Summary of the 2009 CNGS TSG4 irradiation tests

and perspectives for future tests and facilities

D.Kramer on behalf of the RADWG

Thanks to the users, CNGS experiment, J.Lendaro, D.McFarlane, M.Brugger, K.Roeed, EN/MEF, DG/SCR, Fluka team and the RadMon team (T.Wijnands, A.Nyul, C.Pignard)

Outline

- **CNGS test facility overview**
- **Calibration of test positions**
- **Results reported by users** (tunnel / alcoves)
  - **CRYO**
  - **BIC/PIC**
  - **BLM**
  - **BPM**
  - **QPS**
  - **CL heaters**
  - **WorldFip**
  - **Power Converters**
  - **SURVEY**
- **Foreseen test activities in 2010**
- **Conclusions**

Fluka simulations for nominal beam assume
- $100 fb^{-1}$

ARC Fluka simulations use
- 10^7s 3.64×10^{18}p/s 10^{15}mol/m^3

2010 luminosity assumed as
- $0.5 fb^{-1}$

2010 ARC losses assumed as
- 1/40 of nominal

Nominal year assumed as 200 days

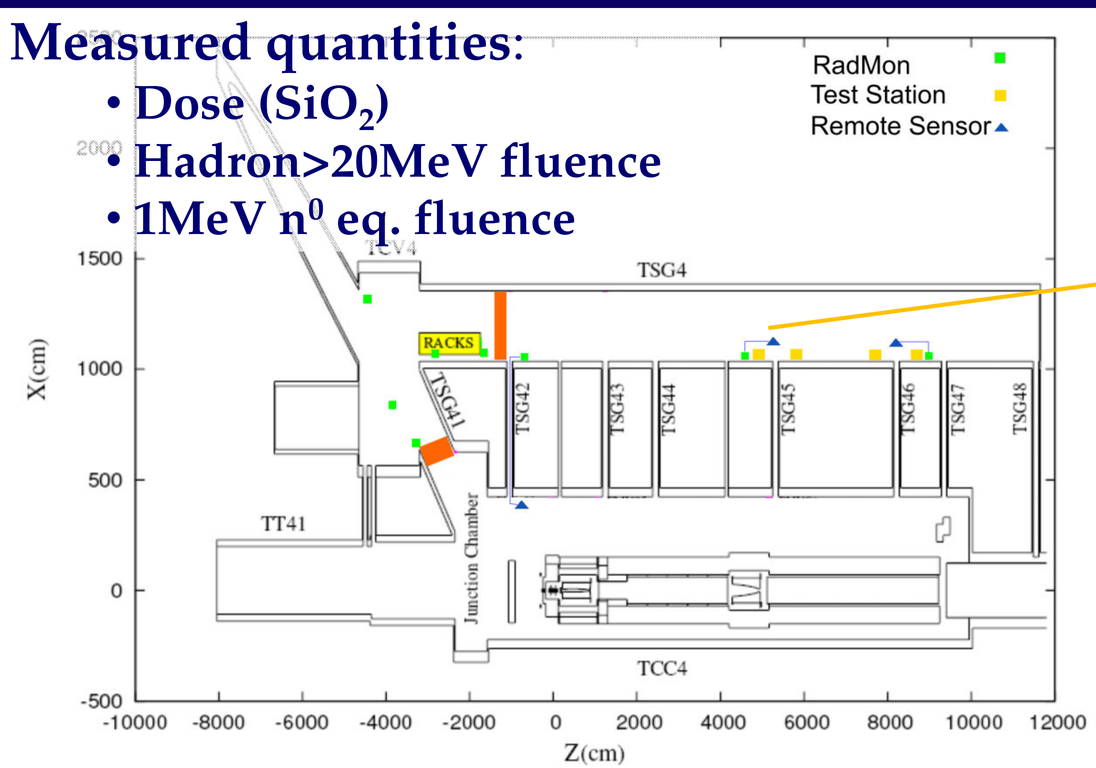
Testing area in the TSG4 side gallery of CNGS

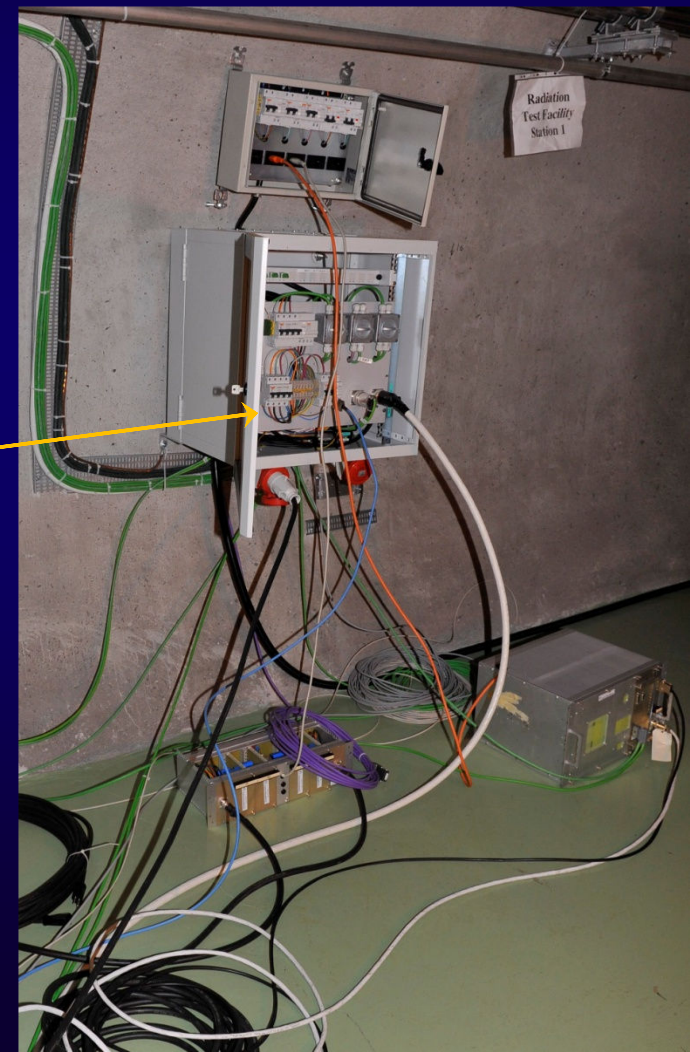
Temporary procedure for handling irradiated electronics was put in place for CNGS. Valid until 30/11/09 and extended from 19 Jan 2010. RADIOACTIVE electronics WORKSHOP has to be used afterwards.

Mixed radiation fields similar to the ones expected in LHC

Measured quantities:

- **Dose (SiO_2)**
- **Hadron>20MeV fluence**
- **1MeV n^0 eq. fluence**





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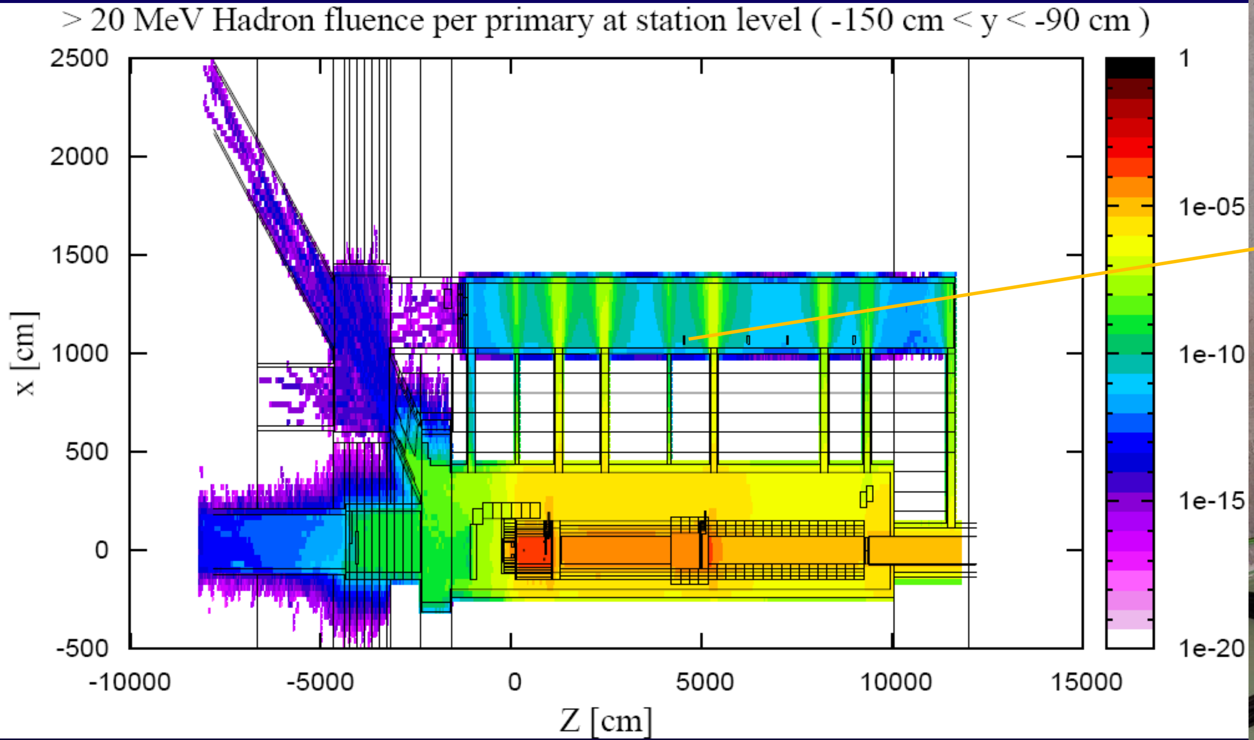
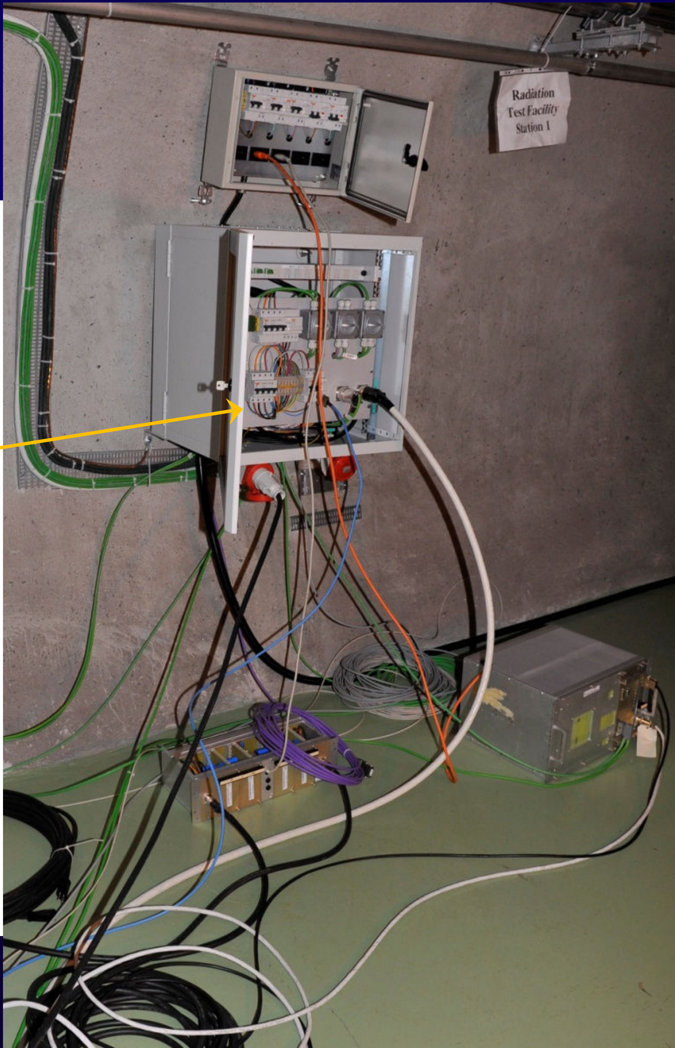
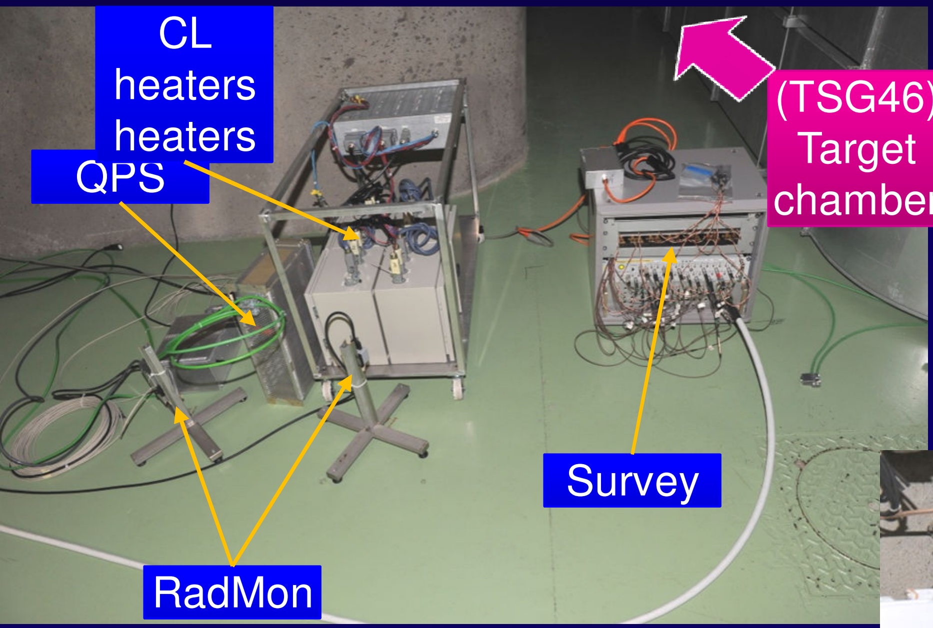




Courtesy of K.Roeed

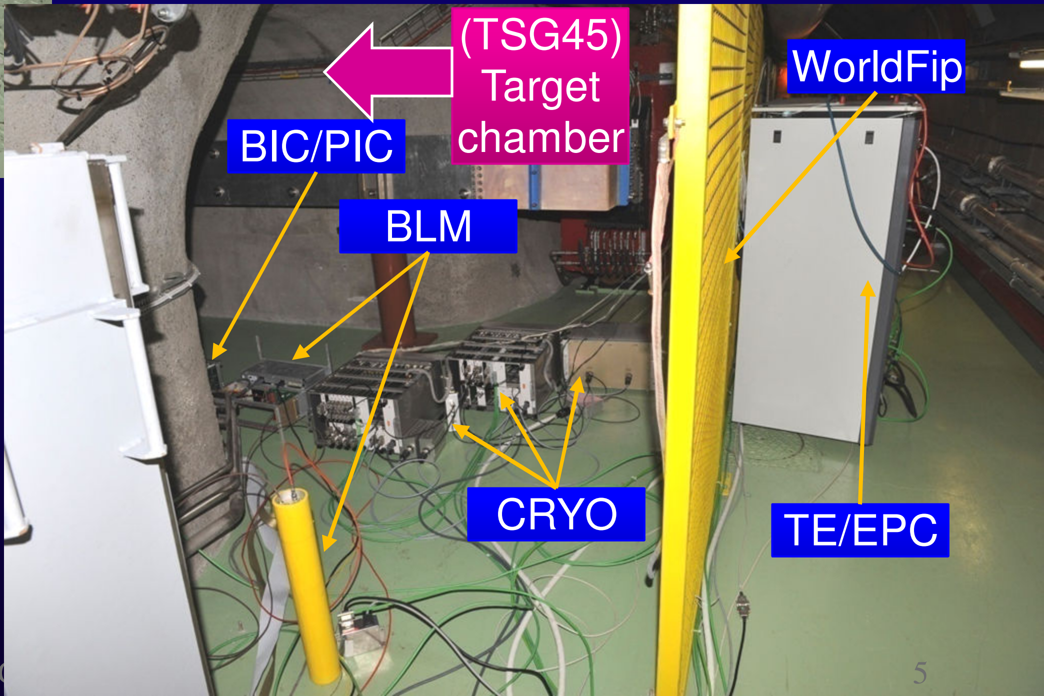
2 Test areas – High & Low flux with multiple calibrated locations



Hottest test area in TSG46:
~ 3.3 Gy(SiO_2)/week
~ 1.8 10^{10}(>20MeV)cm^{-2}/week

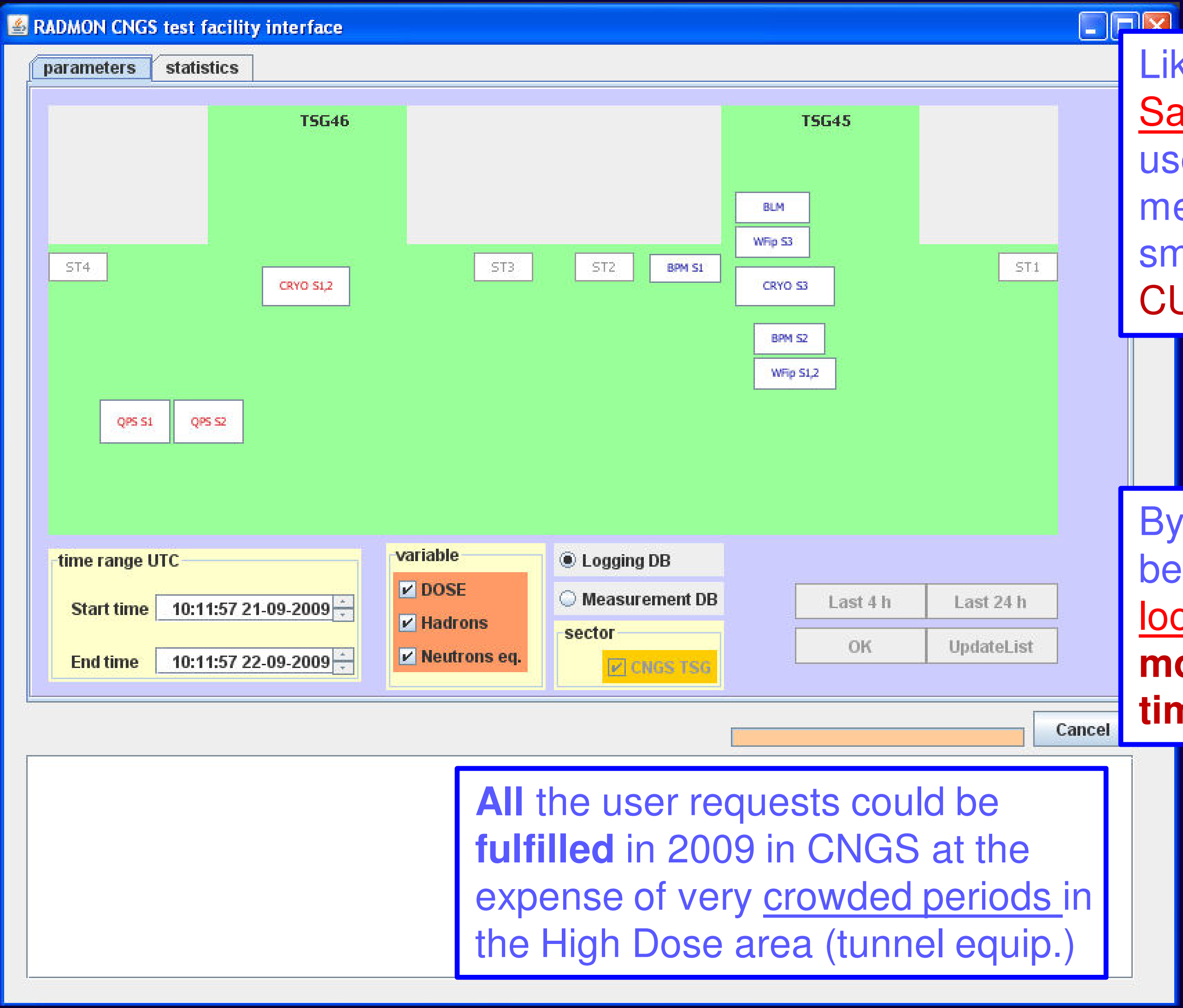
1 Week ~ 1e18pot

Hottest test area in TSG45 :
~ 28 Gy(SiO_2)/week
~ 1.9 10^{11}(>20MeV)cm^{-2}/week
This is expected in the LHC arcs* in 3 nominal years (10Gy/y)



*Alongside a dipole

Calibrated radiation field data for all test locations accessible via dedicated Java <u>GUI</u>



Like it is the case for FLUKA, <u>Safety Factor of 2</u> has to be used for all the CNGS measurements (high gradients, small detector size) for CUMULATIVE effects

By assuming <u>all</u> the devices to be installed in the <u>worst locations</u>, the estimations are **more conservative than 2 times!** (for SEE related failures)

All the user requests could be **fulfilled** in 2009 in CNGS at the expense of very <u>crowded periods</u> in the High Dose area (tunnel equip.)

User test results

- CRYO
- BIC/PIC
- BLM
- BPM
- QPS
- CL heaters
- WorldFip
- Power Converters
- SURVEY

Data provided by E.Gousiou

CRYO Tunnel Electronics

9500** channels in LHC

OK

Equip. tested in CNGS:

-Temperature reading (18 Channels)
- Helium level reading (12 Channels)
- Digital inputs (24 Channels)
- Cold mass electrical heater DC supply (4 Channels)
- FIP communication (8 agents)
- Power supply (2 cards)

Observed Errors in CNGS

None**, accuracy within specs

ARC annual levels below MBB

- $4e9 cm^{-2}$ E>20MeV
- 1Gy

2009/10

- $1e8 cm^{-2}$ E>20MeV
- 25mGy

Safety factor 2x to be applied for all cumulative effects in this talk

		Lifetime in LHC years / MTBF (channel)	Mitigation
TID	>500 Gy	500 (12 in DS*)	Not needed. Upper limit on channel failure rate Largely overestimated
Channel failure cross section upper limit	$3e-13 cm^2$	>18 days**	
MTBF in 2010 lower limit		>3.6y**	

*Some cards up to MBB8 – monitoring required

CRYO - Protected Areas
Cumulative effects

Equip. tested in CNGS:

A. 6 QRL electrical heater AC supplies (45 in LHC)
B. 12 Insulated temperature conditioners (2400 in LHC)

Observed Errors in CNGS

A. Solid State Relay damaged
B. DC-DC converter fails

Annual fields in worst location UJ56,14,16

- $5e9cm^{-2}$ E>20MeV
- 5Gy

2010

- $2.5e7cm^{-2}$ E>20MeV
- 25mGy

A – QRL heater	OK if	Mitigation
TID	10Gy	Will be cured by shielding (& relocation in case of UJ56 to bottom floor)
Nominal lifetime	2y	
Lifetime in 2010	400y	

Only used during machine cool down – with no beam

B – Insul. temp.	OK	Mitigation
TID	140Gy	Not needed
Nominal lifetime	28y	
Lifetime in 2010	OK	

CRYO - Protected Areas
Single Event Errors

Equip. tested in CNGS:
Insulated Temperature Conditioners

Number in alcoves:
2400 channels

Observed Errors in CNGS
SEU on digital isolator

Annual fields in worst location UJ56,14,16

- $5e9cm^{-2}$ E>20MeV
- 5Gy

2010

- $2.5e7cm^{-2}$ E>20MeV
- 25mGy

		Mitigation
Failure cross section (per channel)	$2e\text{-}9cm^2$	soft reset automatically forced by the control system (WFip) in progress
MTBF if all in UJ56 for nominal beam	0.2h	
MTBF in 2010	1.7days	

OK if

User test results

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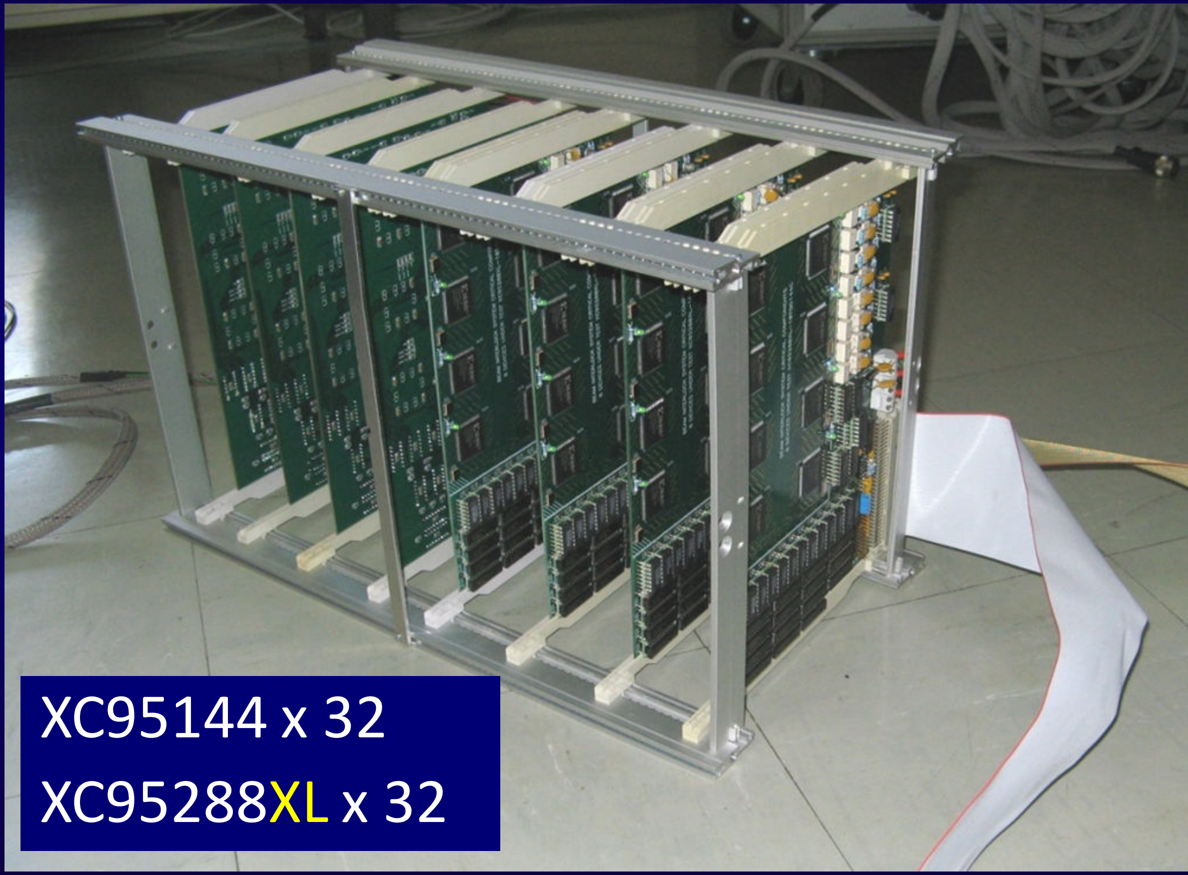

Data provided by M.Zerlauth & B.Todd

BIC - Protected Areas
SEEs of CPLD 3.3V [component test]

Equip. tested in CNGS:
XILINX CPLD XC9500XL 3.3V
part of BIS signal path (critical)

Number in alcoves:
36

Observed Errors in CNGS
A. 20% of SEUs cause loss of redundancy
B. 80% of SEUs cause false dump

Annual fields in worst location UA87,23

- 5e7cm^{-2} E>20MeV
- 0.05Gy

2010

- 1e7cm^{-2} E>20MeV
- 10mGy

A / B		Mitigation
SEU cross section (per device)	2.8e-10cm^2	New quick shielding effective by factor ~10 for TED, maze near TCDI,TDI to be reinforced. Simulations to be performed.
MTBF* loss of redundancy / false dump	10y / 2.5y	
Fault probability in 2010	2e-2 / 8e-2	

*if all in UA87 for nominal beam no shielding

Thermal neutron sensitivity could be an issue with 3.3V

BIS/PIC - Protected Areas
SEEs of CPLD 5V [component test]

Equip. tested in CNGS:

XILINX CPLD XC9500 5V part of BIS/PIC monitoring paths

Number in alcoves:

336 (CIBUs – 300, PIC - 36)

Observed Errors in CNGS

A. 90% of SEUs cause monitoring problem
B. 10% of SEUs cause false dump

Annual fields in worst location RRs

- $1e9cm^{-2}$ E>20MeV
- 1Gy

2010

- $5e6cm^{-2}$ E>20MeV
- 5mGy

OK

A / B		Mitigation
SEU cross section (per device)	$3.8e\text{-}13cm^2$	MTBF ~same as electrical reliability of the CPLD!
MTBF* monitoring problem / false dump	8y / 72y	Relocations from UJ56,14,16 fully prepared so not considered here (contain PLCs).
Fault probability in 2010	6e-4 / 7e-5	

*if all in RR13 for nominal beam

Destructive Latchups of CPLDs should have very low probability in shielded areas due to lower peak energy

User test results

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- BLM
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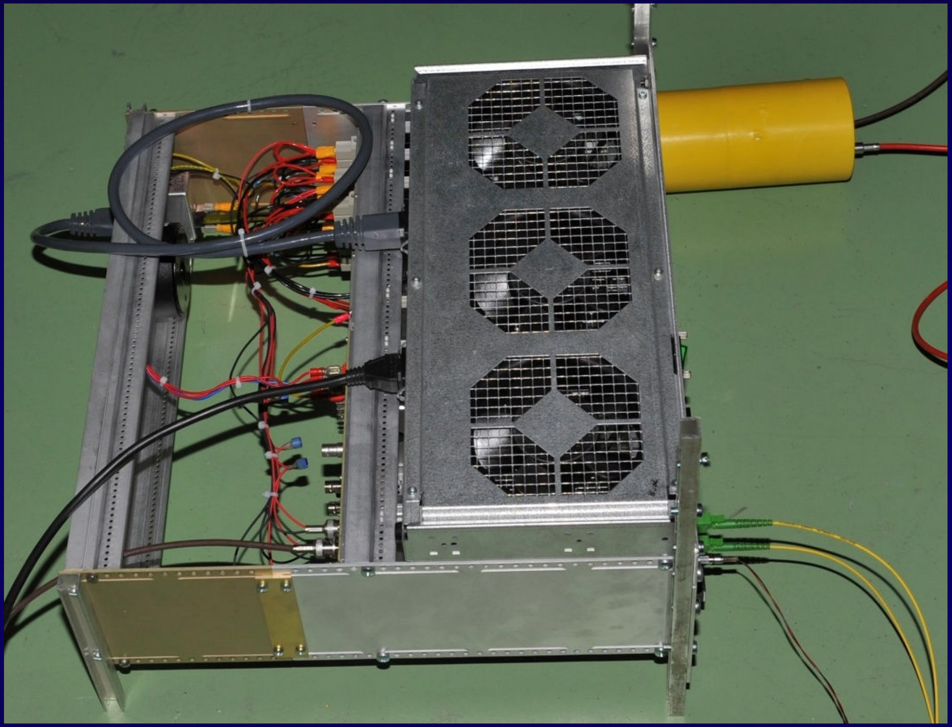
- SURVEY



Data provided by E.Effinger

BLM - Protected Areas and ARCs
Cumulative and SEE effects

OK

Equip. tested in CNGS:

A. Power Supply Haltec 2.5V (37x)
B. Power Supply Haltec 5V (74x)
C. BLECF tunnel card, PS (600x)

Observed Errors in CNGS

A. Total dose effects, voltage drop
B. Total dose effects, voltage drop
C. 1 SEE leading to false dump

Annual fields in worst location RR13 / ARC (MQ)

- 1e9 / 4e10 cm^{-2} E>20MeV
- 1 / 10 Gy

2010

- 5e6 / 1e9 cm^{-2} E>20MeV
- 5 / 250 mGy

A,B Power Supplies		Mitigation
TID	85/33Gy	Not needed
Nominal lifetime	85/33y	
Lifetime in 2010	OK	

B – BLECF		Mitigation
TID	750Gy	Not needed, handled by remote reset via HV
Nominal lifetime	75y	
SEE cross section	1.9e-13cm^2	
MTBF	44days	
MTBF in 2010	8.8y	

User test results

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- BLM
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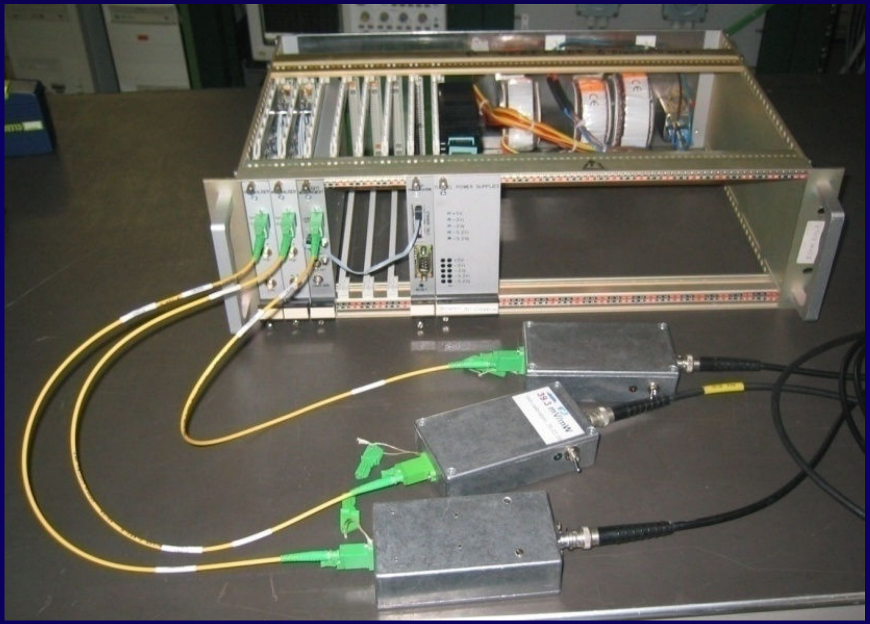
- SURVEY



Data provided by E.Calvo

BPM – tunnel electronics

Equip. tested in CNGS:

A. Intensity card (330x) — Not OK but
B. Power Supply (330x) — OK
C. WorldFIP card (330x)
D. 2 WBTN cards (2160x) — OK

Observed Errors in CNGS

A. After SEE out of range readings
C. After SEE, WBTN calibration off and High sens. mode, max 250um offset for 1min

Annual fields in worst location - ARC (MQ)

- 4e10 cm^{-2} E>20MeV
- 10 Gy

2010

- 1e9 cm^{-2} E>20MeV
- 0.25 Gy

A Int. card / B,C,D WBTN		Mitigation
TID	4/>230Gy	Card needed only for initial operation at low intensity
Nominal lifetime	0.4y/>23y	
Lifetime in 2010	16y/920y	

Not OK but

C – WorldFIP card		Mitigation
SEE cross section	4e-12 cm^2	Channel can be masked by the orbit feedback system
MTBF	3.8days	
MTBF in 2010	152days	

User test results

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- BLM
- BPM
- QPS
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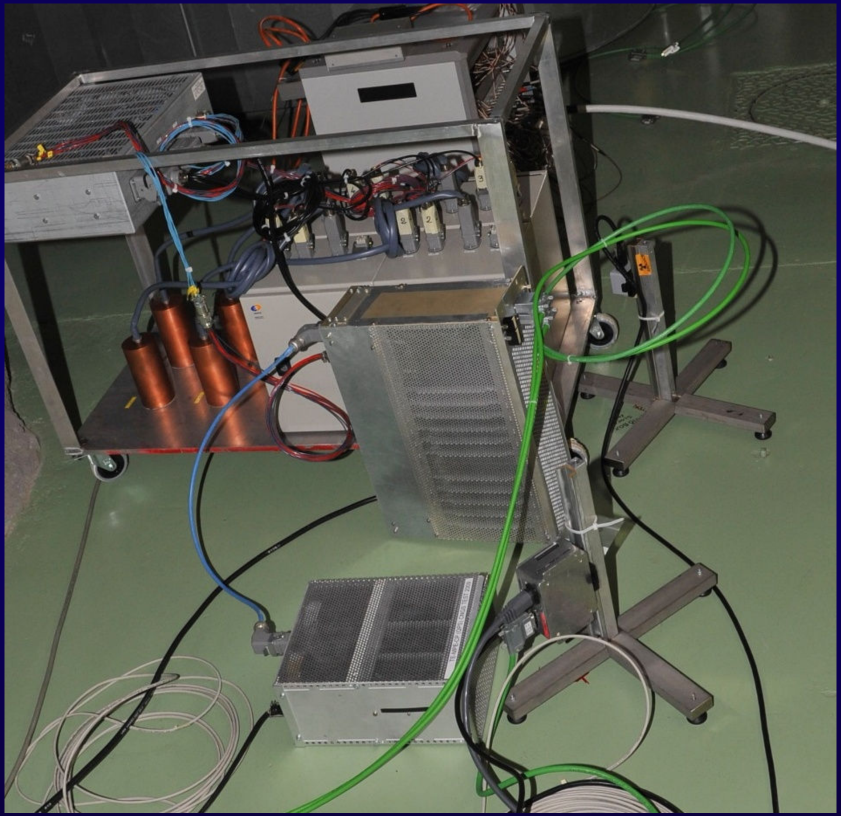
- Power Converters
- SURVEY



Data provided by R.Denz

nQPS – LHC ARCs [new QPS layer]

Equip. tested in CNGS:

Field-bus coupler type DQAMGS

Number in tunnel: 450

Observed Errors in CNGS

SEE in uFip or FieldDrive freezes the supervision path – access needed prior to next fill to restart the card. Observed analog drifts do not pose problems

Annual fields in ARCs under dipoles

- $4e9cm^{-2}$ E>20MeV
- 1Gy

2010

- $1e8cm^{-2}$ E>20MeV
- 25mGy

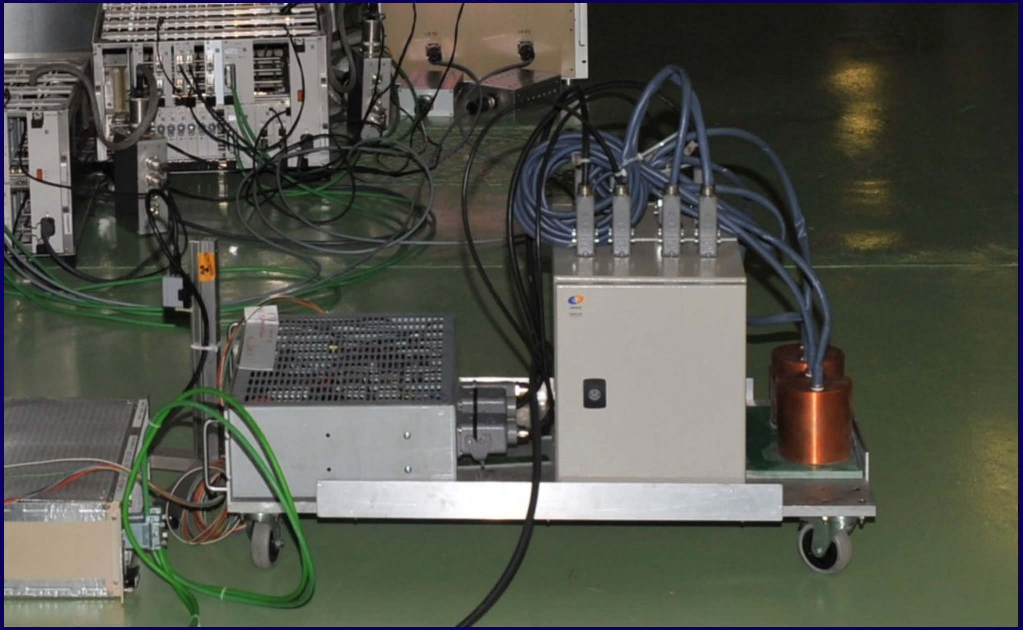
		Mitigation
SEU cross section (per device)	$2.8e\text{-}10cm^2$	Automatic reset of the WorldFIP. Solution **tested successfully in CNGS.** To be implemented when the errors start to appear.
MTBF nominal beam	10h	
MTBF in 2010	16d	

Not OK but

"2009 tests in CNGS confirmed the radiation tolerance of the detection systems of the new QPS layer including the power supplies. Detailed evaluation still to be done"

User test results

- CRYO
- BIC/PIC
- BLM
- BPM
- QPS
- CL heaters
- WorldFip
- Power Converters
- SURVEY



Data provided by S.Le Naour

Current Lead heaters – protected areas

Equip. tested in CNGS:

7 Regulators and Solid State Relays (UJ&RRs 408x, others not counted: 904x)

Observed Errors in CNGS

Destructive SEE in the regulator – ice formation on DFB after dump => Cryo Start removed

Annual fields in the worst location i.e. UJ56

- 5e9 cm^{-2} E>20MeV
- 5 Gy

2010

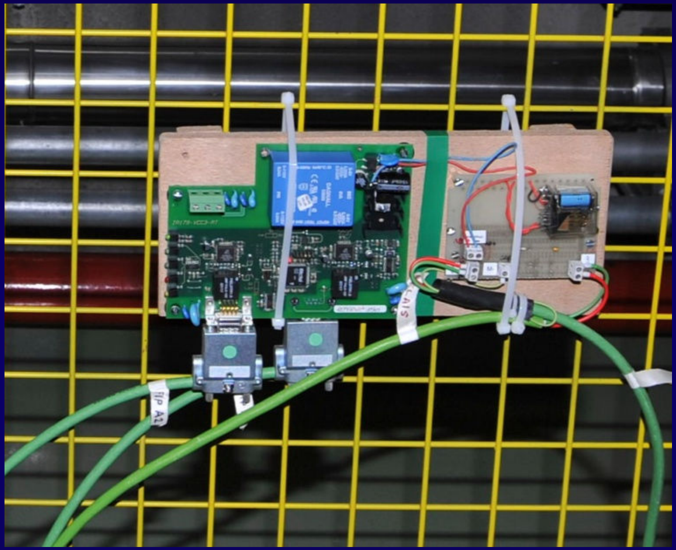
- 2.5e7 cm^{-2} E>20MeV
- 25 mGy

Temperature regulator		Mitigation
SEE cross section	2e-11 cm^2	Not critical for the operation. Only 84 devices in UJs. Shielding will help
MTBF	5days	
MTBF in 2010	5y	

Not OK but

User test results

- CRYO
- BIC/PIC
- BLM
- BPM
- QPS
- CL heaters
- WorldFip
- Power Converters
- SURVEY



Planned development of the new nanoFIP is covered in the talk of J.Serrano

Data provided by J.Palluel

WorldFIP – signal repeaters in the tunnel

OK

Equip. tested in CNGS:

2 Repeaters Cu-Cu (320x in ARC)

Observed Errors in CNGS

Total dose effect – replacement required before beam on

Annual fields in worst location - ARC along MB

- 4e10 cm^{-2} E>20MeV
- 10 Gy

2010

- 1e9 cm^{-2} E>20MeV
- 0.25 Gy

Repeater		Mitigation
TID	165/>250Gy	Device inspected yesterday – drift in an auxiliary part. Annual dose overestimated (cable tray).
Fluence h>20MeV	1.1e12cm^{-2}	
ARC lifetime	16y	

User test results

- CRYO
- BIC/PIC
- BLM
- BPM
- QPS
- CL heaters
- WorldFip
- Power Converters
- SURVEY

For detailed results please look in the talk of Y.Thurel

Data provided by Y.Thurel, S.Dubettier

Power Converters – tunnel and part of alcoves electronics

Equip. tested in CNGS:

A. FGC COD (752xARCs)
B. FGC Generic (189+256xUJs,RRs)
C. High precision part SD360 (as B.)
D. Component tests

Observed Errors in CNGS

A. B. Crashes of FGC requiring power cycle and therefore dump (so far unexplained - half SEL of CPLD?)

C. Very frequent corruptions only in 350**, 360 OK (more tests needed)

Annual fields in worst location – UJ56 / ARC

- 5e9 / 4e9 cm^{-2} E>20MeV
- 5 / 1 Gy

2010

- 2.5e7 / 1e8 cm^{-2} E>20MeV
- 25 / 25 mGy

**Corruptions of SD350 (Generic FGC) are rather critical due to large cross section

A (ARC) / B (UJs) FGCs		Mitigation
TID OK	100Gy	No problems expected from cumulative effects
Nominal lifetime	100y/20y	
Lifetime in 2010	OK	

A+B – FGC	Not OK?	Mitigation
SEE cross section *	2.3e-11cm²	Shielding will help in UJs,RRs not in ARCs. REDUNDANT!
MTBF *	1.8days	
MTBF in 2010	72days	

All crashes occurred only at low fluence -> uncertainty in cross section.
If total fluence considered, MTBF = 7days

User test results

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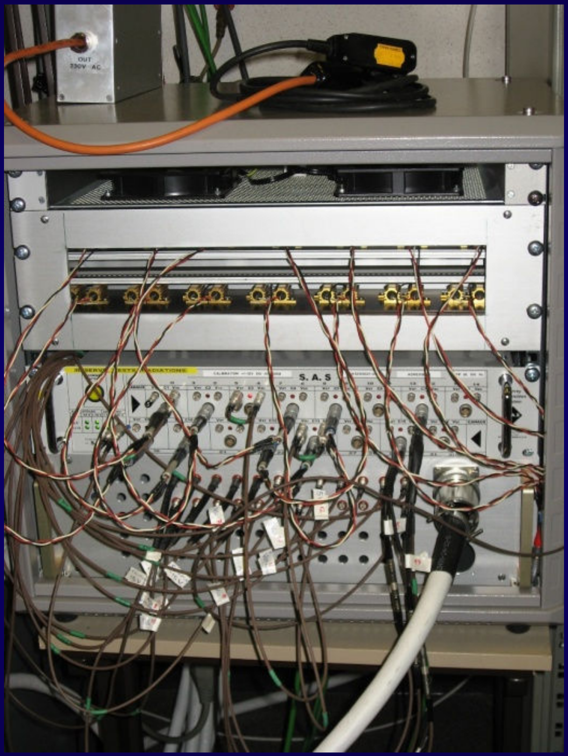

Data provided by A.Marin

SURVEY– controller electronics from protected areas

Equip. tested in CNGS:

1 Controller crate (6x,UJ56)

Observed Errors in CNGS

a) Cumulative effect failure, drifts very small

b) System crashes (likely SEE in the uFip) requiring remote reset via WorldFip, no beam dump

Annual fields in worst location – UJ56

- 5e9 cm^{-2} E>20MeV
- 5 Gy

2010

- 2.5e7 cm^{-2} E>20MeV
- 25 mGy

Triplet motor drivers should remain OFF during beam operation (in the same rack)

a)	OK	Mitigation
TID	100Gy	No problems expected from cumulative effects
Nominal lifetime	20y	
Lifetime in 2010	OK	

b)	OK	Mitigation
SEE cross section	8e-12cm^2	System can remain in 1st floor of UJ56 w/o shielding
MTBF	4y	
MTBF in 2010	800y	

List of tests for LHC electronics in external facilities in 2009

- PSI proton beams 60/250MeV used by
  - QPS for component tests
  - WIC for Siemens remote I/Os
  - RadMon for calibrations
- CEA Valduc 1MeV n, 14/5MeV n
  - BLM, CRYO for NIEL
  - RadMon calibrations
- UCL Louvain la Neuve Heavy ions
  - CPLD tests
- NRI Prague (epi)thermal n
  - RadMon calibration
  - Repeater test
- IRA Lausanne Co60
  - RadMon calibrations

Conclusions – no bad surprises

- Very **large effort** has been dedicated by the **equipment groups** to the radiation tolerance **tests** in CNGS!
- **Most** of the electronics systems form the LHC **tunnel** were **tested** in CNGS TSG4 in similar spectra as expected in the LHC
- Small **part** of the systems from the **alcoves** (RRs, UJs, ..) **tested** as well
- Resulting lifetimes from cumulative effects and failure rates from single events were estimated for nominal beam conditions and for 2010 ($0.5fb^{-1}$) – see the following **Summary Table**
- Many systems suffer from errors in the WorldFip modules (BPM, nQPS, CRYO, SURVEY) - the **nanoFIP** is expected to **help** in some cases
- Most issues solved by **HW/FW modifications**
- Several systems rely on the **shielding** improvements
- The BPM intensity card fails at low dose but is required just for commissioning
- The very complex issue of power converters is better covered in the separate talk of Yves

Outlook

- Several users want to do more tests in 2010 at CNGS
  - CRYO, QPS, TE/EPC
- n_TOF could be eventually used as similar facility (2 options) if too many requests for CNGS (unlikely in 2010/11)
  - Modifications would have to be started very soon
  - Mixed field close to target
  - Broad n^0 spectrum with rather low flux
- HiRadMat can also be accommodated to host the mixed field electronics tests
  - Requests from users would be required to support the decision
- Sharing of test experiences, beam times (=expenses) and results through RADWG can be very helpful

Failure rate and lifetime estimations for 2010 and nominal LHC

SYSTEM	subsystem	MTBF	Lifetime with nominal beam	MTBF 2010	Lifetime 2010
CRYO	Tunnel channels	>18d	500 (12y DS)	>3.6y	∞
	Ins. Temp reading	0.2h	28y	12d	∞
	QRL heater PS		2y		∞
BIC/PIC	BIS l.o.r./dump	10/2.5y		50/12.5y	∞
	Monitoring/dump	8/72y		∞	∞
BLM	PS 2.5/5V		33/85y		∞
	BLECF	44d	75y	8.8y	∞
BPM	WBTN	3.8d	23y	0.75y	∞
	Intensity card		0.4y		16y
QPS	nQPS	10h		16d	
CL heaters	Temp. controller	5d		5y	
WFip rep.	ARC		16y		∞
Power Co.	FGC ARC/UJs	1.8d	100/20y	72d	∞
Survey	Control crate	4y	20y	∞	∞

Lifetime estimations should be divided by safety factor 2

Backup slides - Radmon Calibrations

- The Hadron>20MeV sensitivity is quite well understood in forward shower regions – very good match with Fluka
  - Excellent result behind the TED
  - Most of the CNGS positions (match in line of sight to target chamber)
  - CERF calibration campaign explored combinations of various settings and fields
- Several measurements done in different neutron fields to determine the sensitivity below 20MeV
  - Analysis to be finalized
  - Measurements at PTB mono-energetic neutron beams are scheduled for 2010
- Dose sensitivity calibration measurements yet to be extended to higher doses
  - Calibration in Co60 gamma field
- 1MeV n equivalent fluence calibration to be reviewed for higher fluences
  - Calibration in neutron field of air cooled U235 reactor – data available