Development of a Thin-wall Superconducting Magnet for the Positron Spectrometer in the MEG Experiment

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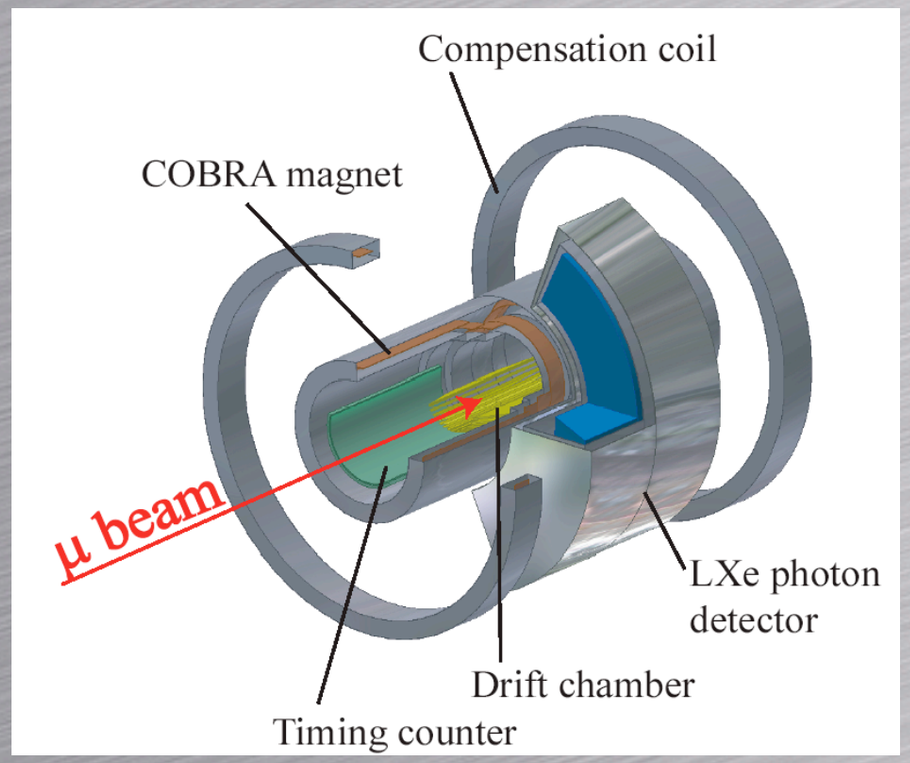
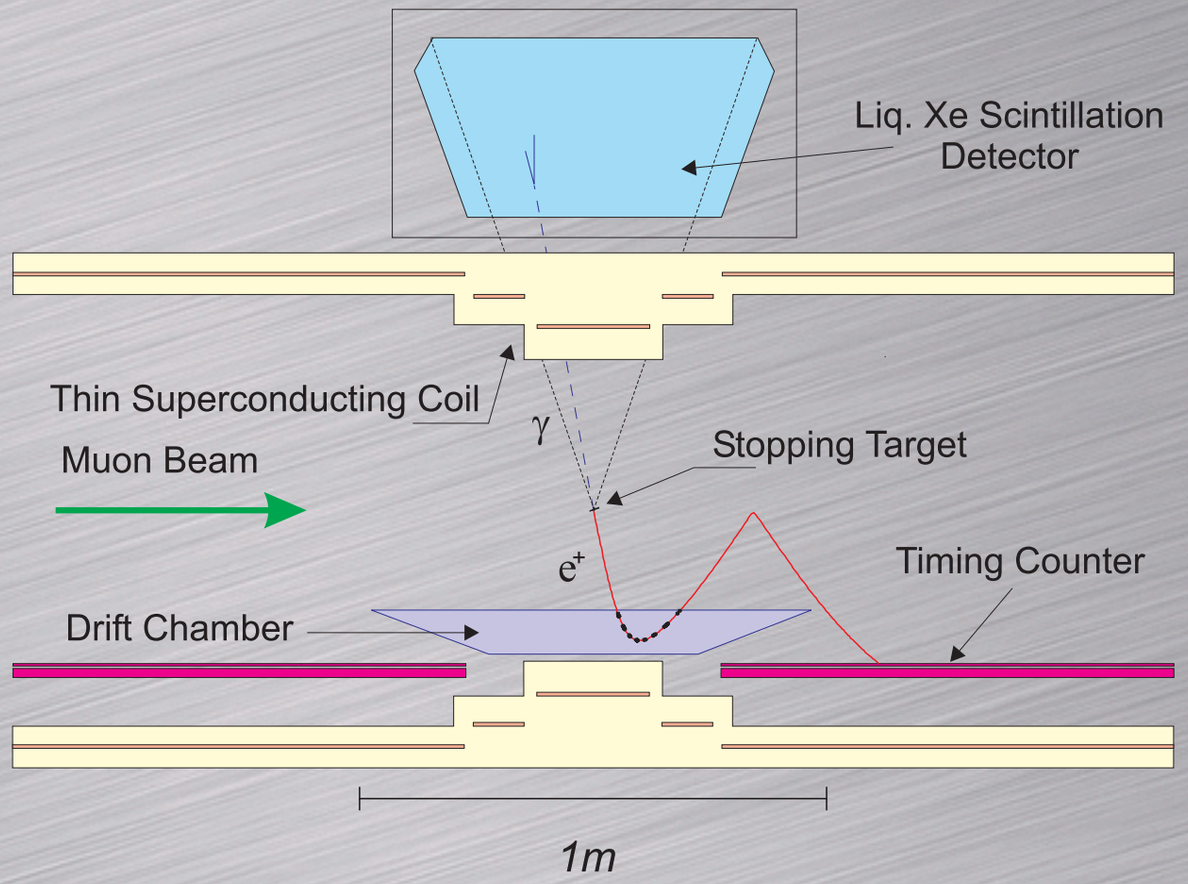
Outline

- MEG Experiment
- COBRA Spectrometer in the MEG experiment
- Magnet Design
- Excitation Tests
- Summary and Conclusion

MEG Experiment

MEG detector



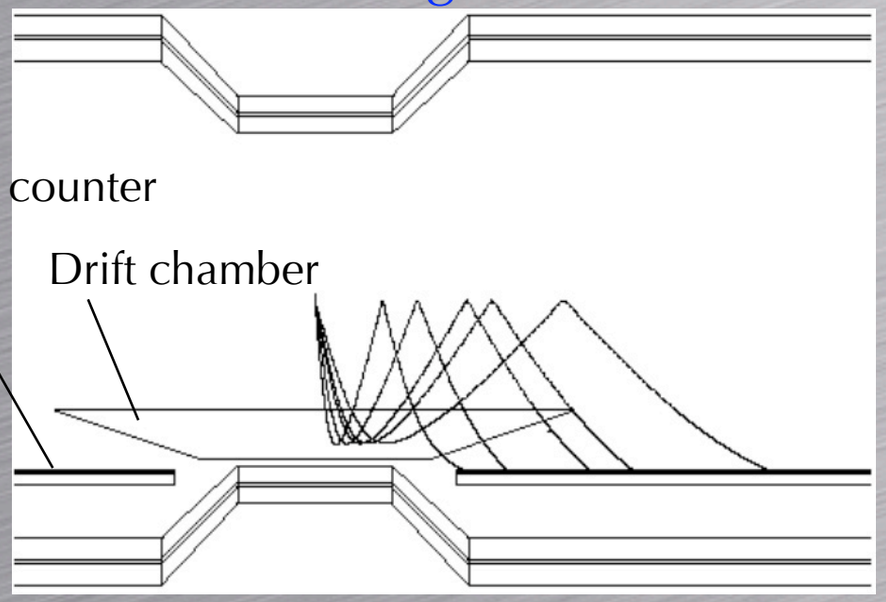


- Search for lepton flavor violating decay, $^{+}\rightarrow e^{+}\gamma$ down to BR~10^{-14}-10^{-13} (SU(5)SUSY-GUT predicts BR>10^{-14}-10^{-12})
- World's most intense DC muon beam at Paul Scherrer Institute, Switzerland
- Liquid xenon photon detector
- COBRA positron spectrometer based on a superconducting solenoidal magnet with a graded B field

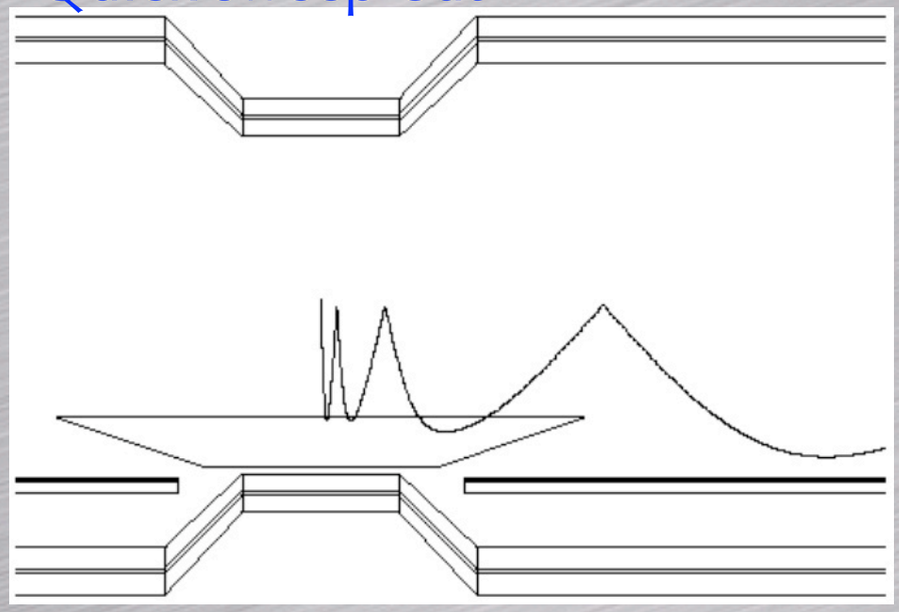
COBRA Spectrometer

- Constant Bending RAdius(COBRA) positron spectrometer
- Special graded B field
  - Constant projected bending radius for monochromatic positron independent of emission angle
    →Easily define momentum window
  - Quick sweep-out of positron
    →Stable operation of chamber system in high rate muon beam

Constant bending radius

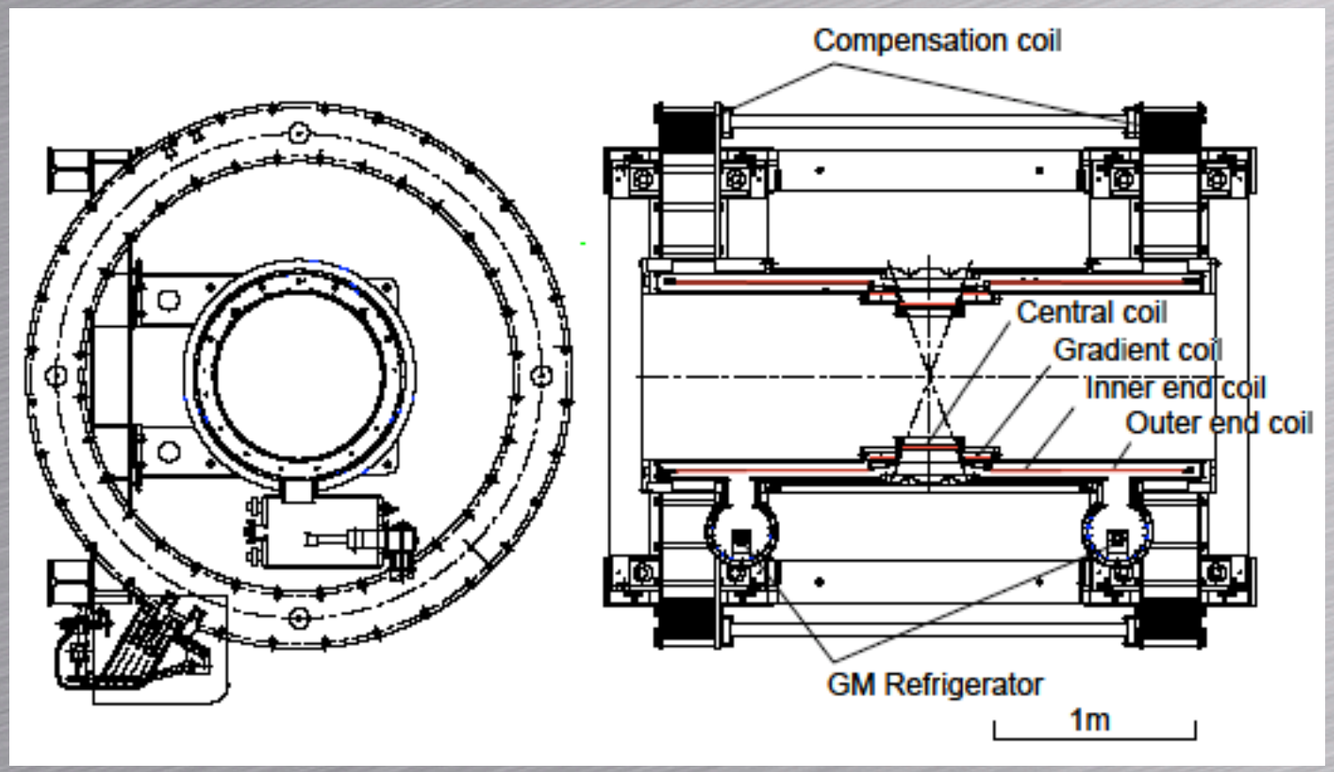


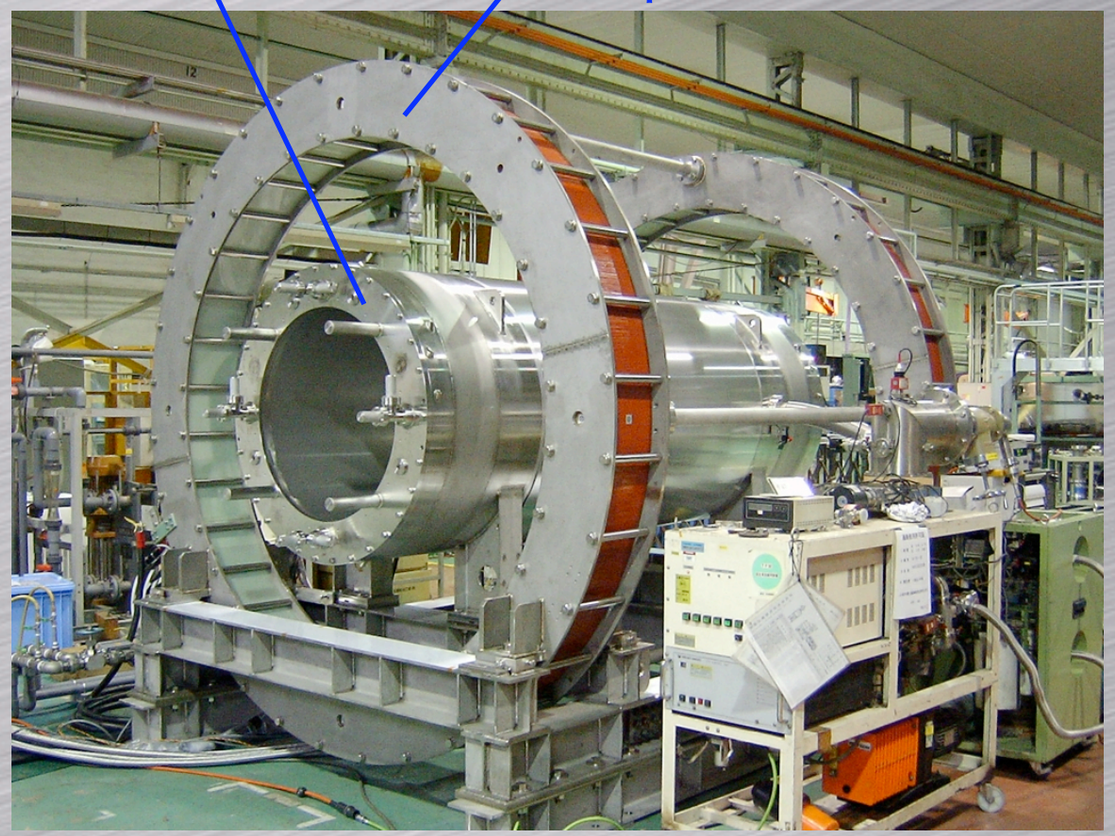
Quick sweep-out



What is needed for the Magnet?

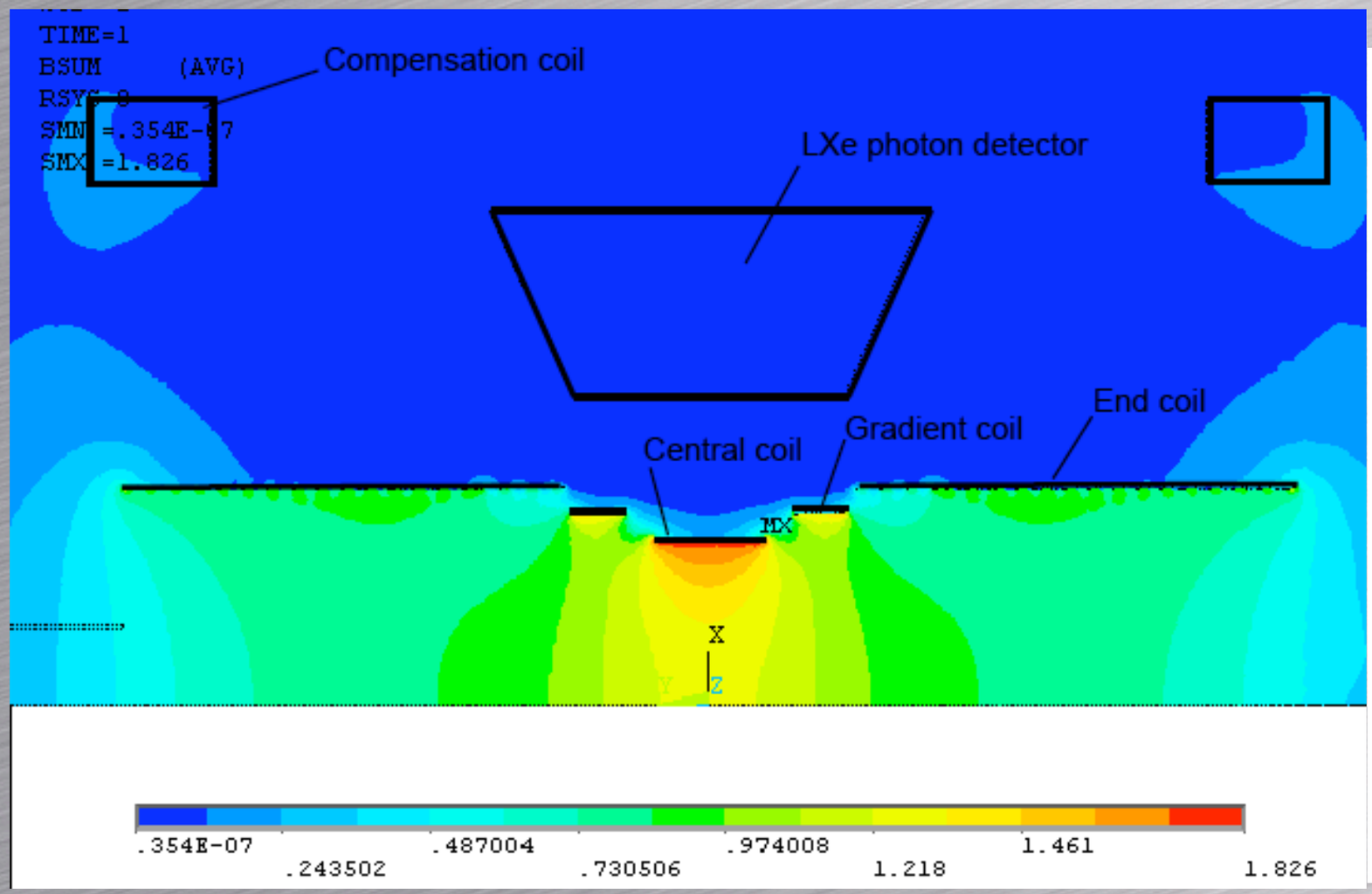
- Transparent for 52.8MeV γ from $^{+}\rightarrow e^{+}\gamma$
- Graded magnetic field for high precision tracking of positron in high rate muon beam
- Cancelation of stray field down to 50Gauss for proper operation of the photon detector



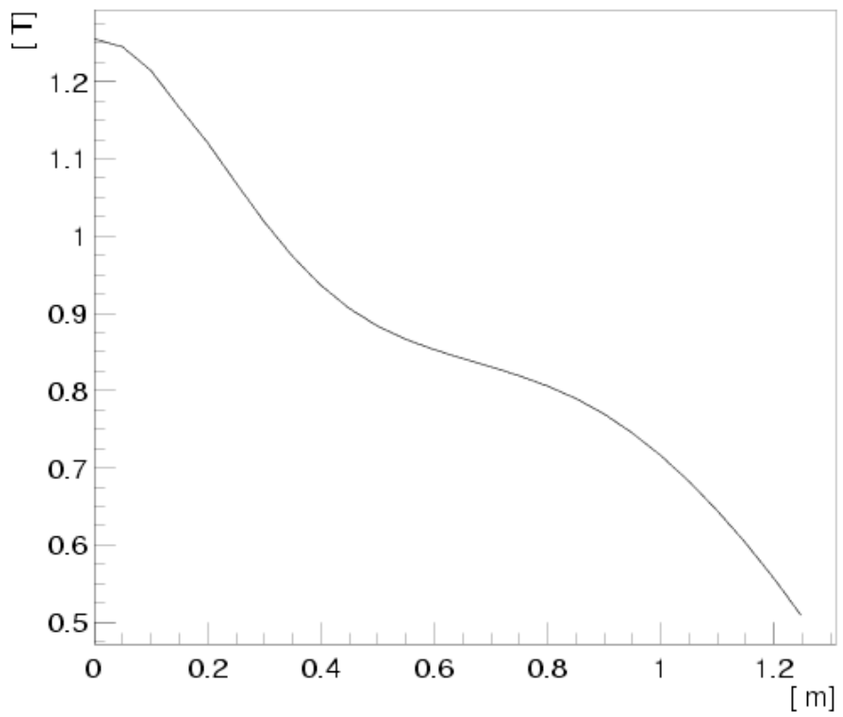


Graded B Field

- Step-structure in the coil layout and adjustment of the current density in each coil to form the good field gradient
- B_C=1.27T $B_{z=1.25m}$=0.49T

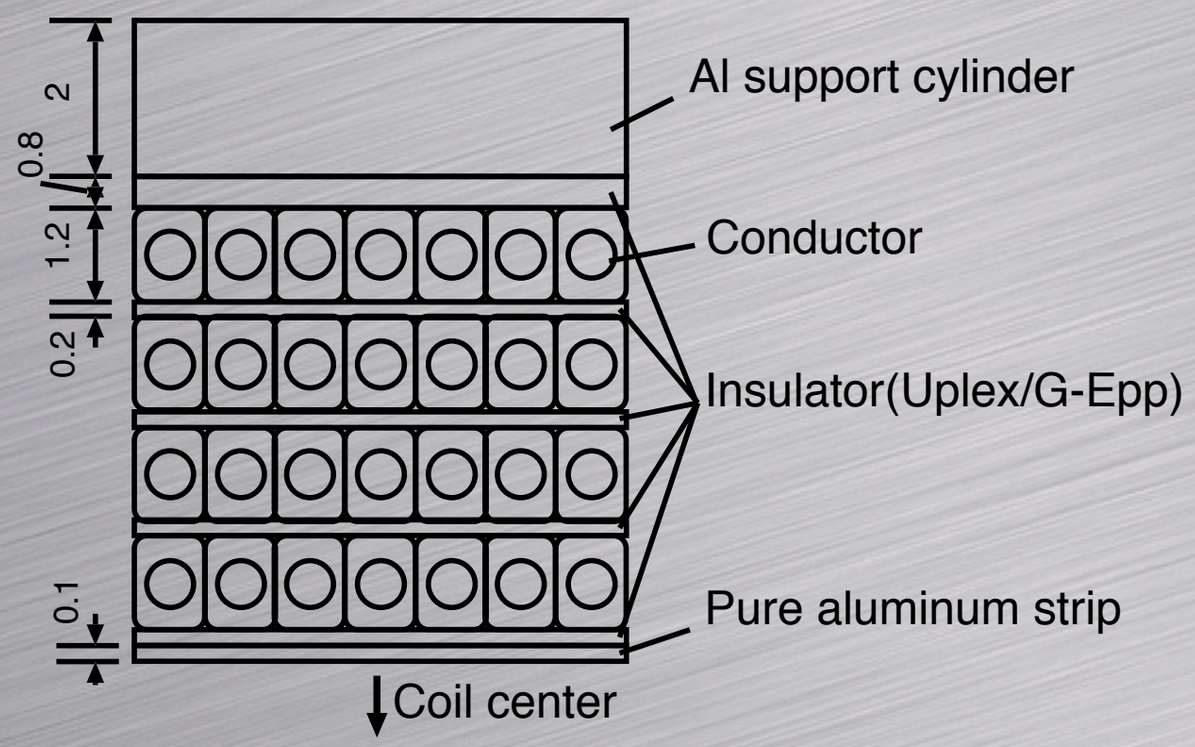


B profile along axis



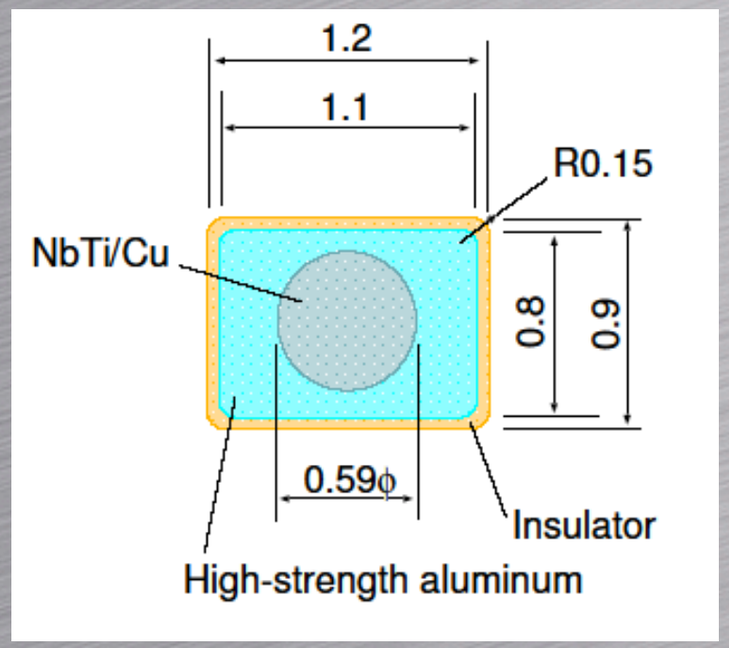
Coil Design

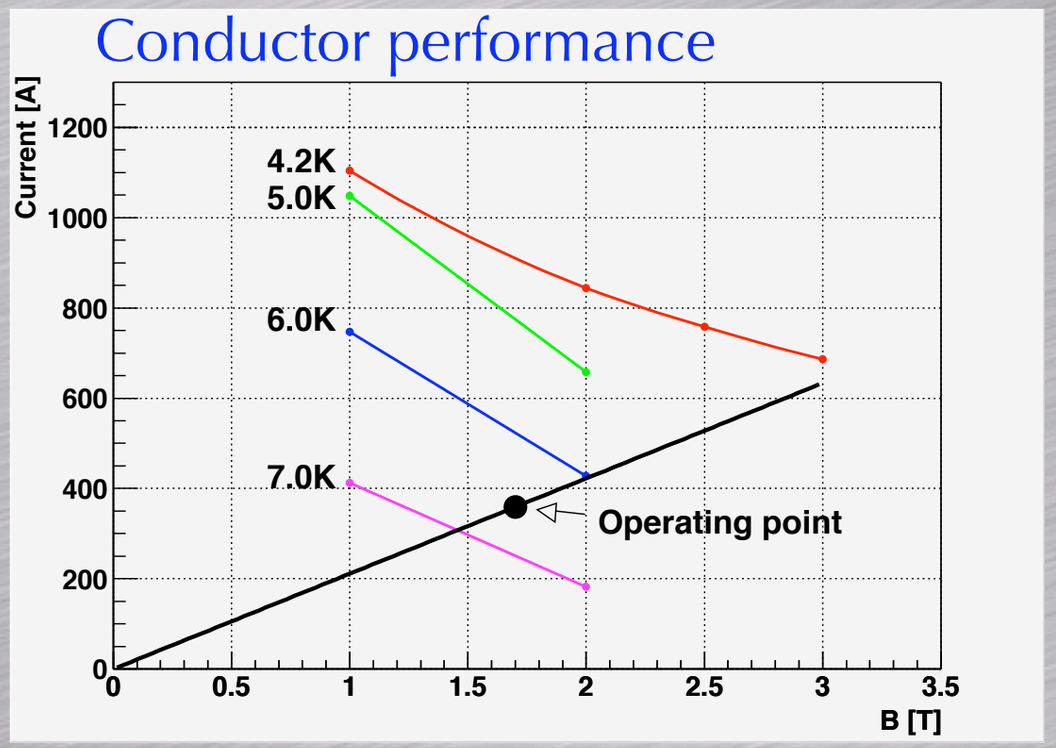
- High-strength Al-stabilized conductor is used to minimize coil thickness.
- The conductor is wound edge-wise in four layers inside 2mm-thick Al support cylinder.
- 0.1mm-thick pure Al-strip is attached inside the coil for fast quench propagation.
- Total thickness of $0.197X_0$(Al 4.7g/cm^2 equiv.) in the central region.



Development of Conductor

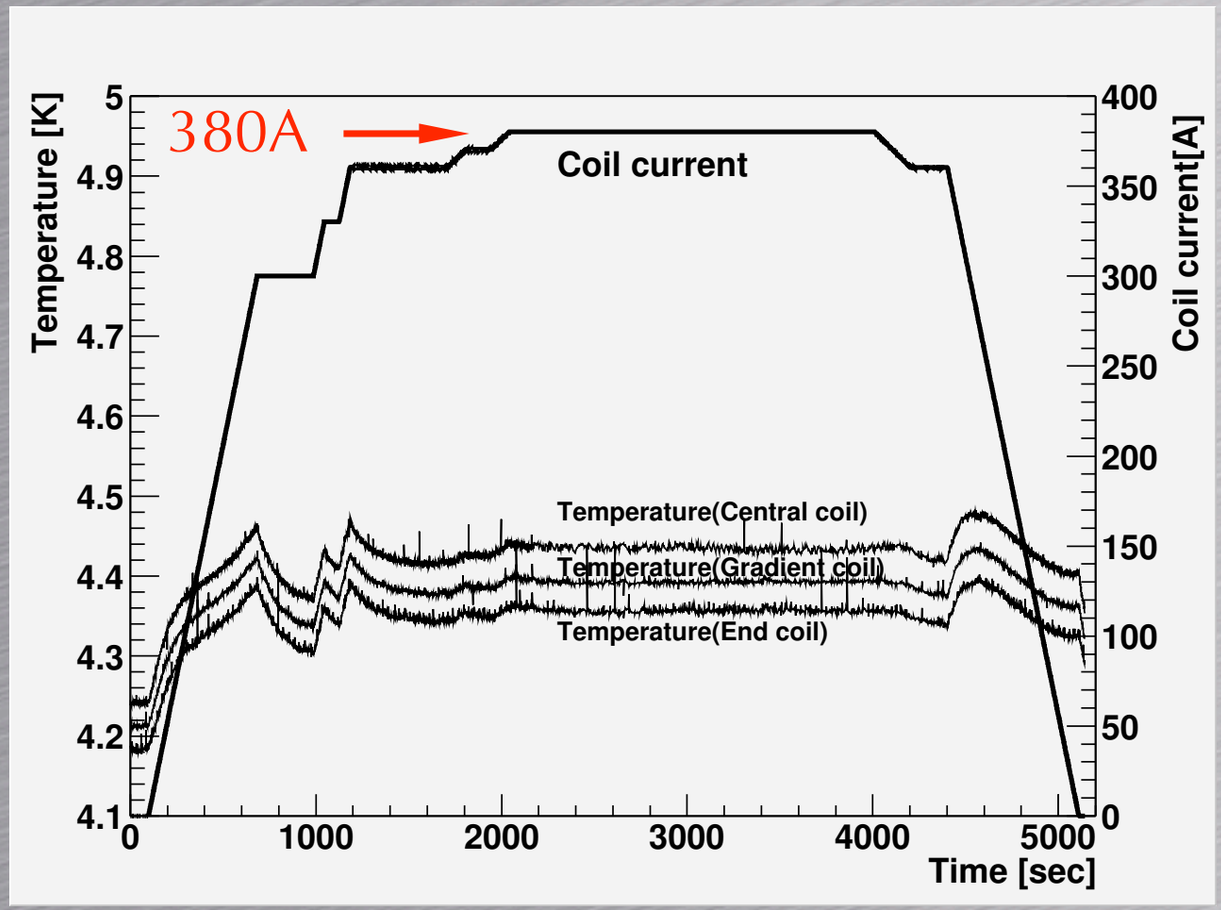
- High-strength Al-stabilized conductor was developed to realize thin coil.
- Al-stabilizer is reinforced by means of “Micro-alloying” and “Cold-work hardening “.
- 5000ppm Ni added into pure Al.
- Al3Ni(contributes to strength) precipitated in pure Al(contributes to conductivity).
- Yield strength = 240MPa (NbTi/Cu/Al) at 4.2K

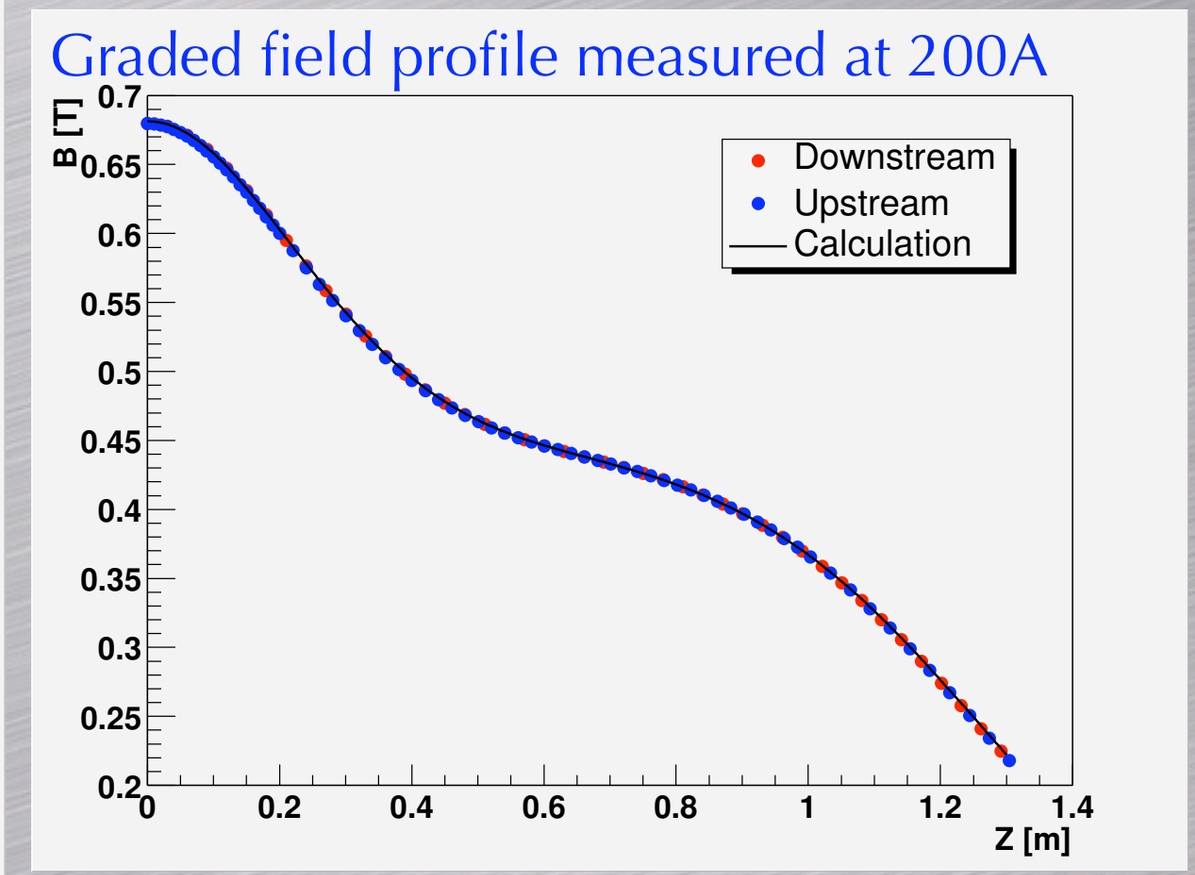




Excitation Tests

- The magnet was successfully tested up to 380A (5.6% higher than operating current)
- Axial field profile was measured at 200A
  Good agreement with calculation!



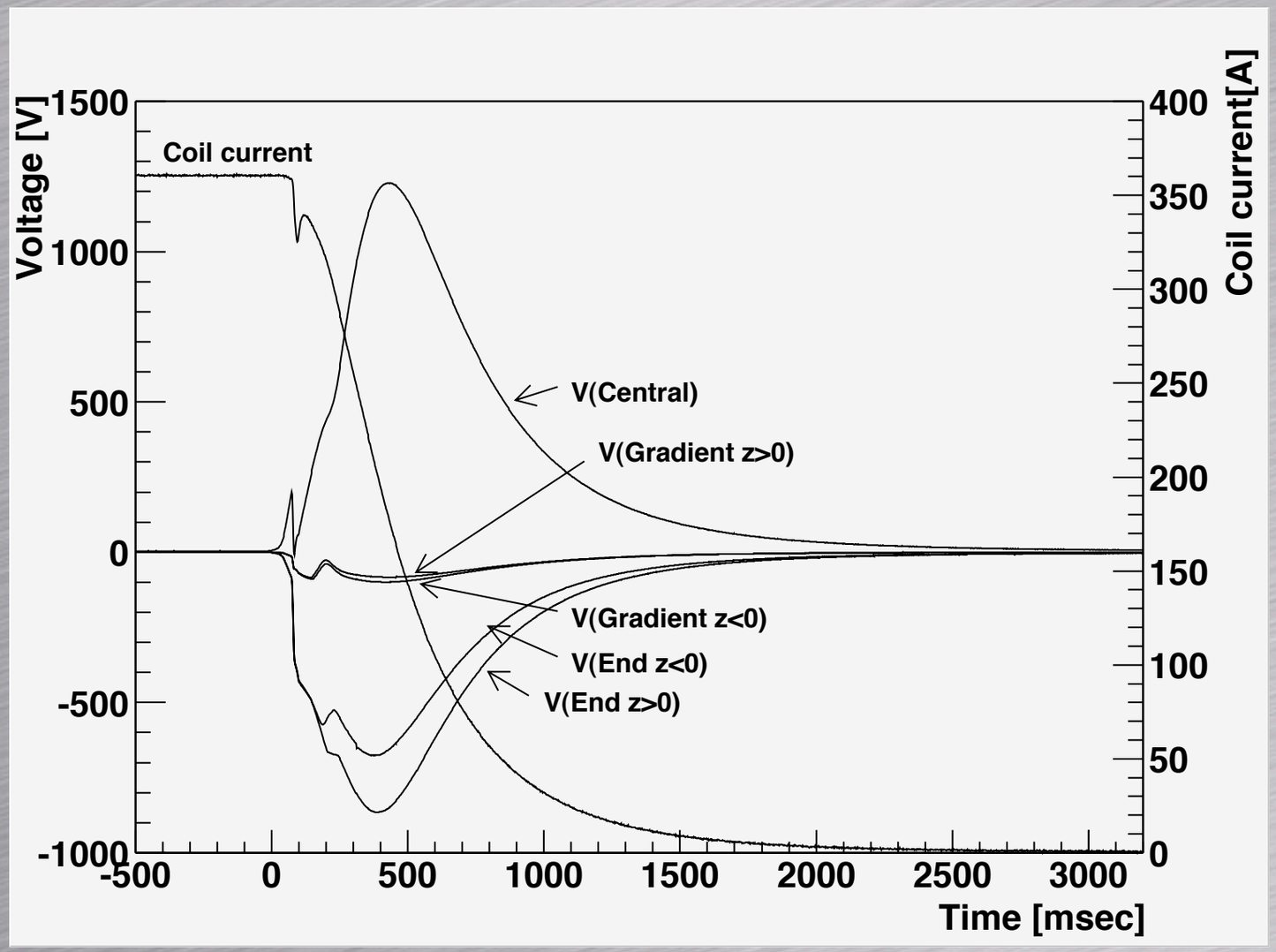


Quench Tests

- Quench propagation observed by voltage taps, temperature sensors and Superconducting quench detectors (SQDs).
- Severest test: heater quench test at central coil at 360A.
  - Quench induced by firing a heater in the central coil, which is the farthest coil from the refrigerator.
  - DC OFF and quench protection heater ON after the quench is detected.

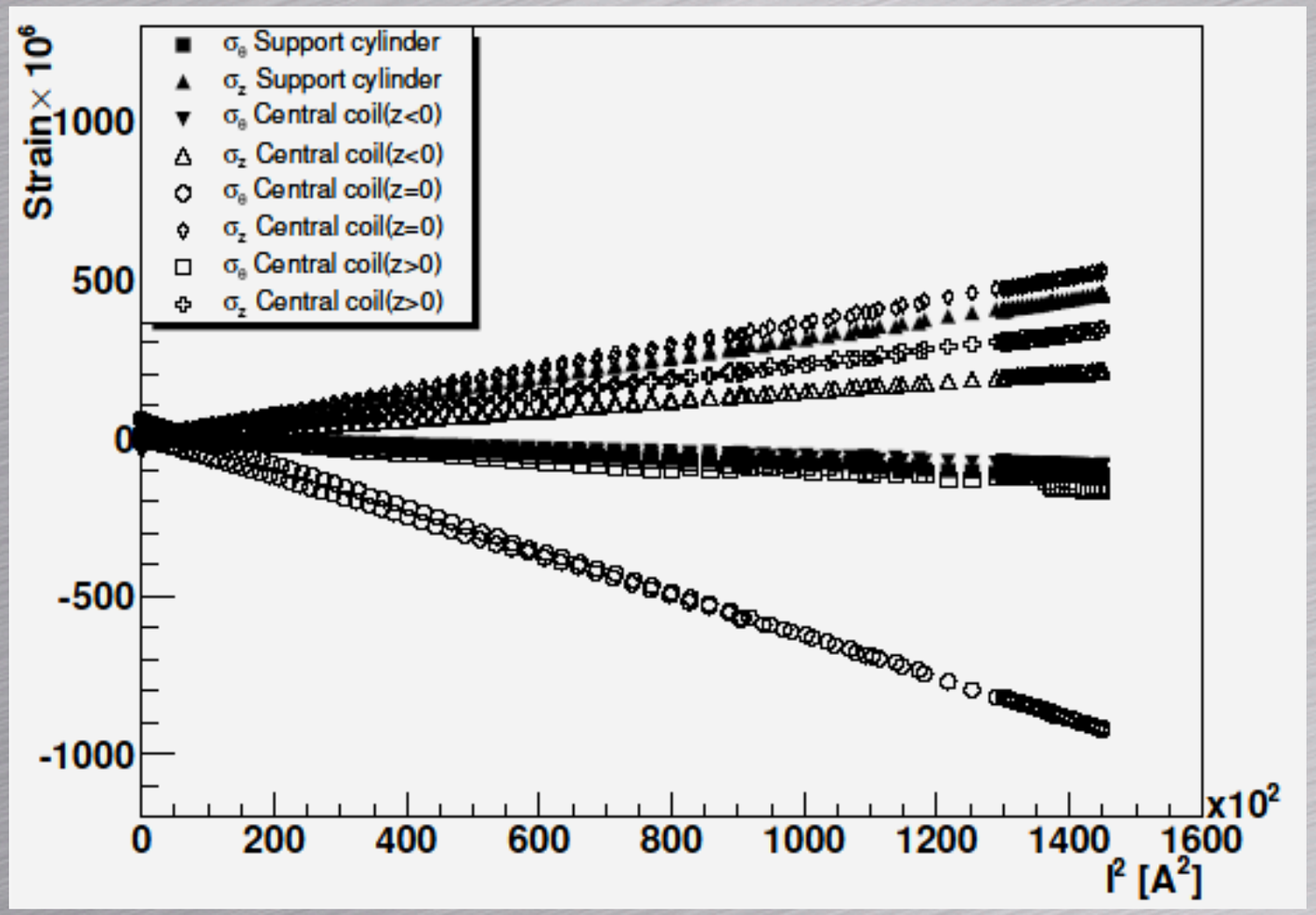
Voltage Change in Quench Test

- Maximum voltage across the central coil of 1200V was observed ~500msec after the quench in the central coil.



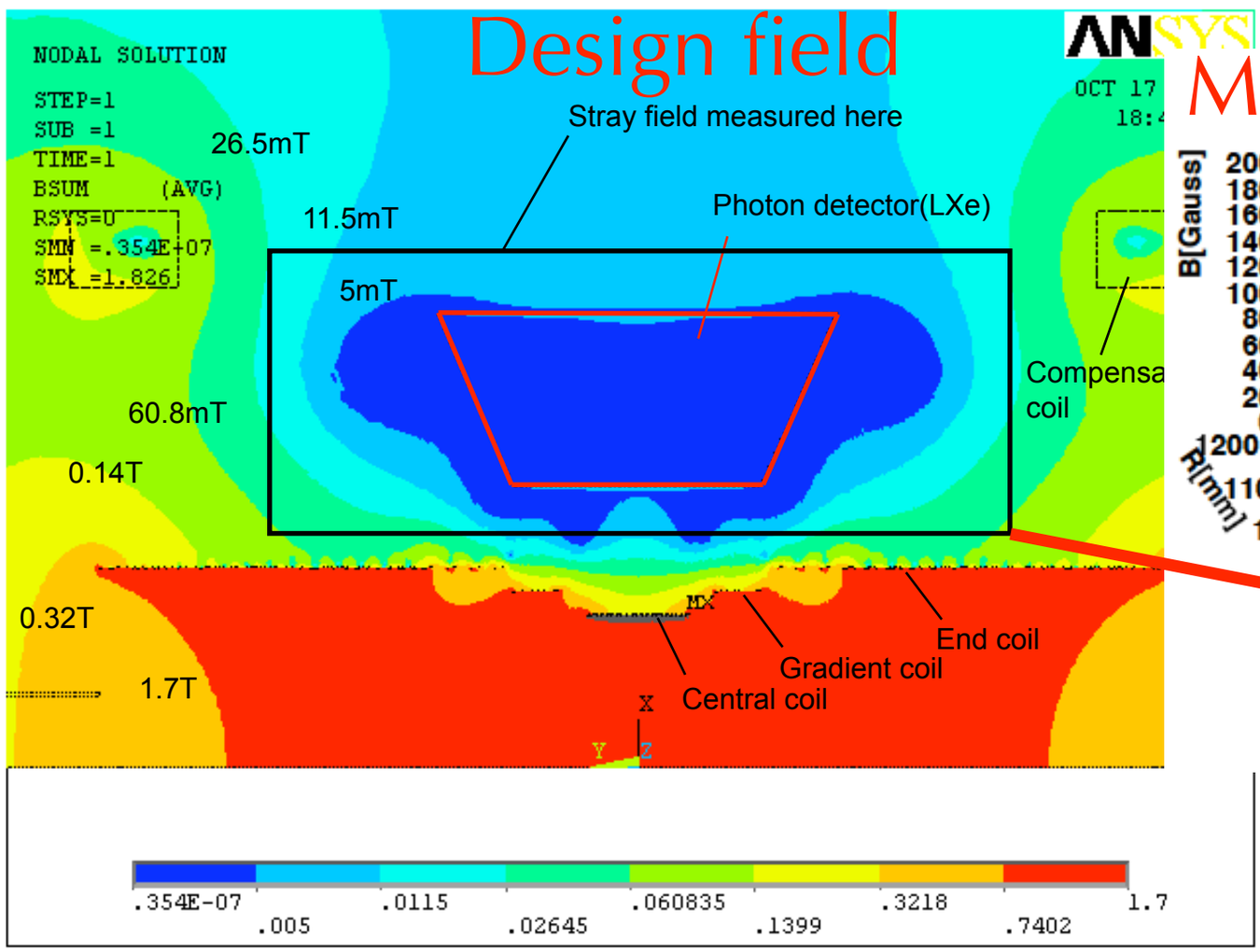
Mechanical Strength

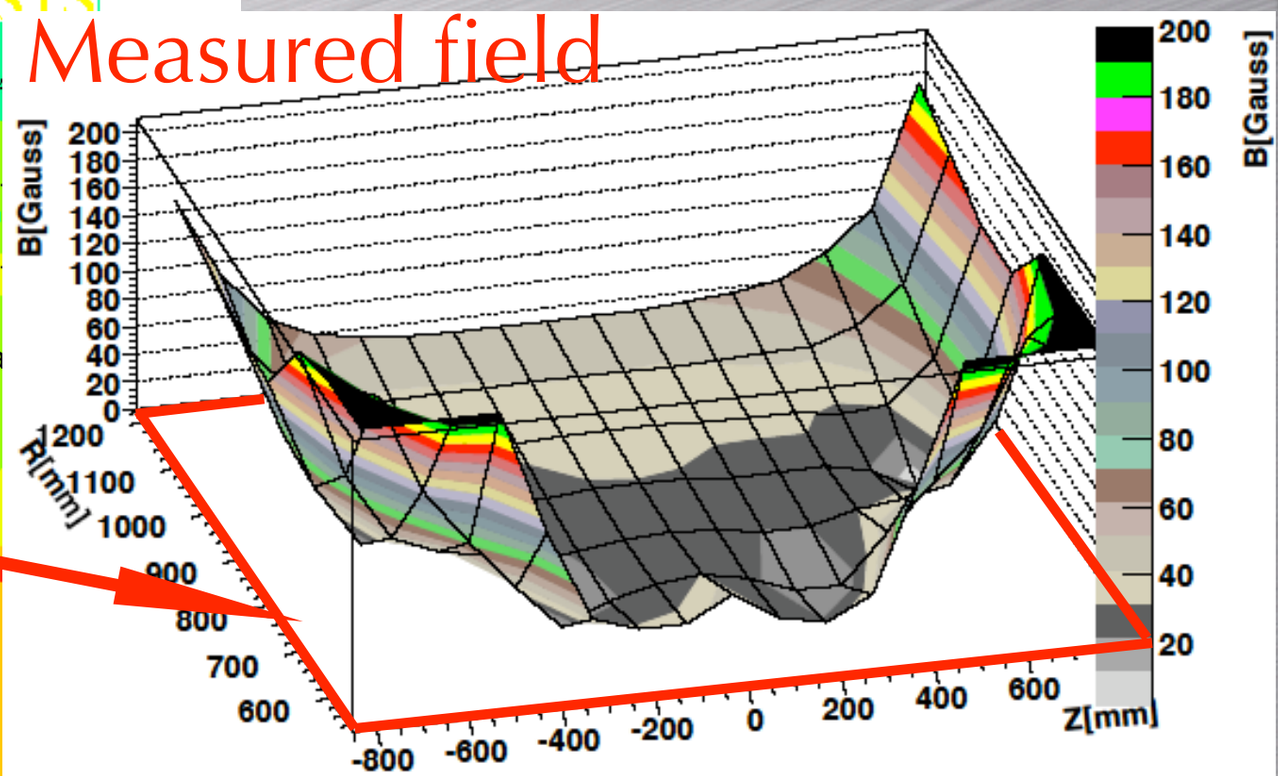
- Strains in the central coil and support cylinder measured up to coil current of 380A.
- Fairly linear relation between strain and I^2
- Sufficient mechanical strength



Stray Field Cancellation

- Cancellation of stray field around the photon detector region by using compensation coils
- Cancellation down to 50Gauss achieved!





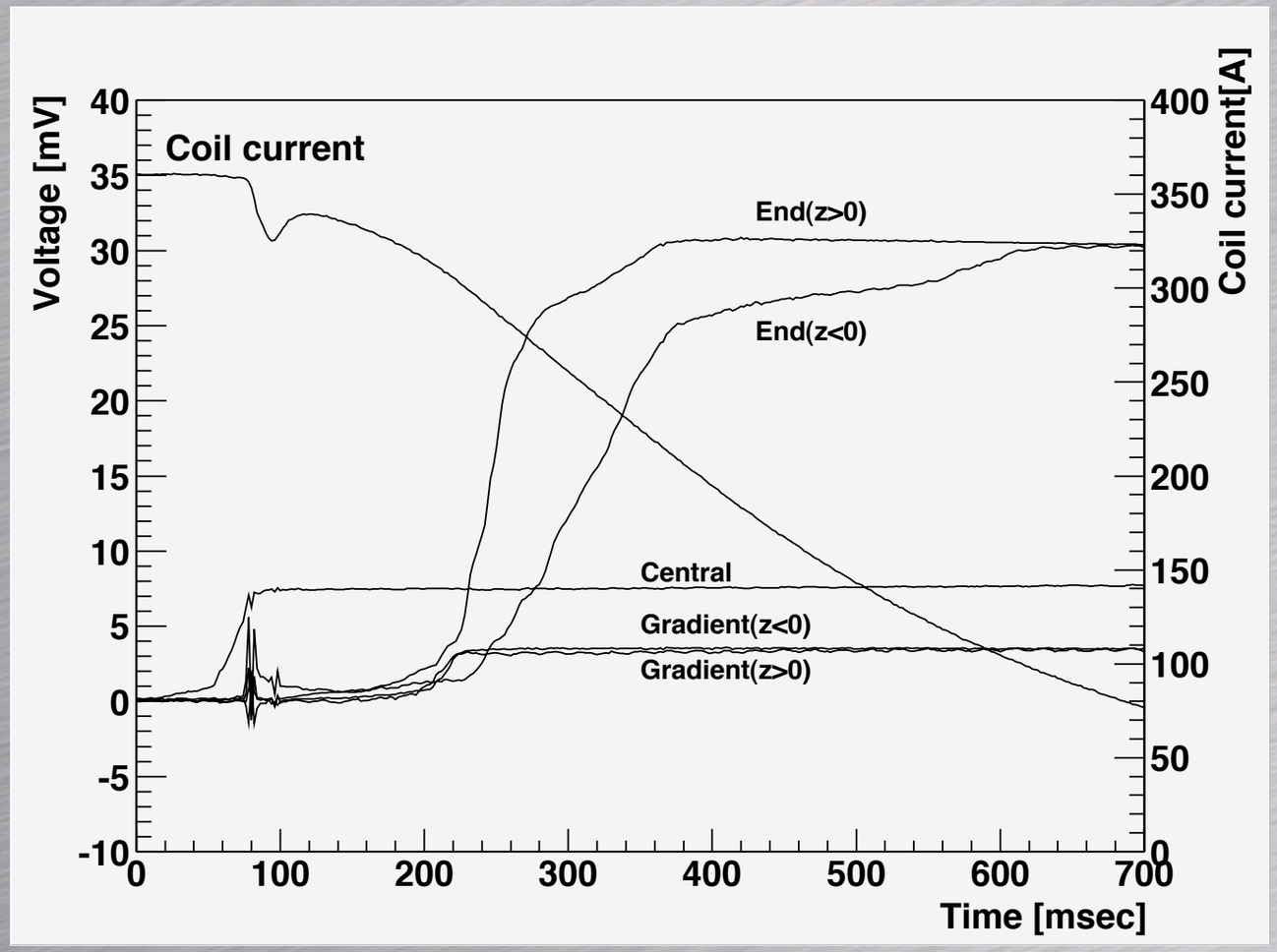
Summary

- A thin-wall superconducting magnet with field gradient was developed for the COBRA positron spectrometer in the MEG experiment.
- Total thickness of $0.197X_0$ is achieved by using a high-strength Al stabilized conductor(overall YS=240MPa at 4.2K).
- The magnet was successfully tested up to 380A(5.6% higher than operating current).
- Measured magnetic field gradient shows a good agreement with calculation.
- Cancellation of stray magnetic field down to 50Gauss around the photon detector by compensation coils is achieved.
- Quench tests up to the operating current were done.
- The results from the tests indicate that the magnet has a good performance with a reasonable margin for operation in the COBRA spectromer.

End of Slides

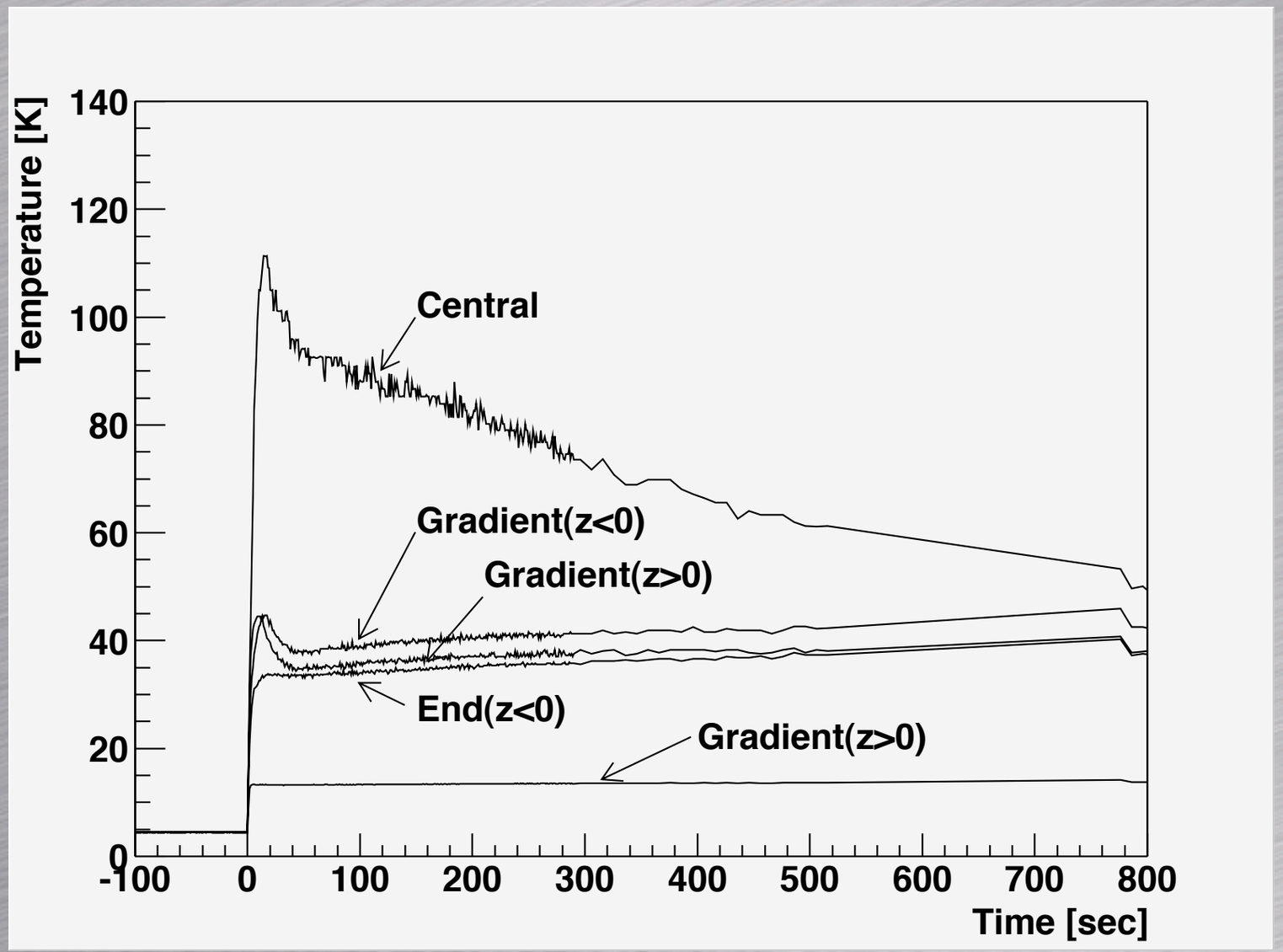
SQD Reaction in Quench Test

Time[msec]	
-130	Heater at central coil is fired
0	SQD reacted at central coil
+54	Protection heaters ON
+74	DC OFF
+(150-200)	SQDs reacted at the other coils



Temperature Rise in Quench Test

- Temperature was peaked at 110K in the central coil 16sec after the quench occurred.



Magnet Parameters

Step structure

Coil	Central	Gradient	Inner end	Outer end	Compensation
Conductivity	Super	Super	Super	Super	Resistive
Inner dia. (mm)	699.1	809.1	919.1	919.1	2210
Outer dia. (mm)	711.6	820.6	929.5	929.5	2590
Length (mm)	240.3	110.4	189.9	749.2	265
z of coil center(mm)	0	$\pm$235	$\pm$405.4	$\pm$874.95	$\pm$1190
Layers	4	4	3	3	14
Turns per layer	267	123 (1st) 92(2nd-4th)	80	624 (1st-2nd) 92(3rd)	20
Turns (total)	1068	399	240	1548	280
Winding density(Turns/m)	4444.4	3614.1	1263.8	2066.2	1056.6
Winding	e-w	e-w(1st) f-w(2nd-4th)	f-w	f-w	double pancake
Inductance(H)	1.64	0.62	0.35	2.29	0.54
Current (A)	360	360	360	360	360
Energy E (kJ)	106	40	23	148	35
Weight M (kg)	9	4	7	28	1620
E/M (kJ/kg)	11.8	10.0	3.3	5.3	0.02

Current density adjustment

Transparency

	Equivalent thickness g/cm^2	Radiation thickness X_0
Coil		
Conductor(Al)	0.745	0.0312
Conductor(NbTi/Cu)	0.868	0.0766
Insulation(Uplex/G-Epp)	0.069	0.0020
Epoxy-resin	0.058	0.001
Support cylinder	0.945	0.0396
Pure Al strip	0.068	0.003
Subtotal	2.753	0.153
Cryostat		
Outer vacuum shell	0.405	0.017
Radiation shield	0.162	0.007
Inner vacuum shell	0.405	0.017
Super insulation	0.105	0.003
Subtotal	1.192	0.048
Total	3.83	0.197

Transmission probability ~0.85 for 52.8MeV photon