Radiation Simulation Considerations for Upgrade II

LHCb Upgrade II Tracking Workshop
March 2024 Evian-les-Bains
Matthias Karacson

Overview

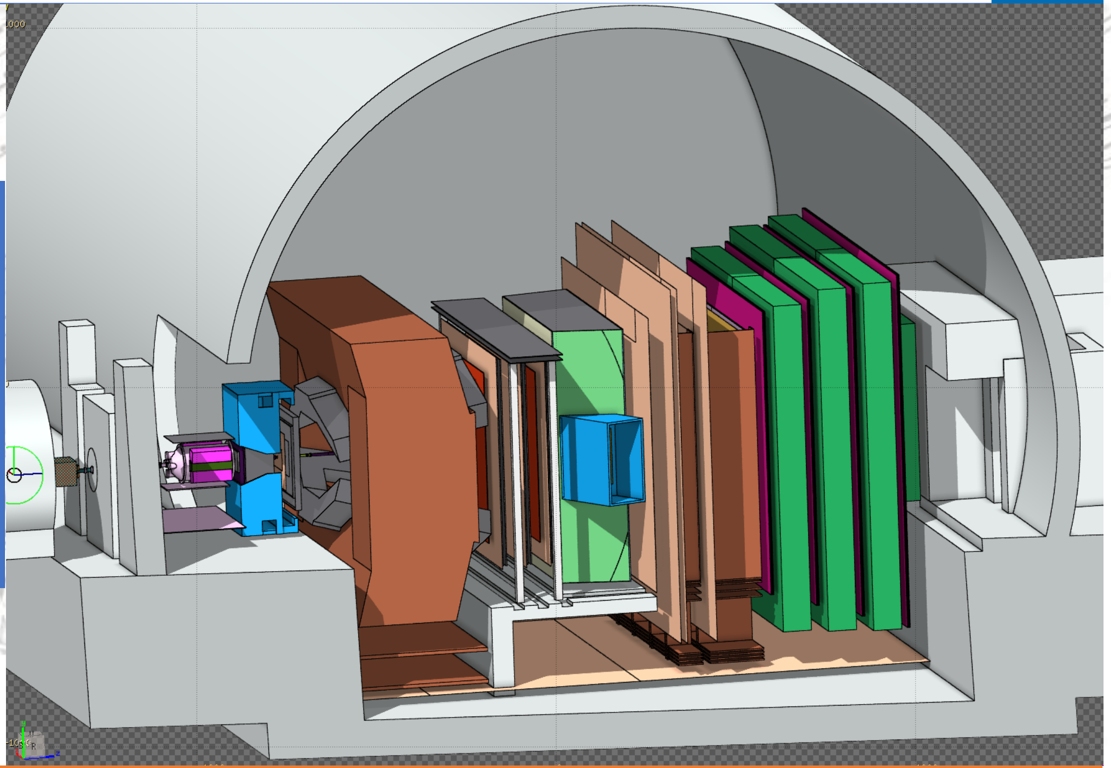
- Current Status of FLUKA Simulations
- Changes and Consequences
- Simulation Update (in progress)
- Considerations for using FLUKA
- Additional Needs

Current Status of FLUKA calculations

Last general simulations performed 2016 for Upgrade I conditions

Approximation only

- M1, PS/SPD/Lead removed
- Neutron shielding installed



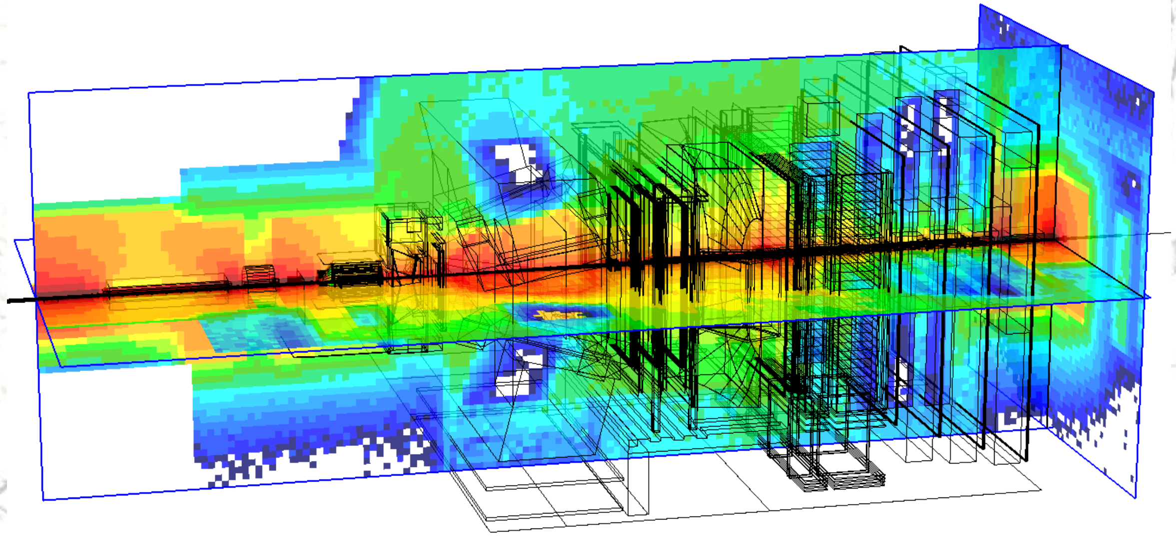
- All other detectors (VELO, RICH1&2, TT, OT+IT, Calorimeter, Muon, all upstream installations) are the same as in Run1&2
- RICH still **without HPDs/MaPMTs** (only shielding & mirrors with gas volume inside)
- **Low amount of support structures** in the experimental hall
- **No balcony or extended cavern (e.g. shielding wall, cryogenics)** -> will become more important for Upgrade II

The available estimates are NOT APPLICABLE to Run4 and Run5!
(Change of ECAL Material)

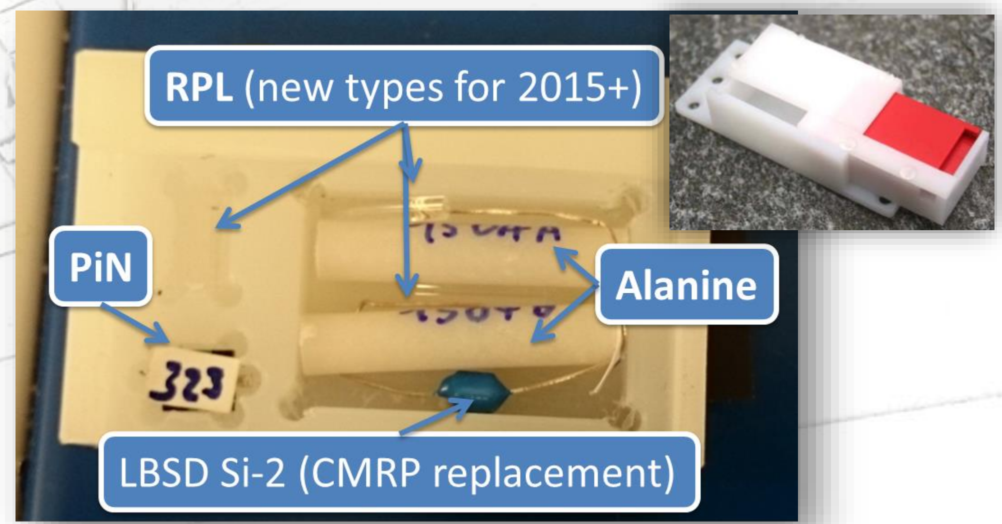
Available simulations and measurements

For Run3, simulations performed in 2016 are available.
In areas farther from the detector (see 3D plot below) only upper limits can be provided.

Available most important simulation estimators
- Total Ionising Dose
- 1 MeV neutron fluence equivalent
- High Energy Hadrons (HEH) > 20 MeV



Passive dosimeter measurements read out in LS1&2 can be **scaled** until LS3 for many currently equipped locations.
(were also used to benchmark simulation)



LHCb Upgrade II – Expected Changes – ECAL Central Area

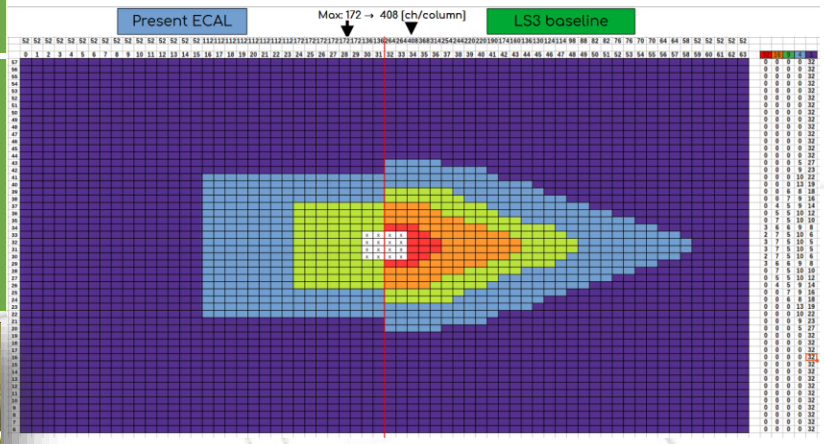
Changes expected to happen before Run5 and their consequences

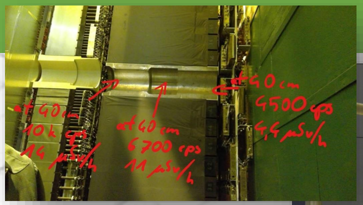
- **ECAL central area**: Tungsten and Lead (exact alloy TBD) SpaCal modules
  - potentially **worse (1 MeV) neutron backsplash** during operation
  - **higher residual dose rates** during maintenance

- **Descope option** (single side readout)
  - no significant change in material budget expected

- **Preliminary FLUKA studies** recently started to determine the general **effect on the prompt radiation field**
  - applicability of Run3 estimations will be re-evaluated for Run4

- **Activation (ACTIWIZ) studies** have already been performed in the past
  - **higher residual activation** (3-4x for exchanged material)
    - **higher risk for maintenance operations** between calorimeters as well as **RICH2 towers** (ECAL open)





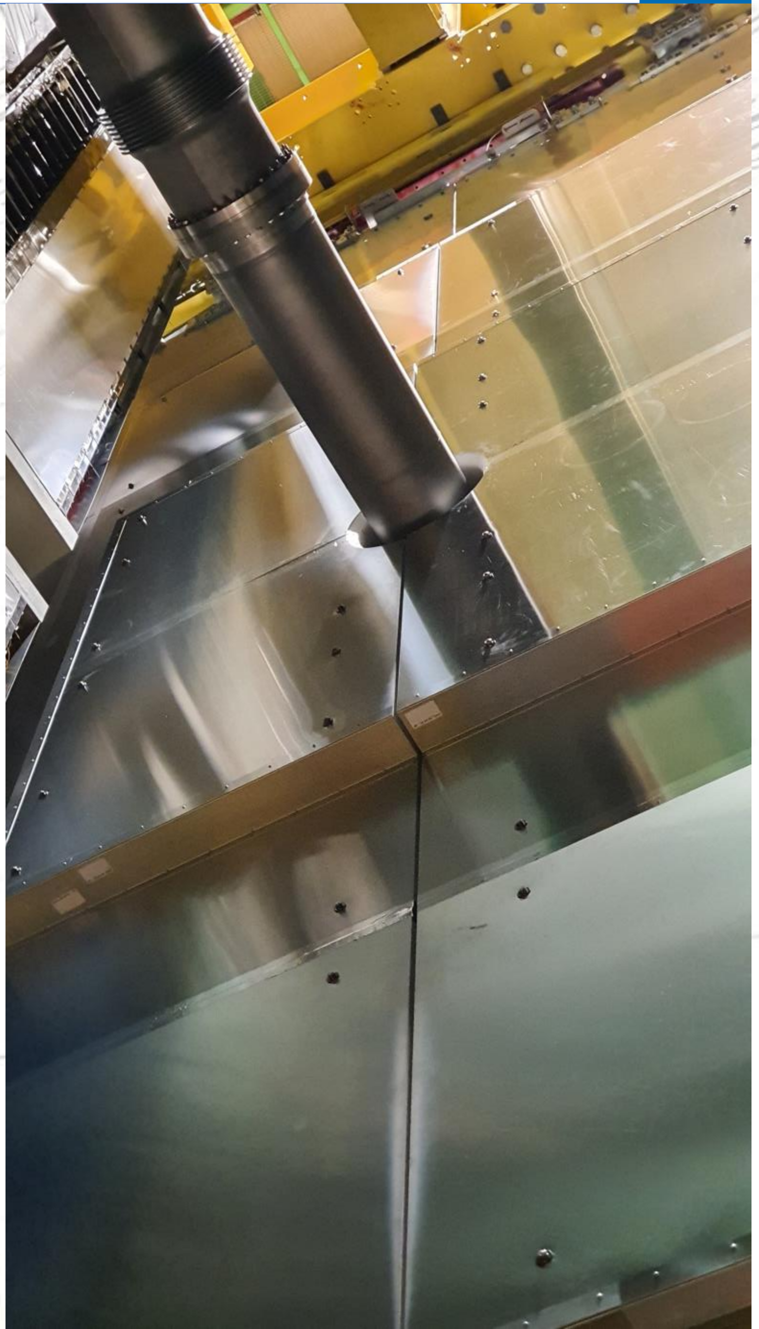
*ACTIWIZ is a tool to assess and compare the radiological hazards of arbitrary materials to be used at CERN's accelerators, allowing fast and simple analysis, see link

LHCb Upgrade II – Potential Changes – Neutron Shielding

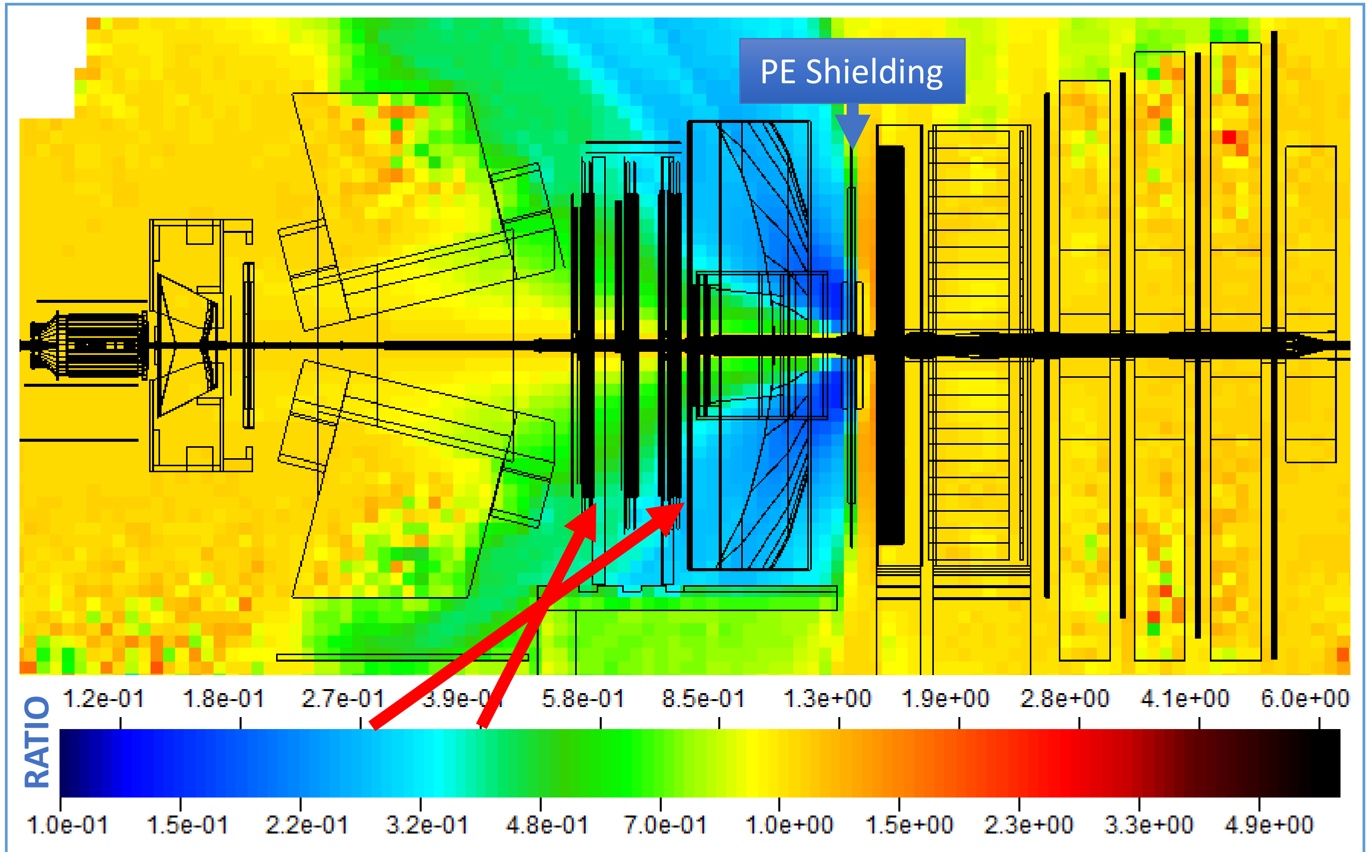
Neutron shielding primary function was to **reduce SciFi SiPM dark current** by **reducing 1 MeV neutron fluence**

Consequences of removal

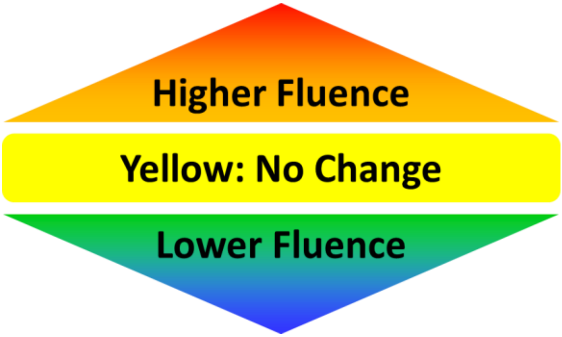
- **increased neutron backsplash** from ECAL (in addition to Tungsten)
- **increased thermal neutron fluence** upstream of calorimeters

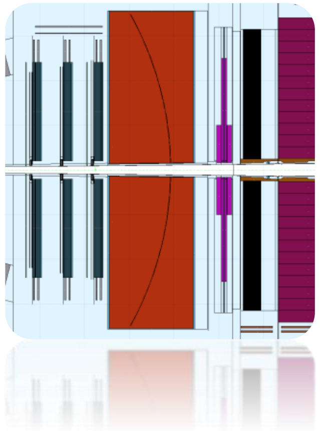


Effect of final shielding design - Studies performed in 2016



1 MeV n. equ. fl.: RATIO between final 30 cm Shielding VS No Shielding





15-18% impr... esign, ...ety margin.

This will revert

Fluence reduction by a factor of 2.5 (T1) to 3.4 (T3)

Absolute prediction values are expected to be precise within a factor of 2:

- densities and materials of new detector are similar to old tracking stations
- no other changes for upgrade detector are expected to have an impact on the radiation field in this area

Run3 prediction (2016)

LHCb Upgrade II – Potential Changes – Neutron Shielding

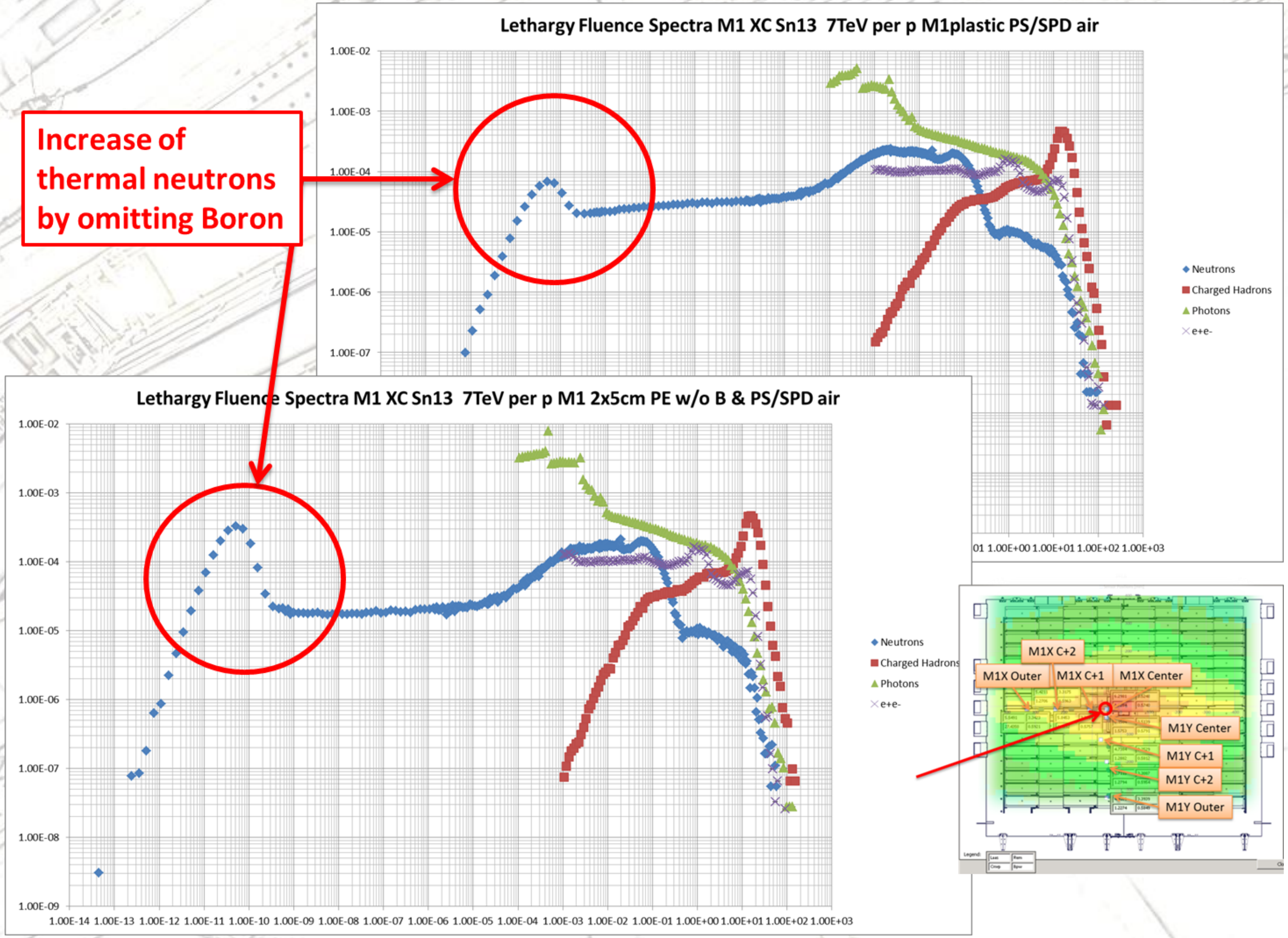
Thermal Neutrons

5% Boron content inside neutron shielding considerably **reduces current thermal neutron fluence** in the area

Removal of the shielding will cause a **strong increase** in fluence.

Some Upgrade II electronics may be more sensitive to thermal neutrons

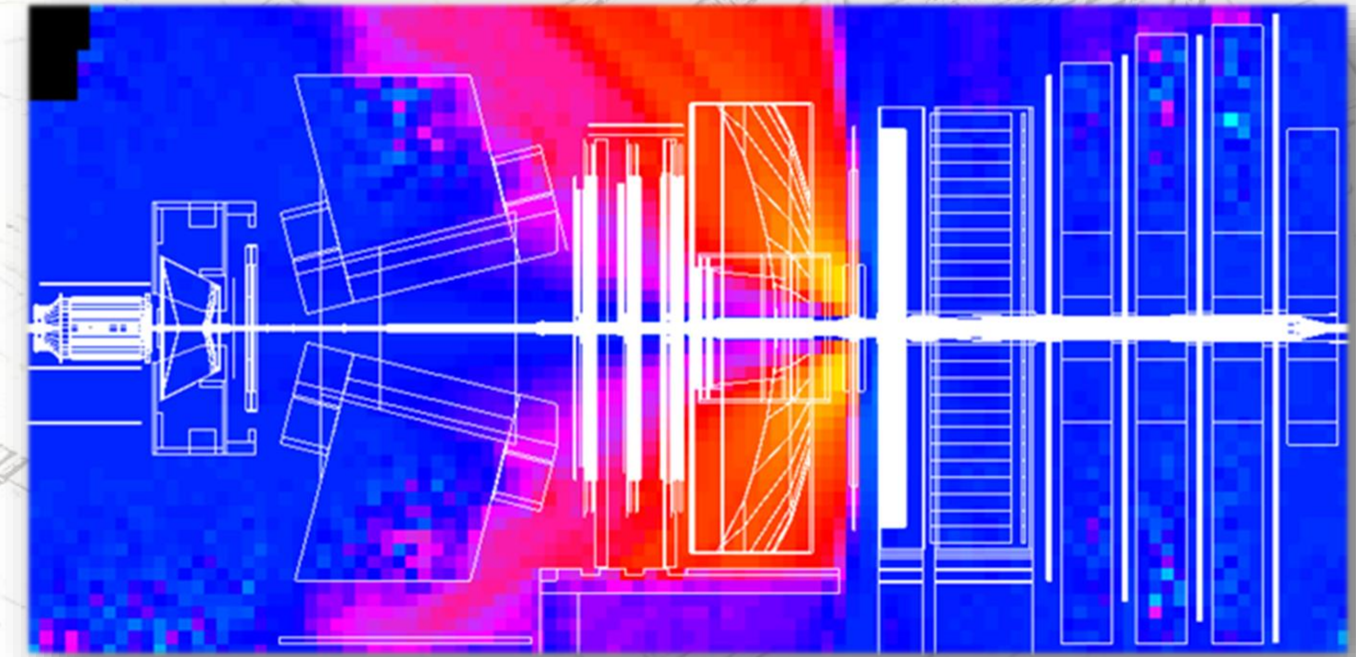
(Activation levels will also increase)

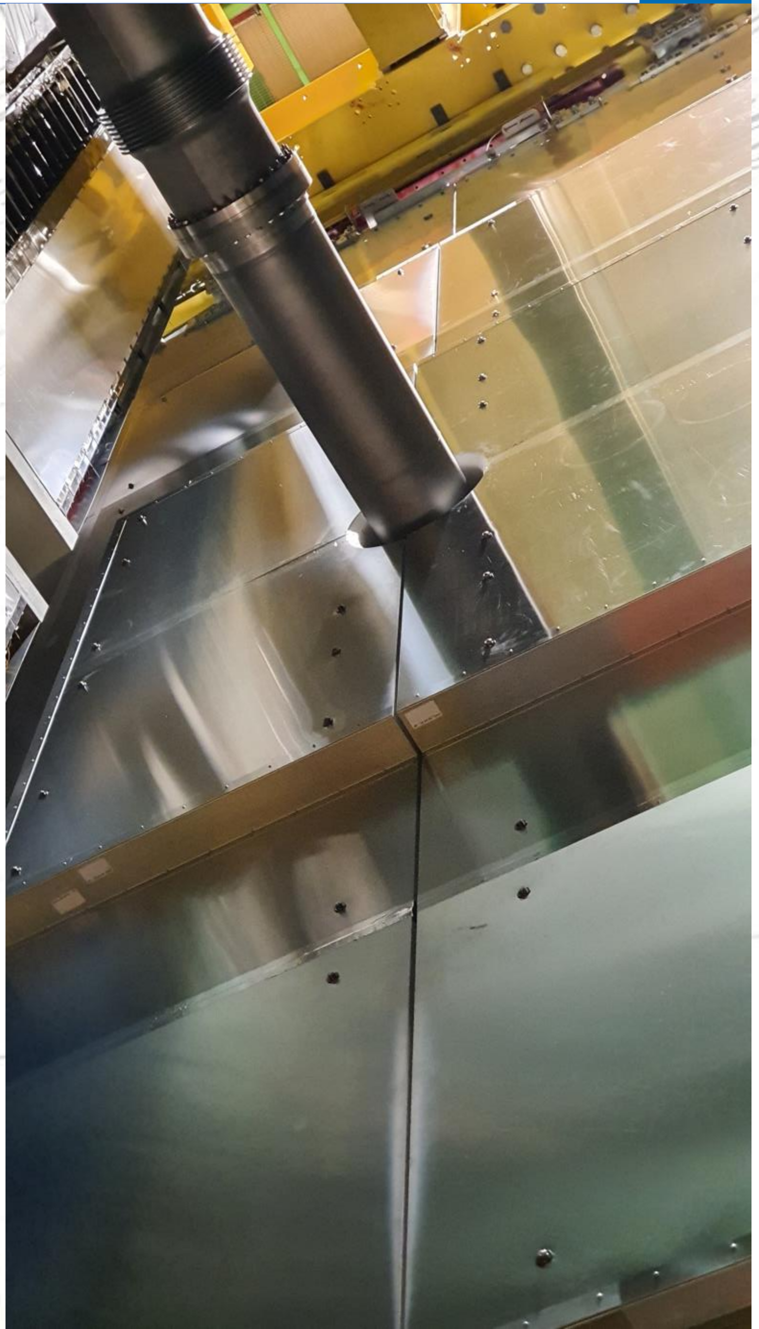


LHCb Upgrade II – ECAL & Neutron Shielding

Large impact on SciFi detector

- ECAL **Tungsten** potentially **adds** to all neutron fluence & 1 MeV neutron fluence equivalent in particular
- Potential **mitigation** measures requiring **modification** of concrete or steel support structures (e.g. relocation of SiPMs towards e.g. Bunker) **require new FLUKA studies** with **accurate geometry**

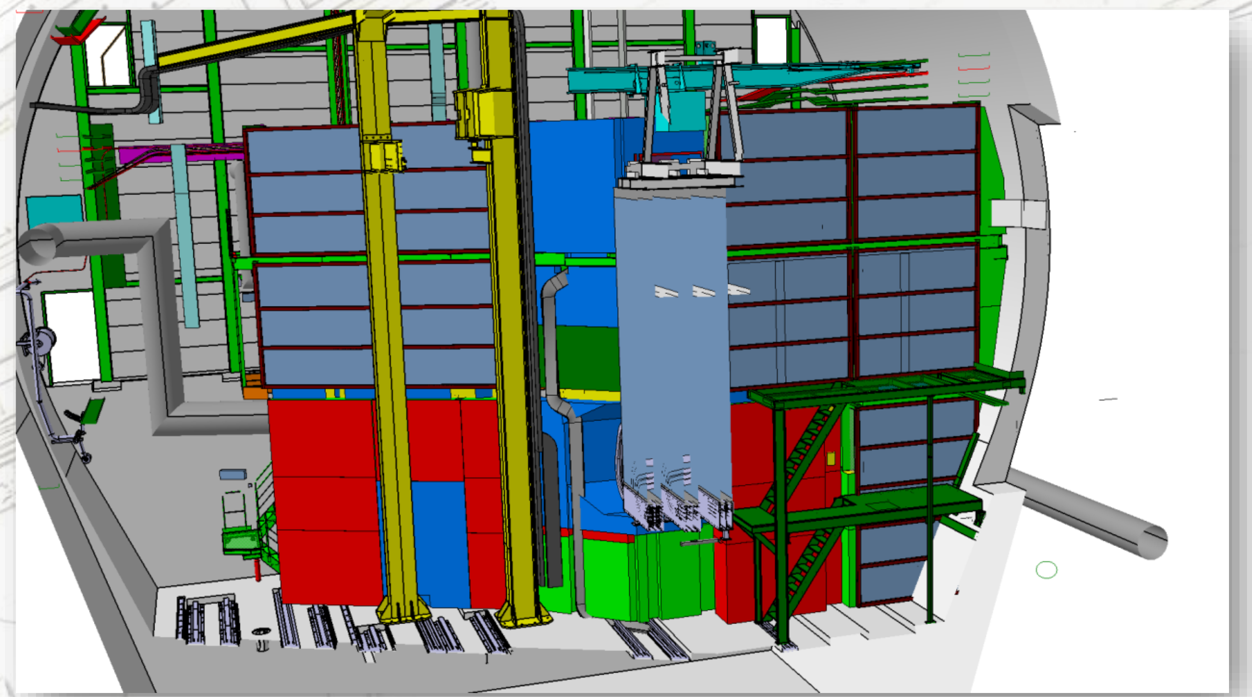




LHCb Upgrade II – Protection for Cryogenic Equipment in UX85

Shielding wall for cryogenic equipment in UX85

- **prompt radiation backsplash** towards C-side (affecting SciFi, pot. RICH2)
- **higher residual dose rates** in C-side area during maintenance periods



Alternative local shielding options are being considered by CERN

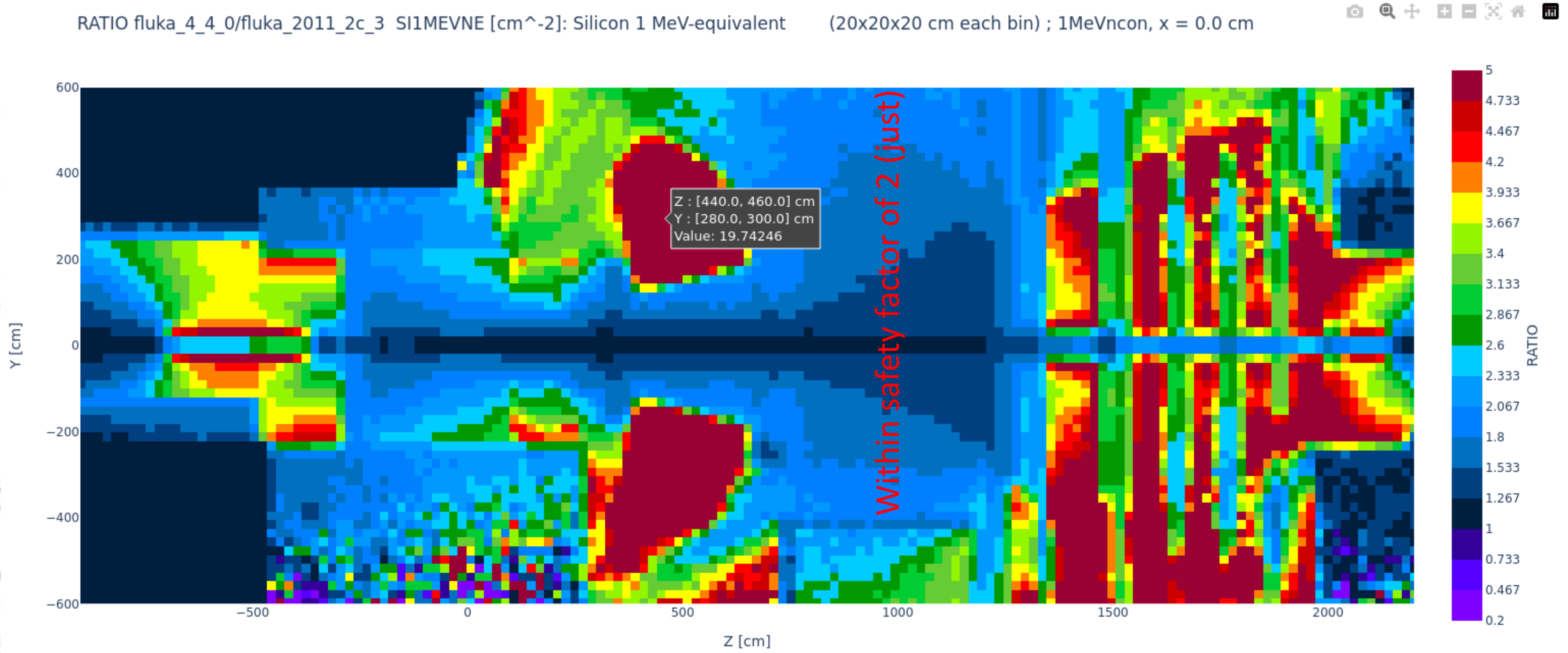
Those changes could still require re-evaluation via FLUKA for C-side radiation environment

FLUKA new simulation – Old geometry <> New results

FLUKA code has improved significantly since last simulations were performed (with 2015 version) (updated physics, cross sections, in particular for **low energy neutrons (<20MeV)**)

Simulations from 2016 reproduced with latest FLUKA & new infrastructure (same configuration):

- **generally higher values** (10-30% depending on situation) for most important estimators (dose, 1MeVne, HEH)
- **1 MeV neutron fl. equ. values very elevated** close to large **iron bodies** (magnet, HCAL, Muon shieldings)

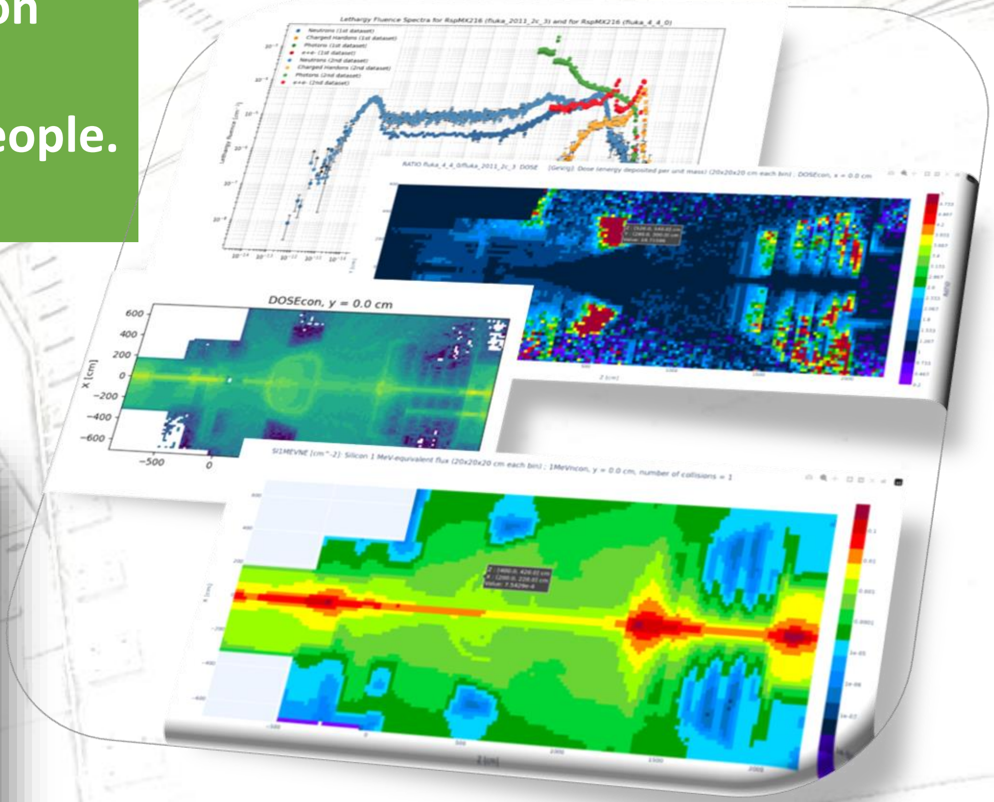


Discrepancies likely to originate from issues with low-energy neutron cross sections used in 2016
(FLUKA was a black box prior to CERN version)

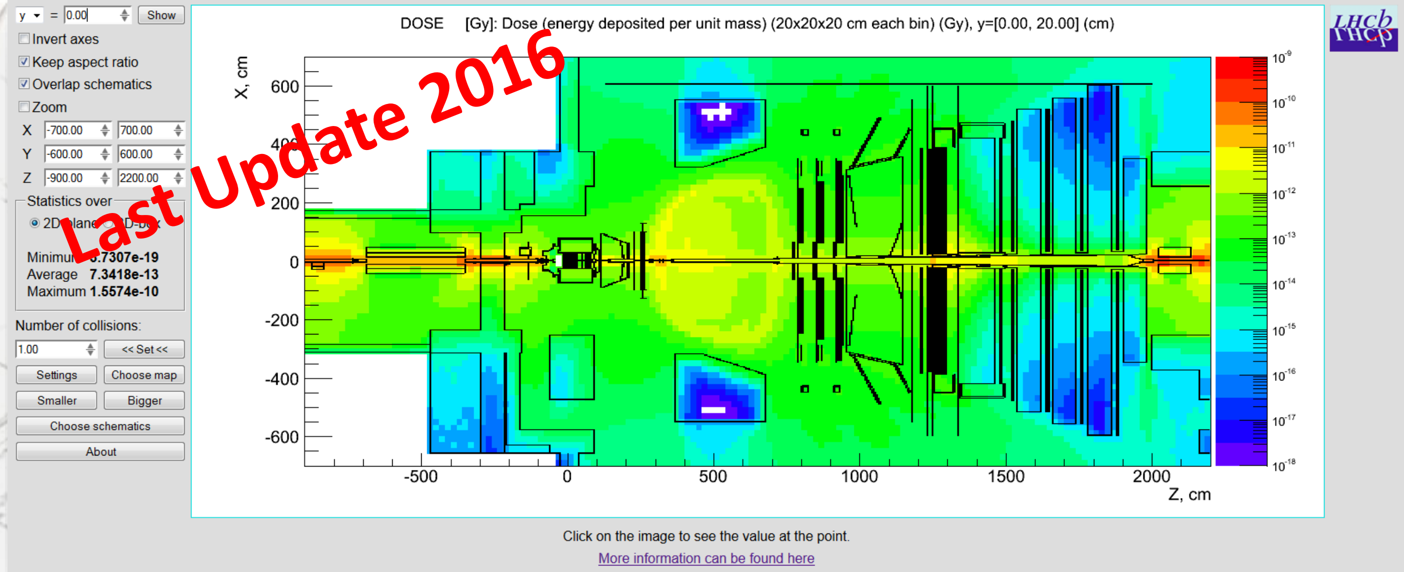
Technical Student Maria Pycior is currently **reproducing Run3** simulations

FLUKA Simulation Web Application

Maria Pycior (tech.) is also working on a new **web-application**
in collaboration with **the Glance LHCb team**
to make simulation results directly retrievable by interested people.
(new design adding more detailed information and tools)



Old webpage with results from 2016 and before, only for experts.

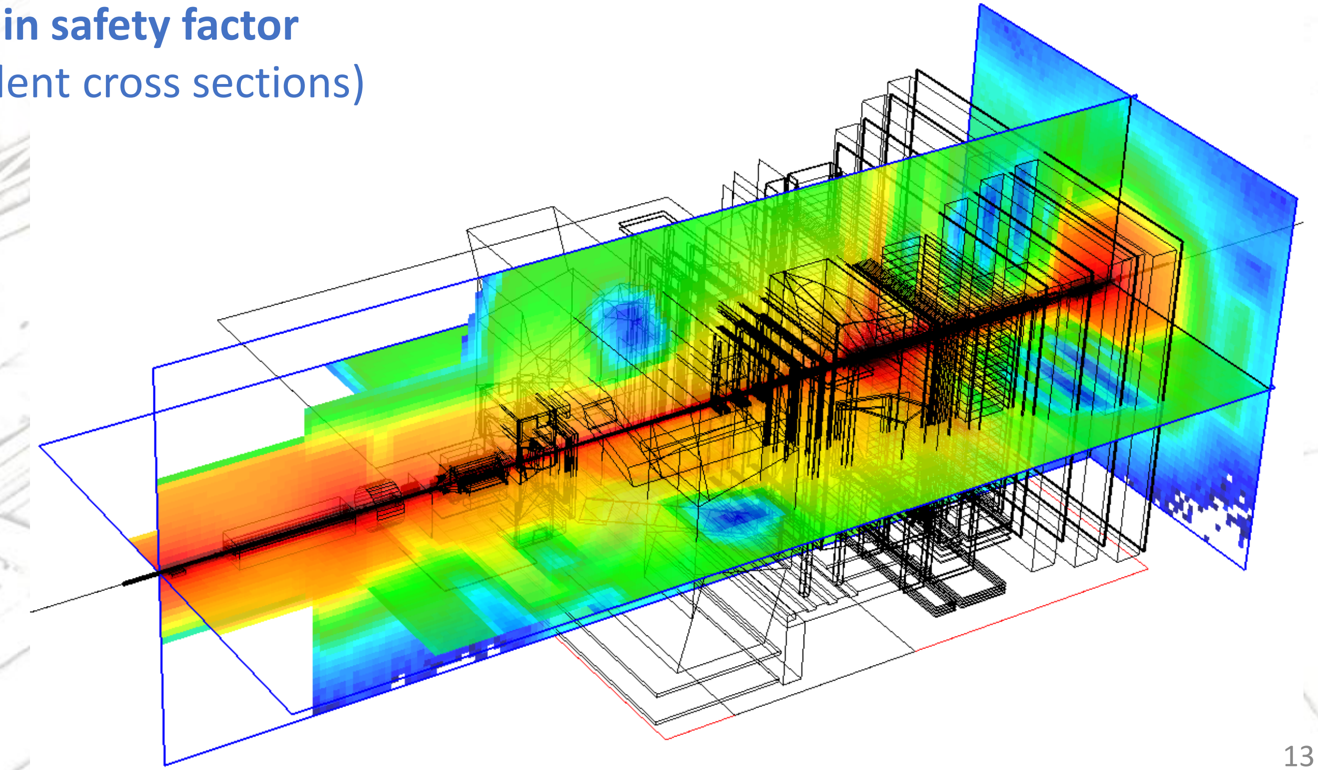


General considerations for new simulations for Run3

Considerations for main estimators for new Run3 simulations

- **Dose values** generally stay **within recommended safety factor** for areas of interest
- **1 MeV neutron fluence equivalent requires re-evaluation** (most areas of interest are just within safety factor of 2 of 2016 results, exceptions for UT SBCs and MUON)
- **High Energy Hadron fluence increase within safety factor** (SEEs have specific particle/energy dependent cross sections)

Safety factor of 2 used in most situations (based on dosimeter benchmarks)



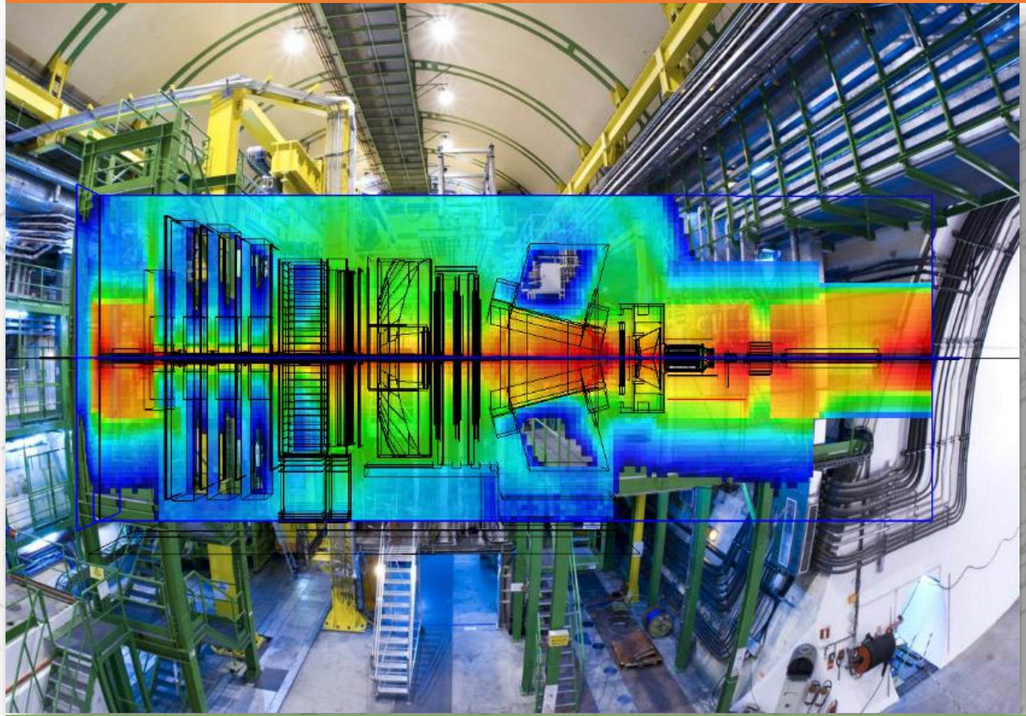
Specific considerations for new simulations

Run3 / Run4 / Run5 (non-exhaustive)
Currently available 2016 simulations should NOT be considered regarding

- **SciFi** 1 MeV neutron fluence equivalent **for Run4&5** (neutron shielding, tungsten)
  (Run3 with adjusted safety factor only)
- **UT Run4** dose and **Run3+ SBC** 1 MeV neutron equivalent fluence estimations
  (updated geometry for detector and re-evaluation of neutrons for SBCs required)
- **VELO Run3+** estimations in sensors and OPBs (HEH should be within safety for Run3)
  (geometry update required, preferably including upstream alcove)
- **VELO alcove/upstream Run3+** dose and neutron fluence (depending on use case, e.g. for test irradiations)
  (new geometry required)
- **MUON Run3 central area** dose, 1 MeV neutron fluence equivalent **everywhere**
- Potentially Mighty Tracker T1 dose after Magnet Station installation (higher electron fluence in dipole)

General considerations for Upgrade II

New studies are required for **reliable simulations of Upgrade II conditions**



- **New geometry** must be built in **FLUKA format**
- **Materials must be carefully described (e.g. ECAL SpaCal alloys)**

This requires input from subdetectors!

LHCb geometry should be extended to **include balcony** and **larger cavern**
(process was started several times but never properly completed)

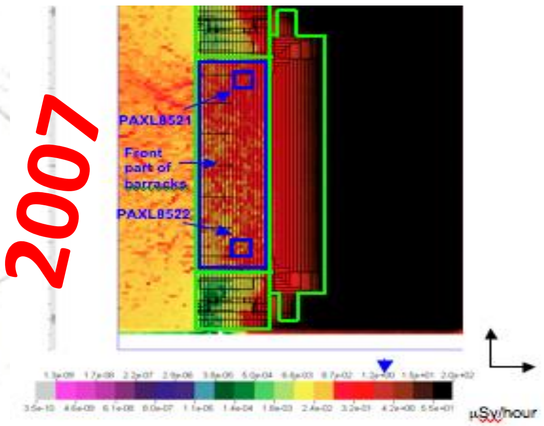
Activation studies require addition of support structures to geometry
Can be done with ACTIWIZ but requires fluences as input obtained from FLUKA.

Addendum Simulation Forecast – Shielding of UX85A

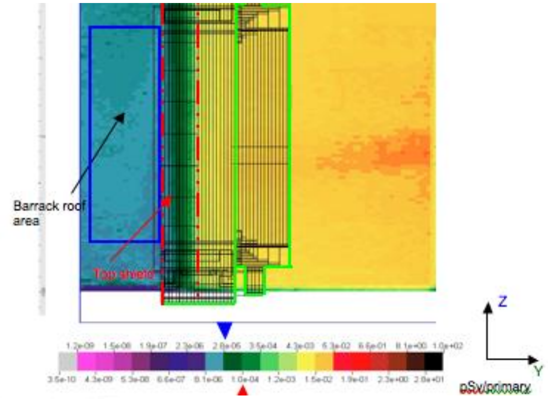
Shielding wall to comply with design limits of 20 mSv ambient dose equivalent in case of a full beam loss

Ambient-dose-in D2 [uSv/hour]

2007



Ambient-dose-equivalent on D3 [pSv/primary proton lost]



LHCb 'nominal' parameters used:

- Beam energy = 7 TeV
- luminosity L = 2 x 10^{32} cm^{-2} s^{-1},
- inelastic cross-section s = 80 mbarn
- collision rate of 1.6 x 10^{7} collisions/s

full beam loss of 4.7 x 10^{14} protons for 1 beam

New openings in shielding wall require **re-evaluation**

For nominal Run1 LHCb operation average rate found to be 5.6 x 10^{-2} µSv/h ± 2% → Still supervised U2

For full beam loss average values in barracks ~4 mSv BUT part of D3 above.
→ Only an issue for HL-LHC if beam current increases

CERN-SC-2007-035-RP-TN, EDMS no. 847155, C. Theis et al.

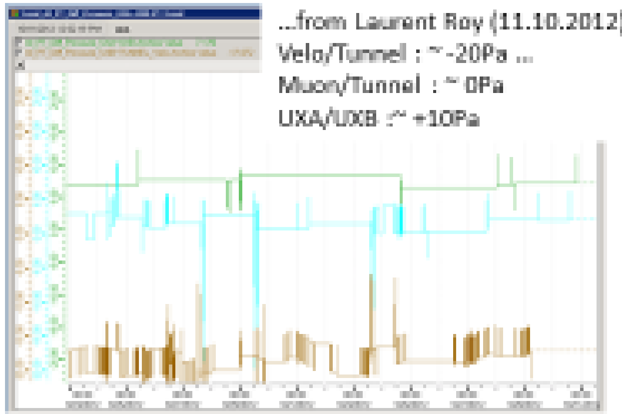
Addendum Simulation Forecast – Air Activation

2013

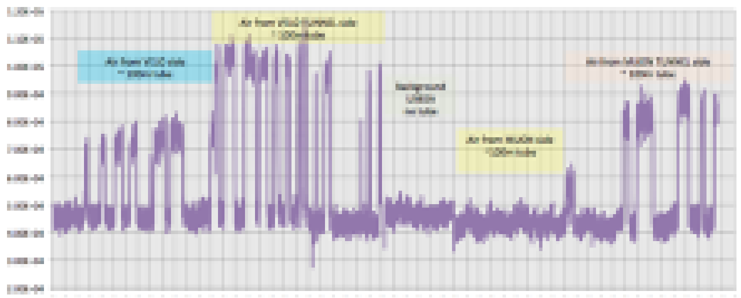
Air activation

- Risk of exposure due to air activation investigated for all experiments by HSE-RP. Recommendation of 15'waiting before access.

CERN-SC-2008-067-RP-TN, EDMS no. 945045



...from Laurent Roy (11.10.2012):
Velo/Tunnel : ~-20Pa ...
Muon/Tunnel : ~ 0Pa
UXA/UX8 :~ +10Pa



...from Isabel Brunner and Nadine Conan
Measurements made from 13 Oct to 7 Nov 2012 with special detector

- Re-evaluated end of 2012 for tunnel area adjacent to IR8 for two different air flow cases

For the current situation dose to personnel from air leaking into LHCb is negligible.
Re-assessment for LHCb upgrade is recommended

Hz. Vincke, HSE-RP, Private Comm.

Re-assessment required

Longer waiting times might be required in future

Summary

- **Preliminary ECAL Tungsten SpaCal study** underway. Results will indicate consequences for Run4 estimations.
- **Removal of Neutron Shielding** causes strong increase of 1 MeV and thermal neutrons upstream of CALO.
- **Cryo area modifications** to be included to estimate influence on C-side detectors.
- **1 MeV neutron fluence equivalent re-evaluation** with current FLUKA version (point-wise low-energy neutron treatment) points to strong increase close to large iron bodies.
- **New studies** with essential **changes in geometry are required**.
- Geometry changes will require **input & contributions from subdetectors**.
- **Activation** calculations require **implementations of surrounding support structures**.

BACKUP

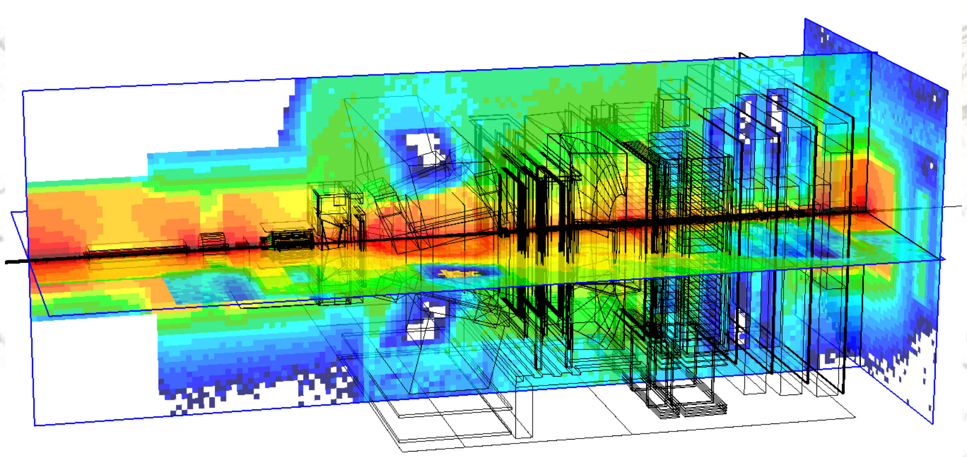
Simulation Forecast

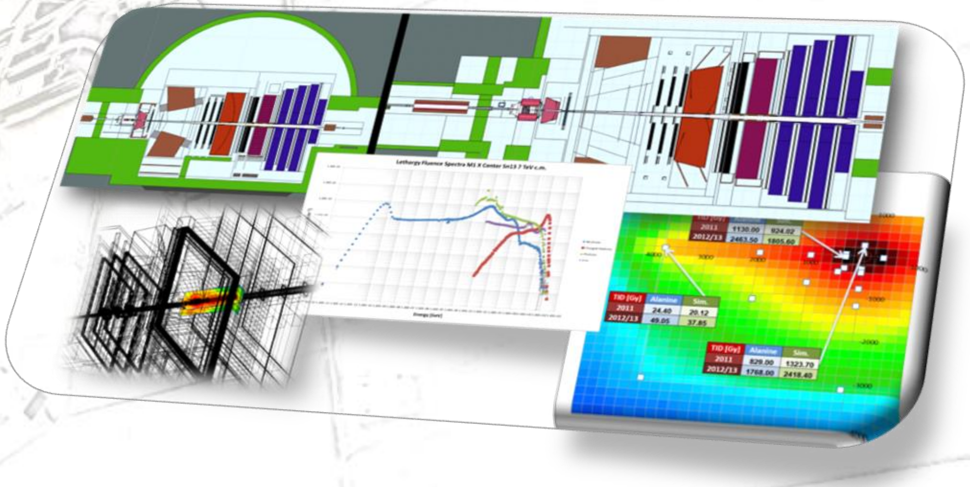
In addition to locations, we also need to know your parameters of interest!

Standard scorings are always set up for:

- **Total Ionising Dose**
- **1 MeV neutron fluence equivalent**
- **High Energy Hadrons (HEH) > 20 MeV**

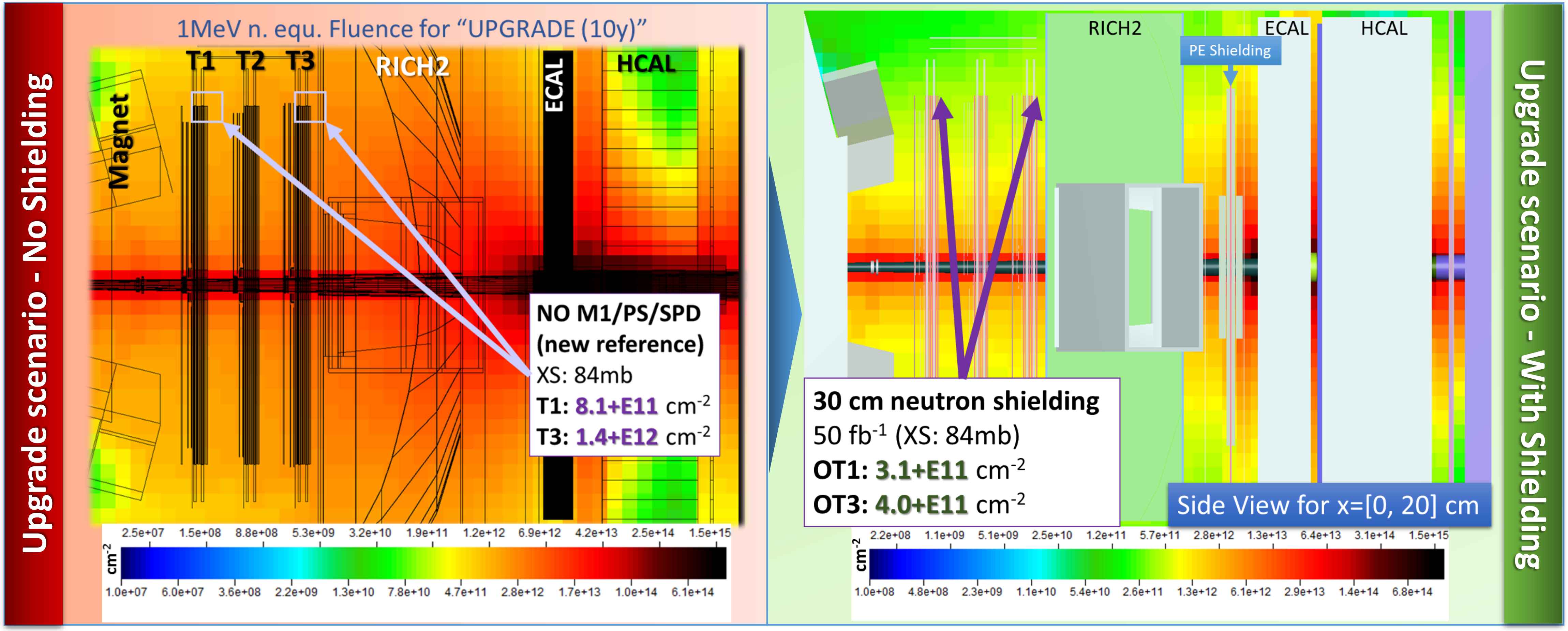
Some different parameters (e.g. fluences and energy spectra for various particles) are available **on request**!





Depending on location and parameter, different safety factors for simulation results may be needed. LHCb RP will provide recommendations.

Effect of final shielding design



Absolute prediction values are expected to be precise within a factor of 2:

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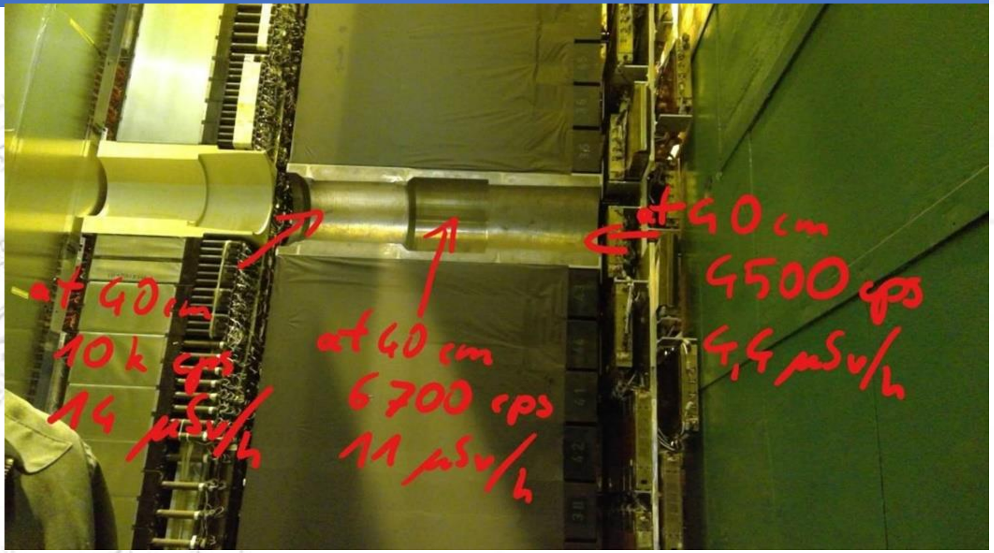
Activation Example – ECAL Center Implications

Example: LS2 survey

Roughly 1 month after beam stop in LS2 with ECAL and HCAL open



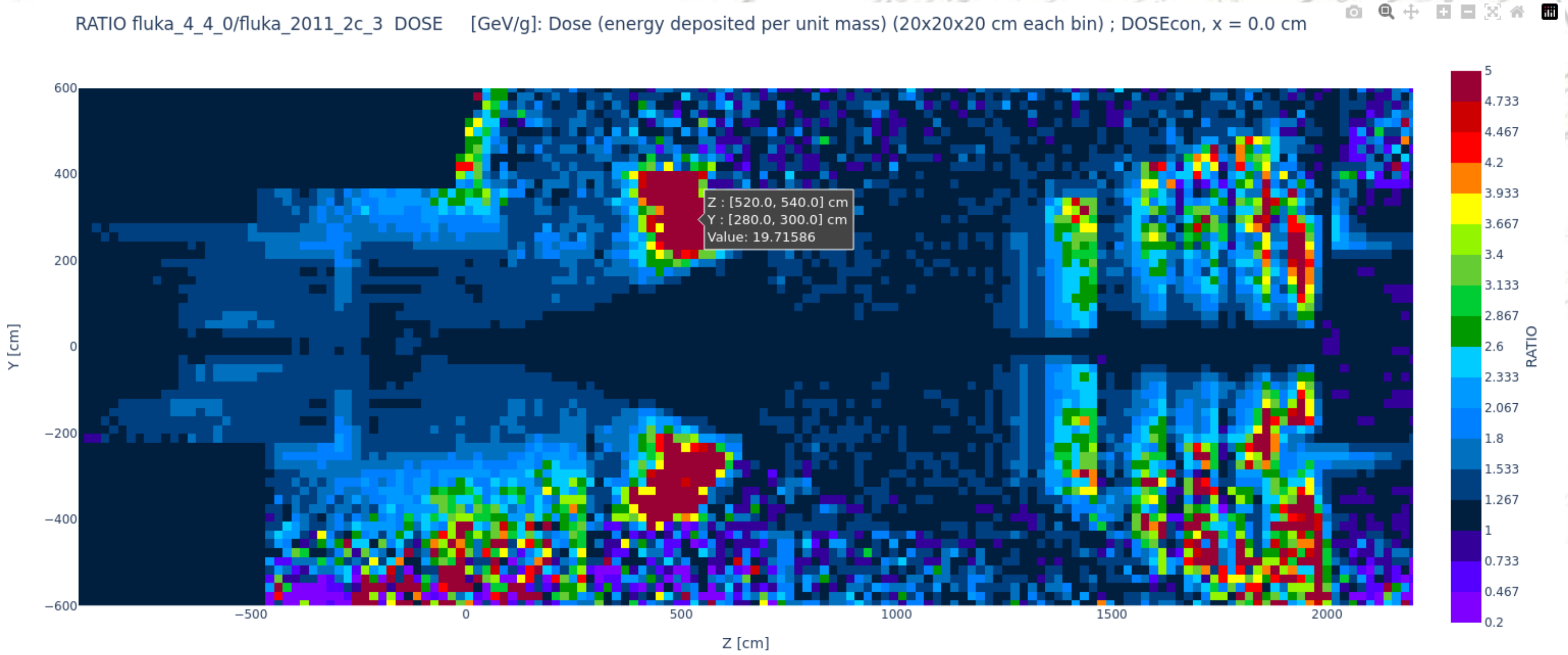
Assumption: Tungsten instead of Lead in ECAL after 1 month cooling

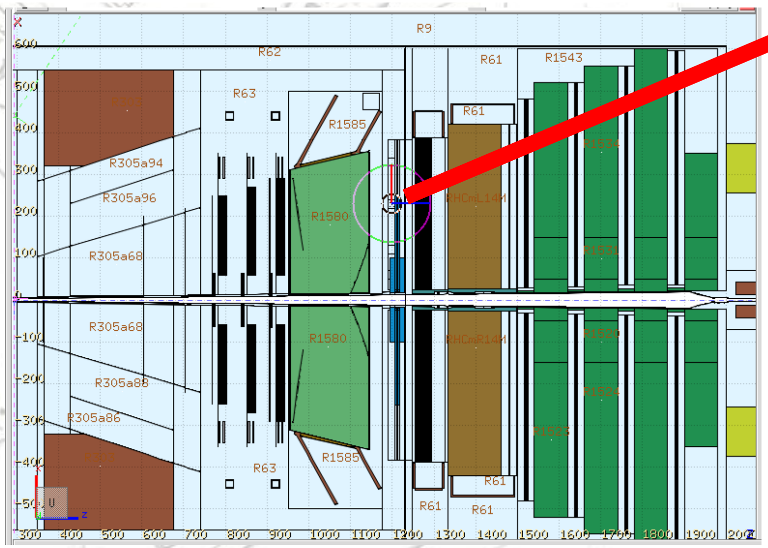
- **Dose rates at 1m** distance would increase by **factor of 3-4**.
- **Contact measurements** would be higher by **orders of magnitude** compared to lead.
- Dose rate **at 40 cm**, which defines **ALARA level**, would be somewhere in between.
- **Luminosity increase** (up to **factor of 7** for U2) has to be taken into account **on top!**

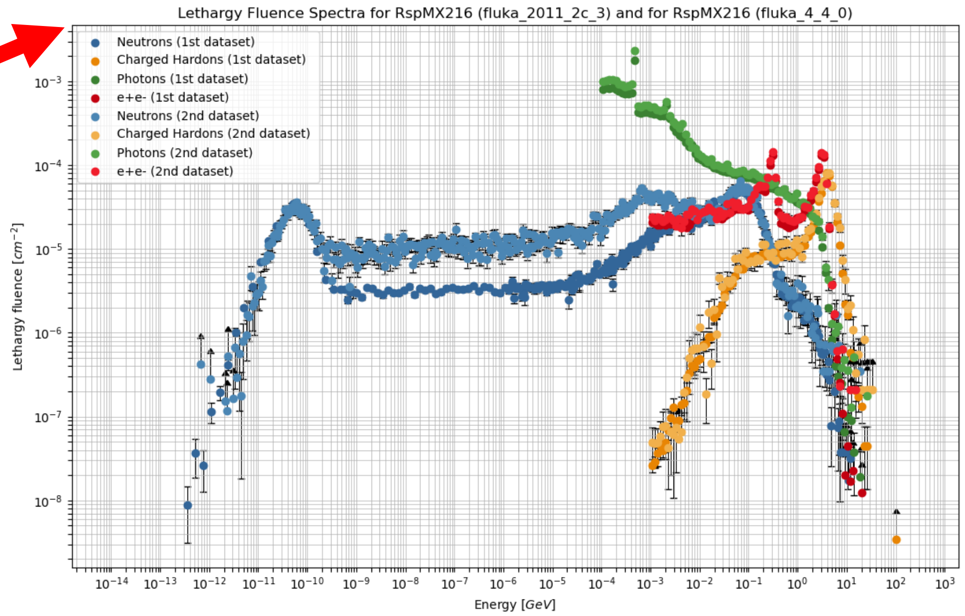
For shorter cooling times, Tungsten is worse than lead!

Short ACTIWIZ studies sent to Andreas et al. (email)

New FLUKA 2024 – Low-Energy Neutrons







New FLUKA 2024 – 1 MeV neutron fluence equivalent increase