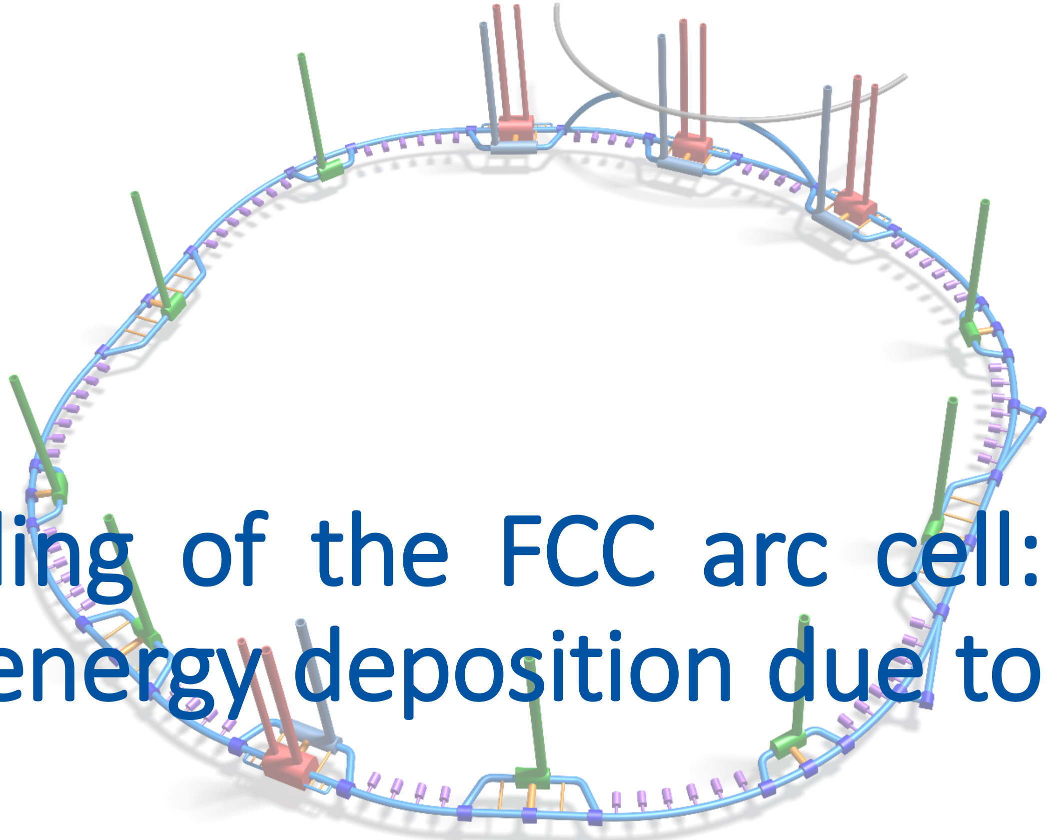
CERN



FLUKA Monte Carlo modelling of the FCC arc cell: radiation environment and energy deposition due to beam-gas interaction

Angelo Infantino, Maria Ilaria Besana, Francesco Cerutti, Markus Brugger

European Organization for Nuclear Research (CERN), Geneva, Switzerland

Outline

Introduction

FLUKA modelling

- **Tunnel & alcove**
- **Magnets**

Results

- **Radiation Levels**
- **Energy deposition**

Summary

Introduction: R2E studies applied to FCC

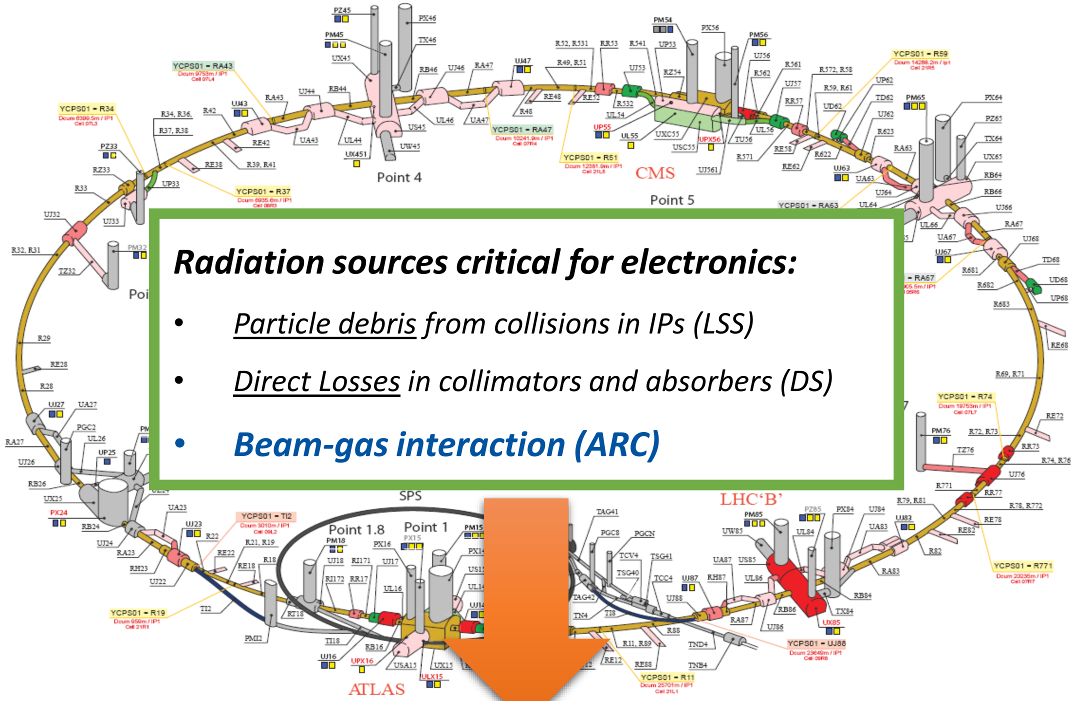
- Consists of *experts in various fields* related to electronics damage
- Coordinates studies to minimize all risks of radiation-induced failures at CERN accelerators
- The main goals of the R2E-oriented studies are:
  - ✓ *to define and quantify the effects of the radiation on the electronics*;
  - ✓ *to monitor and/or estimate the radiation levels in the concerned area*;
  - ✓ to test and develop radiation-hard or sufficiently tolerant electronics;
  - ✓ to implement mitigation options.

- *Integrated* in the R2E mission
- Based on the well-consolidated *experience from LHC*
- Study of the *radiation levels in critical areas* for electronics
- Extensive use of *FLUKA* Monte Carlo simulation

FCC
(Conceptual Design Report)
2018

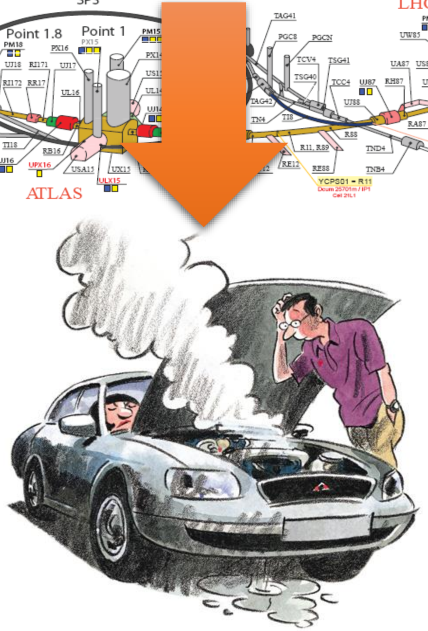
- *Increase FCC reliability* by factors to reach performance goals
- Design of *"optimized"* areas for electronics
- (First) Evaluation of the *requirements and constraints*
- Lifetime and choice of *critical components*

Introduction: R2E studies applied to FCC



Radiation sources critical for electronics:

- *<u>Particle debris</u> from collisions in IPs (LSS)*
- *<u>Direct Losses</u> in collimators and absorbers (DS)*
- ***Beam-gas interaction (ARC)***



Radiation Effects in Electronic Devices

Cumulative Effects

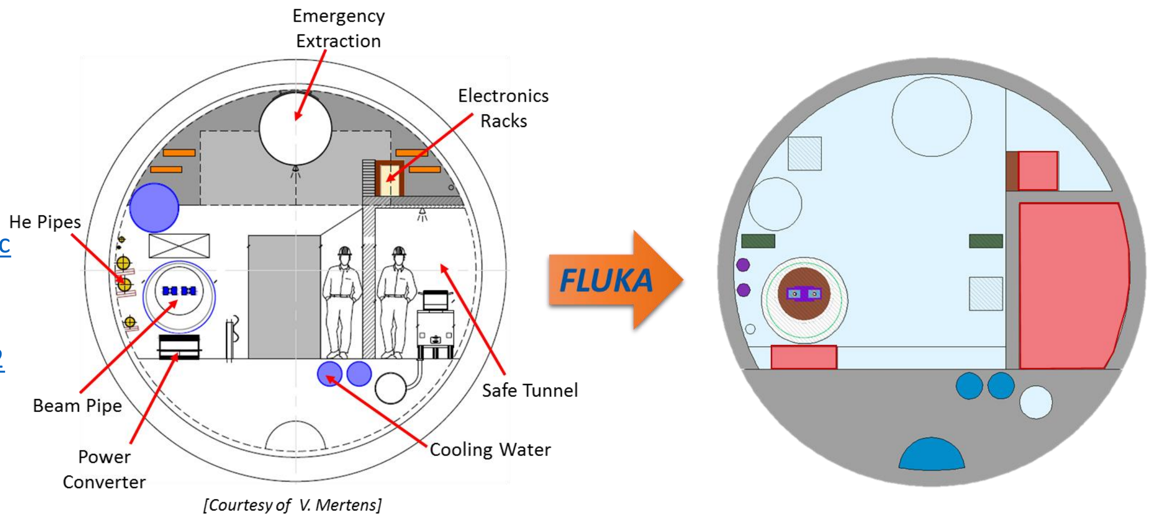
- ***Deterministic Effects***, Easy to predict
- Proportional to ***Total Ionizing Dose (TID)***
- LHC absolute values typically not critical (especially in shielded areas)
- Scaling of components positive for TID (smaller oxides)

Single Event Effects

- ***Stochastic Effects***, Hard to predict
- Proportional to ***High Energy Hadrons fluence***
- Absolute levels are high, even in shielded areas (neutrons)
- Most effects are constant with scaling but they can also increase (proton direct ionization, etc.)

Introduction & Aim

- ✓ Considerable amount of work done in 2016 within the FLUKA team in the FCC framework
  - o *Scaling form LHC data*
    https://indico.cern.ch/event/486275/contributions/1164475/subcontributions/197611/attachments/1282506/1906036/20160601_FCCScaling.pdf
  - o *FLUKA MC simulation of a full arc cell: Radiation Levels*
    https://indico.cern.ch/event/580163/contributions/2351810/attachments/1360751/2065629/20161103_FCC_Rad_Lev_ICRSup.pdf



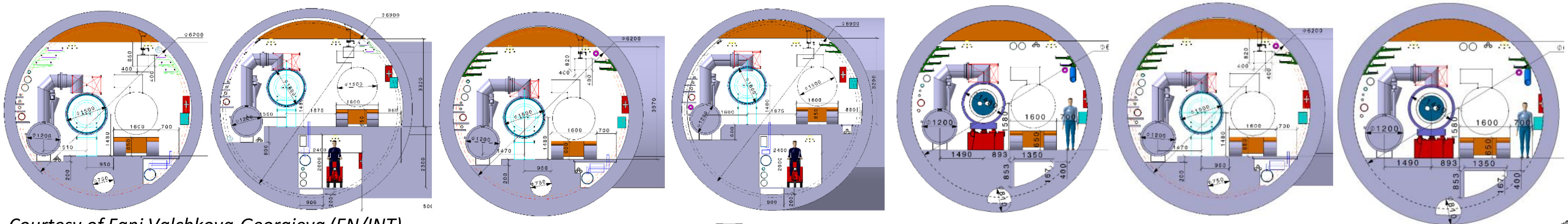
[Courtesy of V. Mertens]

AIM OF THE WORK

- ➢ Significant update of the infrastructure in 2017
- ➢ Assessment of different relevant quantities for the design of the arc:
  - ❑ *R2E: radiation levels in critical areas for electronics*
    - *Dose* -> Cumulative Effects
    - *Fluence*: p, K, π, μ, n, High Energy Hadrons (HEH, >20 MeV) -> SEE
  - ❑ *Magnet and Cooling*
    - *Peak power density*
    - *Total power* in the cold mass and beam screen
    - *Peak dose*

FCC FLUKA modelling: 2017 update

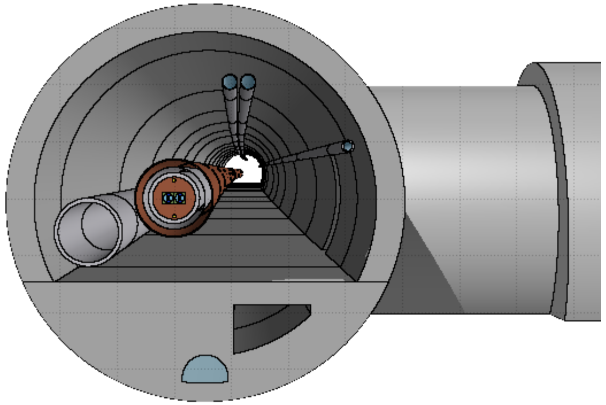
February 2017 | March 2017 | April 2017

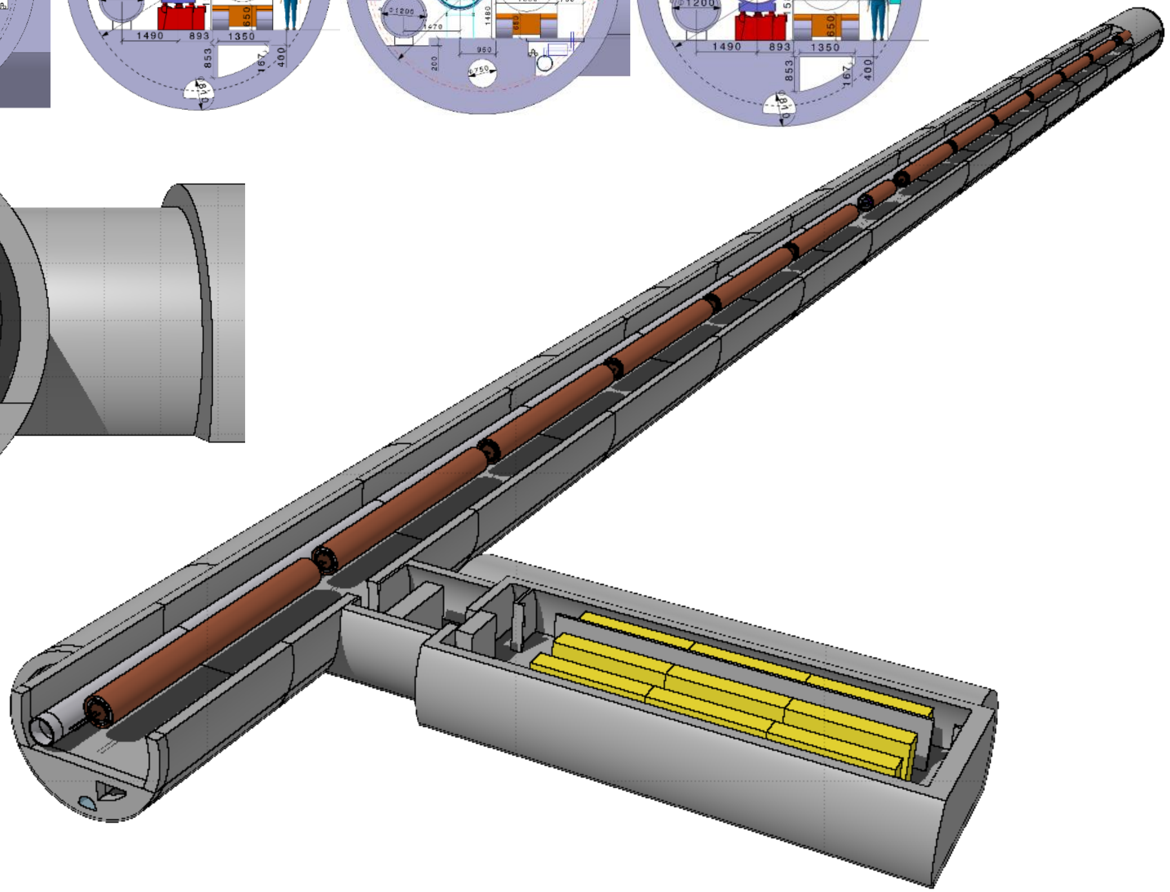


Courtesy of Fani Valchkova-Georgieva (EN/INT)

What's new?

- ➢ New layout of the *tunnel*
- ➢ First tentative layout of the *alcove*
- ➢ Up-to-date tentative *gas-density profile*
- ➢ Latest design of the *main dipole*

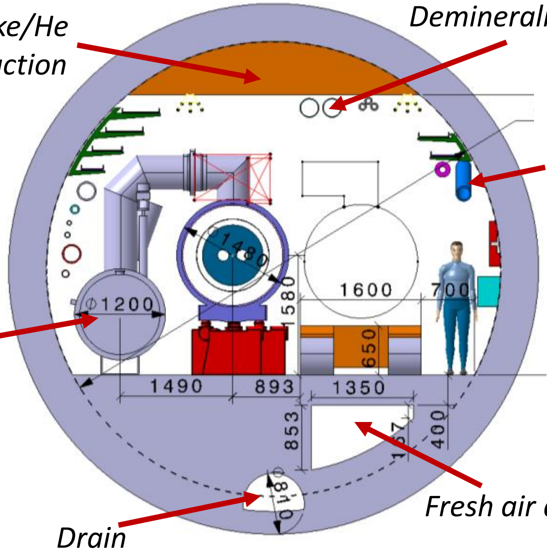


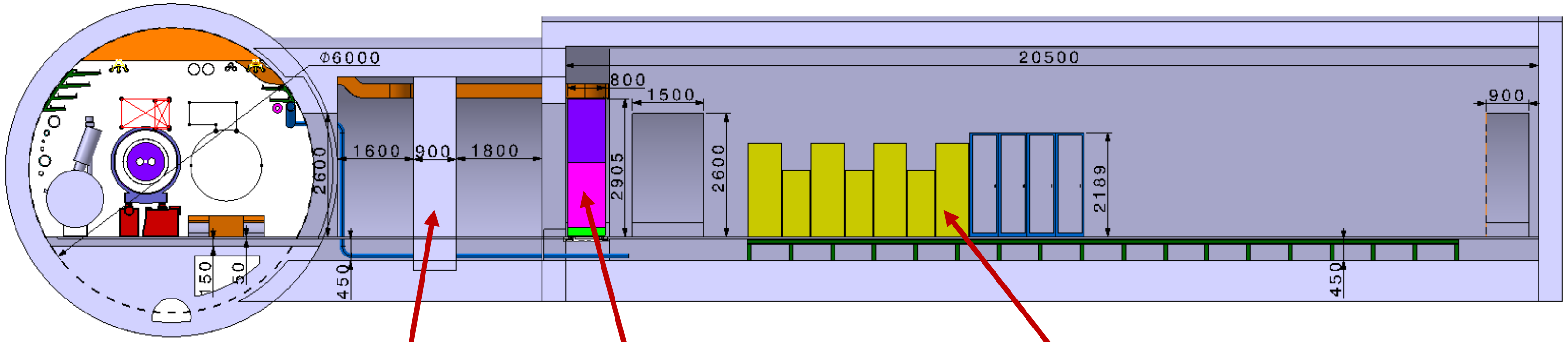


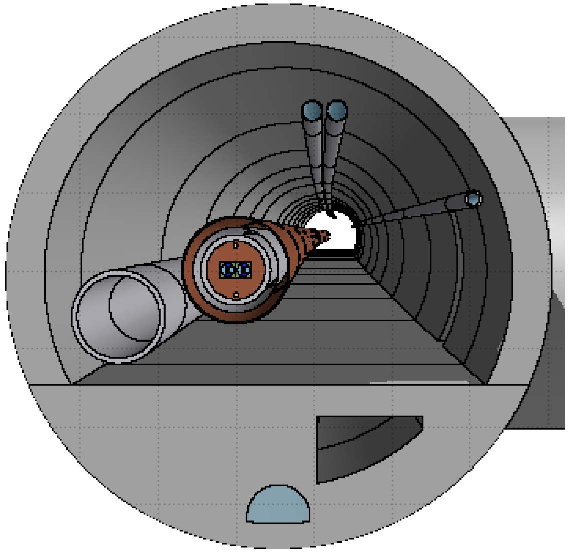
FCC FLUKA model

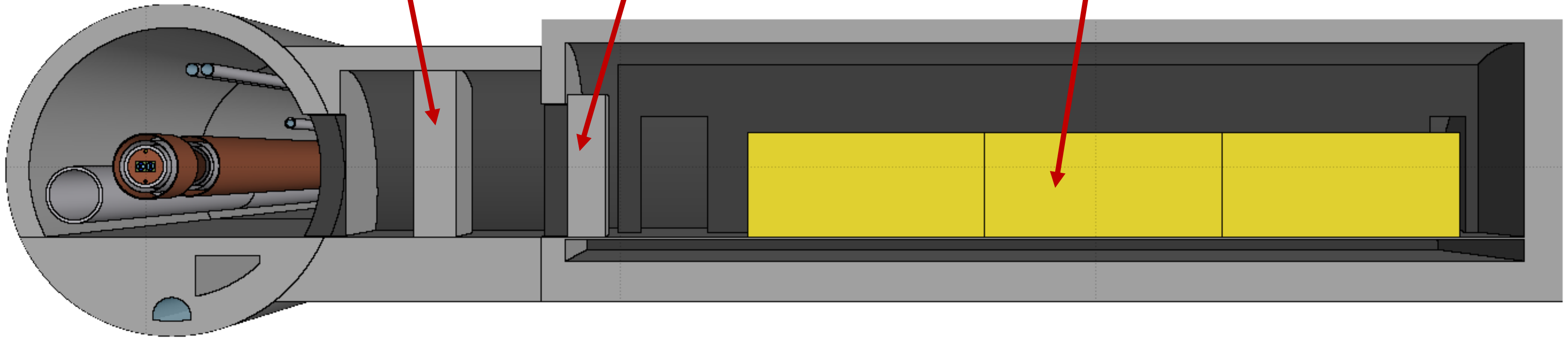
- ✓ *Full arc cell*: ϕ_{int}=6 m *single tunnel* + 21 m long *alcove*
- ✓ *12 dipoles* (14.3 m) + *2 quadrupoles* (6.3m); Total length *~213 m*
- ✓ (Tentative) *Gas-density profile* *[Courtesy of R. Kersevan]*
- ✓ *2x* Proton beam *50 TeV/c*
- ✓ Source term: *Beam-gas interaction*

Model of the arc cell: Tunnel & Alcove



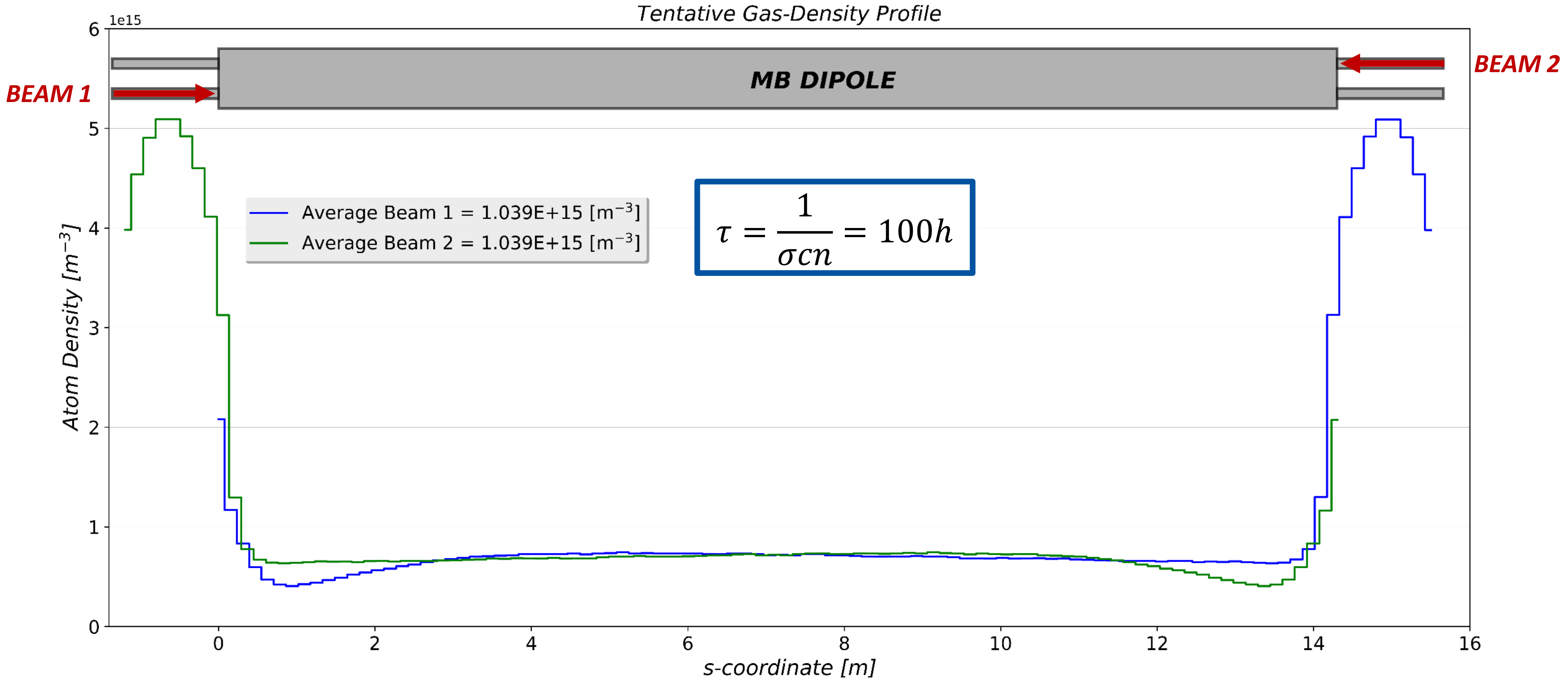






Original drawings courtesy of Fani Valchkova-Georgieva (EN/INT)

Tentative Gas-Density Profile



$$\tau = \frac{1}{\sigma c n} = 100h$$

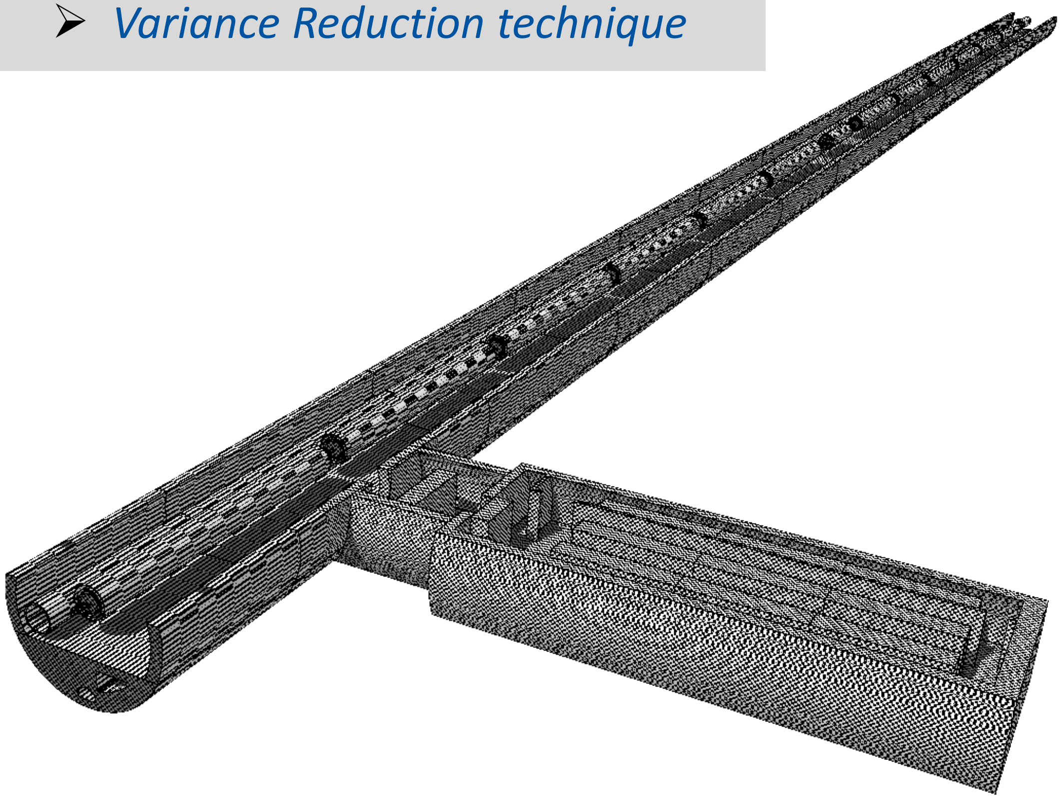
Gas-Density Profile: Courtesy of R. Kersevan & I. Bellafont (TE-VSC-VSM)

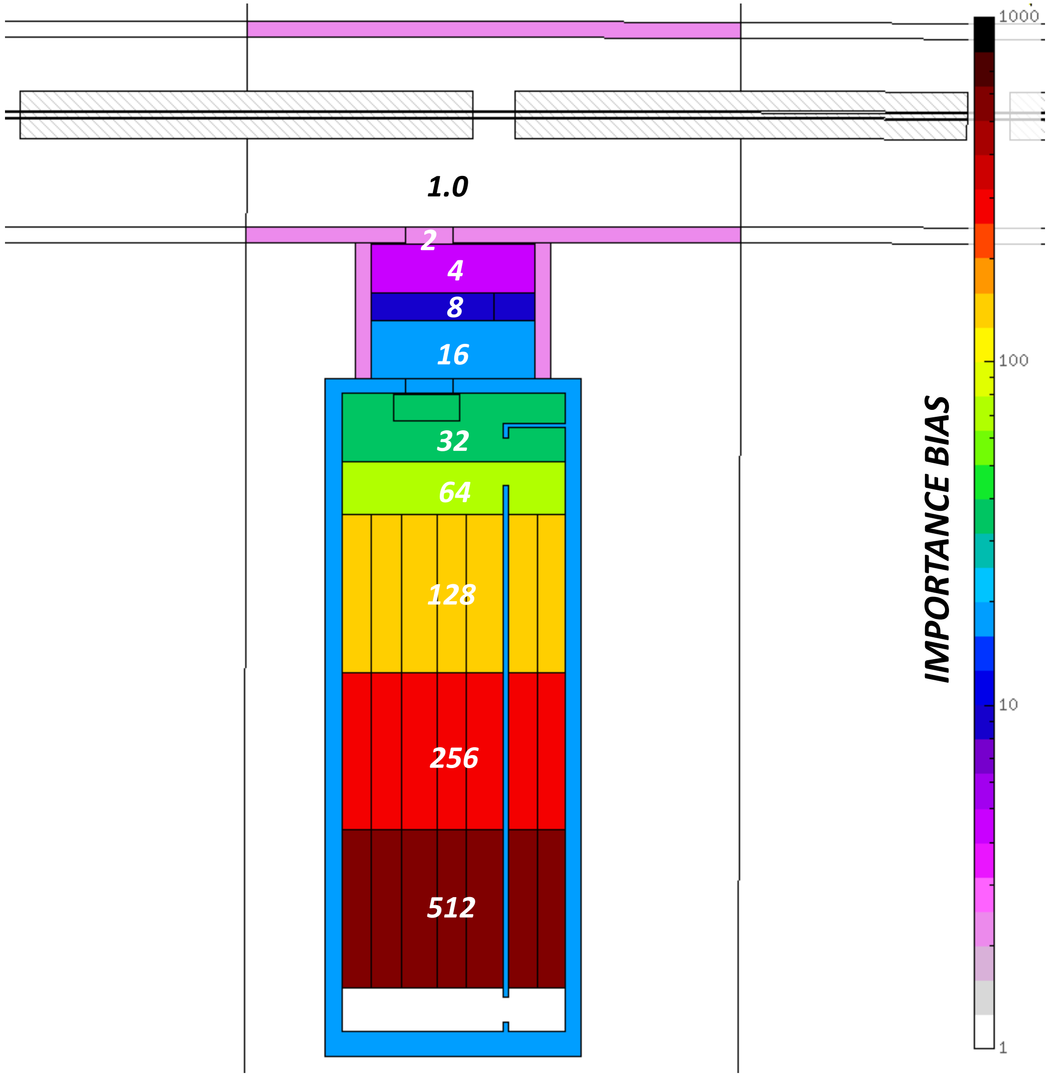
Radiation Levels in the FCC tunnel & alcove

Radiation Levels in the Tunnel

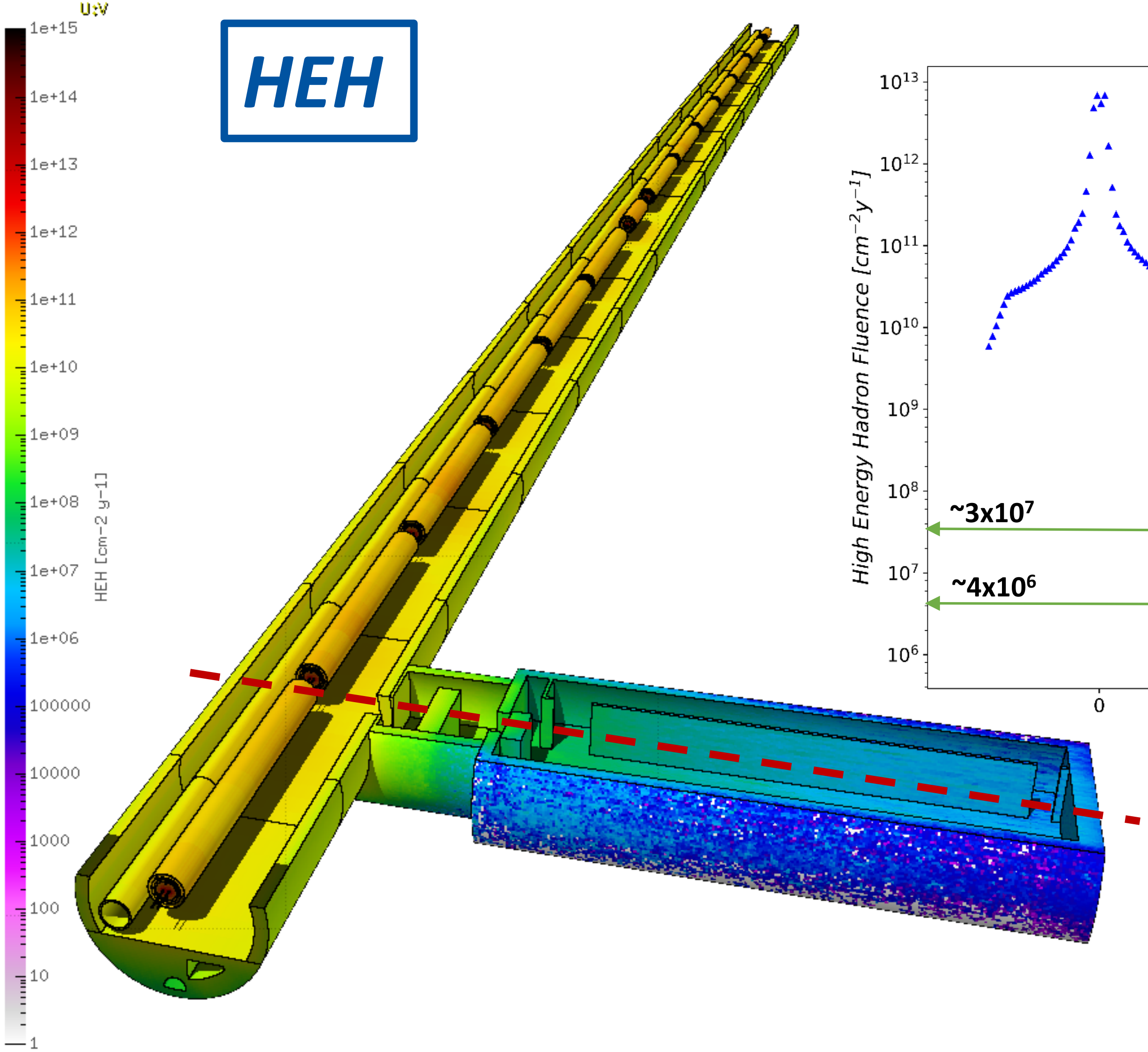
Scoring:

- HEH & DOSE: *tunnel & alcove*
- Cartesian mesh: *~3M elements*
- *Particle Spectra* in the alcove
- *Variance Reduction technique*

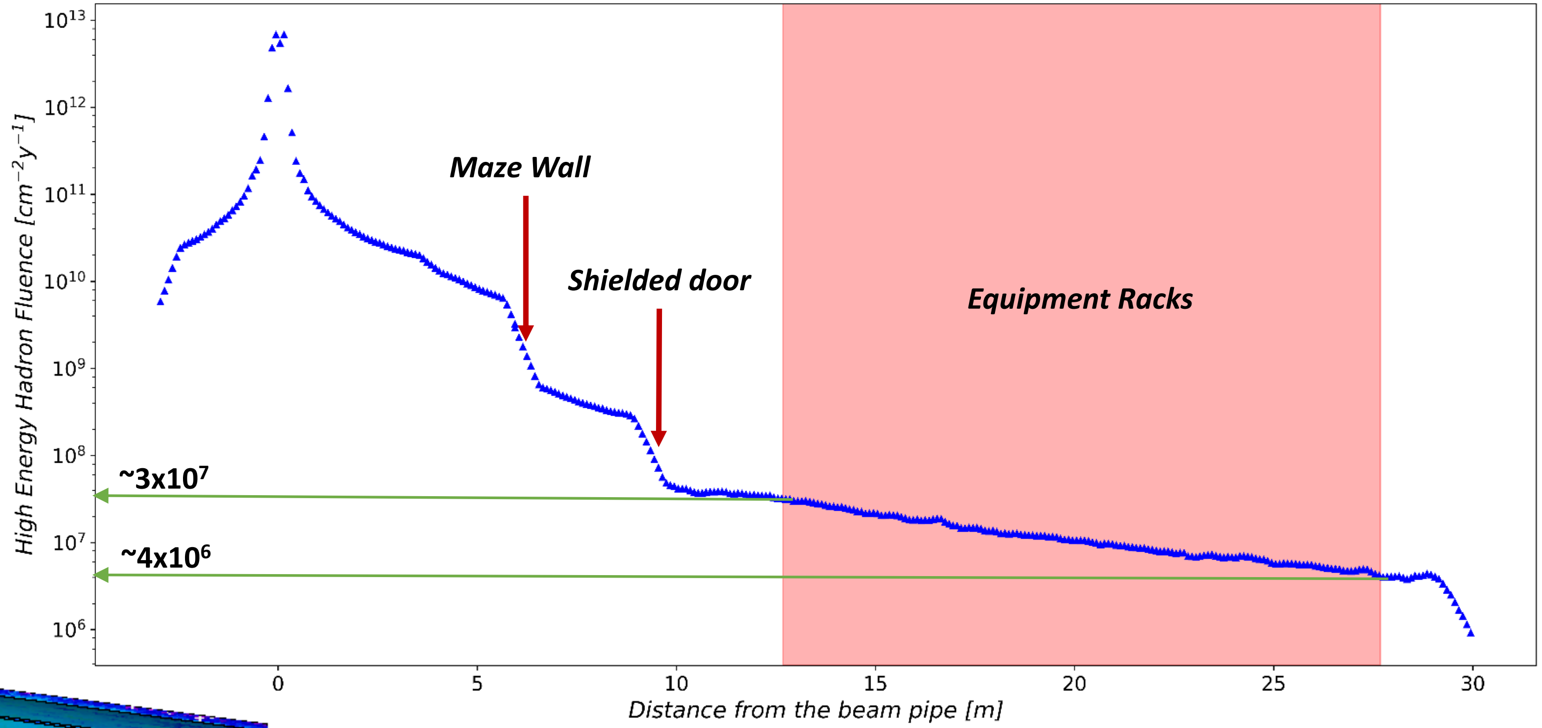




Radiation Levels in the Alcove



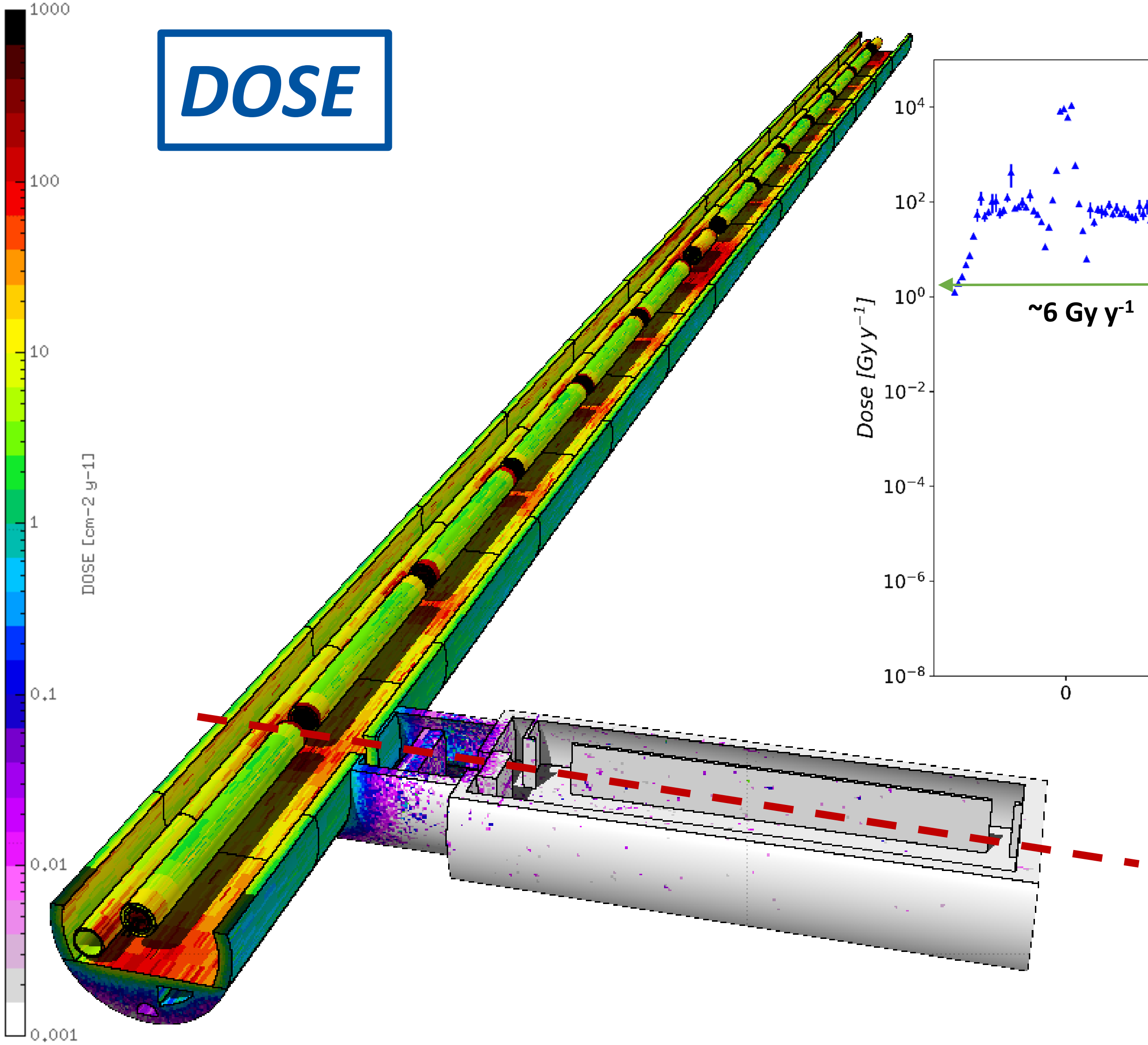
Note: 10^7 seconds in data taking – Statistical uncertainty < 5%



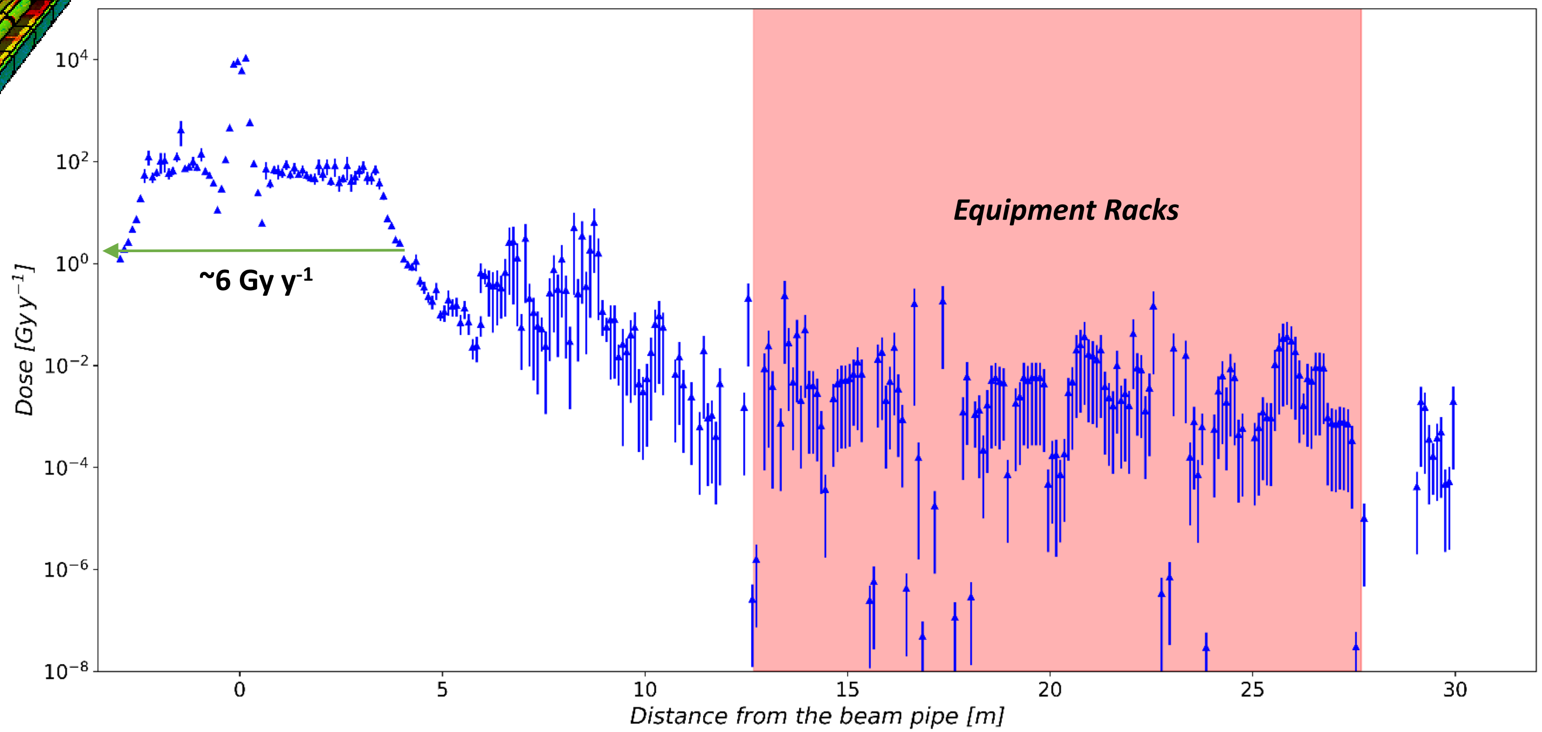
- ✓ Simulations *confirmed* the feasibility of the chicane-shielded door solution
- ✓ HEH fluence, *~3-4* LHC RE areas*
- ✓ *10^5 n/cm²/y* is the atmospheric neutron flux at ground level
- ✓ On going studies with RP for *finalizing the design* of the alcove shielding (thickness of the maze's wall, materials, etc)

**See LHC Project note 363*

Radiation Levels in the Alcove



Note: 10⁷ seconds in data taking

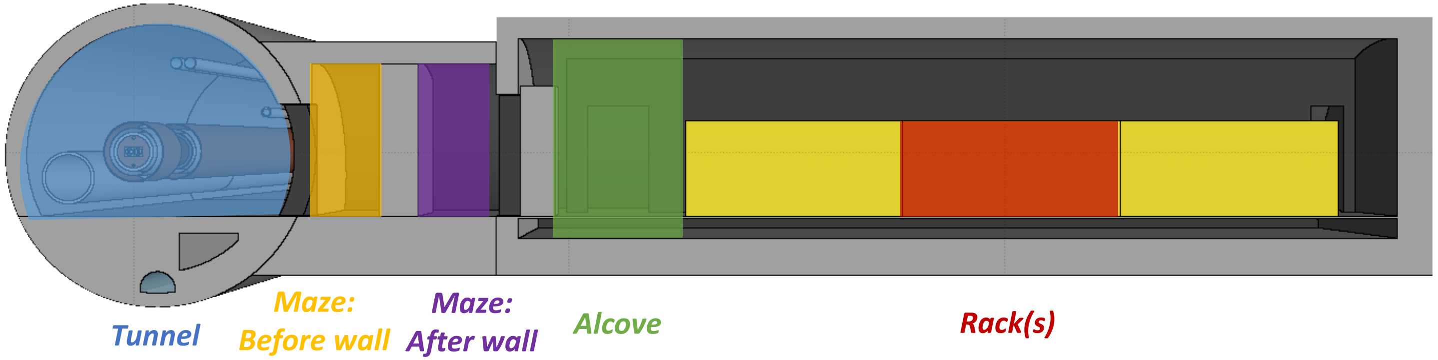


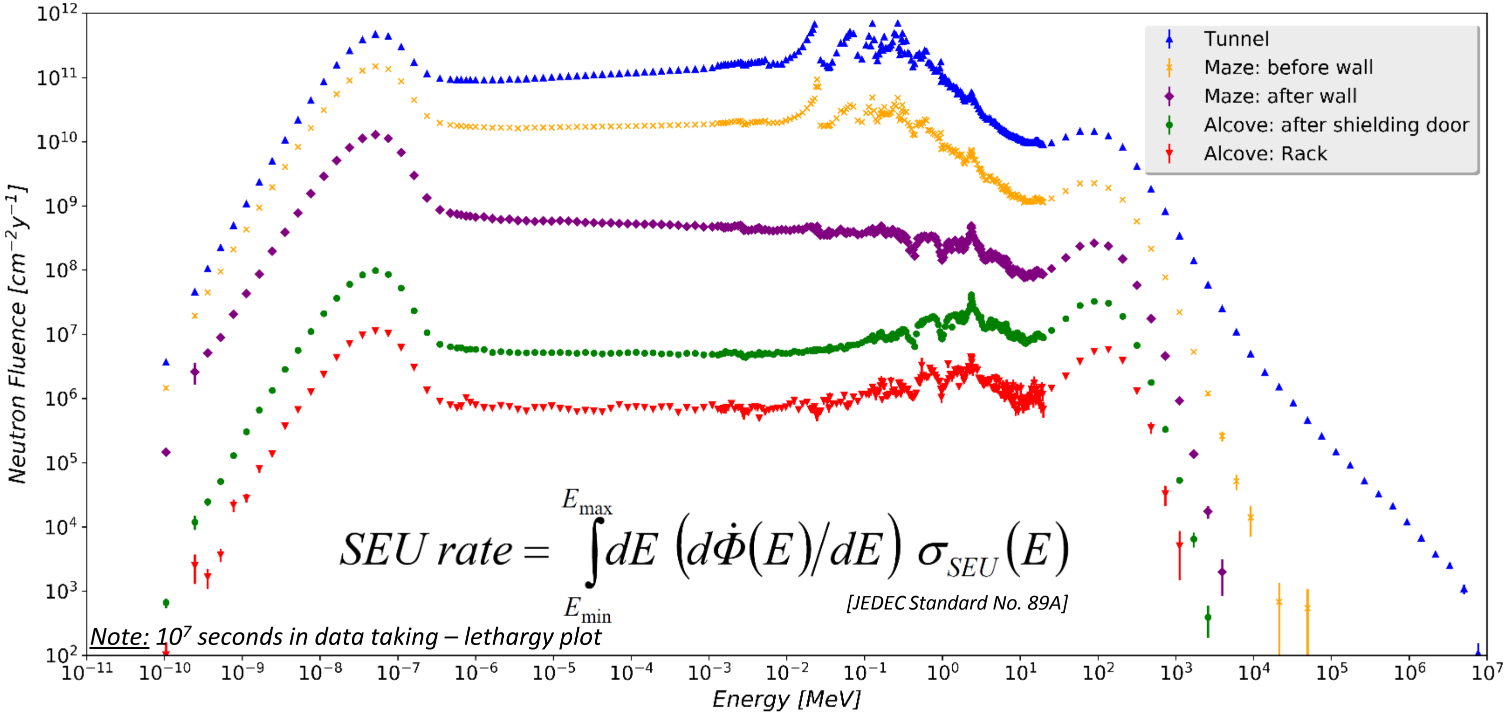
PRELIMINARY

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

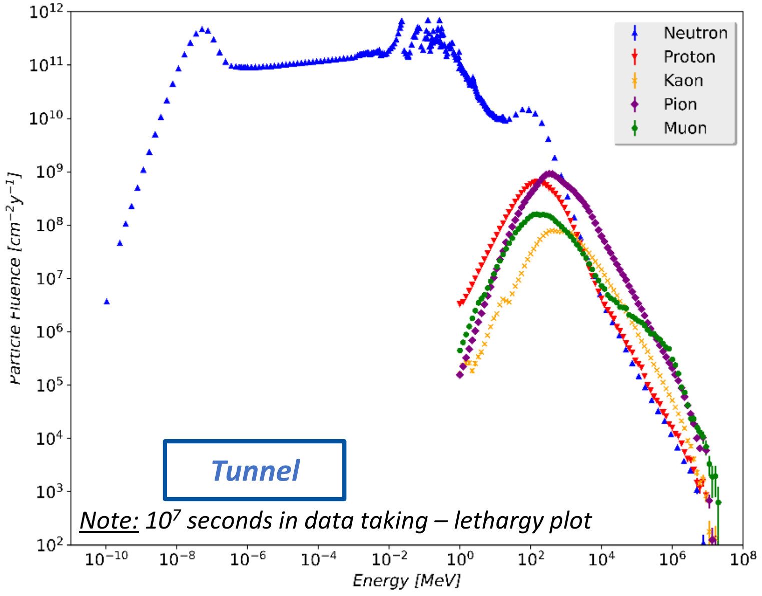
**See LHC Project note 363*

Radiation Levels in the Alcove



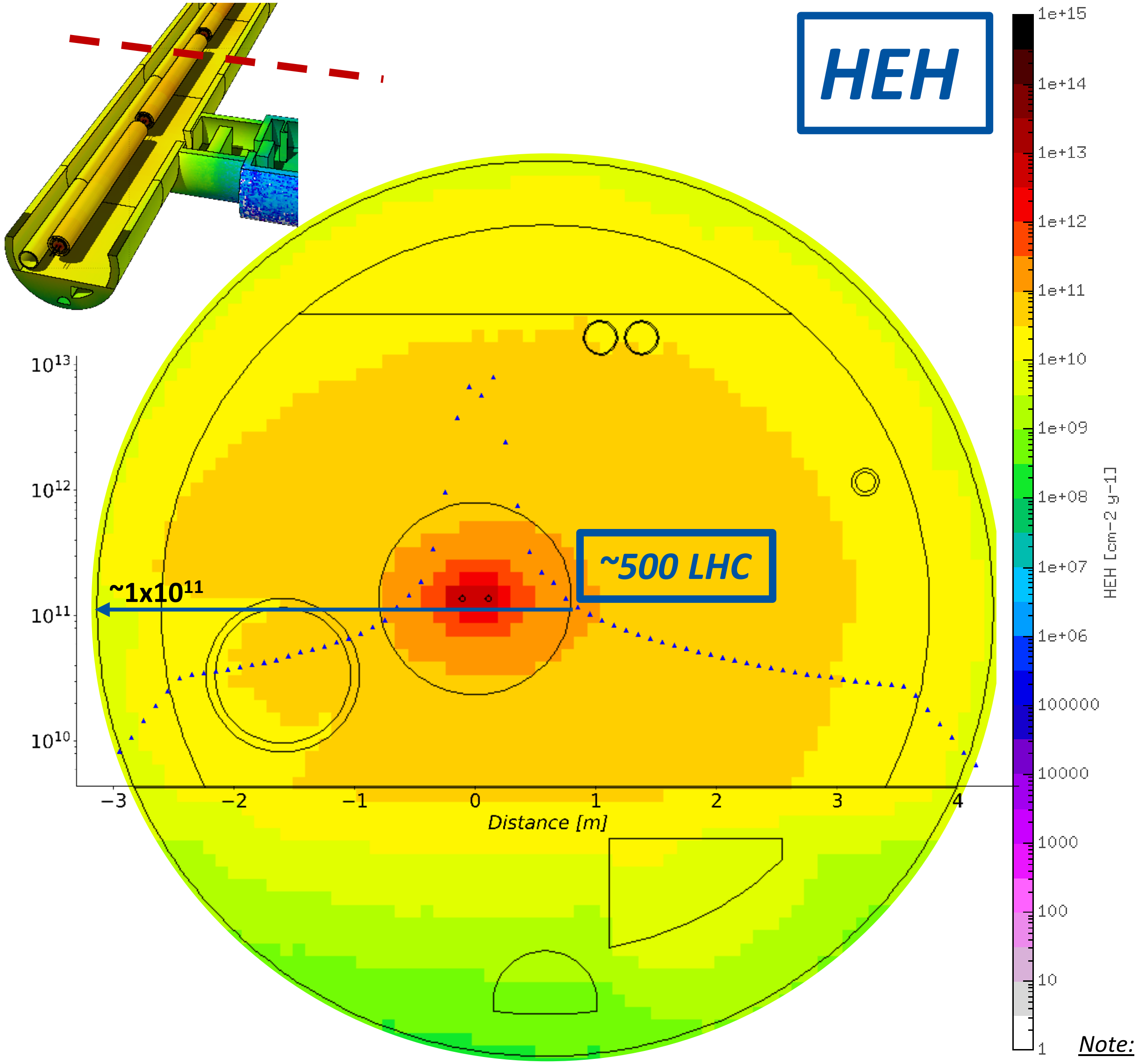


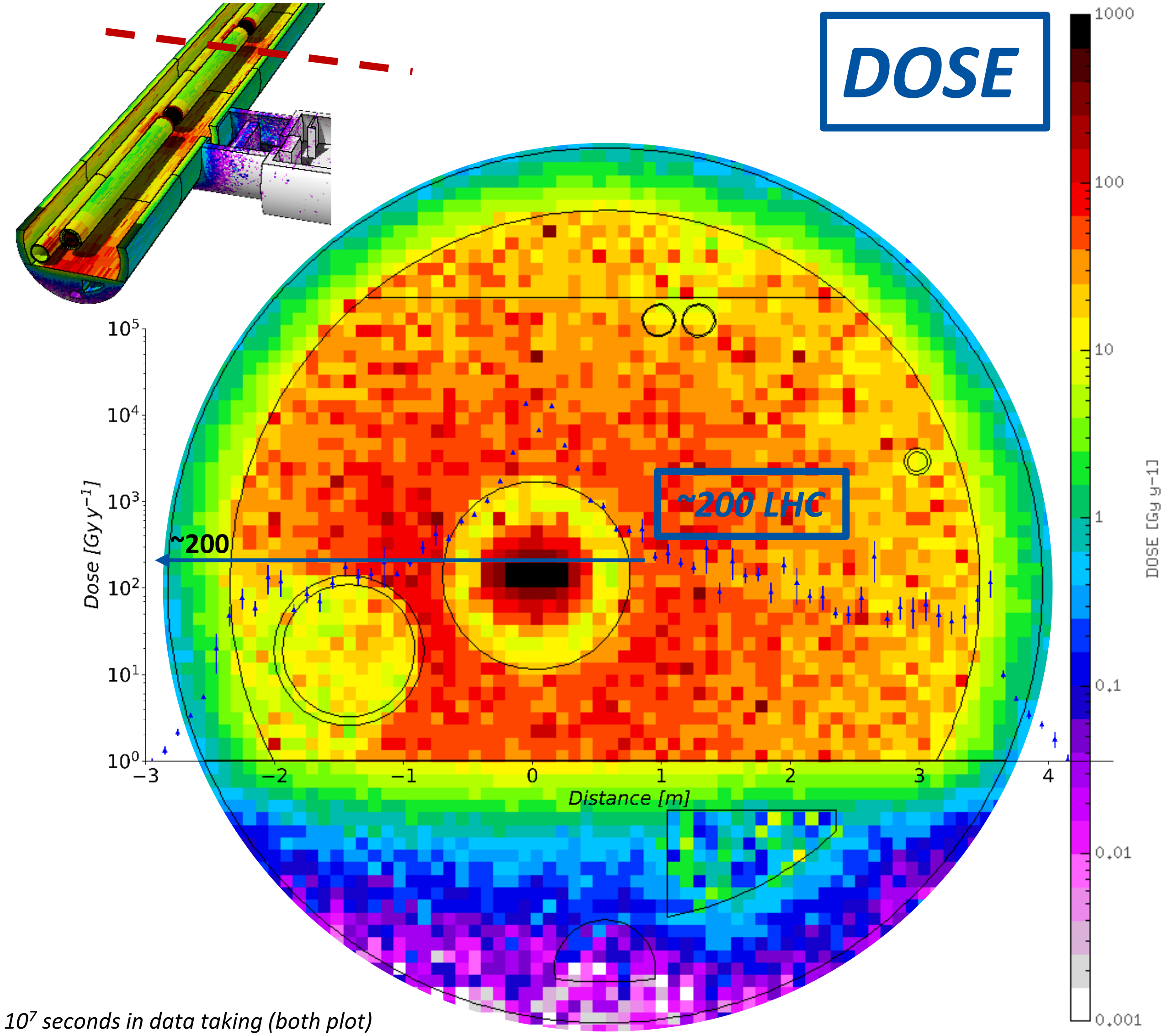
$$SEU\ rate = \int_{E_{min}}^{E_{max}} dE \left(d\dot{\Phi}(E)/dE \right) \sigma_{SEU}(E)$$



- ✓ *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*

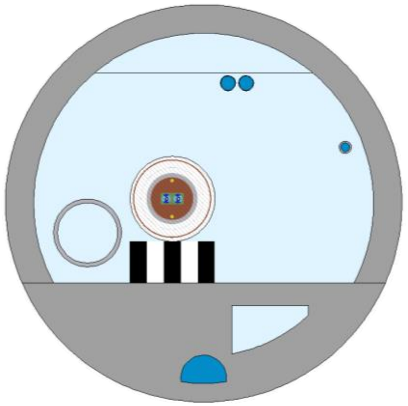
Radiation Levels in the Tunnel

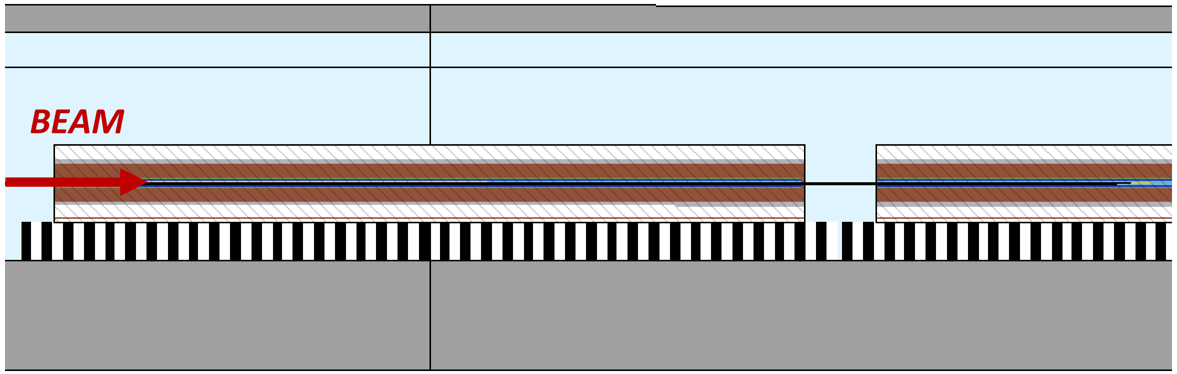




Note: 10^7 seconds in data taking (both plot)

Radiation Levels in the Tunnel

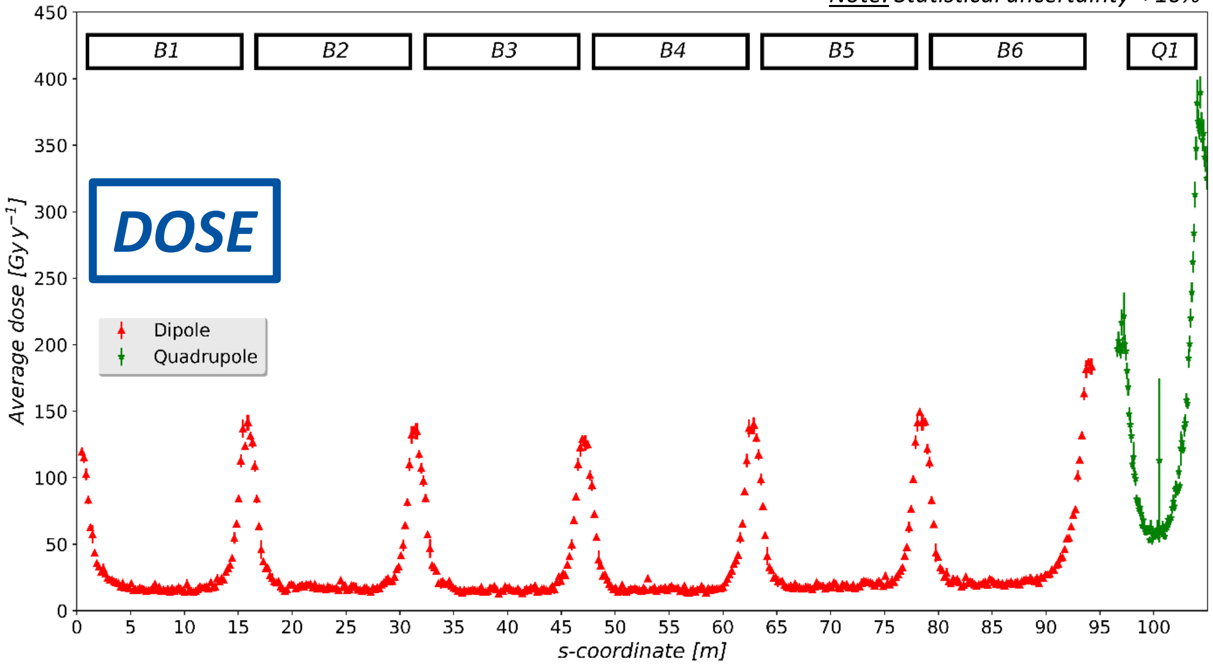




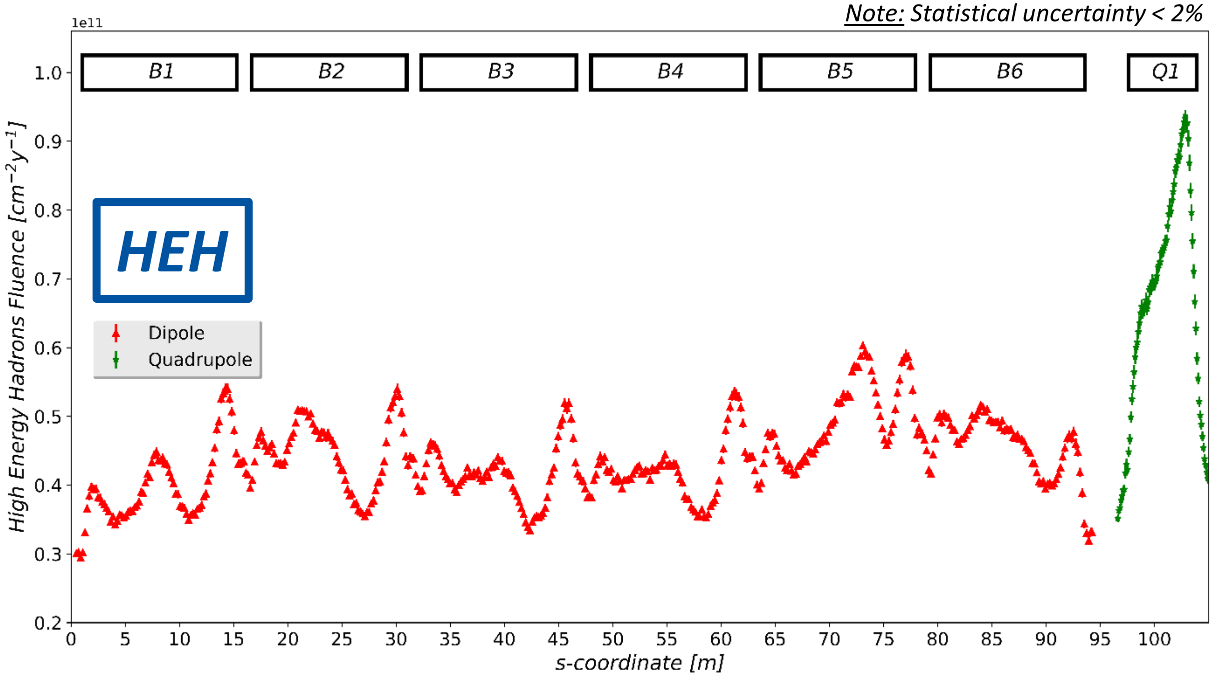
Scoring:

- *Average HEH & DOSE profile*
- Cartesian mesh: *power converter location*
- Normalization: *10^7 s data taking*

<u>Note:</u> *Statistical uncertainty < 10%*



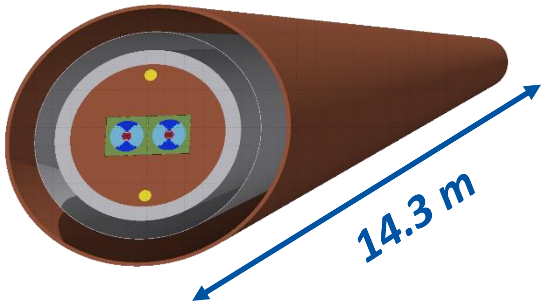
<u>Note:</u> *Statistical uncertainty < 2%*

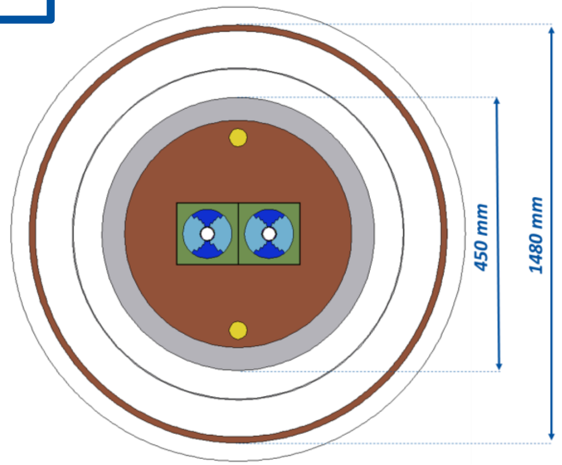


Energy Deposition in the Magnets

MB and MQ magnet

MB

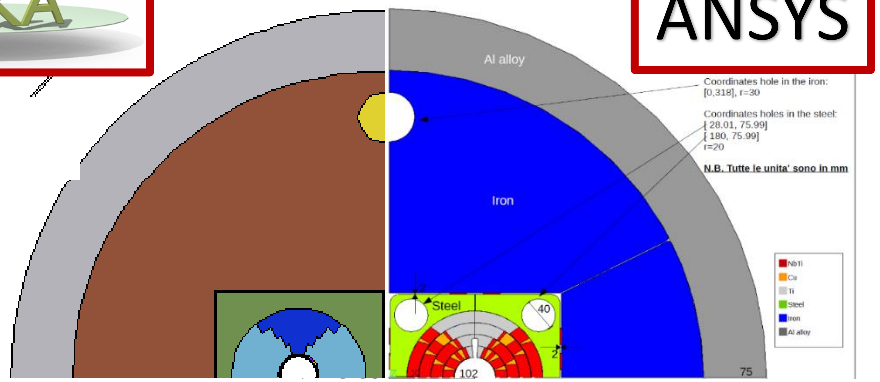




Cryostat design courtesy of Valentina Venturi (TE-MSC-CMI)

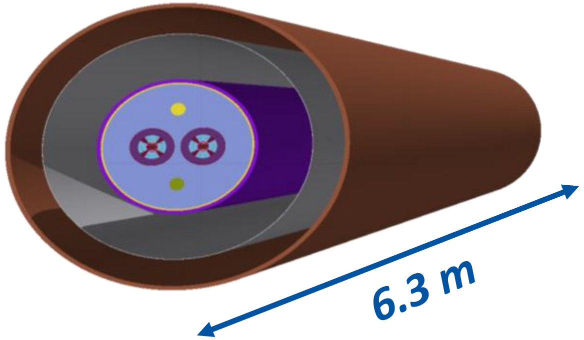
FLUKA

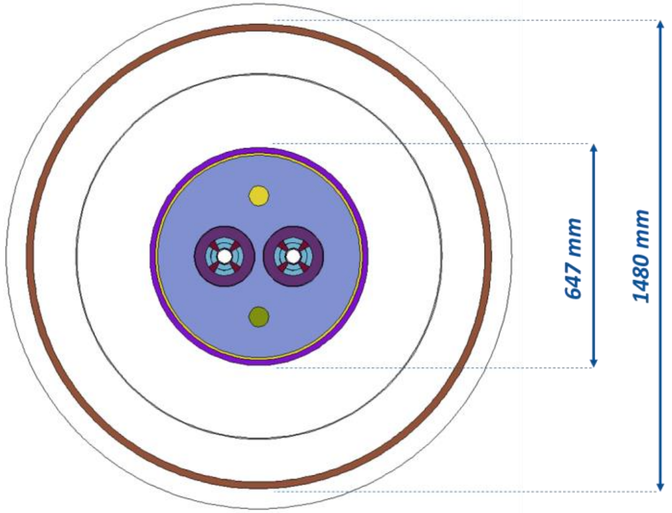
ANSYS



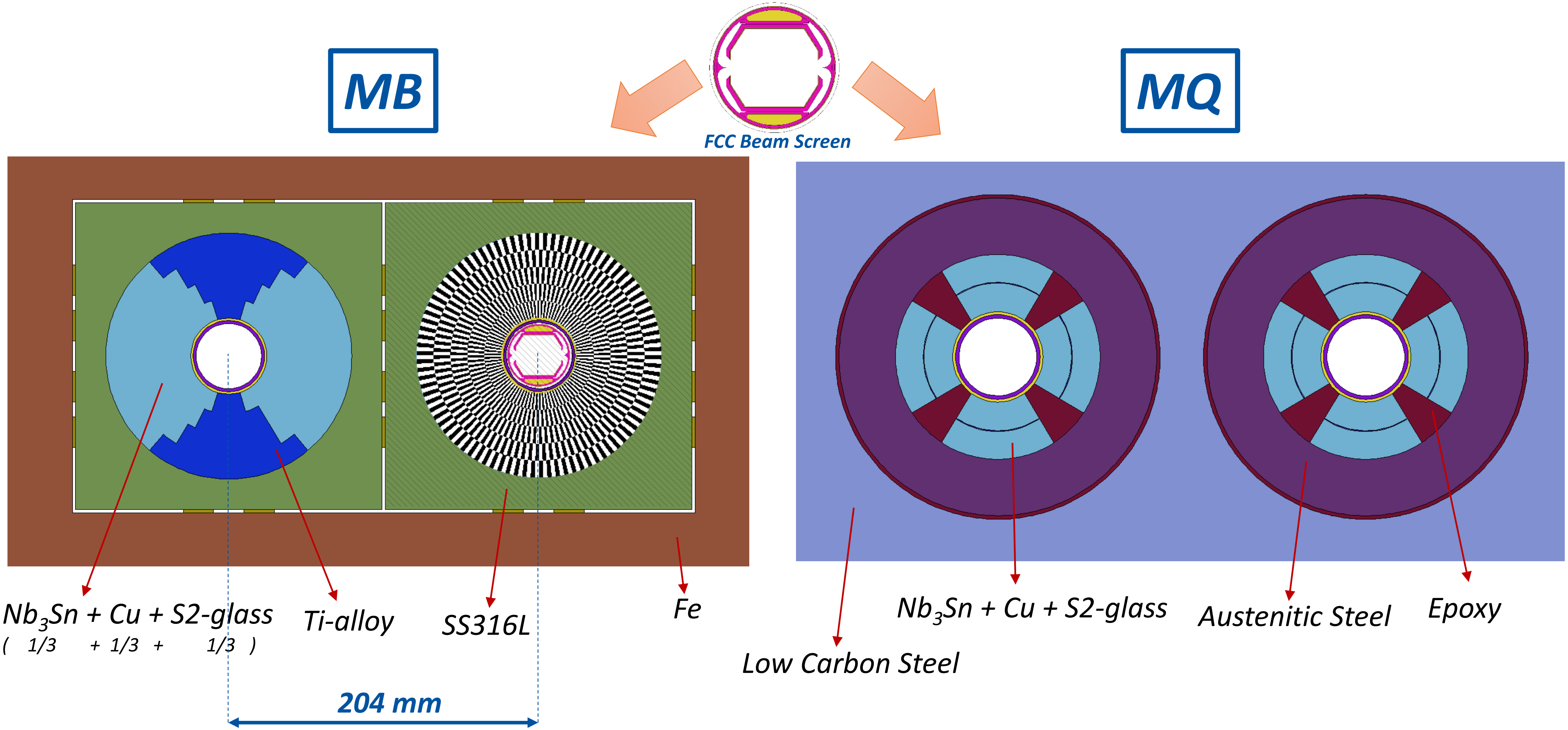
Magnet design: courtesy of B. Caiffi (INFN-GE) & D. Schoerling (TE-MSC-MNC)

MQ

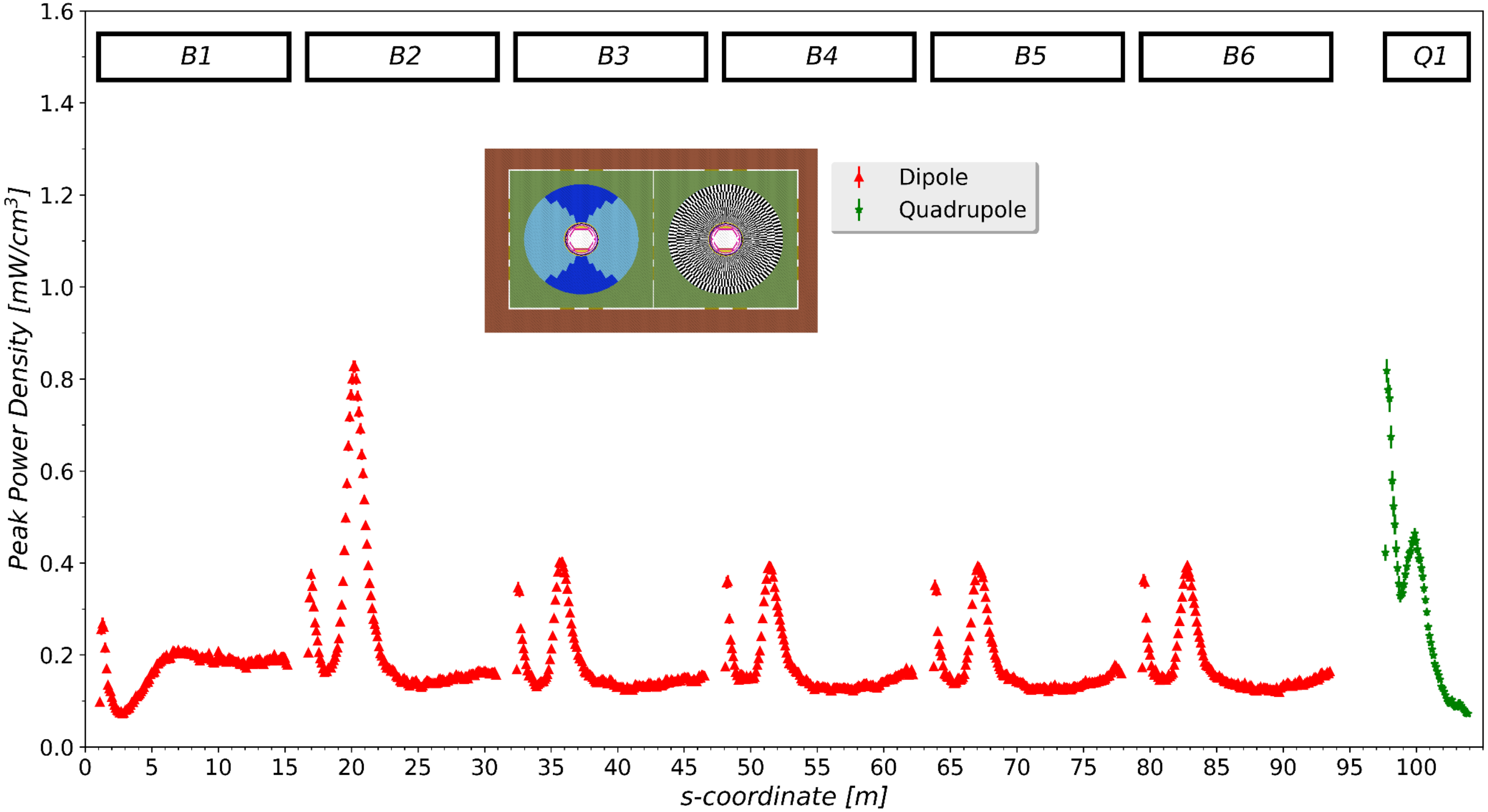




MB and MQ coils



Energy deposition on MB and MQ coils



Note: Beam 1 – Estimated quench limit for Nb_3Sn: 40 mW/cm^3

Energy deposition on MB and MQ coils

Total Power [W]

BEAM 1

Magnet	Cold Mass	Beam Screen
B1	2.73	0.48
B2	3.69	0.83
B3	2.79	0.60
B4	2.78	0.60
B5	2.76	0.59
B6	2.77	0.59
Q1	1.30	0.31
B7	2.47	0.42
B8	3.57	0.80
B9	2.74	0.59
B10	2.72	0.59
B11	2.70	0.58
B12	2.71	0.58
Q2	1.31	0.32

Note: Beam 1 (0.5 A)

Average power loss per unit arc-cell length:
~233 mW/m

Total Power [W]

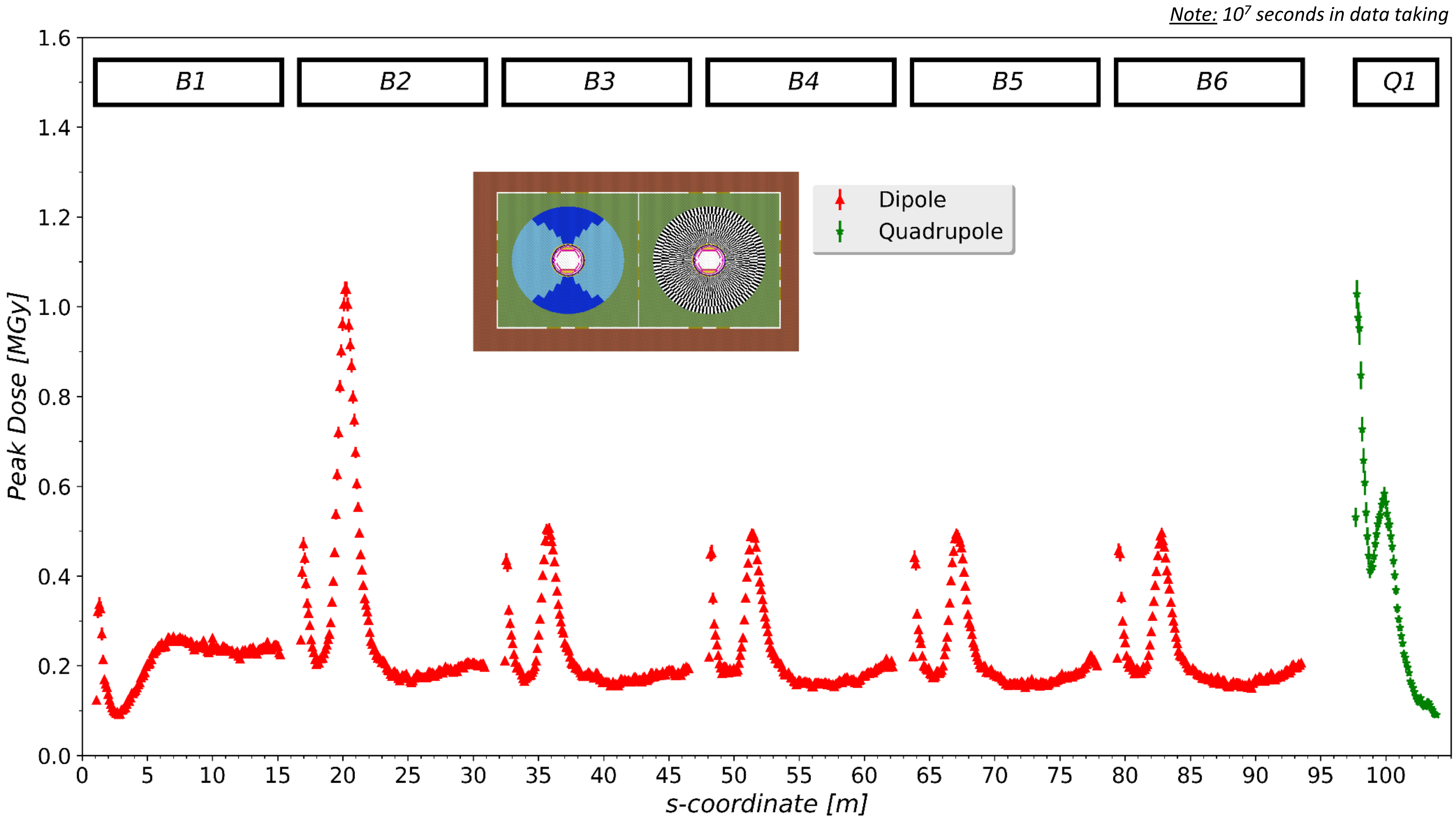
BEAM 1 / BEAM 2

Magnet	Cold Mass	Beam Screen
B1	5.31	1.05
B2	6.43	1.41
B3	5.57	1.19
B4	5.62	1.21
B5	6.72	1.49
B6	5.81	1.13
Q1	2.34	0.53
B7	5.05	0.99
B8	6.22	1.36
B9	5.43	1.16
B10	5.46	1.17
B11	6.48	1.43
B12	5.38	1.04
Q2	2.31	0.53

Note: Beam 1 & 2 (1.0 A)

Average power loss per unit arc-cell length:
~466 mW/m

Energy deposition on MB and MQ coils



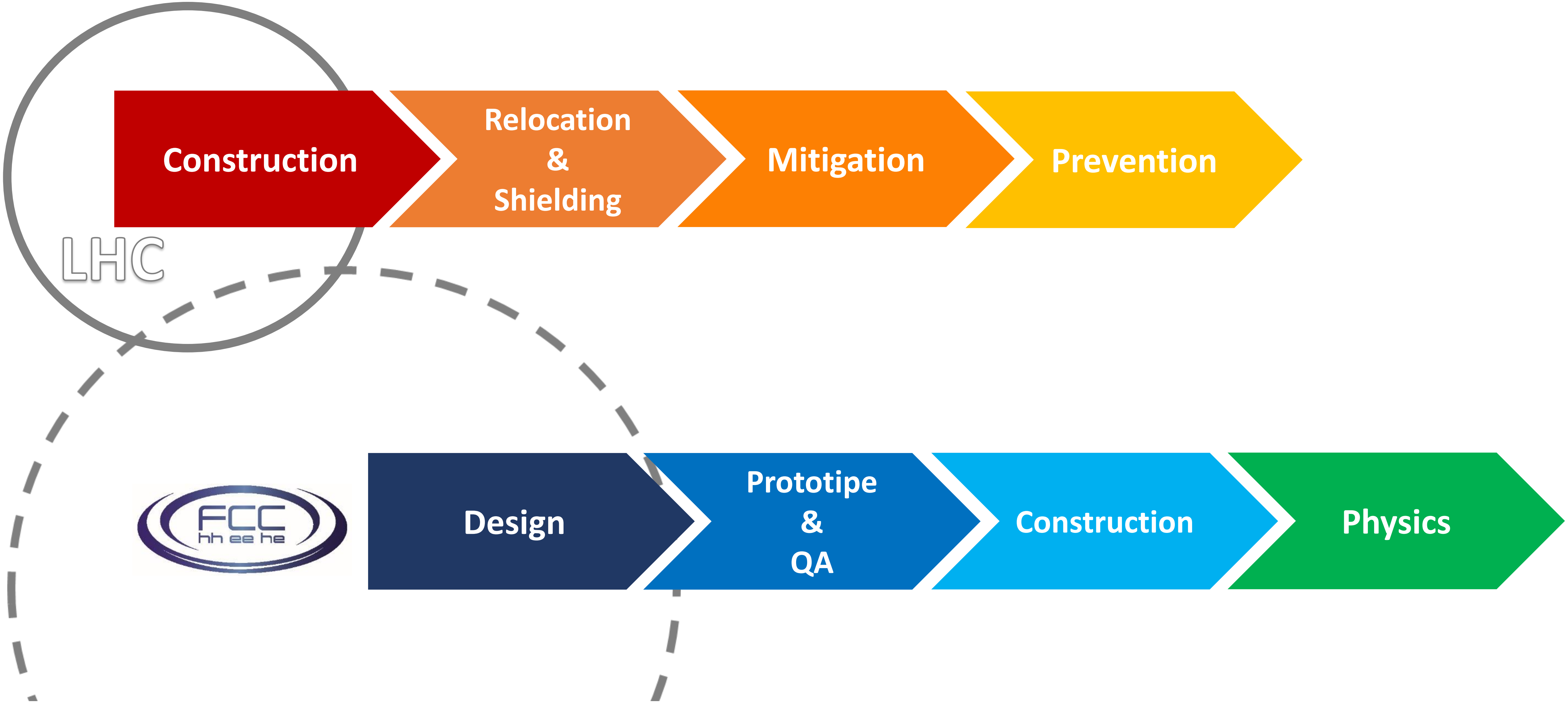
Note: Beam 1 – Baseline SC magnets dose limit: 30 MGy

Summary

Take-Home Message:

- ✓ *Consolidated* experience within the FLUKA team in the evaluation of the *radiation levels* in critical areas for electronics as well as the *radiation load* for magnets
- ✓ *FLUKA* simulation allow for an *accurate modelling of the particle transport at (very) high energy* taking into account all the physics effects, the source term (*Beam-gas interaction*) and the actual geometry of the infrastructures & magnet/coils
- ✓ *Radiation levels* in critical areas for electronics
  - ❑ *DOSE (long term effects):*
    - Tunnel: factor *~200* LHC (power converter locations)
    - Alcove: factor *~3-6* LHC RE areas at the entrance of the maze, more efforts needed for the rack locations
  - ❑ *High Energy Hadrons (Single Event Effects):*
    - Tunnel: HEH *~500* LHC
    - Alcove: HEH *~3-4* LHC RE areas, *neutrons* dominate the particle environment
- ✓ *Radiation load* for the magnets:
  - ❑ Peak power density: max value *~0.85 mW/cm^3* (*<<<* estimated quench limit for *Nb_3Sn*)
  - ❑ Total Power: 2nd and 8th are the most stressed magnets
  - ❑ Peak dose: *~1.1 MGy* in one year of operation (*<<<* baseline dose limit for *SC magnets*)

Summary



Construction
Relocation & Shielding
Mitigation
Prevention
LHC
FCC hh ee he
Design
Prototipe & QA
Construction
Physics

Angelo Infantino

Fellow @ CERN - EN/STI-FDA
R2E Project
angelo.infantino@cern.ch

Special acknowledge to:

Rubén García Alía (EN-STI-FDA), Volker Mertens (TE), Fani Valchkova-Georgieva (EN/INT), Roberto Kersevan (TE-VSC-VSM), Ignasi Bellafont (TE-VSC-VSM), Daniel Schoerling (TE-MSC-MNC), Barbara Caiffi (INFN-GE), Valentina Venturi (TE-MSC-CMI), Davide Bozzini (EN-EL-DDO), Maria Mylona (EN-EL-DDO), Markus Widorski (HSE-RP-AS), and more…