Magnet Energy Deposition Studies for the LHC Luminosity Upgrade

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Fermilab

High Luminosity LHC

DOE LARP Review
July 9-10, 2012

LARP

OUTLINE

- WP10 Mission and Tasks
- Optics, Magnets and Assumptions
- MARS Developments and HL IR Modeling
- MARS/FLUKA Results for 140-mm ID Quad IR
- Peak Power Density and Dose; Possibilities for Their Reduction
- Dynamic Heat Loads
- Summary and Plans

Mission

DOE Review of June 2011, comment on magnet systems:

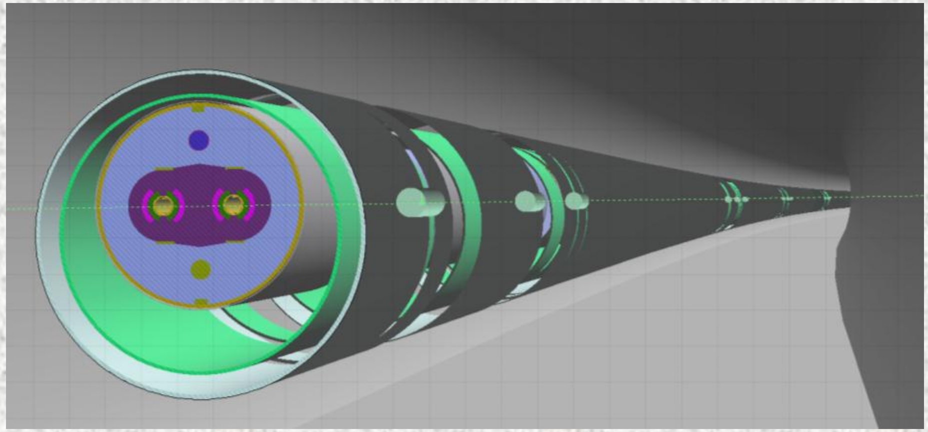
"The effect of beam losses and radiation damage within the magnets is critically important to the operation and performance of the magnet systems, and these effects must be taken into account in the magnet design and construction".

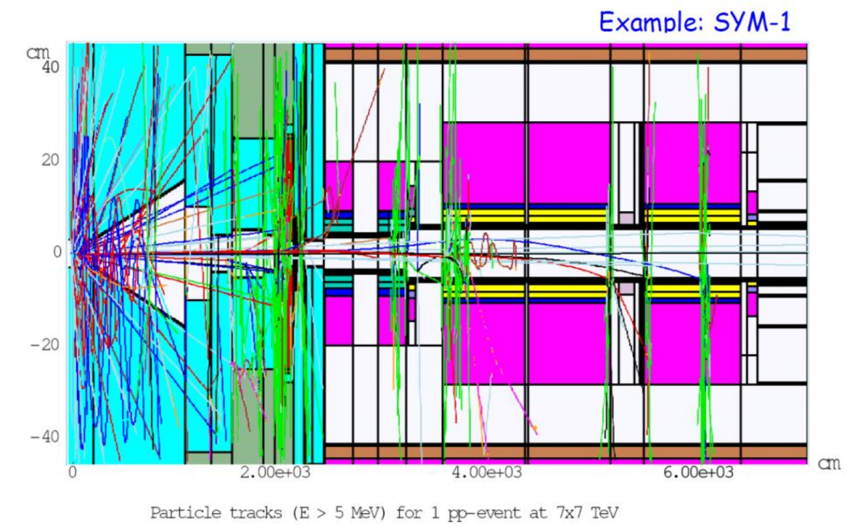
HiLumi LHC WP10 Energy Deposition scope: quench stability (power density in hottest cable), dynamic heat loads, radiation damage (peak absorbed dose and DPA), shielding, collimation, machine protection, radioactivation, remote handling, R2E, LHCb specs, etc. All in communications with other WPs.

WP10 Actors

CERN FLUKA team

F. Cerutti
L. Esposito et al.





Fermilab MARS team

N. Mokhov
Y. Eidelman, K. Gudima
I. Rakhno, S. Striganov
I. Tropin

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WP10 Tasks (1)

1. FLUKA-MARS intercomparison and simulation validation

- Implement in the geometry languages of the two codes a basic test model, verify the consistency of the source term (collision debris from 14TeV com proton collisions) and build equivalent scoring of all relevant quantities (including displacements per atom (dpa) as well as activation related quantities)
- Address possible discrepancies
- Benchmark detailed simulation predictions against measurements from the current LHC operation referring to different scenarios

2. Preliminary investigation of different aperture/material options

- Construct a flexible model of the TAS-D1 region to implement alternative layouts
- Assess peak power deposition in the coils and total power in the different elements from collision debris for 120/140mm NbTi/Nb3Sn quadrupoles
- Optimize design of cold absorber (liner) inside the quadrupole aperture

3. Detailed investigation of the Interaction Regions up to Matching Sections

- Construct complete models of the TAS-D2 region for the preferred triplet aperture and two alternative superconducting materials
- Re-evaluate power deposition maps on the basis of new layout/geometry details
- Assess the peak dose/dpa in all delicate components (coils of quadrupoles, correctors and separation dipoles, cryostat gaskets…)
- Calculate impact of tertiary collimator (TCT) showers on the basis of available loss maps

WP10 Tasks (2)

4. Study of warm absorbers TAS and TAN

- Generate detailed maps of power deposition in the TAS and TAN absorbers
- Assist needed iterations with the successive thermo-mechanical analyses

5. Study of the Matching Section and Dispersion Suppressor (DS)

- Extend the model up to the end of the DS
- Evaluate power deposition profiles all along the line, including beam halo and beam-gas interaction contributions
- Iterate the above evaluation as a function of the active absorber (TCL) scheme

6. Evaluation of working conditions for instrumentation and electronics

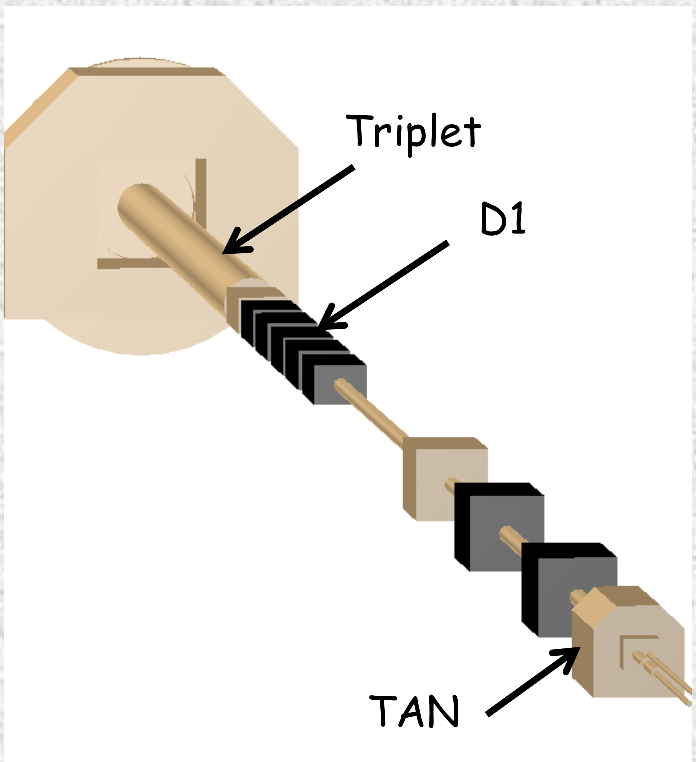
- Characterize the radiation field at the locations of the monitors (e.g., BLMs), supporting a possible optimization of their design/positioning
- Calculate relevant radiation quantities at the electronics locations

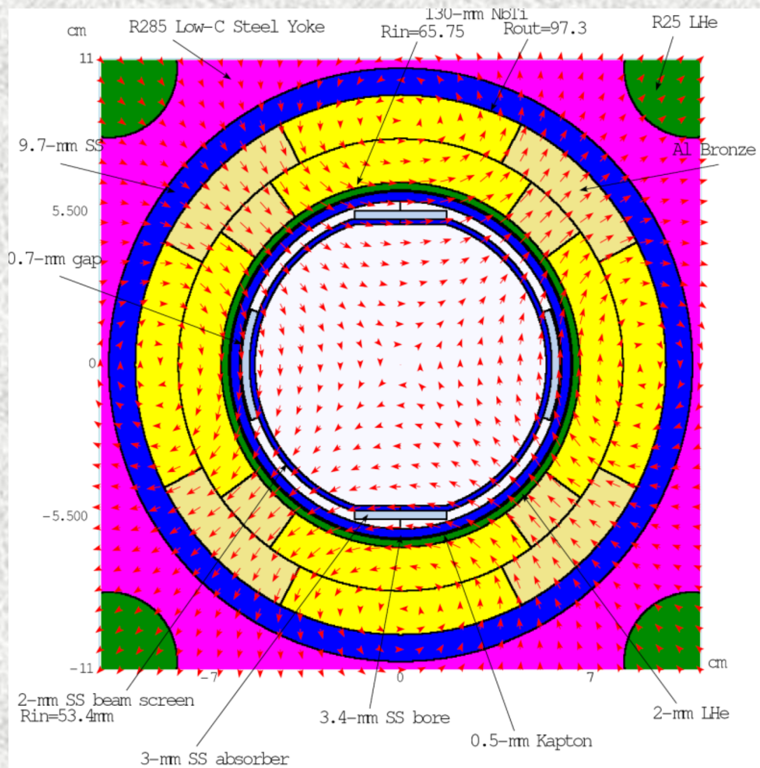
Close interactions (input to ↔ feedback from) with WP2, WP3, WP5, WP6, WP7 and WP8

Energy Deposition Simulations for LHC Upgrades

From LHC through Phase-I upgrade to HiLumi

$$L = 10^{34} \Longrightarrow 2.5\times10^{34} \Longrightarrow 5\times10^{34}\ cm^{-2}\ s^{-1}$$





LARP-2008:
High-Z inserts
in large-aperture
quad mid-planes

HL-LHC Optics: SLHCV3.1b

150 T/m triplets usable optics models
by R. De Maria and S. Fartoukh
twiss files at */afs/cern.ch/eng/lhc/optics/SLHCV3.1b/tables*

WP10 start:

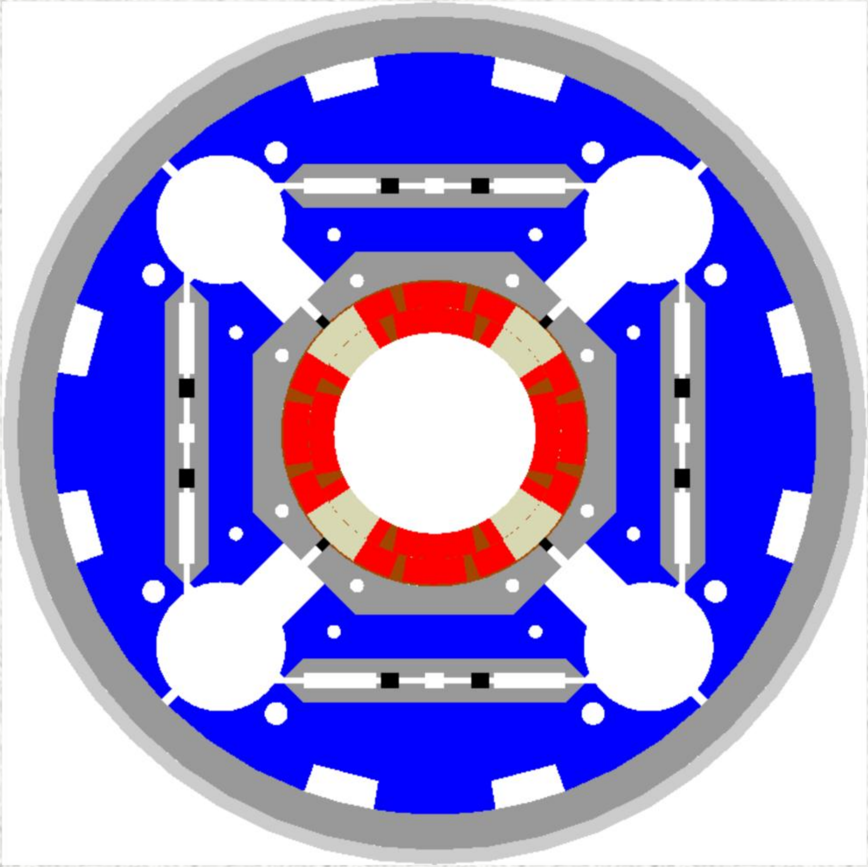
- round optics, *opt_150_0150_0150*
- $\beta_x^* = \beta_y^* =$ 15cm with 295 μrad half crossing angle, vertical
- no beam screen in IT/D1, ~10-mm cold bore for shielding
- TAS aperture: 60 mm for 140 mm triplet quads
- no experimental vacuum pipe

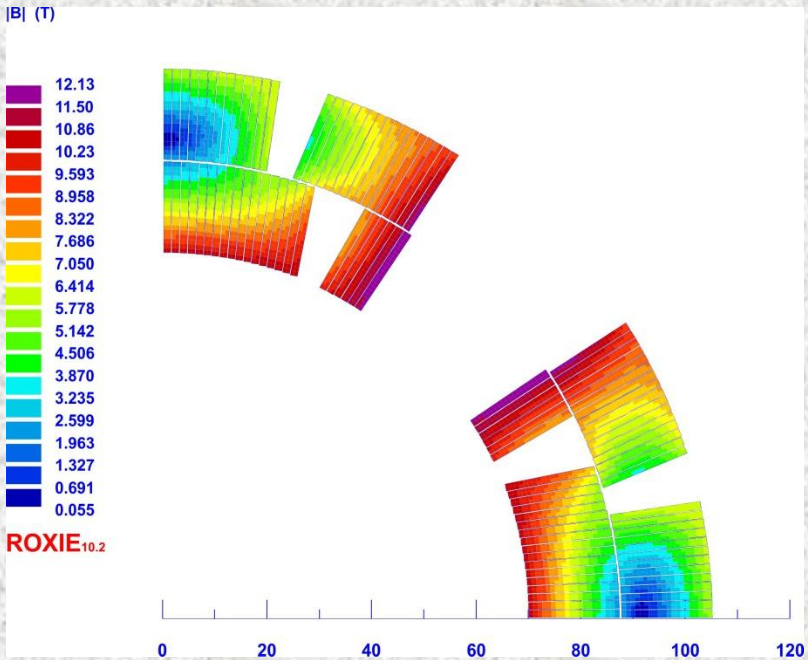
Simulation Parameters in FLUKA and MARS

- 7×7 TeV pp with the current DPMJET, 40000 events
- $L = 5\times10^{34}$ cm^{-2} s^{-1}, σ_{in} = 84.46 mb, N = 4.223×10^{9} int/s

  (σ_{in} = 80 mb in FLUKA)
- MADX field gradients, ROXIE field maps
- Δz = 10 cm, Δr = 1 mm, $\Delta\phi$ = 2 deg
- Cutoff energies: 0.1 MeV (γ), e (1 MeV), 0.001 eV (n) and 0.1 MeV (ch. hadrons, muons and ions)
- Score: power density (mW/g and mW/cm^3), absorbed dose, DPA, particle fluxes, dynamic heat load, energy spectra
- Mechanical length L_B is magnetic length L_M + 0.225m×2 (used to be L_B=L_M in early MARS runs)

150 T/m MQXF



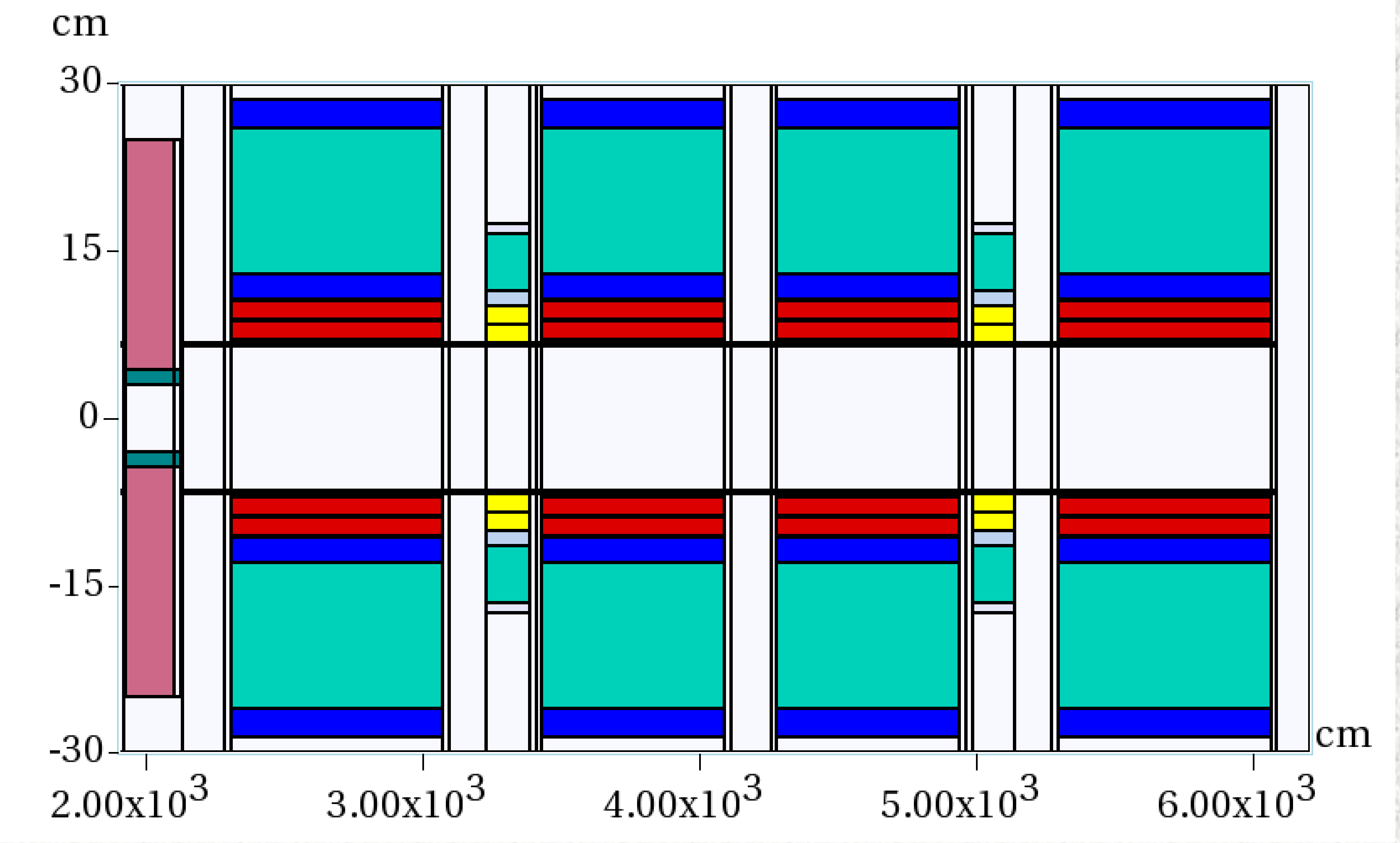


Cold OD = 0.57m, shell thickness = 0.025m

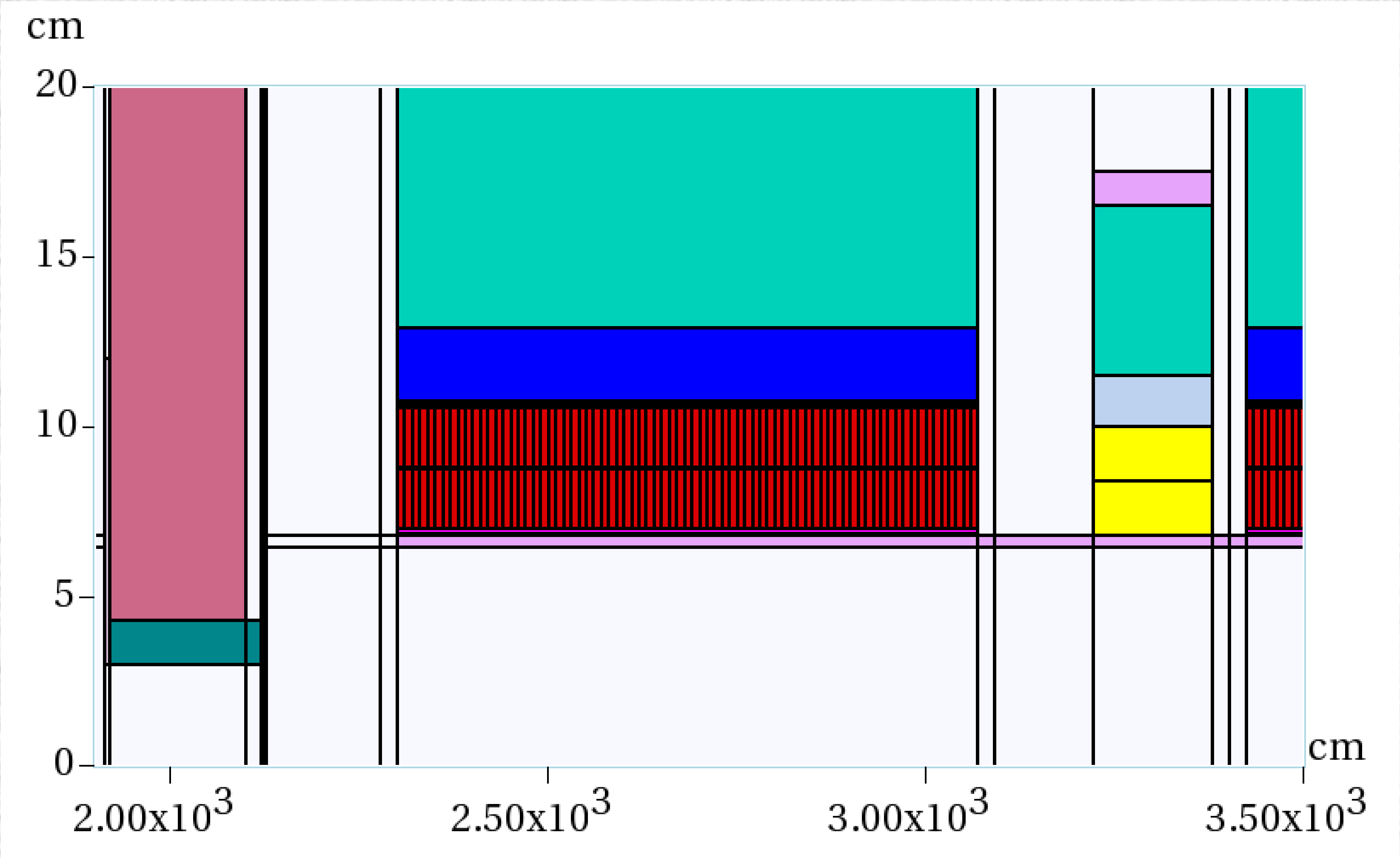
MARS15 Developments for HiLumi LHC Needs (since 2011 DOE review)

Substantial MARS15 developments on physics and geometry sides: event generators (benchmarked up to LHC energies), low-energy EMS (down to 1 keV), displacement-per-atom (radiation damage), nuclide inventory (residial activation), and ROOT geometry (flexibility and 3-D graphics).

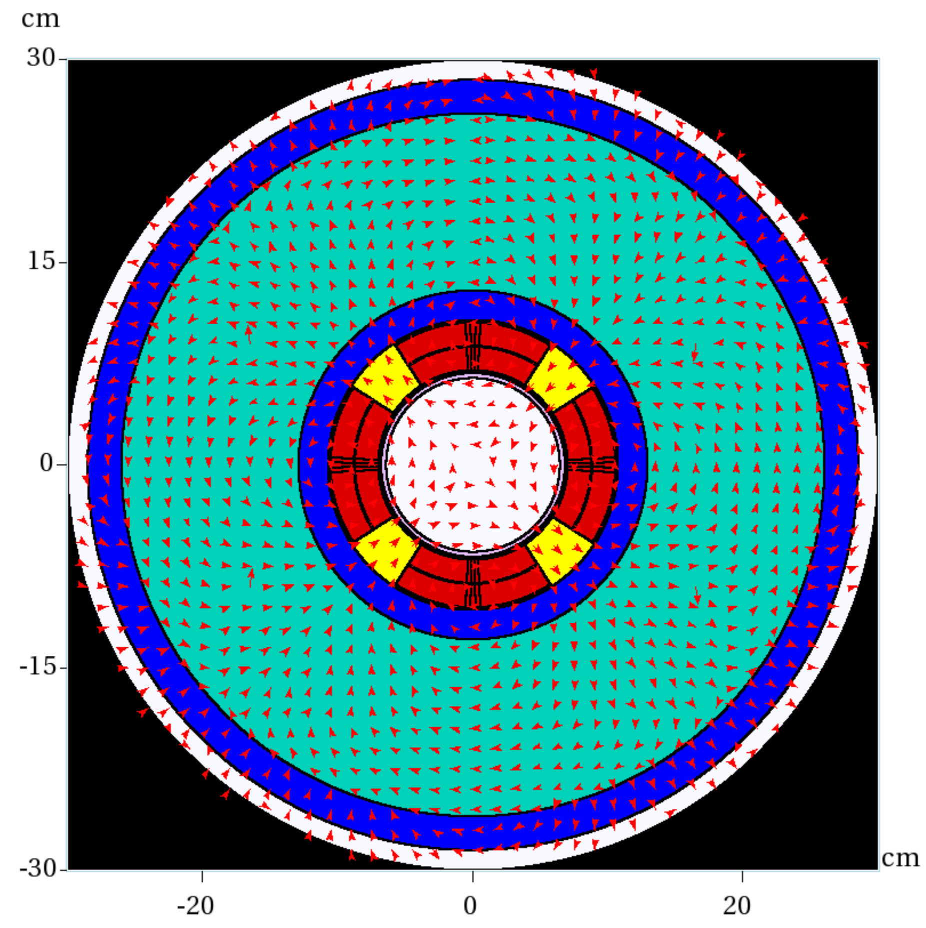
FLUKA Geometry Model Implemented in MARS15 (1)

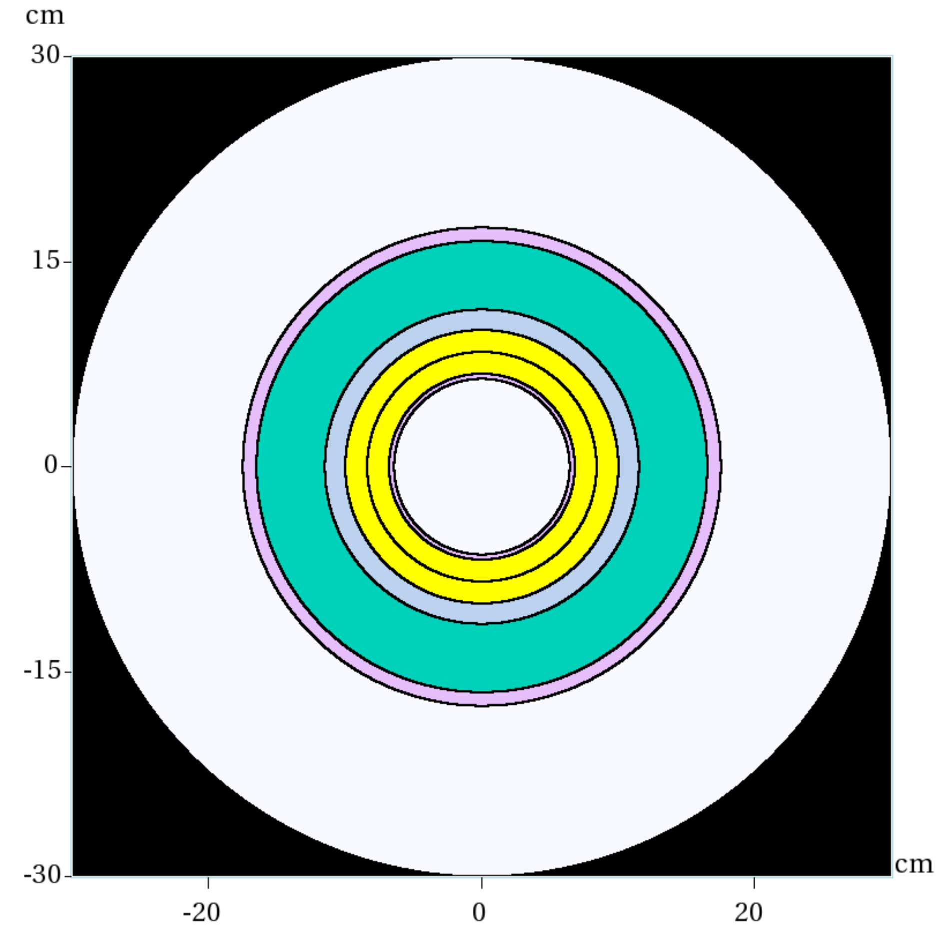


FLUKA Geometry Model Implemented in MARS15 (2)

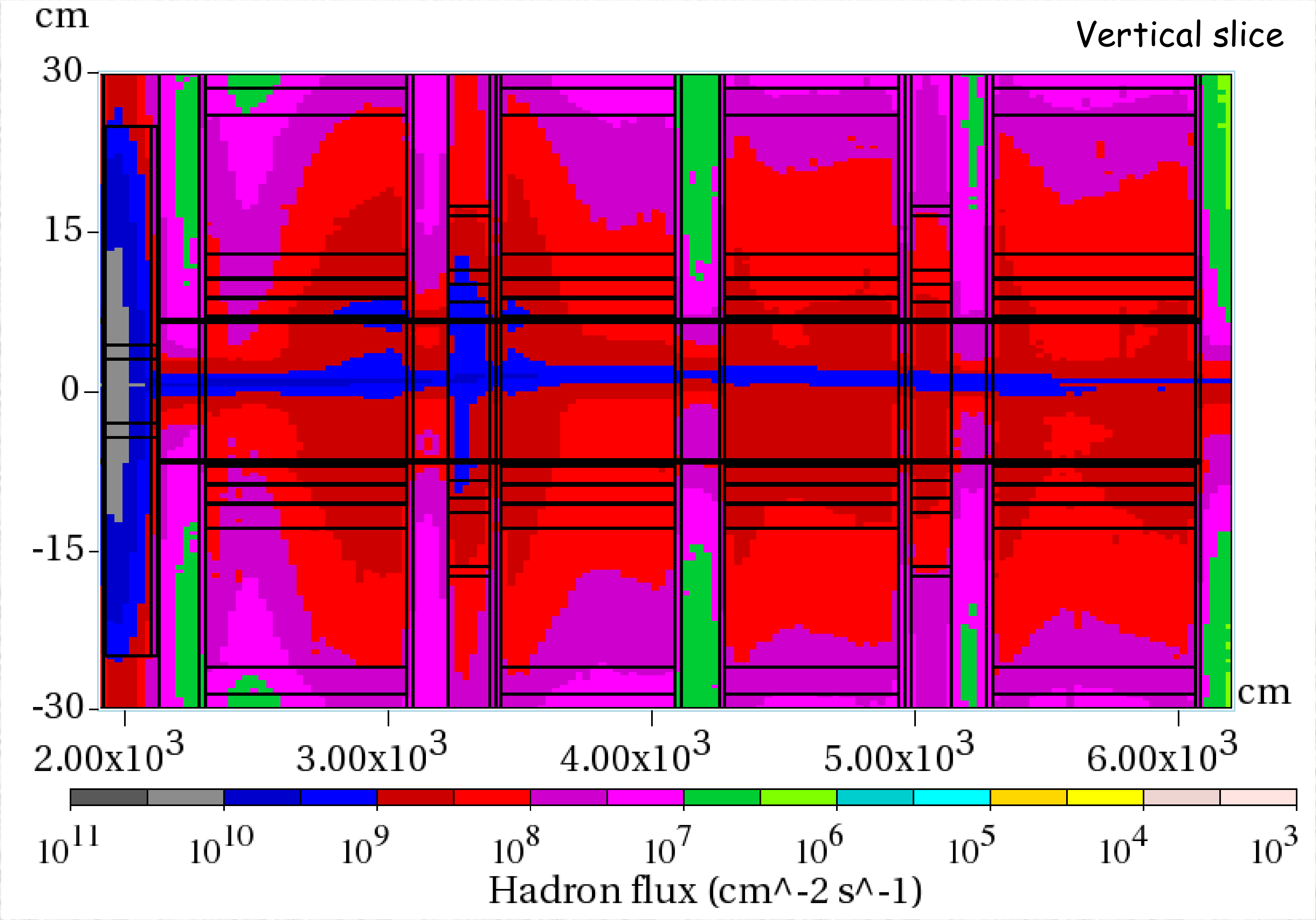


FLUKA Geometry Model Implemented in MARS15 (3)

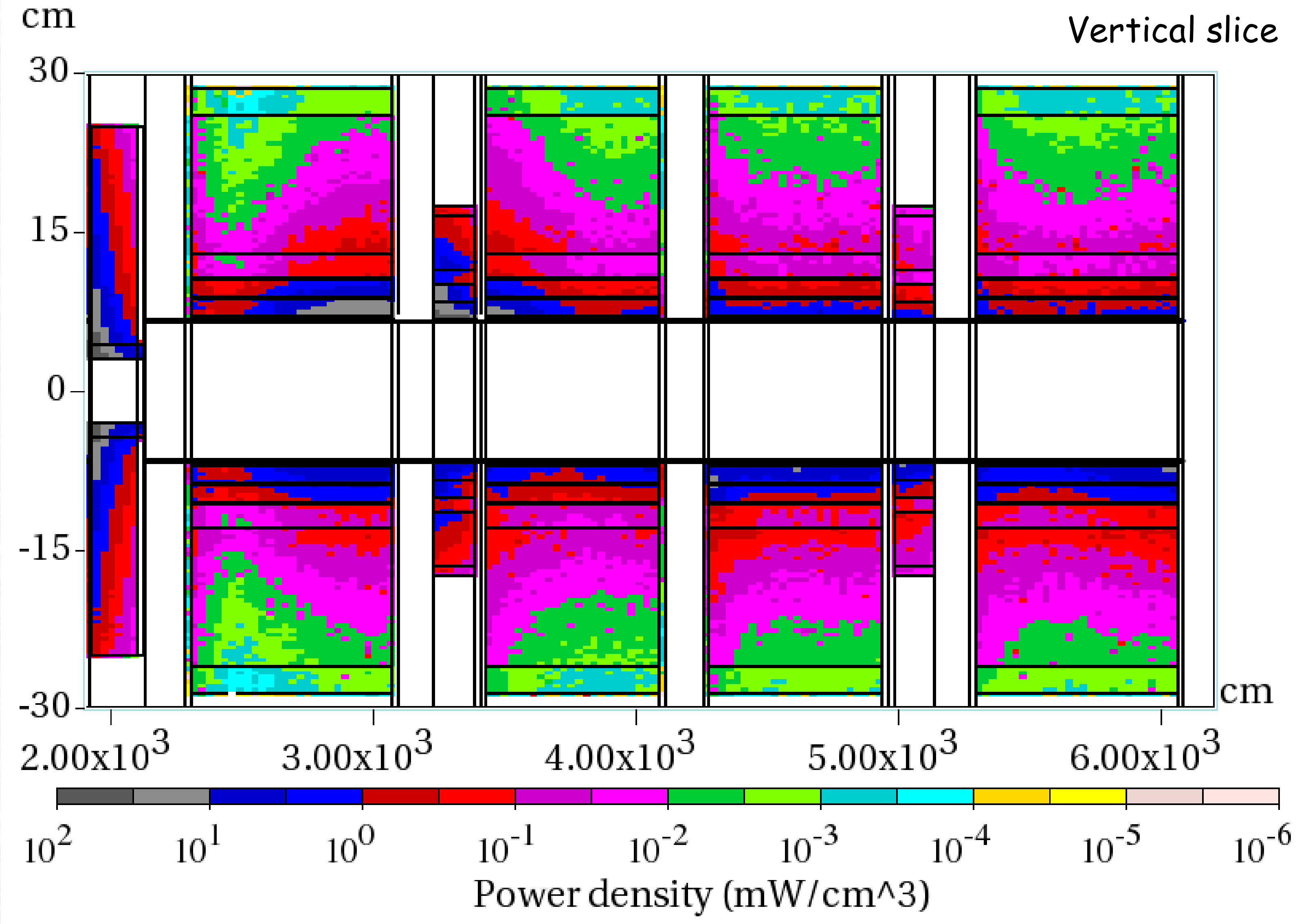




Hadron Flux ($cm^{-2}\ s^{-1}$)



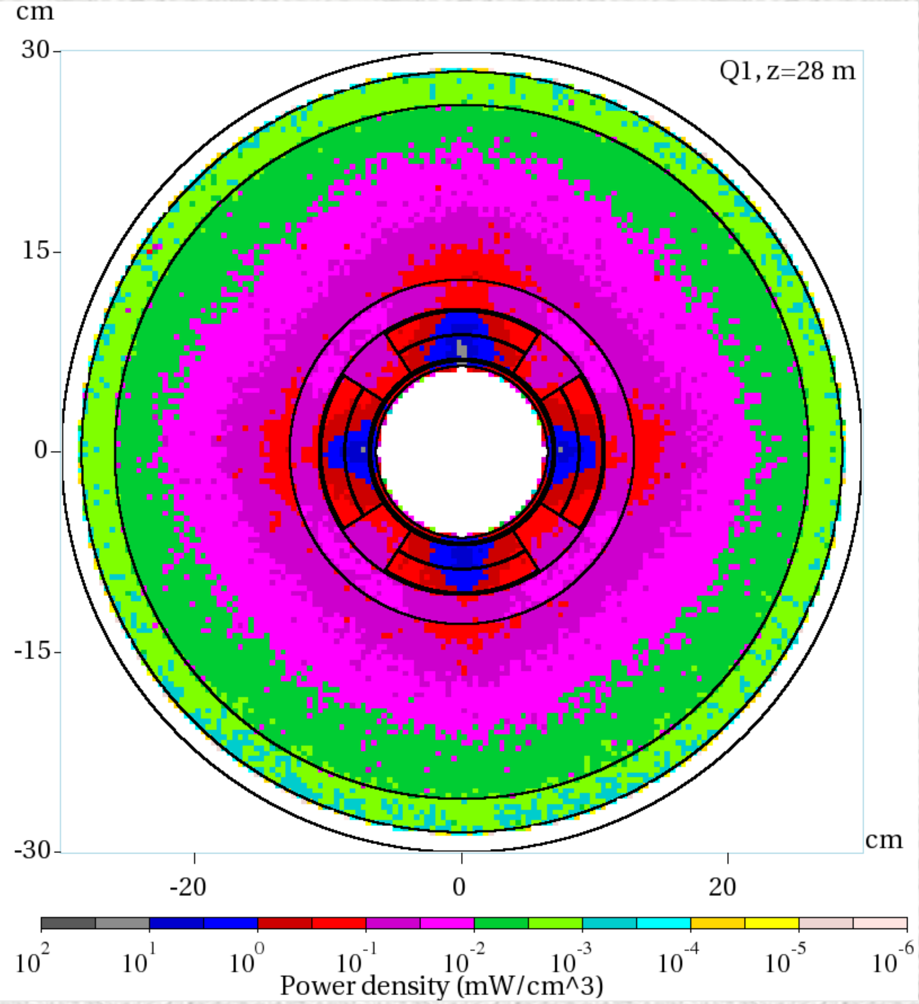
Power Density (mW/cm³)

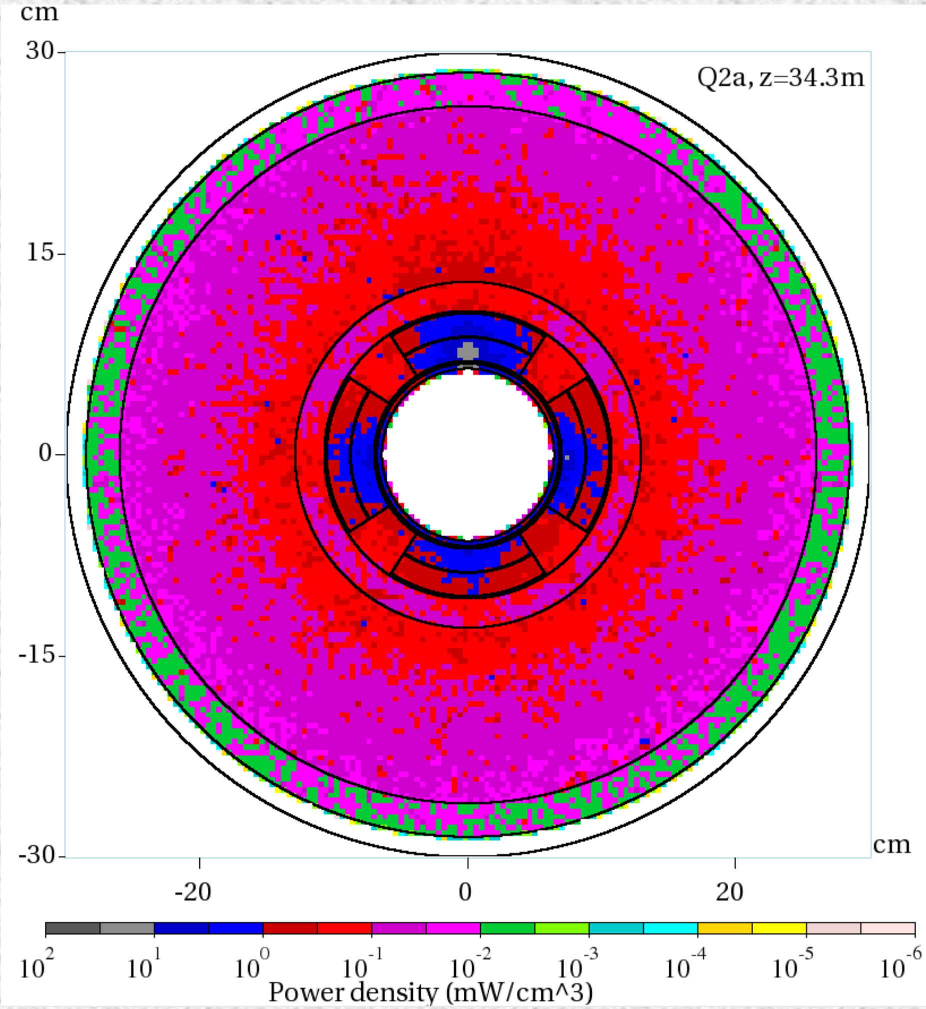


Power Density in Q1 and Q2a (mW/cm^3)

Q1, 2.5 m to non-IP end

Q2a, IP end





MARS/FLUKA Intercomparison

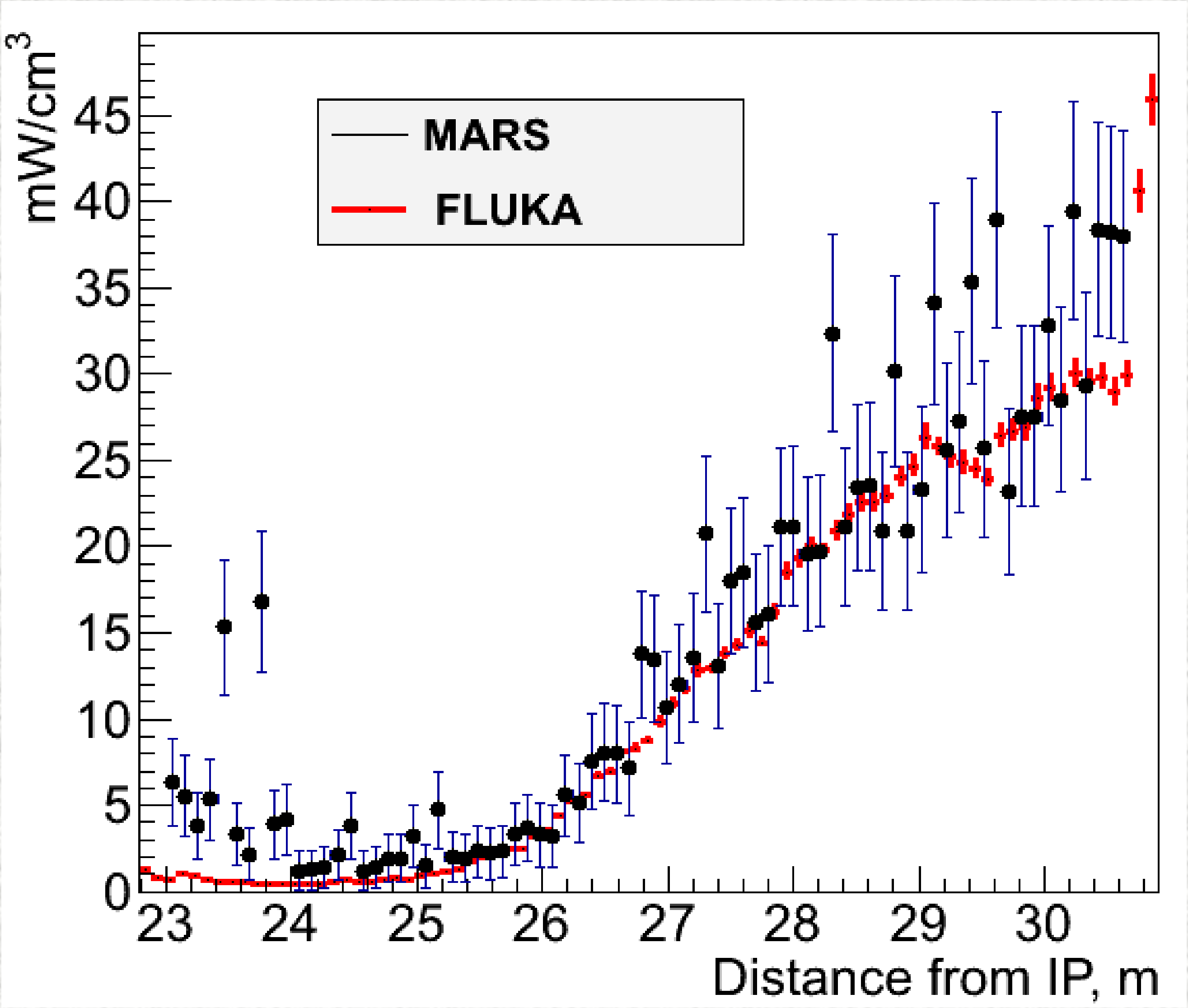
140-mm ID Inner Triplet

Baseline 3.7-mm SS beampipe

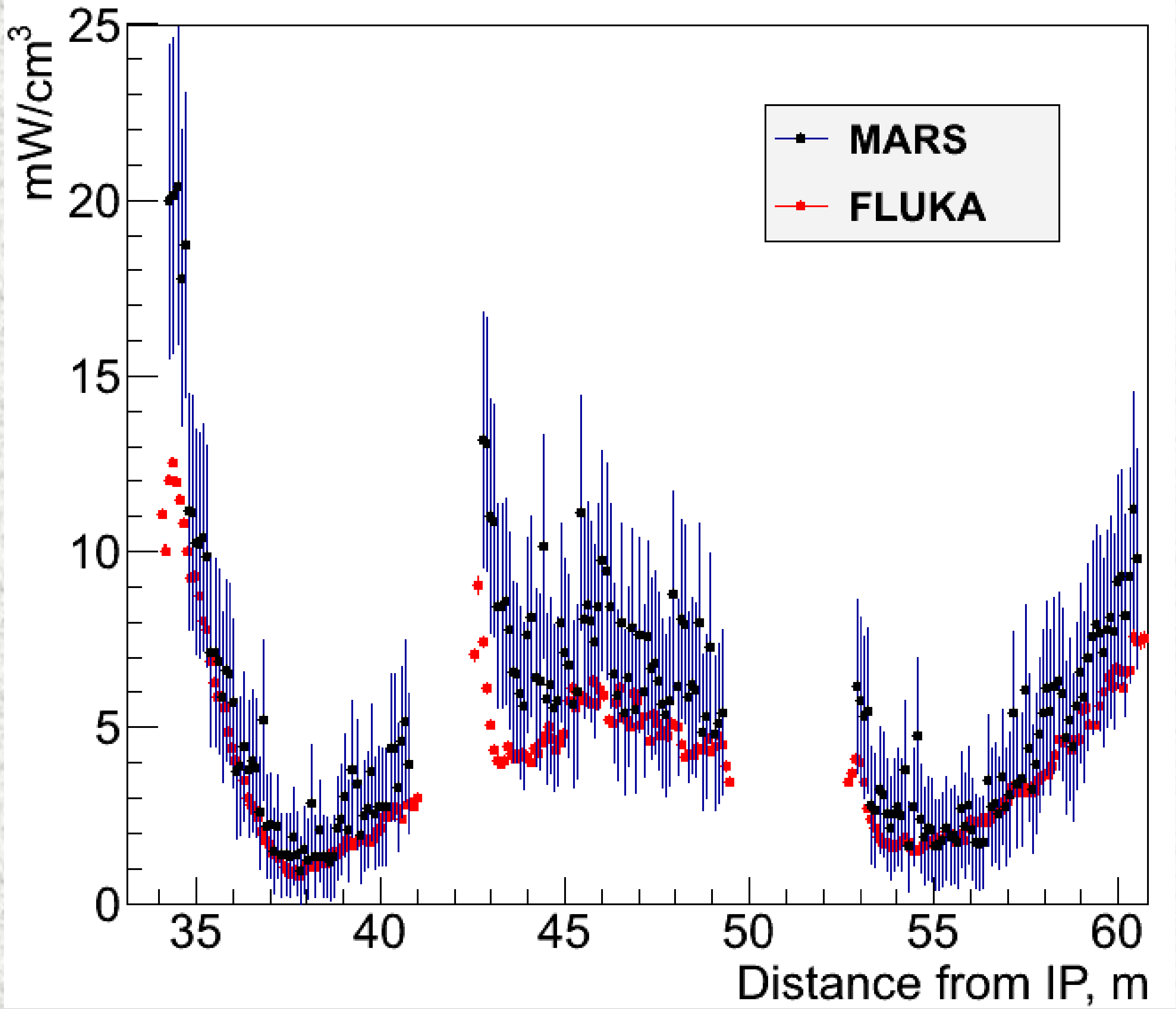
Peak power density *vs* z, r and ϕ

Dynamic heat load

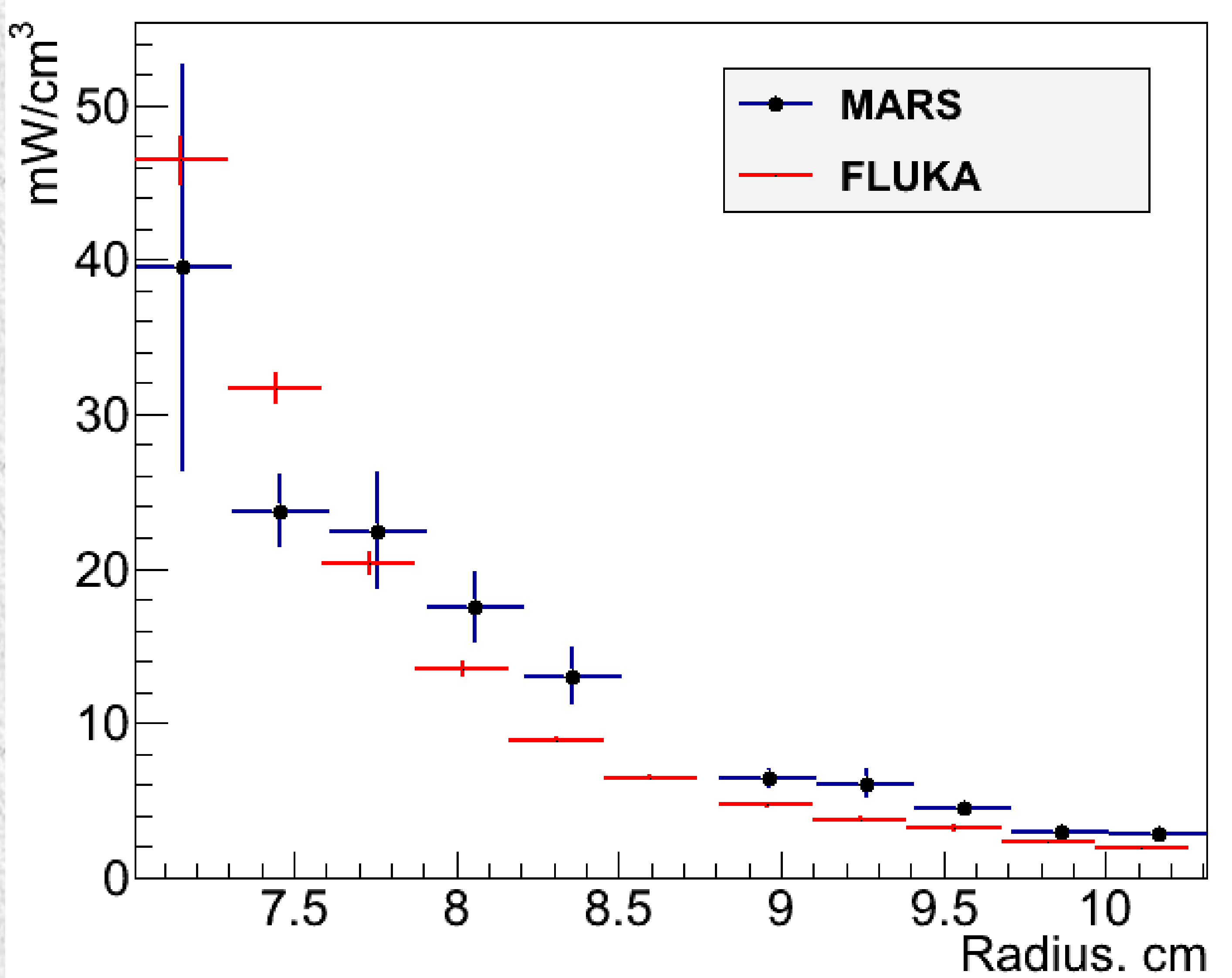
Peak power density in innermost 3 mm of Q1 coil



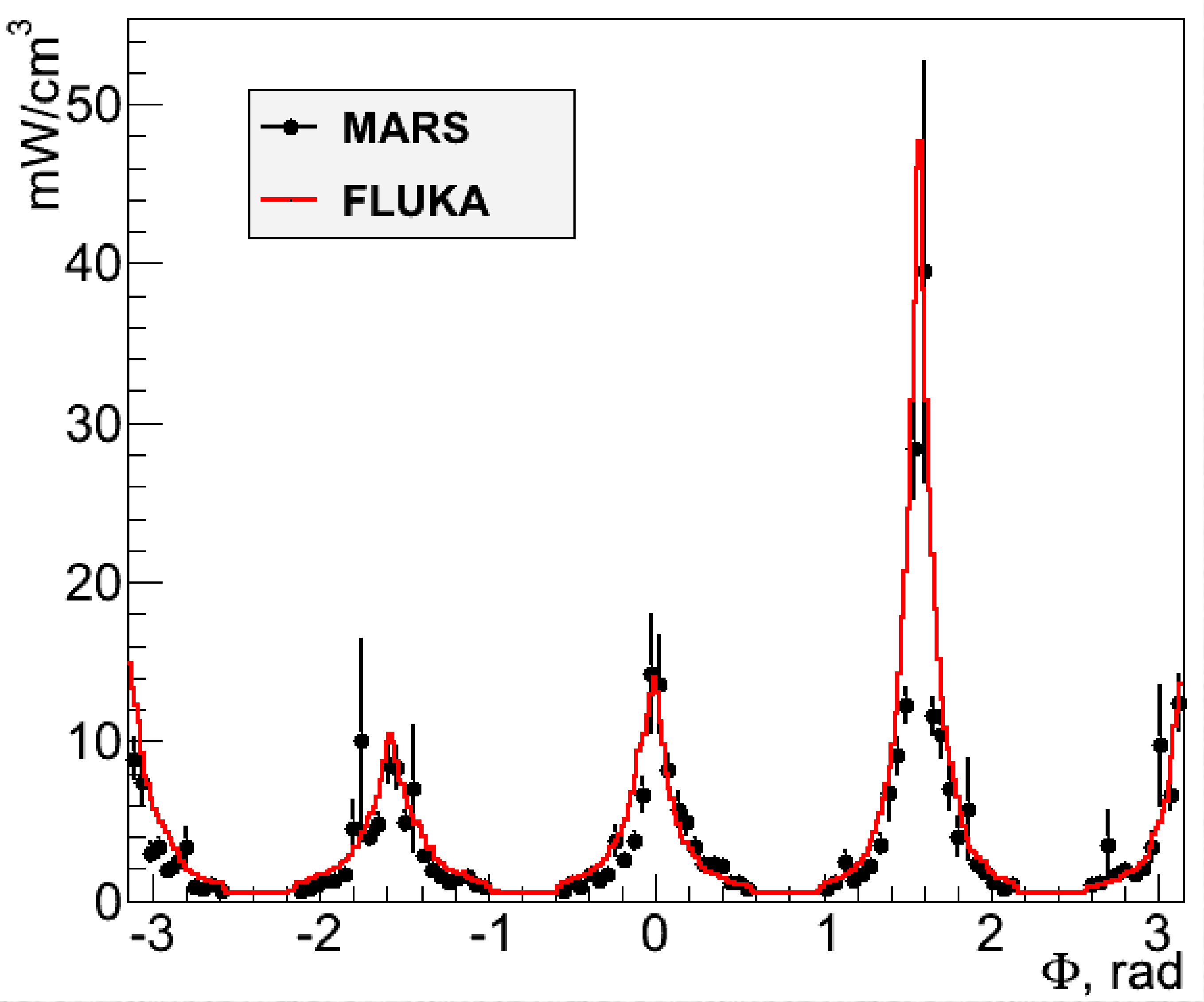
Peak power density in Q2-Q3 inner coils



Radial power density at Q1 peak (mW/cm^3)



Azimuthal power density at Q1 peak (mW/cm^3)



MARS Peak Values in Coil Innermost Regions w/o Inserts

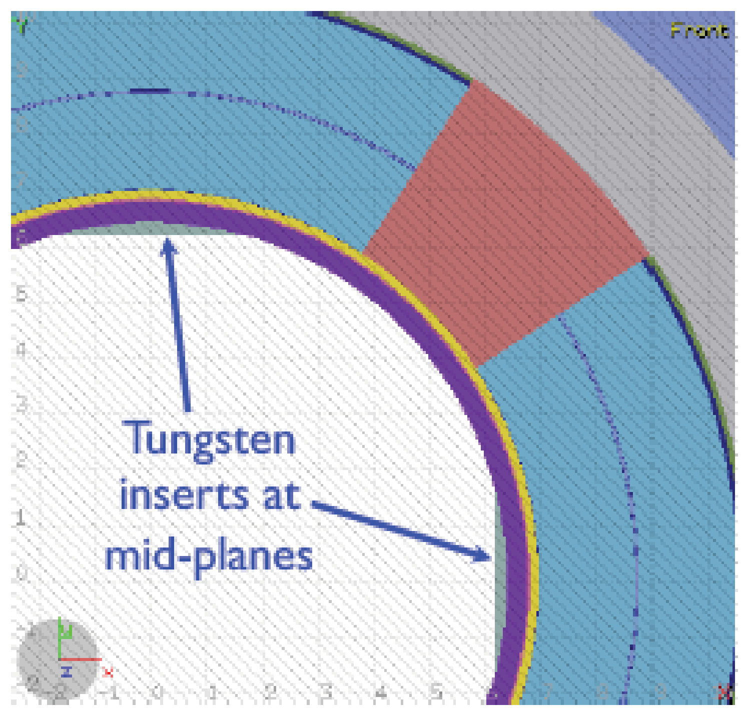
Value	Q1	MCBX1	Q2A
PD (mW/cm^3) in 3-mm bin	39	61	32
Dose (MGy)	300±10	412±7	250±15
F_n > 100 keV (cm^{-2})	5.6×10^{16}	9.5×10^{16}	4.6×10^{16}
DPA	8.2×10^{-4}	1.2×10^{-3}	6.1×10^{-4}

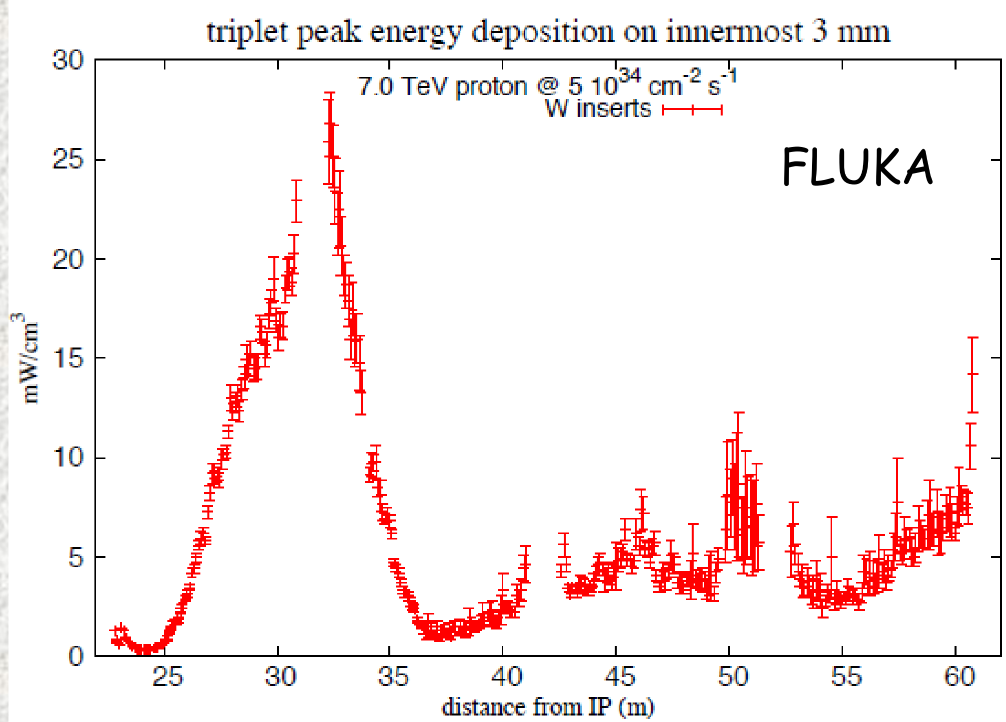
PD a factor of 2 lower if averaged over inner cable width: more relevant for quench stability

Last 3 rows at r=70mm are integrated at 5×10^{34} $cm^{-2}s^{-1}$ over 3000 fb^{-1}

Peak PD in Q1 is at quench limit: need a factor of 3 safety margin
Peak dose is a factor of 12 above the 25-MGy target for insulation
Peak DPA is higher of known limits for metals at cryo temperatures

2.3-mm W Inserts at Mid-planes



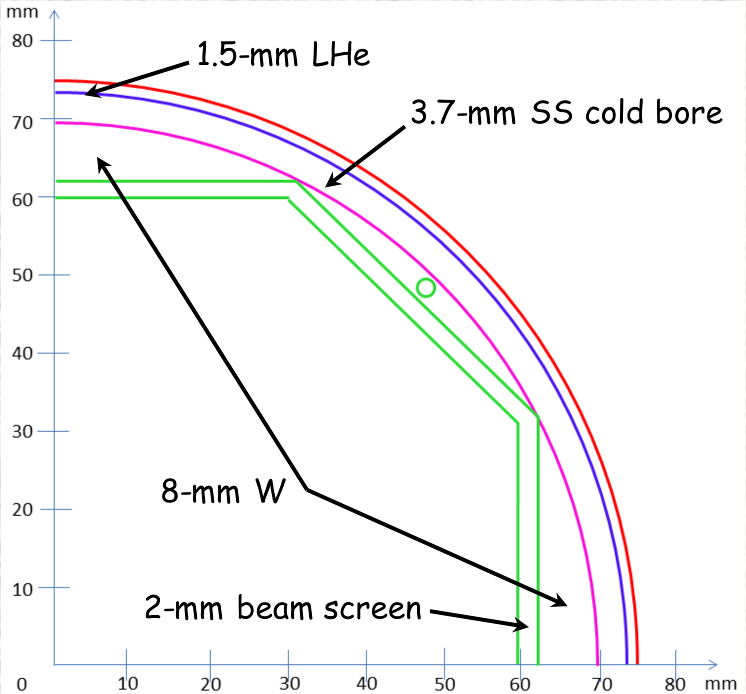


2.3-mm W inserts reduce peak PD and dose by about a factor of two. Need a factor of 12 with a decent safety margin for dose

Factor of 12 Reduction in Peak Dose

Can be achieved by the quad aperture increase from 140 mm to 150 mm with thicker W inserts

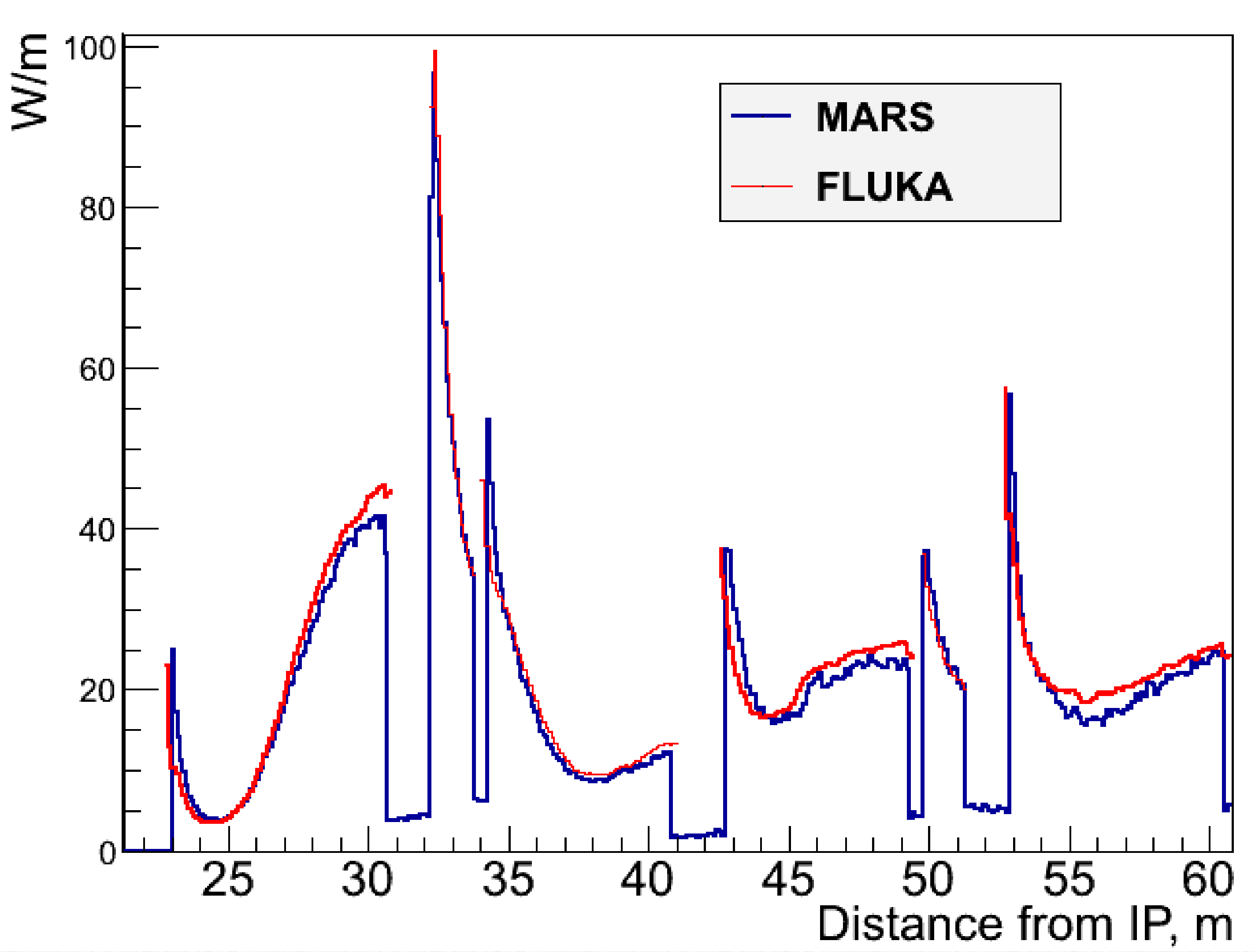
«Adopt 150-mm aperture with Nb_3Sn as baseline (140 T/m, L_M+0.5m, with 120 mm for the beam)» from Ezio's presentation of July 2, 2012



Subject of WP-10 FLUKA-MARS studies this summer

Nb_3Sn technology will be proved by LARP

Dynamic Heat Load (W/m) w/o Inserts



Total Dynamic Heat Load (Watts) w/o Inserts

	TAS	QXC1R	MDVA2R	QXDA2R	QXDB2R	MDVB2R	QXC3R
FLUKA	612.5	174.4	91.2	116.5	158.1	39.6	189.6
FLUKA (w/o endparts)		161.8		105.3	146.1		178.4
MARS (w/o endparts)	614.0	154.8	89.6	102.8	142.6	41.7	165.2

With W-inserts, substantial fraction of heat load is intercepted by them (subject of nearest WP-10 studies)

Summary and Plans

- FLUKA and MARS synchronized models are up, running and used for optimization studies of HL-LHC triplets.
- Overall good agreement between FLUKA and MARS on power density and dynamic heat load in quads; perfect agreement in TAS and correctors: → confidence.
- Peak power density in 140-mm ID quads with 3.7-mm SS BP averaged over the inner coil cable is 50% of the quench limit (=QL for 3-mm bin), and can be reduced by W-inserts. Peak dose and DPA need to be reduced 12 times.
- Perform optimization simulation studies for the 150-mm ID triplet design, with W-inserts providing required safety margins for peak power density, dose and DPA.
- Launch detailed simulations for new IR+DS, and TAS/TAN