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Muon Pulsed Septum Magnet

Magnetic Design

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Magnet Design Review

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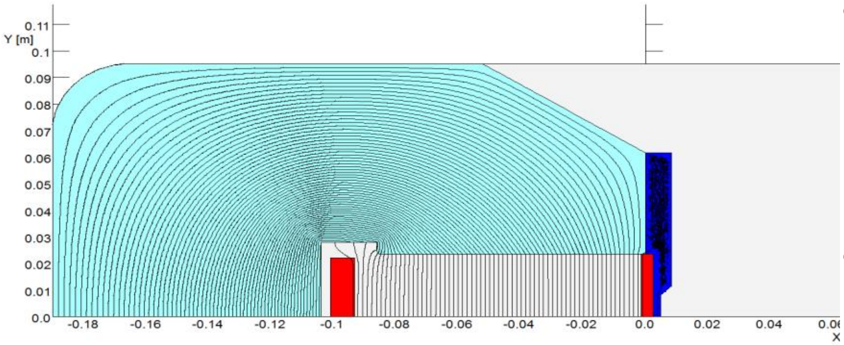
Introduction

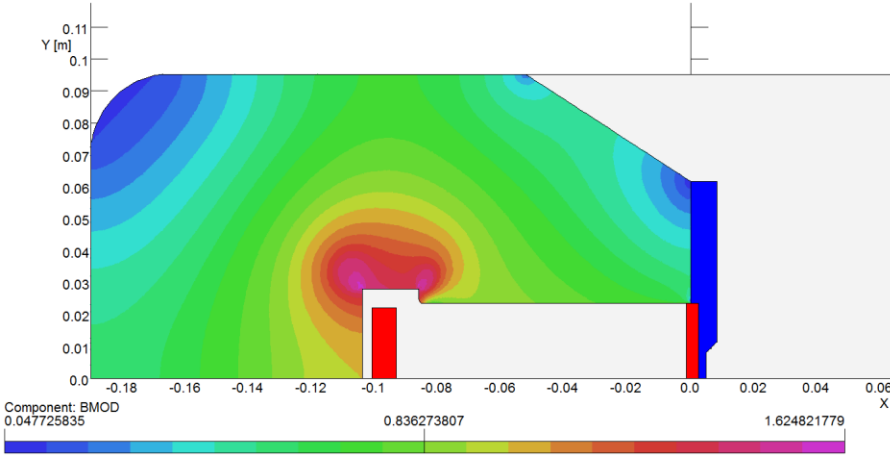
- The pulsed Septum magnet will be used for injecting and aborting 8.89 GeV/c protons (Mu2e mode) and 3.1 GeV/c Muons (g-2 mode) from the Muon Delivery Ring.
- Magnet is a single turn dipole septum magnet.
- In general, the magnet design based on the Booster Pulsed Extraction (BSE) magnet designed and built in 2002.
- Because of short pulse length 250 µm – 300 µm the magnet yoke should be laminated.
- The magnet yoke is curved with the radius 53.3 m and the length of ~1.92 m.
- For the magnet pole ends used Rogowski profile as in BSE.
- Three magnets should be built.

Magnet Specification

Parameter	Unit	Booster Septum (BSE)	Muon Septum (MSE)
Peak Integrated strength (Mu2e/g-2)	T-m	1.5	1.4/0.5425
Maximum air gap field	T	0.94	0.725
Septum radius of curvature	m	38.1	53.3
Air gap	mm	27.94	47.0
Magnet effective length	m	1.6	1.92
Good field area with ≤ ± 0.2 % ΔB/B	mm x mm	25.4 x 25.4	40.64 x 47.0
Integrated field outside the septum/Peak strength	%	≤ 0.1	≤ 0.1
Nominal current pulse width	µs	300	250-300
Average pulses repetition rate (Mu2e/g-2)	Hz	15	6/12
Magnet DC inductance	µH	3.6	4.8
Laminated yoke M15 steel thickness	mm	0.356	0.356

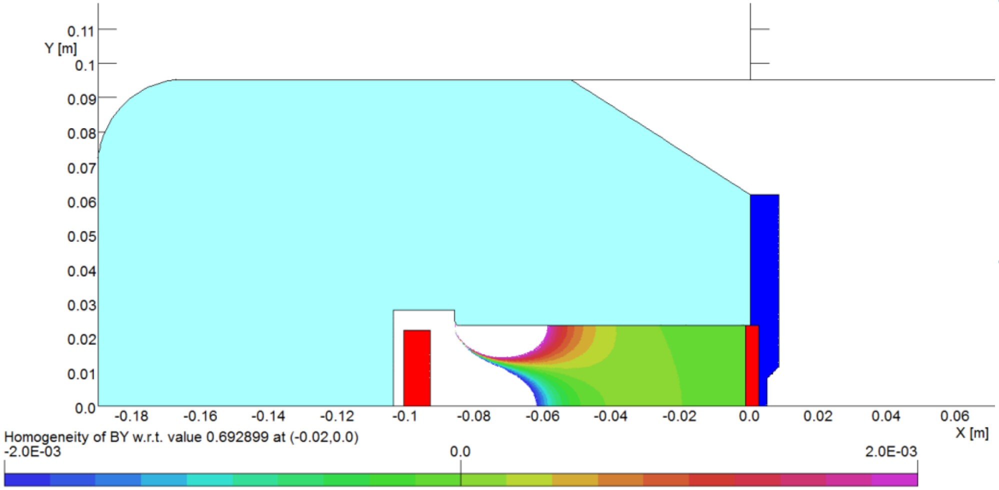
2D Magnet Configuration and Field

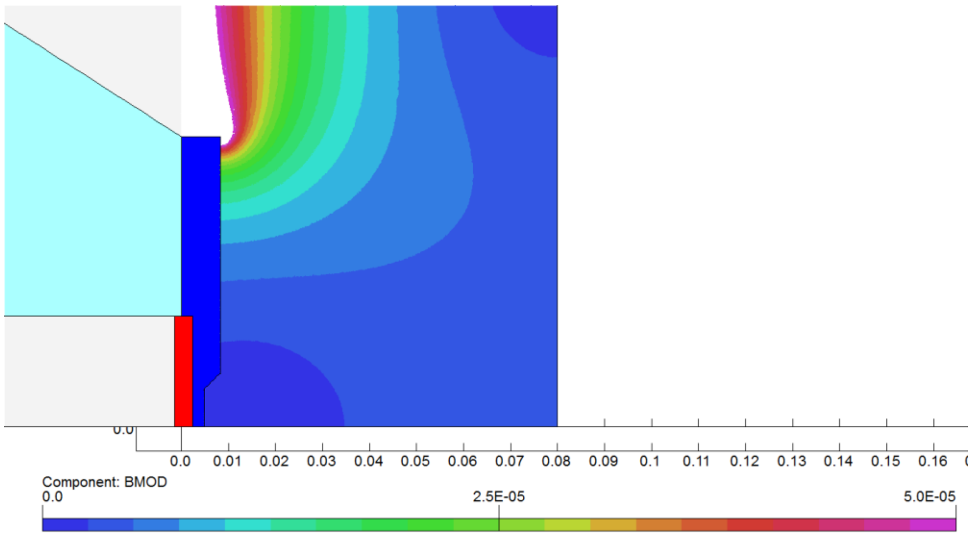




- Used B-H curve of M15 G29 non-oriented steel measured at 1667 Hz frequency.
- The steel lamination thickness 0.014” (0.356 mm).
- The peak field in the yoke 1.62 T.
- The current pulse length is t=125 um (2 kHz)
- The peak field in the gap 0.69 T at 26 kA-turns.

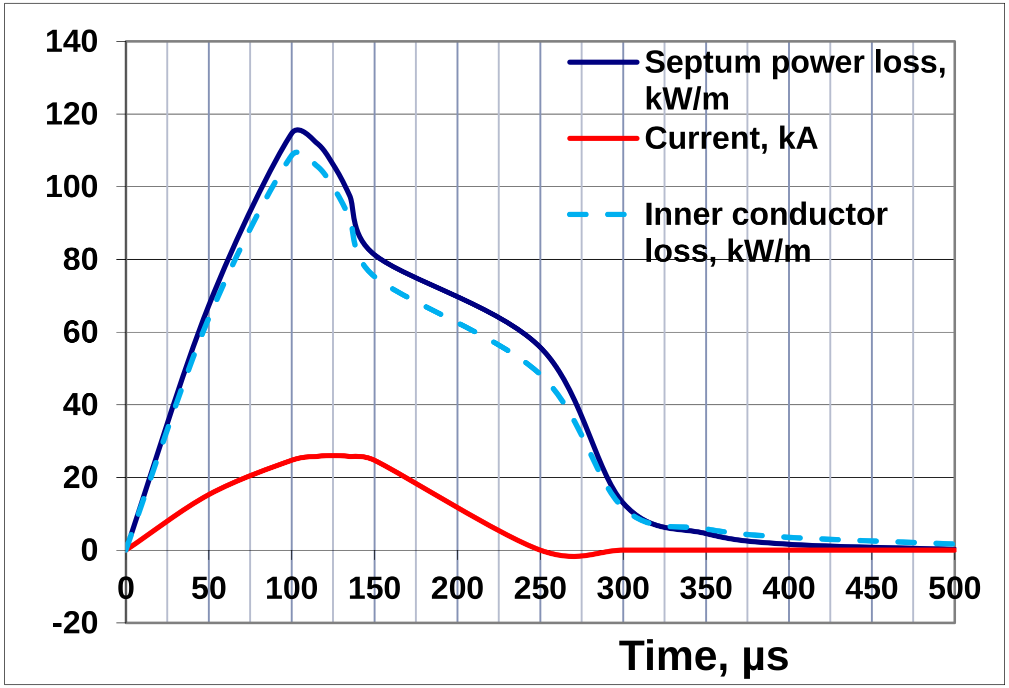
2D Magnet Field Quality





- The good field area is 55 mm x 47 mm, with the homogeneity of +/- 0.2 %.
- The fringe field in the circulating beam area is less than 0.5 Gauss.
- The relative fringe field strength is less than 0.5 /6900*100=0.0073% (spec. <0.1%).
- Ferromagnetic side plate from AISI1010 effectively shield the fringe field.

Power Losses in Conductors



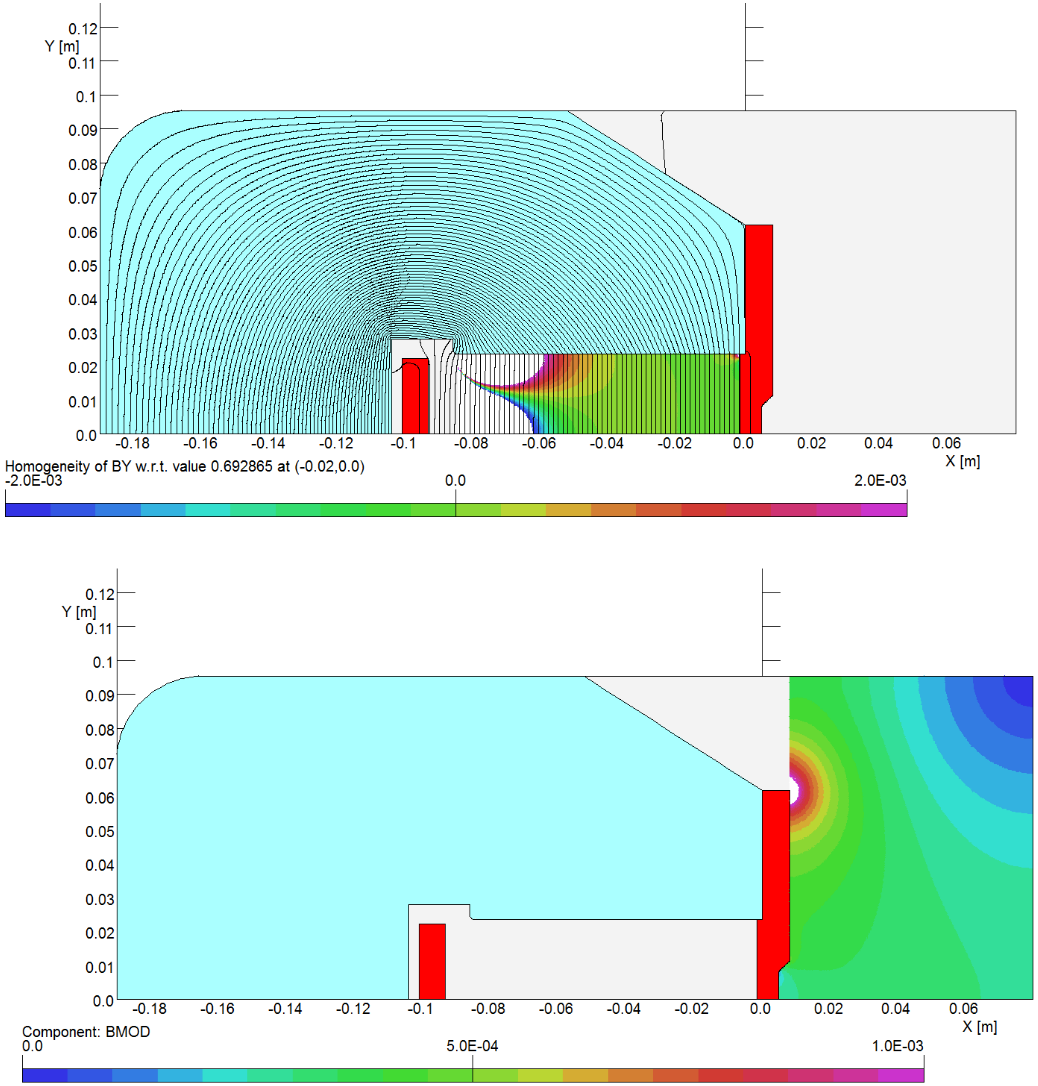
- High peak power losses. In the septum is114 kW/m.
- Low energy 20.6 J/m (septum) dissipation because of short pulse length.
- The average peak dissipated power losses (Mu2e) are

  124 W/m (septum).
- Peak losses in the inner conductor are 5 % lower.
- Total peak losses in conductors
- ~ 300 W/magnet.
- Peak power losses in Fe side plate are 250 W/m.

Skin depth at 2 kHz:

- Copper – 1.59 mm
- M15 - 0.13 mm, mu=1000
- M15 – 0.42 mm, mu=100
- AISI 1010 – 0.25 mm, mu=1000
- AISI 1010 – 0.8 mm, mu=100

2D Field with Cu side plate



- Copper side plate.
- 2 % lower power losses in the septum.
- ~7 Gauss peak fringe field in the circulating beam area.
- The relative integrated fringe field 0.1 %.

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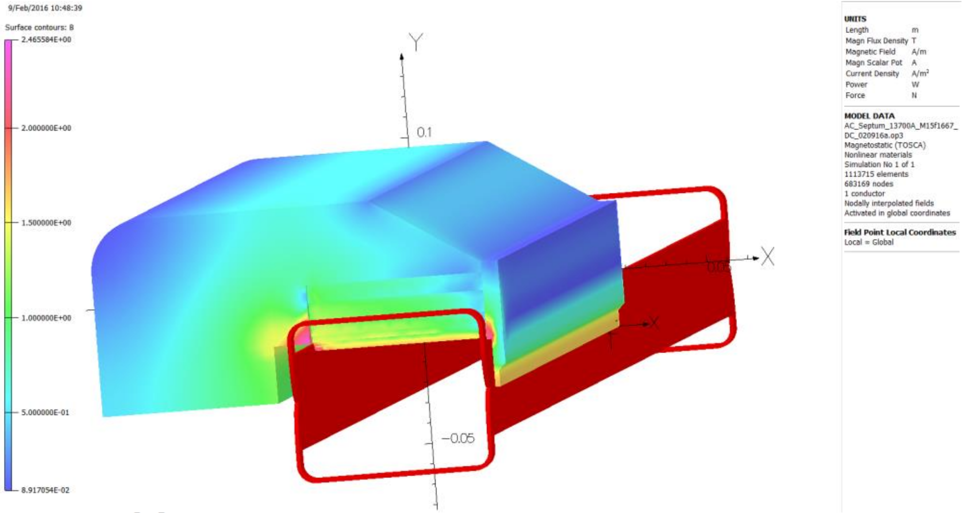
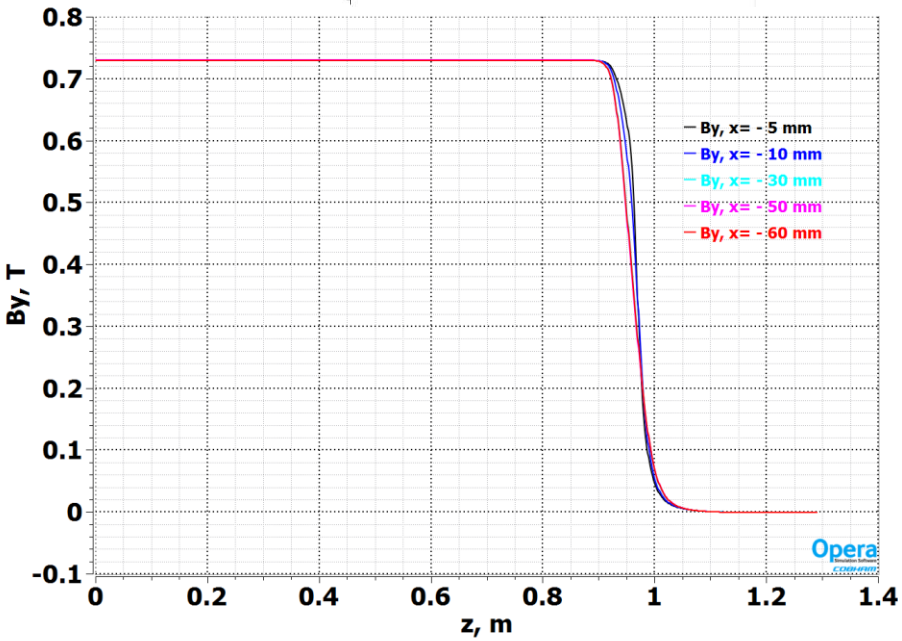
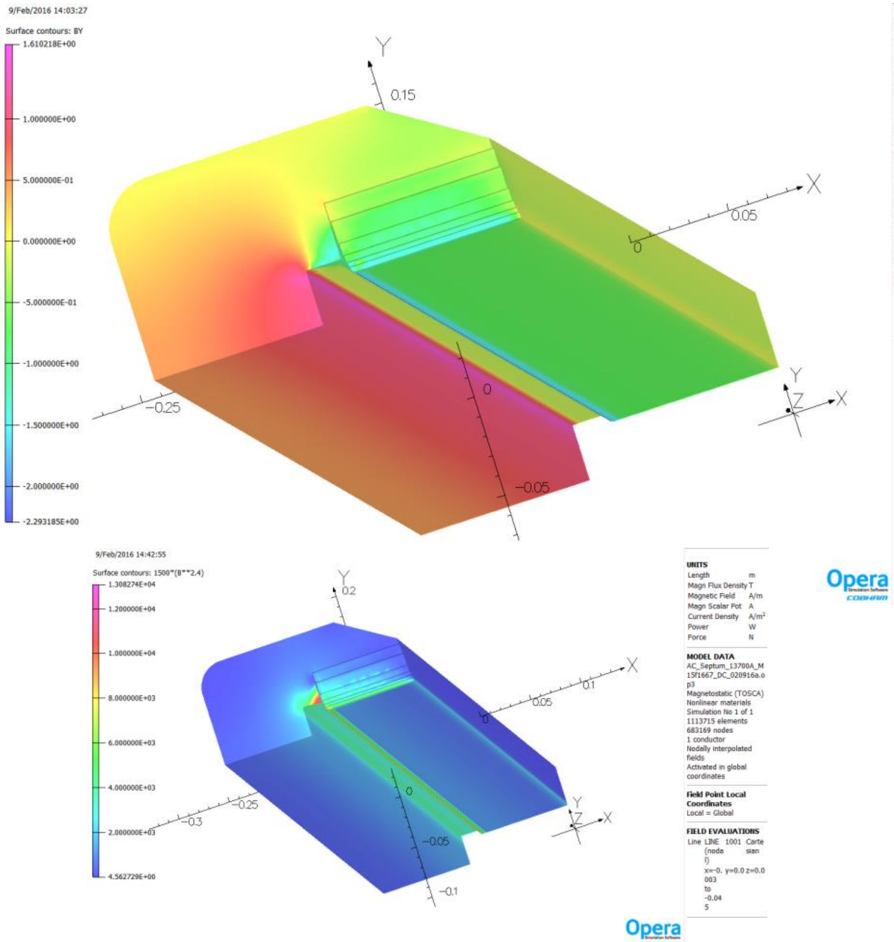
3D DC Field Simulation





- Simulated the straight magnet. Sagitta is 8.6 mm.
- Used B-H curve of M15 at 1667 Hz.
- Integrated field is 1.4 T-m at 27.4 kA current.
- Integrated DC field homogeneity is 0.5 % in the range of 3 – 60 mm from the septum.
- Magnet DC inductance is Ldc= 4.8 uH.

Magnet Laminated Core Losses



$$p' = 1500 \times B^{2.4} \text{ [kW/m}^3\text{]}$$

$$P = \mathrm{Int}(p' x dV)$$

- Laminated core volume is 0.056 m^3.
- Peak power losses 33 kW.
- Average power losses in laminations 50 W. Power average factor at 6 Hz of repetition rate, and 250 µm pulse length is 1.5 e-3.
- Not included end fields power losses.
- At 2 kHz losses will be 20 % higher.

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Summary

- The magnetic design meets specifications.
- Nevertheless, the special attention should be paid on:

  - Electrical insulation between laminations;

  - Fringe fields from the current leads;

  - Fixed and the stable septum conductor position in the magnet gap.

  - Magnet cooling.
- The magnet inductance is larger than specified (BSE) value because of larger pole width and length relatively BSE magnet. So, proportionally larger is the peak voltage Vmax=1.65 kV, specified <2.5 kV.
- The AC magnetic measurements should be made for the magnet prototype to verify the design and fabrication technology.