Energy Deposition Studies for HiLumi LHC: 140 and 150 mm IR Quads

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with WP10 members

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OUTLINE

- 140-mm Coil ID Model w/o Inserts
- MARS/FLUKA Results
- 2012 MARS Developments and New IR Model
- First MARS Results for 150-mm ID Quads with W-Inserts
- Summary and Plans

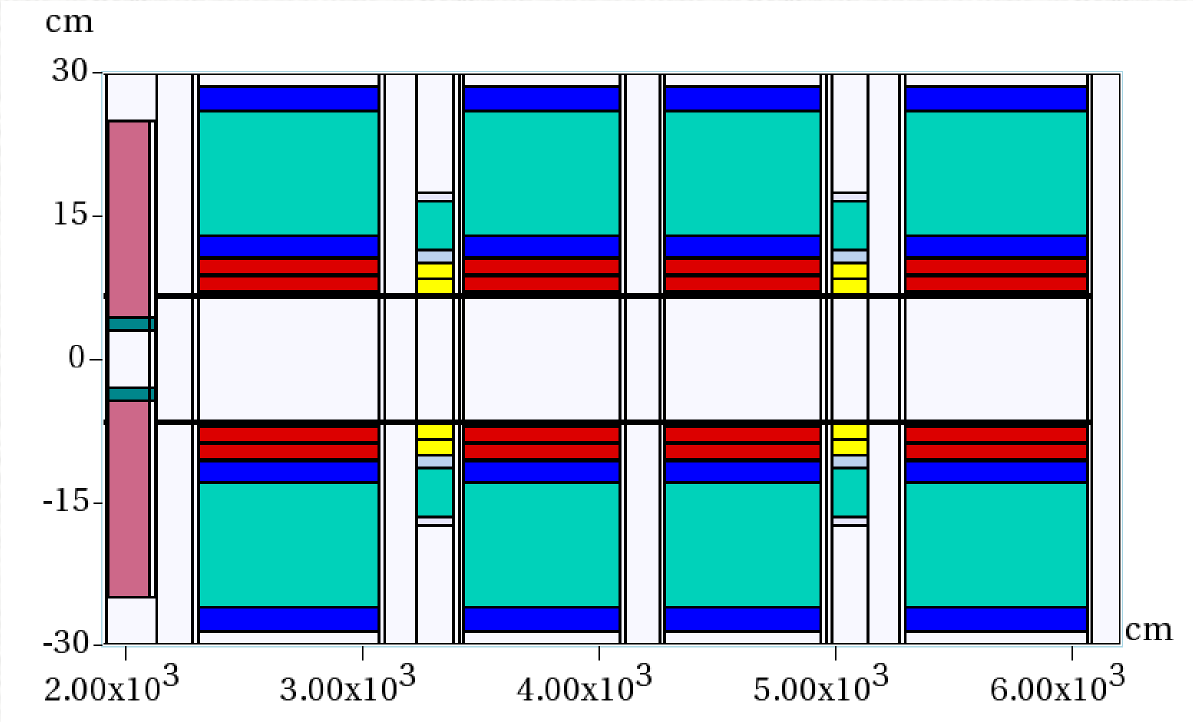
HL-LHC Optics and 140-mm Aperture Quads

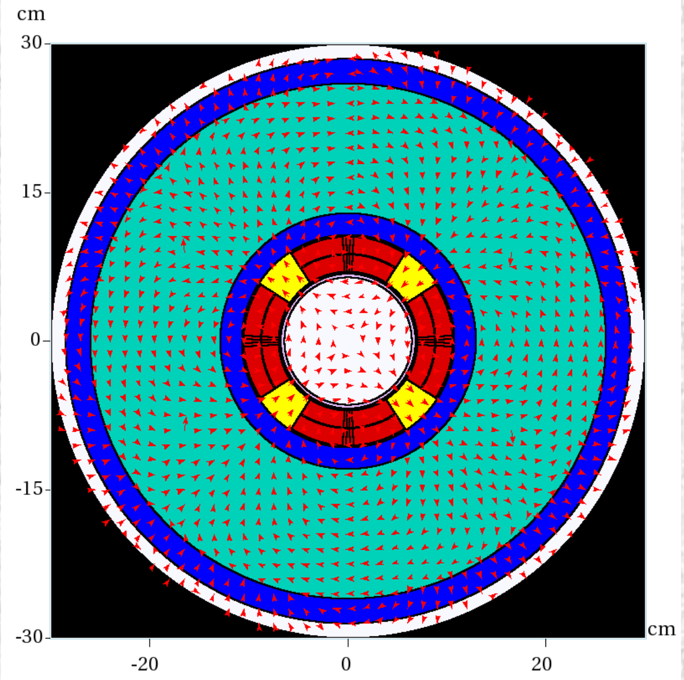
150 T/m triplets usable optics models
by R. De Maria and S. Fartoukh
twiss files at */afs/cern.ch/eng/lhc/optics/SLHCV3.1b/tables*

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
- baseline 3.7-mm SS beampipe
- 60-mm TAS aperture
- no experimental vacuum pipe

MARS/FLUKA IR Model for 140-mm Coil ID



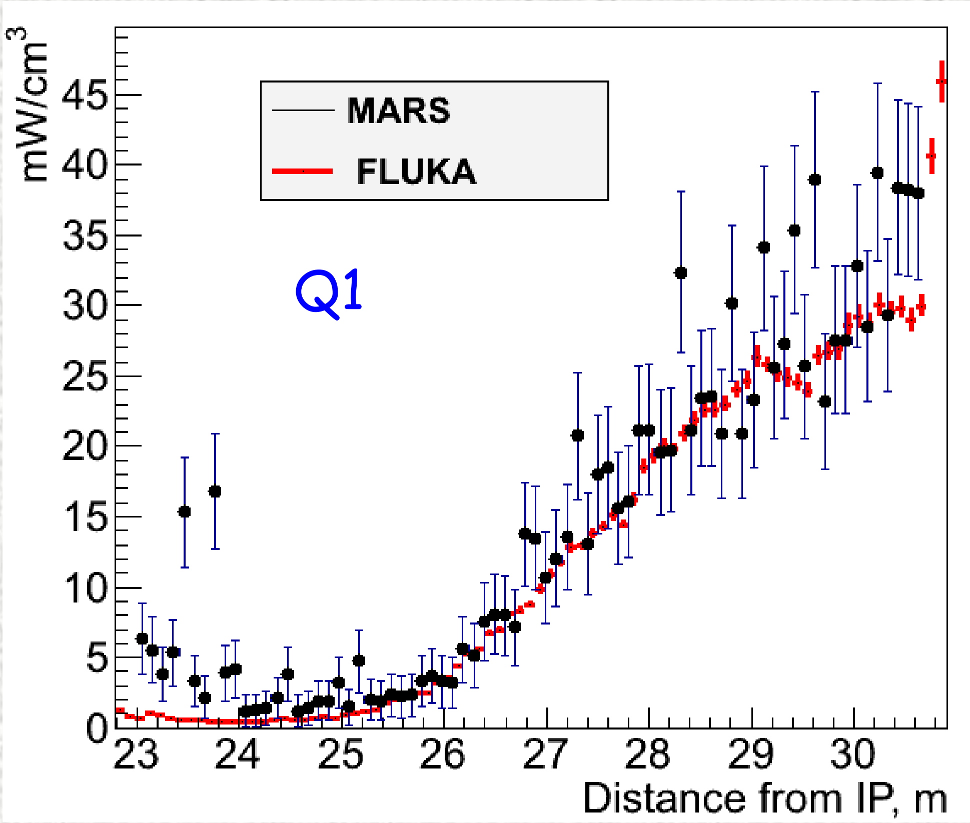


Simulation Parameters in FLUKA and MARS

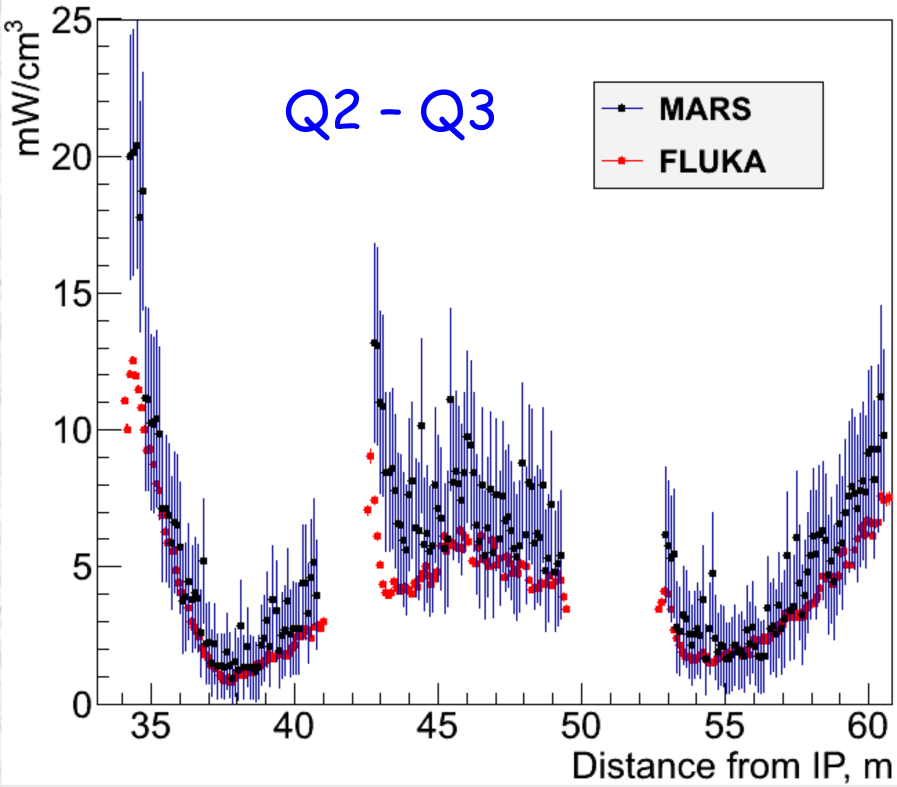
- 7×7 TeV pp with the current DPMJET, 40000 events
- $L = 5\times10^{34}$ cm^{-2} s^{-1}, σ_{in} = 84.46 mb, N = 4.223×10^9 int/s

  (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

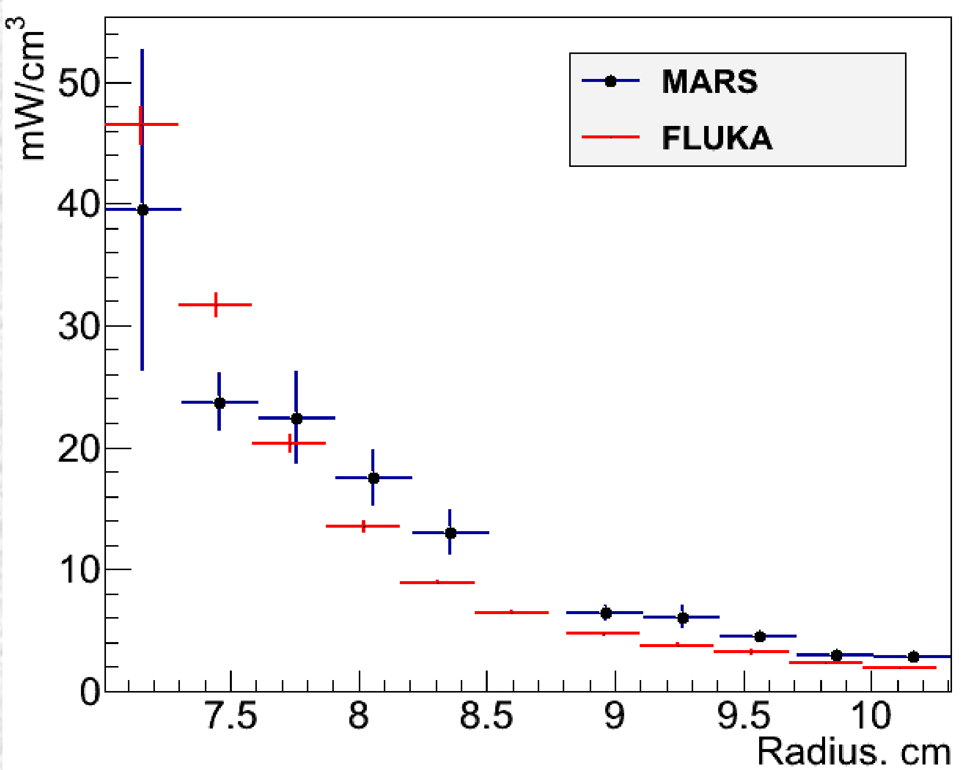
Peak power density in innermost 3 mm of coil



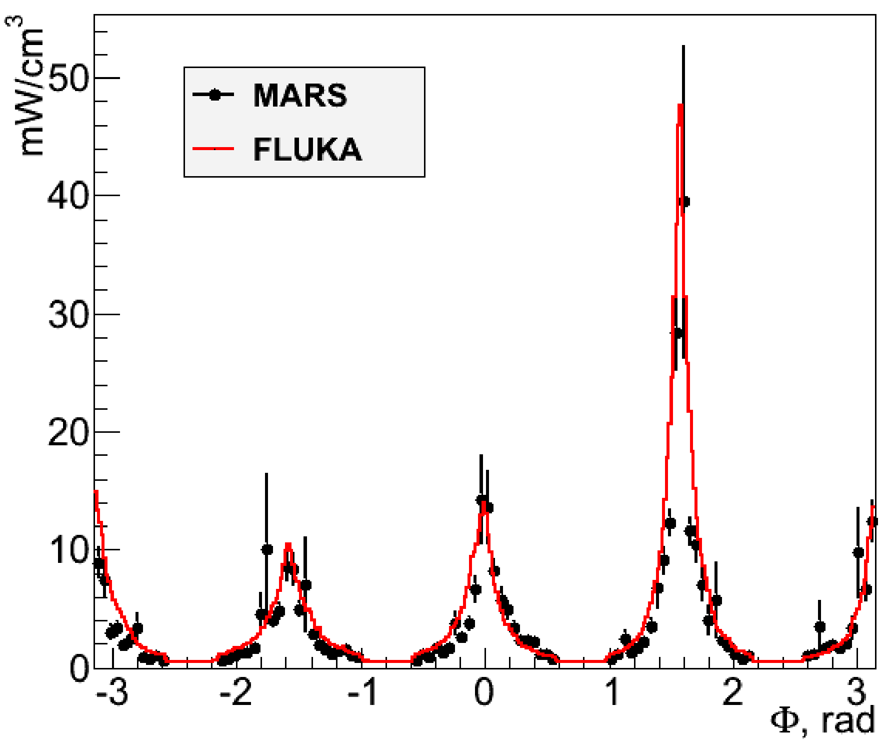
140-mm coil ID



Radial and Azimuthal Power Density at Q1 Peak (mW/cm^3)



140-mm coil ID



MARS Peak Values in the Innermost 3 mm of the 140-mm Coil w/o Inserts

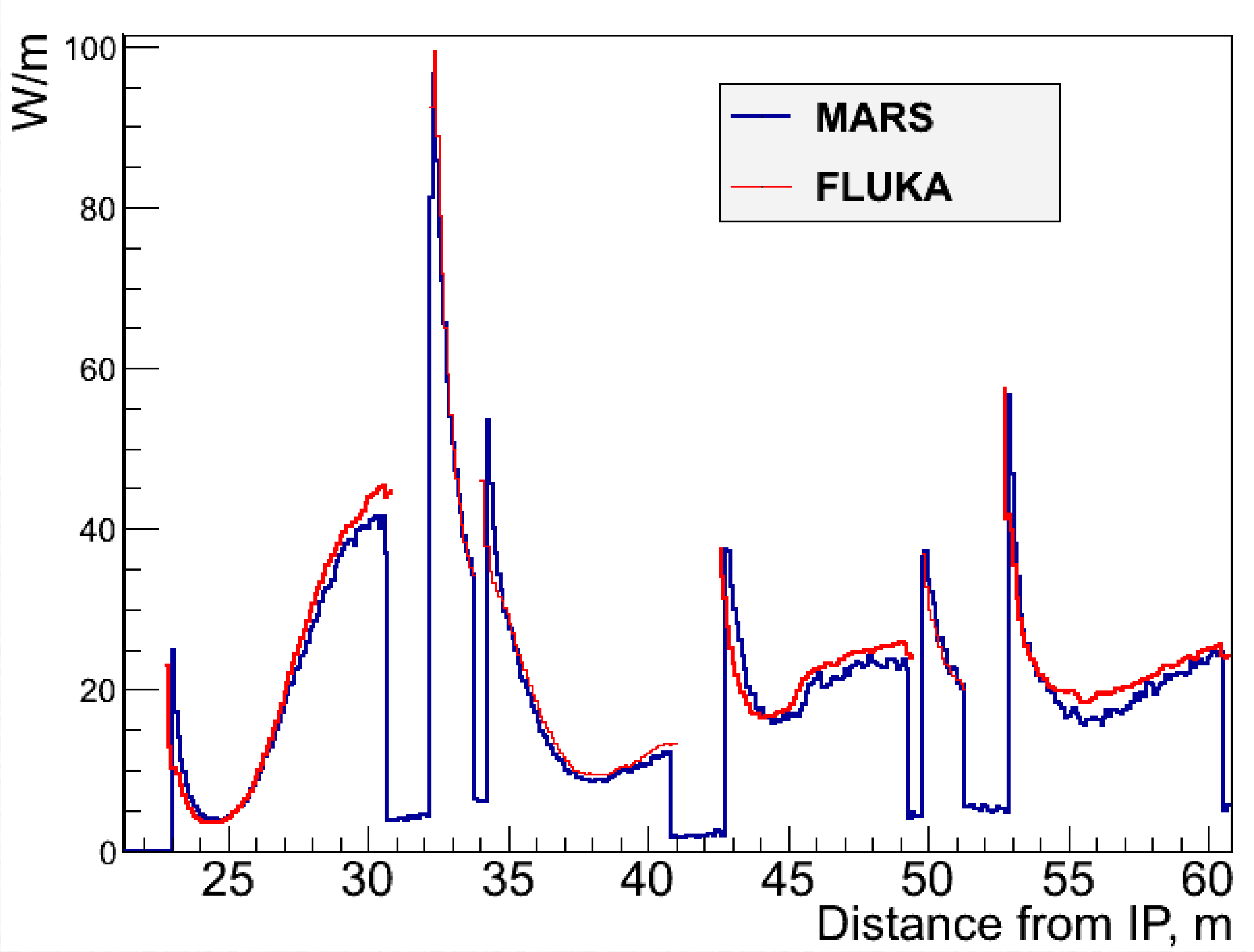
Value	Q1	MCBX1	Q2A
PD (mW/cm^3) in 3-mm bin	39	61	32
Dose (MGy)	290±10	412±7	250±15
F_n > 100 keV (cm^{-2})	5.6×10^{16}	9.5×10^{16}	4.6×10^{16}
DPA	8.2×10^{-4}	1.2×10^{-3}	6.1×10^{-4}

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

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

Peak PD in Q1 is at the quench limit: need a factor of 3 safety margin
Peak dose is a factor of 7.5 above the 40-MGy target for insulation
Peak DPA is higher of known limits for metals at cryo temperatures

Dynamic Heat Load (W/m) in 140-mm coil ID w/o Inserts



Total Dynamic Heat Load (Watts) in 140-mm coil ID Triplet 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

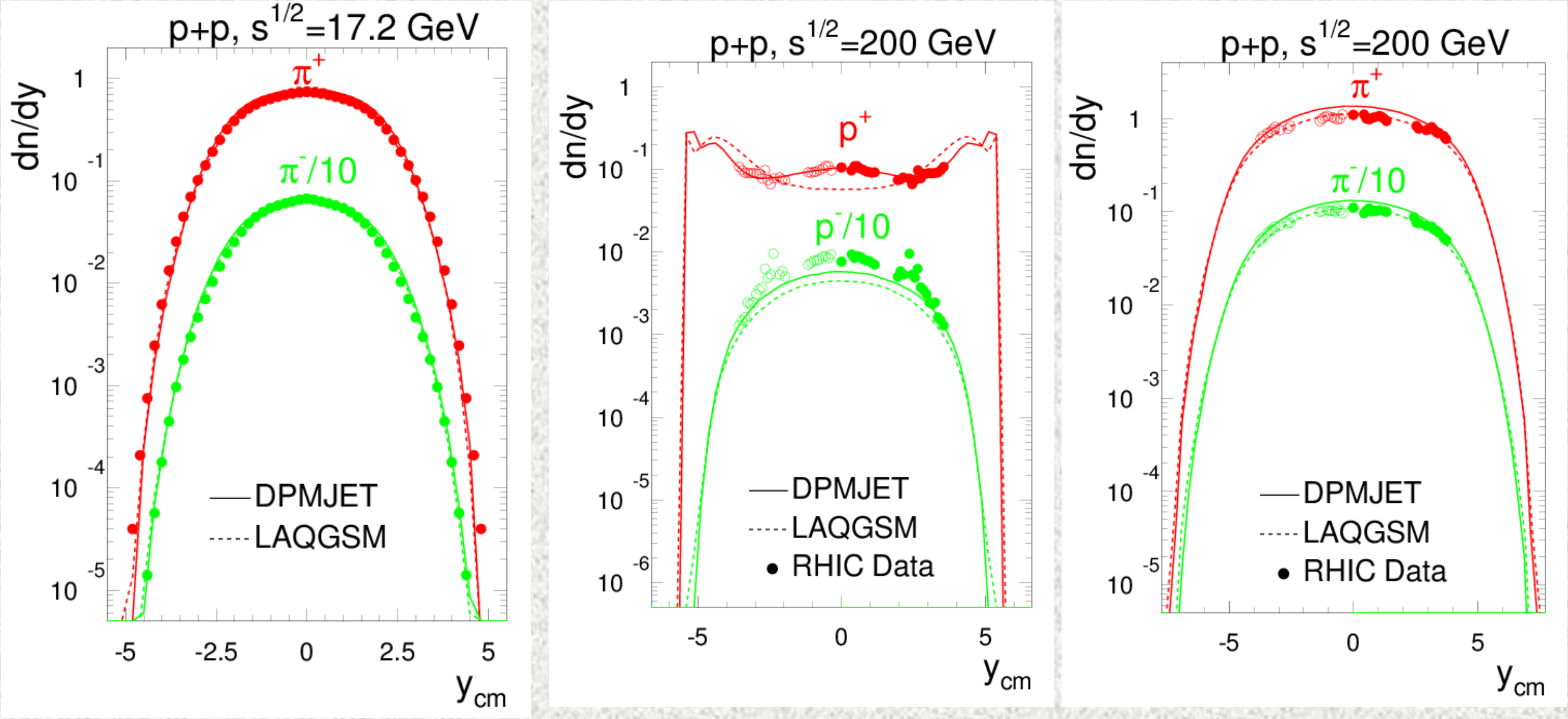
2012 MARS15 Developments for HiLumi LHC Needs

Substantial developments on physics and geometry sides

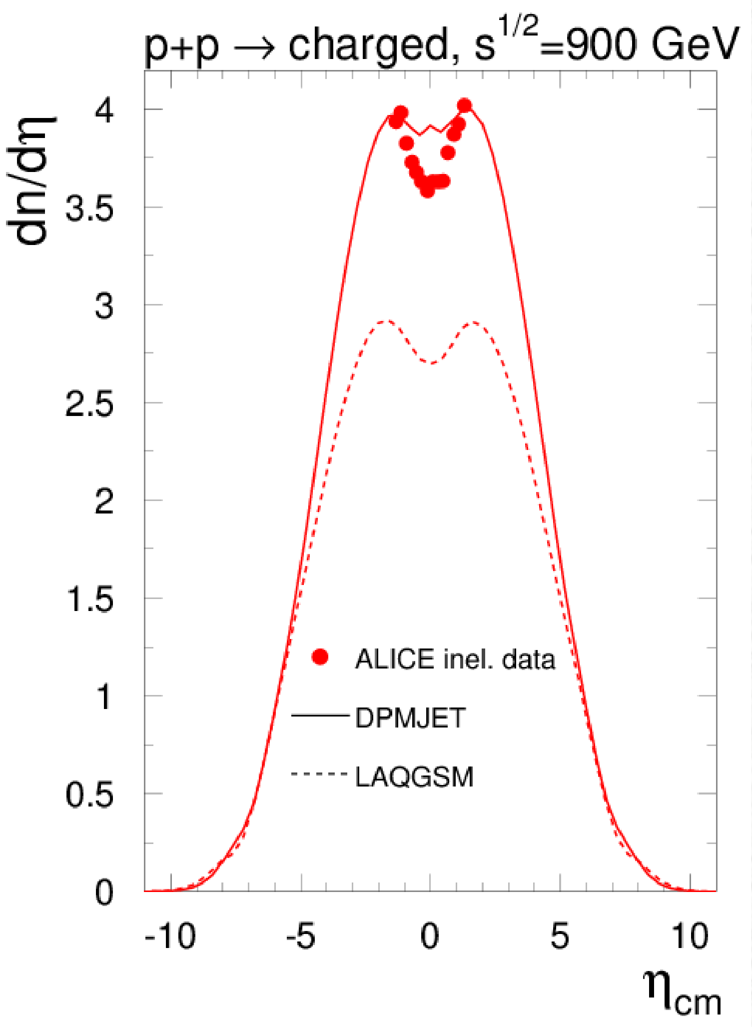
- Particle production ***event generators***: inclusive and exclusive; thoroughly benchmarked at intermediate 1 to 12 GeV energies (majority of particles in showers; HARP issues); first comparisons to LHC data
- ***Low-energy EMS*** (from 1 GeV down to 1 keV, crucial for energy deposition): new modules plus EGS5 option
- ***Displacement-per-atom*** (radiation damage): new module (temperature-dependent, benchmarked); comprehensive 393-nuclide database for neutrons below 20 MeV
- ***Nuclide inventory*** (residual activation)
- ***ROOT geometry***: flexibility, precision and 3-D graphics

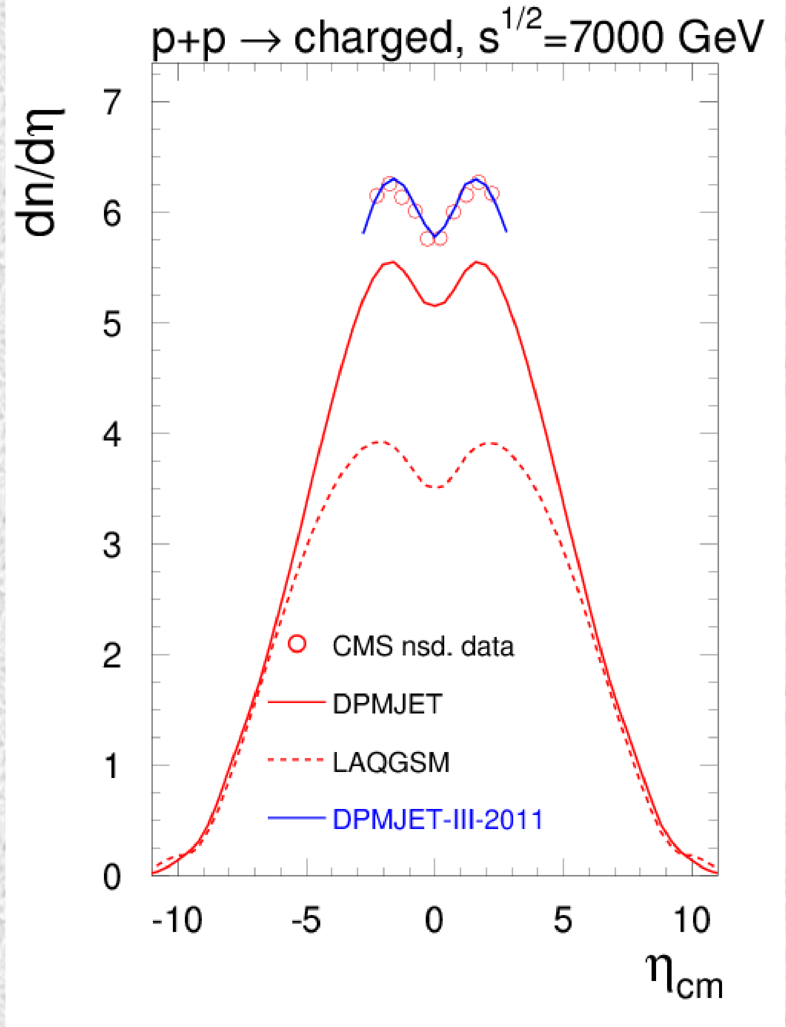
DPMJET and LAQGSM vs NA49 and RHIC Data

T_p = 158 GeV, NA49 RHIC

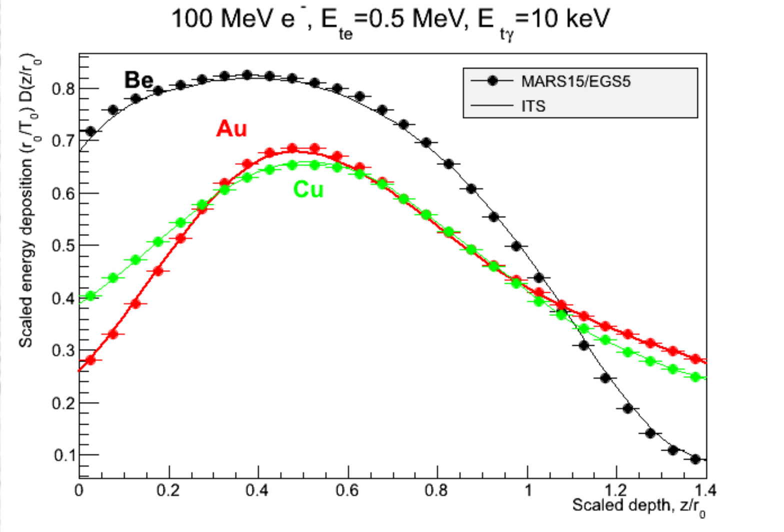


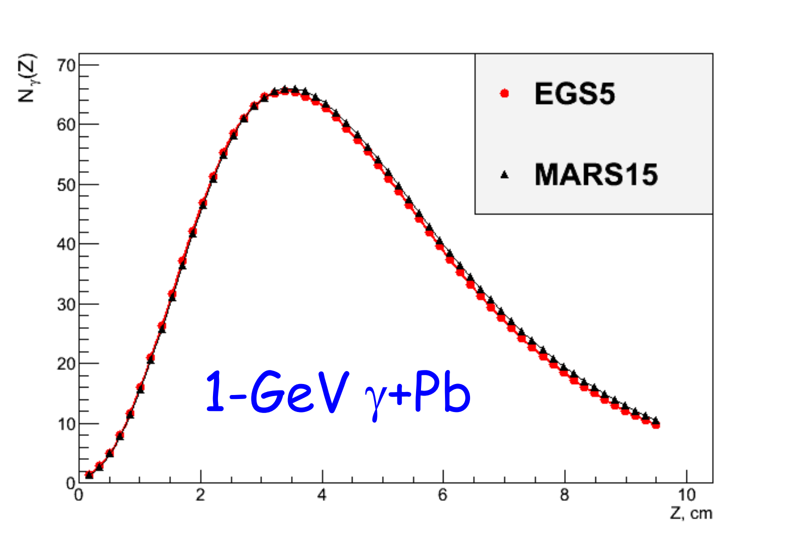
DPMJET and LAQGSM vs LHC Data at √S = 0.9 and 7 TeV

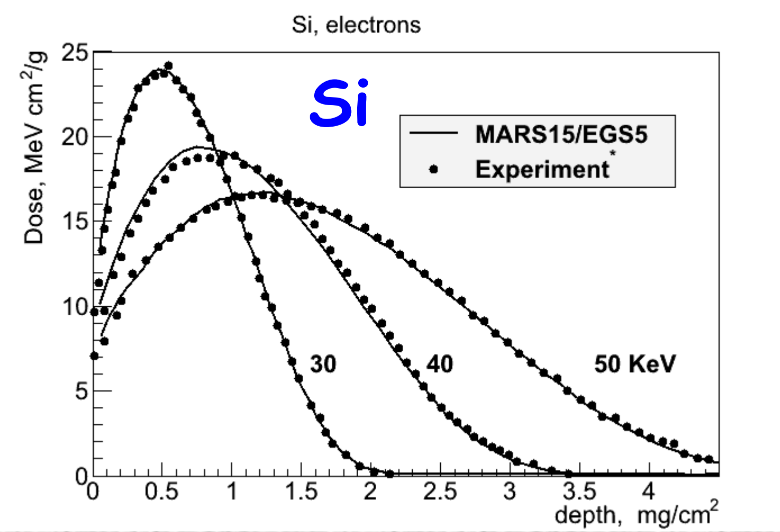


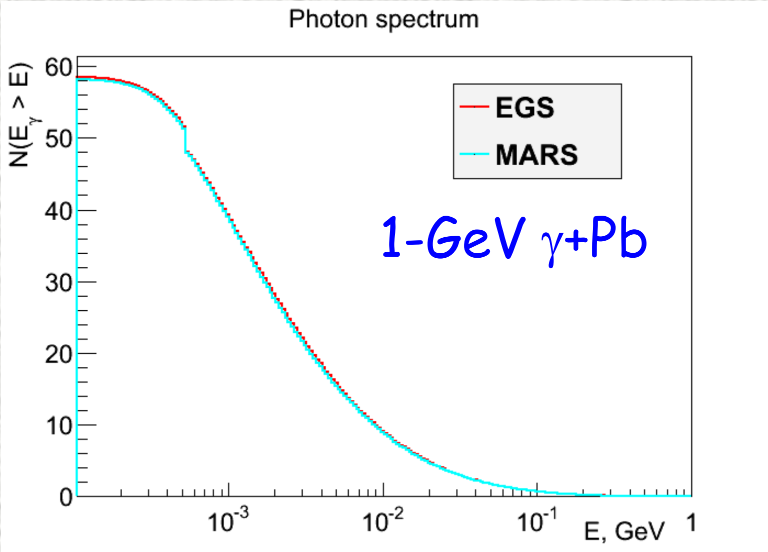


30 keV to 1 GeV EMS

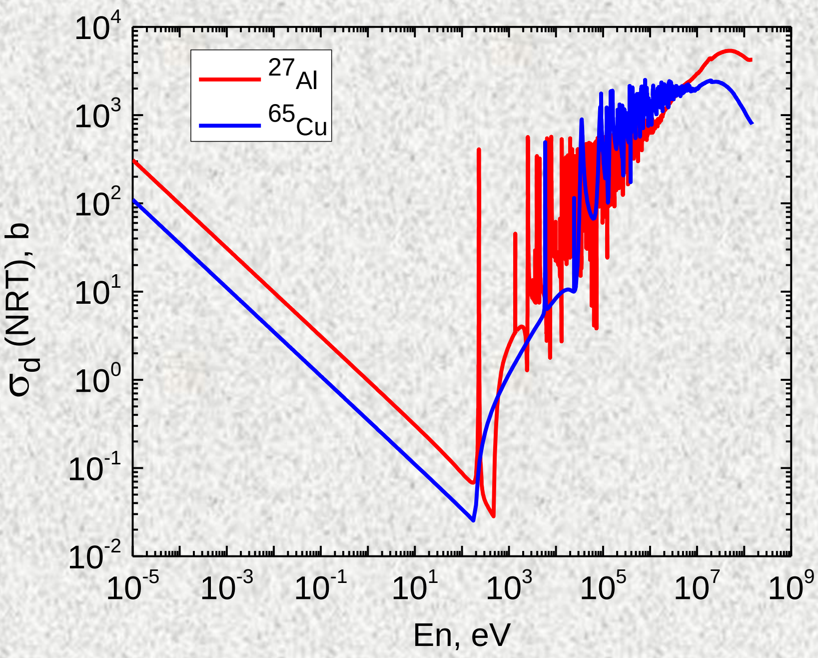


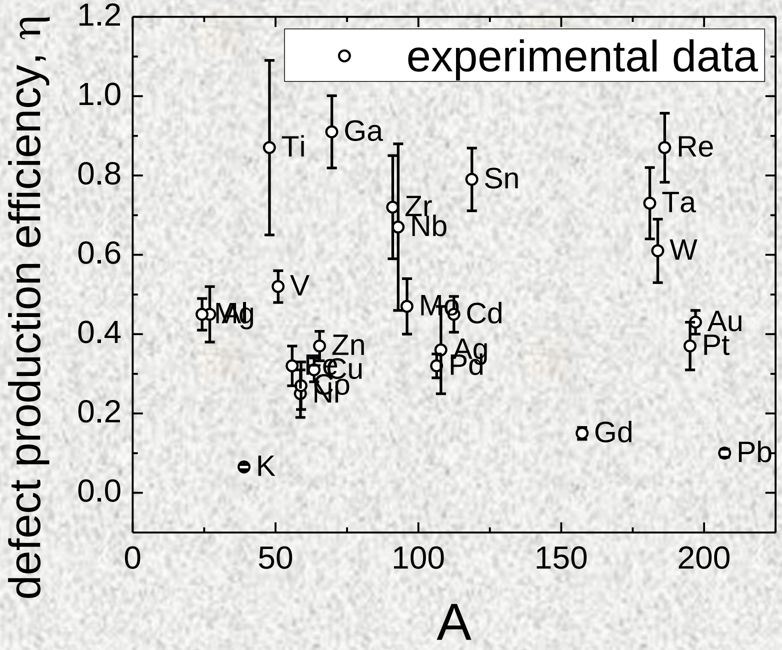






New Neutron DPA Model

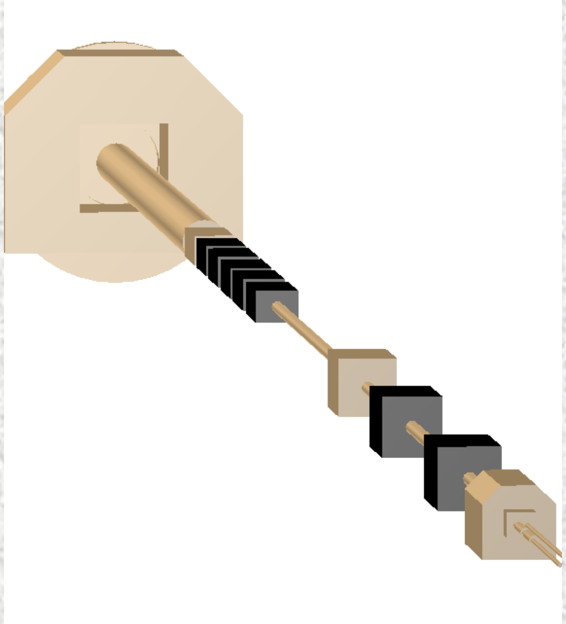




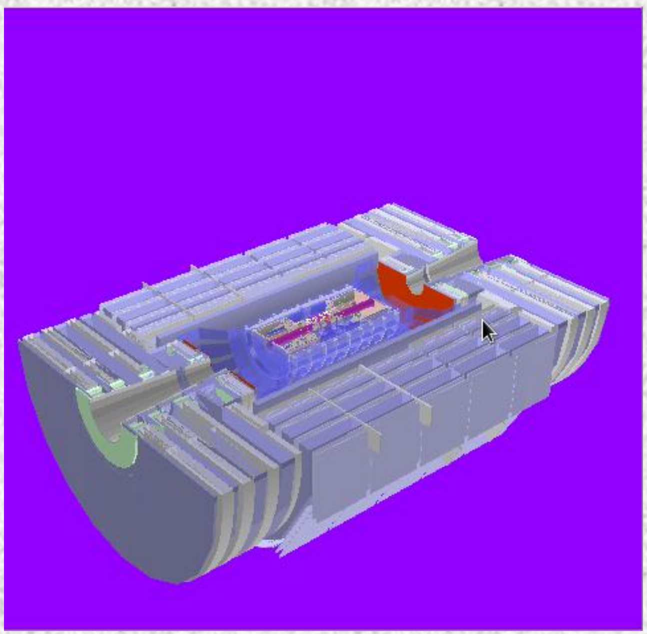
<u>**New for neutrons from 10^{-5} eV to 20(150) MeV**</u>: NJOY99+ENDF-VII database, for 393 nuclides: NRT (industry standard) corrected for experimental defect production efficiency η (Broeders, Konobeyev, 2004), where η is a ratio of a number of single interstitial atom vacancy pairs (Frenkel pairs) produced in a material to the number of defects calculated using NRT model. Temperature dependent.

MARS15-ROOT IP5 Model

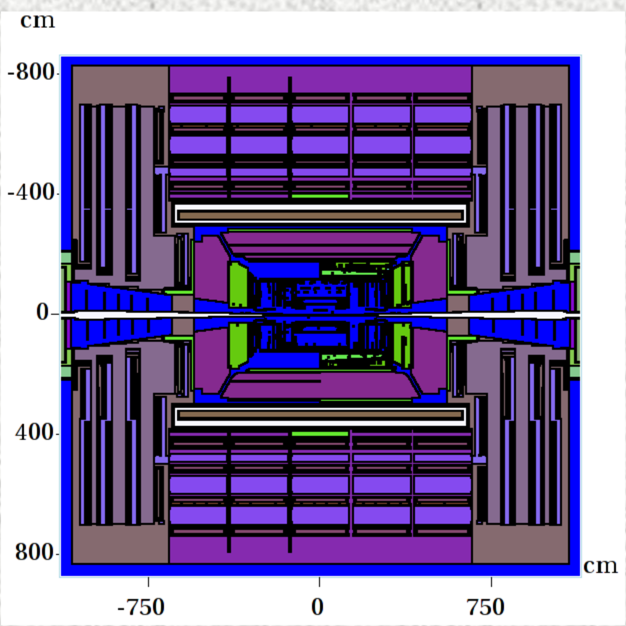
IR5rb1



CMS



CMS upgrade



HL-LHC 150-mm Aperture Quads: First MARS Runs (OK for Q1)

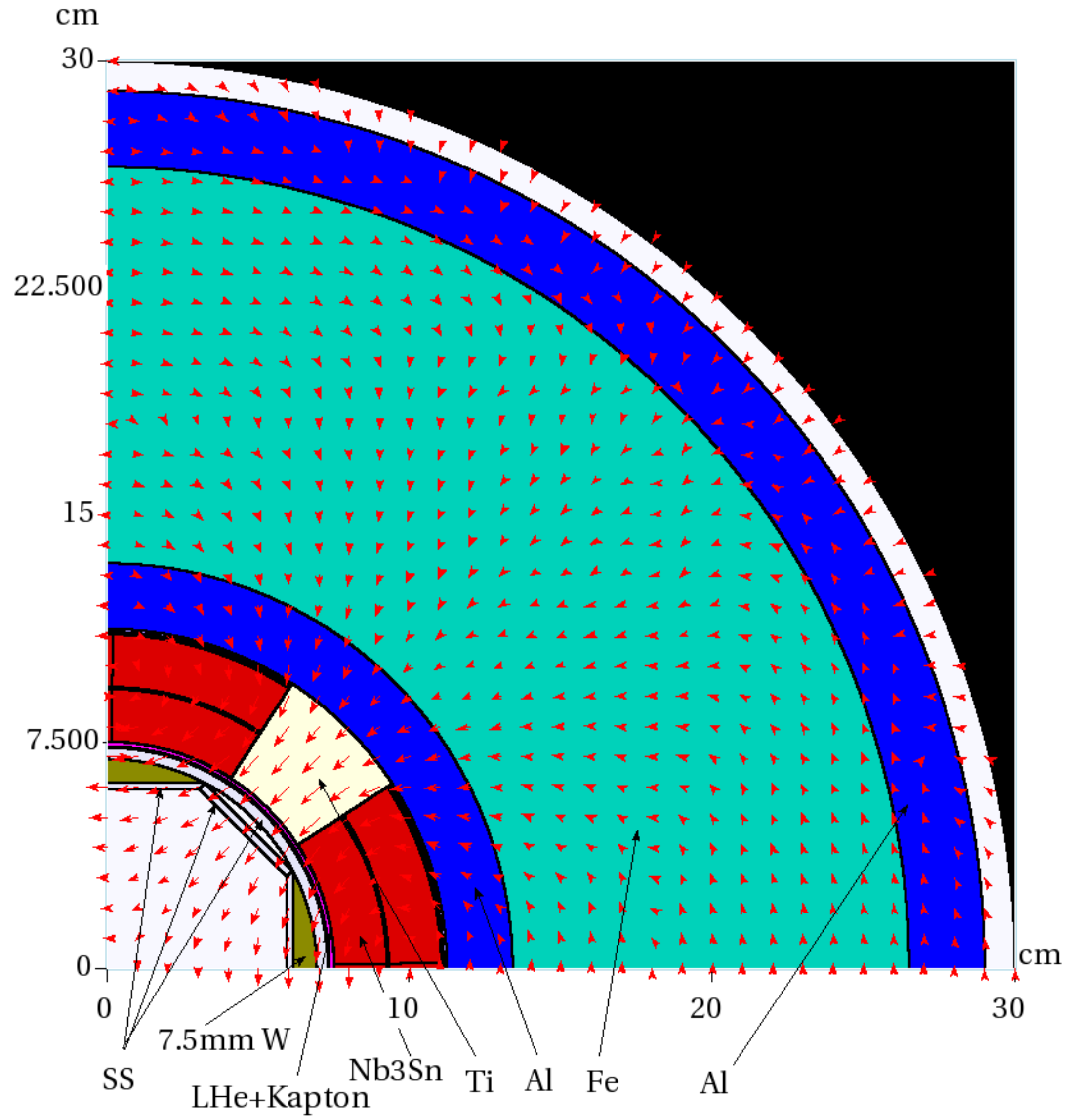
Optics (while waiting for the 150-mm release):

- round optics, *opt_150_0150_0150*
- $\beta_x^*=\beta_y^*$=15cm with 295 μrad half crossing angle, vertical
- twiss files: */afs/cern.ch/eng/lhc/optics/SLHCV3.1b/tables*

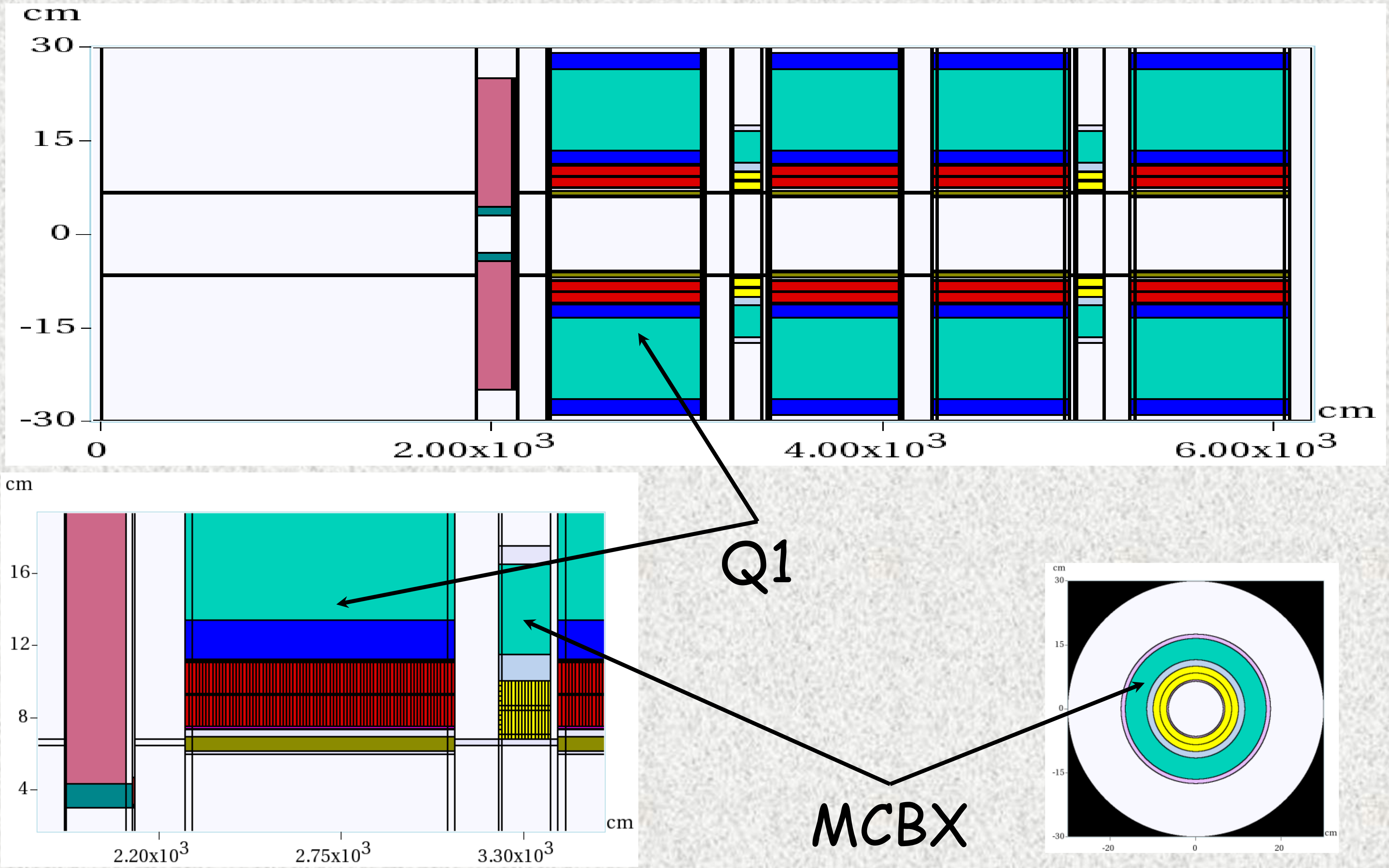
Triplet and quads:

- MQXF 150-mm aperture Nb_3Sn quads of August 2012
  8.5m Q1 and Q3, 6.77m Q2a and Q2b
  140 T/m, 630-mm OD cold mass
- 3.7-mm SS beampipe, 2-mm SS beamscreen and W inserts
  (7.5mm max thickness) in mid-planes (*as we proposed at WAMDO-2006 and published in PRSTAB, 2006*).
- TAS aperture 60 mm OD (currently)
- No experimental vacuum pipe

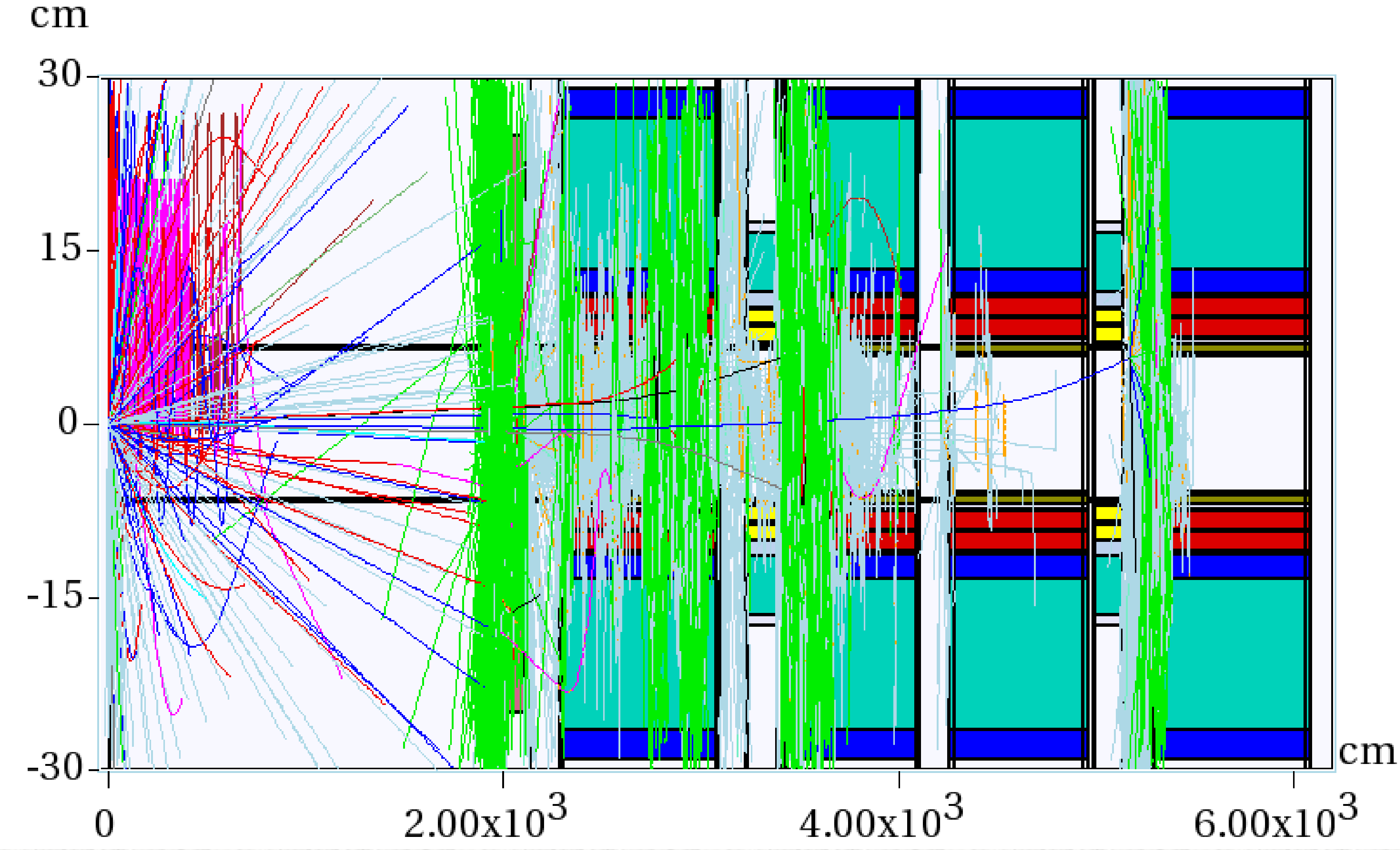
150-mm Nb_3Sn Coil ID Quad with W-inserts



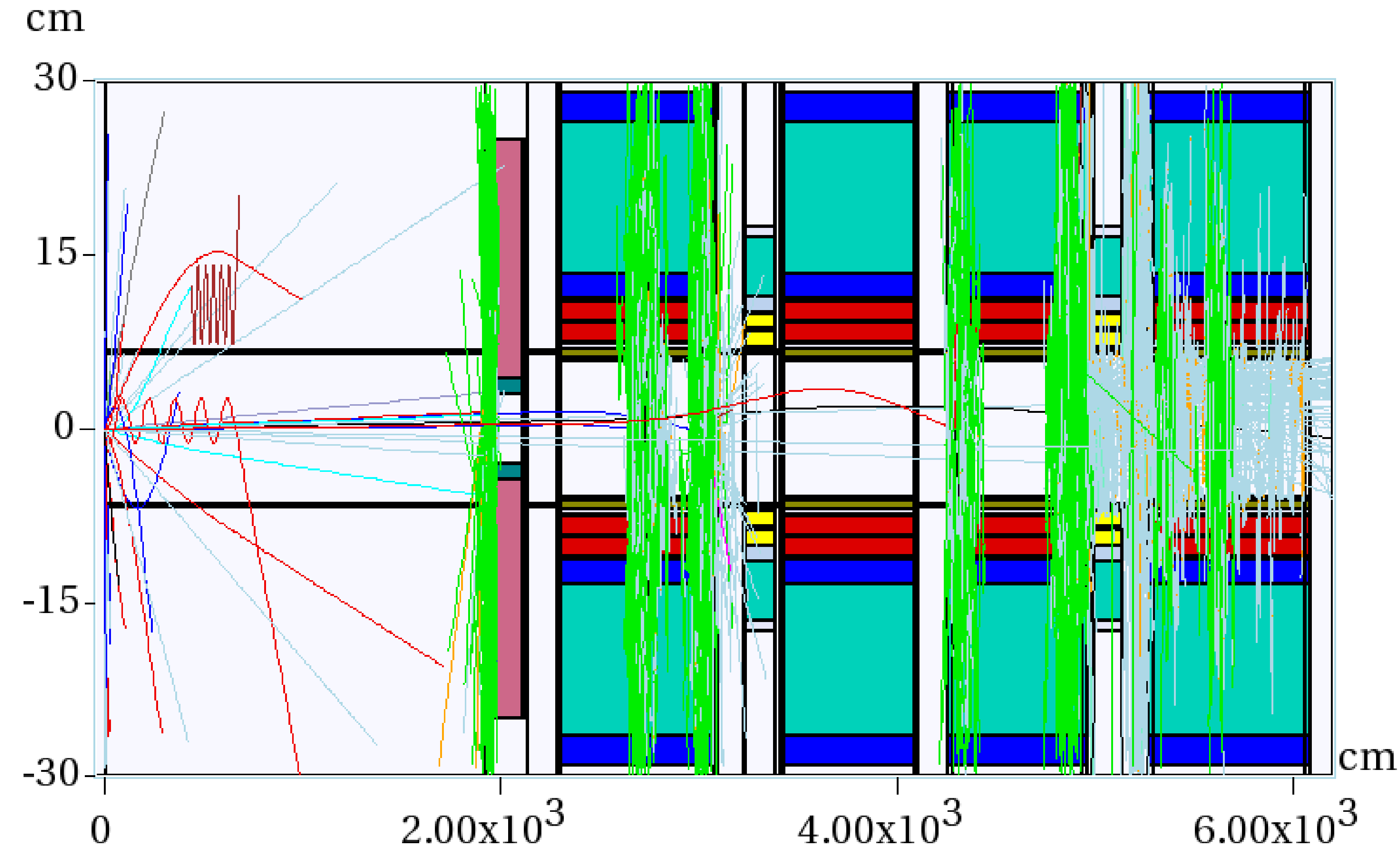
150-mm Aperture Triplet Model



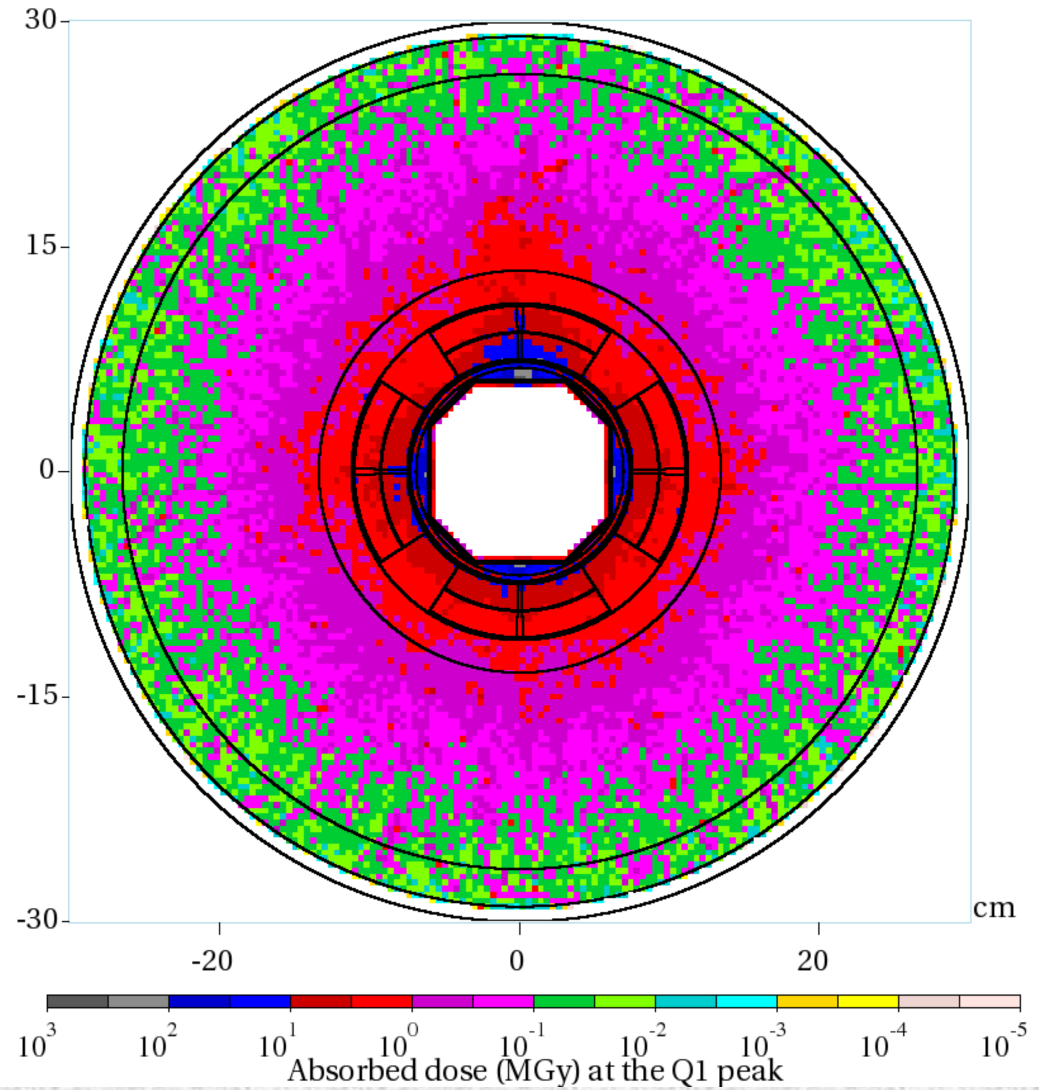
7×7 TeV pp (DPMJET3+MAR15): Event #3



7×7 TeV pp (DPMJET3+MAR15): Event #1



Absorbed Dose at 150-mm Q1 peak with W-inserts



Power density and dose longitudinal peak moved from the non-IP end at z=30.9m to z=29 m

Reduced 5 times in Q1 and 4 times in Q2A compared to the no insert case

Neutron fluence and DPA are slightly up: more neutrons produced in tungsten

MARS Peak Values in the Innermost 3 mm of the 150-mm Coil with 7.5-mm W Inserts

Value	Q1	MCBX1	Q2A
PD (mW/cm^3) in 3-mm bin	8	50	9
Dose (MGy)	58	330	73.6
F_n > 100 keV (cm^{-2})	1.5×10^{17}	7×10^{16}	1.4×10^{17}
DPA (no T-correction)	1.1×10^{-3}	1.5×10^{-3}	1.2×10^{-3}

PD a factor of 2 lower, i.e. 4 mW/cm^3, if averaged over inner cable width: more relevant for quench stability

MCBX needs inserts!

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

Peak PD in Q1 is 5 and in Q2a is 4 times down, 20-25% of the quench limit!
Peak dose in Q1 still above target for insulation, but only by ~50%
Peak DPA (with T-correction) is close to the limits for metals at cryo T

Summary and Plans

- FLUKA and MARS synchronized models are up, running and used for optimization studies of HL-LHC triplets.
- Overall very good agreement between FLUKA and MARS on power density and dynamic heat load in quads.
- MARS15 developments in 2012 add confidence.
- Peak power density in 140-mm ID quads with 3.7-mm SS BP is at the quench limit. Peak dose is 7.5 times above the target of 40 MGy.
- First results for the 150-mm ID triplet with beamscreen and mid-plane W-inserts (7.5-mm max thickness): peak power density and dose in Q1 are reduced by a factor of 5. Another factor of 2 can be achieved by increasing W thickness to 9 mm.
- Repeat with consistent IT optics (including 160-mm ID D1), inserts in MCBX and adjusted TAS ID.
- Further R&D on DPA limits at cryo temperatures (Fermilab-Japan collaboration).