Energy Deposition in Triplet and D1

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WP-10

3rd Joint HiLumi LHC-LARP Annual Meeting
Daresbury, UK
November 11-15, 2013

OUTLINE

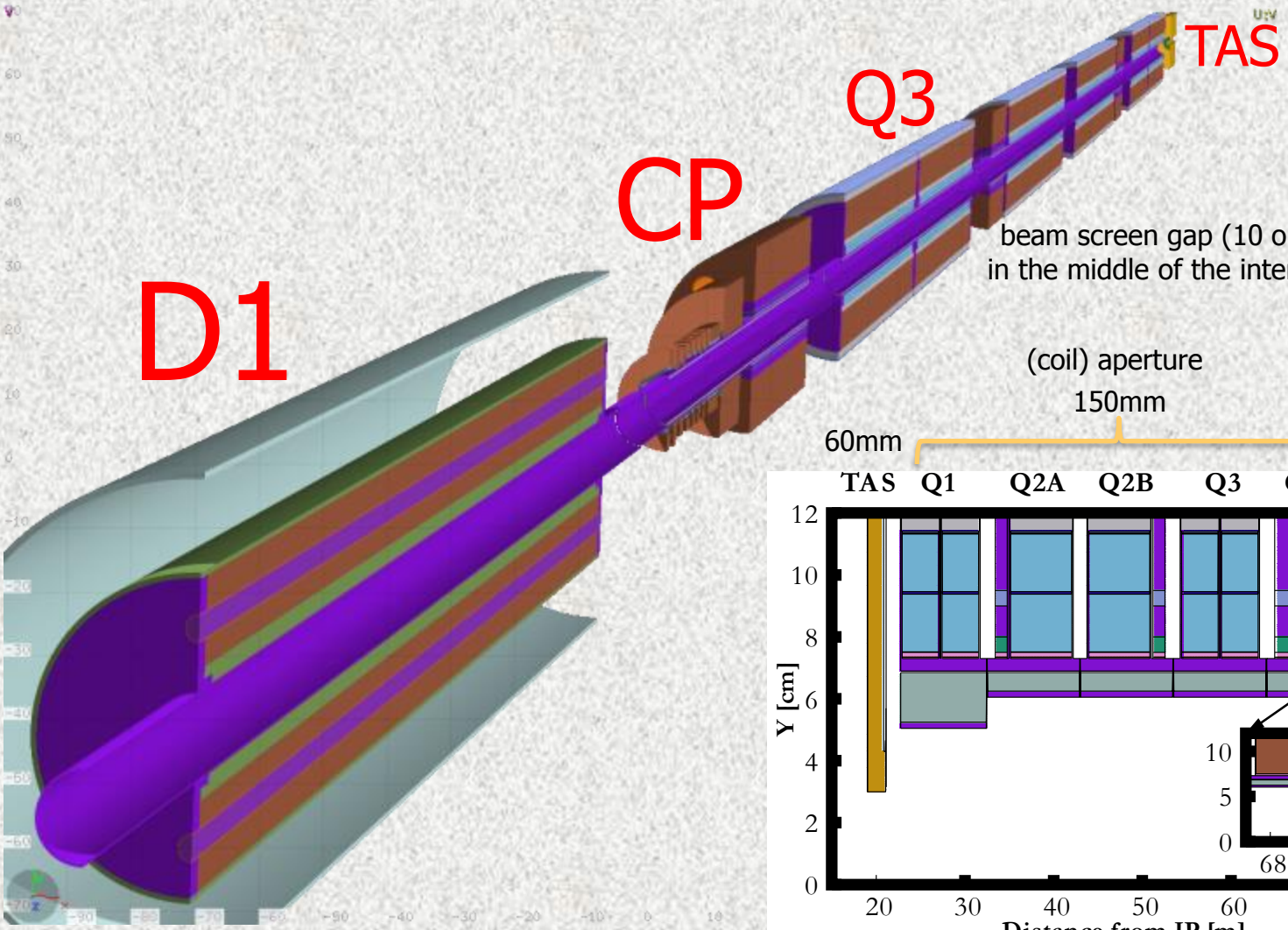
- FLUKA/MARS Model of the HiLumi LHC IT and D1
- Power Density and Absorbed Dose
- Optics Impact
- D1: More Details and Radiation Damage
- Dynamic Heat Load
- Launching Crab Cavity Studies
- Summary

Basic Parameters for FLUKA/MARS Runs

- 295 μrad half-angle in the IP1 vertical crossing plane
- 85 mb proton-proton cross-section at $\sqrt{S}$ = 14 TeV
- Power density @5.e34 cm^{-2} s^{-1}, dose @ 3000 fb^{-1}
- DPMJET III as event generator, 10^5 pp collisions
- Current versions of FLUKA and MARS15 with default cutoff energies
- Binning scoring: $\Delta z \simeq 10$ cm, $\Delta r \simeq 3$ mm*, $\Delta\varphi = 2^0$

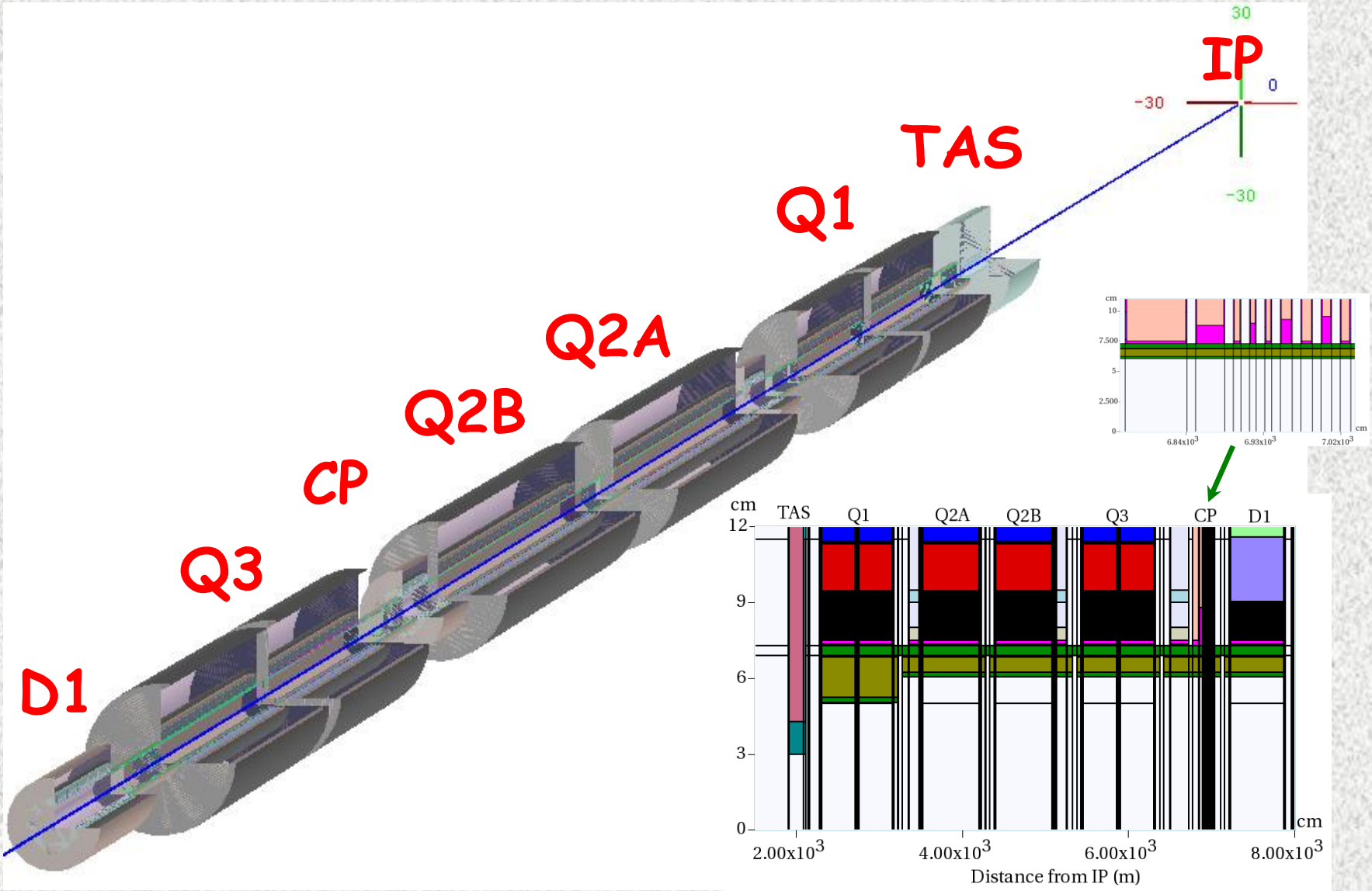
*) or less according to coil/insulator thickness

HL-LHC IT and D1: FLUKA

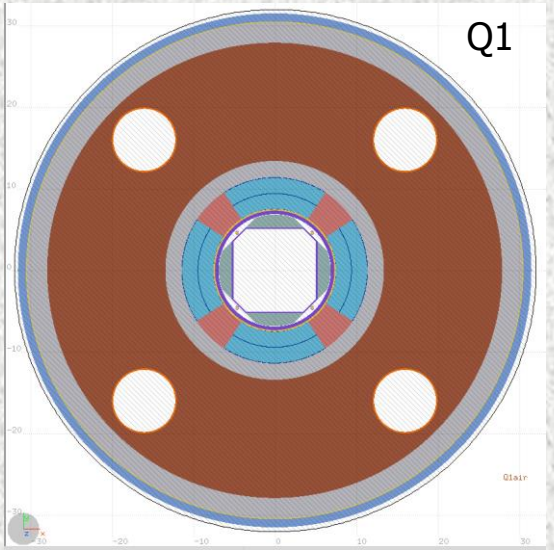


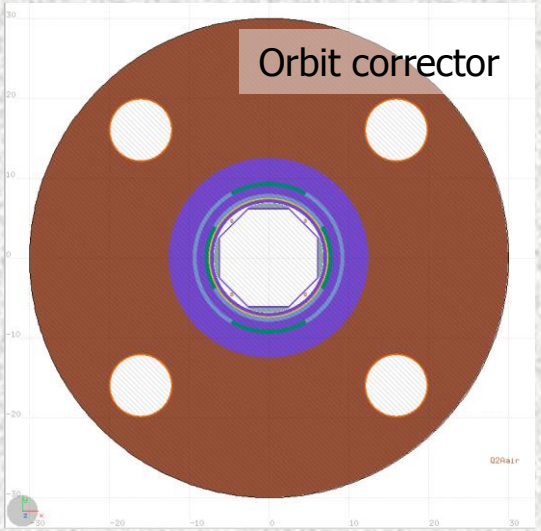
beam screen gap (10 or 50 cm)
in the middle of the interconnects

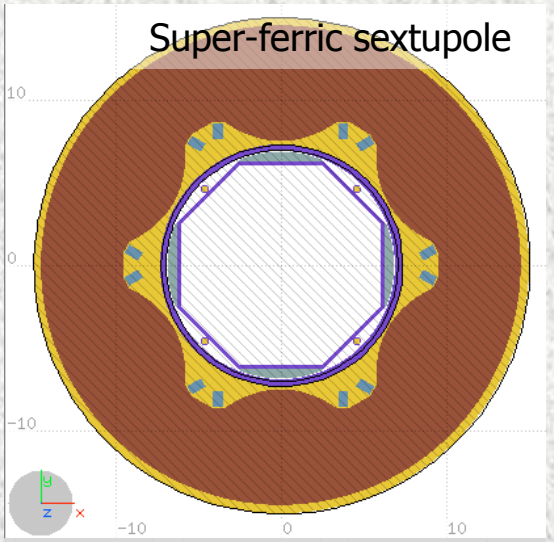
150-mm HL-LHC IT and D1: MARS15

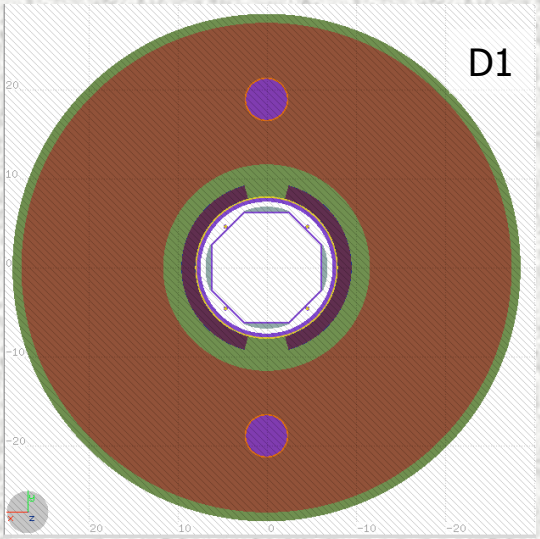


Quads, Correctors and D1: FLUKA

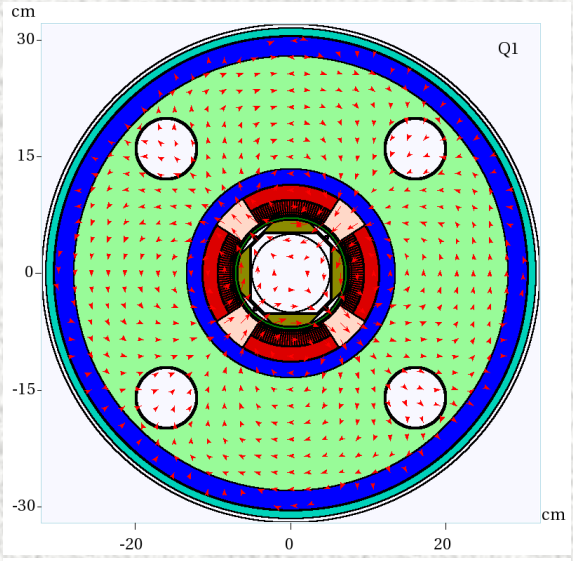


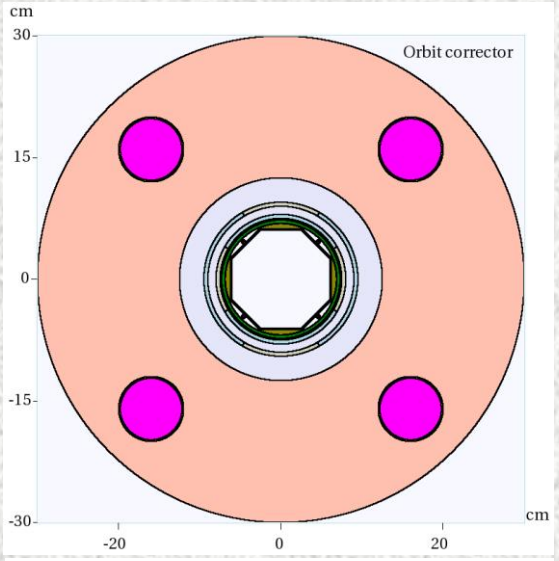


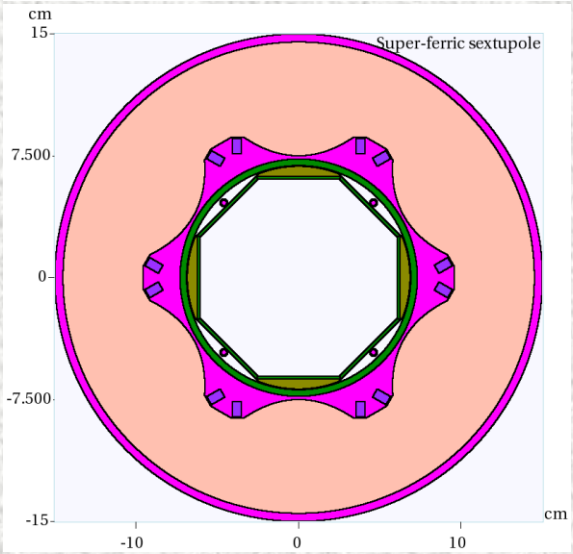


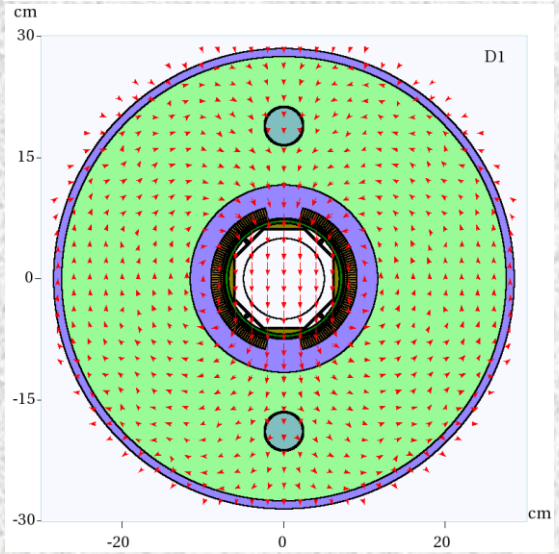


Quads, Correctors and D1: MARS



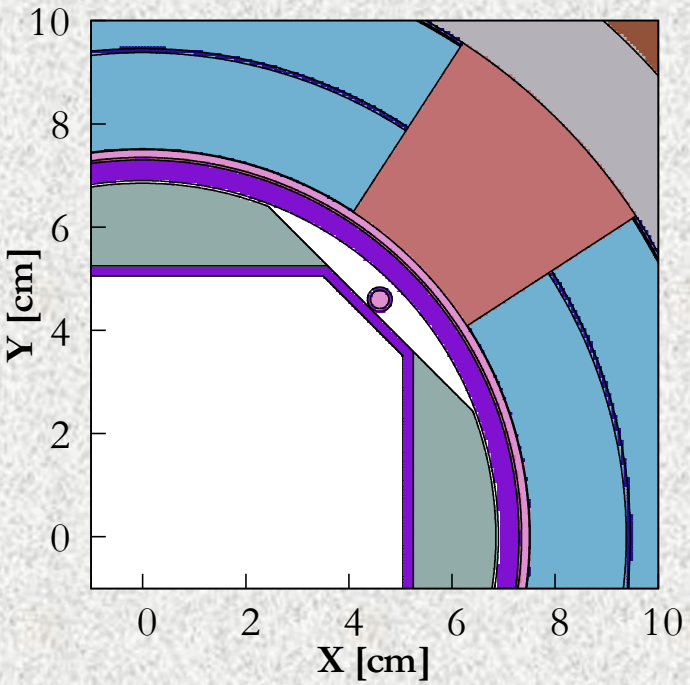


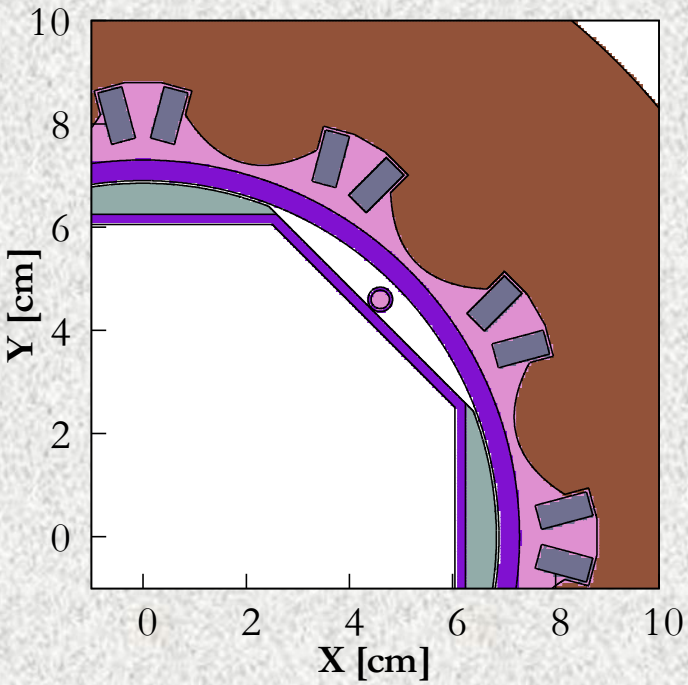




Details Inside Coil Aperture

4 LHe channels with IR = 1.78 mm



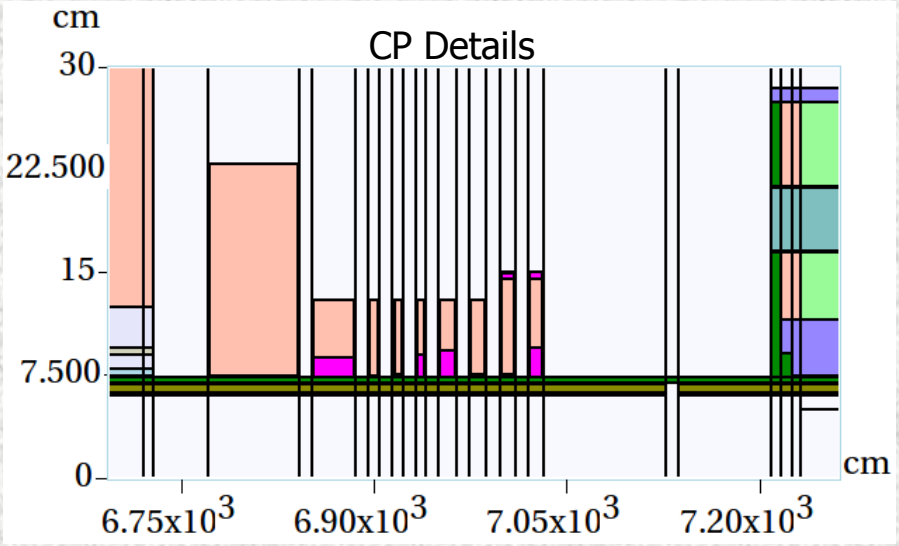


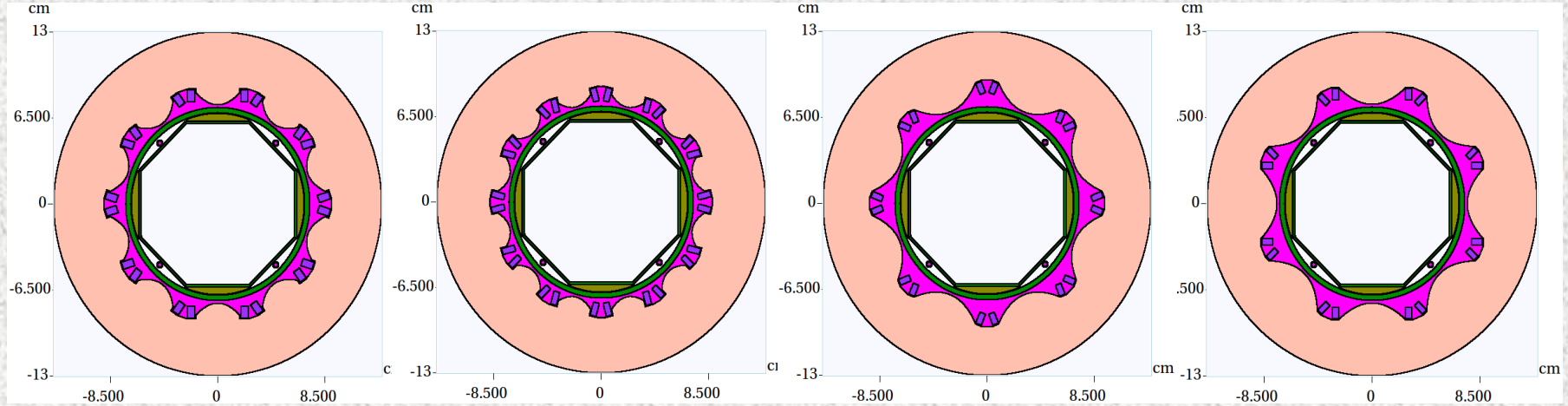
Tungsten (density = 19.3 g/cm^3 , no packing factor)

4mm cold bore

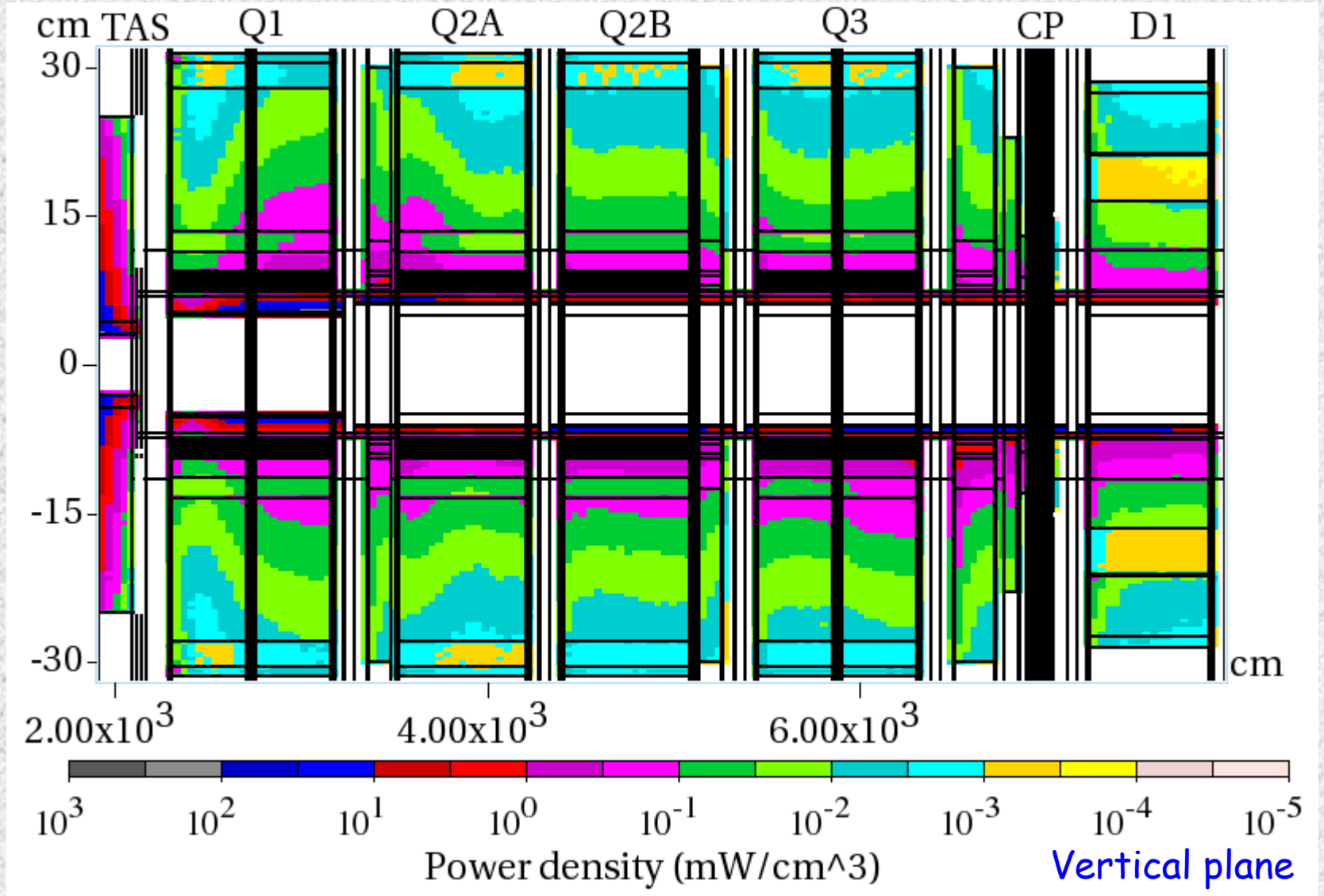
0.5 mm clearance between absorbers and cold bore
in reality should be 1.5mm (including sliding rings)

Corrector Package: MARS





Power Density (mW/cm^3) in IT&D1: MARS15



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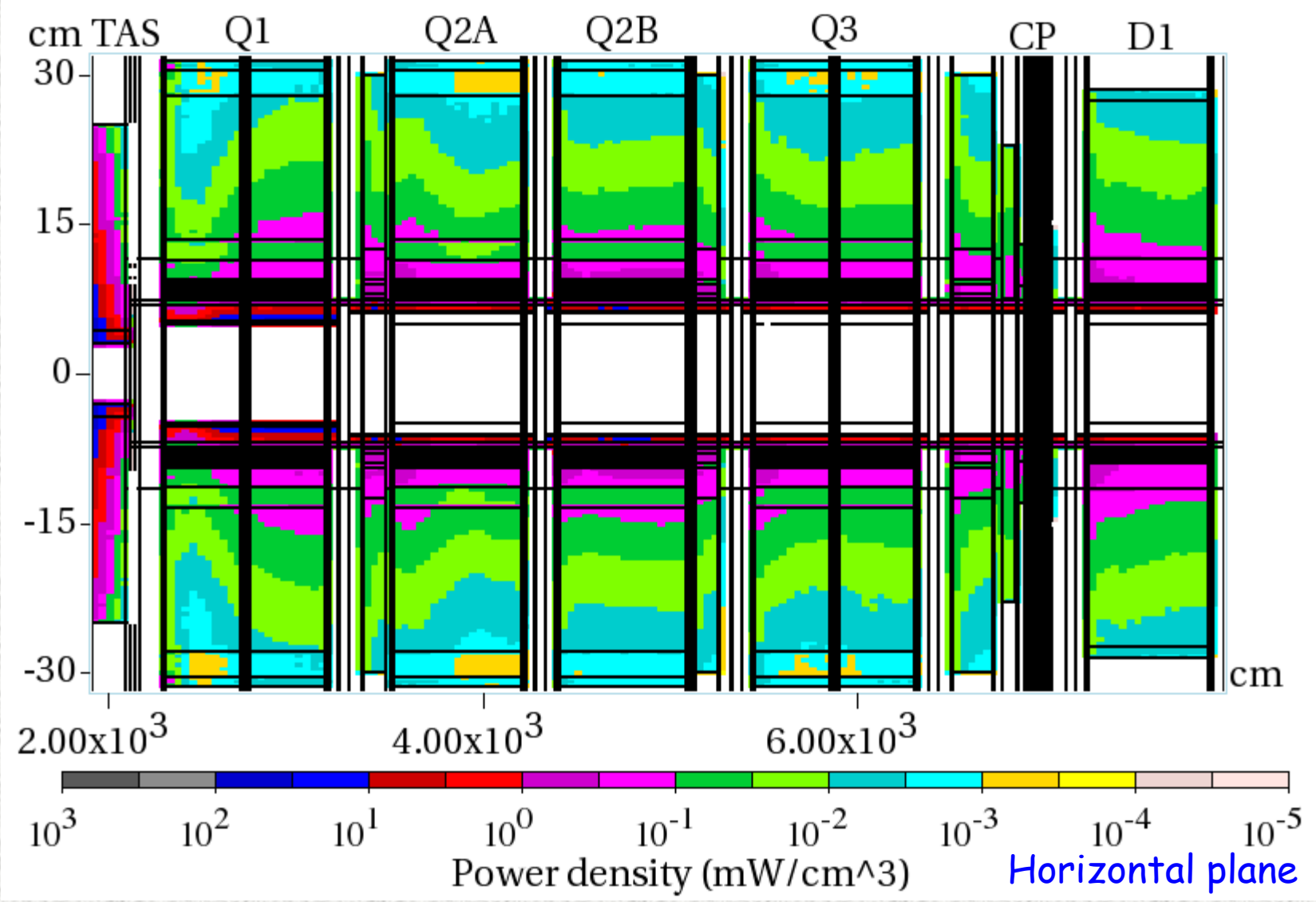
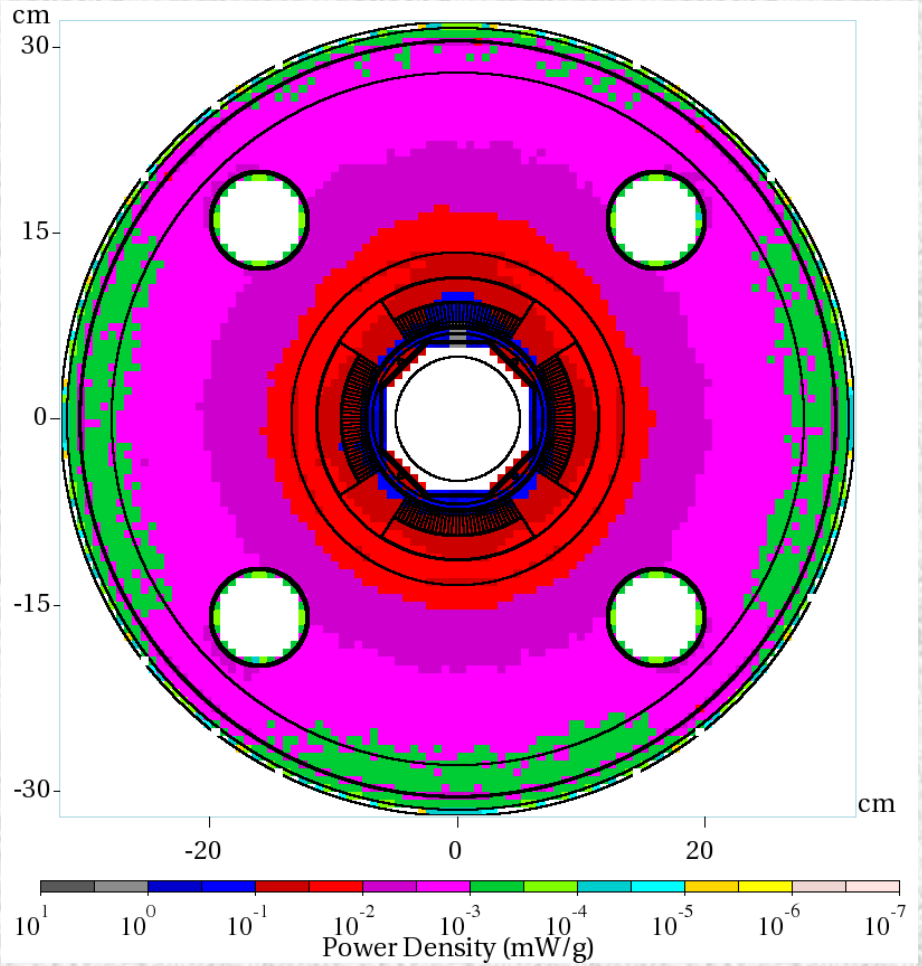
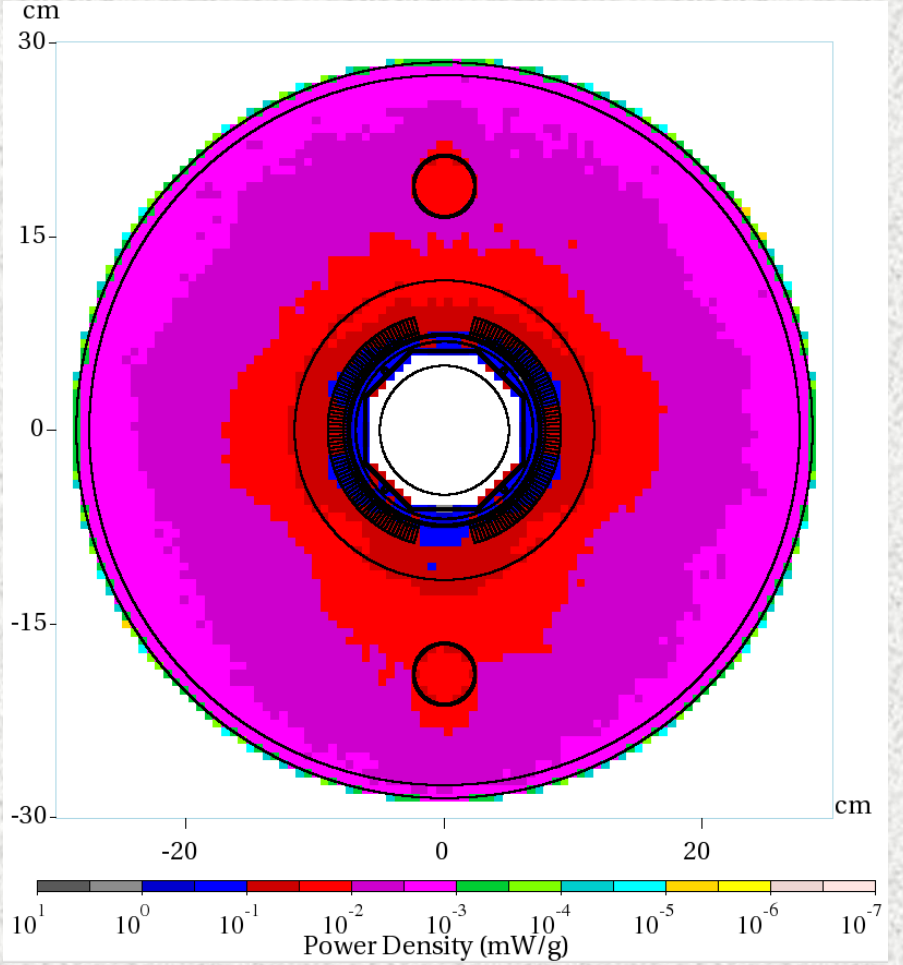


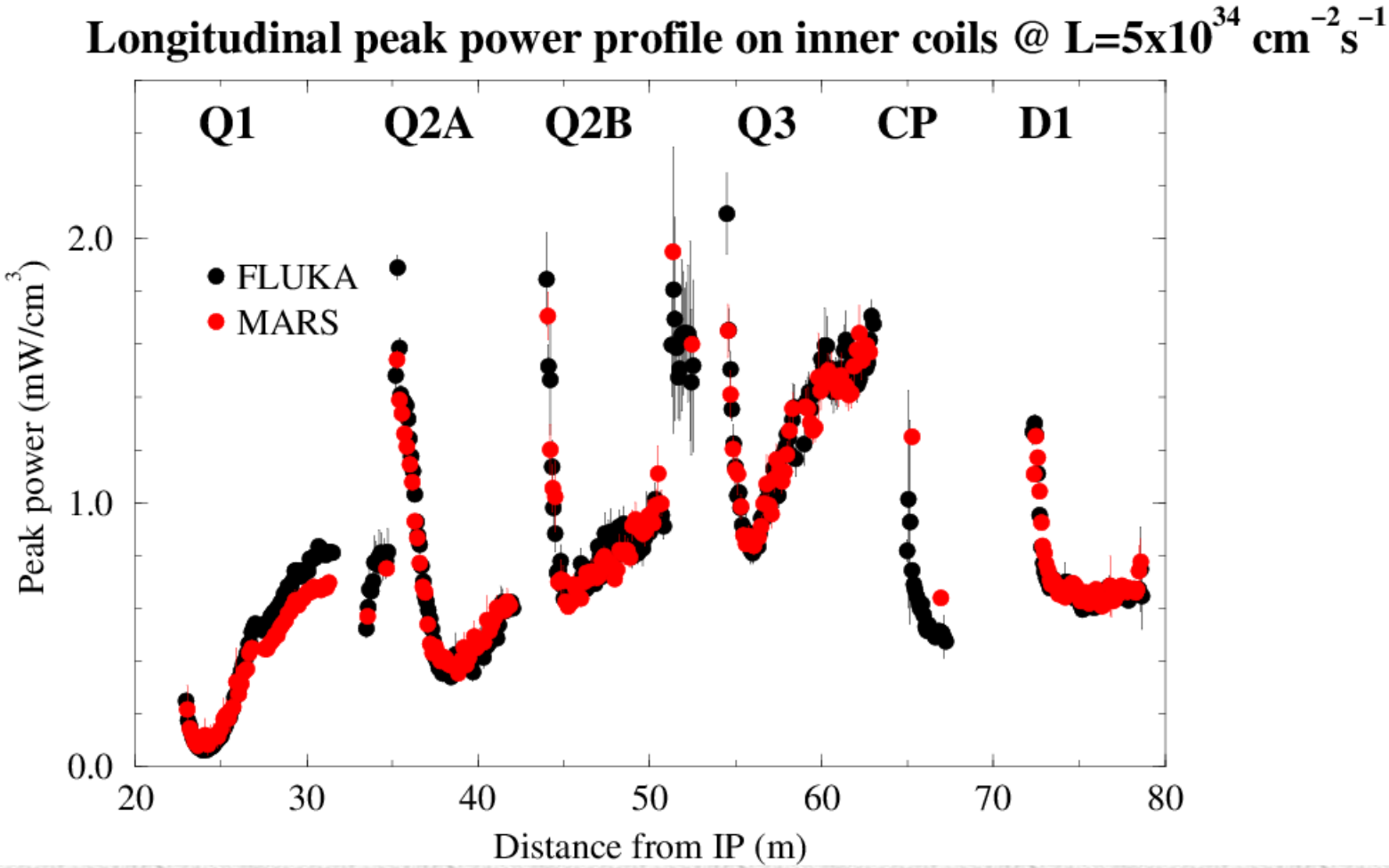
Power Density (mW/g) in Q2A & D1: MARS15

At IP end



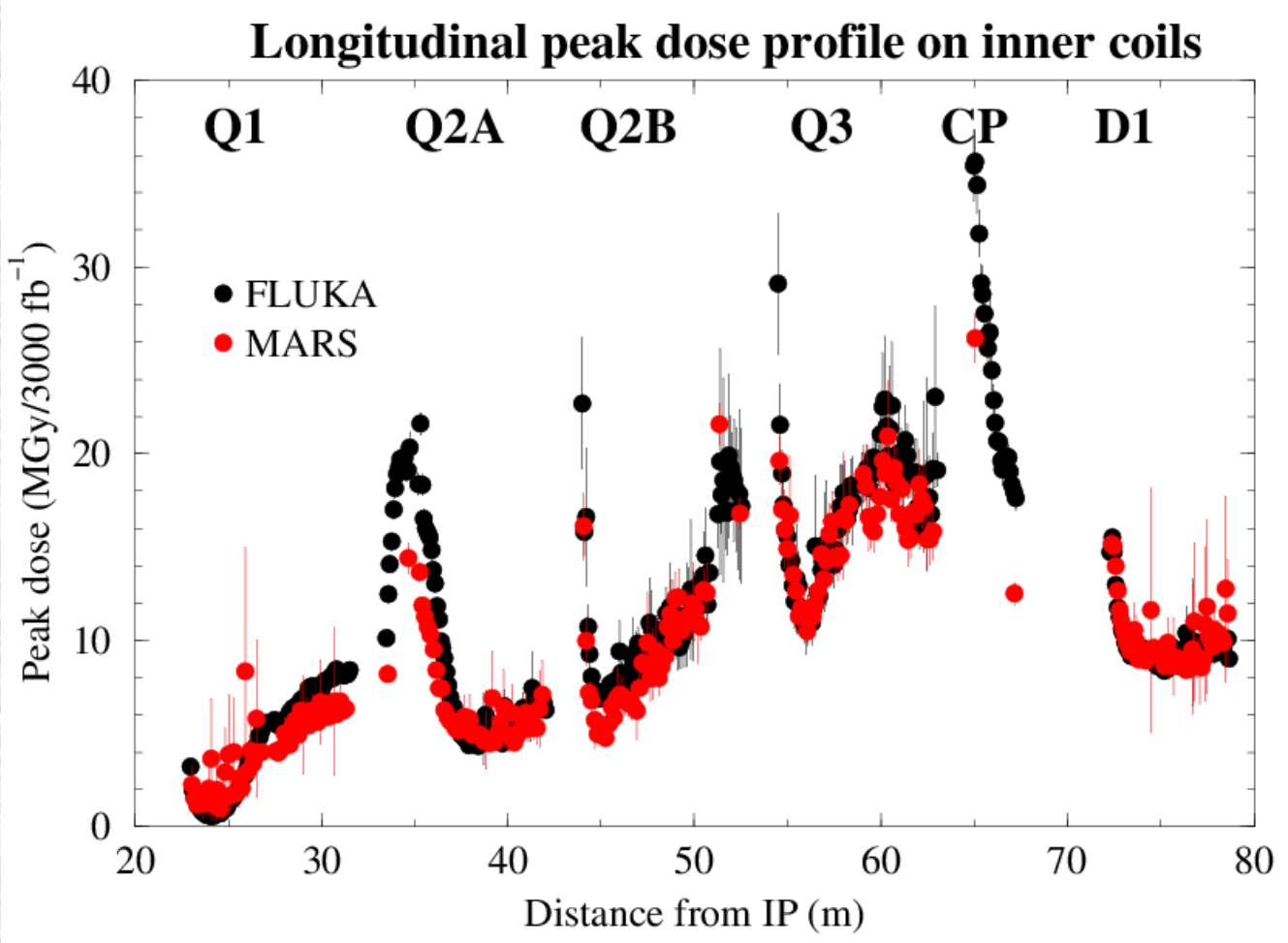


Peak Power Density Longitudinal Profile



Peak power density is averaged over the ***full cable width***; ***50 cm*** beam screen interruption in the interconnects

Peak Dose Longitudinal Profile

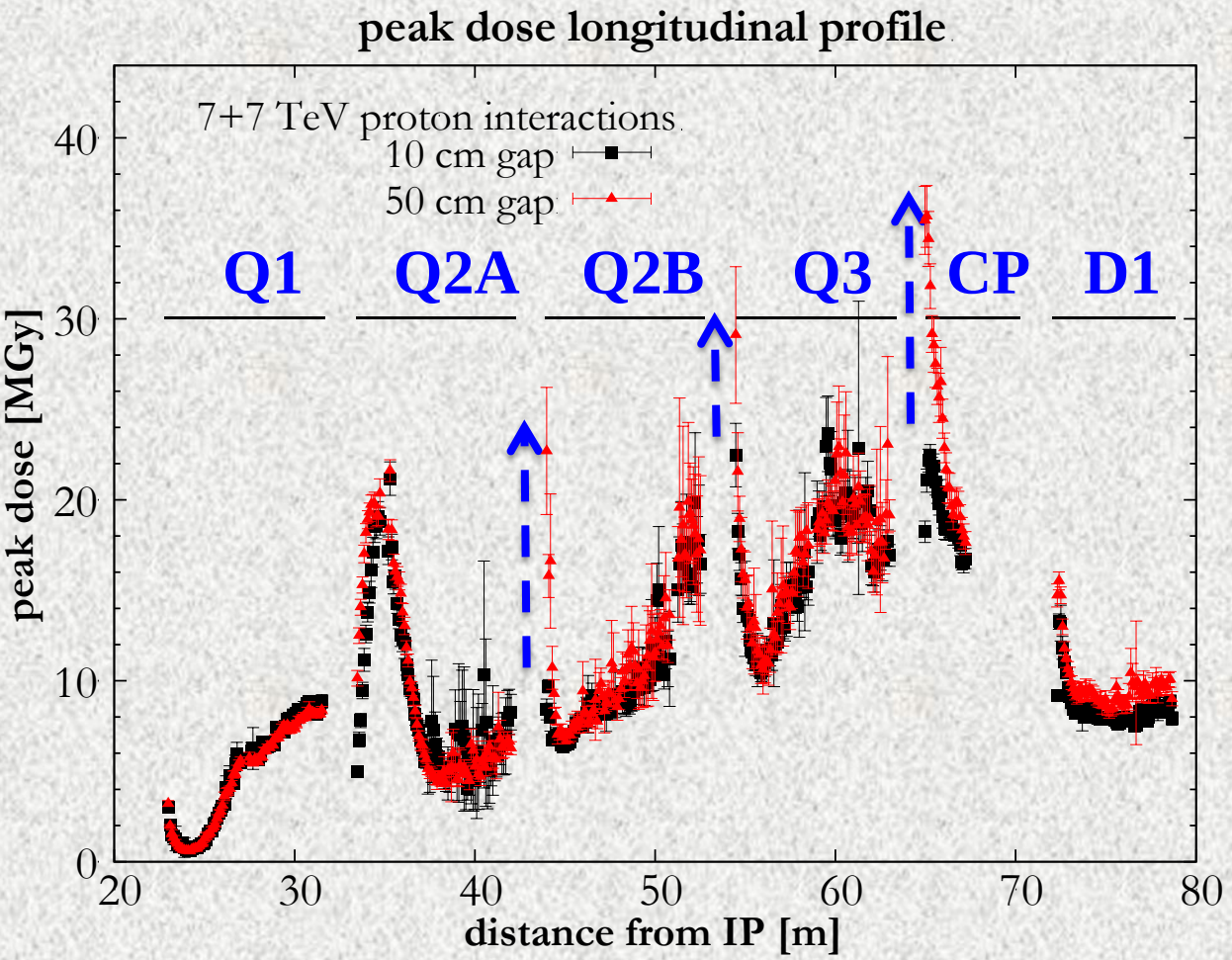


Refined MARS histograming in correctors is coming: expect better agreement there.

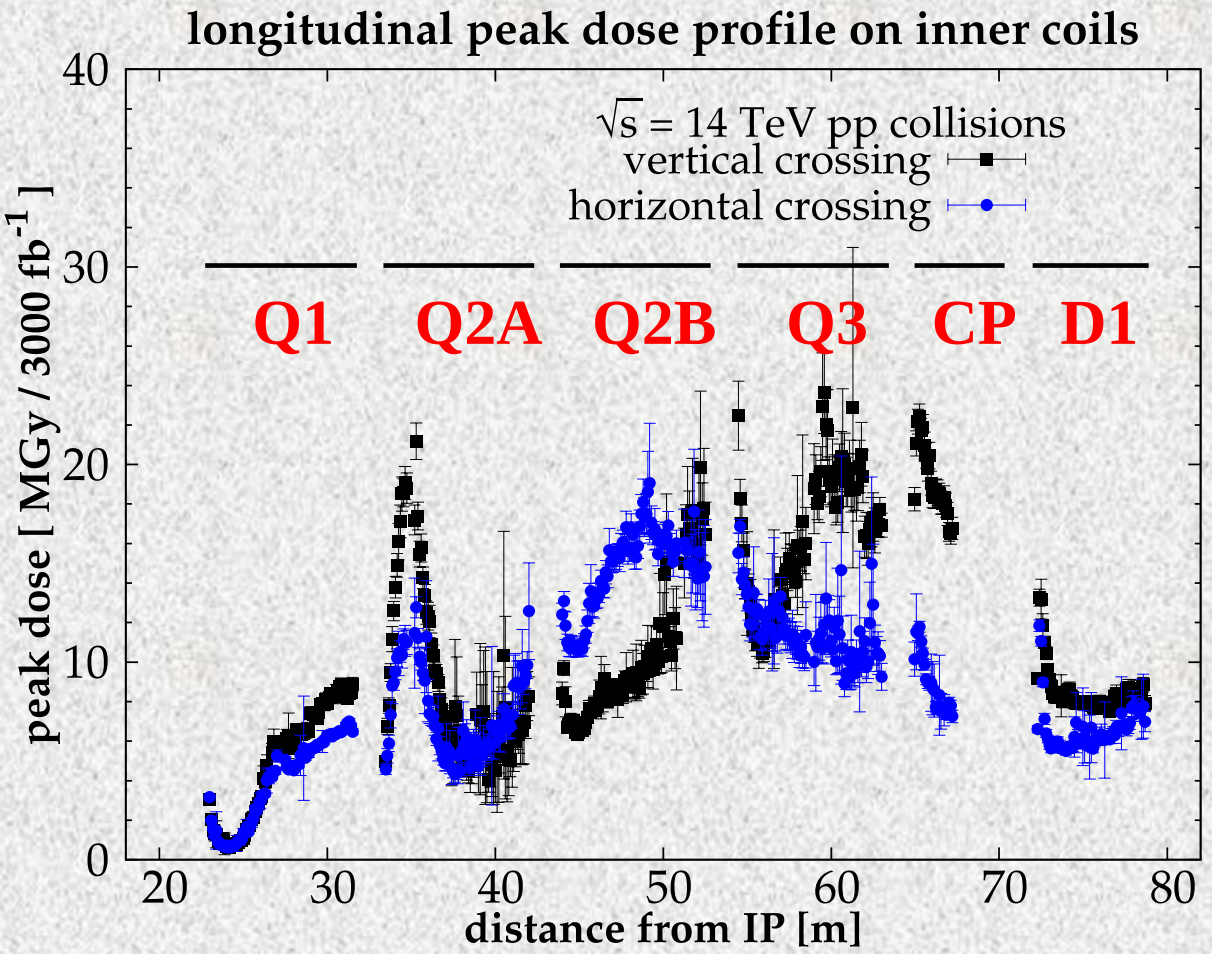
In future runs, MARS will be switched to fully exclusive mode that will reduce fluctuations.

Peak dose is averaged over the ***innermost 3 mm***; ***50 cm*** beam screen interruption in the interconnects

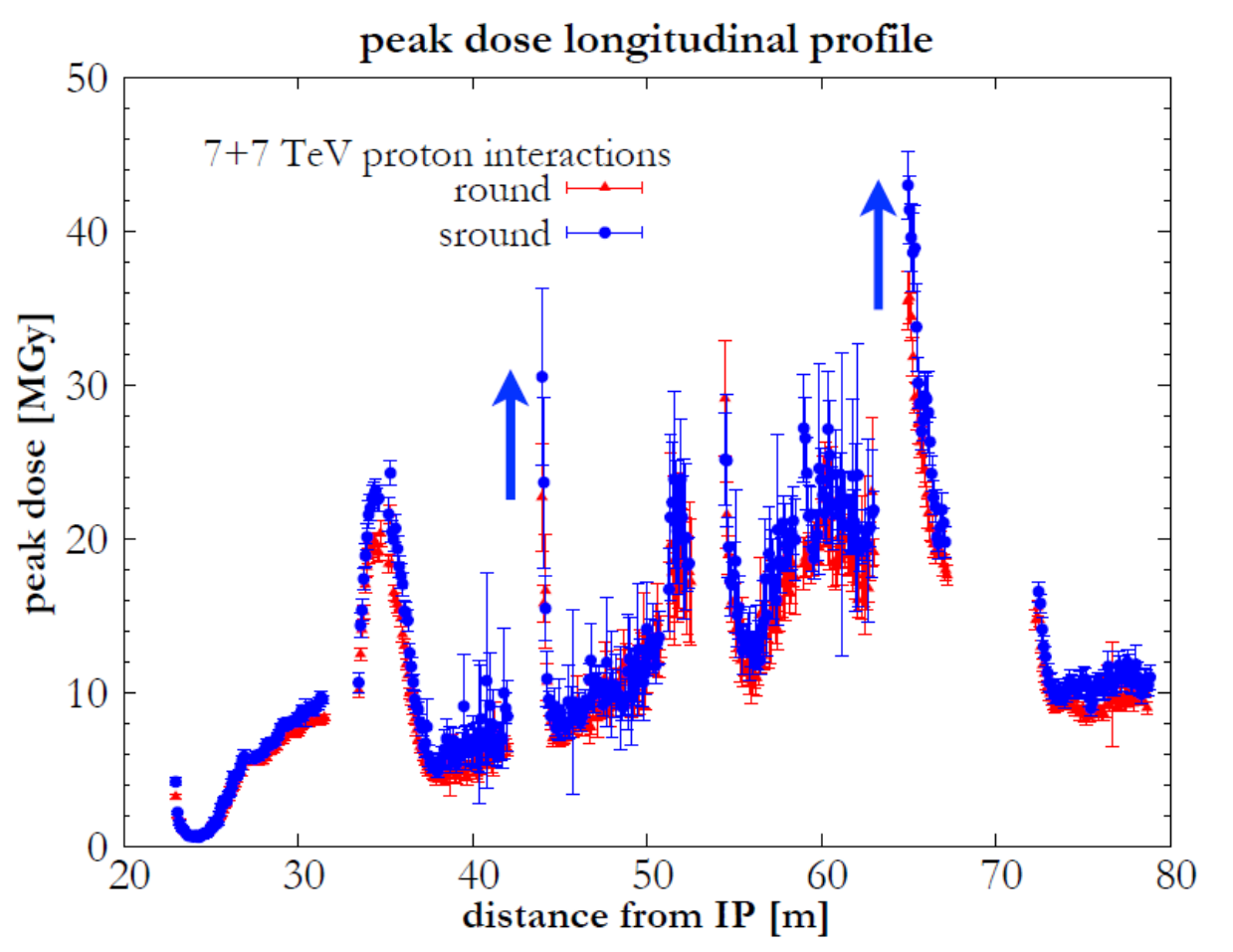
Shielded Beam Screen Interruption (FLUKA)



Horizontal vs Vertical Crossing (FLUKA)

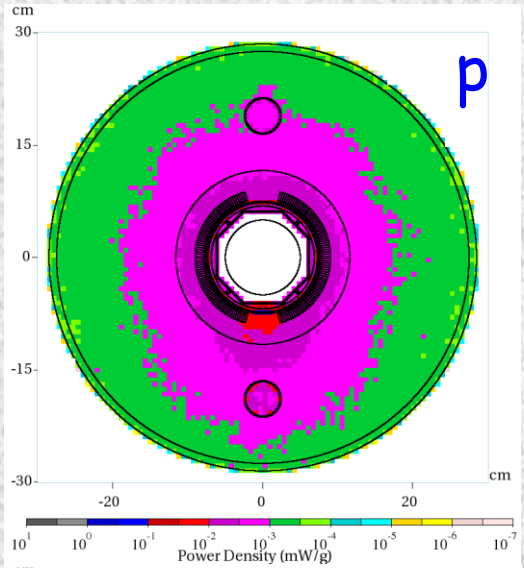


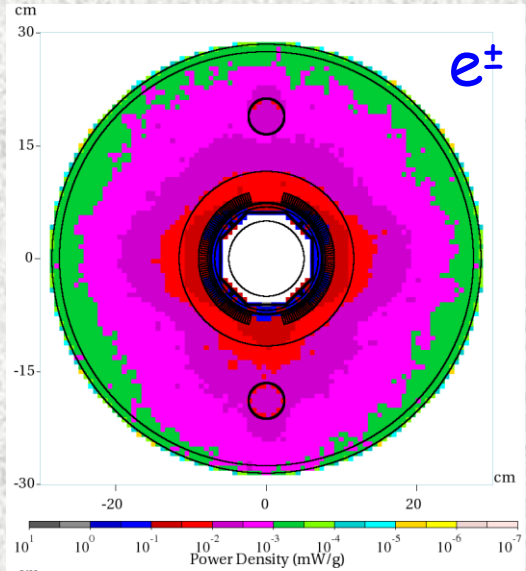
Sround vs Round Optics (FLUKA)

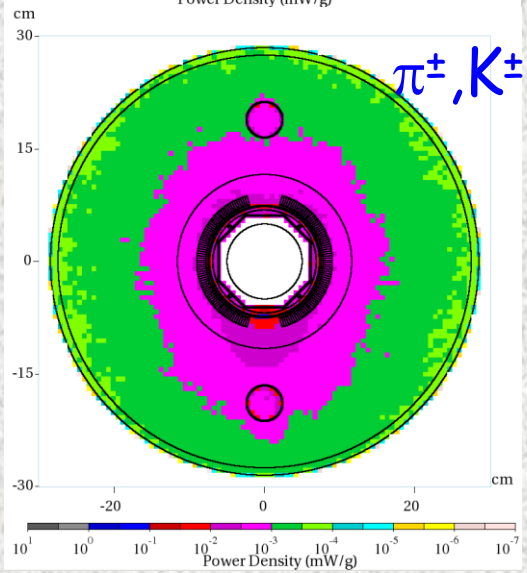


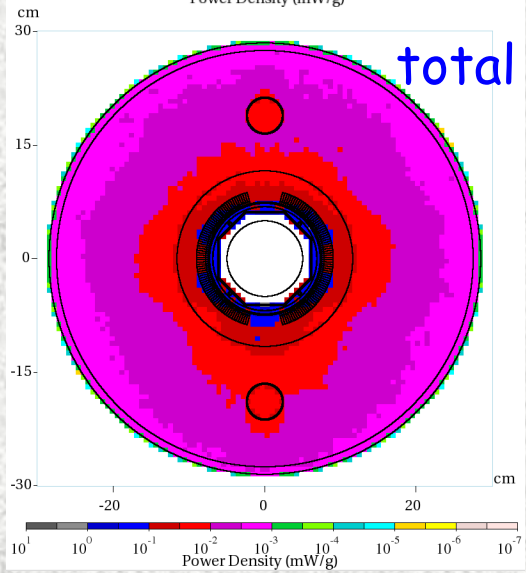
- +20% crossing angle (590 ⇒ 720 μrad) results in 20% increase in the peak dose at Q2B IP side.
- Q1B-Q2A interconnect, the most sensitive IT region to crossing angle, is protected by thick beam screen with 16 mm tungsten absorbers

Power Density (mW/g) in D1: MARS15









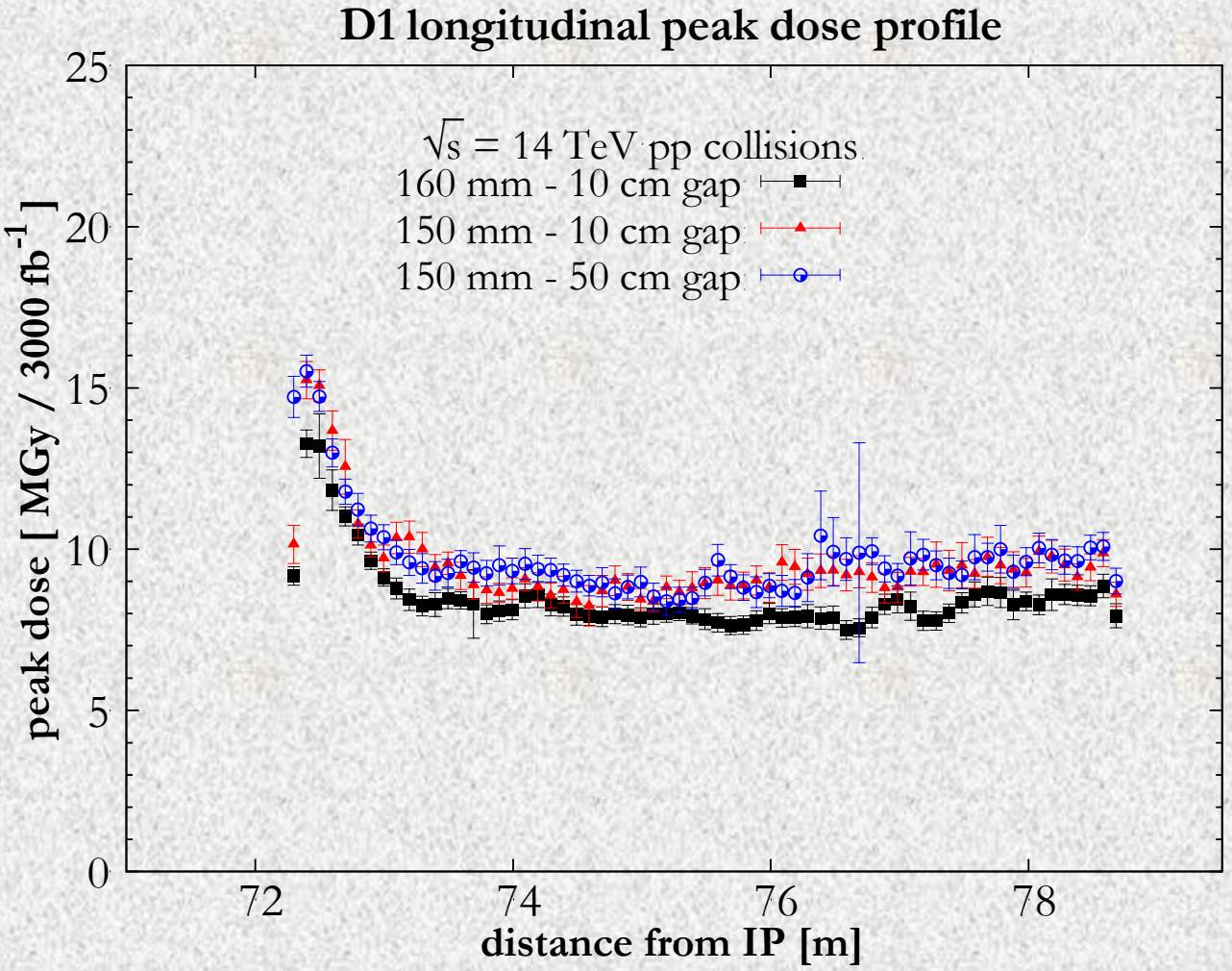
D1 IP end

Peak PD

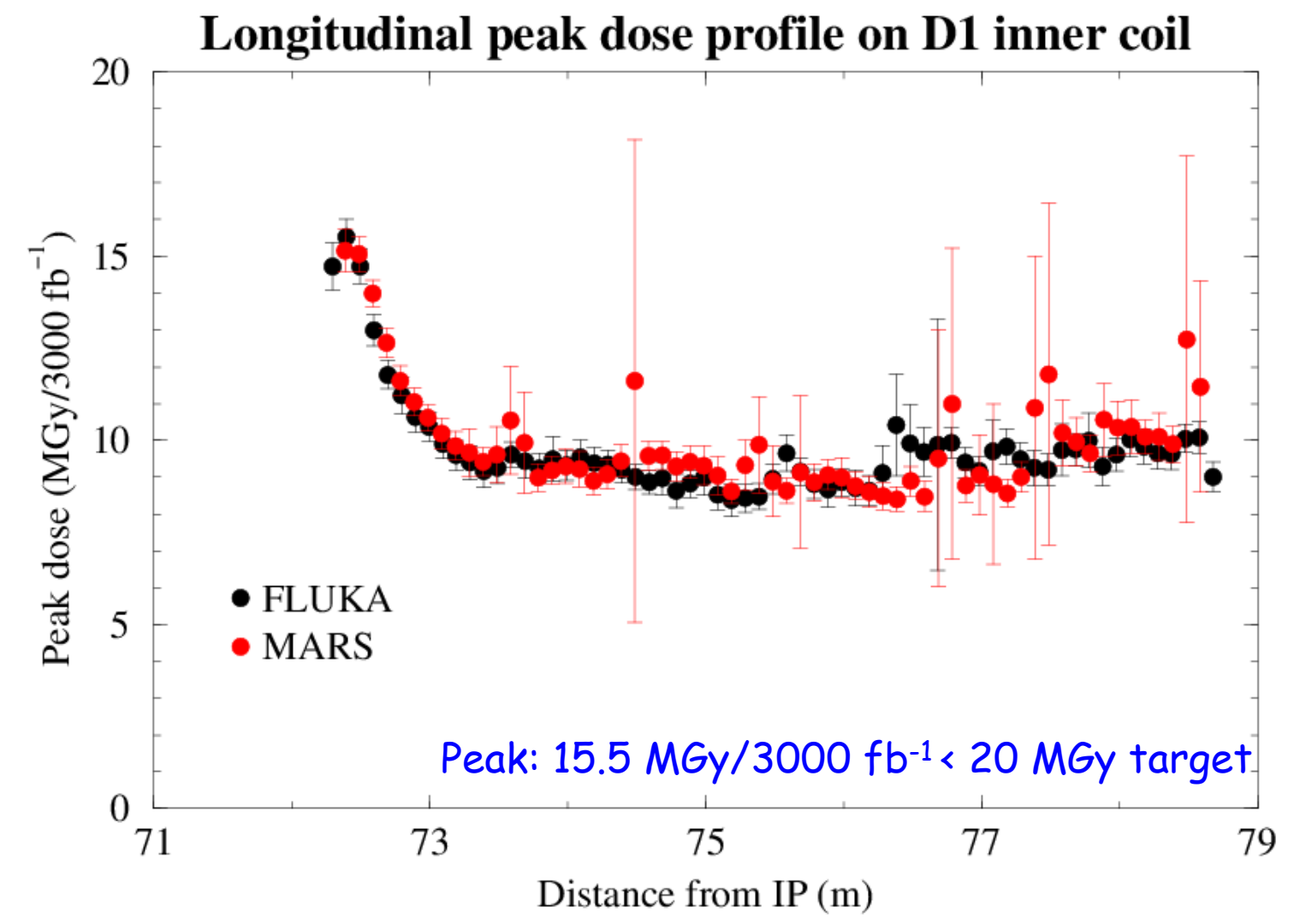
π:p:e = 0.15:0.33:2.5

Below the quench limit

D1 Coil Aperture: 160mm vs 150mm (FLUKA)



150mm D1: Peak Dose Longitudinal Profile



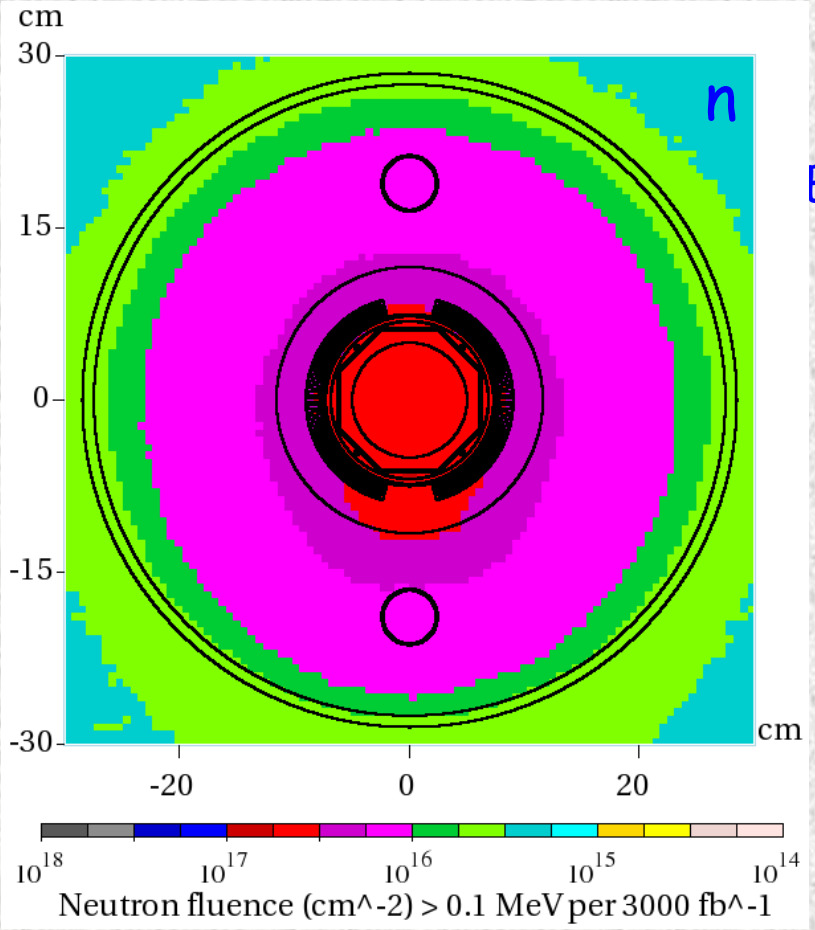
In future runs, MARS will be switched to fully exclusive mode that will reduce fluctuations.

Effect of Radiation on Epoxy Resin or Alike

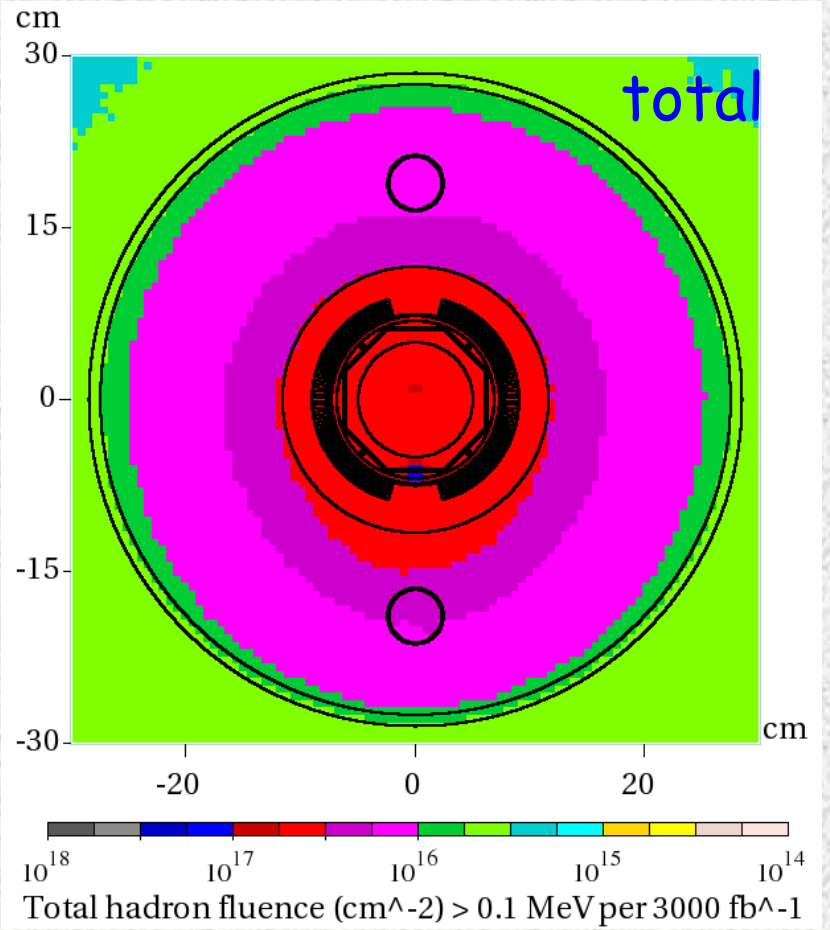
Resin	Gas Evolution ($cm^3\ g^{-1}MGy^{-1}$)	Swelling (%)	25% reduction: dose/shear strength (4.77K)
DGEBA, DGEBF/			
anhydride	1.2	1-5	5 MGy/75 MPa
amine	0.6	1.0	10 MGy/75 MPa
cyanate ester blend	0.6	1.0	50 MGy/45-75 MPa
Cyanate ester	0.5	0.5	100 MGy/40-80 MPa
TGDM	0.4	0.1	50 MGy/45 MPa
BMI	0.3	<0.1	100 MGy/38 MPa
PI	0.1	<0.1	100 MGy

Courtesy Dick Reed

Hadron Fluence at D1 IP End: MARS15



E > 0.1 MeV

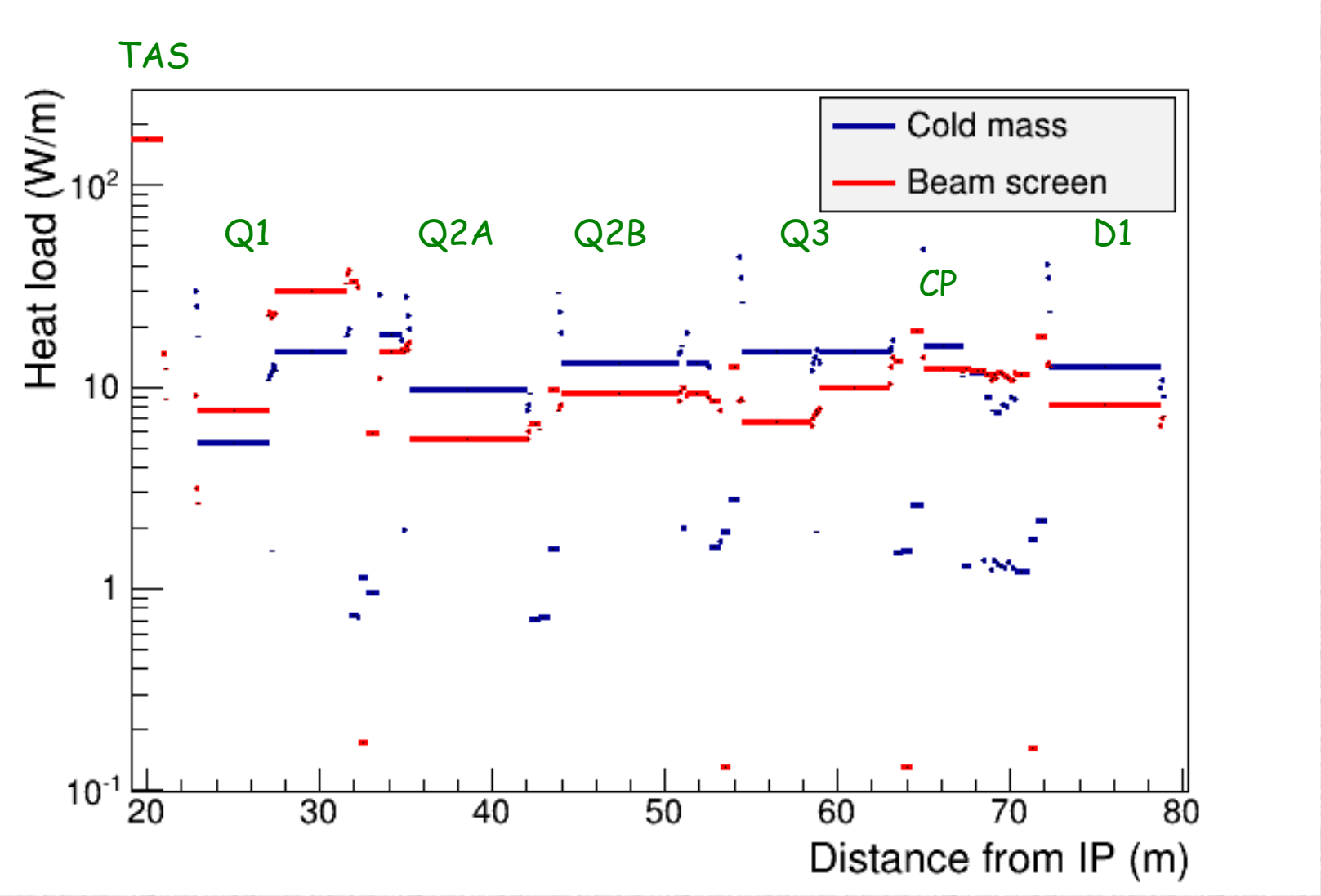


SC Peak: 3.4e16 cm^{-2}/3000 fb^{-1}

SC Peak: 5.5e16 cm^{-2}/3000 fb^{-1}

SC: 5% reduction in J_c at ~5e17 cm^{-2}

Heat Load Longitudinal Profile: MARS15



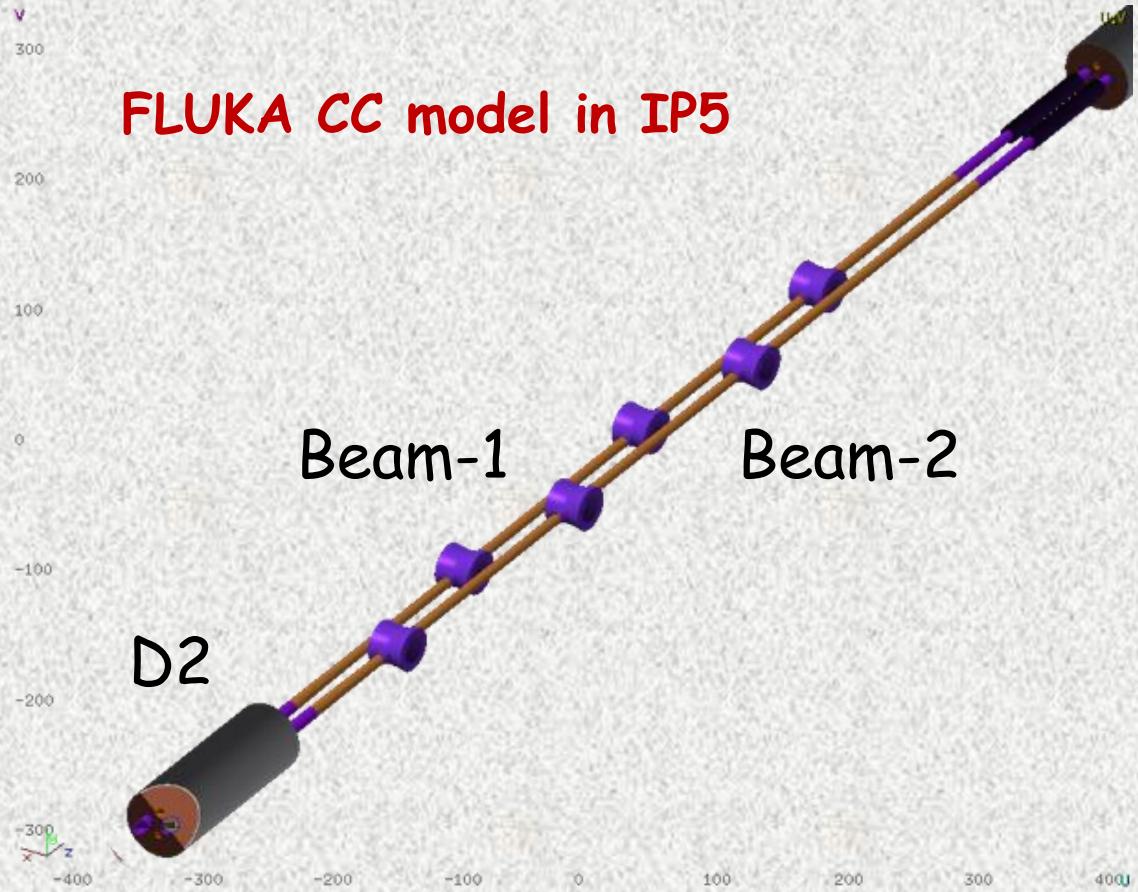
Integral Power Dissipation

	FLUKA		FLUKA		MARS	
	10 cm gap in ICs		50 cm gap in ICs		50 cm gap in ICs	
	Magnet cold mass	*Beam screen*	Magnet cold mass	*Beam screen*	Magnet cold mass	*Beam screen*
	Power [W]					
Q1A + Q1B	100	175	100	170	97	172
Q2A+orb corr.	95	60	100	65	99	65
Q2B+orb corr.	115	80	120	80	117	81
Q3A + Q3B	140	80	140	80	137	75
CP	55	55	60	55	60	65
D1	90	60	90	60	90	56
Interconnects	20	140	20	105	15	86
Total	**615**	**650**	**630**	**615**	**615**	**601**

FLUKA/MARS agree within 2.4%

Crab Cavities

Exposed by radiation directly, not in a shadow of beam screen and inner absorbers. Studies of realistic radiation environment at CC locations are needed. No data on Q-factor vs high-energy particle flux.



Crab Cavities at FNAL

Cryomodule UK design:

EDMS link to CAD model: https://edms.cern.ch/document/1317067/1

Materials by Tom Jones (STFC, UK):

SPS crab cavity cryomodule mass

Item	Volume (mm^3)	Material (s)	Av. Density (kg/mm^3)	Mass (kg)	Quantity	Total Mass (kg)
Cavity	4.90E+06	RRR Niobium	8.60E-06	42	2	84
He vessel	9.80E+06	Titanium Grade 5 Ti-6Al-4V	4.43E-06	43	2	87
Cryoperm	1.19E+06	Cryoperm (Nickel Iron alloy)	8.70E-06	10	2	21
Tuner	4.00E+06	Stainless Steel (316L)	7.90E-06	32	2	63
Input coupler	5.80E+06	Stainless Steel (316L) with copper coated internals	8.00E-06	46	2	93
LOM absorber	4.00E+06	Stainless Steel (316L) with copper coated internals	8.00E-06	32	2	64
HOM absorber	3.00E+05	Stainless Steel (316L) with copper coated internals	8.00E-06	2	4	10
Outer vacuum chamber body	8.10E+07	Stainless Steel (304L)	7.90E-06	640	1	640
Outer vacuum chamber flanges	4.20E+07	Aluminium Alloy (6082 T6)	2.70E-06	113	2	227
Thermal shield	2.30E+07	Aluminium 1000 series	2.70E-06	62	1	62
Mu Metal shield	2.50E+07	Mu Metal (Nickel Iron alloy)	8.70E-06	218	1	218
Internal pipework	5.00E+05	Stainless Steel (316L)	7.90E-06	4	1	4
Miscellaneous	1.00E+07		7.90E-06	79	1	79
					Total (kg)	1651
					Load on translation stage (N)	16193

CAD model in STEP format

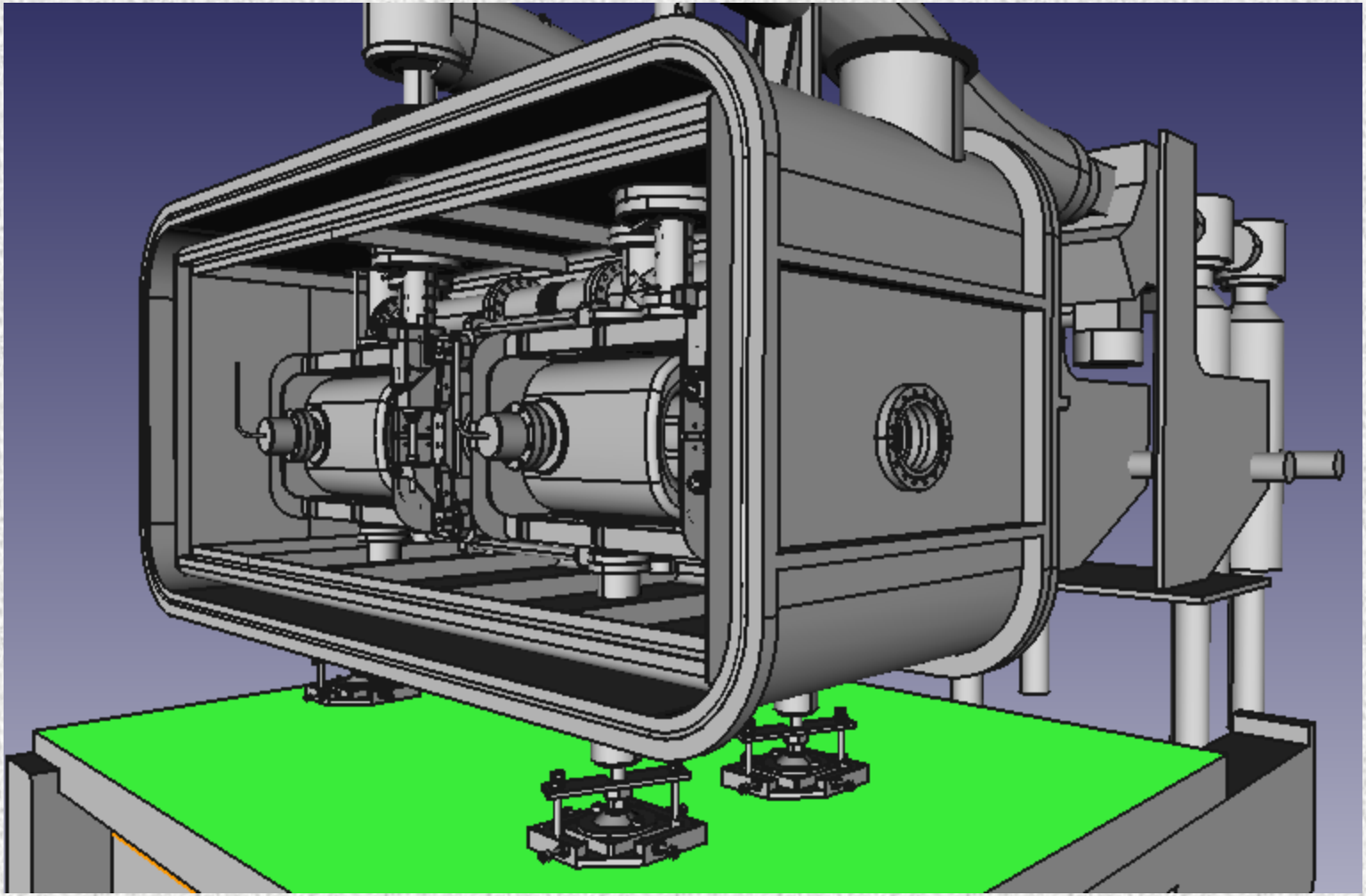
MARS Implementation

1. STEP description converted to STL format
2. Imported to ROOT Tgeo using Unified solid library for Geant4 and ROOT (Usolid) used directly in MARS15.
3. Back export is possible.

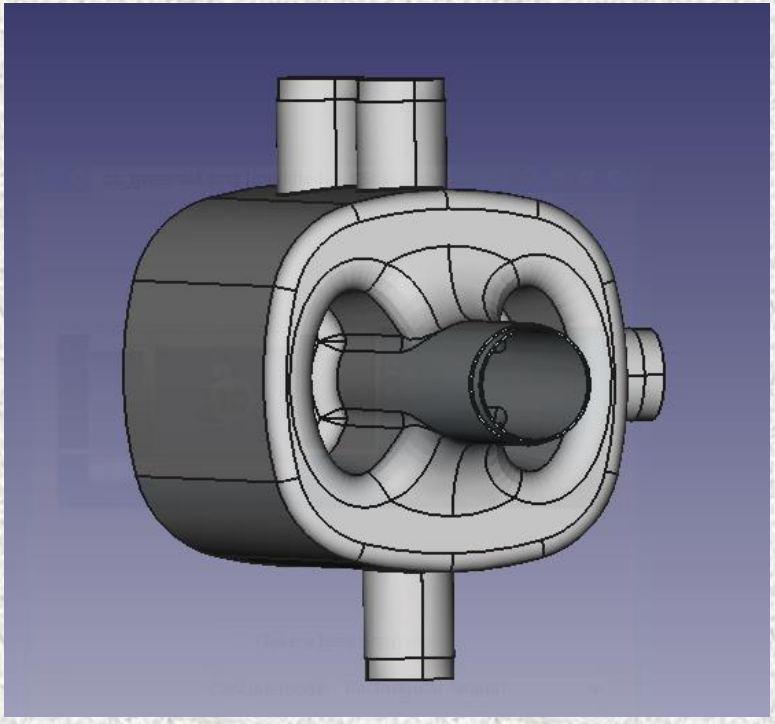
Need:

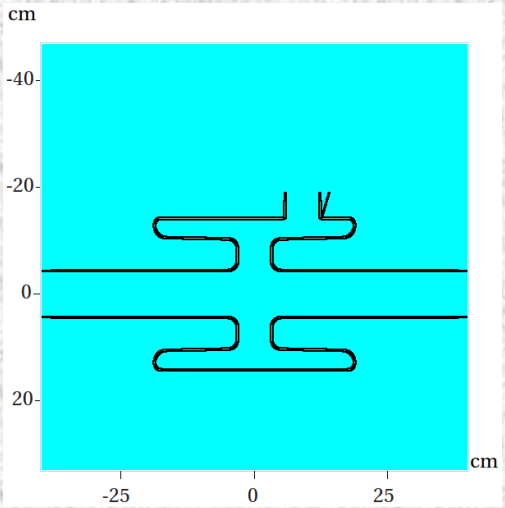
- Correspondence of materials to STEP elements
- EM field maps inside the cavities
- Layout and position in lattice

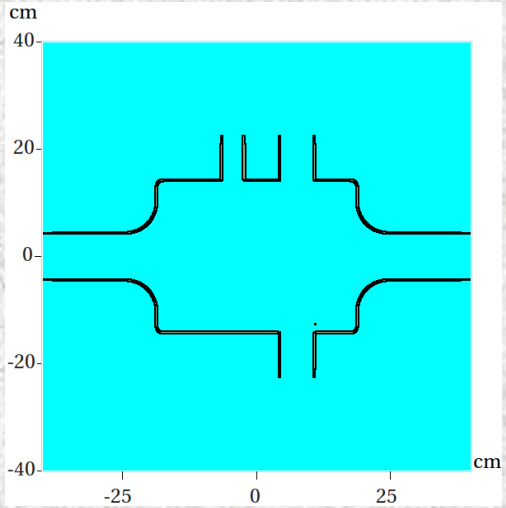
Crab Cavities: UK Design



Crab Cavities: Implementation in MARS







Summary

- FLUKA and MARS synchronized models are up, running and used for ED studies of HL-LHC triplet and D1.
- Overall, a good agreement between FLUKA and MARS on power density, dose and dynamic heat load in quads and D1, that gives us a confidence in predictions for the HL-LHC era.
- Peak power density, peak dose@ 3000 fb^{-1} and power dissipation are within the quench stability, radiation damage and dynamic heat load limits, respectively.
- Crab cavity ED studies launched.
- Important issues (dreaming of the layout stability):
  - Interconnects (BPM incorporation / tungsten shielding)
  - Crossing angle choice
  - Evacuation of 2×600 W global power
  - CC: Info on materials, EM fields, layout and dependence of Q on flux