Magnetic design of small-aperture dipoles of the shell and block type

G. Sabbi, FNAL

- Choice of design parameters
- Shell vs. Block type design:
  - conductor efficiency
  - field quality
- Two-in-one: yoke diameter requirement for horizontal vs. vertical layout
- Conclusions

Aperture requirement

SSC: 40 → 50 mm LHC: 50 → 56 mm

VLHC: 50 → 30 mm?

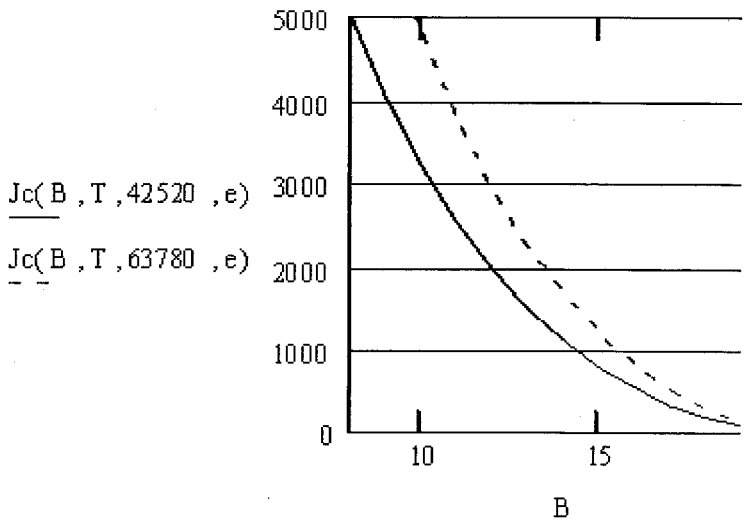
Charge: Guided by the snowmass '96 paramete set, explore and develop innovative concepts th will result in significant cost reductions.

Critical current density

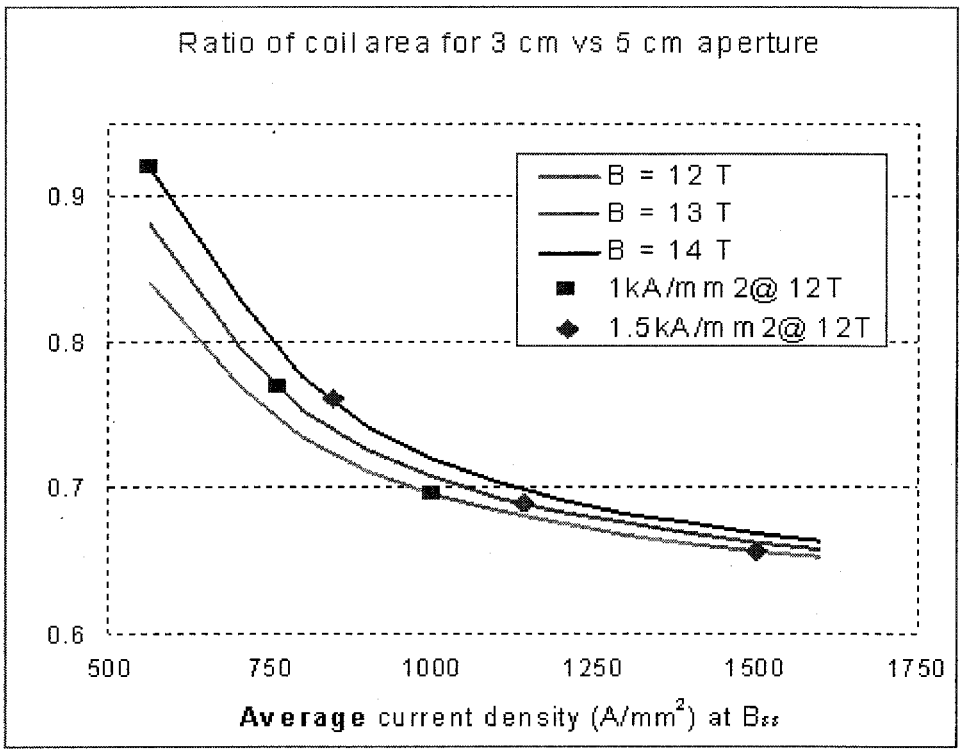
$$Jc(B,T,C0,e) \quad \frac{C(C0,e)}{B} \cdot \left(1 - \frac{B}{Bc2(T,e)}\right)^2 \cdot \left(1 - \frac{T}{Tc0(e)}\right)^2$$

(Summers, L, IEEE Trans. M

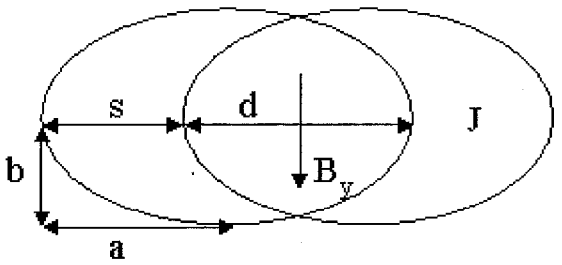
Jc(12T, 4.2K) = 2 - 3 kA



Choice of design parameters: conductor efficiency



Based on intersecting ellipses model



$$By = -\frac{\mu_0 J s b}{a+b}$$

$$s(J,d,B) \quad \frac{2 \cdot d \cdot B}{B \quad mu0 \cdot J \cdot d} \qquad a(J,d,B) \quad \frac{s(J,d,B) \quad d}{2} \qquad b(J,d,B)$$

$$Aoq(J,d,B) \quad a(J,d,B) \cdot b(J,d,B) \cdot \frac{pi}{4} \quad \frac{1}{2} \cdot \frac{s(J,d,B)}{2\, a(J,d,B)} \cdot 1 \quad \frac{s(J,d,B)^2}{4\, a(J,d,B)^2} \quad \frac{1}{2} \cdot asin \quad \frac{}{2}$$

$$Ahc(J,d,B) \quad \frac{pi \cdot a(J,d,B) \cdot b(J,d,B)}{2} \quad Aap(J,d,B)$$

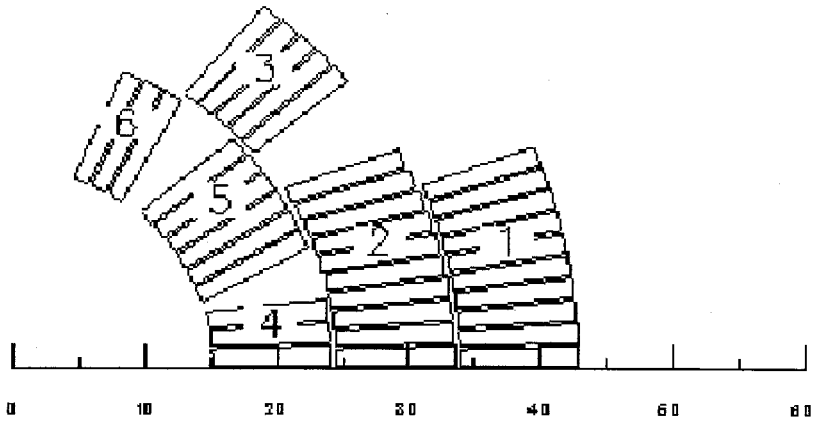
Design parameters

Coil aperture	:	30 mm
Coil width	:	27 mm
Coil layout	:	shell/block
No. of layers	:	3
Maximum field	:	12 T (Jc(12T, 4.2K)=2 kA/1
		13 T (Jc(12T, 4.2K)=3 kA/1
Geom. Harmonics	:	$< 10^{-4}$ @ 1cm
Stress (Lorentz)	:	< 100 MPa

Shell type design: cable parameters

Strand diameter	mm	0.75
Cu/Sc ratio		1:1
No. of strands		24
Area of superconductor	mm^2	5.301
Cable width (bare)	mm	9.0
Cable mid-thickness (bare)	mm	1.35
Keystone angle	deg	1.8
Transposition length	mm	120
Compaction (area)	%	88.3
Compaction (inner edge)	%	80
Compaction (outer edge)	%	100
Radial insulation	mm	0.150
Azimuthal insulation	mm	0.120

Shell-type design: coil cross-section



- 3 layer, 6 block design
- Optimized with F

Shell-type design: coil cross-section

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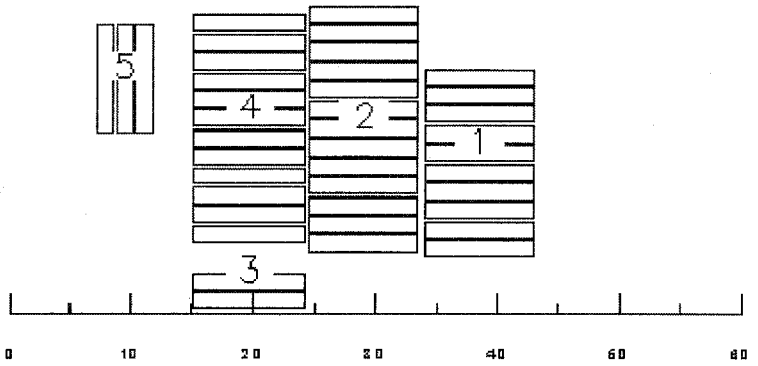
PostScript printer, but not to
other types of printers.

- 3 layer, 6 block design
- Optimized with F

Block type design: cable parameters

Strand diameter	mm	0.75
Cu/Sc ratio		1:1
No. of strands		24
Area of superconductor	mm^2	5.301
Cable width (bare)	mm	9.0
Cable mid-thickness (bare)	mm	1.35
Keystone angle	deg	0.0
Transposition length	mm	120
Compaction (area)	%	88.3
Compaction (inner edge)	%	90
Compaction (outer edge)	%	90
Radial insulation	mm	0.150
Azimuthal insulation	mm	0.120

Block-type design: coil cross-section



- 3 layer, 6 block design
- Optimized with R

Block-type design: coil cross-section

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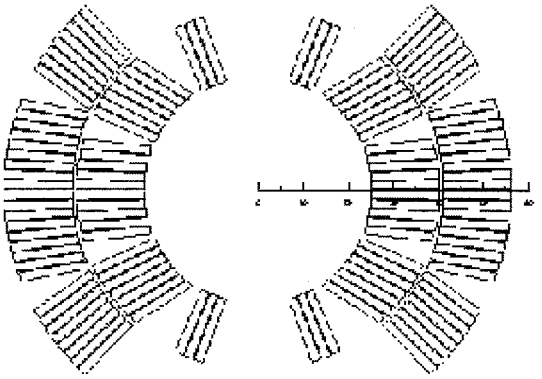
50 mm bore, 2 layer shell type dipole design

- FNAL/LBL/KEK collaboration
- Cross section from FNAL TD-98-035
- Optimization work still underway (last update Oc



50 mm bore dipole, 2 layer, shell type design

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Short sample performance/conductor efficiency

Parameter	Unit	Shell	Block	50 mm
SC area (1 quadrant)	mm^2	196	212	398
Jc(12T, 4.2K) = 2 kA/mm^2				
I_{ss}	kA	10.1	10.1	18.0
$B^{(0)}_{ss}$	T	11.9	12.0	12.9
$B^{(max)}$ (layer 1)	T	12.2	12.2	13.2
$B^{(max)}$ (layer 3)	T	6.2	5.3	
Jc(12T, 4.2K) = 3 kA/mm^2				
I_{ss}	kA	11.0	11.1	19.4
$B^{(0)}_{ss}$	T	13.0	13.1	13.9
$B^{(max)}$ (layer 1)	T	13.3	13.3	14.2
$B^{(max)}$ (layer 3)	T	6.8	5.8	

Energy and forces

Parameter	Unit	Shell	Block	50
Operating current	kA	10.2	10.1	1(
Stored energy	MJ/m	0.35	0.41	0.
Inductance	mH/m	6.7	8.0	5
$-\Sigma F_y$ (1 quadrant)	MN/m	0.9	0.8	1
ΣF_x (1 quadrant)	MN/m	2.0	2.3	3
Stress (Φ/y, 1st layer)	MPa	86	28	1(
Stress (Φ/y, 2nd layer)	MPa	84	36	7

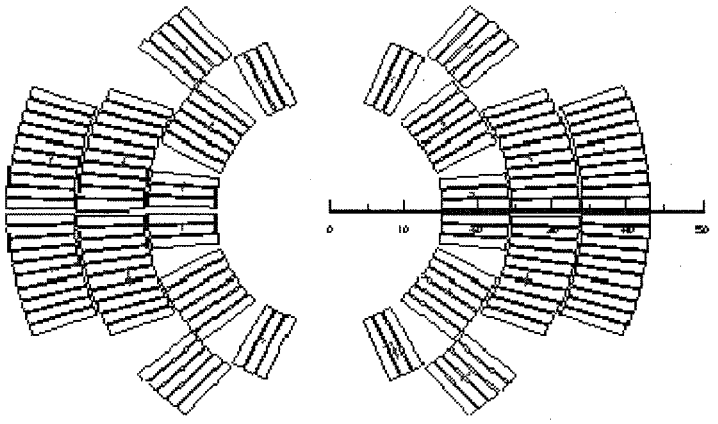
Geometric harmonics

10^{-4} @ 1cm

Component	Shell	Block	50 mm
b_3	0.1	-0.1	0.0
b_5	0.3	0.3	-0.1
b_7	0.7	0.6	0.0
b_9	0.6	-0.8	0.1
b_{11}	2.9	1.2	0.0
b_{13}	-0.5	0.2	0.0

Random errors

Random block displacement simulation using ROXIE
Shell: +/- 50 μm radial/azimuthal displacements
Block: +/- 50 μm horizontal/vertical displacements



Random errors

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Shell: +/- 50 μm radial/azimuthal displacements
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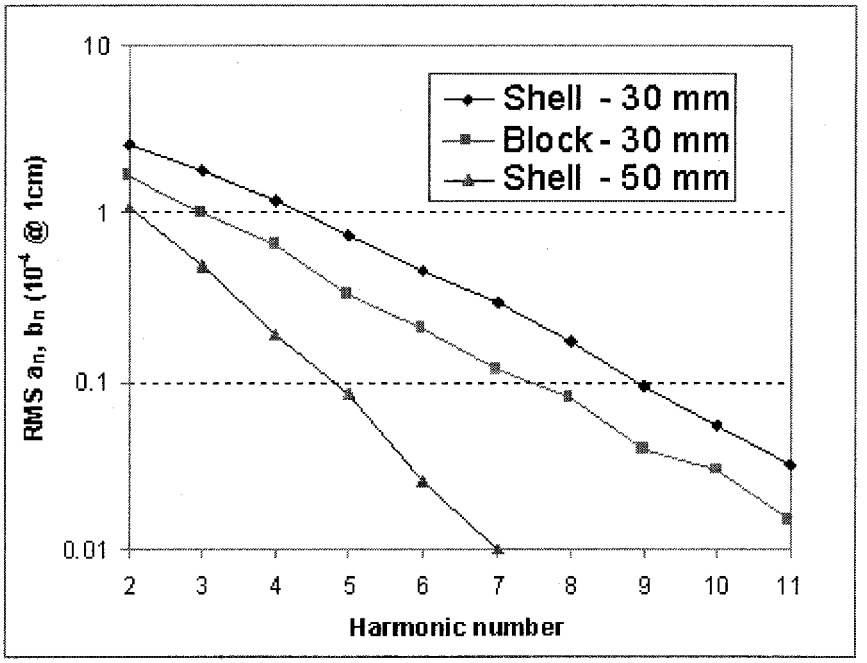
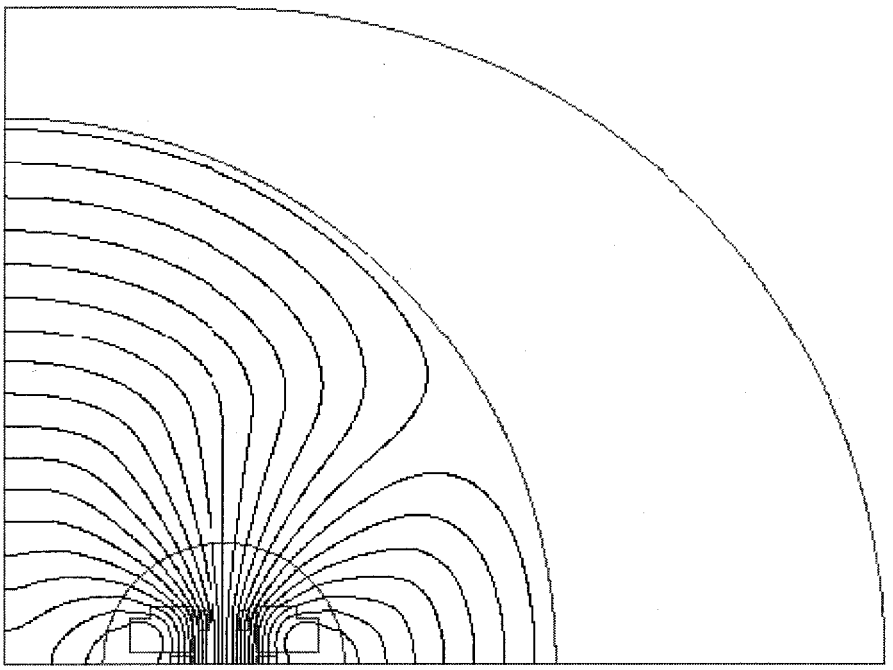
Random errors



- No longitudinal averaging
- Magnetic measureme

Horizontal two-in-one layout



Horizontal two-in-one layout

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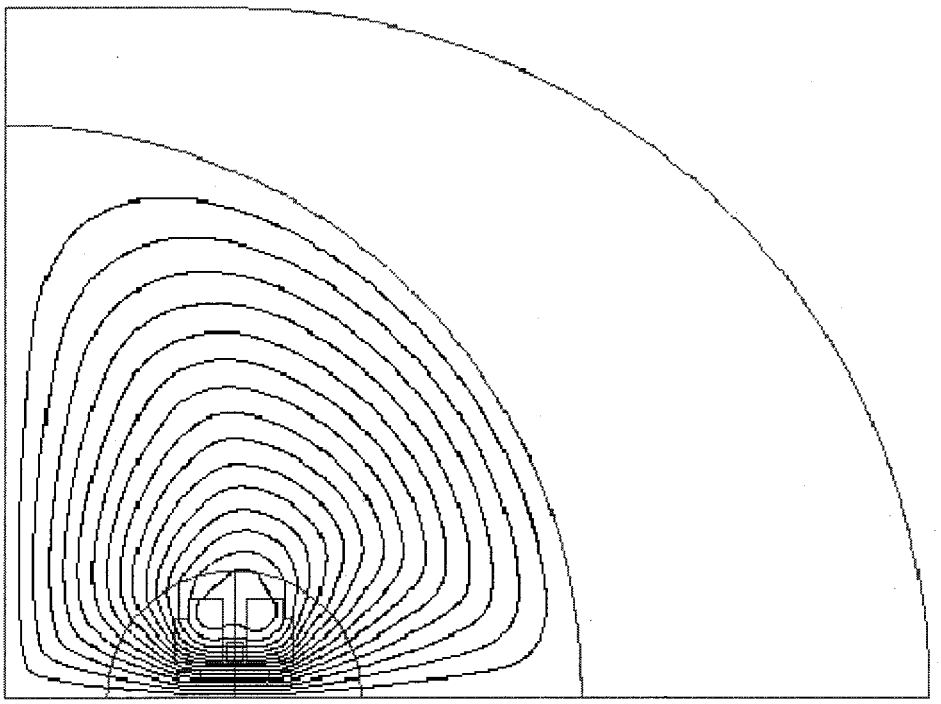
Vertical two-in-one layout



Vertical two-in-one layout

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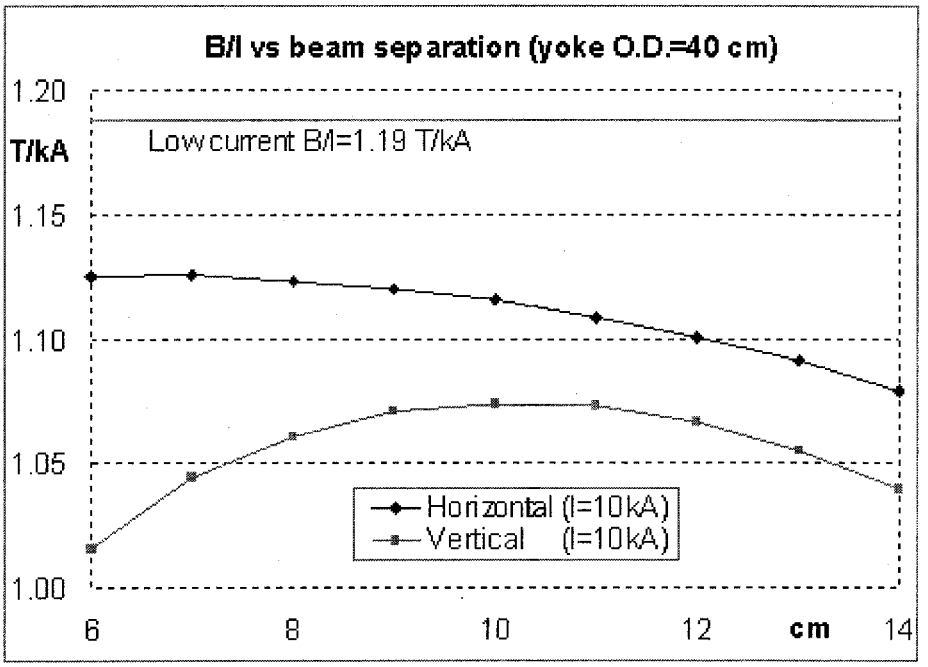
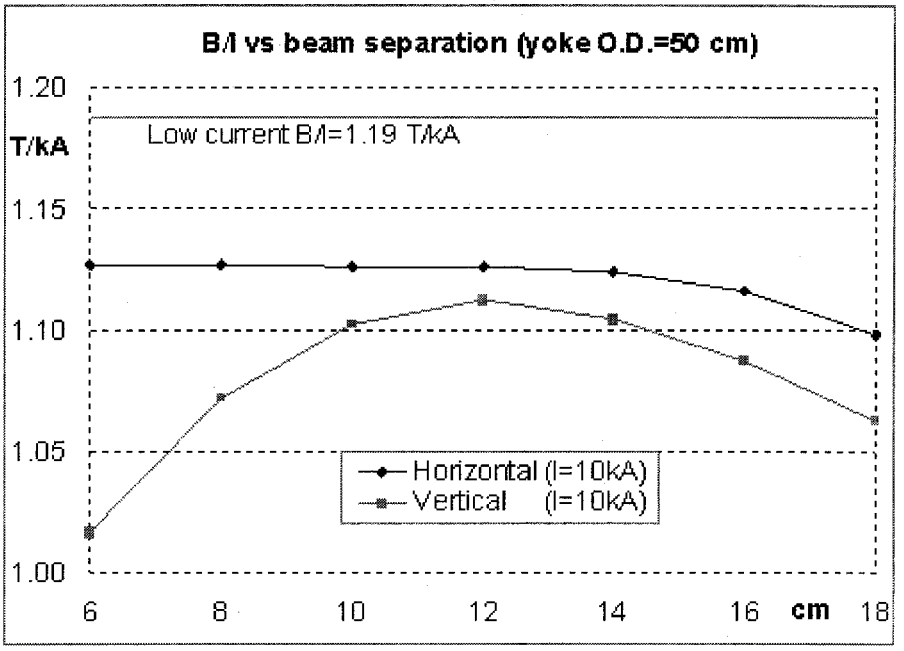
Transfer function for 40 cm yoke diameter



Transfer function for 50 cm yoke diameter



Next steps

- Field quality: further optimize geometric harmoni evaluate magnetic measurement accuracy.

- End field quality (in particular for block type desi

- Mechanical parameters for conductor groups in tl end regions (for shell type design).

Conclusions

- 30 mm bore dipole with 12-13 T design field using Nb3Sn conductor at 4.2 K allows substan savings in superconductor wrt 50 mm bore mag with same design parameters.
- For these design parameters, shell and block de are substantially equivalent in terms of conduct efficiency and field quality.
- Vertical arrangement of the two apertures requi 50% larger yoke radius wrt horizontal arrangen in order to achieve same transfer function.

Slide 29 of 29