tested:**
  LHC60A Converter
- **LHC Equipment concerned:**
  All LHC60A converters, used as orbit correctors.
- **CNGS Test goals:**
  This converter was designed specifically to support 1-2 Gy / year during 20 years. TCC2 are the basis for the radiation test already conducted. CNGS test is another opportunity to verify the converter is complying with initial specification. Goal is to test the crash limit of the converter

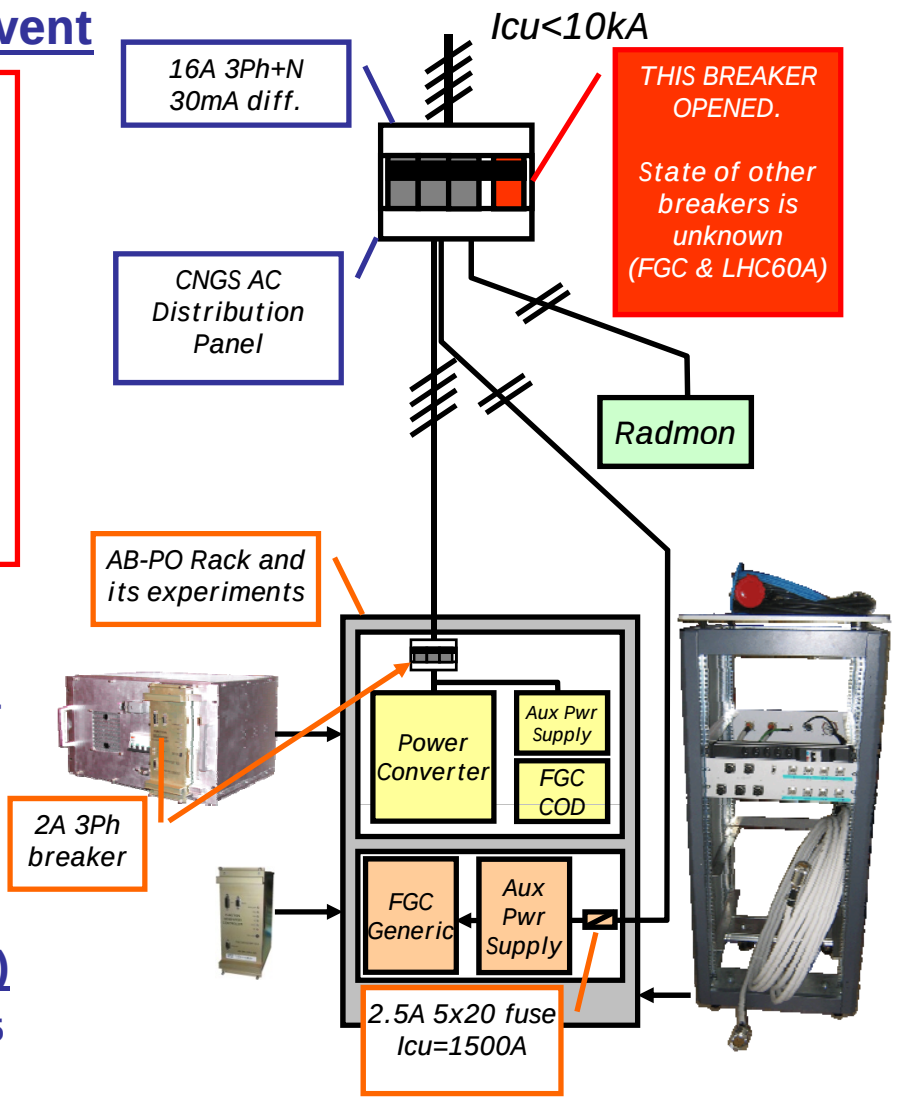
Phase 1: [2008-10-07..2008-10-09]

AB/PO CNGS Crash Radiation Test Analysis – Phase 1

Phase 1: [2008-10-07..2008-10-09] Crash Event

Event Crash

- TSG45 – AB/PO AC Breaker opened 2008-10-09 at 13H00
  (only 2.5 hours after CNGS re-started)
- AB-PO Rack and its 2 experiments lost
- Radmon connected to same AC Breaker lost
- Total Fluence measured by ramon = 2.10^{E9} /cm² = only 10 days of LHC60A operation



Irradiated area Historic (CNGS Tunnel)

- AB-PO Rack and its 2 experiments were installed on 2008-10-07 16H00 and have been running dedicated cycles for rad test up to the crash event (then 1.5 days).
  ➔ No problem was detected on equipments running under non-radioactive environment IN FINAL CONFIGURATION.

Non-Irradiated area Historic (CNGS Ctrl Room)

- AB-PO Rack and its 2 experiments installed on 2008-09-15 and have been running (dedicated cycles for rad test) up move equipment date inside CNGS tunnel (2008-10-07)
  ➔ No problem was detected on equipments running for more than 20 days without any trouble.

Phase 1: [2008-10-07..2008-10-09] Crash Event

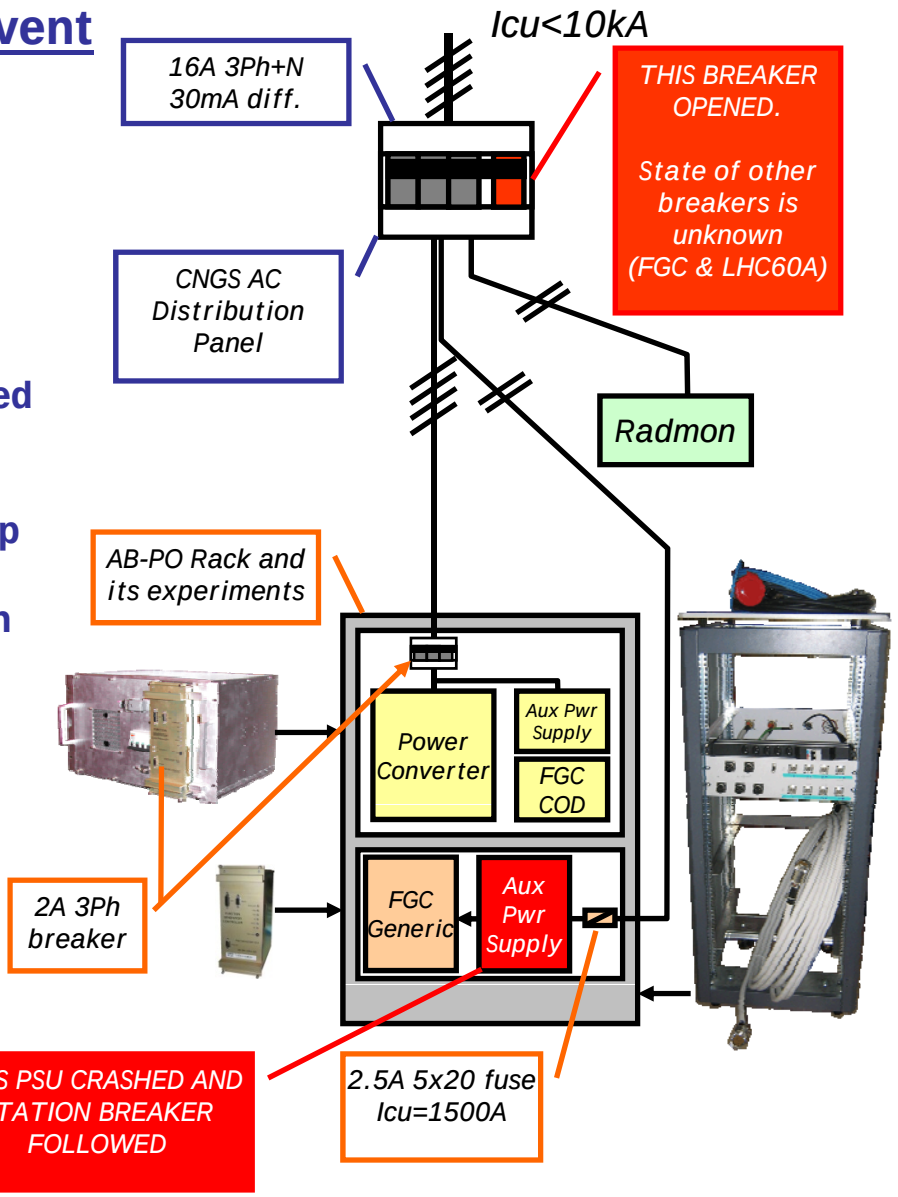
Crash: FGC Generic Experiment Faulty

- **Aux PSU 2.5A delayed 5x20 fuse opened**
  ➔ PSU Out Of Order

Possible Cause

a. Auxiliary Power supply (not a LHC component) crashed because of radiations. (Bizarre since tested same type successfully in TCC2 up to 50Gy)
Possible that:
- Fuse (tempo) made the 16A 3 phases breaker trip
- Fuse not adequate regarding the Icu.
- A component perhaps connected to ground/earth during crash ➔ 30mA breaker opened

b. This PSU simply failed external to irradiations reason.

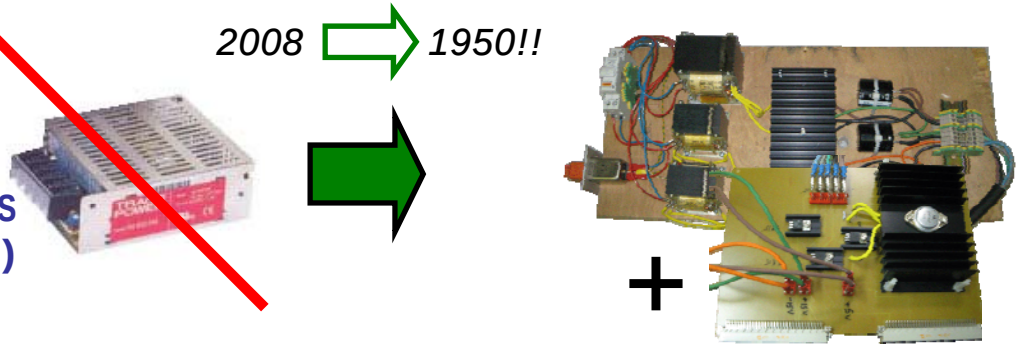


Phase 2: [2008-10-20..2008-11-17]

Phase 2: [2008-10-20..2008-11-17] Test Bed changes

Action N°1

FGC Generic PSU Changed for a AB-PO "home made" linear type (no switching devices). Installed in CNGS low dose location. (close to patch panel)

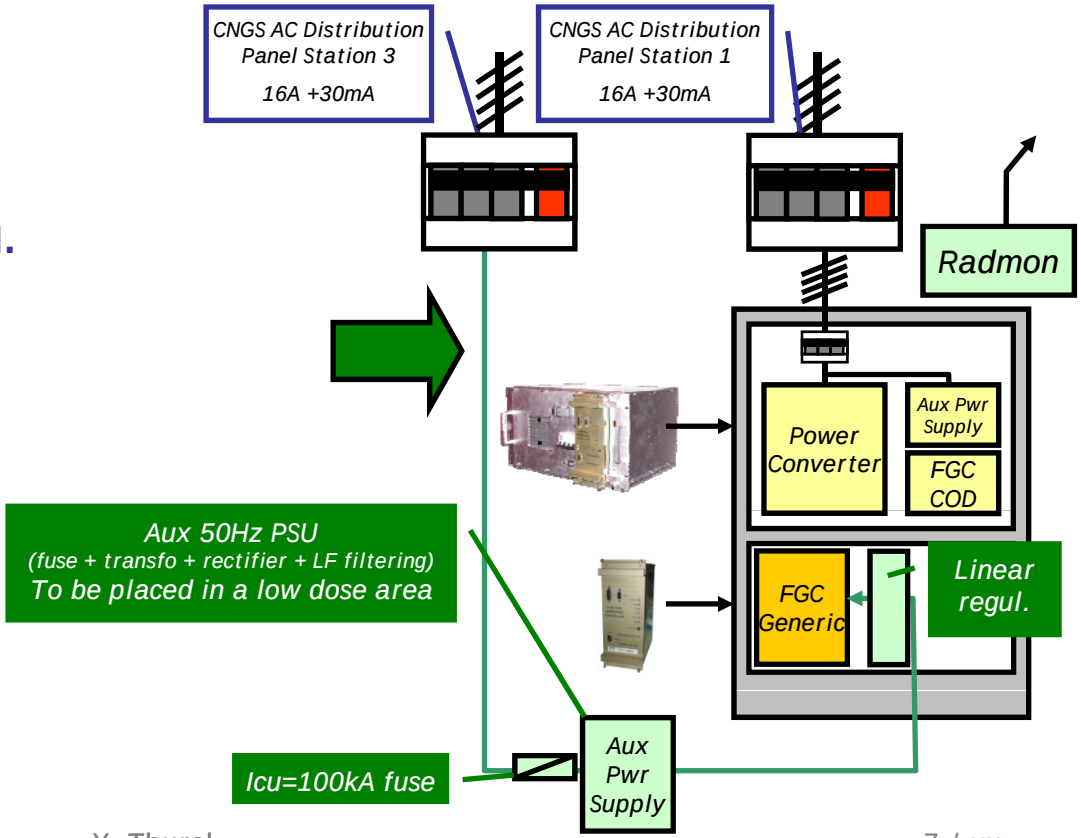


Action N°2

Decoupling as much as possible AB-PO experiments.

FGC Generic:
Powered from Station N°3 Patch Panel.

LHC60A-08V:
Powered alone from Station N°1.



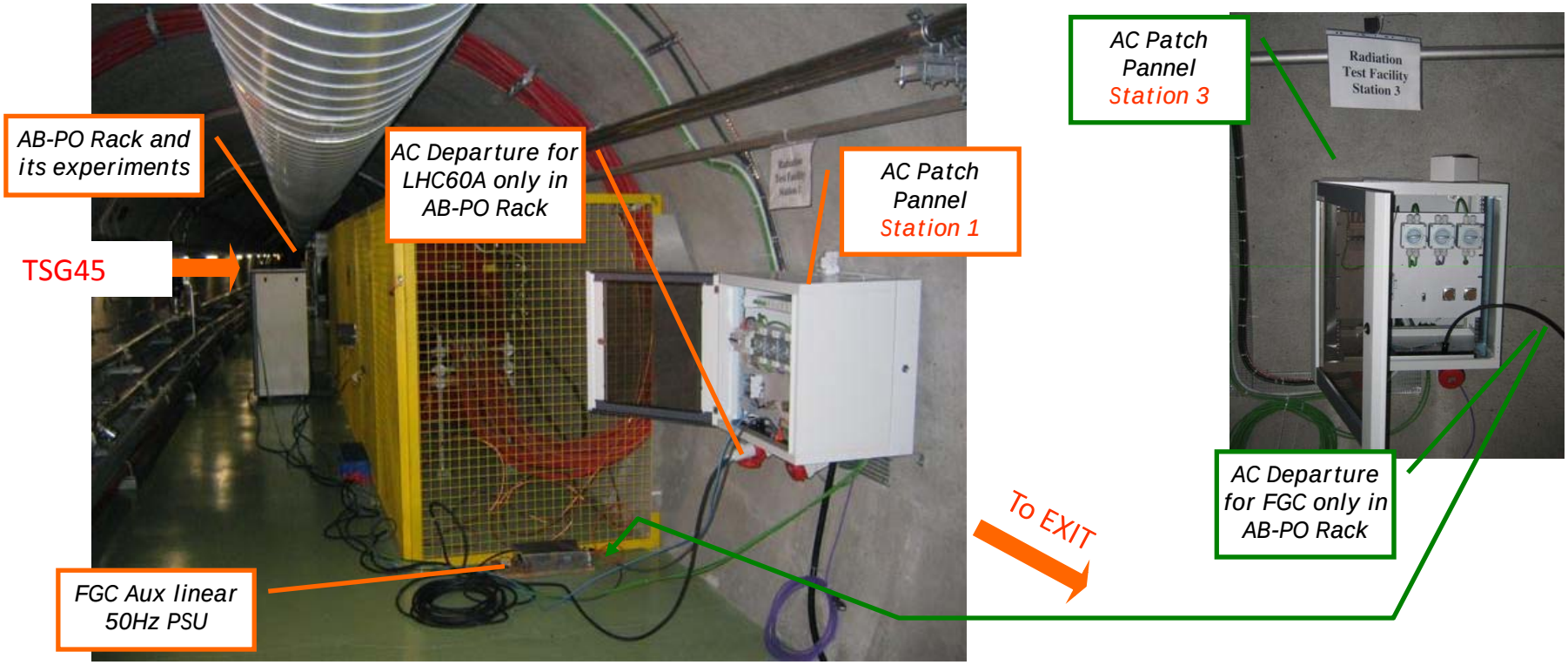
Action N°3

Individual Level of protection checked and re-inforced for better selectivity & safety

Phase 2: [2008-10-20..2008-11-17] Items being tested

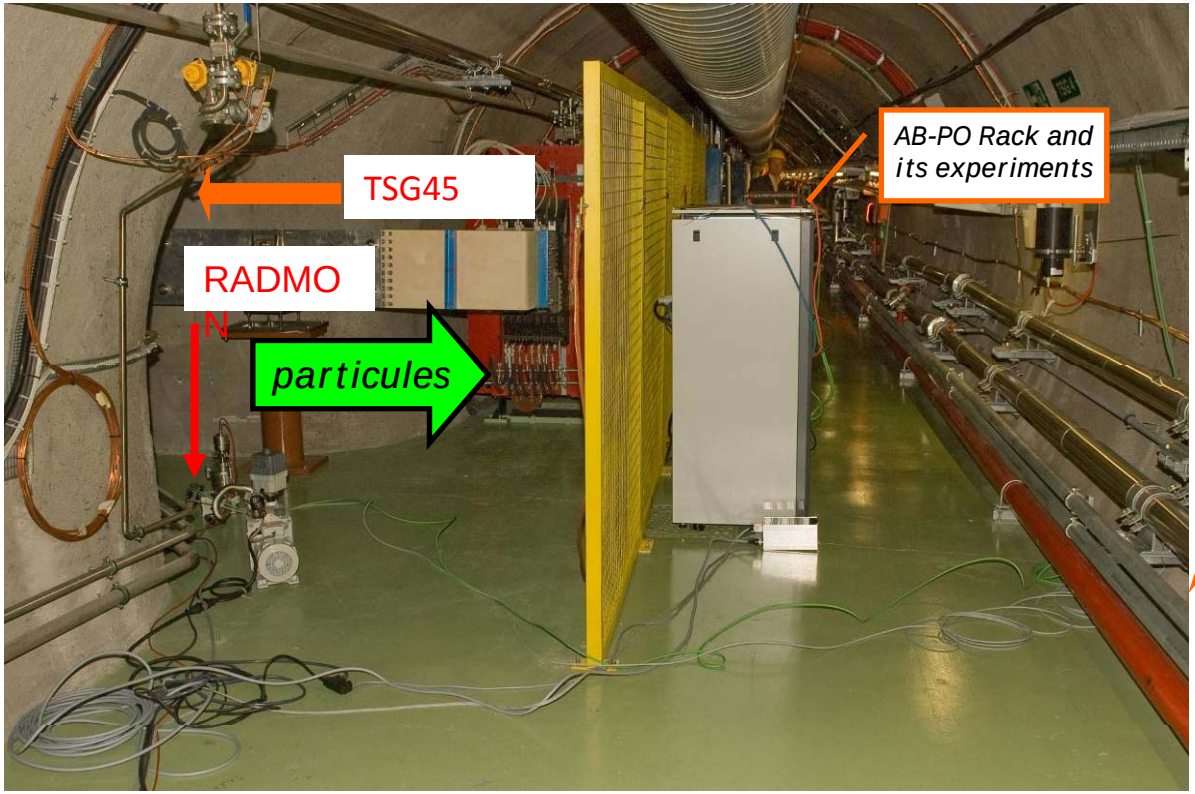
1. **FGC Generic Experiment**
   Initial FGC was kept in place, then starting the 2nd phase with a already accumulated dose of around 80Gy. The old dead PSU was let in CNGS cold place.

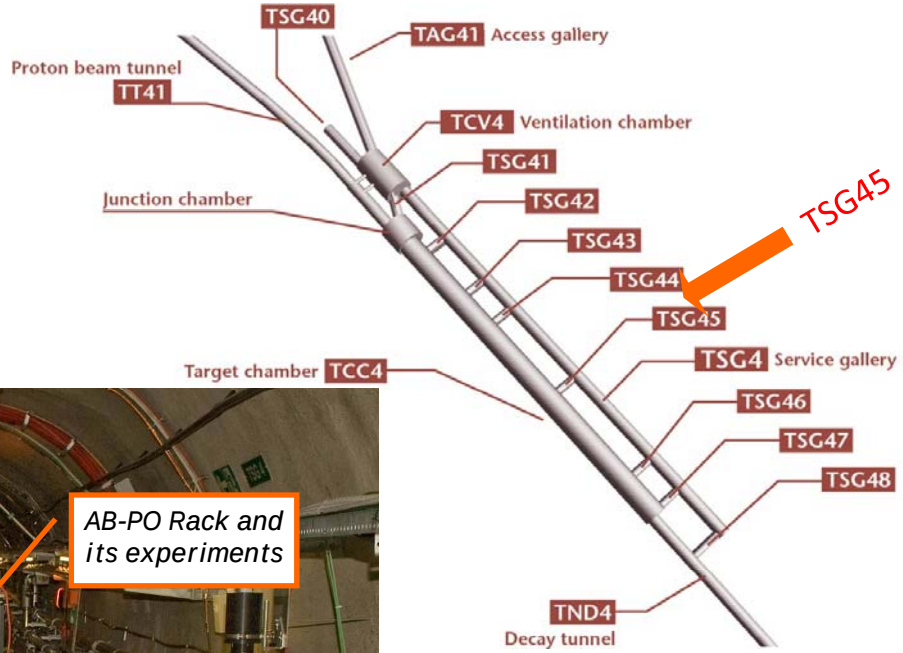
2. **LHC60A-08V Experiment**
   A complete new converter was put in place to re-start phase 2 with 0 Gy (new FGC, new DCCTs, new voltage source).
   The old irradiated LHC60A-08V converter was let in CNGS cold place.

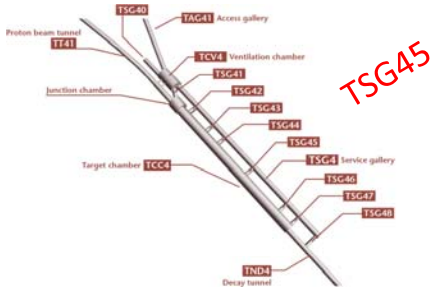


Phase 2: [2008-10-20..2008-11-17] General View

AB/PO Rack is installed at 2-3 meters from radmon. Then radmon data shall be extrapolated to the actual rack location.





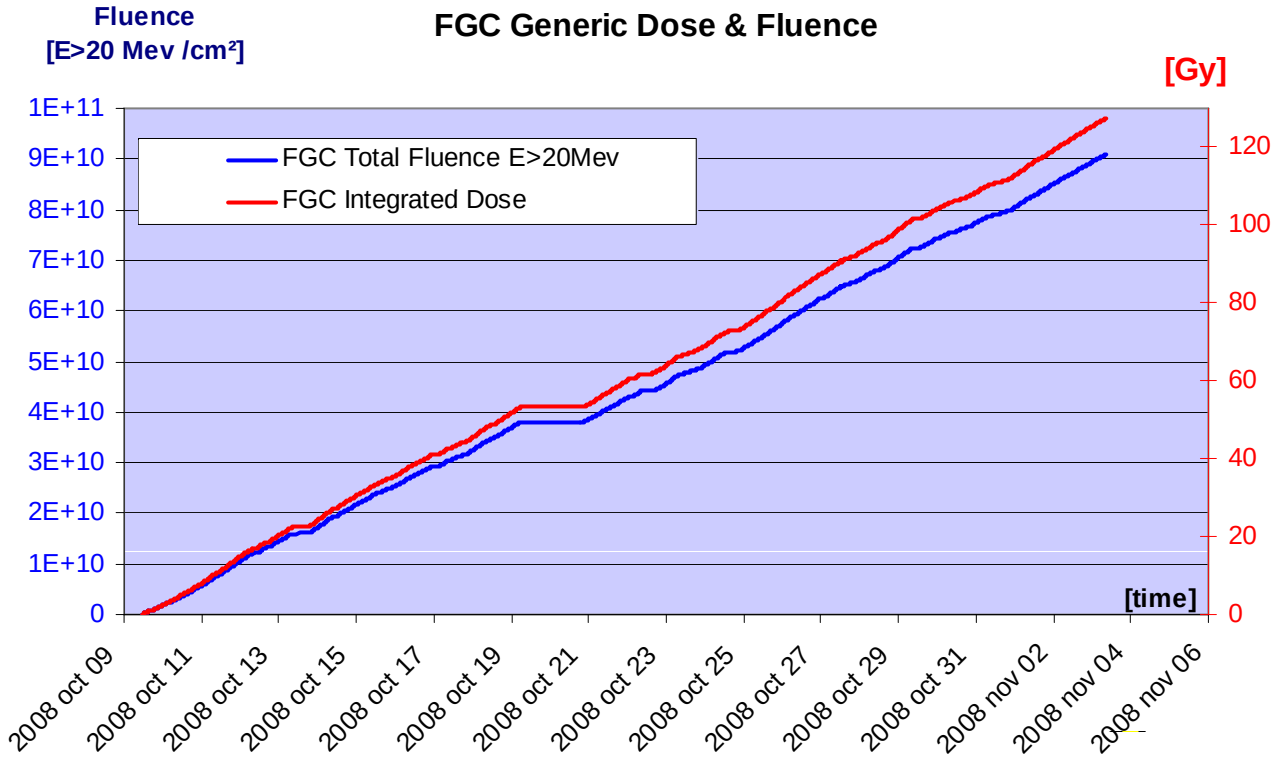


FGC Generic

FGC Generic
Common FGC for all converters except LHC60A

Phase 2: [2008-10-20..2008-11-17] Results

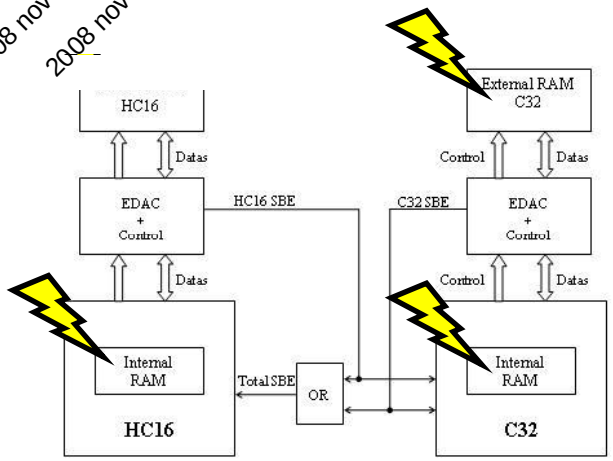
Phase 2: [2008-10-20..2008-11-17] FGC Generic Results



Results

- 3 "Crashes" not explained but recovery ok using Manual-Power Cycle feature
- Still operational at the end of test
  - 9E10 part./cm² = 2.25 LHC-Year
  - 120 Gy = >50 LHC years

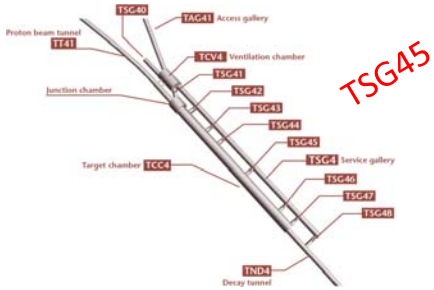
  *1 year of LHC = 4E10 part. /cm²
  = 1-2 Gy /year



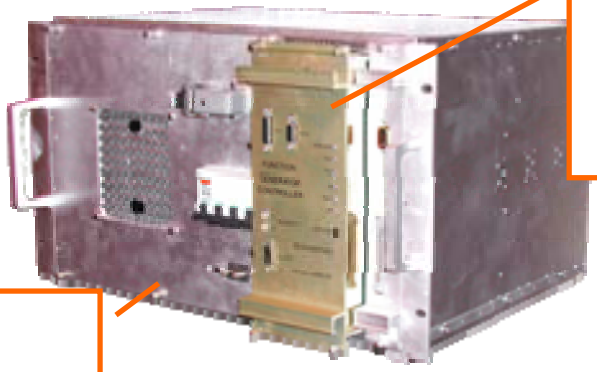
Phase 2: [2008-10-20..2008-11-17] FGC Generic Results

Results

- 7754 SEU counted on FGC Generic memories, all 100% corrected (EDAC)
  ➔ EDAC and memory corruption detection works.....
- Results from Memory corruption deduced fluence by FGC and radmon values are close even if a large difference between 2 same external memories (4x factor) remains not explained in the total number of SBE. More tests in 2009 to better understand events.
  ➔ Louvain Results ≈ CNGS Results.....
- 3-5 SEU on register C32 and HC16 counted (could crash software if critical register)
  ➔ Software Update with corruption detection feature will be developed on 2009.....
- 120 Gy on FGC Generic, and no influence seen on components (Louvain showed that critical limit was below 120 Gy).
  ➔ Louvain results agrees with CNGS results (difficult since no change expected).....
- 6 Stops (slow watchdog detection) but auto-recovering resetting software
  ➔Auto recovery system works.....
- High Precision Digital filter corrupted many times. Would impact on the high precision current level (operation & calcul phase corrupted)
  ➔ Software Update with digital filter corruption detection feature for 2009.....
- 3 crashes not explained (same as FGC COD) but manual-recovering using hardware Power Cycle implemented feature each time.
  ➔ ????.....



LHC60A-08V

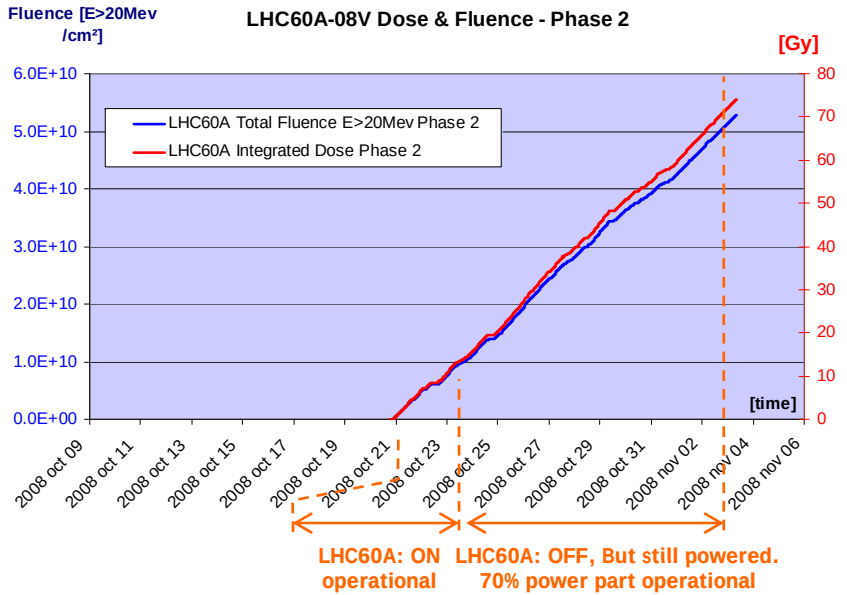


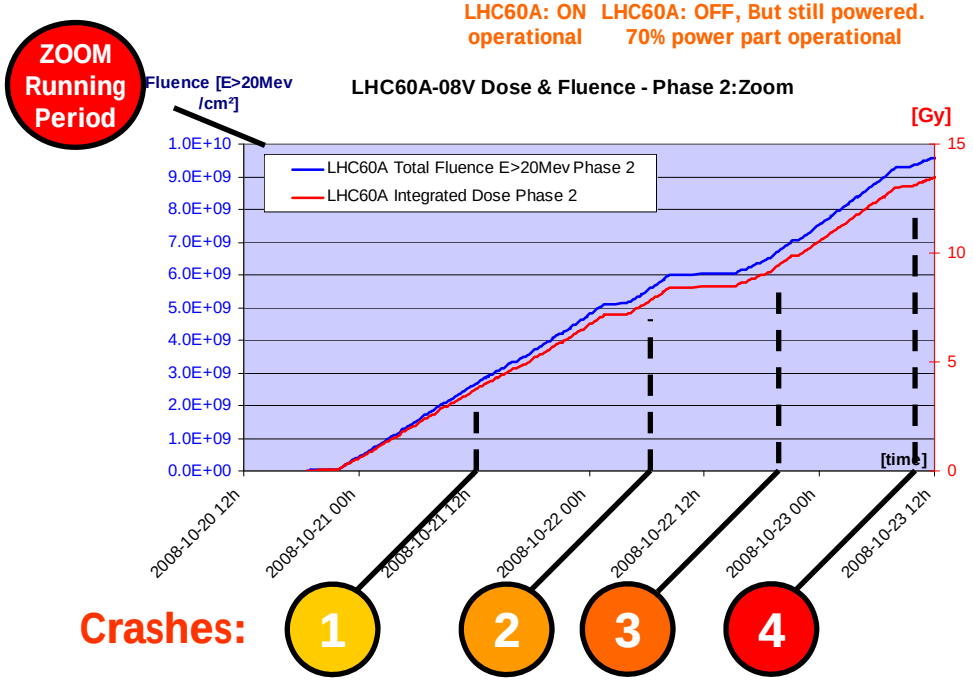
FGC COD Specific Design for LHC60A

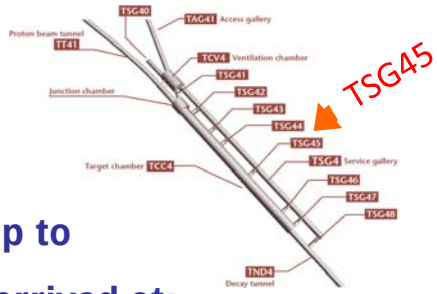
Power Converter Voltage Source

Phase 2: [2008-10-20..2008-11-17] Results

Phase 2: [2008-10-20..2008-11-17] LHC60A Results







Results

- 3 “Crashes” only up to
- 1 last lethal crash arrived at:
  - 8E9 part./cm² = 0.20 LHC-Year
  - 11 Gy = 5-10 LHC years

*1 year of LHC = 4E10 part. /cm²
= 1-2 Gy /year

Results (to be confirmed)

From 1st quick analyze done on 17-11-2008, it seems that power part is still alive and working. Then 70% power part components survived:

- 5E10 part./cm² = 1.2 LHC-Years
- 70 Gy = >35 LHC years

* only an optocoupler was found weak enough to prevent a 100% operational operation, but quick test showed converter was almost ok except this

Phase 2: [2008-10-20..2008-11-17] LHC60A Results

LHC60A Experiment was only 100% operational for 3 days, but even if we lose control, all converter was powered, in OFF mode. (OFF mode: 70% of electronics alive and waiting).

Results

- **Aux Power Supply worked for the whole Phase 2 period**
  ➔ Aux PSU fully validated by this test for LHC needs.....
- **All control electronic circuits survived the whole Phase 2 period**
  ➔ It represents 70% of the converter.....
- **Some optocouplers 4N46 reached their operating limit known to be around 50-60 Gy**
  ➔ Worked as expected, no problem on the converter conception (Design goal : 40Gy max).....
- **Power components were not tested (Power Mosfets, IGBTs, Drivers, LEMs) but 2008-11-17 quick test showed that they were still operational**
  ➔ All these components survived the dose, but no info on Fluence behavior.....
- **3 Stops not explained: FGC COD responsible? (same as FGC Generic) but manual-recovering using hardware Power Cycle implemented feature each time.**
  ➔ ????.....
- **1 Stops lethal, without any recovery possibility: FGC COD responsible?**
  ➔ ????.....

Phase 2: [2008-10-20..2008-11-17] LHC60A Results

Difference between FGC Generic and FGC COD are only at the level of 1 card used for high precision regulation (Analog card). What was touched in FGC COD which resulted in definitive crash has certainly nothing to do with this card.

Then, weak point detected on FGC COD is implemented in FGC Generic. Nevertheless, one survived very far when the other died early.

Possible explanations are then:

1. **Crash of a component MTBF reason, nothing to do with radiation**
2. **Statistics are poor on 2 units being tested giving confusing results**

FGC Generic

COD Generic difference = 1x Analog Card only, used for high precision purpose

FGC COD

Conclusions

LHC60A-08V Power Part

1. Status positive up to now, or at least not negative
2. Re-test in CNGS (mid-2009) without FGC electronic (with change of opto for rad-hard one to go further in dose) to validate power part and influence of radiation on characteristics

FGC

1. Status mitigated:
   -1x crashed early
   -1x survived very far
   Situation not clear since only high precision part is different from both. Deeper analyze in coming weeks on irradiated crashing FGC will give us more data to understand where problem comes from.
2. Test CNGS to validate these results (mid-2009)
3. Test in external lab still under discussion

END.

Thanks to main contributors (this presentation & Actors)

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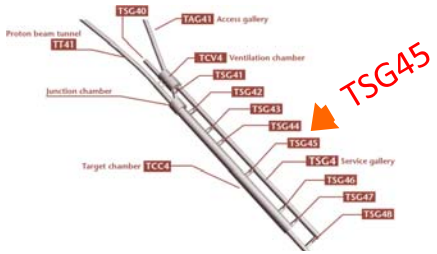
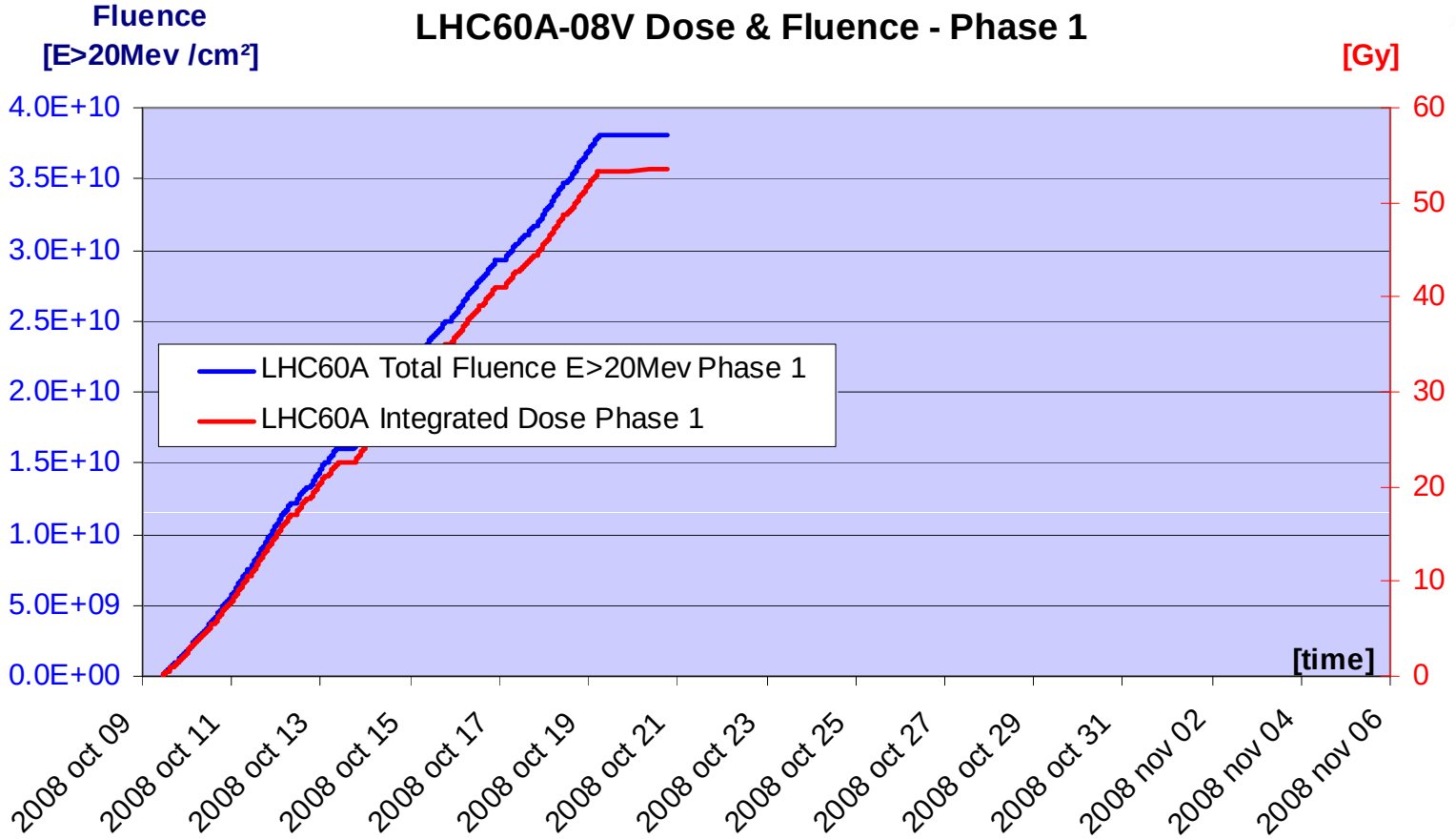
- **Laurent Ceccone**
- **Quentin King**
- **Valérie Montabonnet**

CNGS Test Organization Team:
- **David MacFarlane**
- **Thijs Wijnands**
- **Christian Pignard**
- **RP People**

Annexe: Phase 1 [2008-10-20..2008-11-17]





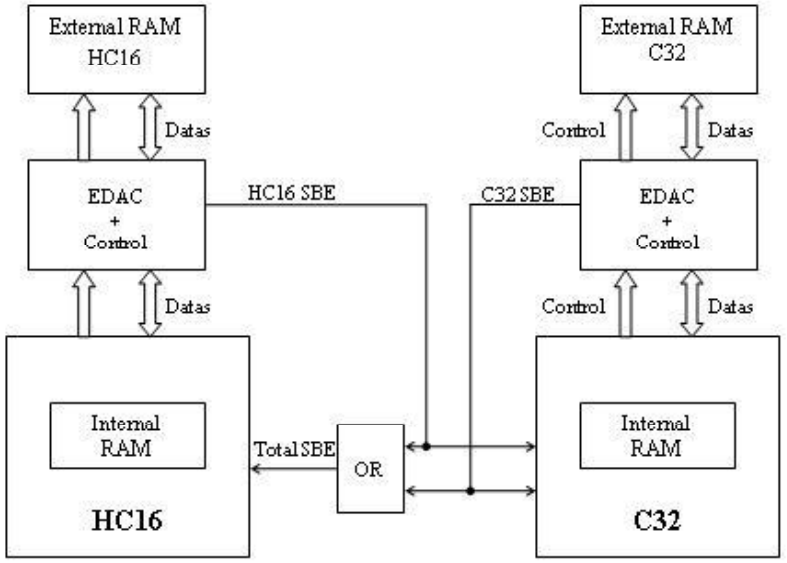
Fluence data (radmon) & FGC Generic Experiment results

FGC Generic experiment

- In that specific experiment (FGC), SBE on FGC memories are counted through a EDAC output.

Test Results

- 7754 total Single Bit Event being corrected by EDAC noticed during the total CNGS FGC Generic Test period
  - 6258 SBE coming from External RAM HC16 (512 kbytes+112kbytes* memory used for EDAC)
  - 1479** SBE coming from External RAM HC32(512 kbytes) (512 kbytes+112kbytes* memory used for EDAC)
  - This memory SEU cross section (measured in Louvain and given by publications) = 1.9×10^{-15} SBE x cm² / bit



Fluence estimation on memories based on these results

- Total Fluence = (Nb SBE) / (DUTs cross section)
  = (Nb SBE) / (2 x $(\text{memories})_{\text{bits}}$ x Cross section/bits)
  = (Nb SBE) / [2x [(512 +112) x 1024 x 8] x 1.0×10^{-15}]
  = $4.6.10^{11}$ particles / cm²

Radmon gives 1.10^{11} particles / cm²

* For each 32-bits of memory there are an additional 7 bits used for the EDAC checksum stored in a fifth memory chip.

** Why so much difference between 2 same memories (HC16 and HC32)??? 4x access on HC32 / HC16 lowers the SBE!!!