The Analytical Treatment of Magnetic Measurements in the Mu2e Detector Solenoid.

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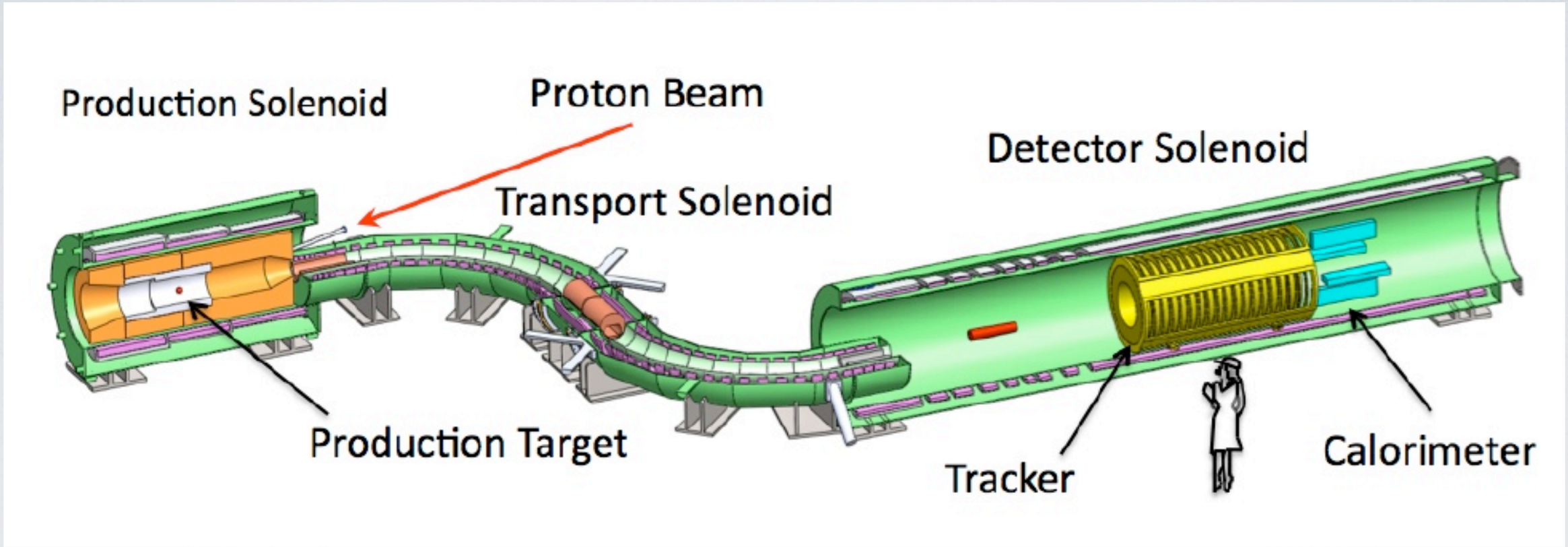
Mu2e Experiment



- Target protons at 8 GeV inside superconducting solenoid (Production Solenoid)
- Capture muons and guide through S-shaped region (Transport Solenoid) to Al stopping target (Detector Solenoid)

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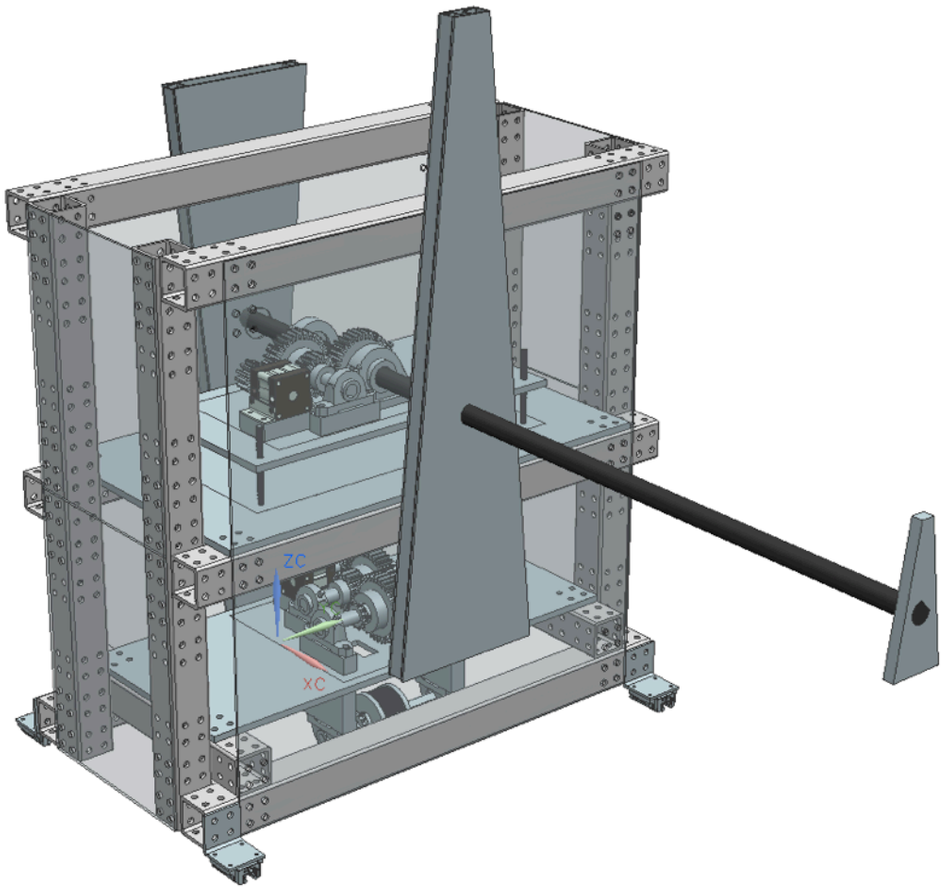
Mu2e Magnetic Measurements

CMS



Mu2e

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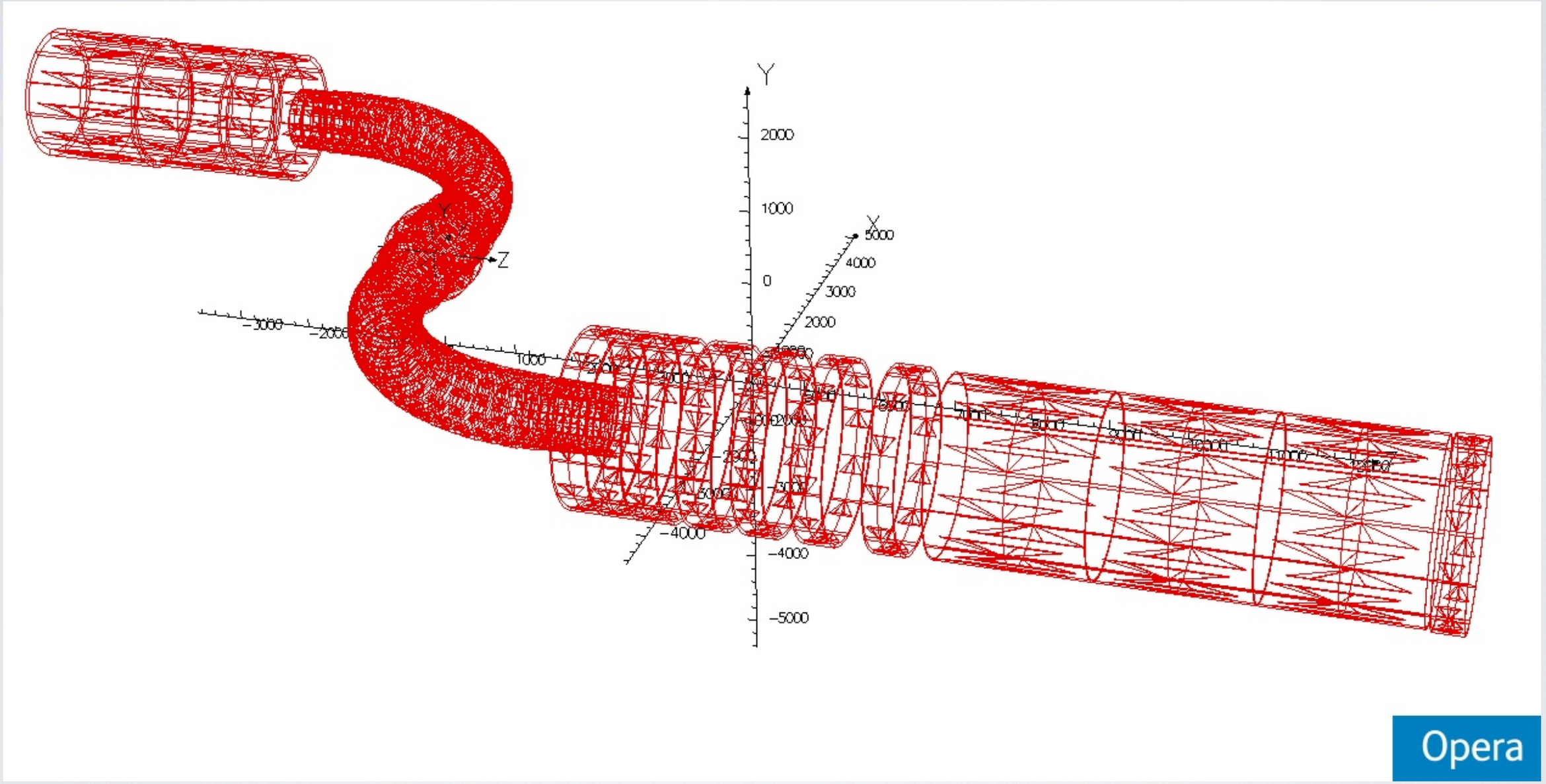
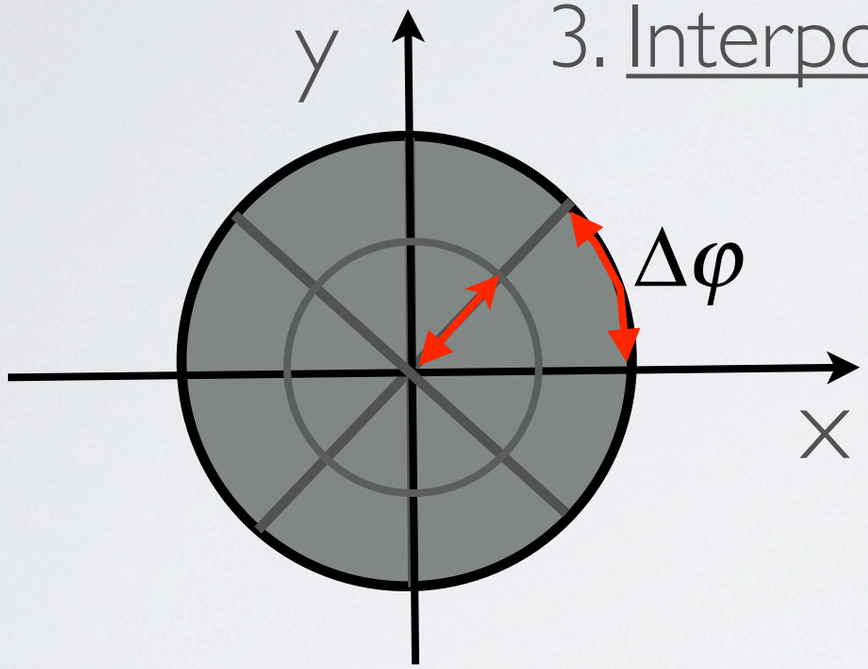
OPERA 3D Simulations



Accuracy of Magnetic Measurements

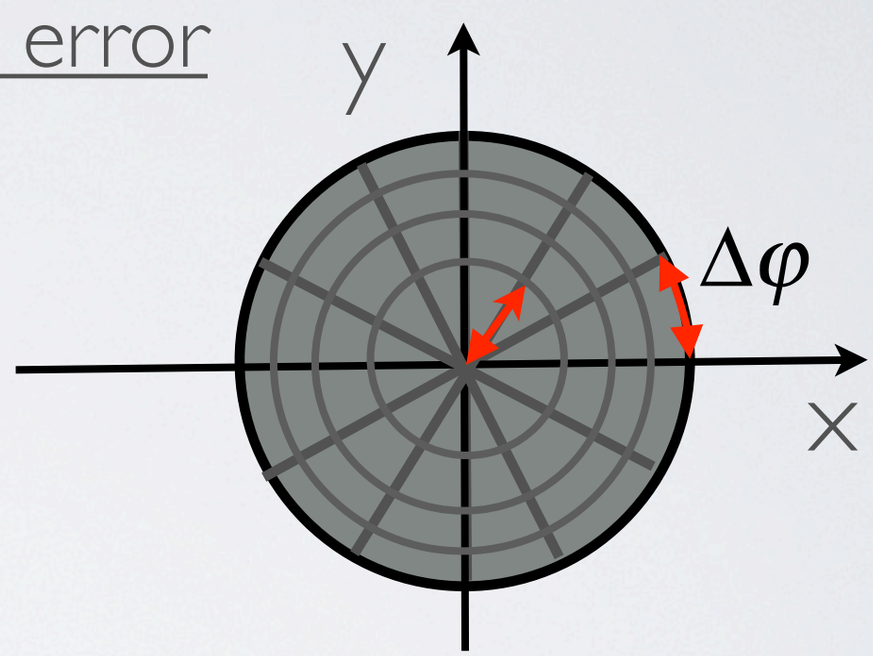
1. Instrumental error
2. Position sensors error
3. Interpolation error



$\varepsilon_B \leq 0.07\%$

$\Delta\varphi = 7.5^o \; \Delta r = 5 \, probes \quad \Delta z = 50 mm$

CMS



$\varepsilon_B \leq 0.01\%$

$\Delta\varphi = 7.5^o \quad \Delta r = ? \quad \Delta z = 50 mm$

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What Type of Polynomial Interpolation?

3 Spline interpolation

- ☑ Hi accuracy
- ☑ Low level of polynomial power does not «oscillate»
- ☑ Continues 1-st and 2-nd derivative
- ☑ Smooth
- ☑ Fast calculus
- — Uniform grid

Polynomial

- ☑ Continues n-1 derivative
- ☑ Fast calculus
- ☑ nonuniform grid
- — «Oscillates»
- — Bad convergence

Chebyshev nods

- ☑ Hi accuracy
- ☑ Continues n-1 derivative
- ☑ nonuniform grid
- — «Oscillates»
- — Slow calculus

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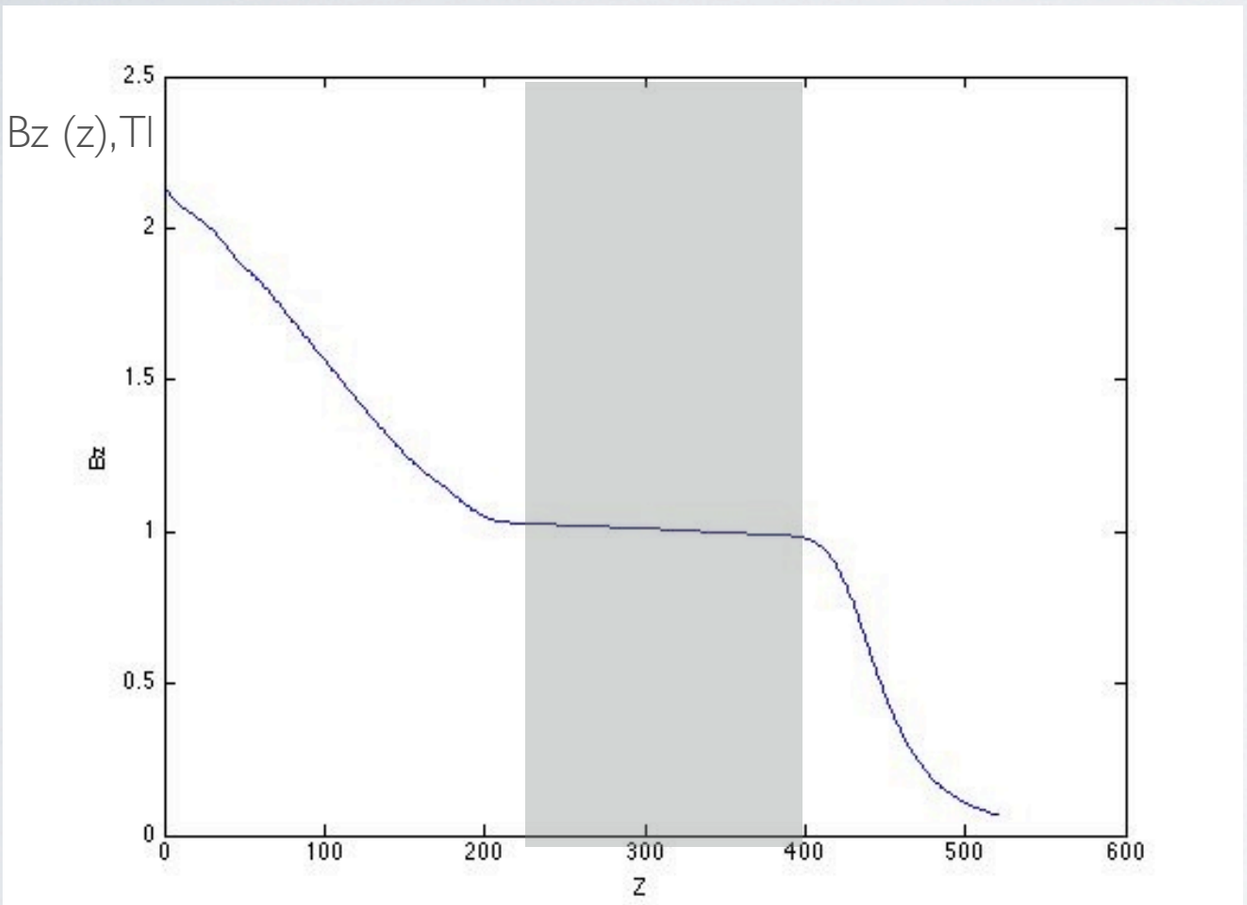
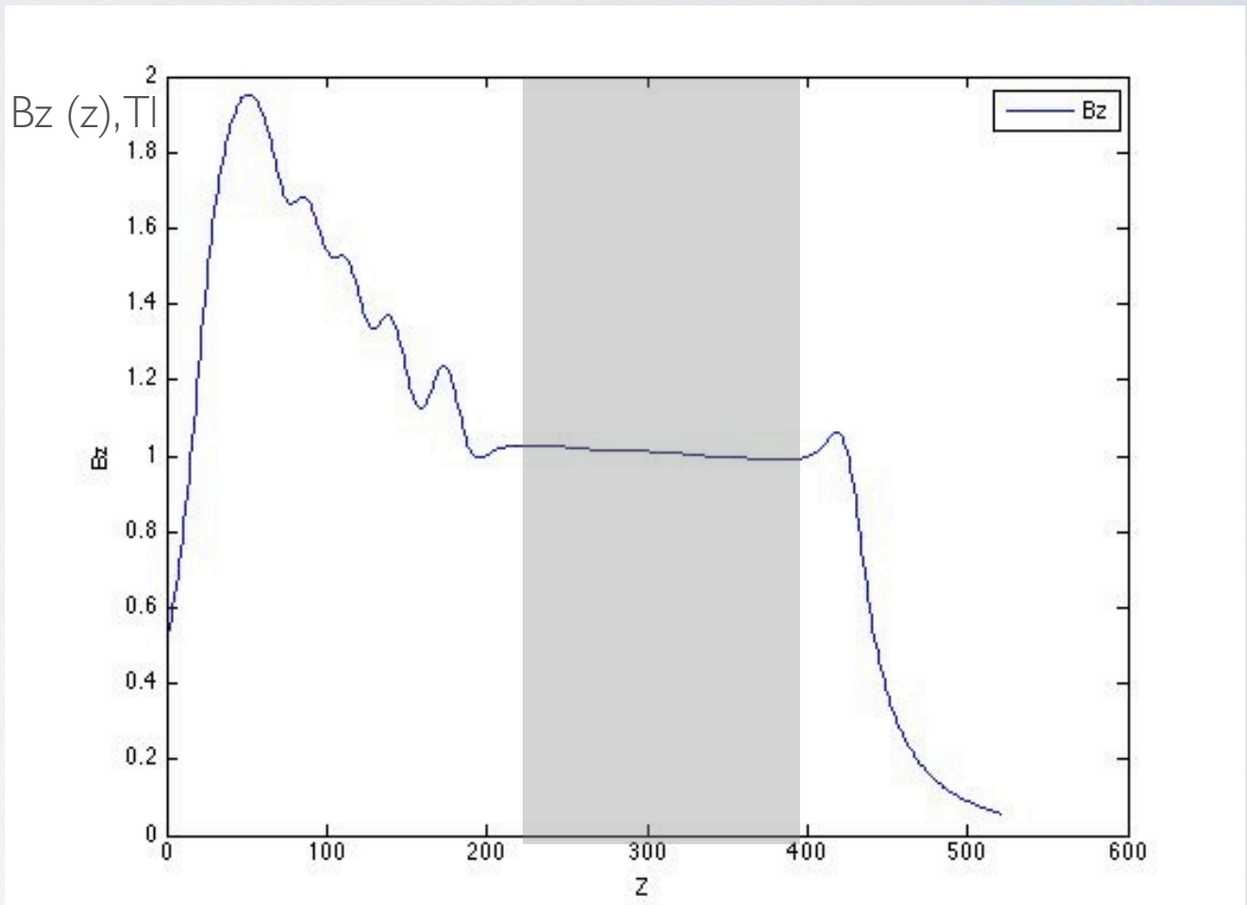
Opera 3D Data

R=0



Z, 25mm step

R=750mm Fi=0



Z, 25mm step

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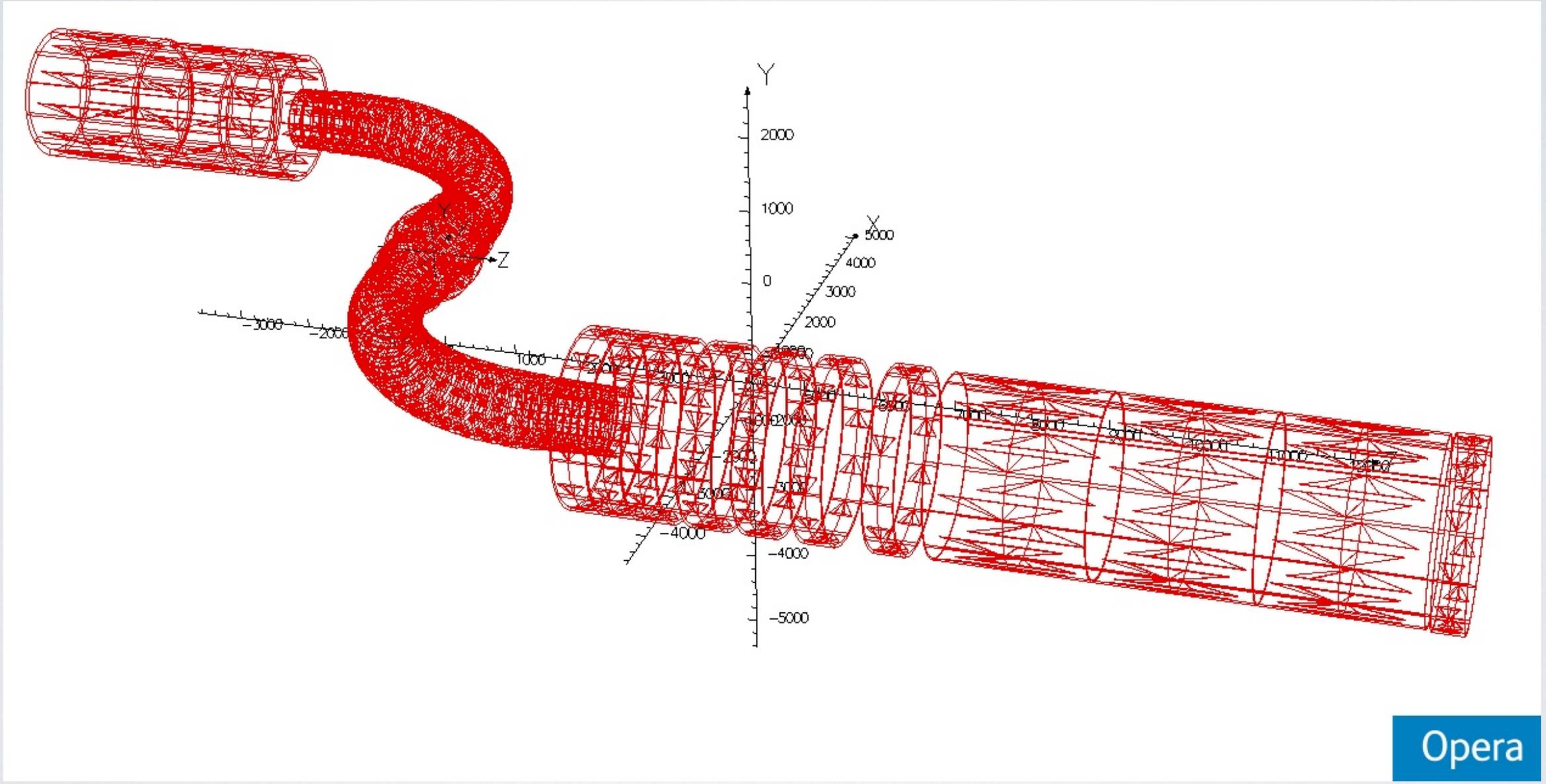
OPERA 3D Simulations



Spline Interpolation Theoretical Background

$$\left\| f(x) - s_h(x) \right\| \leq M_4 h^4 \quad (1)$$

$f(x)$ - accurate function we are interpolating

$s_h(x)$ - interpolating splines

M_4 - maximum 4-th derivative in the region of interpolating

h - grid step

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3-D Spline Interpolation

$$\left\|f(x)-s(x)\right\| \le \underset{i\neq j=1,2,3}{Max}\left|s_i(x,y,z)-s_j(x,y,z)\right| \qquad (2)$$

$f(x)$ - accurate function we are interpolating

$s(x)$ - interpolating splines

$s_i(x,y,z)$ - spline interpolation in a certain way

$$\varepsilon_{\text{int}erp} \approx 0.0001\%$$

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How to calculate the minimum number of sensors?

1. Interpolating the OPERA 3D data (Cartesian Grid Only)
2. «Simulating experimental data» using previous interpolating function with uniform spherical grid
3. Interpolating the data in 6 different ways and calculation the difference with the «accurate» interpolation.
4. Change the number of sensors and repeat.

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Results

- The method of simulating the experimental data has been developed
- The interpolation error of OPERA 3D data has been calculated
- The MatLab program has been created to calculate the maximum error of Magnetic Field Measurements in DS

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To be done

- Calculating the errors for Bx, By, Bz using MatLab script for different number of sensors
- To make MatLab script compatible with OPERA 3D software
- To make MatLab script user friendly

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Reference

[1] V.I. Klyukhin, A. Ball, F. Bergsma, D. Campi «Measurement of the CMS Magnetic Field,» IEEE Trans. Appl. Supercond., vol. 18, no. 2, June 2008

[2] N. Amapane, V. Andreev, V. Drolinger, V. Karimaki, V. Klyukhin, T. Todorov «Volume-based Representation of the Magnetic Field,» CMS Conference Report, Conference on Computing in High Energy and Nuclear Physics, October 31, 2004

[3] V.I. Klyukhin, N. Amapane, V. Andreev, A. Ball «The CMS Magnetic Field Map Perfomance,» IEEE Trans. Appl. Supercond., vol. 20, no. 3, June 2010

[4] OPERA 3D Software Vector Field Ltd... Oxford, U. K.

[5] A.A. Samarski, A. V. Gulin «Numerical Methods,» p. 140-148, 414, Moscow, 1989

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