A low loss Faraday isolator for squeezed vacuum injection in Advanced LIGO

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Outline

Squeezing in ALIGO

Faraday isolators

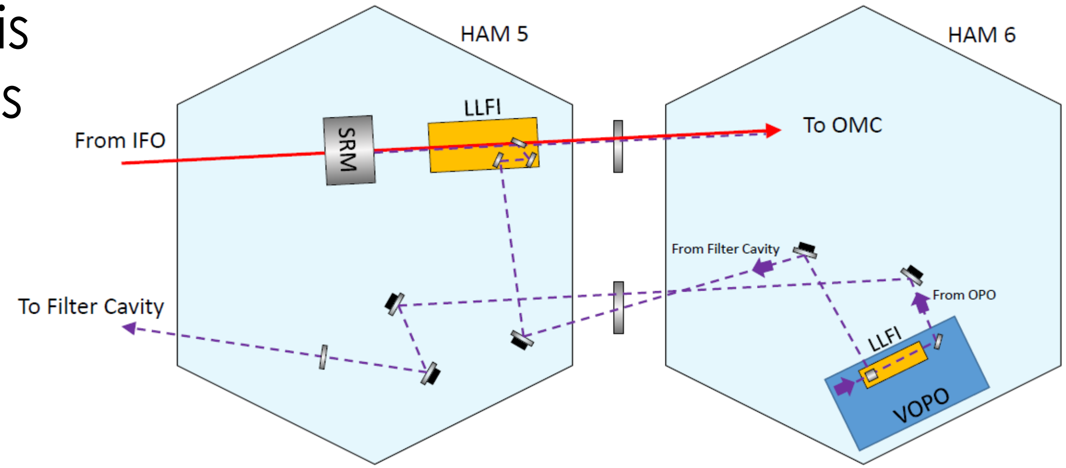
LLFI design and tests

Outlook

Squeezing injection in Advanced LIGO

Effectiveness of squeezing is dependent on injection loss

Injection requires three passes through a Faraday isolator



	Loss source	H1 experiment	Near term goal (6dB)	Longer term goal (10 dB)	Dreaming(15dB)
1	OPO escape efficiency	96%	98%	99%	99.8%
2	Injection path optics	80%	99.7%	99.7%	99.99%
3	viewport	99.8%	99.8%	99.8%	99.99%
4	3 faraday passes	94%, 94%, unknown	97% each (aLIGO input Faradays)	99% each	99.7 % each
7	RF pick off beamsplitter (beam for ISCT4)	98.8%	99%	99.5%	99.8%

Future squeezing efforts will require < 1% power loss per pass of FI

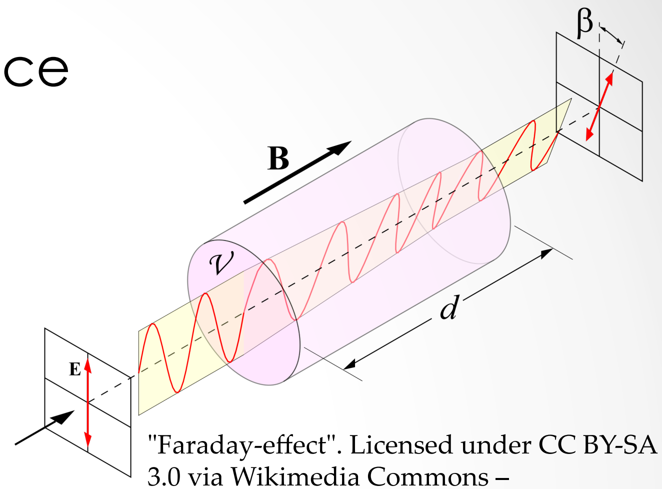
LIGO White Paper, LIGO-T1400316

The Faraday Effect and Faraday Isolators

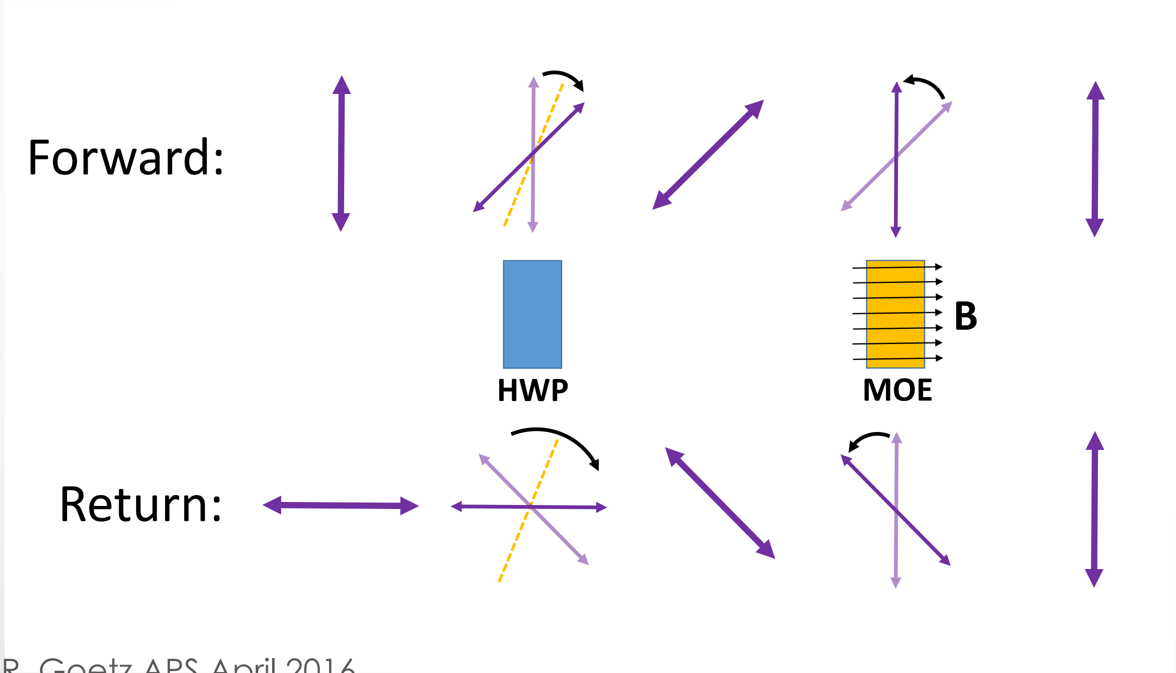
Magneto-optic effect: circular birefringence

$$\beta = V\ B\ d$$

Rotation is independent of propagation direction

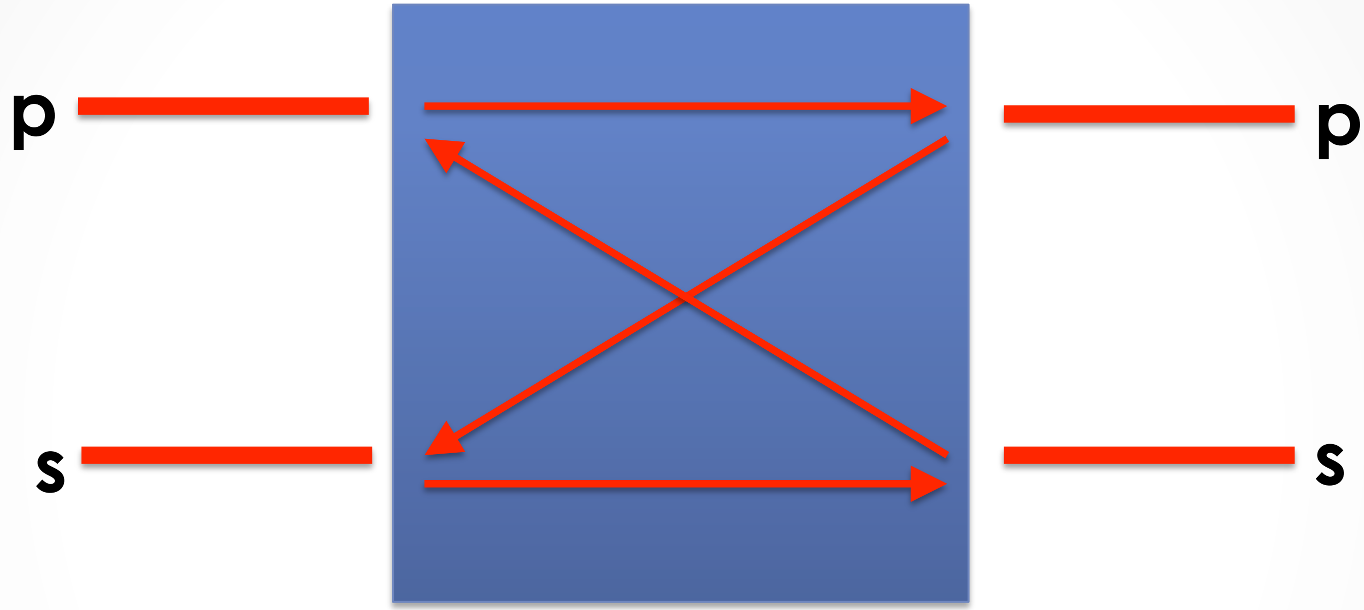


"Faraday-effect". Licensed under CC BY-SA 3.0 via Wikimedia Commons – http://commons.wikimedia.org/wiki/File:Faraday-effect.svg#mediavi ewer/File:Faraday-effect.svg



Adding polarizers at either end, we can create an optical diode

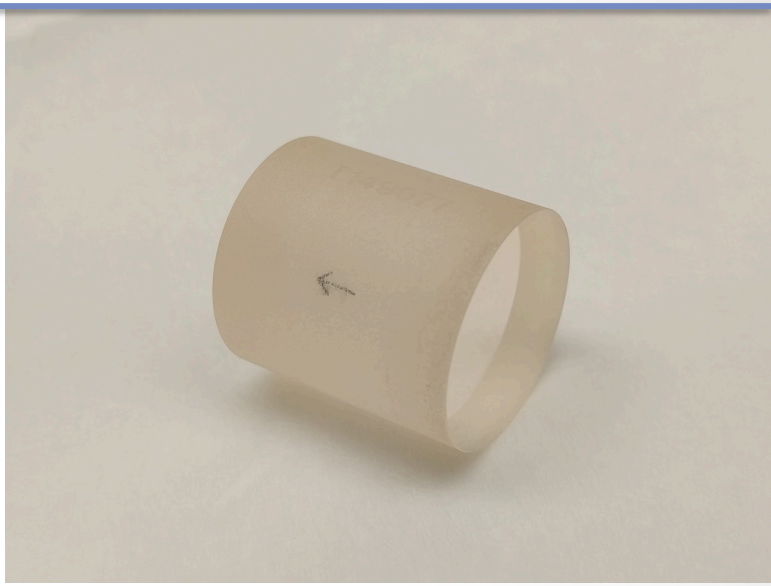
The Faraday Effect and Faraday Isolators



Potential use as beam combiner; must inject orthogonal polarization

LLFI Design:

Terbium Gallium Garnet (TGG)



Commonly used magneto-optic element material

At room temperature for 1064 nm:

$V = -40$ rad/Tm

22 mm TGG, 45 deg. rotation: 0.89 T average field strength required

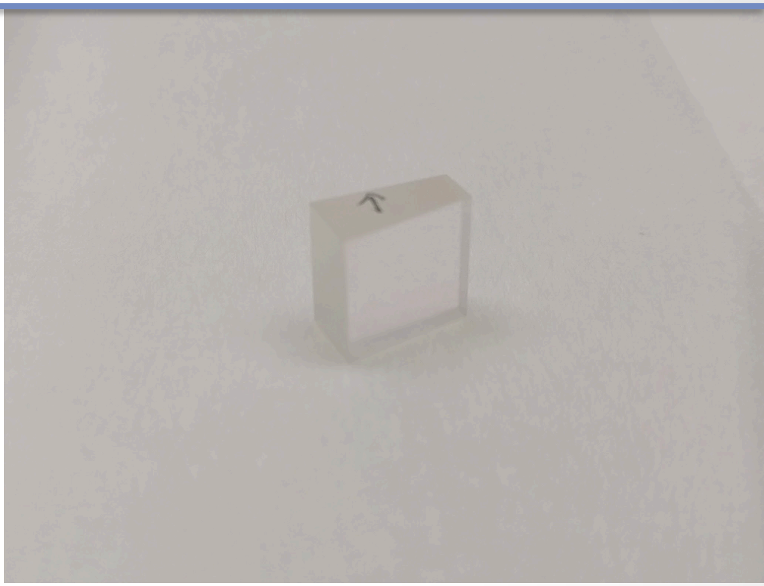
$n = 1.95$ $\alpha = 0.0015\ cm^{-1}$

Produced by Northrop Grumman, polished by Photon LaserOptik, coated by MLD Technologies

Goal of 500 ppm reflection per face

LLFI Design:

Potassium Titanyl Phosphate (KTP)



Birefringent material:

$n_x \approx n_y = 1.74$ $n_z = 1.83$

Wedge geometry gives spatial separation of polarizations

Low absorption: $\alpha < 10^{-5}$ cm^{-1}

Produced by Raicol Crystals, polished by Photon LaserOptik, coated by MLD Technologies

Goal of 500 ppm reflection per face

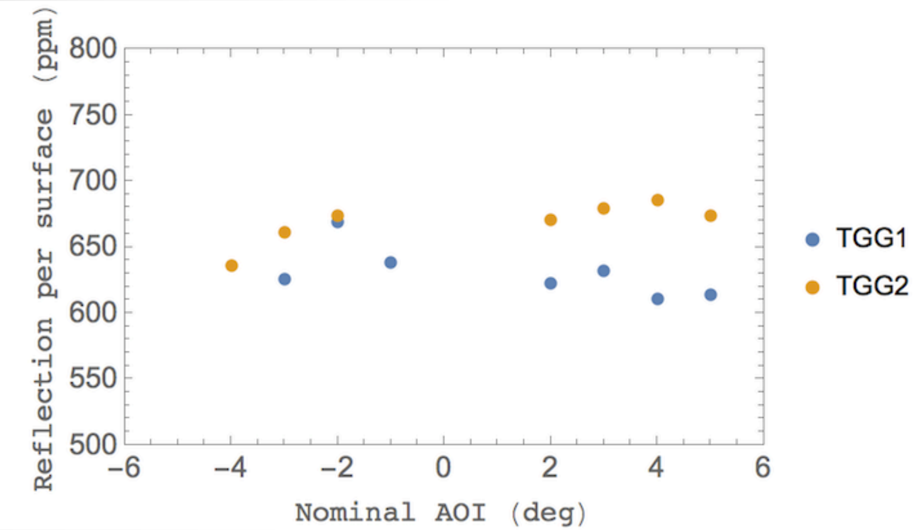
Low Loss Loss Budget

Isolator Element	Optical Loss (ppm)
KTP reflection (per face / total)	*500 / 2000*
KTP absorption (per crystal / total)	*25 / 50*
HWP reflection (per face / total)	*300 / 600*
HWP absorption	*50*
TGG reflection (per face / total)	*500 / 1000*
TGG absorption (20 mm)	*3000*

~ 0.7 % loss per single pass

LLFI Design:

Reflection Measurements



TGG

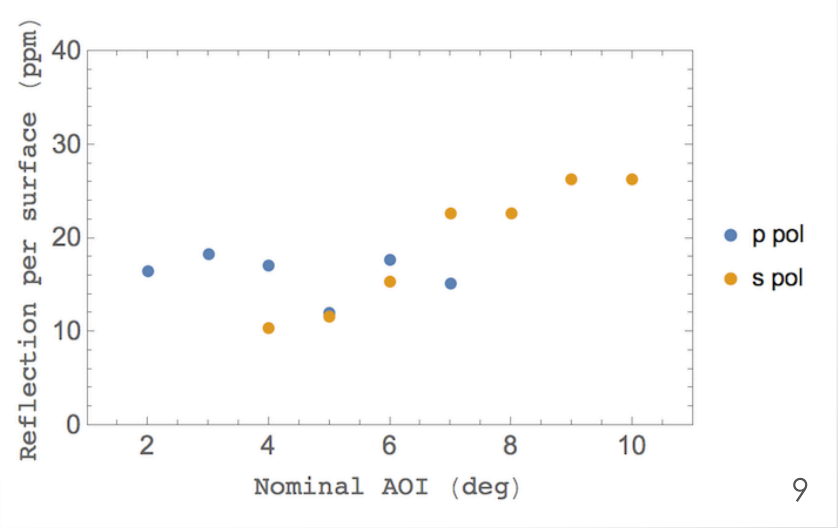
Quoted measured reflection from coaters: 30 ppm

Quick and dirty lab measurements: 650 ppm

KTP

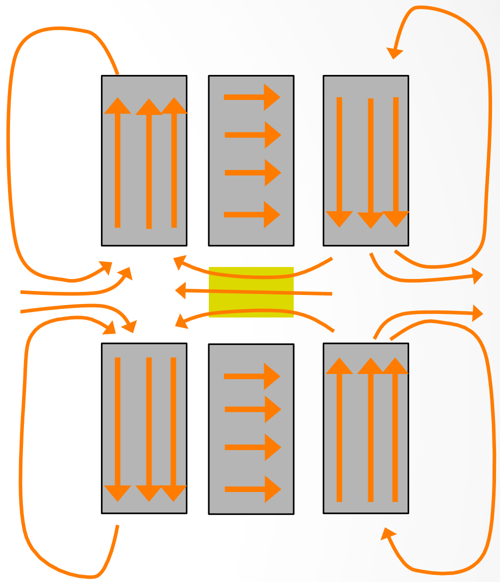
Quoted measured reflection from coaters: 16 ppm

Quick and dirty lab measurements: 20-25 ppm

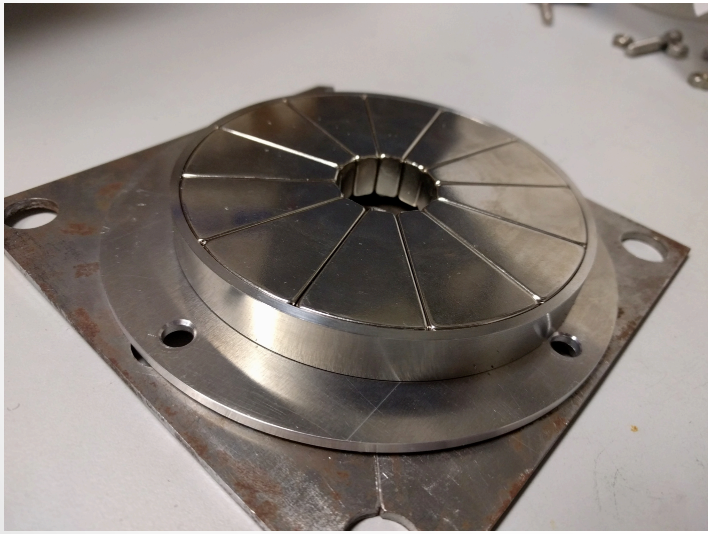


Magnet Design

Combination of axially and radially magnetized permanent magnet disks based on Input Faraday



Disks are stacked to create a composite magnet



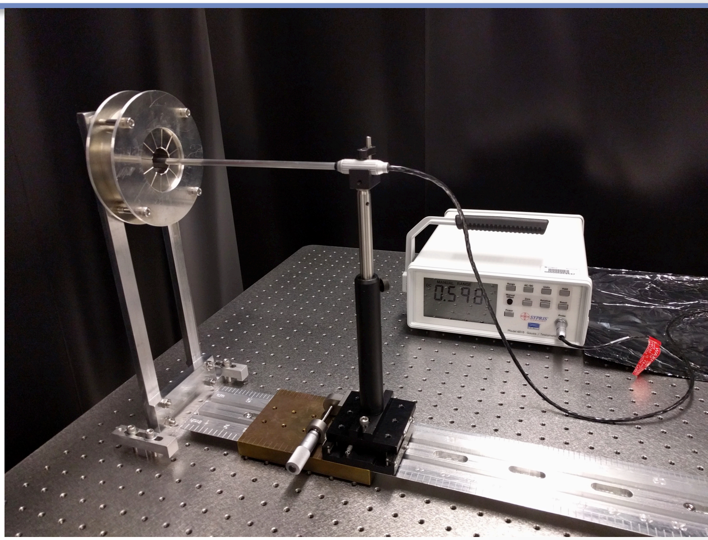
Magnets produced by K&J Magnetics

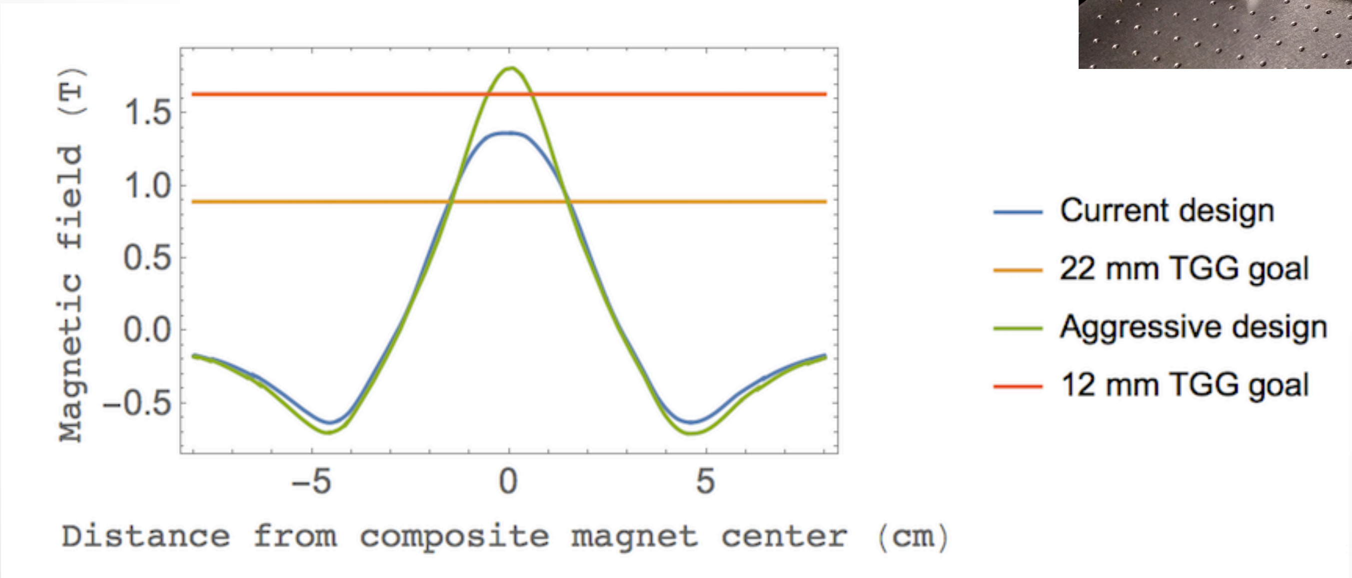
Permanent magnet residual flux densities limited to ~ 1.5 T

Magnet Design

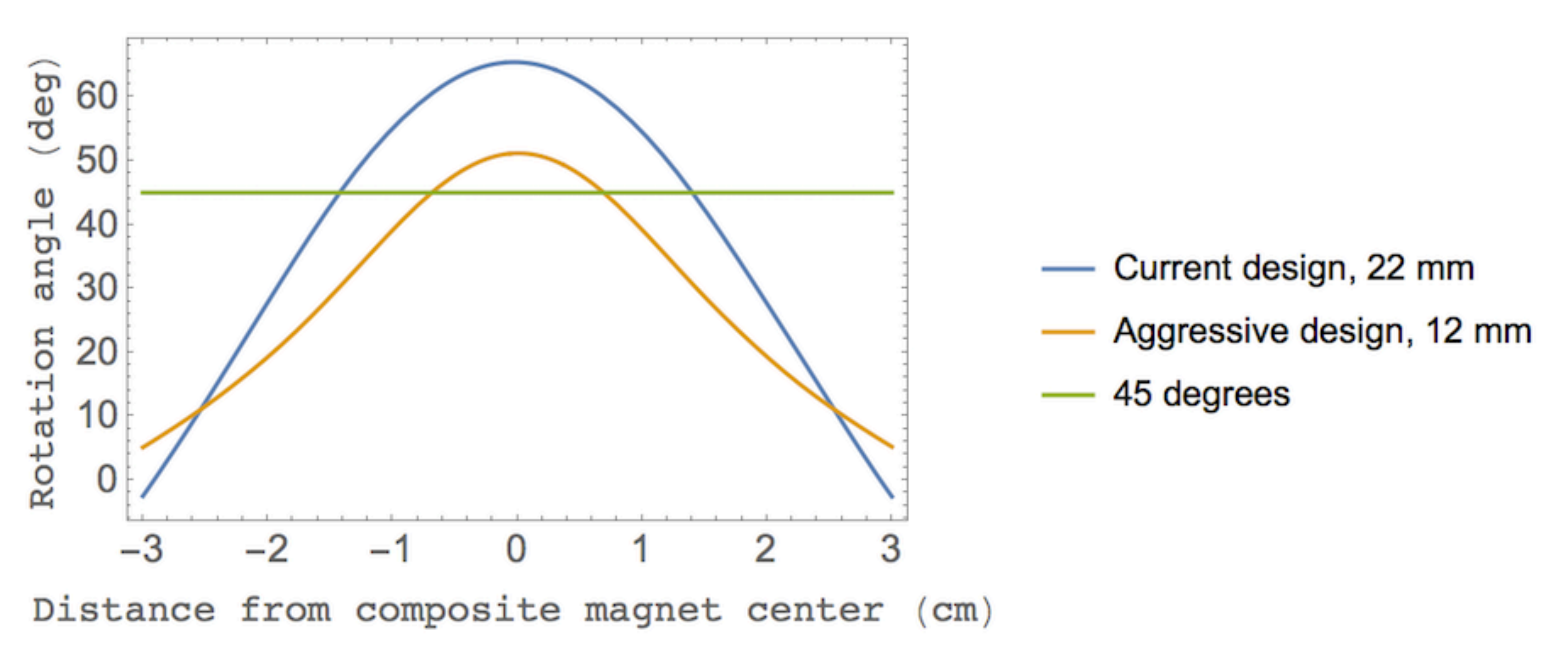
Axial magnetic field measured for each assembled disk with Hall probe

Agreement with COMSOL simulations to within 5%





Magnet Design



Current composite disk concept has lower limit on TGG length of ~ 12 mm

Revised Low Loss Loss Budget

Isolator Element	**Optical Loss (ppm)**
KTP reflection (per face / total)	~~*500 / 2000*~~ **20 / 80**
KTP absorption (per crystal / total)	*25 / 50*
HWP reflection (per face / total)	*300 / 600*
HWP absorption	*50*
TGG reflection (per face / total)	~~*500 / 1000*~~ **650 / 1300**
TGG absorption (20 mm)	*3000*

~ 0.5 % loss per single pass

(~ 0.35 % with 12 mm TGG)

Immediate Prospects

Coatings:

Where does the TGG discrepancy come from?

What allowed for such nice KTP coatings?

Magnets:

Assemble magnet composite without catastrophe

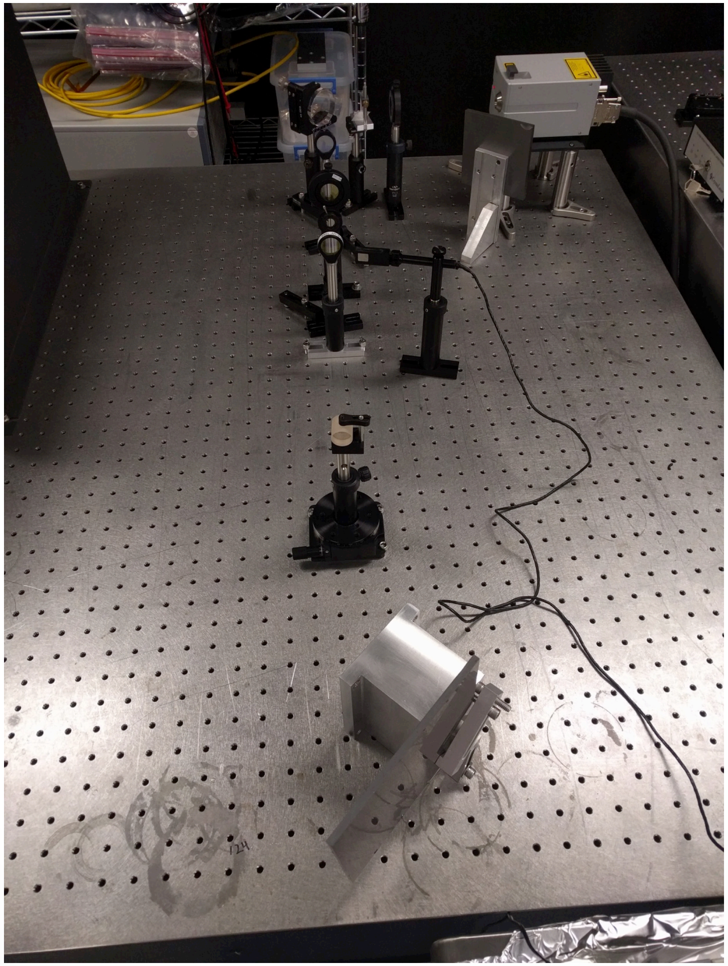
What are the losses when we actually put everything together? Need full optical characterization of the LLFI prototype.

Concluding Remark

For Faraday isolator, current coating technologies at first glance appear sufficient for near and not-too-far future squeezing goals in Advanced LIGO

Questions

Quick reflection measurement



Radial disk field measurements