Update on HL-LHC radiation levels on equipment in the IP1-IP5 LSS

WP10
Energy Deposition & R2E

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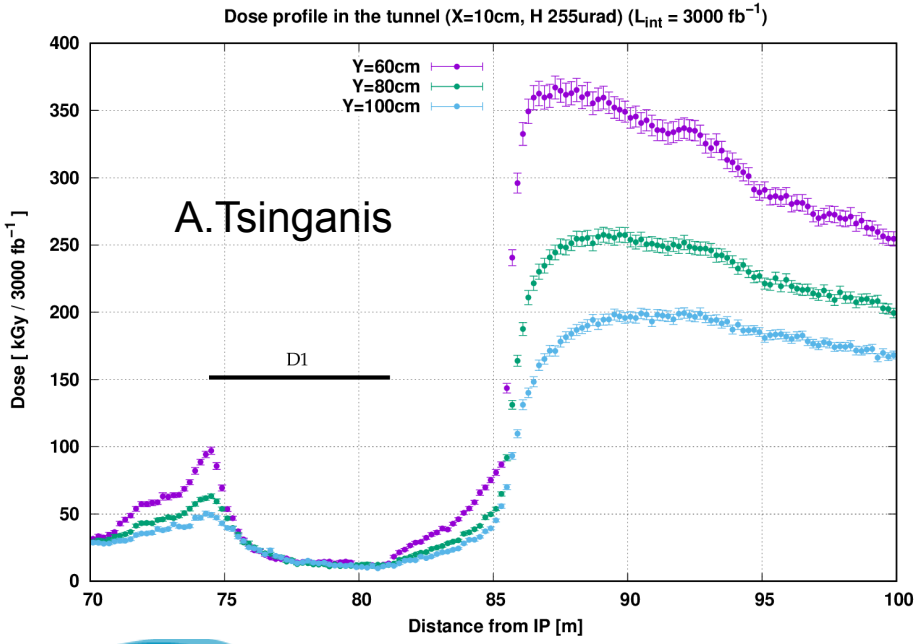
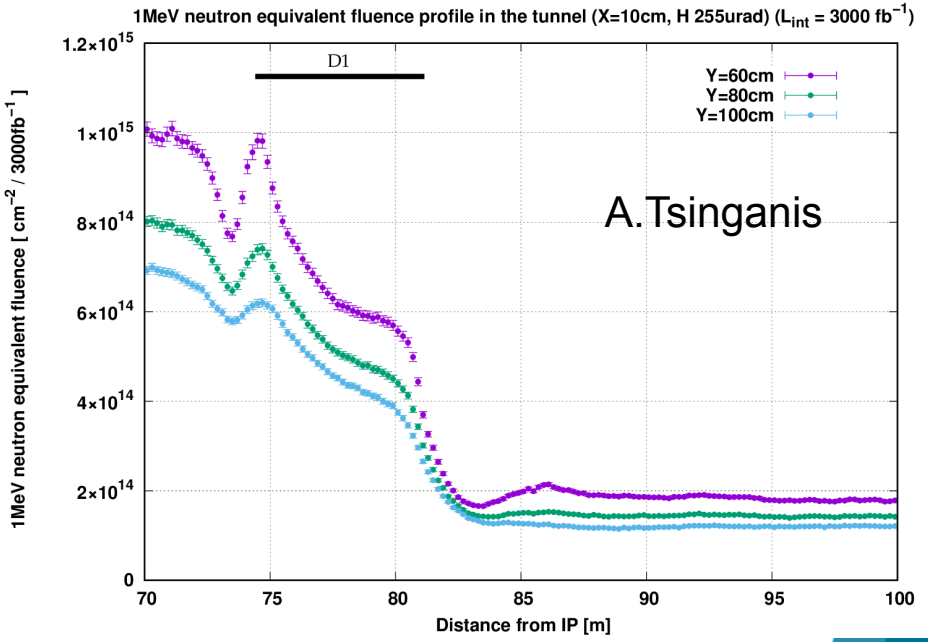
Introduction

- HL-LHC radiation levels in the **IP1-IP5 Long Straight Section (LSS)**.
- No active electronics in these areas → No Single Event Effects (SEEs). The main concern is lifetime degradation caused by:
  - **Total Ionising Dose (TID)**, normally the most relevant effect.
  - **1MeV neutron equivalent fluence (1MeVneq)** that results in Displacement Damage (DD) - often less critical than TID.
- **Content**: radiation levels on D1 cold diode, remote alignment system (e.g. magnet jacks), cryogenic equipment, optical fibres.
- Results based on two versions of FLUKA simulations:
  - Simulation by A.Tsinganis with **optics v1.3**, vertical/horizontal crossing plane in IP1/IP5, TCL4-TCL5-TCL6 at 14σ.
  - Simulation by M.Sabaté Gilarte with **optics v1.5** and many layout updates. Only IP1 with horizontal crossing used in this talk - see Marta's talk for more details.

HL-LHC cold diodes: FLUKA with optics v1.3

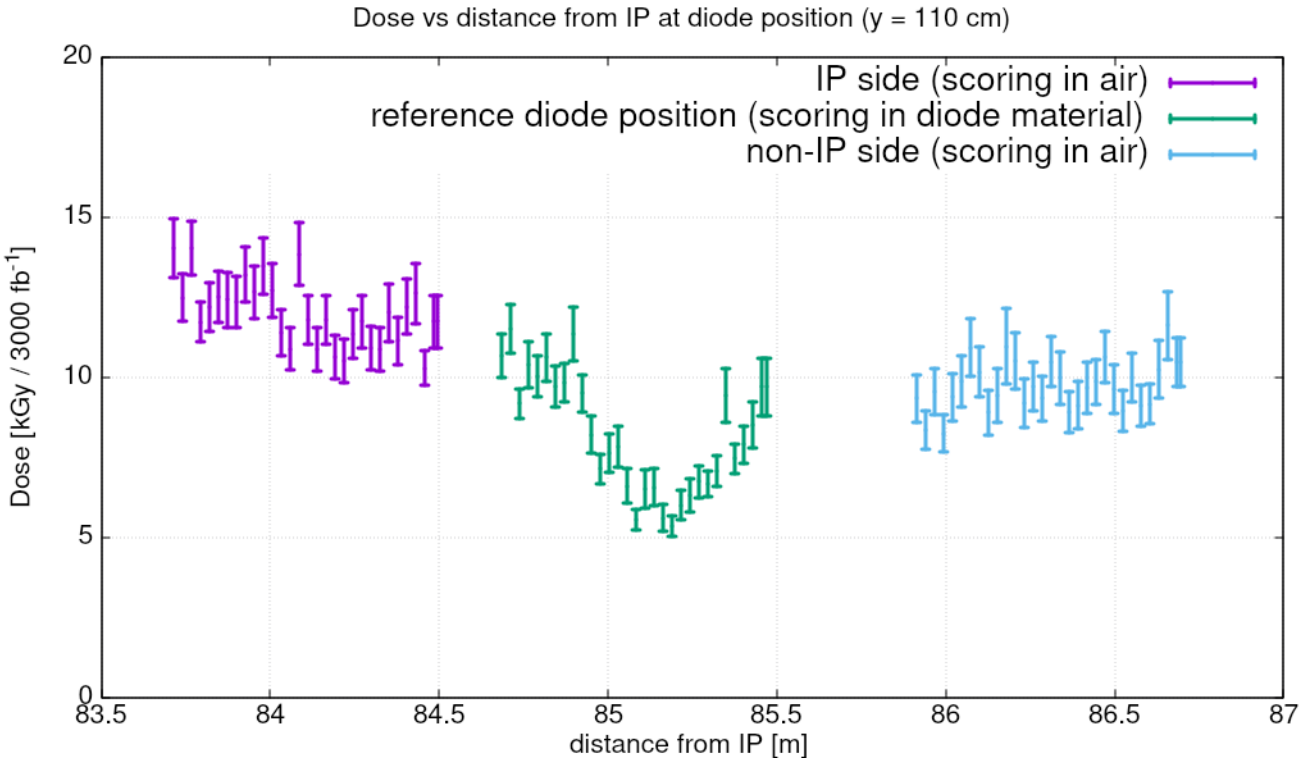
- The levels on the cold diode after the D1 magnet have already been estimated with FLUKA with optics v1.3 at different vertical distances from the beam (up to 1m).
- Opposite trends of dose and 1MeVneq fluence vs z.
- The simulation with optics v1.5 includes the most recent layout and allows to make more accurate predictions (EDMS 2201836).





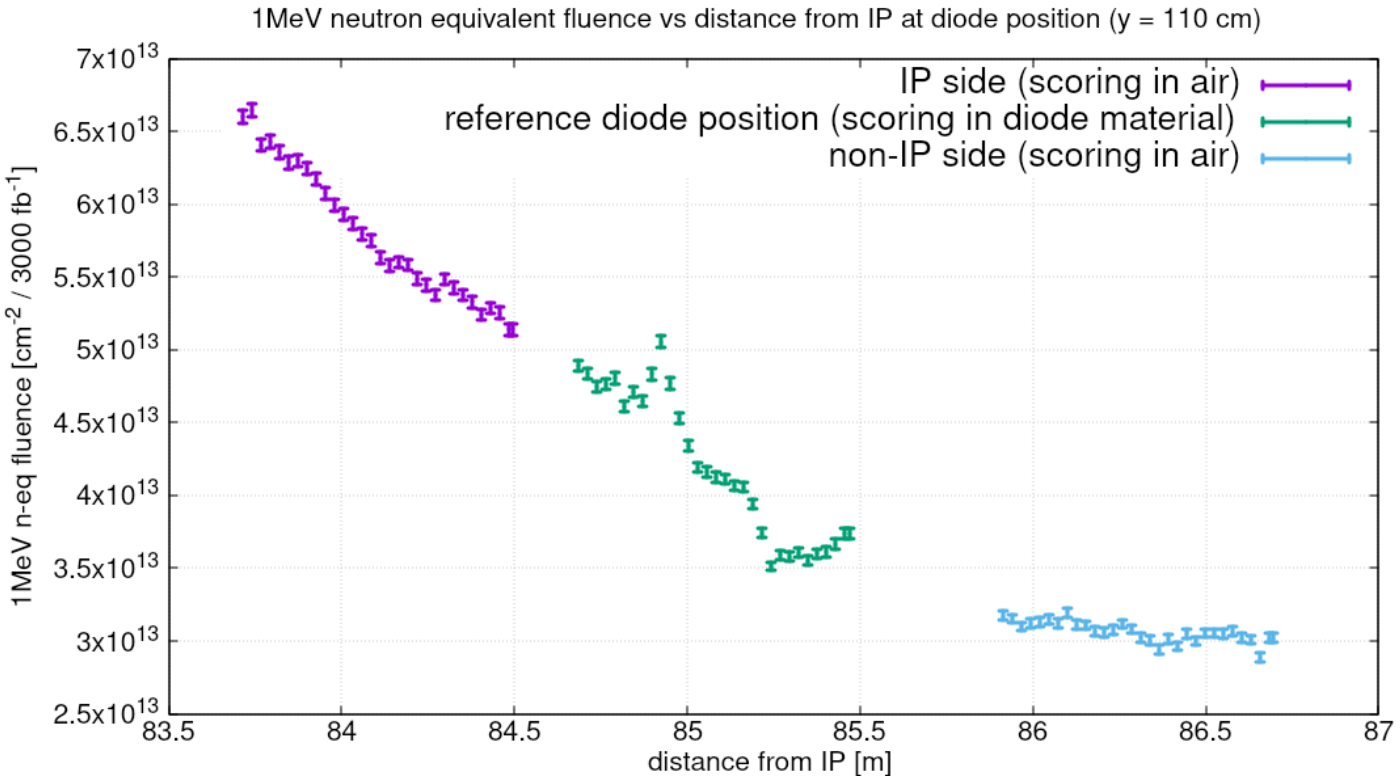
FLUKA with optics v1.5: TID at diode position

- Lower TID due to the updated layout: beam screen extension beyond D1, expansion of beam pipe at ~84m from the IP, larger distance from the beam, cold diode vessel structure (see backup).
- Upper limit of **12 kGy / 3000 fb^{-1}** at reference position, almost equal to the TID reached at the CHARM campaign (~10 kGy, see G.D'Angelo's TCC talk).



FLUKA with optics v1.5: 1MeVneq fluence on diode

- The 1MeV neutron equivalent fluence is also reduced to between $7 \cdot 10^{13}$ and $3 \cdot 10^{13}$ cm^{-2} / 3000 fb^{-1} at different distances from the IP.
- Upper limit of **$5 \cdot 10^{13}$ cm^{-2} / 3000 fb^{-1}** at reference diode position, significantly lower than the value reached in CHARM ($2 \cdot 10^{14}$ cm^{-2}).

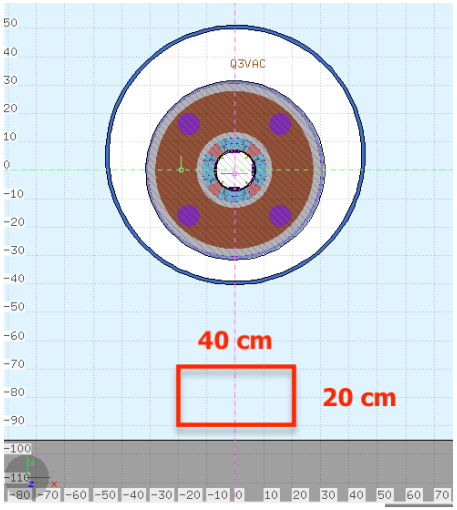


Radiation levels on distributed systems in the LSS

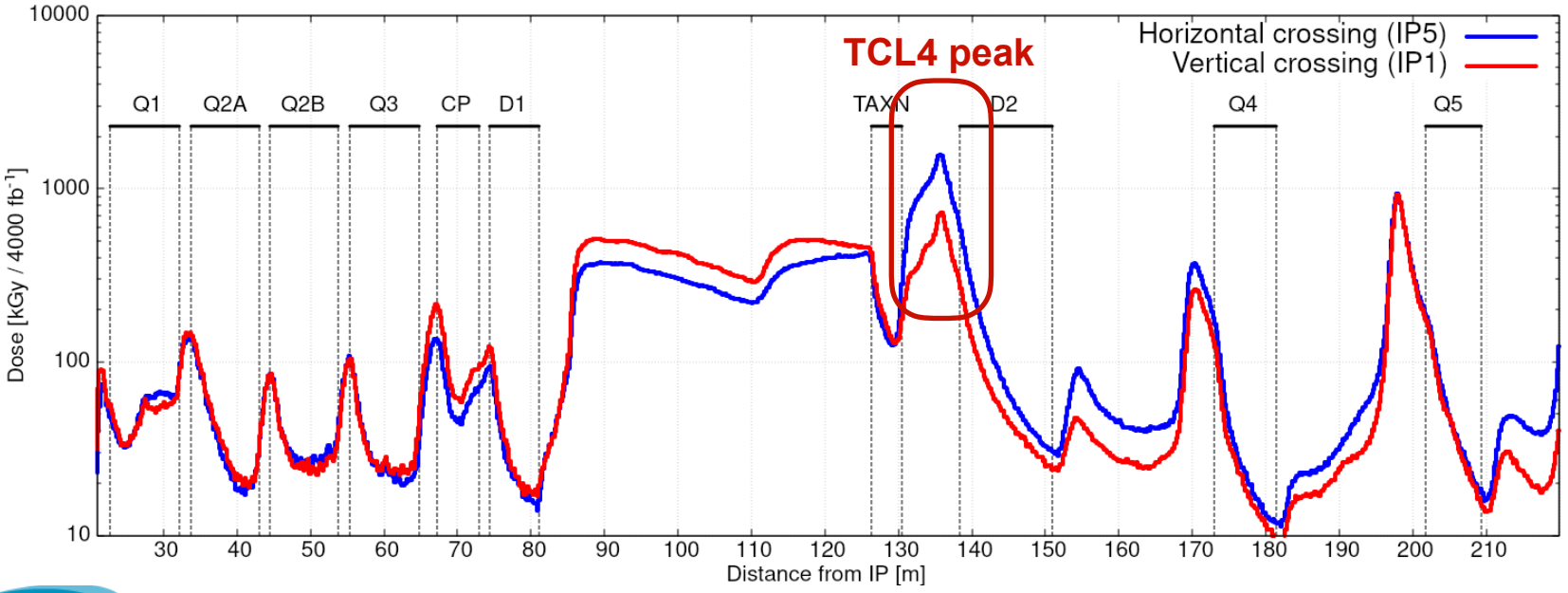
- The LSS of IP1-IP5 hosts a variety of distributed systems that can suffer from radiation damage, typically TID:
  - *Alignment elements (see talk at WP15.4 review, EDMS 2223853):*
    - *below the beamline: jacks, motors of collimators and masks.*
    - *above the beamline: Wire Positioning System (WPS), Hydraulic Levelling System (HLS).*
  - *Cryo distribution system (QXL) on the side of the beamline.*
  - *Optical fibres in cable trays and ducts along the tunnel walls.*
- The radiation levels are studied with FLUKA (optics v1.3) as a function of the longitudinal distance from the IPs, for different positions in the transverse plane.
- Additional predictions for equipment mounted on beamline elements (e.g. collimators, magnets, crab cavities) are provided using FLUKA with optics v1.5.

TID profile below the beamline

- FLUKA (optics v1.3) TID vs distance from IP1-IP5 for **4000 fb^{-1}** below the beamline, at the position of **jacks** and **collimator motors**. Similar profile above the beamline (relevant for **WPS** and **HLS**) and on its side (**QXL**).
- TID peak at TCL4 position between TAXN and D2 for hor crossing, slightly overestimated due to the absence of the stainless steel collimator box in the model.



Total HL-LHC dose 80cm below the beam in the LSS of IP1 and IP5



TID on jacks for magnets, TAXN, crab cavities

- Summary of HL-LHC FLUKA (optics v1.3) TID levels on the jacks for 4000 fb^{-1}, obtained as the maxima below the beamline elements:

Main element	Expected TID [kGy]	Main element	Expected TID [kGy]
Q1	80	TAXN	500
Q2A	150	D2	600**
Q2B	100	Crab cavities	90***
Q3	120	Q4	175
CP	220*	Q5	190
D1	120		

*220 kGy for vertical xing, 150 kGy for horizontal xing

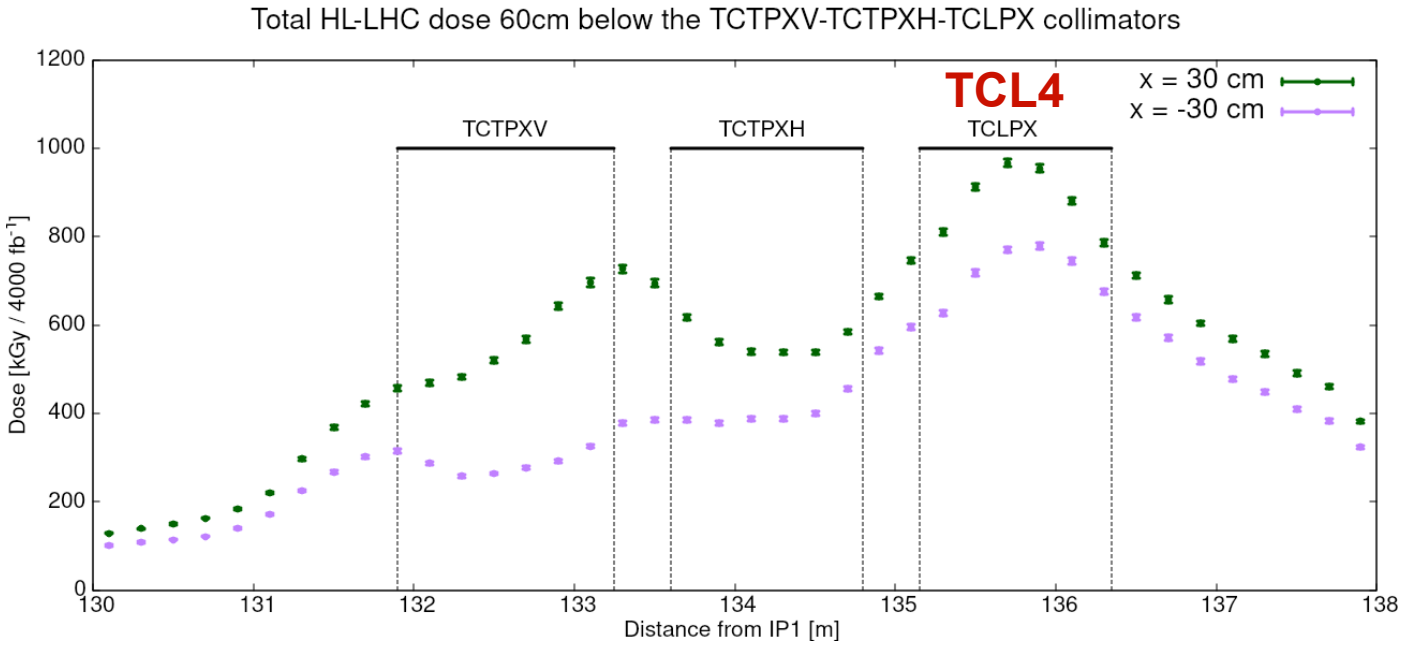
**600 kGy for horizontal xing, 300 kGy for vertical xing

***90 kGy for horizontal xing, 50 kGy for vertical xing

- The TID levels can differ elsewhere (e.g. in the interconnections).
- For reference, higher TID levels on support jacks are expected in other areas, e.g. up to 10 MGy for the SPS dump TIDVG5 (see EDMS 2135822).

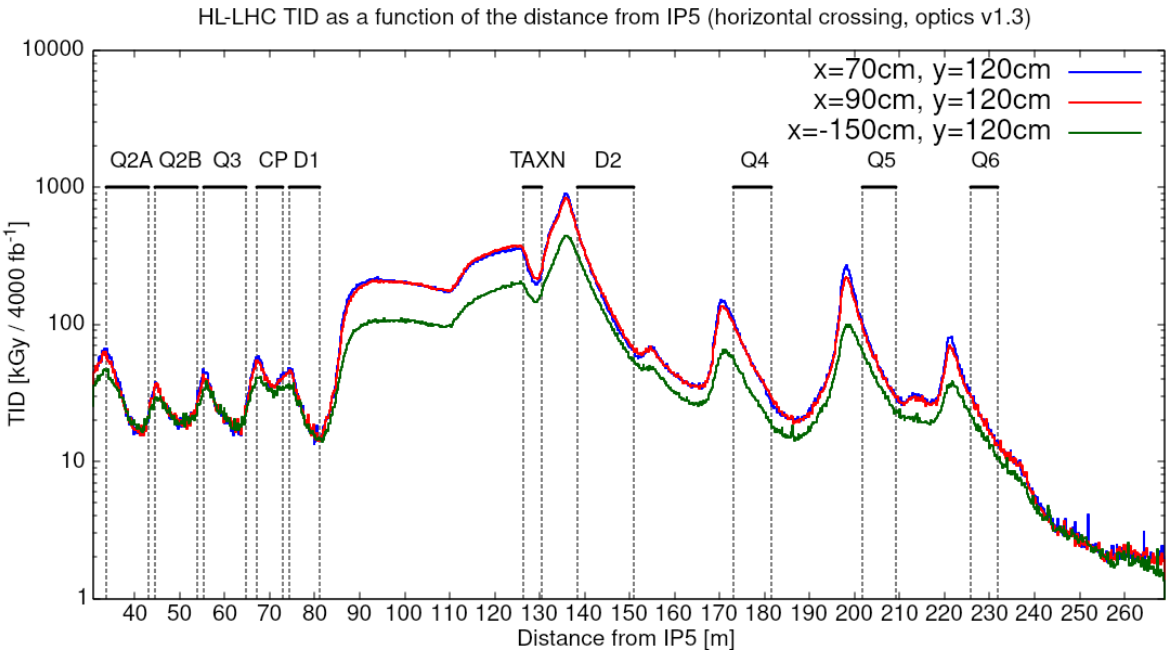
TID peak below TCT-TCL4 collimators

- TID peak between TAXN and D2 from FLUKA simulation with optics v1.5 and horizontal crossing. Stainless steel collimator boxes now implemented (reducing TID by a factor ~3).
- Upper limit of **1MGy / 4000 fb^{-1}** (lower for vert. crossing) valid for:
  - **TCTPXV-TCTPXH-TCLPX collimator motors** located ~60 cm below the beamline and ~30cm on each side.
  - **WPS, HLS and QXL** systems (maximum TID along the full line).

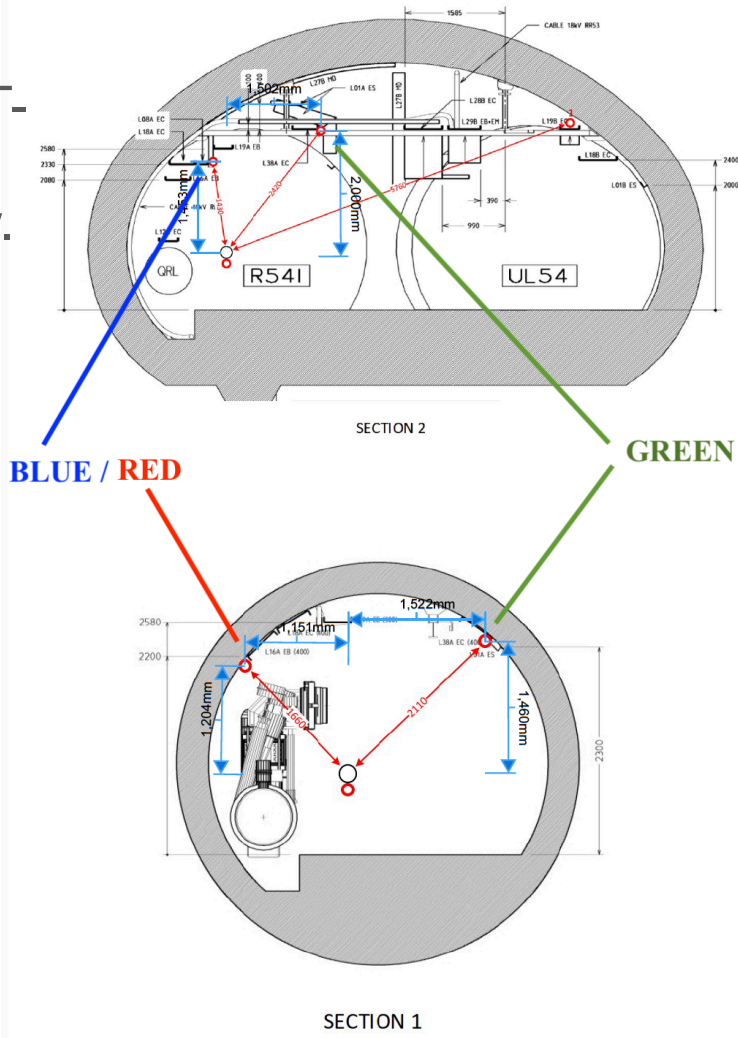


TID profile on the tunnel walls (optical fibre position)

- TID levels by the tunnel walls lower than below the beamline (decrease with radial distance from the beam).
- Reminder: FLUKA with optics v1.3 has no TCT-TCL collimator boxes → TID peak at TCL4 overestimated by a factor 2-3 in the plot below.
- Upper TID limit of **~500 kGy / 4000 fb^{-1}**.

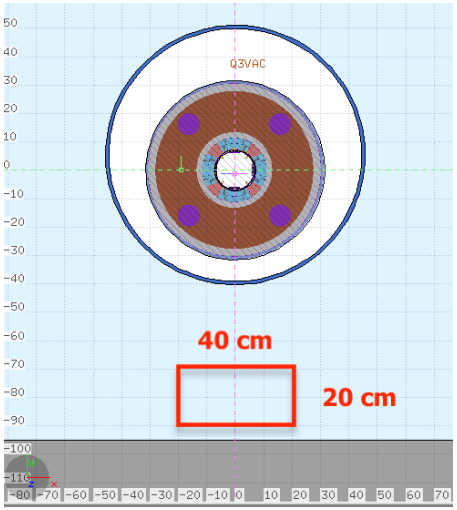


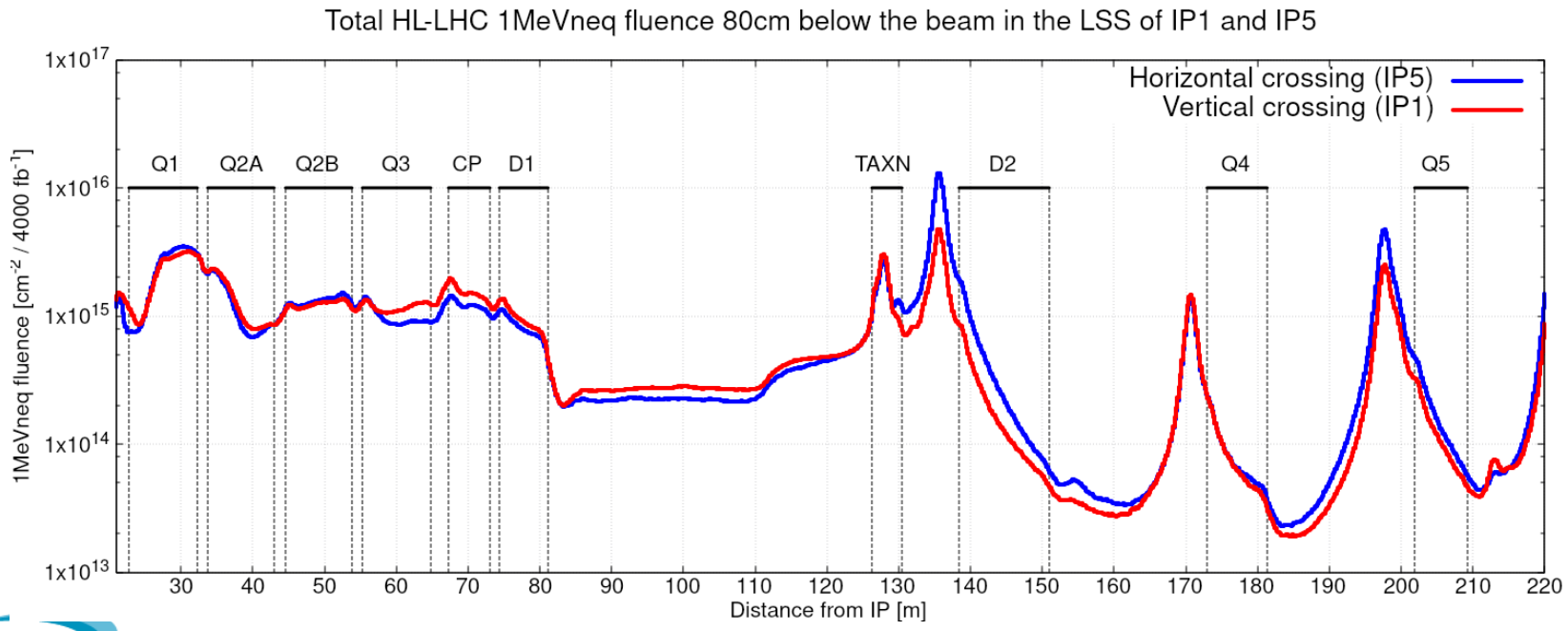
layout input from J.Troller



1MeVneq fluence profile below the beamline

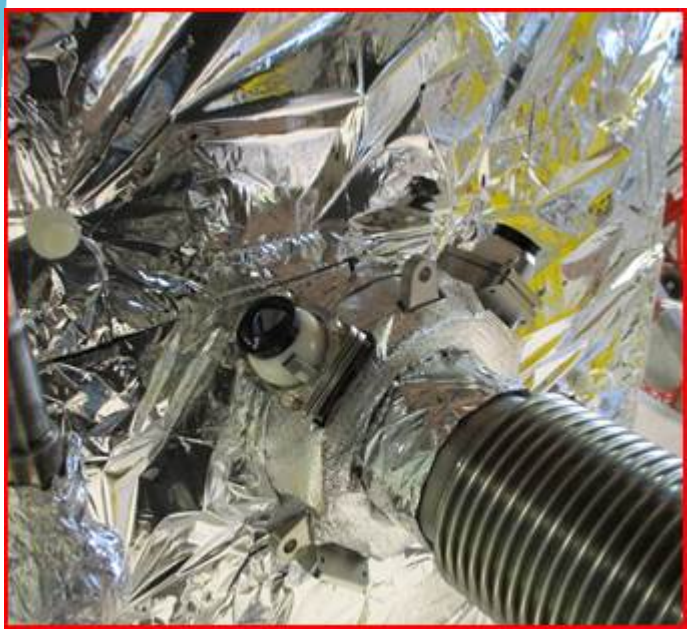
- FLUKA (optics v1.3) 1MeV neutron equivalent fluence vs distance from IP1-IP5 for **4000 fb^{-1}** below the beamline (same transverse position as in slide 7 for TID).
- Differences between TID and 1MeVneq profiles due to different impact of shielding on EM and hadronic radiation.
- 1MeVneq fluence peak at TCL4 position between TAXN and D2 for hor crossing (same as for TID).

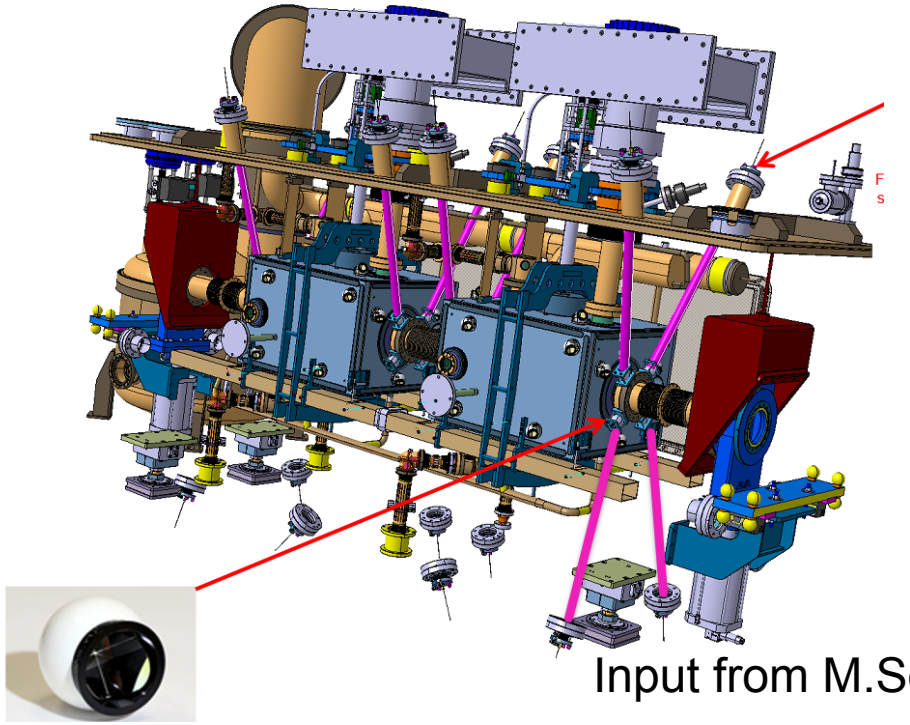




Reflectors on crab cavities

- Request by M.Sosin: crab cavity reflectors at ~10cm from the beam axis and ~5cm from the titanium surface of the He tanks.
- TID scoring available in FLUKA with optics v1.5 on the x-y Titanium surfaces - good approximation of the reflector position.
- The specification given at the WP15.4 alignment system review (EDMS 2223853) was affected by a mistake in the new crab cavity model → **Result now updated** (next slide).

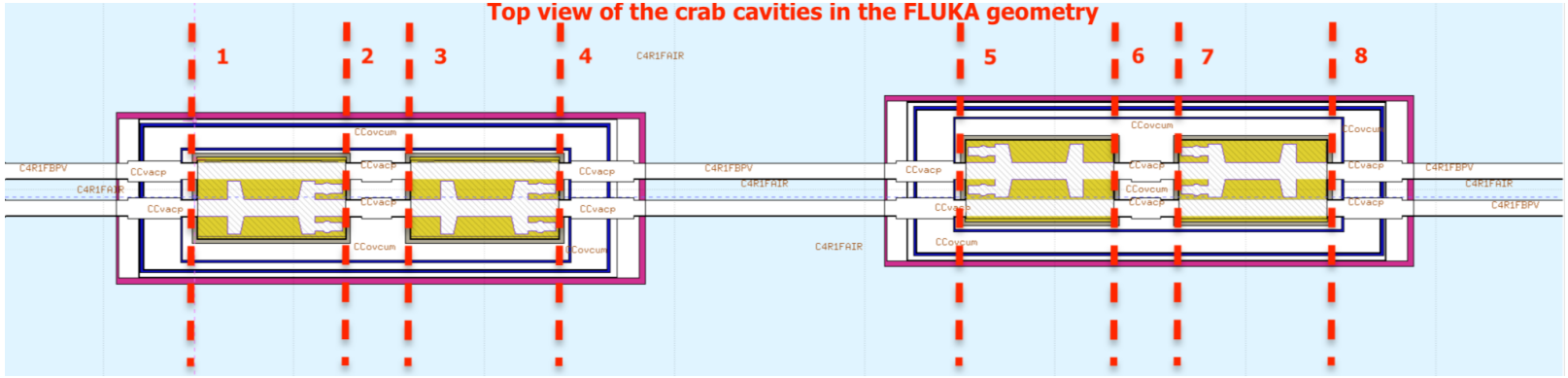




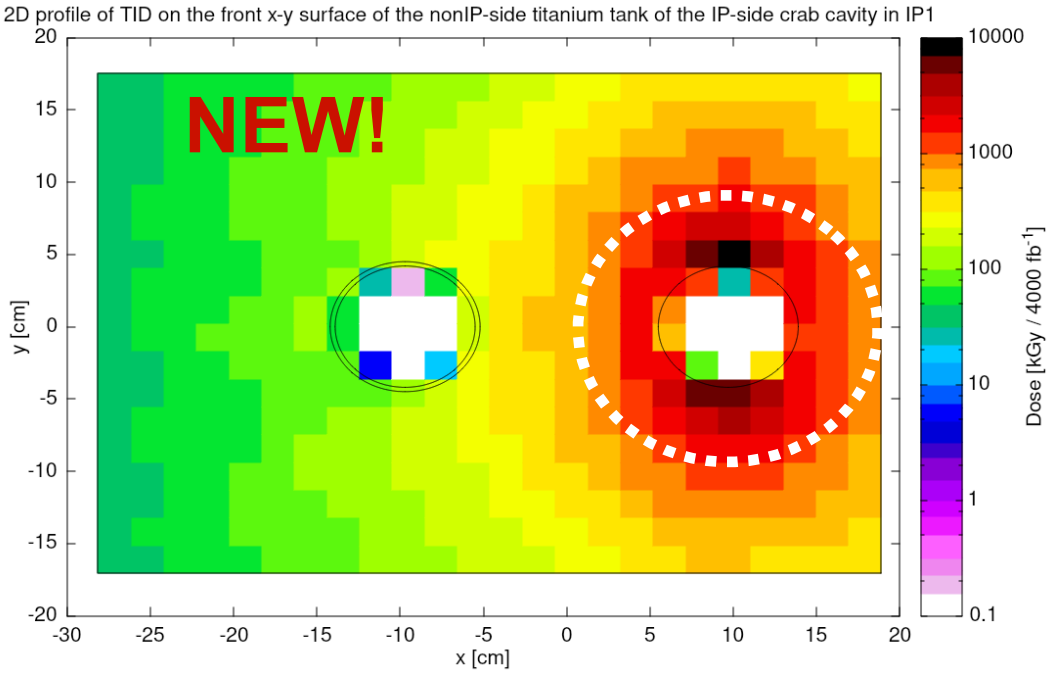
Input from M.Sosin

Reflectors on crab cavities: FLUKA results

- TID scored on the 8 x-y titanium surfaces of the two crab cavities.



- Highest TID levels reached on plane 3.
- New upper limit on the total TID at ~10cm from the beam pipe of interest: **~2 MGy / 4000 fb^{-1}** (factor ~2 higher than the previous estimate).



Summary of radiation level specifications

- Summary table of the radiation level specifications on the various systems discussed in this presentation (TID only, except for the cold diode for which also the 1MeVneq fluence is quoted):

Equipment	Upper limit on radiation levels
D1 cold diode	TID=12 kGy, 1MeVneq = $5 \cdot 10^{13}$ cm^{-2} [for 3000 fb^{-1}]
Support jacks	see detailed table in slide 8
TCTPXV-TCTPXH-TCLPX collimator motors	TID = 1 MGy [for 4000 fb^{-1}]
Reflectors on crab cavities	Peak TID = 2 MGy [for 4000 fb^{-1}]
Wire Positioning System (WPS), Hydraulic Levelling System (HLS)	Peak TID = 1 MGy [for 4000 fb^{-1}] (see slide 7 for full profile)
Cryogenic distribution system (QXL)	Peak TID = 1 MGy [for 4000 fb^{-1}] (see slide 7 for full profile)
Optical fibres on tunnel walls	Peak TID = 500 kGy [for 4000 fb^{-1}] (see slide 10 for full profile)

Extra specifications for cryo and alignment systems

- Upper TID limits on more elements not covered in this talk:
  - Cryogenic equipment (EDMS 2223838).
  - Alignment system (EDMS 2223853).

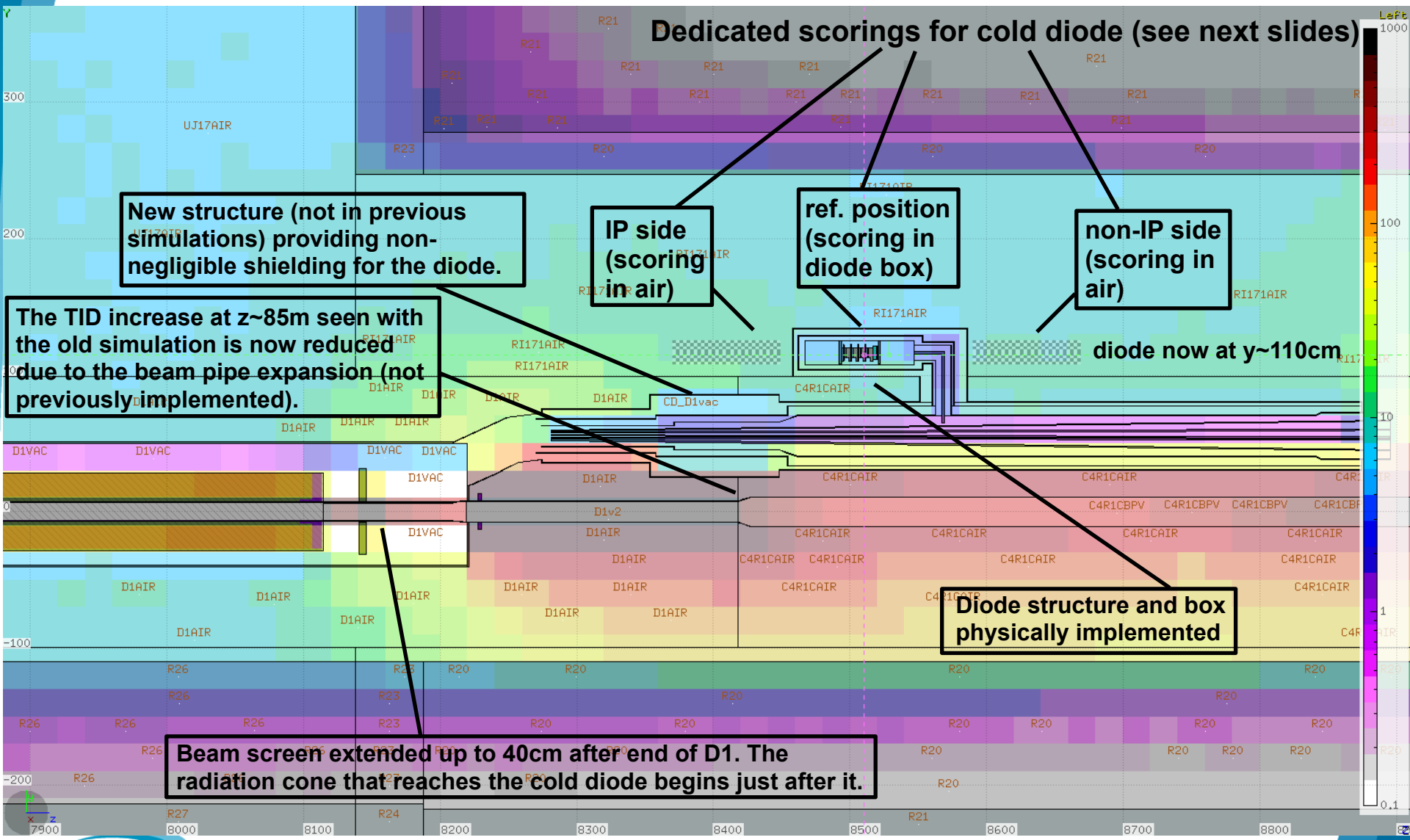
Equipment	TID upper limit [kGy / 4000 fb^{-1}]
IT cold mass thermometers	200
IT warm-up heaters	1500
IT thermometers on phase separators	2000
IT beam screen heaters and thermometers	750
D2 beam screen heater and therm., and heat exchanger level gauges	200
Motors for Q4-Q5 masks	700
Alignment motor of BPM after D1	200

Summary and R2E-R2M implications

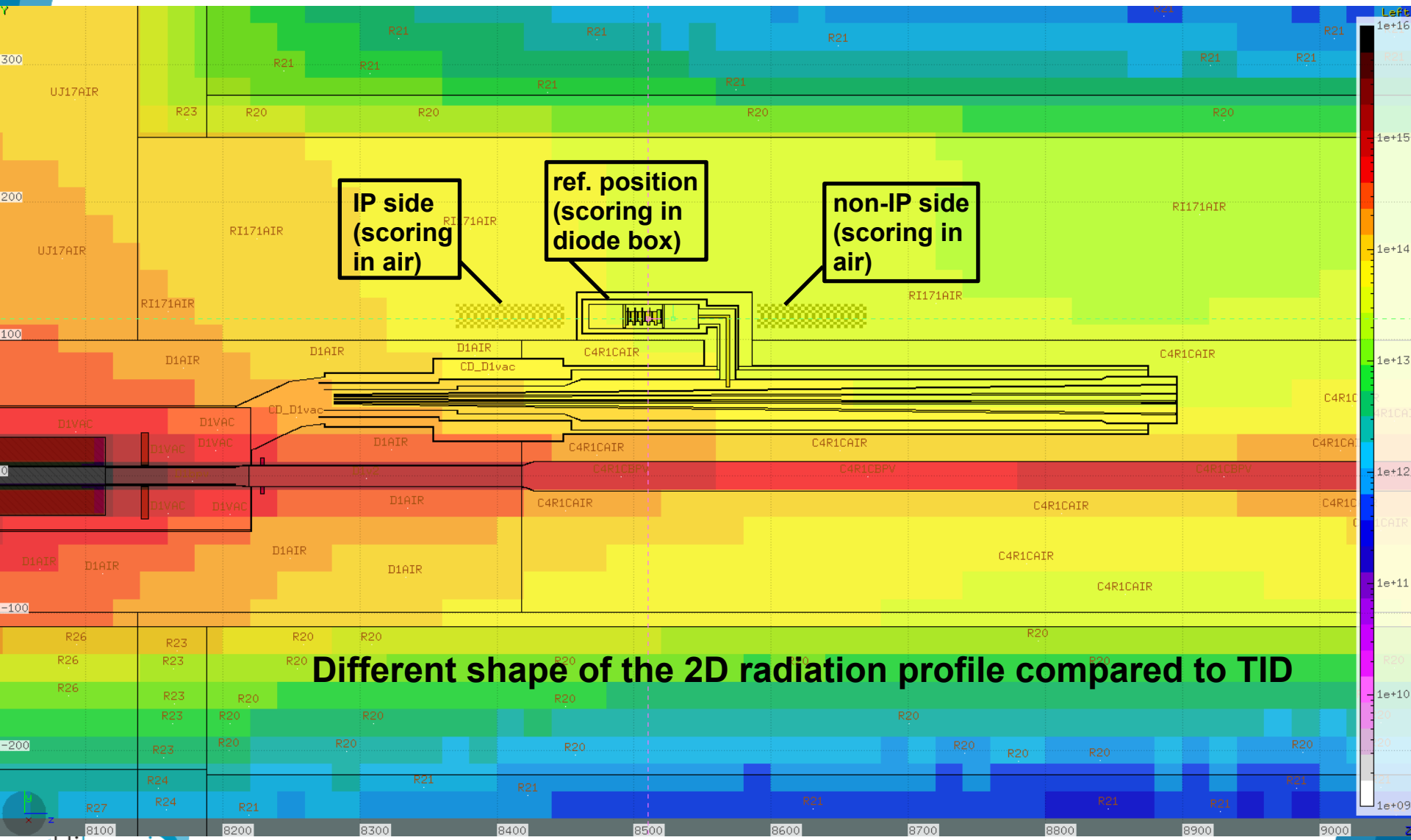
- The radiation levels on the equipment in the LSS of IP1-IP5 have very strong gradients due to the beamline elements. Minimum TID values around **10 kGy**, peaks above the **MGy** scale (note that even higher levels can be reached e.g. on beam screen coatings).
- No active electronics is involved → the main concern is material degradation, e.g. polymers, grease.
- The Radiation to Materials (**R2M**) Work Package within the R2E project supports the evaluation and testing of radiation damage on materials for non-intercepting beam devices, including the coordination of irradiation campaigns at equipment and full system level:
  - *WP leader:* Marco Calviani.
  - *Activity supervisor:* Keith Kershaw.
  - *Technical Responsible:* Matteo Ferrari.
  - *Contact e-mail:* r2m-radiationtomaterials-support@cern.ch
  - *Recent indico event:* https://indico.cern.ch/event/814752/

BACKUP

FLUKA optics v1.5: side view of diode box and TID



FLUKA optics v1.5: side view of diode box and 1MeVneq fluence



R2E implications of radiation levels on cold diode

- The previous plots can be summarised in updated upper limits on the radiation levels on the diode in the reference position (z ~ 85 m from the IP):
  - Dose: **12 kGy / 3000 fb^{-1}.**
  - 1MeVneq fluence: **5·10^{13} cm^{-2} / 3000 fb^{-1}.**
- The 1MeVneq fluence is well below the value accumulated at the end of the dedicated irradiation campaign in CHARM, while the dose is very close to it.

Table 2: Accumulated dose and 1 MeV equiv. neutron fluence at the end of the irradiation campaign in each diode. The uncertainty of the quoted values was estimated to 20 %.

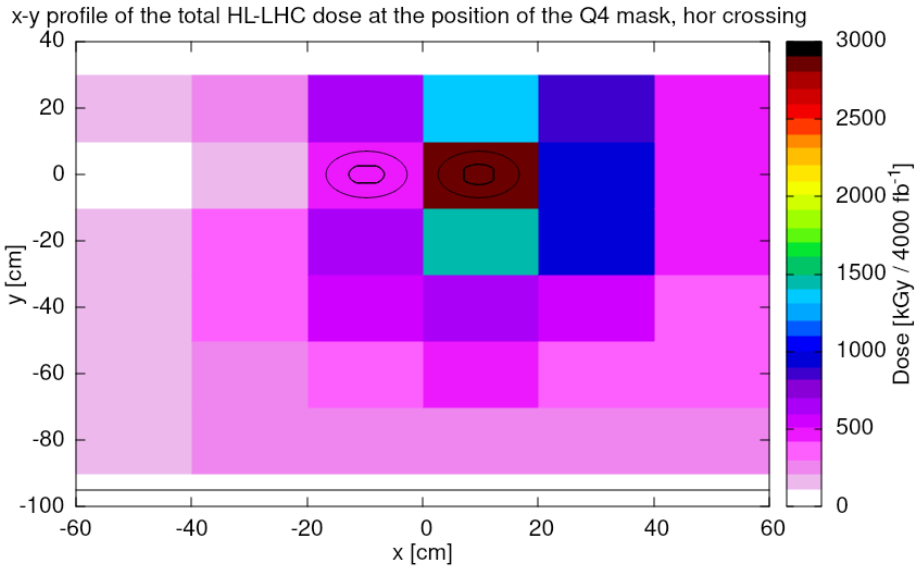
Diode	**D1**	**D2**	**D3**	**D4**
Fluence (10^{14} cm^{-2})	2.09	2.15	2.27	2.28
Dose (kGy)	10.40	11.17	11.06	10.24
Diode	**D5**	**D6**	**D7**	**D8**
Fluence (10^{14} cm^{-2})	1.74	1.75	1.70	1.66
Dose (kGy)	11.00	11.02	12.20	9.75

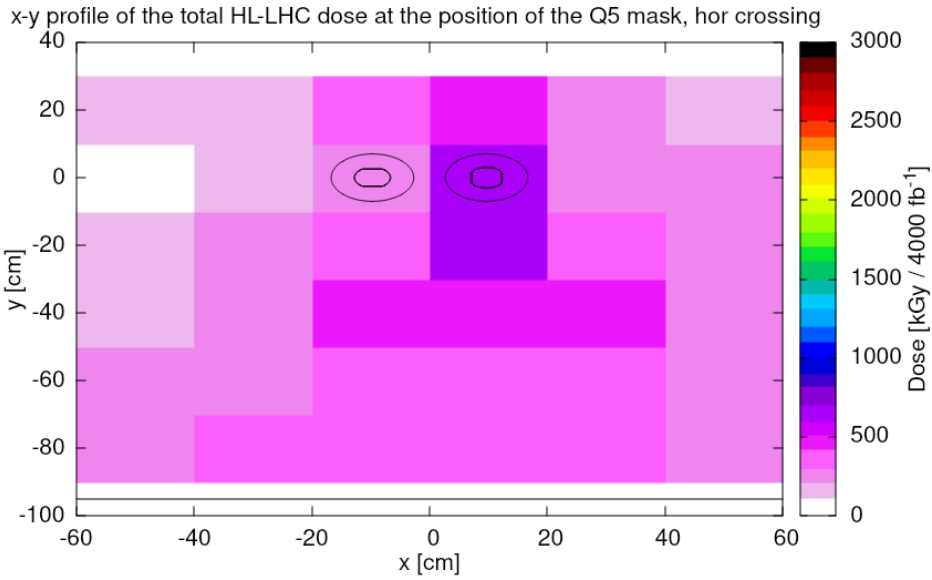
D.Wollman et al., "Characterisation of the radiation hardness of cryogenic bypass diodes for the HL-LHC inner triplet circuit", IPAC19.

See also G.D'Angelo's TCC presentation

TID on Q4-Q5 mask alignment system

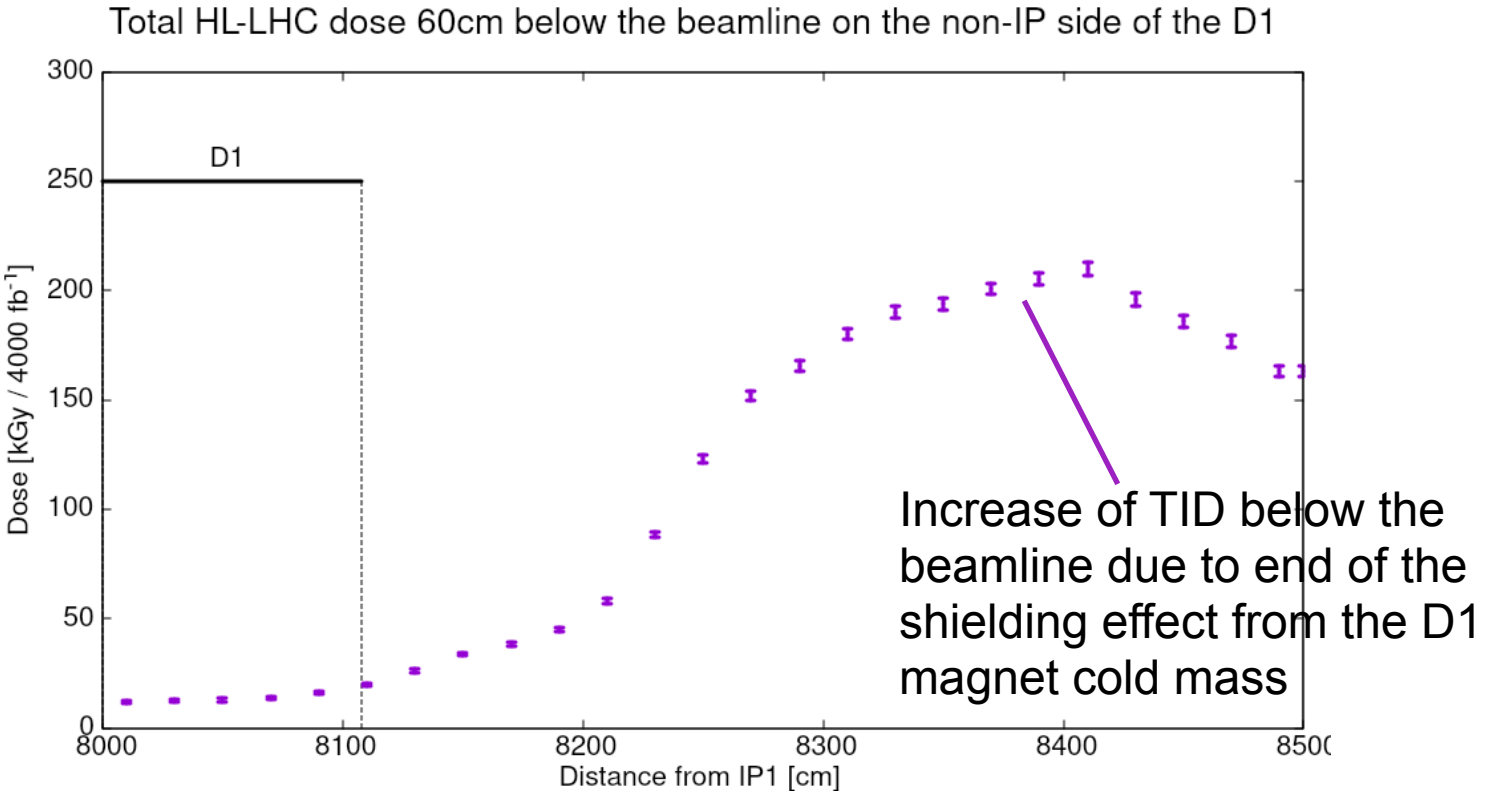
- Remote alignment systems for the masks located before Q4-Q5.
- No design available yet → 2D x-y profiles of TID at the position of the masks obtained with FLUKA with optics v1.3 for horizontal crossing (lower levels expected for vertical crossing).
- Higher levels for Q4, with strong radial gradient in both cases. Upper limit of **~700 kGy** / 4000 fb^{-1}, 40cm below the Q4 mask.





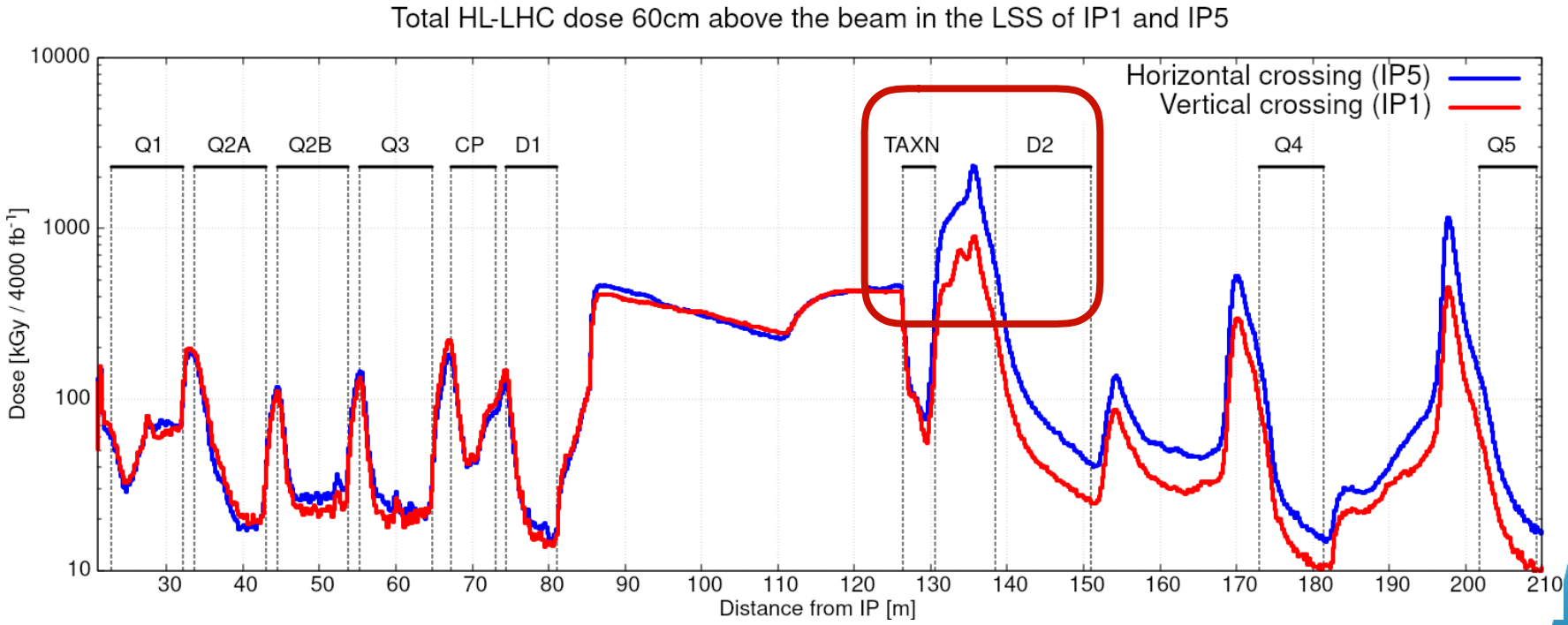
BPM after D1 - TID on alignment system

- The BPM located just after the D1 magnet could be remotely aligned (no official plan/design yet).
- FLUKA (optics v1.5) TID vs distance from IP1 at the end of D1 ~60cm below the beam. The TID grows rapidly with z reaching **~200 kGy** / 4000 fb^{-1}.



WPS and HLS systems: FLUKA with optics v1.3

- Optics v1.3, TID vs distance from the IPs, 60 cm **above the beamline**, to set upper limits on the levels on WPS-HLS systems.
- TID peak of ~2.5 MGy / 4000 fb^{-1} for horizontal crossing above TCL4, where the v1.3 simulation doesn't include the collimator box. A more accurate estimate can be obtained with the optics v1.5 simulation.



WPS and HLS systems: FLUKA with optics v1.5

- The optics v1.5 simulation includes the collimator box and allows to place an upper TID limit of **~1MGy** / 4000 fb^{-1} at the WPS-HLS position (~same pattern seen below the beam).