Quadrupole Model Magnet R&D

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Program Schedule

FY2003-2007 - CDS

FY2006-2010 – model magnet R&D

We start IRQ model R&D in FY06 with simplified 1-m long models (2-layer design) in order to develop basic tooling and infrastructure and start basic technology development.

- **FY2004 – conceptual design of IRQ model**
- **FY2005 – model and tooling design and procurement**

A series of short models will address the issues of magnet quench performance, field quality, mechanics, quench protection, reproducibility, long term performance, etc.

We will start studying length dependent effects with 4-m long coils, as soon as we achieve acceptable quench performance.

FY2010-2012 - Model R&D will be followed by the construction of one or more prototypes containing all of the features required for use in the LHC.

2nd generation Inner Triplet Design Options

Two fundamental inner triplet design approaches:

a) single-bore inner triplet design

b) dipole-first designs with double-bore quadrupoles

a) single-bore inner triplet design

Quadrupoles with largest possible aperture are required, to provide largest beam separation and accommodate the large b-max.

b) dipole-first designs with double-bore quadrupoles

For these IR designs there are two contradictory requirements for IR quads:

- Large b-max requires large aperture
- Twin-bore configuration limits aperture

Requirements & Questions

- Nominal field gradient Gnom=205 T/m
  - Gnom=225 T/m?
- Large aperture
  - more than 90 mm
- Excellent field quality
  - How excellent?
- Operation margin 10+ ($10^{34} \Rightarrow 10^{35}$)
  - How much is +?
- Quench protection

R&D Questions & Preliminary Answers

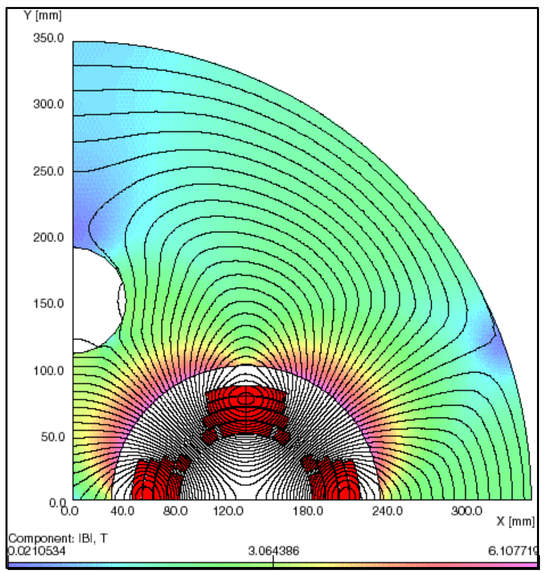
- What are appropriate materials for operational conditions?
  - –Superconductor: Nb_3Sn, high-J_c
  - –Structural materials: metal end parts
  - –Insulation: TBD

Double-bore IRQ

- Are non-parallel axis double-bore quadrupoles feasible?
  - ???

Fermilab **Quad R&D Issues and Options**

Double-bore magnet



Field errors can be < 10^{-4} with bore separation > 250 mm and yoke OD > 700 mm

Bore separation and yoke size can be reduced in a "warm" yoke design,

but the coils would have to have considerable left-right asymmetry and a large number of wedges

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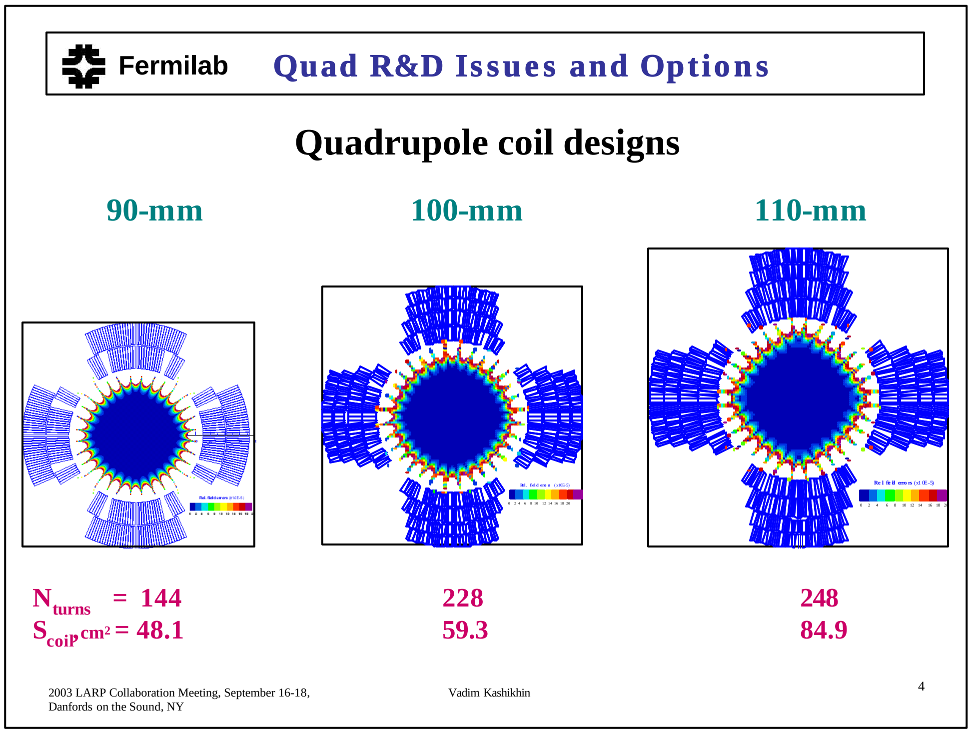
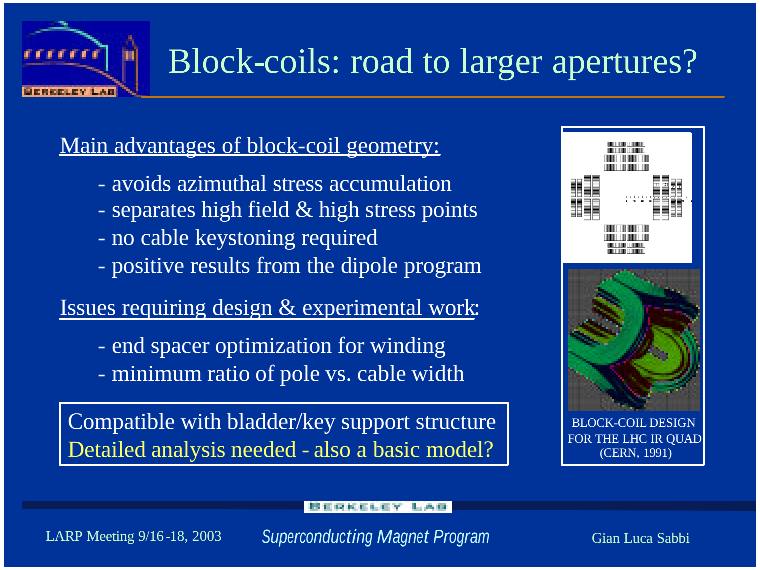
Aperture limit

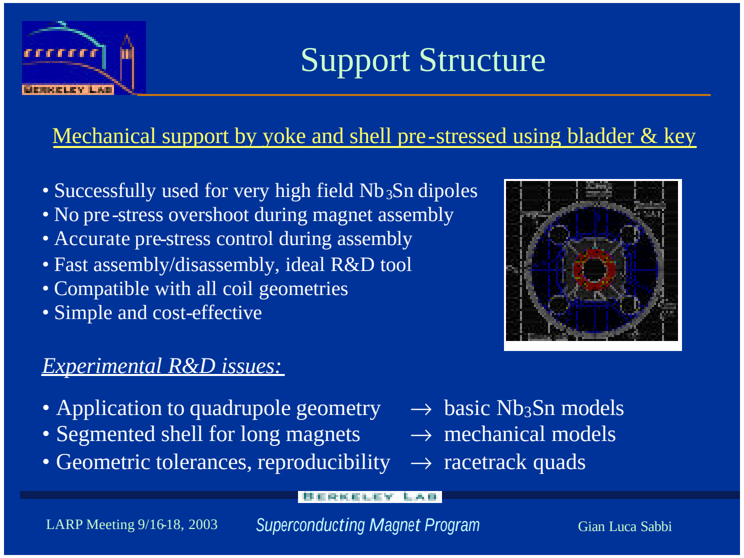
- What is the optimum aperture for single-bore and double-bore quads?
  - Limit is 110 mm (superconductor Jc, mechanics)



Design options

- What is the optimal design for large-aperture Nb_3Sn quads?
  - Coil: four-layer shell-type
  - Support structure:
  - Yoke: cold/warm





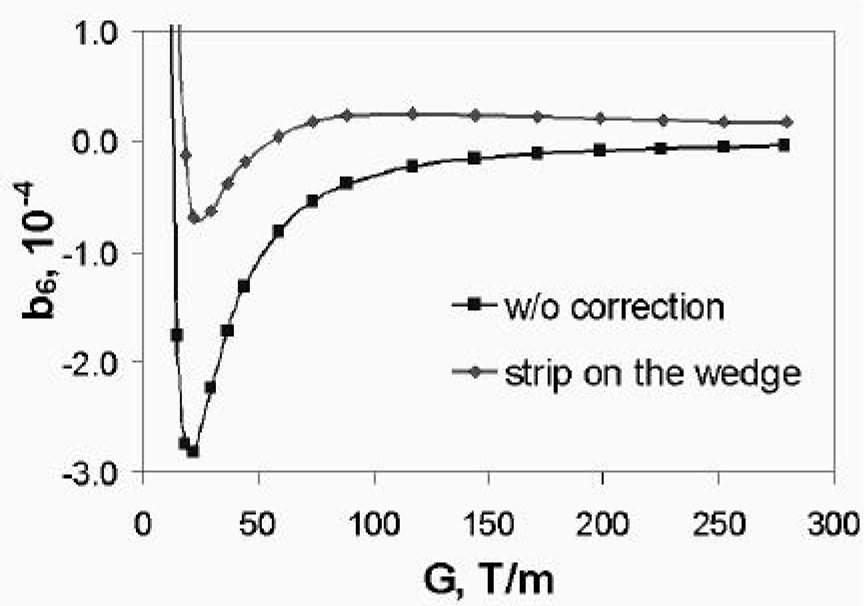
Field quality

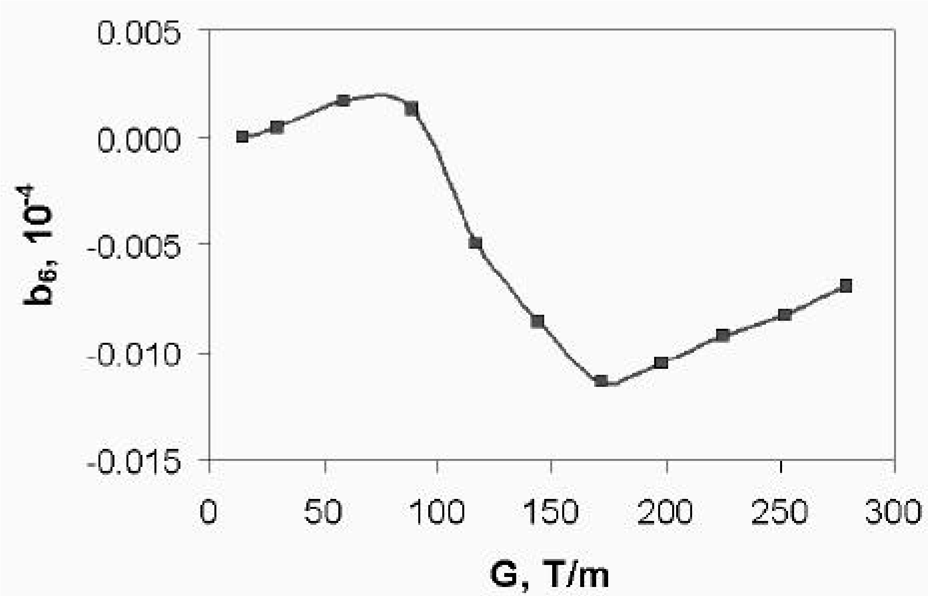
- Can good field quality be maintained in magnets over the full operating range?

•Simulation – error table v.0.1

•Experimental studies

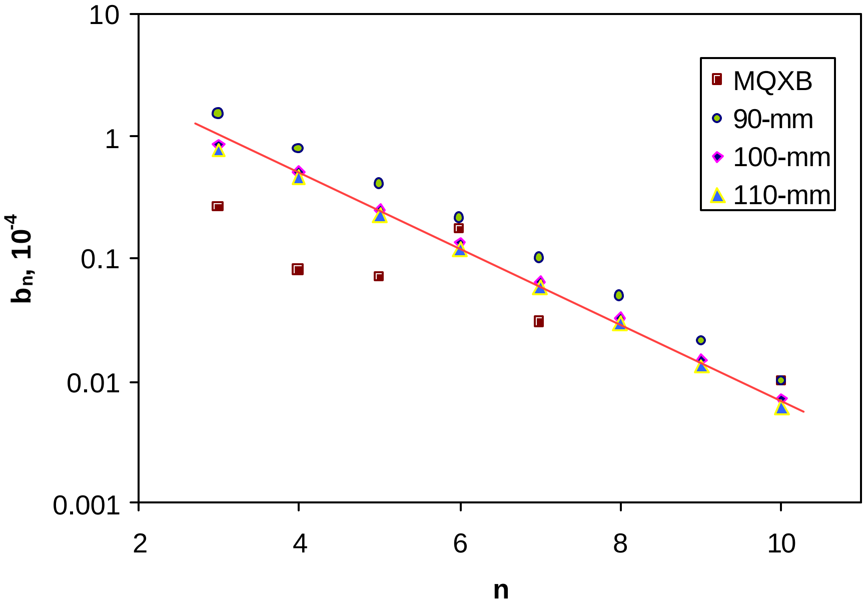
	Systematic, b_n			
n	MQXB	90-mm	100-mm	110-mm
b6	-0.013	0.0006	0.0005	0.0002
b10	-0.001	0.0045	0.0029	0.0118

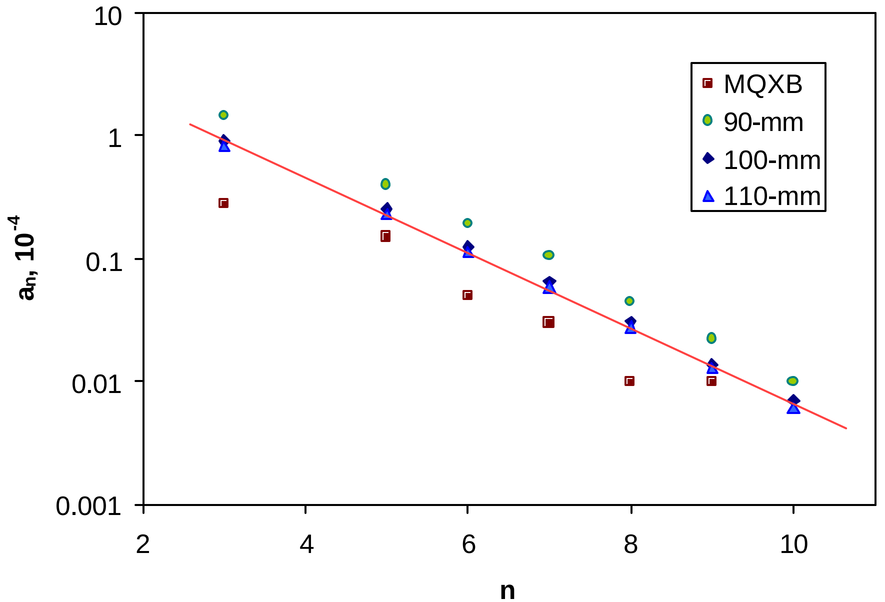




Field quality

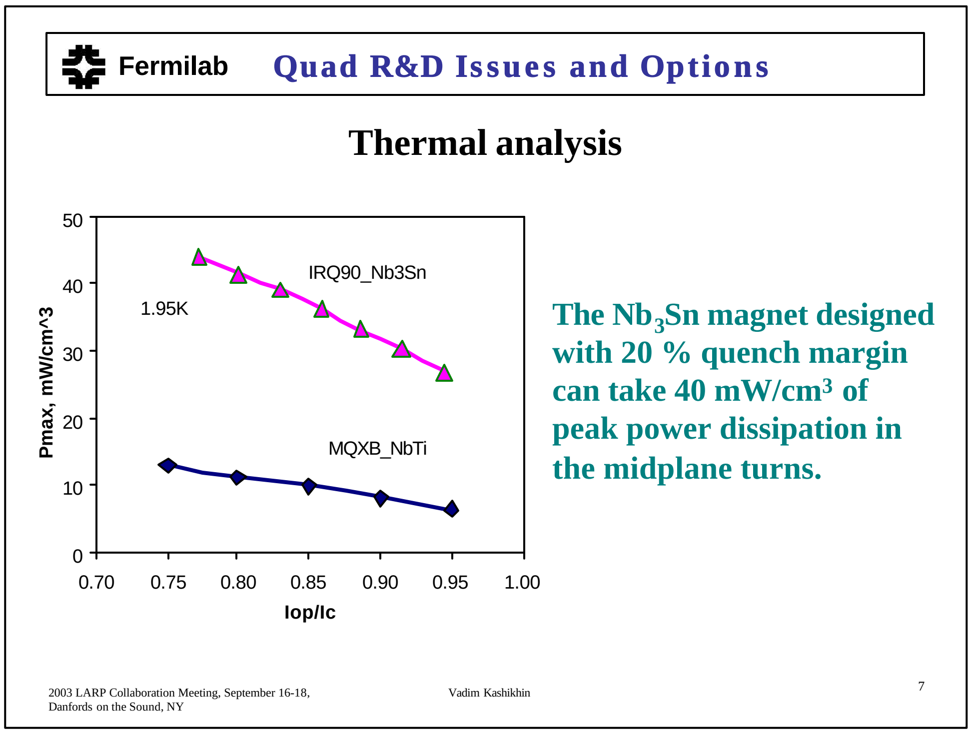
Random errors:





R&D Questions & Preliminary Answers

- Can magnets provide nominal field gradient of 205 T/m in the extreme radiation environment at very high luminosity?
  - Operation margin 10(5) at 1.9K (4.2K) and 20% current margin (Tc=18K?)



Quench protection

- Can magnets be protected in case of quench?
  - Yes, active quench protection

Fermilab **Quad R&D Issues and Options**

Quench protection

The inductance and stored energy the 110-90 mm quads and calculated T_{hs} and T_{blk} are reported below for F_{qh} of 50% and 25%.

The acceptable T_{max} for accelerator magnets is 300-400 K and F_{qh}<50%.

Even for F_{qh}=25% T_{max} is within 315-335 K. With F_{qh}=50% T_{max} does not exceed 250 K.

Parameter		Aperture 110 mm	100 mm	90 mm
L, mH/m		17.46	14.71	4.86
W(205 T/m), kJ/m		1181	703	468
T_{hs}, K	F_{qh}=50%	230	225	230
	F_{qh}=25%	335	320	315
T_{blk}, K	F_{qh}=50%	150	140	127
	F_{qh}=25%	220	200	180

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Quench Protection

Quench analysis for 2-layer and 4-layer designs (90 mm aperture):

- Heater: 26 μm thick stainless steel with distributed Cu plating
- Active sections are 100 mm long, 17% of total magnet length

PROTECTION SYSTEM PARAMETERS

Design	Voltage V	Capacitance mF	RC const. ms	G_{ss} T/m	T_{peak} K
Two-layer	440	13.2	26	245	200
Four-layer	750	6.2	23	266	300

ASC-02, Houston, August 2002

New analysis tools available - experiments are needed to verify results
Recent SM-05 test indicated good tolerance to high temperature/stress

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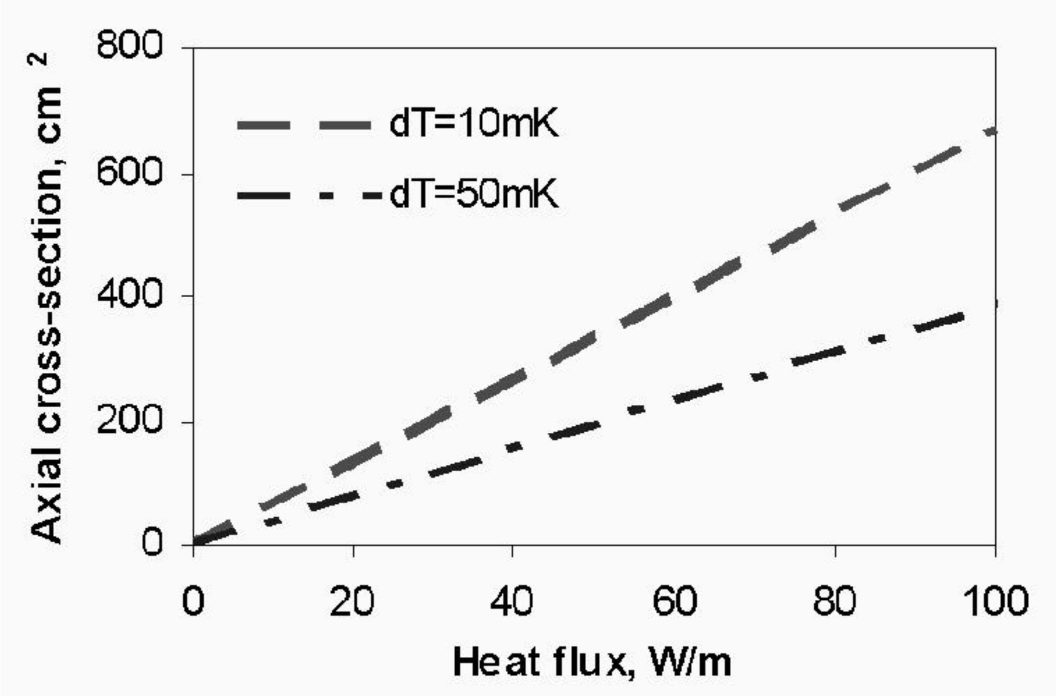
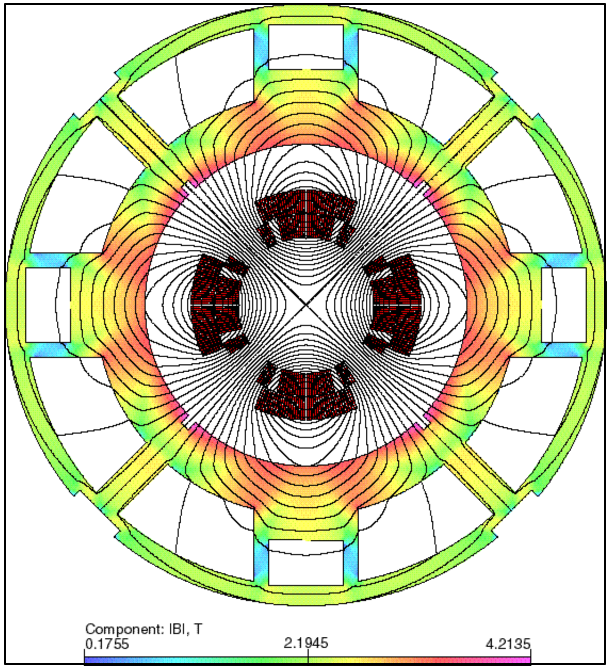
Cold mass heat transfer

- How can the large heat deposition be removed from the magnet cold mass for a tolerable cost?
  - Yes, radial+longitudinal channels.
  - Holes in the iron yoke with total area of 400 cm^2 will restrict the HeII temperature rise inside the cold mass by 10 mK for heat flux up to 60 W/m.





FY2004 issues

CDS:

- Double-bore quads: possibilities and limitations
- Field quality: body/ends
- IRQ operation margin

IRQ model 2D cross-section:

- aperture: target 110 mm
- coil: 4-layer graded shell-type
- cable: keystone, 1 mm strand
- strand: Nb_3Sn, 1 mm
- Mechanical structure

Technology support: Strand and cable

- 1 mm strand
  - technology?
  - Jc=3 kA/mm^2 +
  - Deff~50 microns (stability, magnetization)
  - Cu:nonCu=1.2

- Cables
  - Large keystone angle
  - Small aspect ratio
  - Low cabling degradation
  - Low sensitivity to pressure

Parameter	Aperture			
	110-mm		100-mm	
Coil layers	outer	inner	outer	inner
Number of strands	24	18	18	14
Strand Ø, mm	1.0			
Cable width, mm	12.33	9.23	9.23	7.17
Inner edge, mm	1.59	1.66	1.61	1.67
Outer edge, mm	1.94	1.87	1.92	1.86
Keystone angle, deg	1.7	1.3	1.9	1.5
Aspect ratio	7	5	5	4

Technology support: mechanical structure

Mechanical structure:

- Aluminum shell and bladder technology
- Collar-yoke structure

The maximum stress in the coil, induced by Lorentz forces, accedes 100 MPa, approaching the level of stress which may cause significant degradation or even damage of brittle Nb_3Sn coils.