Radiation levels in the IR1 and IR5 shielded alcoves

WP10
Energy Deposition & R2E

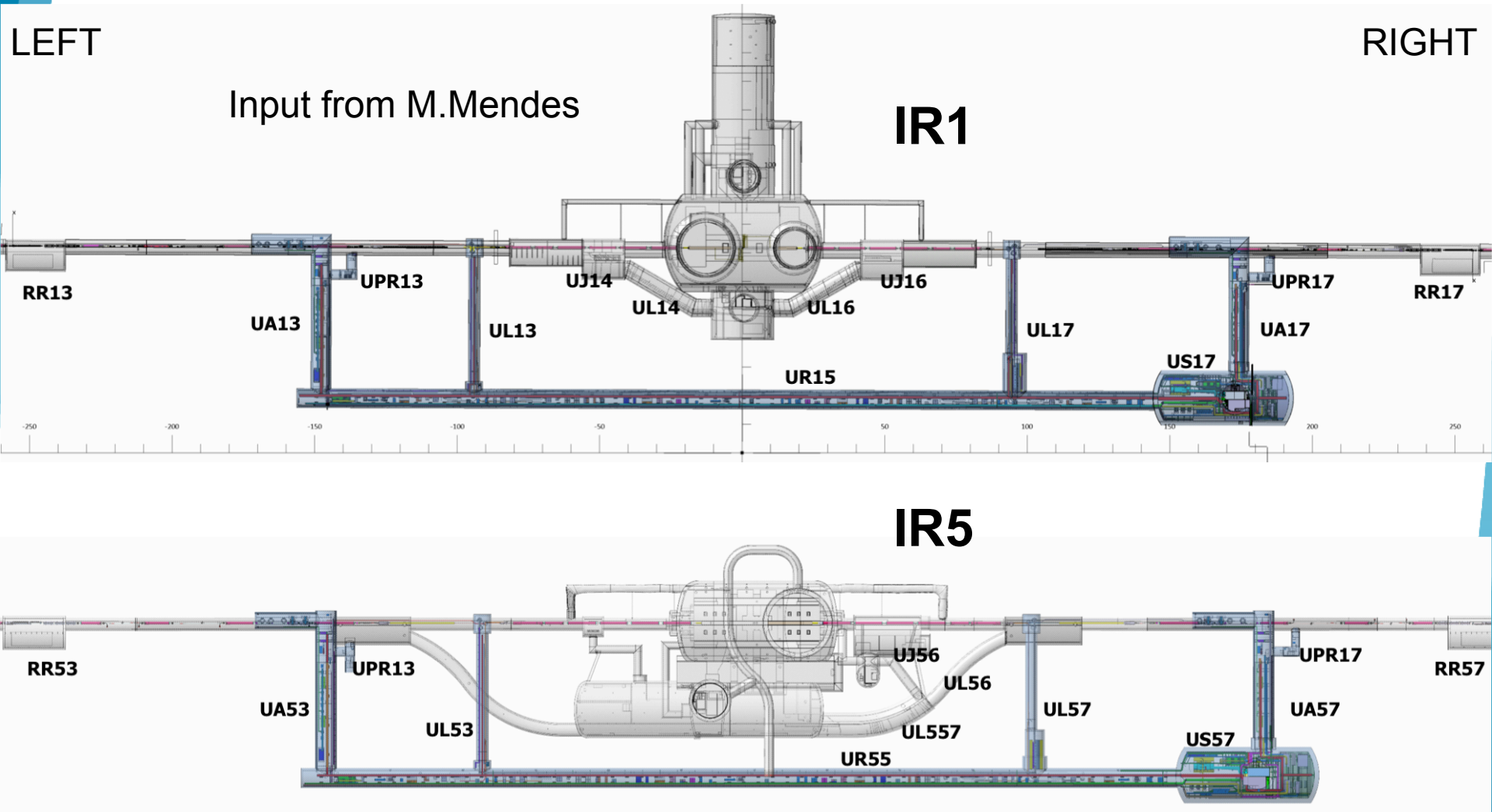
Giuseppe Lerner, Rubén García Alía
with input from: M.Sabaté Gilarte, F.Cerutti, A.Infantino

Review of HL-LHC radiation level specification document
12th December 2019

Introduction

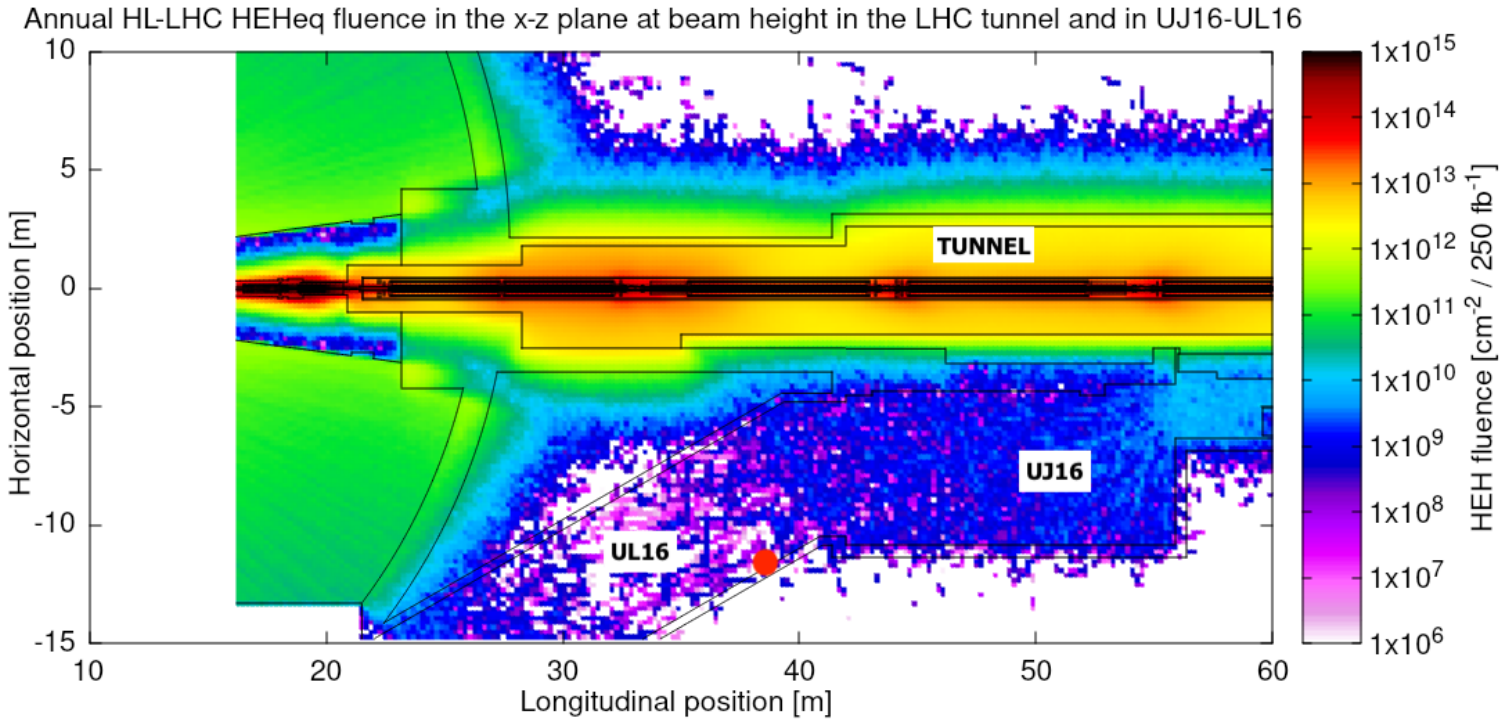
- The levels in the shielded areas in IR1 and IR5 are dominated by collision debris during **proton operation**.
- HL-LHC integrated luminosities:
  - Cumulative → 4000 fb^{-1} (ultimate HL-LHC scenario).
  - Annual → 250 fb^{-1} (used for the specifications in these areas).
- FLUKA simulations:
  - HL-LHC optics v1.5, horizontal (IR1) and vertical (IR5) crossing for the LSS (M. Sabaté Gilarte). Same simulations used for the LSS.
  - RP simulation for new UPR-UA galleries (A. Infantino).

Layout of IR1 and IR5



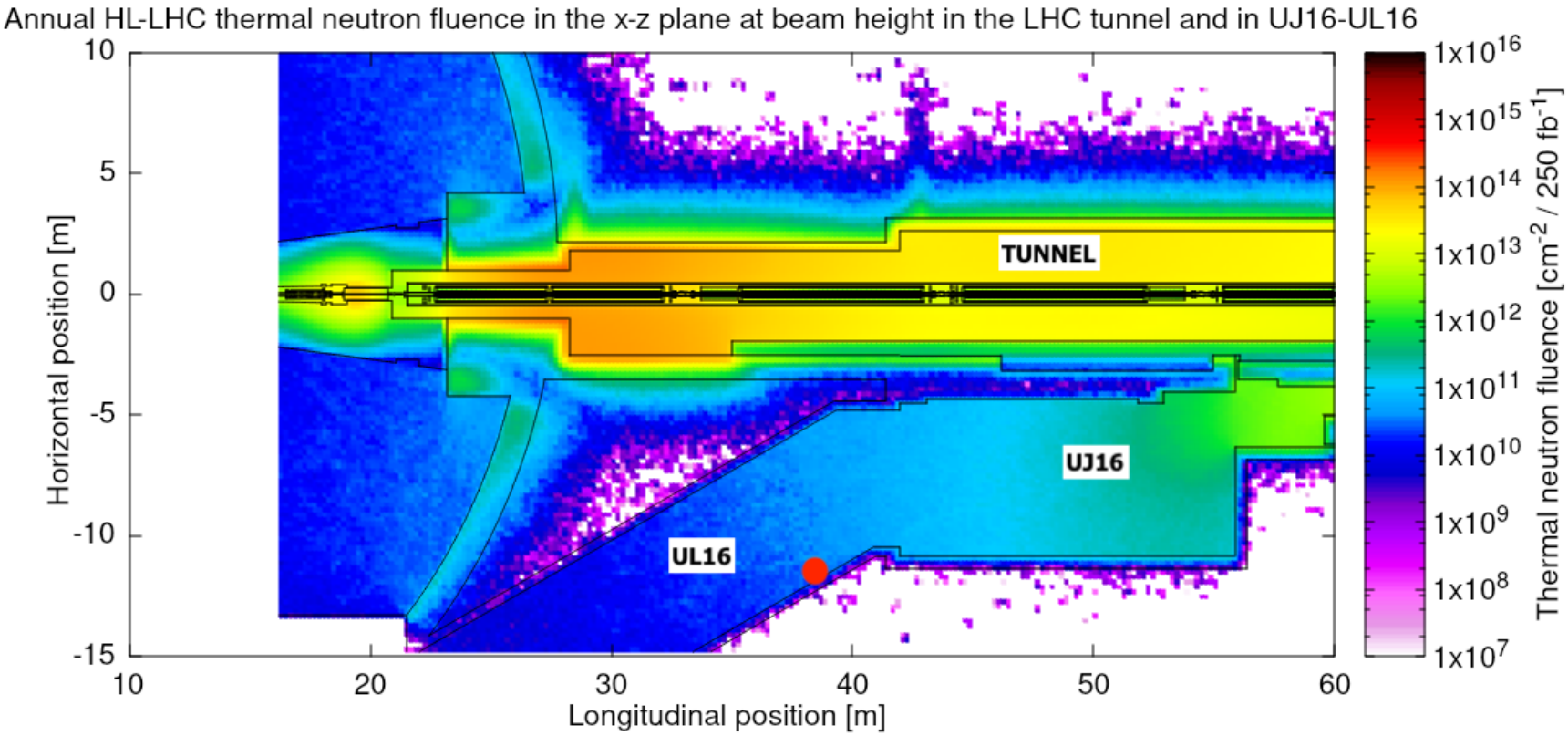
Radiation levels in UJ16-UL16: HEH fluence

- Heavily shielded areas near IP1. Main concern: SEE-related quantities. HEH leakage in UJ16 through the concrete walls and through the entrance on the non-IP side (UJ17).
- HEH fluence reduced from 10^{13} cm^{-2} in the tunnel to 10^{9} cm^{-2} in the shielded area. Lower levels in UL16.



Thermal neutron fluence in UJ16-UL16

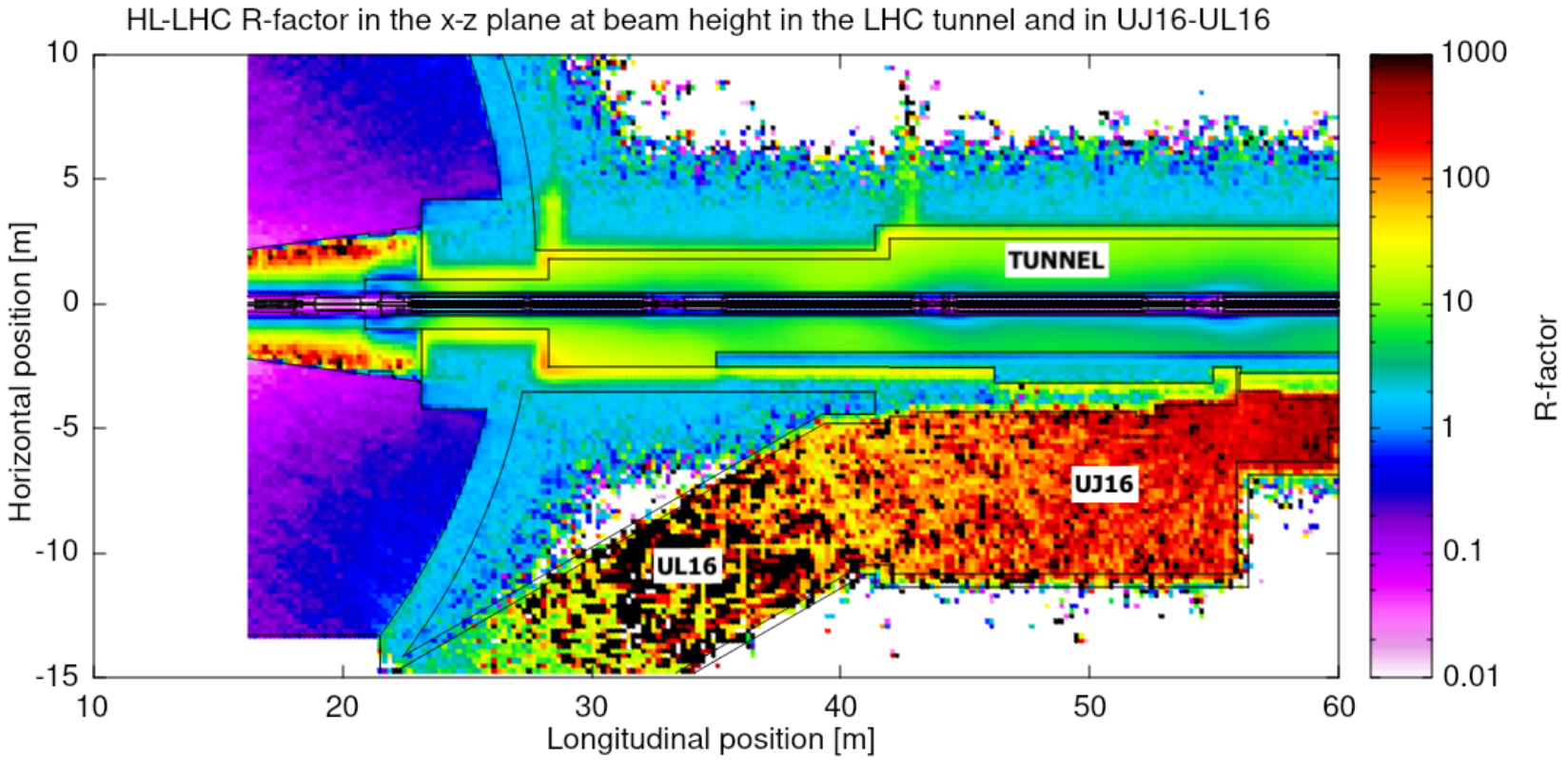
- Important thermal neutron leakage from the non-IP side entrance of UJ16.



R-factor in UJ16-UL16

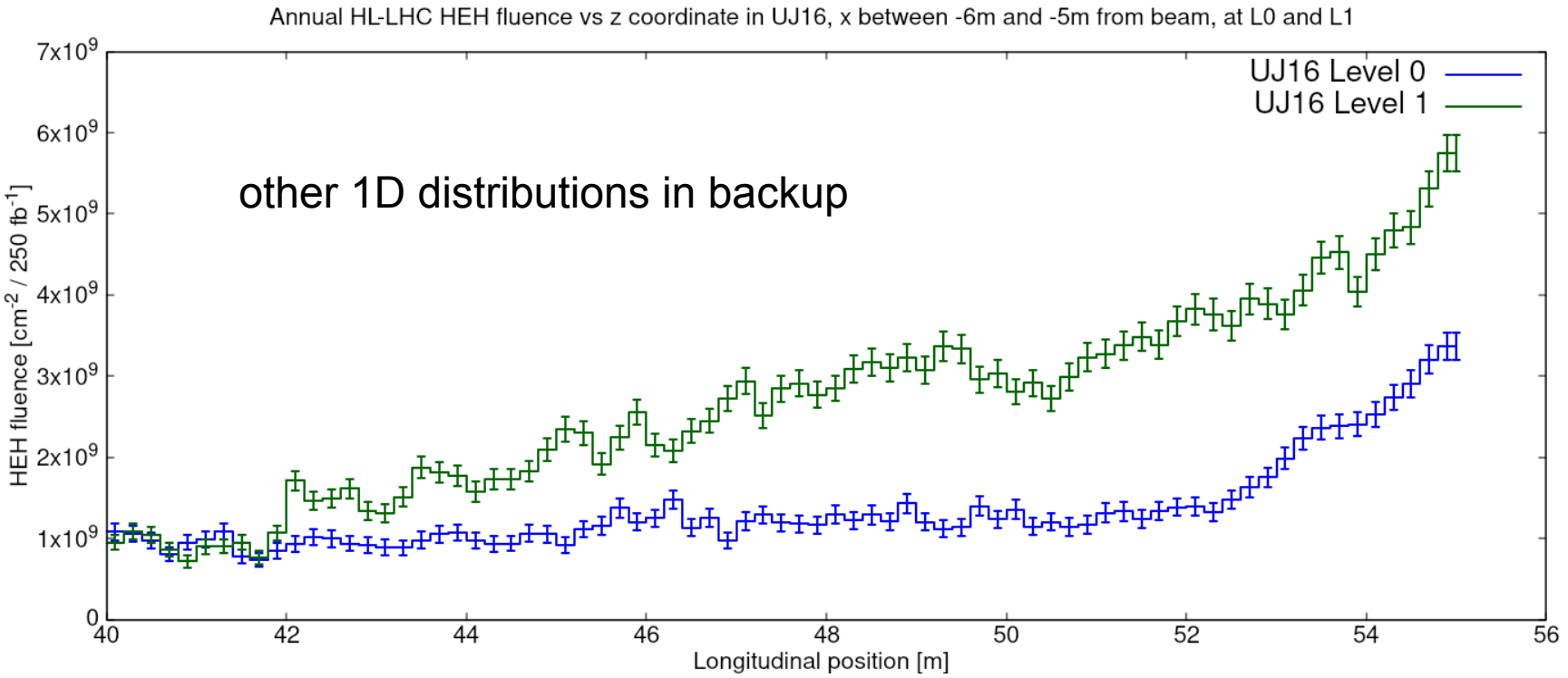
- R-factor (ratio of thermal and HEH fluence) up to >100 in UJ16, especially on the non-IP side.

Note: the high R-factors in UL16 come from statistical fluctuations of HEH fluence



HL-LHC specs in UJ16 for 250 fb^{-1}: 1D profiles

- HL-LHC specifications obtained from 1D projections of each R2E-relevant quantity both at L0 and L1.
- Consistent observation: higher levels on the non-IP side → we provide specifications up to z=52m.



HL-LHC specs in UJ16 (and UJ14) for 250 fb^{-1}

- Specifications valid for the whole UJ16, with the caveat of the area beyond z=52m.
- **The levels increase when approaching the non-IP side of UJ16** (see the 1D plot in the previous slide and the additional ones in the backup).

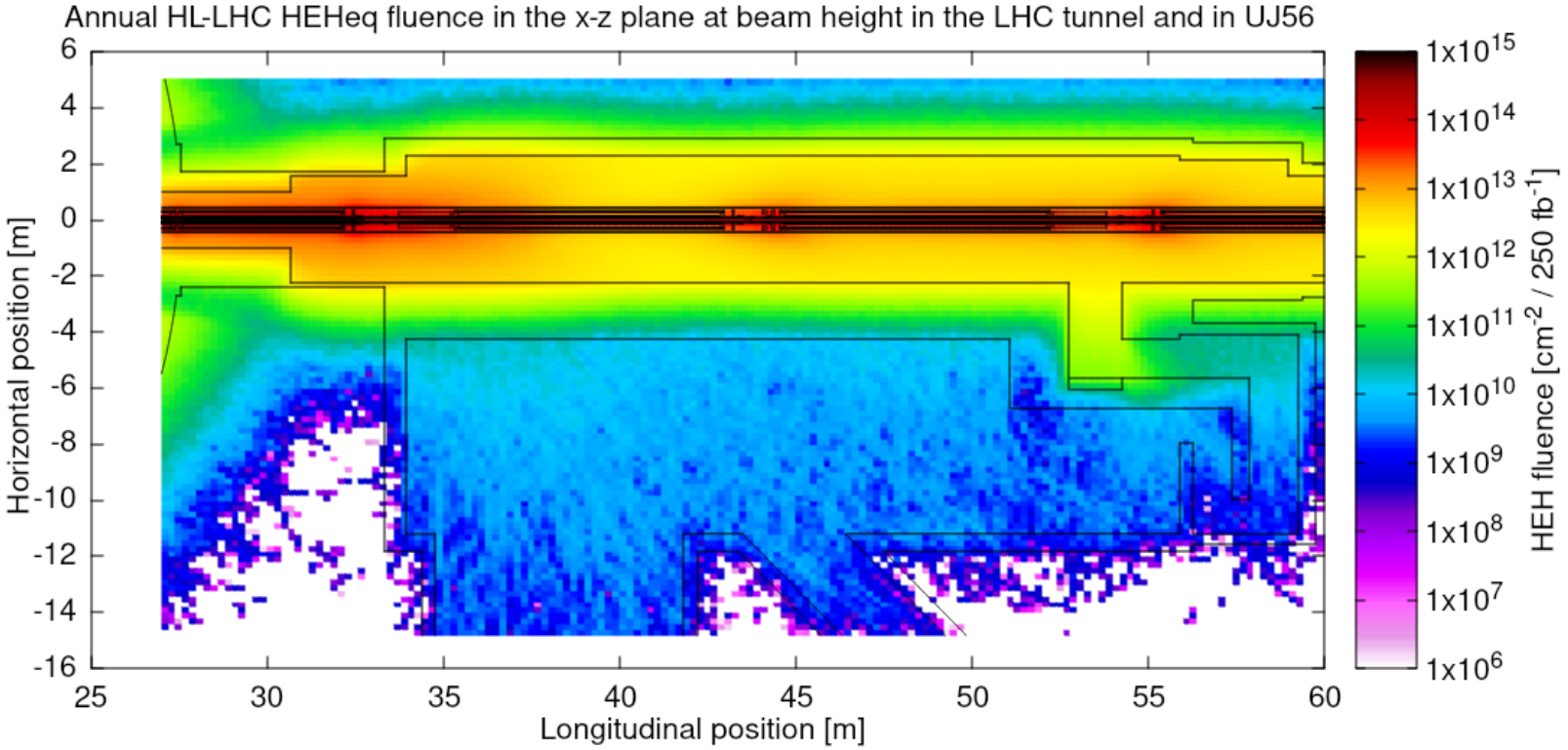
  - HEH fluence: $2 \cdot 10^{9}$ cm^{-2}/yr.
  - Thermal neutron fluence: $3 \cdot 10^{11}$ cm^{-2}/yr.
  - TID: 5 Gy/yr
  - 1MeVn-eq fluence: $3 \cdot 10^{10}$ cm^{-2}/yr

HL-LHC specs in UL16 (and UL14) for 250 fb^{-1}

- In UL16 the FLUKA simulation runs out of HEH fluence statistics → we base our specifications on a rescaled RadMon (1RM01S) measurement from Run 2 (position indicated in the 2D views with a red marker).
- Lower levels compared to UJ16.
  - HEH fluence: $1 \cdot 10^{8}$ cm^{-2}/yr.
  - Thermal neutron fluence: $2 \cdot 10^{10}$ cm^{-2}/yr.
  - TID: < 1 Gy/yr.
  - 1MeVn-eq fluence: $< 10^{10}$ cm^{-2}/yr.

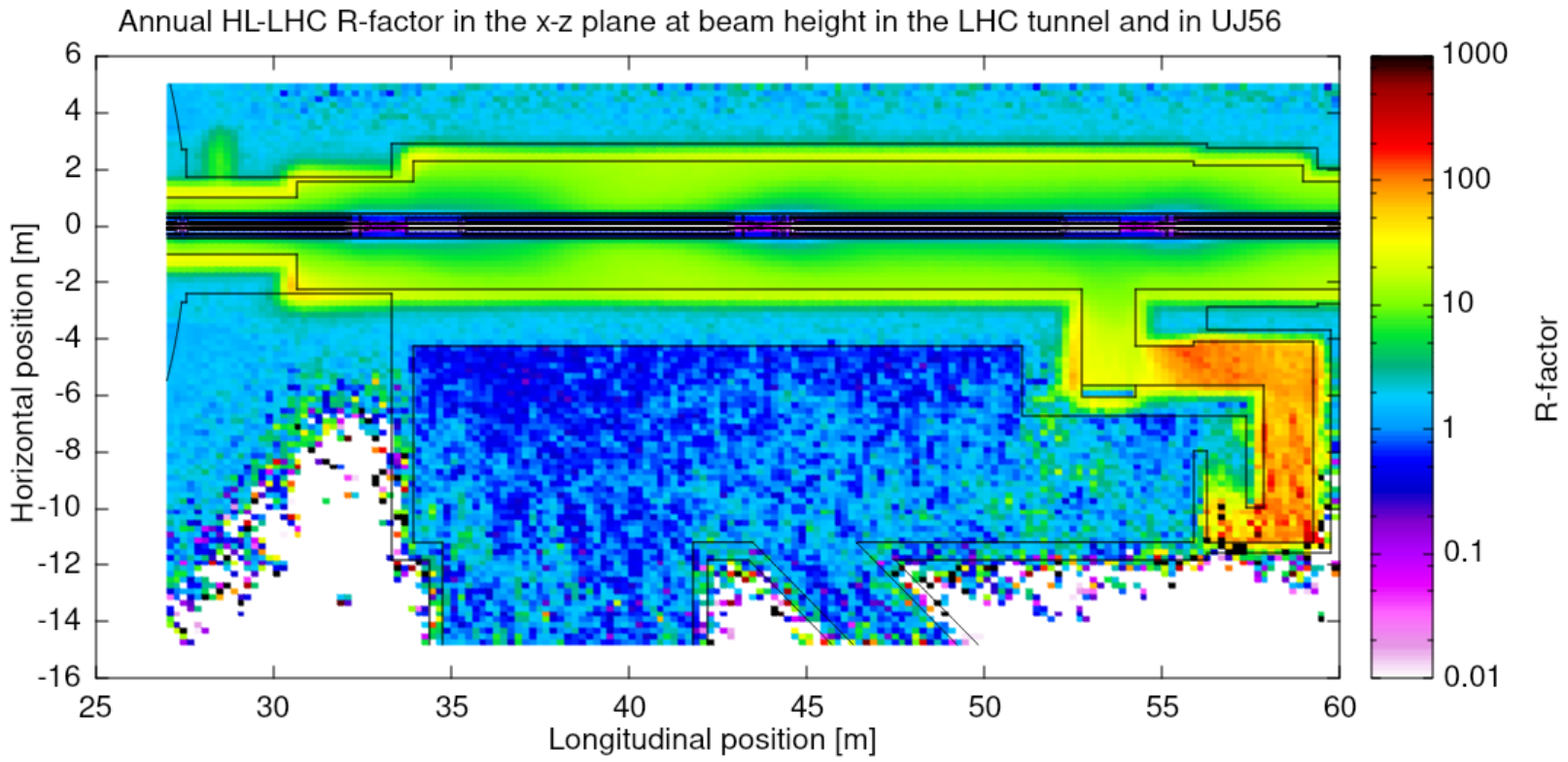
Radiation levels in UJ56: HEH fluence

- Heavily shielded area near IP5. Similar to UJ16 but different layout (and no corresponding UJ on the left side).
- Similar suppression of HEH fluence from the tunnel to the inner part of the UJ.



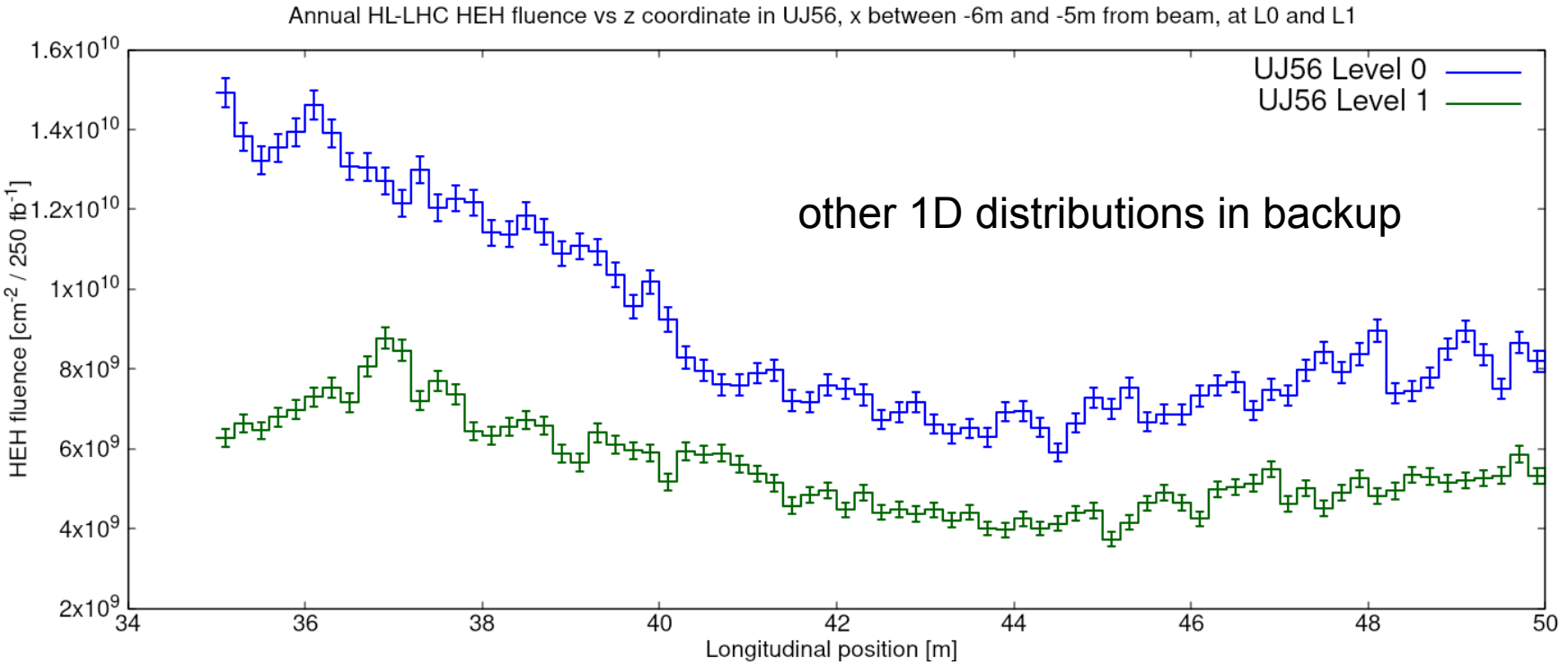
Radiation levels in UJ56: R-factor

- Major difference between UJ16 and UJ56: in UJ56 the thermal neutron component is less relevant (R-factor around 1) due to the different shape of the non-IP side entrance. 2D plot of thermal neutron fluence in backup.



HL-LHC specs in UJ56 for 250 fb^{-1}: 1D profiles

- HL-LHC specifications obtained again from 1D projections of each R2E-relevant quantity.
- Here the difference of HEH fluence at L0 and L1 is not negligible (especially on the IP side).



HL-LHC specs in UJ56 for 250 fb^{-1}

- Different specifications at L0 and L1 in UJ56, mainly due to the different HEH fluence.
- If it is preferred we can reduce this to a single specification (but it may be better to stay on the conservative side, using the higher HEH values).

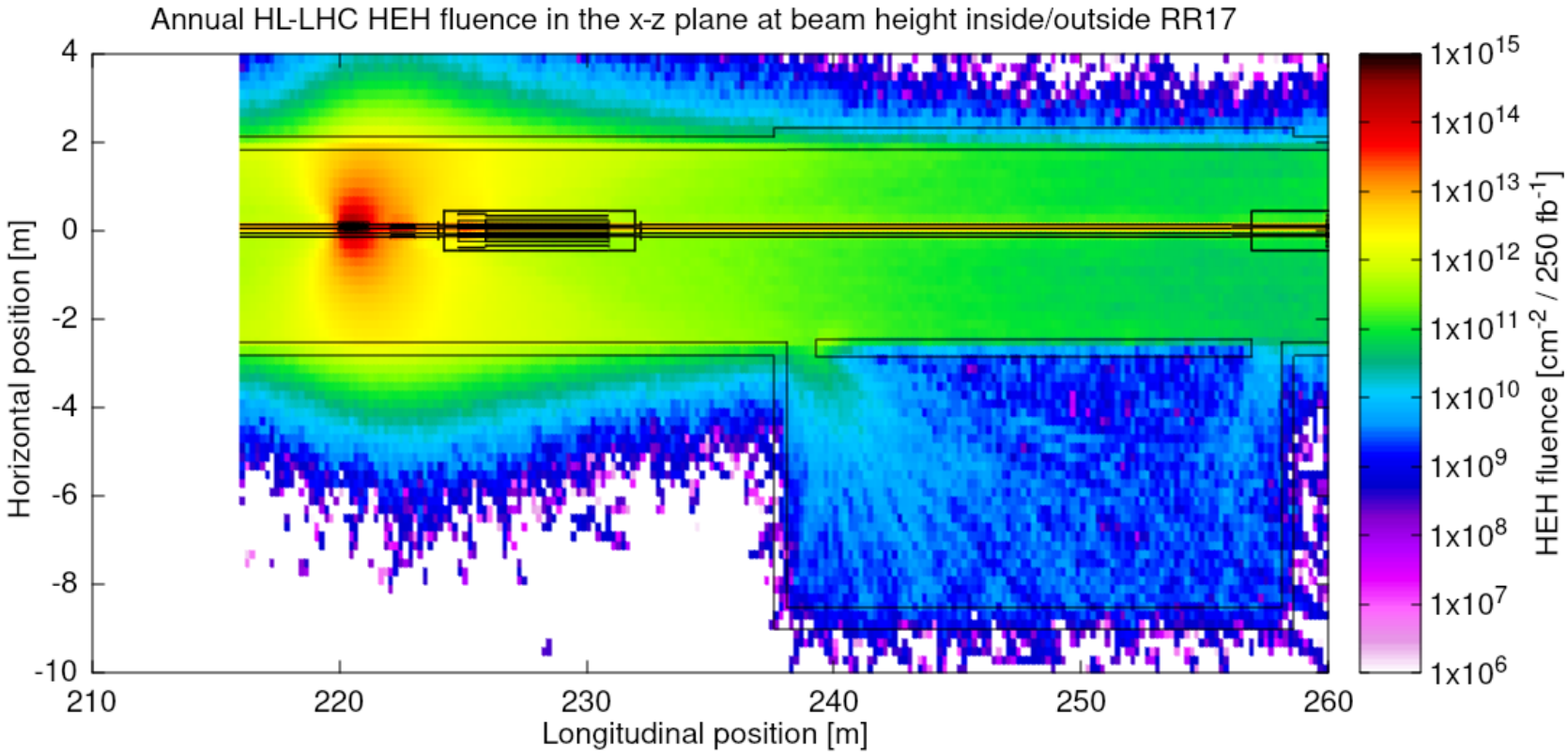
- HEH fluence: $1 \cdot 10^{10}$ cm^{-2}/yr (L0), $6 \cdot 10^{9}$ cm^{-2}/yr (L1).
- Thermal neutron fluence: $7 \cdot 10^{9}$ cm^{-2}/yr (L0), $6 \cdot 10^{9}$ cm^{-2}/yr (L1).
- TID: 2 Gy/yr (both L0 and L1).
- 1MeVn-eq fluence: $3 \cdot 10^{10}$ cm^{-2}/yr (L0), $1.5 \cdot 10^{10}$ cm^{-2}/yr (L1).

Radiation levels in the IR1-IR5 RRs: considerations

- A careful radiation level analysis has been carried out for the IR1 and IR5 RRs using the new FLUKA simulations with HL-LHC optics v1.5.
- Main observations:
  - With horizontal crossing in IR1 and vertical crossing in IR5 we see higher levels in the tunnel next to the RRs in IR1.
  - The IR1 layout is not identical to IR5 (tunnel diameter, beamline height) and seems to favour a slightly higher leakage of radiation in the RR.
- This implies that IR1 can be treated as a worst-case scenario for the RRs.

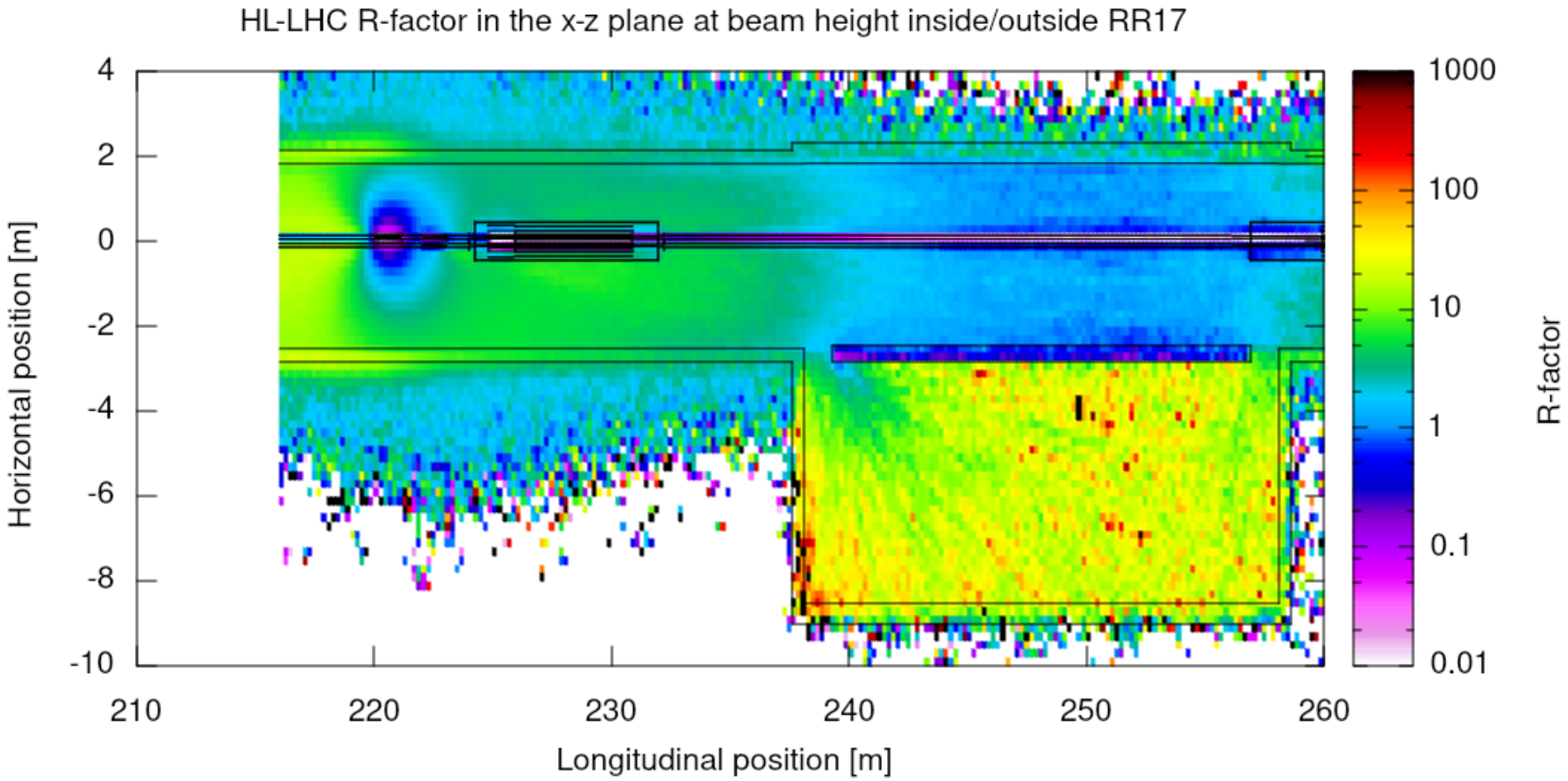
Radiation levels in the IR1-IR5 RRs: HEH fluence

- ~250m from IP1, 2.8m cast iron wall (40 cm thick) with two 1m wide apertures.
- Main source of radiation: TCL6 (here assumed at 14σ).



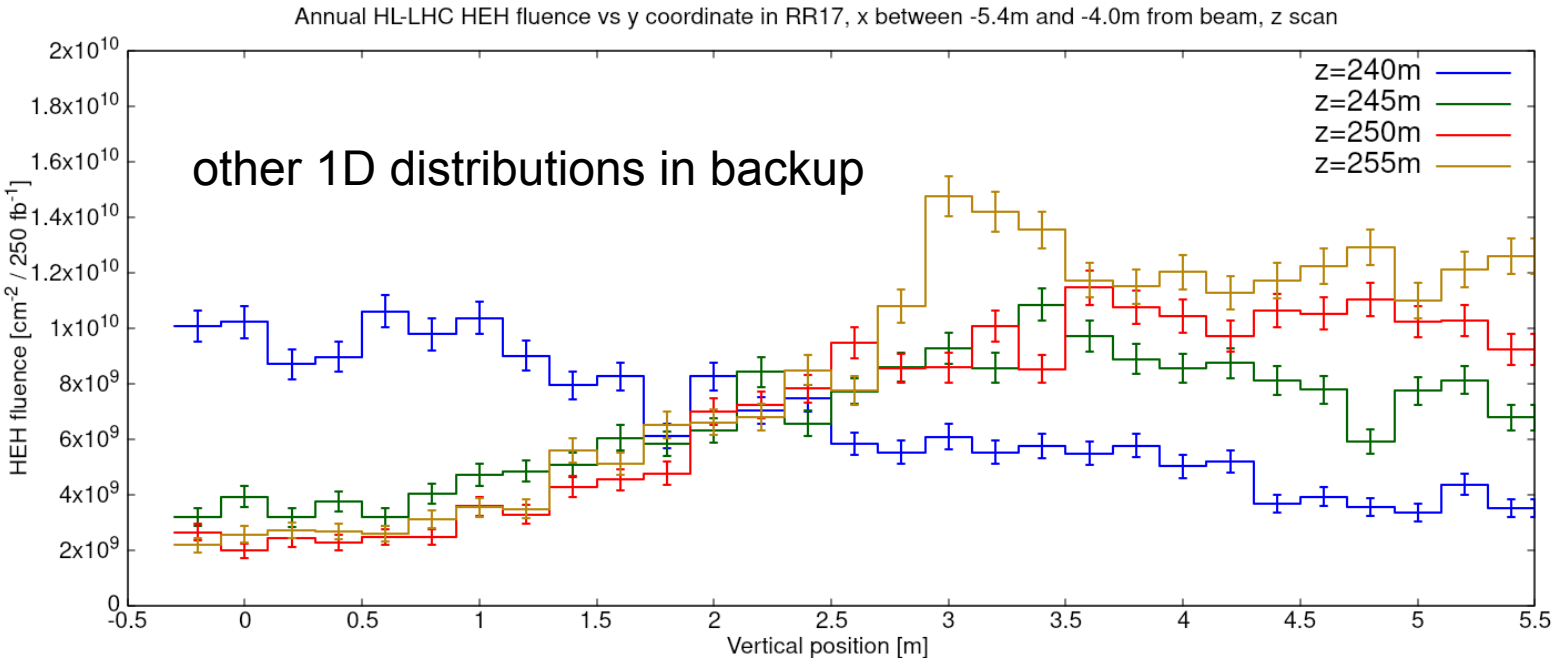
Radiation levels in the IR1-IR5 RRs: R-factor

- Intermediate R-factor between the UJ16 and UJ56 cases. Thermal neutron fluence shown in backup.



HL-LHC specs in IR1-IR5 RRs for 250 fb^{-1}: 1D profiles

- 1D profiles vs y at different z positions in RR17, from IP to non-IP side.
- HEH fluence at L0 higher on the IP side (due to leakage through the entrance).
- At L1 the IP side is shielded because up to the RR entrance the tunnel diameter is smaller, creating a shadow effect, while the bulk of the RR is exposed because the cast iron wall is only 2.8m heigh.



HL-LHC specs in the IR1-IR5 RRs for 250 fb^{-1}

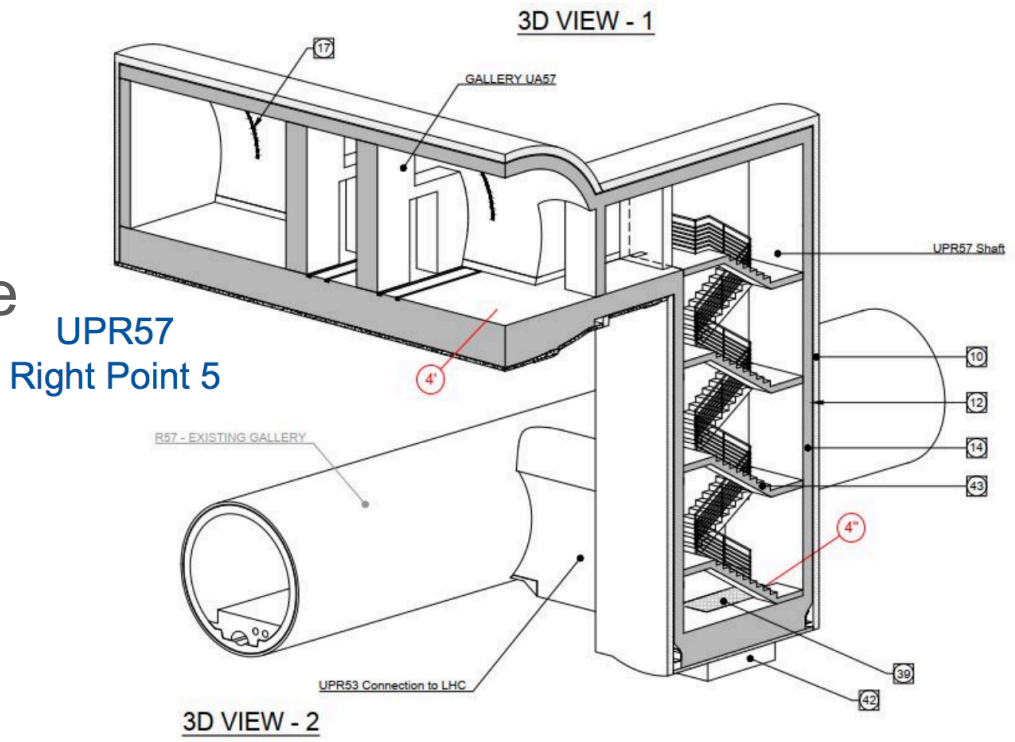
- Different specifications at L0 and L1 in the RRs due to the observed differences between the corresponding radiation levels.
- Values for RR17, which represents a worst case scenario. Specifications valid for all 4 RRs.

– HEH fluence: $6 \cdot 10^9$ cm^{-2}/yr (L0), $1 \cdot 10^{10}$ cm^{-2}/yr (L1).
– Thermal neutron fluence: $6 \cdot 10^{10}$ cm^{-2}/yr (L0), $8 \cdot 10^{10}$ cm^{-2}/yr (L1).
– TID: 8 Gy/yr (L0), 16 Gy/yr (L1).
– 1MeVn-eq fluence: $5 \cdot 10^{10}$ cm^{-2}/yr (both L0 and L1).

Radiation levels in the UPRs-UAs

- New galleries in construction in IR1 and IR5. Radiation levels estimated with a FLUKA simulation by A. Infantino (from RP) - see recent talk at 39th MCWG meeting.
- 4 UPR-UA galleries, one per IP side in IR1 and IR5.
- The layout and distance from the IPs is not the same. **The worst case is found to be UPR13 (~137m left of IP1).**

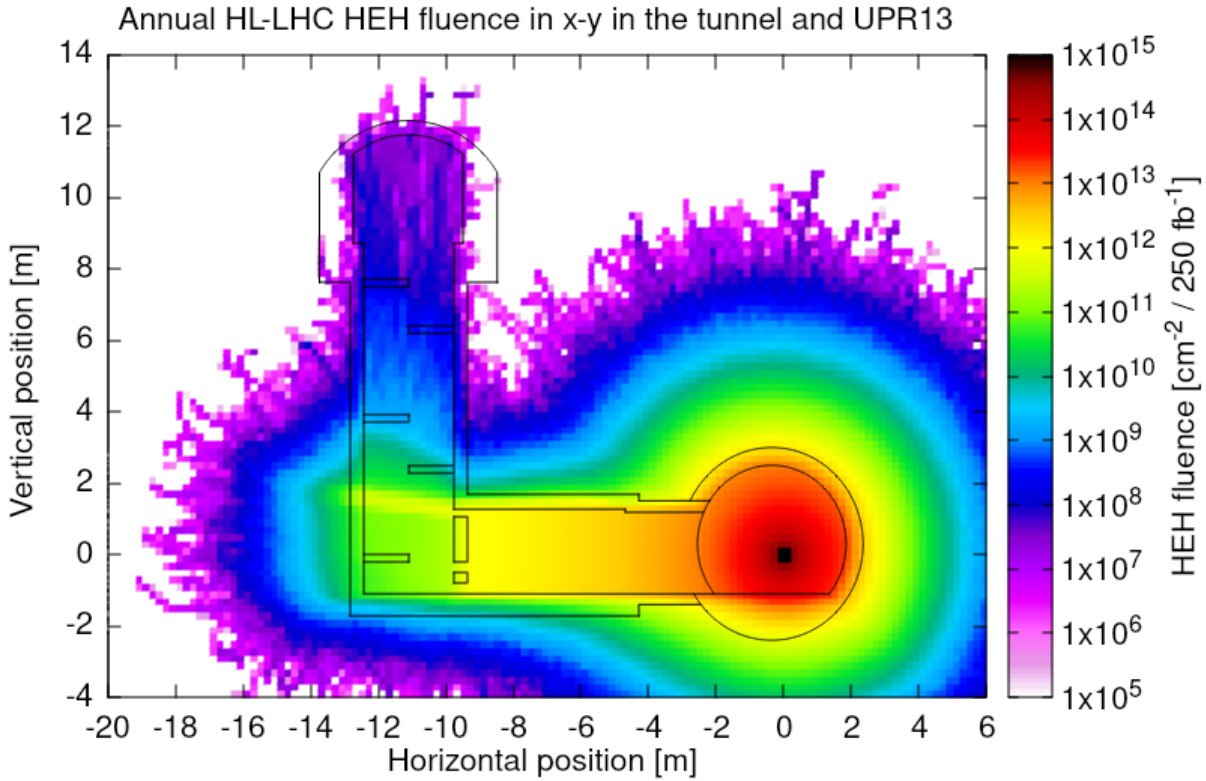
Example of UPR57 layout from A.Infantino's talk



Radiation levels in UPR13 and UA13

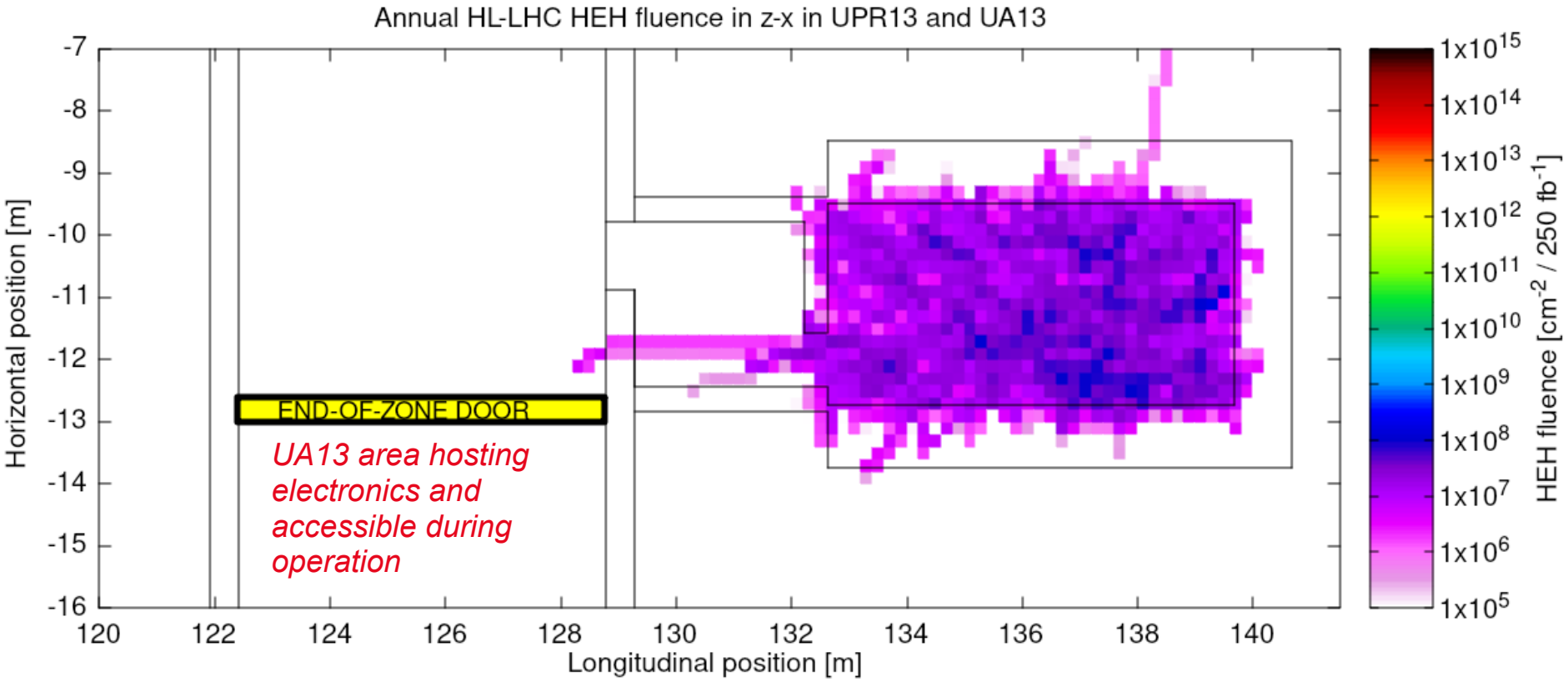
- FLUKA simulation of beam losses on a target near the UPR13 entrance → well representative of beam losses on the TCL4 collimator (~137m left of IP1). Levels scaled to annual losses on TCL4 (250 fb^{-1}).

- Transverse view of HEH fluence propagating through UPR13 and reaching the upper floor, close to the UA entrance.



Radiation levels in UPR13 and UA13 (top floor)

- At the top floor we examine the HEH fluence profile in the x-z plane. The UA is on the left (with accessible part below the end-of-zone door). More details in backup.



Radiation level specifications for the UAs

- From the FLUKA simulation we are able to conclude that the annual HEH and thermal neutron fluence in the accessible area of UA13, below the end-of-zone door, are below the thresholds that we set to define **R2E-safe** areas.
- This conclusion applies also to all other UAs, and by extension also to the **UR15-55** and **US17-57** alcoves.
- No specifications are set for the UPRs, because of the very large gradients from bottom to top floor (and because no presence of electronics is foreseen).
- Note: a second part of the UAs, located above the main LHC tunnel and connected through it by dedicated ducts, is not yet simulated in FLUKA → no specifications available.

Summary of specifications in IR1-IR5 shielded areas

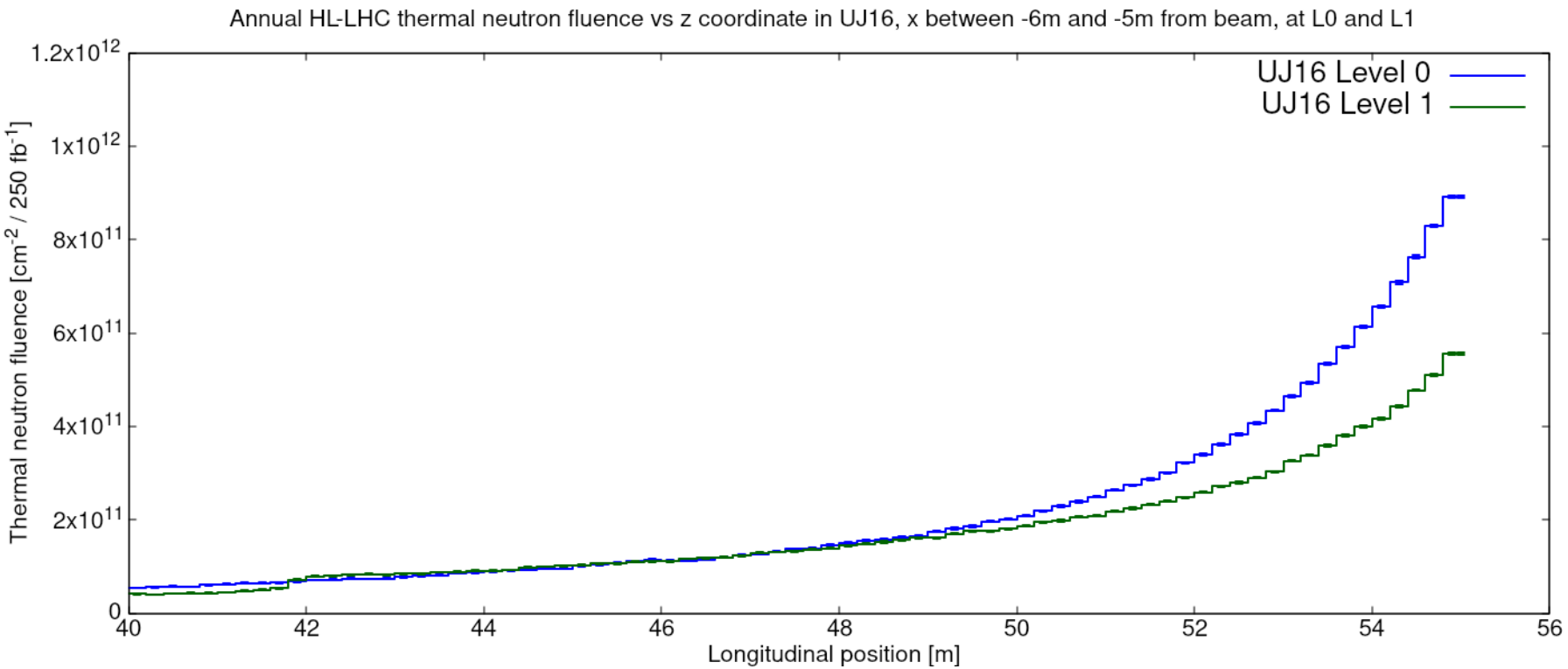
Table 4: Annual expected HL-LHC radiation levels in the IR1 and IR5 shielded areas, normalised to 250 fb^{-1}.

	Annual (250 fb^{-1}) HL-LHC radiation levels			
	TID [Gy]	HEH [cm^{-2}]	Th. neut. [cm^{-2}]	1MeVn-eq [cm^{-2}]
RR13-17-53-57 L0	8	$6 \cdot 10^9$ cm^{-2}	$6 \cdot 10^{10}$ cm^{-2}	$5 \cdot 10^{10}$ cm^{-2}
RR13-17-53-57 L1	16	$1 \cdot 10^{10}$ cm^{-2}	$8 \cdot 10^{10}$ cm^{-2}	$5 \cdot 10^{10}$ cm^{-2}
UJ14-UJ16	5	$2 \cdot 10^9$ cm^{-2}	$3 \cdot 10^{11}$ cm^{-2}	$3 \cdot 10^{10}$ cm^{-2}
UL14-UL16	< 1	$1 \cdot 10^8$ cm^{-2}	$2 \cdot 10^{10}$ cm^{-2}	$< 10^{10}$ cm^{-2}
UJ56 L0	2	$1 \cdot 10^{10}$ cm^{-2}	$7 \cdot 10^9$ cm^{-2}	$3 \cdot 10^{10}$ cm^{-2}
UJ56 L1	2	$6 \cdot 10^9$ cm^{-2}	$6 \cdot 10^9$ cm^{-2}	$1.5 \cdot 10^{10}$ cm^{-2}
UL557	to be defined			
UR15-55	R2E-safe			
US17-57	R2E-safe			
UA13-17-53-57	R2E-safe			

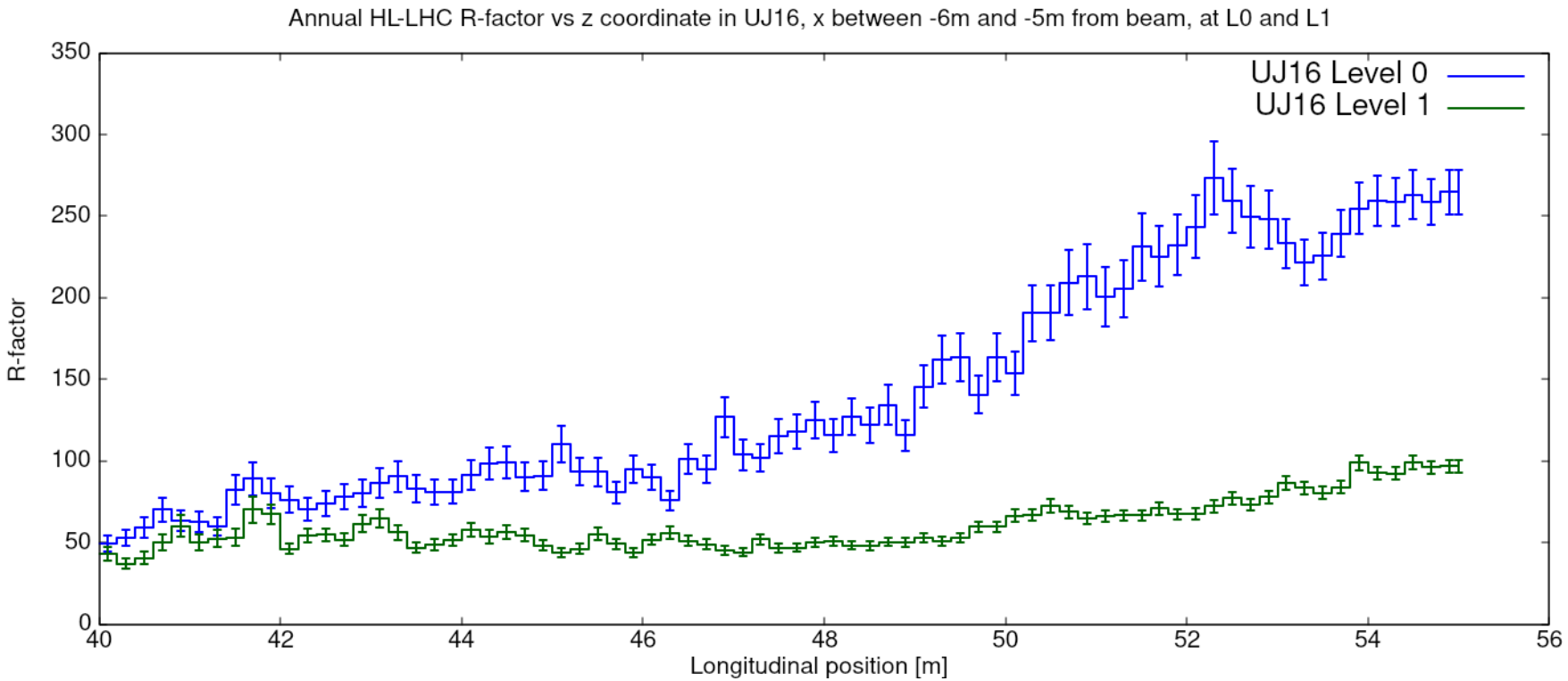
- Not included: UL557, UPS14-16-54-56.

BACKUP

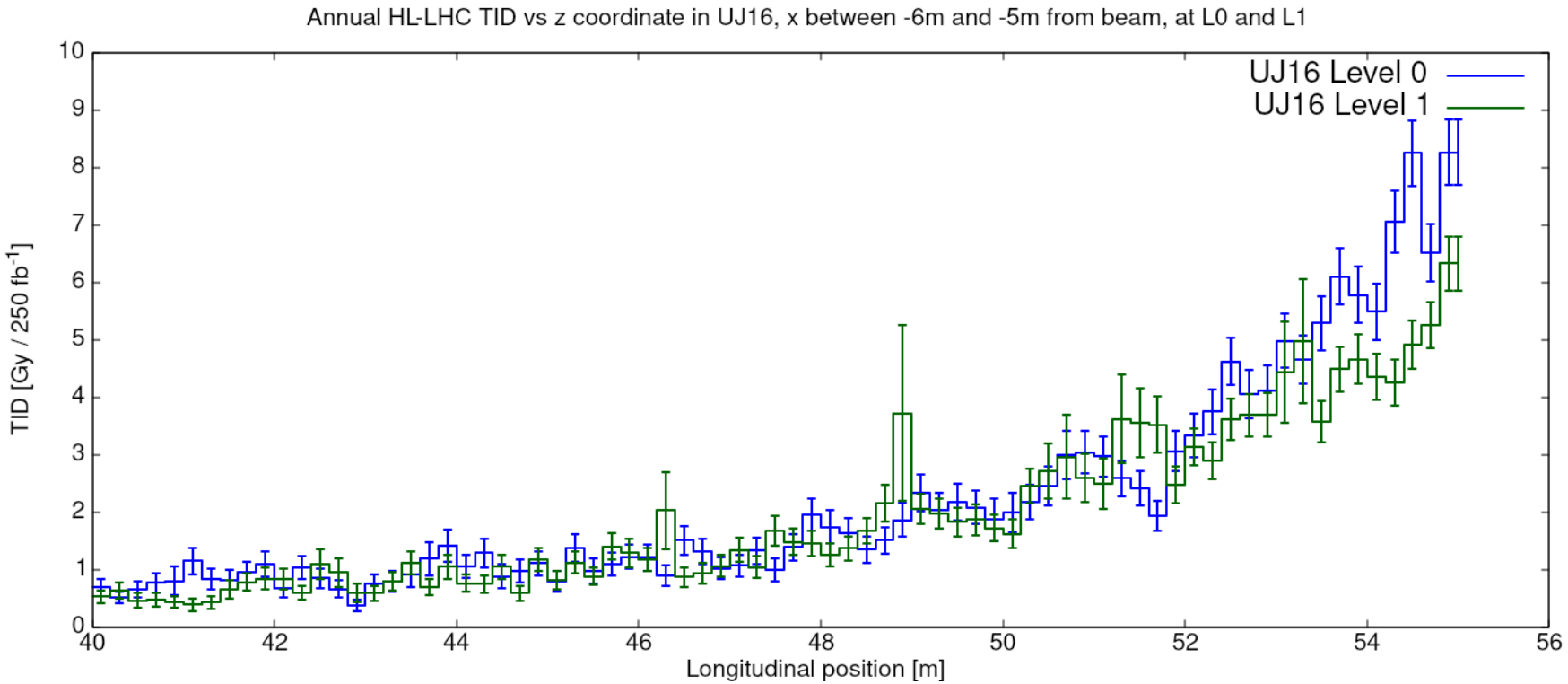
HL-LHC specs in UJ16: thermal neutron fluence



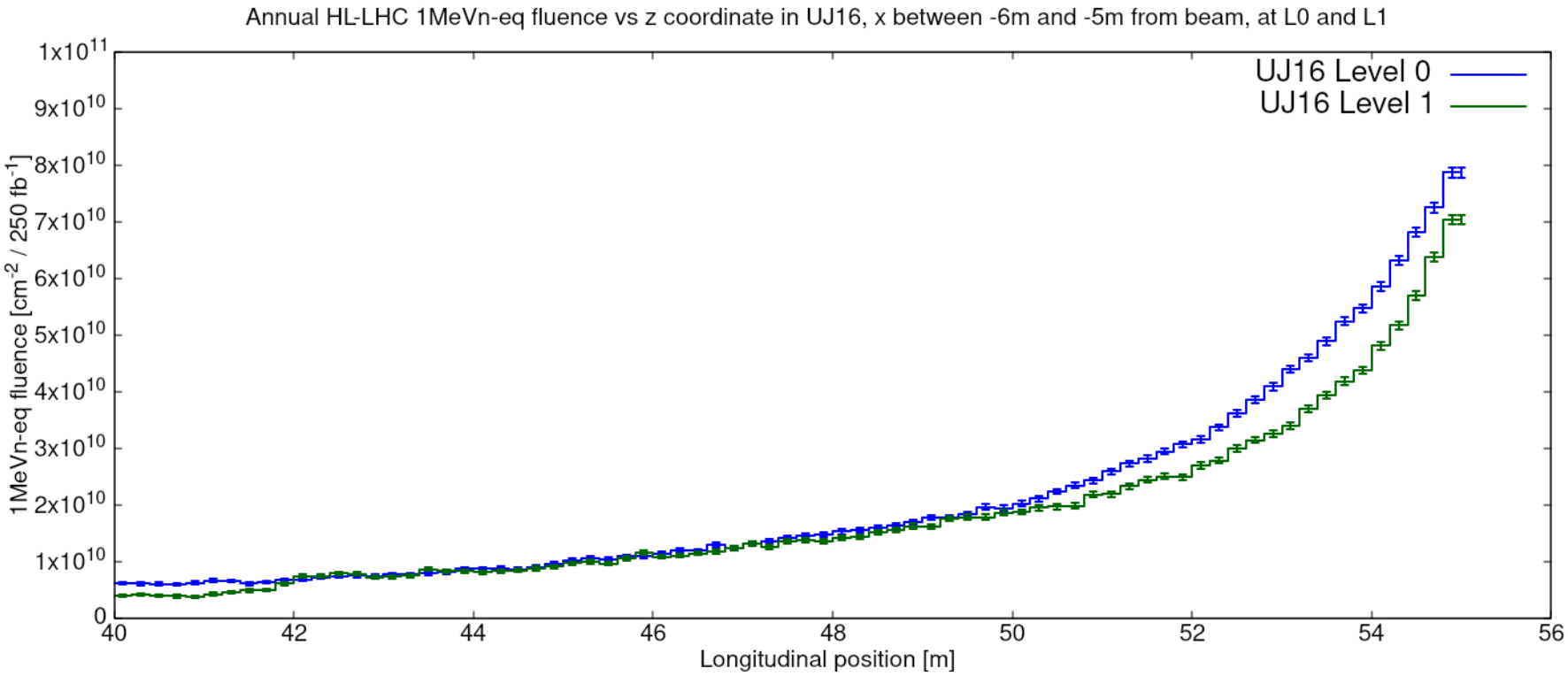
HL-LHC specs in UJ16: R-factor



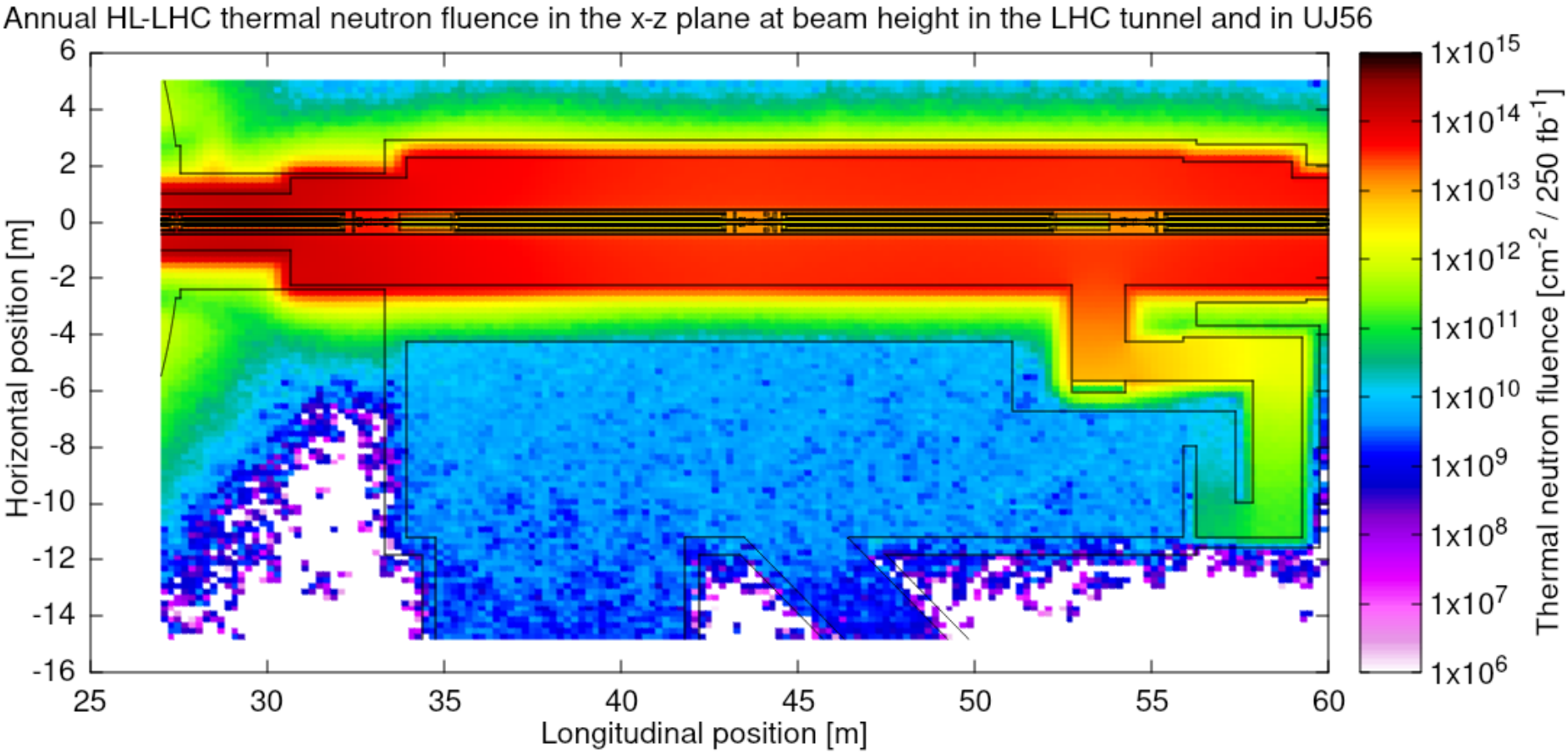
HL-LHC specs in UJ16: TID



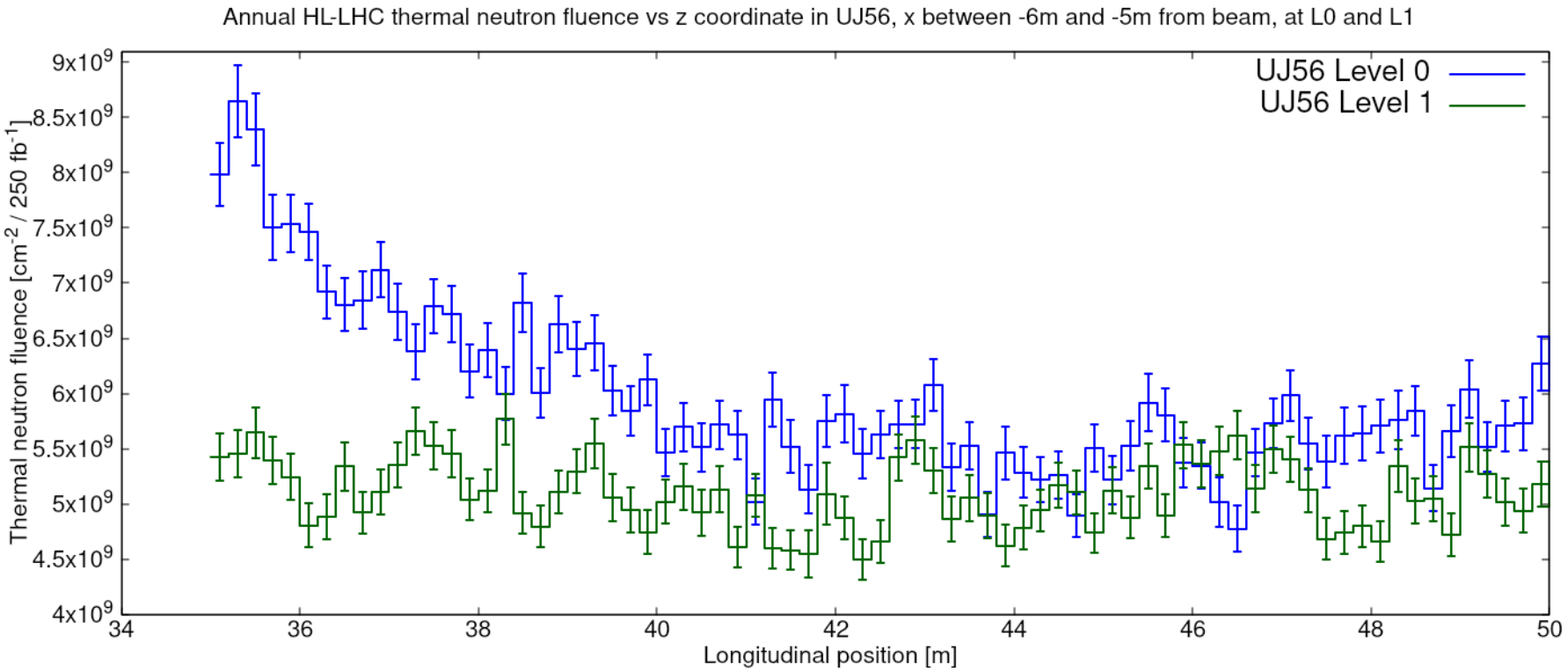
HL-LHC specs in UJ16: 1MeVn-eq



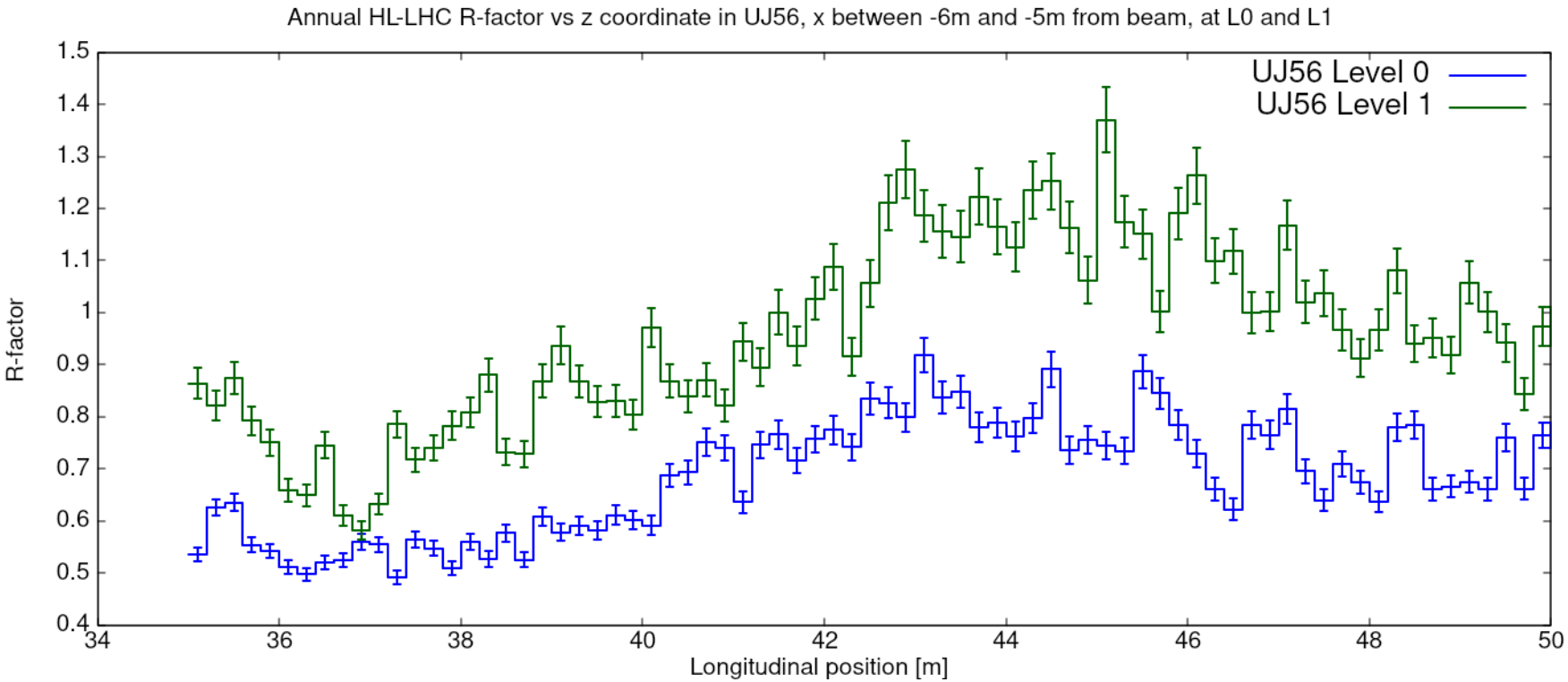
Radiation levels in UJ56: thermal neutron fluence



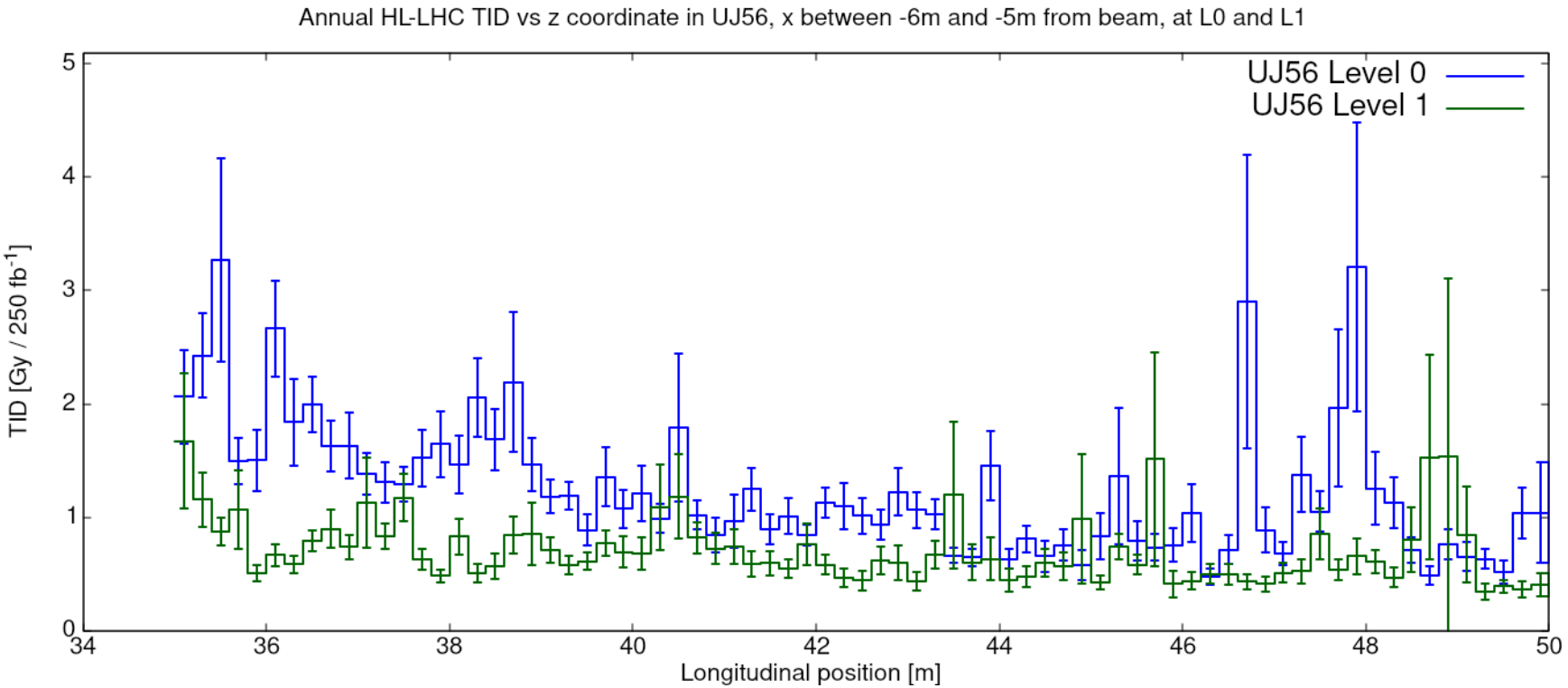
HL-LHC specs in UJ56: thermal neutron fluence



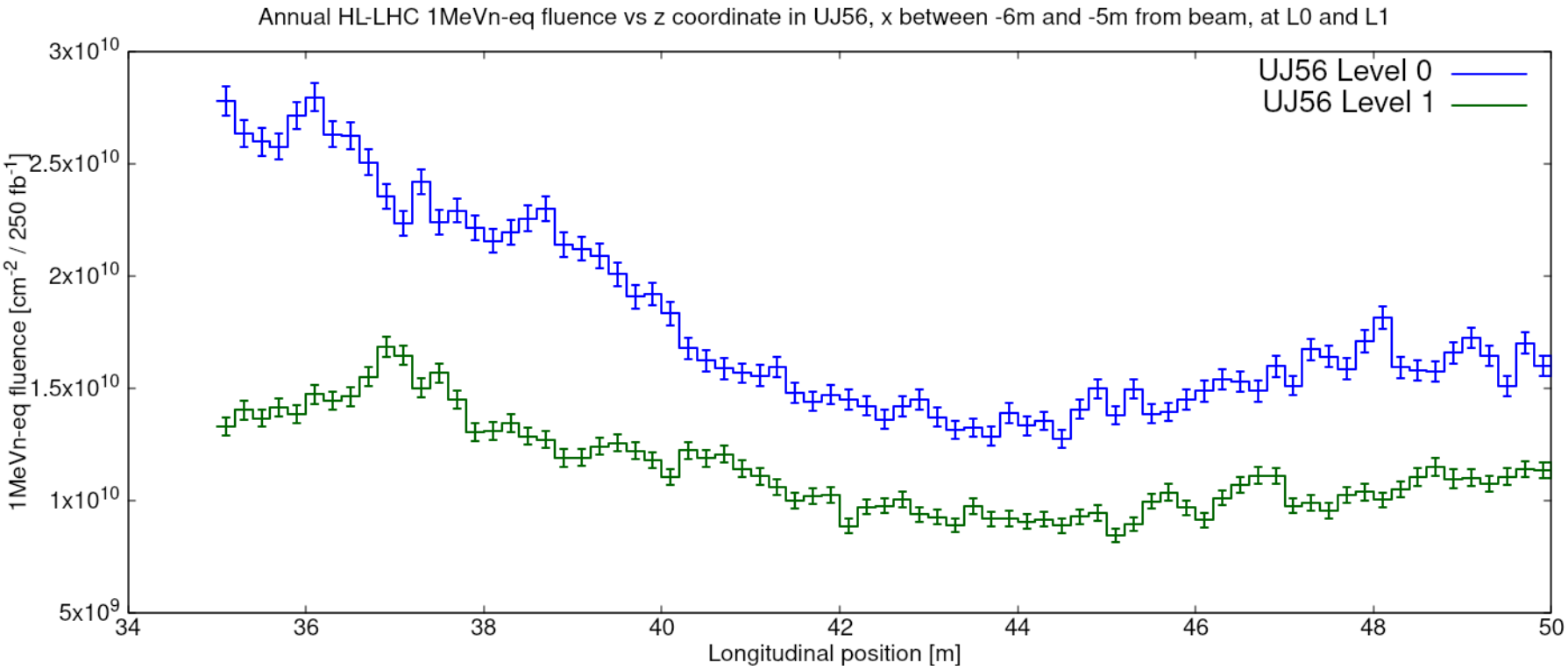
HL-LHC specs in UJ56: R-factor



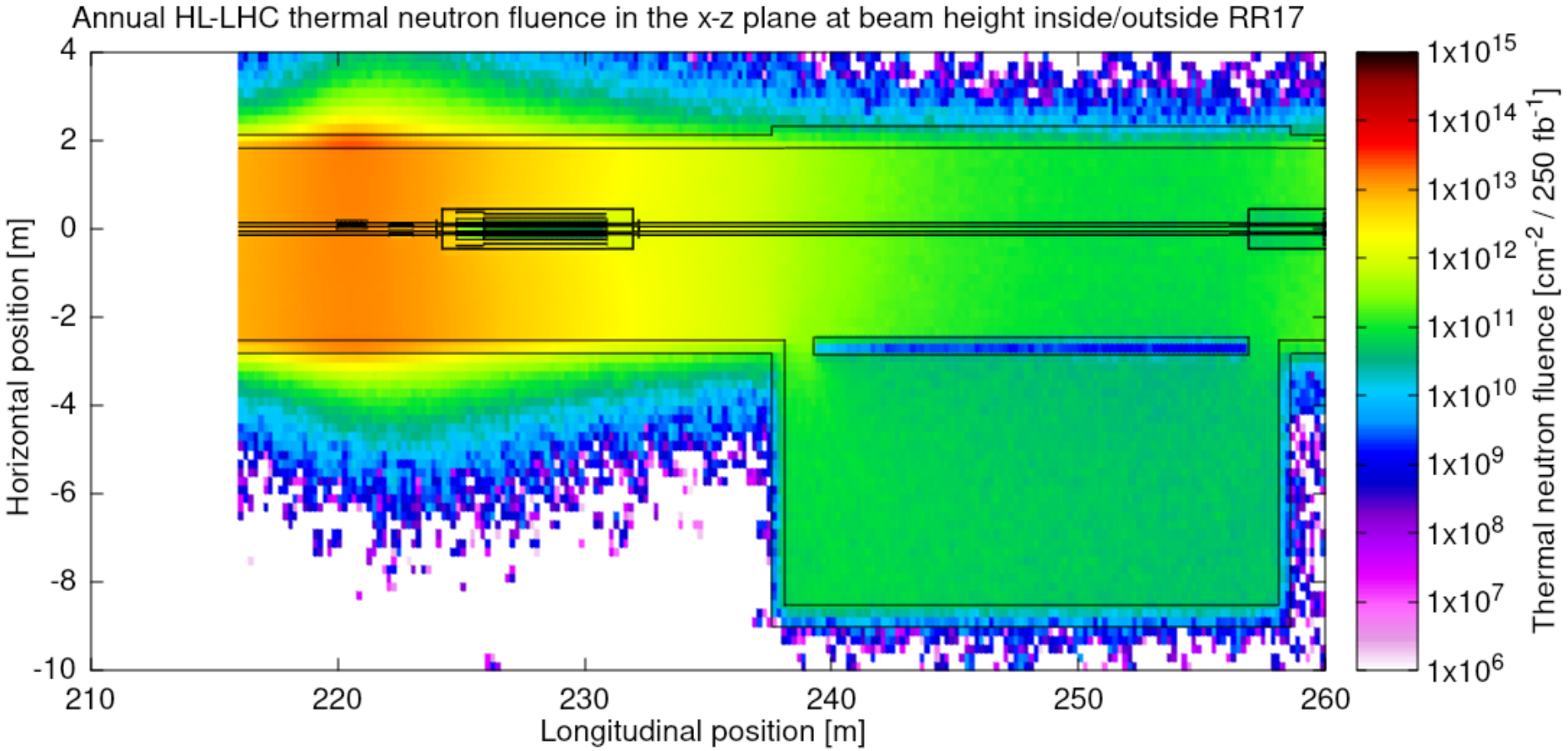
HL-LHC specs in UJ56: TID



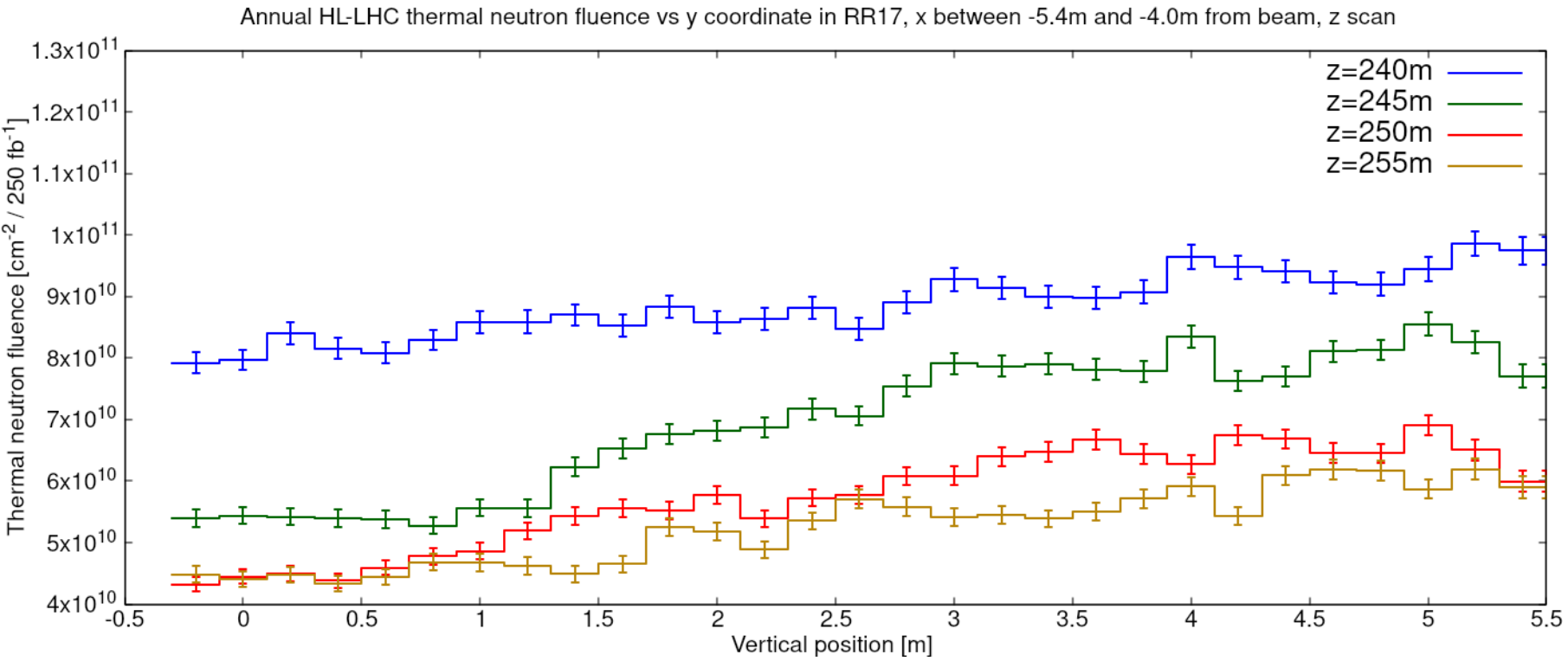
HL-LHC specs in UJ56: 1MeVn-eq fluence



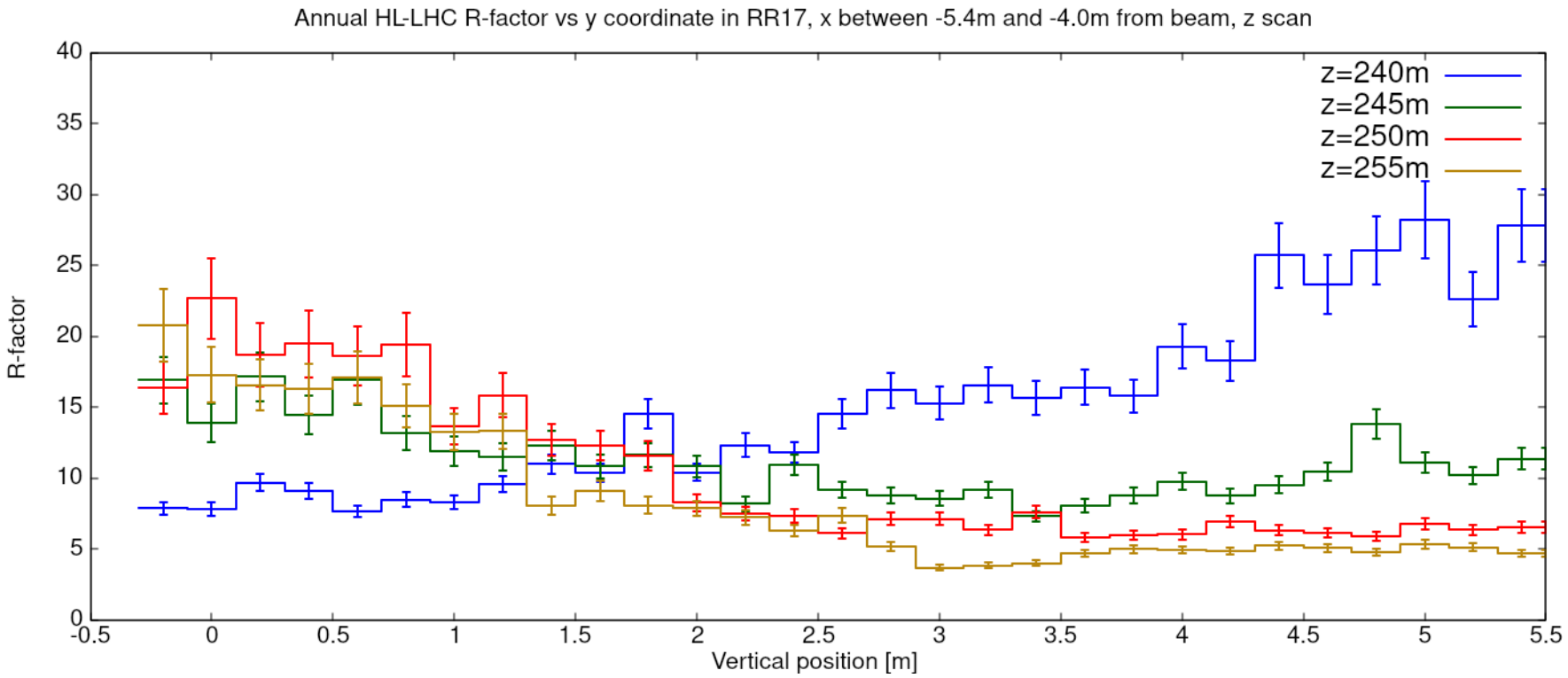
Radiation levels in IR1-IR5 RRs: thermal neutrons



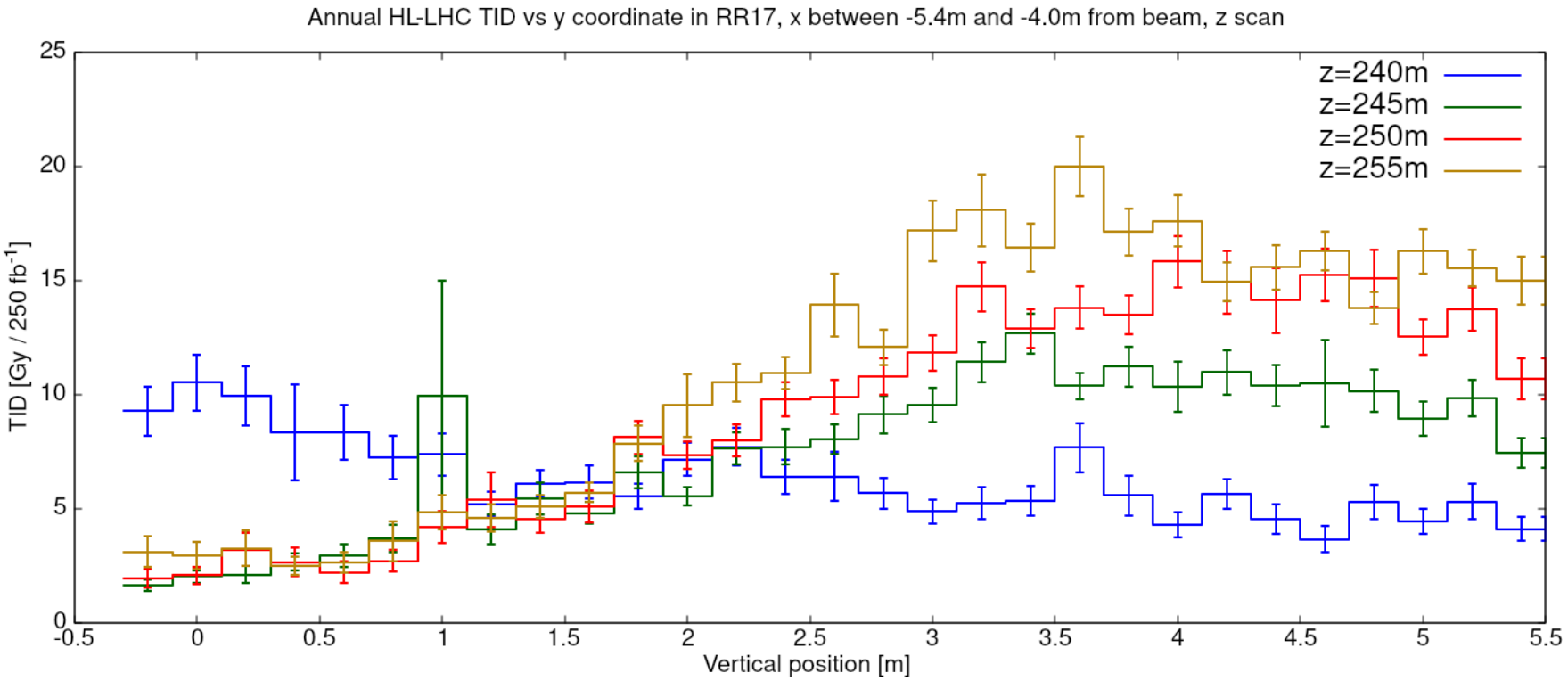
HL-LHC specs in IR1-IR5 RRs: thermal neutrons



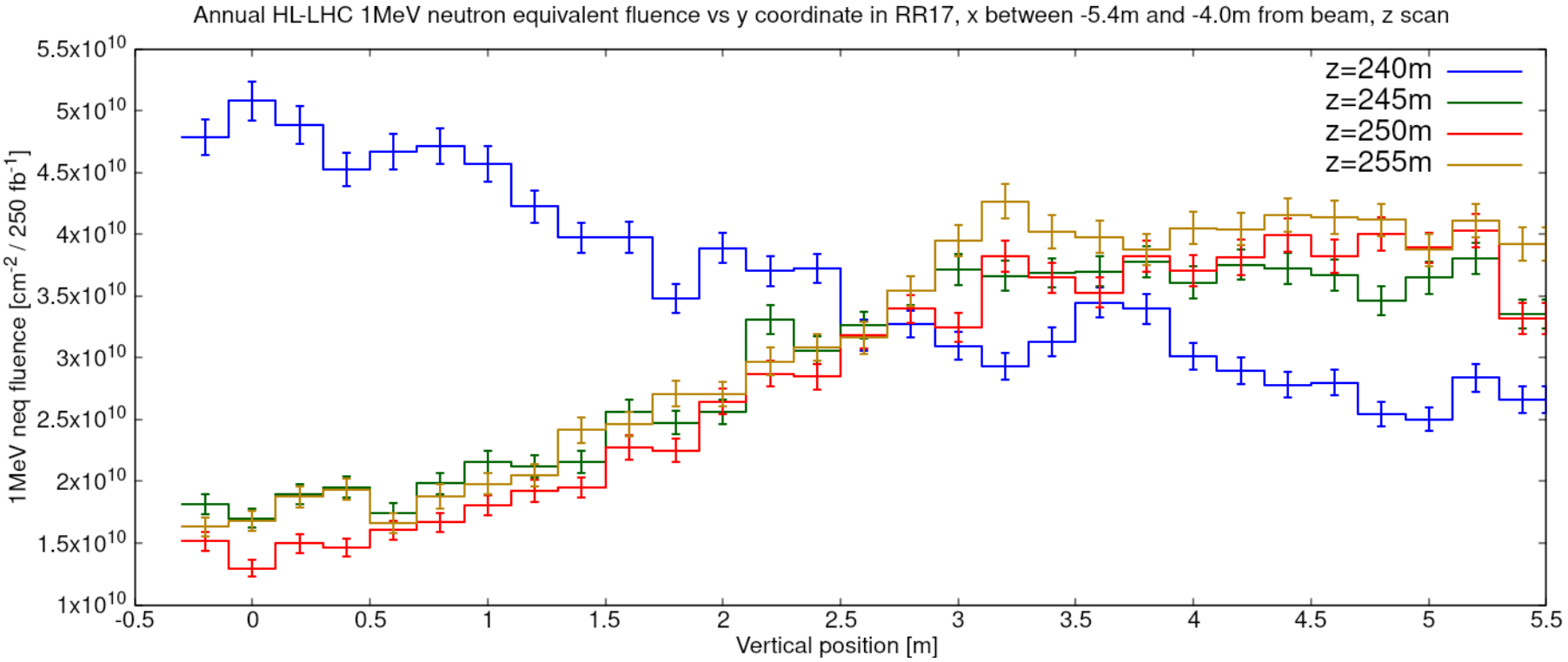
HL-LHC specs in IR1-IR5 RRs: R-factor



HL-LHC specs in IR1-IR5 RRs: TID

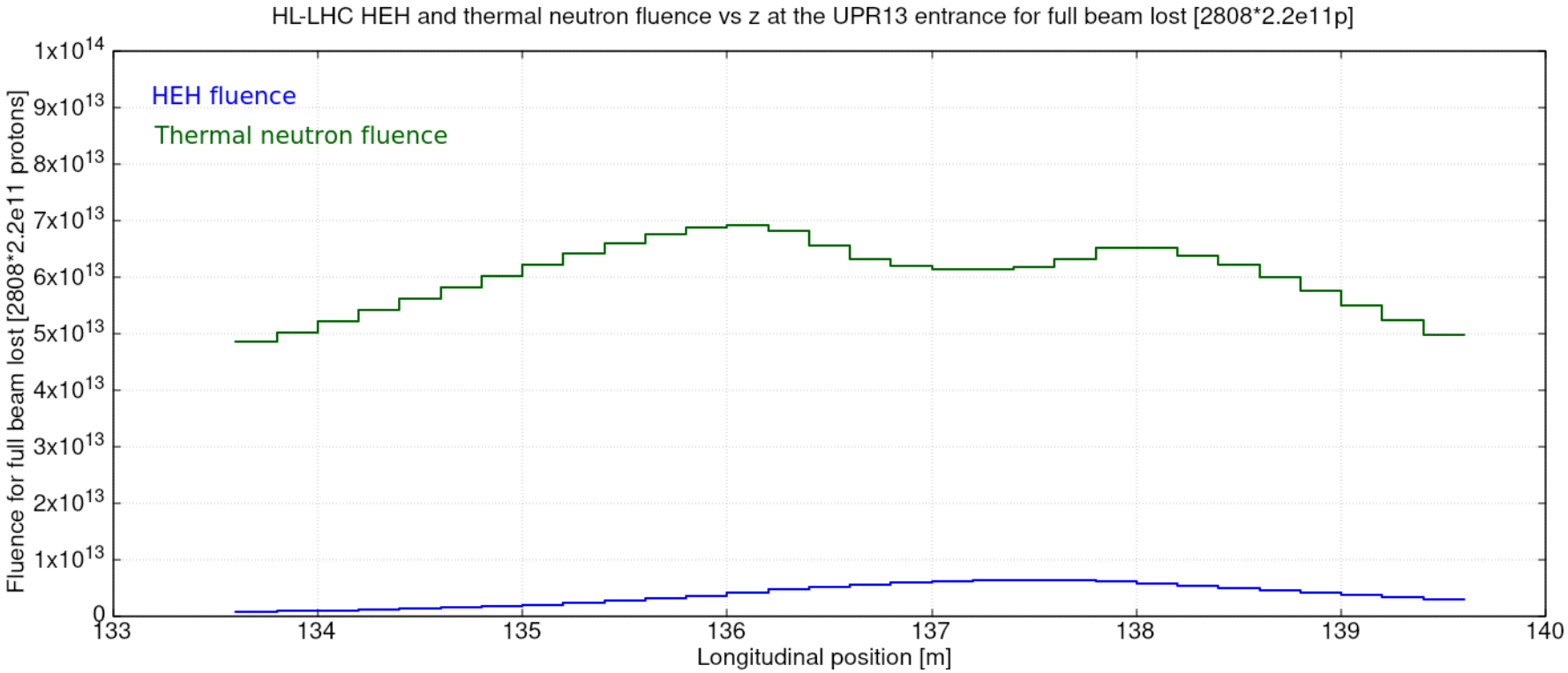


HL-LHC specs in IR1-IR5 RRs: 1MeVn-eq



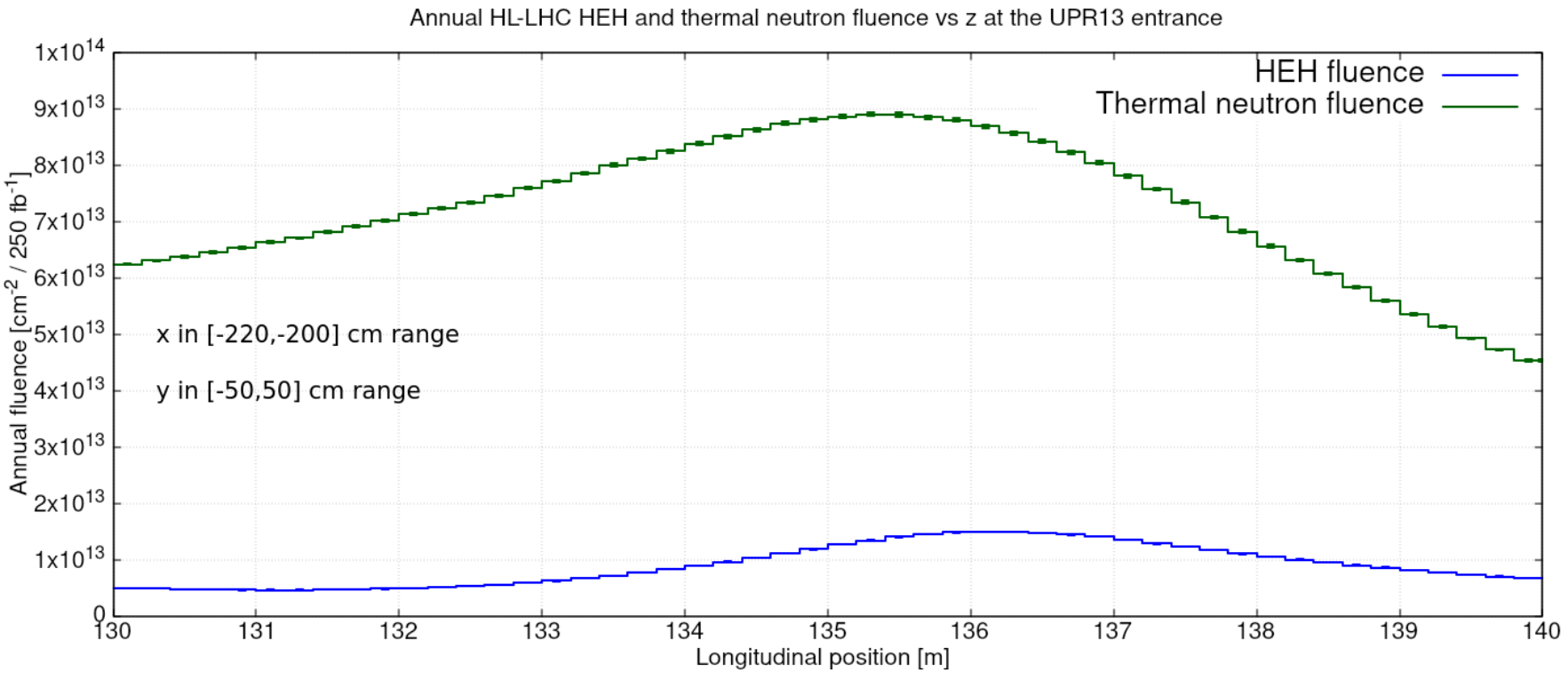
Radiation levels at UPR13 entrance - 1

- HEH and thermal neutron fluence normalised to a full proton beam lost on a target.

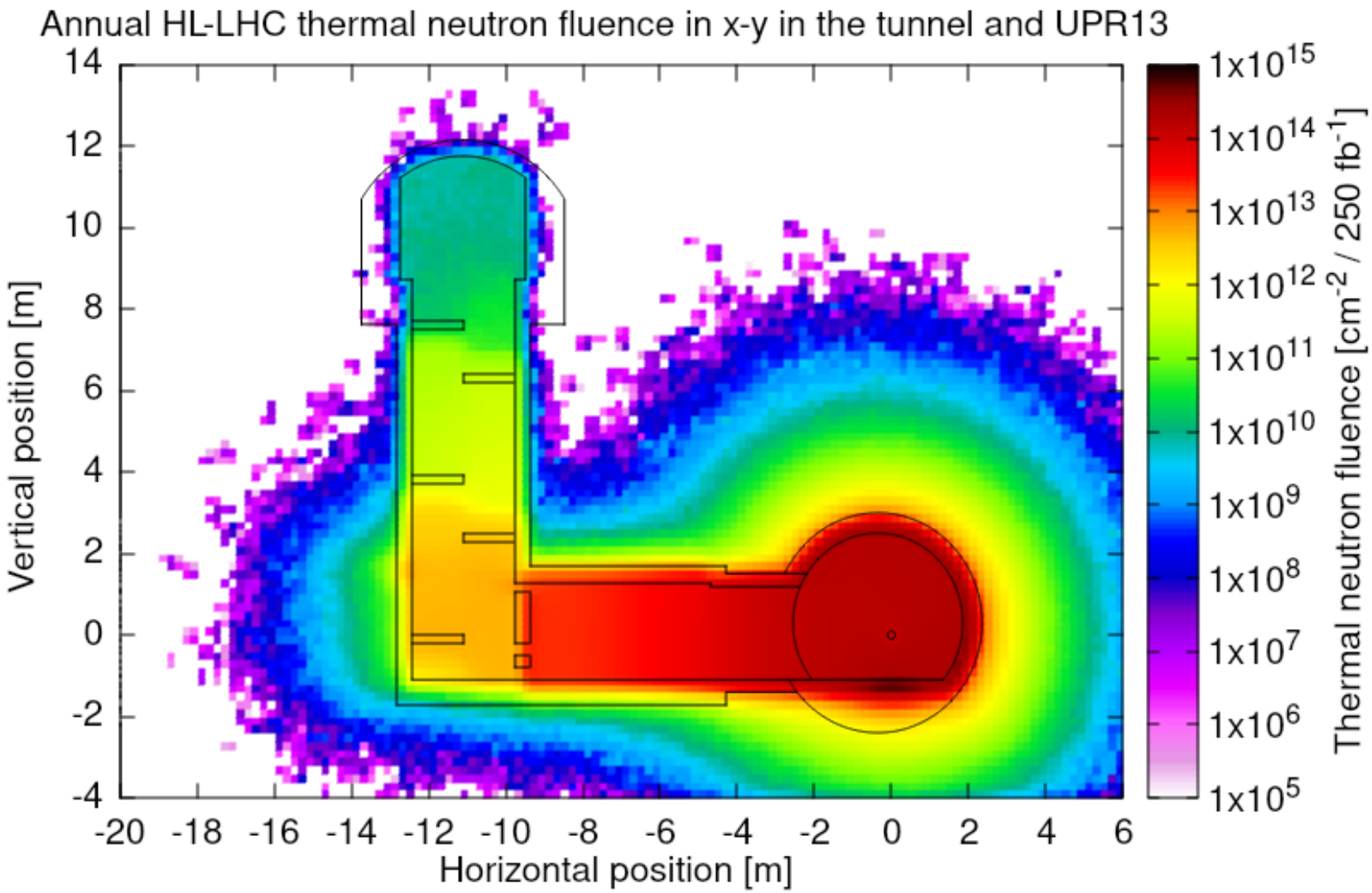


Radiation levels at UPR13 entrance - 2

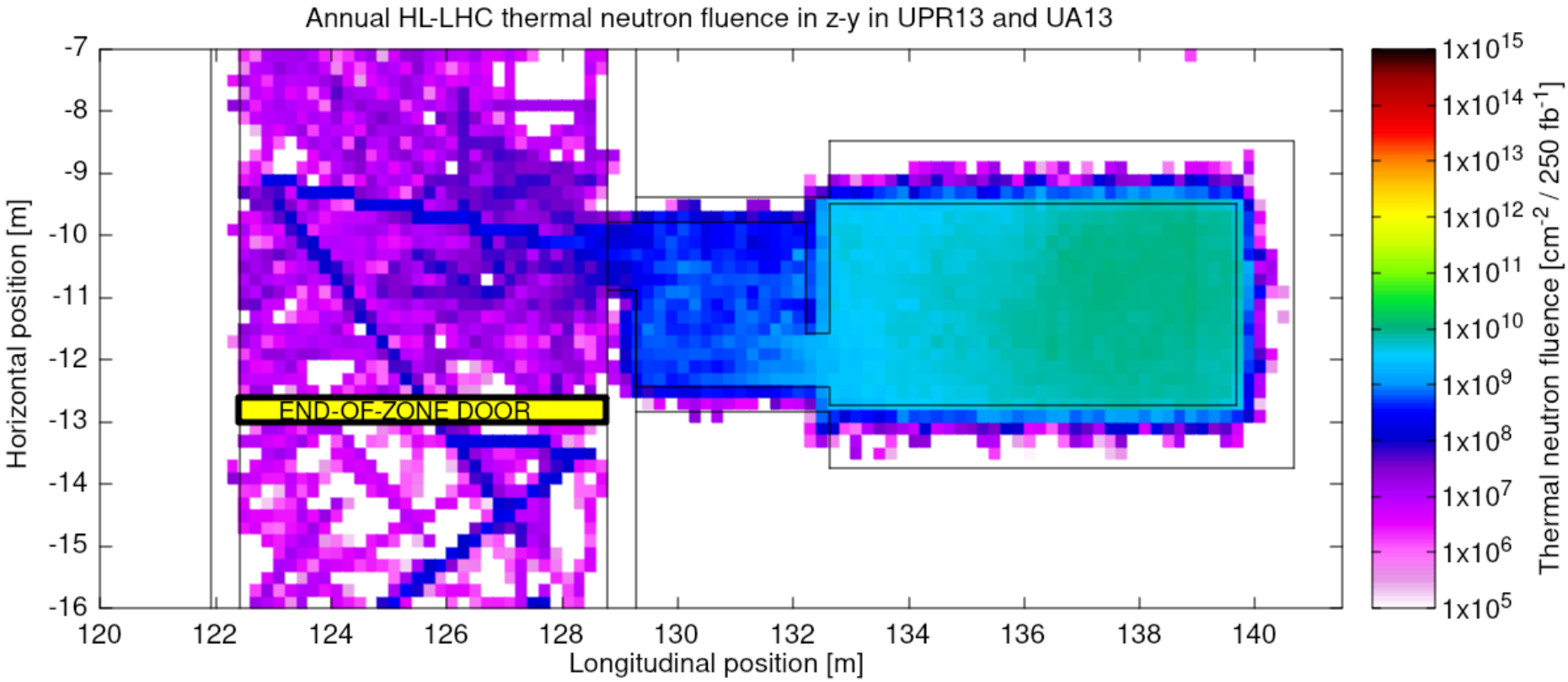
- HEH and thermal neutron fluence normalised to an annual integrated luminosity of 250 fb^{-1} (HL-LHC optics v1.5).
- The normalisation of the RP simulation is obtained by fitting the HEH fluence distribution to the peak value below.



Radiation levels in UPR13 and UA13



Radiation levels in UPR13 and UA13 (top floor)



Radiation levels in UPR13 and UA13 (top floor)

- 1D projection of HEH and thermal neutron in UPR13 and UA13.