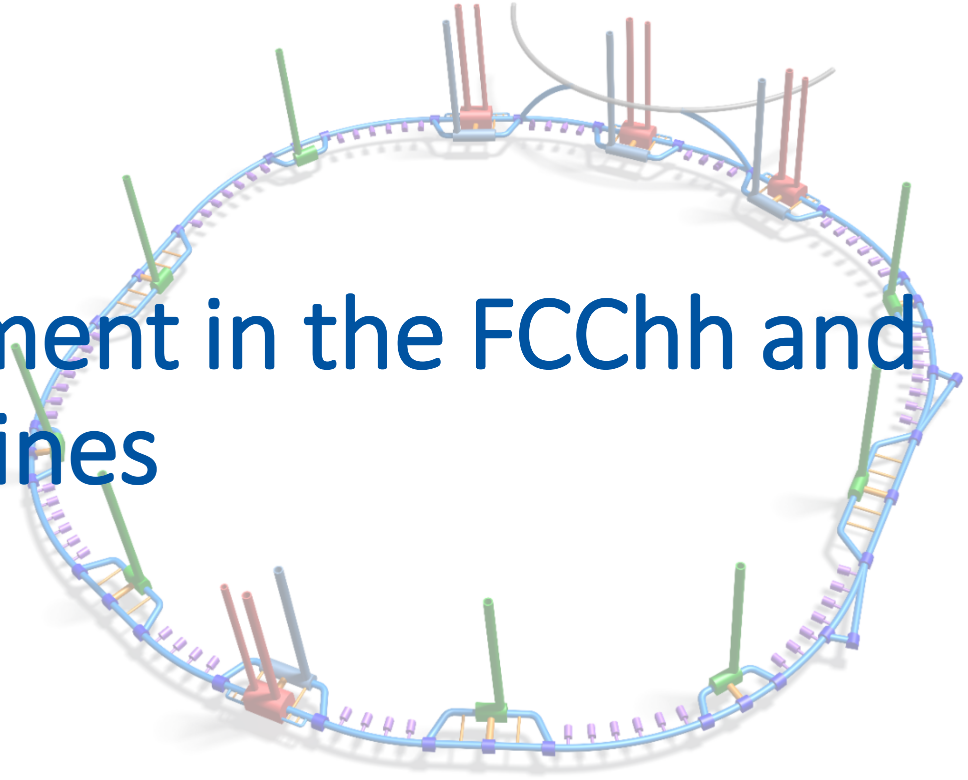
CERN

Radiation environment assessment in the FCChh and FCCee machines



Angelo Infantino, Rubén García Alía, Markus Brugger, Francesco Cerutti

CERN

FLUKA Team & R2E-Project

<u>With additional inputs from:</u> Mohammad Varasteh (EN-STI-BMI), Maria Ilaria Besana (EN-STI-BMI), Andrea Tsinganis (EN-STI-BMI), Luigi Salvatore Esposito (EN-STI-BMI), Eleftherios Skordis (EN-STI-BMI), Cristina Bahamonde Castro (EN-STI-BMI), Anton Lechner (EN-STI-BMI), Jacqueline Keintzel (BE-ABP-HSS), Mar Capeans Garrido (TE-PPR), Volker Mertens (TE), Fani Valchkova-Georgieva (EN-ACE-INT), Roman Martin (BE-ABP-LAT), Andrea Apollonio (TE-MPE-PE), Arto Niemi (BE-ICS), Roberto Kersevan (TE-VSC-VSM)

Outline

Introduction

R_2E-FLUKA studies

- ➢ FCChh
  - Arc
  - Detector
  - Experimental Insertion Region (IP A and G)
  - Betatron cleaning (IP J)
- ➢ FCCee
  - Arc
- ➢ HE-LHC

Radiation Levels

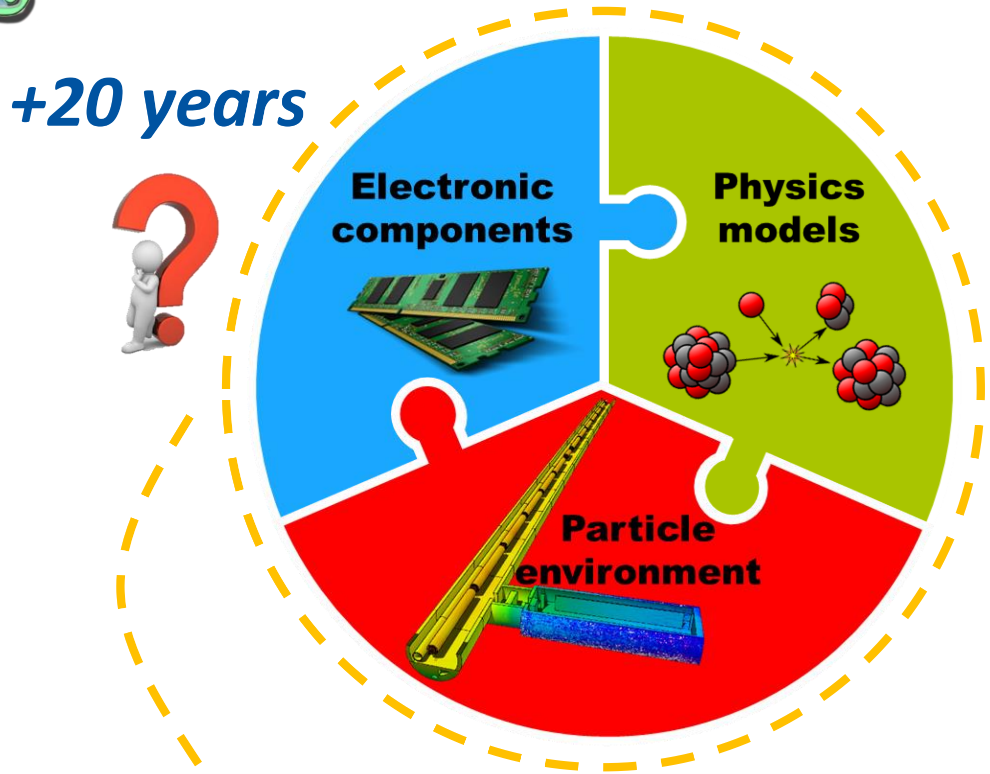
- ✓ Total Ionizing Dose
- ✓ High Energy Hadrons fluence
- ✓ 1MeV neutron equivalent fluence
- ✓ Comparison with LHC/HL-LHC

Summary

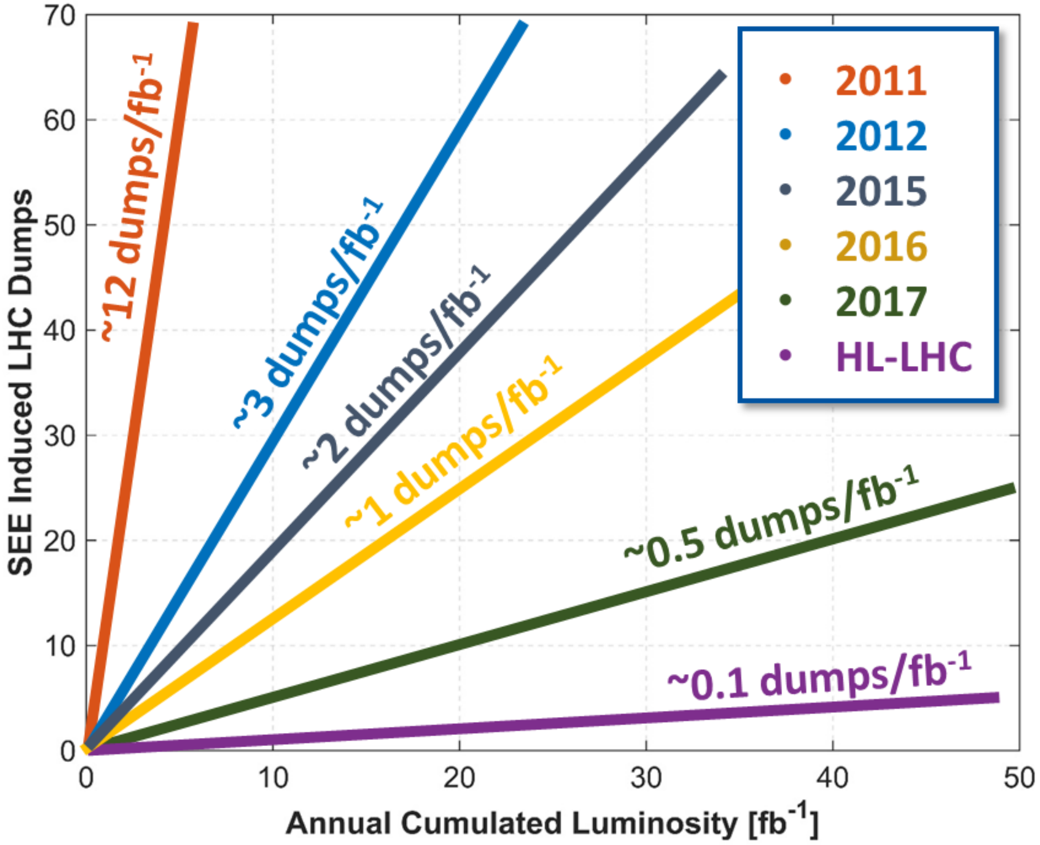
DISCLOSURE:
*Due to time constraints, **only results/main achievements** will be presented in this talk. More information about the FLUKA models/simulations are reported in the backup-slides or related talks.*

Introduction: “R2E”: What, How, Why?

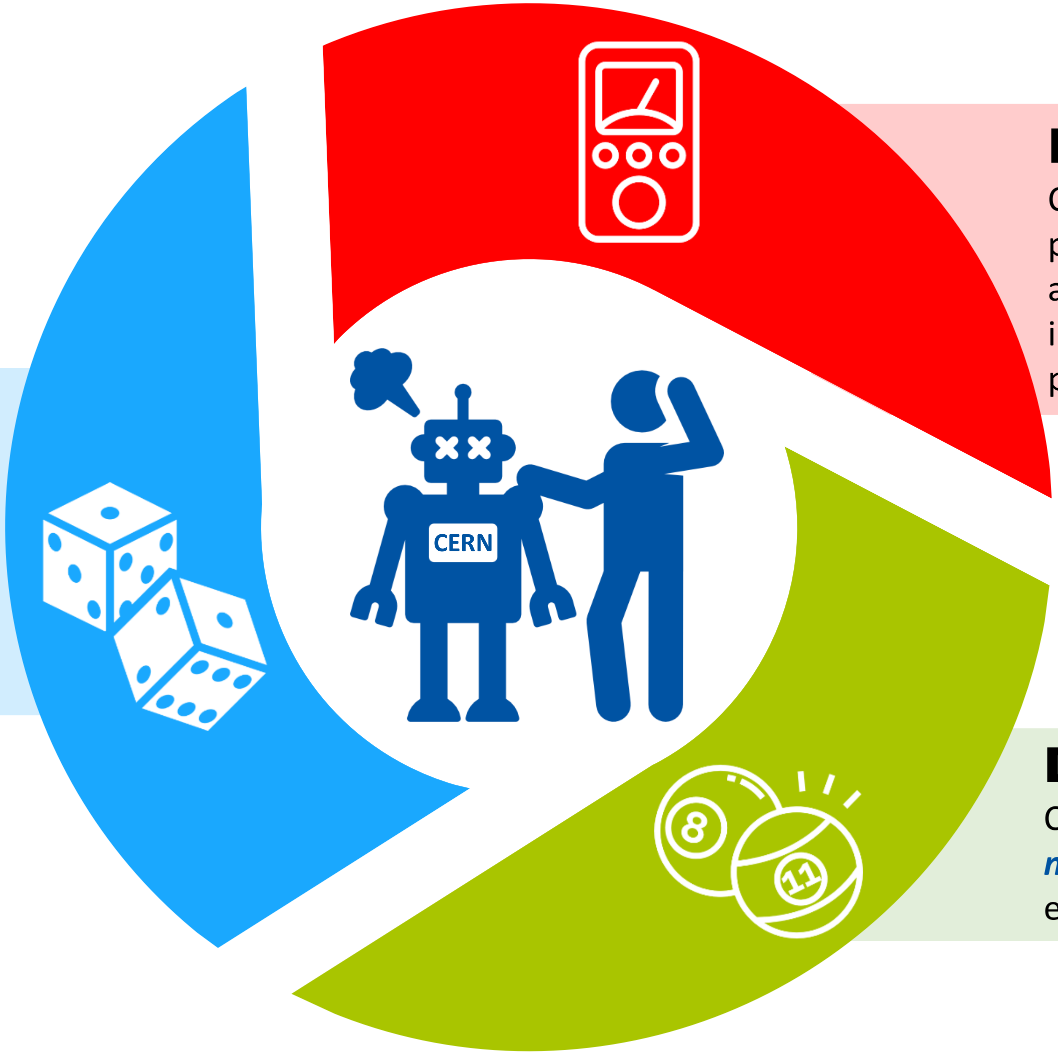
Radiation to Electronics -> Coordinates studies to minimize all risks of radiation-induced failures at CERN accelerators



R2E strategies and actions



Introduction: Relevant quantities for R2E



DETERMINISTIC EFFECTS

Cumulative effects (easy to predict) proportional to ***Total Ionizing Dose (TID)***. LHC absolute values typically not critical (especially in shielded areas). Scaling of components positive for TID (smaller oxides).

SINGLE EVENT EFFECTS

Stochastic Effects (hard to predict) proportional to ***High Energy Hadrons (HEH) fluence***. LHC absolute levels are high, even in shielded areas (neutrons). Most effects are constant with scaling but they can also increase (proton direct ionization, etc.).

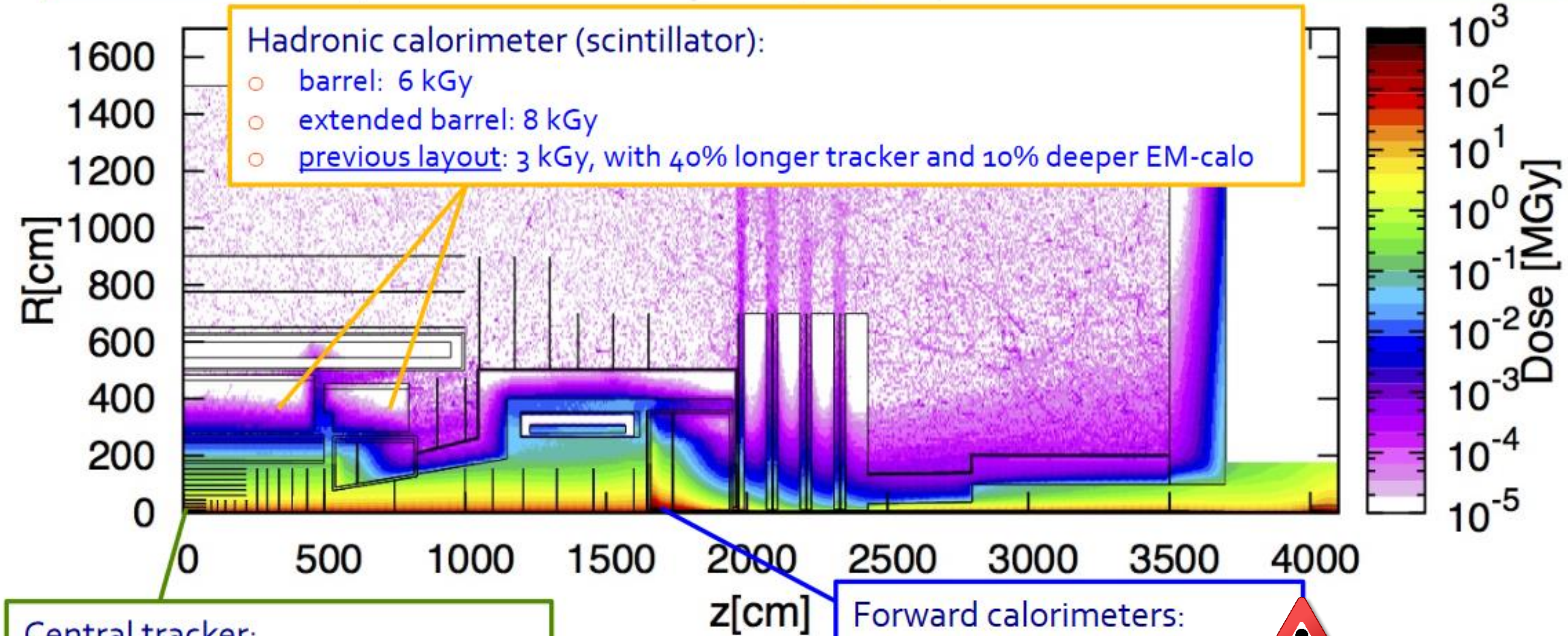
DISPLACEMENT DAMAGE

Cumulative effects proportional to ***1MeV neutron equivalent fluence***. Relevant for the experiments (detectors).

FCChh: DETECTOR (IP A and G)

FCChh: Detector (FCC Week 2017)

Dose for 30 ab^{-1}



Hadronic calorimeter (scintillator):

- barrel: 6 kGy
- extended barrel: 8 kGy
- previous layout: 3 kGy, with 40% longer tracker and 10% deeper EM-calo

Central tracker:

- first IB layer (2.5 cm): ~400 MGy
- external part: 0.1 MGy

Forward calorimeters:

- EM-calo: 5000 MGy
- HAD-calo: ~1000 MGy
- at R=2 m the dose is ~1 MGy

Simulations courtesy of
Maria Ilaria Besana (EN-STI-BMI)
Ref: FCC Week 2017

FCChh: Detector (FCC Week 2017)

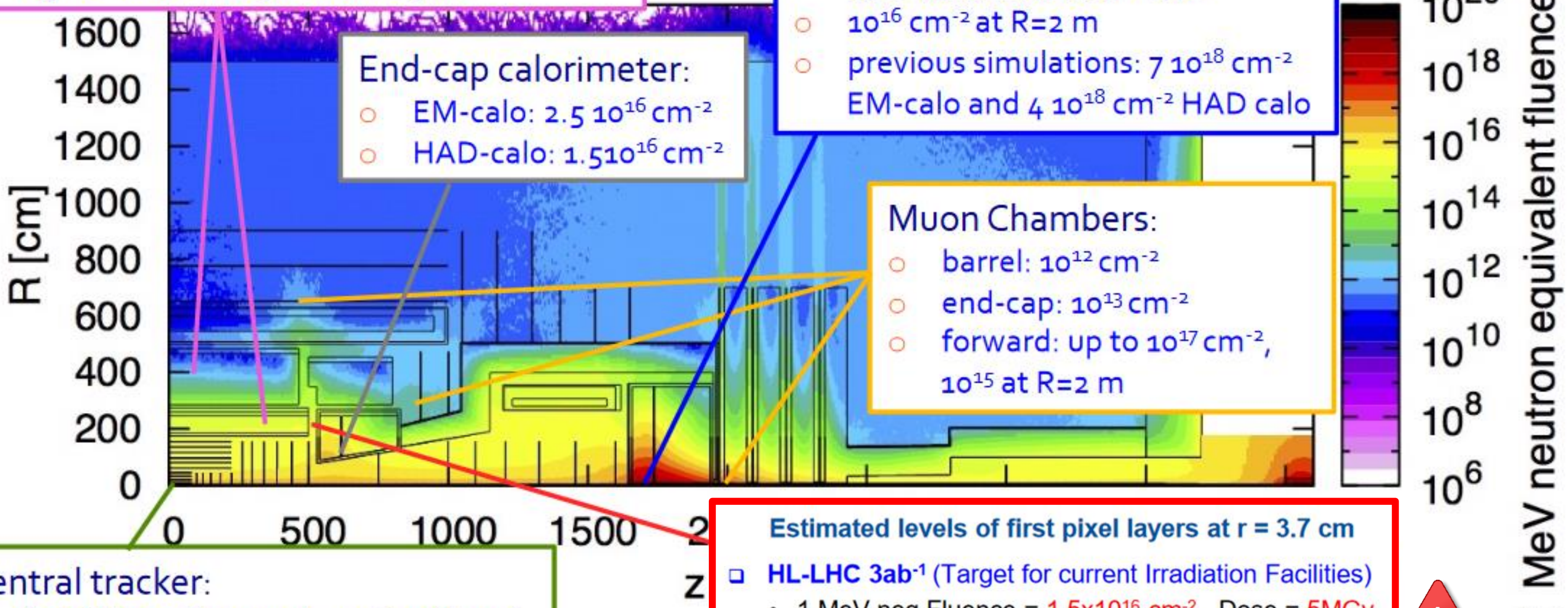
1 MeV Neutron Equivalent Fluence for 30 ab^{-1}

Barrel calorimeter:
- EM-calo: $4\ 10^{15}\ cm^{-2}$ & HAD-calo: $4\ 10^{14}\ cm^{-2}$
- higher values wrt previous layout

End-cap calorimeter:
- EM-calo: $2.5\ 10^{16}\ cm^{-2}$
- HAD-calo: $1.5 10^{16}\ cm^{-2}$

Forward calorimeters:
- maximum at ~$5\ 10^{18}\ cm^{-2}$ for both the EM and the HAD-calo
- $10^{16}\ cm^{-2}$ at R=2 m
- previous simulations: $7\ 10^{18}\ cm^{-2}$ EM-calo and $4\ 10^{18}\ cm^{-2}$ HAD calo

Muon Chambers:
- barrel: $10^{12}\ cm^{-2}$
- end-cap: $10^{13}\ cm^{-2}$
- forward: up to $10^{17}\ cm^{-2}$, 10^{15} at R=2 m



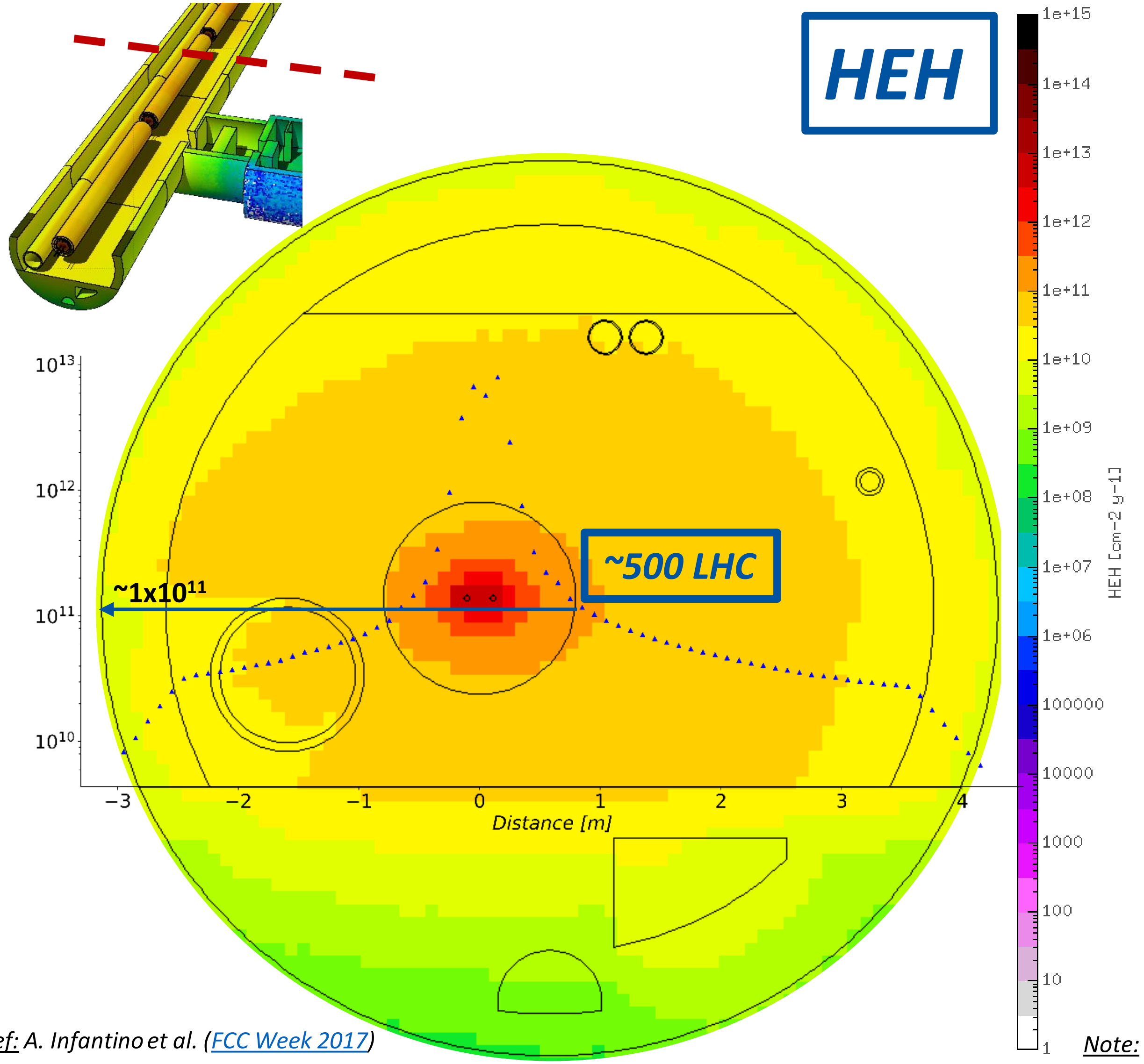
Central tracker:
- first IB layer (2.5 cm): ~$5\text{-}6\ 10^{17}\ cm^{-2}$
- external part: ~$5\ 10^{15}\ cm^{-2}$

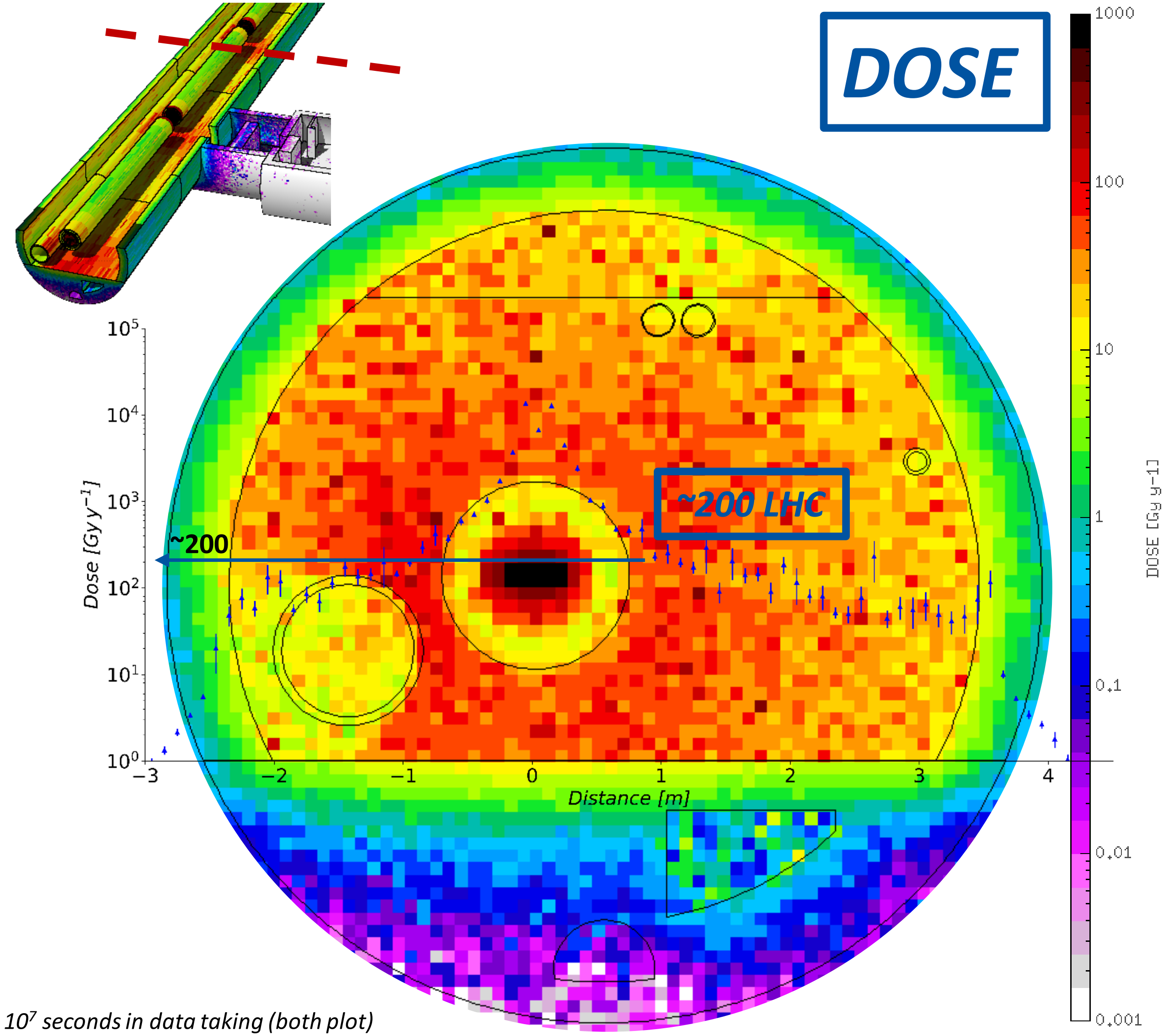
Estimated levels of first pixel layers at r = 3.7 cm
- **HL-LHC 3ab^{-1}** (Target for current Irradiation Facilities)
  - 1 MeV neq Fluence = $1.5\times10^{16}\ cm^{-2}$, Dose = 5MGy
- For radii< 50-60 cm fluence exceeds the value expected at HL-LHC ($10^{16} cm^{-2}$) by ~2 orders of magnitude

Simulations courtesy of Maria Ilaria Besana (EN-STI-BMI)

FCChh: ARC

FCChh: ARC (FCC Week 2017)

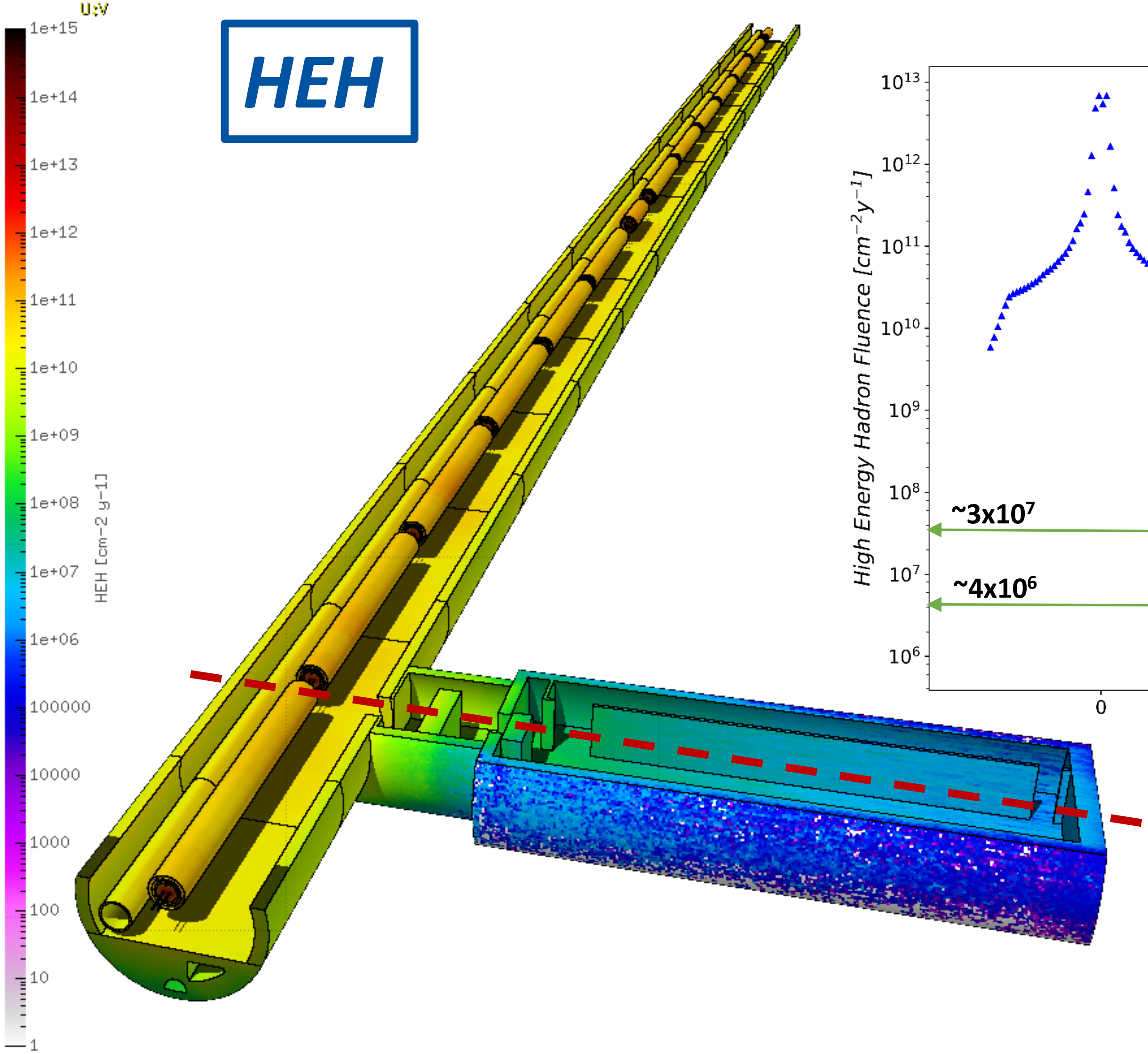


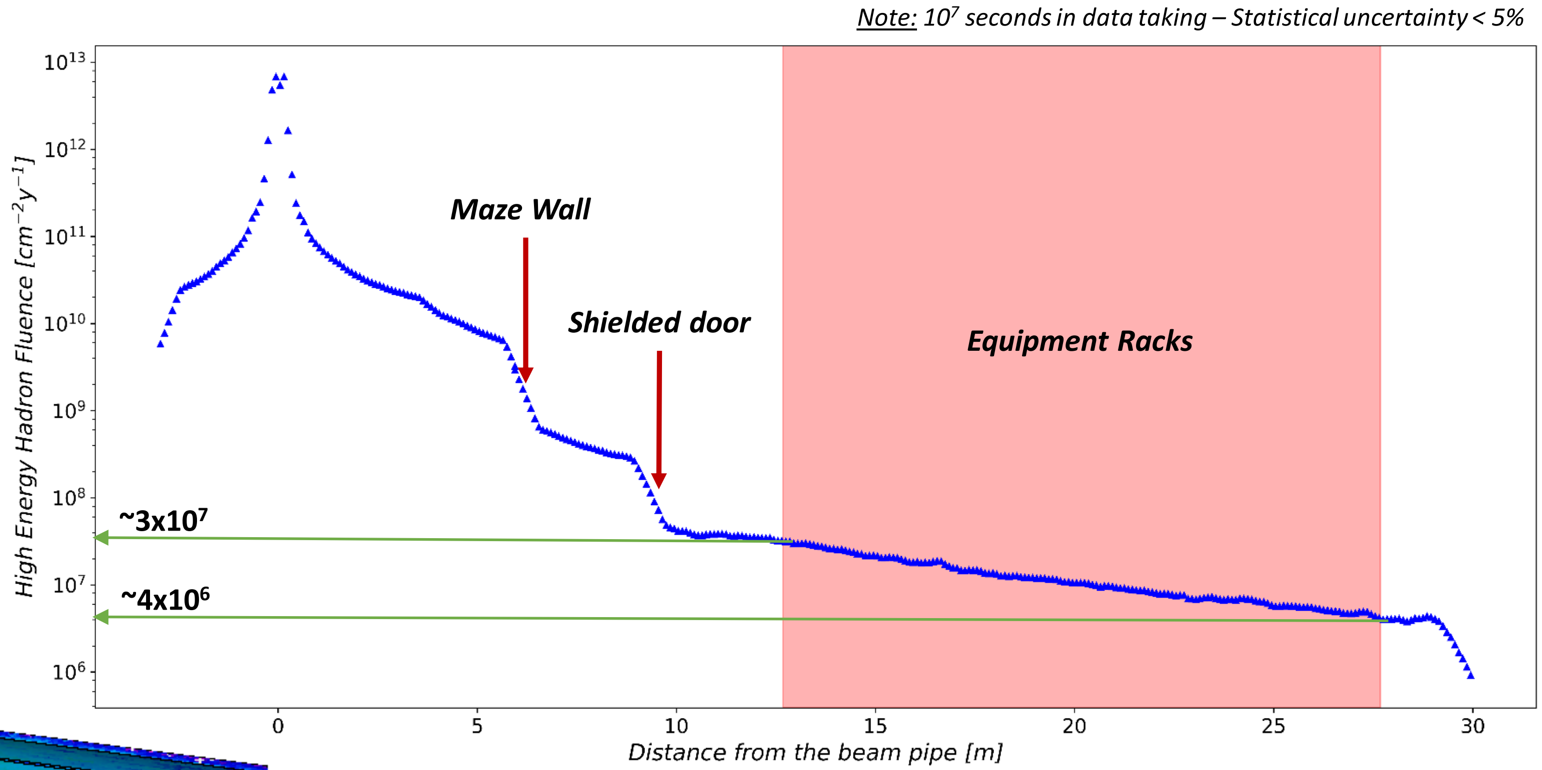


Ref: A. Infantino et al. (FCC Week 2017)

Note: 10^7 seconds in data taking (both plot)

FCChh: ARC/ALCOVE (FCC Week 2017)



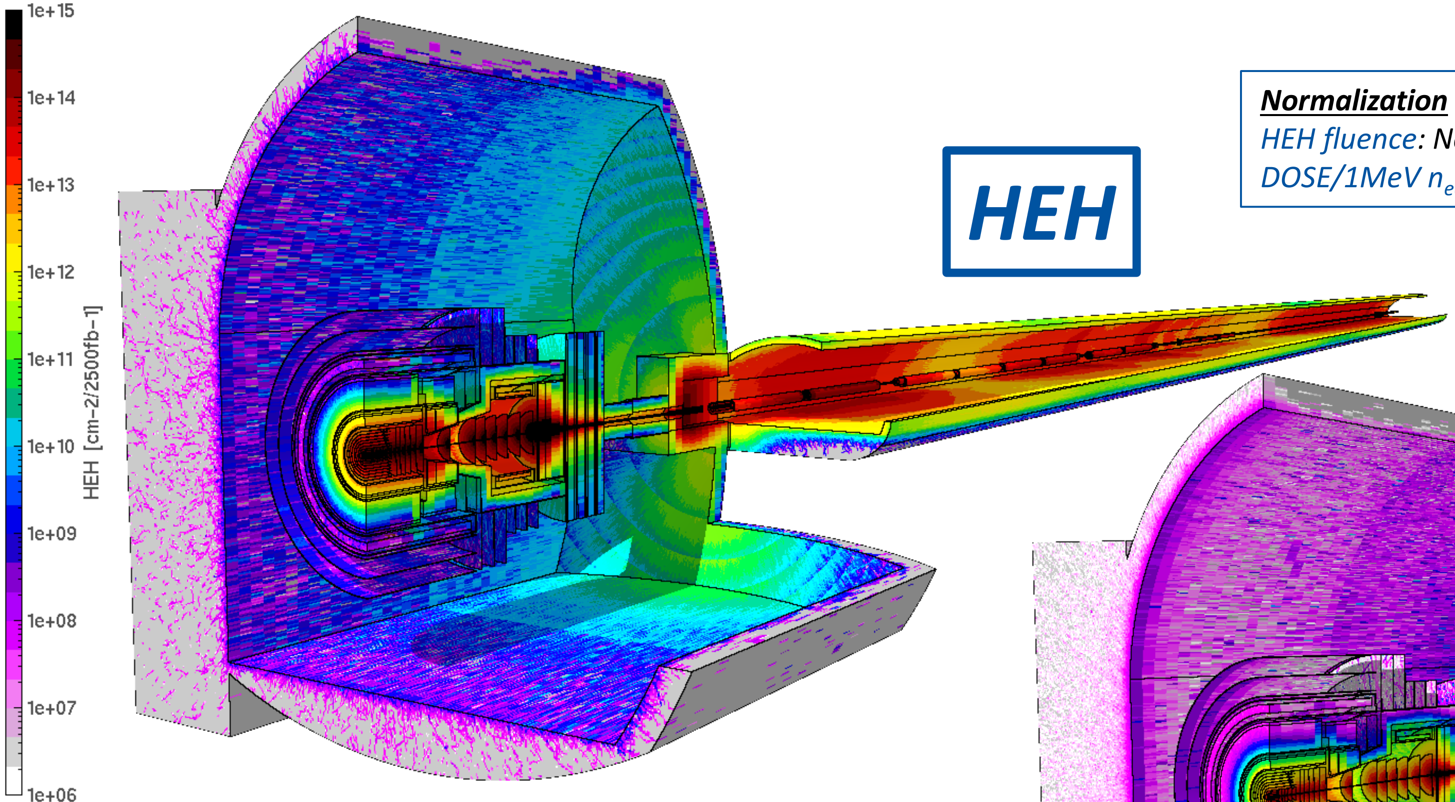


- ✓ Simulations *triggered and finalized* the design of dedicated alcoves for the electronics
- ✓ Studies of *R2E-quantities* -> HEH fluence & DOSE *~3-4* LHC RE areas*
- ✓ *Vacuum quality*: *~10^{15} H_2/m^3* (pessimistic scenario) -> A better vacuum quality can further reduce the radiation levels

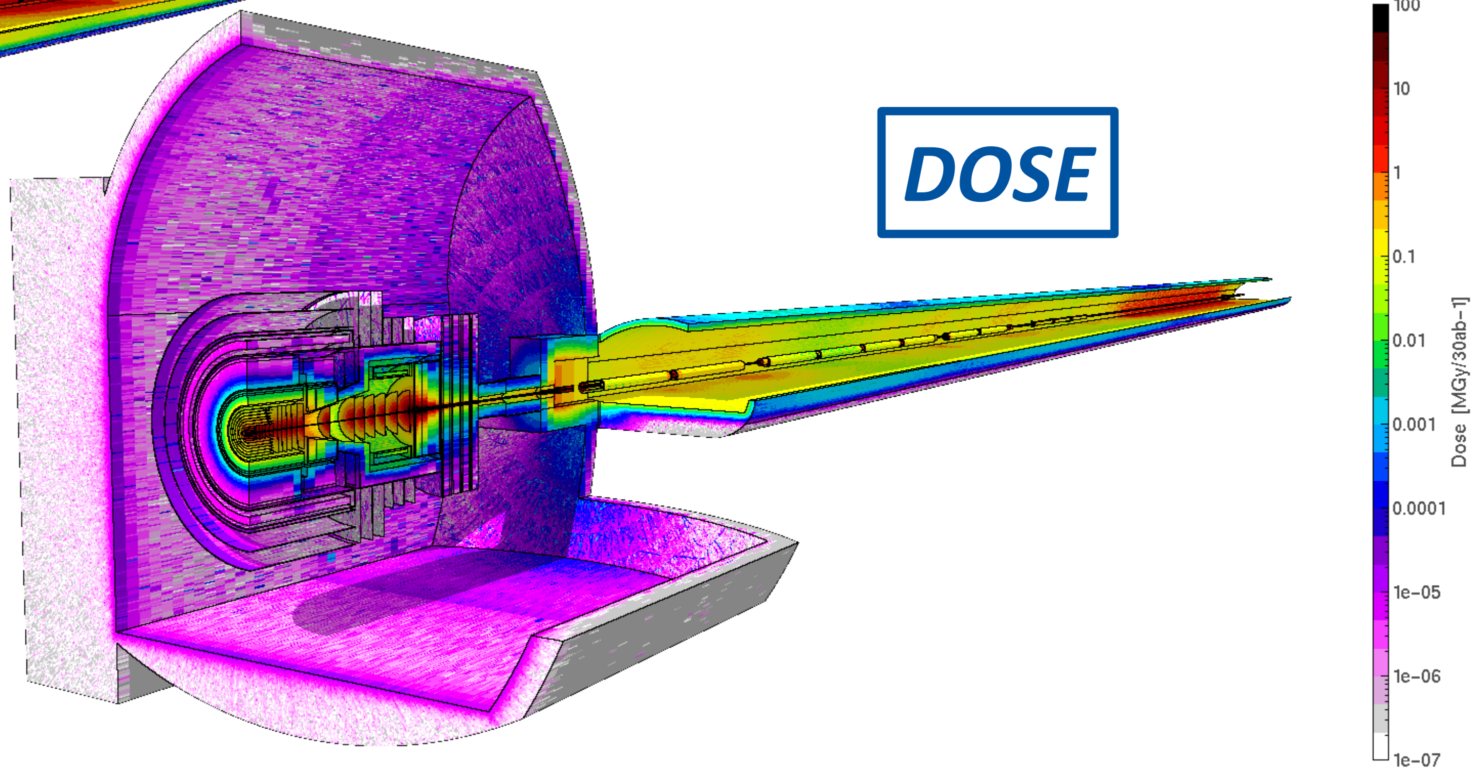
*See LHC Project note 363

FCChh: EXPERIMENTAL INSERTION REGION (IP A and G)

FCChh: Experimental Insertion Region (2018)

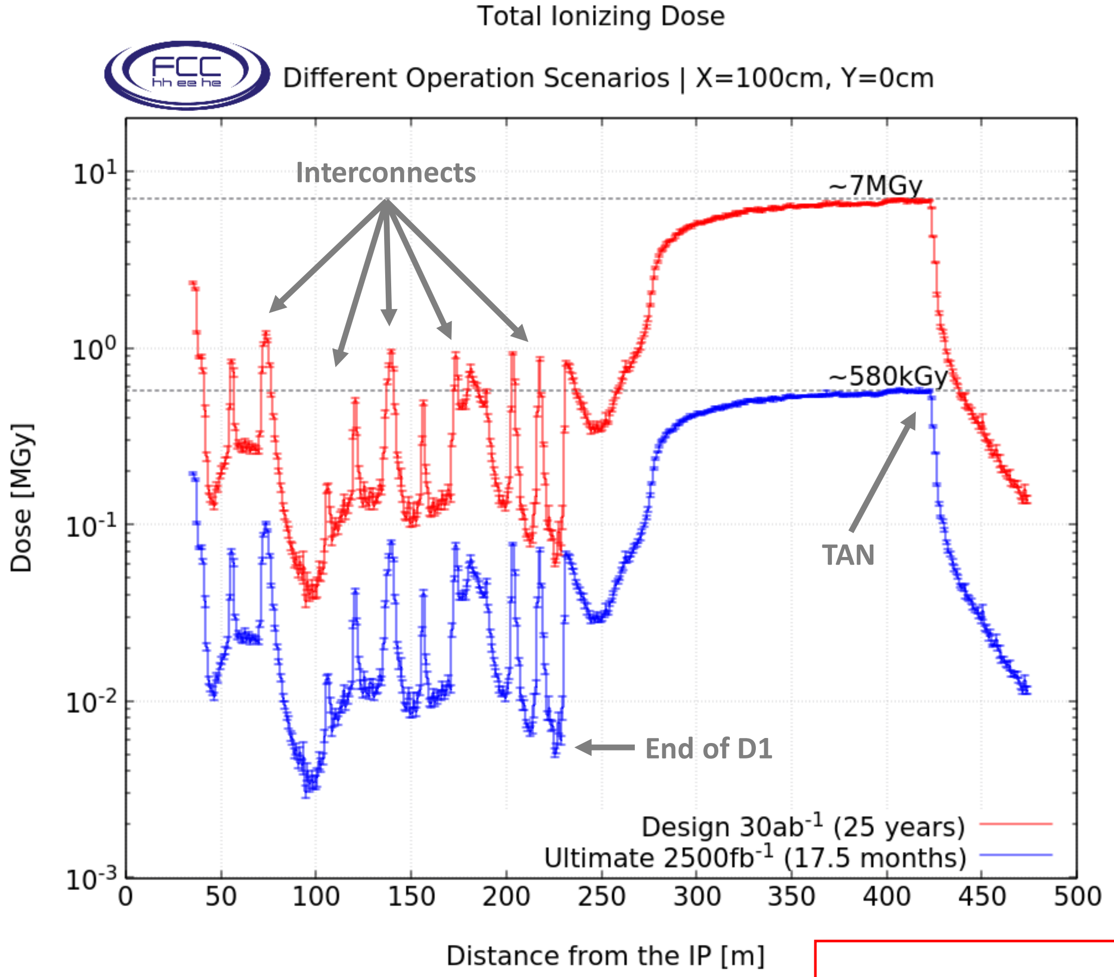


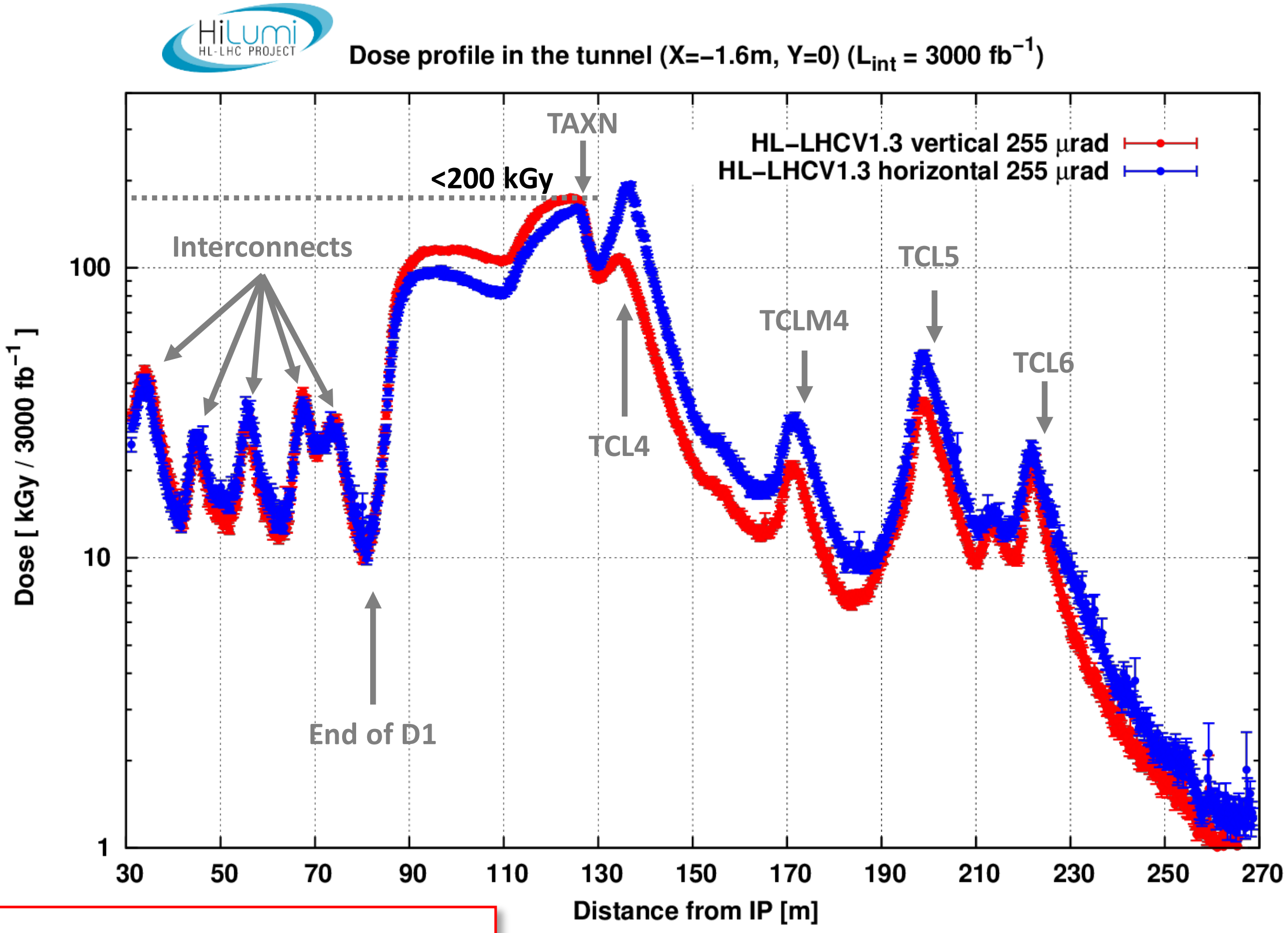
Normalization
HEH fluence: Normalized to ultimate conditions and worst case year ($2500fb^{-1}$/year)
DOSE/1MeV n_{eq} fluence: Normalized to ultimate conditions $L_{int}=30ab^{-1}$



Ref: A. Infantino et al. (FCC Week 2018)

FCChh: Experimental Insertion Region (2018)



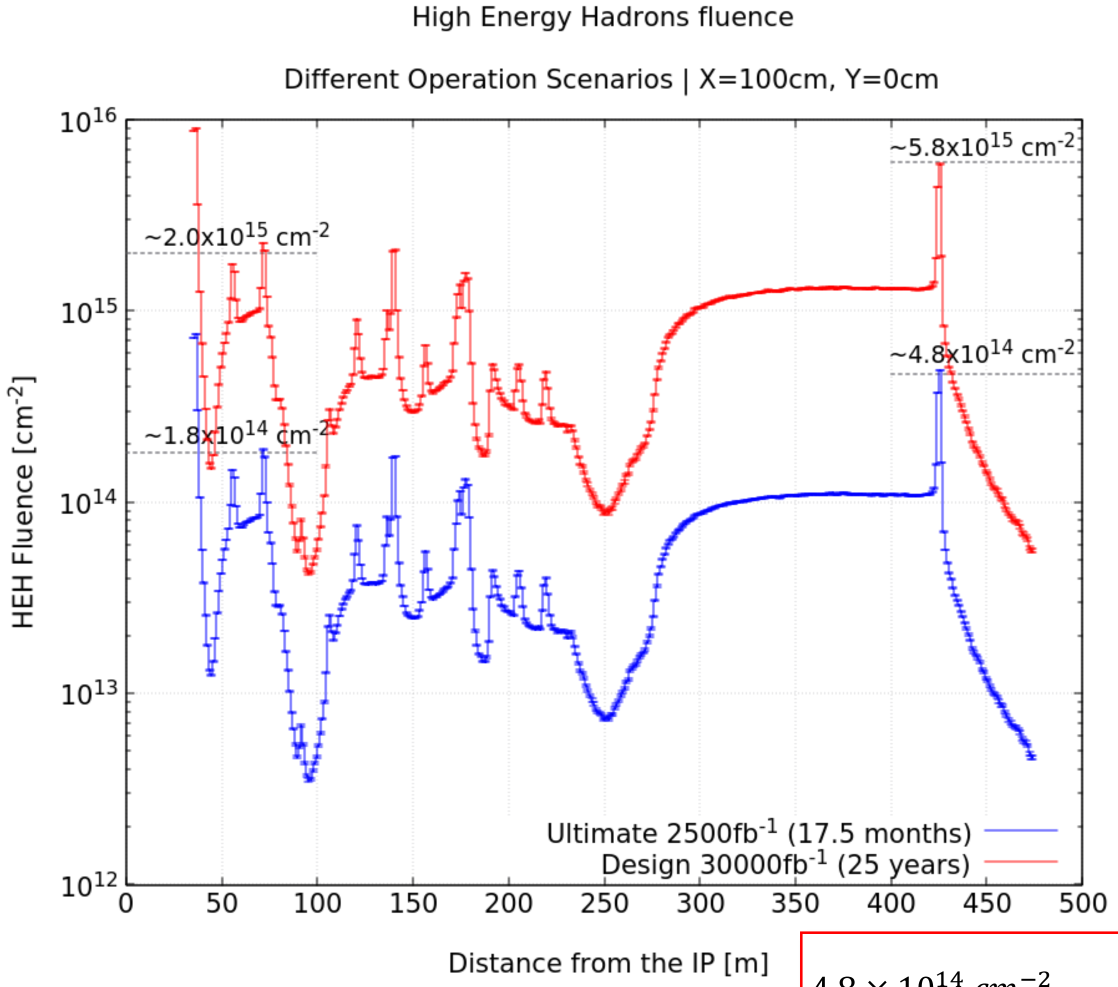


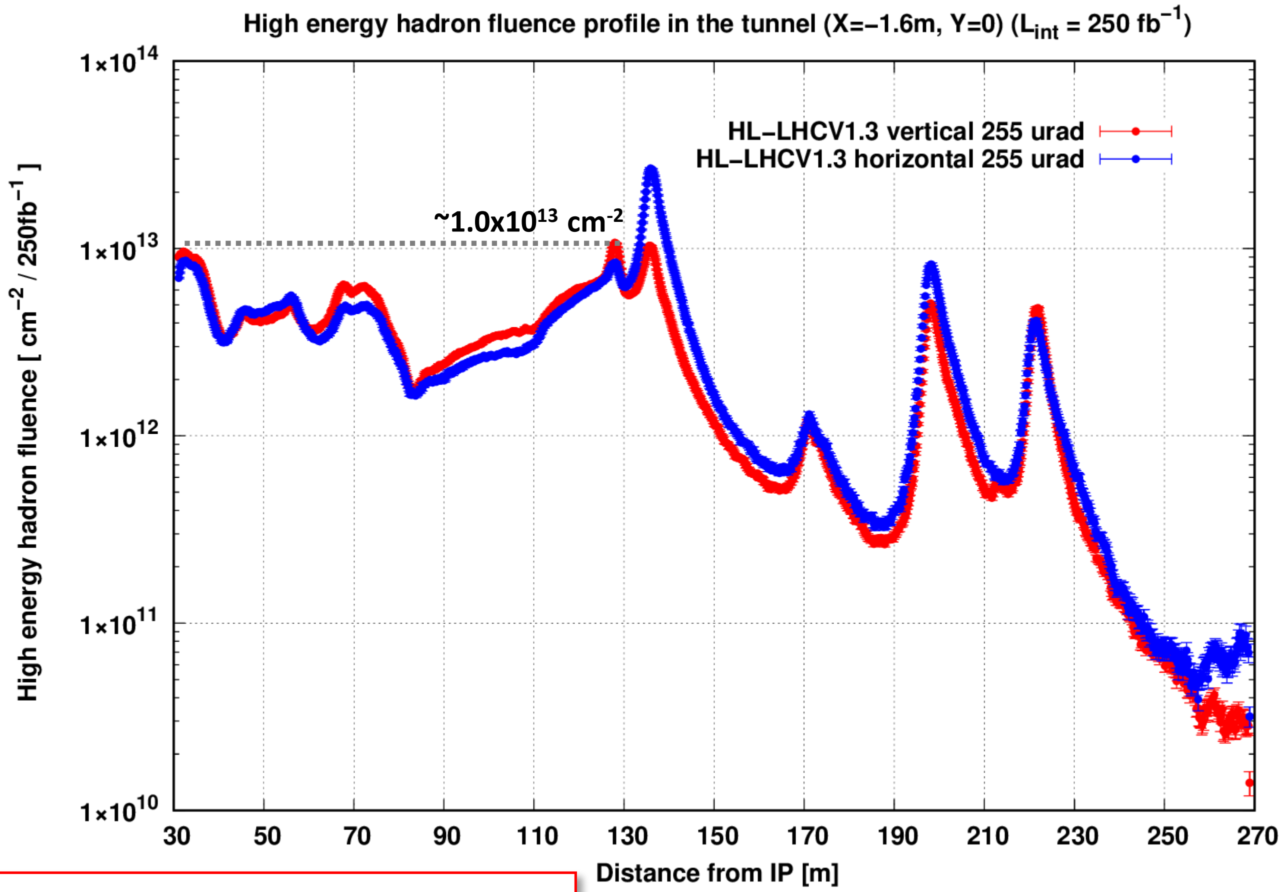
$$\frac{7000\ kGy}{200\ kGy} = 35 < \frac{30000 fb^{-1}}{3000 fb^{-1}} \times \left(\frac{50TeV}{7TeV}\right)^{m=0.8} \cong 48$$

Scaling: Exponent m=0.75-0.87
Ref: T.A. Gabriel et al., NIM A338 (1994) 336-347.

HL-LHC courtesy of Andrea Tsinganis (EN-STI-BMI)

FCChh: Experimental Insertion Region (2018)

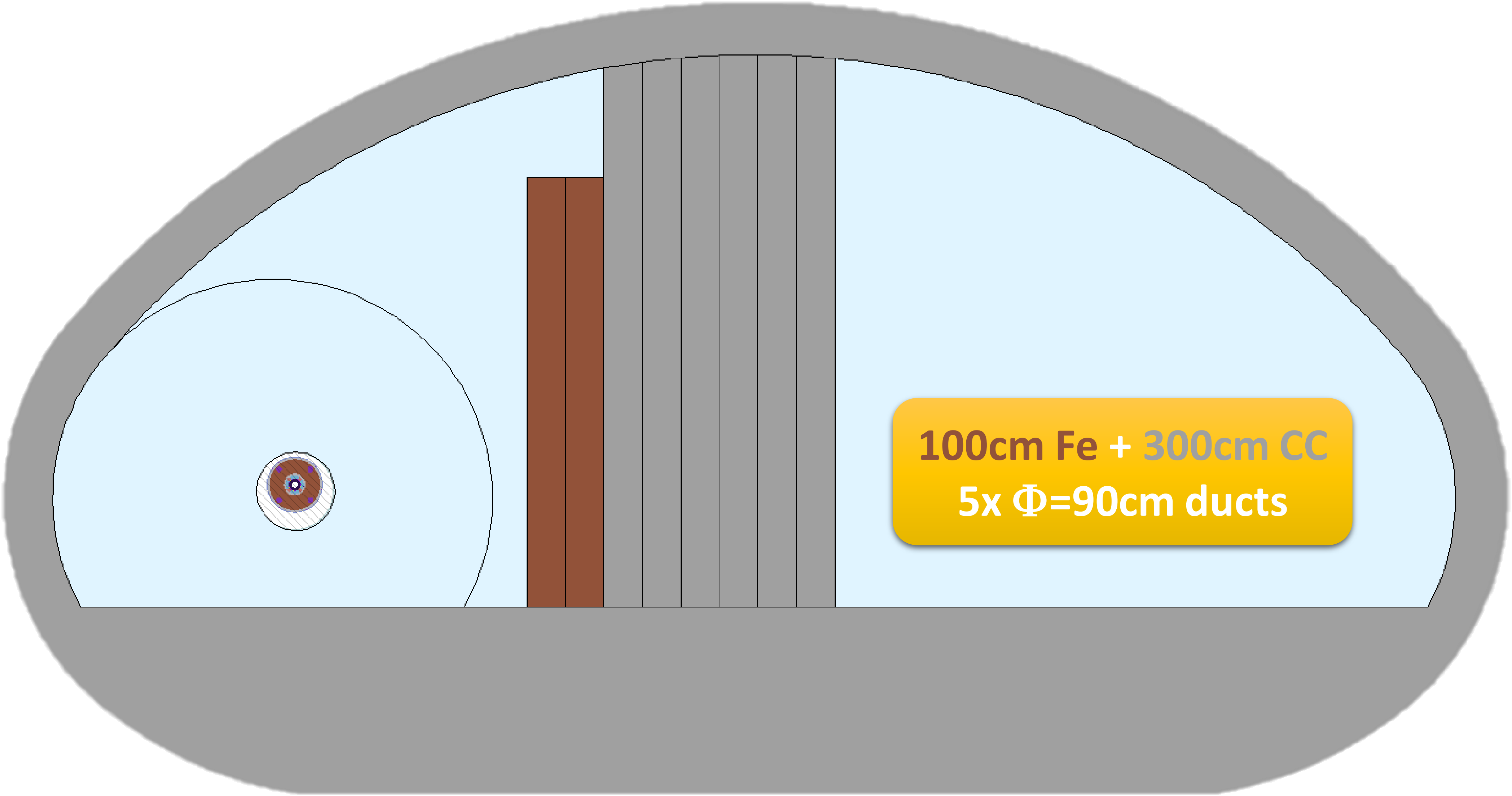




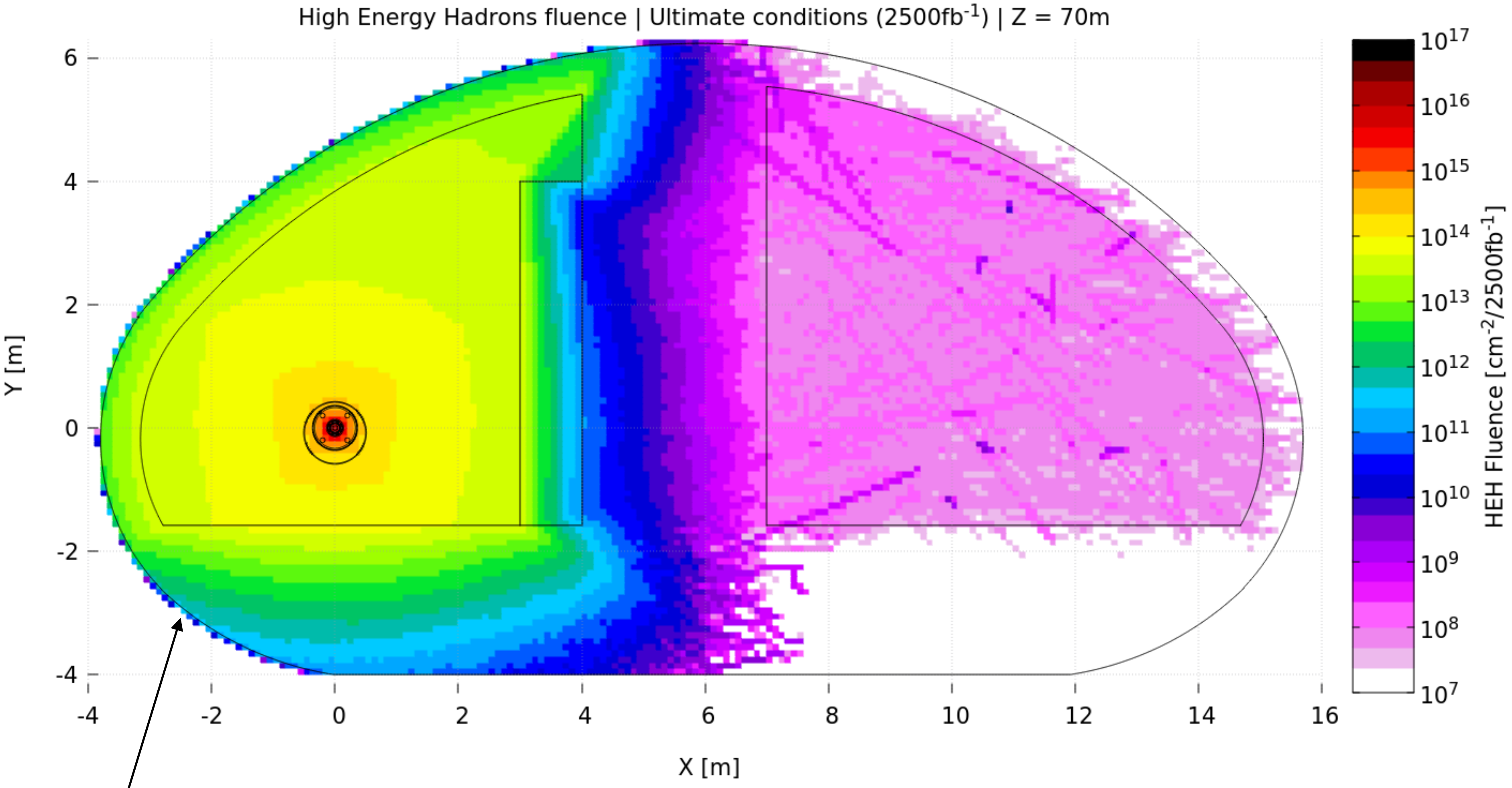
$$\frac{4.8\times10^{14}\ cm^{-2}}{1.0\times10^{13}\ cm^{-2}} = 48 \approx \frac{30000fb^{-1}}{3000fb^{-1}} \times \left(\frac{50TeV}{7TeV}\right)^{m=0.8} \cong 48$$

HL-LHC courtesy of Andrea Tsinganis (EN-STI-BMI)

FCChh: Experimental Insertion Region (2018)

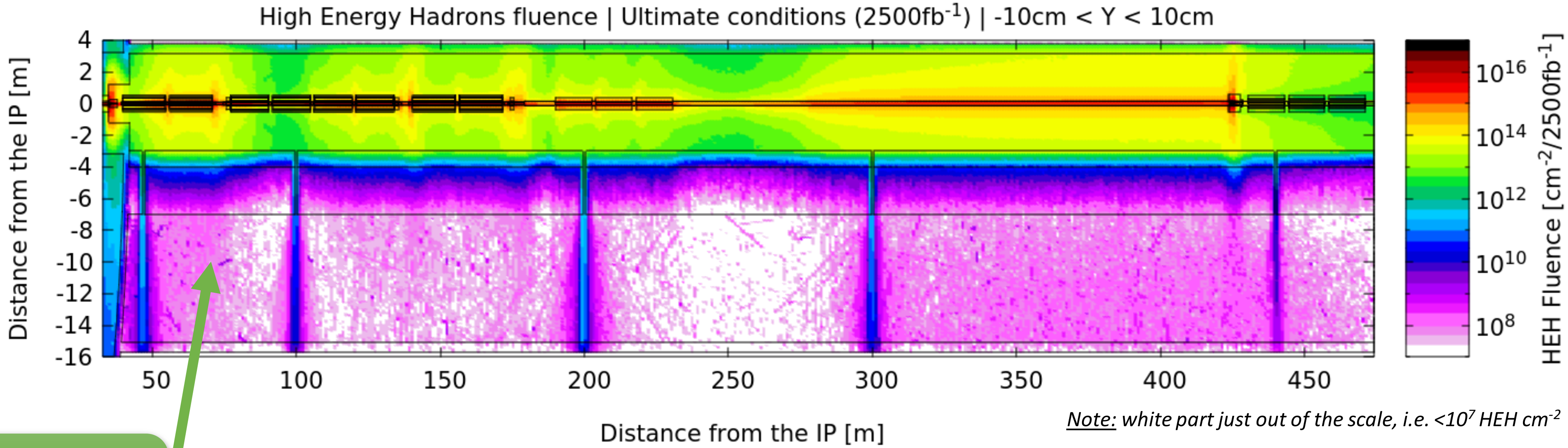


FCChh: Experimental Insertion Region (2018)



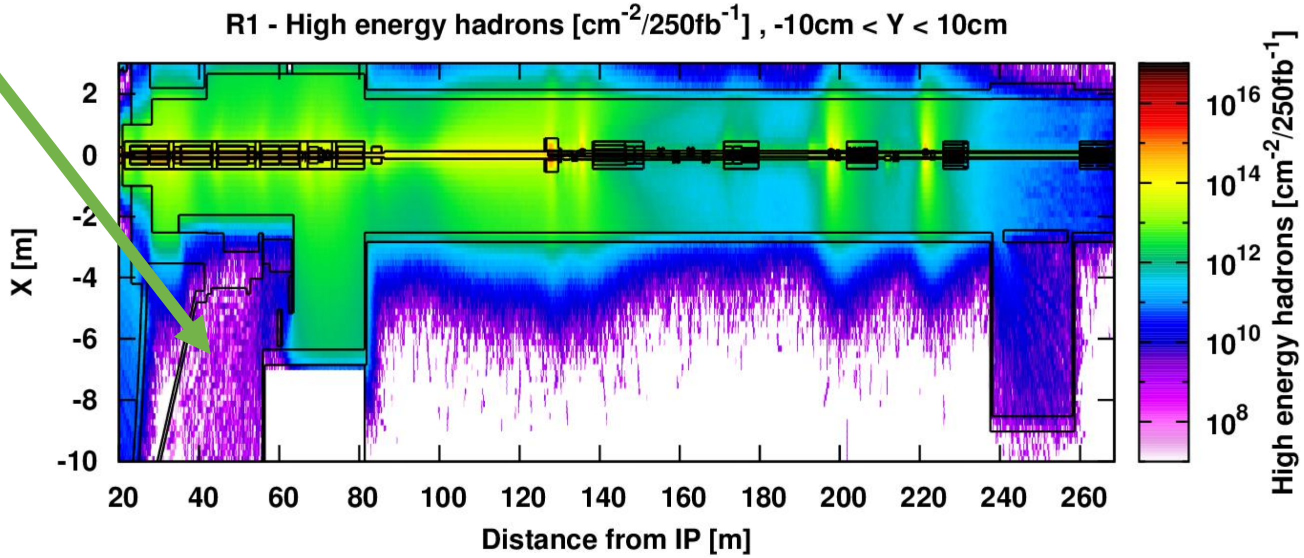
Note: Artefact to speed-up the simulation!

FCChh: Experimental Insertion Region (2018)



Note: white part just out of the scale, i.e. $<10^7$ *HEH* cm^{-2}

~10^8-10^9 cm^{-2} -> same as HL-LHC!!!



Disclosure:

This is an ***extreme case*** *to show how it could be possible to reuse the space available in the tunnel!*

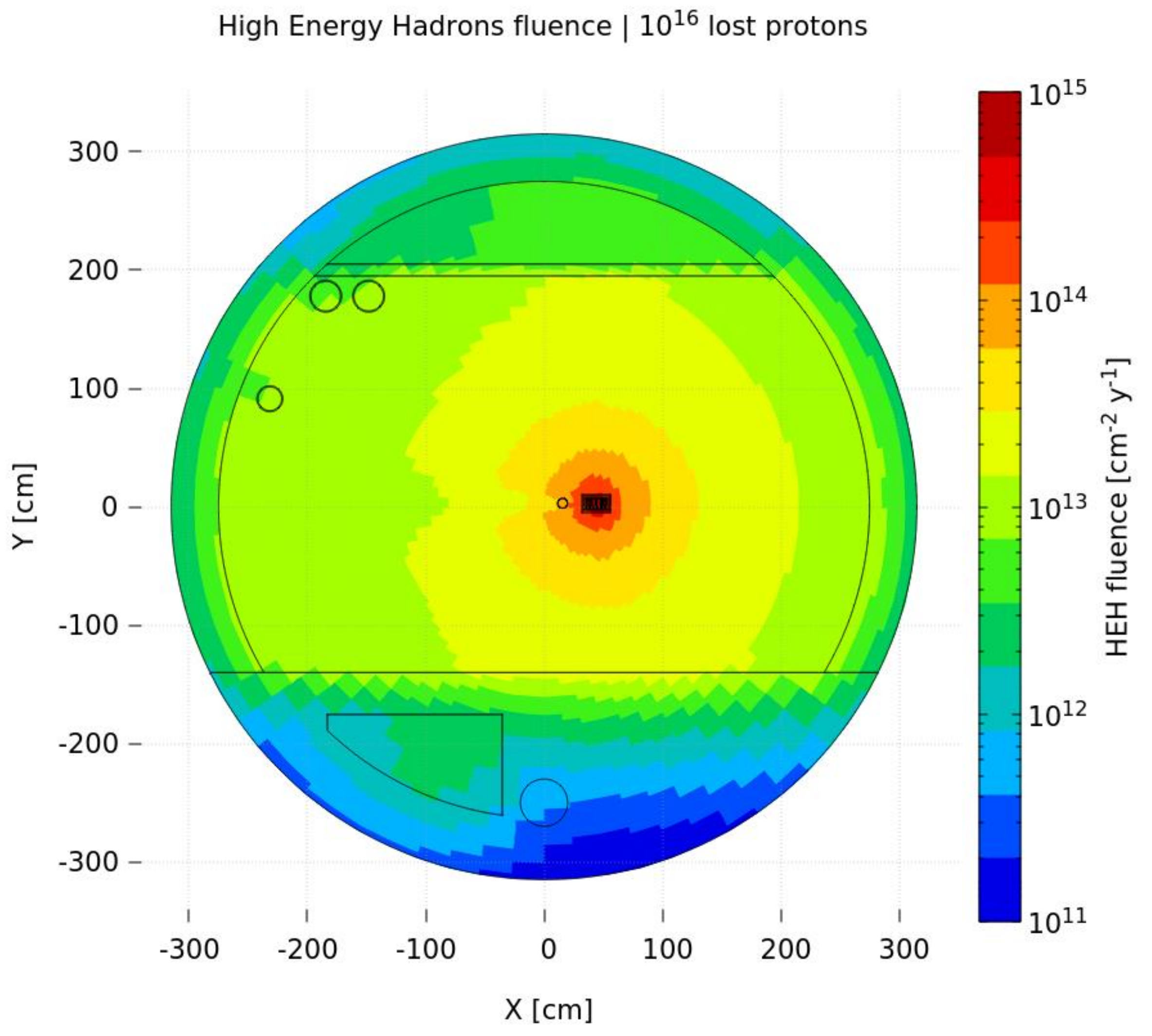
A ***real optimized engineering solution*** *must be discussed in the IOWG and iterate with different groups (CE, RP, CV, EL, ….).*

A factor ***10-100x*** *HL-LHC UJ can be expected* ***in real life****.*

HL-LHC courtesy of Andrea Tsinganis (EN-STI-BMI)
Ref: CERN-2017-007-M, p.278-279

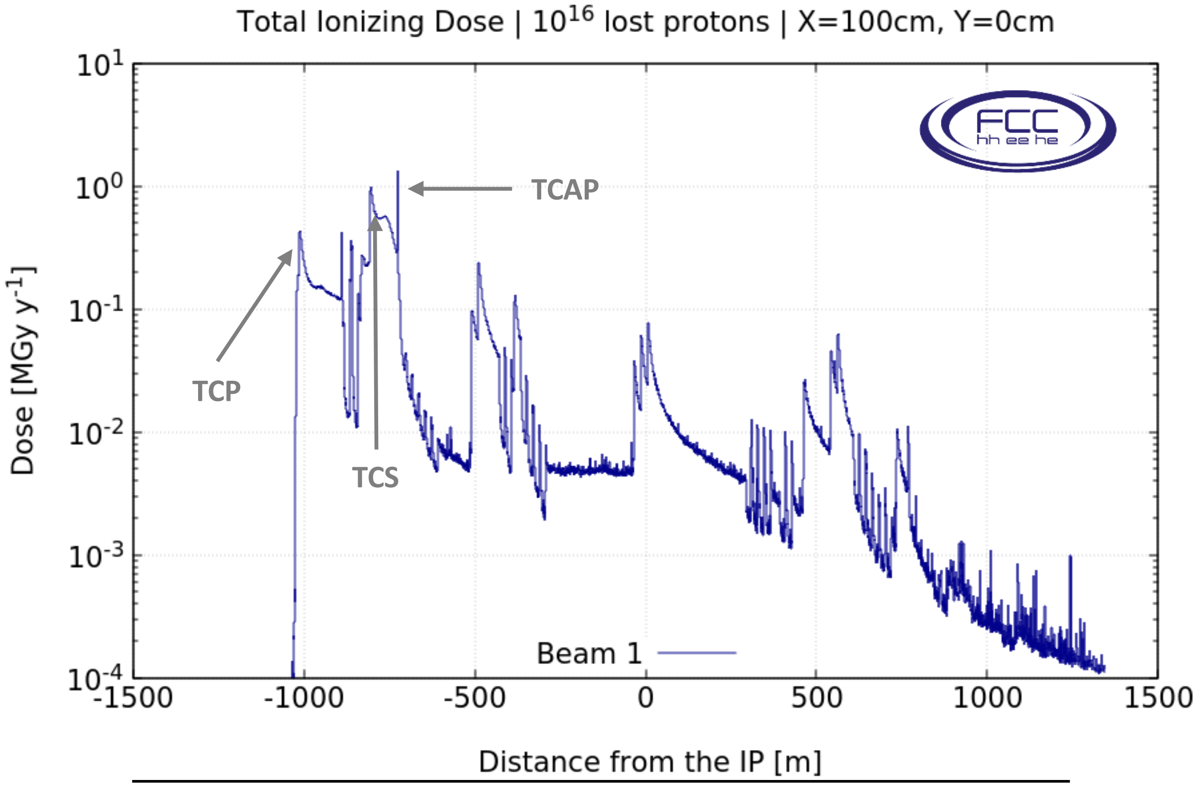
FCChh: BETATRON CLEANING (IP J)

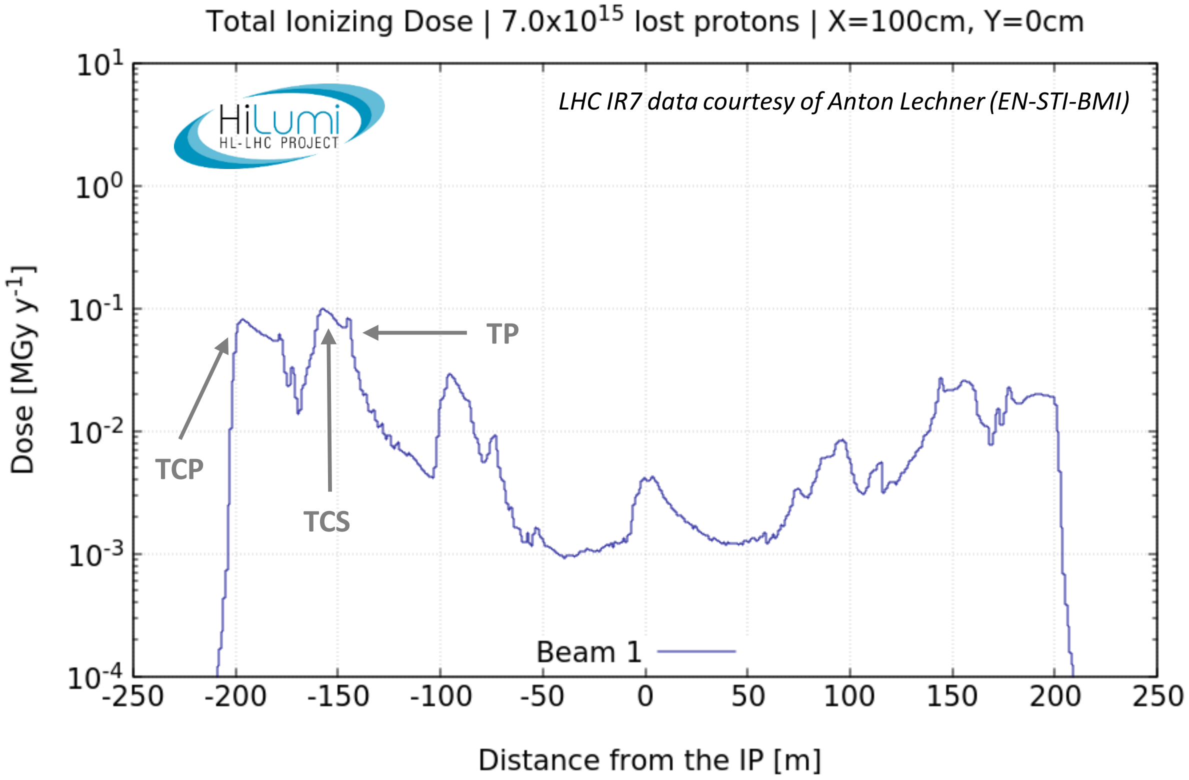
FCChh: Betatron cleaning insertion (2018)



Note: 2D map refers to Beam 1 only at the level of the second TCP

FCChh: Betatron cleaning insertion (2018)





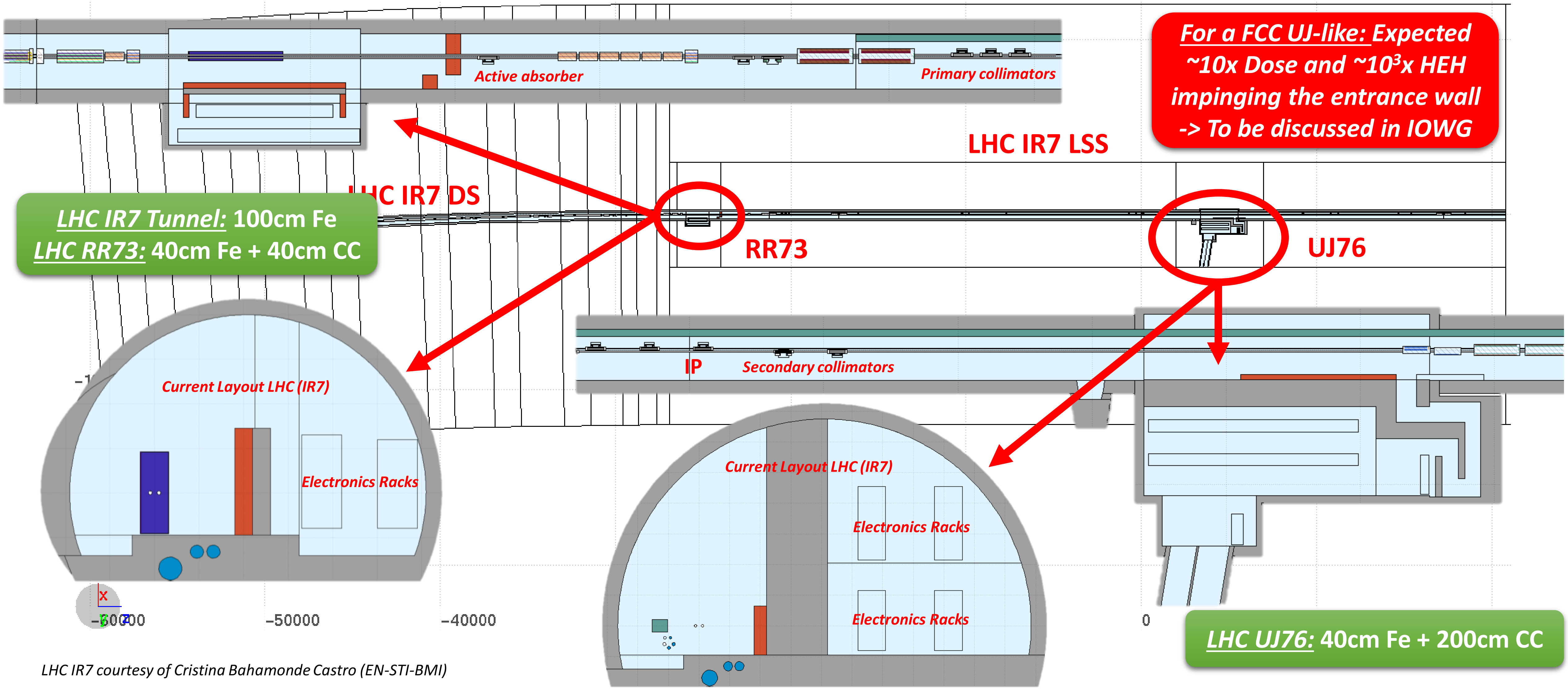
	FCC		HL-LHC		FCC/HL
TC(X)	***|Z|*[m]***	***D[kGy]***	***|Z|*[m]***	***D[kGy]***	
TCP	1010	430	200	80	**5.4**
TCS	810	980	160	100	**9.8**
TCAP	725	1330	145	80	**16.6**

*__Note:__ numbers rounded for presentation purposes; *absolute distance from the IP*

A few considerations…

- **HL-LHC:** *7x10^{15} lost p/year/beam* based on intensity scaling
- **FCC:**
  - Assumption of *10^{16} lost p/year/beam*: beam intensity difference FCC/HL < 2
  - *Shift of the peak dose* w.r.t. HL-LHC: *Skew TPC removed*, *TCP jaws shorten* (60->30cm) and *thicken* (2.5->3.5cm), *TCS thicken*

FCChh: Betatron cleaning insertion (2018)



LHC IR7 courtesy of Cristina Bahamonde Castro (EN-STI-BMI)

FCChh: Summary

What we have:

✓ Excellent coverage of the machine with *several IPs already studied*:
- *High-luminosity experiments* (IP A and G): detector + insertion region
- *Arc*: FLUKA-R2E studies crucial in the design & optimization of safe-areas for electronics
- *Betatron cleaning* (IP J): Overview of the radiation levels

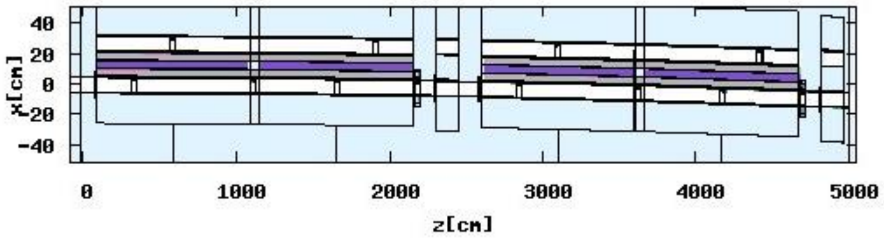
What we need:

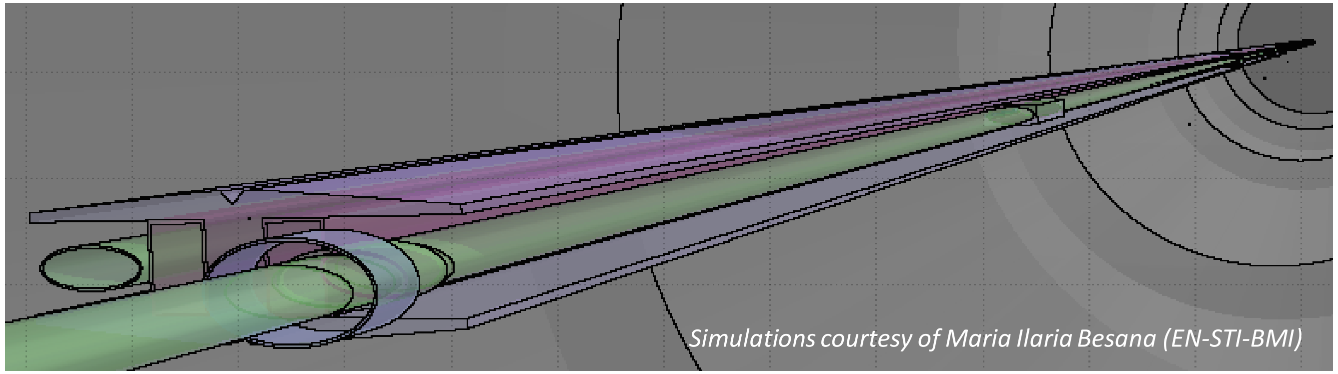
- ❑ *Detector*: new iterations planned for post-CDR
- ❑ EIR: Need for a suitable solution for *safe-areas for electronics* (UJ/RR-like? embedded alcove? Junction tunnel?)
- ❑ Betatron cleaning:
  - iterate in the IOWG for a *dedicated infrastructure* design which fits R2E-needs
  - *DS*: typically of interest for R2E
- ❑ *Dump* (IP D): dedicated studies are necessary, but information needed for R2E-studies are still partially available
- ❑ *Injection*: no specific requests at moment

FCCee: ARC

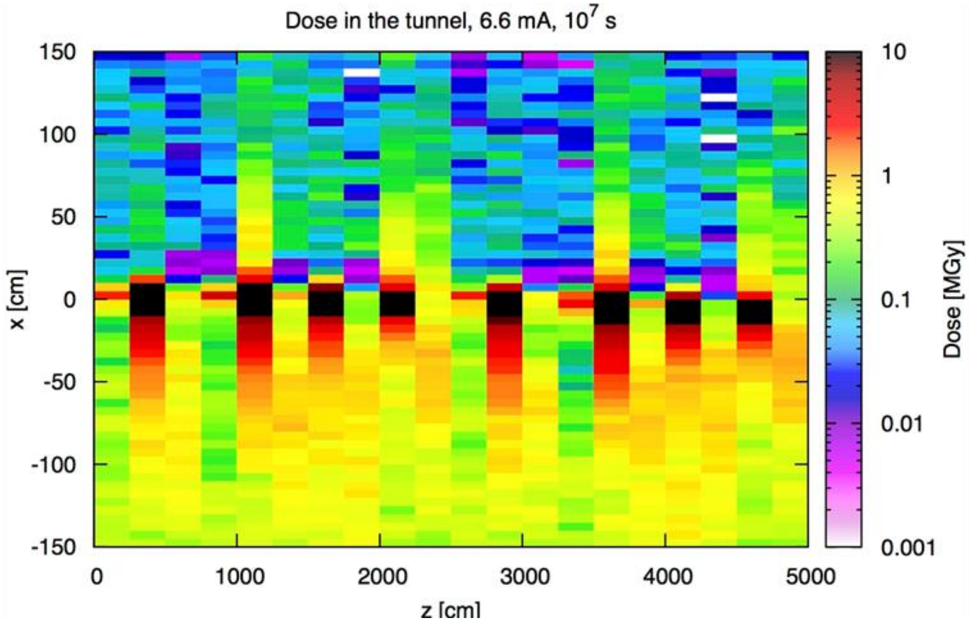
FCCee: Arc (FCC Week 2016)

Cell top view:

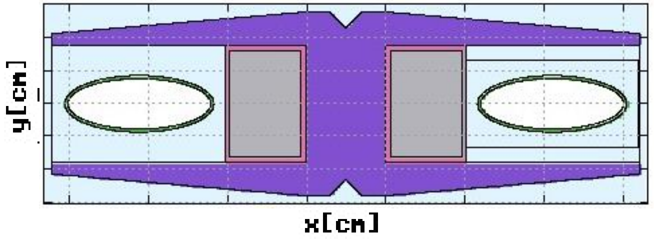




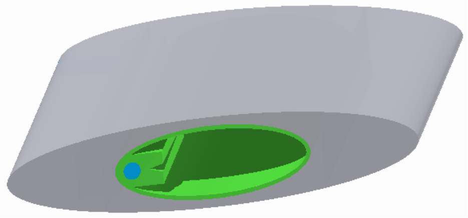
Top view: -5cm < y < 5cm



Dipole:



Absorber:



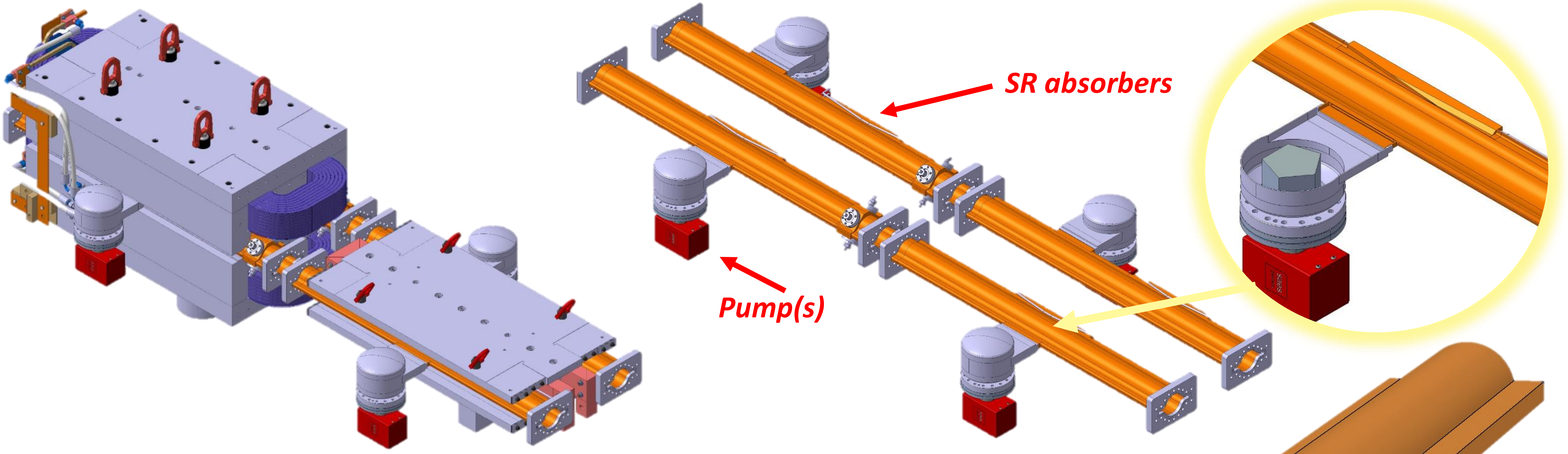
- ✓ Dose in the tunnel up to ~1-2 MGy (difference between internal/external beam due to absorbers)

Note on FCCee Experiments (IP A and G):

e^-e^+ event generator currently not implemented in FLUKA

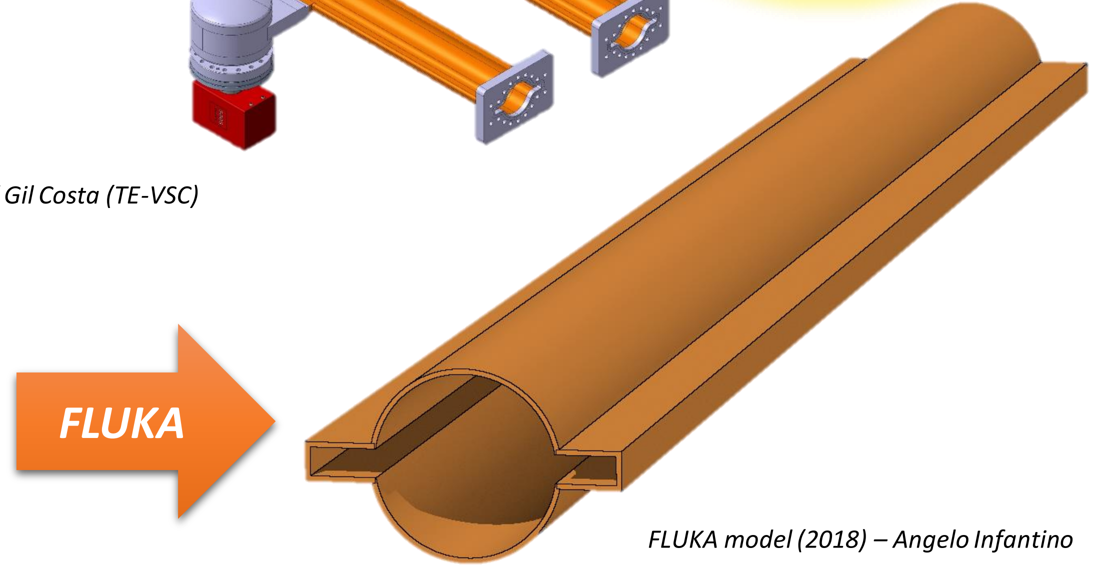
-> possible 2-steps simulation with an external e^-e^+ event generator

FCCee: Arc – Update of the model (2018)



Courtesy of Roberto Kersevan & Miguel Gil Costa (TE-VSC)

- Vacuum chamber cross section: 70 mm ID with ”winglets” in the plane of the orbit (SUPERKEKB-like)
- More information on the vacuum system in R. Kersevan at FCC Week 2018
- Missing inputs/data necessary to perform FLUKA simulations!



FLUKA model (2018) – Angelo Infantino

FCCee: Summary

What we have:

- ✓ First estimate (2016) of the radiation levels in the arc close to magnet

What we need:

- ❑ A *major revision/update* of the FCCee FLUKA model is *currently ongoing* in order to take into account:
  - Up-to-date lattice in the arc (usable twiss?)
  - Up-to-date design of magnets
  - Up-to-date vacuum chamber layout and absorbers
  - Up-to-date infrastructure (tunnel)
- ❑ With all the necessary inputs, an updated study might be performed for the second revision of the CDR
- ❑ *Event generator* for e^+/e^- collisions at IP -> to be interfaced

HE-LHC

HE-LHC

- *General lack* of results/available studies up to a few weeks ago
- *Already some requests* on the table of the FLUKA team but:
  - Simulations rely on inputs/data coming from different groups (optics, CE, vacuum, magnets, etc) -> *up to today, many information are missing*!
  - Need of resources in terms of *manpower* to cover all the requests (both R2E and non-R2E related studies)

What we have:

What we need:

- *ARC (Beam-gas interactions)*:
  - Already on the table of FLUKA team
  - Shopping list: Optics? Magnets? Vacuum?
  - Adapted tunnel layout available -> Radiation levels to be verified
- Other IR: EIR? Betatron cleaning? Dump?

Summary

Take-Home Message:

- ✓ *Consolidated* experience within the FLUKA team in R2E-related studies, particularly the evaluation of the *radiation levels* in critical areas for electronics -> e.g. *strong impact* in the design/optimization of *alcoves* in the FCChh arc
- ✓ *FLUKA* simulation allows for an *accurate modelling of the particle transport at (very) high energy* taking into account all the physics effects, the source term (*particle debris*, *direct losses*, *beam-gas interaction*, *synchrotron radiation*), beam optics and the actual geometry of the infrastructure
- ✓ Monte Carlo simulation is a very powerful tool but relies on the accurate description of the physics problem to be studied, i.e. *information from different groups are needed to perform accurate simulations!*
- ✓ *FCChh*:
  - Good coverage of the main critical areas for electronics
  - Radiation levels expected to be factors higher than HL-LHC -> dedicated alcoves for electronics and R2E-qualification strategies are needed
  - FLUKA simulation already used in the design/optimization of safe-areas for electronics
- ✓ *FCCee*: ongoing major update of the arc model -> simulations ready by II-review of the CDR (if all inputs acquired)
- ✓ *HE-LHC*: requests already on the table of the FLUKA tam but several information are missing to perform simulations
- ✓ A *considerable* amount of work has been done in these years within the FLUKA team and even more is expected in the short-mid term, i.e. *FLUKA modelling doesn't stop with the CDR -> manpower is needed to cover all these studies!*

Summary

LHC

Construction → Relocation & Shielding → Mitigation → Prevention

FCC hh ee he

Design → Prototype & QA → Construction → Physics www.cern.ch

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BACKUP SLIDES

www.cern.ch

List of related talks

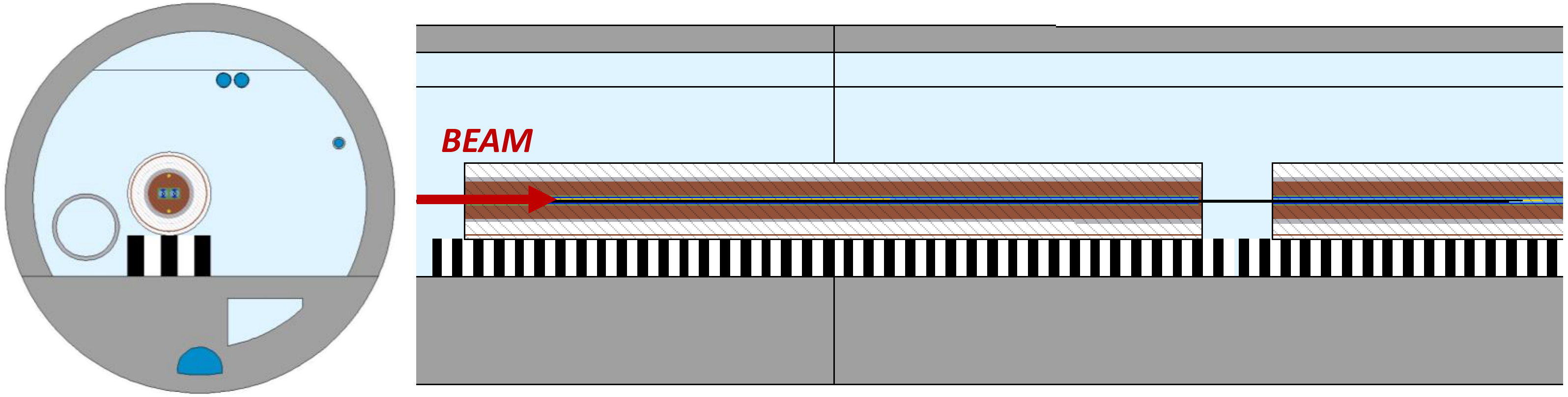
FCChh

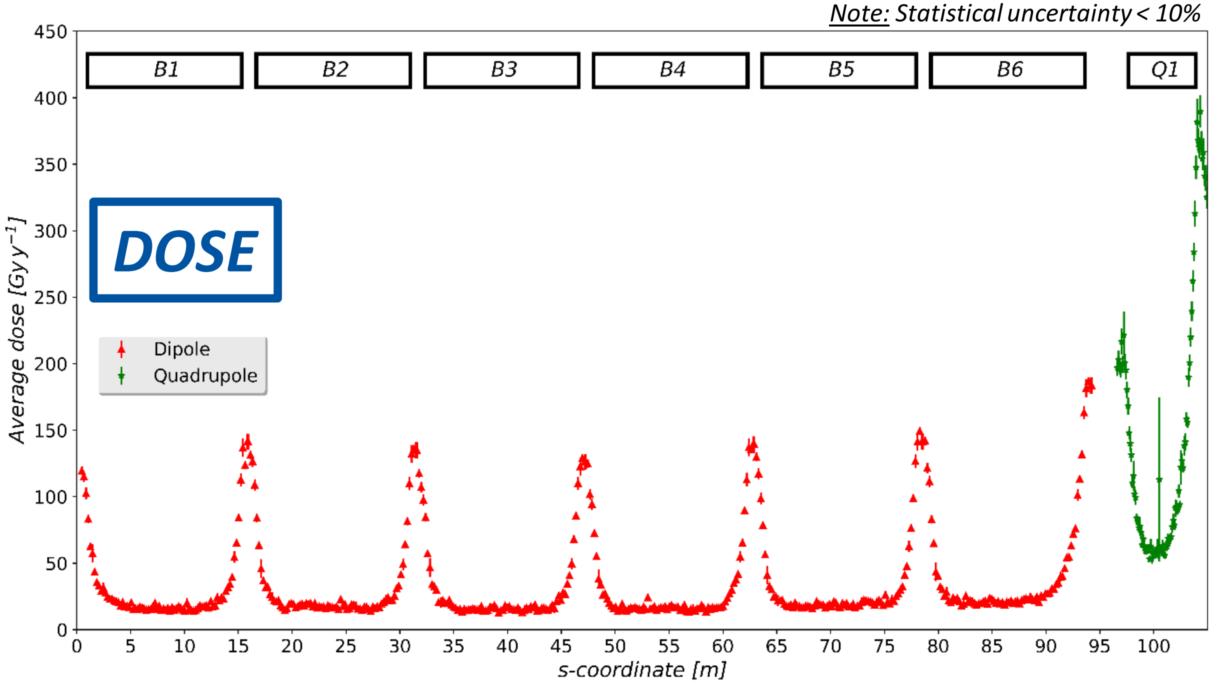
- R. Garcia Alia et al., *Radiation Hardness of Electronics in the FCC*. FCC Week 2016.
- A. Infantino et al., *FLUKA Monte Carlo modelling of the FCC arc cell: radiation environment and energy deposition due to beam-gas interaction*. FCC Week 2017.
- R. Garcia Alia et al., *Status overview of the radiation hardness assurance studies for FCC*. FCC Week 2017.
- M.I. Besana et al., *Radiation environment*. FCC Week 2017.
- M.I. Besana et al., *Update on Energy Deposition for L* 40 m*. WP3 meeting.
- A. Infantino et al., *Baseline EIR: Energy Deposition Studies for L* = 40m*. EuroCirCol Meeting.
- M.I. Besana et al., *Energy deposition studies: 30cm TCPs with thicker jaws and no skew*. FCC collimation design meeting #14
- J. Keintzel et al., *Updated picture of the collision debris impact on the FCChh triplet-D2 region*. FCChh General Design meeting
- A. Infantino et al., *Radiation environment assessment in the Experimental Insertion Region and Betatron Cleaning*. FCC Week 2018.
- M. Varasteh et al., *Energy Deposition in the FCC-hh Betatron Cleaning Insertion Region*. FCC Week 2018
- R. Garcia Alia et al., *Overview of radiation hardness assurance studies for FCC*. FCC Week 2018.

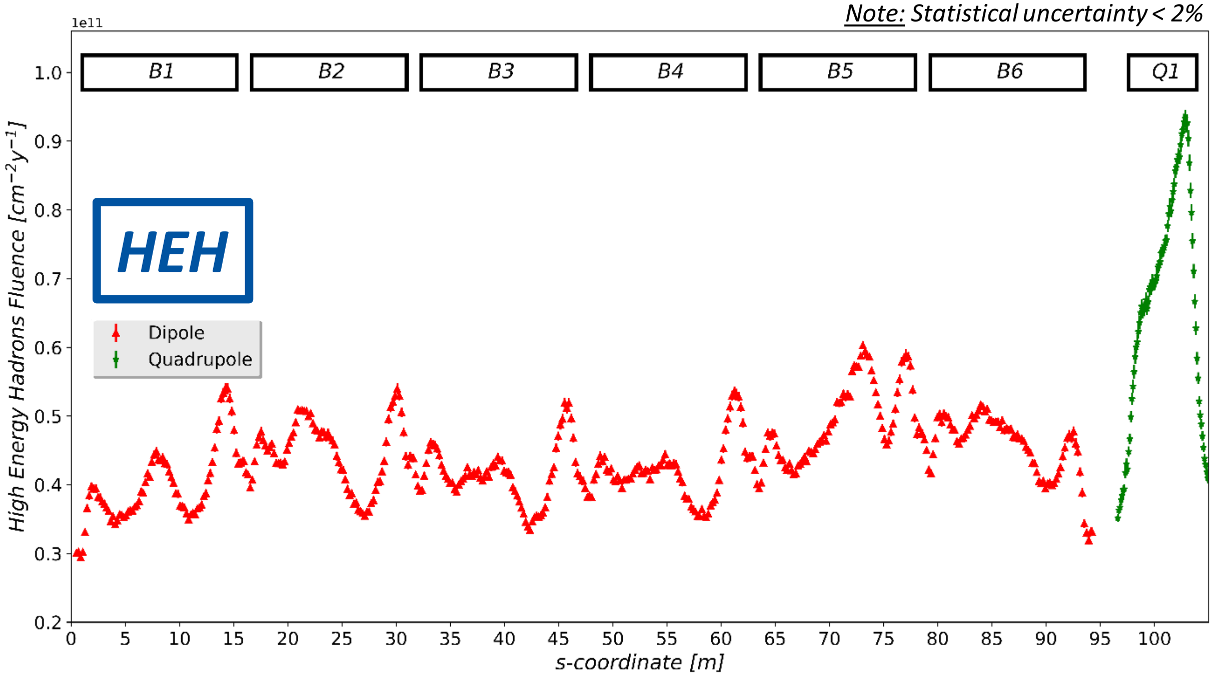
FCCee

- R. Kersevan et al., *FCC-ee Vacuum Effects and Simulations*. FCC Week 2016.

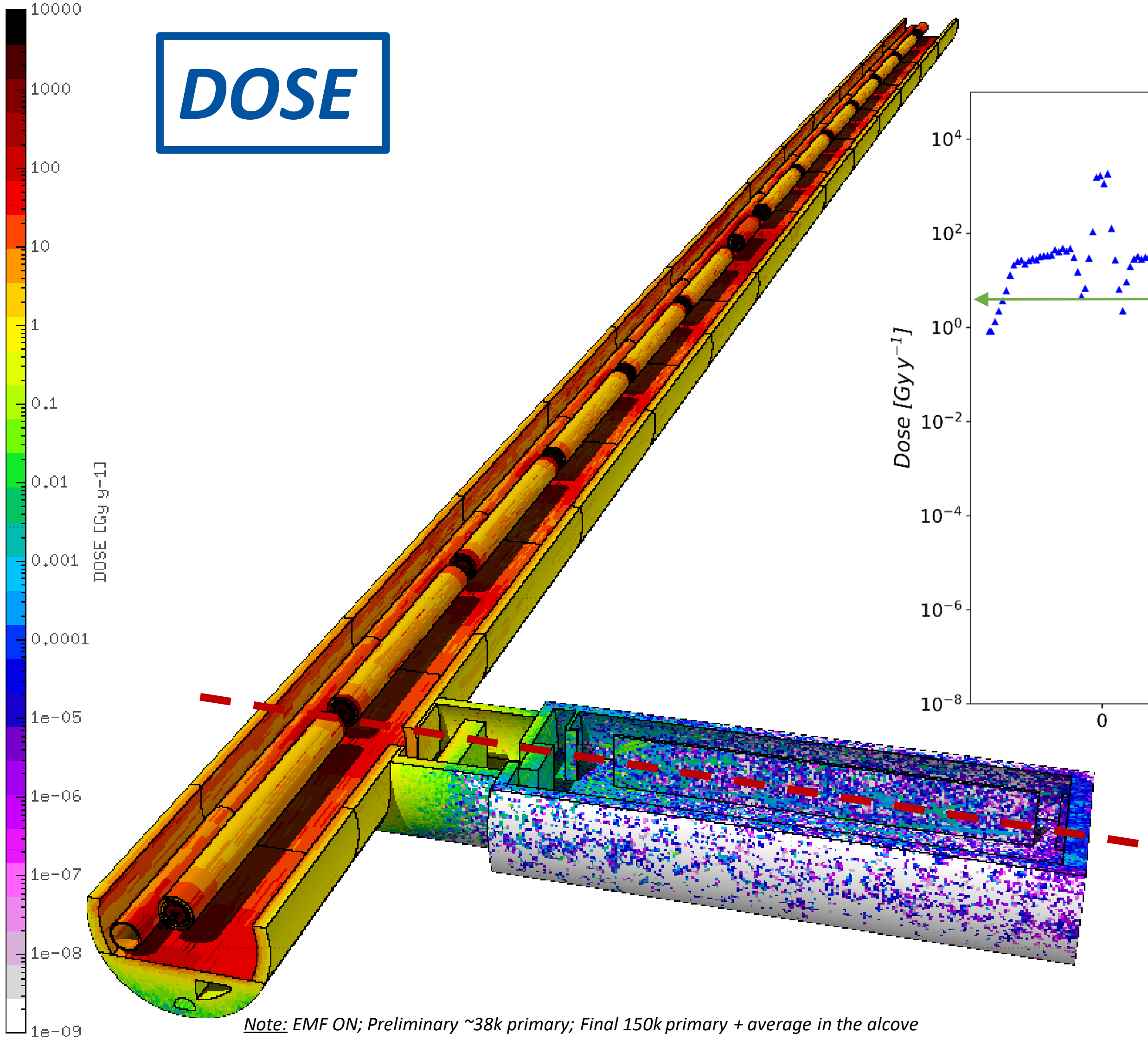
FCChh: ARC - Radiation Levels in the Tunnel



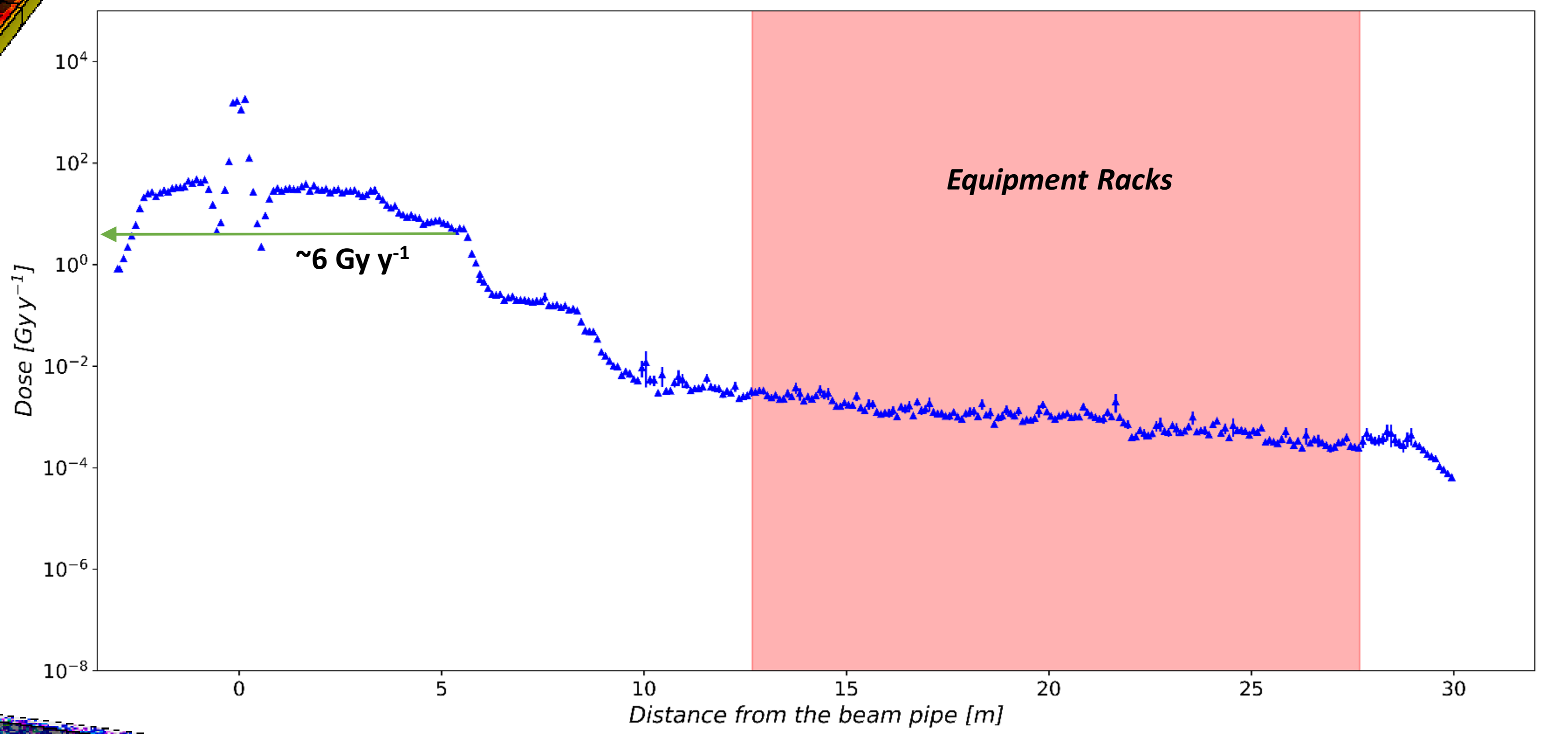




FCChh: ARC - Radiation Levels in the Alcove



Note: 10⁷ seconds in data taking

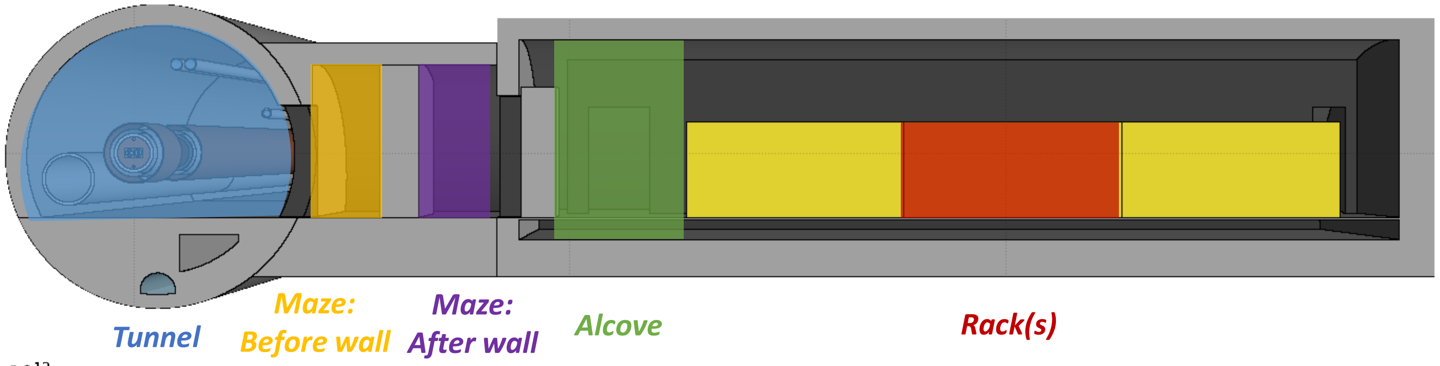


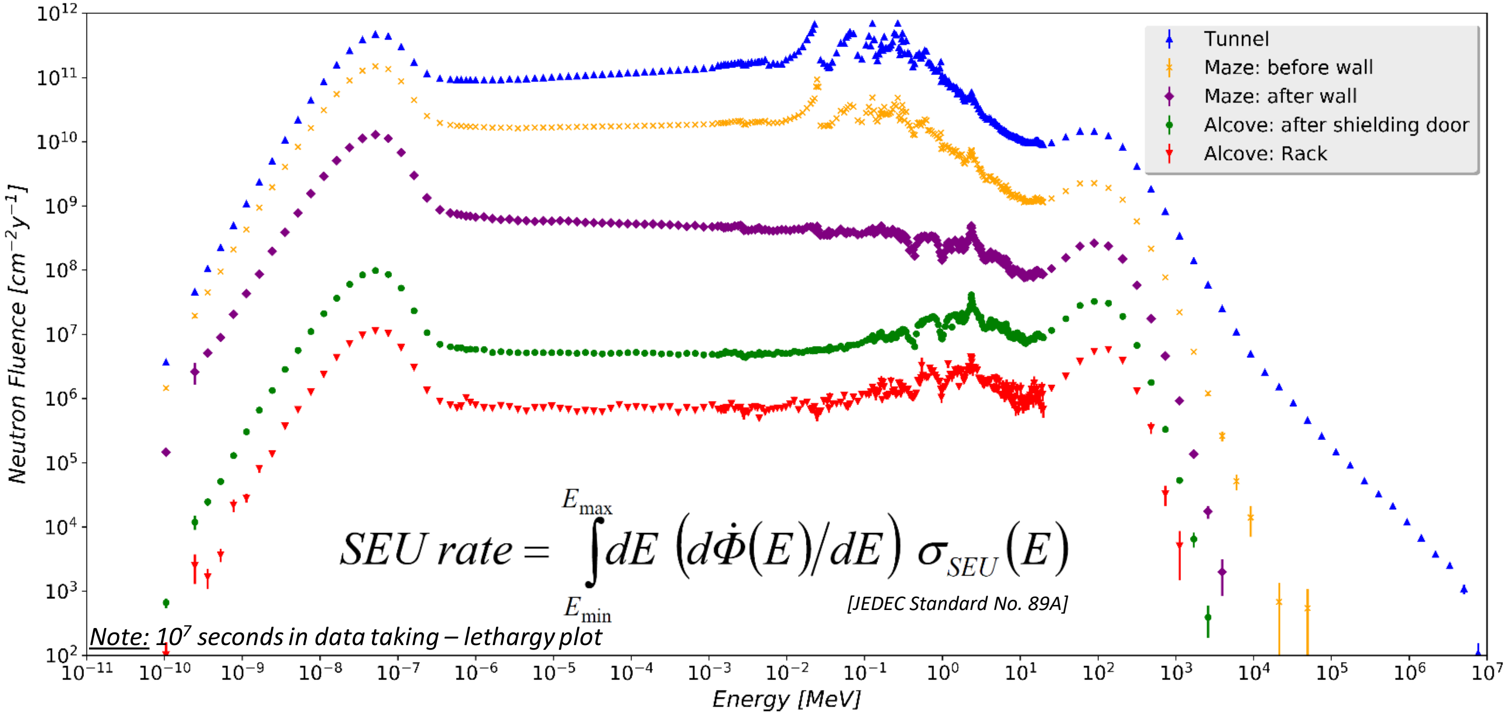
- ✓ *Convergence* of the simulation very slow compared with HEH -> *more efforts* were needed
- ✓ Dose at the *entrance of the maze ~3-6* LHC RE areas*

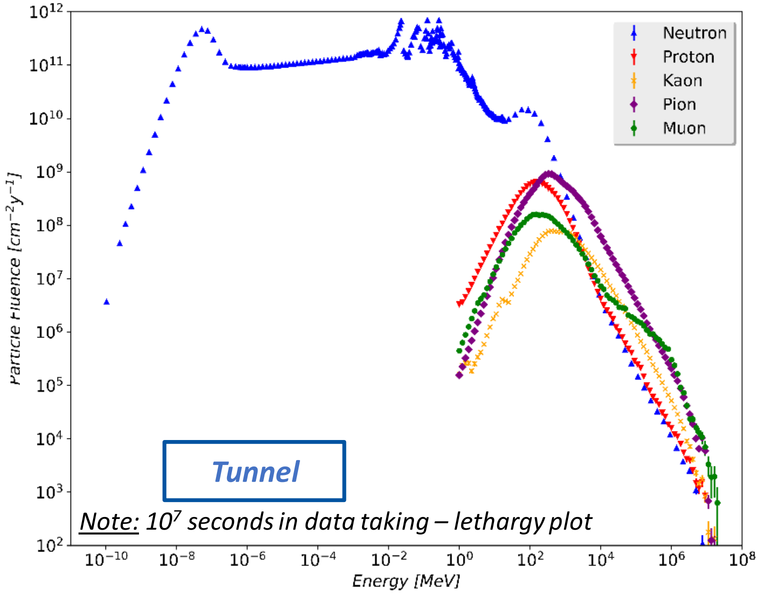
Note: EMF ON; Preliminary ~38k primary; Final 150k primary + average in the alcove

*See LHC Project note 363

FCChh: ARC/ALCOVE (FCC Week 2017)

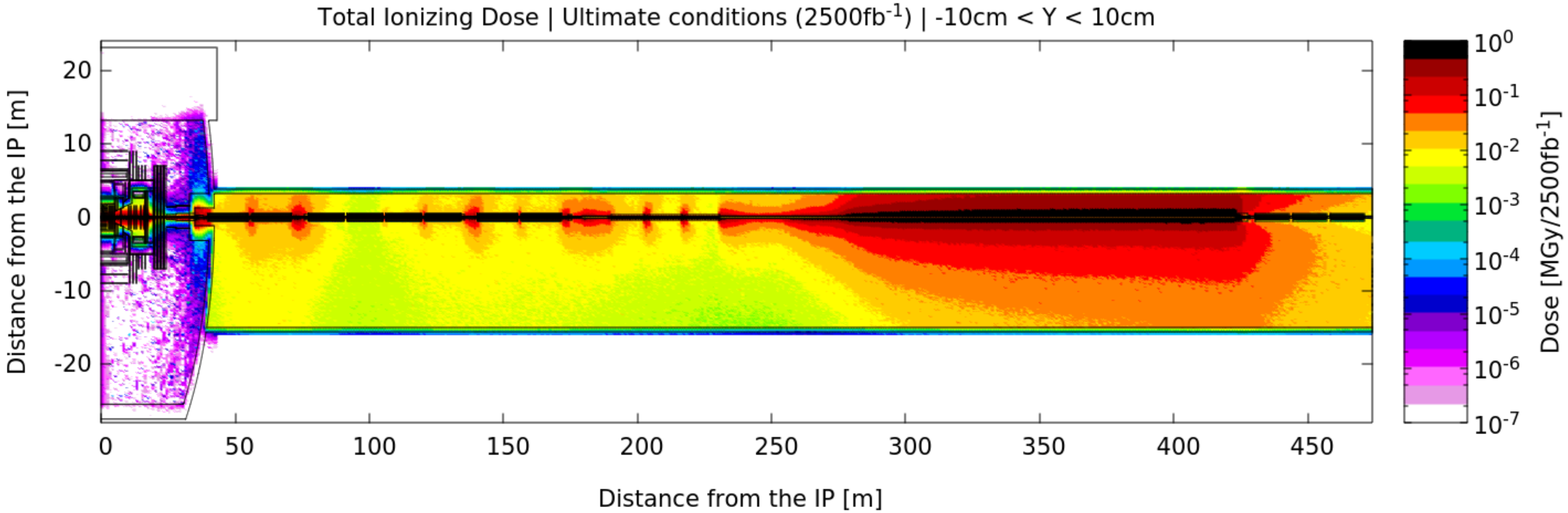


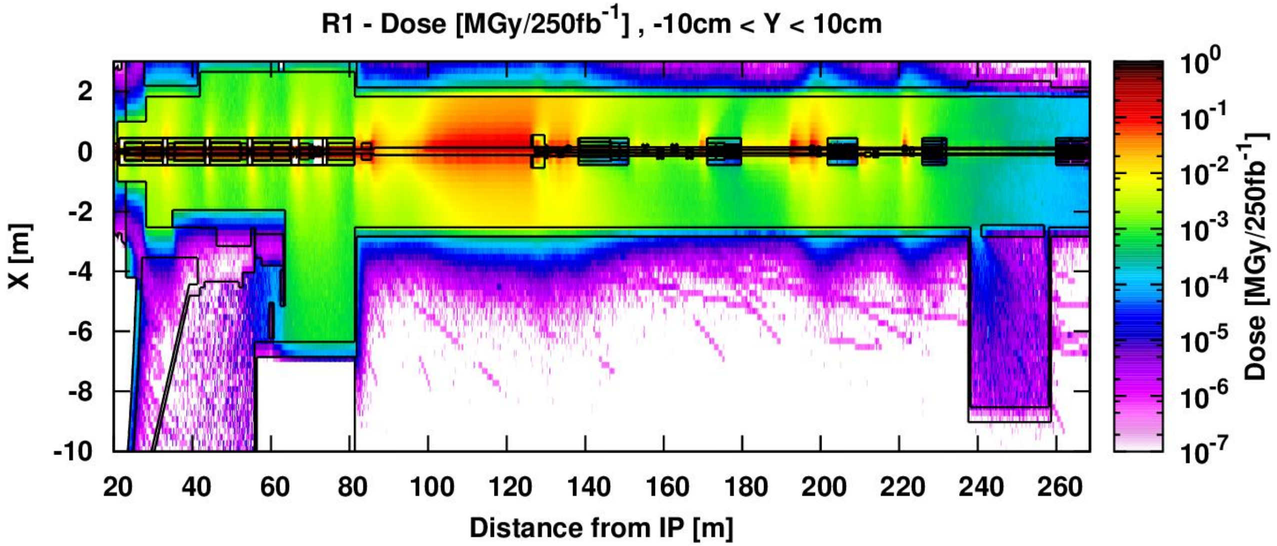




- ✓ *Differential particle distribution in energy* for SEE rate calculation
- ✓ *Unknown* SEE-cross section
- ✓ Tunnel: *HEH fluence* drives the SEE rate -> potential *direct ionization* from charged particle [A. Infantino et al., IEEE Transactions On Nuclear Science, 64(1), 2017]
- ✓ Alcove: particle environment *dominated by neutrons* -> *indirect ionization*

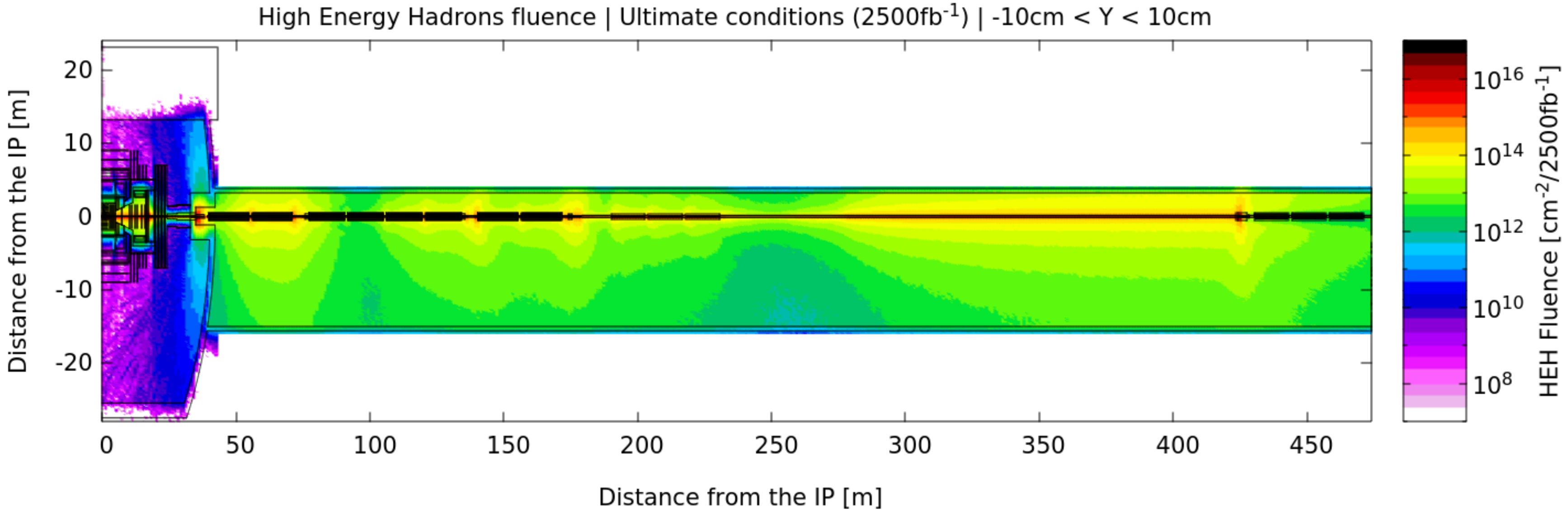
FCChh: EIR - Total Ionizing Dose

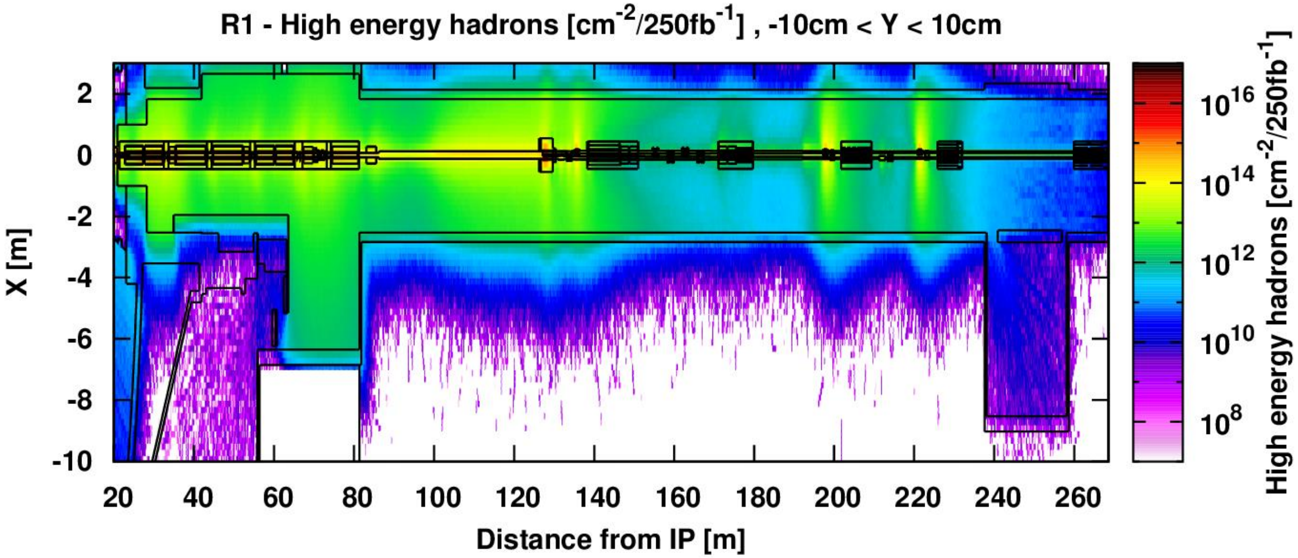




HL-LHC courtesy of Andrea Tsinganis (EN-STI-BMI)
Ref: CERN-2017-007-M, p.278-279

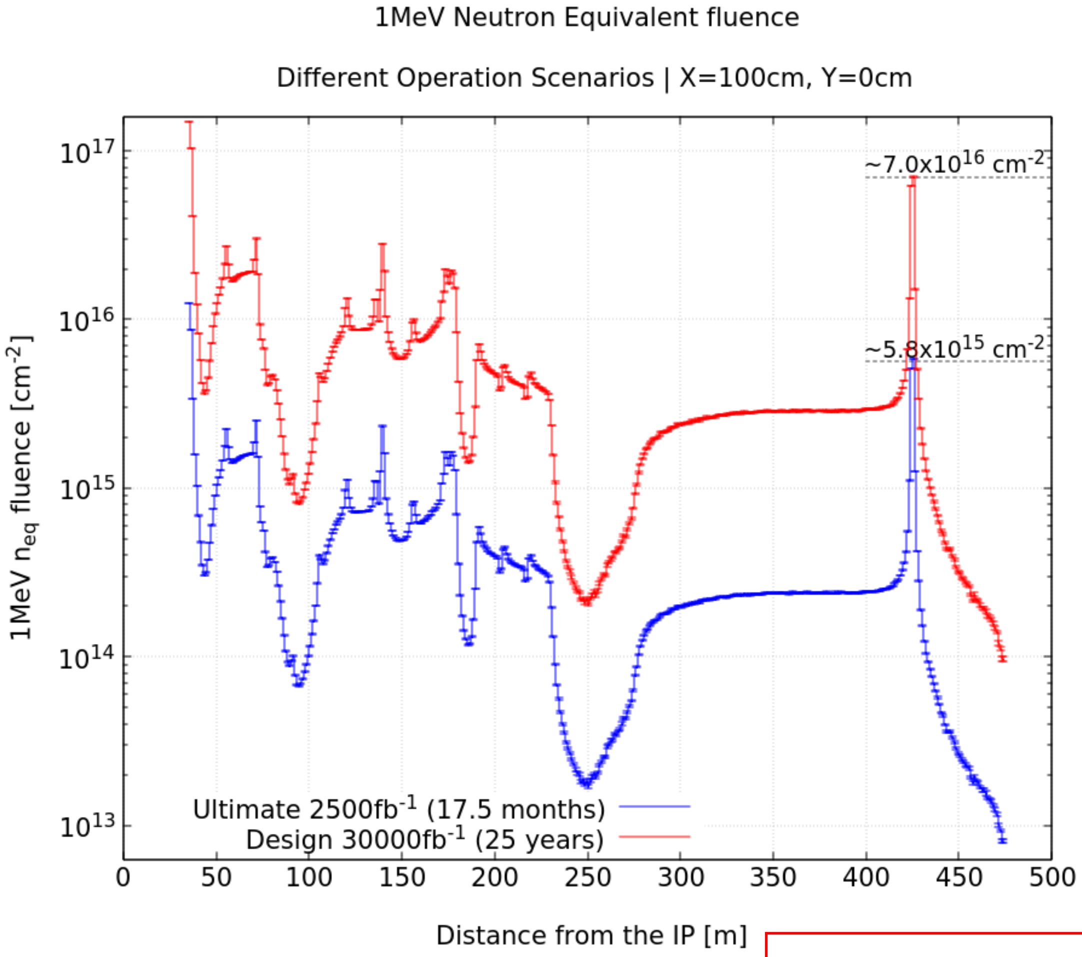
FCChh: EIR - High Energy Hadrons fluence

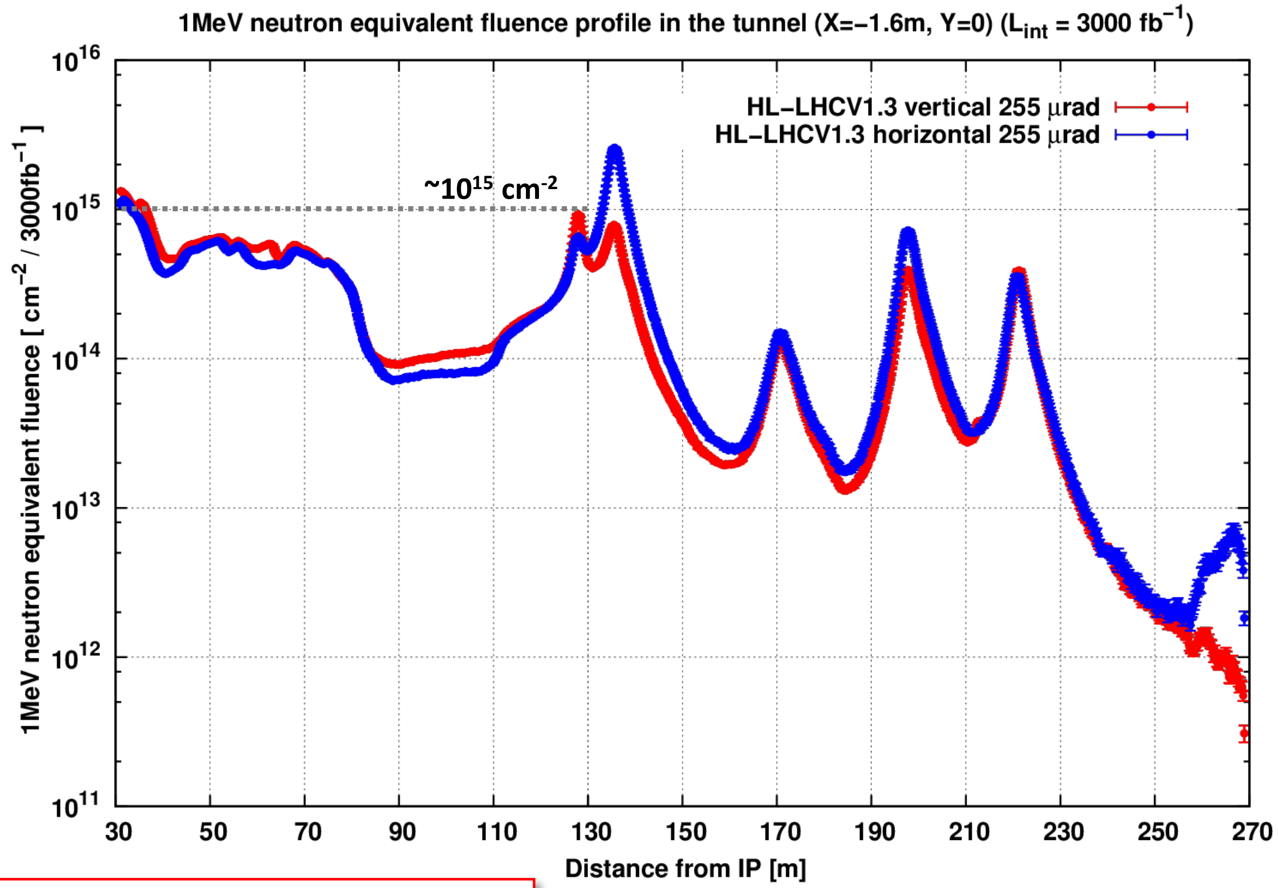




HL-LHC courtesy of Andrea Tsinganis (EN-STI-BMI)
Ref: CERN-2017-007-M, p.278-279

FCChh: EIR - 1MeV Neutron Equivalent fluence

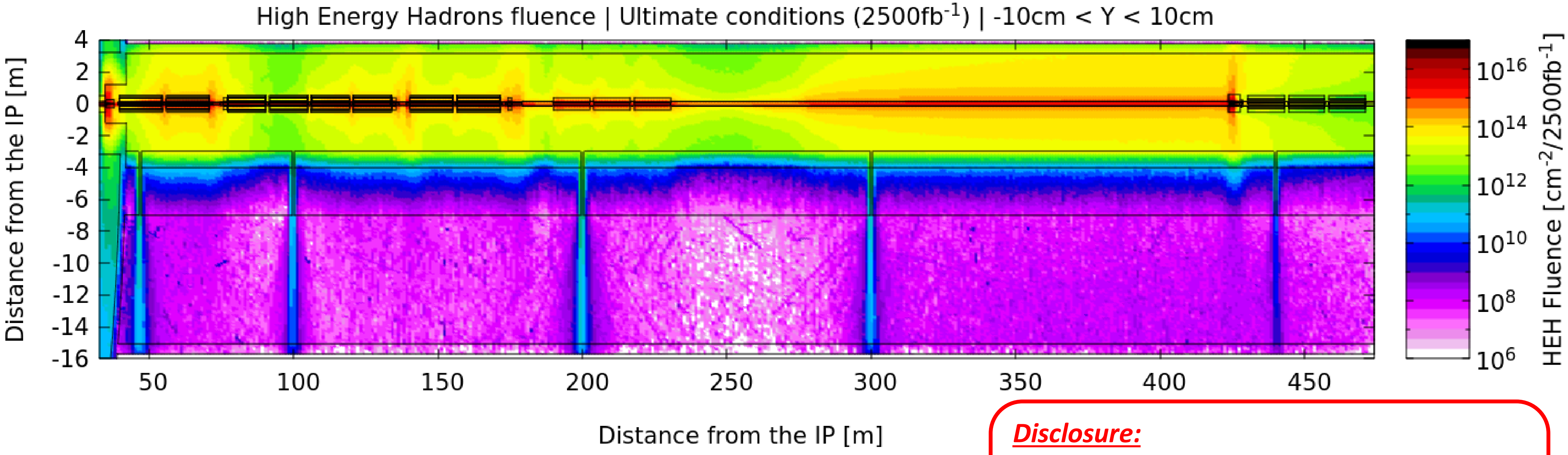




$$\frac{7\times10^{16}\ cm^{-2}}{1\times10^{15}\ cm^{-2}} = 70 > \frac{30000fb^{-1}}{3000fb^{-1}}\times\left(\frac{50TeV}{7TeV}\right)^{m=0.8} \cong 48$$

HL-LHC courtesy of Andrea Tsinganis (EN-STI-BMI)

FCChh: EIR - Tentative UJs/RRs alcove

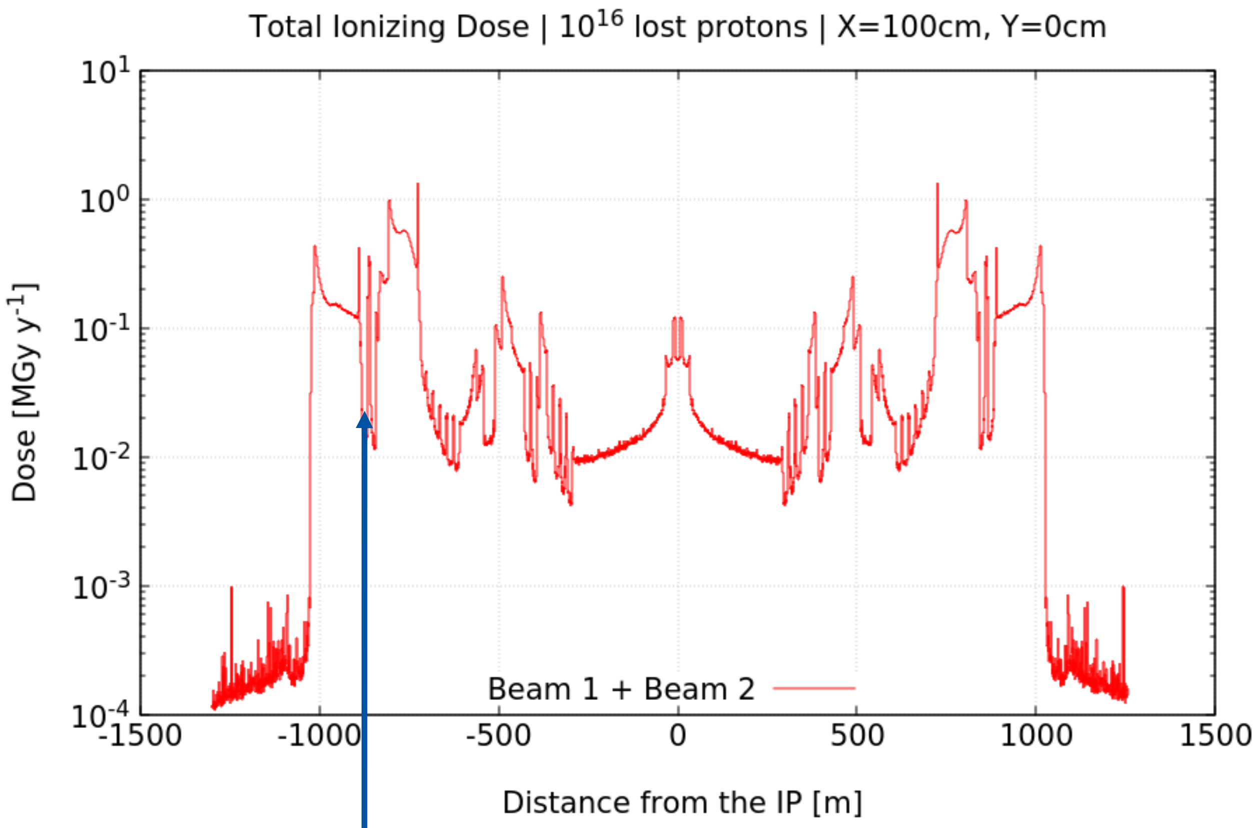


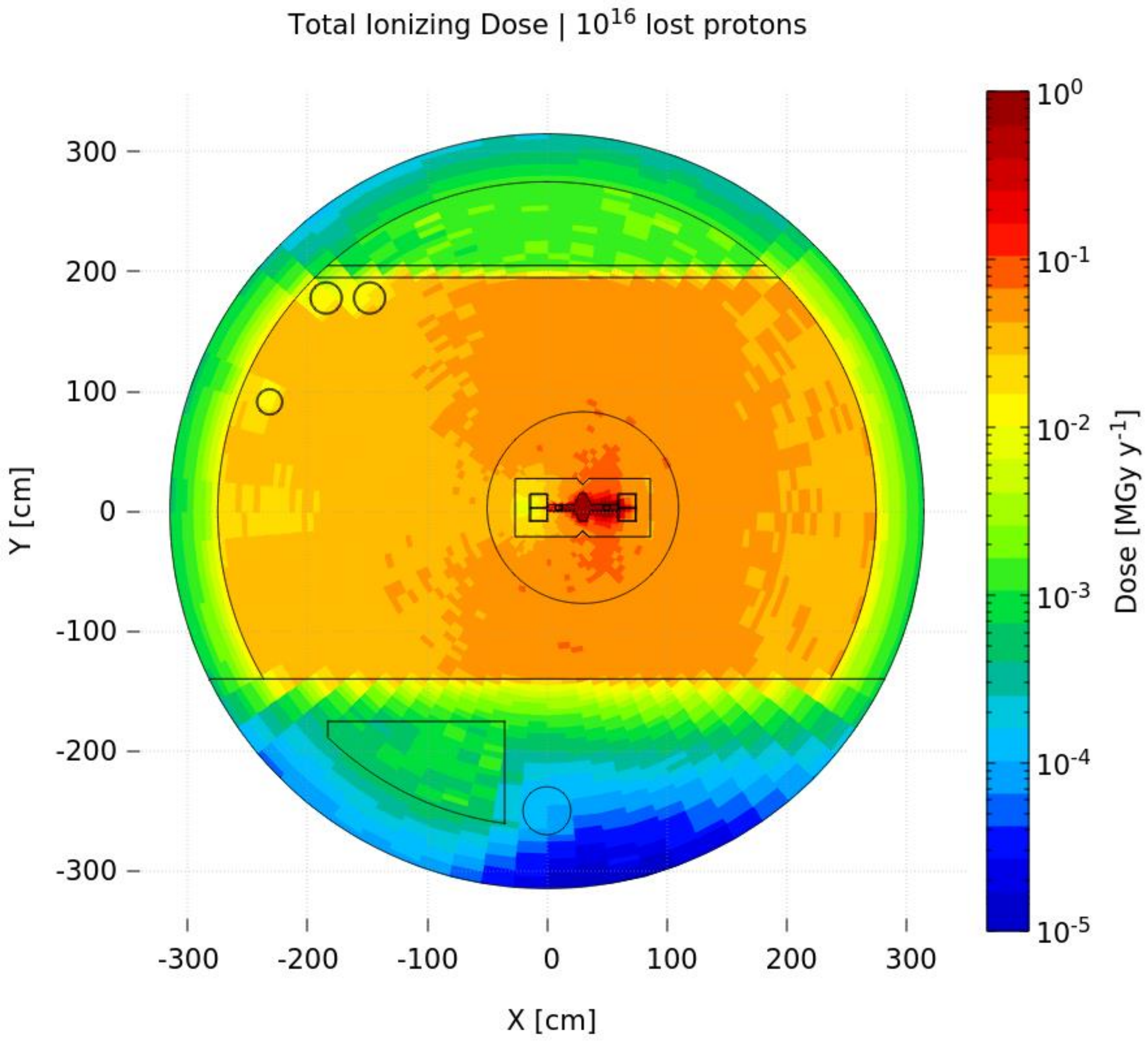
Disclosure:

*This is an **extreme case** to show how it could be possible to reuse the space available in the tunnel! A **real optimized engineering solution** must be discussed in the IOWG and iterate with different groups (CE, RP, CV, EL, ….).*

*A factor **10-100x** HL-LHC UJ can be expected **in real life**.*

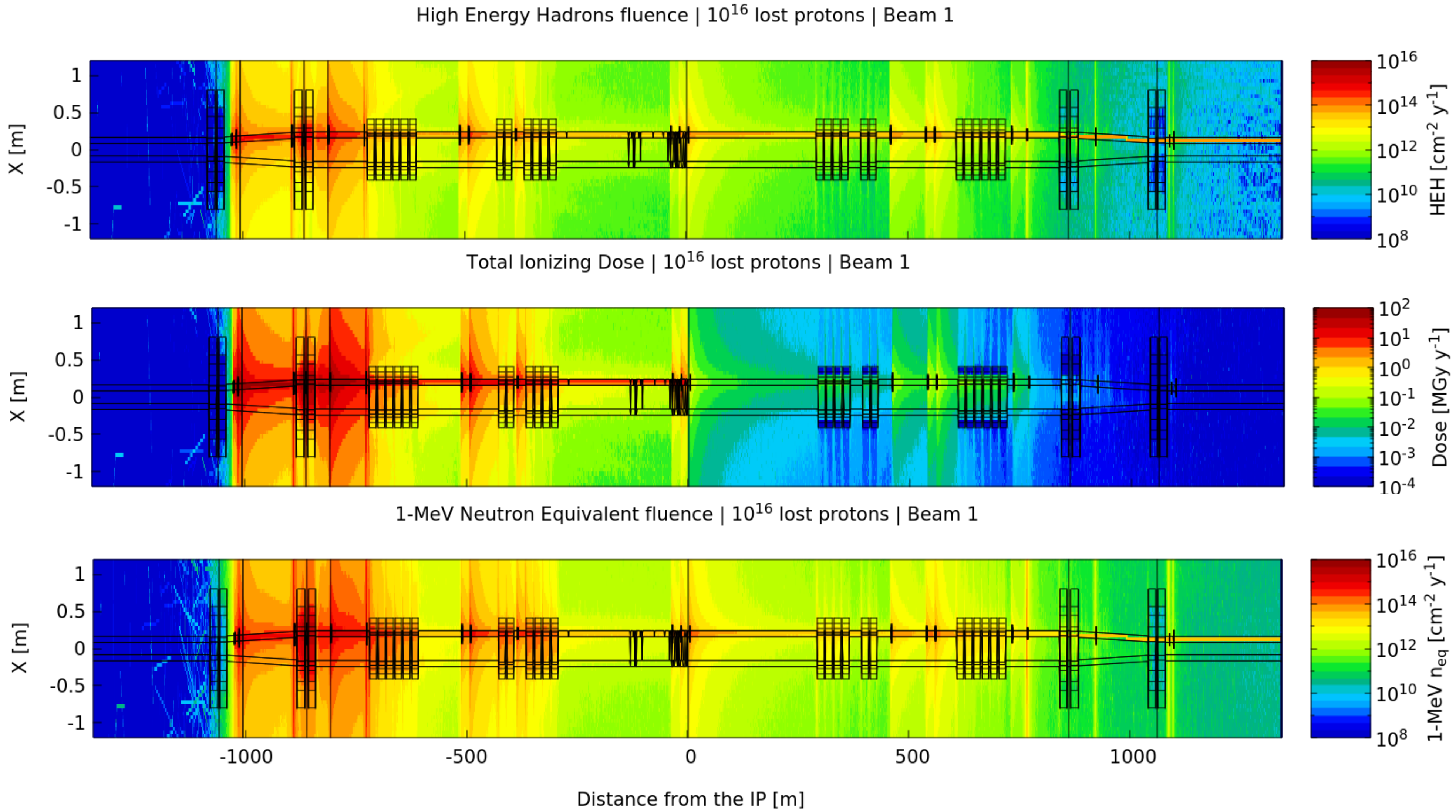
FCChh: Betatron - Total Ionizing Dose





Note: 2D map refers to Beam 1 only at the level of the MBW just after the 1st TCAP

FCChh: Betatron - Radiation Levels maps



FCChh: Betatron - Radiation Levels maps