

# Measurements of field quality for quadrupole magnets using harmonic coils

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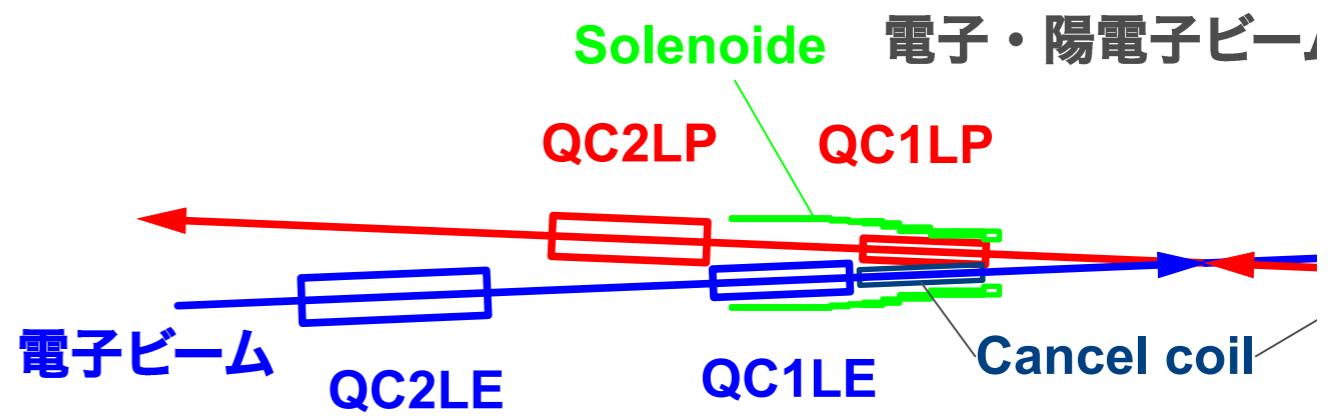
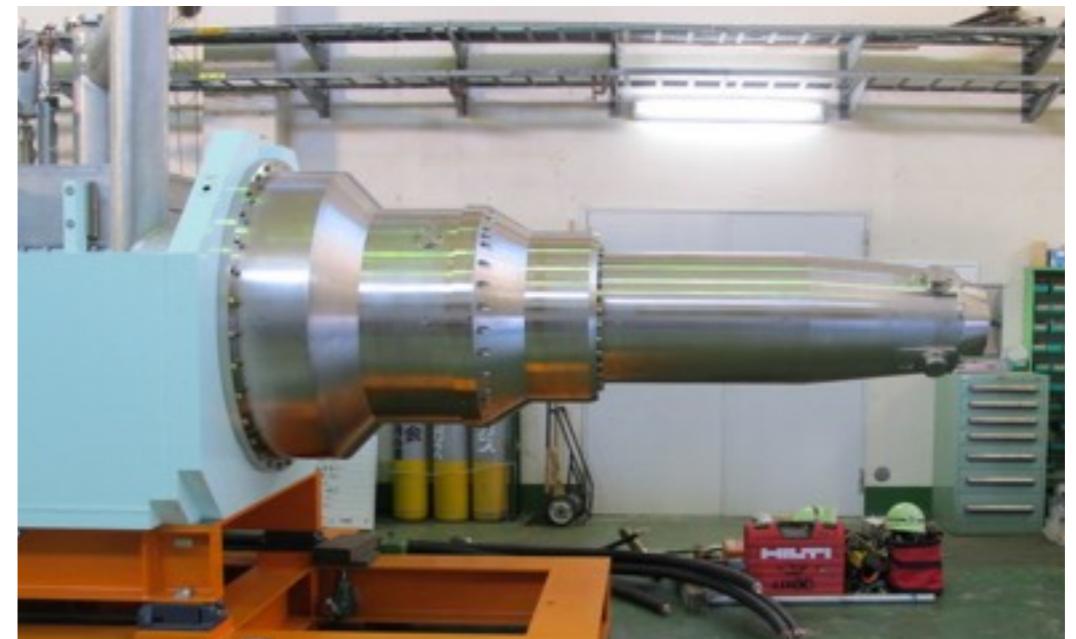
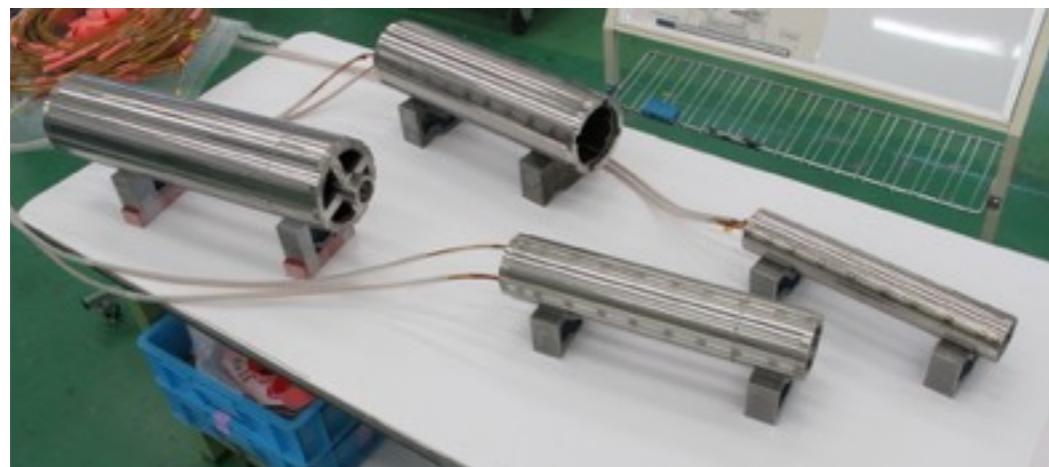
# Introduction

# Outline of magnetic measurements

- Individual magnets
  - Warm measurements after collaring and yoking at factory
    - \* Integral field using harmonic coil
    - \* Check of collaring and yoking process
  - Cold measurements
    - \* Field profiles using harmonic coils
    - \* Integral field using harmonic coils
    - \* acceptance test
- Assembled magnets at preparation building
  - Magnets are installed into final cryostats
  - Integral fields using harmonic coils
  - Field profiles using harmonic coils
  - Magnet centers with single stretched wire (SSW)
  - QCS-L
- Assembled magnets at beam line
  - Harmonic coils, Hall probe, and SSW
  - QCS-L and QCS-R
  - Confirm effect of Belle-II solenoid field

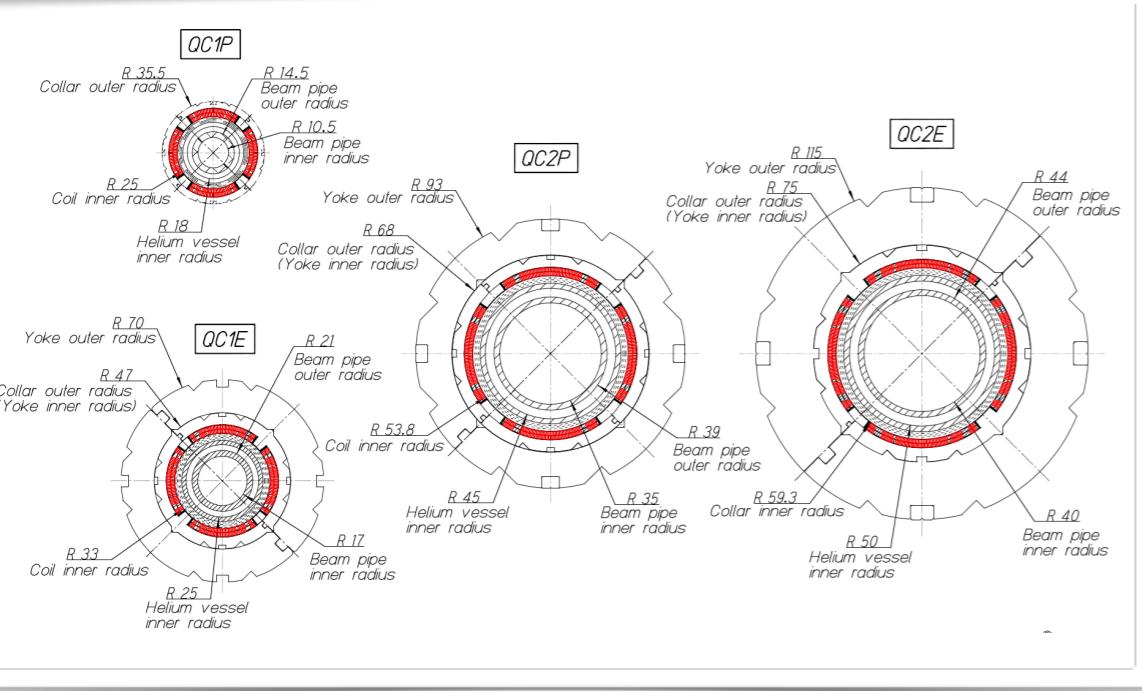
# Configuration QCS-L

- Consists of four quadrupole magnets with correctors, a set of cancel magnet and a compensation solenoid
  - QC1LE with 4 correctors
  - QC2LE with 4 correctors
  - QC1LP with 4 correctors
  - QC2LP with 4 correctors
  - Cancel magnet
  - Compensation solenoid (ESL)



# QCS quadrupole magnets

	Coil I.R. [mm]	Magnet O.R. [mm]	Maximum Field [T]	Effective Length [m]	Field Gradient [T/m]	Design Current [kA]	Yoke material
QC1LP/RP	25.0	35.5	2.0	0.334	76.4	1.8	NA
QC1LE/RE	33.0	70.0	2.8	0.373	91.6	2.0	Permendur
QC2LP/RP	53.8	93.0	2.1	0.410	32.0	1.0	Permendur
QC2LE/RE	59.3	115.0	2.1	0.537/0.419	36.4/41.0	1.25/1.35	Iron / NA



- Quadrupoles are equipped yoke except for QC1LP/RP.

# Overview of magnetic measurements using harmonic coils

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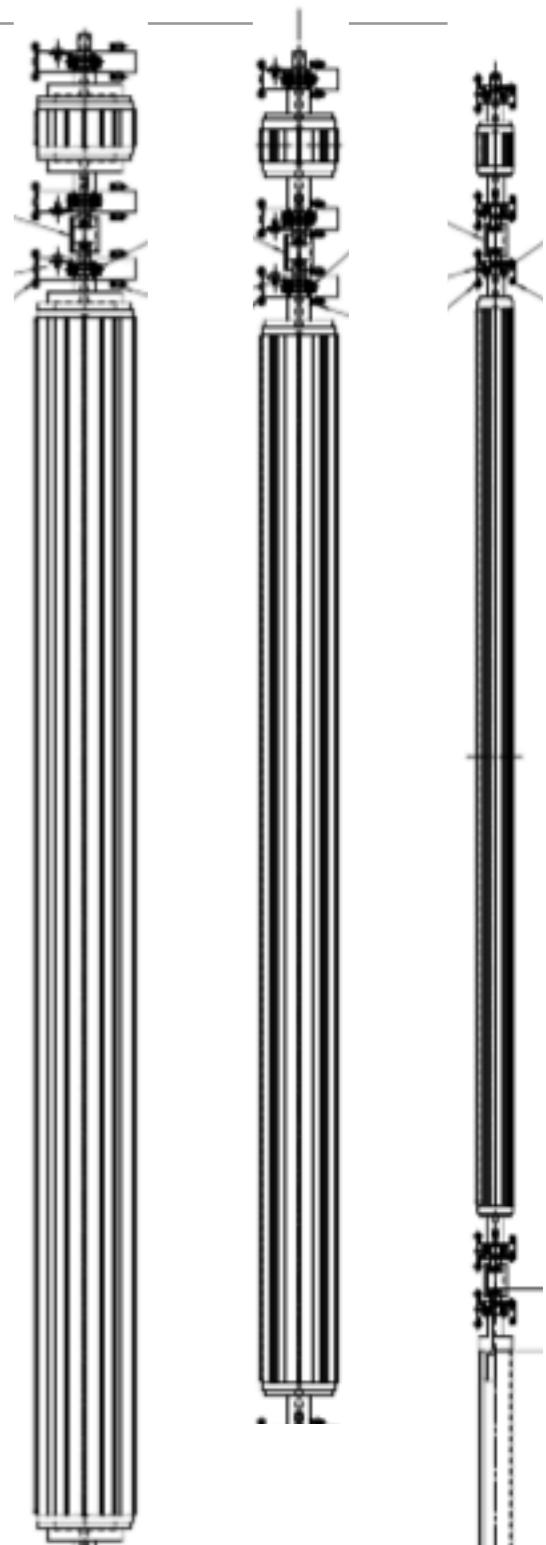
- Measurement period : 2016 Mar. - Apr.
- Although we measured individual magnets, we need to measure assembled magnets, because we want to know more precise harmonics and skew and normal components with respect to direction of gravity.
  - Precise harmonics : measured using larger-radius harmonic coil
  - Roll angle: Calibration with standard quad and Inclinometer
  - Bug fix of measurement system for measurement at beam line

# Apparatus

# Harmonic coils

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- Three set of harmonic coils. Each set has
  - short length windings (**for field profiles**)
    - \* Tangential winding with quadrupole and dipole bucking
    - \* one dipole winding
    - \* 2 quadrupole windings (for digital bucking)
  - long length windings (**for integral field**)
    - \* Tangential winding with quadrupole and dipole bucking
    - \* one dipole winding
    - \* 2 quadrupole windings (for digital bucking)
- The three set of harmonic coils are different in radius
  - $R=12$  mm (QC1LE, QC1LP;  $R_{ref}=15, 10$  mm)
  - $R=25$  mm (QC2LP,  $R_{ref} =30$  mm)
  - $R=33$  mm (QC2LE,  $R_{ref}=35$  mm)

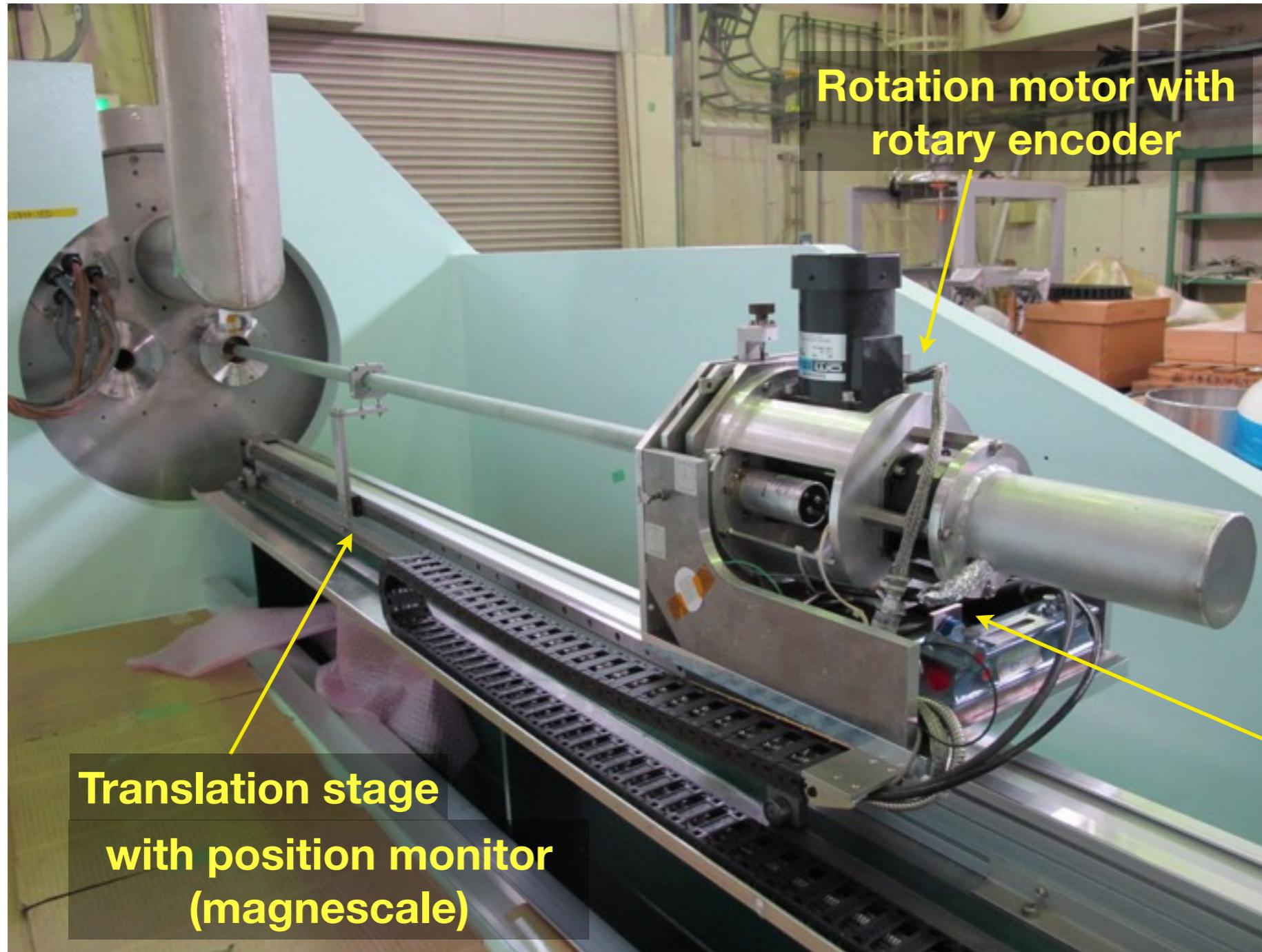


# Harmonic coil

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# Moving stage



## Inclinometer specifications

Range	± 5 degrees
Resolution	0.001 degrees
Sensitivity	400 mV/degree
Non linearity	< ±0.02 degree
Sensitivity shift	<2%
Temp. drift	±0.002 deg./K



# Measurement results

# Field strength

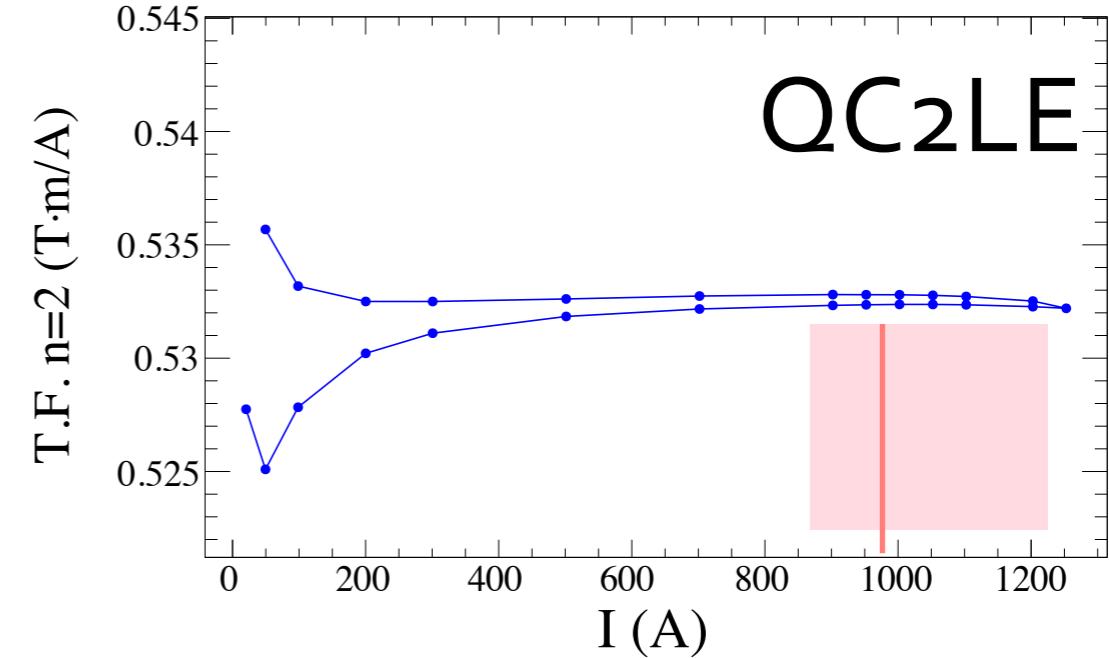
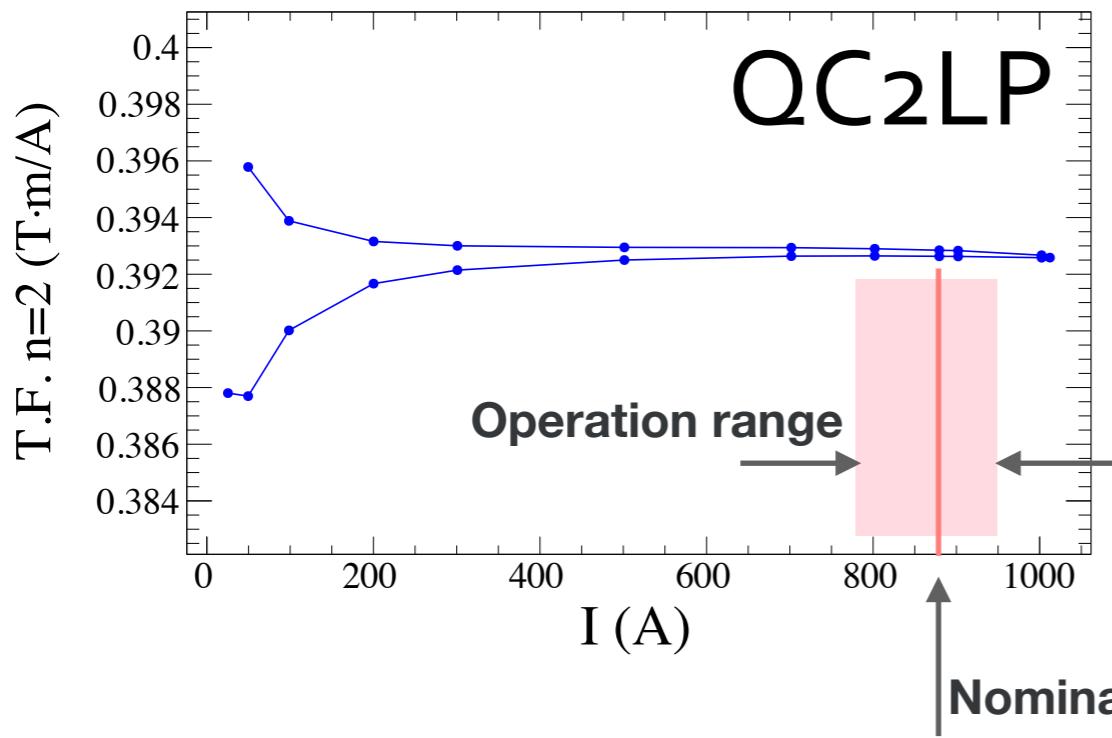
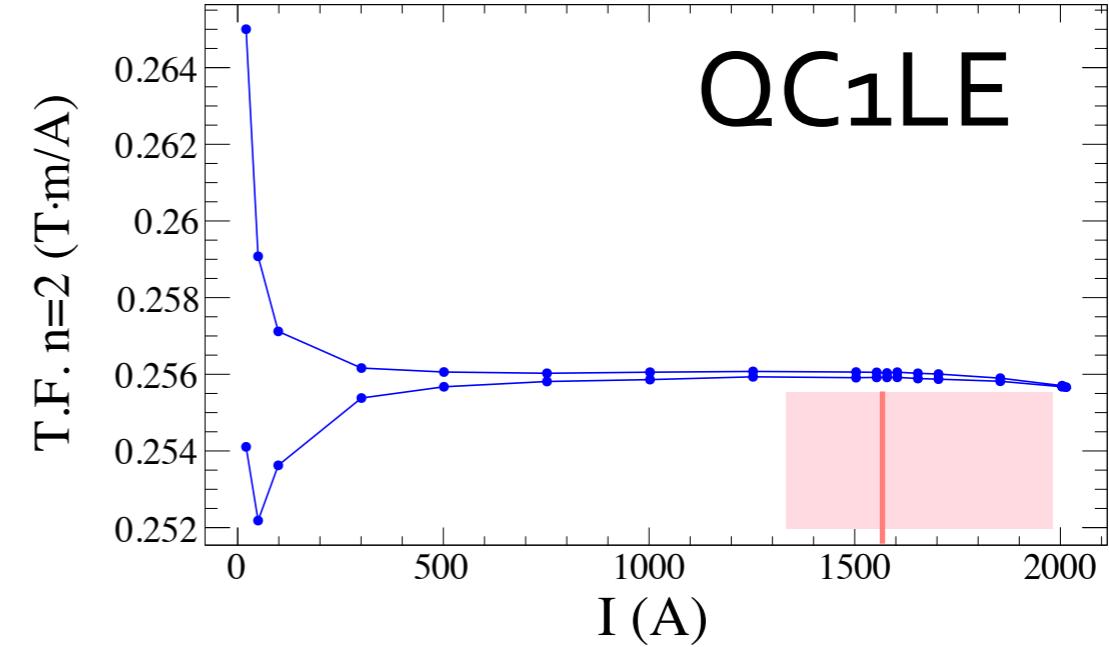
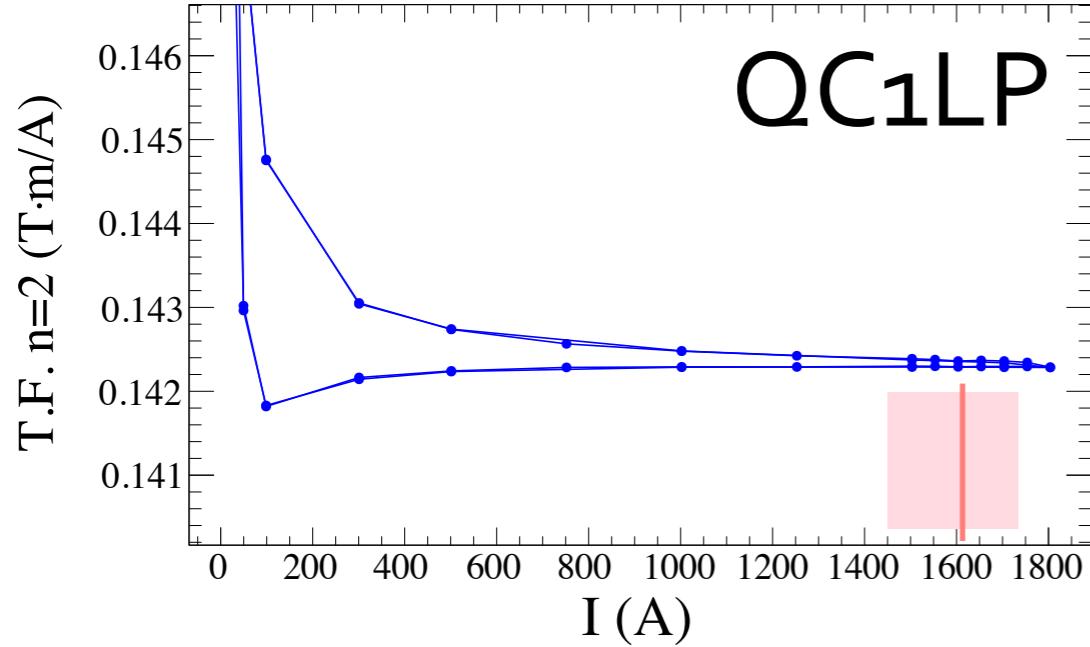
$$\int GdL/I$$

G : field gradient  
 L : length along magnet axis  
 I : magnet current

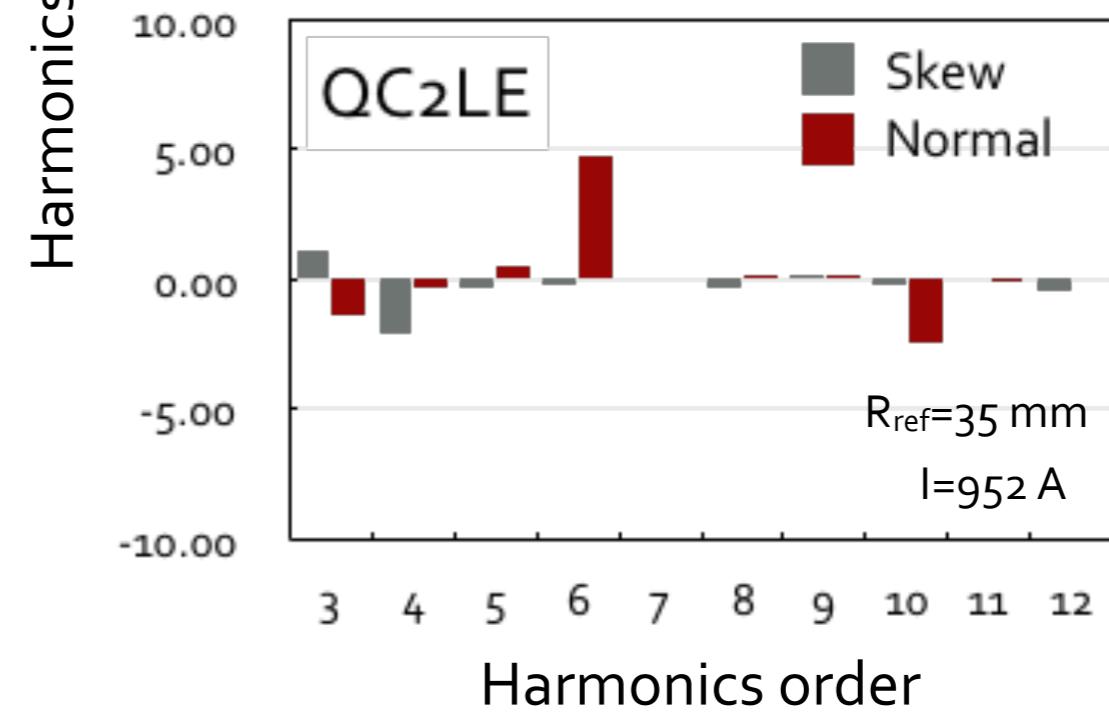
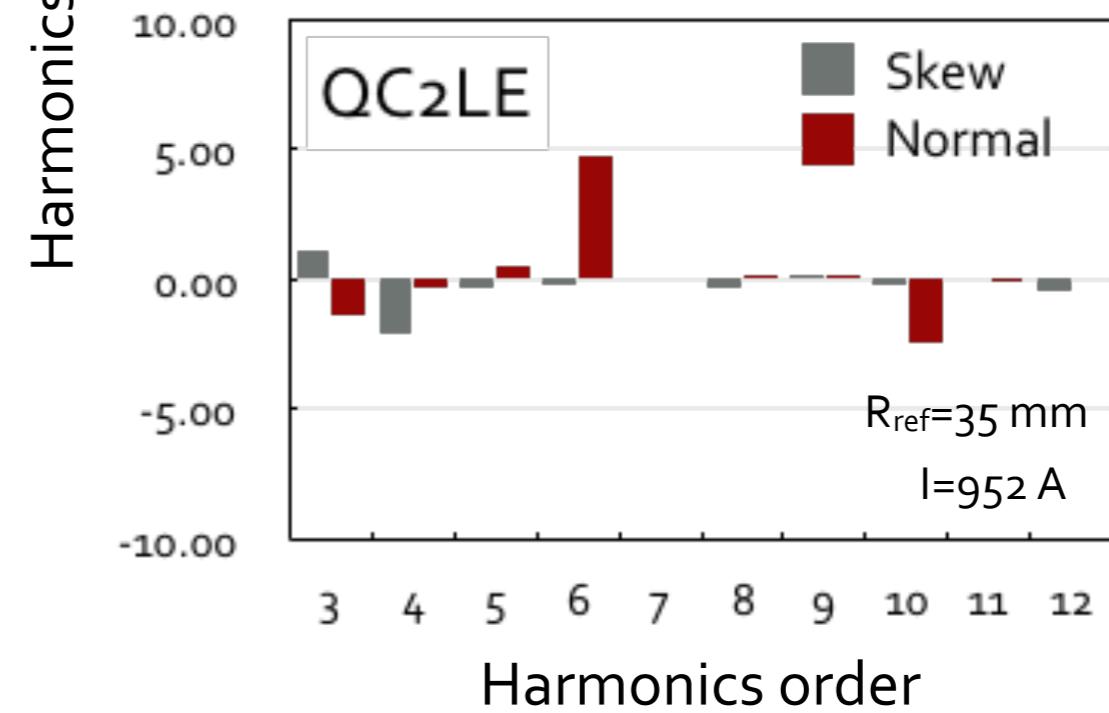
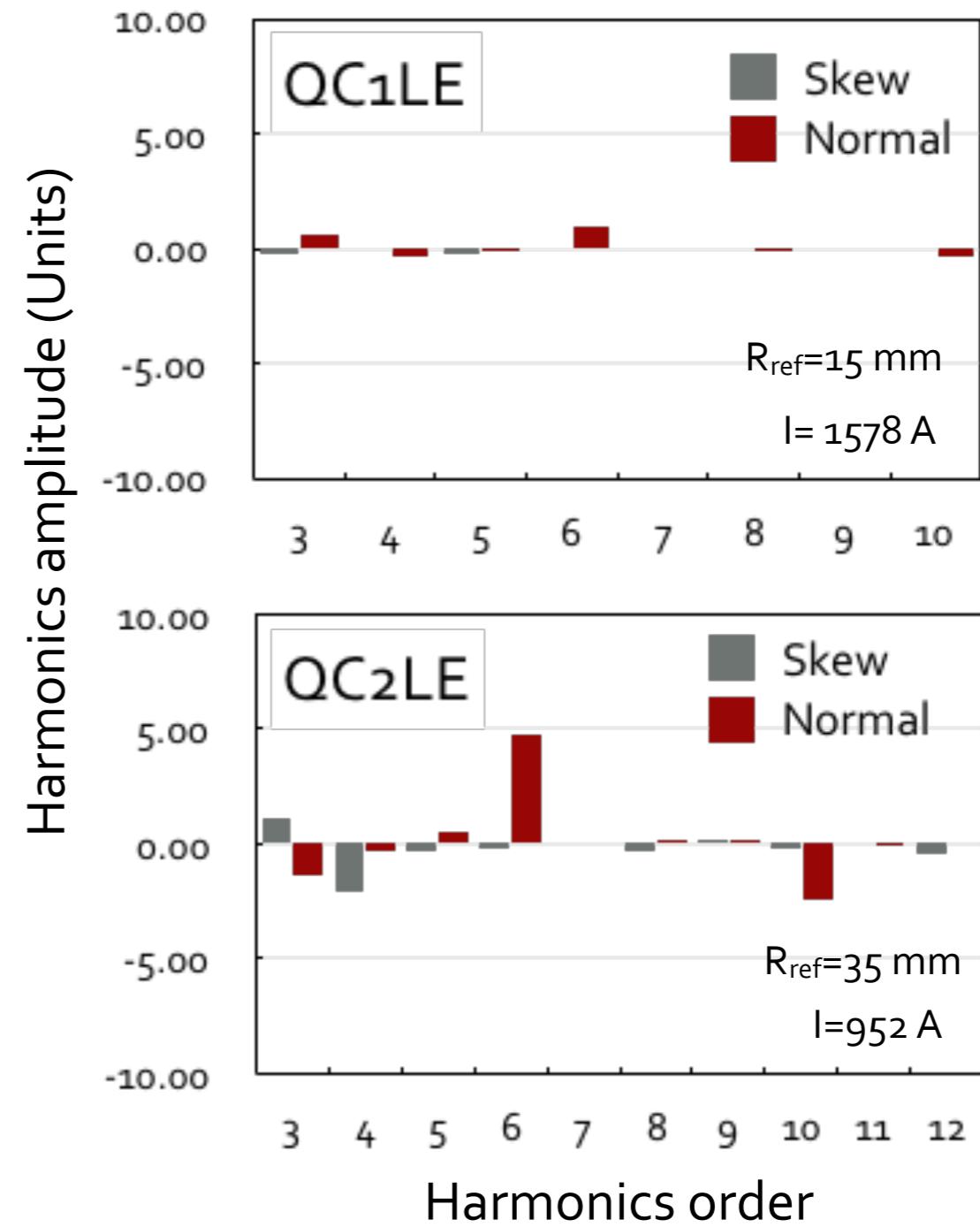
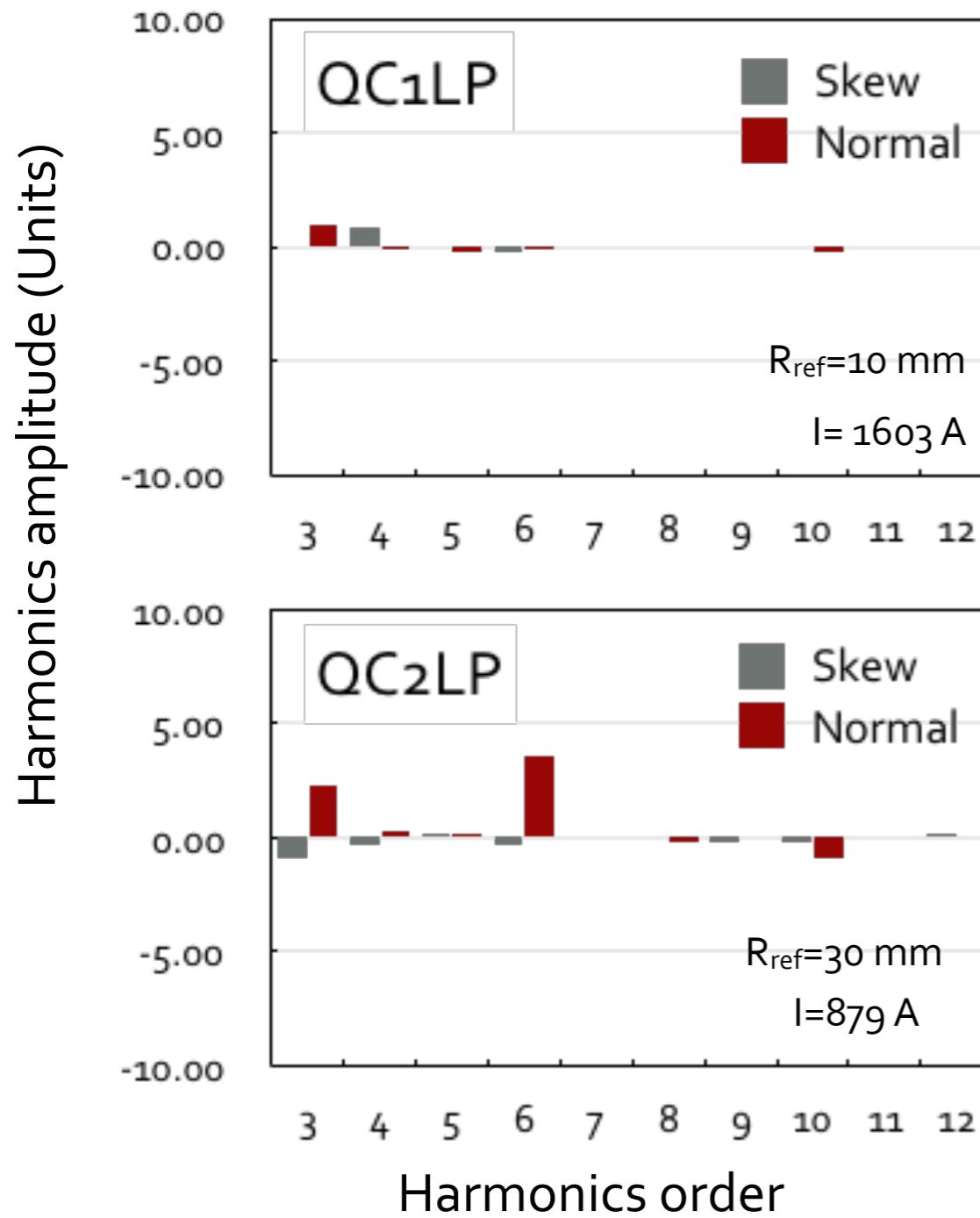
	I <sub>meas</sub> [A]	Design [T/A]	Meas. [T/A]	Diff. [%]
QC1LP	1,603.4	0.01413	0.01423	0.71
QC2LP	879.4	0.01308	0.01309	0.08
QC1LE	1578.4	0.01708	0.01706	-0.12
QC2LE	952.2	0.01563	0.01521	-2.69

Measured with long length harmonic coil

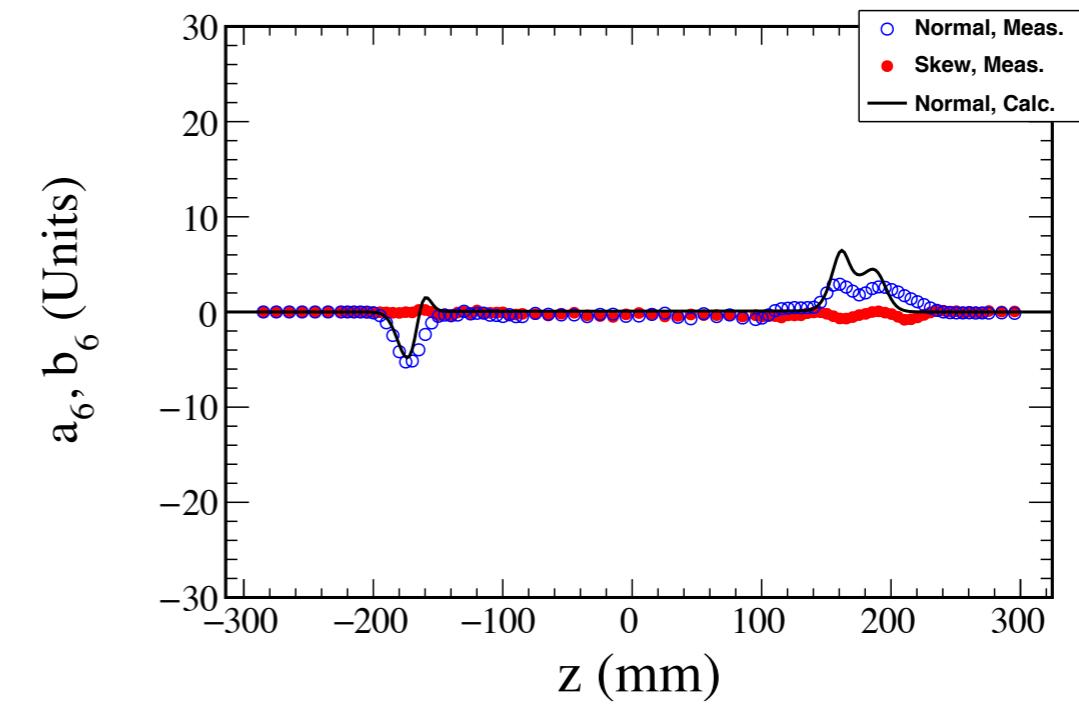
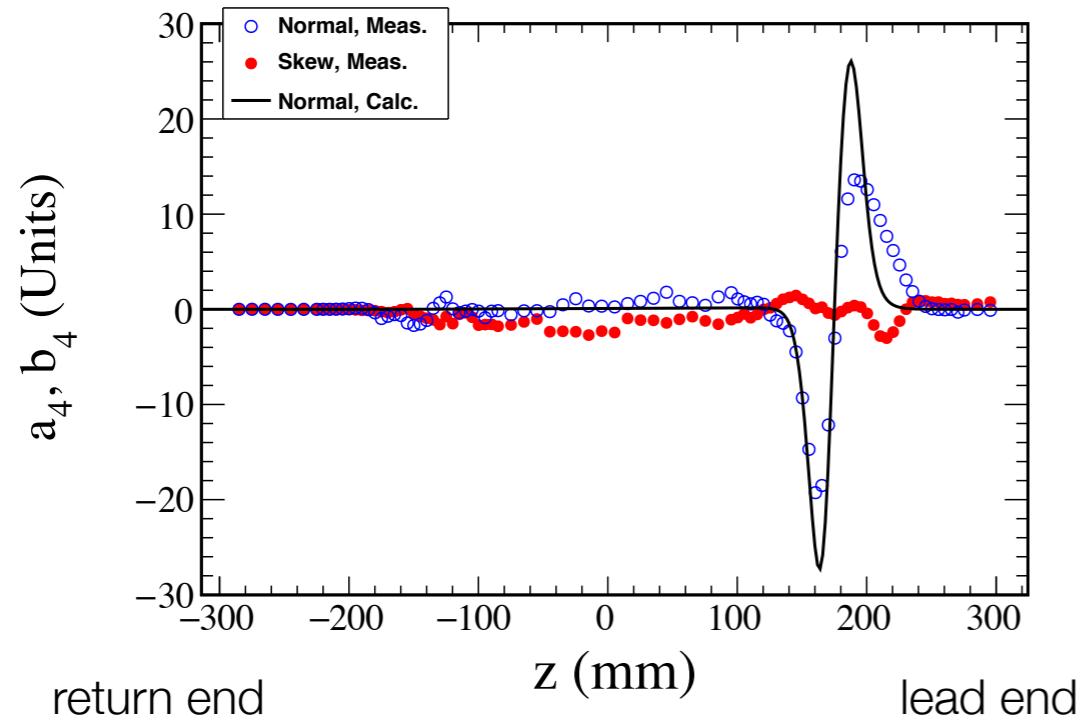
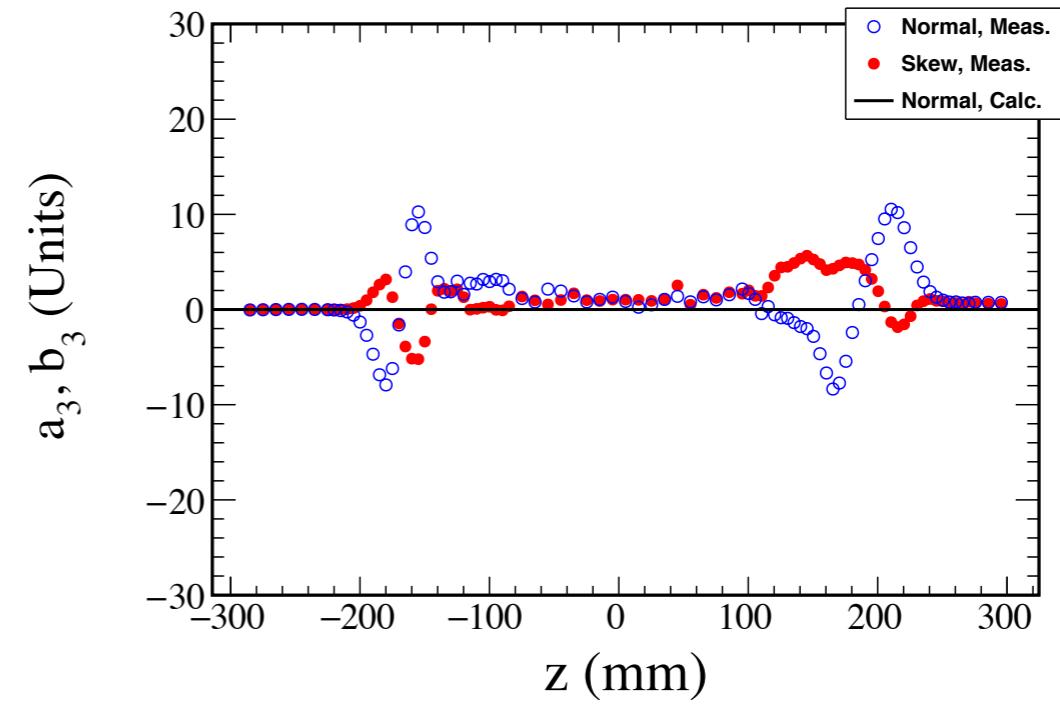
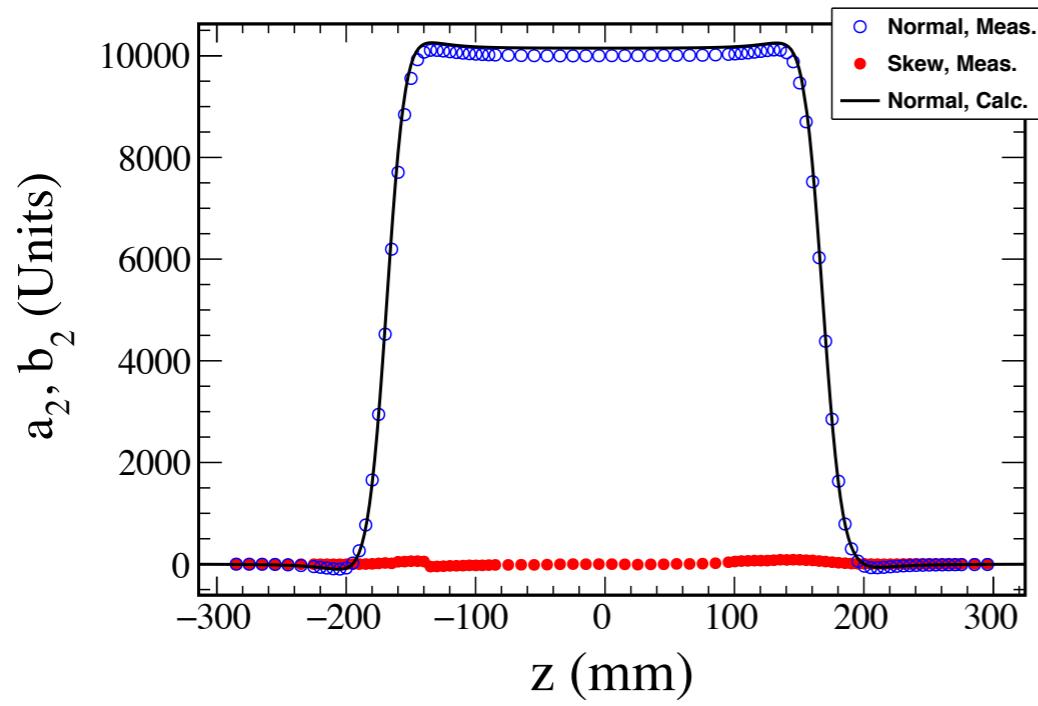
# Transfer function of quadrupole component



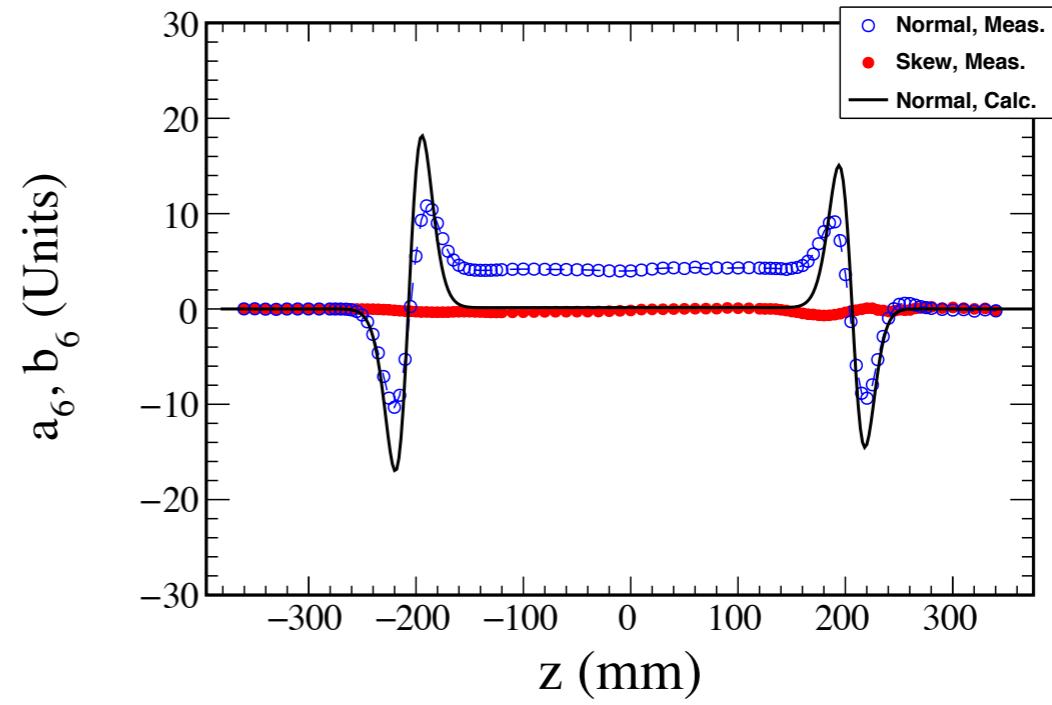
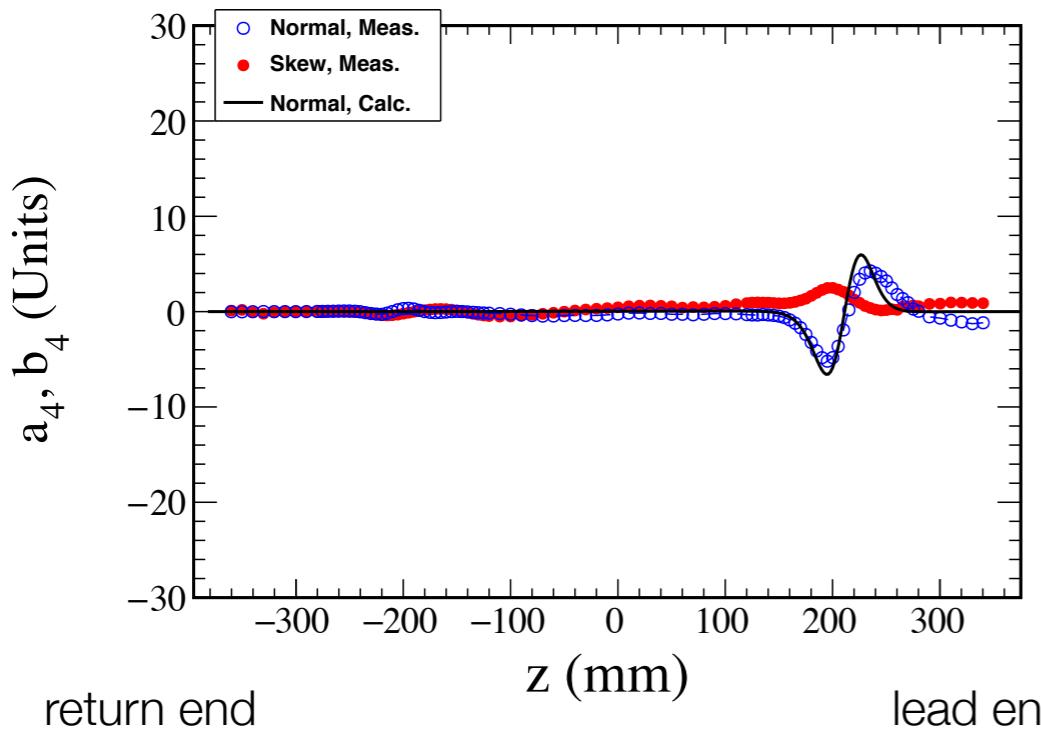
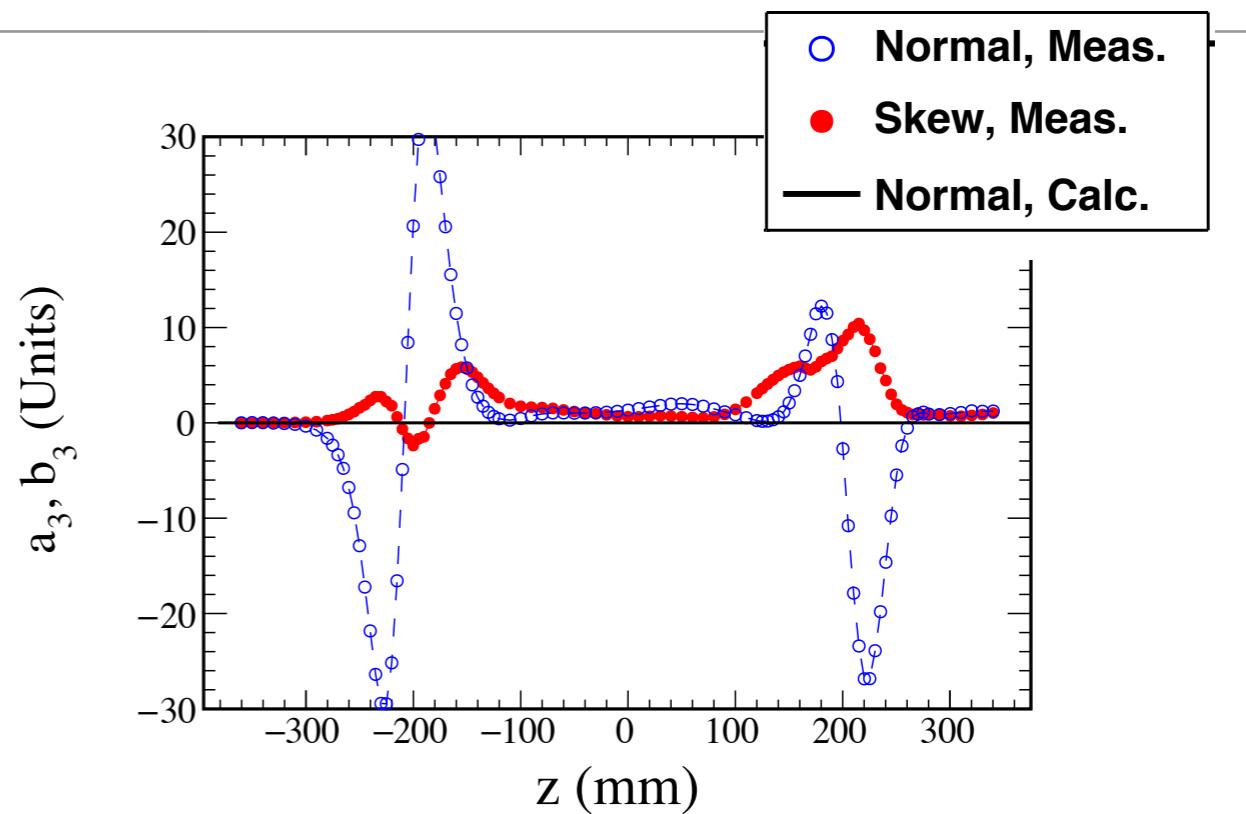
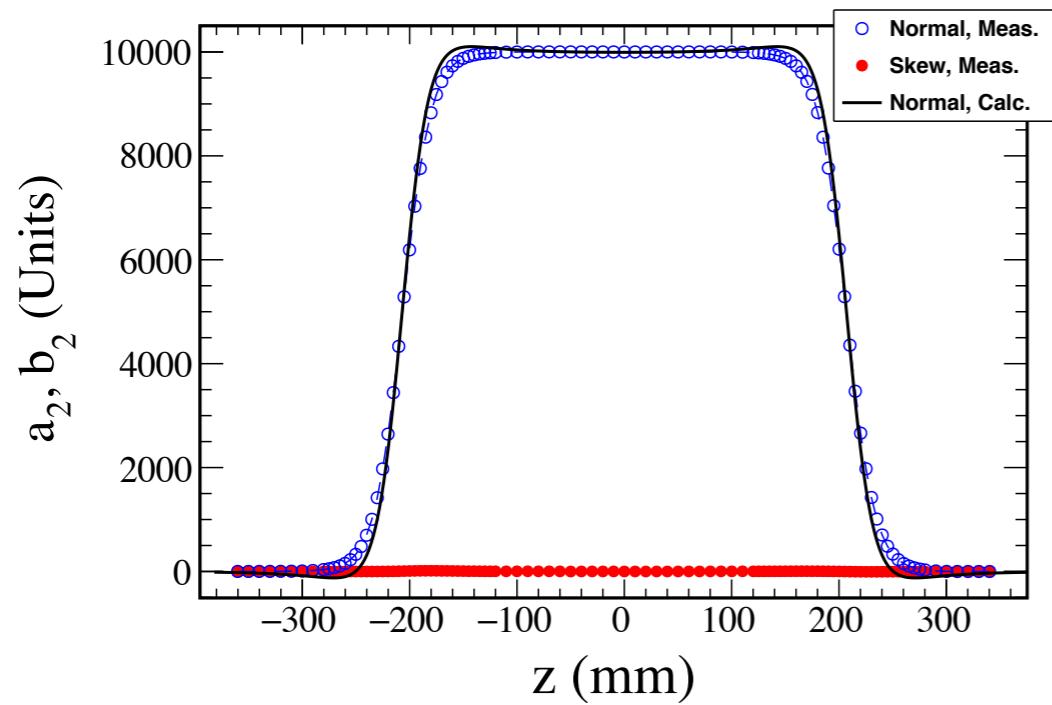
# Harmonics amplitude



# Field Profiles ( QC1LP )



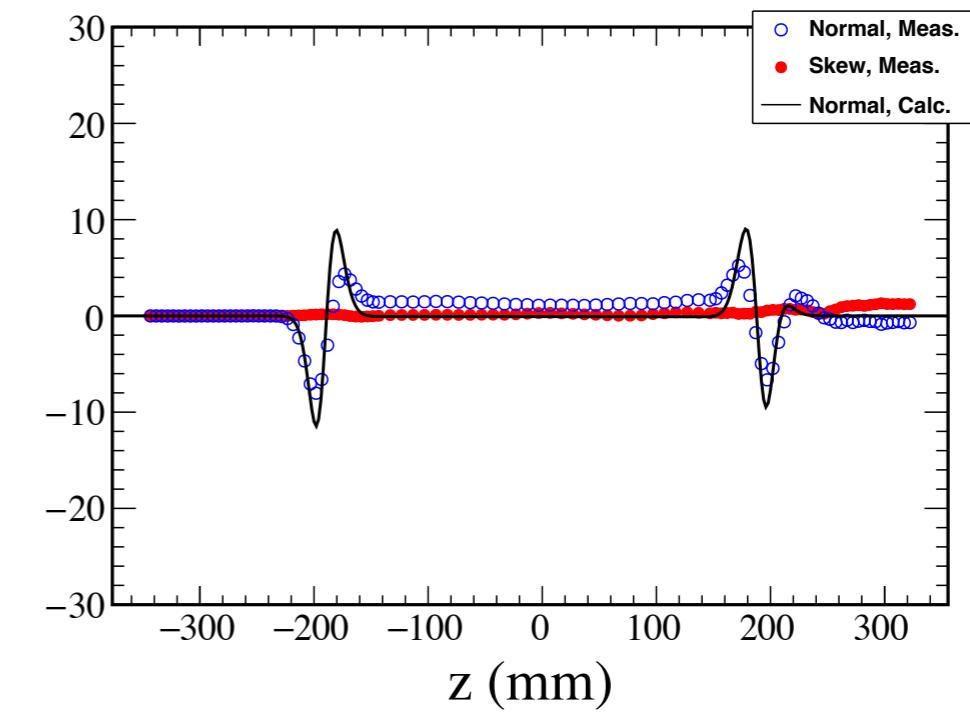
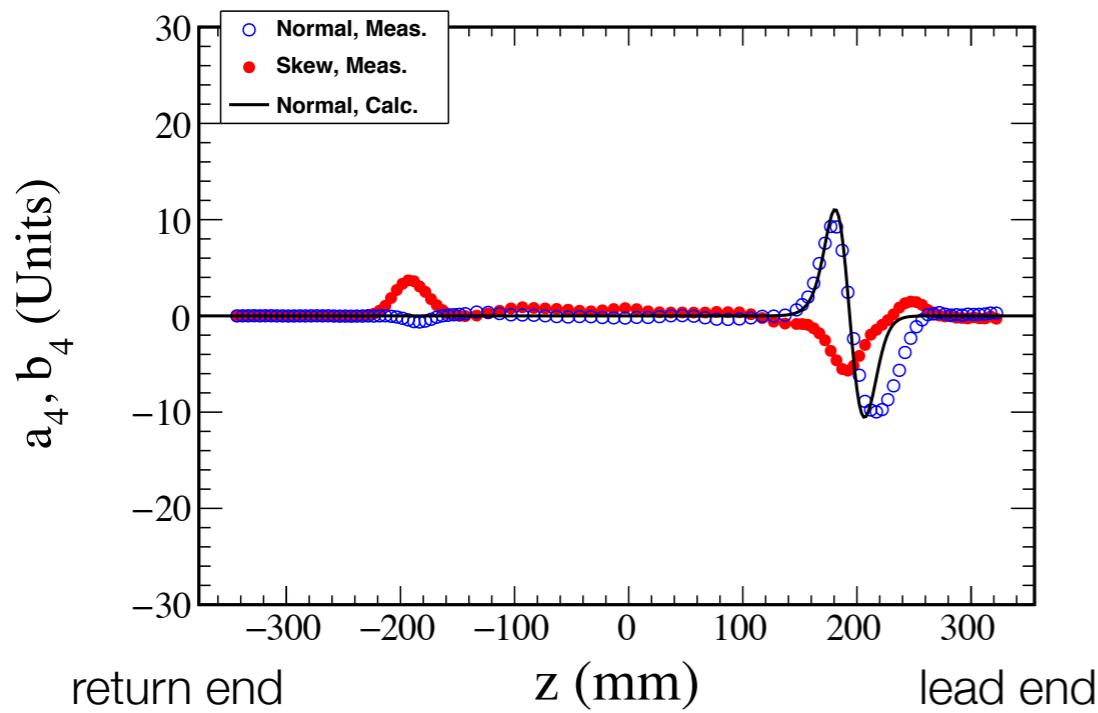
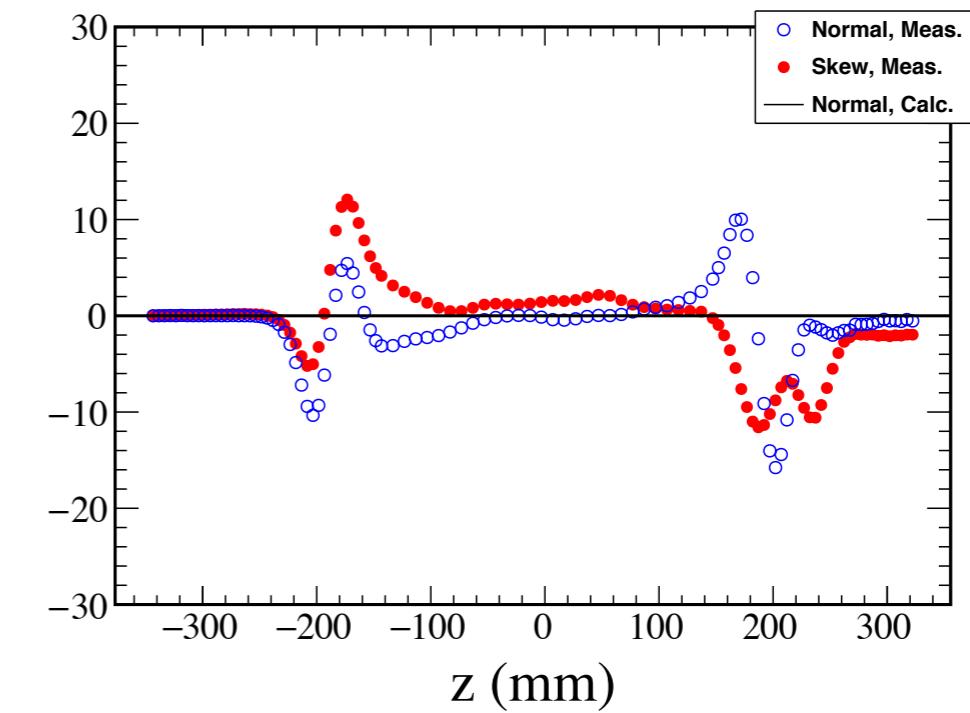
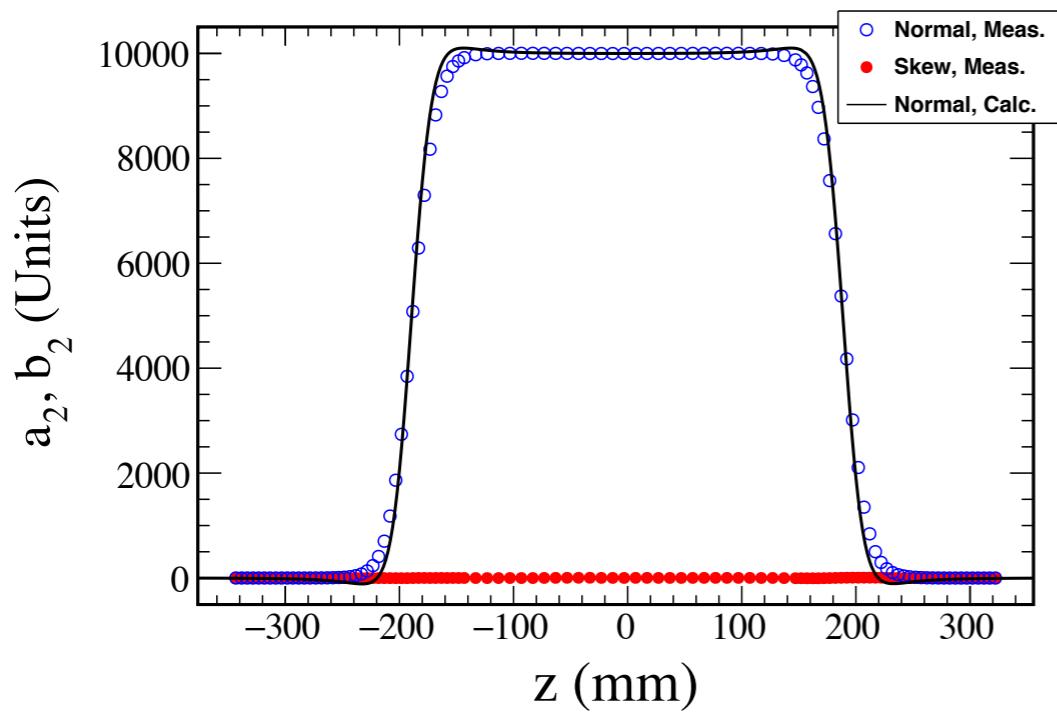
# Field Profiles of QC2LP



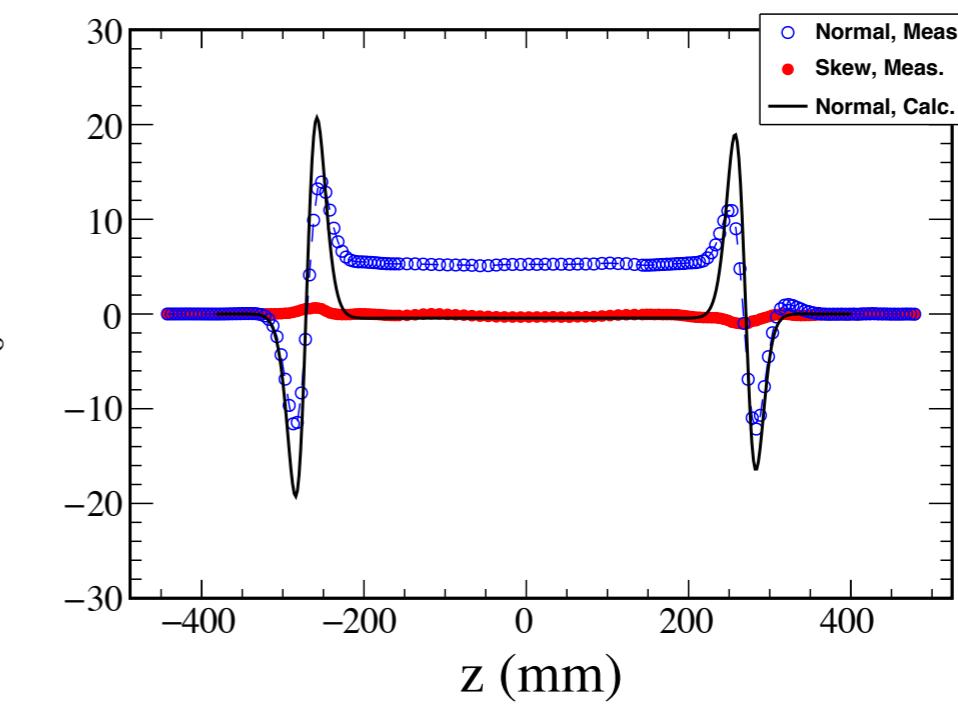
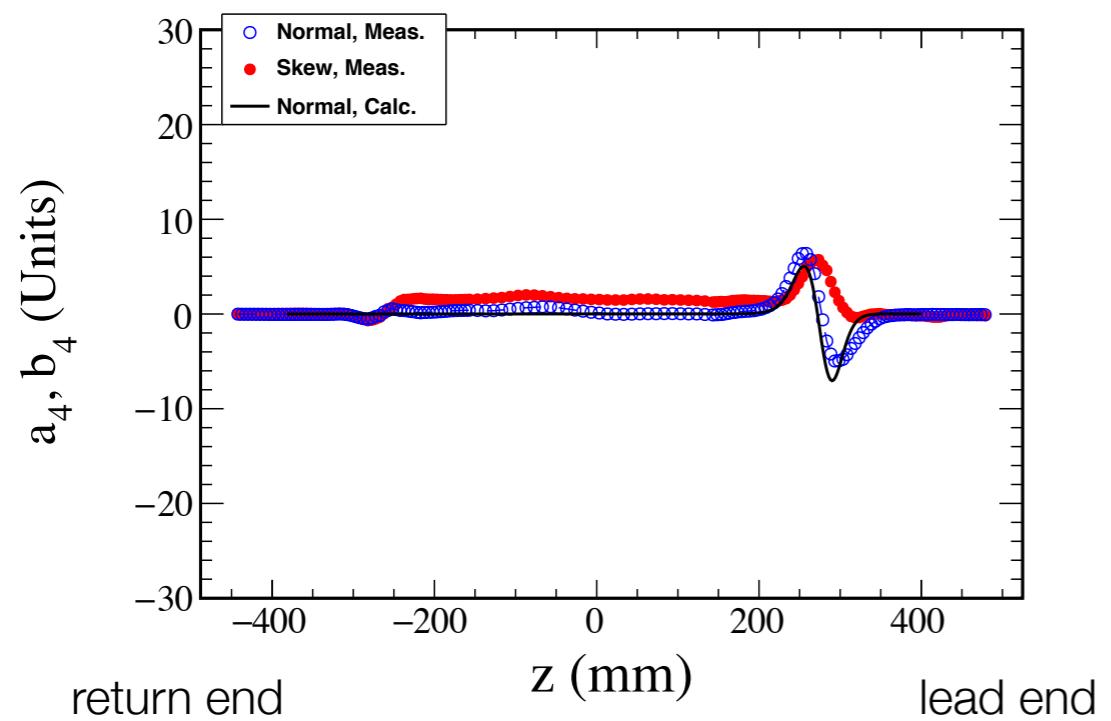
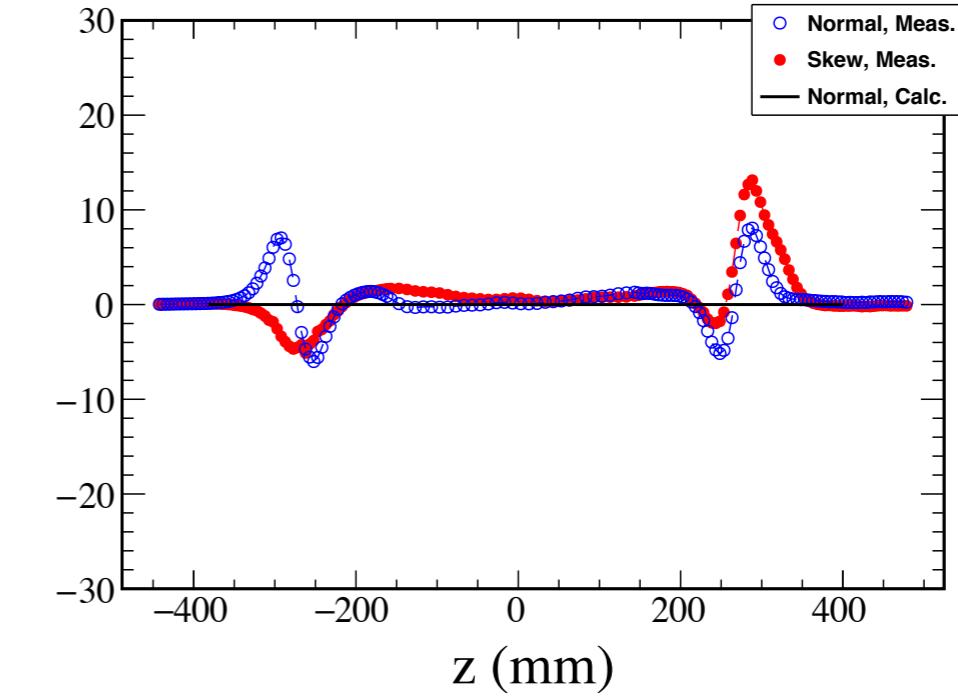
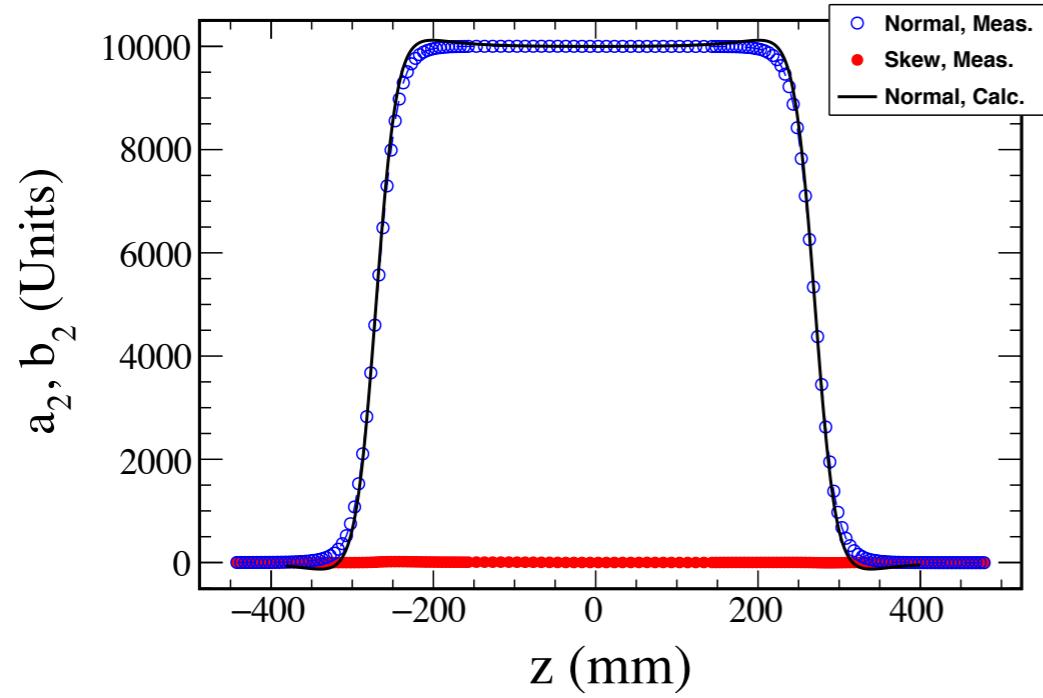
return end

lead end

# Field Profiles of QC1LE



# Field Profile of QC2LE



# Summary

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- We performed magnetic field measurement of quadrupole magnet in QCSL cryostat using harmonic coils.
- We prepared new harmonic coils which have larger radius than previous measurements of individual magnets with a vertical cryostat.
- Transfer function exhibits small hysteresis and magnetic saturation due to yoke.
- Harmonics amplitude for all magnet are smaller than 5 units.
- Field profiles for quadrupole components show good agreements with design (calculation) values.
- It is concluded that the field quality of the quadrupole magnets meet requirements by beam optics.