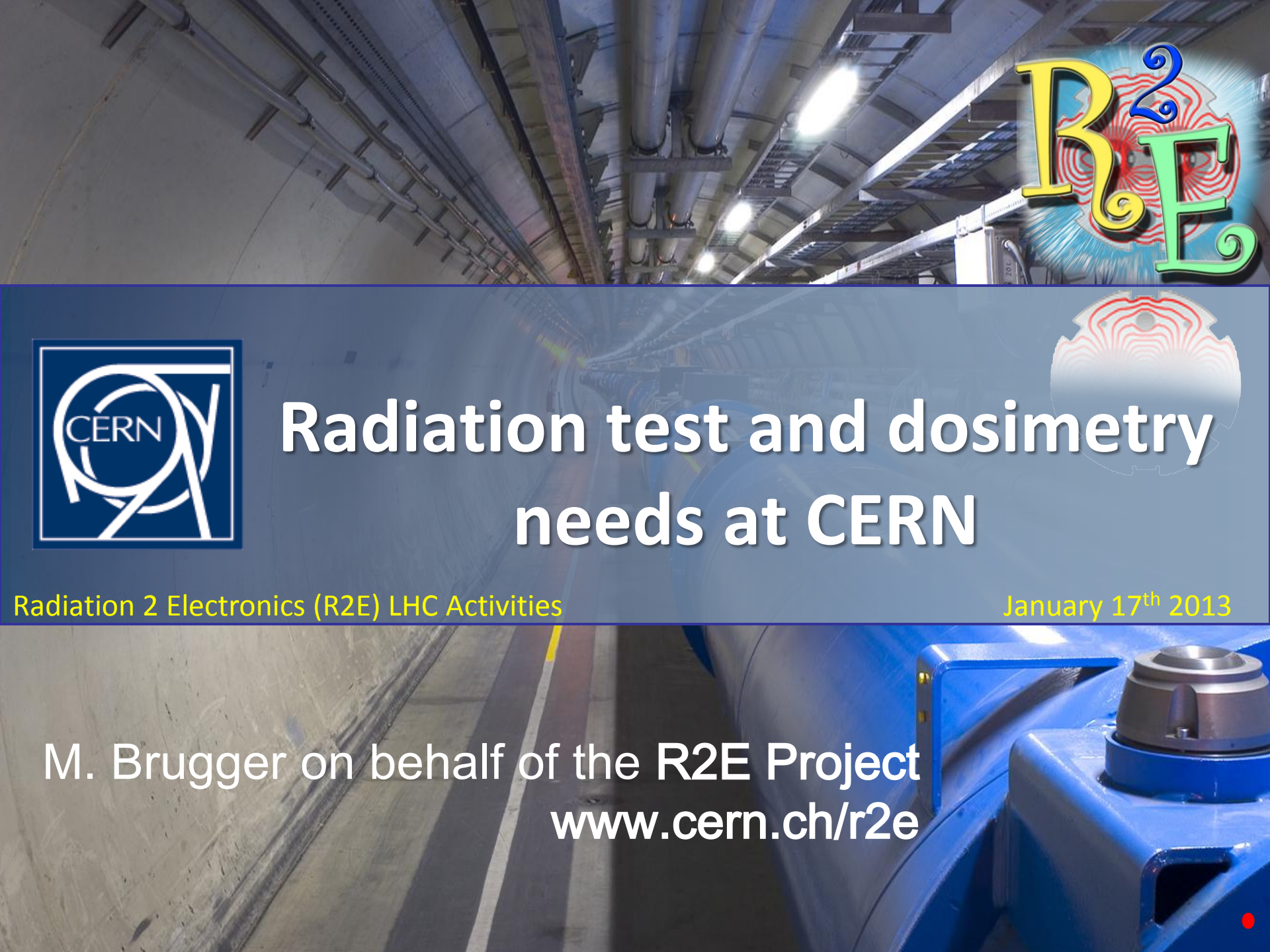


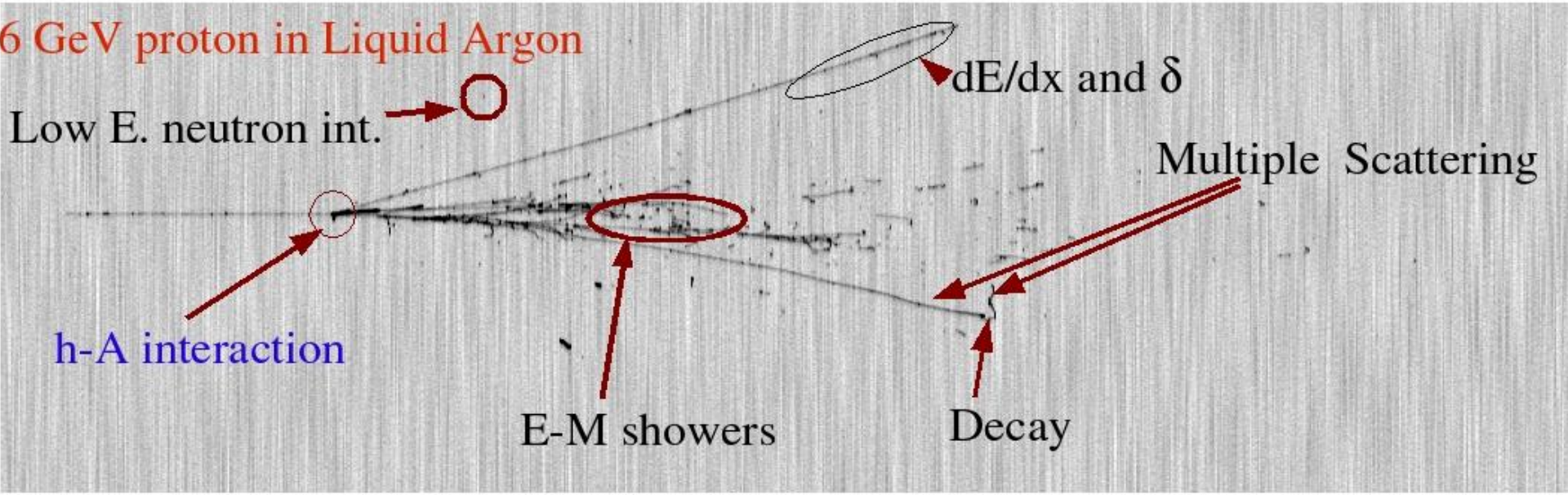
Radiation test and dosimetry needs at CERN

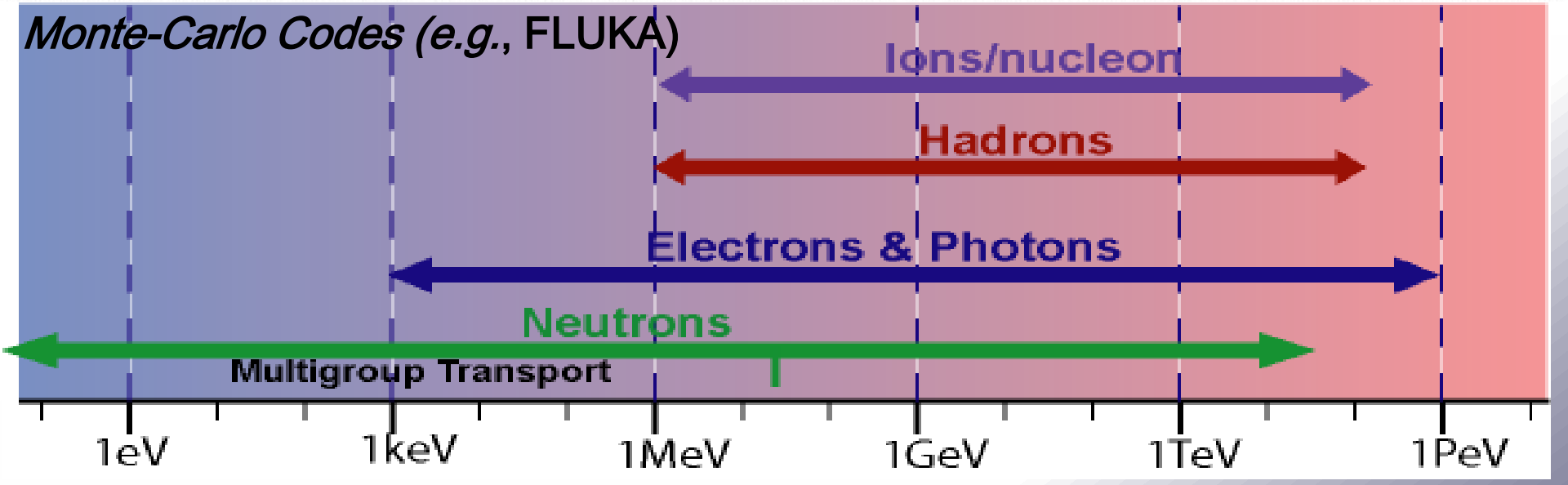
Radiation 2 Electronics (R2E) LHC Activities

January 17th 2013

M. Brugger on behalf of the R2E Project
www.cern.ch/r2e

High-Energy Particle Interactions

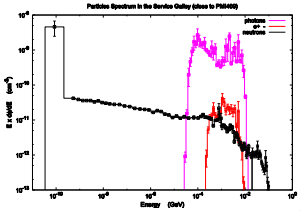


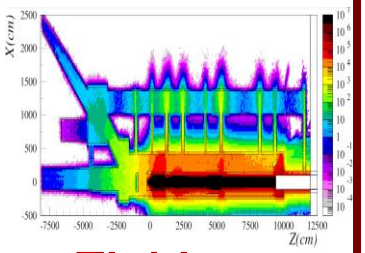


Radiation Physics/Effects/Monitoring

nuclear cascade

h > 20 MeV





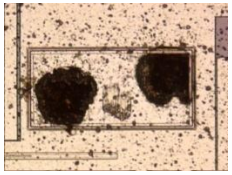
Radiation Field

h, e,.. > 100 KeV

EM cascade

radiation damage in semiconductors

Single Events



Effect in the Device

Displacement

Dose

Radiation Monitor

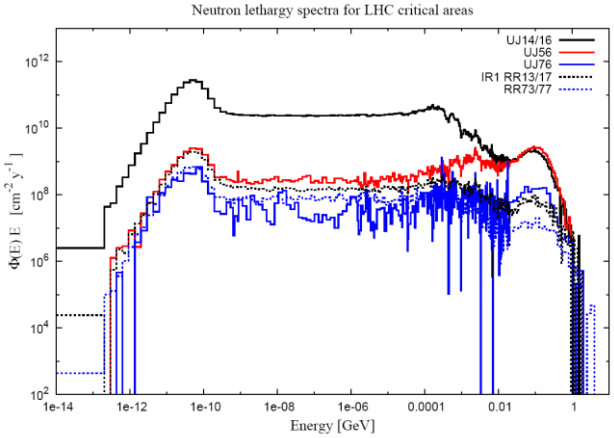
SEU counter

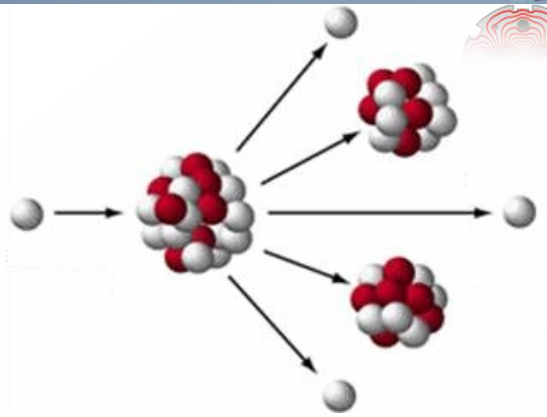
Measurement

PIN Diodes

Radfet

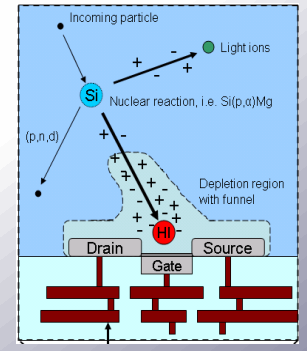
Approach & Requirements



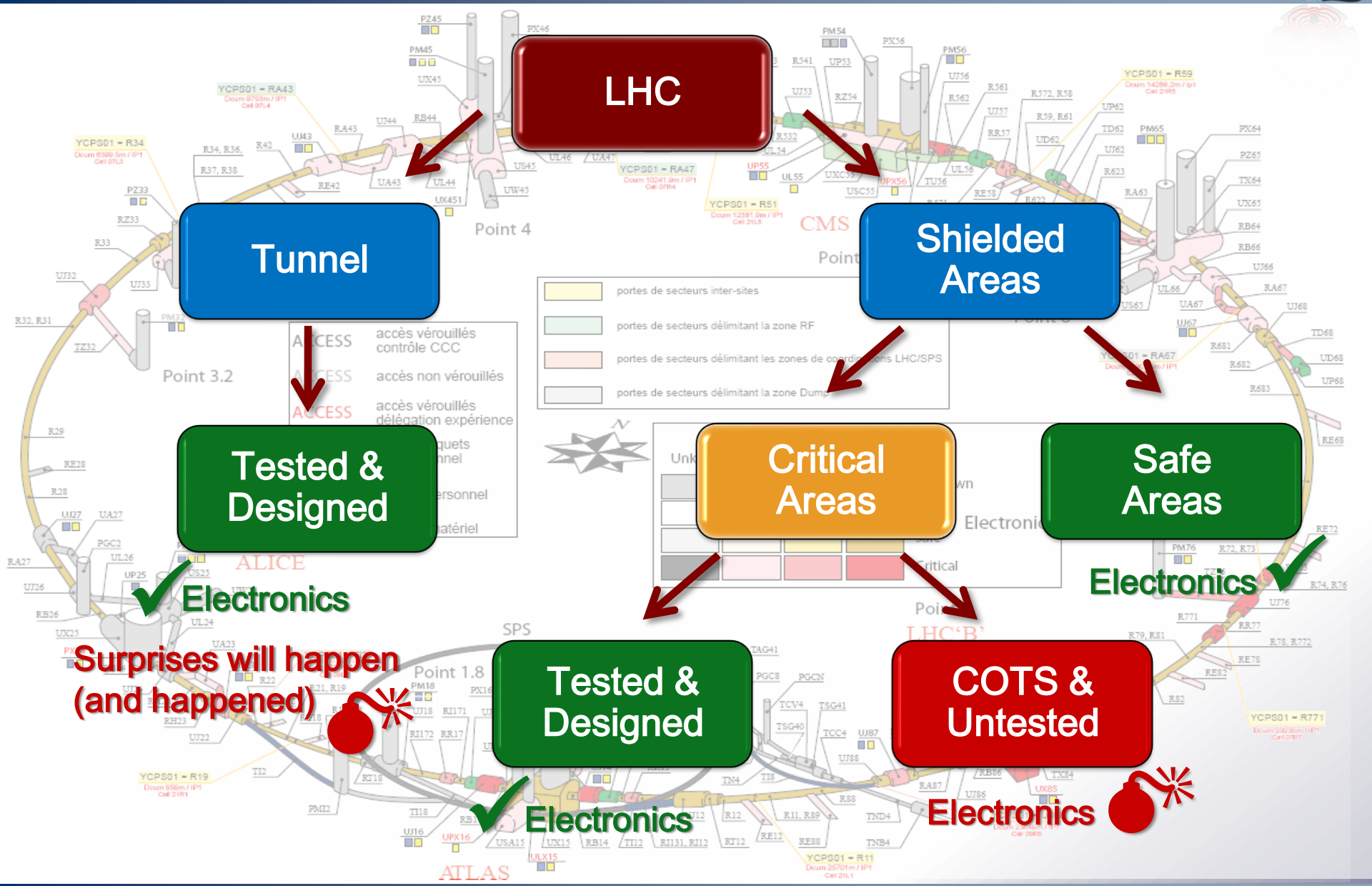


ELECTRONIC COMPONENTS ⟷ RADIATION ENVIRONMENT ⟷ PHYSICS MODELS

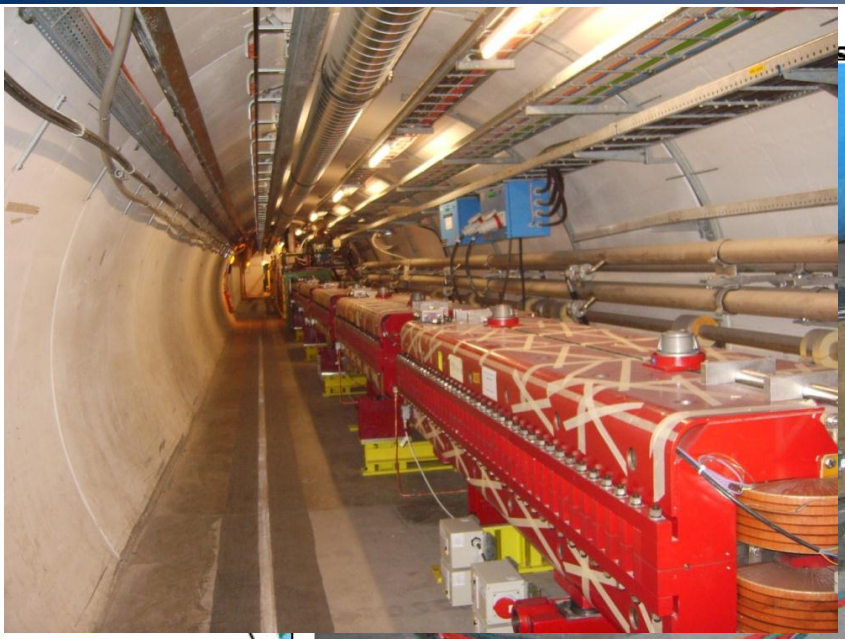
RADIATION EFFECTS
ANALYSIS
TESTS
MITIGATION



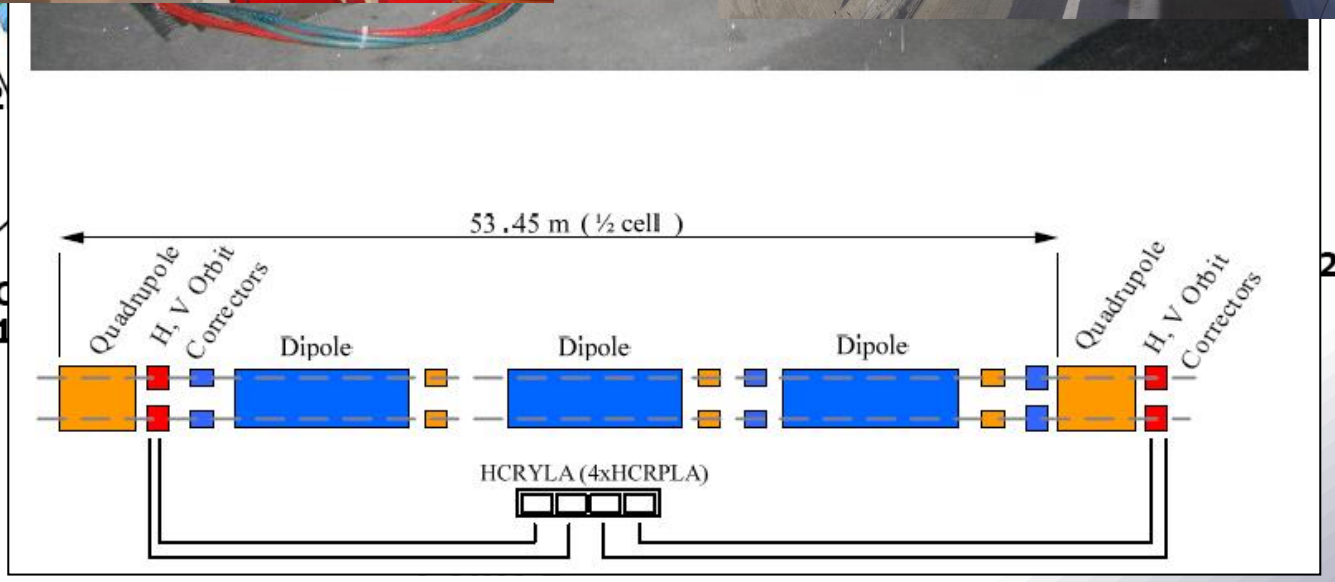
The LHC Challenge



Tunnel: LSS/DS/ARC



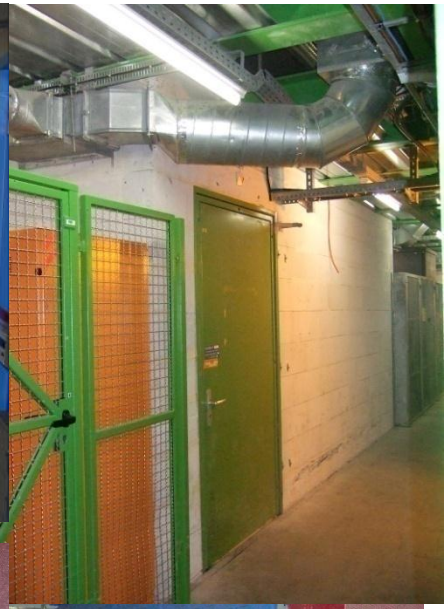
Cellules
12R2-----12

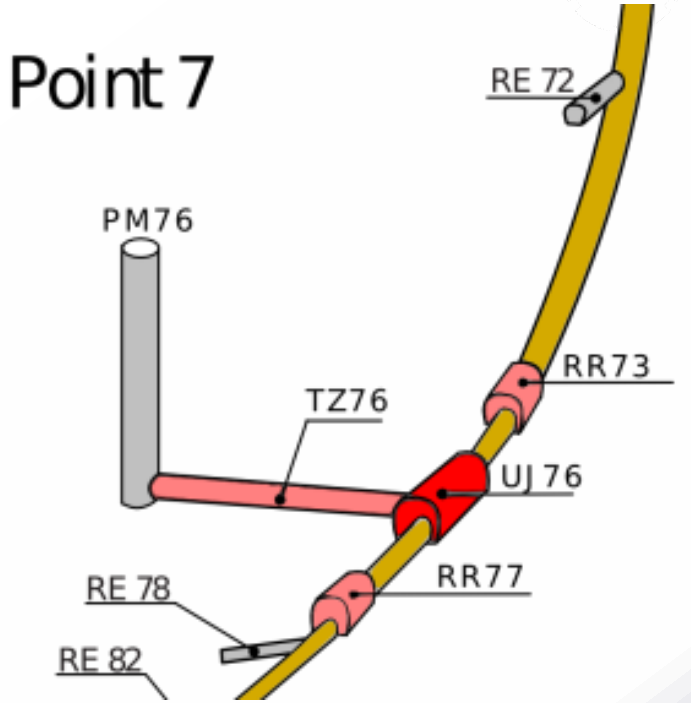


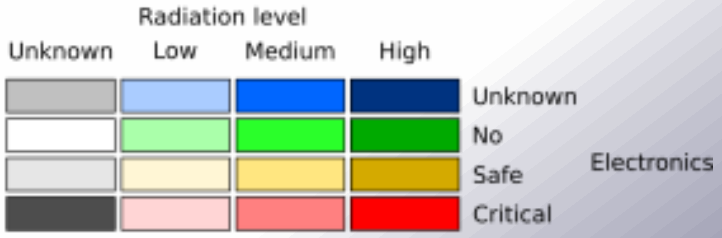
Point 2

2R7

Shielded Areas







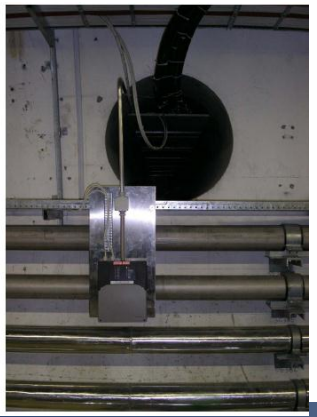
Typical Shielding

Point 2

Point 3

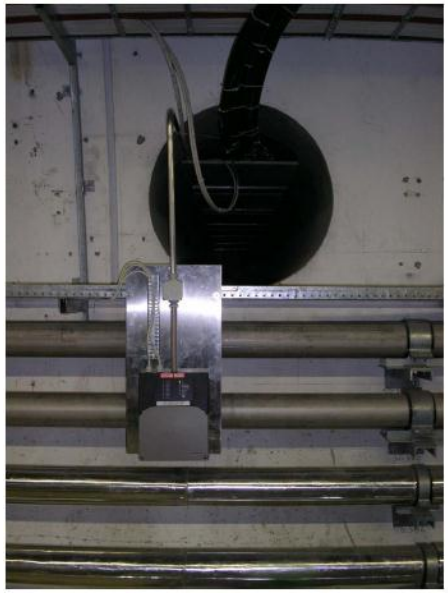
Point 5

Point 6

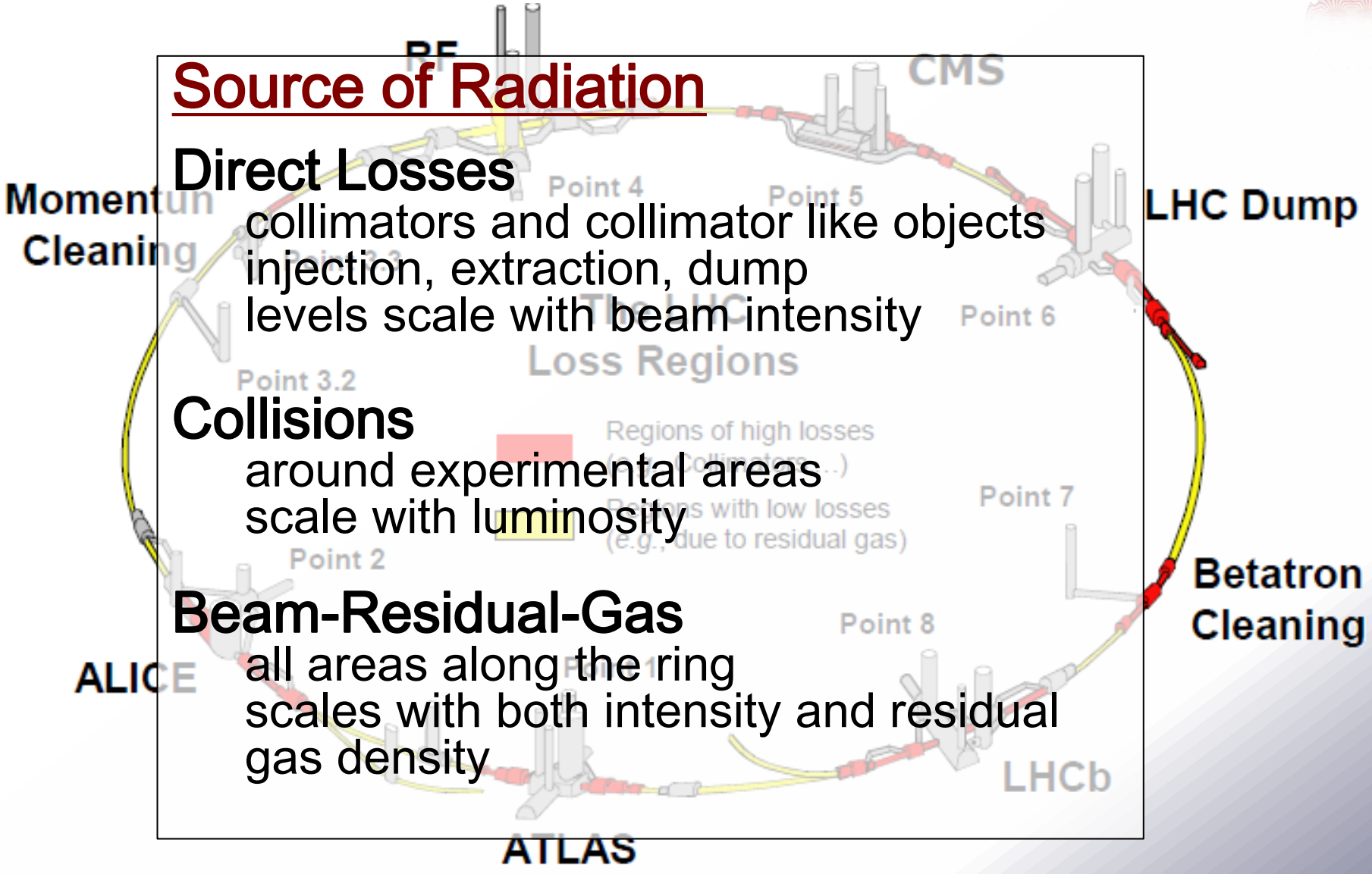


Point 7

Commercial Electronics



The LHC & 'Radiation Areas'



Source of Radiation

Direct Losses

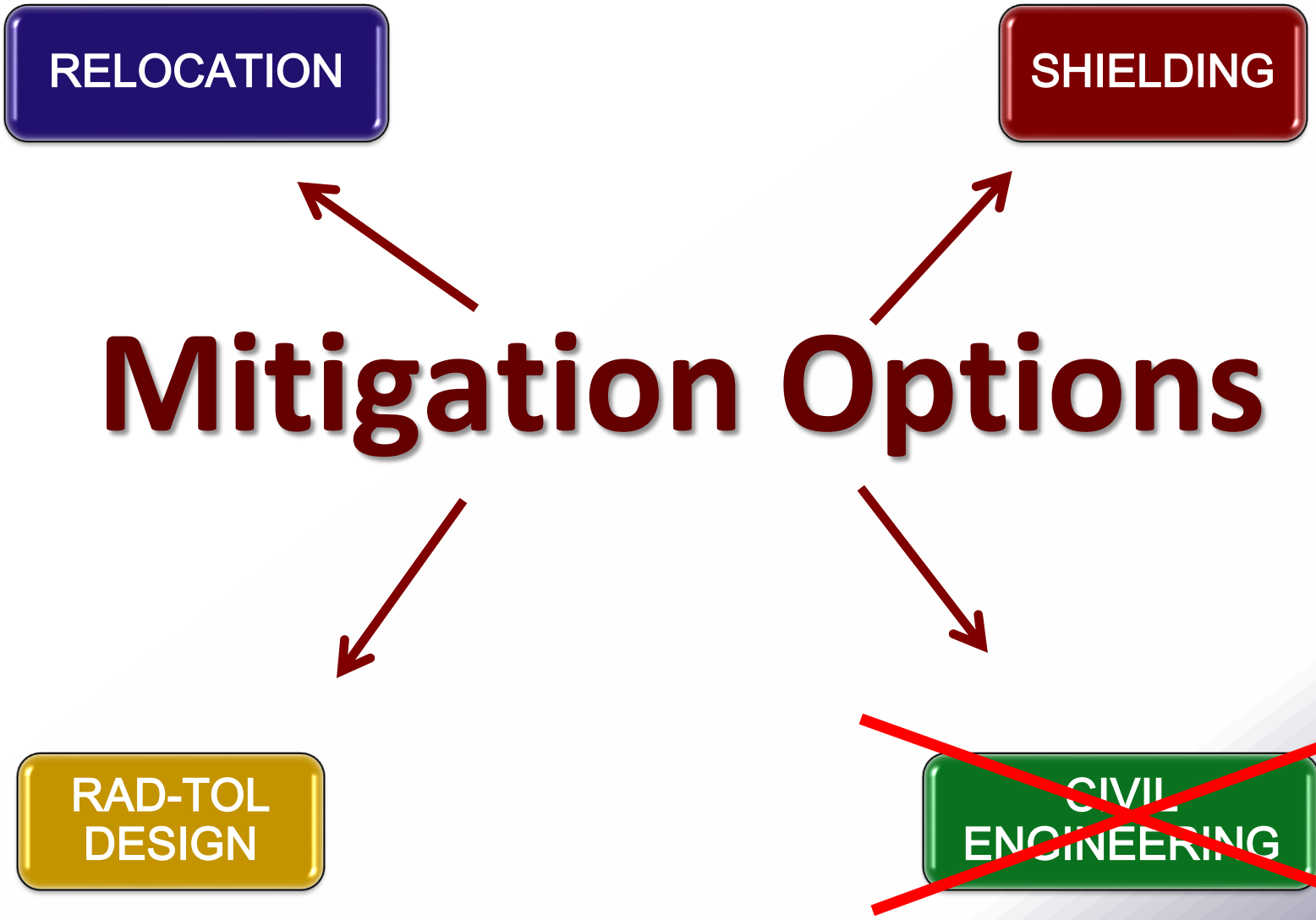
collimators and collimator like objects
injection, extraction, dump
levels scale with beam intensity

Collisions

around experimental areas
scale with luminosity

Beam-Residual-Gas

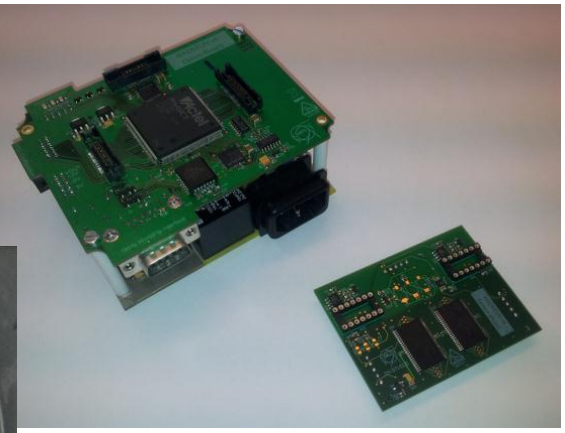
all areas along the ring
scales with both intensity and residual gas density

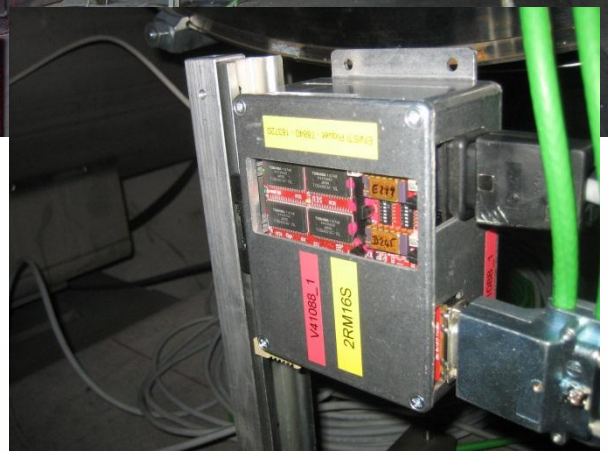

RELOCATION
SHIELDING
Mitigation Options
RAD-TOL DESIGN
CIVIL ENGINEERING

The LHC Radiation Environment & Detector Requirements

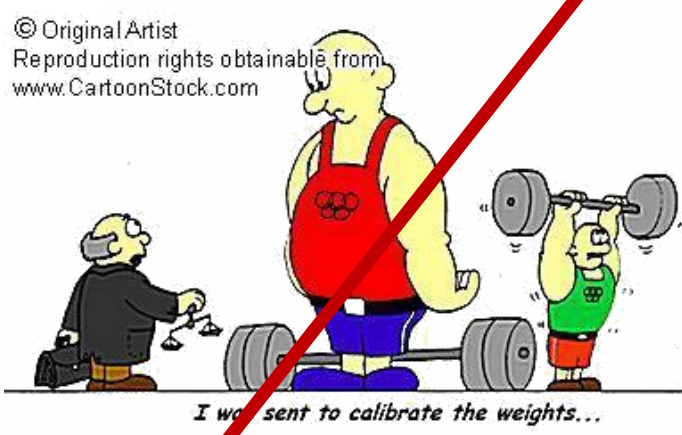
The RadMon Usage

Operation

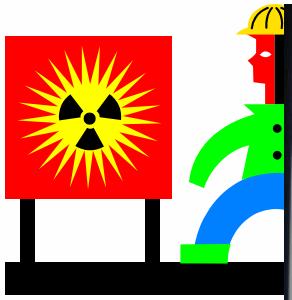




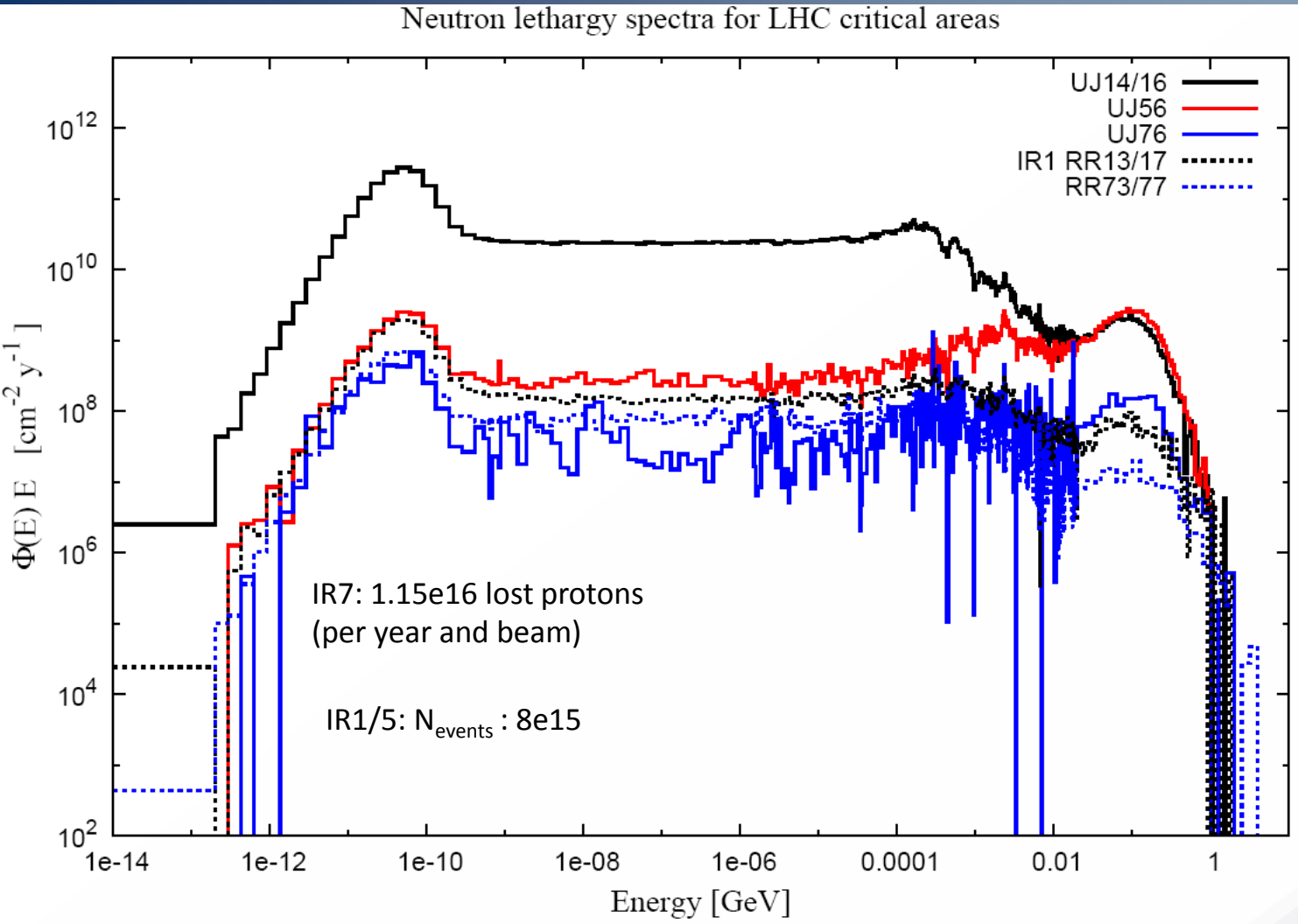
Calibration



Radiation Tests



CERN/LHC Particle Energy Spectra



High-energy hadrons:

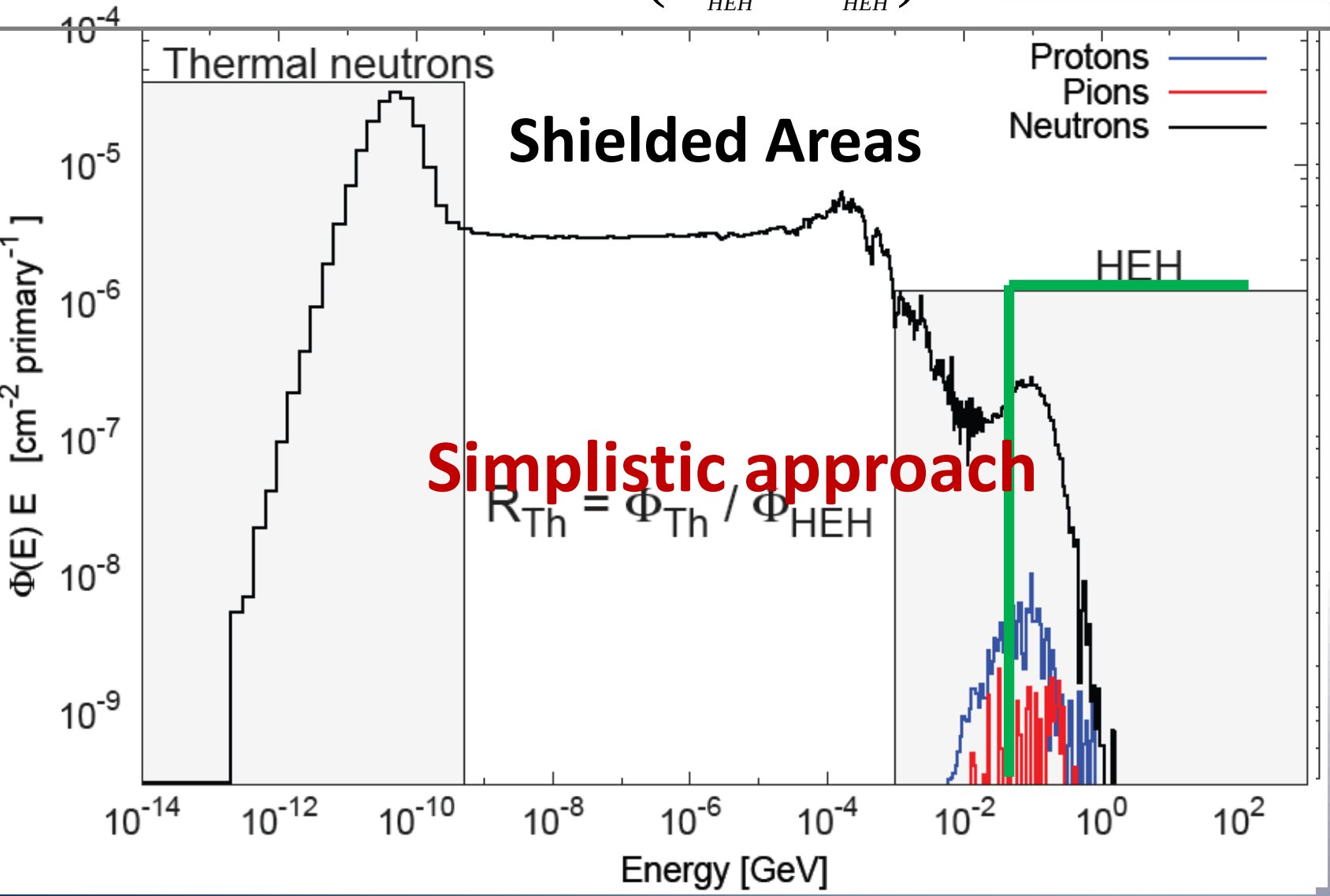
Shielded:
70-90% neutrons

Tunnel:
Neutrons (35%), Protons (10%), Pions,(40%)…

Fluences, Energies and particle types vary between areas!

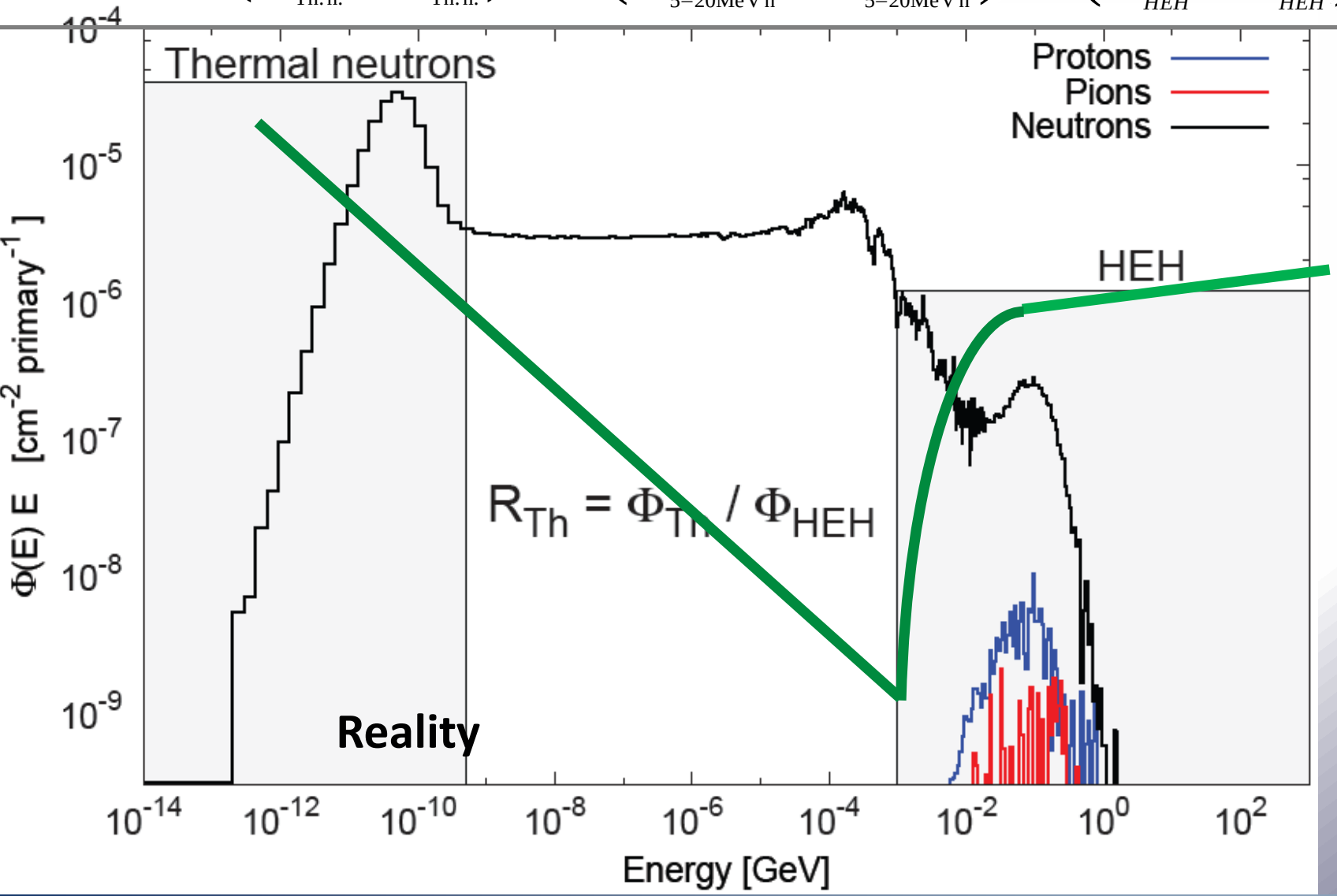
Radiation field and device sensitivity

$$\#SEE = \Sigma(\sigma_{HEH} \cdot \Phi_{HEH})$$



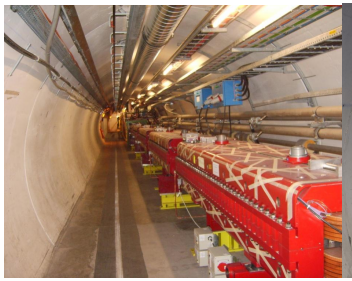
Radiation field and device sensitivity

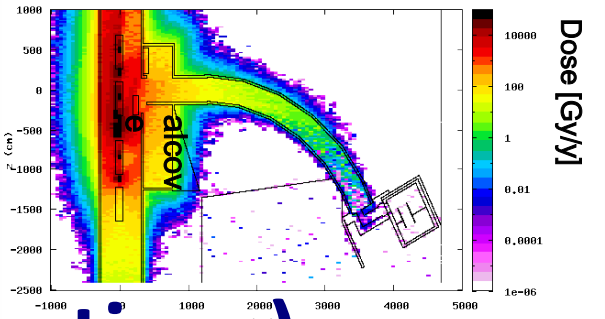
$$\#SEE = \sum(\sigma_{\text{Th.n.}} \cdot \Phi_{\text{Th.n.}}) + \sum(\sigma_{\text{5–20MeV n}} \cdot \Phi_{\text{5–20MeV n}}) + \Sigma(\sigma_{HEH} \cdot \Phi_{HEH})$$



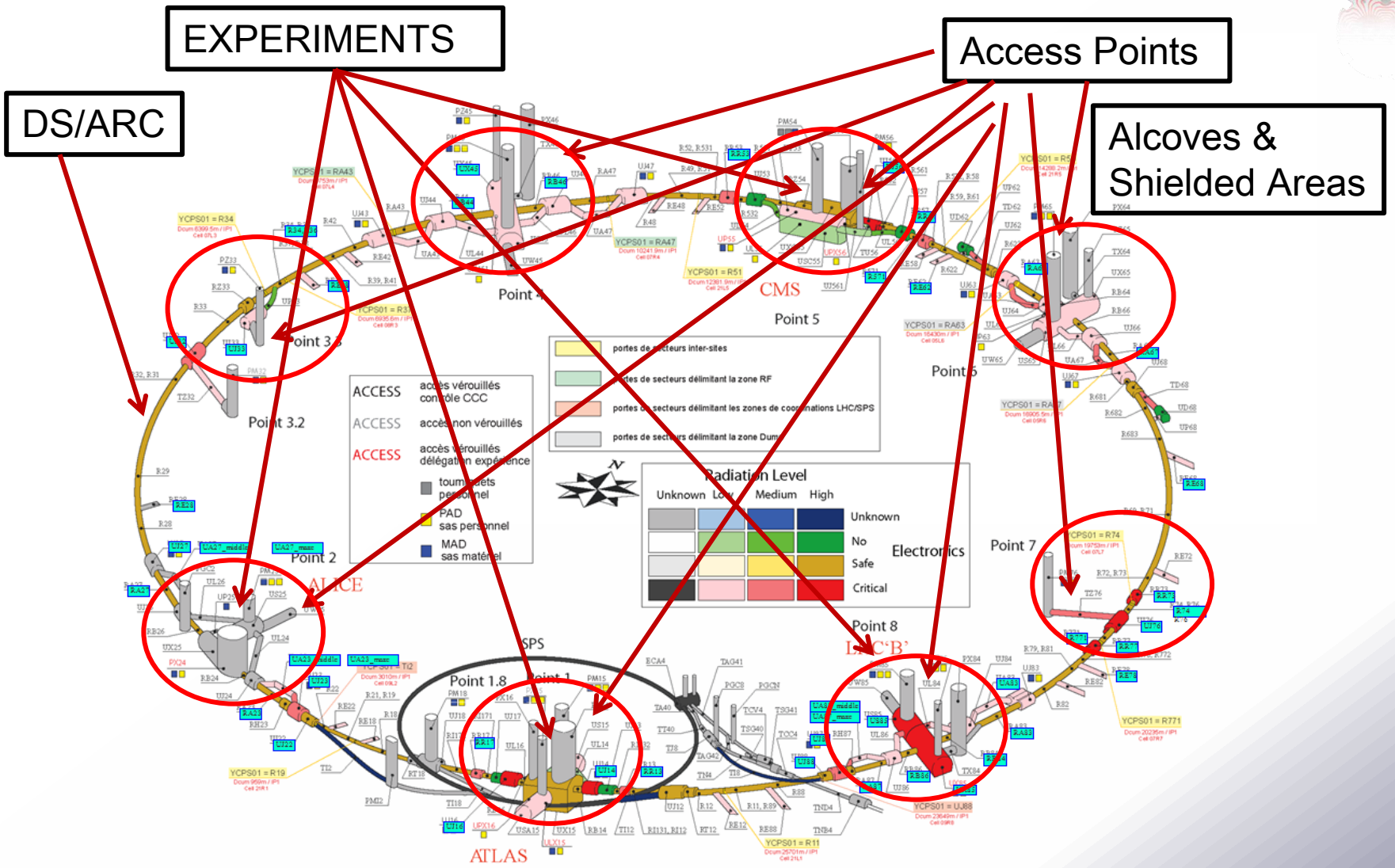
Current Installations

- LHC
  - Tunnel
  - Adjacent shielded areas
  - Experiments
- PS, PSB, SPS, AD
  - Tunnel (future electronic locations)
  - Service areas (partly shielded)
- Test areas, Facilities
  - CTF (CLIC)
  - PS-EAirrad and others (nTof, etc…)



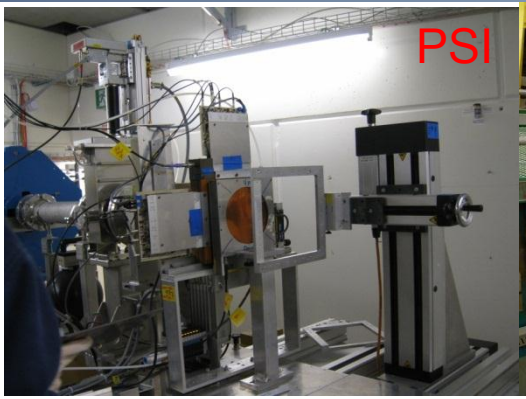


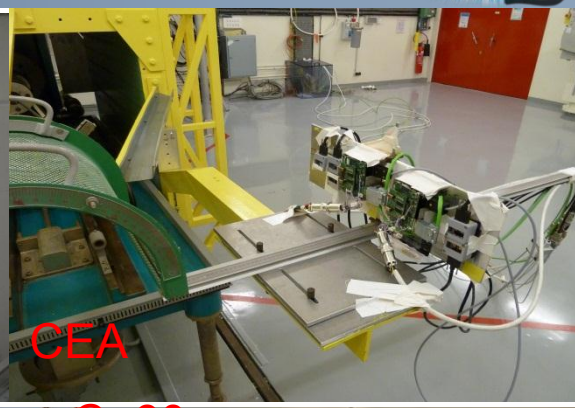
LHC -> The Where



Test Areas & Facilities

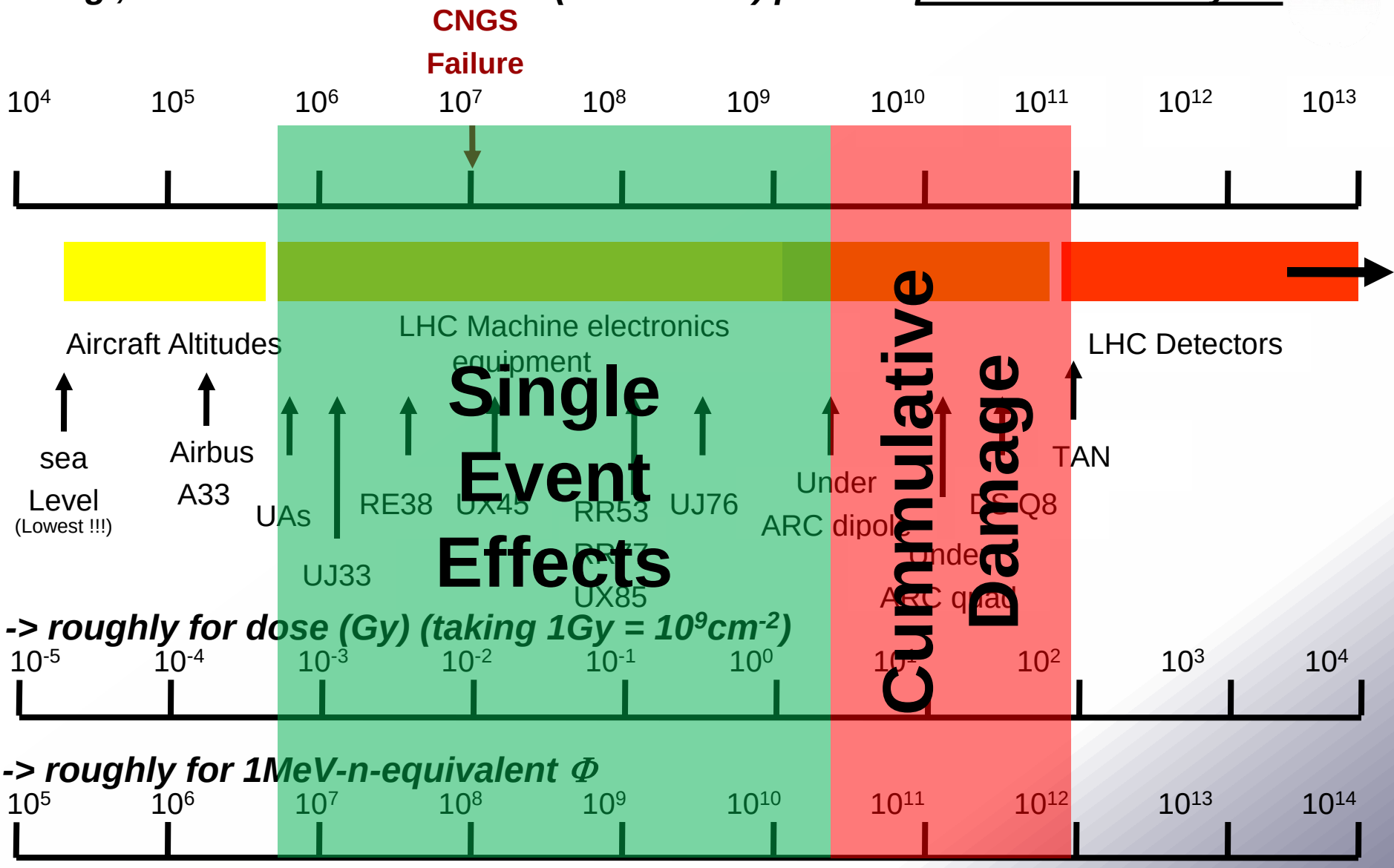
- **Standard facilities**
  - PSI [Protons]
  - Co60 [TID]
  - CEA [DD]
- **Test areas**
  - CNRAD
  - H4IRRAD (past: CERF)
- **Other**
  - JLAB, JPARC, …





Range of Radiation Levels

e.g., LHC-Levels for Hadrons (E > 20 MeV) per cm² per LHC nominal year



SEE & HEH Fluence – Lower End?

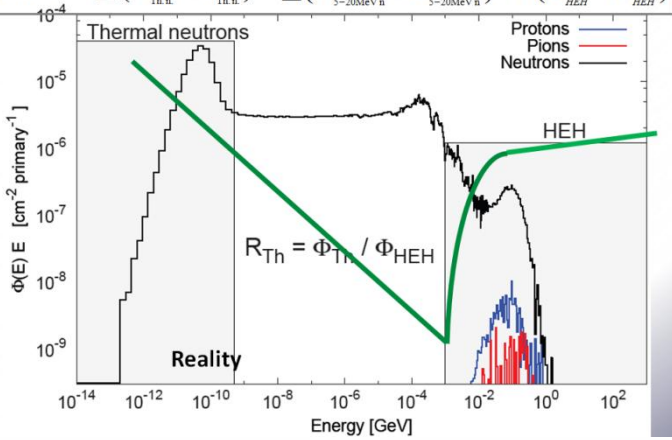
- **@ Ground level**: ~10^5
- **CNGS & LHC experience**
  (QPS dig. Isolator ~$10^6 cm^{-2}$ other 'soft' failures ~10^7-10^8)
  (PLC and Fire Detector failures at ~10^7)
- **Power-Converters & Others**
  (first destructive failures in the order of 10^8)
- **Risks always remains**
  (cross section, fluence, number of devices)

- **We should be able to measure 1/10 – 1/100 below where problems start to appear -> $10^5 cm^{-2}$ – $10^6 cm^{-2}$?**

Thermal Neutrons

- **Affected Areas**
  - Protected by shielding, but with limitations (e.g, REs in the LHC)
  - Streaming through ducts/mazes (e.g, UAs in the LHC)
  - Partyl high ‘risk factor’ (strongly depending on layout/materials/etc.)
- **Equipment of concern**
  - Commercial equipment
  - Partly (very) old technology
  - Partly (very) new technology
- **Safe level**
  - Unknown (from experience), but expected to be in the order of 10^6-10^7cm^{-2}?

$$\#SEU = \Sigma(\sigma_{Th.n.} \cdot \Phi_{Th.n.}) + \Sigma(\sigma_{5-20MeV\,n} \cdot \Phi_{5-20MeV\,n}) + \Sigma(\sigma_{HEH} \cdot \Phi_{HEH})$$



$$R = \frac{\Theta_{Th}}{\Theta_{HEH}}$$

Measurement Range

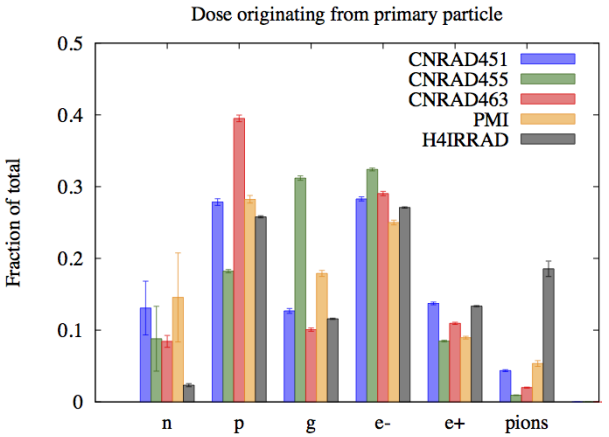
ANNUAL DESIGN VALUES (ROUGH & PRELIMINARY)

NOMINAL	Tunnel			Shielded Areas	'Safe Areas'
	DS		ARC		
	High	Low		RR (Power-Converters)	REs,UAs,UJs (rem.)
HEH [cm^{-2} y^{-1}]	$1.0 \cdot 10^{11}$	$2.0 \cdot 10^{10}$	$1.0 \cdot 10^{9}$	$2.0 \cdot 10^{8}$	$1.0 \cdot 10^{7}$
1 MeV eq. [cm^{-2} y^{-1}]	$4.0 \cdot 10^{11}$	$8.0 \cdot 10^{10}$	$4.0 \cdot 10^{9}$	$8.0 \cdot 10^{8}$	$4.0 \cdot 10^{7}$
Dose [Gy y^{-1}]	200	40	2	0.4	0.02
ULTIMATE	Tunnel			Shielded Areas	'Safe Areas'
	DS		ARC		
	High	Low		RR (Power-Converters)	REs,UAs,UJs (rem.)
HEH [cm^{-2} y^{-1}]	$4.0 \cdot 10^{11}$	$8.0 \cdot 10^{10}$	$4.0 \cdot 10^{9}$	$8.0 \cdot 10^{8}$	$1.0 \cdot 10^{7}$
1 MeV eq. [cm^{-2} y^{-1}]	$1.6 \cdot 10^{12}$	$3.2 \cdot 10^{11}$	$1.6 \cdot 10^{10}$	$3.2 \cdot 10^{9}$	$4.0 \cdot 10^{7}$
Dose [Gy y^{-1}]	800	160	8	1.6	0.02

- **+ Injector Requirements (SPS, PS,…)**
  - **large areas with >1kGy**
  - **Partly strong gradients (and higher peaks)**

Calibration Requirements

- **Energy Response (for HEH)**
  - High-energies (> some tens of MeV)
  - Intermediate energies (1-20MeV)
  - Thermal neutrons
- **Dose (TID in Silicon)**
  - Mixed-particle energy spectra
    - Charged + Neutrons: Tunnel
    - Neutrons, Gammas: Shielded areas
- **Sensitivity**
  - Low exposed areas -> SEEs -> 10^5 – $10^6 cm^{-2}$ possible? (there also thermal neutrons matter)?
  - TID: important > 1Gy, how high can we go? (important for tunnel applications)



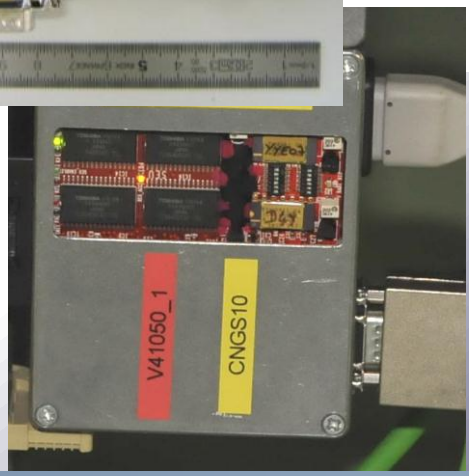
Linked Challenges

- **Representative for actual applications**
  - Similar technology (required?)
- **Sensitivity, Response**
  - Dose rate dependency
  - Cross-talk between TID, DD and SEE
  - Do we need field-calibration coefficients (*e.g,* existing 400/1000nm issue)?
- **Resolution, Linearity**
  - Improve accuracy (e.g, finer look-up tables)
  - Linear response (e.g, higher pre-irradiation for DD)
- **Reliability, Accuracy**
  - Life-time of components
  - Spread between components/batches (< few %?)

How Accurately Can We Measure With the Existing System?

RadMon System in the LHC

- **Online (through WorldFIP)** and **Standalone version**
- **Deported unit** (for TID/1MeV)
-
-
-



RadMon Calibration

© D. Kramer, G. Spiezia

© K. Røed

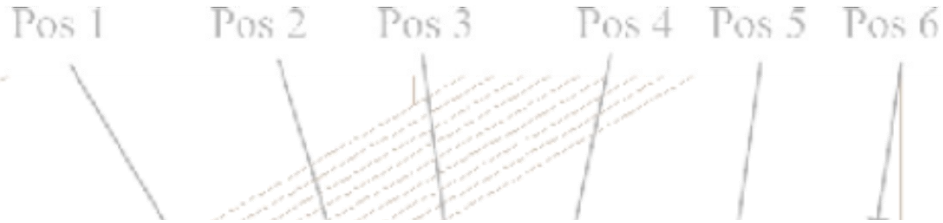
Chip/Chip variation (1 batch) dominate the uncertainty

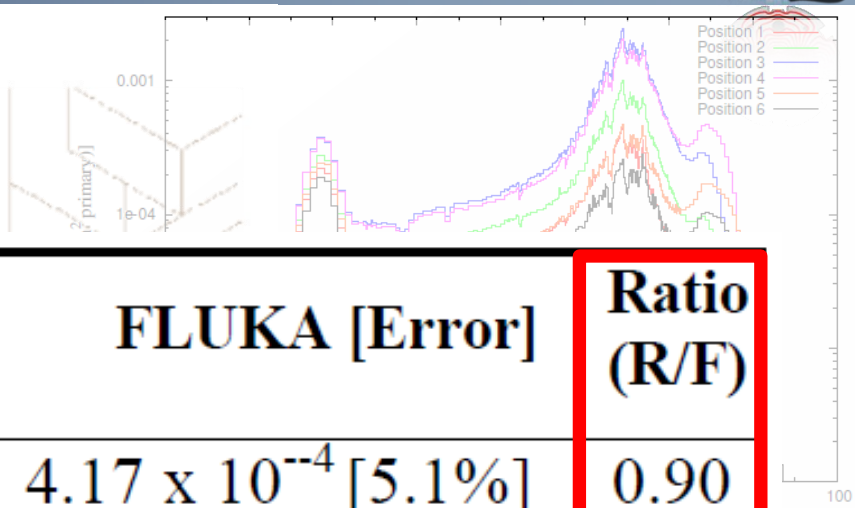
ID	σ_{SEU} 5V (Err) $[cm^2/bit]$	σ_{SEU} 3V (Err) $[cm^2/bit]$
B1_A	$2.9\ 10^{-14}$ (0.4)	$7.1\ 10^{-14}$ (0.8)
B1_B	$2.1\ 10^{-14}$ (0.3)	$5.6\ 10^{-14}$ (0.6)
B1_C	$3.7\ 10^{-14}$ (0.5)	$8.8\ 10^{-14}$ (1.0)
B1_D	$3.1\ 10^{-14}$ (0.4)	-
Average	$3.0\ 10^{-14}$ (0.4)	$7.2\ 10^{-14}$ (0.5)
B2_A 2	$2.2 \cdot 10^{-14}$ (0.3)	-
B2_B 3	$2.0 \cdot 10^{-14}$ (0.3)	-
B2_C 5	$2.4 \cdot 10^{-14}$ (0.3)	-
B2_D 6	$2.5 \cdot 10^{-14}$ (0.3)	-
Average	$2.3\ 10^{-14}$ (0.2)	-

Thermal-Neutron/HEH Ratio can be measured!

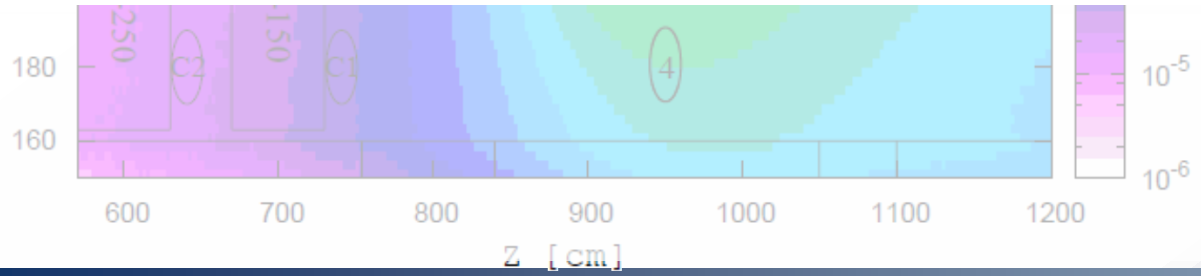
Few MeV neutrons can contribute ~factor of two

CERF Benchmark



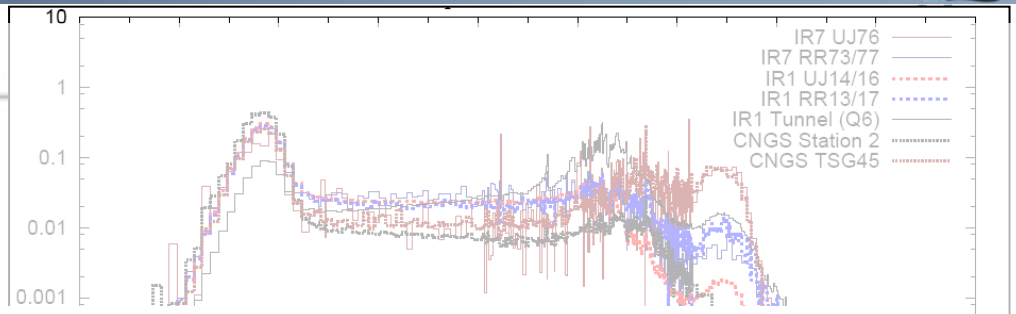


Location	RadMon [Error]	FLUKA [Error]	Ratio (R/F)
Pos1	3.77×10^{-4} [20.0%]	4.17×10^{-4} [5.1%]	0.90
Pos2	5.76×10^{-4} [20.0%]	5.76×10^{-4} [4.6%]	1.00
Pos3	1.99×10^{-3} [20.0%]	1.97×10^{-3} [2.8%]	1.04
Pos4	1.75×10^{-3} [20.0%]	1.71×10^{-3} [3.4%]	1.02
Pos5	1.53×10^{-3} [20.0%]	1.67×10^{-3} [3.2%]	0.92
Pos6	2.19×10^{-3} [20.0%]	2.19×10^{-3} [2.9%]	1.00



© K. Røed

CNRAD Test Area "Benchmark"



Location	RadMon [Error]	FLUKA [Error]	Ratio (R/F)
TSG45	1.9×10^{-7} [20.0%]	2.1×10^{-7} [5.7%]	0.9
TSG46	2.0×10^{-8} [20.0%]	1.9×10^{-8} [6.8%]	1.05

© K. Røed

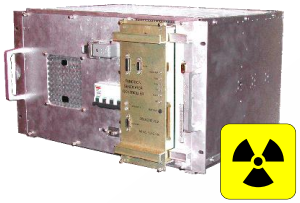
Electronics & Radiation Sensitivity

LHC POWER CONVERTERs

© V. Montabonnet, Y. Thurel

- Minimize the number of converter types:
  - Only the LHC60A-08V was specified for a radioactive environment !
  - 3 other converter types are part now of the radioactive sensitive areas!

LHC60A-08V
4-Quadrant
752 Units



Units : Quantity in all machine (UA, RR, UJ, tunnel)

LHC120A-10V
4-Quadrant
300 Units

LHC600A-10V
4-Quadrant
400 Units

LHC4..6kA-08V
1-Quadrant
200 Units

PCs: What was tested and where?

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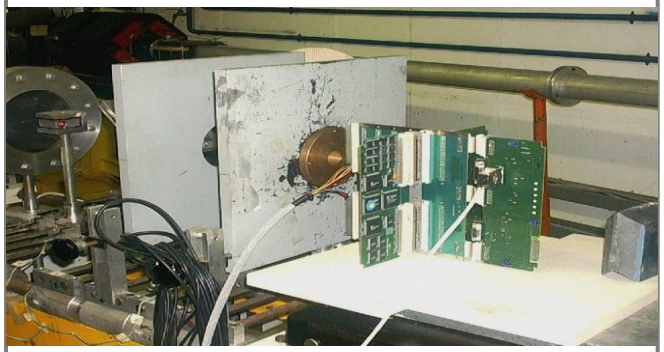
LOUVAIN (2003 - FGCs)

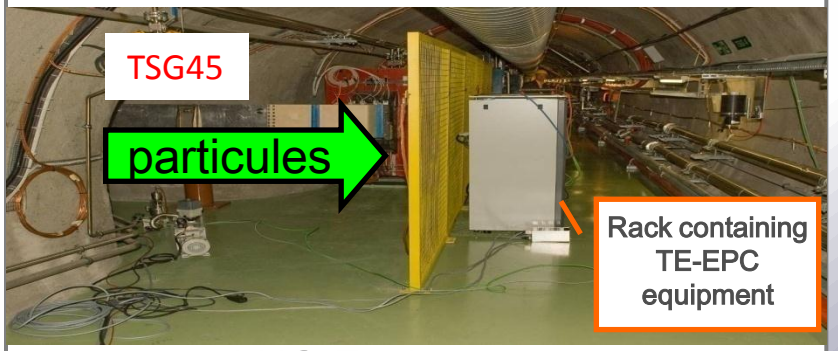


60 MeV proton components tests

PROSPERO (2009 - FGCs)

1MeV neutron displacement damage tests

CNGS (2008..2009 – FGCs, 60A, PSUs)



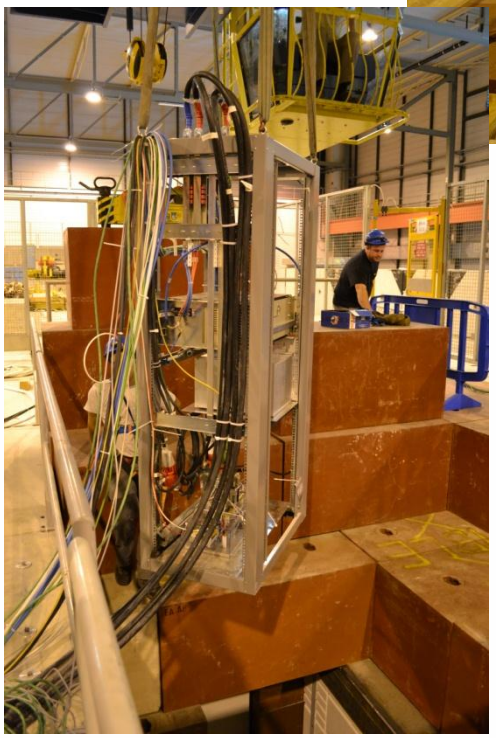
LHC-Environnement System Test

What it Means in Reality

TEST THIS:

HERE

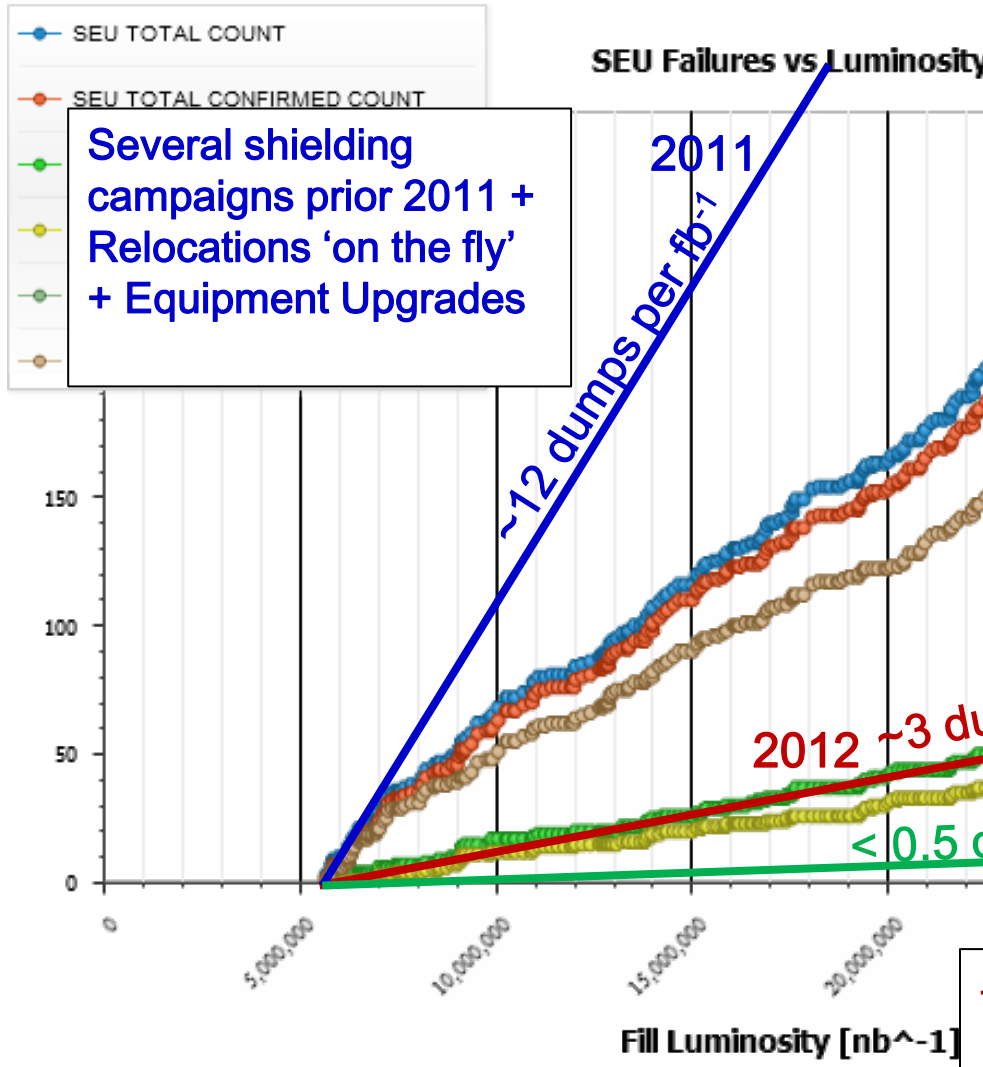
AND AFTER …



DANGEROUS LIQUID:

(W)HOW ???

R2E: Past/Present/Future



2011/12 xMasBreak
'Early' Relocation
+ Additional Shielding
+ Equipment Upgrades

R2E-Project aiming for …
>LS1 (nominal -> ultimate)

- Equipment relocations @ 4+ LHC Points (>100 Racks, >60 weeks of work)
- Additional shielding
- Critical system upgrades (QPS, FGC)

Radiation Tests

Where do we test (so far)

- CERN
  - CNRAD (mixed-beam)
  - H4IRRAD (mixed-beam)
- PSI (protons)
- CEA Reactor (neutrons)
- Heavy-Ion Facilities (LET)
- Thermal neutron facilities (old components)
  (Prague, Oslo, Rome)
- Others (mainly for calibration, e.g., PTB)

PSI

Cabling

- Beam time available via special agreement
  (1 slot [**weekend**] per month)
- Proton beam 30-**230 MeV**
- Beam spot < 9 cm
  (5cm Uniformity ~90%)
- Maximum Flux (230 MeV):
  1.5×10^8 p/cm2/sec
- TID, DD, tested at the same time
- Accelerated rad test
  (**ELDRS** not tested)
- **Limitation on SEL+ conclusions**

CNRAD Test Area

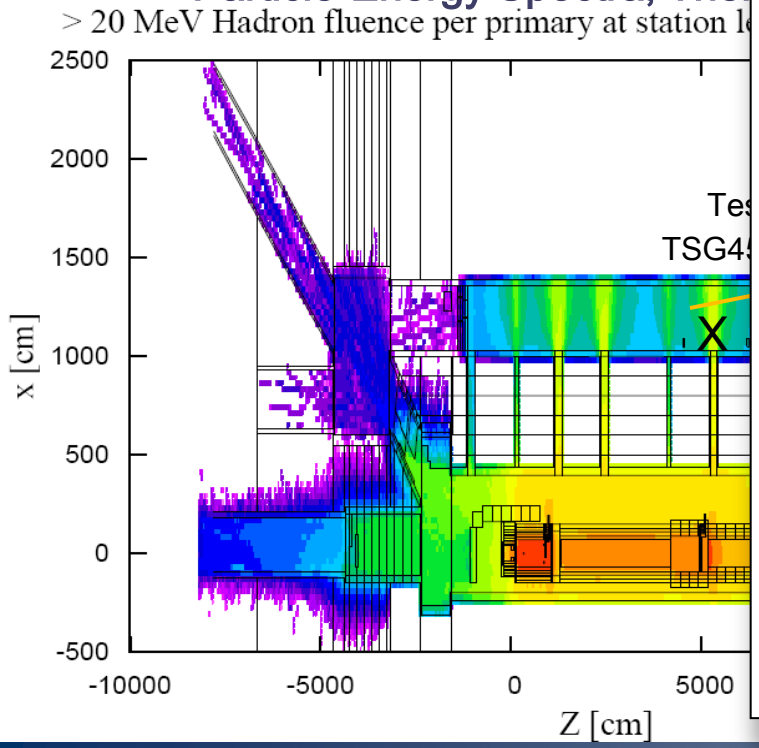
Mixed radiation fields simi

Extensive Monitoring:

- RadMons
- Compared to BLMs
- +GoldFoils, TLDs,…

Detailed FLUKA Simulations for

- TID (air), Hadron>20MeV flue
- 1MeV neutron-equivalent flue
- Particle-Energy Spectra, Ther



Advantages:

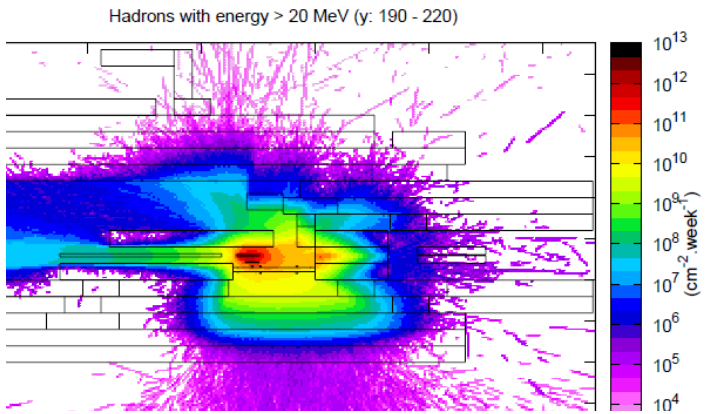
- mixed particle field -> **LHC-like**
- Stable radiation field conditions
- **Four measurement stations** fully equipped for remote control and readout
- **Large test volumes**

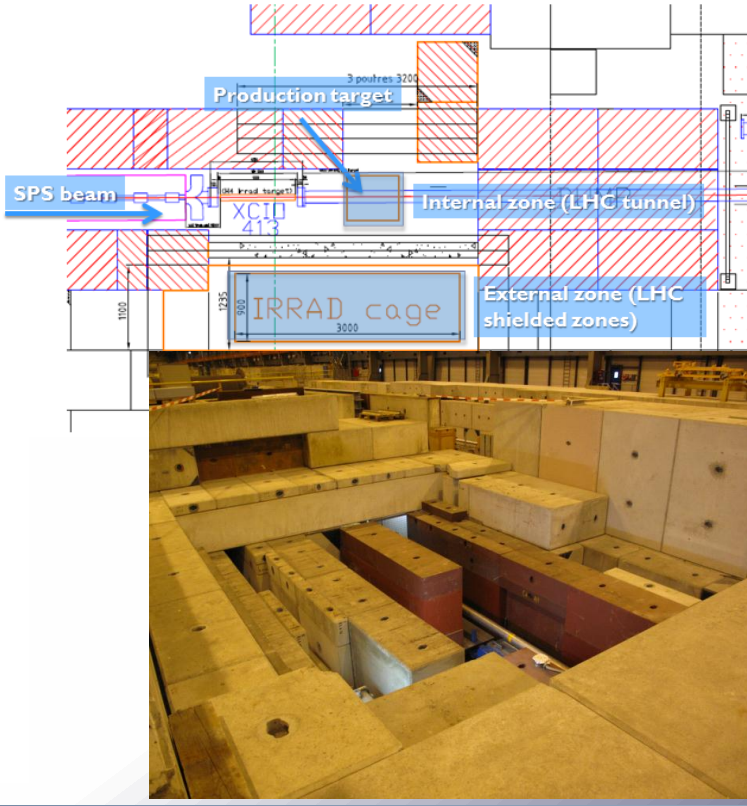
Limitations

- **Parasitic** to CNGS
- Access only **during TS** (~6w)
- Long access to the tunnel
- Cabling/Signals

H4IRRAD Test Area

- **Mixed-Particle Test Area -> LHC**
- Secondary beam from the SPS – 280 GeV –> 1m Cu-target
- **Internal/External radiation zones**
- For **“small” to “bulky”** equipment
- Pulse intensity ~10^9 p/spill, ~1.5×10^{12}p/day **(~5×10^5 HEH/cm^2/min)**
- Typical rad levels:
  - Internal: ~2×10^9 HEH/cm^2/day, **~1 Gy/day**
  - External: ~4×10^8 HEH/cm^2/day **~200 mGy/day**

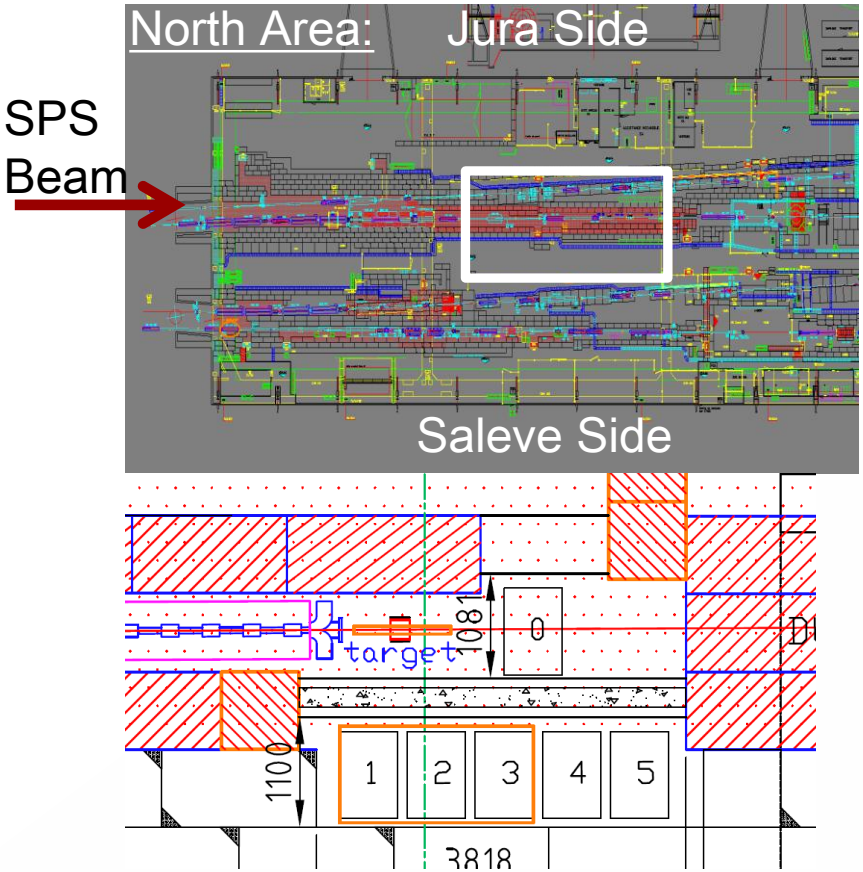




New Facilities

Extensive and **complex radiation test campaigns** exceed our current test possibilities (CNRAD, PSI) – Important to think ahead!

H4IRRAD (2011)



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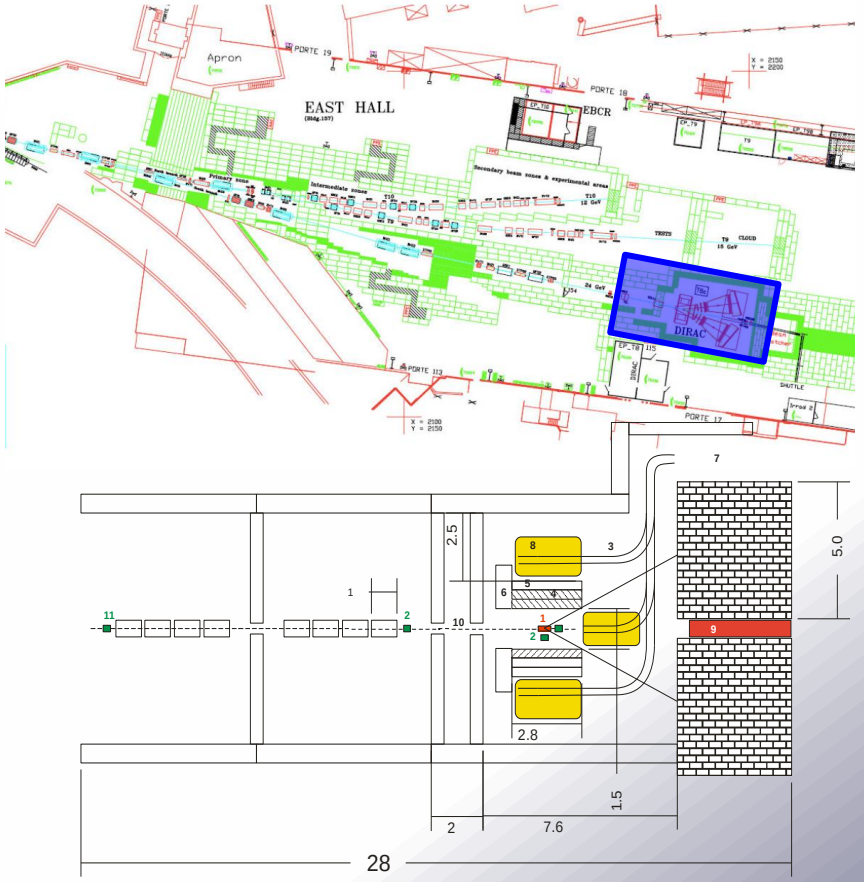
PS-EastArea (2013?)



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Mitigation & Project Status

Mitigation Strategy

1st Safety Critical	→	Immediate Relocation
2nd Shielding	→	"Fast" & Global Improvement
3rd Most Sensitive	→	Highest Impact on Operation: (1)Relocation (2)Shielding
4th Remaining	→	(1)Relocation (2)Shielding (3)New Design

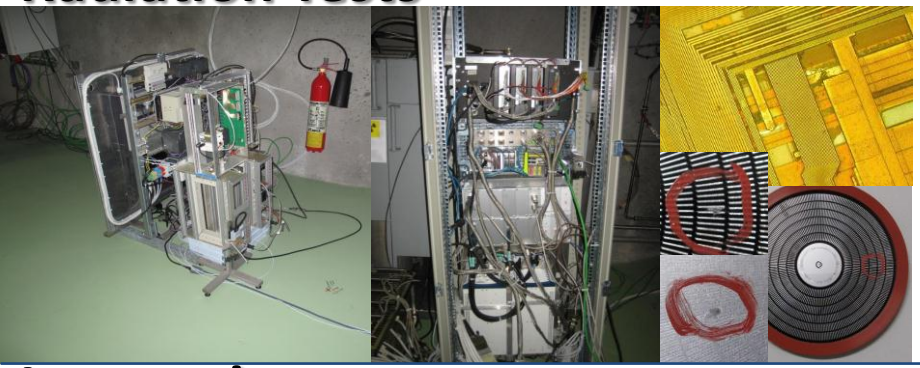
R2E Project Status

- **"Timely" start allowed** us to:
  - **avoid safety critical situations**
  - **focus** first on most important/**effective actions** -> highest impact on LHC operation
- **Dense (and costly) mitigation program**
  - **shielding/relocation** for the long-shutdown, **Radiation tolerant R&D** in parallel and beyond
- **Long-term radiation effects are not to be forgotten**
- **Optimization must also consider long-term LHC needs**

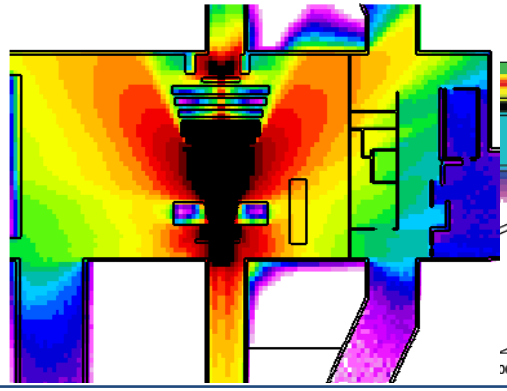
- **We're on track (thanks to many people), but a lot of work is still ahead of us**

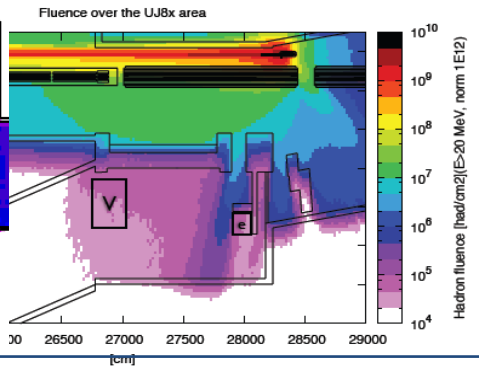
R2E Mitigation Project Building Blocks

Radiation Tests

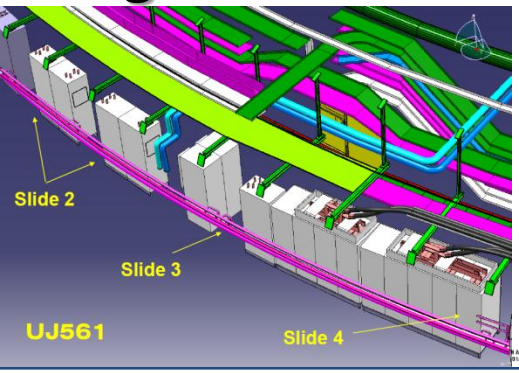


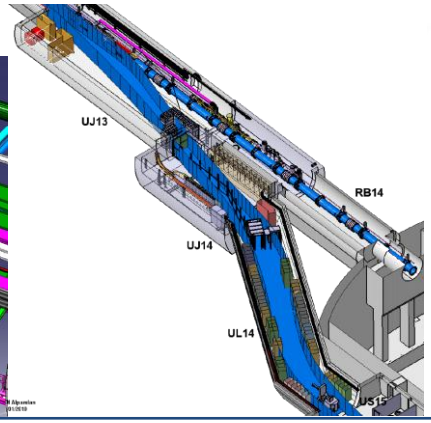
Calculations



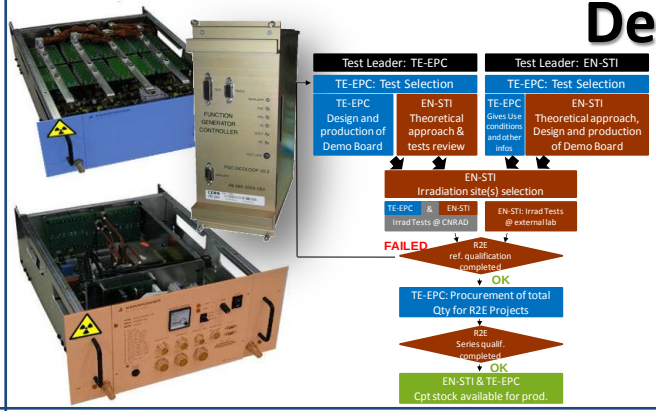


Integration

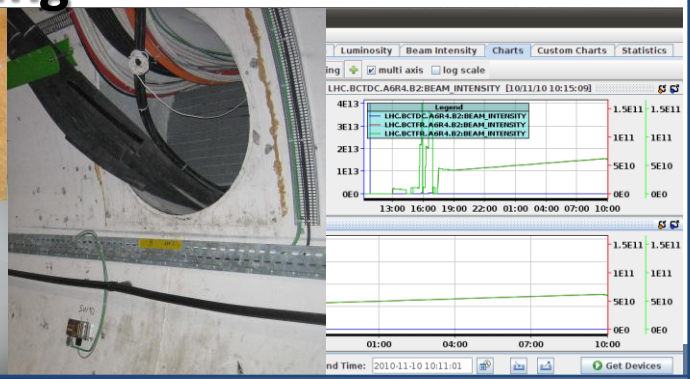




Developments



Monitoring



Implementation