Status of COBRA Magnet

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for the MEG collaboration

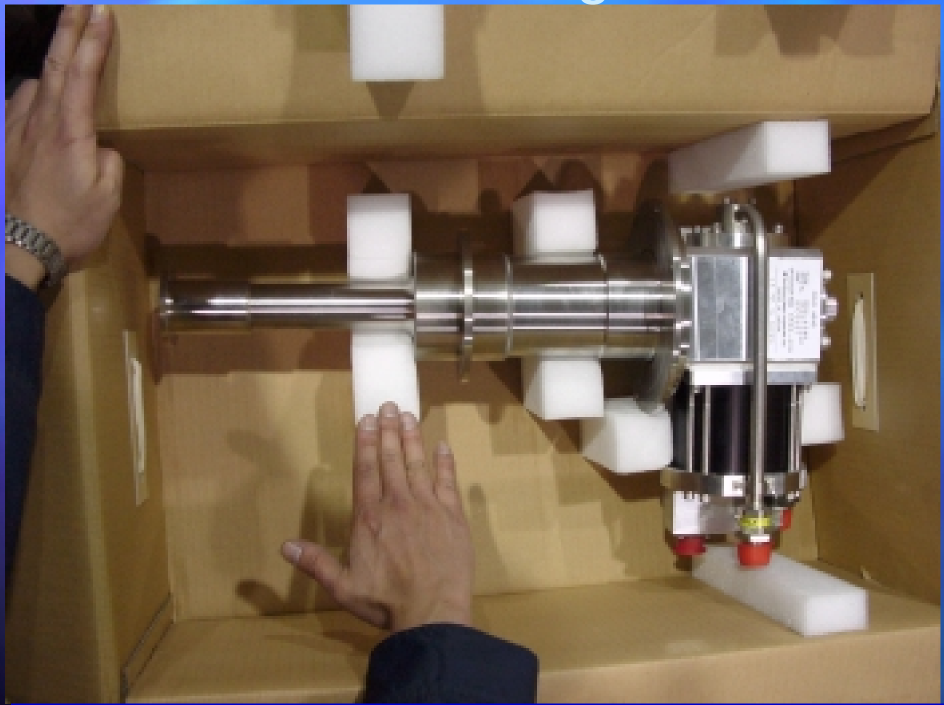
Construction Status

Detailed design was almost finalized and construction started.

- Main magnet
  - Detailed mechanical calculations were performed to optimize the mechanical design of the magnet.
  - Related experimental tests were performed. No problem found.
  - Winding of the cable is in progress. Central coil was completed.
  - Construction of the cryostat is starting.
  - Power supply is being ordered.
- Compensation coil
  - Winding completed and various test were performed. No problem.
  - Case and support structure are being constructed.
  - Power supply is being ordered.
- Field reconstruction
  - Accurate calculation based on realistic magnet condition is under development .
  - Design work on the mapping machine is starting.
  - Field reconstruction algorithm is being optimized.

Refrigerator for Main Magnet

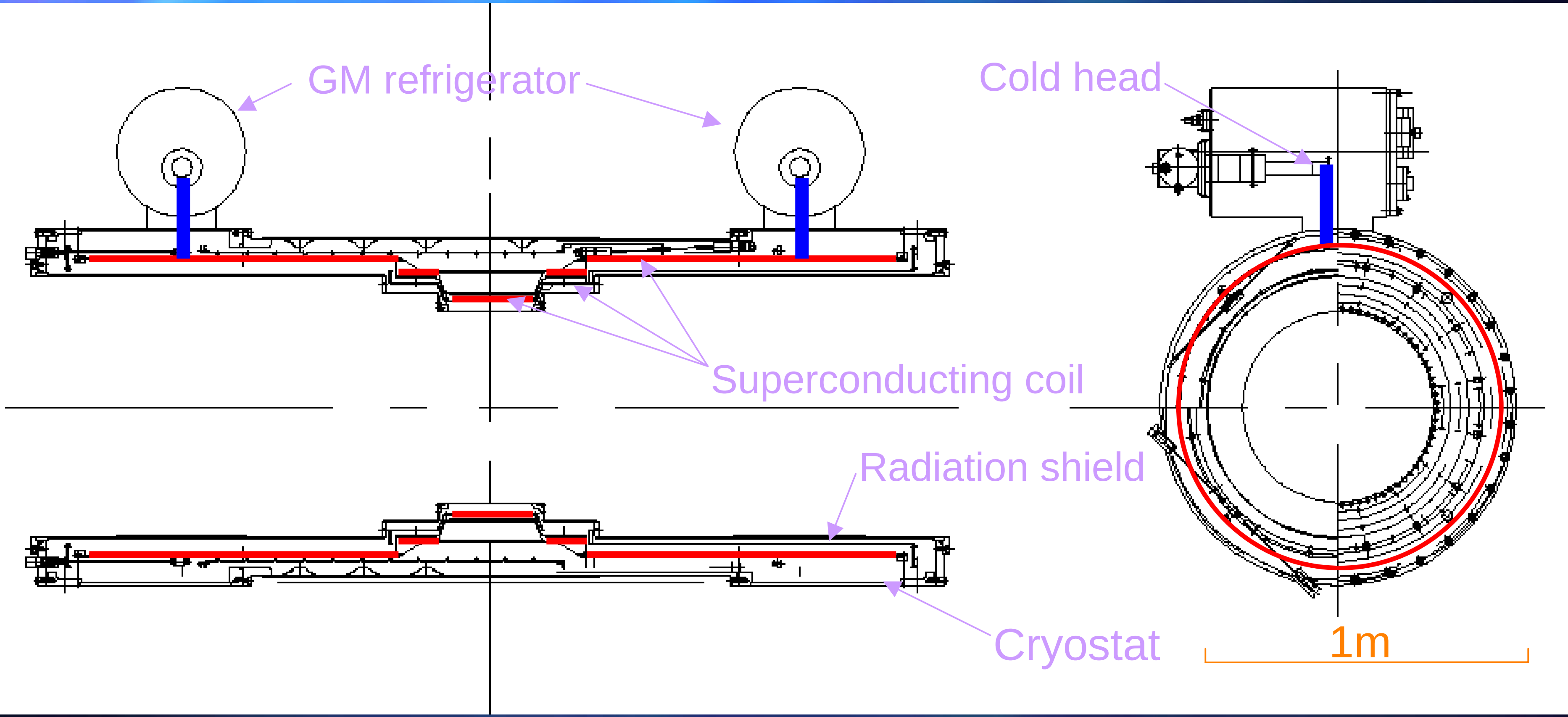
SHI 4K GM-refrigerator



Compressor

- Moving part in the refrigerator should be replaced once a year
- This maintenance work takes 3-4 weeks.
- Quick supporting service is expected from the SHI supporting center in Germany

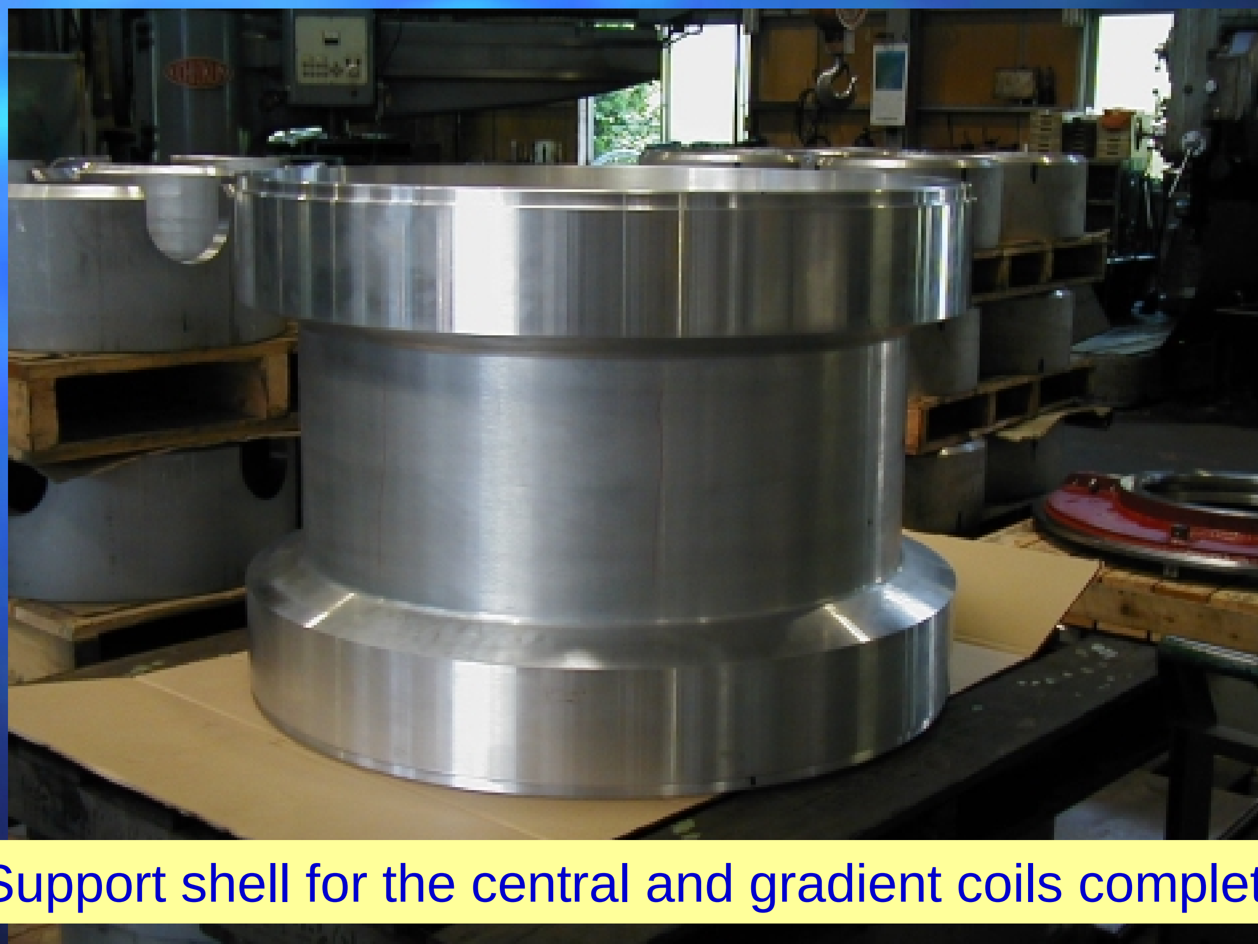
Refrigerator for Main Magnet



Winding of Coil

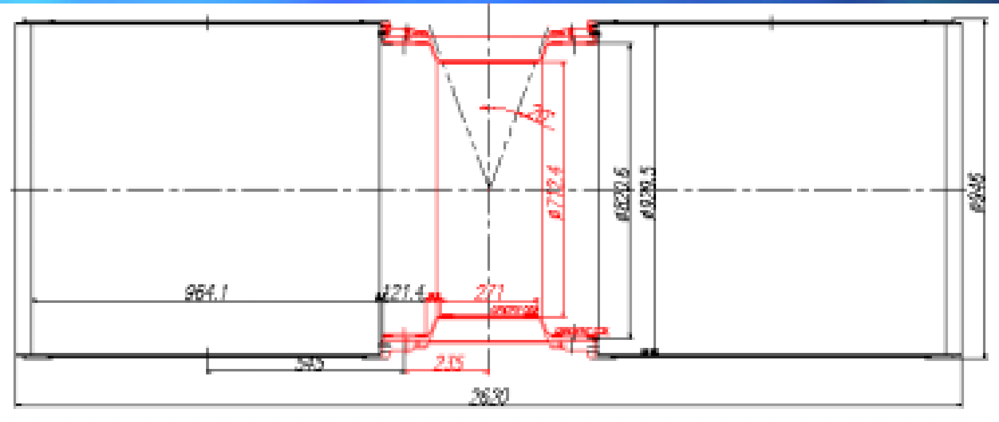
Winding of superconducting cable is going on at Toshiba

Construction of Support Shell



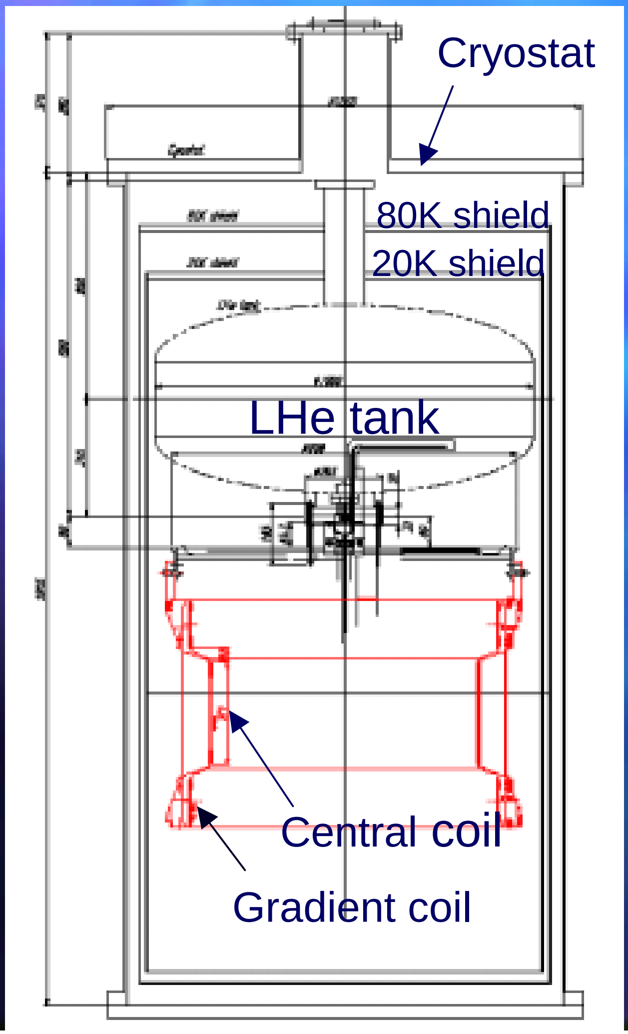
Support shell for the central and gradient coils completed.

Excitation Test of Central and Gradient Coils



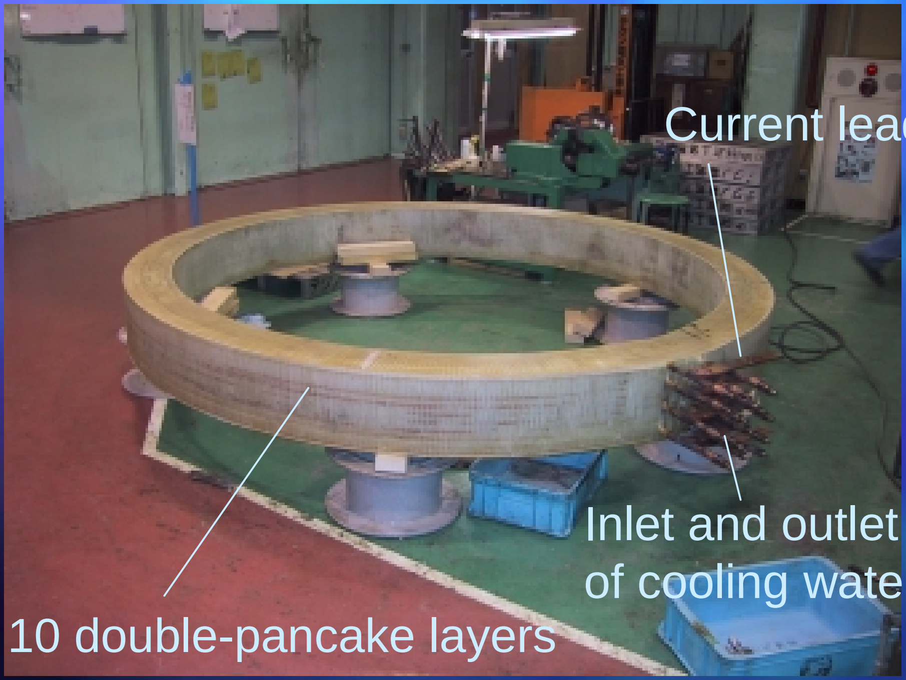
- Excitation test of the assembly of the central coil and two gradient coils with the support shell will be performed in this summer.
- Essential part in the COBRA magnet from the viewpoints of superconducting and mechanical characteristics.
- Design of the experimental setup is almost finished.
- This test will be an important milestone in the magnet construction.

Excitation Test of Central and Gradient Goils



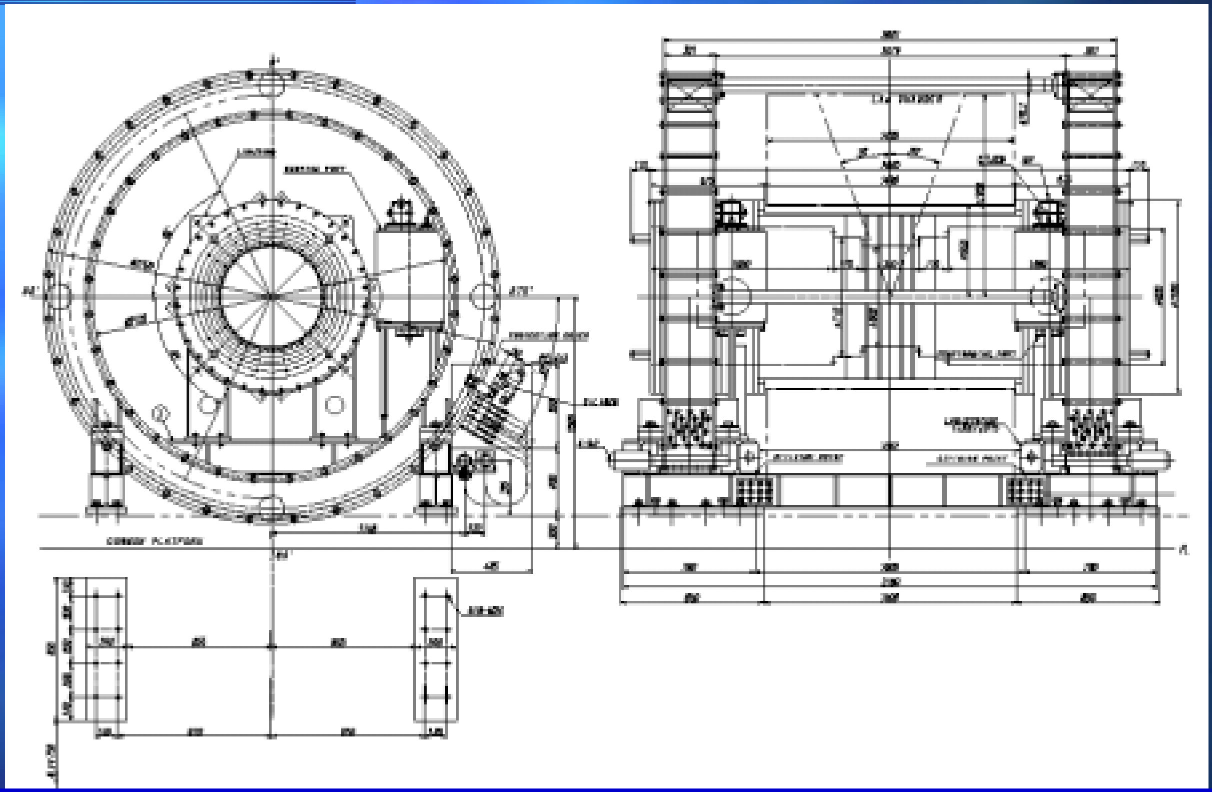
- Existing cryostat will be used.
- The coils are cooled down to ~4K using a cold finger from a LHe tank
- Possible tests
  - Quench test
    intentional quench caused by a heater
    I = 125, 177, 250, 360A (design value)
  - Superconducting load test
    simulate the same load ratio as that in the final magnet. I = 375A
  - Axial force test
    simulate the same axial force as that in the final magnet. I = 468A

Compensation Coil



- Winding of the hollow conductors was finished.
- All double-pancake windings were stacked with insulator.
- Various tests of the coils were performed.
  Dimension, resistivity, insulation
  , water pressure tolerance
  , pressure drop, field meas.
  , inductance, …
  No problem found.
- Case for the coil and support structure are under construction.

Design of Magnet Assembly



- Detailed engineering design is almost finalized.
- Should be modified for final design of other detector components and beam transport magnet
- Scheme for the survey and alignment is being investigated.

Field Reconstruction

- High quality tracking (σ_p /p ~ 0.3%) requires a precise knowledge of the magnetic field (magnitude and shape).
- Accuracy requirements for the field reconstruction
  $\Delta B/B$ ~ 0.1% at each point (ΔB ~ 10Gauss for 1T)

- Essentially two tools for the field reconstruction
  - Calculation
  - Field measurement

Field Reconstruction

Calculation

- Complex of simple air-core solenoids.
  - → Field is safely calculated by direct application of the Biot-Savart law.
- Precise knowledge of the coil geometry is required for an accurate calculation.
  - Basic geometrical parameters (radius, length, relative position , tilt of the coil) can be measured at room temperature prior to the installation to the cryostat.
    - → can be extrapolated to the actual operating condition (at low temperature and with current on) using the well known thermal expansion rate and magnetic pressure.
  - Deformation of the coil will be smoothed out by magnetic pressure.
    - → Roundness ~ 5×10^{-4}

Field Reconstruction

Calculation, cont'd

  - Relative location of the coil complex to the cryostat can be measured with potentiometers to be equipped in the cryostat.
  - Alignment between the main magnet and compensation coils is not so important.

- The accuracy of the field calculation was 0.2% in the previous experiment (H1)

- Accurate calculation will be necessary for an extensive field reconstruction even if the field measurements are performed.

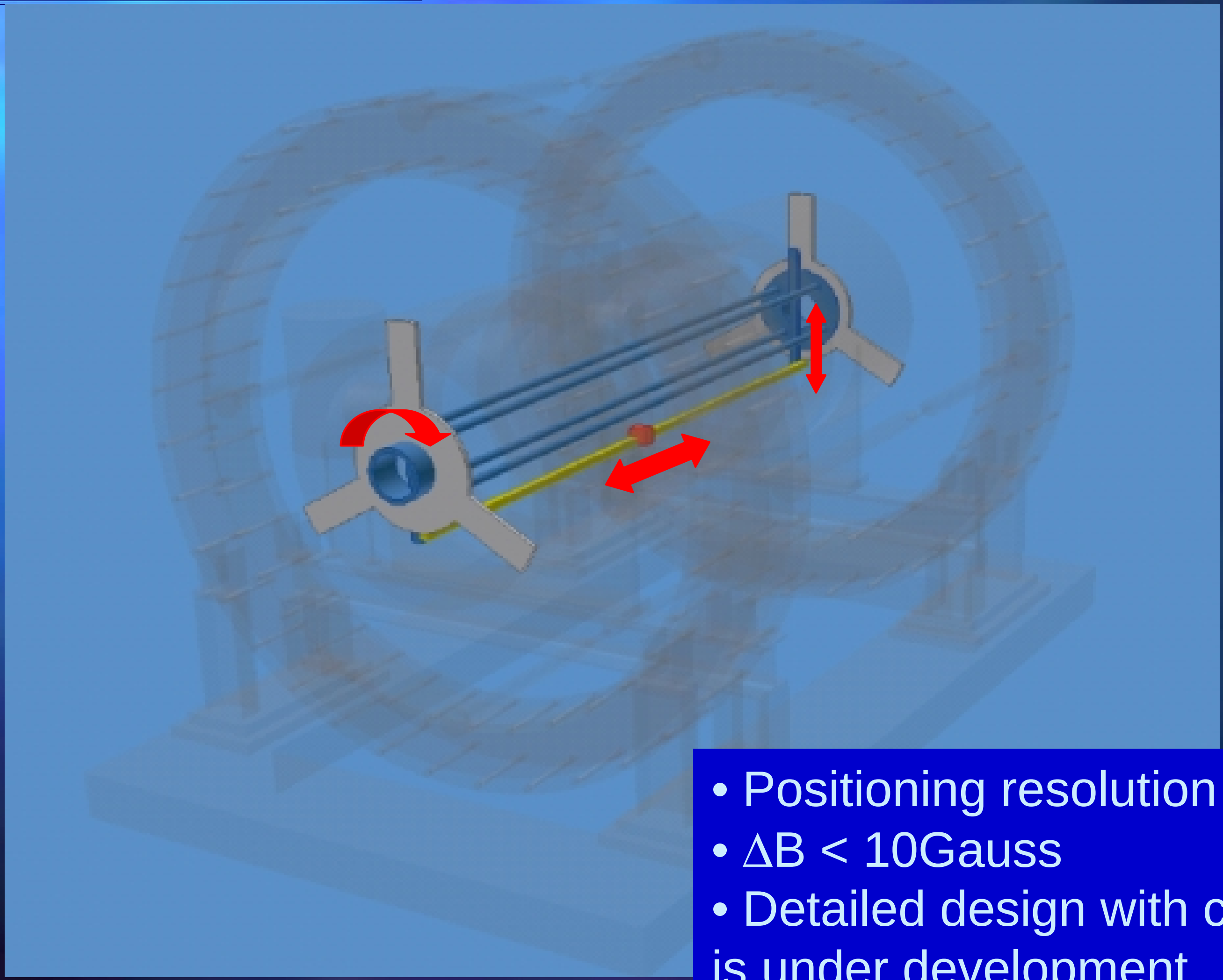
Field Reconstruction

Field measurement

- Field measurement will be performed after installation at PSI , if possible, together with the transport solenoid.
- 0.1% accuracy achieved in the ALEPH, DELPHI, H1 magnet
- Use mapping machine in the previous experiment?
- Mapping device with movable Hall probes is under consideration
  - Ultrasonic motor or high-torque motor placed far from the magnet as a motion driver
  - Non magnetic guide and rail
  - Three orthogonally oriented Hall sensors

Field Reconstruction

Conceptual design of the mapping machine



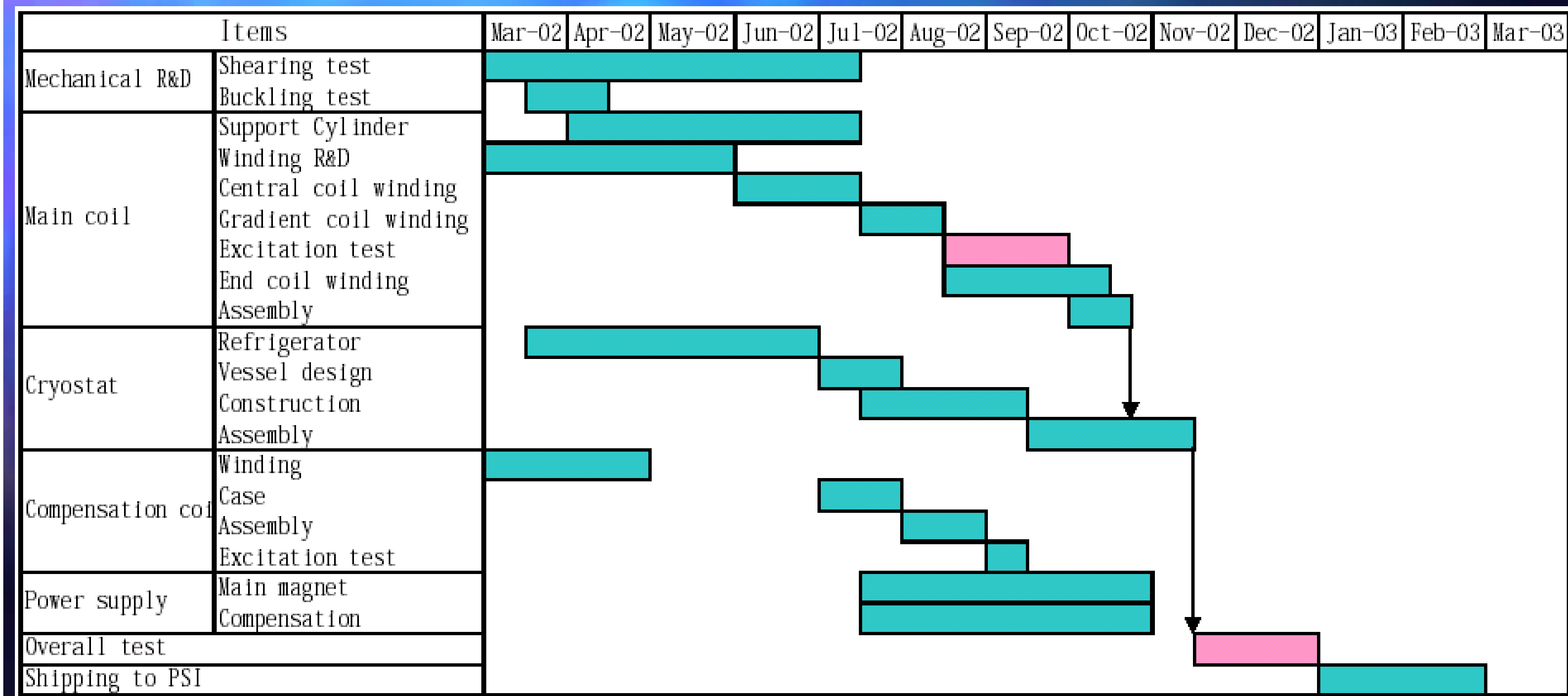
- Positioning resolution < 0.5mm
- ΔB < 10Gauss
- Detailed design with cost estimation is under development

Field Reconstruction

Field measurement, cont'd

- Density of measuring points depends on the algorithm to interpolate between the measuring points.
  - Intervals of a few cm in the tracking region (10^5 measuring points)
- How to calibrate an overall scale?
  - Difficult to use NMR which requires highly-uniform field at the level of 10^{-4}/cm.
    (~10^{-3}/cm at the center of the COBRA magnet)
- Field monitoring during the experiment life.

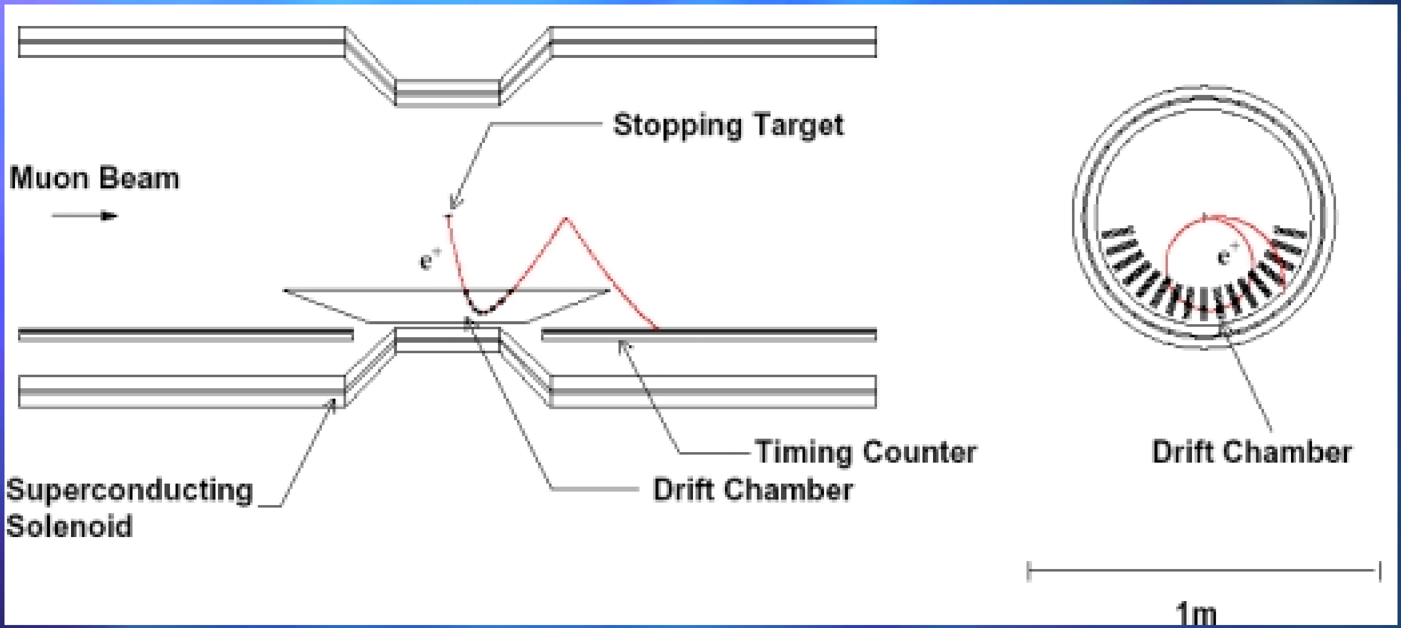
Construction Schedule



Schedule of field measurement is not fixed yet.

End of Slides

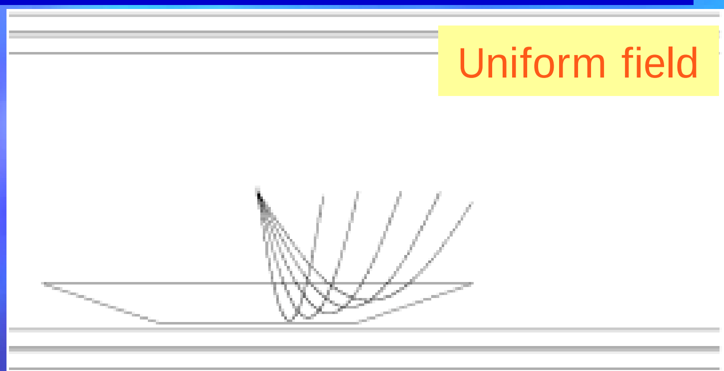
COBRA spectrometer

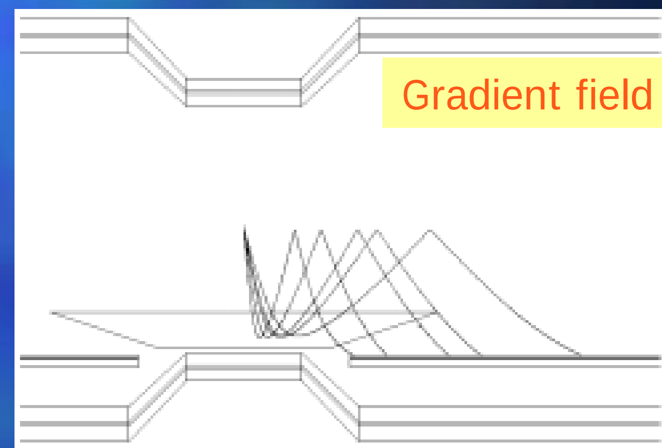


- Specially designed to form a gradient field
- Constant bending radius independent of the emission zenith angle
- Quick sweep out of low momentum Michel positrons

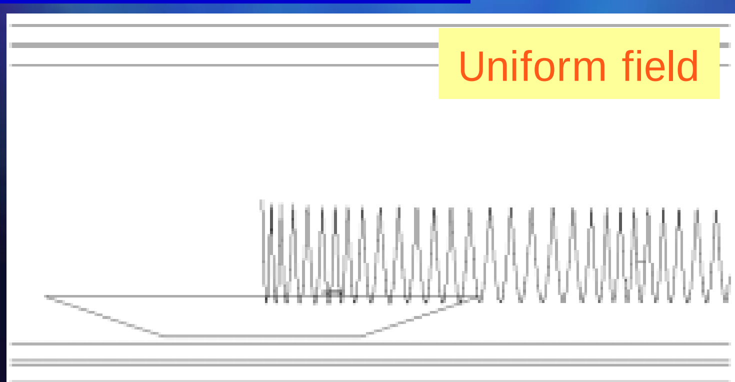
Concept of COBRA

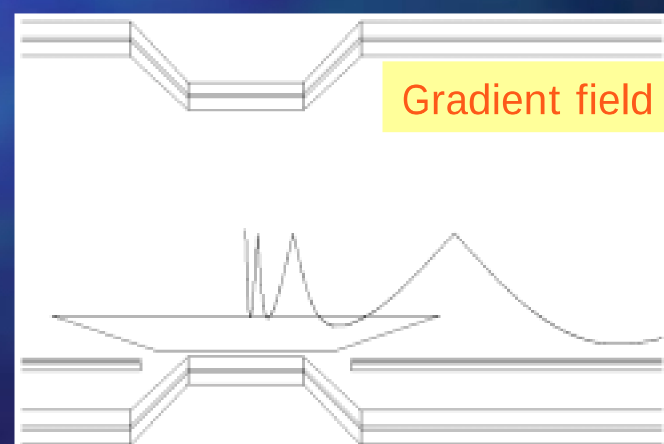
Constant bending radius



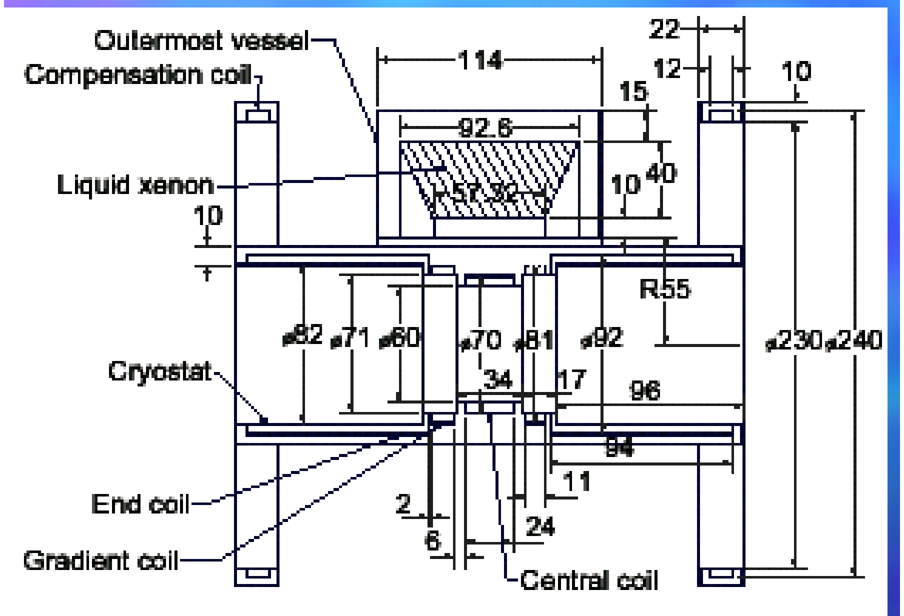


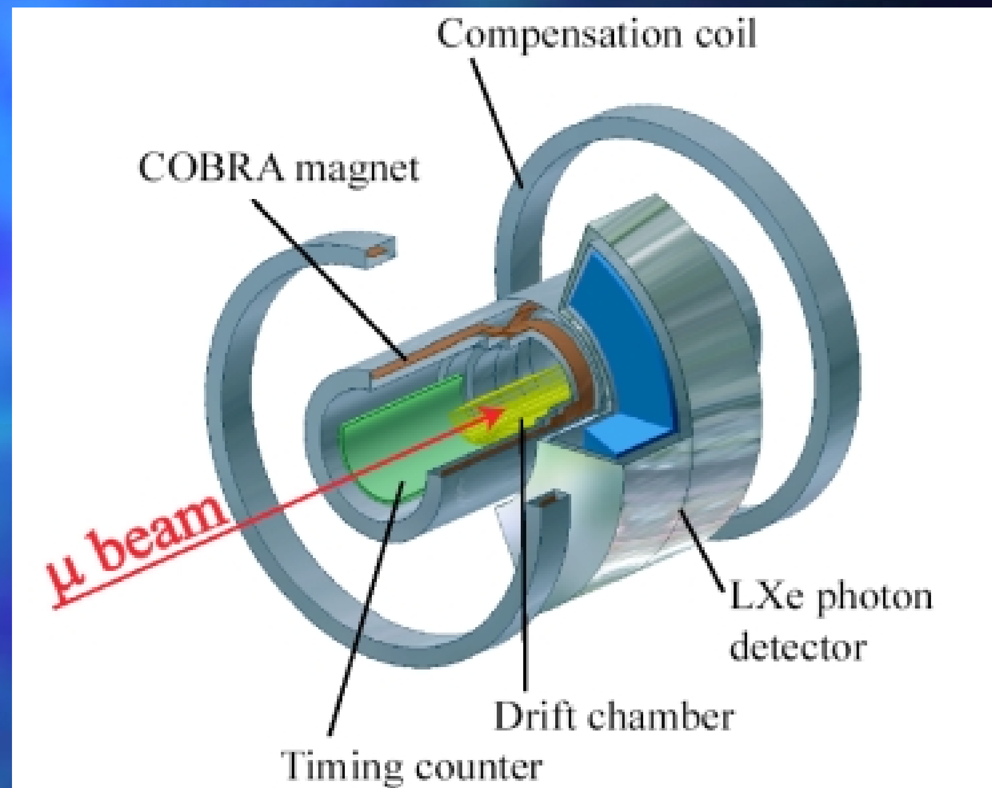
Quick sweep out





Layout of COBRA magnet



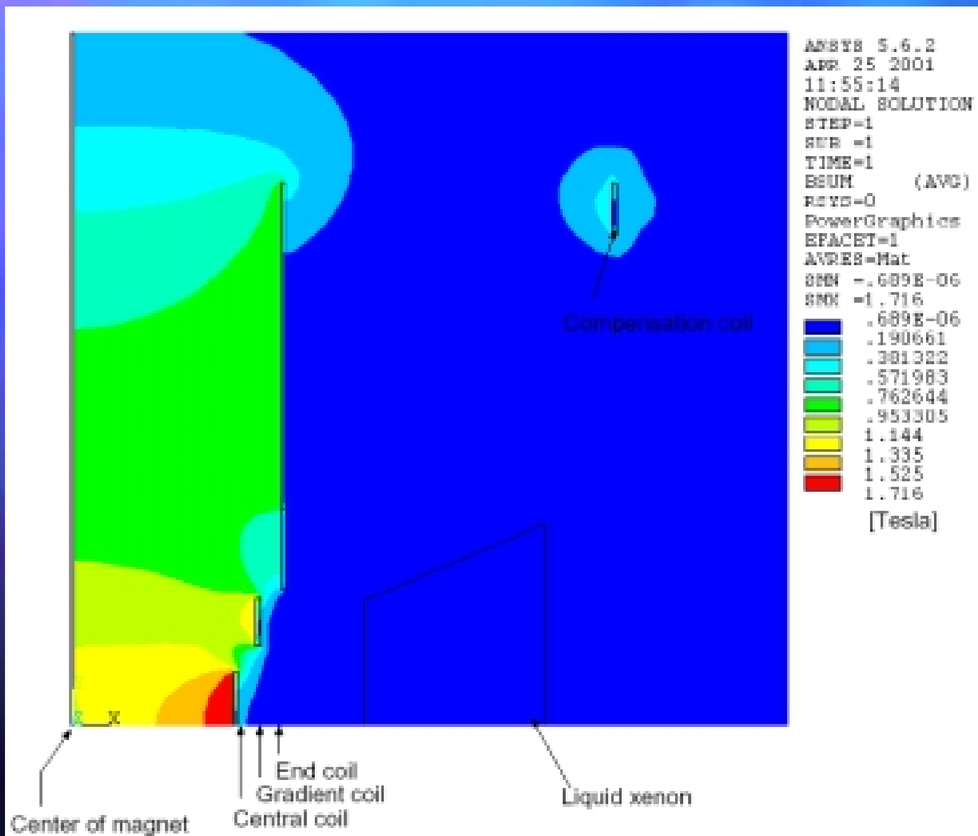


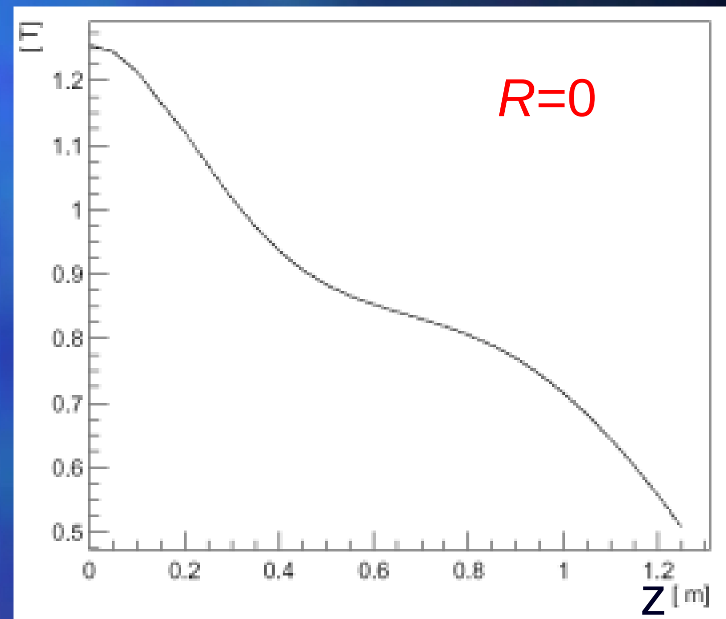
- Main SC magnet consists of central, gradient, end coils
- Compensation coil consists of a pair of conductive coils
- Coil radius is 10% smaller than that in the proposal.

Basic Parameters of Magnet

Coil	Central	Gradient	Inner end	Outer end	Compensation
Conductivity	Super	Super	Super	Super	Resistive
Inner dia. (mm)	700	810	920	920	2210
Outer dia. (mm)	712.4	820.6	929.5	929.5	2590
Length (mm)	240.3	110.4	189.9	749.2	265
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 [2]	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
I_{op}(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

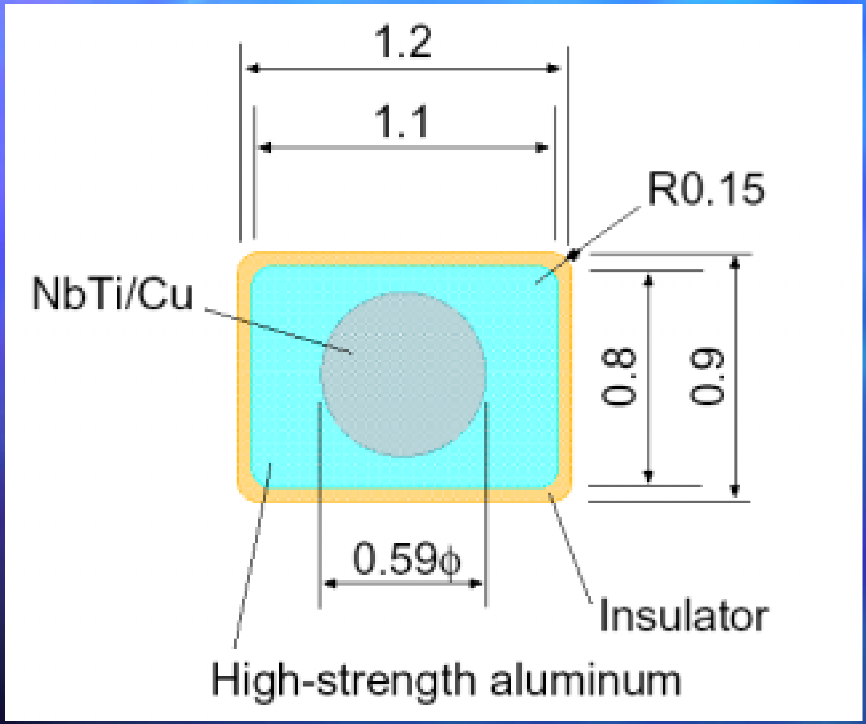
Magnetic Field Distribution





- B_c = 1.27 T
- $B_{z=1.25m}$ = 0.49 T
- Magnitude is larger by 10% than that in the proposal

Development of SC cable



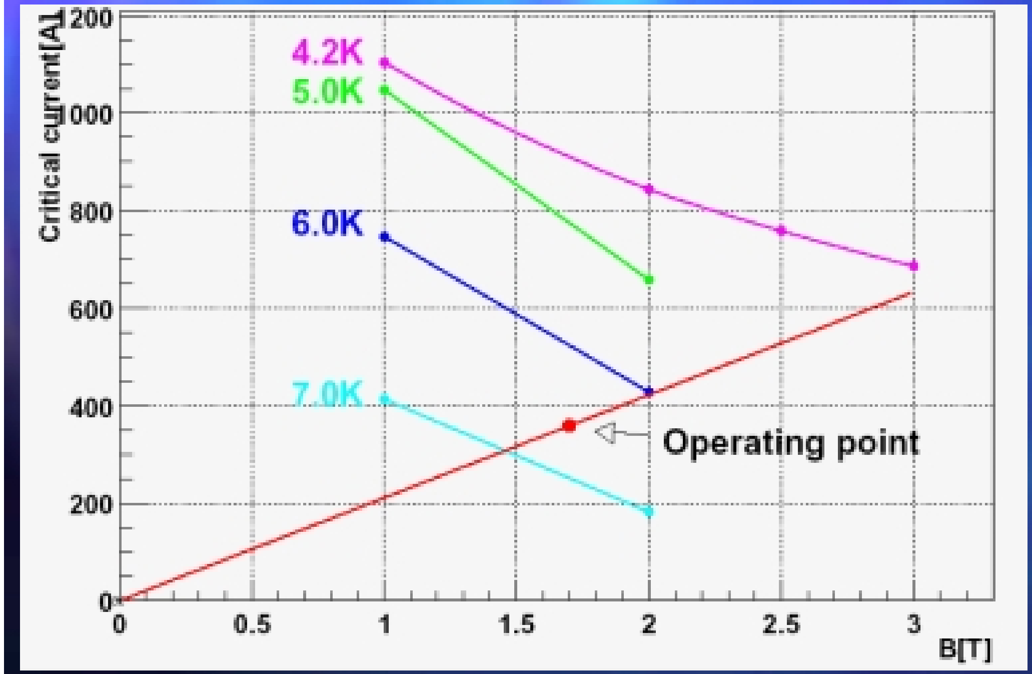
- Superconducting cable with Al stabilizer
- Al stabilizer is reinforced by "micro-alloying technology"
- Nickel (5000ppm) is added into the stabilizer
- Overall yield strength ~ 220MPa while keeping RRR > 280.

SC Cable Performance

Conductor material	NbTi/Cu
NbTi/Cu diameter	0.59 mm
NbTi/Cu Cu ratio	0.82
Insulator	Kapton polyimide tape
Overall cross section	$0.8 \times 1.1\,\mathrm{mm}^2$
Overall cross section with insulator	$0.9 \times 1.2\,\mathrm{mm}^2$
Critical current density	$5476\,\mathrm{A/mm}^2$ at 4.2 K, 2.0 T
Critical current	851 A at 4.2 K, 2.0 T 666 A at 5.0 K, 2.0 T
RRR	Cu 55.9 Al 280
0.2 % yield strength (conductor)	598 MPa at 4.2 K
0.2 % yield strength (Al stabilizer)	105 MPa at 4.2 K
0.2 % yield strength (overall)	221 MPa at 4.2 K

SC Cable Performance, cont'd

Critical current measured for various temperature and magnetic field



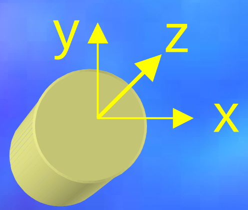
Operating condition of COBRA magnet

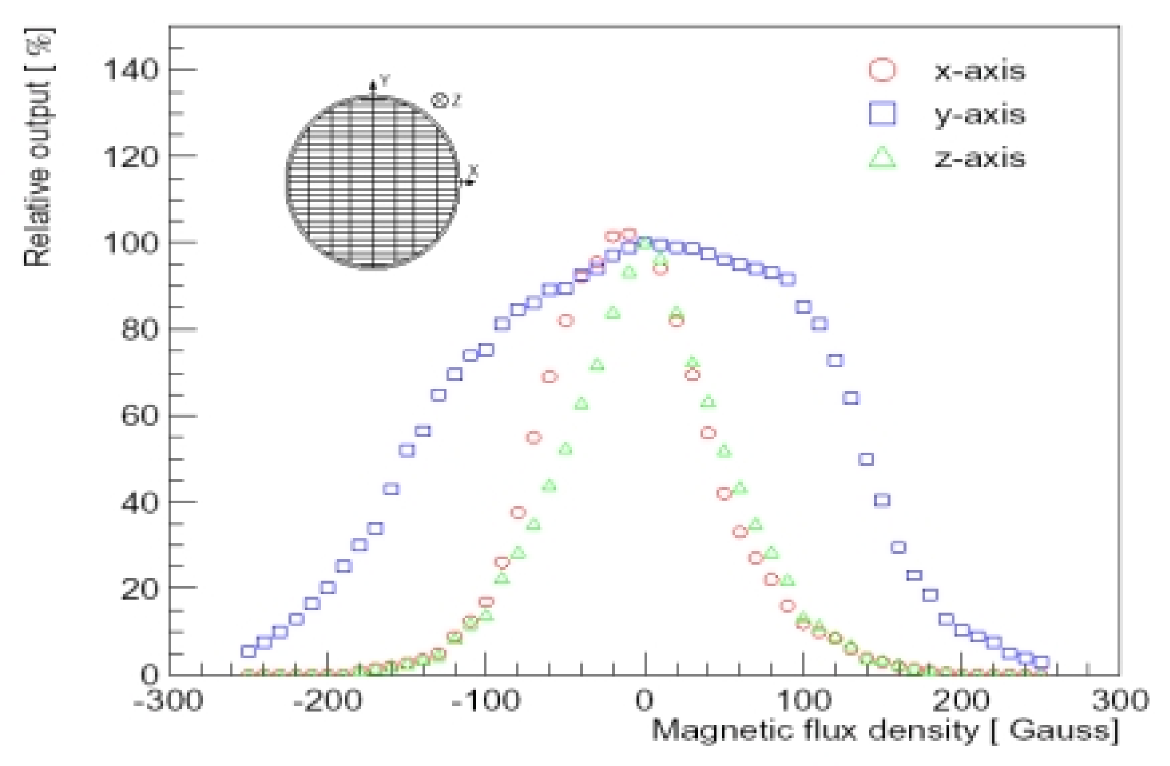
I_{op} = 360A and B_{peak} = 1.7T

Cable performance has a safety margin of ~ 30%

Suppression of Stray Field

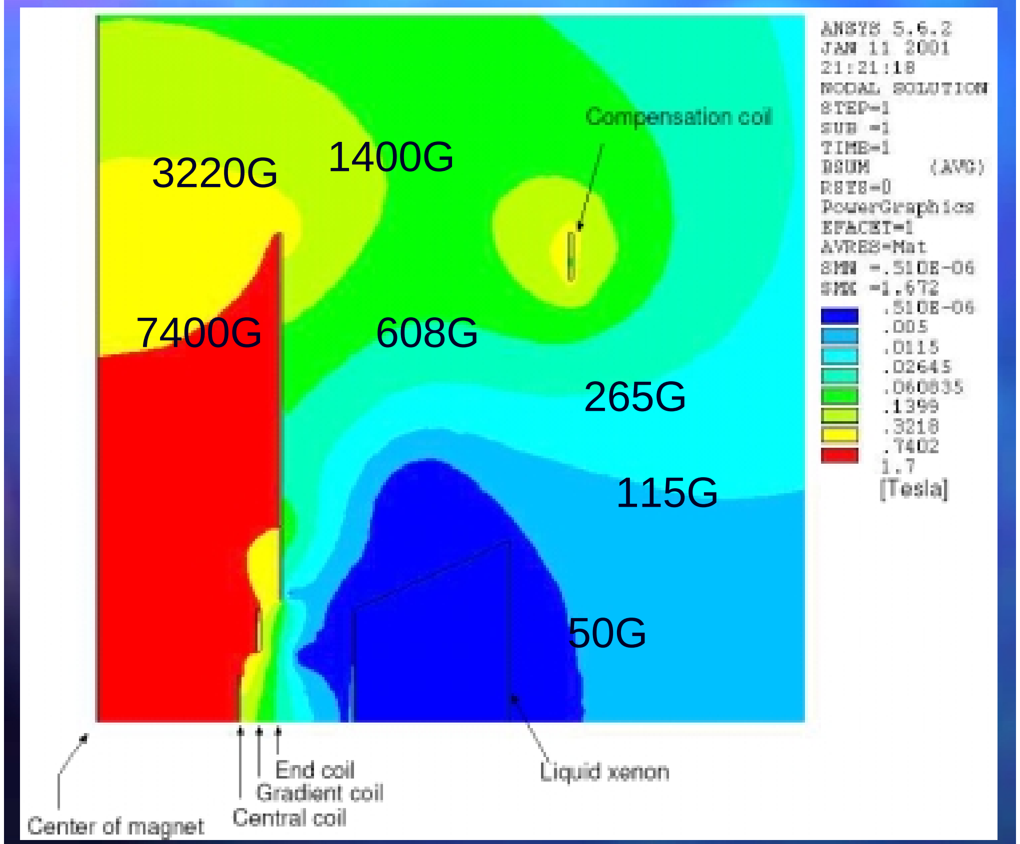
Tolerance to the magnetic field of the PMT

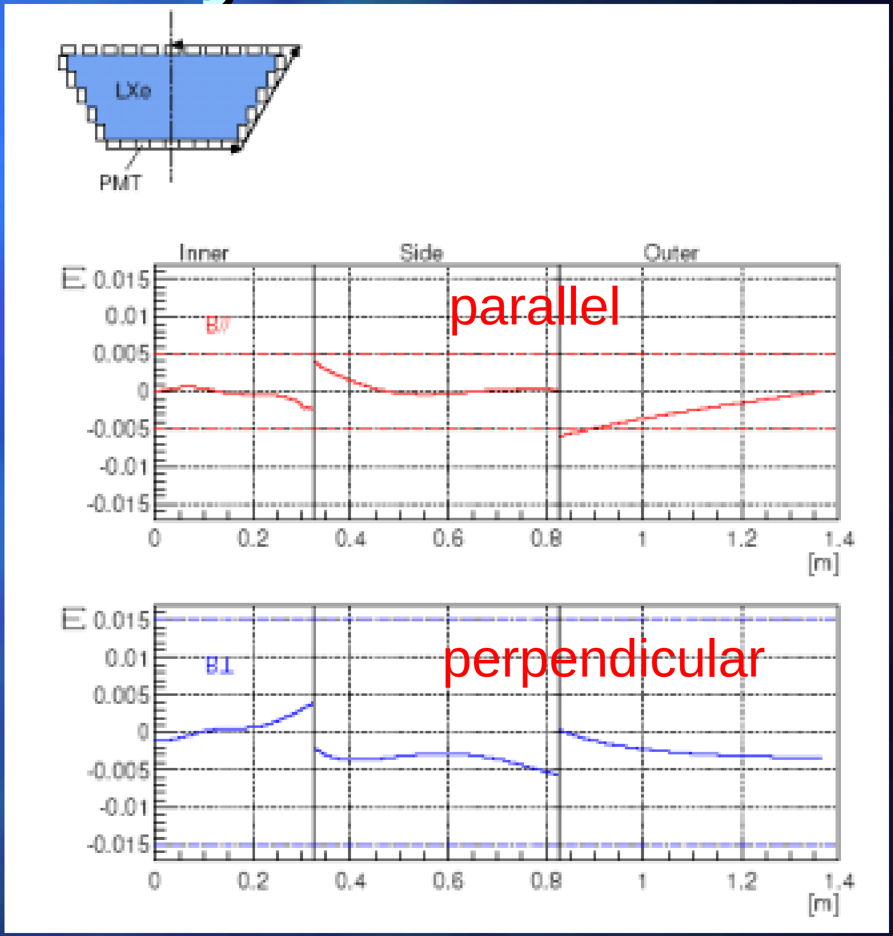




- Strong dependence on the field direction relative to the tube axis
- Maximum allowed magnitude $B_{parallel}$ ~ 50Gauss $B_{perpendicular}$ ~ 150Gauss

Suppression of Stray Field

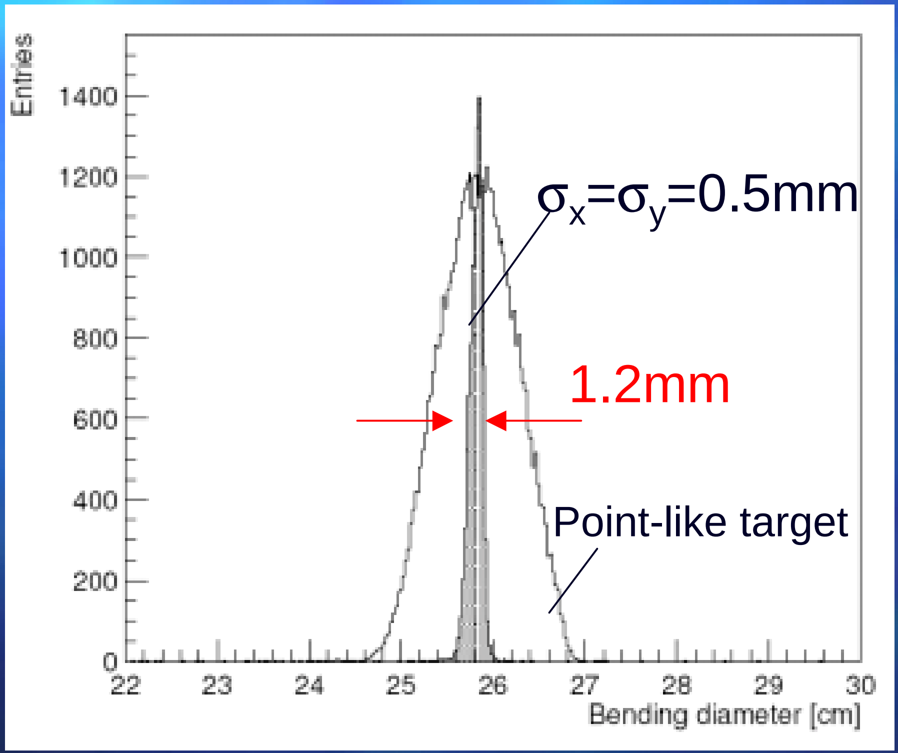




Stray field is successfully reduced down to ~50Gauss
all over the photon detector by using a pair of compensation coils

Performance of spectrometer

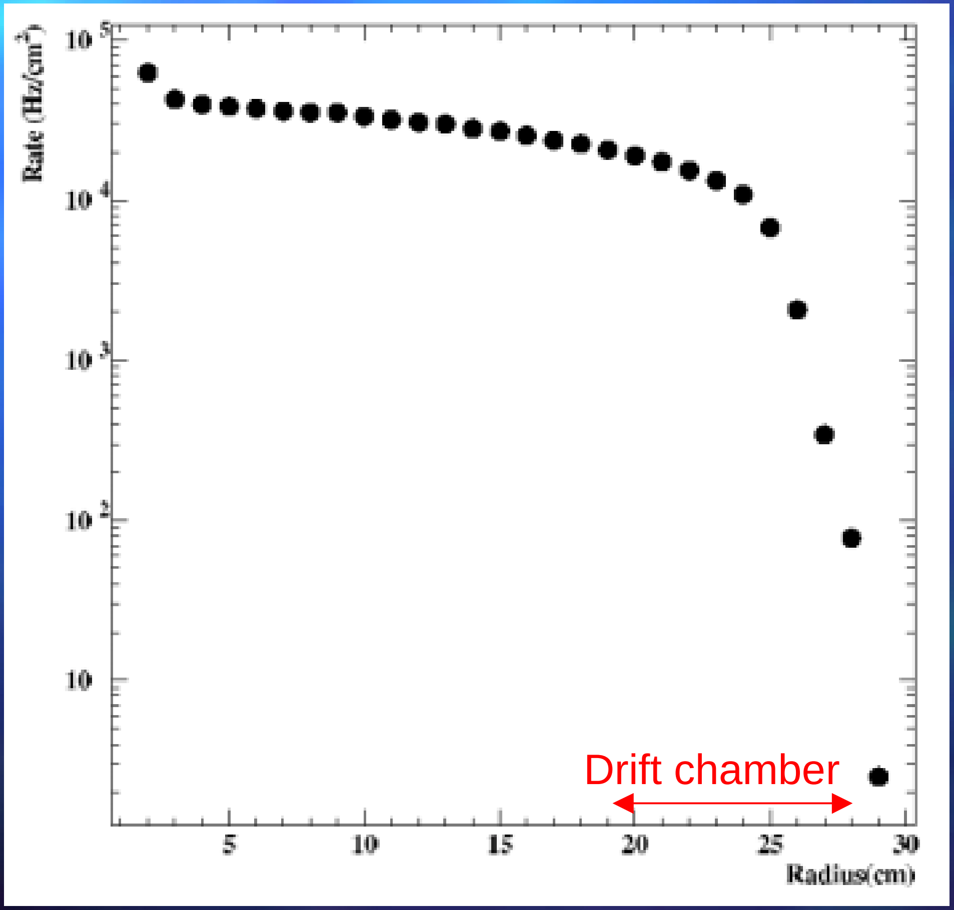
Bending diameter distribution (w/o track fitting)



Bending-radius fluctuation is much smaller than that caused by the muon beam spread.

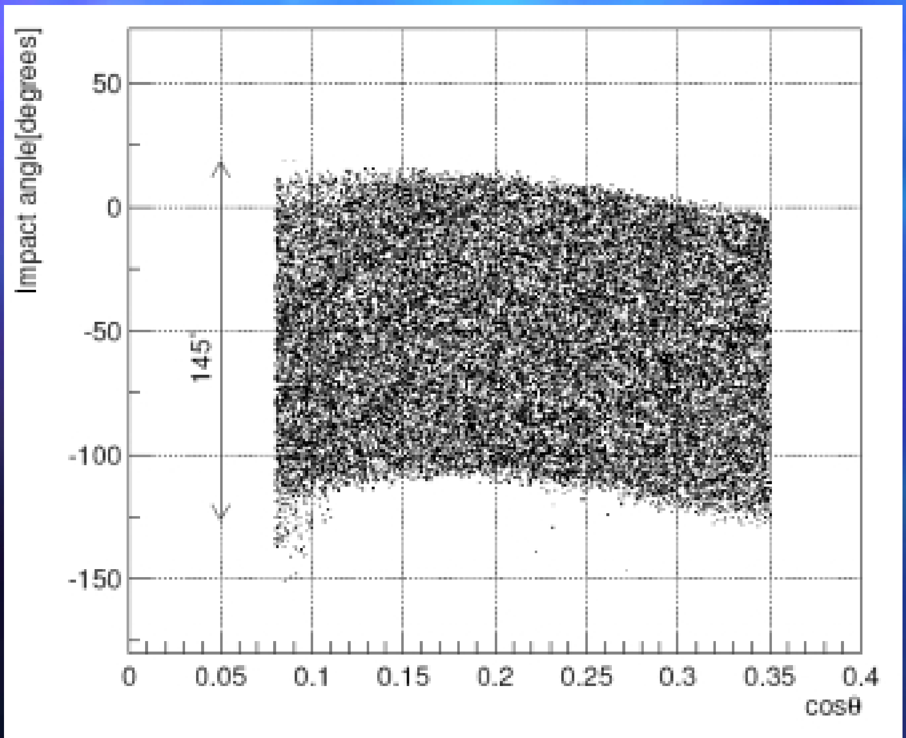
Performance of spectrometer

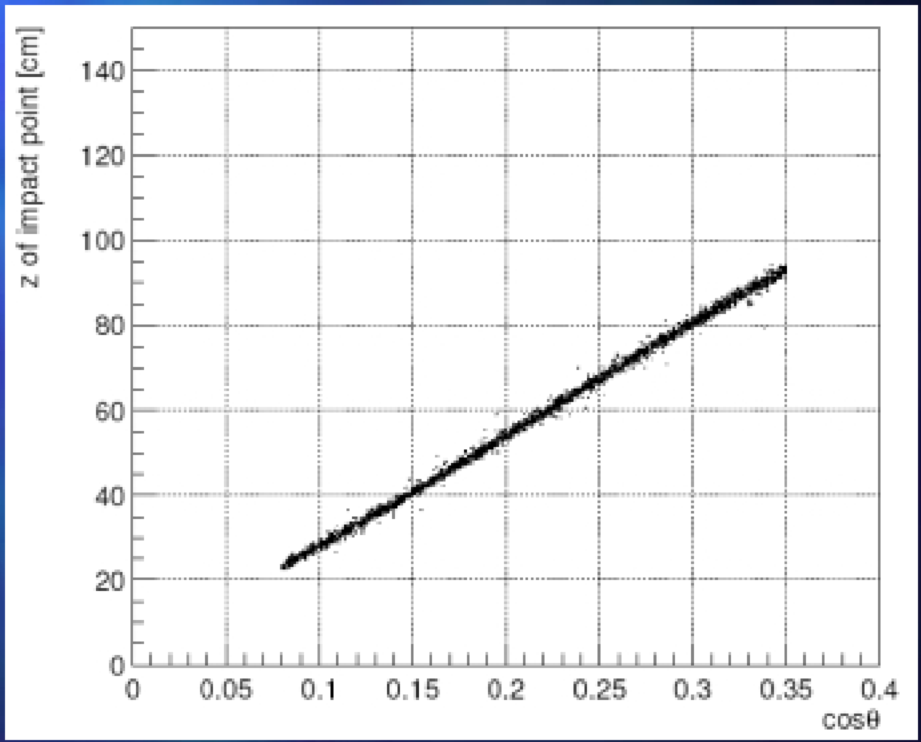
Hit rate of Michel positrons at drift chamber for 10^8 muons/sec



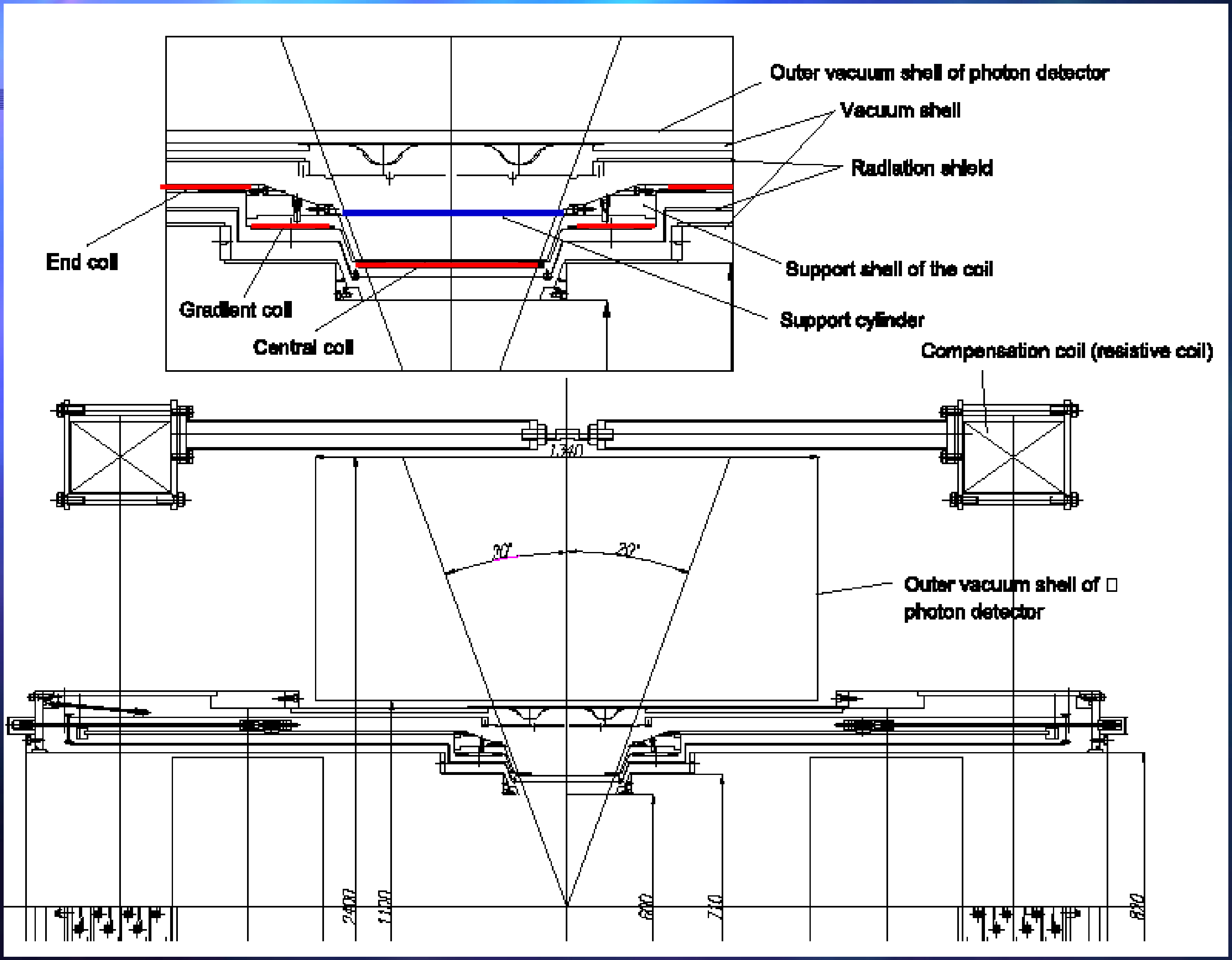
Performance of spectrometer

Distribution of the impact point on the timing counter (*R*=30cm)



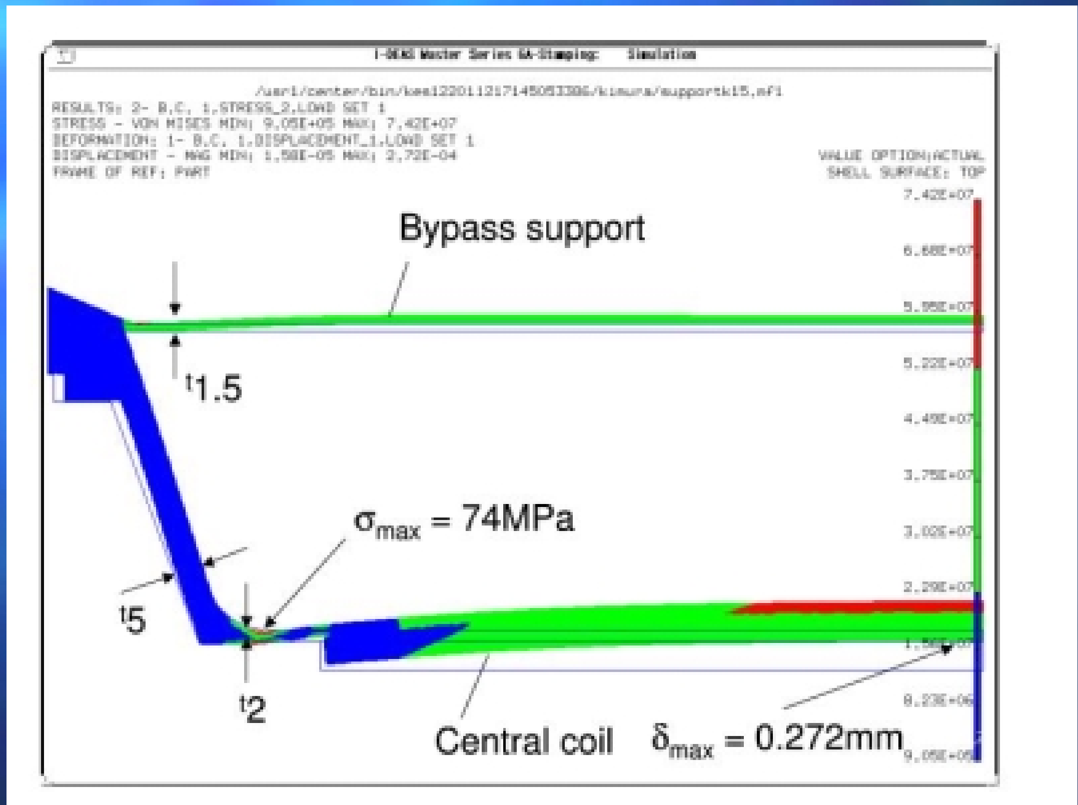


Mechanical Design of Magnet



Mechanical Design of Magnet

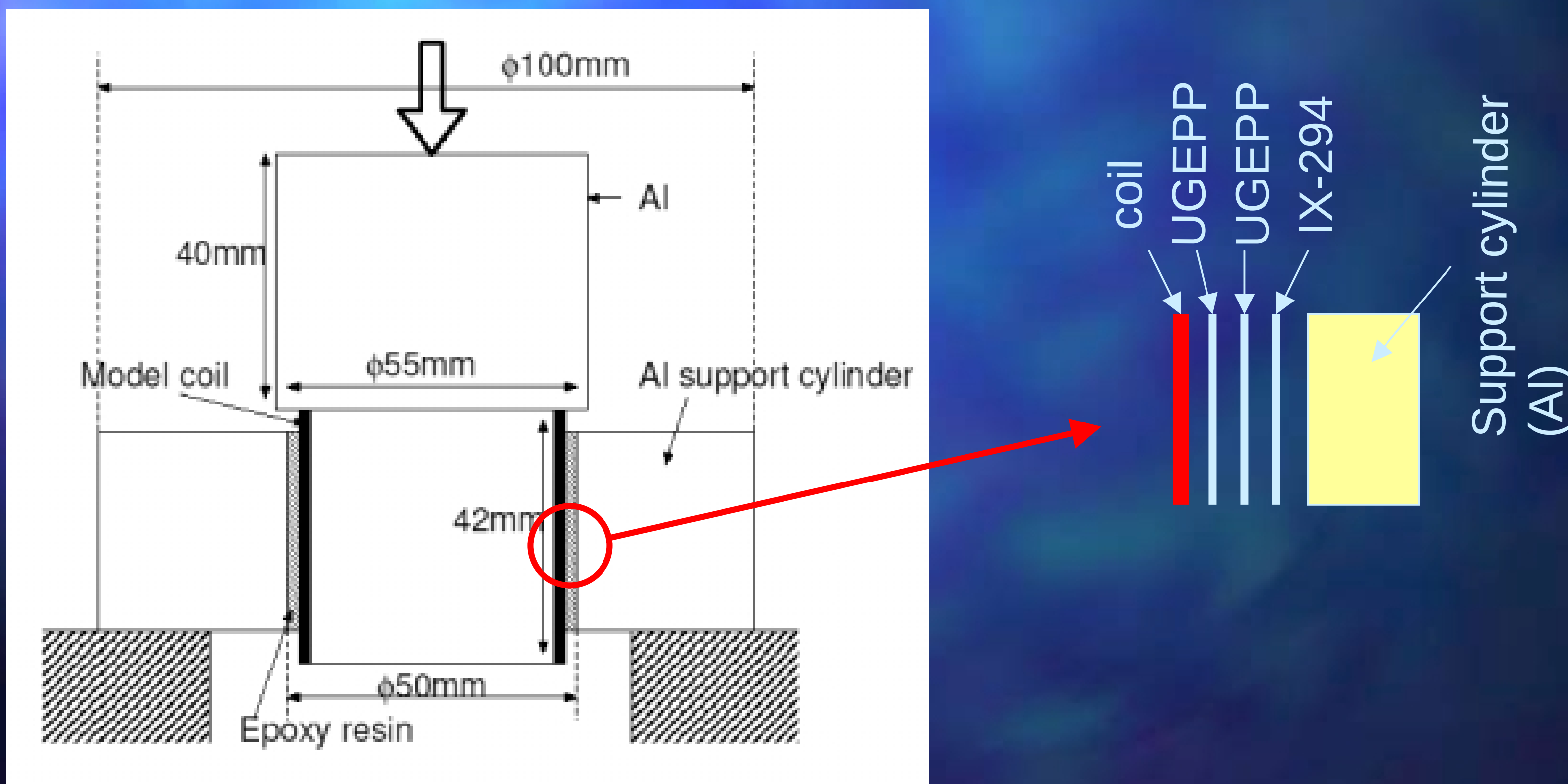
Stress distribution around the central coil



Stress level is acceptable for the support shell design

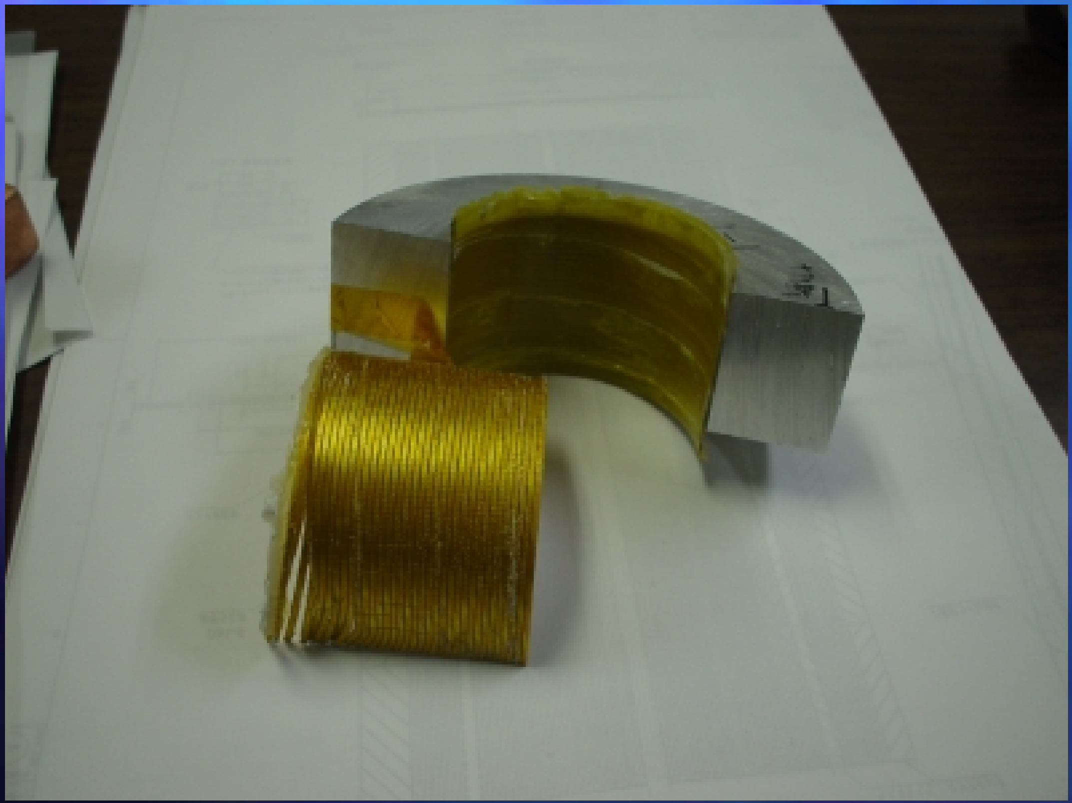
Mechanical Design of Magnet

Shearing test to measure the strength of the glueing between the coil and support shell



Mechanical Design of Magnet

Shearing test, Result



Measured breaking stress
~ 7.8MPa

↓

- Almost acceptable
- Could be improved by using another type of insulating tape

Mechanical Design of Magnet

Buckling test for support cylinder(1.5mm^t)
bypassing over the central coil

Buckling stress
~ 6.97kg/mm^2
→ Good!

Expected stress
~ 5.4kg/mm^2

Transparency of Magnet

	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