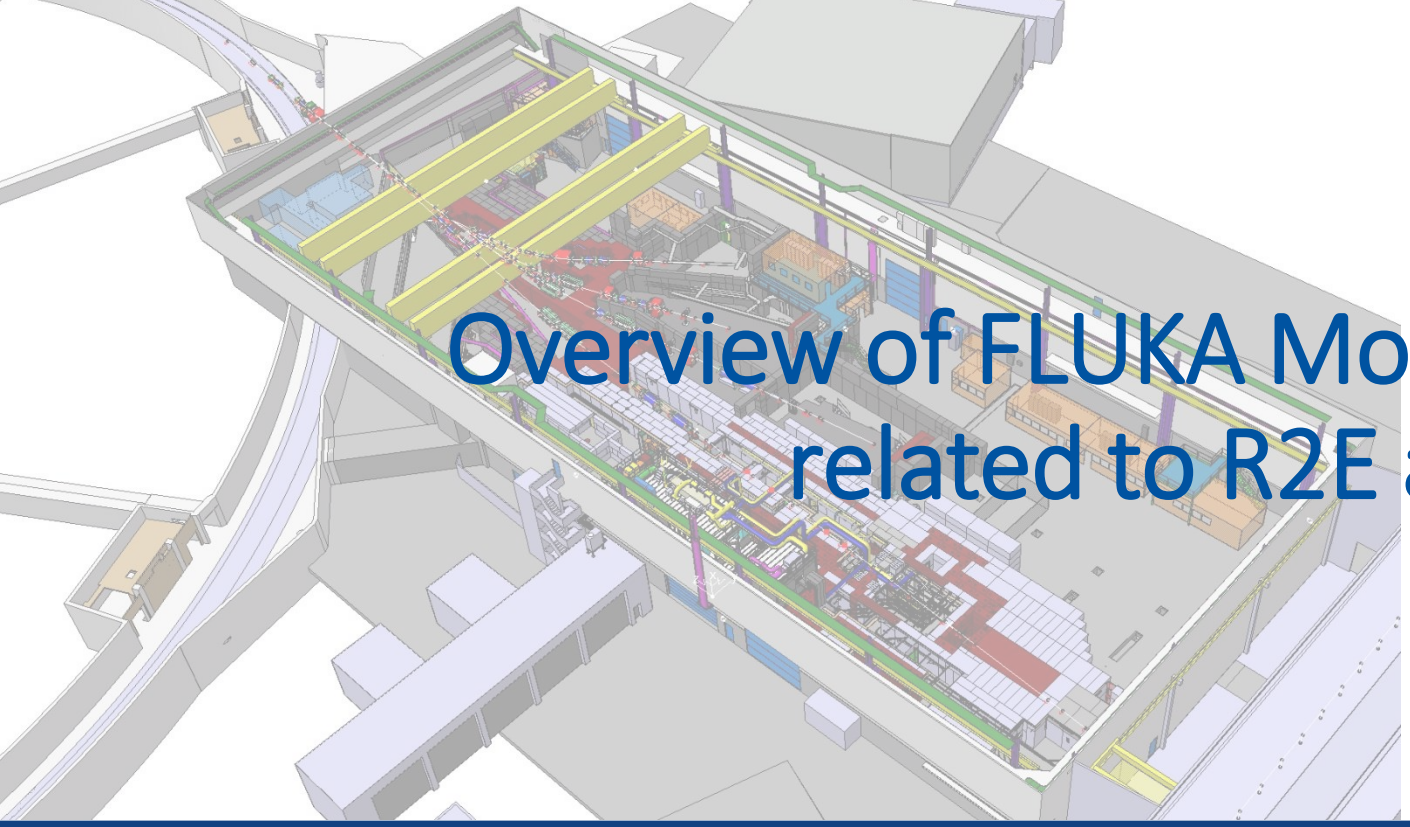
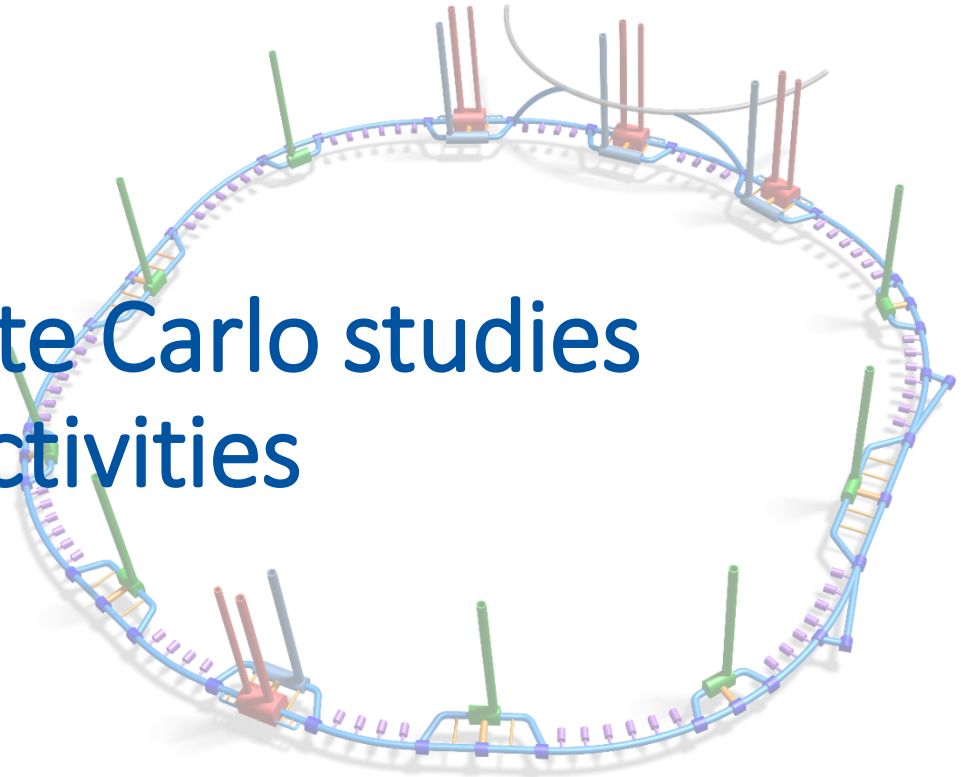




Overview of FLUKA Monte Carlo studies related to R2E activities

Angelo Infantino

CERN EN-STI-BMI

Context-Aim

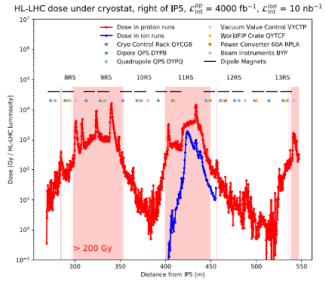
Acknowledges

- ❑ *Markus Brugger* (former R2E-project leader)
- ❑ *Francesco Cerutti* (BMI section leader)
- ❑ *CHARM & IRRADS teams* (Salvatore, Federico, Chiara, Matteo, …)
- ❑ *HSE-RP* (Robert, Elpida, Markus W., Stefan, …)
- ❑ *FCC*-related (Volker, Mar, Fani, Davide, … -> really long list!)

FLUKA R2E calculations

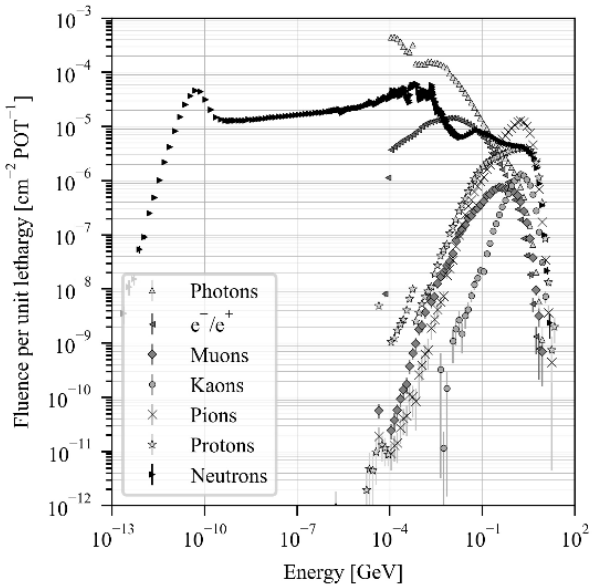
- Key in determining radiation levels for LIU and HL-LHC configuration and operational conditions
- Efficiently covering large majority of HL-LHC (WP10) areas of concern for equipment groups:
  - Shielded areas (UJ, UL, RR) around IP1, 5 and 7
  - DS in IP1, 5 and 7 (including possible cell

Activity includes also simulations for test facilities (CHARM, CC60) and FCC



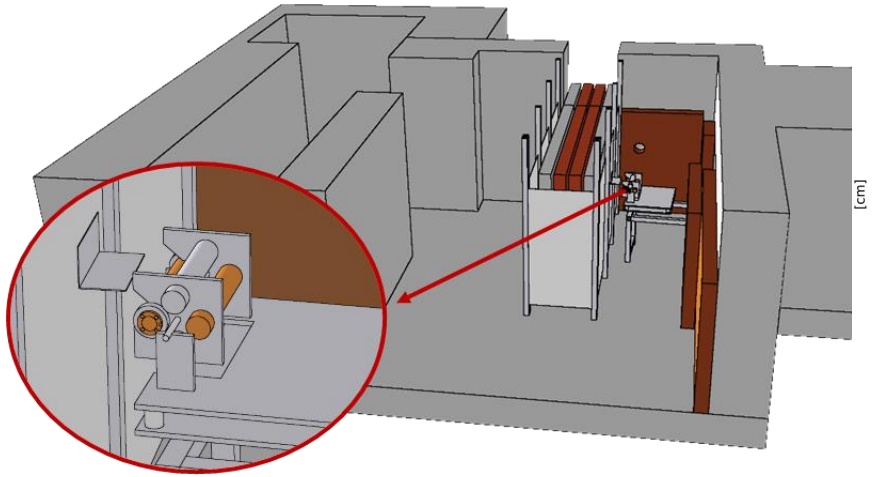
- ✓ *Overview & main achievements* of last *+3.5 years of activities* on FLUKA MC studies relevant for R2E (*building-block!*)
- ✓ *Complex FLUKA modelling* of the radiation environment for fixed-target facilities and particle colliders
- ✓ +3.5 years in 12 minutes -> IMPOSSIBLE. Today's talk:
  - *CHARM*: characterization of the *radiation environment* for p^+ and ion (NEW!) runs; *non-standard irradiations*;
  - *^{60}Co-calibration facility*: upgrade to a 100 TBq-source and R2E/RP implications
  - *FCC-project*: radiation environment for *FCC-hh*; role in the CD of this machine
- ✓ Out from this presentation (just for time constraints): *RP-Week/KEK-collaboration* (CHARM/CSBF); *optical fiber benchmark*; FCC-hh detector, FCC-ee, HE-LHC; *GCR*; and more … -> those are just the ones specifically related to R2E!
- ✓ *Links* to reference talks and publications in the backup-slides

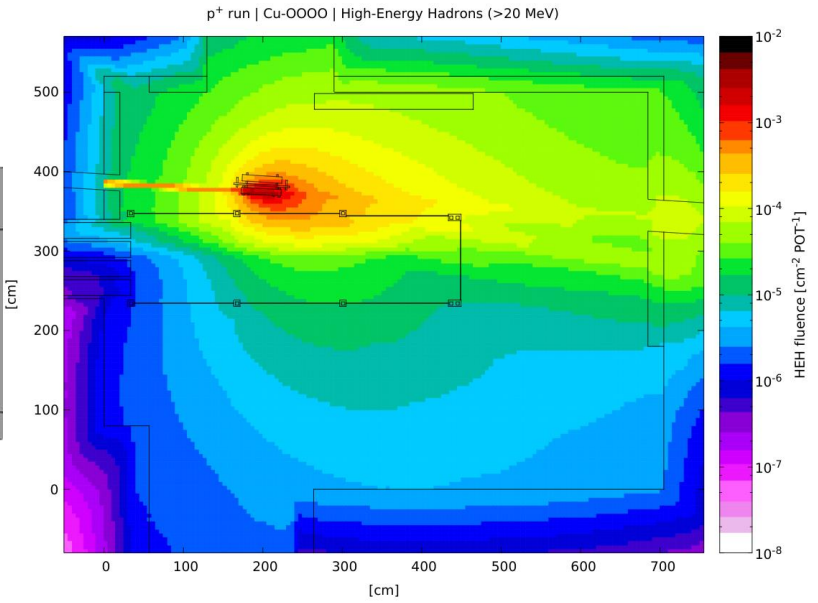
CHARM FLUKA model & Environment

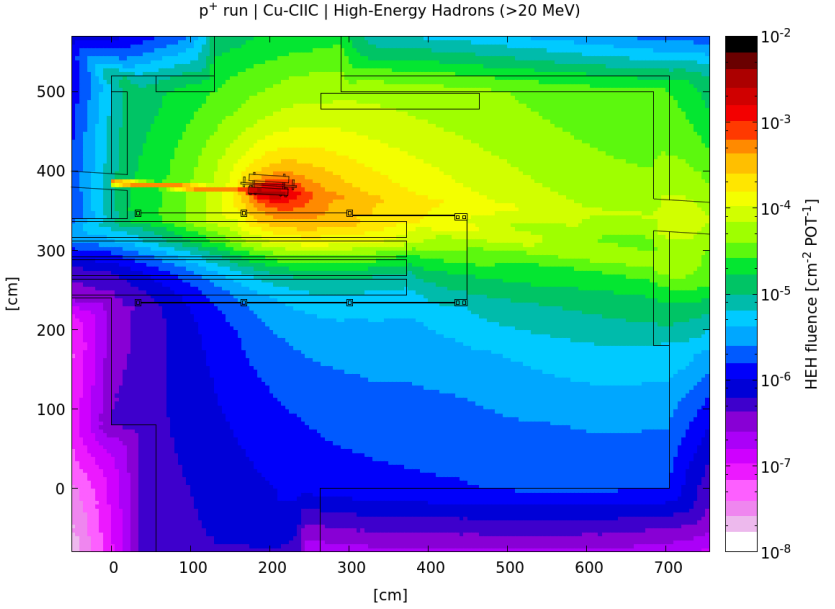


CHARM FLUKA model

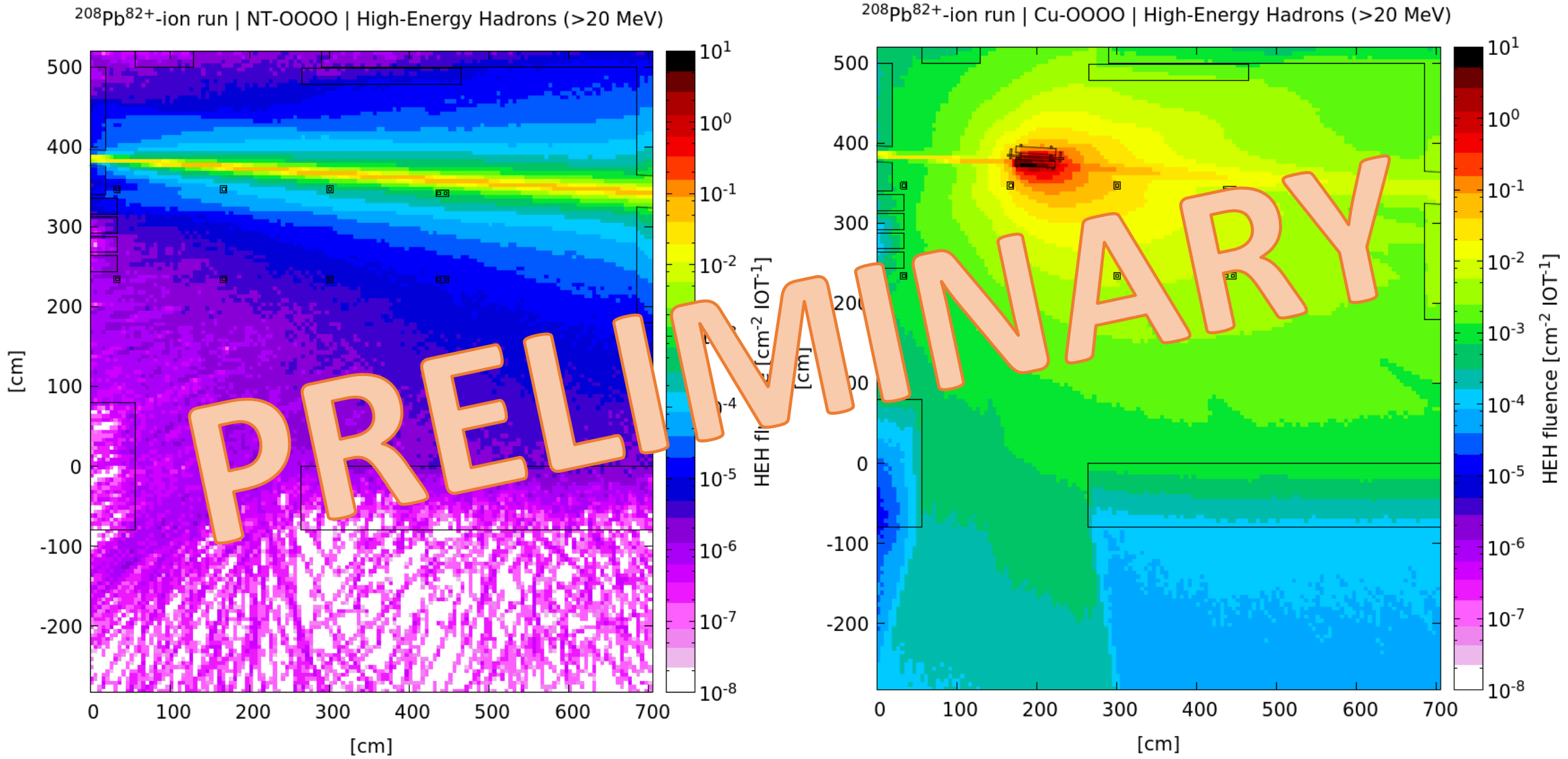
- From 2015, *constant update* of the model wrt new needs of the facility/new experimental setups/… -> *v.2019 now ready*!
- From 2016 dedicated *CHARM account* on clueet cluster, i.e. dedicated CPUs for CHARM studies.
- *Extensively validated and benchmarked* in different applications.
- *Huge amount* of work for standard & non-standard irradiations -> requests on a *weekly basis*.
  - Recently, up to 300 simulations in ~2-3 weeks… -> in general, manpower underestimated!
- Currently available the *full characterization* of the radiation environment for *all the facility-configurations* (>3000 values only for p^+) -> ***REFERENCE (!)*** ATS note in 2017.



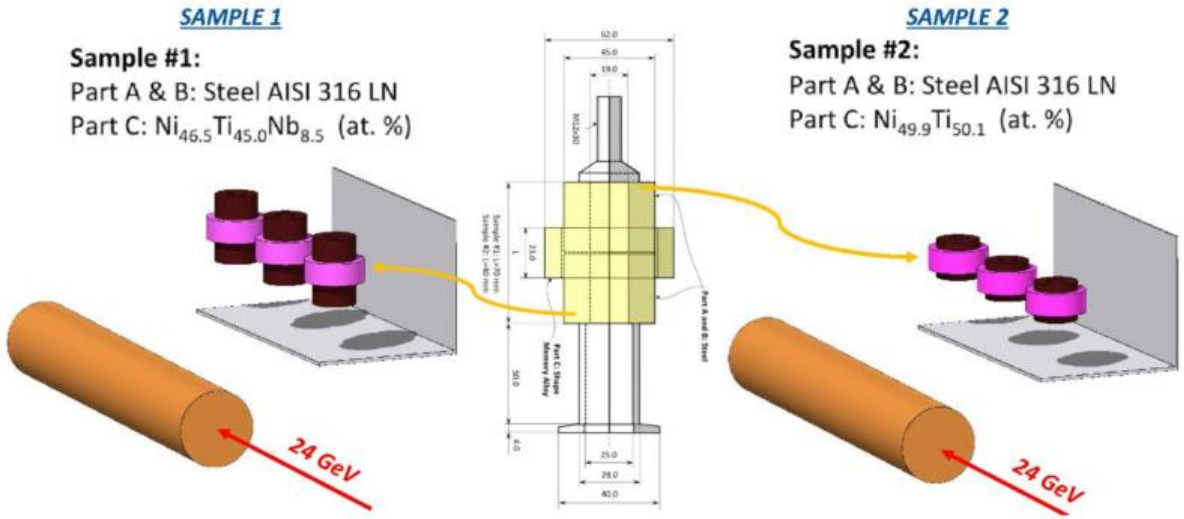


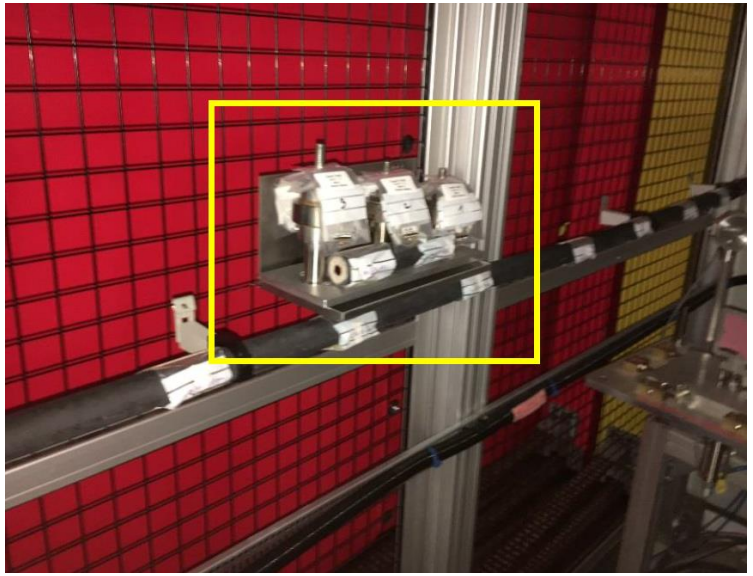


CHARM FLUKA model & Environment - IONS

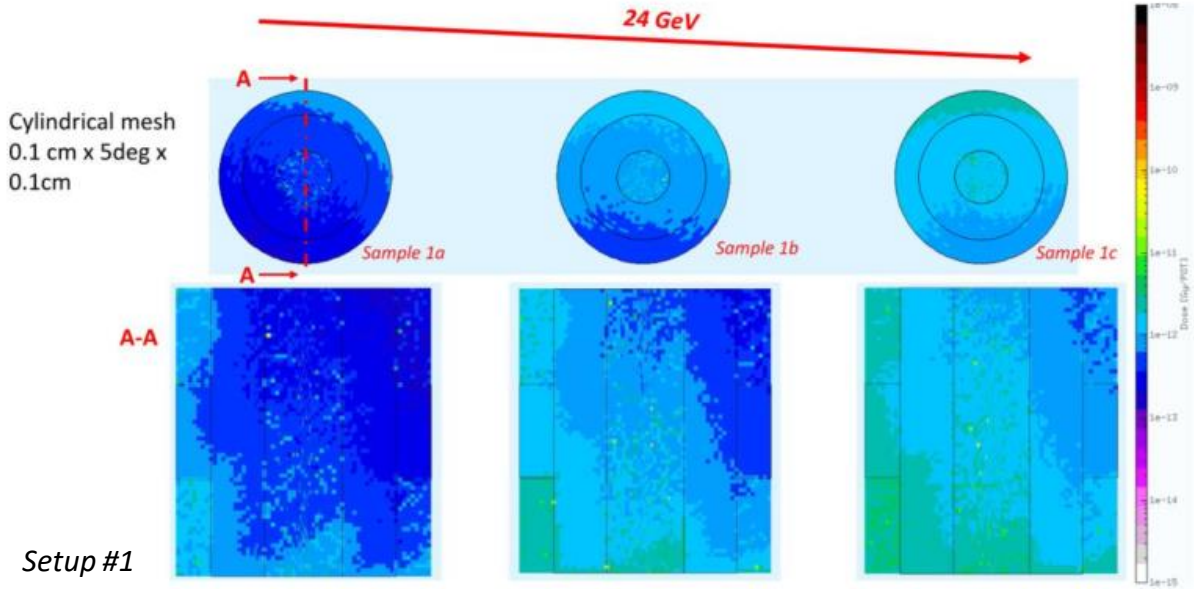


CHARM: Radiation gradient assessment (why?)



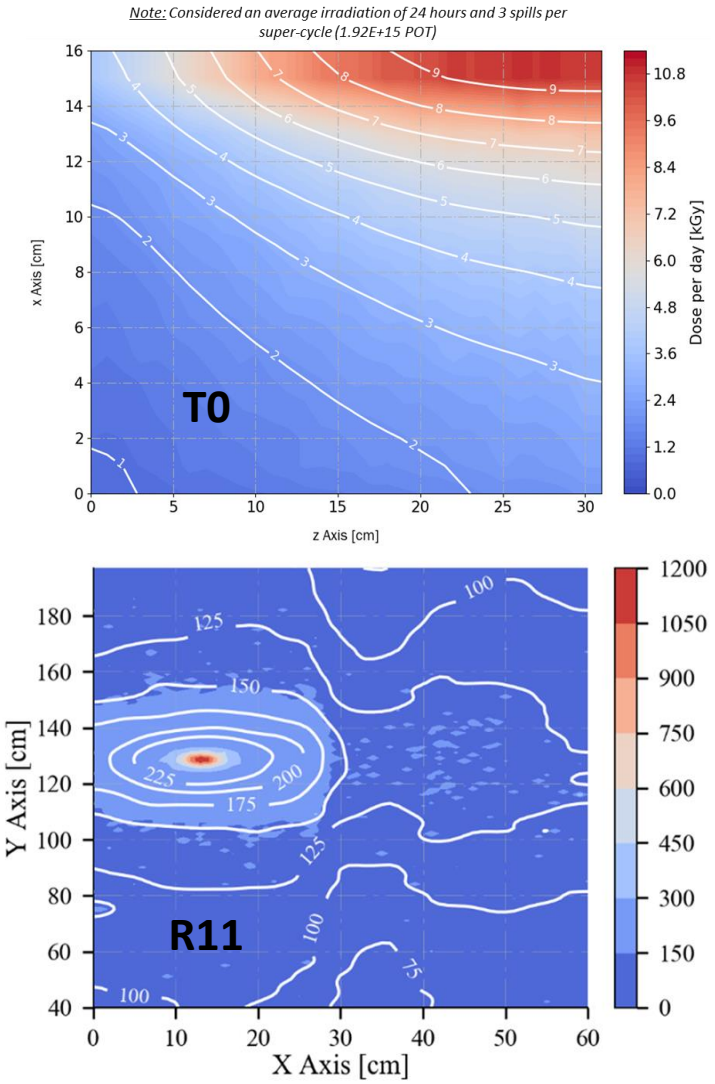


- First experimental tests in 2016
- NiTiNb *Shape Memory Alloy (SMA)* rings are planned to be used as Ultra-High vacuum (UHV) connectors in different CERN accelerators.
- To achieve the dose goal (*~100 kGy*), test conducted at CHARM in *position T0*.
- First Dosimetry Vs FLUKA: Bingo!



Setup #1

CHARM: Radiation gradient assessment

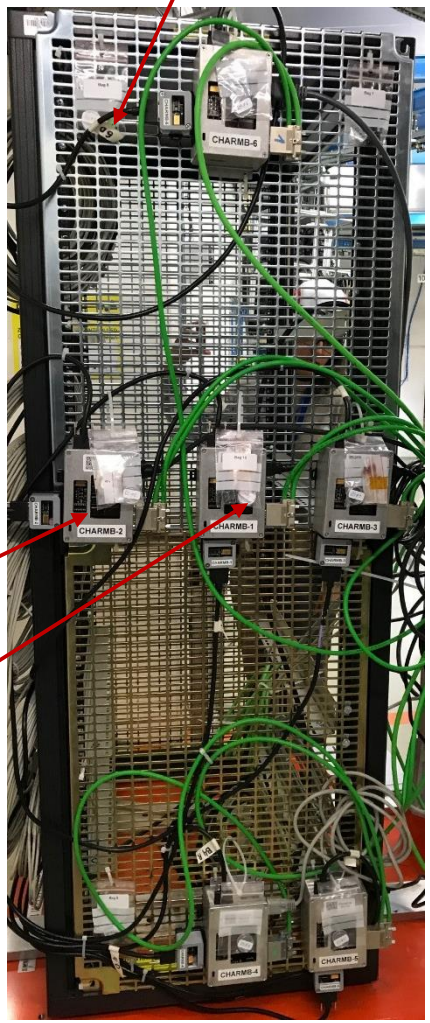


Gradient Assessment

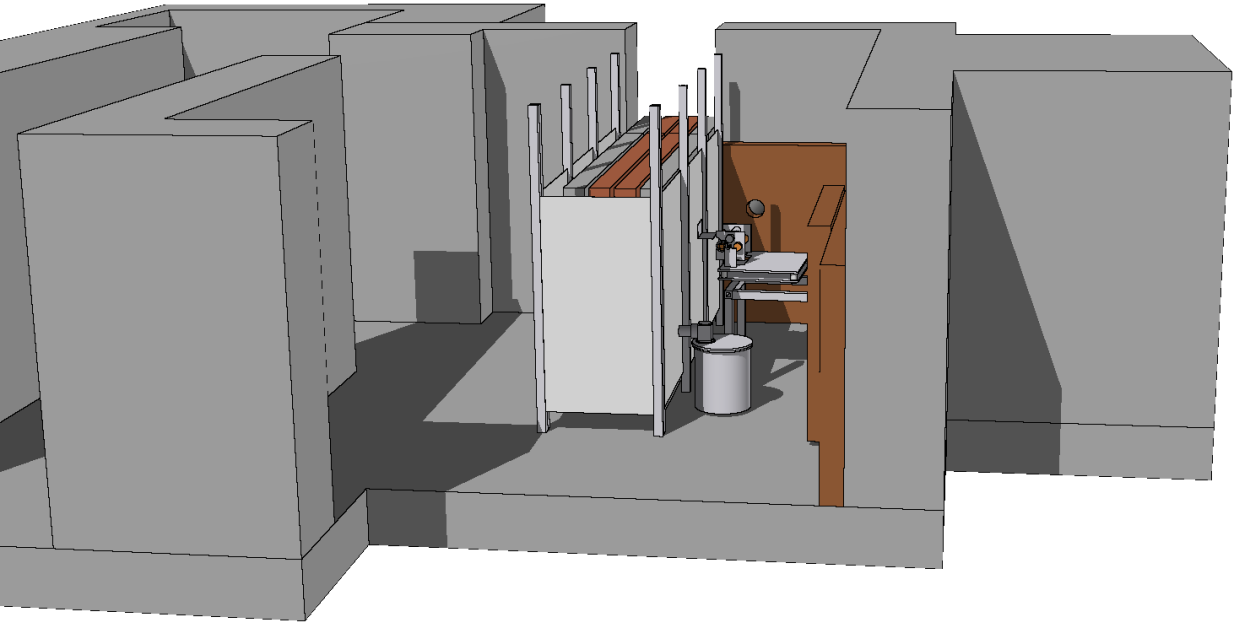
- Tests conducted in *2017/2018*
- *Crucial collaboration* with CHARM team
- Project funded 1-year technical student
- Several *test locations*: T0, R13, R11, R10, R11
- Dose (RPL/RadFET), HEH (SRAM), 1MeV neut. Eq. (p-i-n diodes)
- Detectors intercomparision & FLUKA benchmark
- *Outcome*: useful for *operation* and *scientifically* relevant
- Publication in RPC and conferences (IRRMA-X & SATIF-14)

Pos.	RPL [Gy]	RF [Gy]	FLUKA/RPL	FLUKA/RF
1	15.0 ± 0.4	10.6 ± 2.7	0.89 ± 0.18	1.3 ± 0.4
2	14.3 ± 0.3	8.7 ± 2.3	0.80 ± 0.17	1.3 ± 0.4
3	11.0 ± 0.4	n/a	1.15 ± 0.23	n/a
4	21.4 ± 0.9	16 ± 6	1.36 ± 0.28	1.8 ± 0.5
5	17.3 ± 0.6	11 ± 4	1.05 ± 0.21	1.7 ± 0.5
6	14.1 ± 0.5	10 ± 3	1.23 ± 0.25	1.8 ± 0.5
7	14.5 ± 0.5	10 ± 3	1.11 ± 0.25	1.6 ± 0.5
8	10.8 ± 0.3	7.7 ± 2.0	0.91 ± 0.19	1.3 ± 0.4
9	12.0 ± 0.4	8.5 ± 2.7	1.11 ± 0.24	1.6 ± 0.5

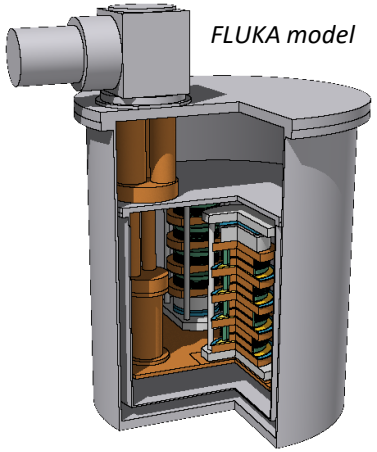
Note: The reported expanded uncertainty is 1 σ



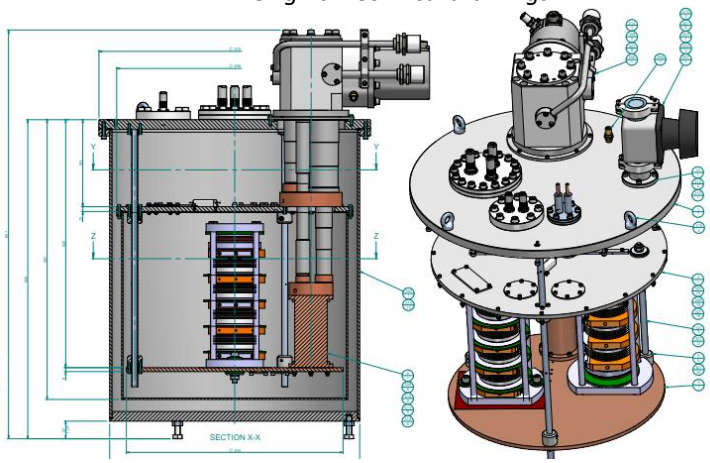
CHARM: Cold bypass diode for HL-LHC triplet

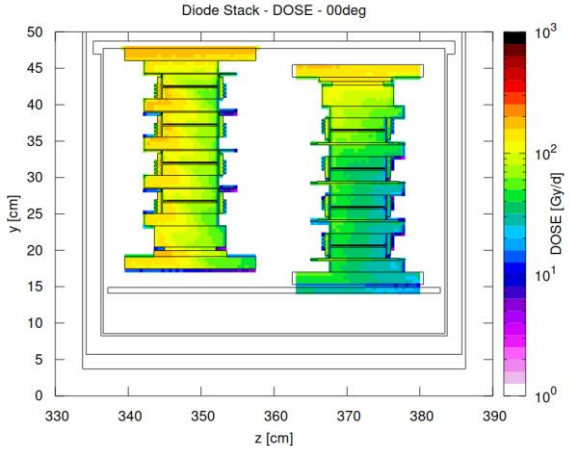


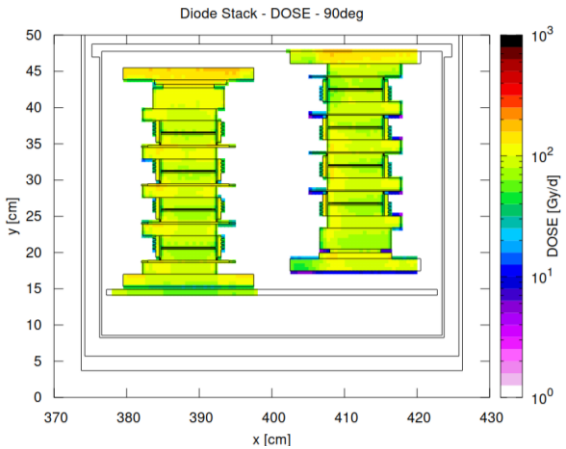
- Clear example of the *importance of the radiation gradient study*!
- FLUKA simulations *crucial* for the *planning* of the irradiations and for *safety* (strong collaboration with RP) -> impossible to obtain the same degree of detail experimentally.
- Tests *successfully* conducted in *2018*

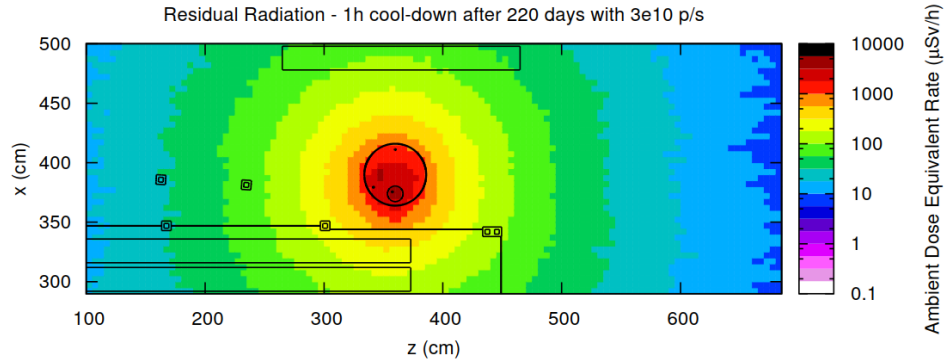


Original Technical drawings

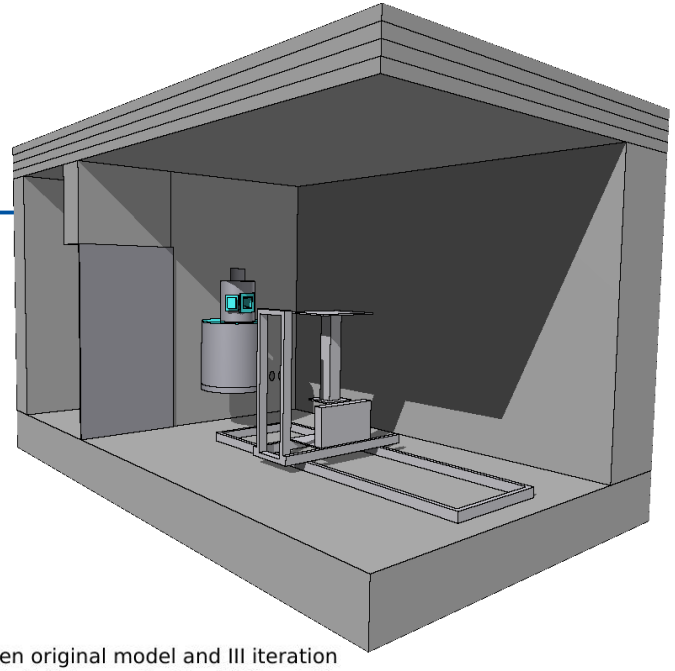




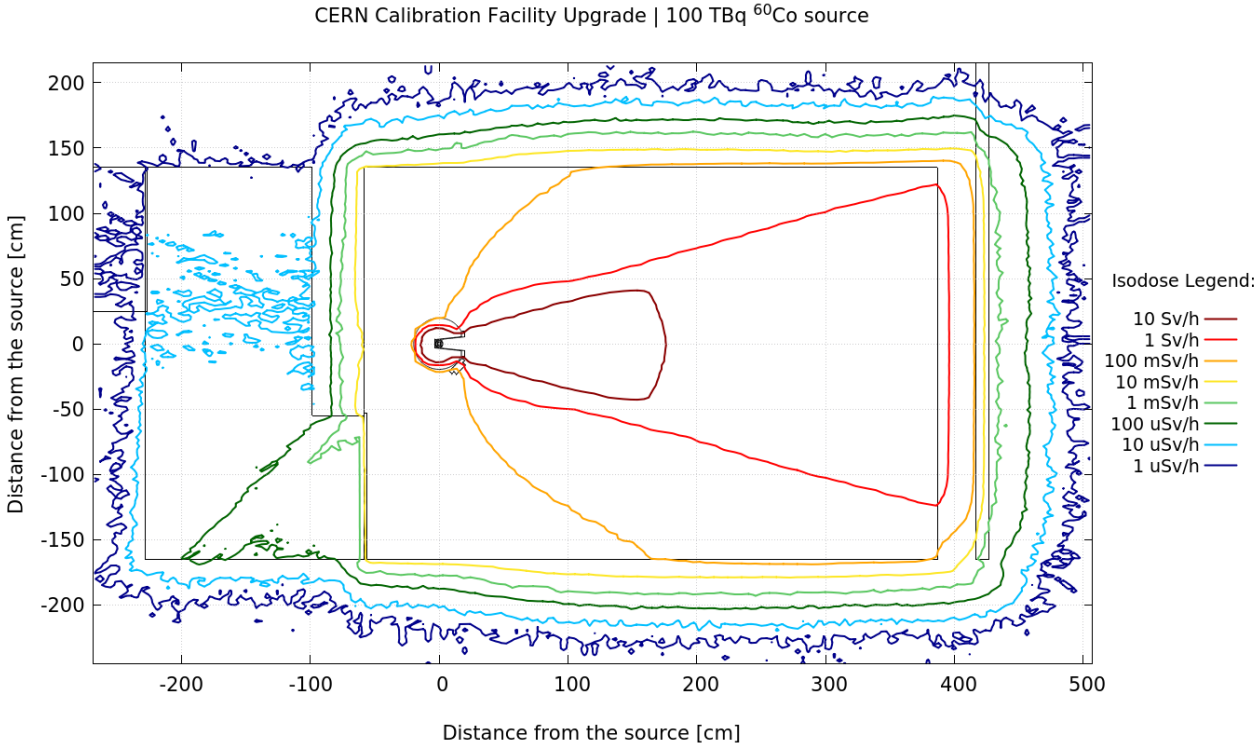


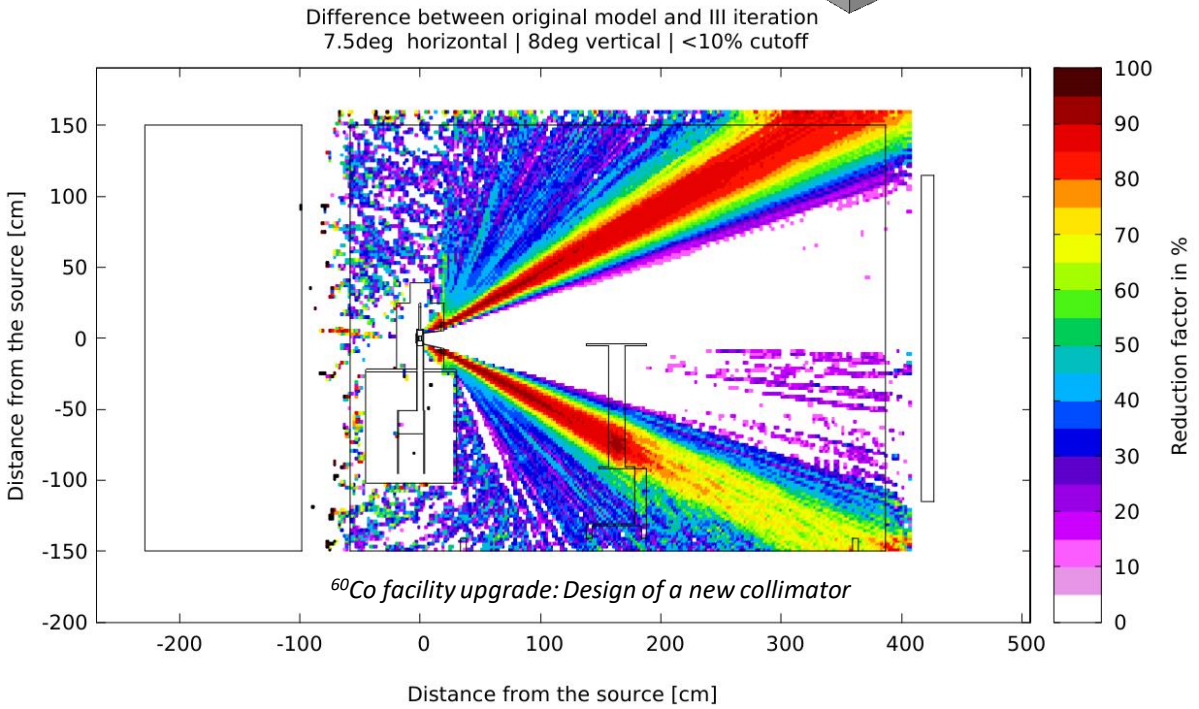


Calibration facility (^{60}Co) & upgrade

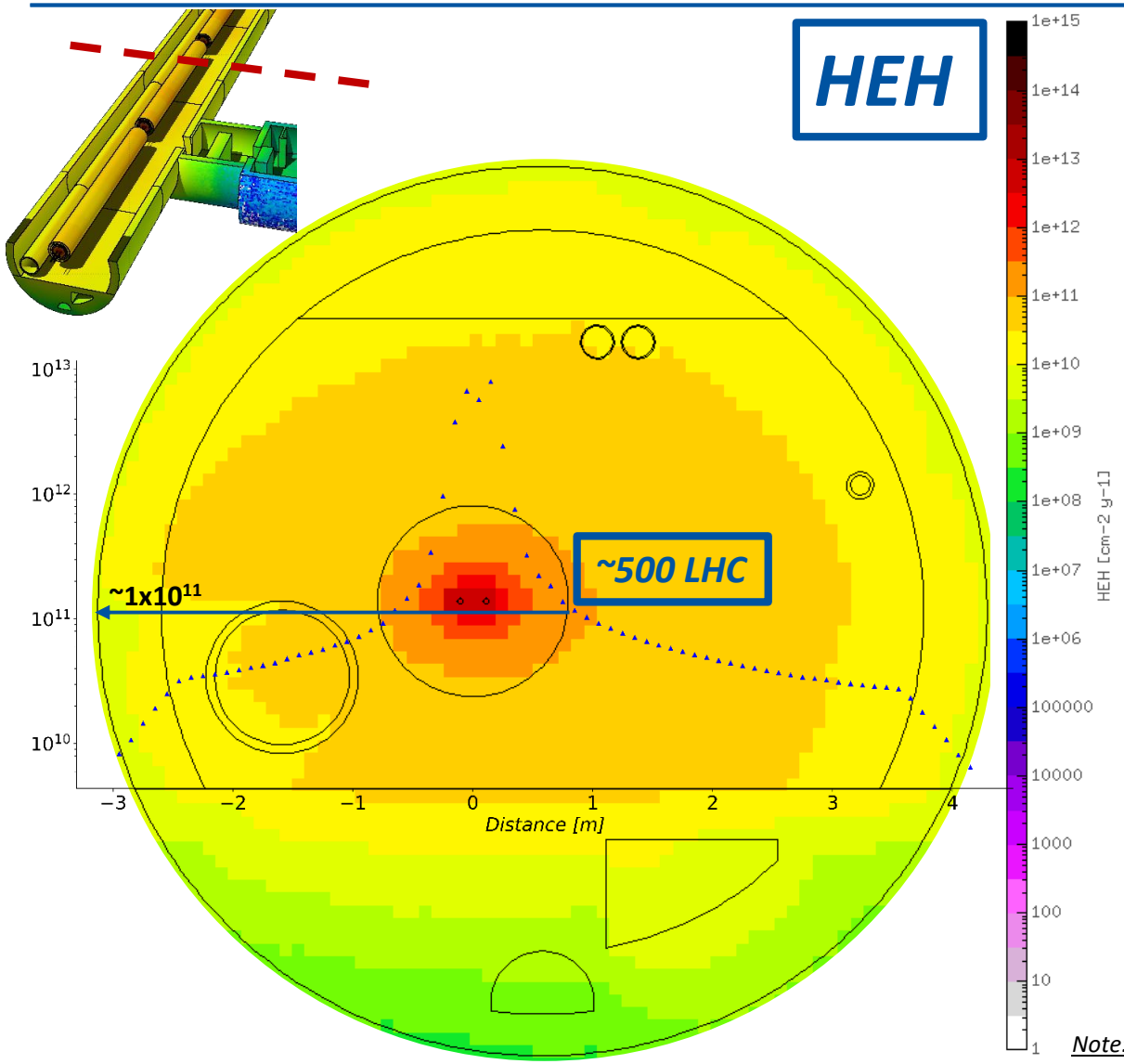


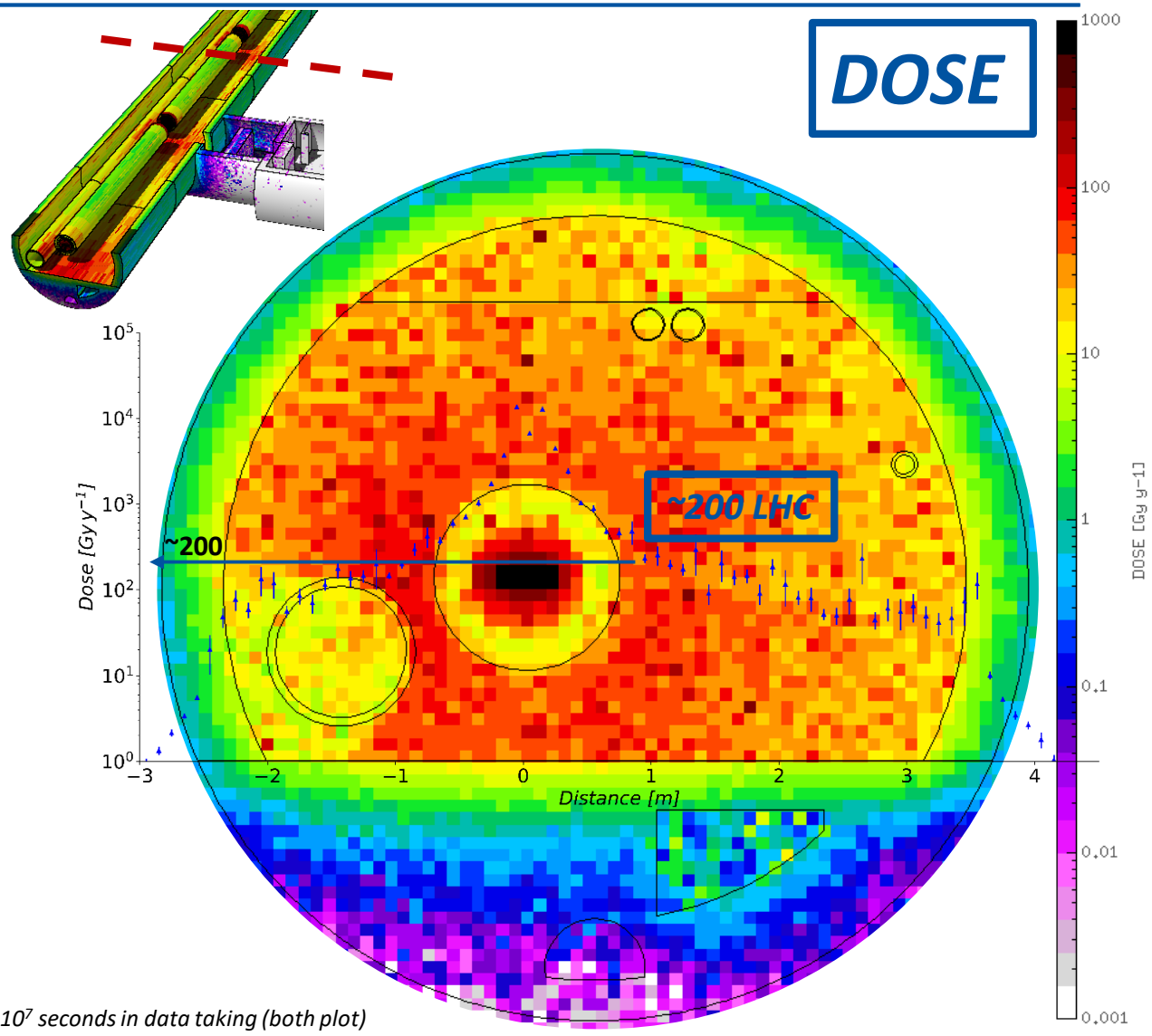
- *Full characterization* of the radiation field for R2E-purposes and comparison with experimental measurements (*detector intercomparison*).
- *Characterization of RPLs* dosimeters (collaboration with RP).
- Recently, study for the *upgrade* of the facility (^{60}Co, bat. 772) -> *100 TBq* (~10x current source)
- Need for *higher dose rate* for R2E-purposes, but:
  - *Additional shielding* required? (problematic especially for the roof)
  - *Design of new collimator*





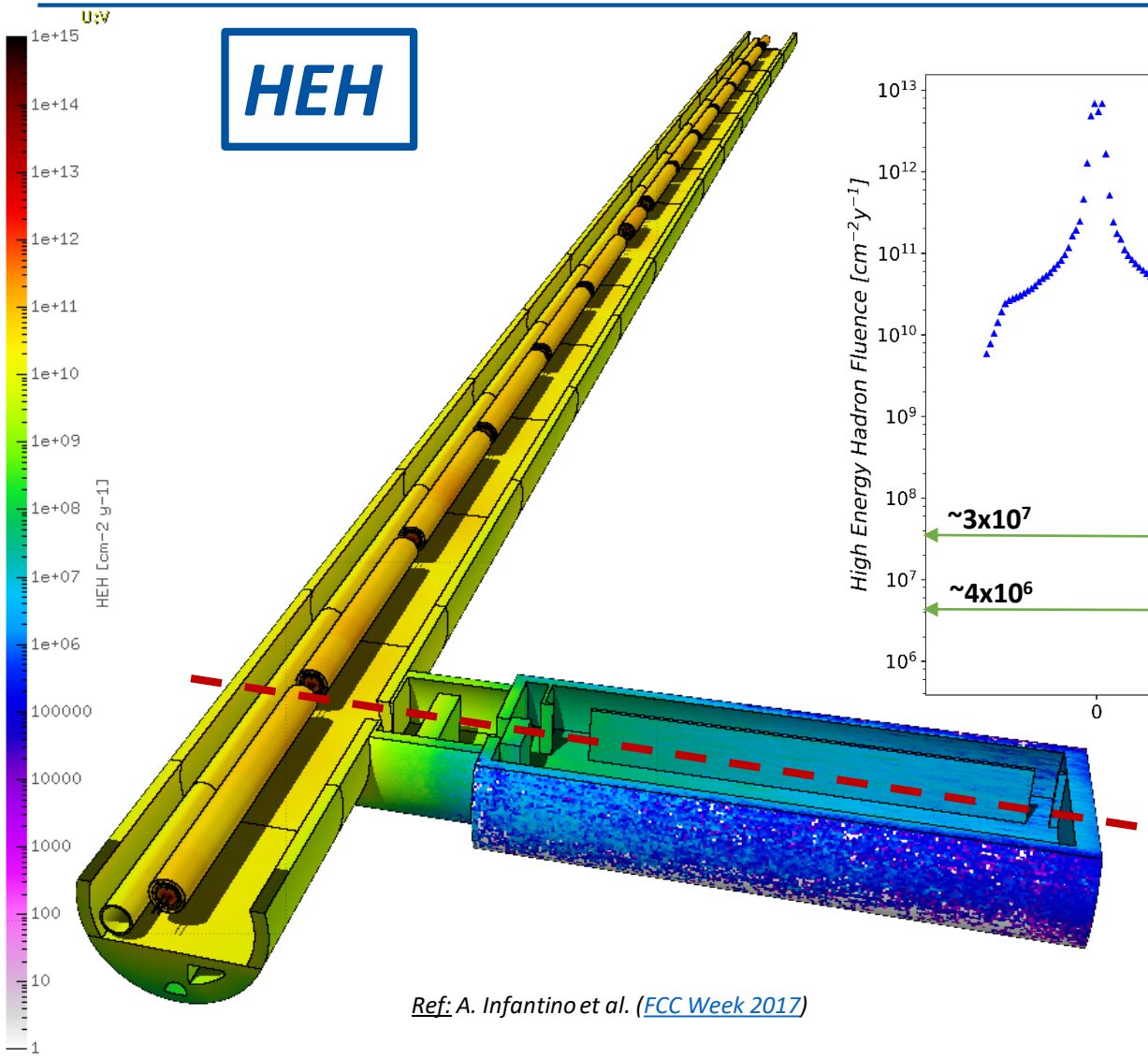
FCChh: ARC (FCC Week 2017)





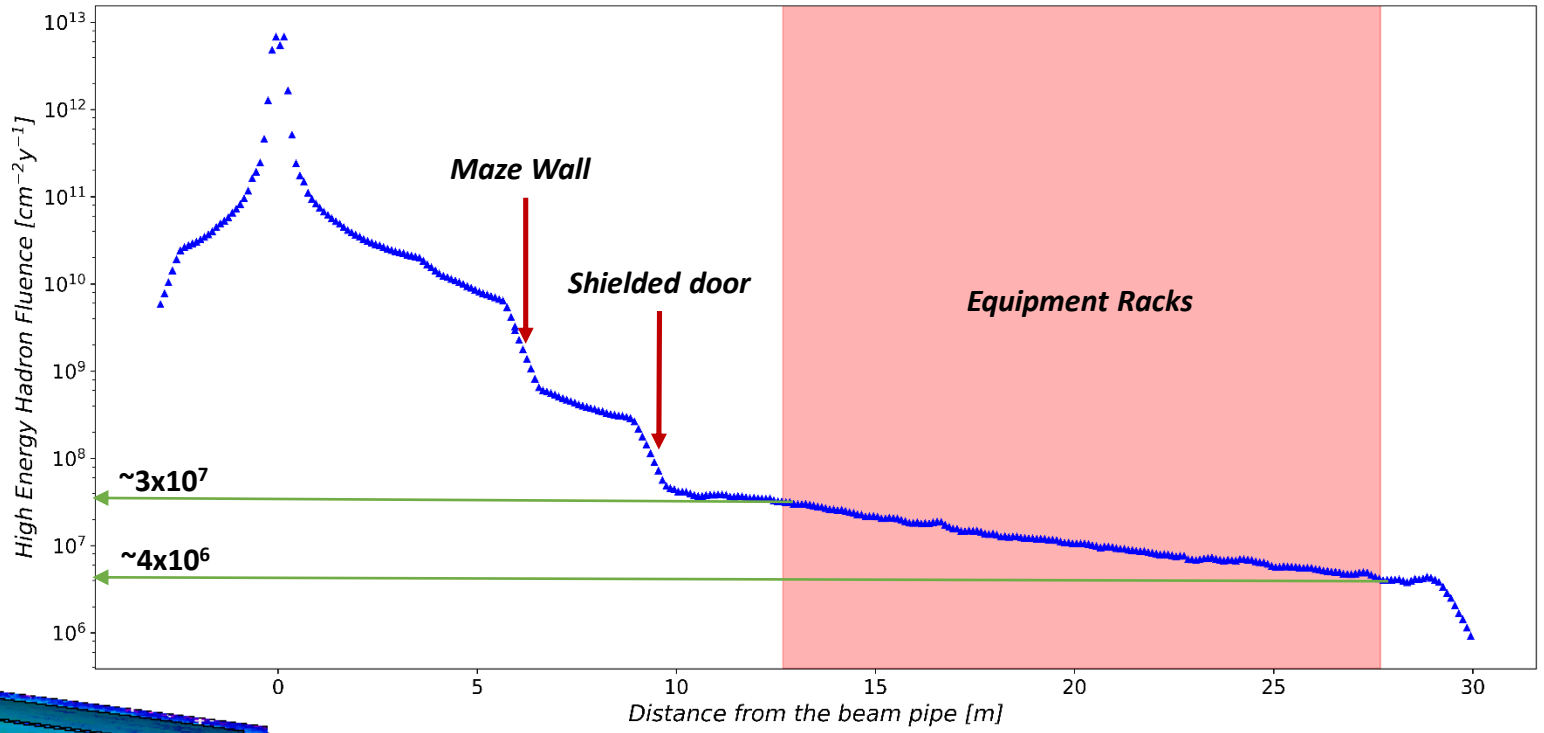
Note: 10^7 seconds in data taking (both plot)

FCChh: ARC/ALCOVE (FCC Week 2017)



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

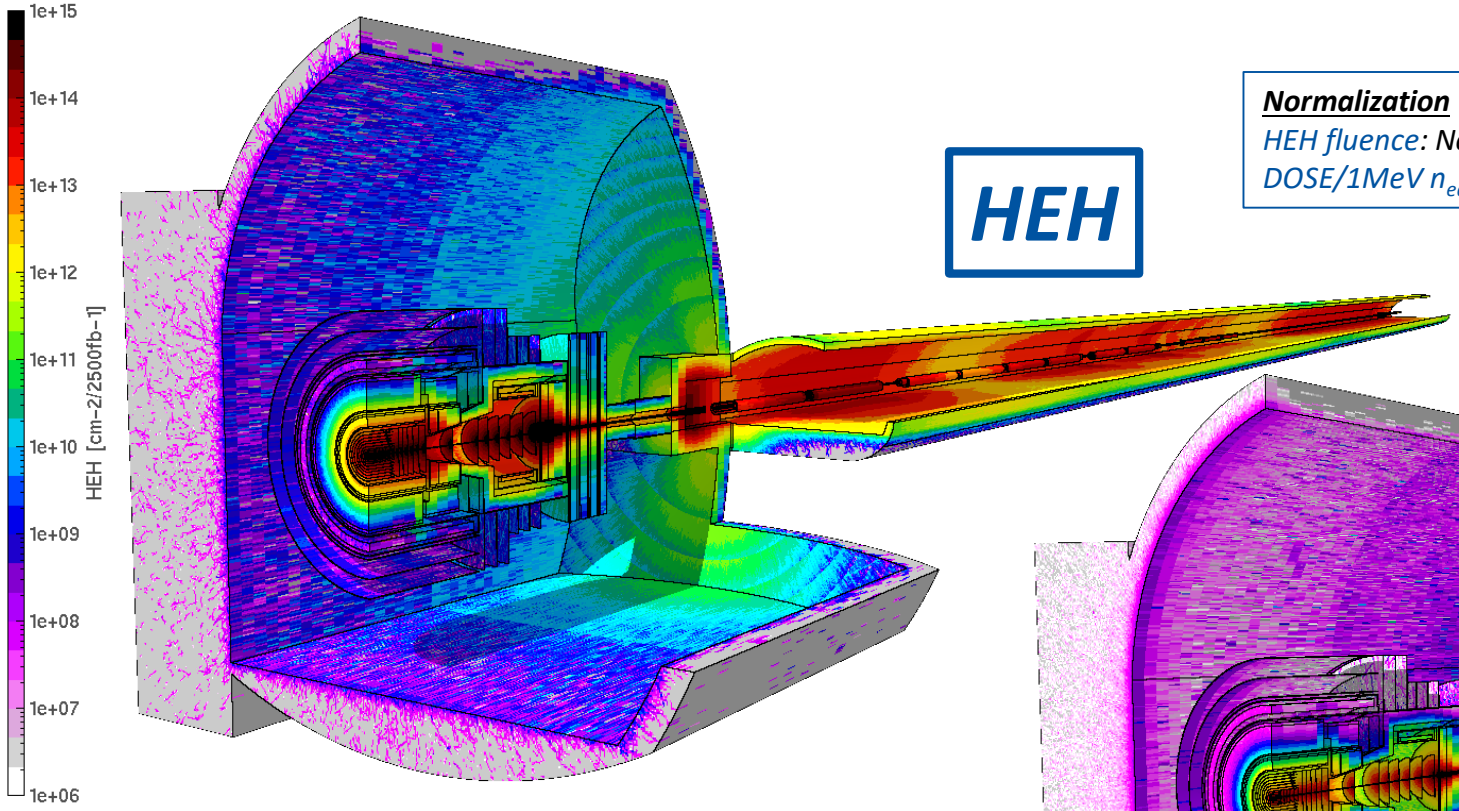
Note: 10^7 seconds in data taking – Statistical uncertainty < 5%



- ✓ 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 (2018)

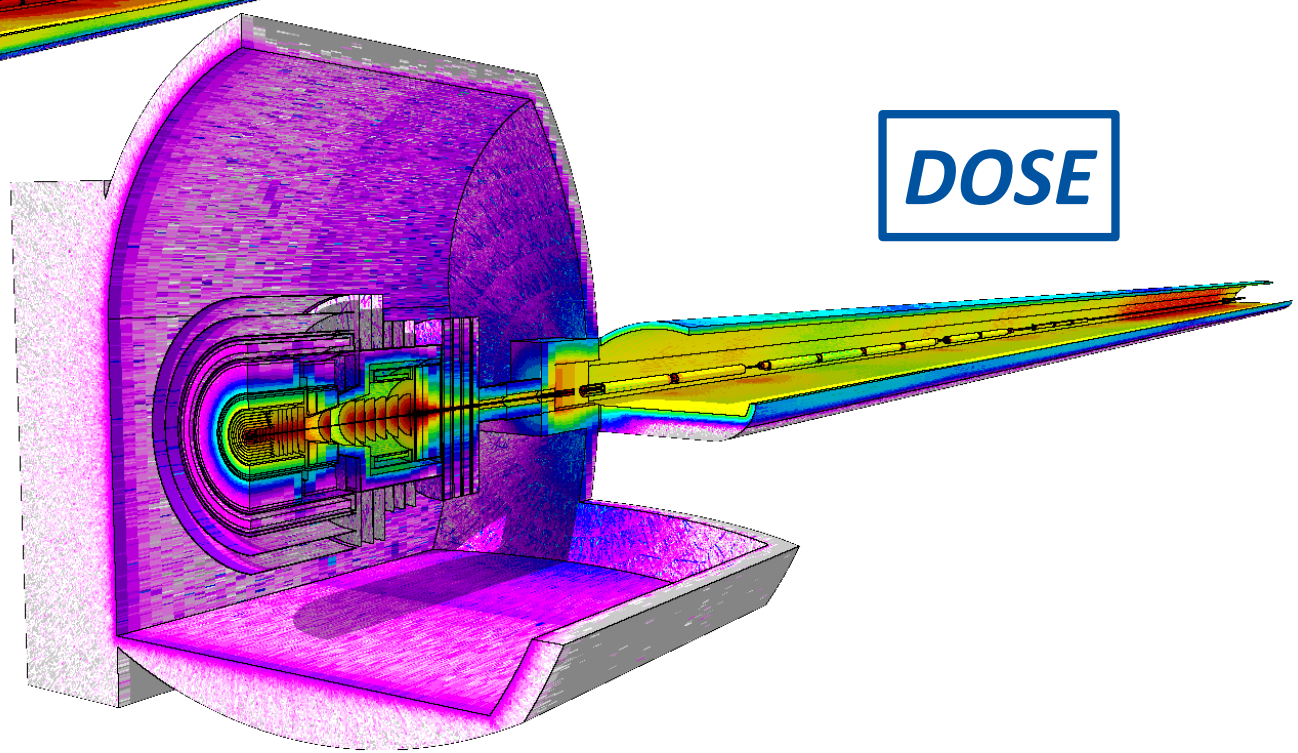


HEH

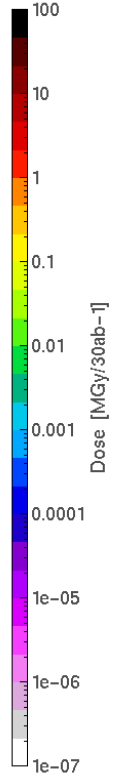
Normalization

HEH fluence: Normalized to ultimate conditions and worst case year ($2500fb^{-1}$/year)

DOSE/1MeV n_{eq} fluence: Normalized to ultimate conditions $L_{int}=30ab^{-1}$

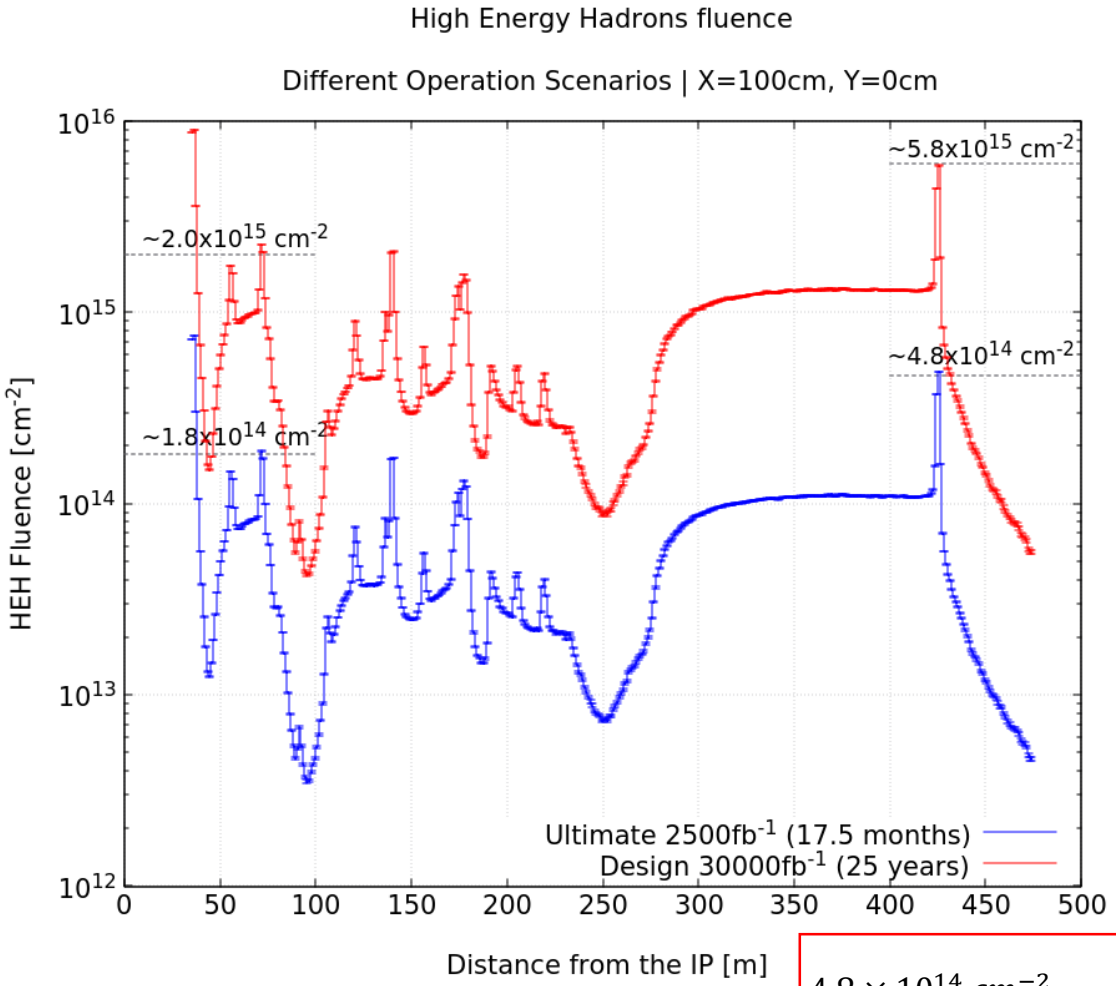


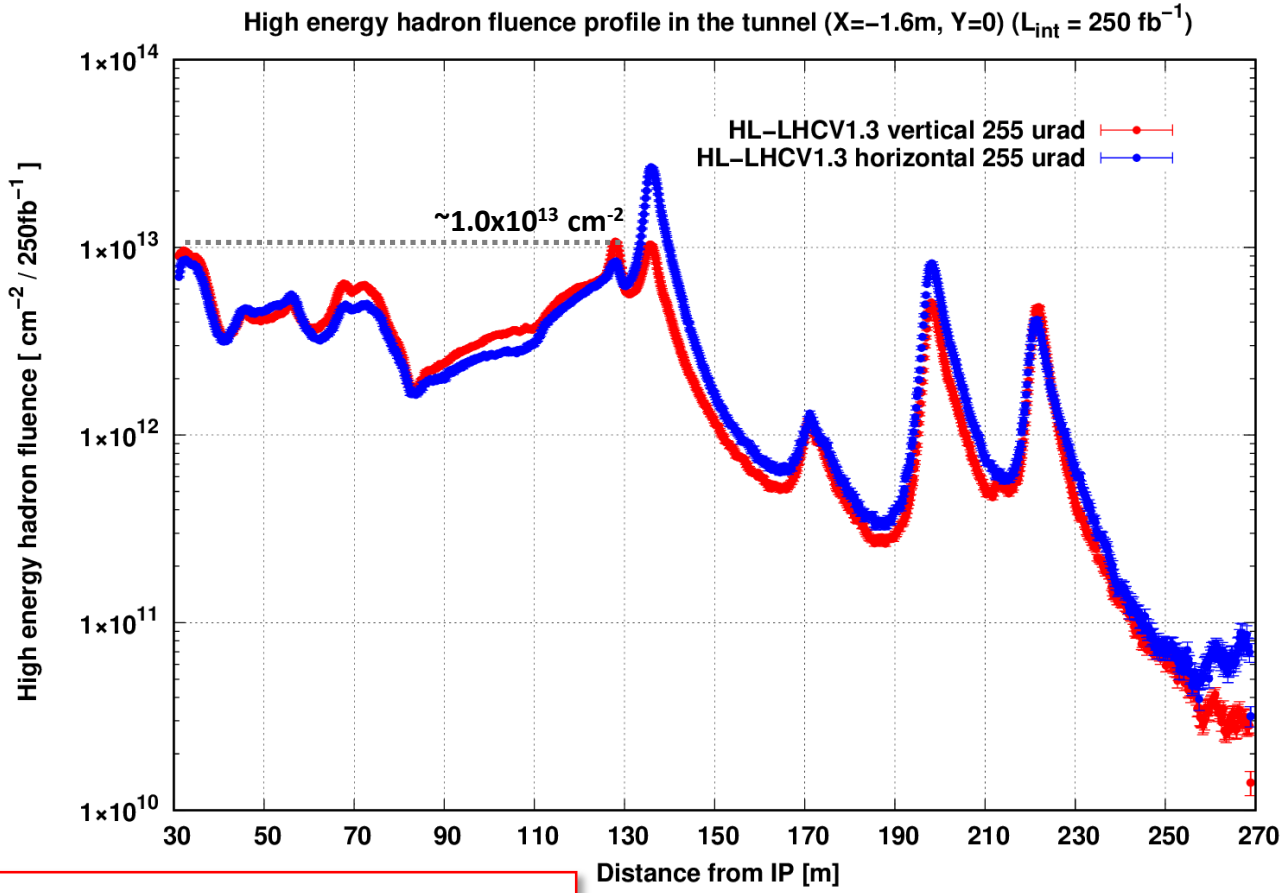
DOSE



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

FCChh: Experimental Insertion Region (2018)

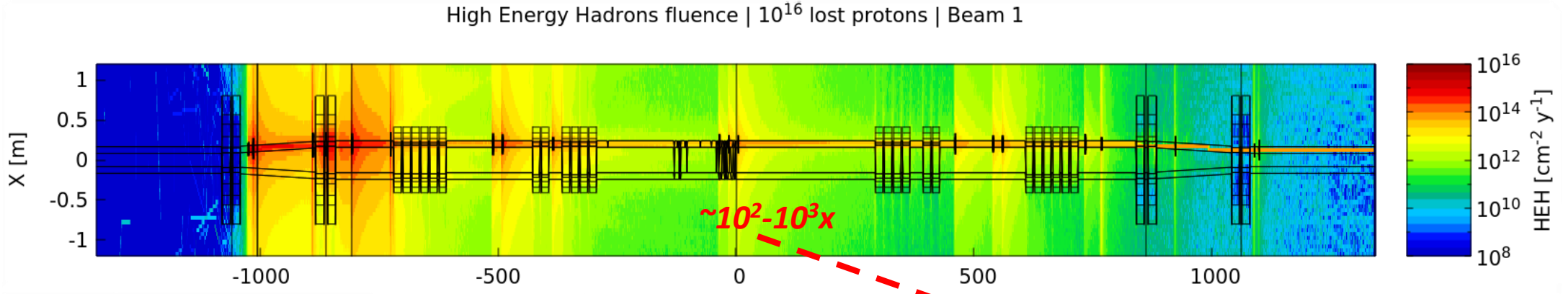


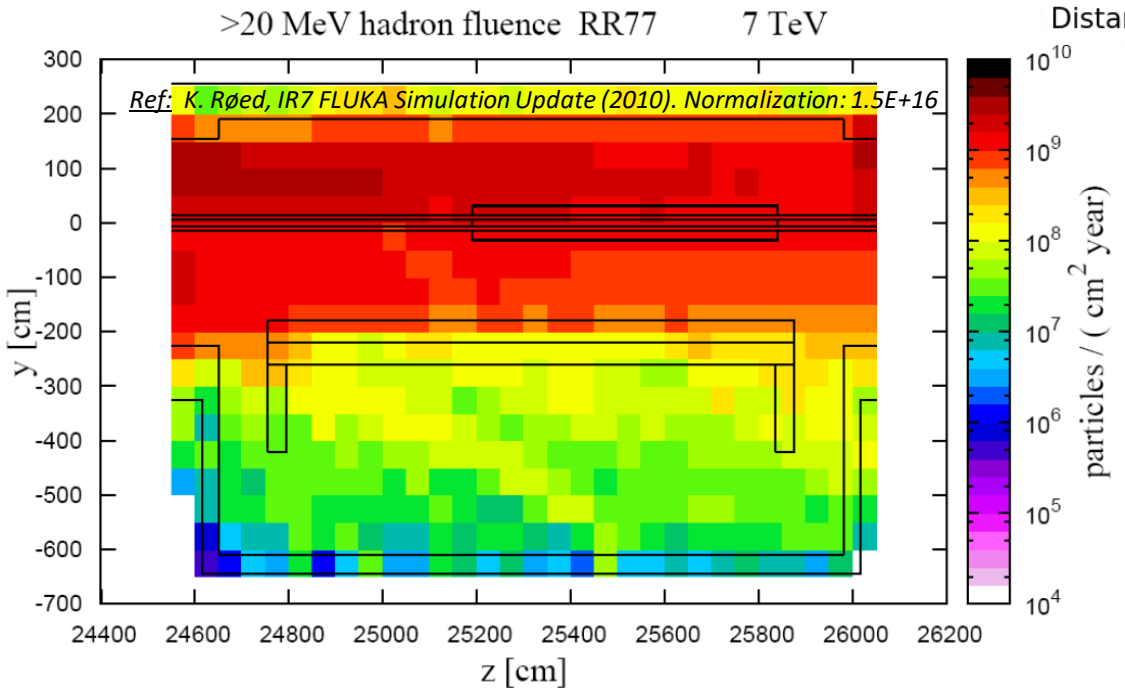


$$\frac{4.8\times10^{14}\ cm^{-2}}{1.0\times10^{13}\ cm^{-2}} = 48 \approx \frac{30000 fb^{-1}}{3000 fb^{-1}} \times \left(\frac{50TeV}{7TeV}\right)^{m=0.8} \cong 48$$

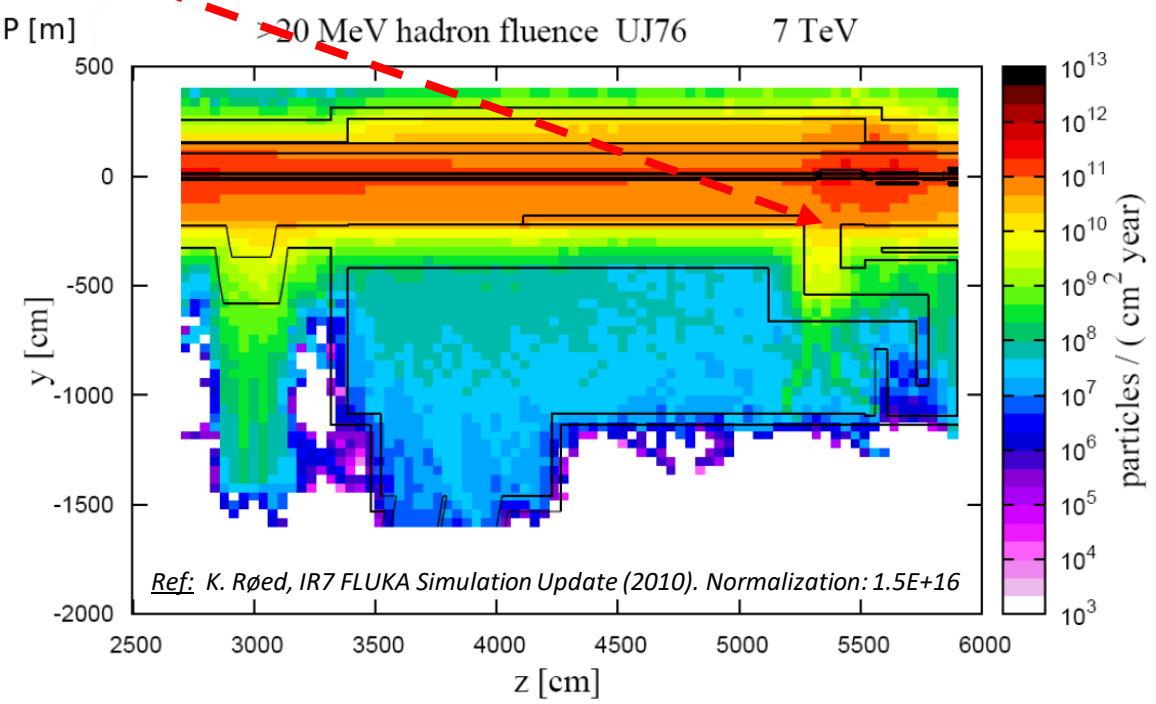
HL-LHC courtesy of Andrea Tsinganis (EN-STI-BMI)

FCChh: Betatron cleaning insertion (2018)





Distance from the IP [m]



Summary

Main achievements of the last 3.5 years?

- FLUKA MC modelling was *essential* for the *support, calibration and benchmark of the CHARM facility*. This activity produced an *extensive amount of data* which had a beneficial impact in the *operation* of the facility (standard and non-standard irradiations) as well as produced a number of *publications* in peer-reviewed journals and *contributions* in international conferences.
- FLUKA simulations assumed a *crucial* role in the *conceptual design of FCC* (all machines). Wrt R2E-purposes, the "*Infrastructure and Operation*" and the "*Special Technologies*" WP particularly benefited of this activity, which *met the original milestones and went well beyond them*. Up today, *>90% of the FCC-hh machine has been already simulated* and the practical solutions have been already found for the arc.
- Many other activities didn't find place in today's talk: anyway, their contribution was crucial across many different applications and groups (e.g. *RP-Week/KEK collaboration* -> thanks, once more, to Markus' vision; *optical fiber benchmark* -> renovated collaboration with EA & publication).
- All the above mentioned activities represent a *building-block* of the R2E project, which contributed to the strengthening of the project itself, of CHARM (high appreciation in SATIF-14!) and the FCC conceptual design.

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BACKUP SLIDES

List of related talks* & publications**

❑ CHARM

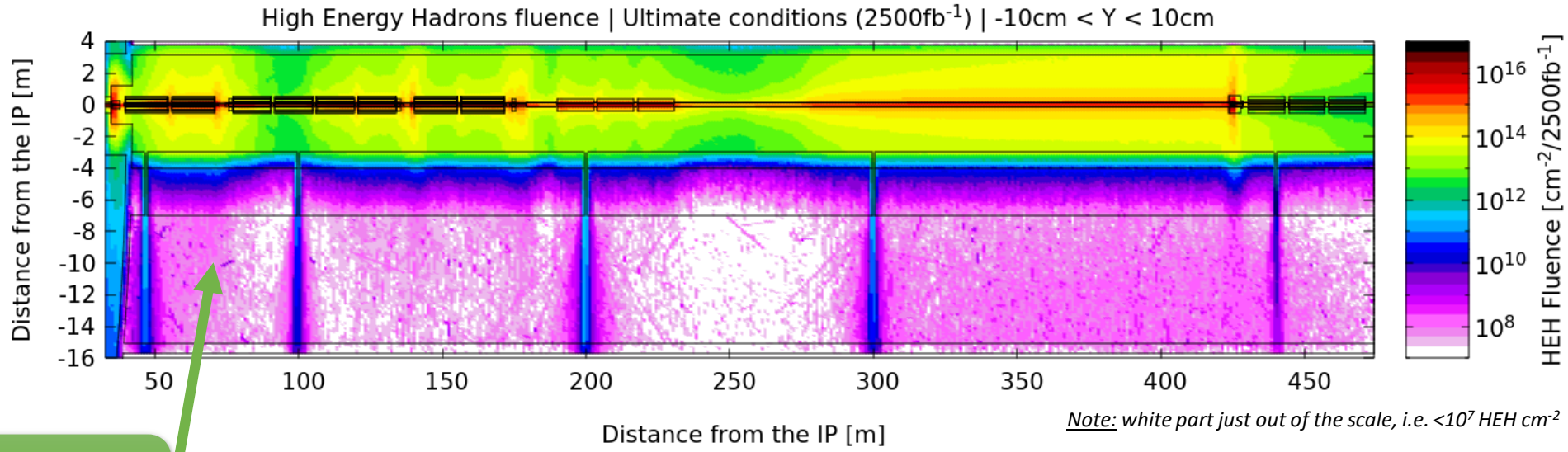
- A. Infantino et al., Monte Carlo Evaluation of Single Event Effects in a Deep-Submicron Bulk Technology: Comparison Between Atmospheric and Accelerator Environment. IEEE Transactions on Nuclear Science, Volume 64 , Issue 1 , Jan. 2017.
- A. Infantino. FLUKA Monte Carlo Modelling of the CHARM Facility's Test Area: Update of the Radiation Field Assessment. CERN-ACC-NOTE-2017-0059
- A. Infantino. R2E & RP FLUKA simulations for the CHARM cryocooler test. EDMS 1907770.
- D. Di Francesca, Dosimetry Mapping of Mixed Field Radiation Environment through Combined Distributed Optical Fiber Sensing and FLUKA Simulation. IEEE Transactions on Nuclear Science, In Press.
- A. Infantino et al., Radiation gradient evaluation at the CERN CHARM mixed-field facility using RPL, RadMON and FLUKA simulation. SATIF-14
- A. Infantino et al., Dose gradient assessment at the new CERN CHARM irradiation facility. Radiation Physics and Chemistry 155 (2019) 225–232.

❑ FCC

- 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.
- A. Infantino et al., *Radiation environment assessment in the Experimental Insertion Region and Betatron Cleaning*. FCC Week 2018.
- A. Infantino et al., Radiation environment assessment in the FCChh and FCCee machines. FCC Week 2018.
- A. Infantino et al., Energy deposition from collision debris in FCC-hh. 4th EuroCirCol meeting 2018.
- FCC CDR, In Press.

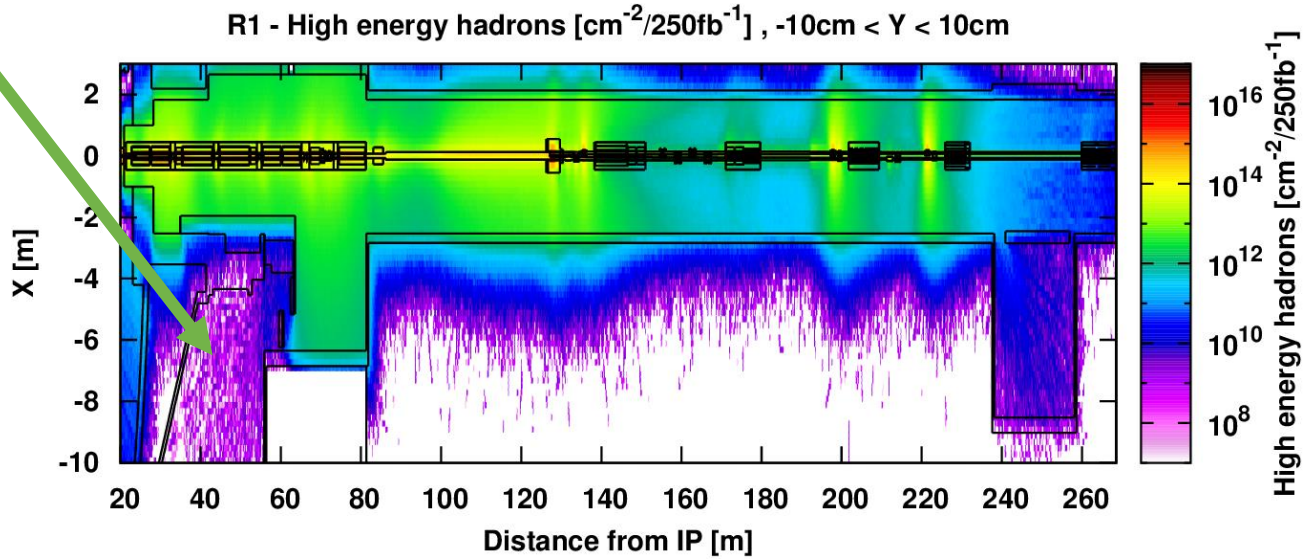
* Non-exhaustive list. Only the most up-to-date talks at the time of this presentation.
** Non-exhaustive list. RP-Week-related not included

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!!!

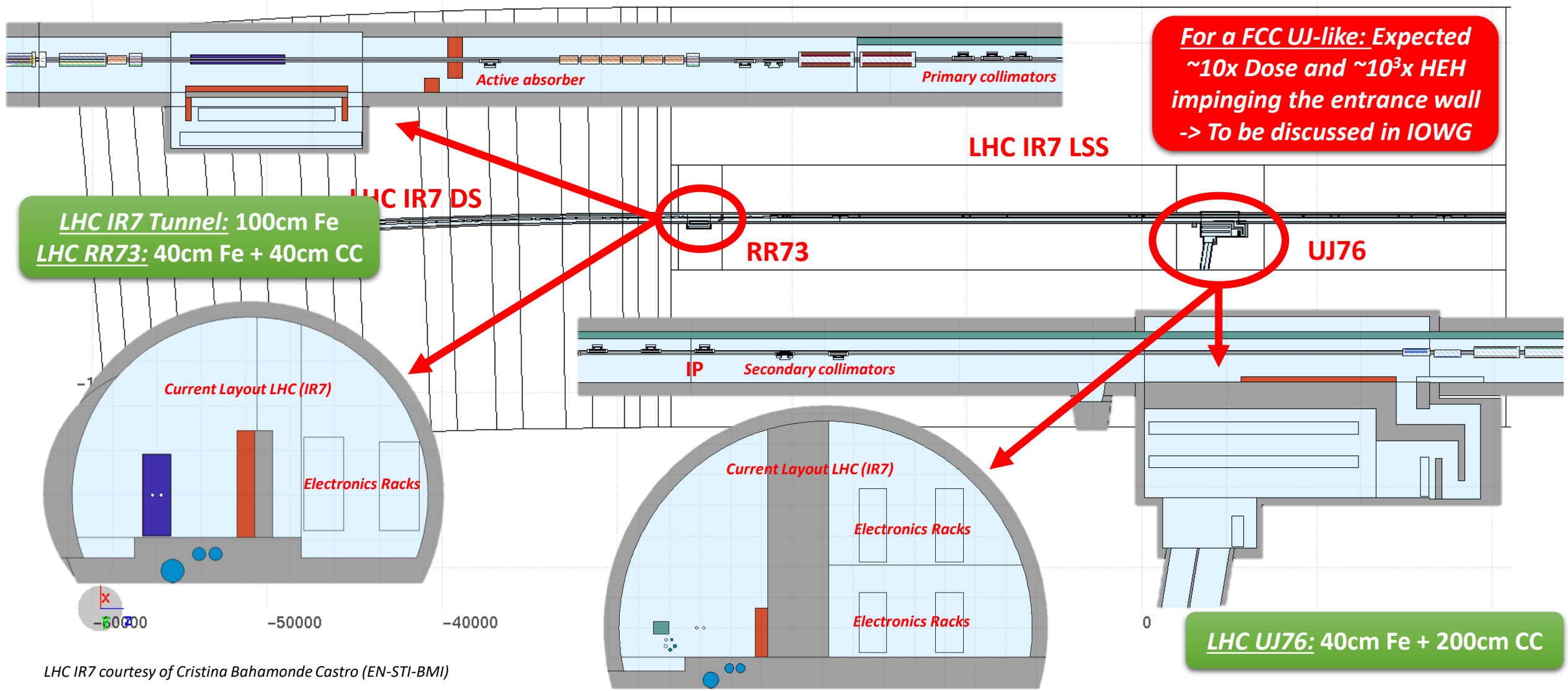


Disclosure:

*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 insertion (2018)



***For a FCC UJ-like:* Expected ~10x Dose and ~10^3x HEH impinging the entrance wall -> To be discussed in IOWG**

***LHC IR7 Tunnel:* 100cm Fe**
***LHC RR73:* 40cm Fe + 40cm CC**

***LHC UJ76:* 40cm Fe + 200cm CC**

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