LHC Radiation Environment and Future Electronics Policy for the Accelerator Sector

1st R2E RADIATION SCHOOL & WORKSHOP

Divonne, June 2nd/3rd 2009

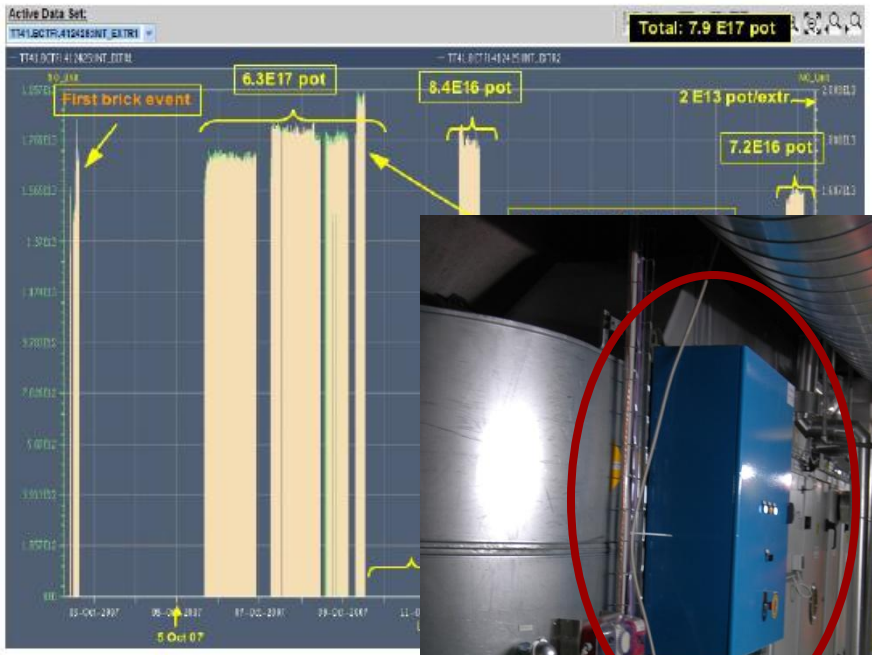
M. Brugger for the R2E Study Group

A Bit of Recent History

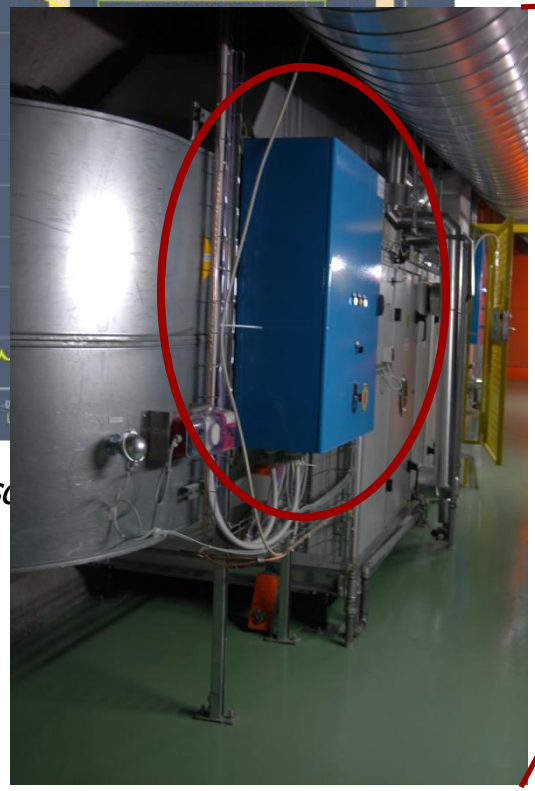
- the 2007 operational stop of CNGS due to electronics failures "triggered" a closer look to the risk of SEUs and what equipment finally was installed in the various LHC areas – in short: **many surprises**
- a dedicated working group on "**Radiation to Electronics in the LHC**" performed a first study looking at known critical areas, respective radiation levels, as well as what type of equipment is installed
  - **results were reported to the LTC and ICC in the beginning of 2008**
- given the criticality, to help better understand and quantify the possible risk, as well as to avoid uncoordinated actions: based on the first working group the **"Radiation to Electronics (R2E) Study Group"** was created in April/May 2008
- a first analysis of the situation lead to the actions integrated into the **2009 shutdown work** (see list in backup slides if interested)
- **a deeper analysis is ongoing with important work ahead of us -> this school is part of it**
- many details and information is available at: **www.cern.ch/R2E**

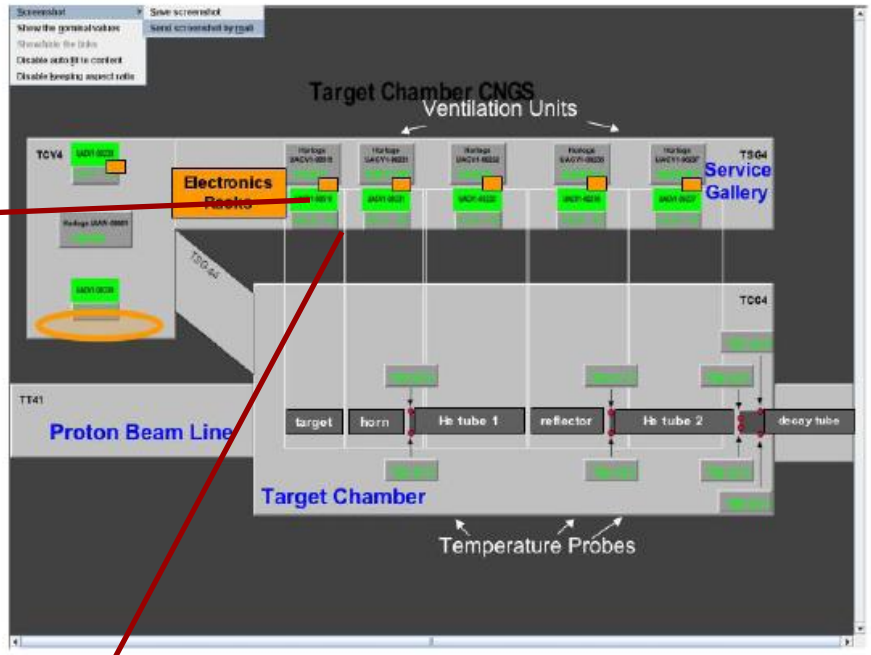
The CNGS Incident (2007)

After two weeks of run at low intensity the beam has been stopped due to loss of the ventilation control.



E. Gsc

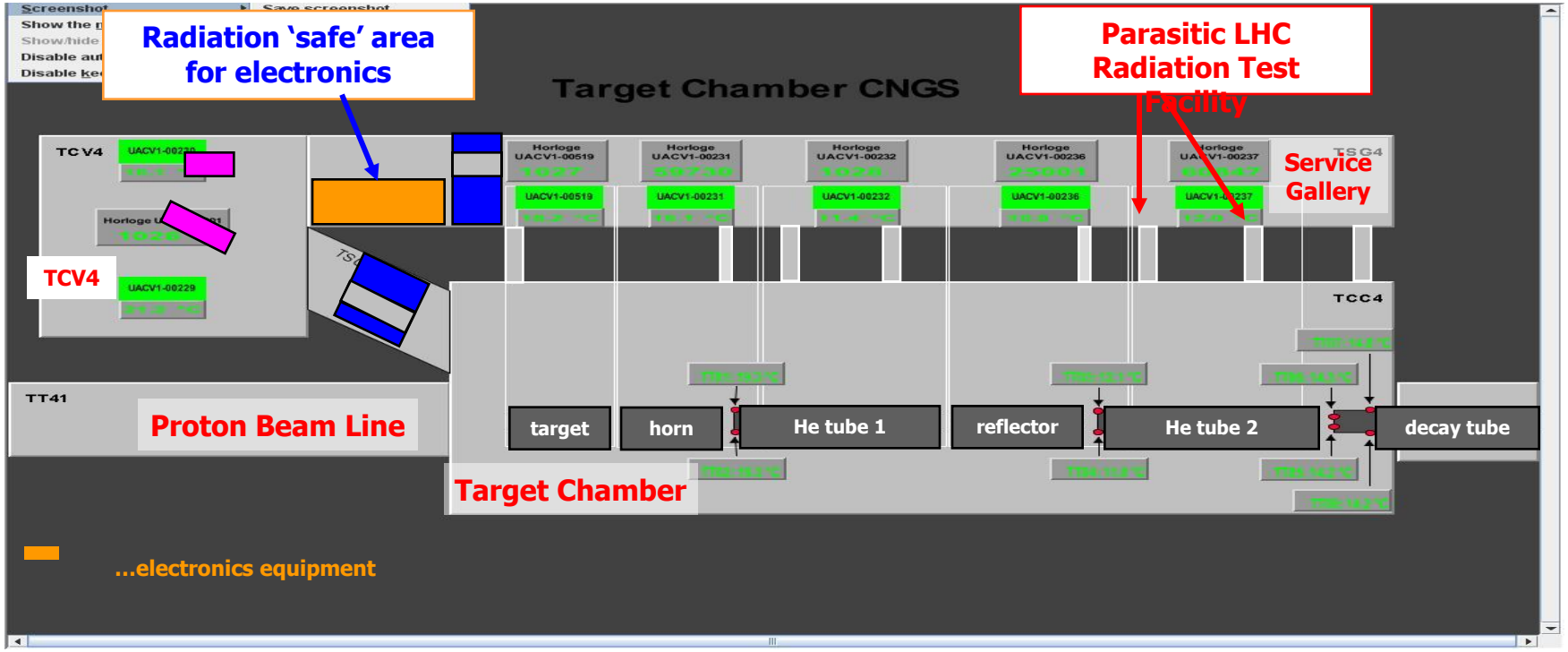




CNGS Modifications due to Radiation Issues

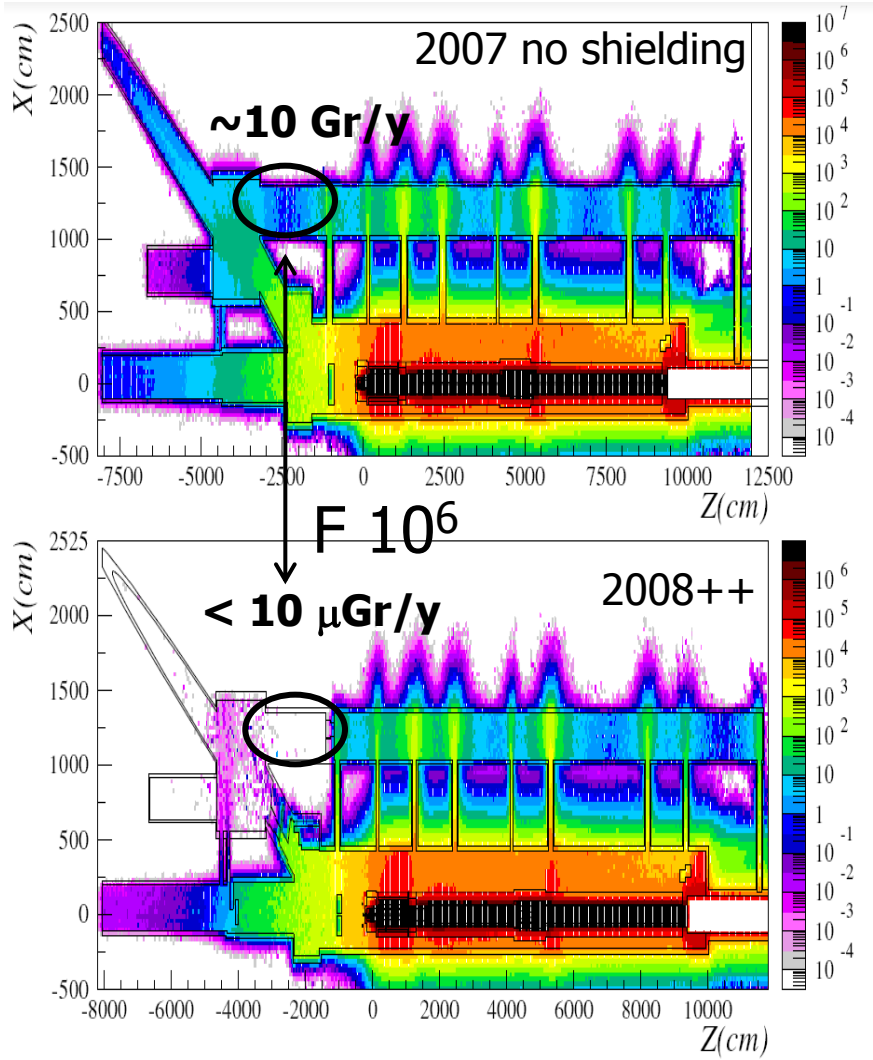
-> with detailed FLUKA Studies

1. Move as much electronics as possible out of CNGS tunnel area
2. Create radiation safe area for electronics which needs to stay in CNGS
3. Add shielding: concrete walls up to 6m thick, in total ~53m^3 concrete
   - Movable shielding plugs in TSG4 and TSG41 remotely controlled, connected to access system → will be opened before any access to CNGS is granted
   - Bypass of ventilation ducts

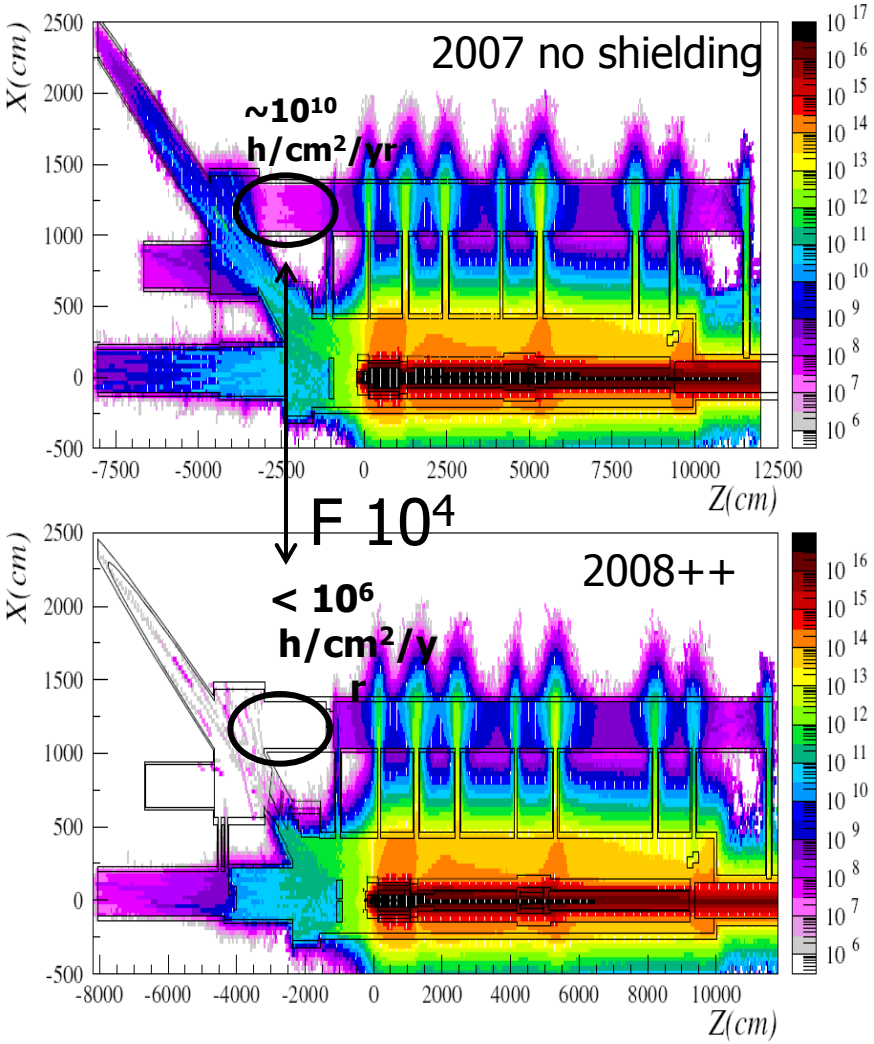


CNGS FLUKA Simulations

Prompt Dose in Gray for a nominal year (4.5 E19 pot)



High-E (>20 MeV) hadron fluence in cm^{-2} for a nominal year (4.5 E19 pot)



LHC

What Are the Issues?

What Are the "Issues"? – Typical Shielding

Point 2

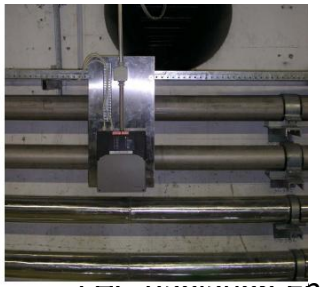
Point 3

!!!

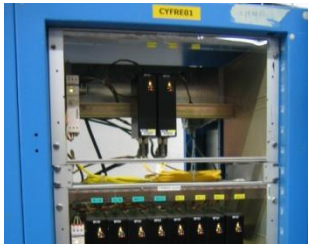
AND MANY MORE …

!!!

Point 6



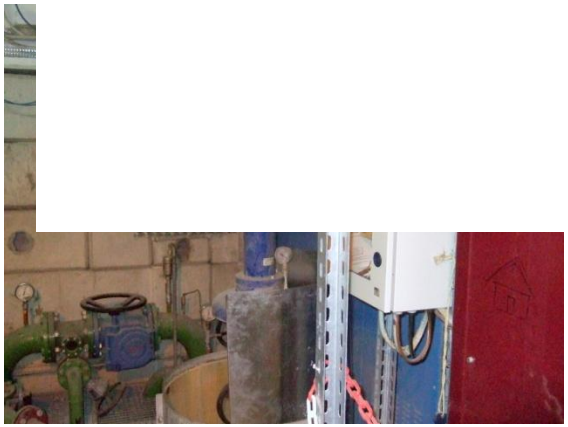
What Are the “Issues”? – Electronics

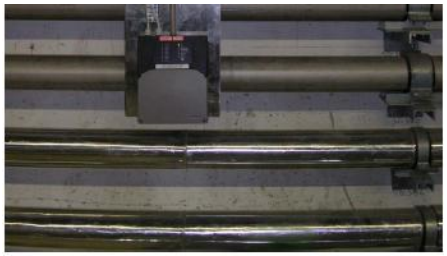


!!!

AND MANY MORE …

!!!





Radiation To Electronics (R2E) Study Group

- The R2E Study Group forms a small committee consisting of experts in the various fields related to electronics damage and shall drive other working groups (RADWG). This way R2E assists LHC operations and equipment groups with expert knowledge and assessments of radiation-induced failures in electronics of the accelerator, as well as directly coordinates studies of remedial actions:

- *Immediate*
  - propose and evaluate short-term measures to reduce failure risks
  - establish, extend and evaluate the inventory of information needed to assess radiation-induced electronics failures
  - ensure accurate monitoring of radiation fields in critical areas to evaluate risks of electronics failures
  - advice on planned CNGS irradiation tests, including calculations
  - commission and evaluate machine studies to understand the possibility of reducing/displacing losses

- *Long-Term*
  - coordinate studies of radiation-induced failures, including calculations and proposals of solutions, and complement the inventory with measured data and experience gained during operation
  - advice on further dedicated irradiation tests, including calculations
  - assist LHC operations and concerned groups in the identification and short-term mitigation of failures

Short-Term

Inventory

Prioritization

Testing

Monitoring

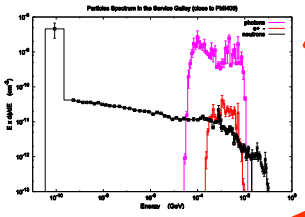
Mid-Term

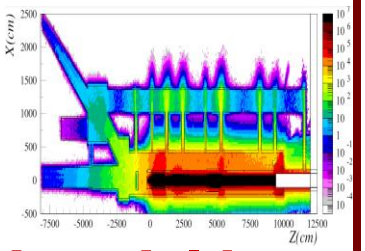
Coordination

Long-Term

Radiation Physics/Effects/Monitoring

nuclear cascade





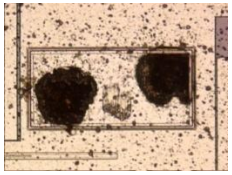
h > 20 MeV

Radiation Field

h, e,.. > 100 KeV

EM cascade

radiation damage in semiconductors



Single Events

Effect in the Device

Displacement

Dose

Radiation Monitor

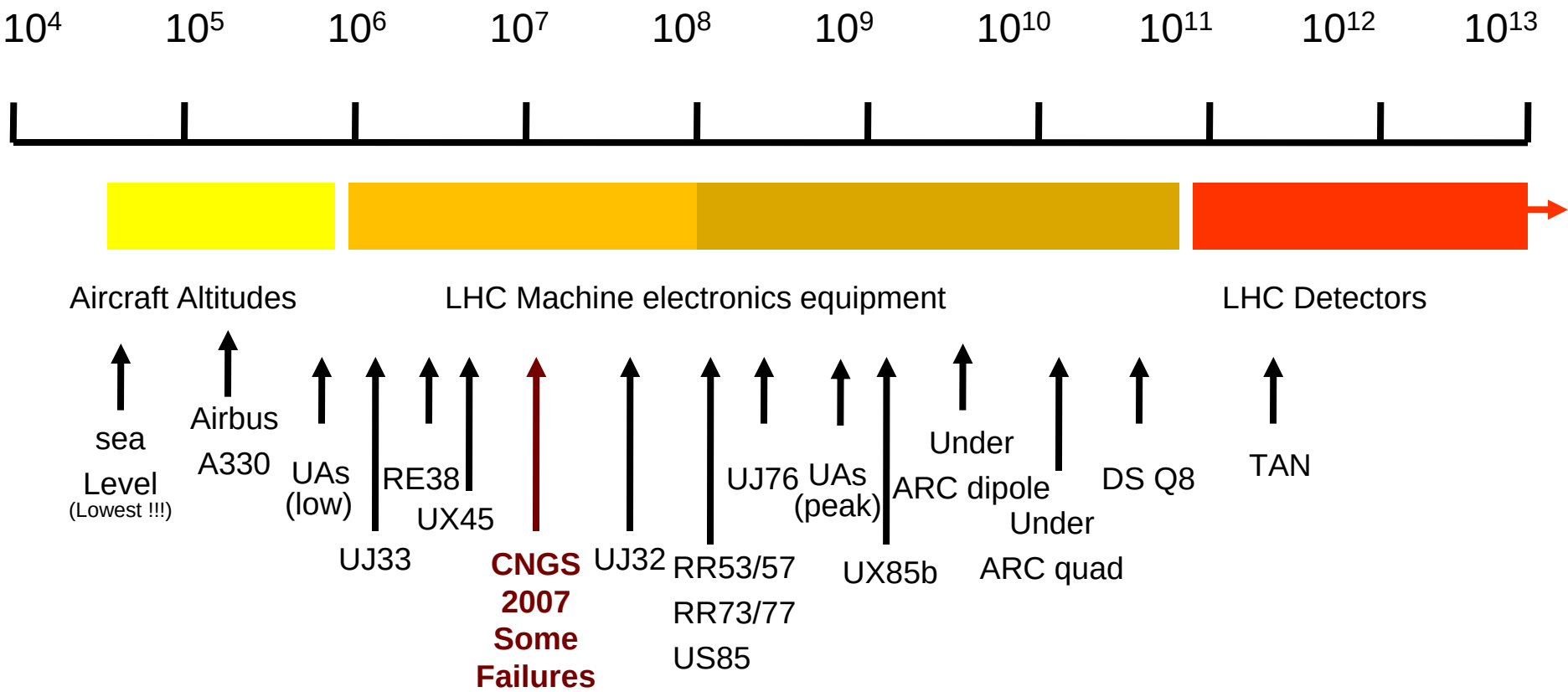
SEU counter

Measurement

PIN Diodes

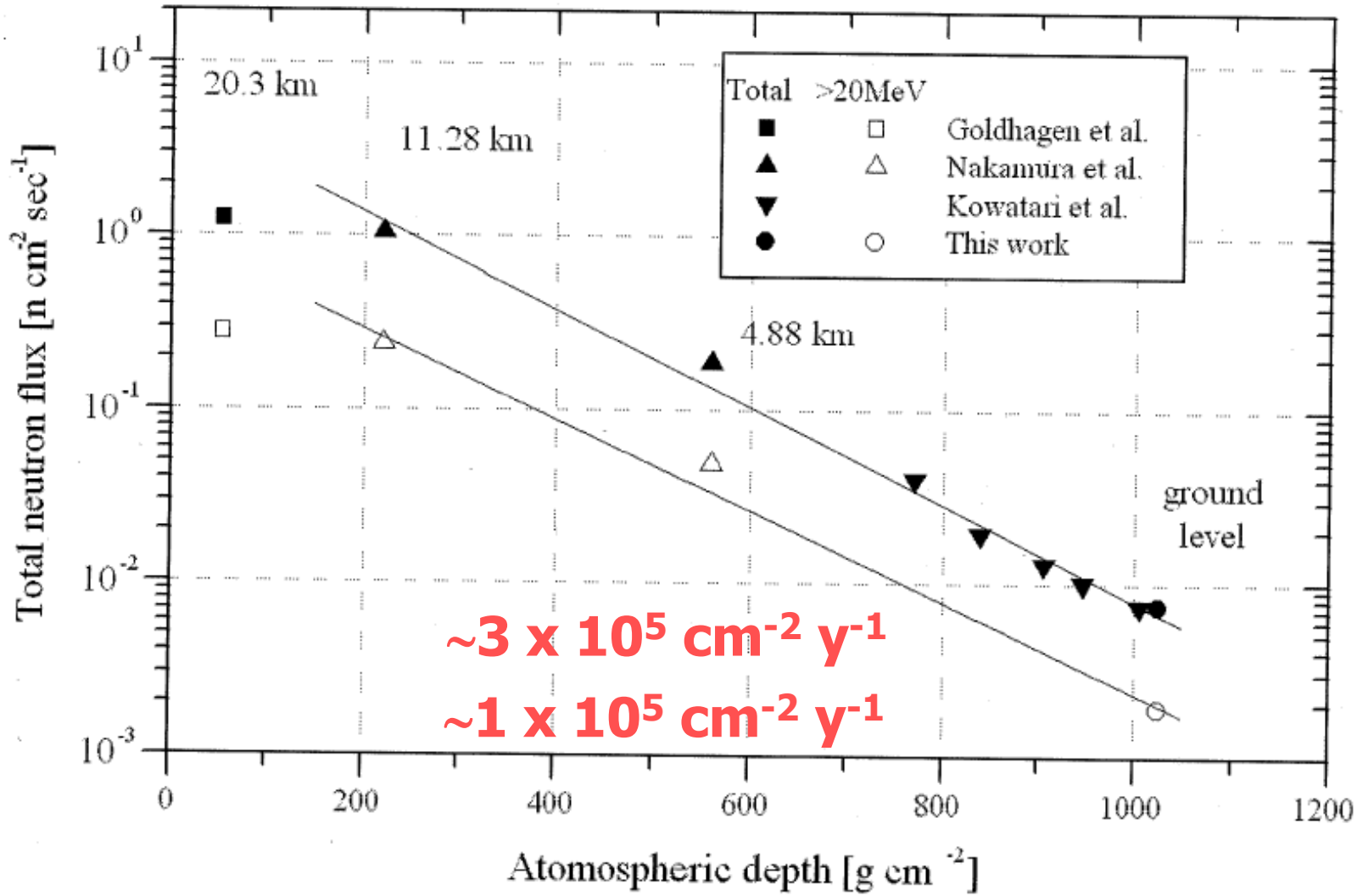
Radfet

High-Energy Hadron Fluences



e.g., some rough LHC-Levels for Hadrons (E > 20 MeV) per cm^2 <u>per nominal year</u>

Neutron flux (> 20 MeV) in the atmosphere



© *Nakamura et al.: Terrestrial Neutron-Induced Soft Errors in Advanced Memory Devices*

Overview/Content

This lecture aims giving a:

- A quick reminder about '**The Problem**'
- **A Brief outline** about R2E and related activities
- **An overview** of currently known '**critical**' LHC regions **[without going into details (see respective collected presentations)]**
- The latter **shall trigger many of you**
- An overview how **related information is currently centralized** to allow easier access and better coordination and prioritization
- An introduction into a **future Electronics Policy** for LHC machine related radiation areas

All **R2E activities, presentations, minutes, publications and related information** are continuously updated and available at:

www.cern.ch/R2E

The Objective of A Complete Overview

!!! R2E Iterations Ongoing !!!

- **critical LHC areas** where electronic
  d pose a problem
- **perspective** with respect to:
  - in terms of **simulations** & calculations
  - **monitoring**
  - cy on actual operation – **scaling** with:
    - sses at beam elements (*e.g.*, collimation)
    - luminosity (*e.g.*, UJs at IR1/5)
    - beam-gas density (*e.g.*, REs)
  - options for **solutions** (*e.g.*, shielding)
  - installed electronics (**criticality**)
    - failure consequences
    - radiation sensitivity
    - possibilities for (re)design

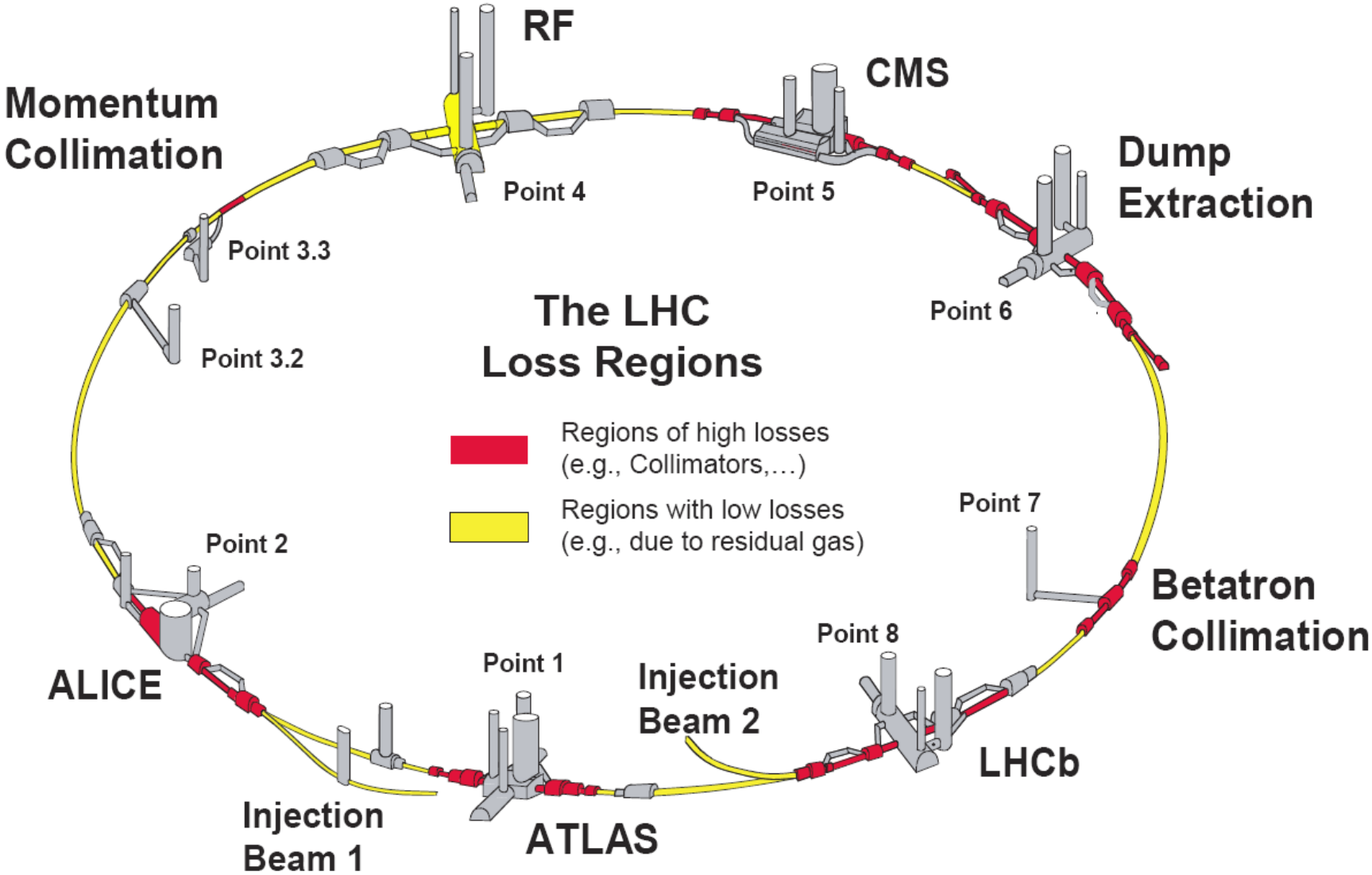
this lecture

Your Presence

- **Assign priorities** according to a clear logic, however with iterations allowing to consider important (partly missing) information and discussions
- Putting this **in relation with the operational schedule** and planning

LHC Areas and Radiation Levels

Quite a lot of 'Dangerous' Regions …



Normalisation & Scaling

- **Direct losses** (collimation, TCDQ,…)
  - total losses depend on beam intensity, however as well as on machine performance and stability and required aperture settings of beam intercepting devices
  - already in early operation one could possibly "locally" reach levels close to ½ nominal
  - high uncertainty in distribution of losses which can locally raise radiation levels (*e.g.*, TCLA <-> RR77)
- **Beam-Beam** (areas adjacent to experiments,…)
  - mainly luminosity dependent
- **Beam-Gas** (REs, UX45,…)
  - depend on residual beam-gas densities, the respective gas composition as well as the actual beam intensity
- **Combinations of the above**

Classification of Regions

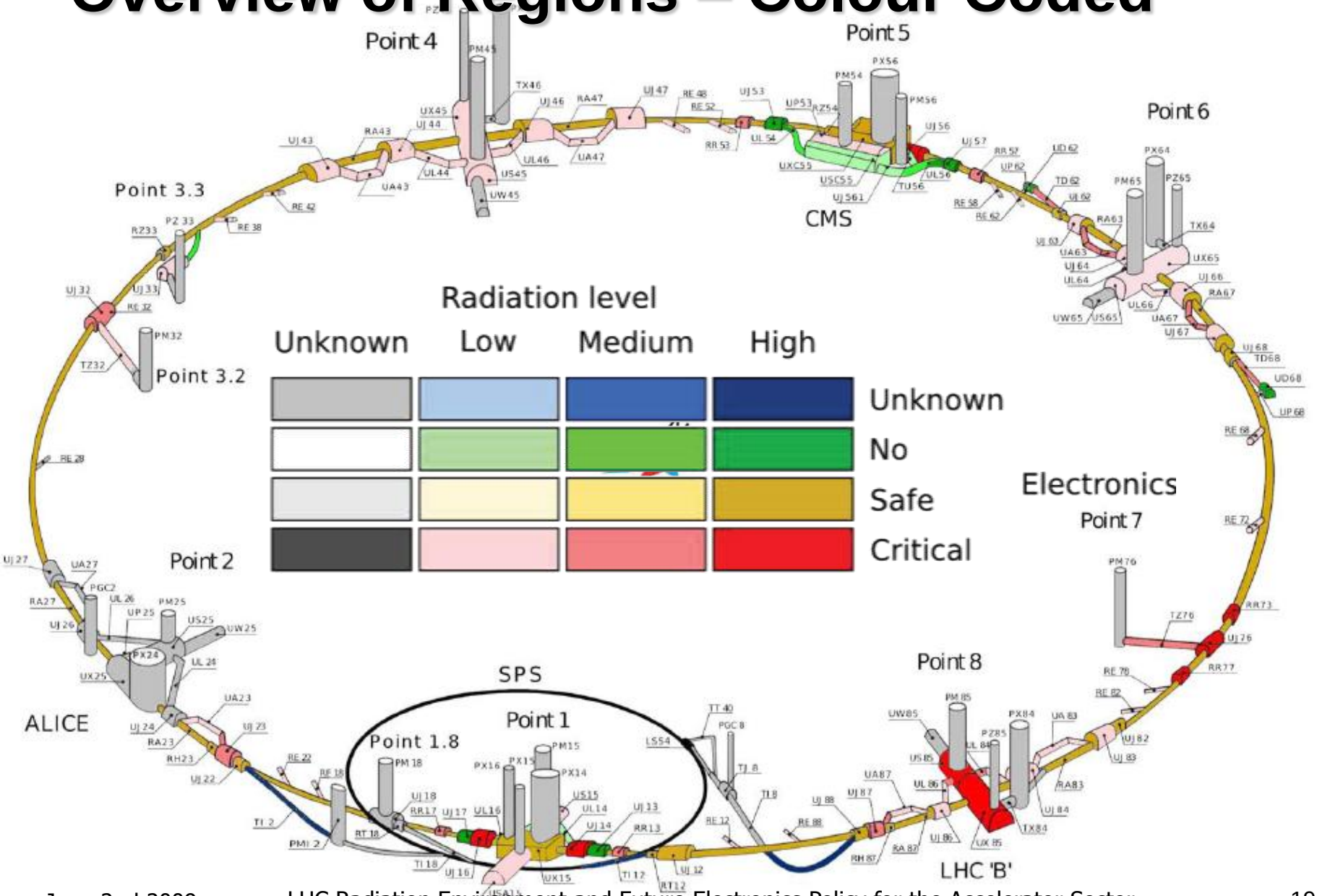
Selected Levels – Defined Thresholds

- **Installed Electronics (always)**
  - no electronics
  - unknown electronics
  - off-the shelf or known to be weak electronics
  - special designed electronics
- **High-E Hadrons (20MeV)**
  - Fluence < $1x10^7 cm^{-2}$
  - $1x10^7 cm^{-2}$ < Fluence < $1x10^9 cm^{-2}$
  - $1x10^9 cm^{-2}$ < Fluence
- **Dose**
  - Dose < 1Gy/y
  - 1Gy/y < Dose < 1kGy
  - 1kGy/y < Dose
- **Displacement Damage 1MeV**
  - Fluence < $1x10^8 cm^{-2}$
  - $1x10^8 cm^{-2}$ < Fluence < $1x10^{10} cm^{-2}$
  - $1x10^{10} cm^{-2}$ < Fluence

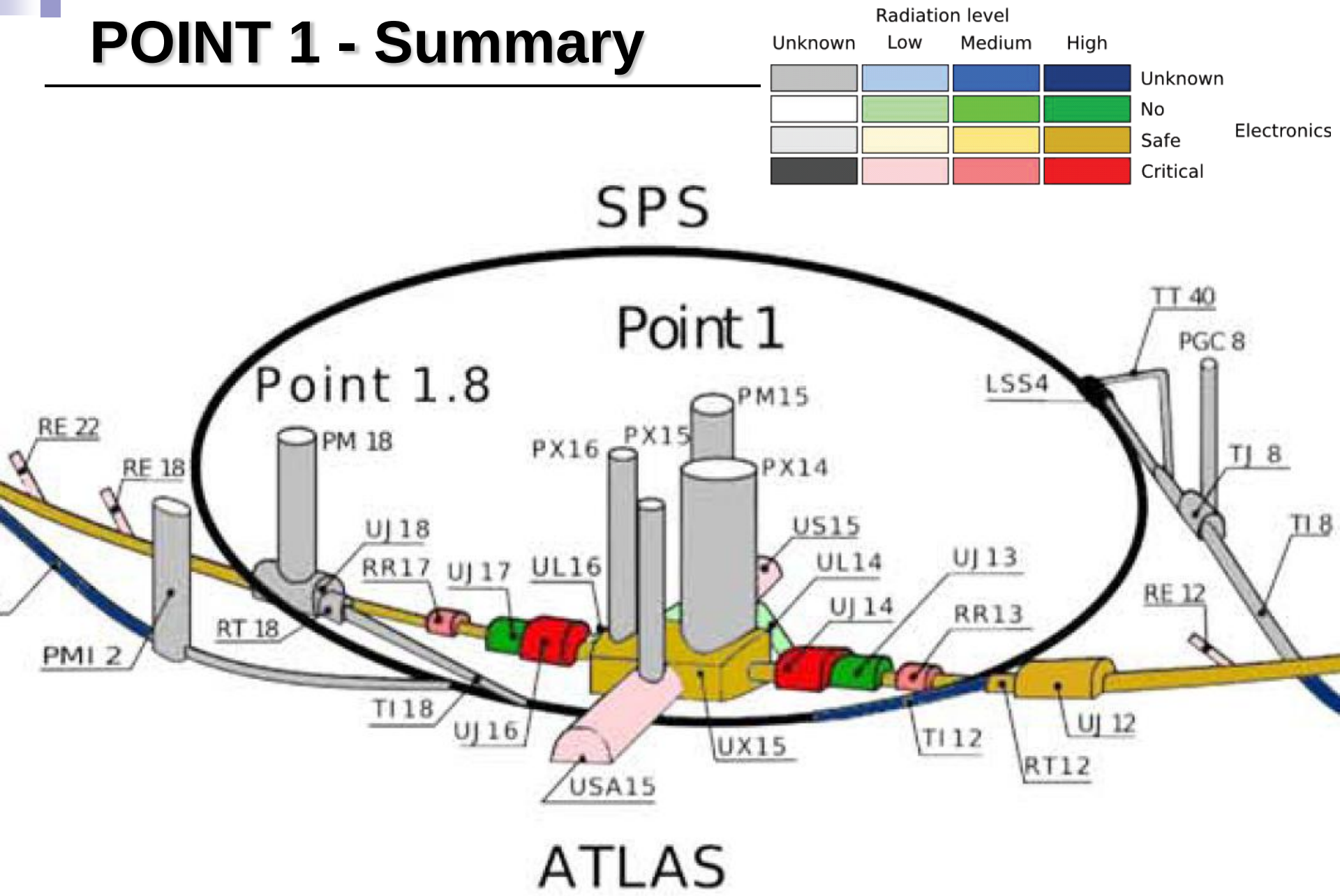
Area Codes:

- **Unknown Radiation Levels (grey)**
  - white: no electronics and unknown levels
  - light: safe electronics unknown levels
  - medium : **unknown** electronics and unknown radiation levels
  - dark: critical electronics & unknown levels
- **Unknown Electronics + Radiation (blue)**
  - light blue: unknown electronics, low radiation levels
  - medium blue: unknown electronics, medium levels
  - dark blue: unknown electronics, high levels
- **No Electronics (green)**
  - light green: no electronics, low levels
  - medium green: no electronics, medium levels
  - dark green: no electronics, high levels
- **Safe Electronics (orange)**
  - light orange: safe electronics, low levels
  - medium orange: safe electronics, medium levels
  - dark orange: safe electronics, high levels
- **Critical Electronics (red)**
  - light red: critical electronics, low levels
  - medium red: critical electronics, medium levels
  - dark red: critical electronics, high levels`

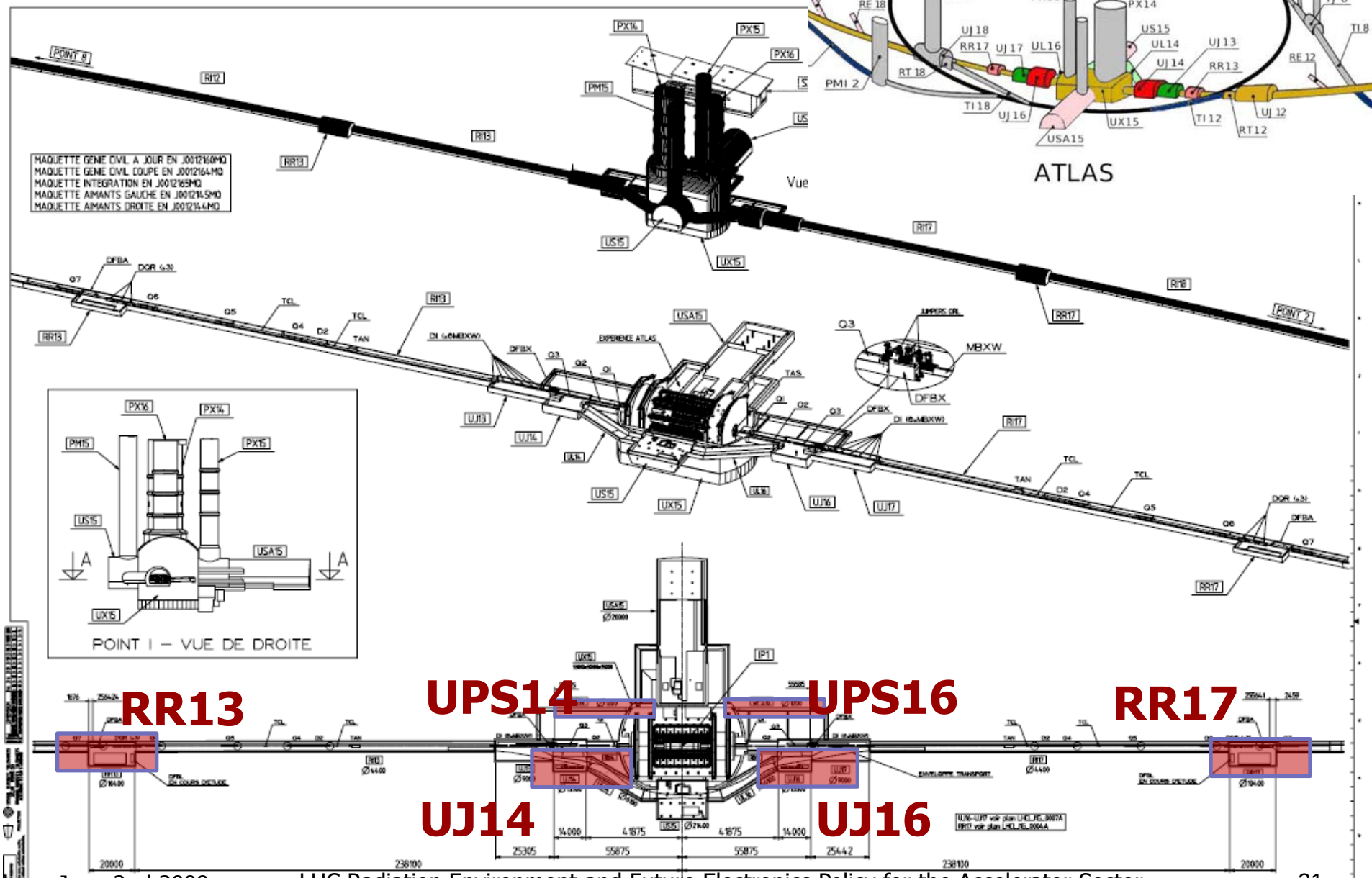
Overview of Regions – Colour Coded



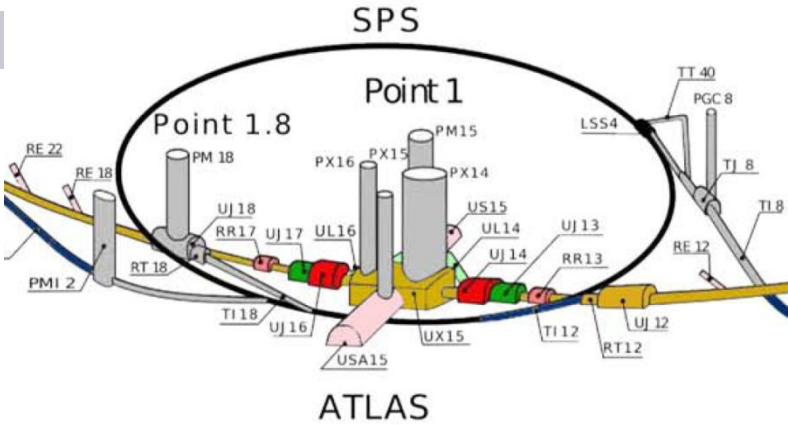
POINT 1 - Summary

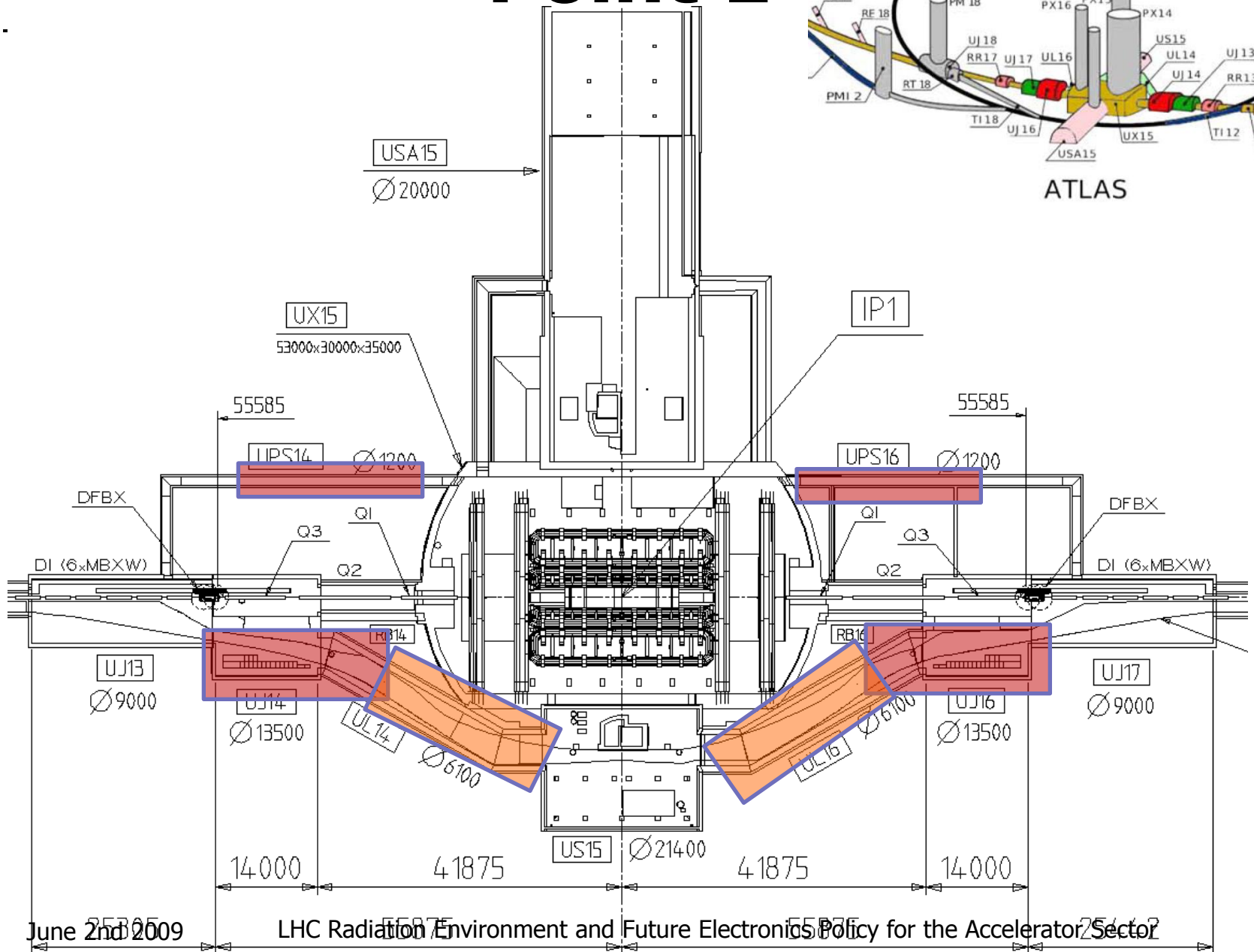


Point 1


SPS
Point 1
Point 1.8
ATLAS
RR13
UPS14
UPS16
RR17
UJ14
UJ16
POINT I – VUE DE DROITE

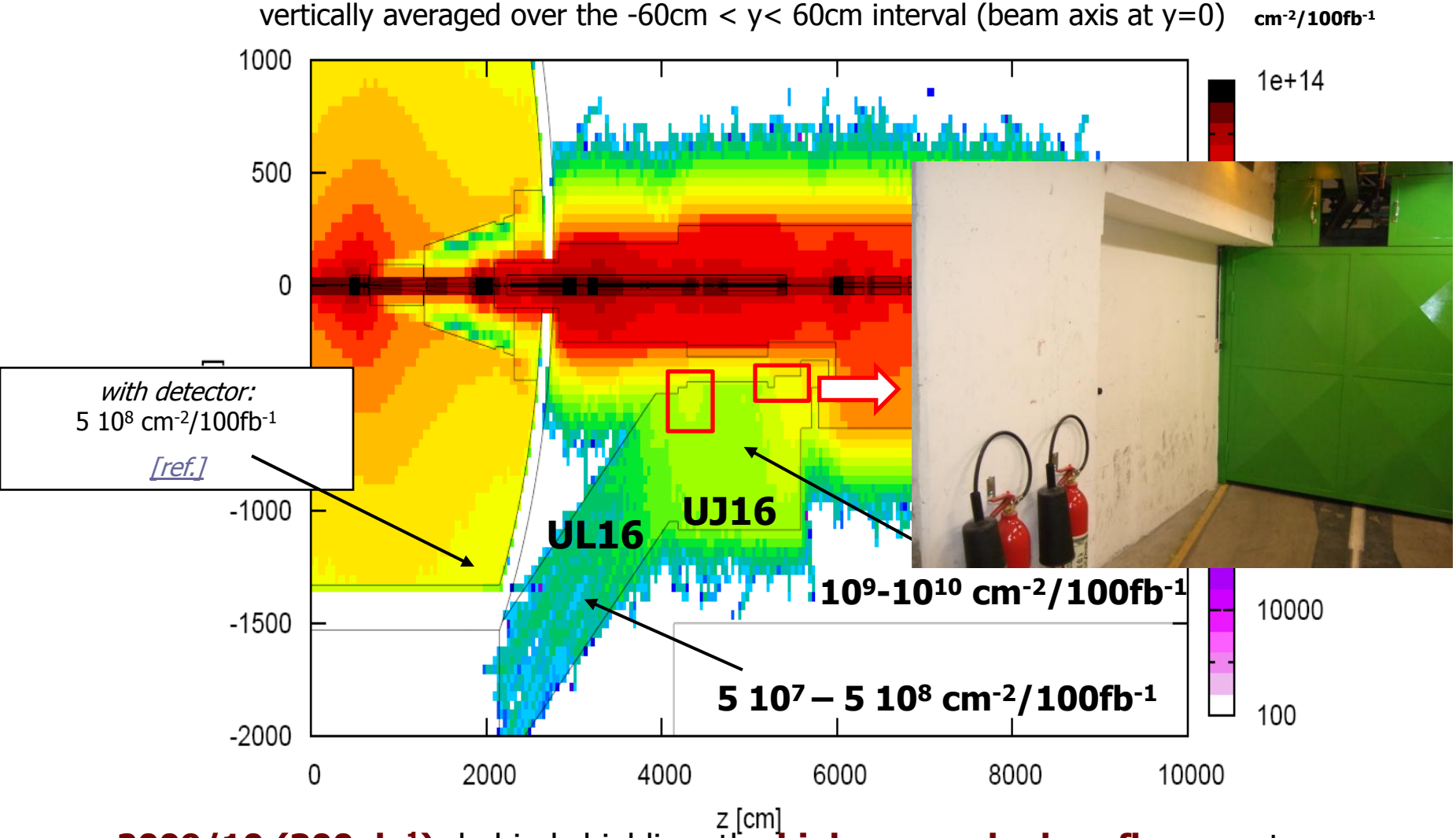
Point 1


SPS
Point 1
Point 1.8
ATLAS
RE 22
RE 18
PM 18
PX16
PX15
PM15
PX14
LSS4
TT 40
PGC 8
TJ 8
TI8
UJ 18
RR17
UJ 17
UL16
US15
UL14
UJ 13
UJ 14
RR13
RE 12
PMI 2
RT 18
TI 18
UJ 16
UX15
USA15
TI 12
RT12
UJ 12


USA15
∅20000
UX15
53000x30000x35000
IP1
55585
55585
UPS14
∅1200
UPS16
∅1200
DFBX
DFBX
Q1
Q1
Q3
Q3
Q2
Q2
DI (6xMBXW)
DI (6xMBXW)
RB14
RB16
UJ13
∅9000
UJ14
∅13500
UL14
∅6100
UL16
∅6100
UJ16
∅13500
UJ17
∅9000
US15
∅21400
14000
41875
41875
14000

High Energy Hadron Fluence

vertically averaged over the -60cm < y< 60cm interval (beam axis at y=0)



2009/10 (300pb^{-1}): behind shielding, the **high energy hadron fluence** at beam level ranges from **4x10^6 up to 4x10^7** cm^{-2} y^{-1}

USA15 and US15

ATL-GEN-2005-001
S. Baranov et al.

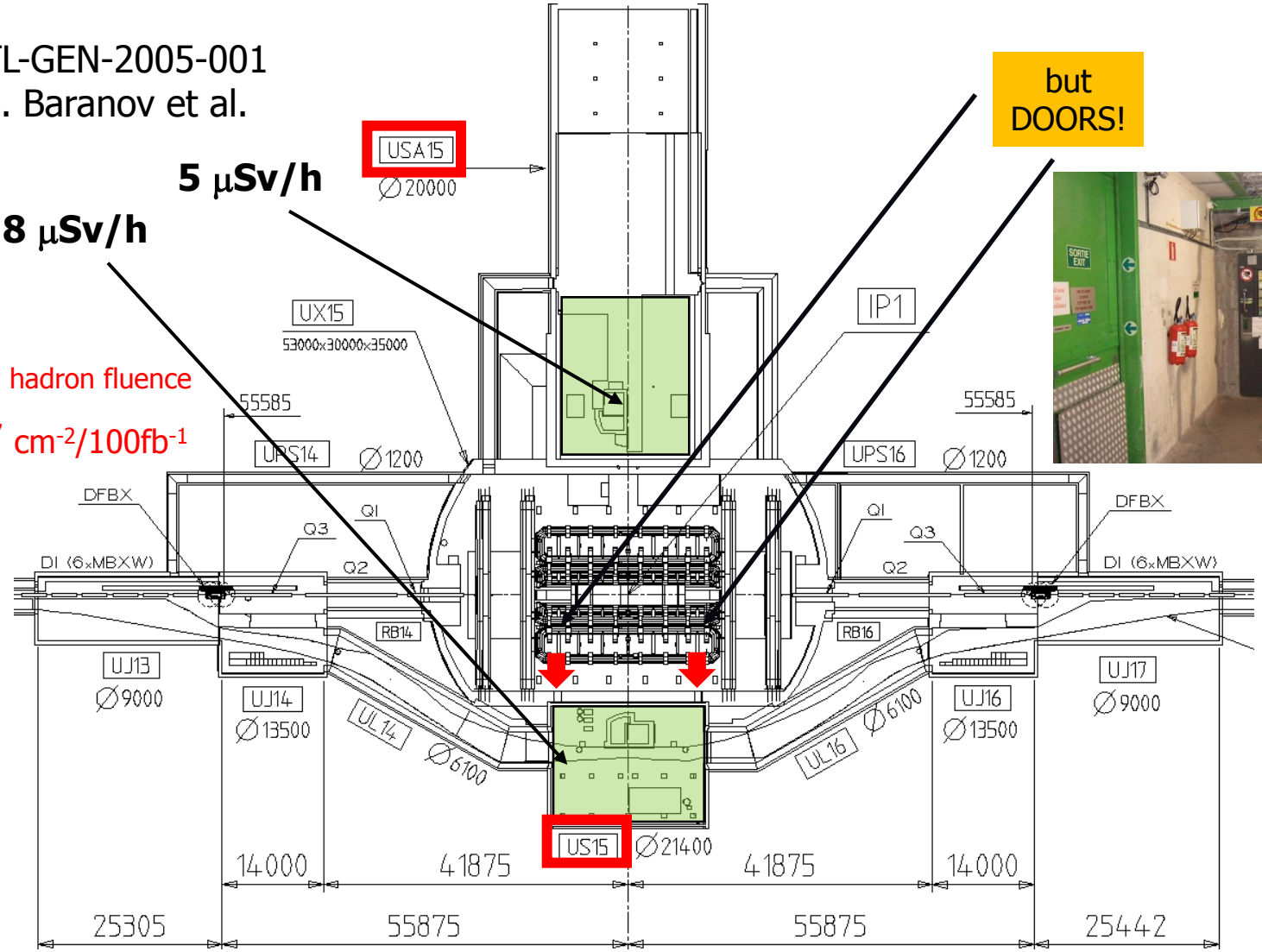
5 μSv/h

8 μSv/h

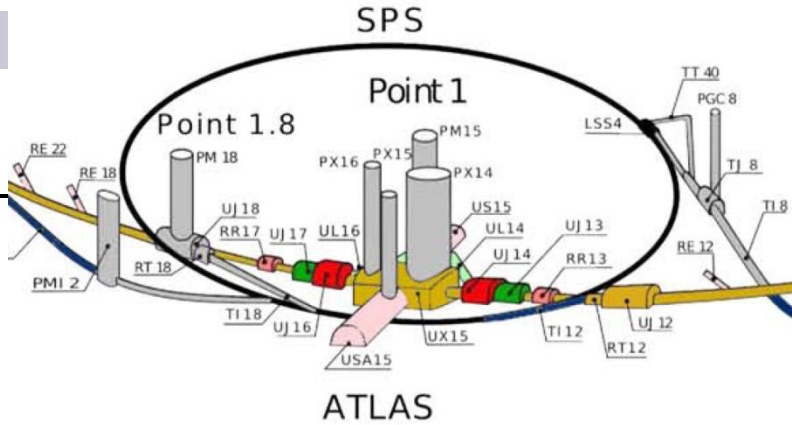
high energy hadron fluence

max ~10^7 $cm^{-2}/100fb^{-1}$

but DOORS!



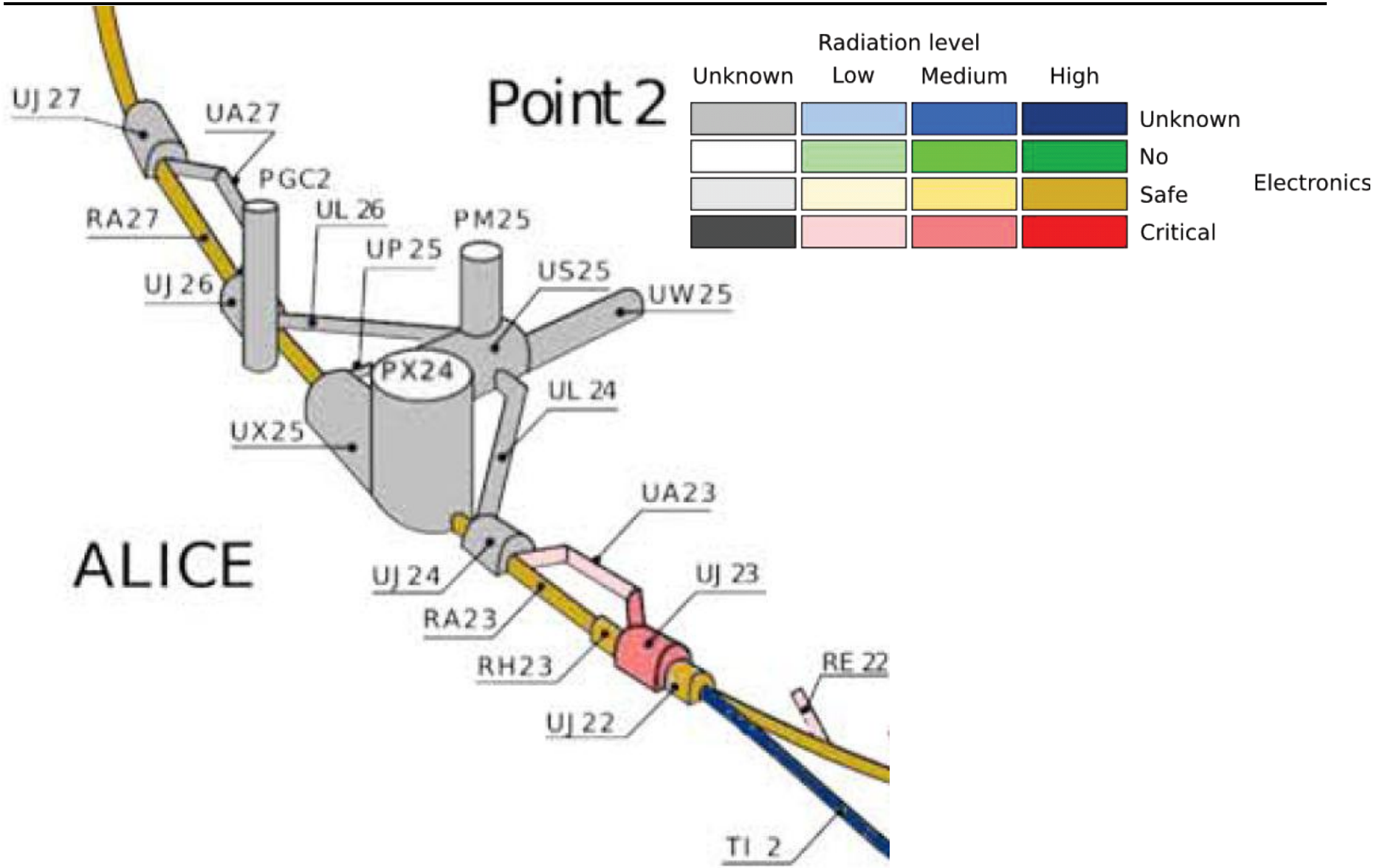
POINT 1 - Summary



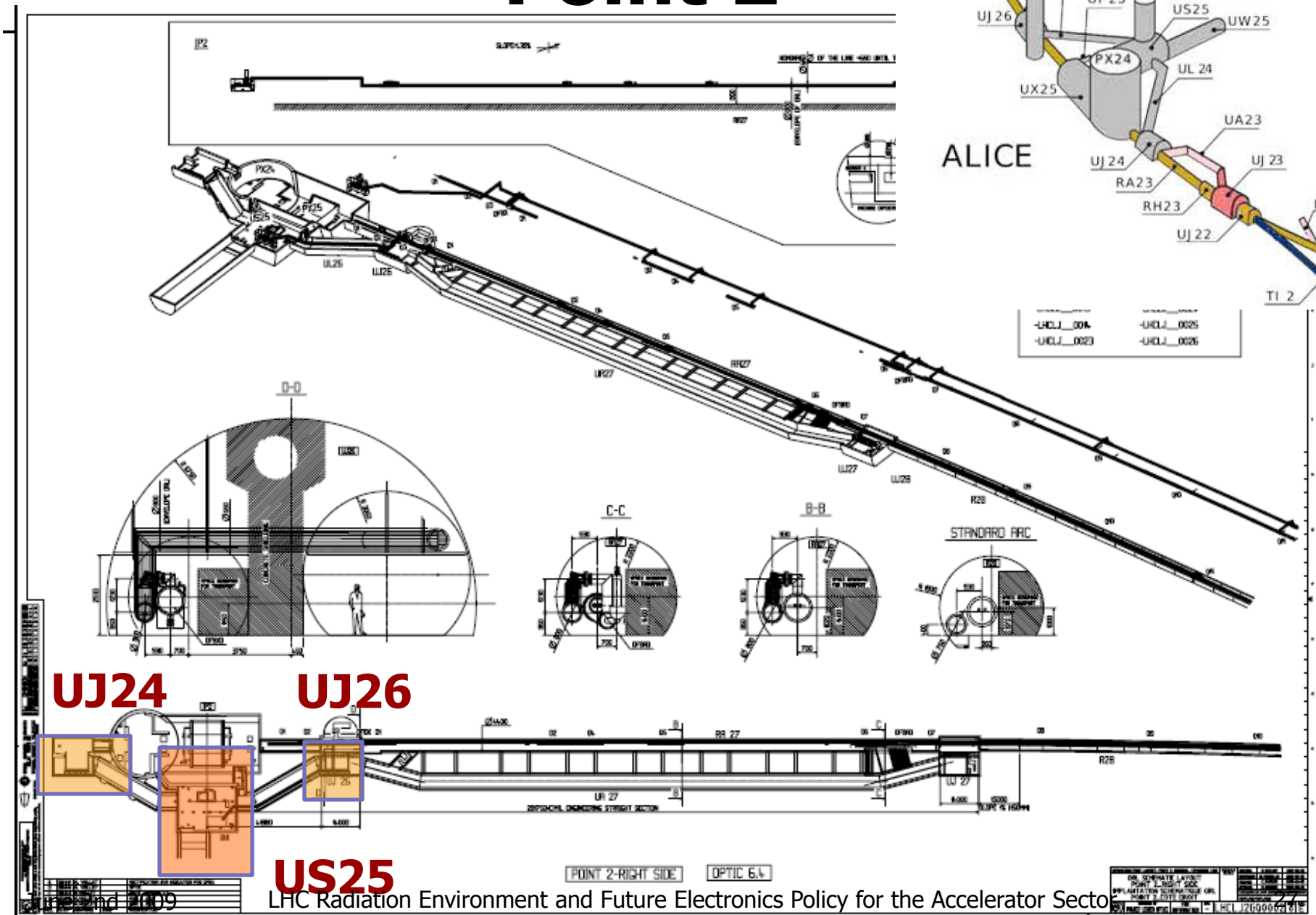
- Critical Areas: **UJ14, UJ16, RR13, RR17, UPS14, UPS16**
- Critical Electronics:
  - not all details known yet, Point-Iteration scheduled
  - assumption: all types similar to other UJs – QPS,PO, CTR,COM,CV,SFT, COLL, VAC,BI **+ …**
- Radiation Levels
  - **High-E Hadrons:** **UJs:$1x10^9$-$1x10^{10}$ / RRs: $3x10^7$-$9x10^7$ cm^{-2} / UPSs: ~$1x10^8$ cm^{-2}**
  - **1MeV Equ.:** **RRs: $1.5x10^8$-$4.5x10^8$ cm^{-2} / UPSs: ~$5x10^8$ cm^{-2}**
  - **Dose:** **RRs: 0.01 – 0.2 Gy/y**
  - Normalization: UJs: 100 fb^{-1} / RRs: 70 fb^{-1}
  - Scaling: luminosity, (and a bit residual beam-gas)

- Monitoring: RADMON, IG5 (UJs), PMI, BLM
- Shielding options: UJs: possible but not sufficient, RRs: improvement possible
- Relocation possibility: UJs: challenging, RRs: very very difficult, limited place available in ULs

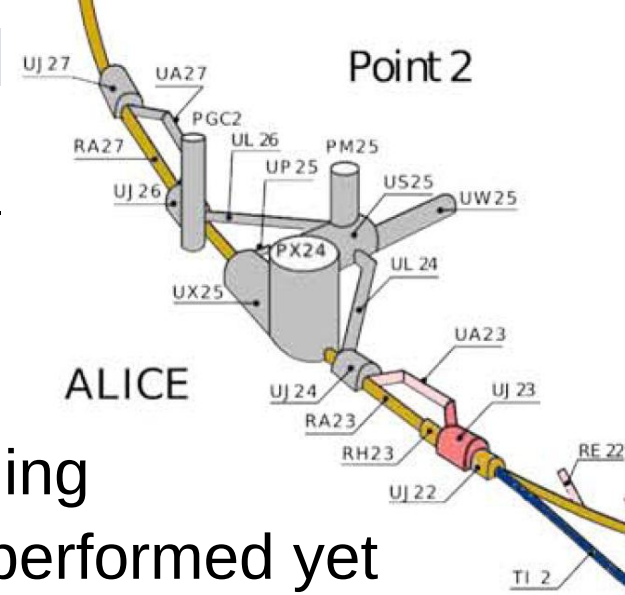
POINT 2 - Summary



Point 2


Point 2
UJ 27
UA27
PGC2
RA27
UL 26
PM25
UP 25
UJ 26
US25
UW25
PX24
UL 24
UX25
UA23
ALICE
UJ 24
UJ 23
RA23
RH23
RE 22
UJ 22
TI 2
D-D
C-C
B-B
STANDARD ARC
UJ24
UJ26
US25
POINT 2-RIGHT SIDE
OPTIC 6.4

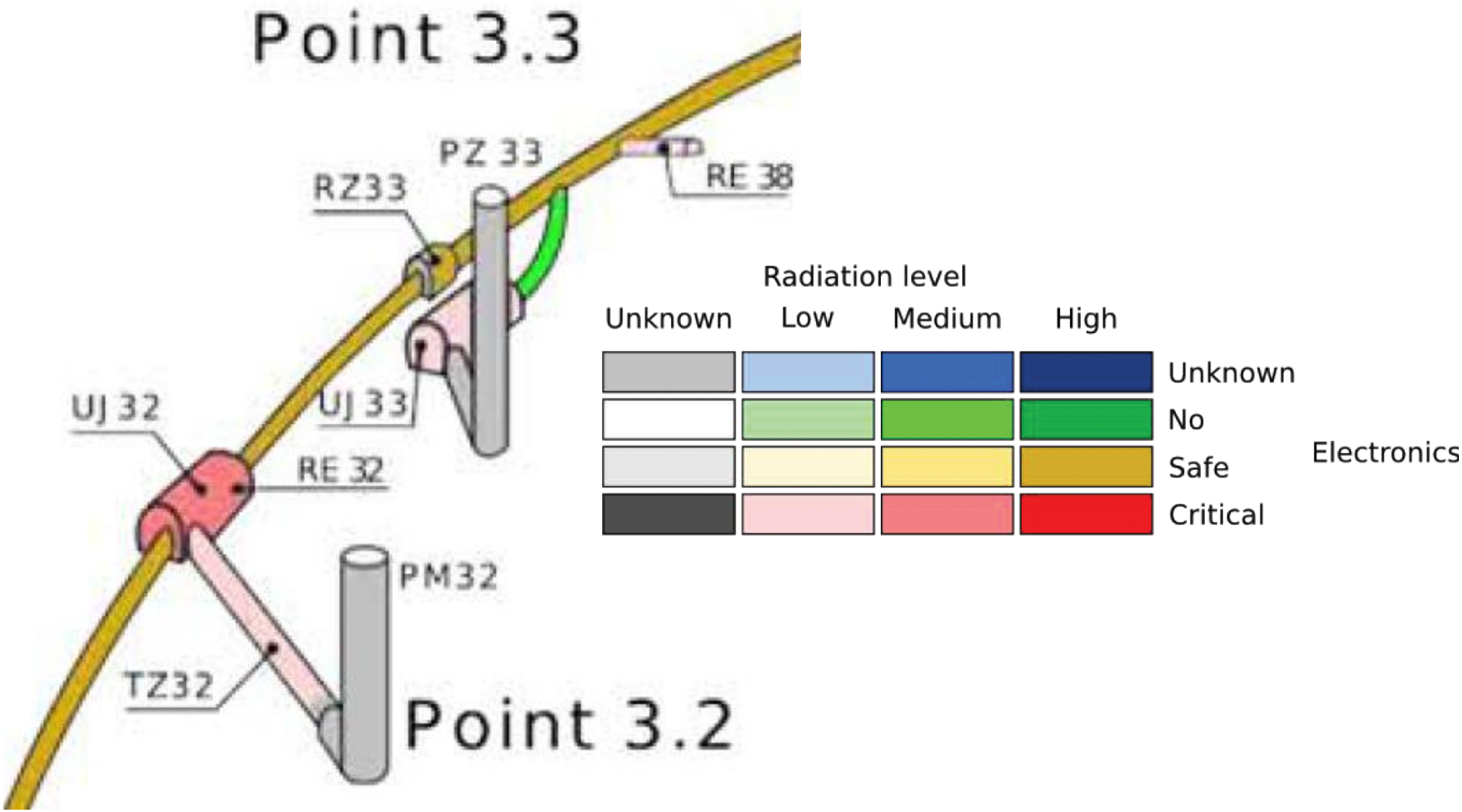
POINT 2 - Summary



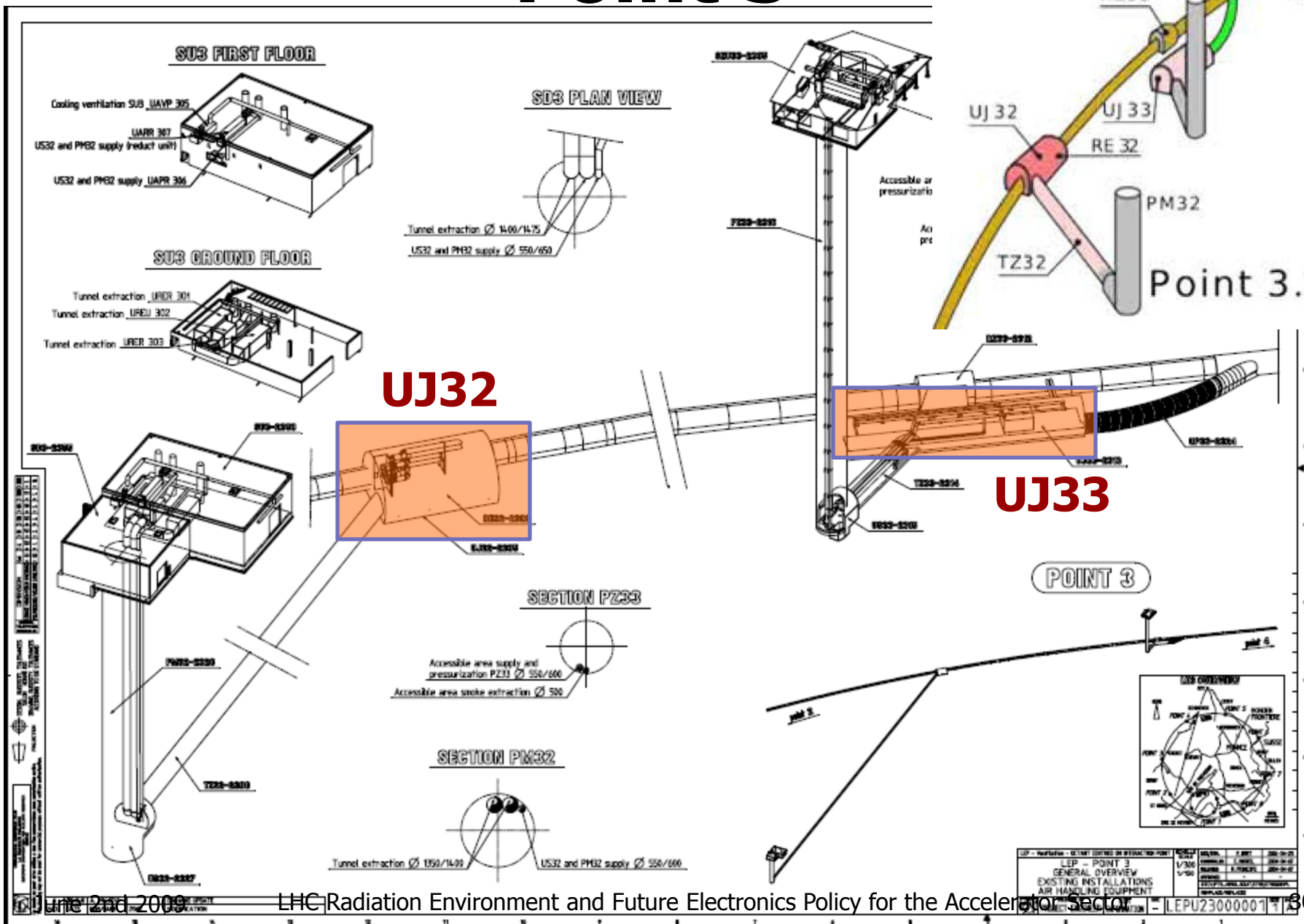
- no Point-Iteration performed yet
- levels assumed to be low due to low luminosity and important detector shielding
- no specific electronics related analysis performed yet
- **Available Information (A. Morsch FLUKA Studies)**
  - ITS, TPC, TRD,…:
  - UX25:
  - Platforms:
  - PX24:

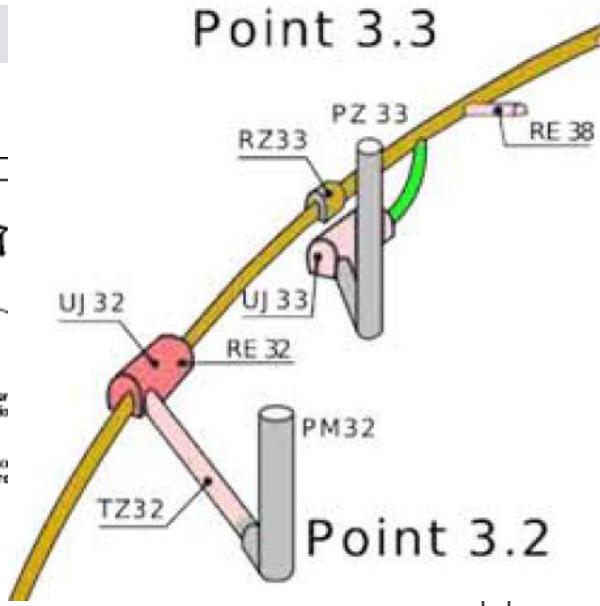
- **Comments:**
  - shielding penetrations in UJ24/26
  - calculations are not specific for electronic damage (mainly dose only and general particle energy fluences)
  - particle energy spectra exist for many locations

POINT 3 - Summary

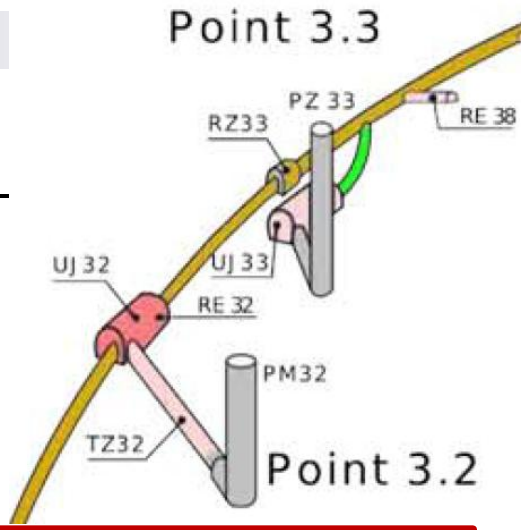


Point 3


SU3 FIRST FLOOR
Cooling ventilation SU3 UAVP 305
UARR 307
US32 and PM32 supply (reduct unit)
US32 and PM32 supply UAPR 306
SD3 PLAN VIEW
Tunnel extraction Ø 1400/1475
US32 and PM32 supply Ø 550/650
SU3 GROUND FLOOR
Tunnel extraction UREF 301
Tunnel extraction UREU 302
Tunnel extraction UREF 303
UJ32
UJ33
POINT 3
SECTION PZ33
Accessible area supply and pressurization PZ33 Ø 550/600
Accessible area smoke extraction Ø 500
SECTION PM32
Tunnel extraction Ø 1350/1400
US32 and PM32 supply Ø 550/600
LEP - POINT 3
GENERAL OVERVIEW
EXISTING INSTALLATIONS
AIR HANDLING EQUIPMENT
LEPU23000001

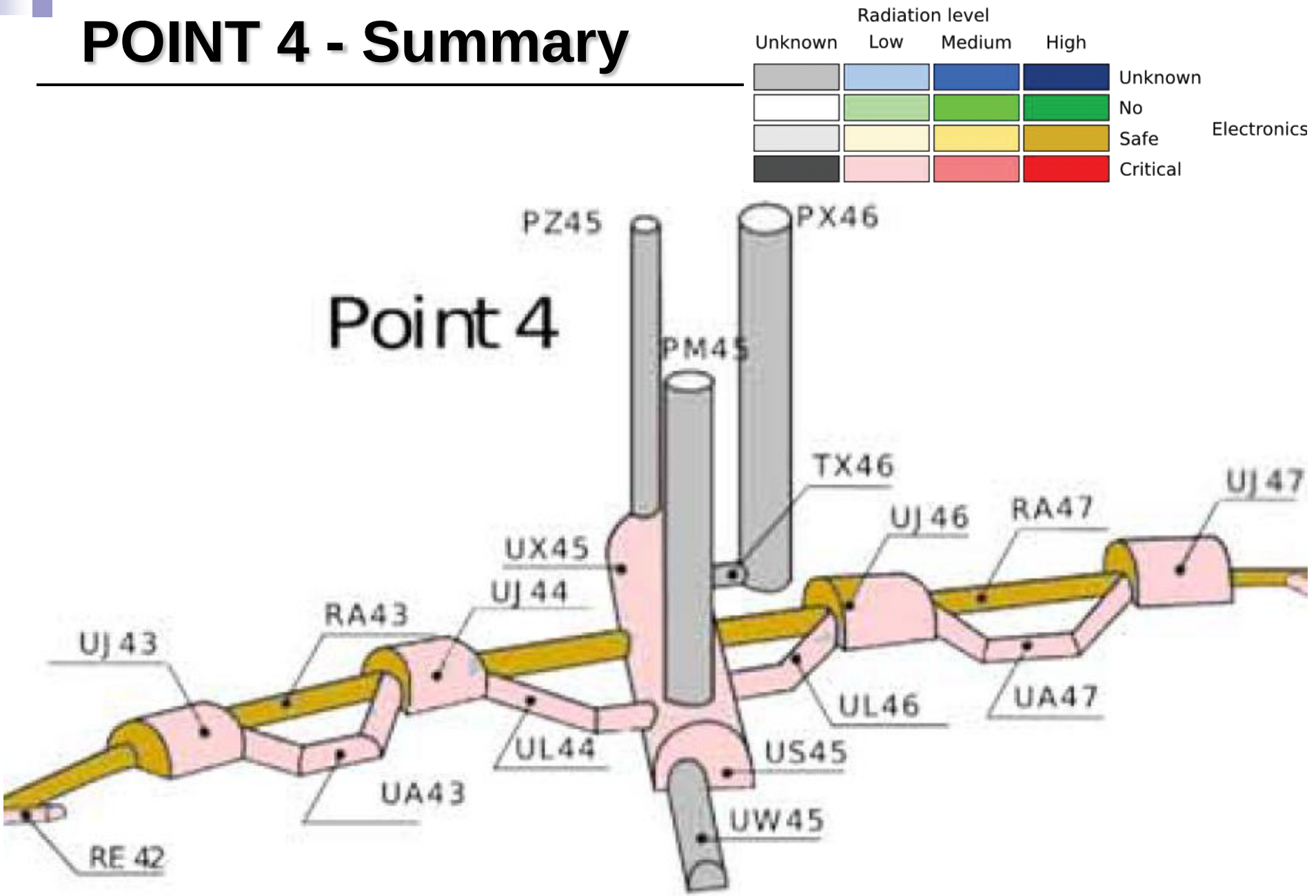

Point 3.3
PZ 33
RZ33
RE 38
UJ 32
UJ 33
RE 32
PM32
TZ32
Point 3.2

POINT 3 - Summary

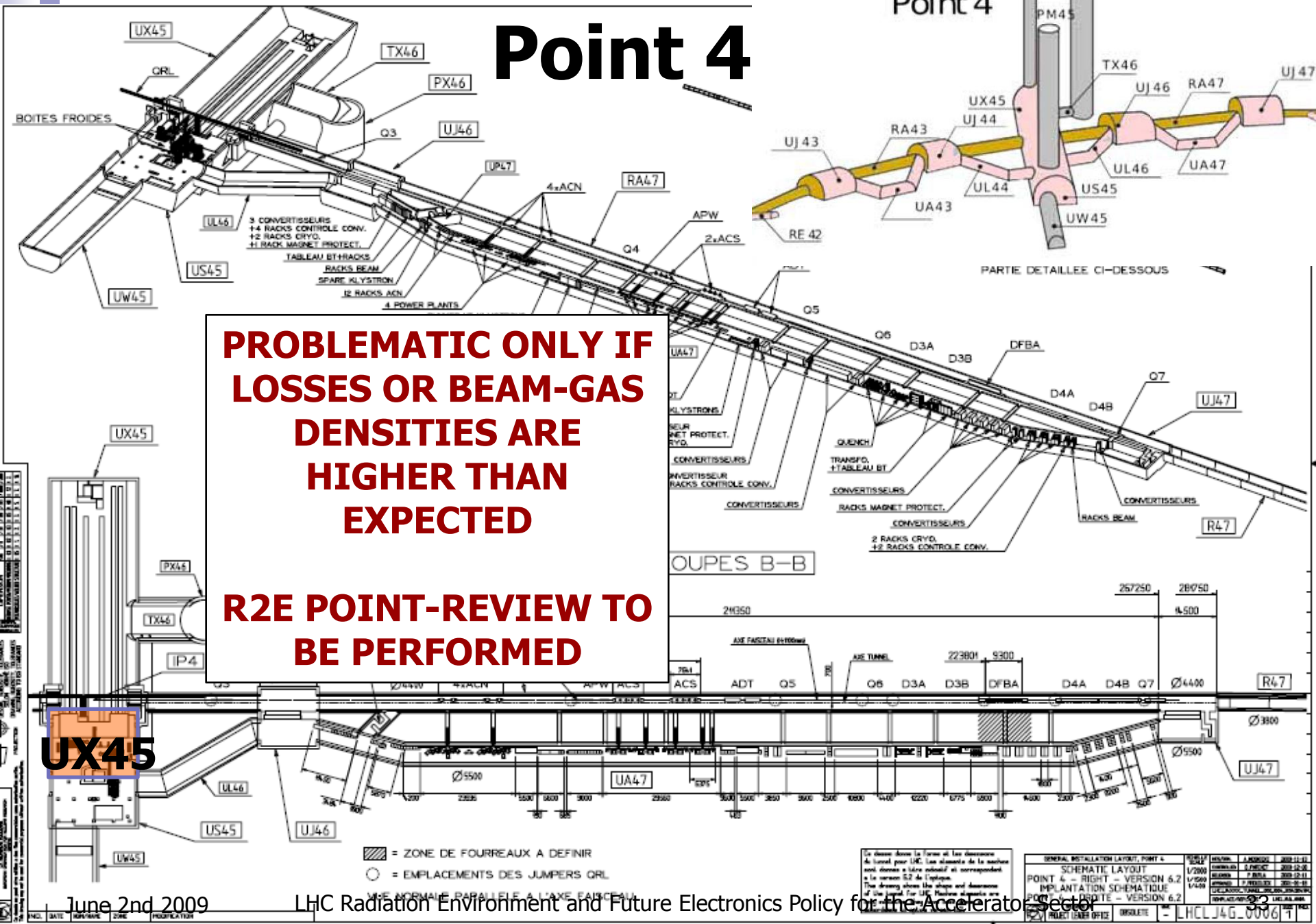


- Critical Areas: **UJ33, UJ32, RE38**
- Critical Electronics:
  - not all details known yet, Point-Iteration scheduled
  - assumption: all types similar to other UJs – QPS,PO, CTR, CRY, COM,CV,SFT,VAC,BI **+ …**
- Radiation Levels
  - **High-E Hadrons:** **UJ33:1x10^4-2x10^6 / UJ32: 1x10^7-1x10^8 cm^{-2} / RE38: 2x10^5-1x10^7 cm^{-2}**
  - **1MeV Equ.:** **UJ33:5x10^4-7x10^6 / UJ32: 1x10^8-1x10^9 cm^{-2} / RE38: 1x10^6-5x10^7 cm^{-2}**
  - **Dose:** **UJ33:< 1x10^{-3} Gy/y/ UJ32: < 0.01 Gy/y / RE38: < 1x10^{-3} Gy/y**
  - Normalization: UJ33: 1x10^{16} p/y, UJ32/RE38: 1.65x10^{11}m^{-1}y^{-1}
  - Scaling: UJs: Direct proton losses, RE: beam-gas
  - Comments: possible pessimistic beam-gas assumptions for UJ32
    maze layout of UJ32 to be checked
- Monitoring: RADMON, IG5 (UJ33), PMI (outside), BLM (outside)
- Shielding options: Not needed (UJs: difficult if needed)
- Relocation possibility: UJ32 -> TZ32 (if needed which is unlikely!)
- Replacement/Redesign: low priority
- Comments:
  - influence of realistic loss assumptions including uncertainties to be studied
  - check for Cryo installation at UP/UJ junction

POINT 4 - Summary



Point 4

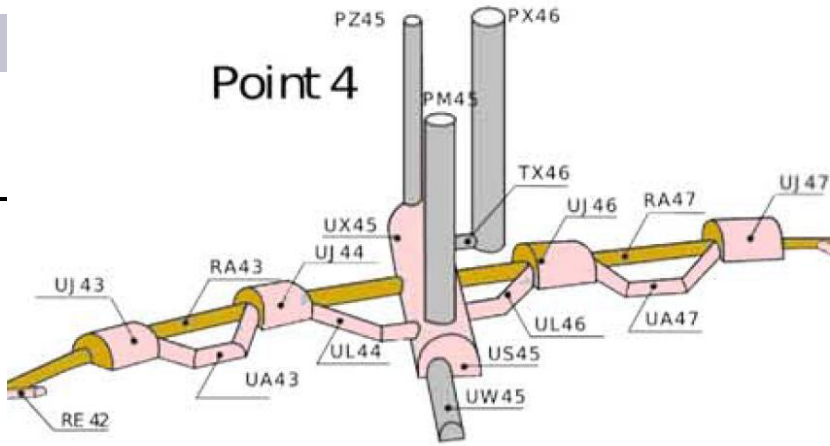


PROBLEMATIC ONLY IF LOSSES OR BEAM-GAS DENSITIES ARE HIGHER THAN EXPECTED

R2E POINT-REVIEW TO BE PERFORMED

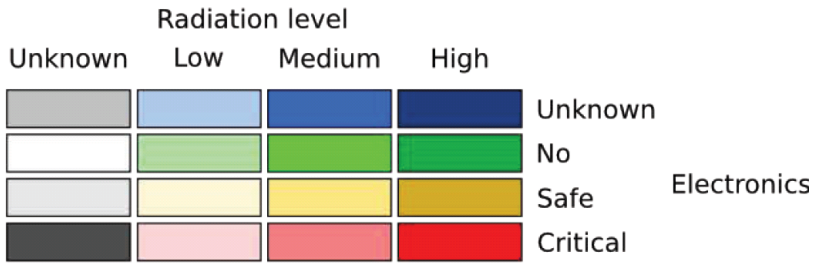
UX45

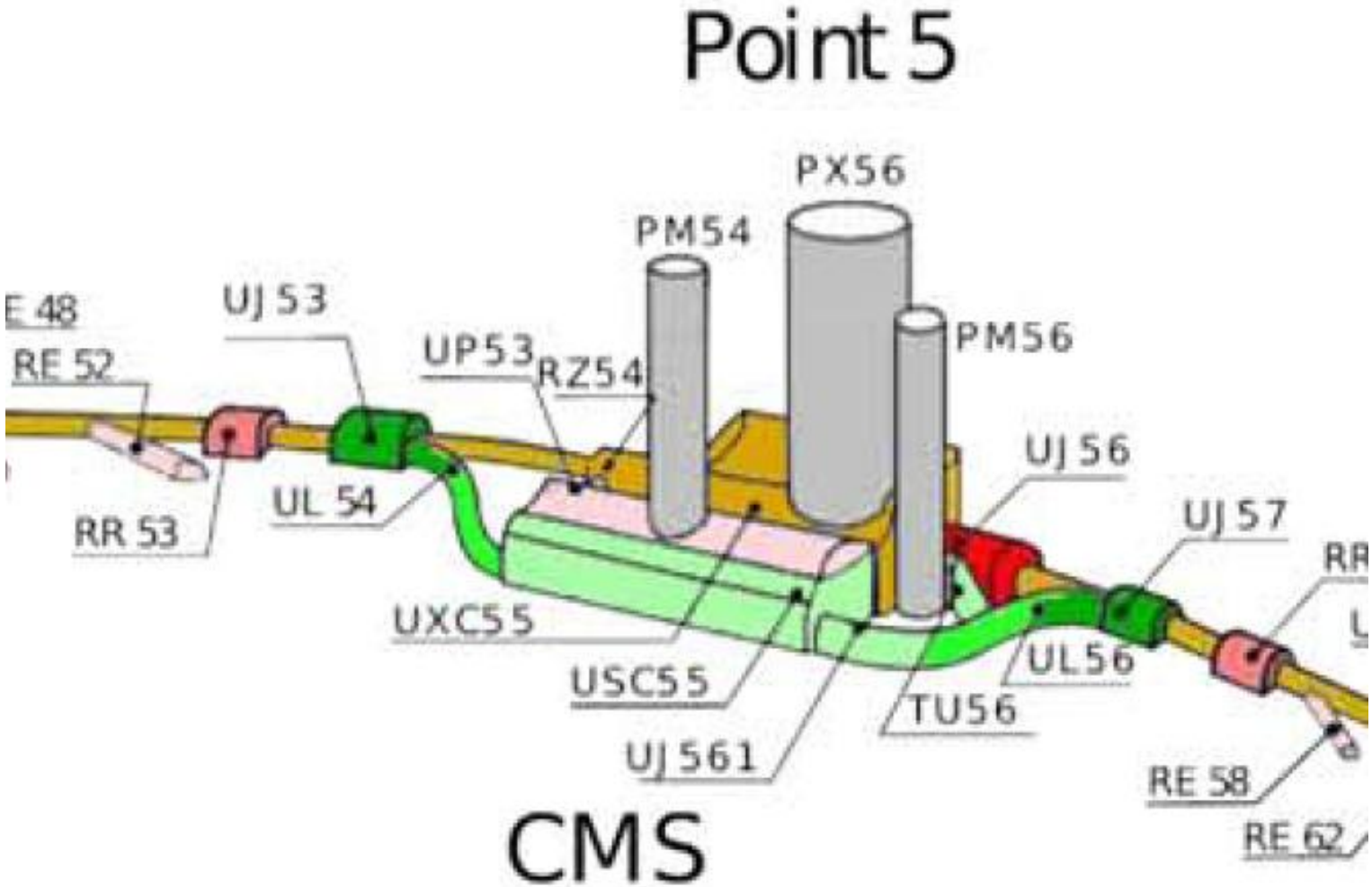
POINT 4 - Summary



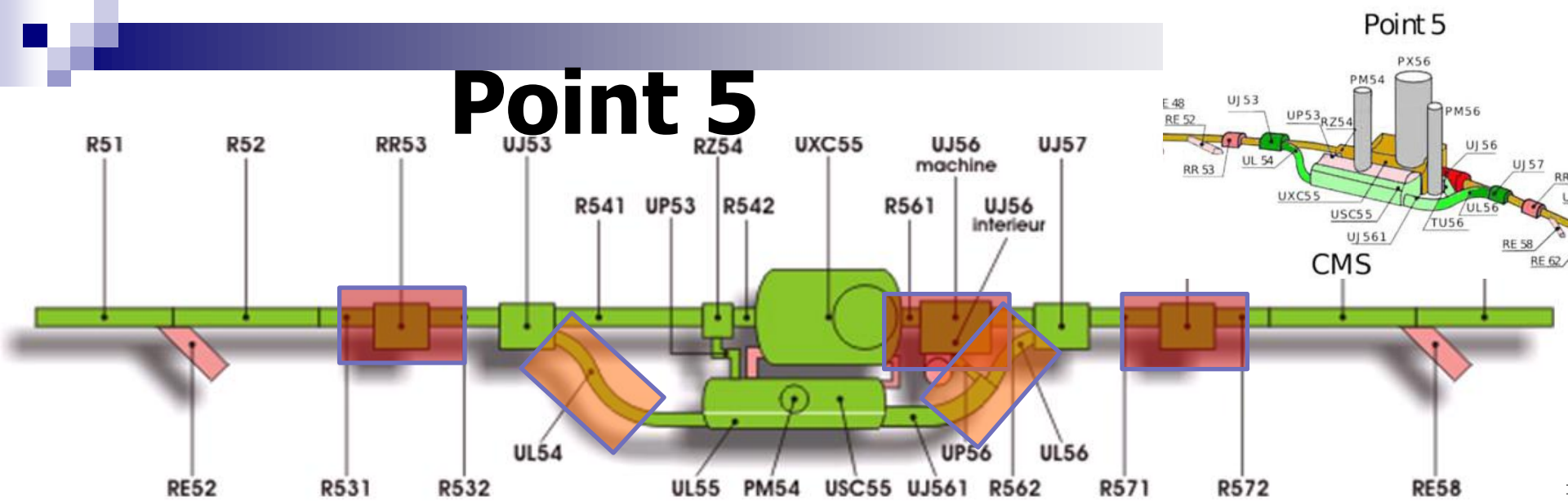
- Critical Areas:
  - **UX45**
- Critical Electronics:
  - CRY, RF,CO,CV, **+ …**
- Radiation Levels
  - High-E Hadrons: $5x10^6$ cm^{-2}/y
  - 1MeV Equ.: $1.5x10^7$ cm^{-2}/y
  - Dose:
  - Normalization: $2.4x10^{10}$ $m^{-1}y^{-1}$
  - Scaling: Beam-Gas
  - Comments: normalisation is different for various elements, stated =dominating
- Monitoring: to be updated
- Shielding : to be updated
- Relocation possibility: to be updated
- Replacement/Redesign: to be updated

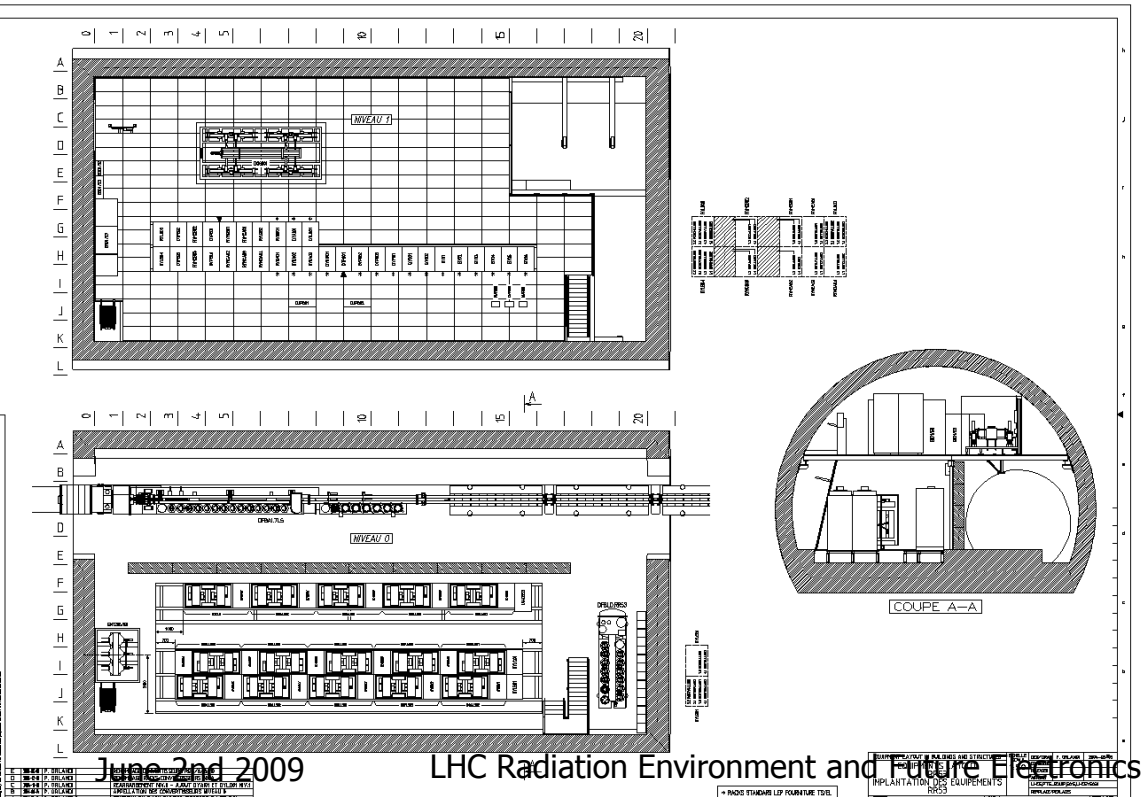
POINT 5 - Summary

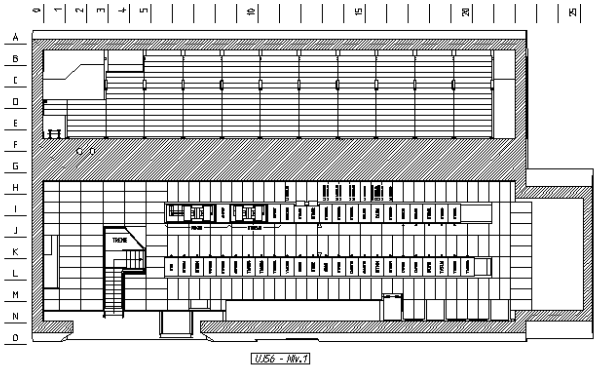


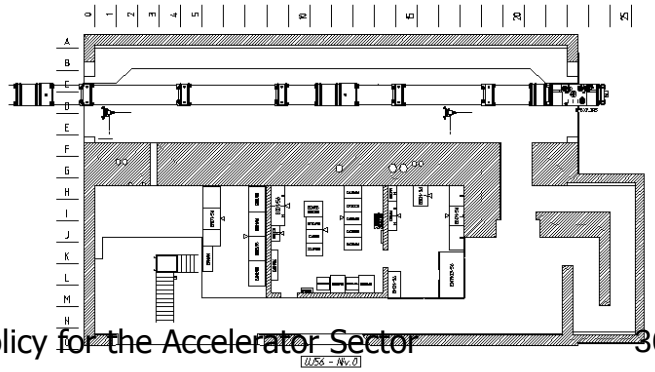


Point 5


Point 5
R51
R52
RR53
UJ53
RZ54
UXC55
UJ56
machine
UJ57
R541
UP53
R542
R561
UJ56
interieur
UL54
UP56
UL56
RE52
R531
R532
UL55
PM54
USC55
UJ561
R562
R571
R572
RE58
PX56
PM54
PM56
UJ53
UP53
RZ54
UJ56
UJ57
UL54
UXC55
USC55
UL56
TU56
UJ561
RE 58
RE 62
CMS


NIVEAU 1
NIVEAU 0
COUPE A-A

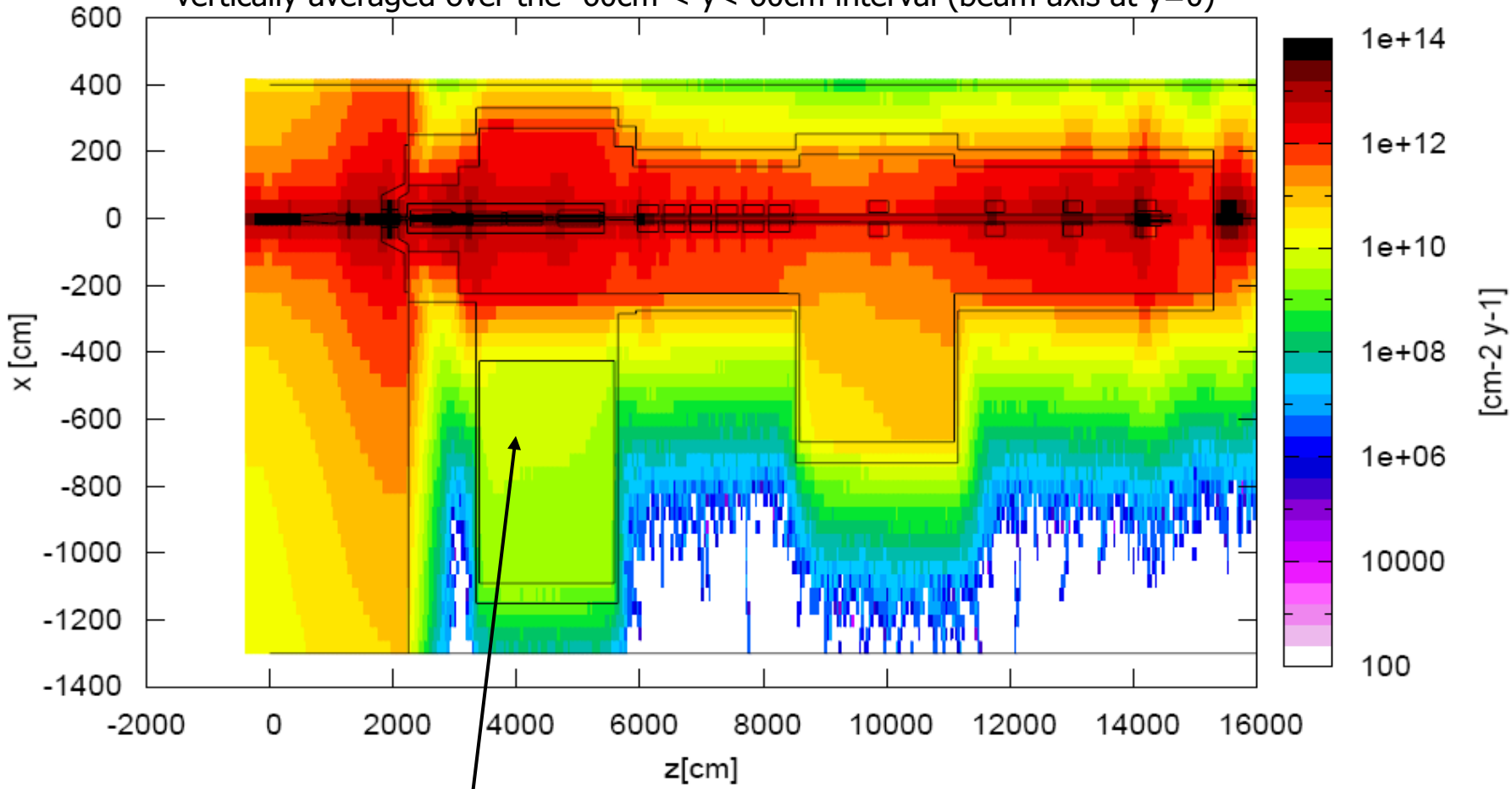

UJ56 - Niv.1


UJ56 - Niv.0

High Energy Hadron Fluence

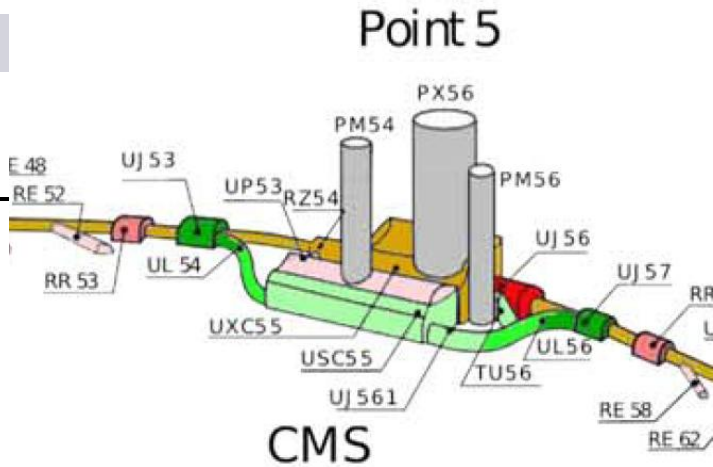
for a total luminosity of **100** fb^{-1} y^{-1} (*i.e.*, $L=L_0$ for 10^7 s/y)

vertically averaged over the -60cm < y< 60cm interval (beam axis at y=0)



2009/10 (300pb^{-1}): after a 2m concrete shielding, the **high energy hadron fluence** at beam level ranges from **4x10^6 up to 4x10^7** cm^{-2} y^{-1}

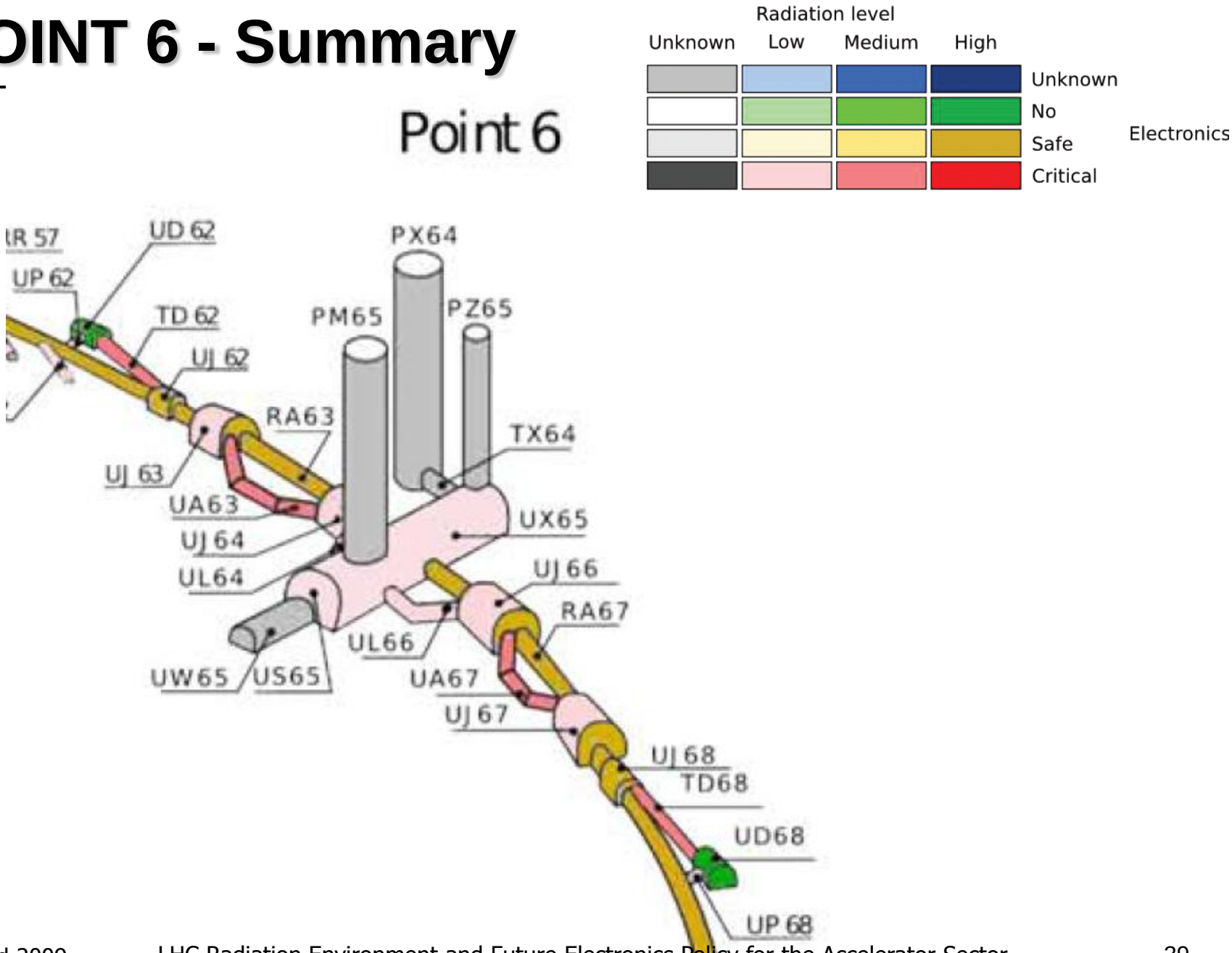
POINT 5 - Summary



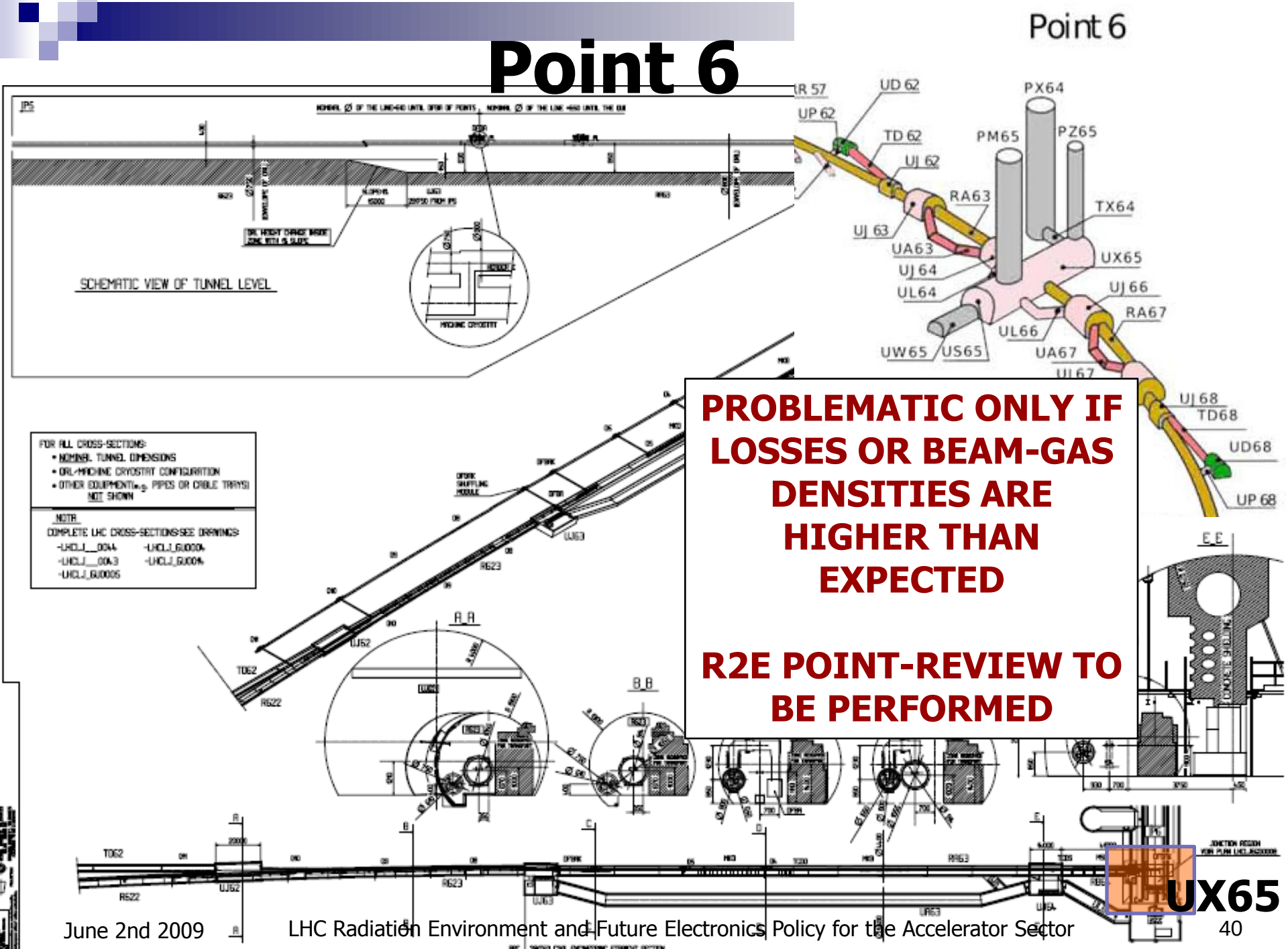
- Critical Areas:
  - **UJ56. RR53, RR57**
  - **UPS54, UPS56**
- Critical Electronics:
  - not all details known yet, Point-Iteration scheduled
  - assumption: all types similar to other UJs – QPS,PO, CTR,COM,CV,SFT,COLL,VAC,BI **+ …**
- Radiation Levels
  - **High-E Hadrons: UJ56:1x10^{9}-1x10^{10} / RRs: 3x10^{7}-9x10^{7} cm^{-2} / UPS: ~1x10^{8} cm^{-2}**
  - **1MeV Equ.: UJ56:1x10^{10}-1x10^{11} / RRs: 1.5x10^{8}-4.5x10^{8} cm^{-2} / UPS: ~5x10^{8} cm^{-2}**
  - **Dose: UJ56: 1-10Gy/y / RRs: 0.01 – 0.2 Gy/y**
  - Normalization: UJs: 100 fb^{-1}, RRs: 70 fb^{-1} / 2.5x10^{9}– 6.3x10^{10} m^{-1}
  - Scaling: luminosity, beam-gas ???

- Monitoring: RADMON, IG5 (UJs), PMI, BLM
- Shielding options: UJs: possible but not sufficient, RRs: improvement possible
- Relocation possibility: UJ: challenging, RRs: very very difficult,

POINT 6 - Summary



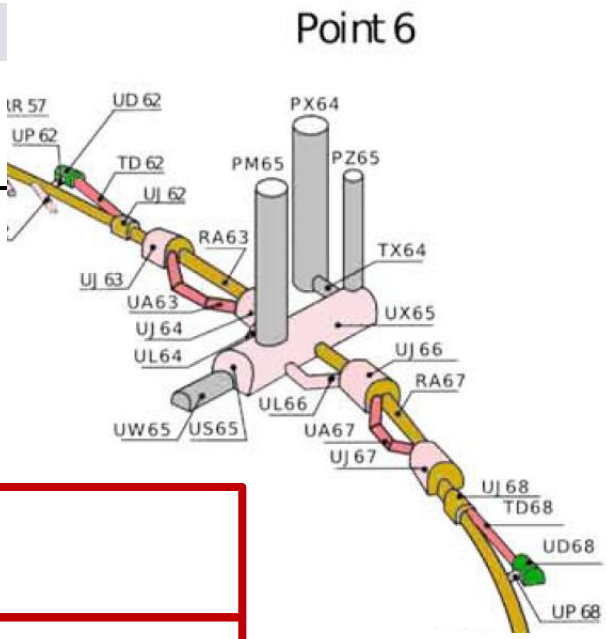
Point 6



PROBLEMATIC ONLY IF LOSSES OR BEAM-GAS DENSITIES ARE HIGHER THAN EXPECTED

R2E POINT-REVIEW TO BE PERFORMED

POINT 6 - Summary

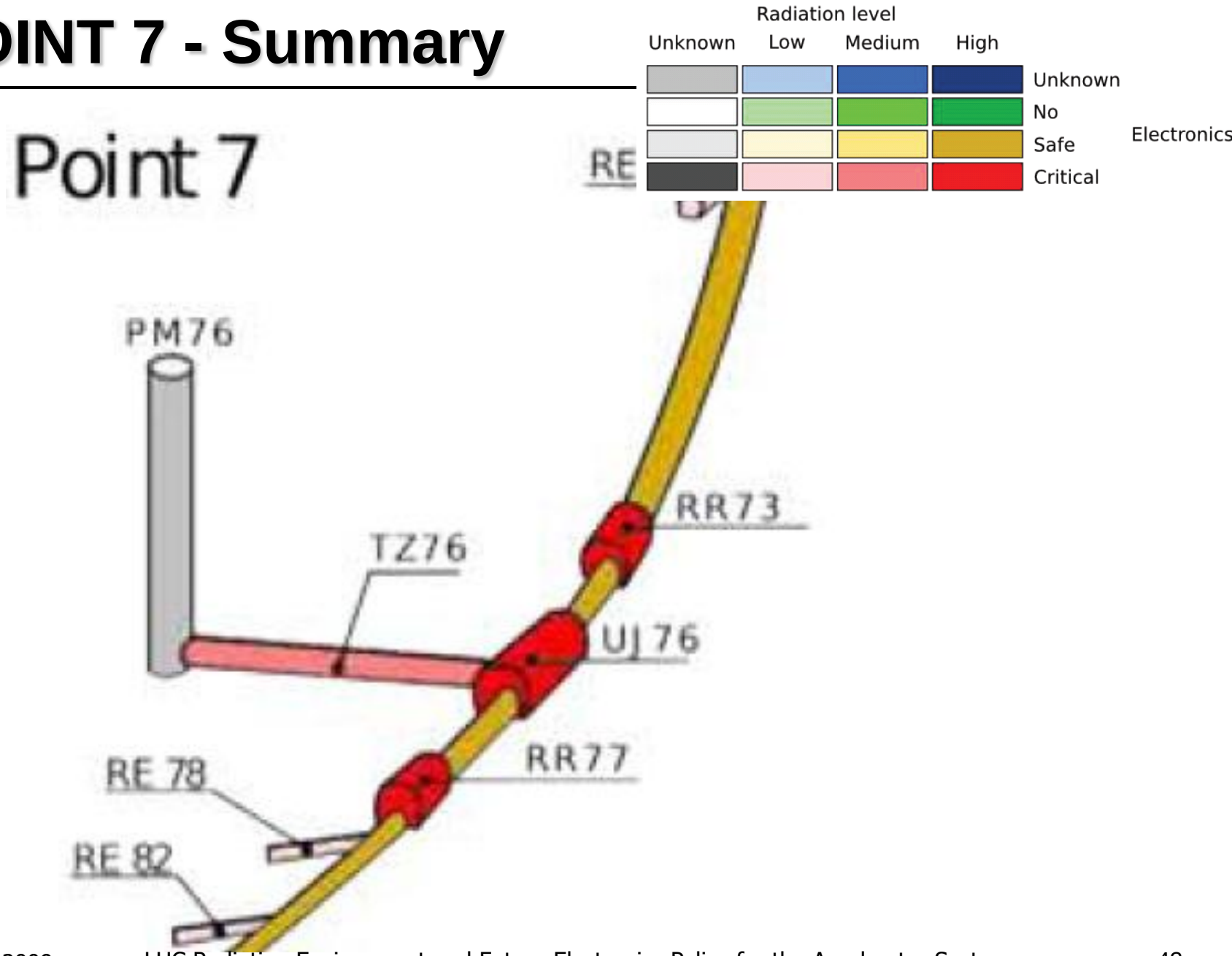


- Critical Areas:
  - **UA64, UA67**
- Critical Electronics:
  - not all details known
  - assumption: QPS,PO,CRY,CO,COM,CV,SFT,VAC,BI, **+ ???**
- Radiation Levels
  - **High-E Hadrons:** **UAs (unshielded): $1x10^6$-$1x10^9$ cm^{-2}**
  - **1MeV Equ.:** **UAs (unshielded): $1x10^7$-$1x10^{10}$ cm^{-2}**
  - **Dose:**
  - Normalization: $3.4x10^{13}$ p/y (on TCDQ)
  - Scaling: Direct beam losses
  - Comments: Simplified simulation
    Startup: less losses on TCDQ

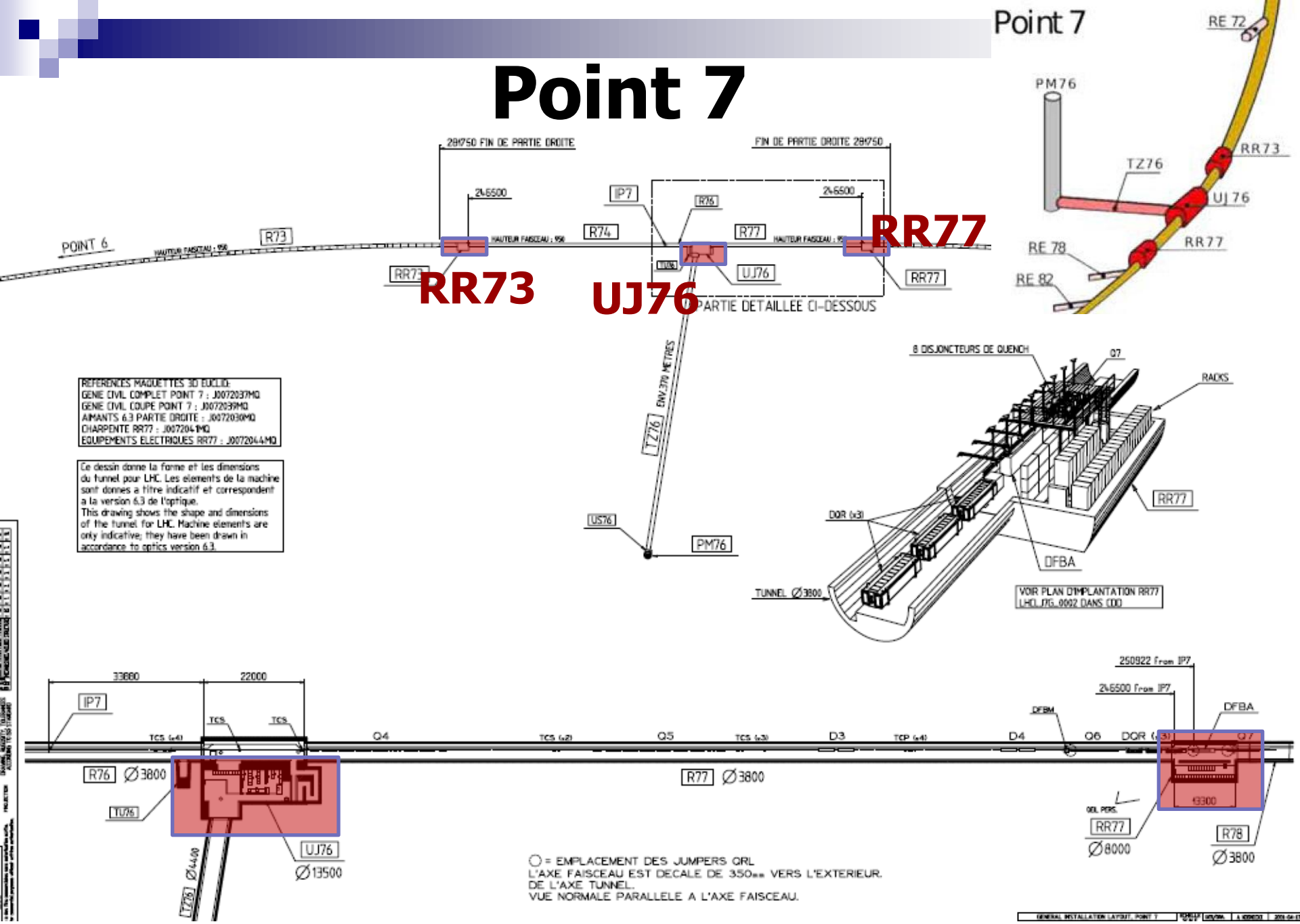
- Monitoring: RADMONs, PMIs, BLMs
- Shielding options: holes filled during this shutdown (improvement possible)
- Relocation possibility: to be studied if necessary
- Replacement/Redesign: to be studied if necessary

- Comments:
  - expected TCDQ/TCSG/TCSM losses for 2008/9/+ (when compared to nominal)
  - cryo-equipment in UX65 if beam-gas or losses are higher than expected
  - electronics in dump cavern (adjacent UPs)

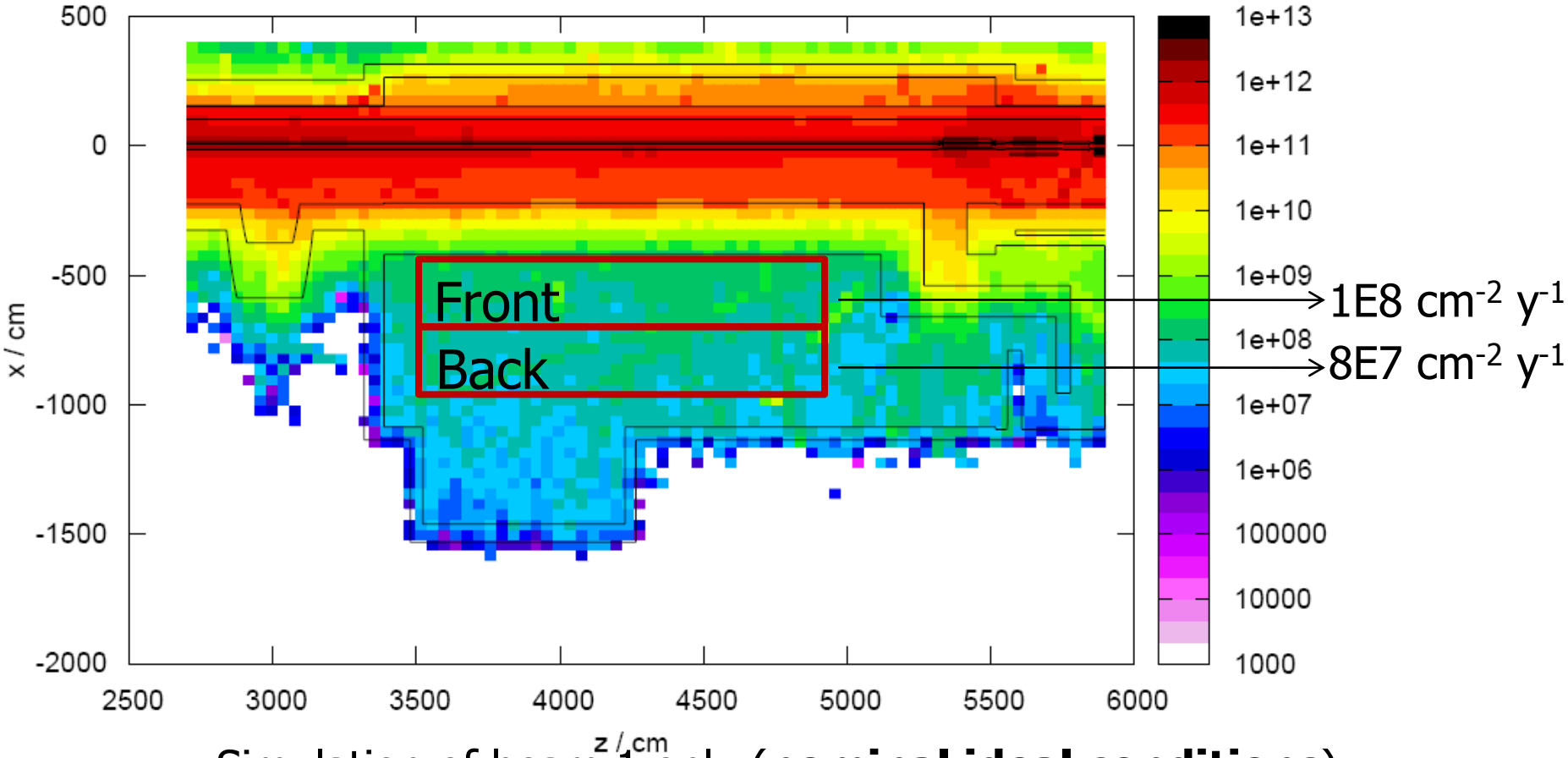
POINT 7 - Summary



Point 7


Point 7
RE 72
PM76
RR73
TZ76
UJ76
RR77
RE 78
RE 82
28750 FIN DE PARTIE DROITE
FIN DE PARTIE DROITE 28750
246500
IP7
R76
R74
R77
R73
POINT 6
HAUTEUR FAISCEAU : 956
RR73
UJ76
RR77
RR77
PARTIE DETAILLEE CI-DESSOUS
TZ76
ENV.370 METRES
US76
PM76
REFERENCES MAQUETTES 3D EUCLID:
GENIE CIVIL COMPLET POINT 7 : J0072037MQ
GENIE CIVIL COUPE POINT 7 : J0072039MQ
AIMANTS 6.3 PARTIE DROITE : J0072030MQ
CHARPENTE RR77 : J0072041MQ
EQUIPEMENTS ELECTRIQUES RR77 : J0072044MQ
Ce dessin donne la forme et les dimensions du tunnel pour LHC. Les elements de la machine sont donnes a titre indicatif et correspondent a la version 6.3 de l'optique.
This drawing shows the shape and dimensions of the tunnel for LHC. Machine elements are only indicative; they have been drawn in accordance to optics version 6.3.
8 DISJONCTEURS DE QUENCH
Q7
RACKS
RR77
DQR (x3)
DFBA
TUNNEL Ø3800
VOIR PLAN D'IMPLANTATION RR77
LHCL/7G_0002 DANS CDD
33880
22000
IP7
TCS
TCS
TCS (x4)
Q4
TCS (x2)
Q5
TCS (x3)
D3
TCP (x4)
D4
DFBM
Q6
DQR (x3)
Q7
250922 from IP7
246500 from IP7
DFBA
R76
Ø3800
TU76
UJ76
Ø13500
TZ76
Ø4400
R77
Ø3800
13300
RR77
Ø8000
R78
Ø3800
○ = EMPLACEMENT DES JUMPERS QRL
L'AXE FAISCEAU EST DECALE DE 350mm VERS L'EXTERIEUR.
DE L'AXE TUNNEL.
VUE NORMALE PARALLELE A L'AXE FAISCEAU.

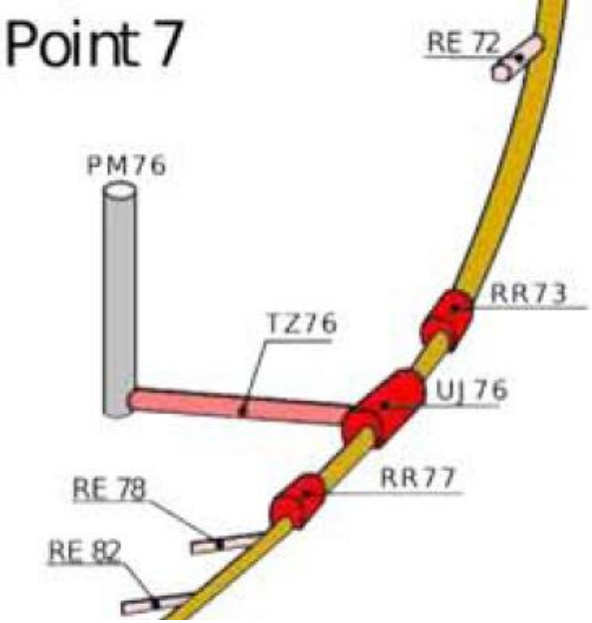
UJ76, High-Energy Hadron Fluence



Simulation of beam 1 only (**nominal ideal conditions**),
7 TeV, mixed halo, normalization: 1.15E16 p/y

2009/10 (300pb^{-1}): low-intensity can still lead to significant losses during early operations; in addition, the reality of loss distributions can be significantly different from the assumptions, thus **high energy hadron fluence** at beam level can easily exceed already **some 10^{7}** cm^{-2} y^{-1}

POINT 7 - Summary

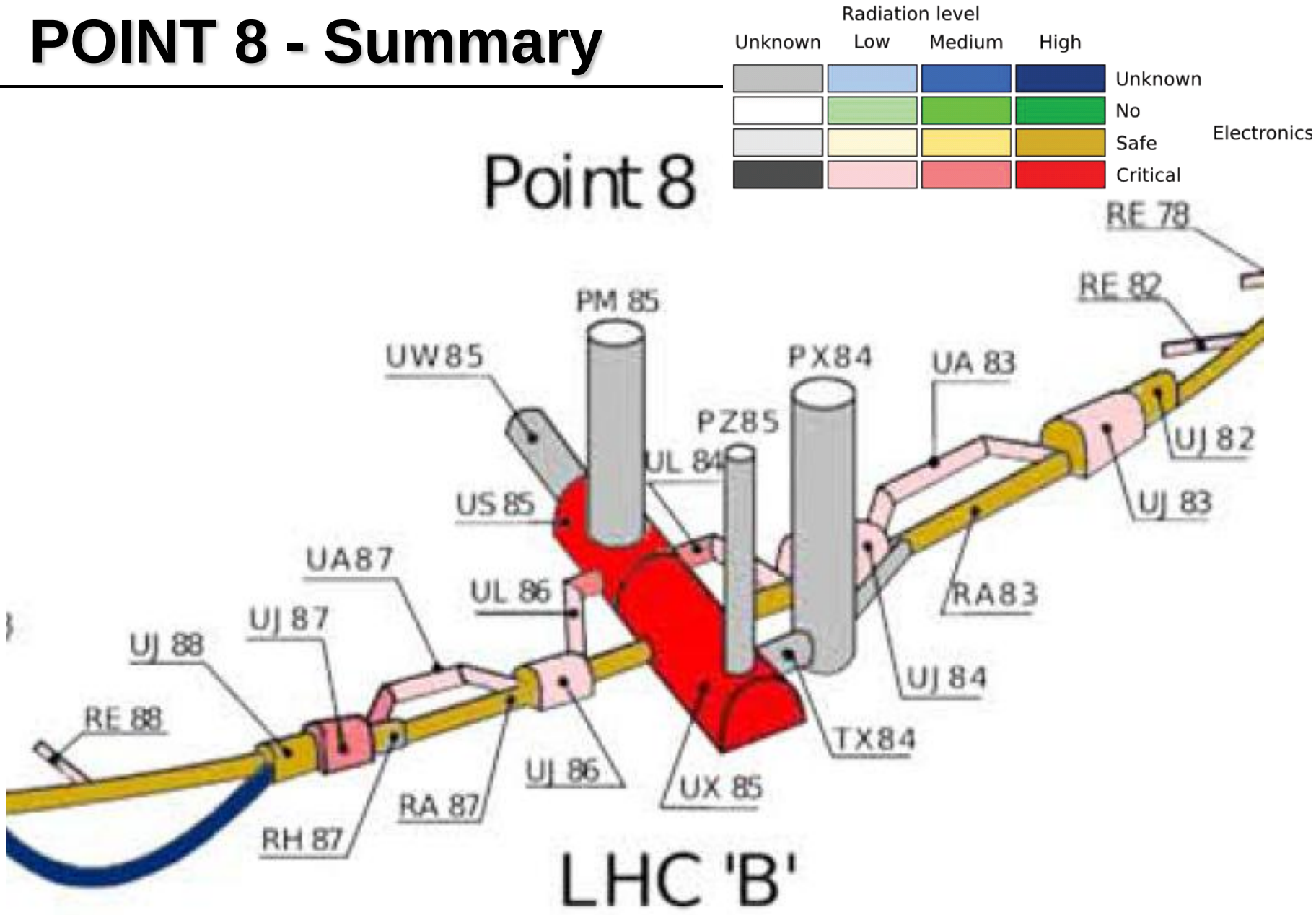


- Critical Areas:
  - **UJ76 (TZ76)**
  - **RR73, RR77**
- Critical Electronics:
  - ECR exists
  - QPS,PO,CRY, CO,COM,CV,SFT,VAC,BI, **+ …**
- Radiation Levels

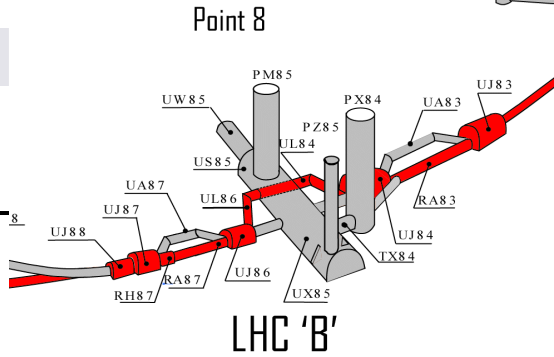
High-E Hadrons:	**UJ:1x10^{7}-1x10^{9}**	**/**	**RRs: 1x10^{7}-1x10^{8}**	**/ TZ: < 1x10^{8} cm^{-2}**
1MeV Equ.:	**UJ:5x10^{7}-5x10^{9}**	**/**	**RRs: 5x10^{7}-8x10^{8}**	
Dose:	**UJ: 0.001 – 1.**	**/**	**RRs: 0.01 – 2. Gy/y**	
Normalization:	1.15x10^{16} p/y			
Scaling:	Direct beam losses			

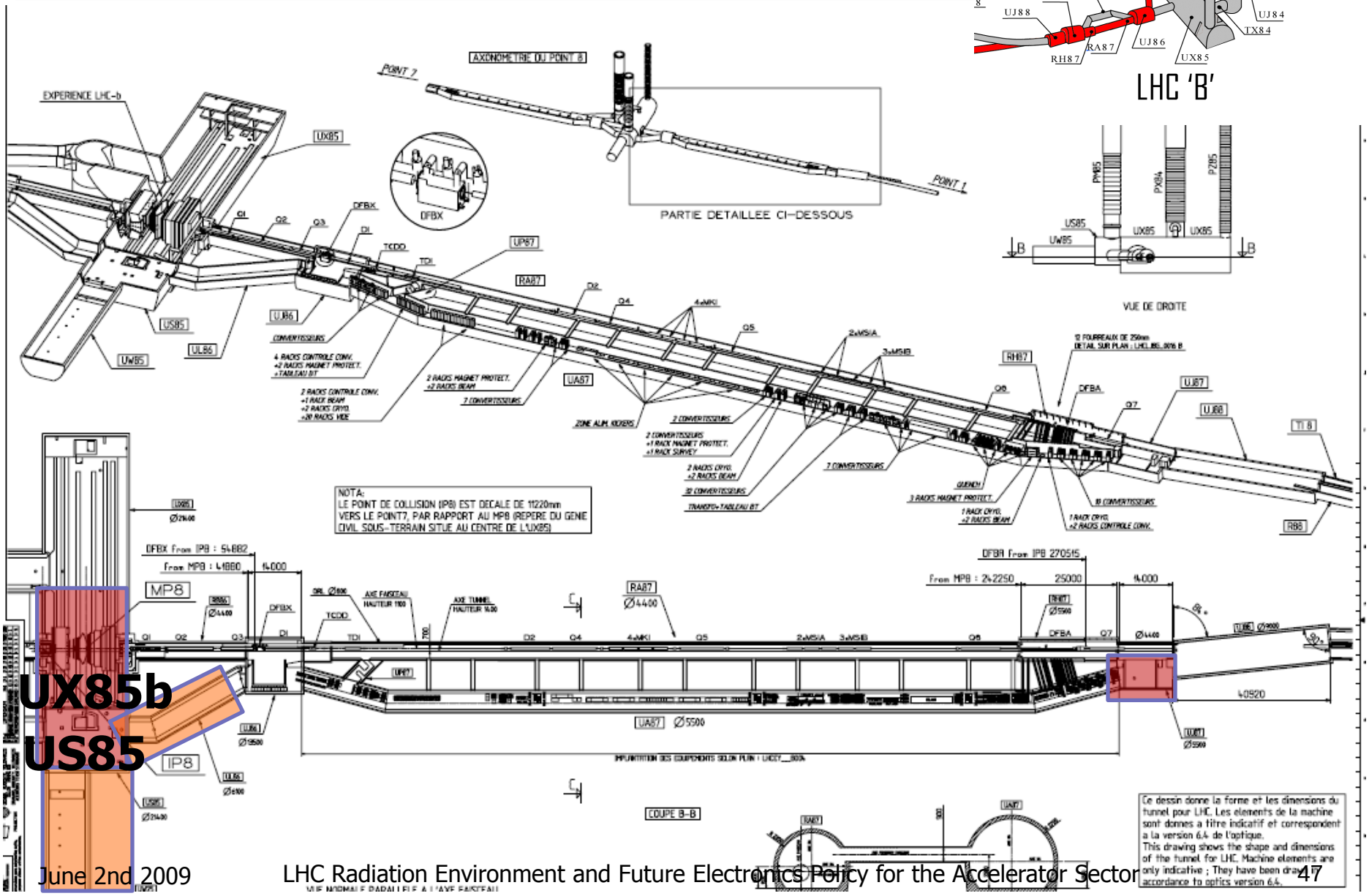
- Monitoring: RADMON, IG5 (UJs), PMI (outside), BLM (outside)
- Shielding options: UJ: limited and installed, RR: final shielding installed
- Relocation possibility: UJ: into TZ, RRs: very difficult
- Replacement/Redesign: to be studied

POINT 8 - Summary



Point 8





Ce dessin donne la forme et les dimensions du tunnel pour LHC. Les elements de la machine sont donnes a titre indicatif et correspondent a la version 6.4 de l'optique.
This drawing shows the shape and dimensions of the tunnel for LHC. Machine elements are only indicative ; They have been drawn in accordance to optics version 6.4.

High-Energy Fluence – @ Level1

UL Levels unphysical due to full absorption at the edge

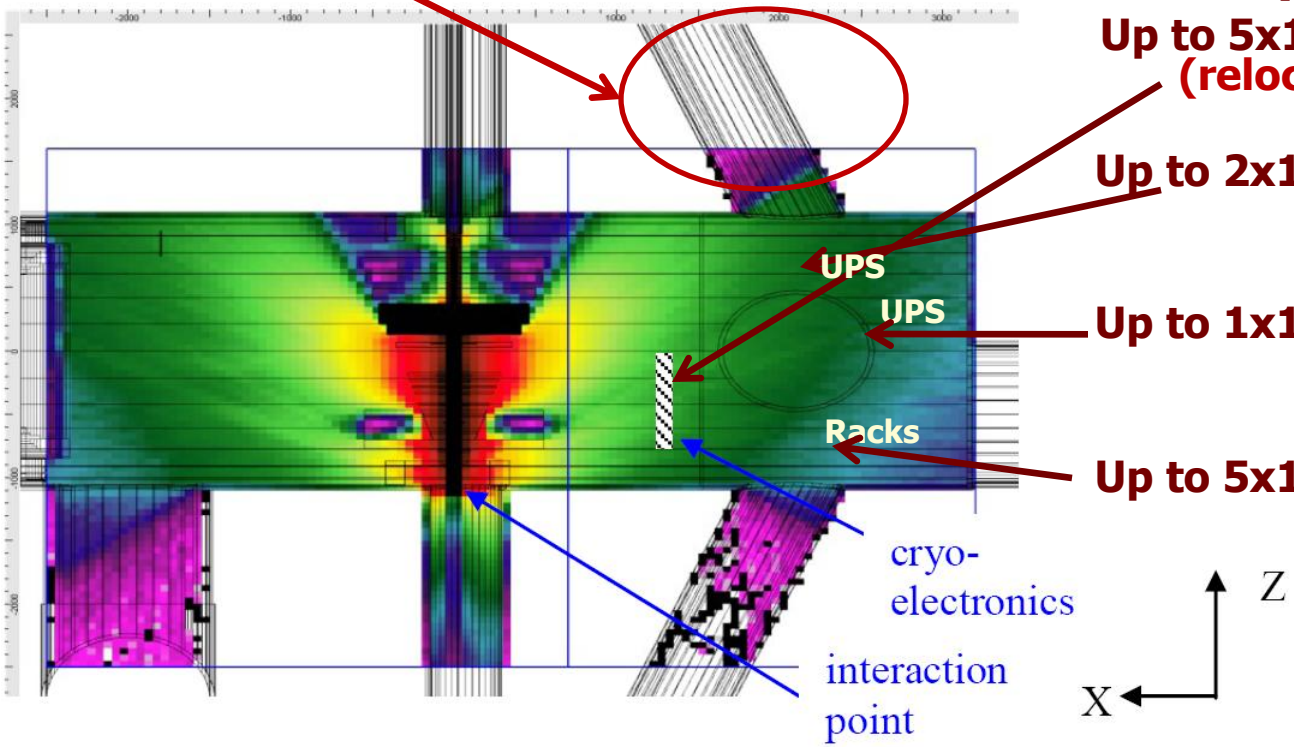
2009/10 (100pb^{-1})

Up to 5x10^{7} cm^{-2} (relocated, repl.)

Up to 2x10^{7} cm^{-2}

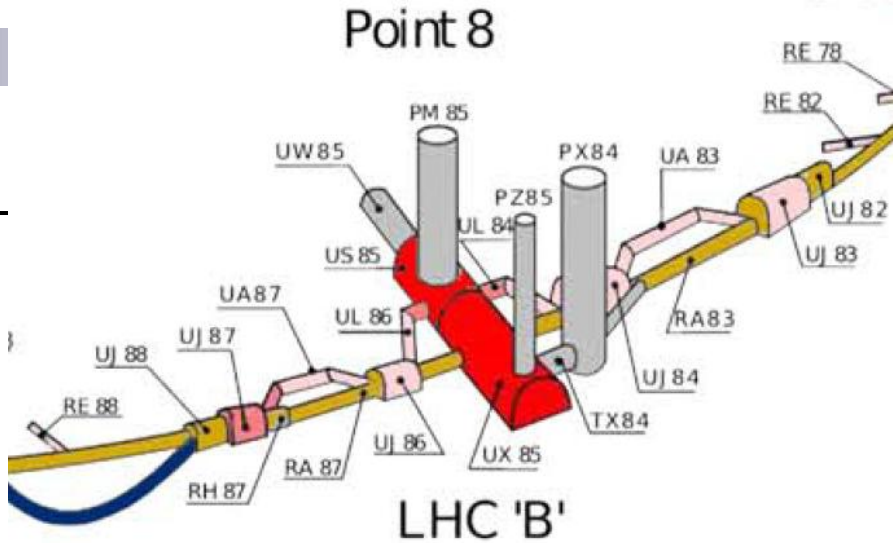
Up to 1x10^{7} cm^{-2}

Up to 5x10^{6} cm^{-2}



Colour Code - Applied Normalization: 2x10^{32} cm^{-2}s^{-1} , nominal LHC year (1x10^{7}s) -> 1.6x10^{7} pp/s, including a safety factor of two and for 10 years of operation!

POINT 8 - Summary



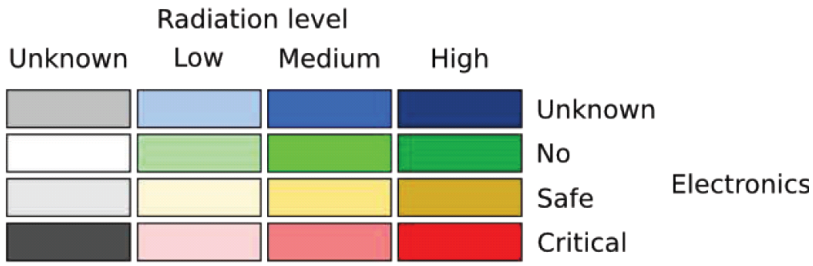
- Critical Areas:
  - **UX85b, US85**
- Critical Electronics:
  - CRYO, AL3, UPS, TIM, RR, EL, + **…**

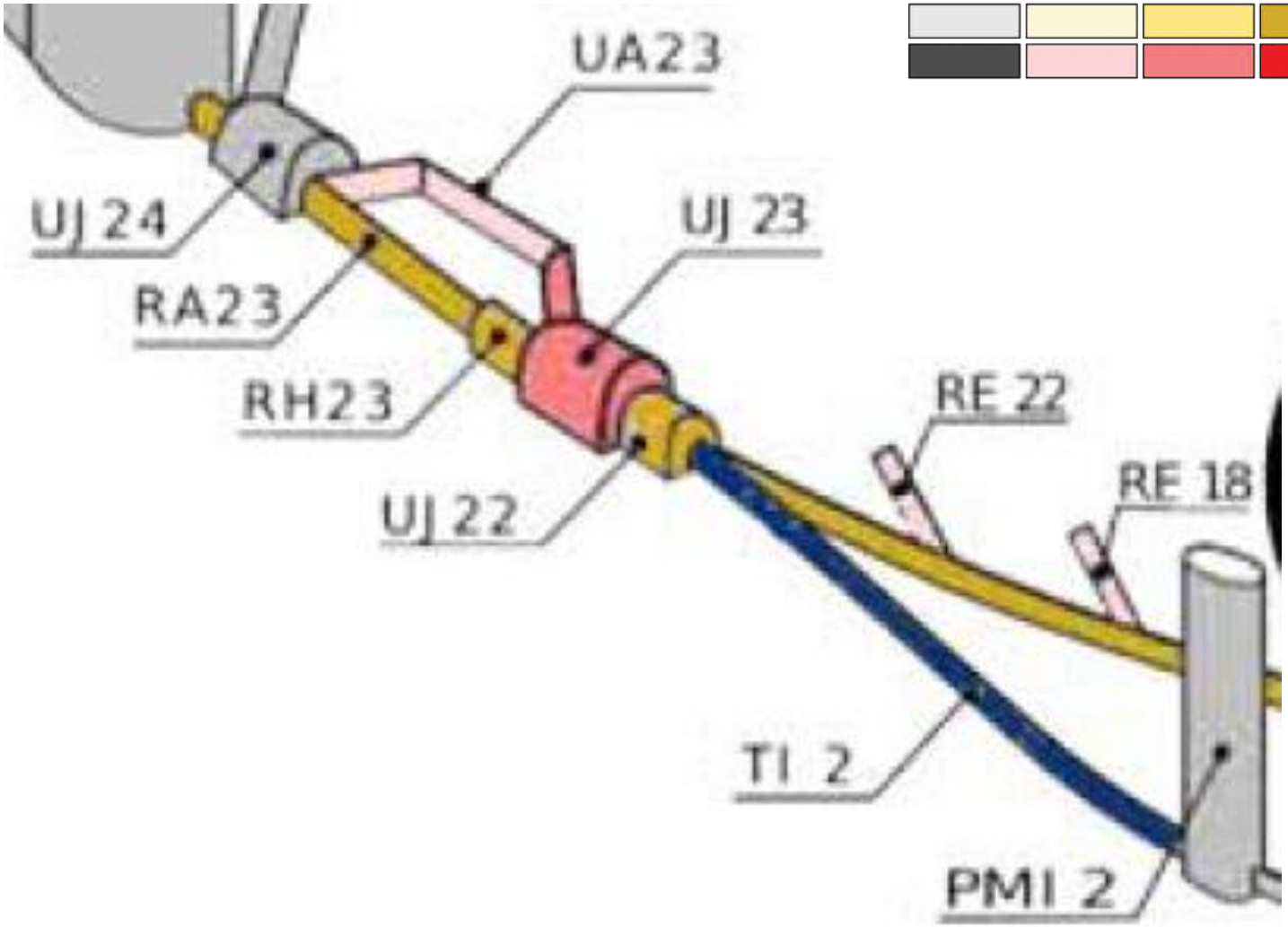
- Radiation Levels

High-E Hadrons:	**UX: 5×10^{8} - 1×10^{10} cm^{-2}/y**	**/ US: 5×10^{7} - 5×10^{8} cm^{-2}/y**
1MeV Equ.:	**UX: 1×10^{9} - 2×10^{10} cm^{-2}/y**	**/ US: 2×10^{8} - 2×10^{9} cm^{-2}/y**
Dose:		
Normalization:	3.2×10^{14} pp/y	
Scaling:	Luminosity	

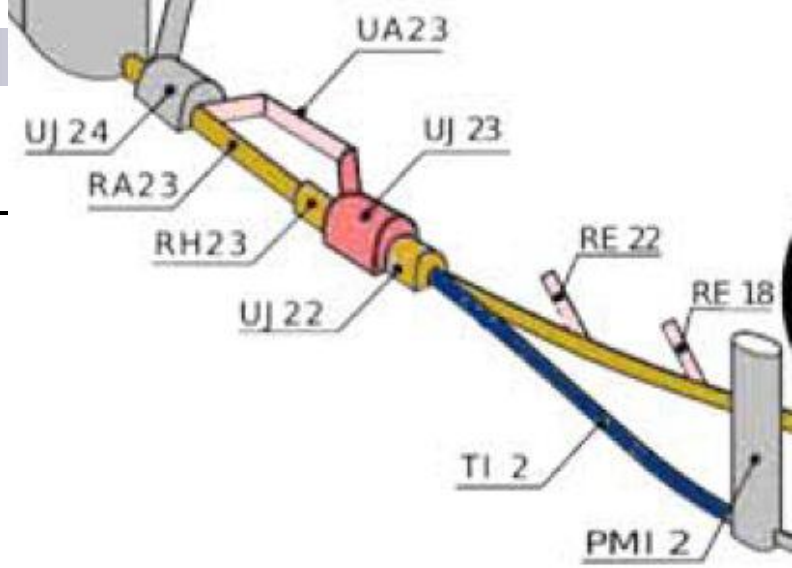
- Monitoring: RadMons, PMIs, IG5, BLMs
- Shielding options: very limited (safe room mainly)
- Relocation possibility: UX85b already moved, US85 studied
- Replacement/Redesign: to be studied

TI2 - Summary


Radiation level
Unknown
Low
Medium
High
Unknown
No
Safe
Critical
Electronics

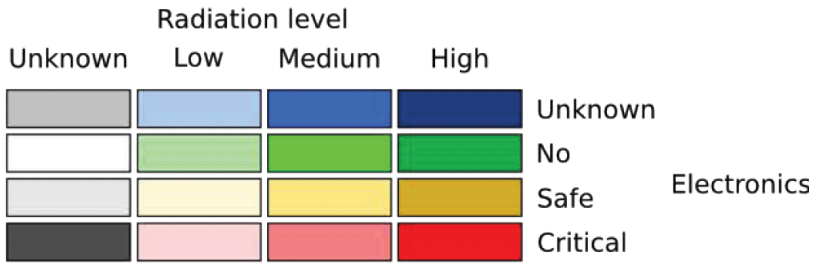

UA23
UJ 24
UJ 23
RA23
RH23
RE 22
RE 18
UJ 22
TI 2
PMI 2

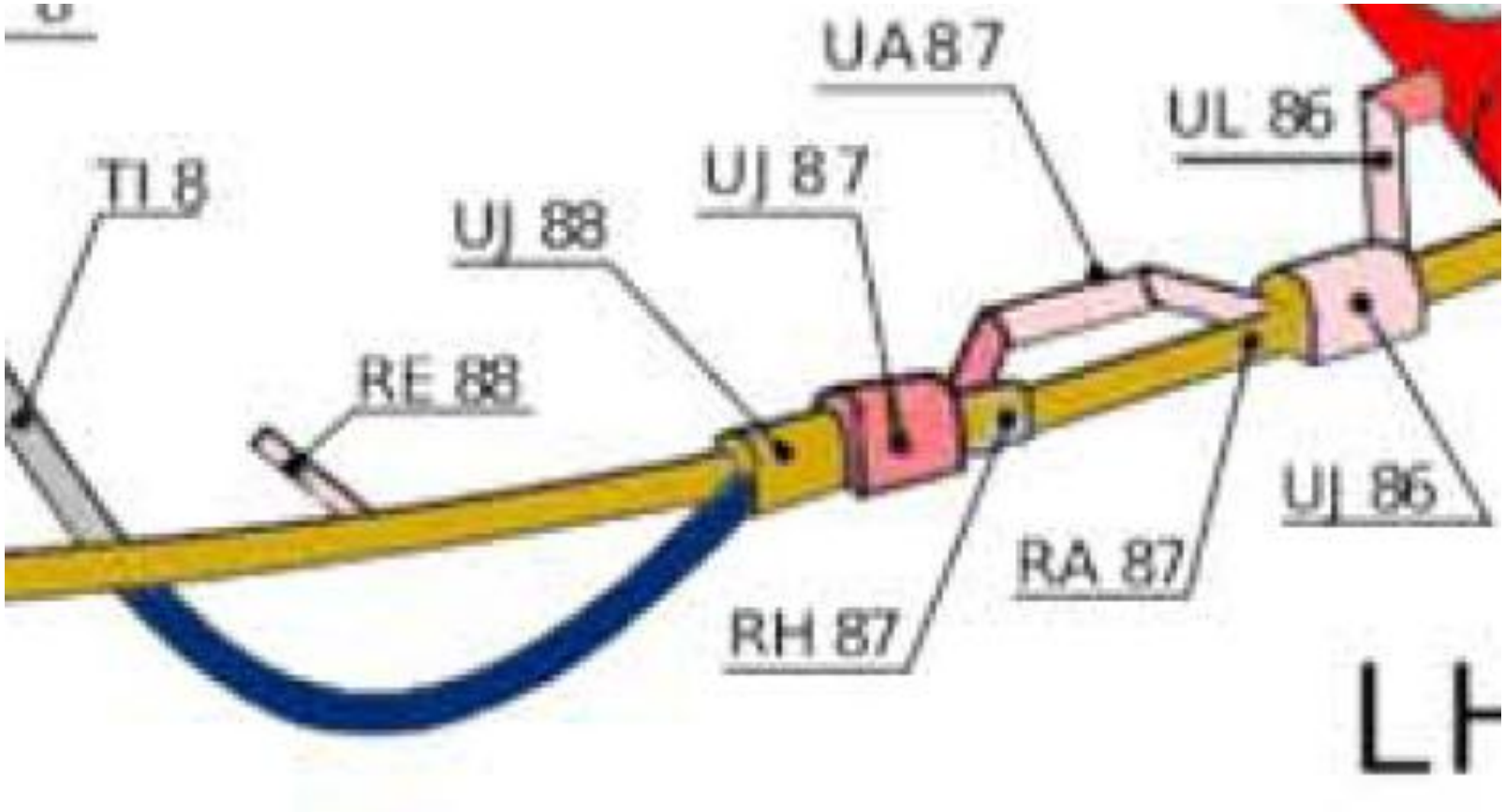
TI2 - Summary



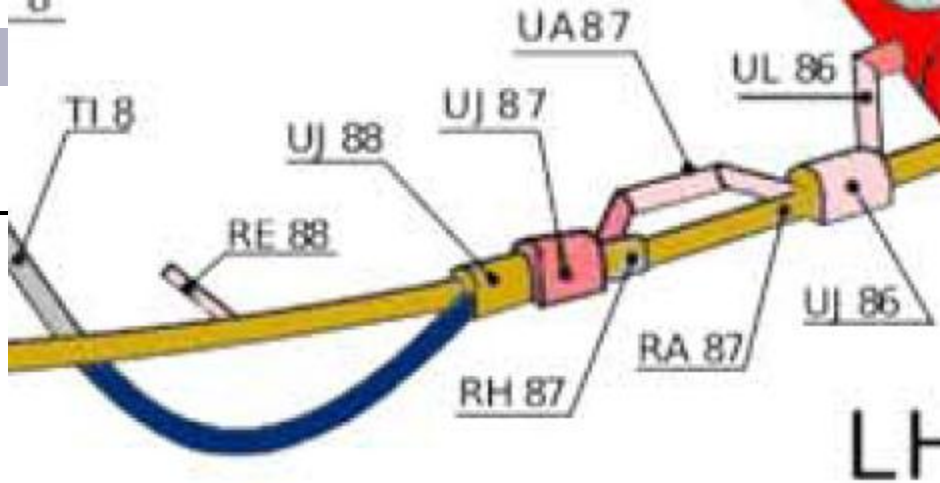
- Critical Areas:
  - **UJ23, UA23**
- Critical Electronics:
  - point-iteration to be performed
  - PC, ACC, CV, **+ …**
- Radiation Levels
  - **High-E Hadrons: UJ23:>5x10^{9} / UA23: <7x10^{8}**
  - **1MeV Equ.:**
  - **Dose:**
  - Normalization: 1.44x10^{16} p/y
  - Scaling: Direct beam losses
  - Comments: assuming 2 shots per day on the TED
- Monitoring: RadMons, PMIs, BLMs
- Shielding options: Possible, improvements rather easy
- Relocation possibility: to be studied if necessary
- Replacement/Redesign: to be studied if necessary

TI8 - Summary


Radiation level
Unknown
Low
Medium
High
Unknown
No
Safe
Critical
Electronics


UA87
UL 86
TI 8
UJ 87
UJ 88
RE 88
UJ 86
RA 87
RH 87

TI8 - Summary



- Critical Areas:
  - **UJ87, UA87**
- Critical Electronics:
  - point-iteration to be performed
  - PC, ACC, CV, **+ …**
- Radiation Levels
  - **High-E Hadrons: UJ87:>5x10^{9} / UA87: <7x10^{8}**
  - **1MeV Equ.:**
  - **Dose:**
  - Normalization: 1.44x10^{16} p/y
  - Scaling: Direct beam losses
  - Comments: assuming 2 shots per day on the TED
- Monitoring: RadMons, PMIs, BLMs
- Shielding options: Possible, improvements rather easy
- Relocation possibility: to be studied if necessary
- Replacement/Redesign: to be studied if necessary

Radiation Levels- Summary - Prioritized

- Knowledge based on **simulations only**, thus detailed analysis and iteration required during early operation
- **Important uncertainties** due to assumptions going into loss terms (real integrated luminosity, distribution of losses, additional attenuations…)
- **Priorities** assigned according to
  - system sensitivity and criticality
  - uncertainty of loss assumptions (*e.g.*, UJ76)
  - possible short-term measures (*e.g.*, UA63/67)
- Continuous evaluation – Prioritization (colour coding)

  Ongoing work during this shutdown

  Highest priority for upcoming iterations/evaluations

  Second priority, cross-check with measurements

  Lowest priority, layout check and evaluation
- Other color codes:

  areas which require additional calculations analysis

  to be done

Radiation Levels - Summary - Prioritized

!!! Simulations Only !!! **!!! Loss Assumptions !!!**

LHC Point	Area(s)	Radiation Levels						Priority
		20MeV [cm^{-2}/y]	1MeV [cm^{-2}/y]	Dose [Gy/y]	Normalisation	Scaling	Comments	
Point 1	UJ14 UJ16	1.E9-1.E10	1.E10-1.E11	5-100	100 fb-1	Luminosity	1st Shielding Studues performed	2
	RR13 RR17	1E8-5E9	2.E10-2.E11	0.1-1	100 fb-1	Luminosity Beam-gas	shielding as currently installed (full shielding as in ECR would reduce it by ~20-50)	2
	UPS14 UPS16	~1E8	~5E8		100 fb-1	Luminosity Beam-gas	direct contribution, estimate based on FLUKA calculations and gradient as from I. B.	3
	US15 USA15	1E6-1E7		0.001-0.02	100 fb-1	Luminosity	partly based on extrapolation	4
Point 2	UX25							4
	US25							4
Point 3	UJ33	1E4-2E6	5E4-7E6	1E-6-1E-3	1E16 p/y	Direct beam losses	Cryo Equipment at Entry Point ("Worst Location")	4
	UJ32	1E7-1E8	1E8-1E9	< 0.01	1.65E11m-1y-1	Beam-gas	very conservative beam-gas assumptions	3
	RE38	2E5-1E7	1E6-5E7	5E-5-1E-3	1.65E11m-1y-1	Beam-gas	very conservative beam-gas assumptions	3
Point 4	UX45	5.0E+06	1.5E+07		2.4E10m-1y-1	Beam-gas	Different norm. for various beam-elements, dominating stated: can the density be higher?	3
Point 5	UJ56	1.E9-1.E10	1.E10-1.E11	5-100	100 fb-1	Luminosity	1st Shielding Studues performed	2
	UPS14 UPS16	~1E8	~5E8		100 fb-1	Luminosity Beam-gas	direct contribution, estimate based on FLUKA calculations and gradient as from I. B.	3
	RR53, RR57	1E8-5E9	2.E10-2.E11	0.1-1	100 fb-1	Luminosity Beam-gas	shielding as currently installed (full shielding as in ECR would reduce it by ~20-50)	2

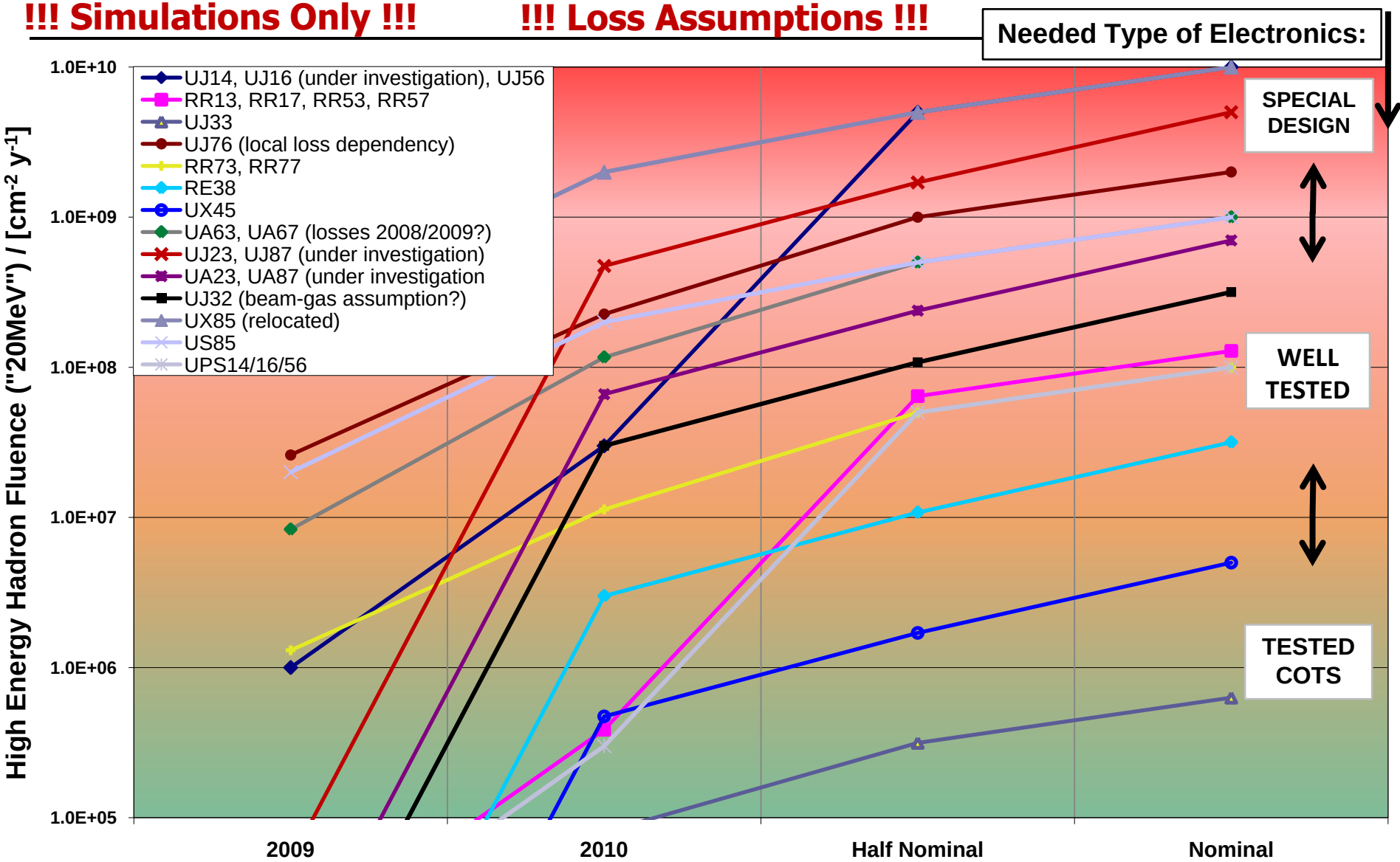
Radiation Levels- Summary - Prioritized

!!! Simulations Only !!! **!!! Loss Assumptions !!!**

LHC Point	Area(s)	Radiation Levels						Priority
		20MeV [cm^{-2}/y]	1MeV [cm^{-2}/y]	Dose [Gy/y]	Normalisation	Scaling	Comments	
Point 6	UA63 UA67	1E6-1E9	1E7-1E10		3.4E13 p/y	Direct beam losses	Simplified simulation	1
	UD62 UD68						crane and ventilation equipment	3
	UX65							4
Point 7	UJ76	1E7-1E9	5E7-5E9	1E-3-1E0	1.15E16 p/y	Direct beam losses	loss dominated by secondaries interacting in lateral beampipe	1
	RR73 RR77	1E7-1E8	5E7-5E8	0.01-2	1.15E16 p/y	Direct beam losses Beam-gas	real losses to be evaluated (monitoring @start-up), strong dependency on TCLAs	1
	TZ76	<1E8			1.15E16 p/y	Direct beam losses	TZ maximum levels to be evaluated after measurements at higher intensities	4
Point 8	UX85b	5E8-1E10	1E9-2E10		3.2E14 pp/y	Luminosity	values refer to valve location	1
	US85	5E7-5E8	2E8-2E9		3.2E14 pp/y	Luminosity		2
TI2	UJ23	>5E9			1.44E16 p/y	Direct beam losses	2 shots per day on the TED crane only!!!	3
	UA23	<7E8			1.44E16 p/y	Direct beam losses	2 shots per day on the TED	3
TI8	UJ87	>5E9			1.44E16 p/y	Direct beam losses	2 shots per day on the TED crane only!!!	3
	UA87	<7E8			1.44E16 p/y	Direct beam losses	2 shots per day on the TED	3
ALL	ARC	1E9-1E12	3E9-3E12	1-1000	1.65E11m-y-1	Beam-gas	Equipment spec. designed, Issue with 60A power converters?	2
	REs	2E5-1E7	1E6-5E7	5E-5-1E-3	1.65E11m-1y-1	Beam-gas	very conservative beam-gas assumptions	4
	DS	1E9-1E12	3E9-3E12	1-1000	1.65E11m-1y-1	Direct beam losses Beam-gas	Equipment spec. designed, Issue with 60A power converters?	2

Radiation Levels – Evolution

!!! Simulations Only !!! **!!! Loss Assumptions !!!**



[***Loss/Intensity-Scaling: M. Lamont***]

Policy

Why Do We Need A Policy

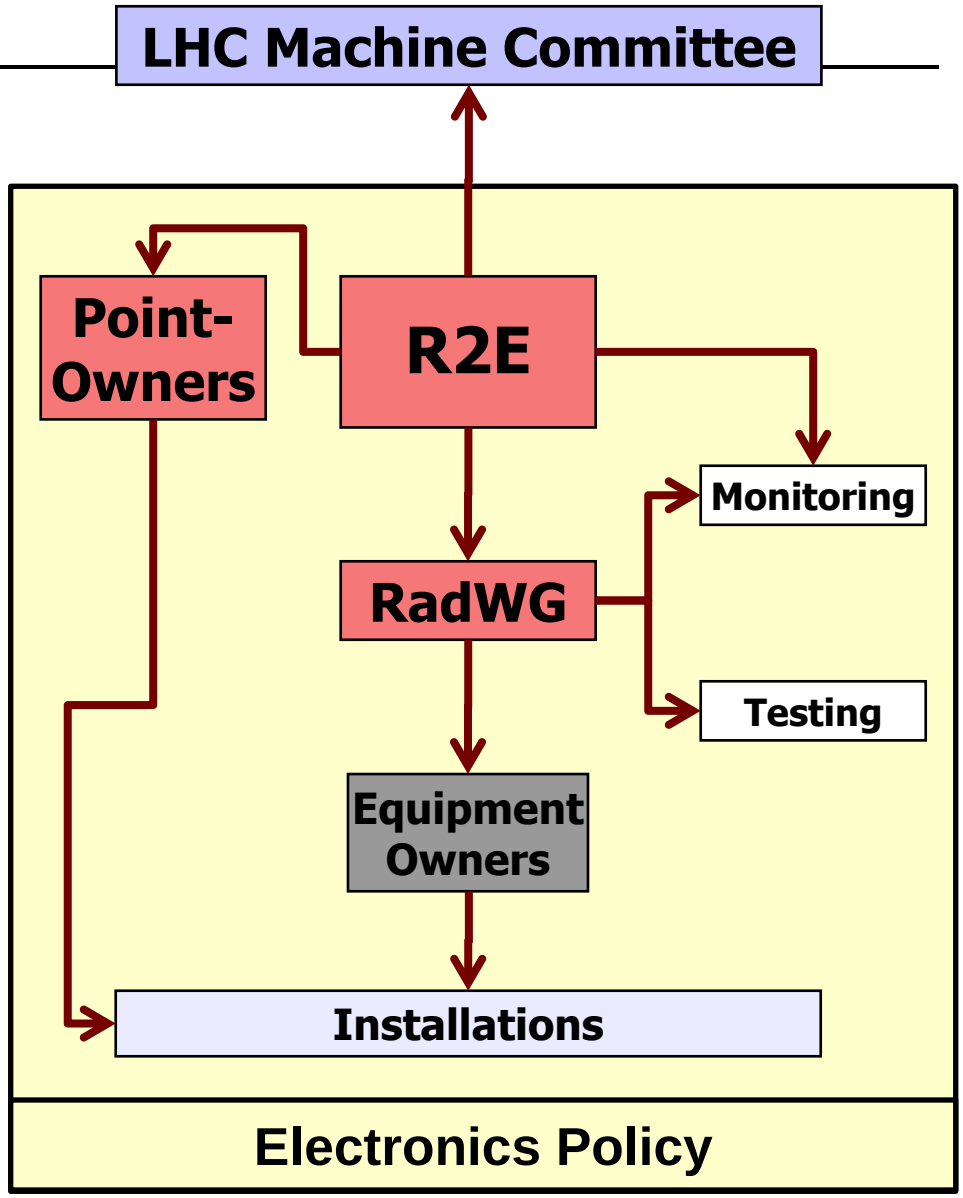
- **Signiciant radiation levels in many LHC areas** where machine electronics is installed
- The **knowledge of radiation levels is not always sufficient**:
  - “We’re behind the shielding, thus there is no radiation.”
  - “The expected annual dose levels are marginal, there isn’t a problem”
- …**also when it comes to testing**:
  - see citation of Philippe: “We made neutron irradiation up to 10krad”
- **Numerous different systems and components**, partly custom built, partly based on COTS
- **… To avoid future R2E related problems**

Radiation Policy - General

- A **solution for electronics already installed in critical LHC underground areas** must be found and respective solutions will involve (this is **to be done in parallel!**):
  - shielding
  - relocation
  - and re-design
- For the required **re-design and all new electronics** to be installed in areas prone to radiation **a new policy** needs to be defined and put in place
- Lots of '**The**'s:
  - The policy will have to be developed in detail during the coming year
  - The following slides only sketch a possible structure
  - The experience (good and bad) as obtained by the LHC experiments will be of valuable help
  - The input from equipment owners and responsible will be fundamental
- What we learn during this course is the first step…

R2E Structure

1. **Policy** for Electronics installed in areas with elevated radiation levels (**R2E**)
2. **Evaluation** of Radiation Levels: simulations, monitoring, proposal of measures and general coordination (**R2E**)
3. Structure to **implement** the Policy (**RadWG**)
4. Organization and Analysis of **Radiation Tests** (**RadWG**)
5. **Control** (**LHC Point-Owners**)



The Aim of the Policy

- All **safety related systems must remain functional** at all time
- The **operational reliability** of the accelerator **must not be significantly limited** due to electronics failures due to radiation
  - failure rates of transient or (limited!) destructive SEE must be acceptable (the latter 'quantity' is to be defined)
  - the estimated lifetime of machine critical components must cover the foreseen lifetime of the accelerator, or at least a large fraction of it
- **Radiation tests shall be carried out in a unified and comprehensive way**, ideally based on recognized test methods (*e.g.*, guidelines developed by the LHC experiments, ESA, …)
- All groups being responsible for machine equipment installed in possible radiation areas follow a **common approach**

Three Important Goals

- Defining (and updating after first measurements) the **radiation levels in all LHC areas** possibly housing electronics (present & future)
- Providing support for equipment owners to **develop electronics complying with the levels of radiation tolerance** necessary at the respective locations:
  - minimum doses and fluences as defined above
  - maximum acceptable rate of soft, hard or destructive Single Event Effects (SEE) as a function of equipment class (operational constraints)
- Providing electronics **test and selection guidelines** for both custom design and selected COTS and seperately for:
  - components
  - systems

Main Ingredients – Part 1

- **What areas** show no or lowest radiation
  - !!! keeping ‘safety margins’ !!!
- What **components/systems to choose from**?
  - can this be provided?
  - at least recommendations?
- Definition of **‘Radiation Tolerance Criteria’ for the accelerator environment**
  - LHC tunnel
  - shielded areas
- **Strict application of SEE constraints**
  - error rates must be a ‘design constraint’ for systems being installed in areas prone to radiation
  - destructive SEE failures must be avoided
- Application of **unified radiation test methods**
- Continuous **organisation & analysis of test results**

Main Ingredients – Part 2

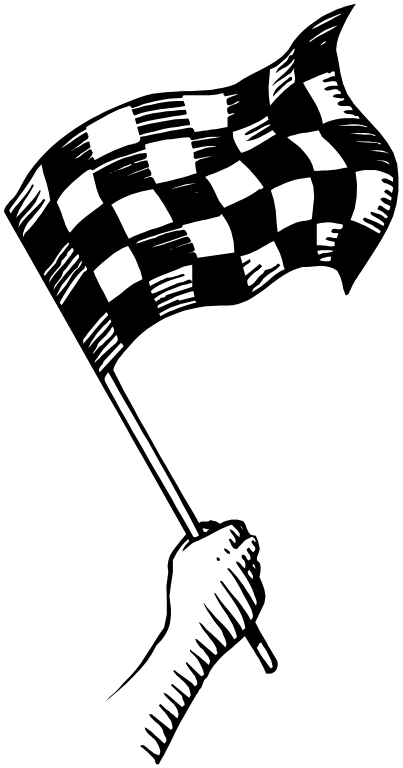
- **Knowledge of equipment inter-dependencies and failure consequences**
  - what happens if my device fails?
  - from what equipment do I depend on and vice-versa?
- **Defined review and acceptance process**
  - All devices to be installed in LHC radiation areas need to fulfil a minimum set of requirements
- **Certain executive power and strong support from the management**
- **Support**
  - Expertise from the experiments
  - Organised radiation test campaigns, lists of radiation facilities
  - Standardized test reports
- A **Police**!

TIME TO DEFINE, BUILD AND APPLY THE ABOVE

1st Step - How To 'Build' The Policy

- Carefully **'build' on available experience** as available from the experiments
- **Adopt** (and add) respective points to the needs of the accelerator and in the context of respective radiation levels
- **'Radiation Maps'** of areas as based on simulations and later updated with measurements
- Define **a small team of experts**, ideally from both:
  - LHC experiments
  - LHC machine

Start small (but fast) and evolve over time…



Finally

Some More Comments & Challenges

- The solution of the **existing problems** will take an important amount of:
  - effort
  - time
  - money
  - patience
- We're **running against time** and 'machine performance' and radiation induced **failures will be part of the game**
- There is no **easy** and **perfect** solution, we try to get the **best possible**
- The **LHC will evolve in intensity and luminosity** and it will not get easier
- New technologies will require to worry about **additional 'constraints'** (*e.g.*, enhanced failure rates due to low-energy neutrons)
- Not speaking about upgrades and 'other ideas'

References and Documentation

- Presentations, Minutes on the R2E Website: www.cern.ch/R2E
- Collection of Surveys, Documents & Pictures in the R2E Document Database: www.cern.ch//info-r2e-documents
- Useful Links at: www.cern.ch/R2E/Links.htm
- Overview of Areas: www.cern.ch/R2E/AreaOverview.htm

R2E Related Publications and External Presentations:
www.cern.ch/R2E/Publications_Presentations.htm

- Reports of LHC Point-Iterations (in preparation)
- R2E Report on required mid/long-term measures (in preparation)
- S. Weisz et al., Mobile Shielding for RR73/77 (see ECR)
- R2E_Report published through the proceedings of the 2009 LHC Performance Workshop held in Chamonix (see paper)
- R2E Study Group, Protection of equipment located in UJ76 (see ECR)
- Memorandum for temporary move of betatron cleaning to IR3

Key Messages

- Many LHC underground areas are prone to radiation
- Some of them are ‘critical’
- Many of them house not specifically installed electronics, most of it critical for LHC operation (some of them you’re responsible for)
- Radiation levels are known and continued simulations and measurements will improve this knowledge
- Radiation levels evolve over time (of operation) and depend on several factors (beam intensity, luminosity, direct losses, residual gas density)
- A dedicated study group (R2E) exists and a new structure was put in place
- Detailed documentation exists and is continuously updated
- Dedicated Point-Reviews are performed to evaluate possible solutions
- A new ‘Policy’ will be developed and you can contribute to it

CERN Equipment Specialist…

… after
LHC Operation…

Thanks to All People Having Contributed To This Talk…

"Hi, honey… I'm Ohm!"

BACKUP

R2E Achievements (2009) Part 1

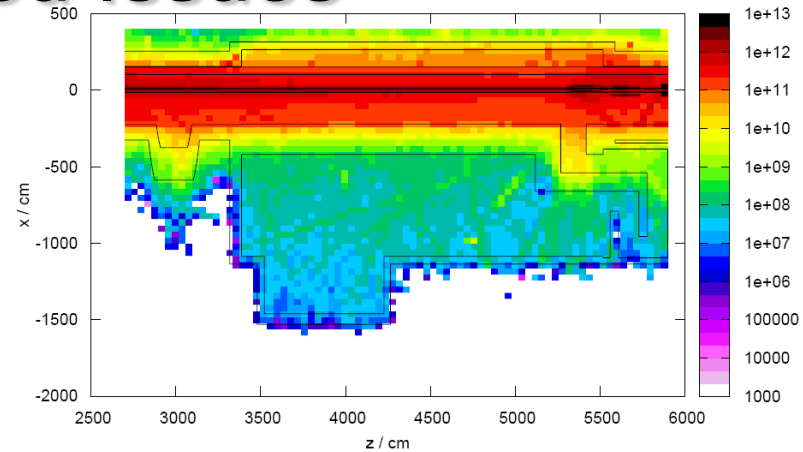
- **Priority List of Areas** — **Prioritization**
  - based on available Monte-Carlo simulations
  - linked to operational assumption for the various 'years'
- **Update and detailed analysis of Simulations** — **Inventory**
  - Collection of existing simulations
  - Launch of new simulation effort
  - clear identification of critical areas and respective radiation levels (over time!)
- **Relocation/Replacement of equipment from UX85** — **Short-Term**
  - currently completed
- **Preparation of TZ76 and displacement of equipment in UJ76**: — **Short-Term and Mid/Long-Term**
  - Relocation in TZ76 fully integrated
  - preparation of infrastructure done.
  - Cabling and displacement analysed (but not done!!)
  - action limited by LHC schedule
  - UPS relocation and pre-cabling for PC relocation)
- **Additional shielding** — **Short-Term**
  - UJ76, RRs, new maze, P6 ducts (kicker electronics)

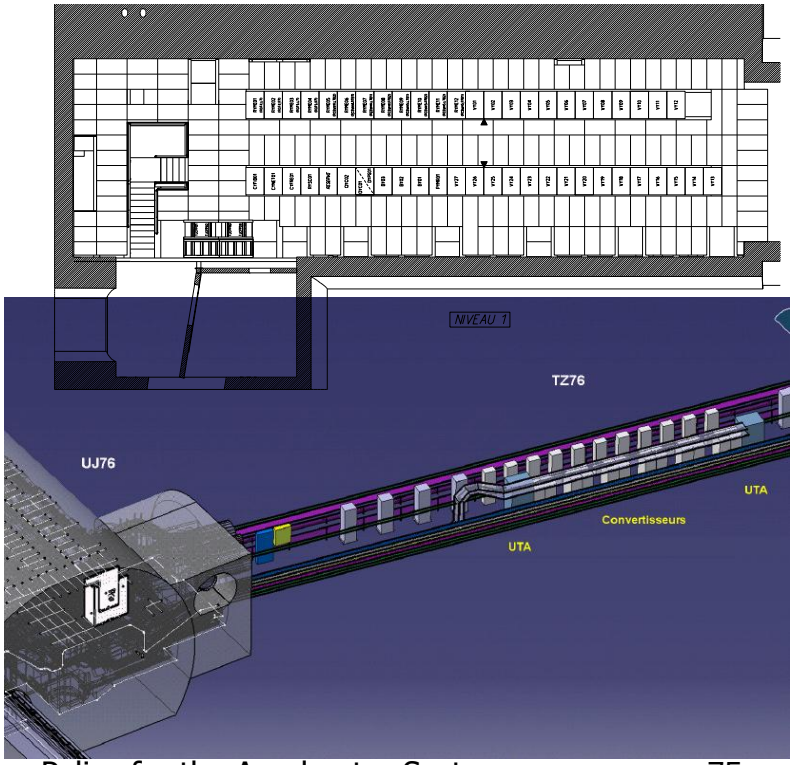
R2E Achievements (2009) Part 2

- **Detailed Point-Iterations** **Inventory, Monitoring**
  - visit of areas looking into integration options, available monitoring (Etat de Lieu)
- **Priority List of Equipment (Classes)** **Prioritization**
  - direct interaction with equipment groups (starting with machine protection)
  - identified safety related
  - proposal to prepare 'short-term' actions **Mid-Term**
- **Organization of radiation tests in CNGS and outside CERN (FIP, QPS, Cryo, Power Converters …)** **Testing**
  - Tests conducted at PSI, Louvin, Prospero, waiting for beam in CNGS
- **Radiation monitoring** **Monitoring**
  - calibration experiment at CERF shows problematic RadMon calibration, more beam-time required **Mid-Term**
  - additional measurement proposal at PTB (including funding through EFNUDAT)
  - study of required installation/displacement of RADMONS, additional TLD monitoring
  - development of monitoring tool for offline analysis, first beta-version available
- **Radiation school**
  - Organised with PH-ESE, 2-3 June: ~65 participants, 16 lecturers **Long-Term**
- **Documentation**
  - R2E Website (Presentations, Minutes), R2E Library, Picture Gallery of Critical Areas, Inventory of Monitor, Publications (ECRs, Chamonix, Point-Reviews…)

UJ76/RR73/77 SEE Related Issues

- **Early awareness** of high radiation levels
- **Detailed analysis** based on **tracking studies** (SIXTRACK) and **cascade simulations** (FLUKA) to estimate the distribution and maximum radiation doses and fluences
- Analysis of **related uncertainties** (assumptions, models, statistics, limitations)
- **Inventory** and location of installed electronics
- Study of **consequences in case of failure**
- Study of **different solutions** (shielding, relocation, combinations)
- **Proposed solution** outlined and discussed in respective ECR (LHC-EC-UJ76)
- **Staged implementation approach** to allow for additional measurements during operation





SEEs related 2008/9 Shutdown's Activities

- IR7
  - **RR73/77** installation of final shielding
  - **TZ76** preparation
  - **UJ76**
    - UPS removal (from UJ76 into TZ76)
    - additional shielding wall to increase protection of safe room
- IR6
  - Shielding of ducts between tunnel and **UA63/67**
- IR8
  - **UX85b** installation of remote controllers
- Additional identified holes in shielding were already mostly closed before first start-up (e.g., geometer holes)
- Critical Areas: check for **additional monitoring**, iterations