



Radiation To Electronics: Reality or Fata Morgana (Mirage)

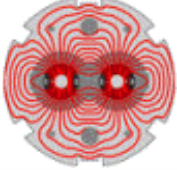
... thanks Ralph ...

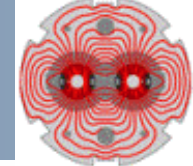
Radiation 2 Electronics

Chamonix 2011

M. Brugger for the R2E Project

!!! Many Thanks To Everybody !!! www.cern.ch/r2e

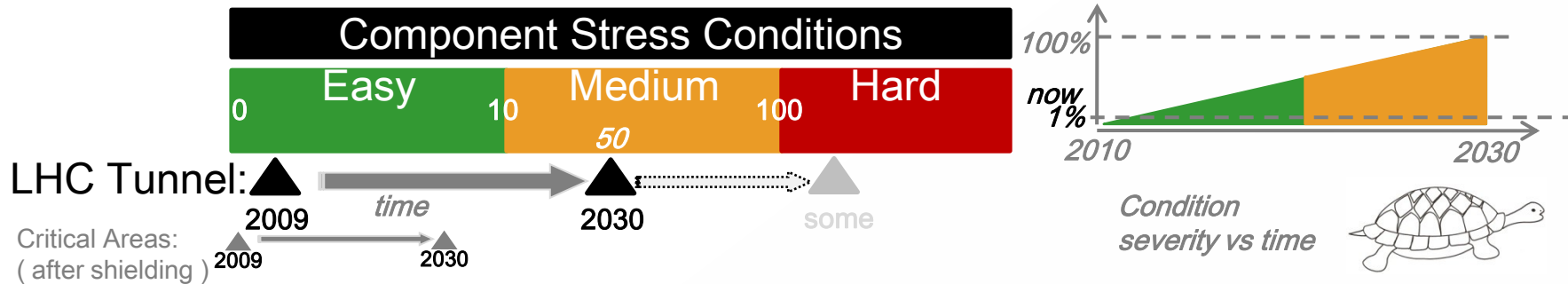




↗ Total Ionizing Dose (TID) + Displacement Damage (DD)

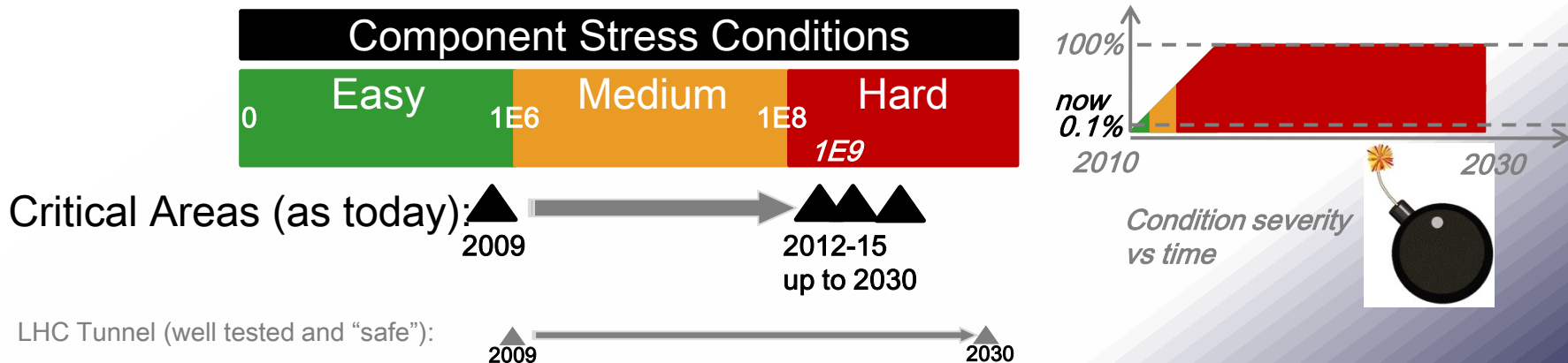
Thanks to Y. Thurel

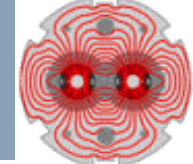
- ☺ Cumulative effect (Effect will be seen after given time, giving some freedom to react)
- ☺ Low stress level (50 Gy max in 2030 when "standard component" can survive 20-30 Gy)



↗ Single Event Effects [SEE]

- ☹ Stochastic Effect ("Events scale with number of affected components")
- ☹ Very High stress level (Failures observed $<1 \times 10^6 \text{cm}^{-2}$)



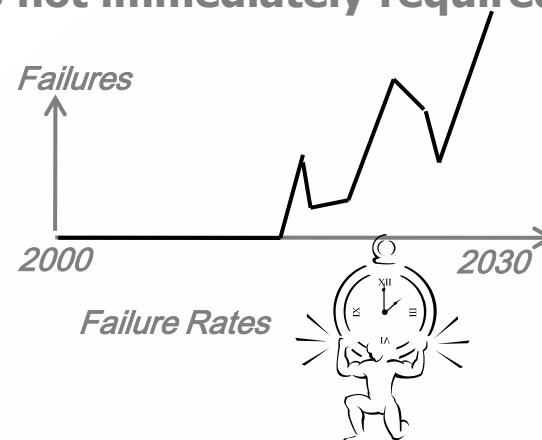
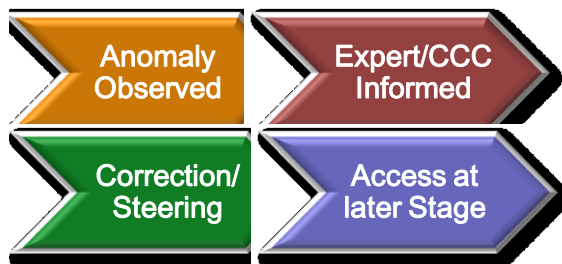
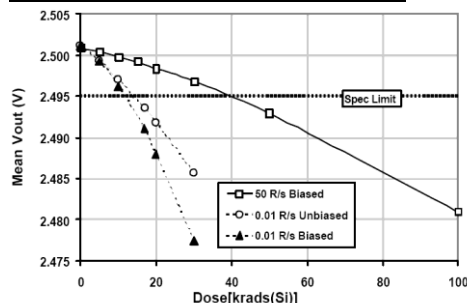


⚡ TID + Displacement Damage

- ☺ Devices get slowly out of tolerance (final failure can often be anticipated; access not immediately required)
- ☺ No 'early' failures (due to radiation)

Thanks to Y. Thurel

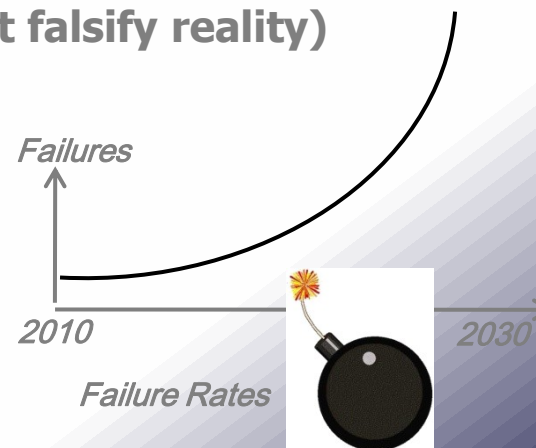
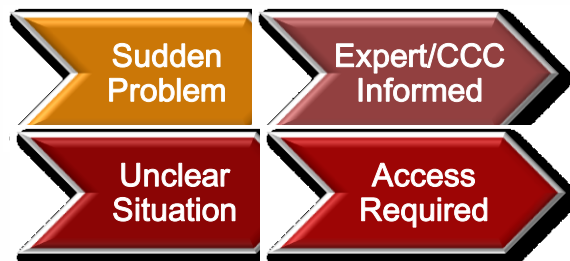
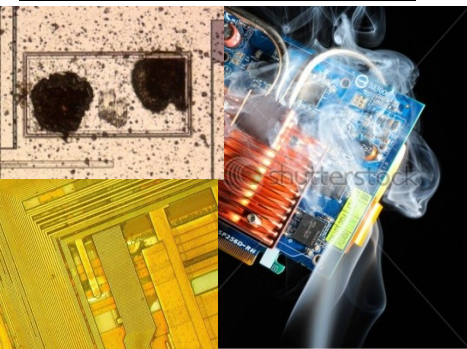
Possible Scenario:

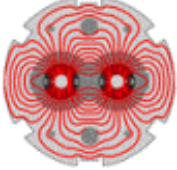


⚡ Single Event Effects

- ☹ Failures will appear and rapidly increase in frequency (destructive failures possible; access often required)
- ☹ 'Early Operation' problem (observation might falsify reality)

Possible Scenario:





Tested Equipment:

- ⊗ **PLC-S7-200 (CV)**
[profibus lost, reset needed]:
- ⊗ **24V DC Power Supply (CV)** [burned]:
- ⊗ **PLC-S7-300 (CV)**
[blocked, reset needed]:
- ⊗ **PLC-Schneider (CV)** [PS burned]:
- ⊗ **WIC Rack** [beam dump and access]:
PLC S7-300 + FM352-5 Siemens
- ⊗ **Fire Detectors ASD** [power cycle]:
- ⊗ **Ethernet Switch**
[blocked, reset needed]:
- ...

Failure xSection:

$1.8 \times 10^{-7} \text{ cm}^2$

$1.1 \times 10^{-8} \text{ cm}^2$

$7.8 \times 10^{-8} \text{ cm}^2$

$1.1 \times 10^{-7} \text{ cm}^2$

$1.1 \times 10^{-7} \text{ cm}^2$

$1.0 \times 10^{-9} \text{ cm}^2$

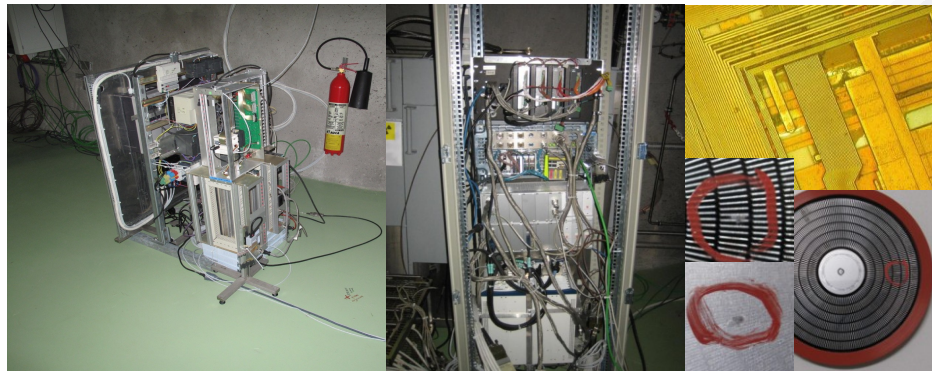


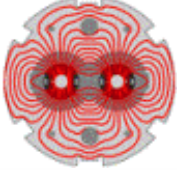
**~200 failures
in a nominal
year in
UJ14/16**

“Reset Req.”: 1 every 10^6 - 10^9 cm^{-2}

“Damaged”: 1 every 10^7 - 10^{10} cm^{-2}

Uncertainty: up to one order of magnitude (but both directions!)



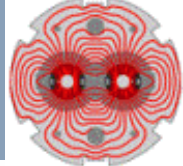


Location	Monitors	Source	Agreement	Comments
CERF, CNGS, ...	RadMon, RAMSES, TLDs	Beam on target	Within 10-20%	Benchmark setup
TI2/8	RadMon	Controlled loss on TED and TCDI	Within 30%	Source term well controlled
UX/US85	RadMon, RAMSES	LHCb collisions	Within 30-50%	Detector update required
IR7/UJ76/R R77	RadMon	Losses on Collimators	Mostly within a factor of two	Very sensitive on loss distribution
IR1/5	RadMon	Collisions	Within a factor of 2-3	Only QUALITATIVE check

Uncertainty: Dominated by the source term and the considered details!



IR7 FLUKA Application Benchmark

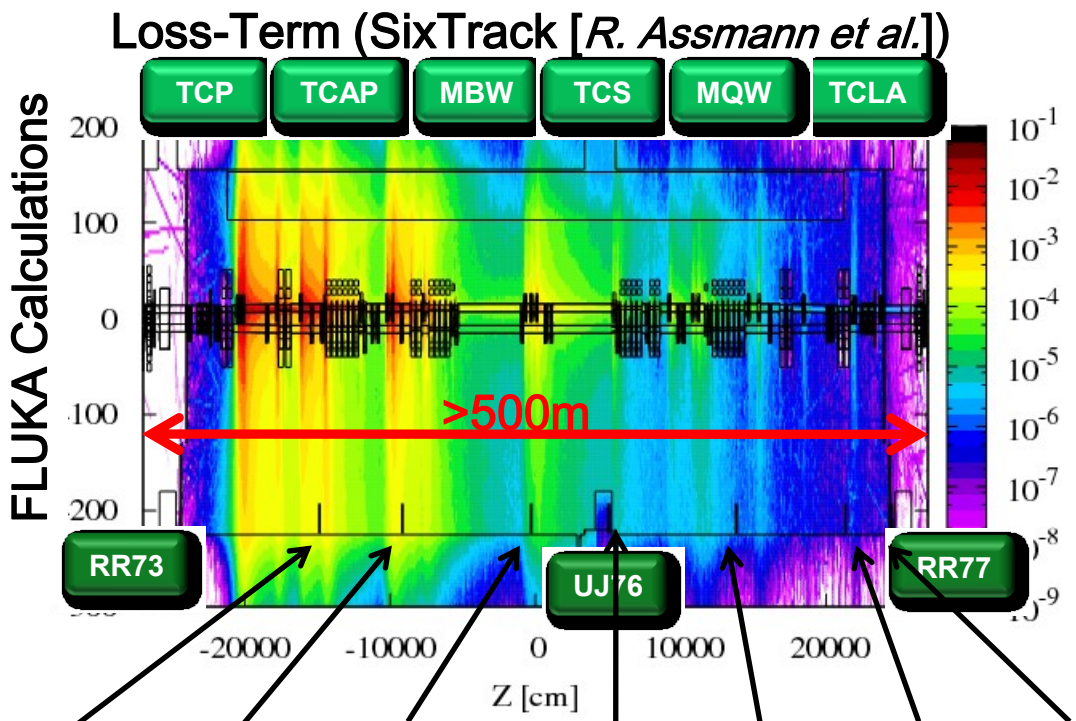


© K. Roedig

→ Assumptions



Normalisation

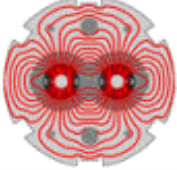


LM01 LM02 LM03 RM03 RM04 RM05 RM06

RadMon	Dcum	Rth	SEU (3V) Measured	Beam contribution	SEU (FLUKA) Expected	Error [%] Stat. only	Exp./Mes.
6L7.7LM03S	19846	5	14401	B1	15015	3	1.04
5L7.7LM02S	19904	3	5253	B1	9765	3	1.86
4L7.7LM01S	19991	5	2689	B1+B2	3116	6	1.16
4R7.7RM03S	20045	3	950	B1+B2	401	6	0.42
5R7.7RM04S	20133	5	18727	B2	13032	4	0.70
6R7.7RM05S	20208	31	303	B2	962	8	3.17
RR77.7RM06S	20241	1	13	B1+B2	17	22	1.33

In	6.02E+15	
Dumped	5.82E+15	96.70%
Lost in Machine	1.99E+14	3.30%
<i>Of Lost protons</i>		
Collisions	2.33E+13	11.73%
Elsewhere	1.76E+14	88.27%

	Ratio	% Loss in IR7
TCSG.A6L7.B1 / TCSG.5L3.B1	3.1	76
TCSG.A6R7.B2 / TCSG.5R3.B2	5.6	85



@ Source terms, operational conditions as well as monitor readings have to be carefully evaluated



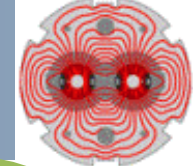
Threshold of monitors is $\sim 10^6$!
 (lower values only by 'trick'
 [big uncertainties!])

VERY GOOD AGREEMENT (given the underlying uncertainties)

	FLUKA & Operation		MEASUREMENTs	
	2010 using 2009 estimations	2010 with actual operation	2010 with RadMON (FLUKA r)	2010 with RadMON (TLD r)
UJ14 UJ16	2.5E+06	1.3E+06	1.6E+05	1.1E+06
RR13 RR17	5.0E+05	2.5E+05	1.0E+05	6.2E+05
UJ56	2.5E+06	1.3E+06	2.1E+05	
RR53 RR57	5.0E+05	2.5E+05	1.0E+05	6.2E+05
UJ76	6.9E+06	1.1E+06	5.9E+05	2.1E+06
RR73 RR77	3.4E+06	5.7E+05	2.1E+05	3.1E+06
UX85b	1.0E+07	1.3E+07	4.8E+07	1.0E+07
US85	5.0E+06	6.3E+06	3.6E+06	2.9E+06



Possible SEE Failures Observed in 2010



WIC crate failure in TI8

Observed in 2009
Known problem with moderate x-section

QPS Tunnel Card Failures

(2x in 9L7 [ions], 2x in 8R8 [inj.], + others)
ISO150 -> permanent PM trigger
SEE confirmed (EMC has same effect)

QPS tunnel Card Failures in 9R7 & 9L7

uFip communication lost (2x)
SEE confirmed (seen in CNRAD)

CONFIRMED or very LIKELY

CRYO tunnel card SEE in 8L2

1 Fault in uFip
(as observed in CNRAD 2010)
SEE confirmed

TE/EPC power supply burnout in UA87

Same effect observed in CNRAD
SEE is very likely the cause
(Streaming through Maze)

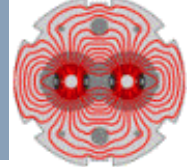
NOT CONFIRMED (unlikely)

VAC power supply burn out

In UA23 between maze and duct
(TDI losses + TCDI losses)
SEE rather unlikely

~~PXI power supply burnout in UA16~~

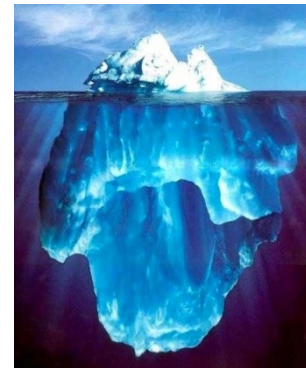
~~To be confirmed by producer
(comparison with CNRAD burnouts)
SEE unlikely (early 2010 operation)~~



Single Event 2010 Review

– Levels in the machine

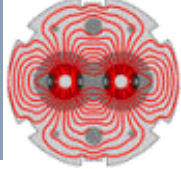
- Only 10^5 - 10^8 cm⁻² “measured” around (UJ, RR, Tunnel) equipments
- Only ~0.1% of nominal integrated luminosity, up to 2% of peak luminosity, ~1% of nominal lost beam, “no” scrubbing (yet)



– What is good?

- Simulations correctly verified in many pla (controlled tests & standard operation)
- Not too many failures occurred

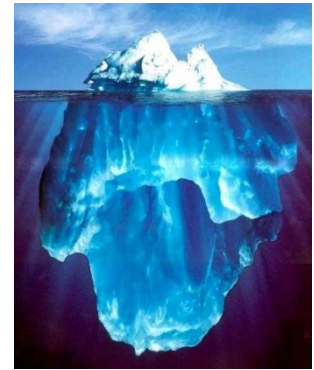




Single Event 2010 Review

– What is worrying?

- Critical areas: previsions beginning of 2010 expected quite some events in critical areas (several candidate/s, within error margins)
- Tunnel: 5-10 SEE events already seen in 2010 causing Machine Stop (mostly mitigated)
- *“we are already wrong”* ... in the bad direction



– What can make things worse

- equipments can be more sensitive (most is untested)?
- we didn't see “critical” levels (mostly $< 1 \times 10^6$)
- losses can also be higher than expected (*e.g.*, electron cloud, injection losses, life-time for ions)

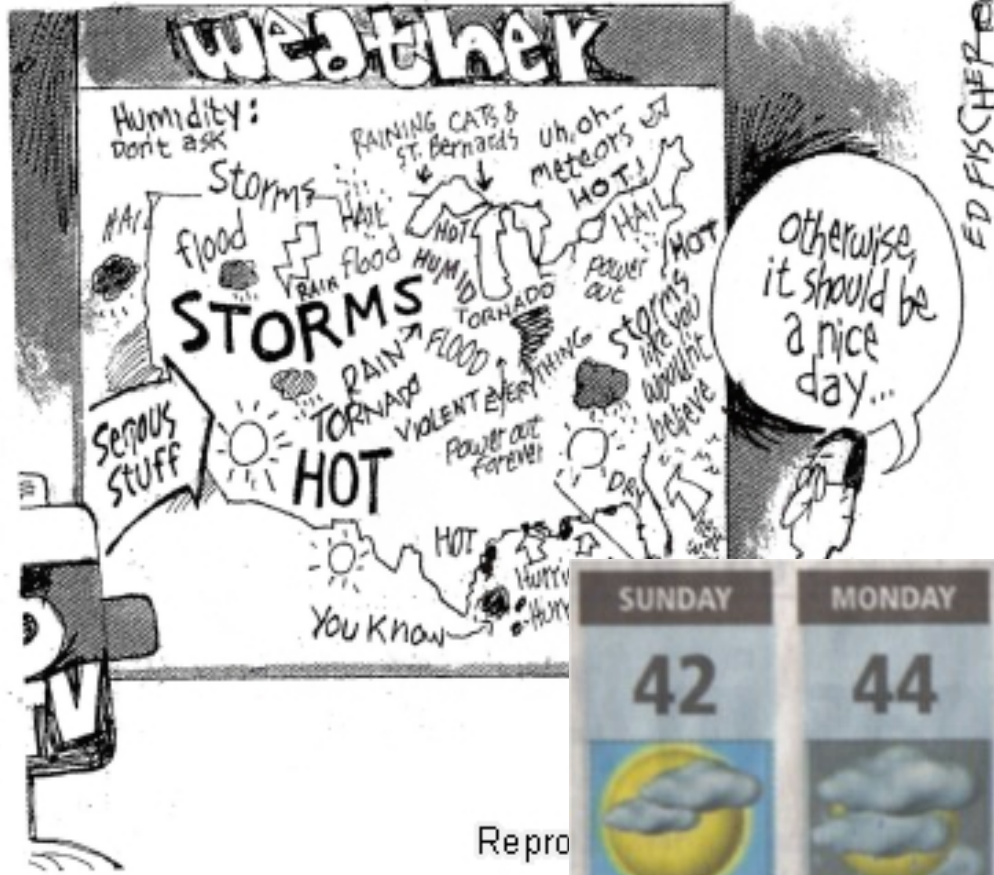
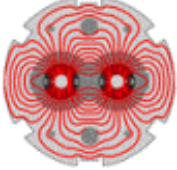
© D. Kramer

	FLUKA & Operation		ME
	2010 using 2009 estimations	2010 with actual operation	2010 Radl (FLU
UJ14 UJ16	2.5E+06	1.3E+06	1.6E
RR13 RR17	5.0E+05	2.5E+05	1.0E
UJ56	2.5E+06	1.3E+06	2.1E
RR53 RR57	5.0E+05	2.5E+05	1.0E
UJ76	6.9E+06	1.1E+06	5.9E
RR73 RR77	3.4E+06	5.7E+05	2.1E
UX85b	1.0E+07	1.3E+07	4.8E
US85	5.0E+06	6.3E+06	3.6E



!!! Amazing !!! Close t





Failures (estimate of July)
HIGH BUT OK
 radiation levels and xSections

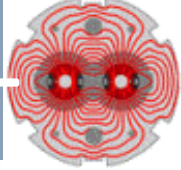


Xsect. rescaled

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
42	44	47	48	49	50
32	35	37	39	41	40

Other	7	56
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R2E Mandate -> radiation induced MTBF <= 1 per week for Ultimate Intensities, losses and luminosities (a long way to go, even with uncertainties)

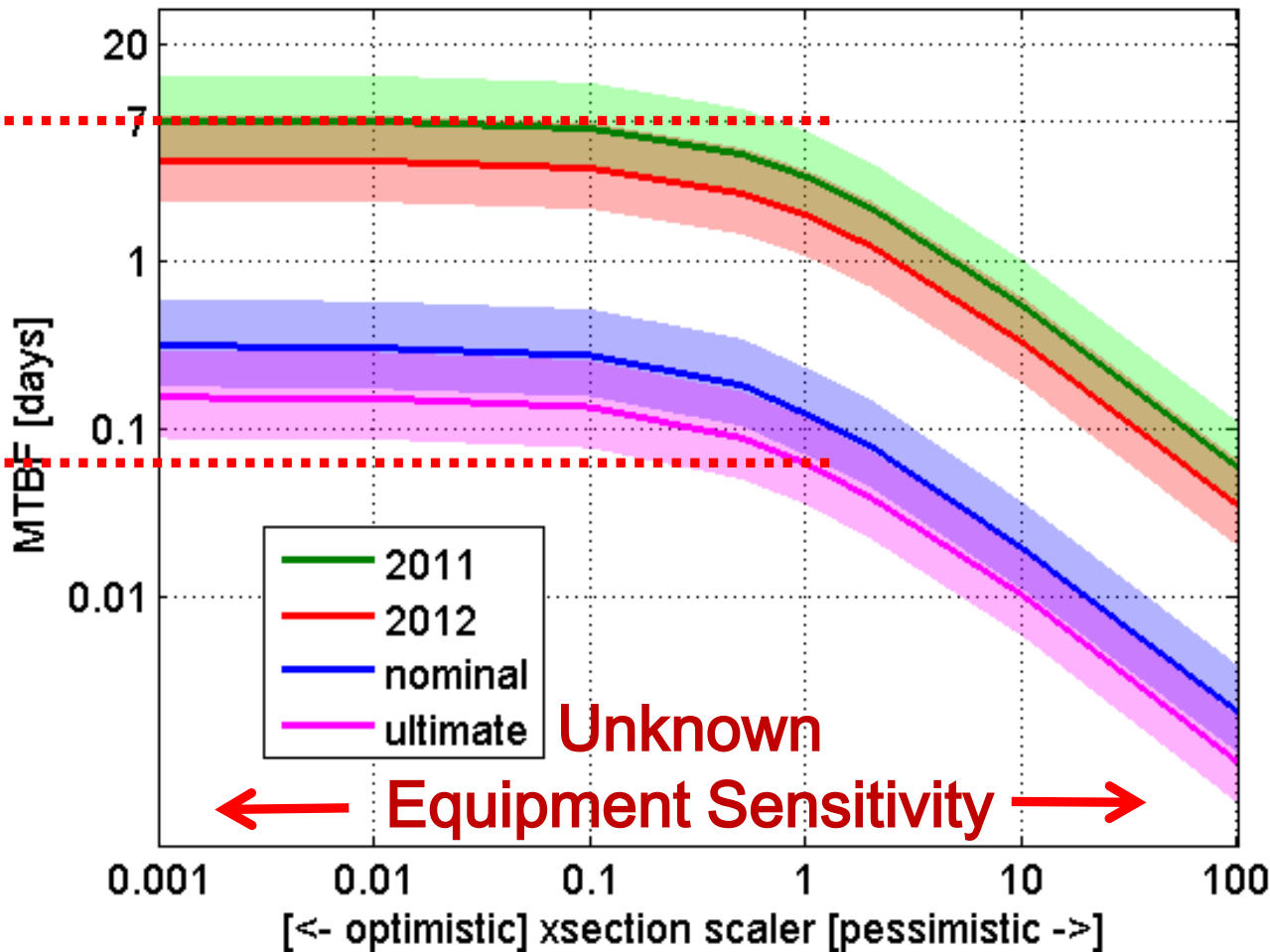


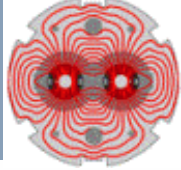
Sensitivity analysis based on failure xSections

© D. Kramer

⊗ **Uncertainties: LHC operation & machine behavior.**
radi

We're missing a Factor 100



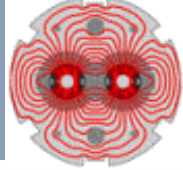


Energy greater than 3.5TeV:

- ⊙ Only **minor impact on radiation levels**, thus not an issue from the R2E point-of-view

Impact of 2012 operation

- ⊙ Will lead to a **delay of R2E mitigation measures** (shielding/relocation)
- ⊙ **Impact on operation not to be excluded**
- ⊙ **Risk of destructive failures**
- ⊙ Failure rate expected to be (just) acceptable

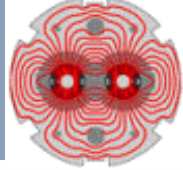


What We Will Do...

- ⊙ Preparation of **shielding & relocation** measures
- ⊙ 2011 experience together with detailed monitoring & scheduled radiation tests (full power-converters) will allow us a **further optimization** step
- ⊙ **Monitoring** and preparation of **patch solutions**

Our Strategy:

- ⊙ **Anticipate problems** whenever possible
- ⊙ Aim to be **ready for 2012** shutdown in any case
- ⊙ **Optimize the long-term solution**



To be kept in mind...

Tests with (LHC) beam

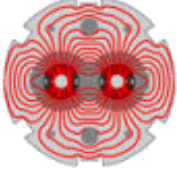
- ⊗ Field-calibration (for detectors) measurements:
 - ⊗ quench-test location would be ideal for additional loss/radiation-field studies
 - ⊗ TCDI near UJ87 would be an additional good spot

Scrubbing & Beam-Gas © V. Baglin

- ⊗ (So far) very low radiation levels in most of the ARC/DS locations (only specific loss locations [including some surprises] are concerned already ~1Gy in some cases!)
- ⊗ Minor effect on shielded areas
- ⊗ Tunnel equipment will be exposed

Ion-Operation

- ⊗ One month of ions is in some locations worse than one year of nominal!



Panic

Study Phase (2008-2010)

Calculations, Early Actions, Strategy

Evaluation

Struggling

Project Proposal (2010)

Testing, Evaluation, Mitigation Plan

Resources

R2E Mitigation Project (2011-2016)

Medium Term

R&D For Long-Term

Evaluation

Long-Term

Shielding & Relocation

Power-Converters

Monitoring

Combination

P1, P5, P7, P8
(+ small items)

Rad-Tol Solution

Analysis,
Calibration

Relocation
Rad-Tol Equipment

Collimation

Betatron in IR3

SCLs

Horizontal/
Vertical Links

Testing

Component &
System Tests

SCLs
(Civil Engineering)

Key Dates (Status 01.2011):

02.11. (Cables)

11.11. (1st Test Results)

2010 Operation

08.11. (CE pre-study)

03.11. (SafeRoom1)

12.11. (1st CD Review)

06.11. (UX/UL@P1)

06.12. (CE Study)

06.11. (SafeRoom2)

2012 (FGCs Production)

10.11. (Refine)

2013 (Hori-SCLs)

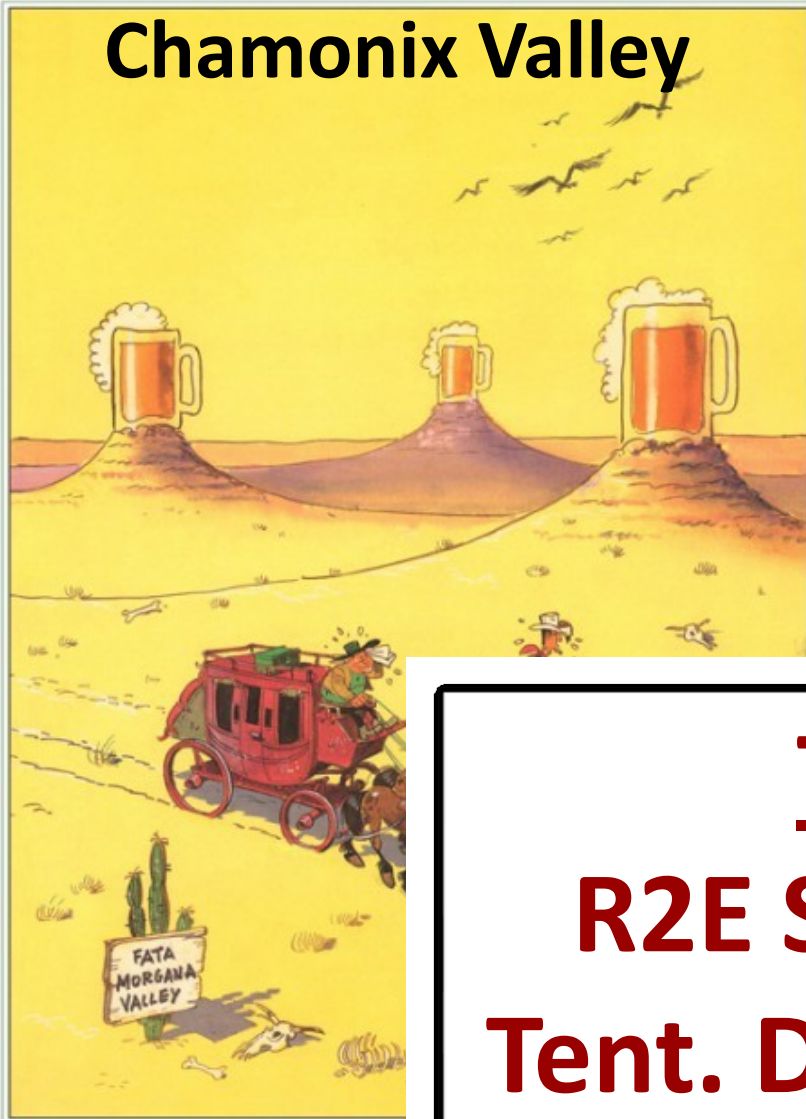
07.11. (Orders for SD)

2013 (Prototype)

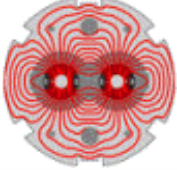
2014 (Production)

2014 (PCs and/or SCLs)

Chamonix Valley



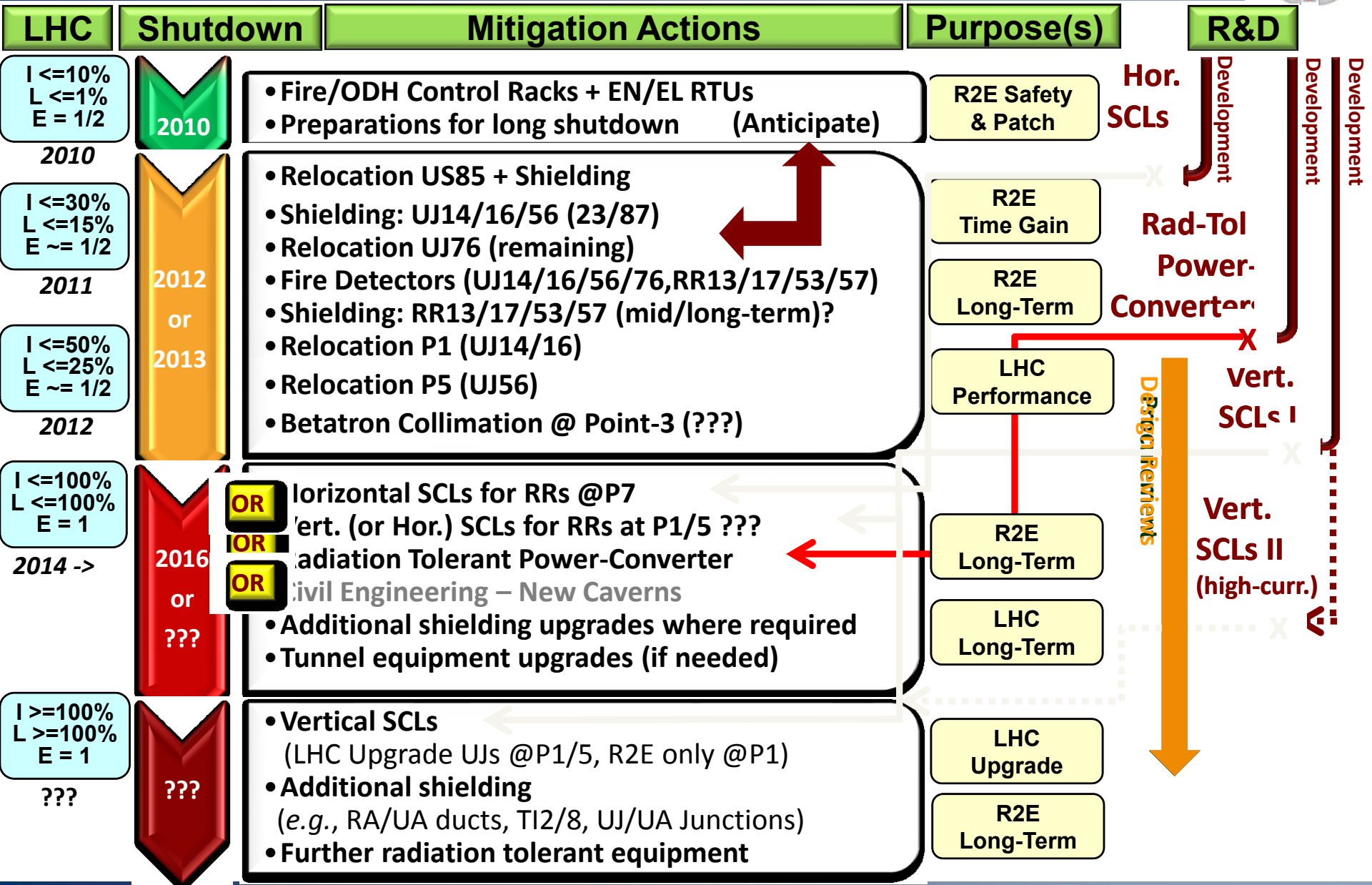
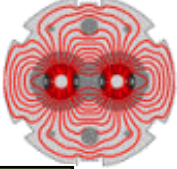
THANK YOU
R2E Seminar (+Drink)
Tent. Date: February 18th



Backup

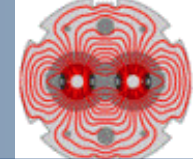


R2E Mitigation Project Plan

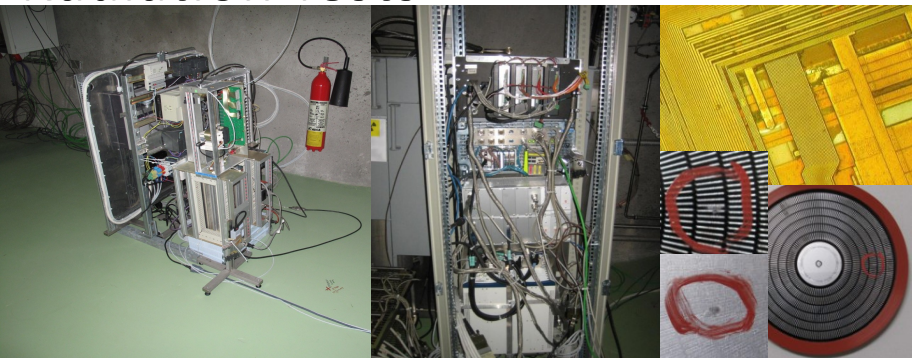




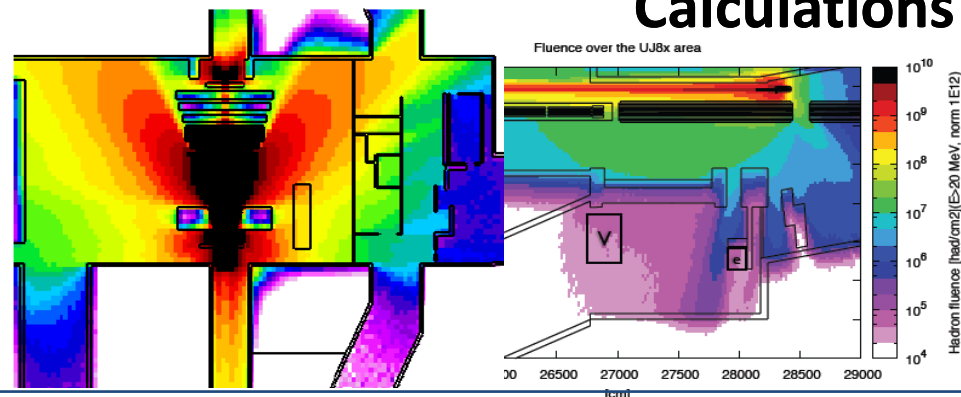
R2E Mitigation Project Building Blocks



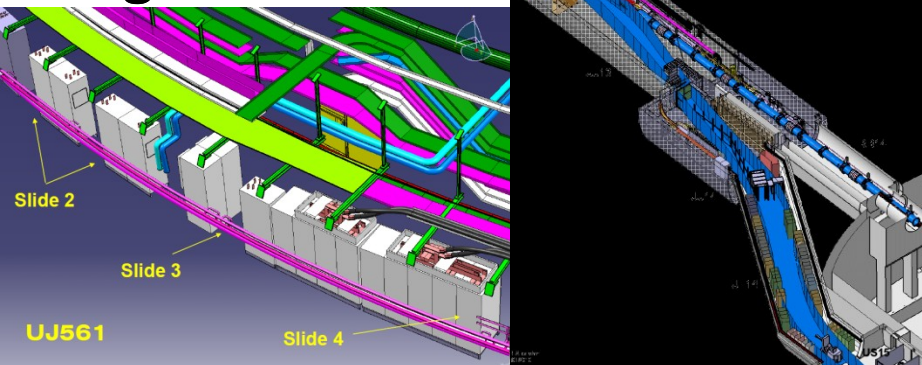
Radiation Tests



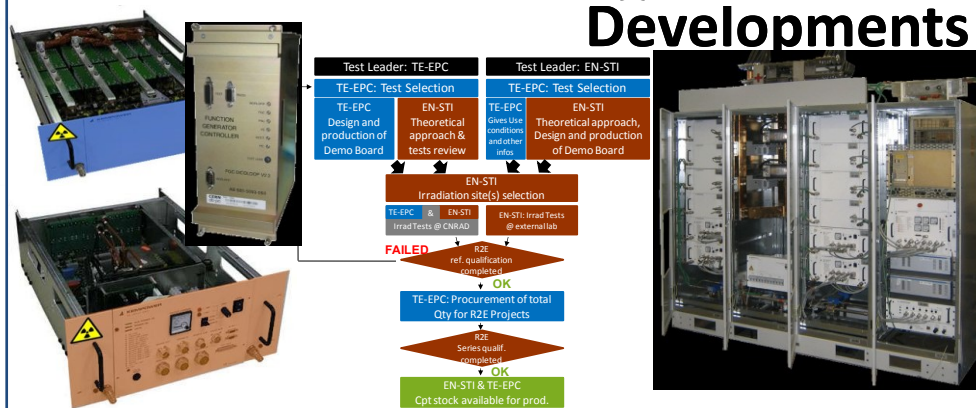
Calculations



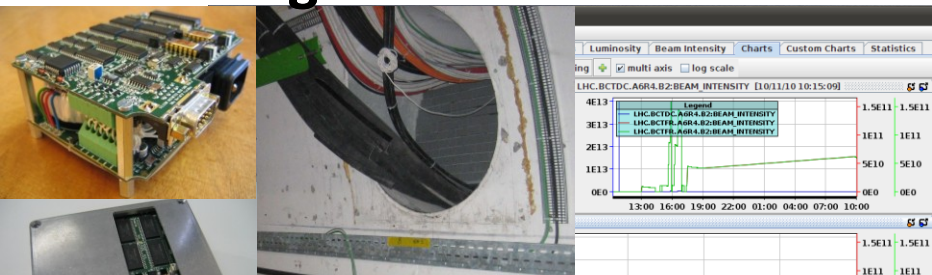
Integration



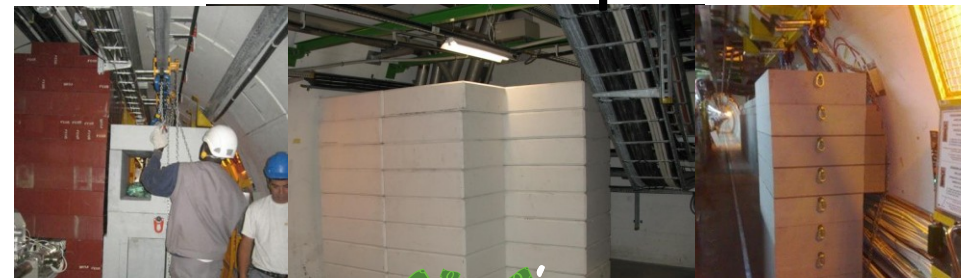
Developments



Monitoring



Implementation

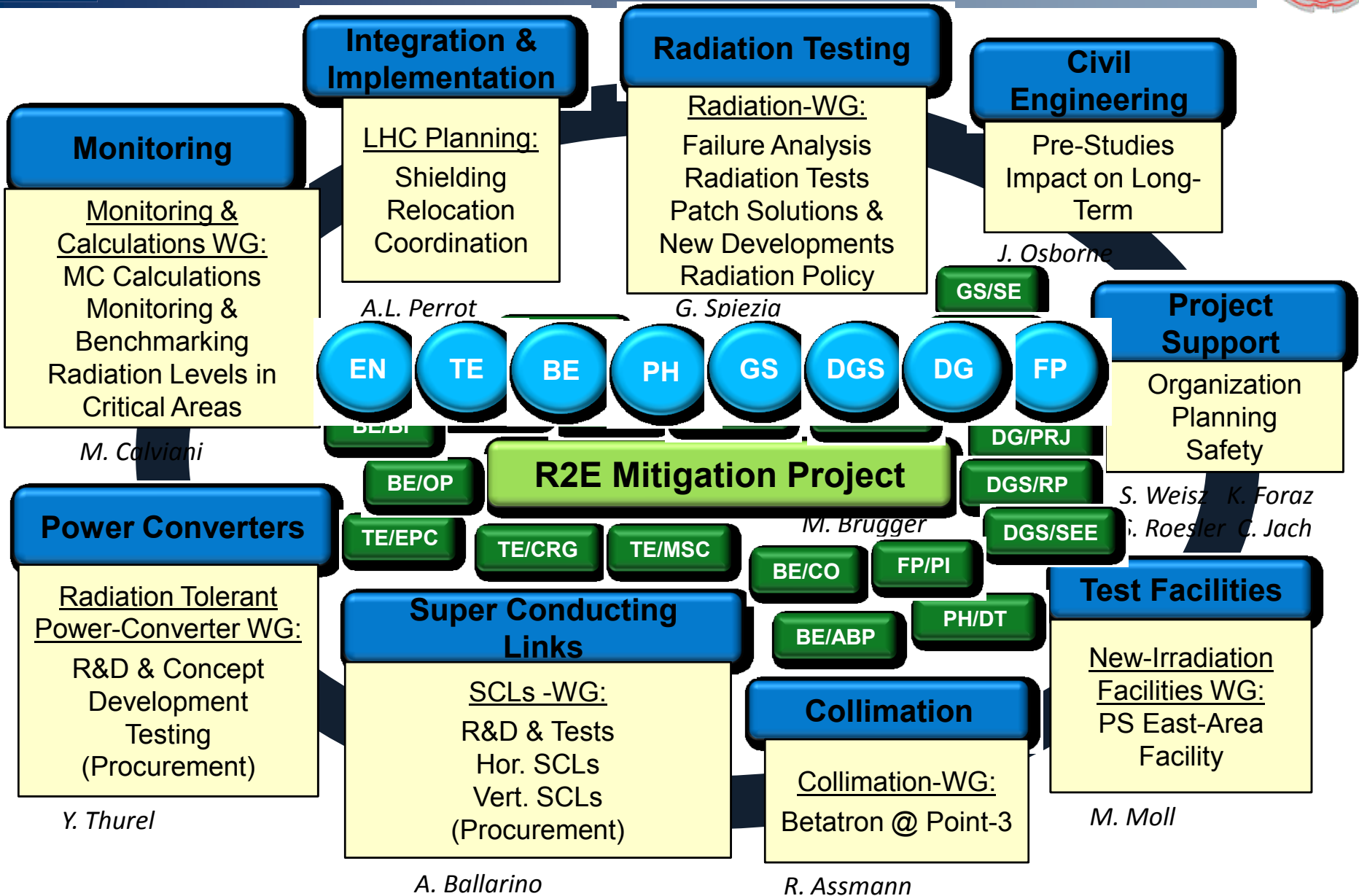
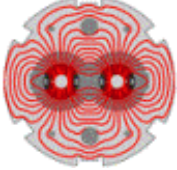


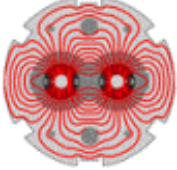
People, Planning & Money





Building Blocks for the R2E Project



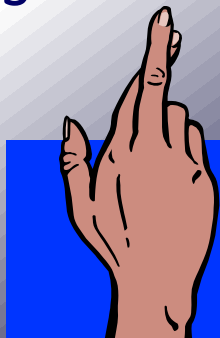


@ Constraints & Mandate:

- @ Minimize (Avoid) any risk of radiation induced failure to electronics
- @ Foresee a mitigation plan fitting in the planned shutdown periods
- @ Optimize with respect to planning and costs

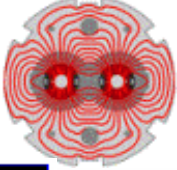
@ Strategy:

- @ Monitor and benchmark to refine actions and planning
- @ Prepare “Patch-Solutions” where available (not many left!)
- @ Shield and Envisage/Prepare/Perform Relocations
- @ Study/Pursue Major Long-Term Solutions (R&D for SCLs and Rad-Tol PCs, CE as backup)
- @ ... cross fingers, review, optimize, cross fingers...





What's to Be Avoided



LHC Page1 Fill: 1147 E: 3500 GeV 10-06-2010 08:45:49

ACCESS: LHC REPAIR

Energy: 0 GeV I(B1): 0.0e+00 I(B2): 0.0e+00

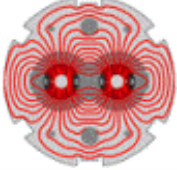


Comments 10-06-2011 06:46:12 :

NO BEAM DUE TO SEE PROBLEMS

BIS status and SMP flags	B1	B2
Link Status of Beam Permits	false	false
Global Beam Permit	false	false
Setup Beam	false	false
Beam Presence	false	false
Moveable Devices Allowed In	false	false
Stable Beams	false	false

LHC Operation in CCC : 77600, 70480 PM Status B1 **ENABLED** PM Status B2 **ENABLED**



LHC Point-7:

- @ UJ76 **shielding** wall; done
- @ UJ56-TZ76: **relocation** of the ODH and fire detection control central; done
- @ UJ56-TZ76: RTUs **relocation**; (done) 24th January;

LHC Point-5:

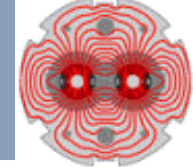
- @ UJ56-USC55: **relocation** of the fire detection control central; done (reception on the 25th January)
- @ UJ56- USC55: RTUs **relocation**; (to be done) 31rd January;

LHC Point-8:

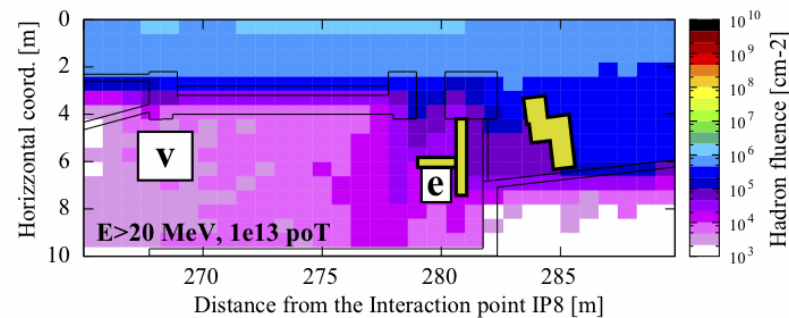
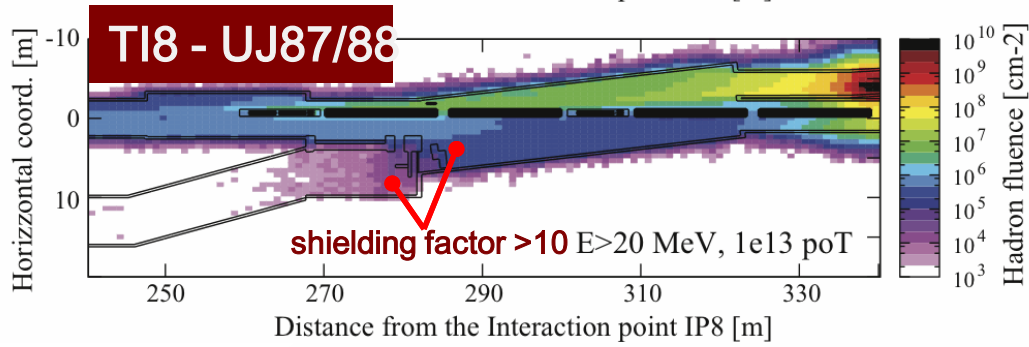
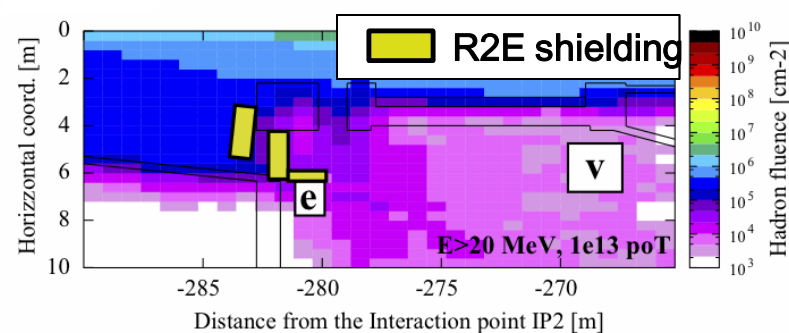
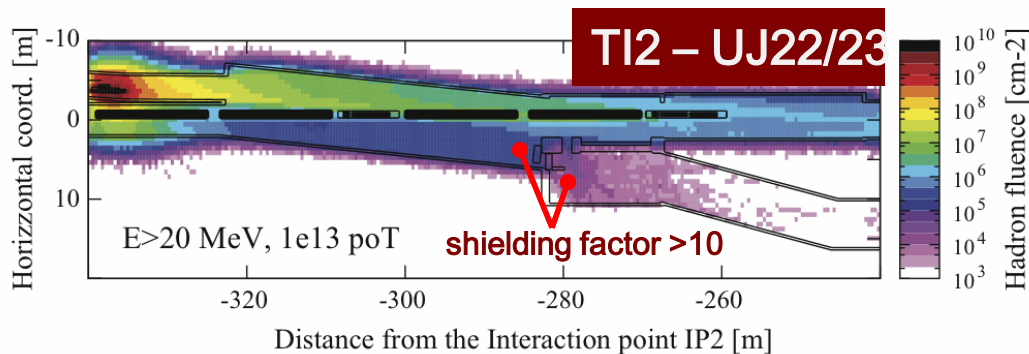
- @ EN/EL: advance on the **cables** installation work foreseen during the next long shut down;

LHC Point-1: (optional and kept in pipeline)

- @ UJ/UL: relocation of the fire detectors

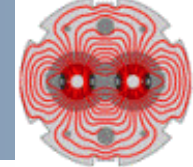


Injection lines - High Energy Hadron fluence - Beam on the TEDs:

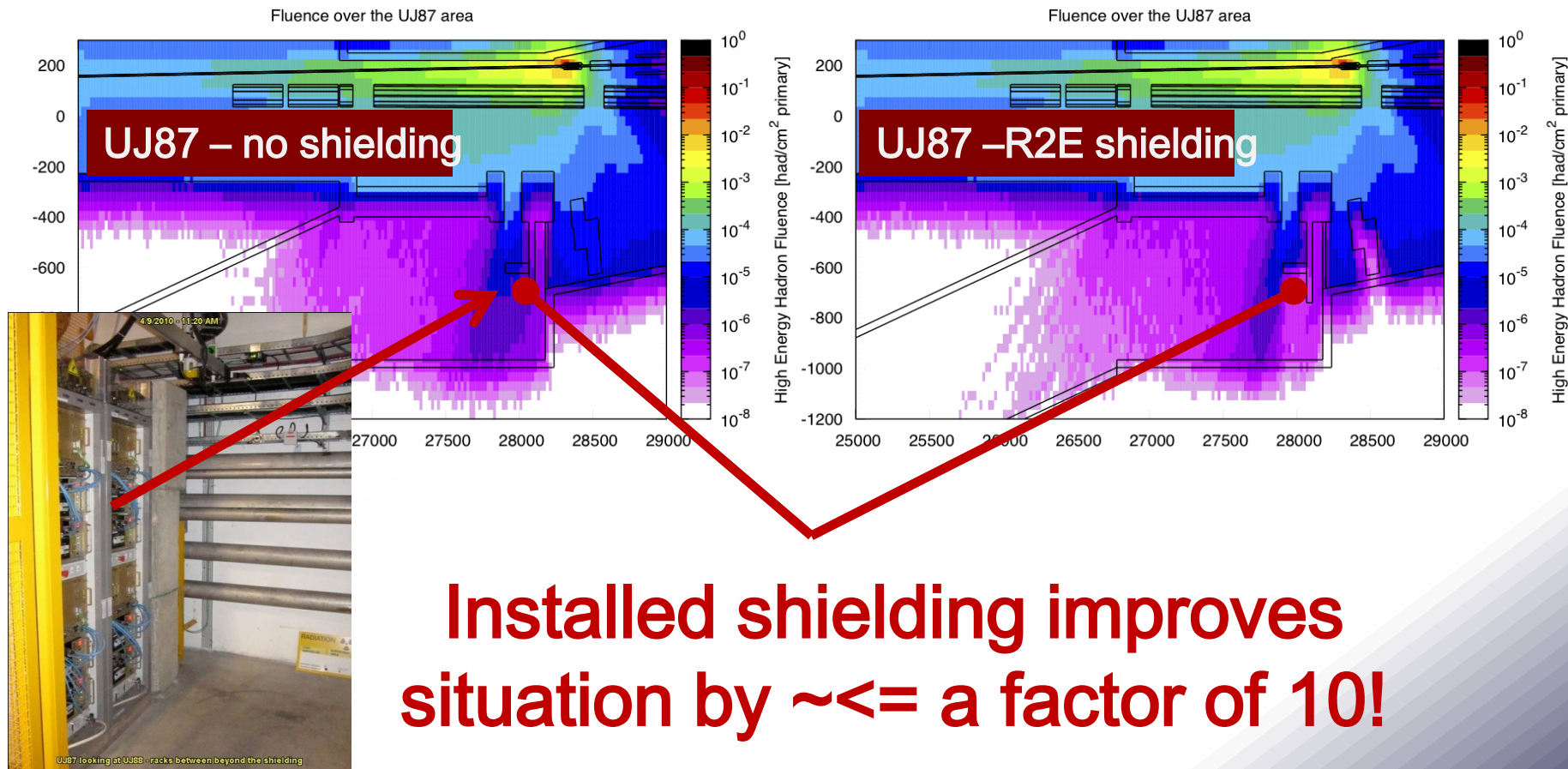


Installed shielding improves situation by $\sim \leq$ a factor of 10!

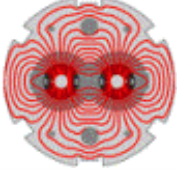
Reminder: installed shielding for UJ23, UJ87, UJ76, RR73/77, UA63/67



Injection lines - High Energy Hadron fluence - Beam on the TCDI:



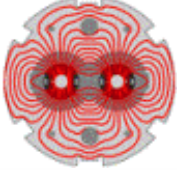
Reminder: installed shielding for UJ23, UJ87, UJ76, RR73/77, UA63/67



Failure Rate Estimate



Failure Rate Approach



(1) Use the 'Aging' Radiation Level

LHC Point	Area(s)	High-Energy Hadron Fluence [cm-2/y]						Thermal Ratio	Action Priority
		2010	2011	2013	2014	Nominal	Ultimate		
Point 1	UJ14 UJ16	2.5E+06	2.5E+07	3.0E+08	7.0E+08	2.5E+09	5.0E+09	200.0	2
	RR13 RR17	5.0E+05	5.0E+06	6.0E+07	1.4E+08	5.0E+08	1.0E+09	10.0	3
Point 3	UPS14 UPS16	5.0E+05	5.0E+06	6.0E+07	1.4E+08	5.0E+08	1.0E+09	2 (guess)	4
	UJ33	2.2E+04	1.9E+05	5.3E+05	5.7E+05	1.3E+06	1.4E+06	3 (guess)	4
Point 4	UJ/RE32	2.3E+06	2.2E+06	1.9E+07	6.7E+07	2.5E+08	3.7E+08	50 (guess)	3
	RE38	4.6E+05	4.4E+05	3.7E+06	1.3E+07	5.0E+07	7.5E+07	20 (guess)	3
Point 5	UX45	2.3E+05	2.2E+05	1.9E+06	6.7E+06	2.5E+07	3.7E+07	50 (guess)	4
	UJ56	2.5E+06	2.5E+07	3.0E+08	7.0E+08	2.5E+09	5.0E+09	2.0	2
Point 6	RR53 RR57	5.0E+05	5.0E+06	6.0E+07	1.4E+08	5.0E+08	1.0E+09	10.0	3
	UPS54 UPS46	5.0E+05	5.0E+06	6.0E+07	1.4E+08	5.0E+08	1.0E+09	2 (guess)	4
Point 8	UA63 UA67 (next to TCDD)	8.6E+04	1.7E+05	9.3E+05	1.0E+06	5.0E+06	5.7E+06	50-400 (guess)	1

(2) Check for each equipment in each area

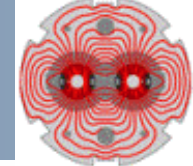
LHC Point	Area(s)	number of devices					
		120A immediate dump and access	120A scheduled access	120A other	600A immediate dump and access	4-6/8kA (inner Tr) immediate dump and access	4-6/8kA (oth) immediate dump and access
Point 1	UJ14 UJ16	10			16	4	
	RR13 RR17		36		28		30
	UPS14 UPS16						
	UJ33			10	70		
Point 5	UJ/RE32						
	UJ56	5			8	2	
	RR53 RR57		36		28		30
	UPS54 UPS46						
Point 6	UJ76				12		
	RR73 RR77			20	48		
Point 8	UX85b US85						
	UW85						
Ti2	UJ23			8			
Ti8	UJ87			8			

(3) Apply the expected failure cross section

	LHC80A-08V	LHC120A-10V	LHC800A-10V	LHC4-6-8kA-08V	Inner-Triplet
Type	BP1A	BP1B	BPMB	BP1H	BPxx
Cross Section	[1E-10..1E-11] /cm²	[5E-9..1E-11] /cm²	[5E-8..5E-9] /cm²	[5E-8..5E-9] /cm²	[2E-8..1E-9] /cm²
Hypothesis & Comments (DCCTs being excluded since redundant and low risk)	<ul style="list-style-type: none"> power part relatively safe, with some SEGR on some Power MosFets FGC cross section @ 1E-11 is correct 	<p>Not Rad Tested</p> <ul style="list-style-type: none"> power part relatively safe, with some SEGR on some Power MosFets Converter more complex than 60A (more components) CPLD in Digital control board only 1x CPLD, then not adding too high extra failure FGC cross section @ 1E-11 is correct 	<p>Not Rad Tested</p> <ul style="list-style-type: none"> power part relatively safe, with some SEGR on some Power MosFets 5x CPLD in Digital control board only 1x CPLD, not adding too high extra failure FGC cross section @ 1E-11 is correct 3x DC-DCs unknown AC-DC unknown but high AC voltage range 48x Power MosFets used in 4QLS 	<p>Not Rad Tested</p> <ul style="list-style-type: none"> power part relatively safe, with some SEGR on some Power MosFets 8x CPLD in Digital control board only 1x CPLD, adding extra failure FGC cross section @ 1E-11 is correct 1 DC-DC no AC-DC 	<p>Not Rad Tested</p> <ul style="list-style-type: none"> power part relatively safe, with some SEGR on some Power MosFets 8x CPLD in Digital control board only 1x CPLD, adding extra failure FGC cross section @ 1E-11 is correct no AC-DC AC-DC unknown + 1 CPLD Additional Thyristor + 1 DCDC
Risk factor (DCCTs being excluded since redundant and low risk)	No High Risk. Well tested in CNGS.	No high Risk, since CERN Design, and very few critical or unknown components. A security hole remains on current lead protection (CPLD based).	High Risk since some unknown integrated devices: 5x CPLD + 1x AC-DC + 3x DC-DC in power part.	High Risk since some unknown integrated devices + 8x CPLD + 1x DC-DC in power part	High Risk since some unknown integrated devices + 8x CPLD + 1x DC-DC in power part + Inner-Triplet additional components with DC-DC or CPLD
Rad Status	Well tested.	Converter not Tested under radiation. Estimation provided assuming no unexpected very high sensitive device included in unknown / untested parts, which would completely change the situation.			

(4) Result: failures per equipment/area

LHC Point	Area(s)	FAILURES PER YEAR EXPECTED IN 2011					
		120A immediate dump and access	120A scheduled access	120A other	600A immediate dump and access	4-6/8kA (inner Tr) immediate dump and access	4-6/8kA (oth) immediate dump and access
Point 1	UJ14 UJ16	1	0	0	20	10	0
	RR13 RR17	0	1	0	7	0	8
	UPS14 UPS16	0	0	0	0	0	0
	UJ33	0	0	0	1	0	0
Point 3	UJ/RE32	0	0	0	0	0	0
	UJ56	1	0	0	10	5	0
Point 5	RR53 RR57	0	1	0	7	0	8
	UPS54 UPS46	0	0	0	0	0	0
	UJ76	0	0	0	8	0	0
	RR73 RR77	0	0	1	16	0	0
Point 8	UX85b US85	0	0	0	0	0	0
	UW85	0	0	0	0	0	0
Ti2	UJ23	0	0	0	0	0	0
Ti8	UJ87	0	0	0	0	0	0

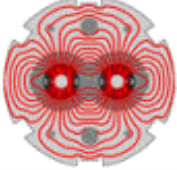


Failure Mode	EXPECTED FAILURES PER YEAR - LHC ALCOVES																
	CV	Pconv Opt	Pconv Pess	CRYO	BPWIC	Fire/ODH	QPS	CL heaters	IT	VAC	SURVEY	Collim	EN/EL	TIMING	REM RESET	BI	RP
immediate dump and access	1	29	544	13	35		14		4			0.2	0.6				
immediate dump				9	3							7	0.3	0.0			
Scheduled access	8	0.0	15	0.0		13		0.4		9			3		0.9		
other	3	0.0	9	8							0.0	12	1.3			0.1	5

Optimistic		Pessimistic		Guess/Tested
SUM	MTBF [days]	SUM	MTBF [days]	Ratio
98	4	614	1	2.7
19	19	19	19	0.02
35	10	50	7	0.6
30	12	39	9	0.4

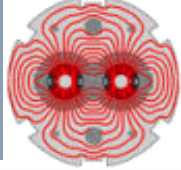


2012 Estimation



Failure Mode	EXPECTED FAILURES PER YEAR - LHC ALCOVES																
	CV	Pconv Opt	Pconv Pess	CRYO	BPWIC	Fire/ODH	QPS	CL heaters	IT	VAC	SURVEY	Collim	EN/EL	TIMING	REM RESET	BI	RP
immediate dump and access	2	48	912	22	60		24		8			0.4	1.1				
immediate dump				14	5							12	0.7	0.0			
Scheduled access	14	0.1	26	0.0		22		0.7		16			5		1.6		
other	7	0.0	16	14							0.0	21	2.4			0.2	8

Optimistic		Pessimistic		Guess/Tested
SUM	MTBF [days]	SUM	MTBF [days]	Ratio
166	2.2	1031	0.35	2.6
33	11	33	11	0.02
60	6	86	4	0.5
52	7	68	5	0.5

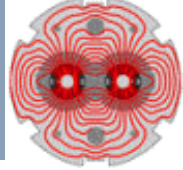


NOMINAL OPERATION	No Changes	Additional Shielding	+ relocation
UJ14 UJ16	1666	17	8
RR13 RR17	376	75	75
UJ33	1	1	1
UJ/RE32	3	3	3
UJ56	265	265	0
RR53 RR57	376	75	75
UA63 UA67	4	4	4
UJ76	85	85	0
RR73 RR77	166	33	33
UX85b	8	8	0
US85	25	25	0
UW85	2	2	2
UJ23	0	0	0
UJ87	0	0	0
SUM	2977	594	201
MTBF [d]	0.12	0.61	1.82

Most systems (QPS, MKS etc) excluded from UA63/7 list as duct shielding can be added if necessary

Only few equipments included in UW85 list

Power converters 120A in UJ23/87 classified as "other" SEE => no DUMP



Nominal Estimation (After Shielding & Relocation)

Failure Mode	EXPECTED FAILURES PER NOMINAL YEAR - LHC ALCOVES																
	CV	Pconv Opt	Pconv Pess	CRYO	BPWIC	Fire/ODH	QPS	CL heaters	IT	VAC	SURVEY	Collim	EN/EL	TIMING	REM RESET	BI	RP
immediate dump and access	2	108	2001	3	0		60		3			0.1	0.0				
immediate dump				20	0							2	0.0	0.0			
Scheduled access	39	0.2	90	0.0		9		1.6		0			2		0.0		
other	21	0.1	64	2							0.0	4	2.4			0.3	0

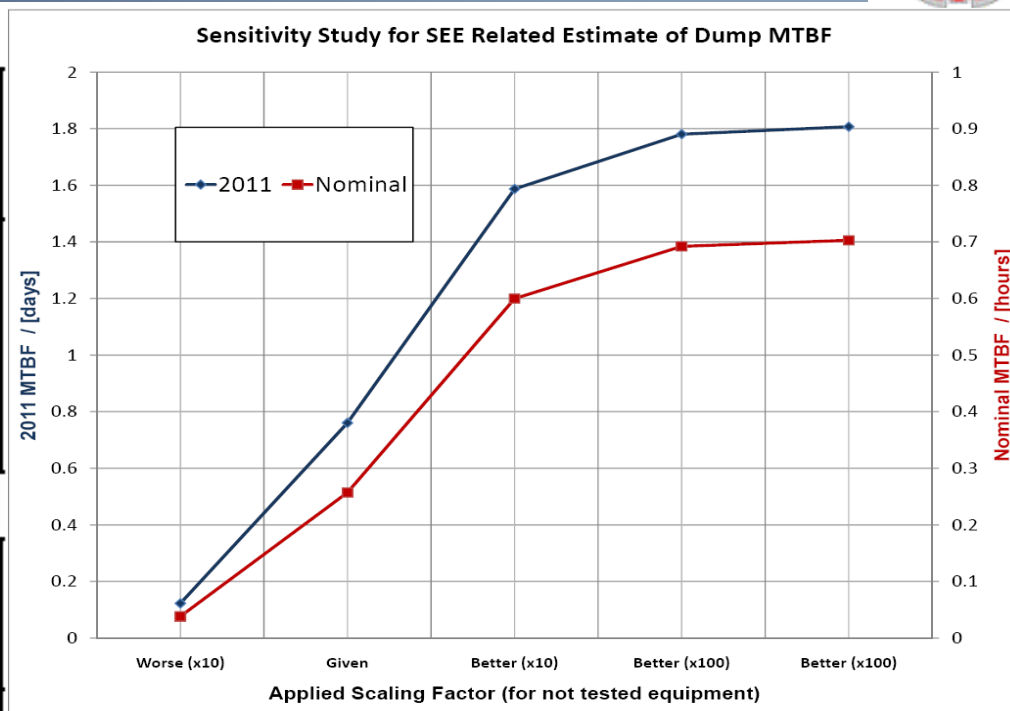
Failure Mode	Optimistic	
	SUM	MTBF [days]
immediate dump and access	176	2.1
immediate dump	22	17
Scheduled access	52	7.0
other	29	13

2011 LHC Operation:

Failure Mode	Failure Estimate		Confidence (Tested vs. Assumed)
	SUM	MTBF [days]	Ratio
Immediate Dump and Access	332	1	0.06
Immediate Dump	146	2	7
Scheduled Access	133	3	0.4
Other	104	3	1

Nominal LHC Operation:

Failure Mode	Failure Estimate		Confidence (Tested vs. Assumed)
	SUM	MTBF [hours]	Ratio
Immediate Dump and Access	24709	0.3	0.03
Immediate Dump	7500	1.0	9
Scheduled Access	4210	1.2	1
Other	4682	1.4	4

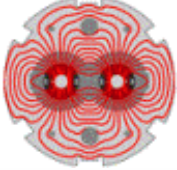


⊗ **Best possible estimate today**

⊗ **Uncertainties:** LHC operation & machine behavior, radiation levels, equipment sensitivities
-> see next slides

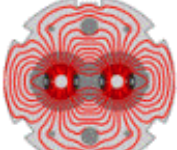
⊗ **2011 will be at the edge (and above)** and possibly show first limitations

⊗ In order **not to have problems** with nominal LHC operation we would have to be **wrong by a factor 500-1000 !**

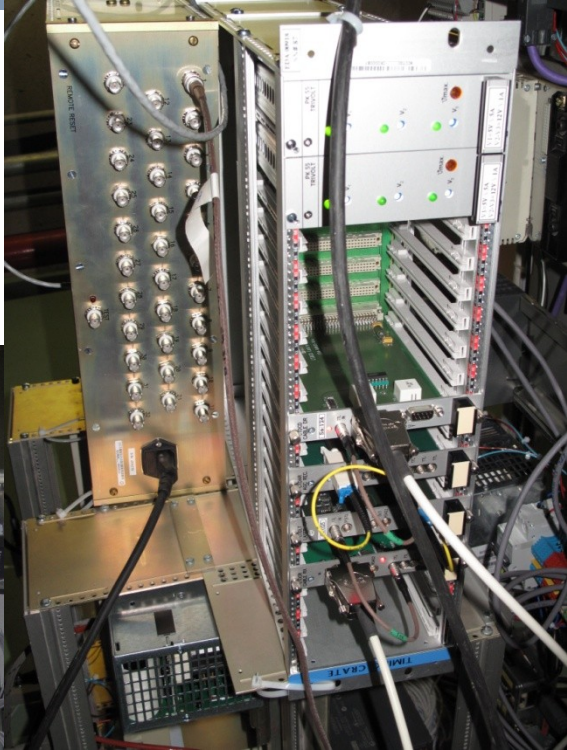
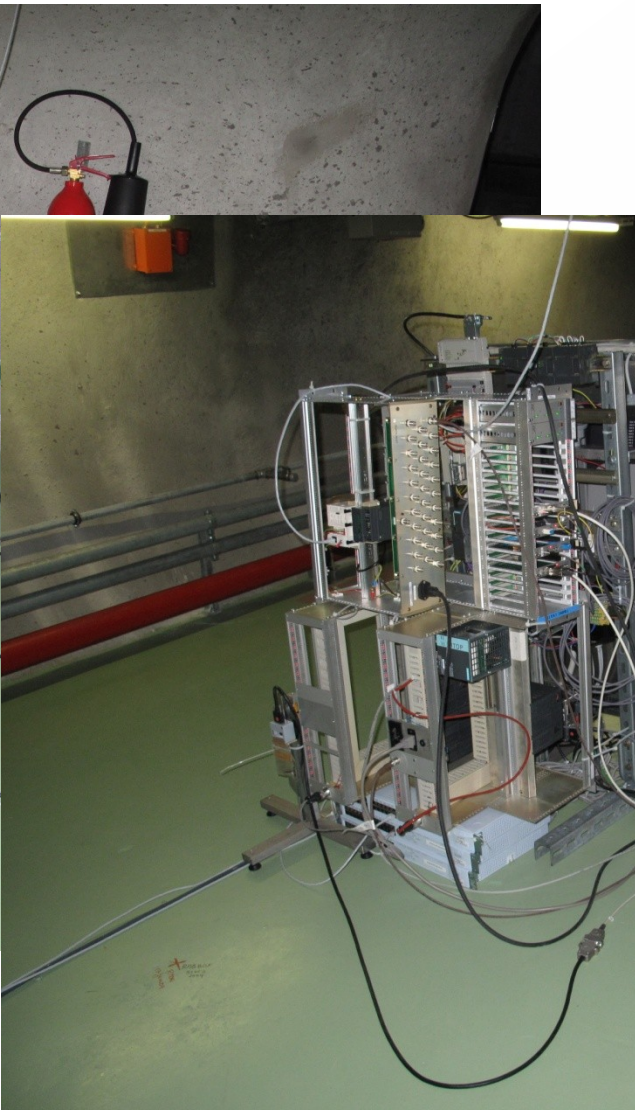
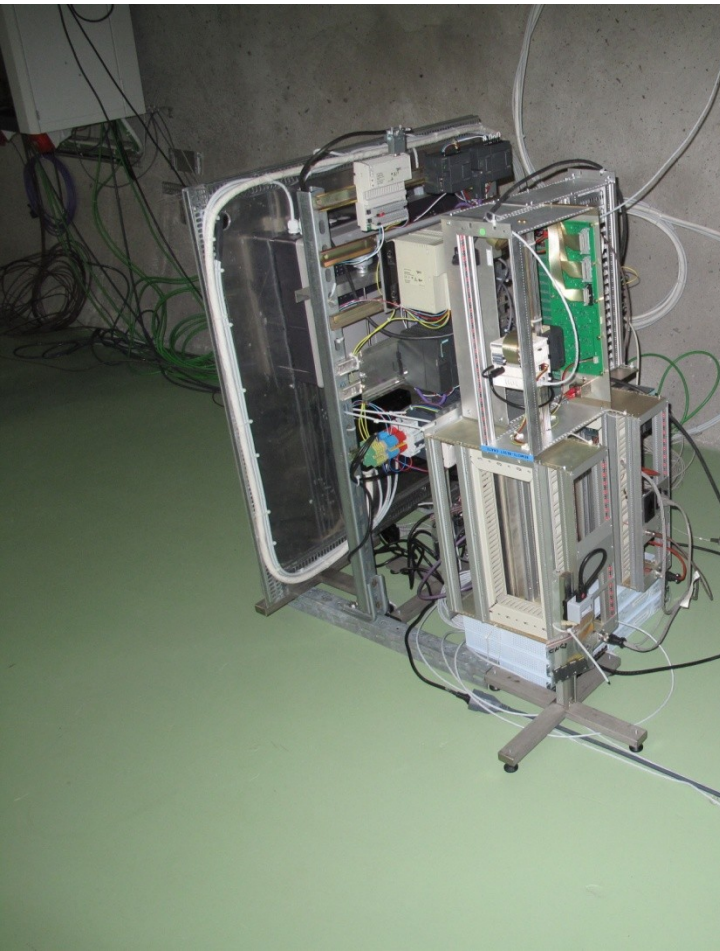


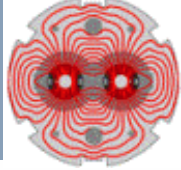
Radiation Tests

'Only' a selection could be tested!



© CNRAD, some pictures: The 'Tower of Pisa'





CERN:

CNRAD (Mar-Nov 2011)

- Tests on Power converters, QPS equipment, Cryogenics

H4IRRAD (start May)

- Tests on Power Converters and EN/EL equipment.

Outside CERN:

PSI - Villigen (2011)

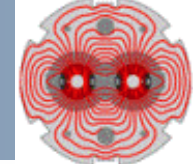
- Agreement with PSI to get 1 weekend test per month;
- Test of Amplifier, ADC buffers, and ADC for the PC redesign;
- Continue calibration of the RADMONs.

CEA – Valduc (Feb 2011)

- Calibration of PinDiodes (RADMON) for the Displacement Damage measurements.

TRIGA– Rome (or Prague facility) (2011)

- RADMON memory calibration with a thermal neutron beam.



@ Cooling and Ventilation (H. Jena)

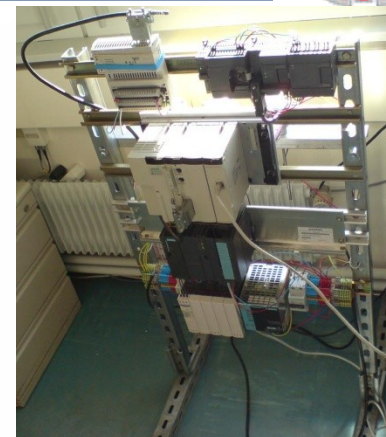
- ❁ Siemens S7-300, S7-200
- ❁ Schneider Telemecanique Premium

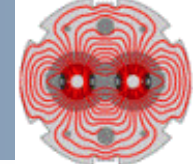
@ Warm Interlock Rack (P. Dahlen)

- ❁ PLC 315F 2 DP, Ethernet controller
- ❁ 24 DI safety input modules, 2 x DO Relay modules, 2 x 32 DO modules
- ❁ IM153.1 - ET 200M
- ❁ Boolean Processor - FM 352-5

@ Ethernet (E. Sallaz)

- ❁ Three Ethernet Switches
- ❁ 3Com 4400





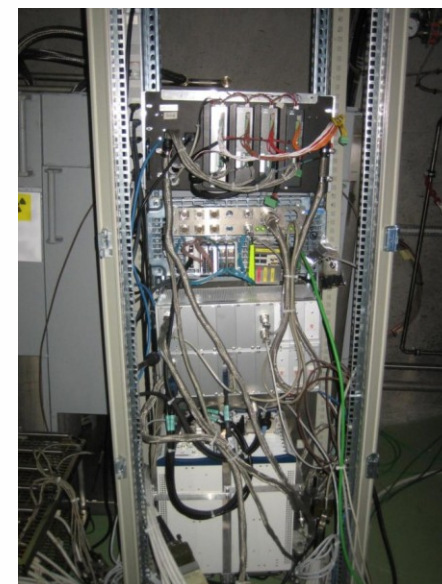
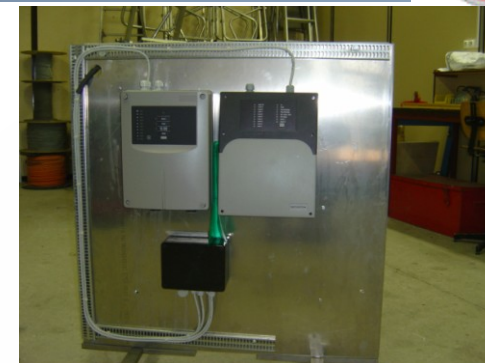
@ Fire Detectors (S. Grau and Team)

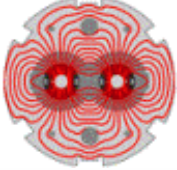
- ✿ 4 Detectors (different types)

@ Collimation (G. Spiezia and Team)

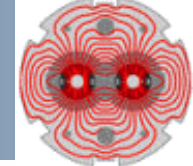
- ✿ Full Rack with Drivers, I/O RIO
- ✿ National Instruments PXI MDC + PRS (ADC, DAC, FPGA card, power supply)
- ✿ Europa crate (custom electronic for LVDTs and Resolvers excitation/acquisition, power supply)

@ Timing & Remote Reset (R. Chery)





Benchmarks

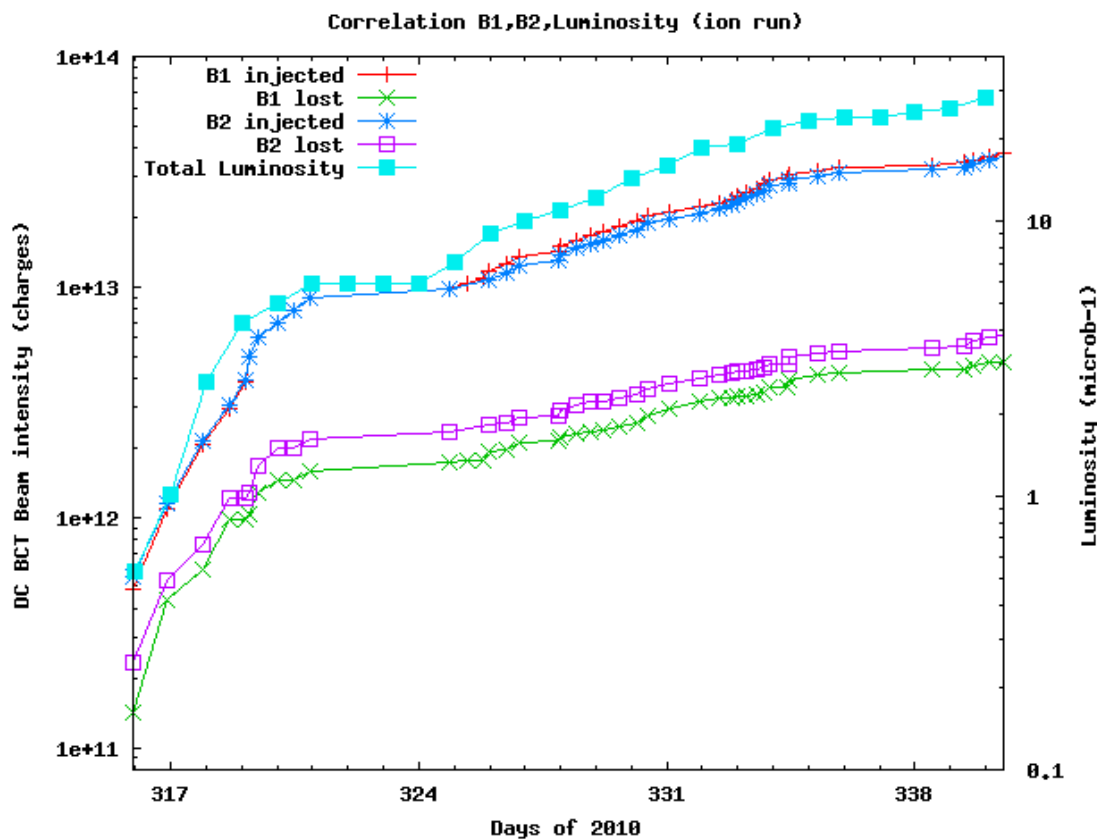


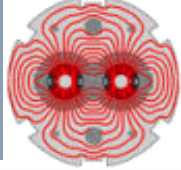
Summary (Protons)

In	6.02E+15	
Dumped	5.82E+15	96.70%
Lost in Machine	1.99E+14	3.30%
<i>Of Lost protons</i>		
Collisions	2.33E+13	11.73%
Elsewhere	1.76E+14	88.27%

Summary (Ions)

In	7.46E+13	
Dumped	6.36E+13	85.25%
Lost in Machine	1.10E+13	14.75%
<i>Of Lost protons</i>		
Collisions	3.77E+10	0.34%
Elsewhere	1.10E+13	99.66%



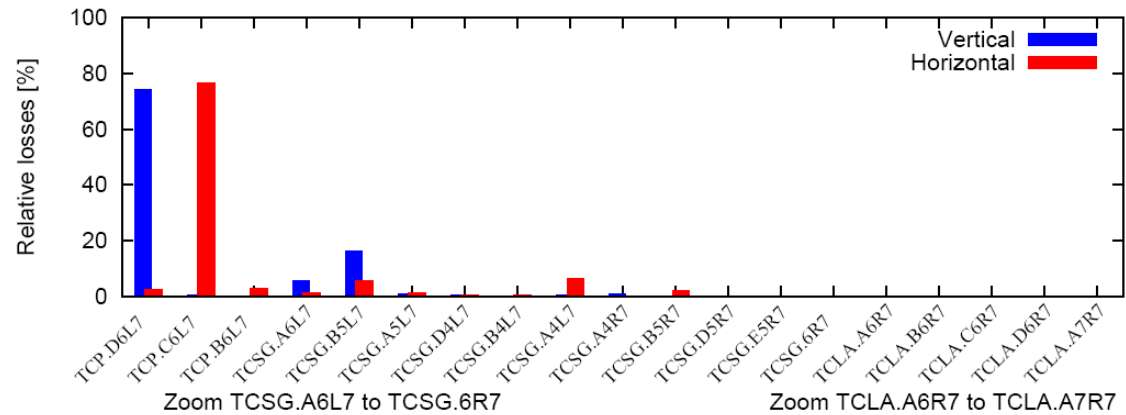


Summary (Protons B1)		
In	3.53E+15	
Dumped	3.44E+15	97.26%
Lost in Machine	9.67E+13	2.74%
<i>Of Lost protons B1</i>		
Collisions	1.17E+13	12.07%
Elsewhere	8.50E+13	87.93%

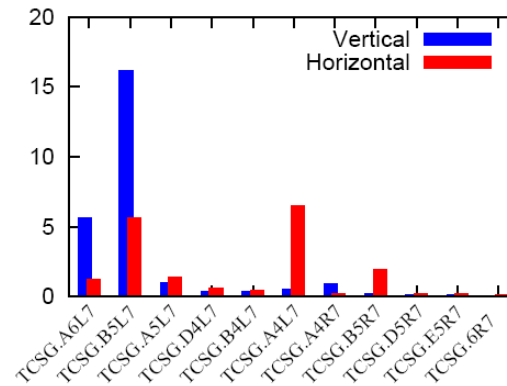
Summary (Protons B2)		
In	2.49E+15	
Dumped	2.38E+15	95.89%
Lost in Machine	1.02E+14	4.11%
<i>Of Lost protons B1</i>		
Collisions	1.17E+13	11.42%
Elsewhere	9.05E+13	88.58%

BLM ratio IR7 / IR3		
	Ratio	% Loss in IR7
TCSG.A6L7.B1 / TCSG.5L3.B1	3.1	76
TCSG.A6R7.B2 / TCSG.5R3.B2	5.6	85

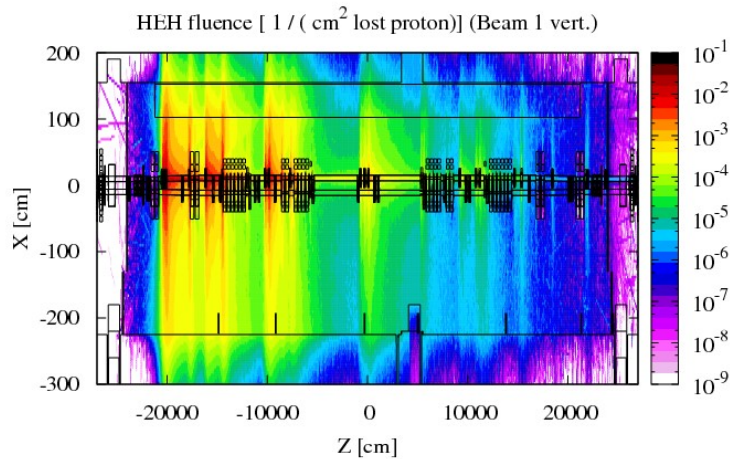
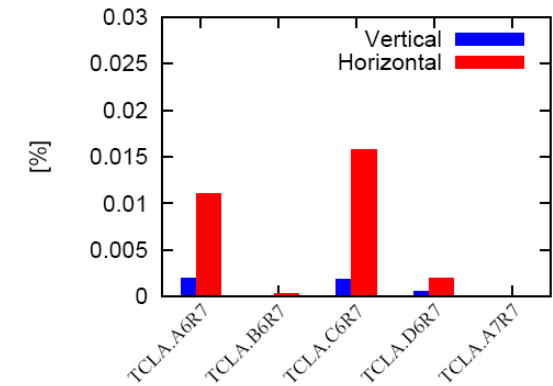
3.5 TeV loss distributions IR7 (Beam 1)

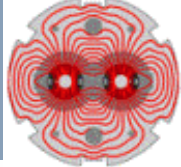


Zoom TCSG.A6L7 to TCSG.6R7

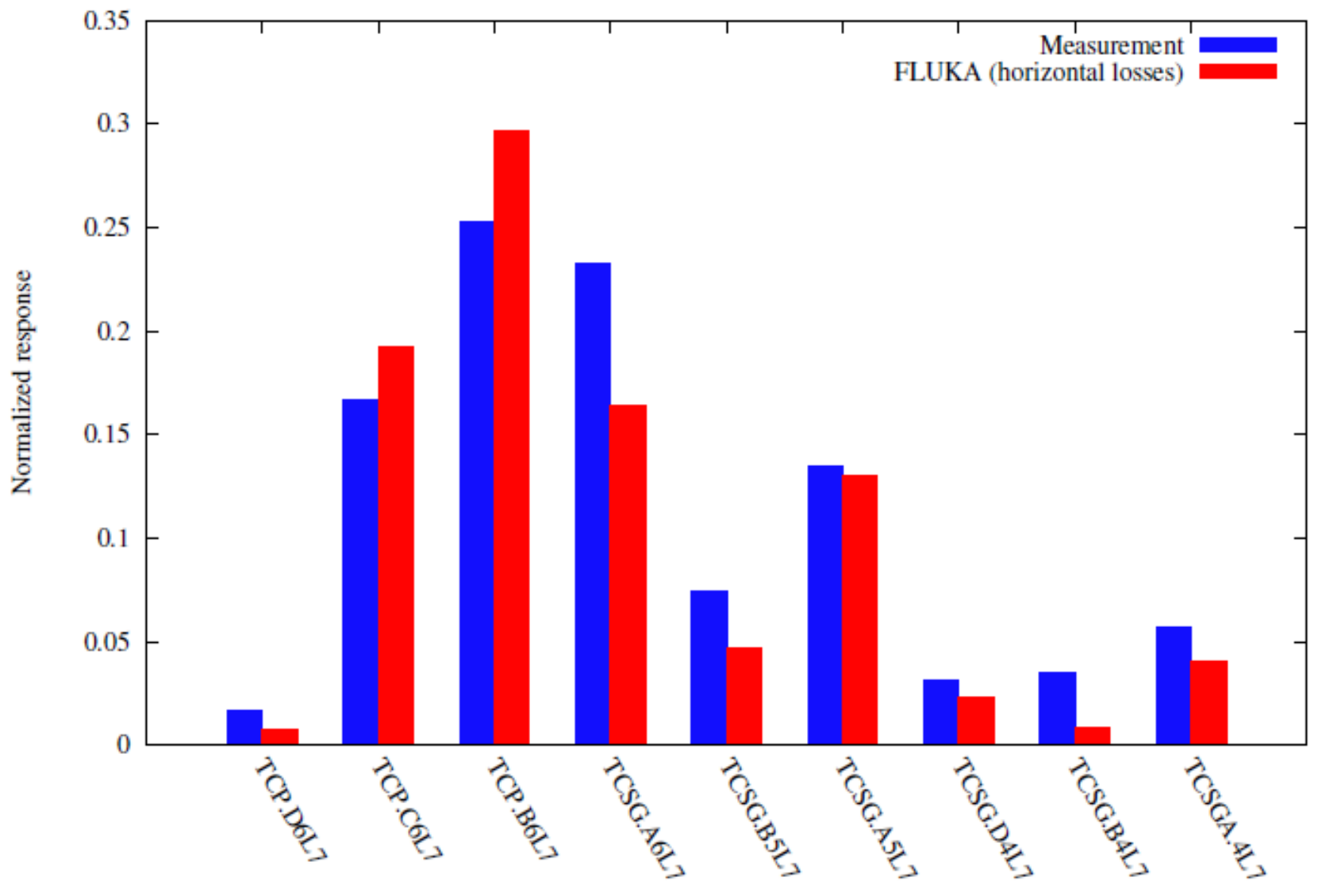


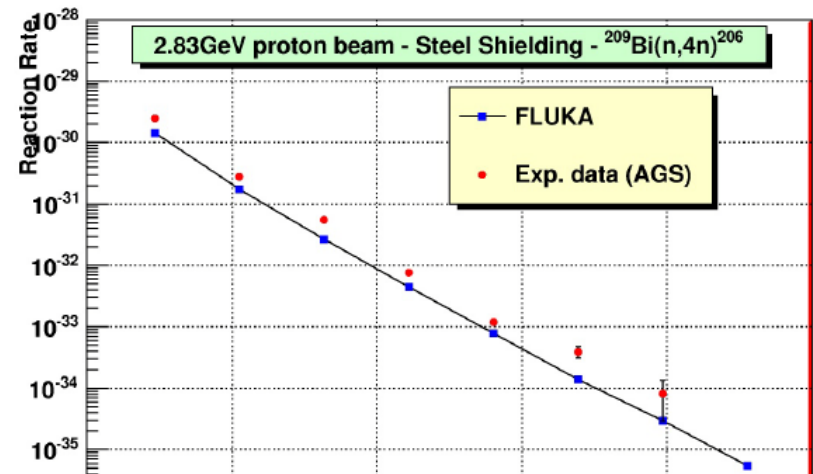
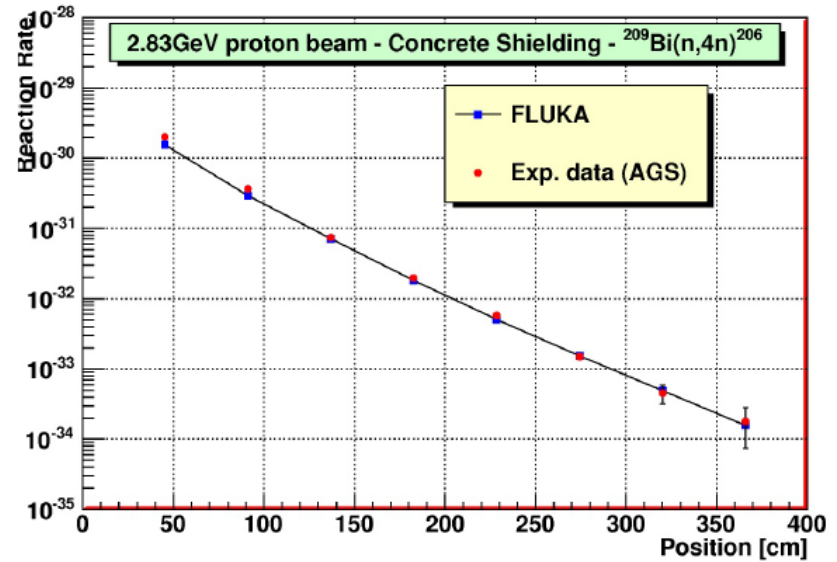
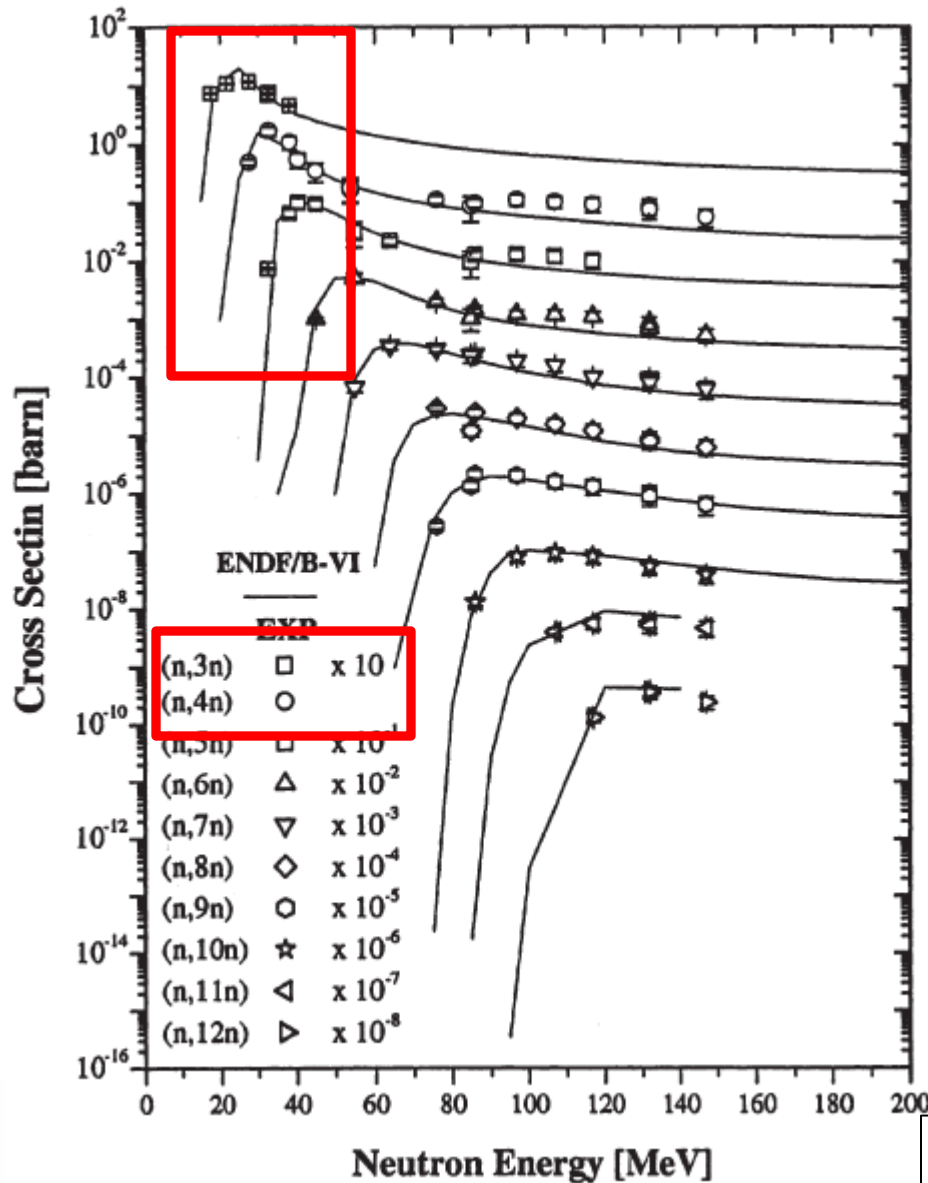
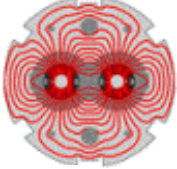
Zoom TCLA.A6R7 to TCLA.A7R7



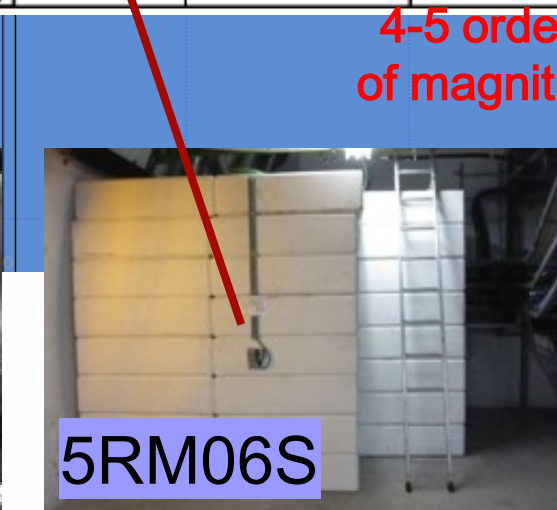
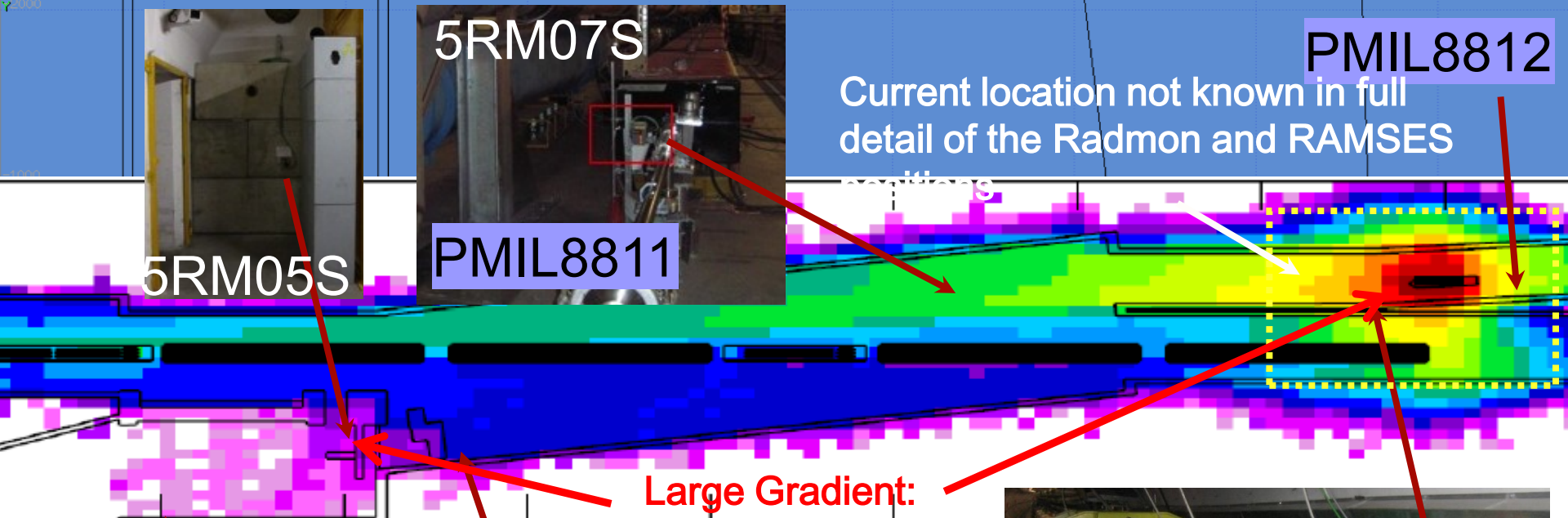
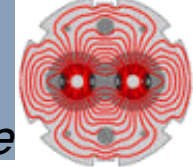


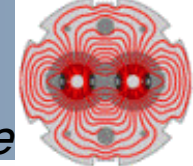
Normalized BLM response distribution for straight section left of IR7



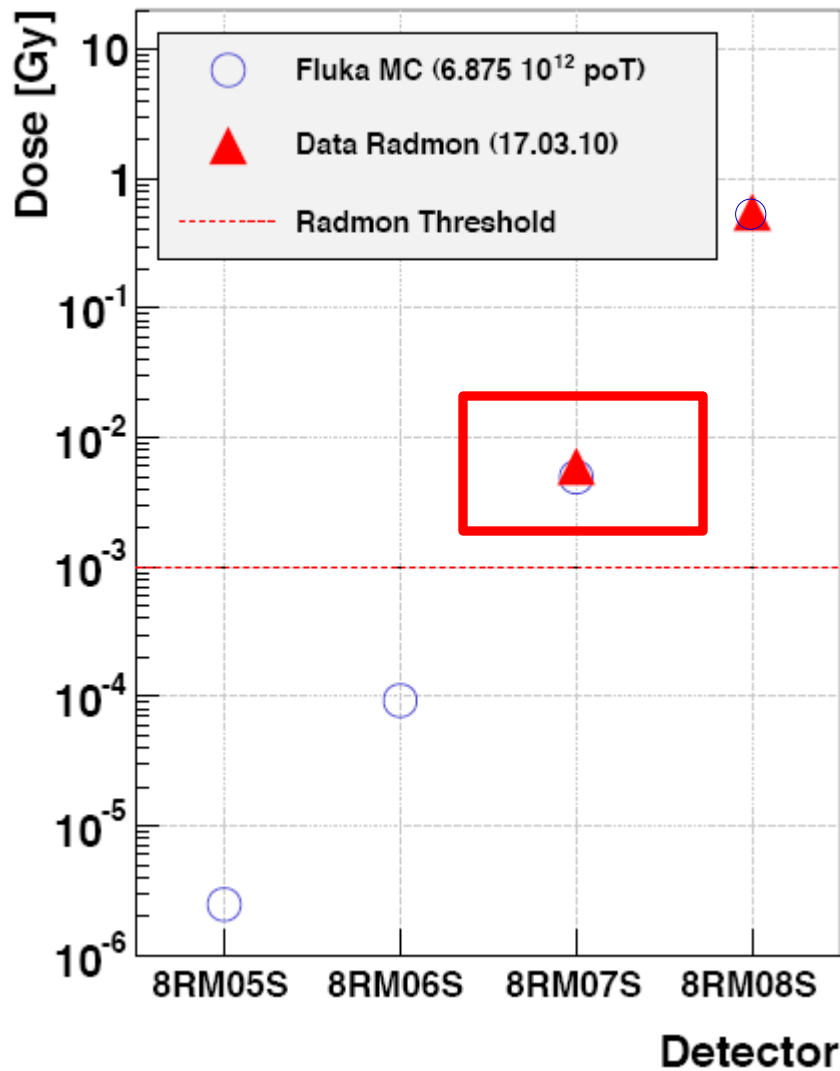


T. Nakamura, Journal of Nuclear and Radiochemical Sciences, Vol. 4, No.2, pp. R15-R24, 2003

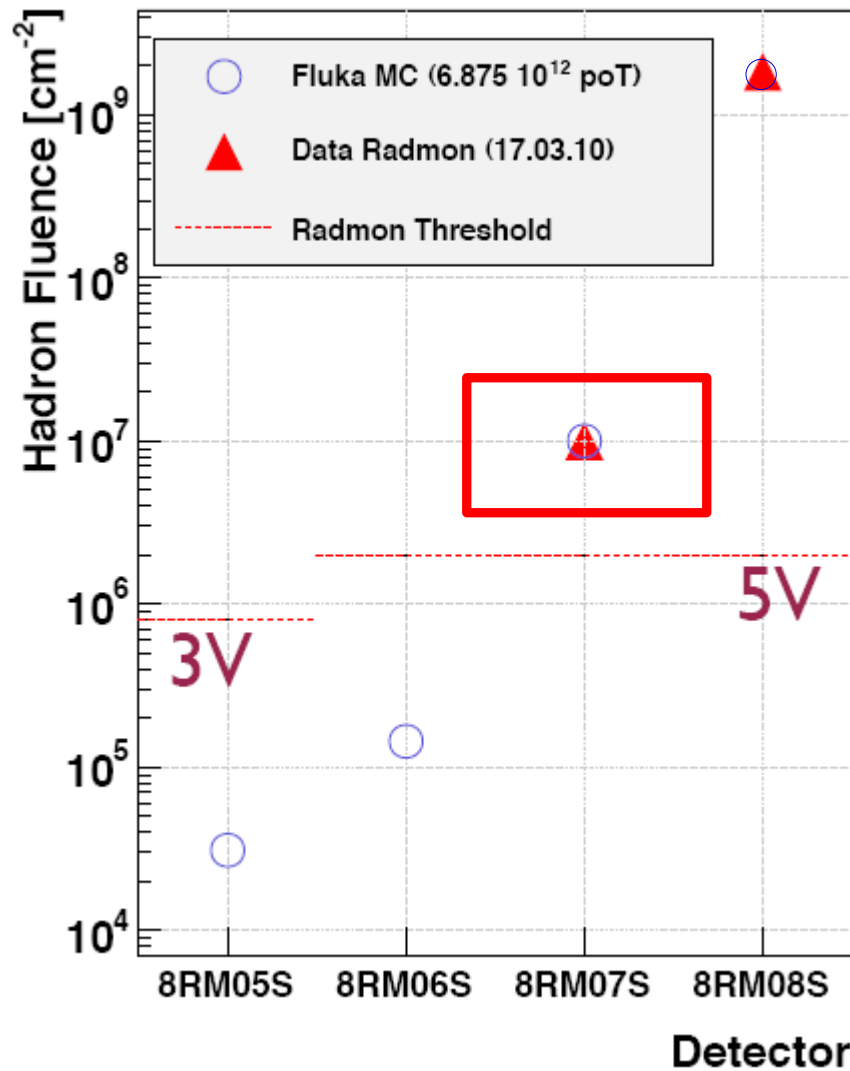


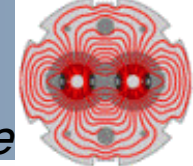


Dose in UJ87/UJ88 - Radmon and Ramses

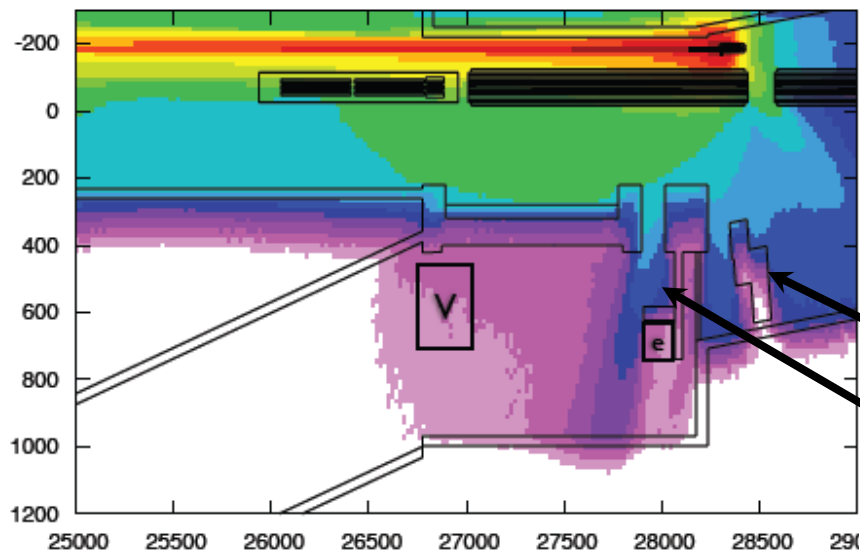


Hadron Fluence in UJ87/UJ88 - Radmon and Ramses

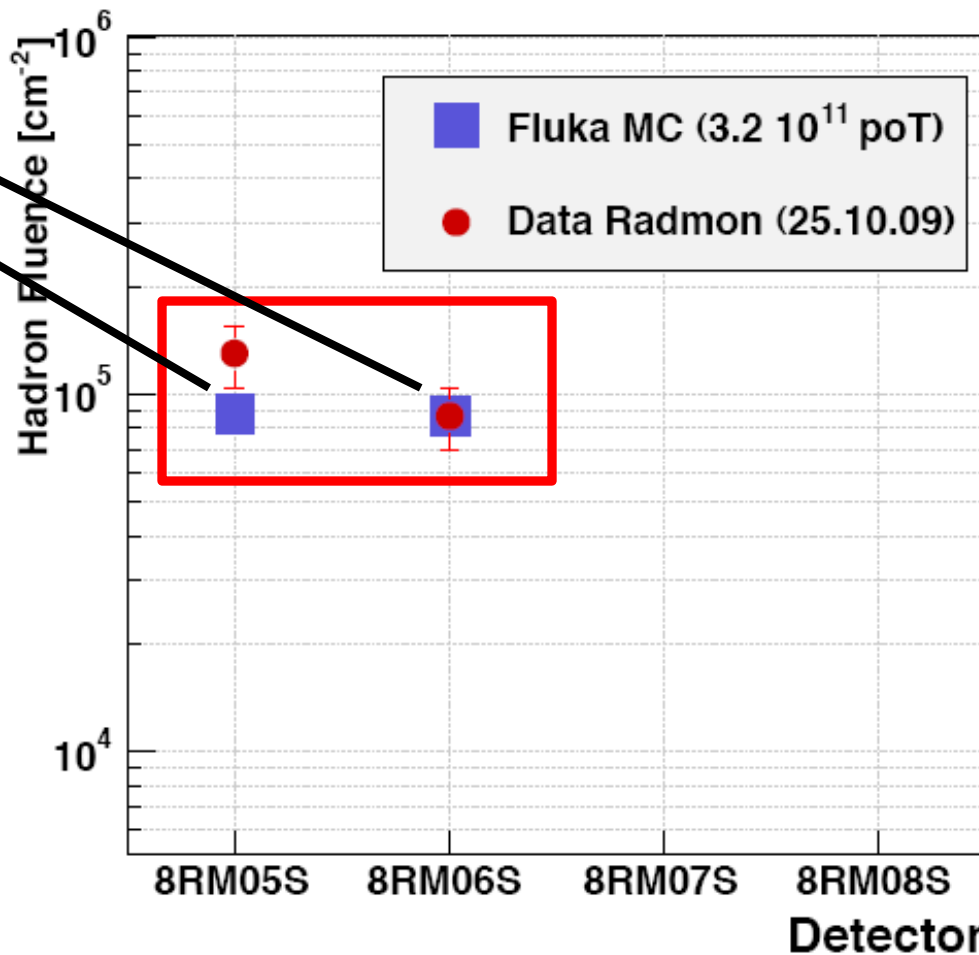




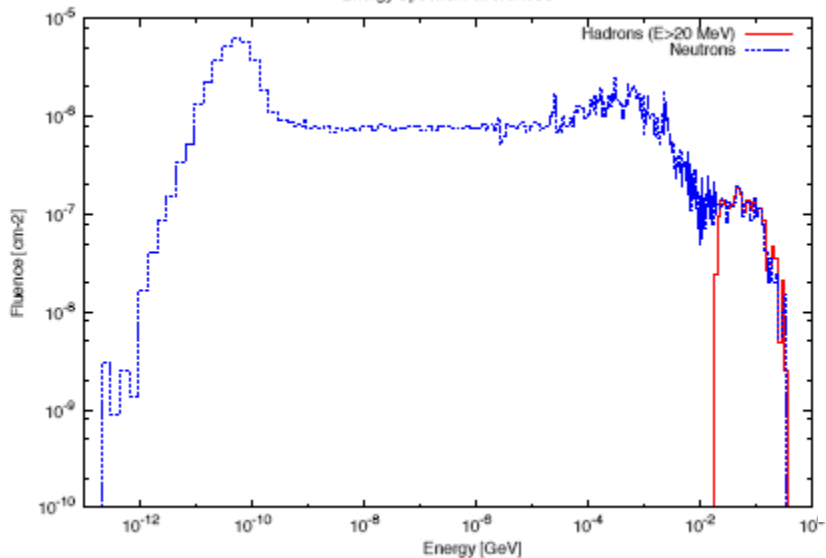
Fluence over the UJ8x area

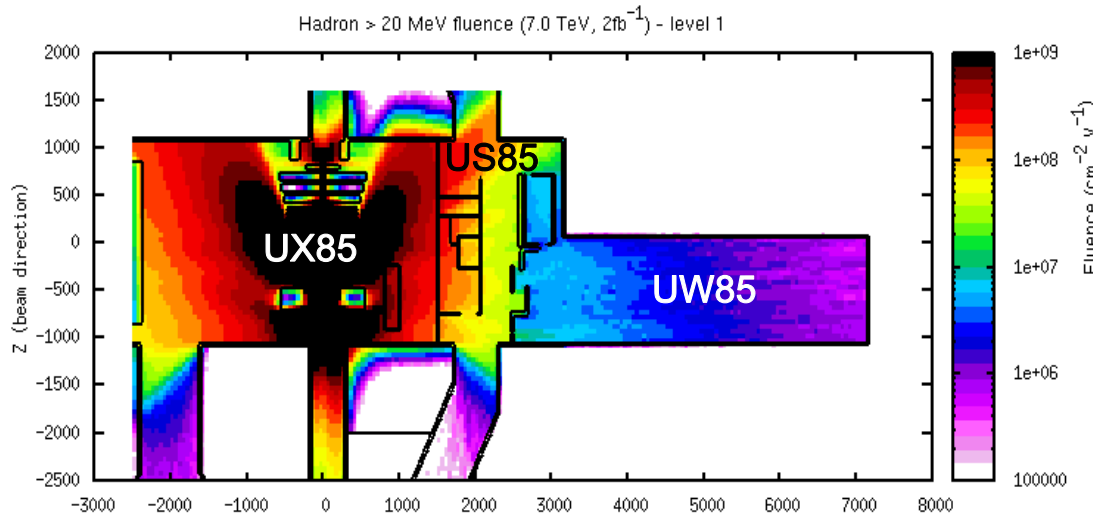
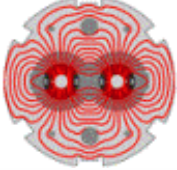


Hadron Fluence in UJ87/UJ88 - Radmon and Ramses



Energy Spectrum at 8RM05S





FLUKA/RAMSES benchmark

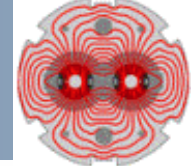
Detector	Measured dose (μSv/h) @10.6MHz	Ratio (meas/simu)
PMI8501 (UX85)	24.0	1.1
PMI8511 (UX85)	120.0	0.8
PAT8511 (US85)	36.7	0.6

FLUKA/RadMon benchmark

Detector	Ratio (FLUKA exp/measure)
8LE10S	1.6
8LE07S	2.0
8LE04S	1.6
8LE08S	2.2

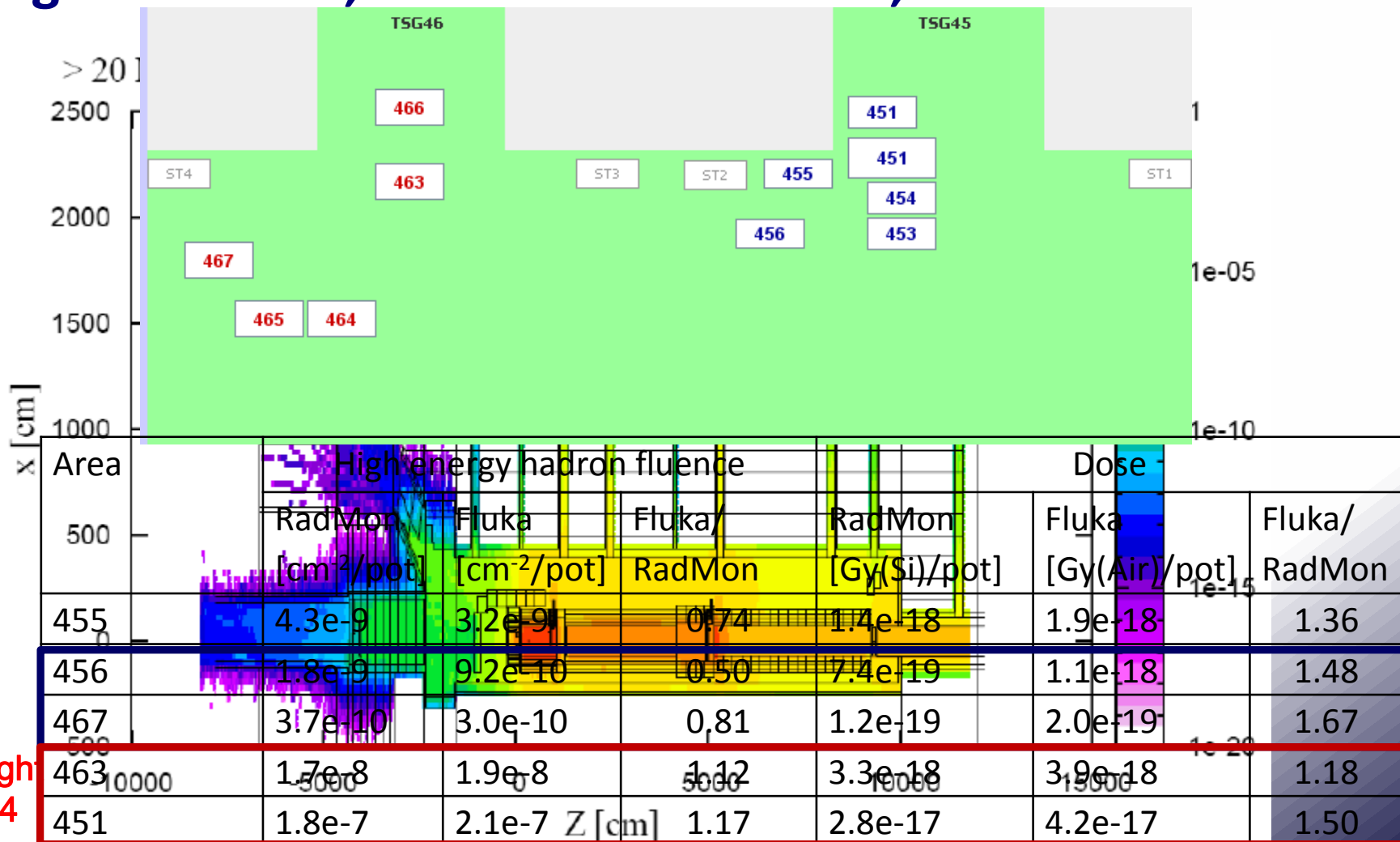
FLUKA Simulations provide high energy hadron fluence, dose and 1 MeV Si equivalent in the LHCb cavern according to the Phase-2 shielding implementation proposed in the R2E Project

- ⊗ Very good agreement with PMIs and PATs RAMSES detectors
- ⊗ RadMons set at 3V more difficult (at low count rates)
- ⊗ Significant uncertainties to be considered (thermal neutron contribution, detector geometry, etc...)
- ⊗ Uncertainty at least a factor of 2

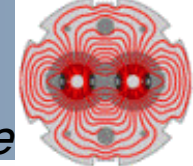


⊗ Very Complex Geometry

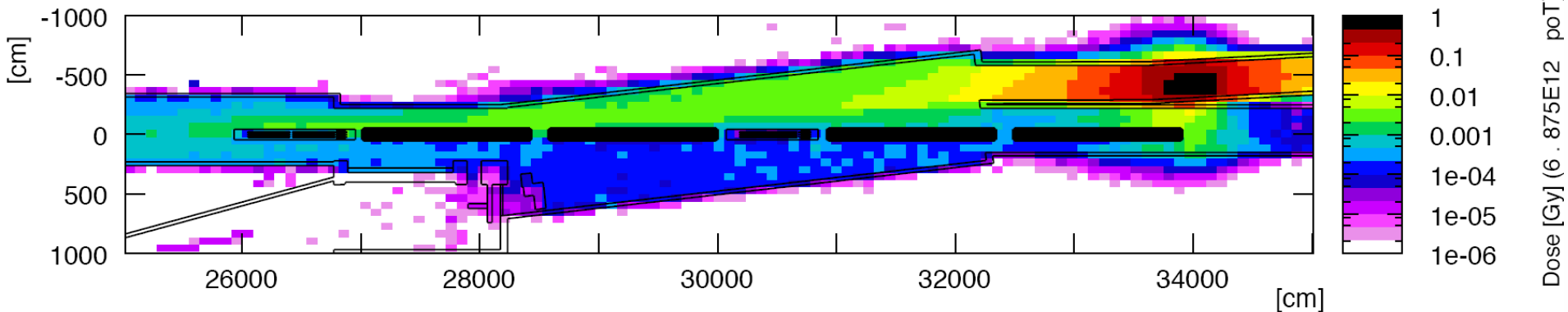
⊗ Large Distances, 'unknown' materials, ...



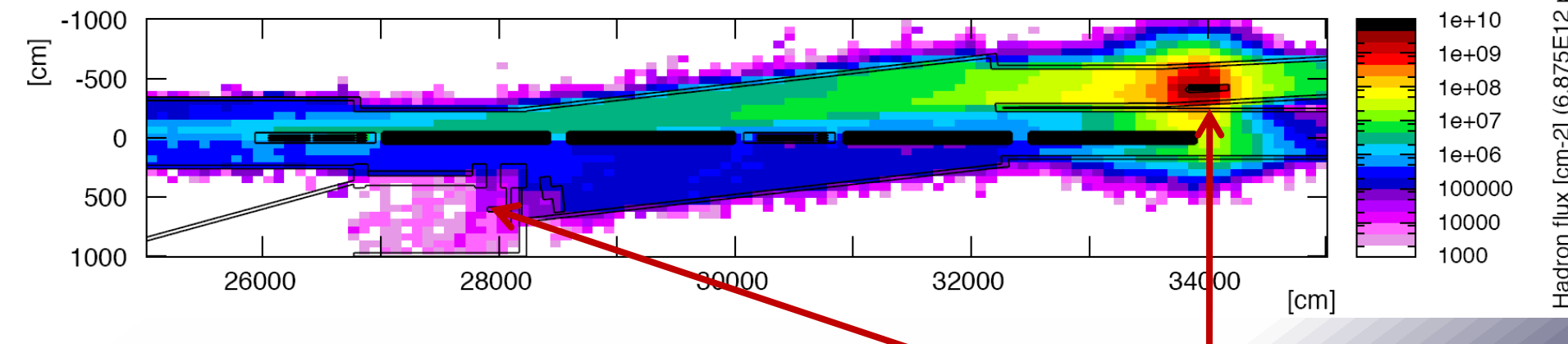
off-axis
line-of-sight
to TSG4



Dose over the T18-IR8 area



Hadron flux over the T18-IR8 area

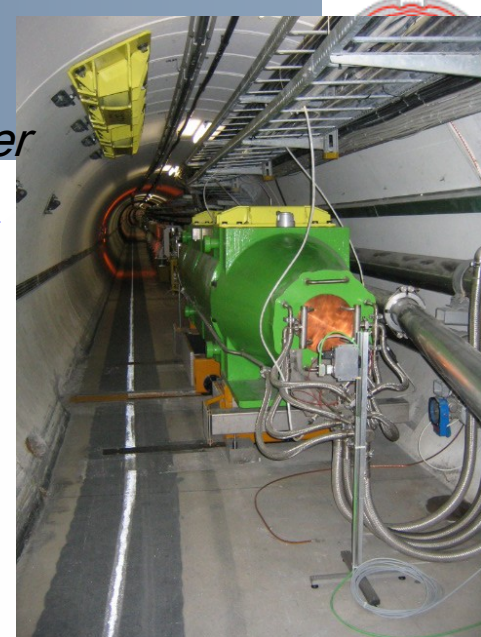


Large Gradient



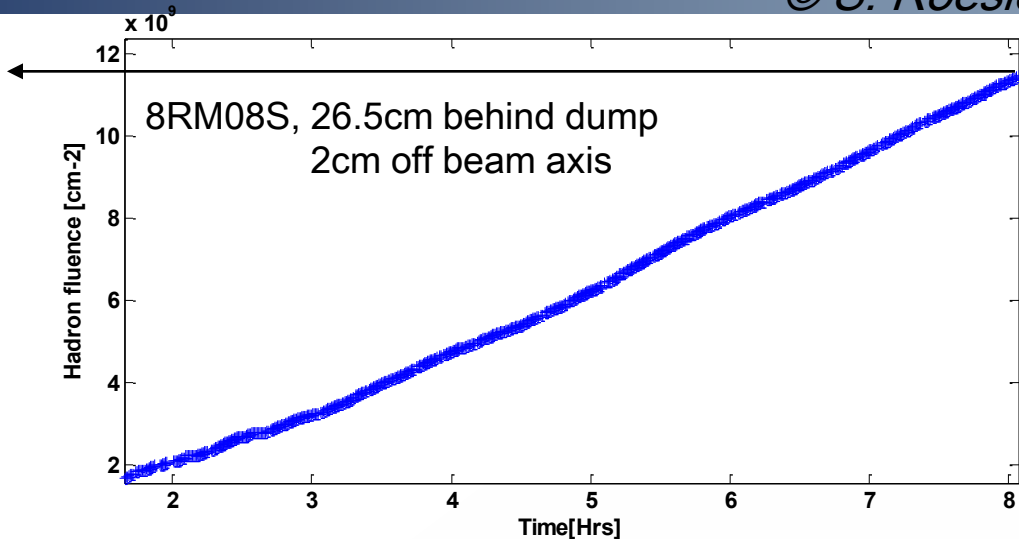
Injection: TED – High-E Fluence

© S. Roesler



RADMON

$1.2 \times 10^{10} \text{ cm}^{-2}$



FLUKA

$0.96 \times 10^{10} \text{ cm}^{-2} \pm 3.2\%$

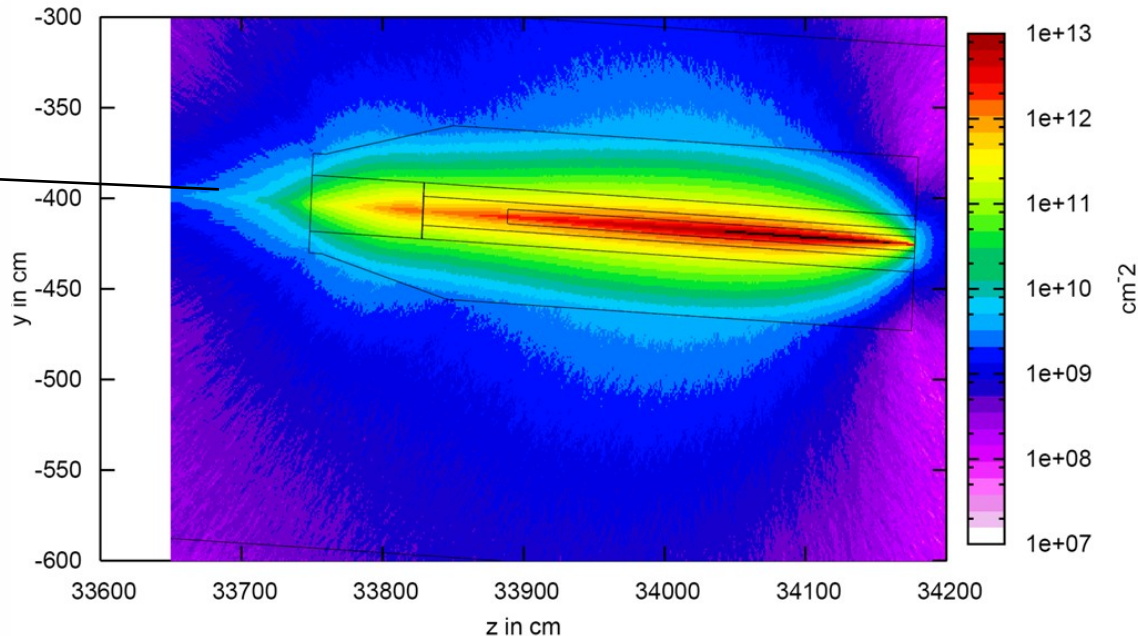
(scoring in a volume of $2 \times 2 \times 2 \text{ cm}^3$)

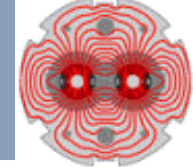
- protons: 9.8%
- neutrons: 34.1%
- pos. pions: 21.9%
- neg.pions: 22.4%
- others: 11.8%

$(1.03 \times 10^{10} \text{ cm}^{-2} \pm 3.2\%$

scoring in a volume of $5 \times 5 \times 5 \text{ cm}^3$)

High energy hadron fluence ($E > 20 \text{ MeV}$), $6.8 \text{ E}12$ protons on TED, 260 groups, ss





© S. Roesler

RADMON

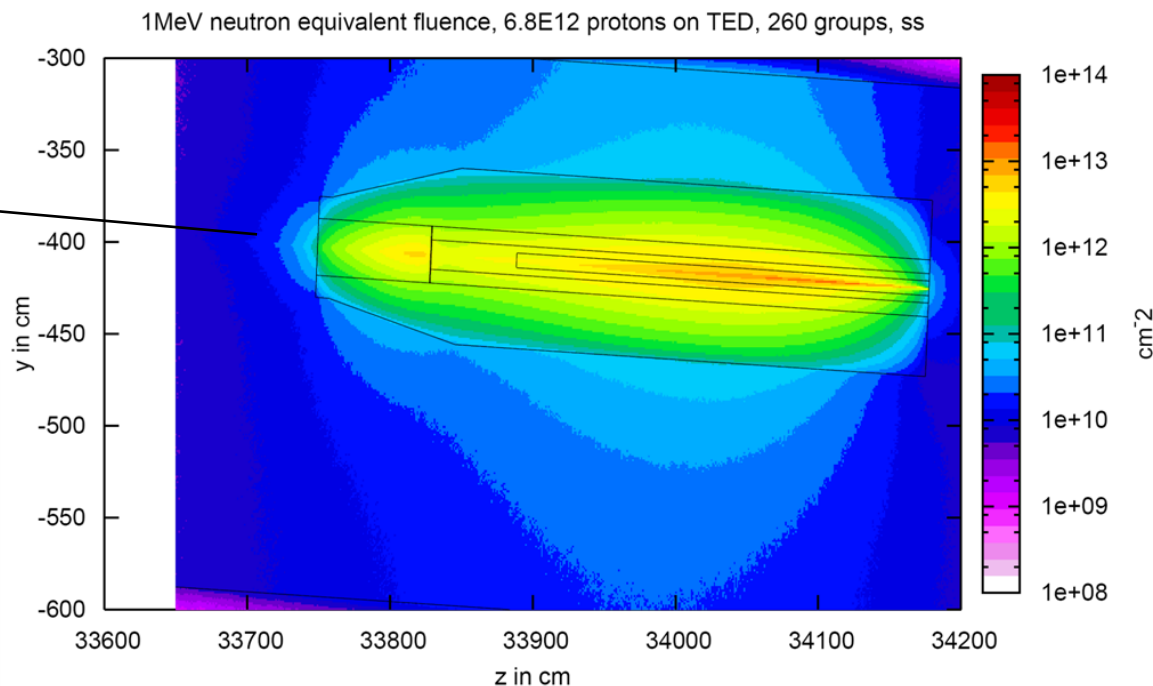
$2 \times 10^{10} \text{ cm}^{-2}$

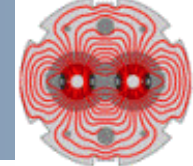
FLUKA

$2.1 \times 10^{10} \text{ cm}^{-2} \pm 2.5\%$
 (scoring in a volume of $2 \times 2 \times 2 \text{ cm}^3$)

protons: 4.6%
 neutrons: 81.6%
 pos. pions: 5.3%
 neg. pions: 5.6%
 others: 2.9%

$(2.25 \times 10^{10} \text{ cm}^{-2} \pm 1.8\%$
 scoring in a volume of $5 \times 5 \times 5 \text{ cm}^3$)

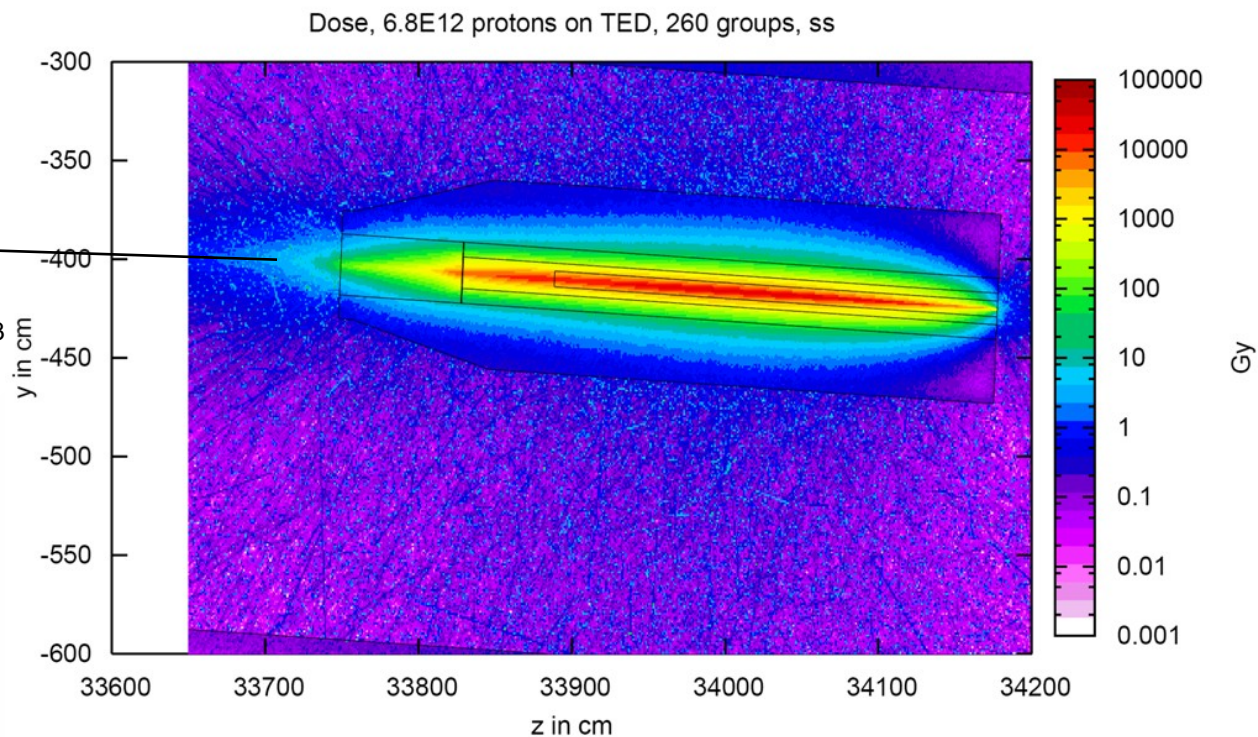


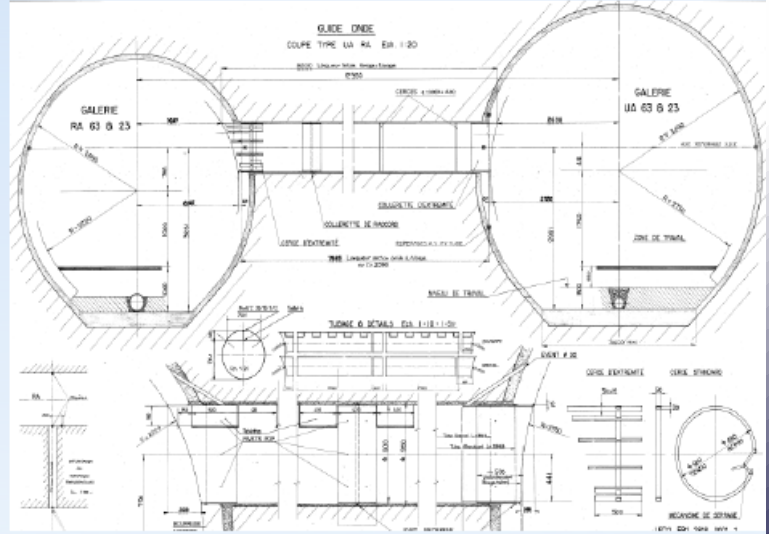
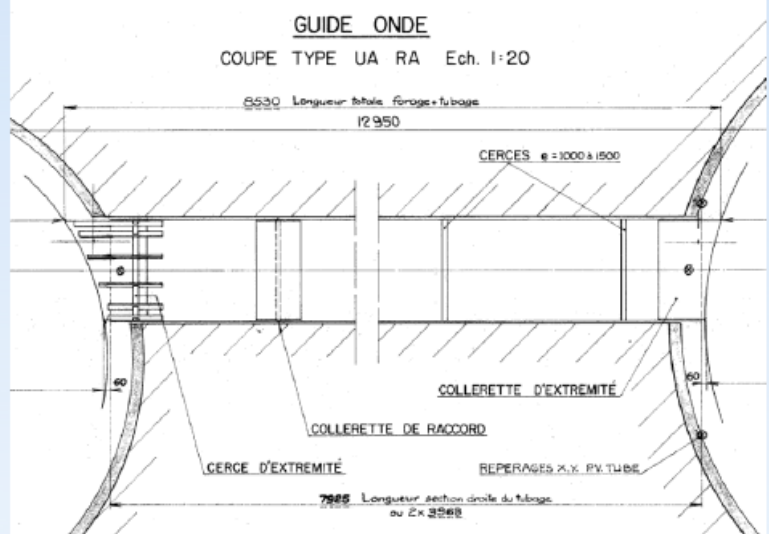
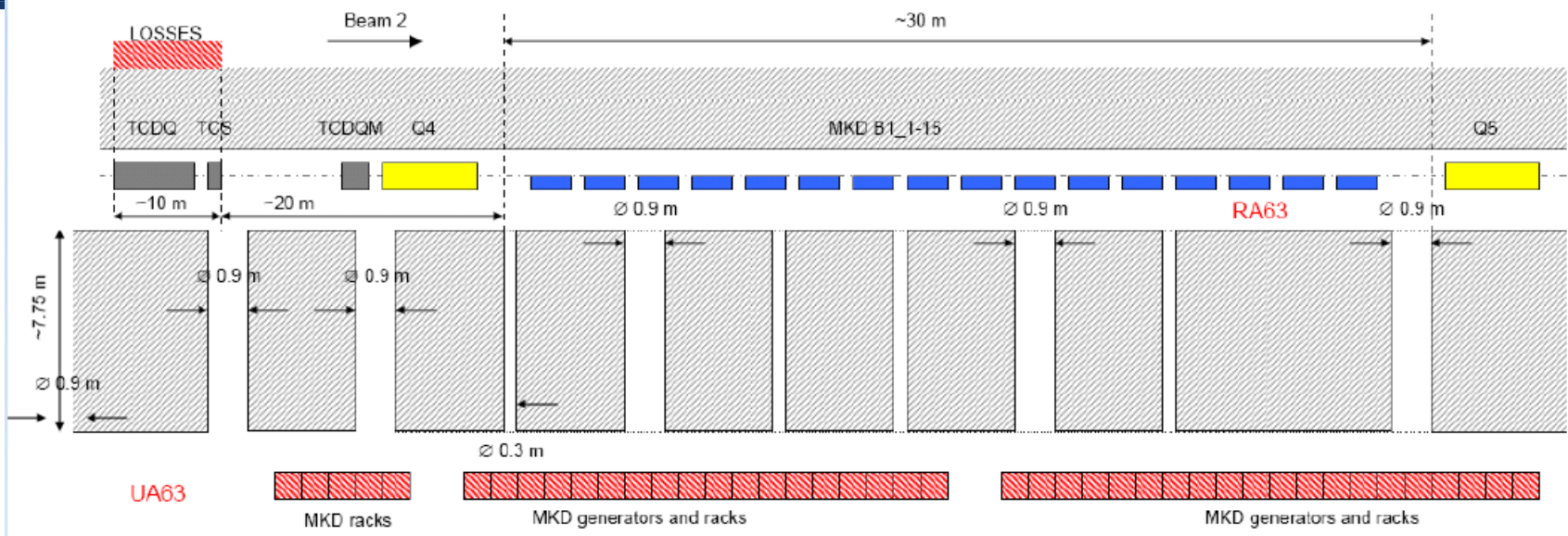
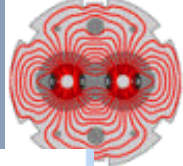


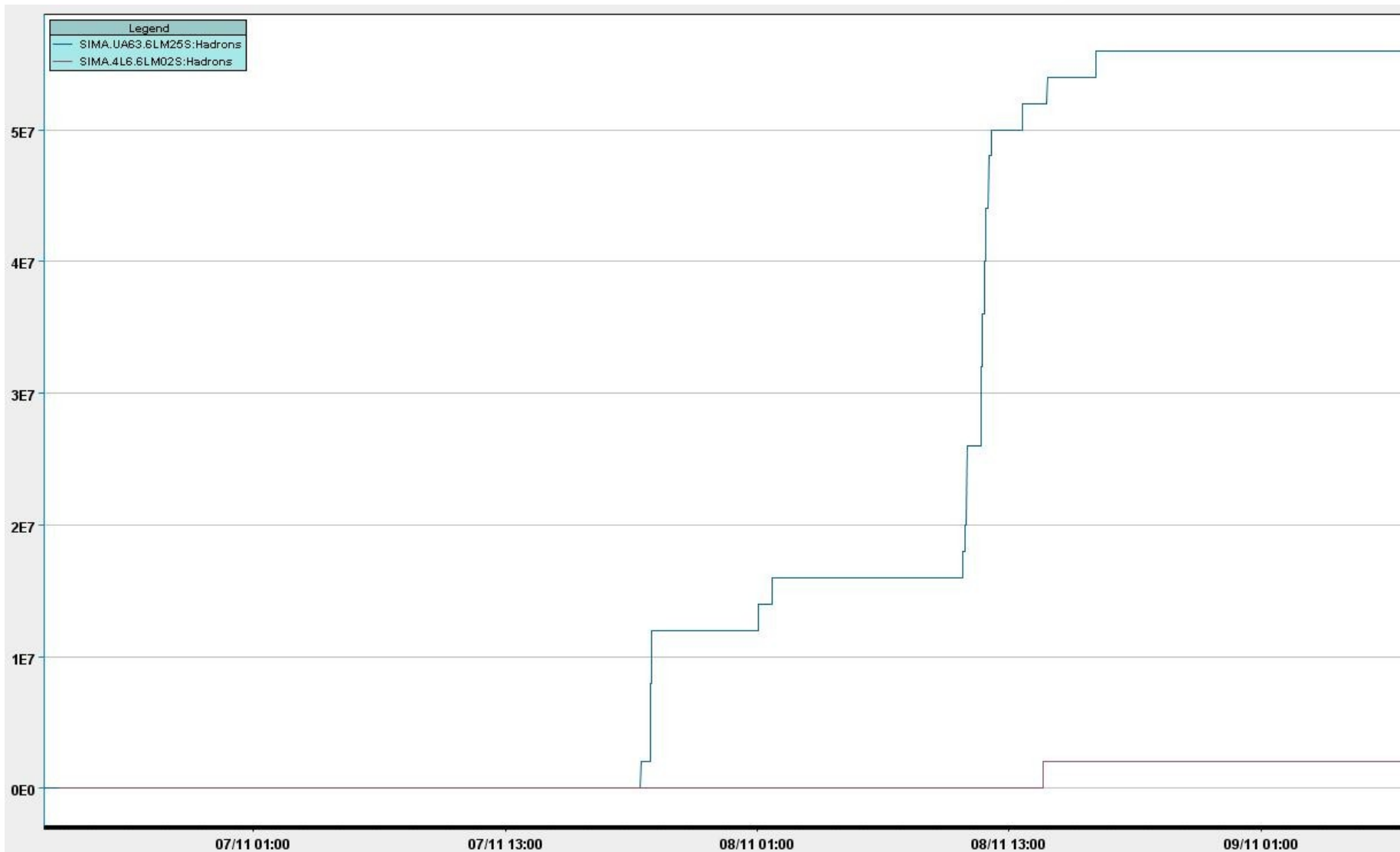
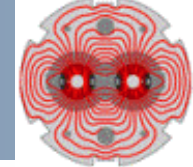
© S. Roesler

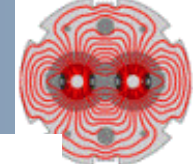
RADMON
4.73 Gy (Si)

FLUKA
5.0 Gy (air) \pm 10%
(scoring in a volume of $5 \times 5 \times 5 \text{cm}^3$)

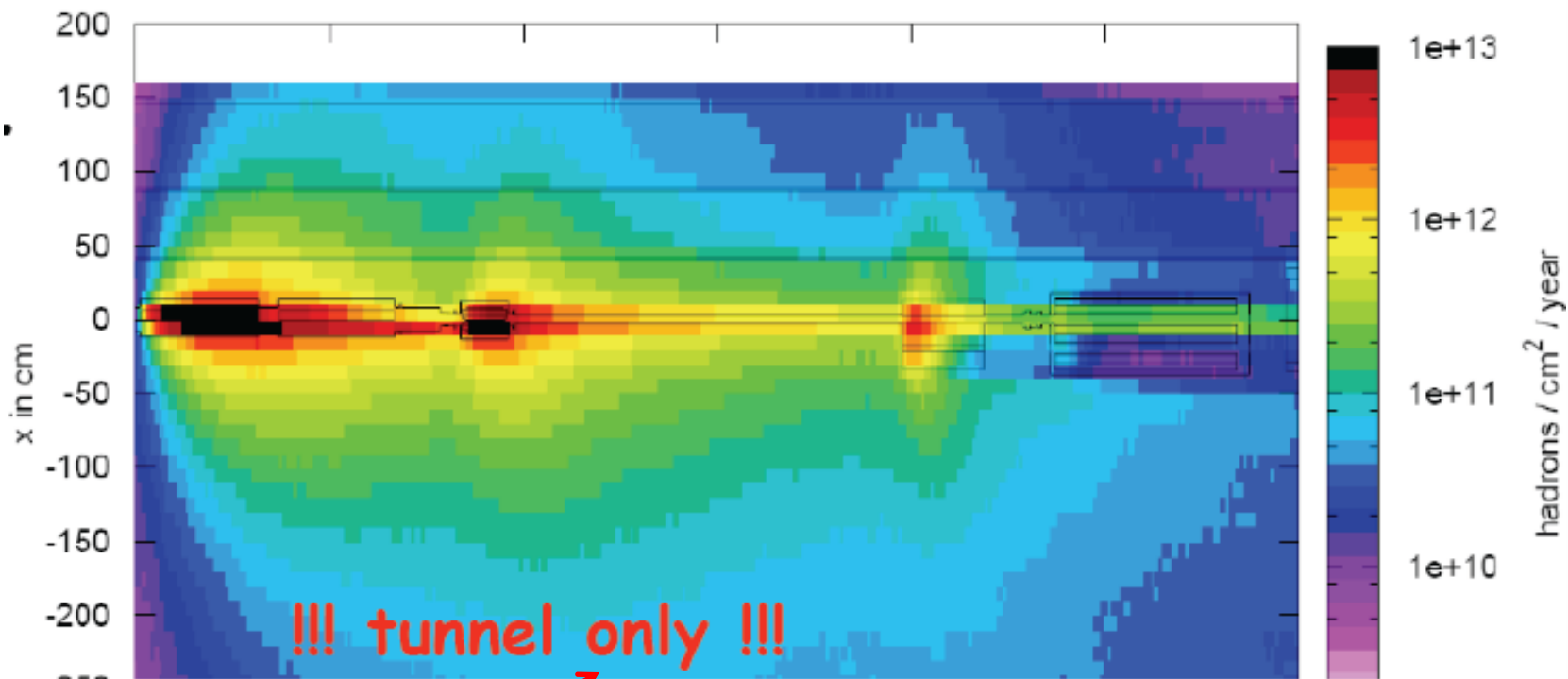




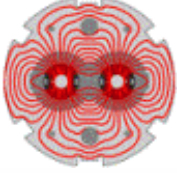




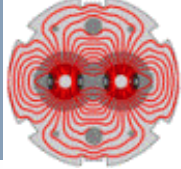
High energy (>20MeV) hadron fluence for (2.6+0.74)E13 protons/year



- $\sim 3 \times 10^{10} \text{ cm}^{-2}$ high-E hadrons for 7TeV and 2.6×10^{13}
- rough scaling: $\sim 2 \times 10^9 \text{ cm}^{-2}$ at 450GeV
- this results in $\sim 4 \times 10^5$ per 5×10^9 shot
- We had about 50 (full) shots on the TCDQ -> $\sim 2 \times 10^7$ expected
- 5.6×10^7 measured at the tunnel location (~ 30 counts!)
- In the UA, the monitor is set to 3V (factor of 10 more sensitive) -> nothing measured -> confirms the expected attenuation factor of ~ 1000



Remarks

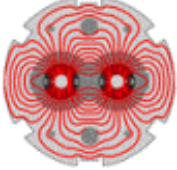


- ⊙ In all our estimates and predictions **we try being as ‘accurate’ as possible (conservative but fairly close to reality)**, thus uncertainties strictly apply in all directions
 - ⊙ **NO BIG SAFETY MARGINS LEFT**
- ⊙ **Safety factors usually used** in the field of SEE estimates are **in the order of 10-100** and more (depending on the application: space missions, airplanes,...)



This we can't do (afford) at the LHC, even after the mitigation actions are applied



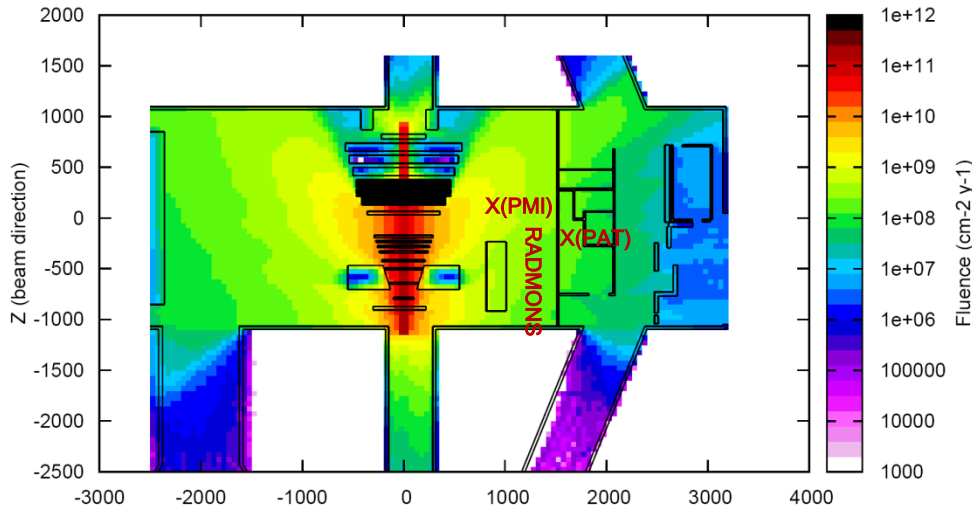


⊙ Uncertainties go in both directions, thus as we try to be ‘as accurate as possible’, it’s **not necessarily conservative!**

⊙ Example: LHCb (UX/US85: measurements versus ‘expectation’):

Updated FLUKA Simulations, ‘old’ detector

Hadron > 20 MeV fluence (3.5 TeV, 1fb-1, 2x SF) - level 1



© M. Calviani, C. Theis

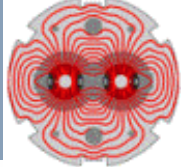
⊙ PMI sees up to $30\mu\text{Sv/h}$ at a luminosity of $10^{31}\text{cm}^{-2}\text{s}^{-1}$ (expected: $10\mu\text{Sv/h}$)

⊙ PAT sees a few $\mu\text{Sv/h}$ (expected: less than one)

⊙ RadMons: see equivalent counts, however less statistics (expected: first count only)

⊙ **Reason:** old detector geometry and magnetic field (in work!)


⊙ Other areas: low-energy neutrons not to be forgotten! (then our estimates would be even less conservative)



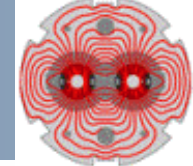
- @ In our estimations, **we have to be ‘wrong’ by a factor of 500-1000 (only in one direction)** in order to reach acceptable SEE induced failure rates for the LHC (if nothing is done)!

Nominal LHC Operation:

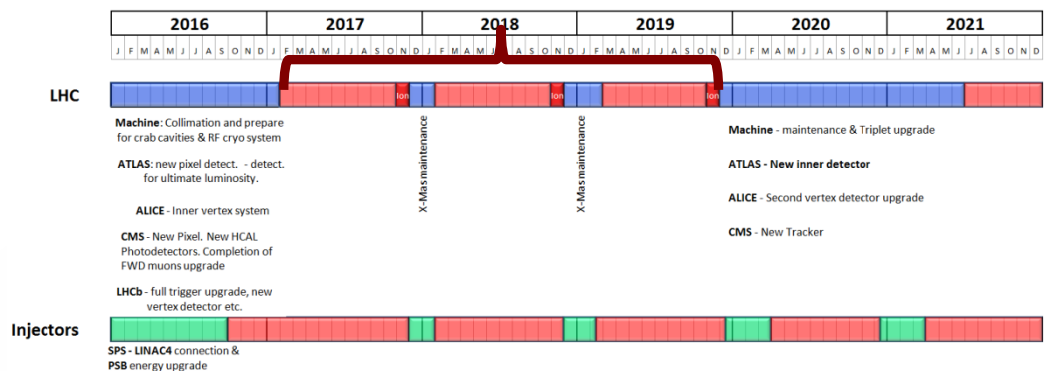
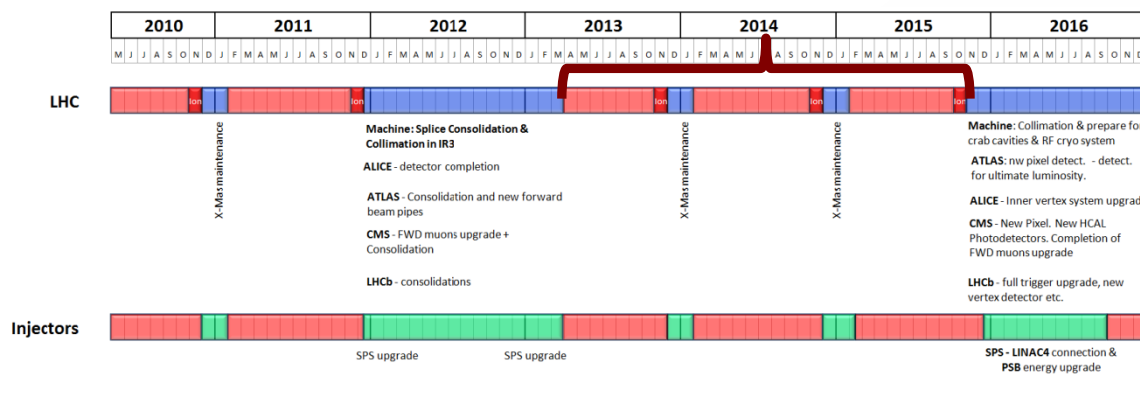
Failure Mode	Failure Estimate		Confidence (Tested vs. Assumed)
	SUM	MTBF [hours]	Ratio
Immediate Dump and Access	24709	0.3	0.03
Immediate Dump	7500	1.0	9
Scheduled Access	4210	1.2	1
Other	4682	1.4	4


 We're looking for a MTBF of 150-300h what concerns ‘acceptable’ SEE induced problems (tunnel equipment not included!)

- @ **All test results we get, all the analysis** from the available early monitoring (some shown today), **make this impossible**
- @ **SEE induced problems happened already once or twice** (WIC in injection line, QPS during ‘dirty’ injection [unlikely])



Seeking maximum LHC performance, **we're bound to fit all R2E related work in the shutdown planning.** Operational periods between long shut-downs will be challenging and require the possibility to react in case of problems

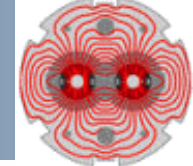


Needed:

- preparation of patch-solutions (equipment level)
- radiation tolerant developments (R&D for power converters)
- strong RadWG
- radiation test possibilities at CERN



Left of IR7 “Bad Ion Fill (1488)”



- Beam intensity for ions -> ‘equivalent’ of Ions/Protons to be scaled (208/82) -> $\sim 9 \times 10^{11}$
- At the same time, this corresponds to 68 bunches, thus about 10% of nominal.

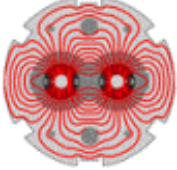
Timeseries Chart between 2010-11-11 17:04:44.519 and 2010-11-12 15:23:02.699 (UTC_TIME)

→ LHC.BCTFR.A6R4.B1:BEAM_INTENSITY → LHC.BCTFR.A6R4.B2:BEAM_INTENSITY → SIMA.11L7.7LM09S:SEU_COUNT → SIMA.13L7.7LM11S:SEU_COUNT
 → SIMA.15L7.7LM13S:SEU_COUNT → SIMA.17L7.7LM15S:SEU_COUNT → SIMA.9L7.7LM07S:SEU_COUNT



RadMons nicely ‘counting’ at uneven MQs (9-17), below Interconnects
 this dataset: RM9-11 set to 5V, RM13-17 set to 3V
 this fill: with th. neut. ratio of 1: $\sim 1E6 \text{cm}^{-2}$ (@Q9), $\sim 1E7 \text{cm}^{-2}$ (@Q17) >20MeV
 VERY simplified scaling to nominal (7TeV) and 1 month of Ions: $\sim 1E10 \text{cm}^{-2}$

Left of IR7 “Good Proton Fill (1450)”



- To be compared with $\sim 9 \times 10^{11}$ as equivalent number of protons of previous ion fill
- Again running at about 10% of nominal

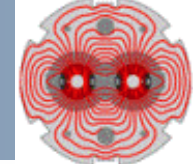
Timeseries Chart between 2010-10-27 18:39:46.286 and 2010-10-28 14:31:07.142 (UTC_TIME)



- RadMons have **low statistics** (2 counts in critical locations)
- Voltage settings are the same as before **RM9-11 @5V, RM13-17@3V**
- **VERY simplified scaling** to nominal (7TeV) and 1 LHC year: $\sim 5E9 \text{cm}^{-2} > 20 \text{MeV}$
(nicely agreeing with the simulation estimates: $1E9-1E10 \text{cm}^{-2}/\text{year}$)



Right of IR7 “Bad Ion Fill (1488)”



- Beam intensity for ions -> “equivalent” of Ions/protons to be scaled (208/82) -> $\sim 9 \times 10^{11}$
- At the same time, this corresponds to 68 bunches, thus about 10% of nominal.

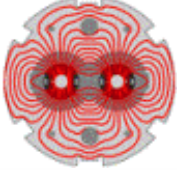
Timeseries Chart between 2010-11-11 17:04:44.519 and 2010-11-12 15:23:02.699 (UTC_TIME)

→ LHC.BCTFR.A6R4.B1:BEAM_INTENSITY → LHC.BCTFR.A6R4.B2:BEAM_INTENSITY → SIMA.11R7.7RM11S:SEU_COUNT → SIMA.9R7.7RM09S:SEU_COUNT



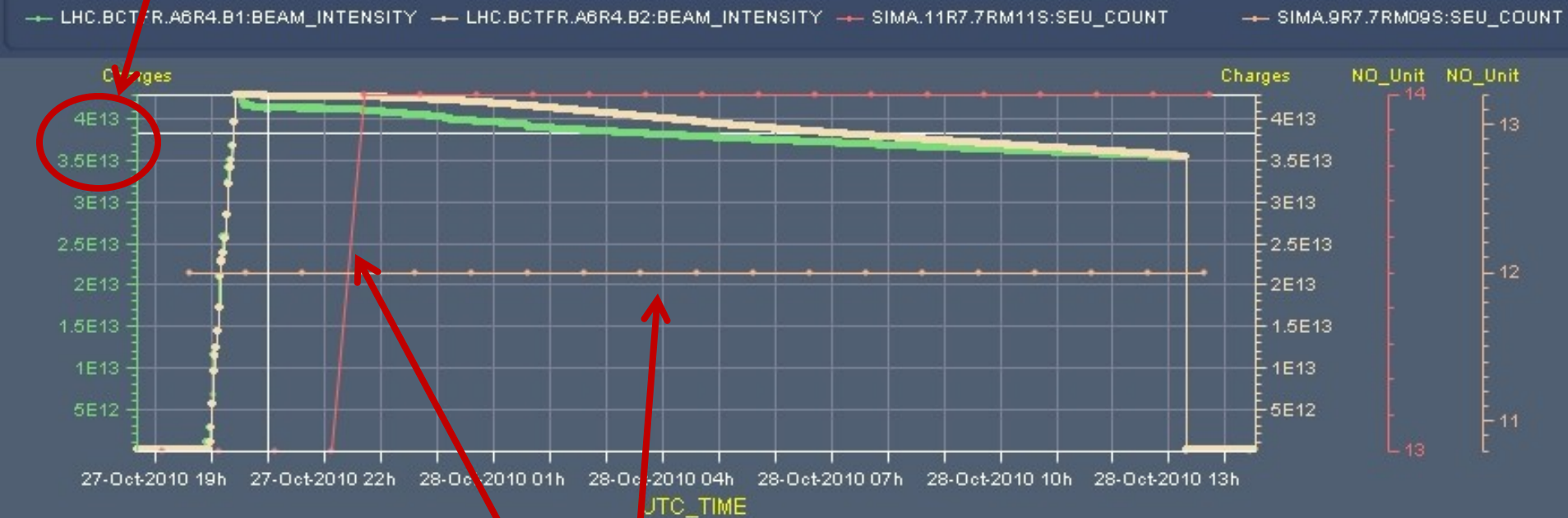
- RadMons nicely ‘counting’ at different locations (mainly Q9 and Q11)
- this dataset: RM9-11 set to 5V, RM13-17 set to 3V
- this fill: with th. neut. ratio of 1: $\sim 7E6 \text{cm}^{-2}$ (@Q9), $\sim 1E7 \text{cm}^{-2}$ (@Q11) >20MeV
- VERY simplified scaling to nominal (7TeV) and 1 month of Ions: $\sim 1E10 \text{cm}^{-2}$

Right of IR7 “Good Proton Fill (1450)”



- To be compared with $\sim 9 \times 10^{11}$ as equivalent number of protons of previous ion fill
- Again running at about 10% of nominal

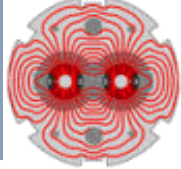
Timeseries Chart between 2010-10-27 18:39:46.286 and 2010-10-28 14:31:07.142 (UTC_TIME)



- RadMons have **VERY** low statistics (only one has 1 count)
- Voltage settings are the same as before **RM9-11 @5V, RM13-17@3V**
- **VERY** simplified scaling to nominal (7TeV) and 1 LHC year: $\sim 4 \text{E}9 \text{cm}^{-2} > 20 \text{MeV}$
(still nicely agreeing with the simulation estimates: $1 \text{E}9\text{-}1 \text{E}10 \text{cm}^{-2}/\text{year}$)



Ions: Preliminary 'Conclusion'



- ❑ Ions (at least during 'bad fills') lead to **high losses in the DS/ARC**
-> ratio Ion/Proton based on Radmon signal and normalized to proton equivalent is in the order of 600
- ❑ Scaling for nominal
 - ❑ **Protons: coherent with simulation estimates**
(bad statistics, can be improved by looking at more fills, ongoing) -> **levels might reach up to $1E10\text{cm}^{-2}$ per year**
 - ❑ Ions: **similar levels can be 'achieved' within one month of ions** in case 'bad fills' would become 'nominal'
- ❑ **QPS crates affected from Q9-Q17**, firmware upgrade possibly needed soon (under investigation - R. Denz)
- ❑ Quickly checked for **P3, and DSs adjacent to experiments** -> only little counts so far, **levels significantly lower** but more statistic/time needed to give some estimates