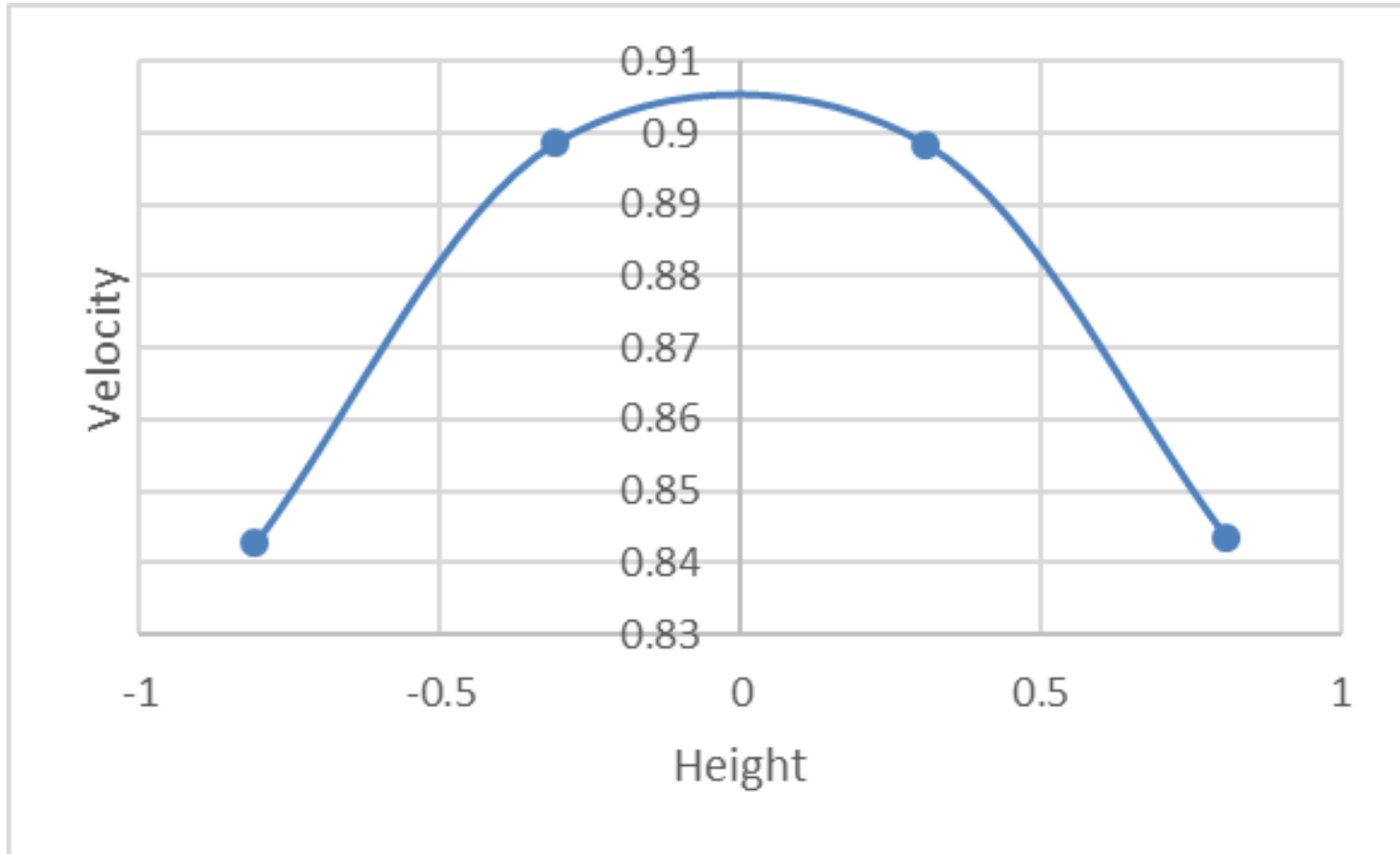# An Investigation Into The Performance And Diagnostics From Different Chordal Integration Schemes In Asymmetric Flow

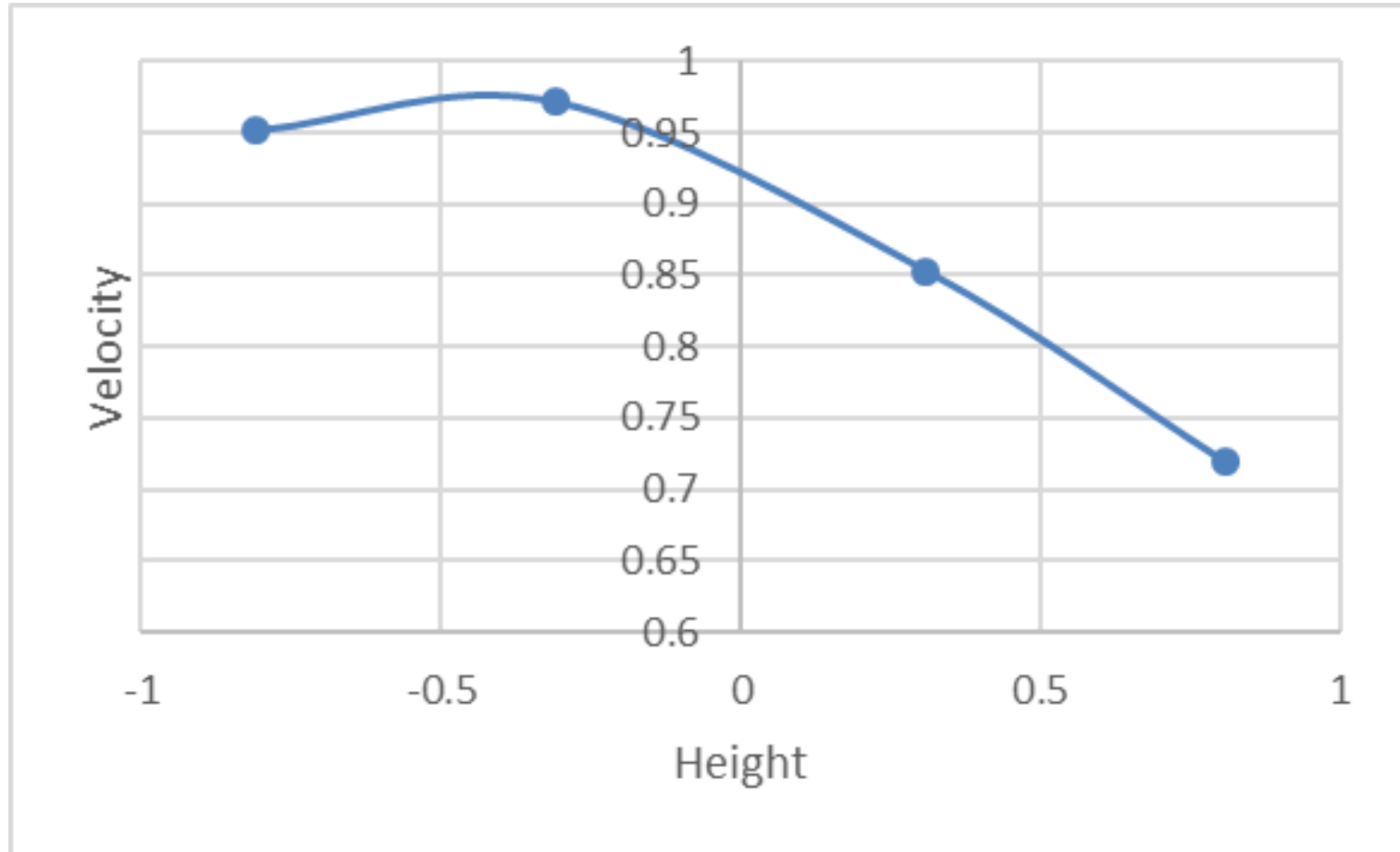## by

Patrick Arnould, Oil & Gas Authority

Apparent Flow Profile

Profile factor 1.07, symmetry ratio 1.0

Actual Axial Flow Profile

Profile factor 1.09, symmetry ratio 0.82

Overview

Motivation for paper and definitions

Effects of more chords in axial asymmetry

Review of profile factor correlation for correcting axial asymmetry

Benefits of more paths and swirl cancellation

Swirl and interference with diagnostics

Summary

Motivation For Paper

K. J. Zanker, T. Mooney. Limits on achieving improved performance from gas ultrasonic meters and possible solutions, NSFMW 2012

With more than 4 paths there appears little effect on the integration (mathematically modelled using the power law profile)
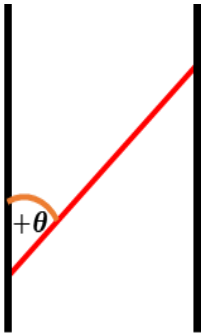
Show effect of more chords in the presence of axial asymmetry

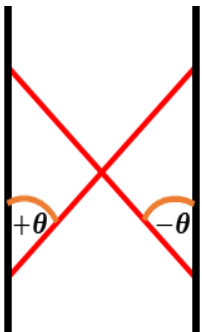Review benefits of more paths for swirl cancellation

Definitions
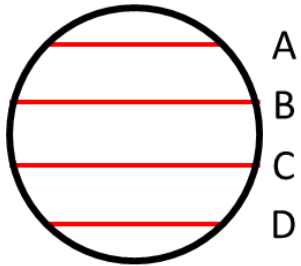
Chord - the straight line connecting two points on the circumference of a circle
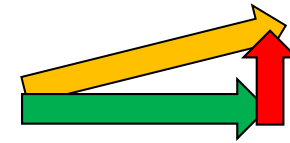
Path - the straight line connecting transducers

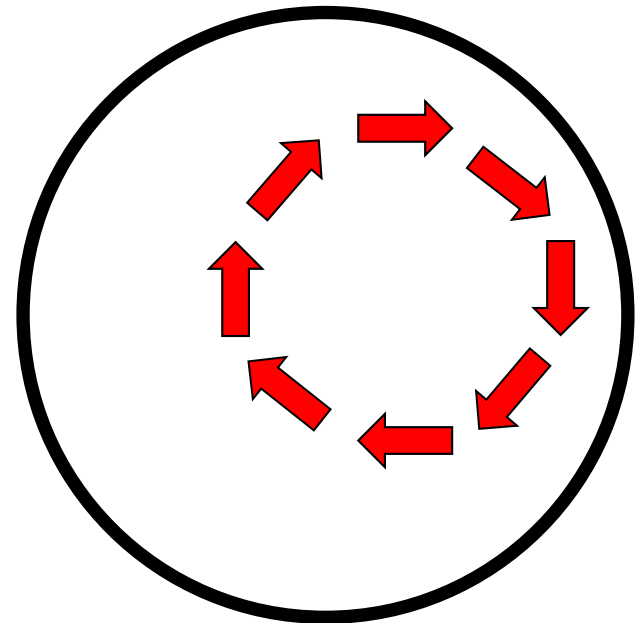Can have multiple paths on the same chord

Designs Discussed

Chord	Parallel Chord	Parallel Crossed Chord	In-Plane Crossed Chord
A			
B			
C			
D			

Asymmetric Swirl
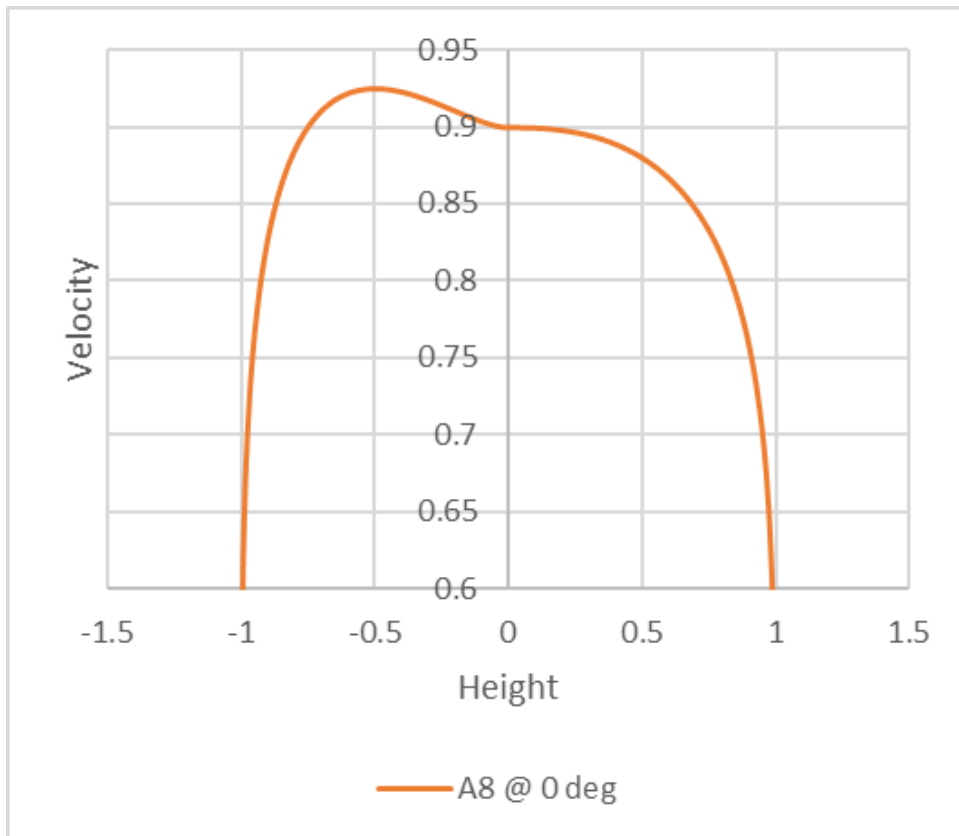
Swirl - non-axial components of flow

Single or double vortex which is not centred in the pipe

Axial Asymmetry

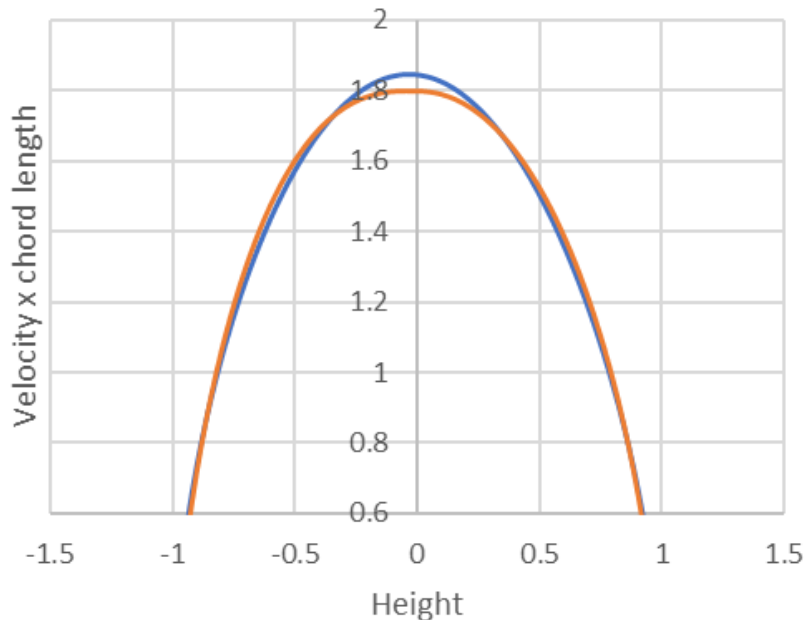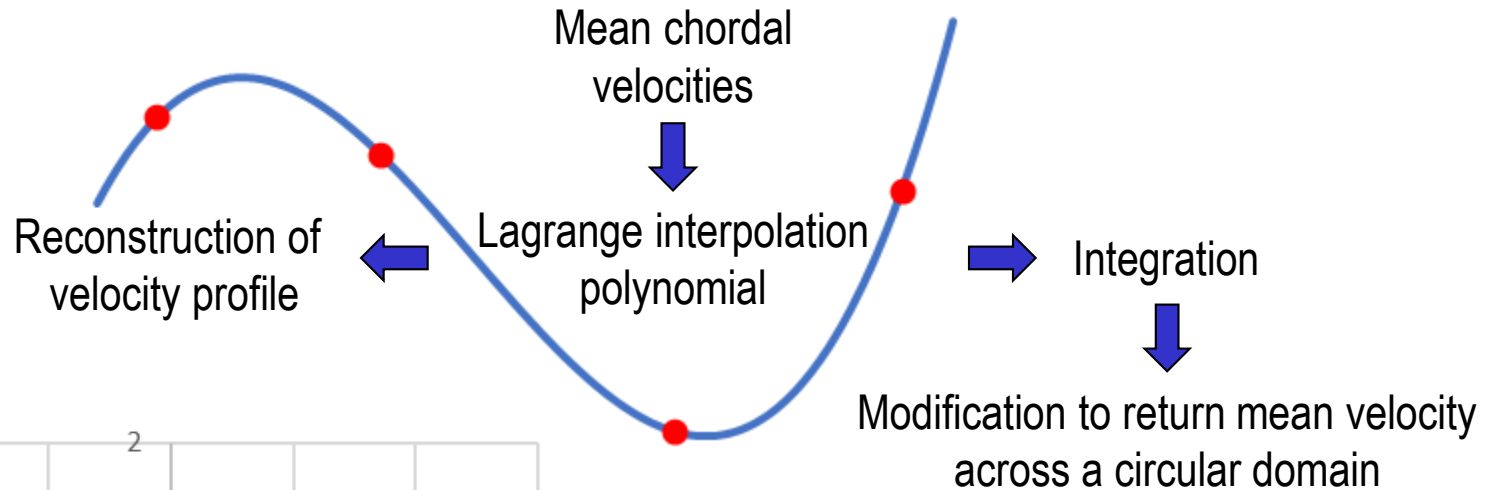An *axial* velocity profile which is not distributed symmetrically about the pipe centre

Axial asymmetry can be present without swirl

Swirl can be present without axial asymmetry

They can also both be present simultaneously

Profile Reconstruction

Mean chordal velocities

⬇

Reconstruction of velocity profile ⬅ Lagrange interpolation polynomial ➡ Integration

⬇

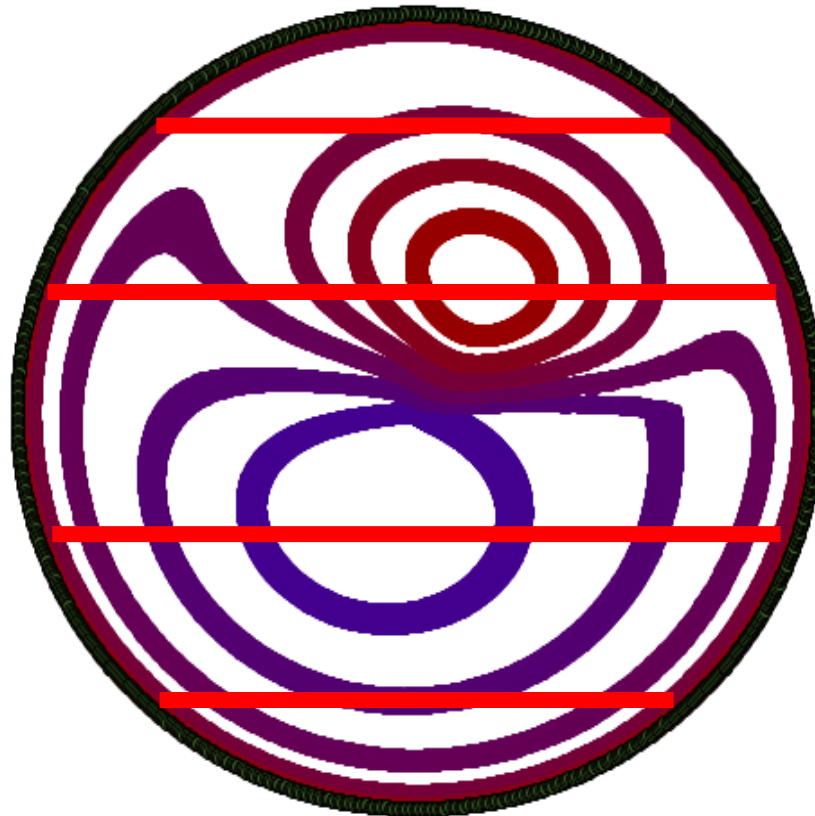Modification to return mean velocity across a circular domain

⬇

$$MeterVelocity = \sum_{k=1}^{n} f(x_k) \boldsymbol{A_k}$$

Gives the meter an ability to adapt to asymmetric profiles

Interpolation polynomial can be reconstructed to aid visualisation

Velocity x chord length (y-axis) vs Height (x-axis)

—— interpolation polynomial   —— A8 @ 0 deg
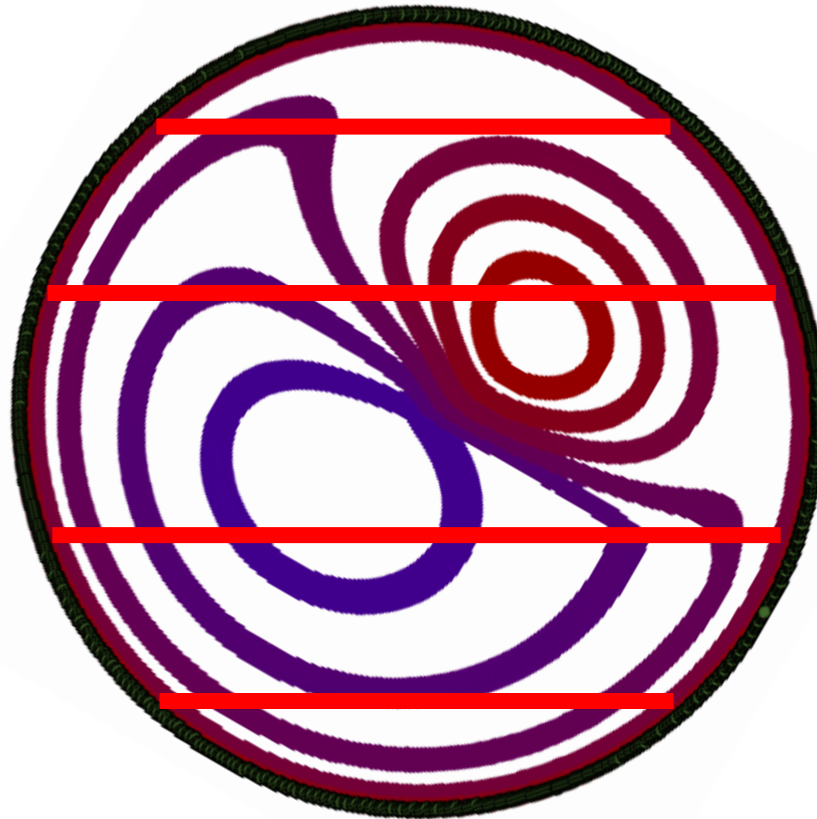
Modelling Axial Asymmetry

10 x asymmetric profile functions + power law

Rotation of profile yields more diagnostic data for analysis

Modelling Axial Asymmetry

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Modelling Axial Asymmetry
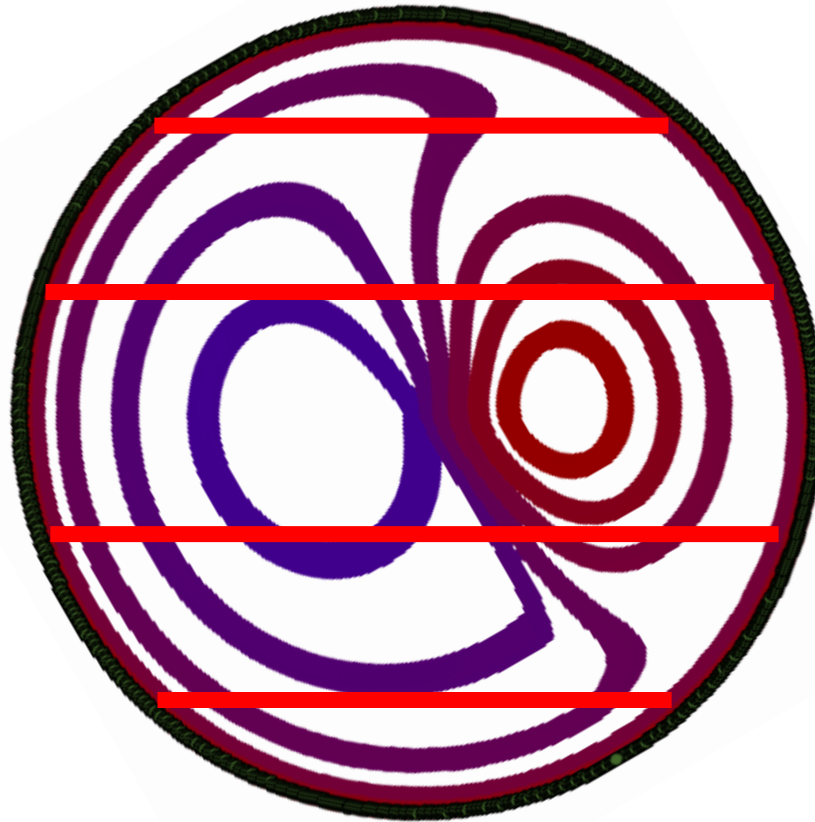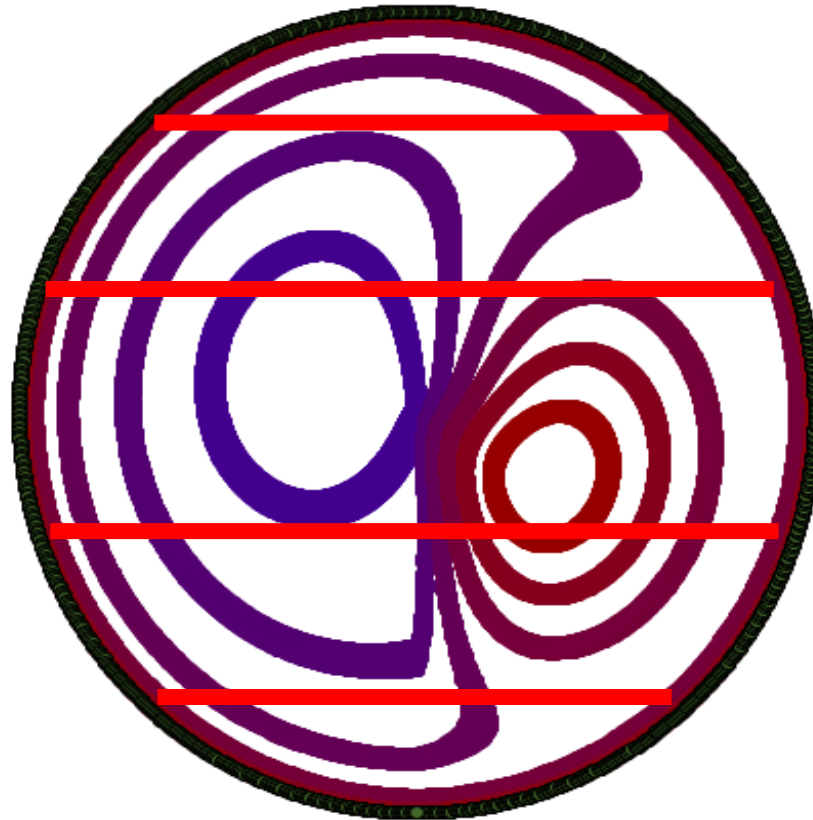
North Sea
FLOW
Measurement Workshop

10 x asymmetric profile functions + power law

Rotation of profile yields more diagnostic data for analysis

Modelling Axial Asymmetry

10 x asymmetric profile functions + power law
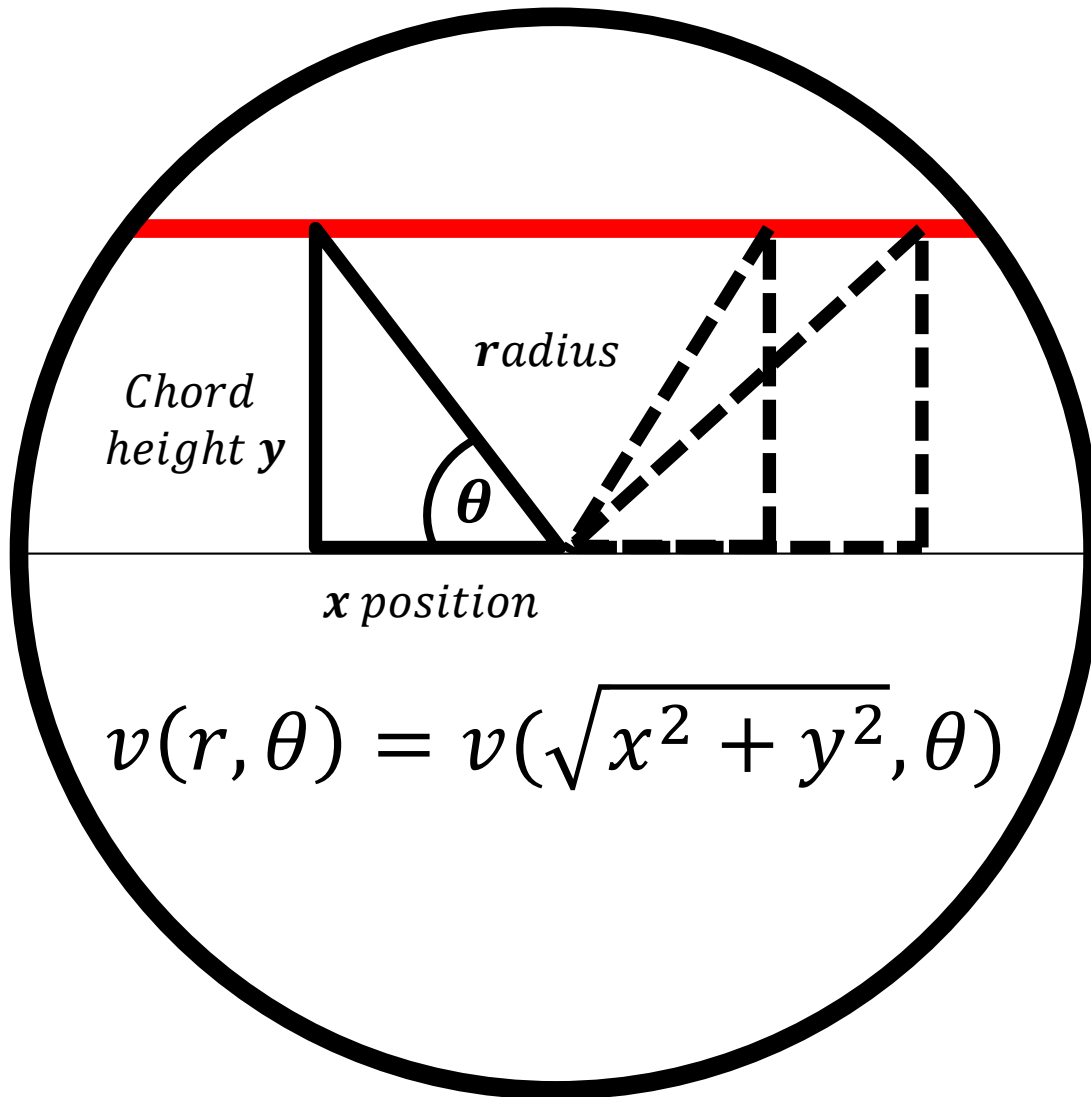

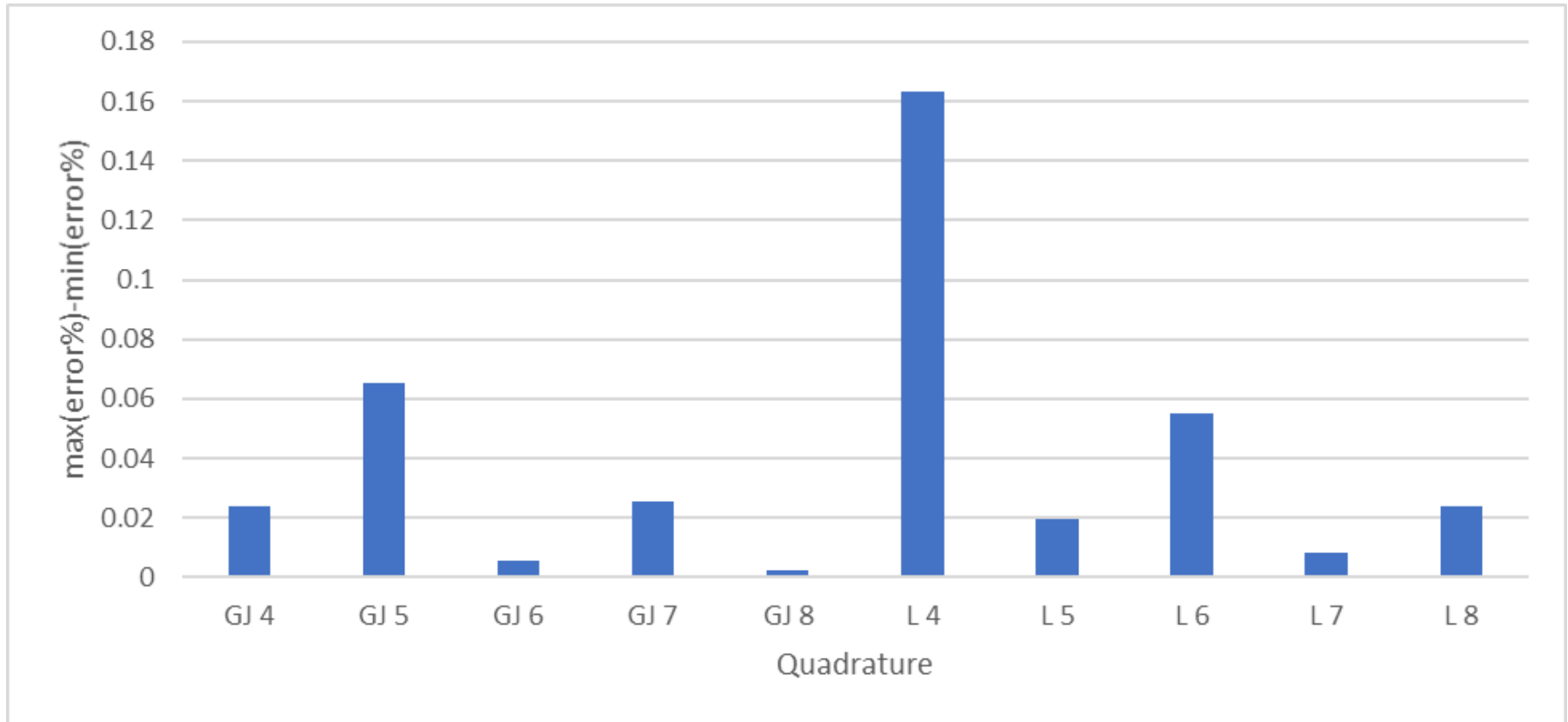**Rotation of profile yields more diagnostic data for analysis**

Modelling Axial Asymmetry

Gauss-Jacobi &
Gauss-Legendre
chord spacings

$Chord\ height\ y$

$r adius$

θ

$x\ position$

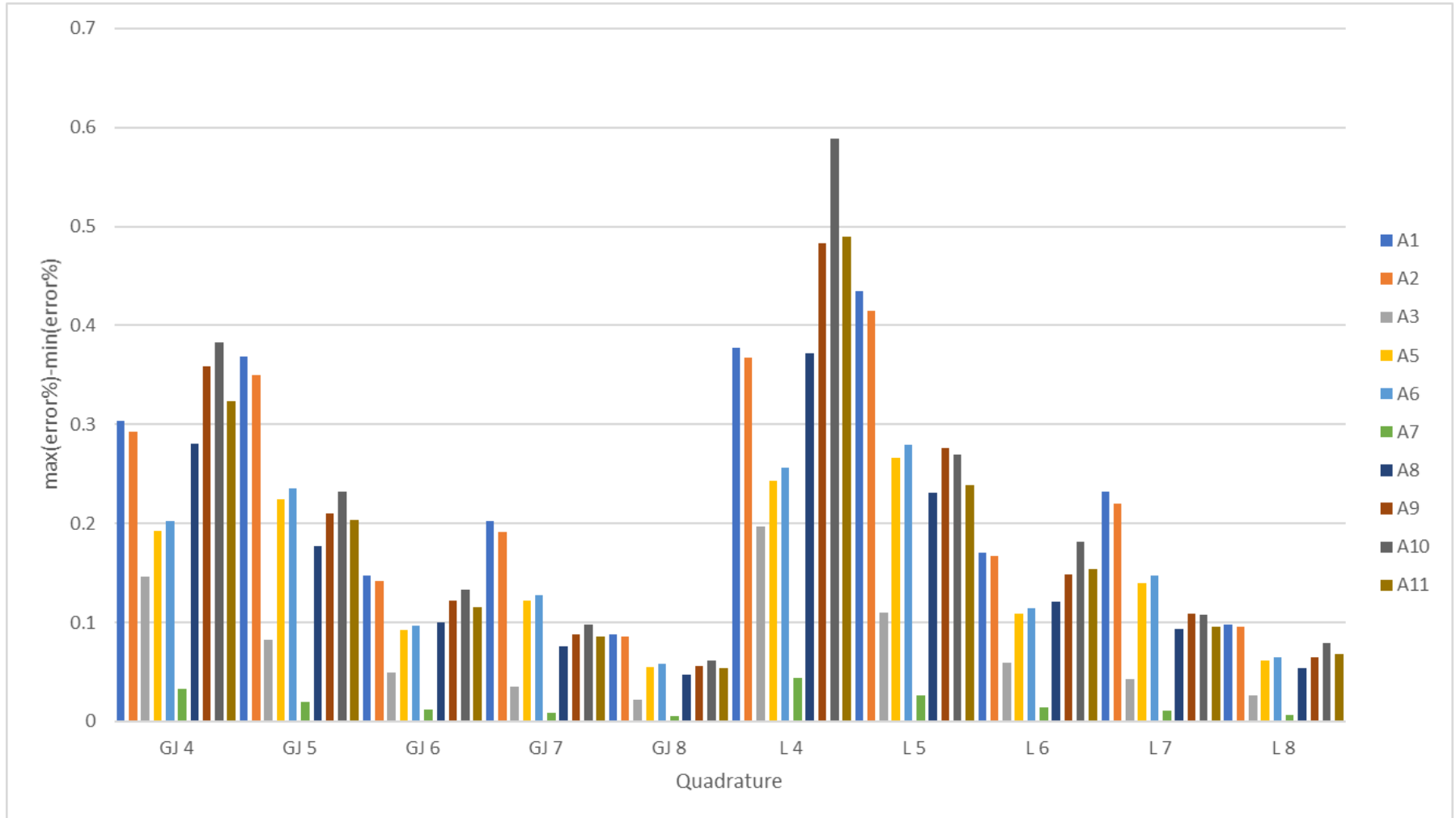$$v(r,\theta) = v(\sqrt{x^2 + y^2}, \theta)$$

$$\bar{V} \approx \sum_{k=1}^{N} \bar{v}_k A_k$$

$v(r,\theta)$ is defined
therefore $\bar{V}$ can be found

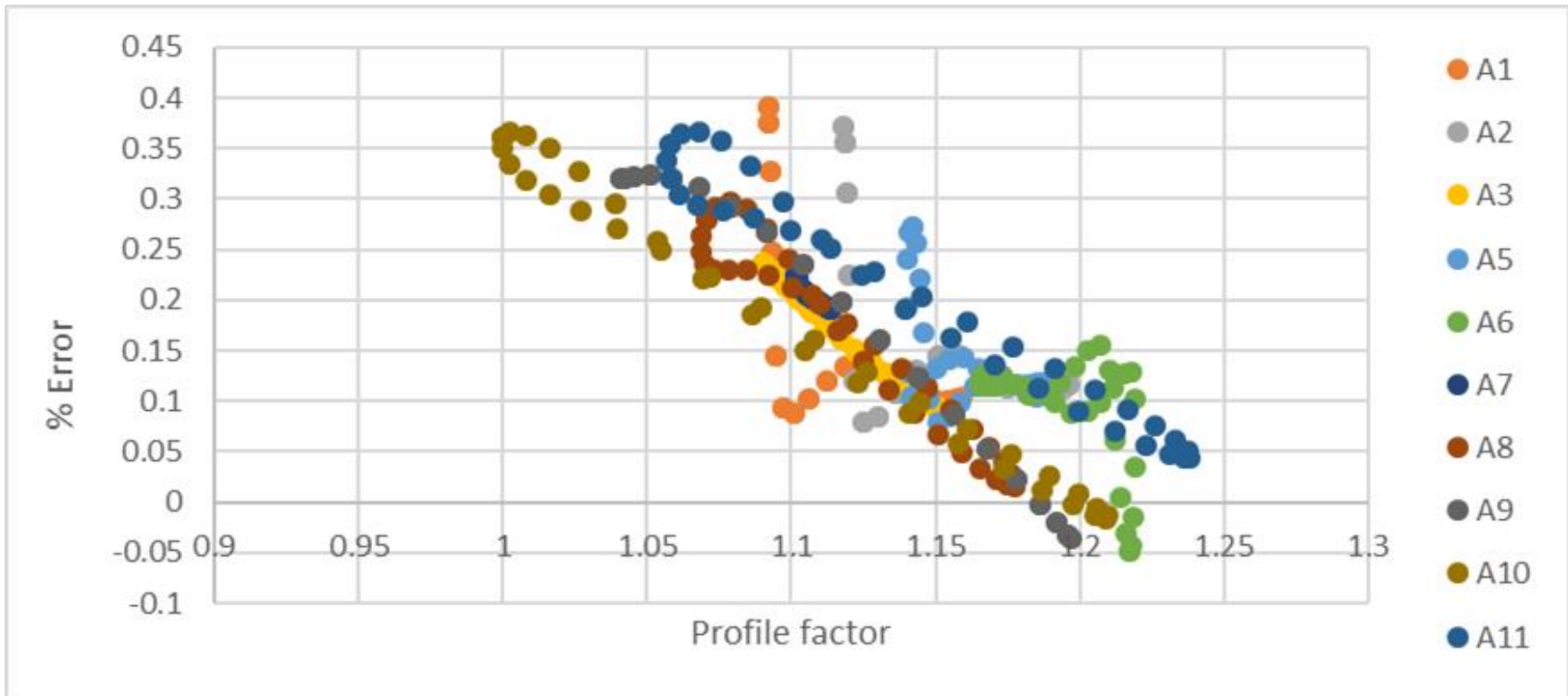# Results – Power Law Profile
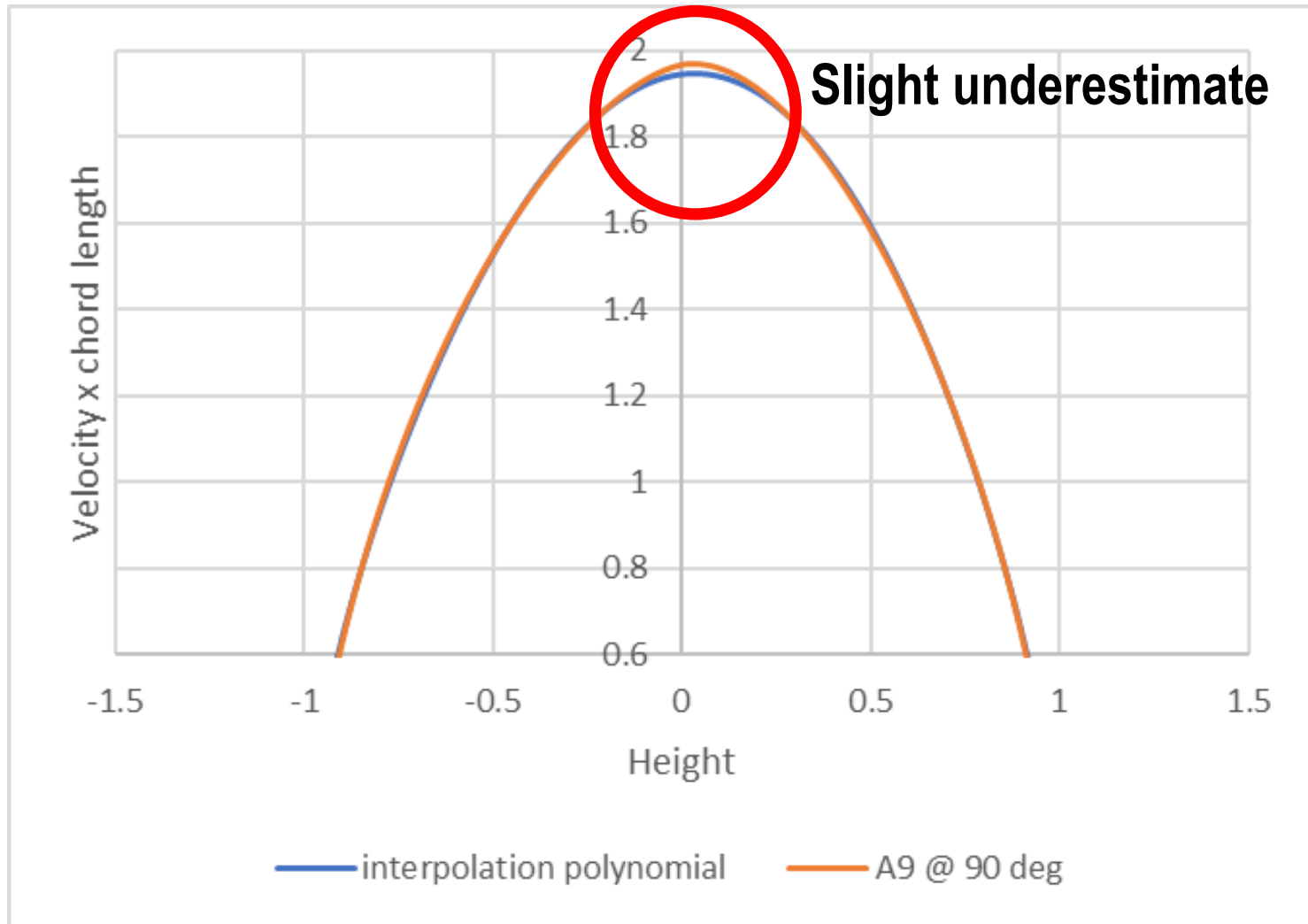
Results – Asymmetric Profiles

Diagnostic Correction - Axial Asymmetry

One has been mentioned in literature and uses profile factor to correct for the presence of axial asymmetry

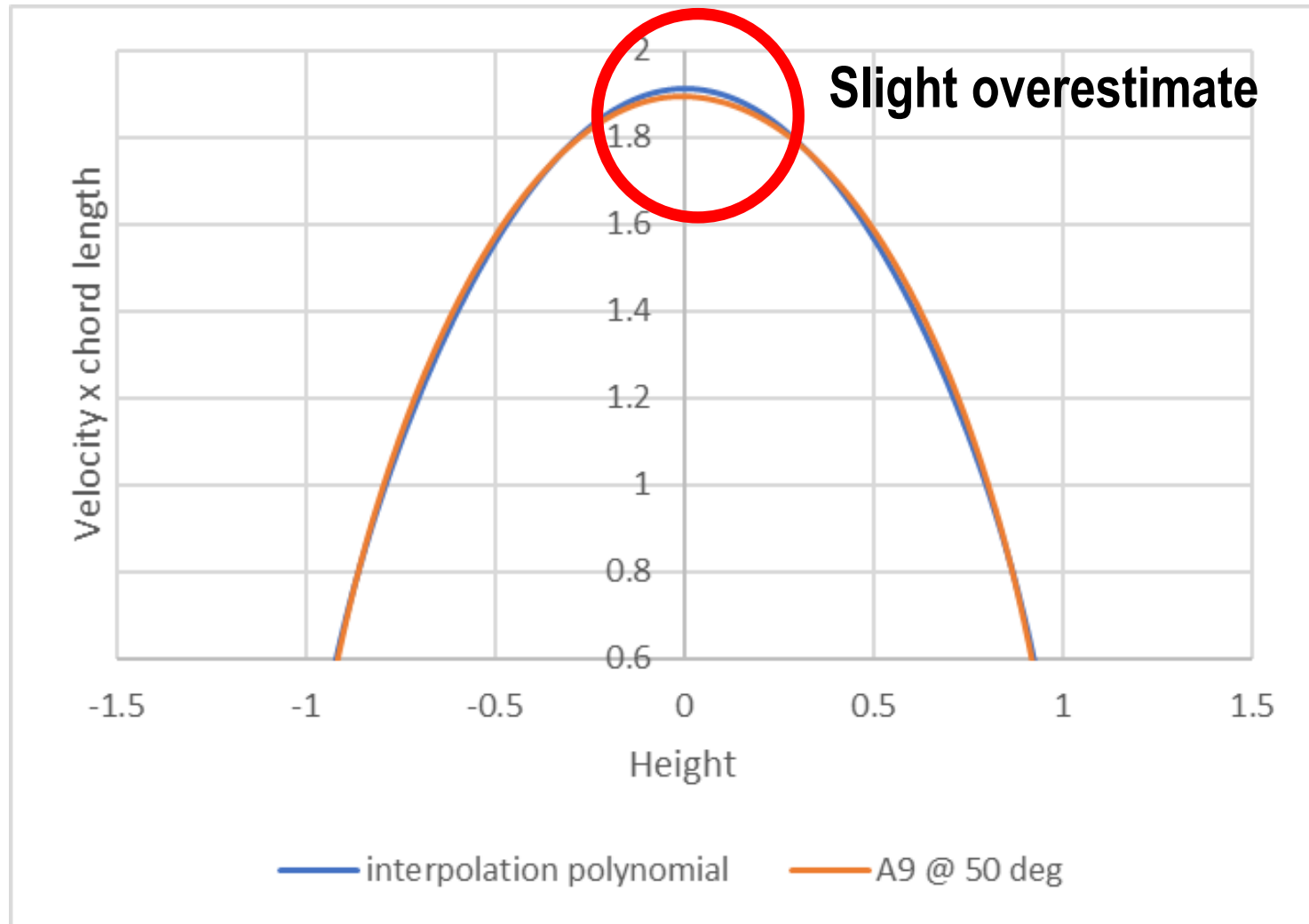*Why does the correlation work?*
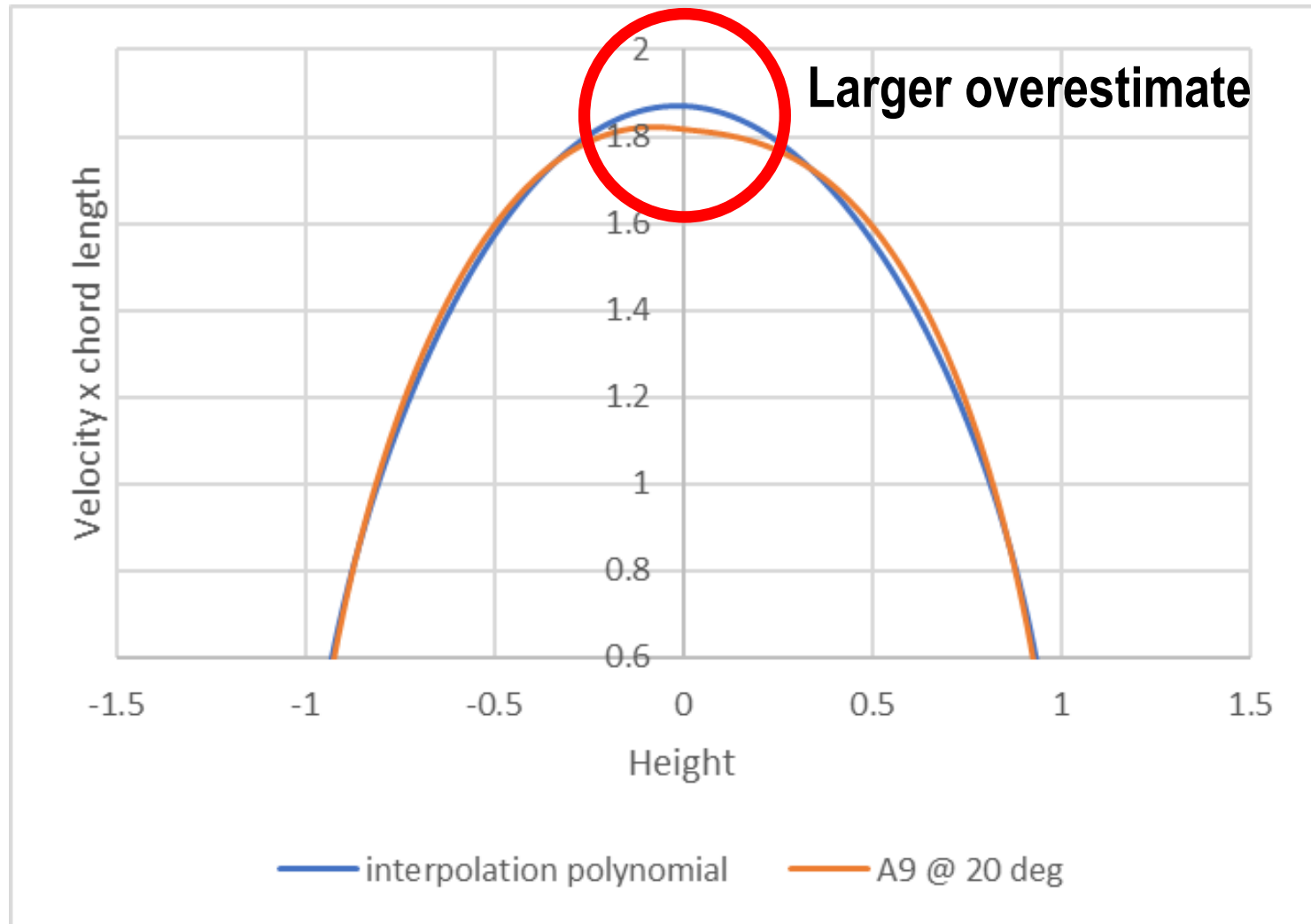
Profile Factor Correlation

Error = -0.04%   Profile factor = 1.2

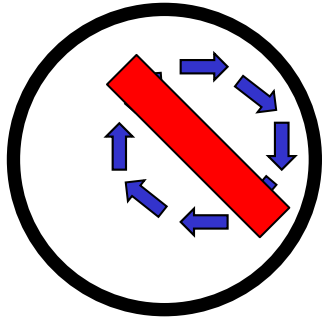# Profile Factor Correlation

Error = 0.16%   Profile factor = 1.13

Profile Factor Correlation

Error = 0.32%   Profile factor = 1.06

Profile Factor Correlation

The correlation can be fooled by swirl

More chords did not strengthen the correlation

$$R^2 \qquad R^2$$
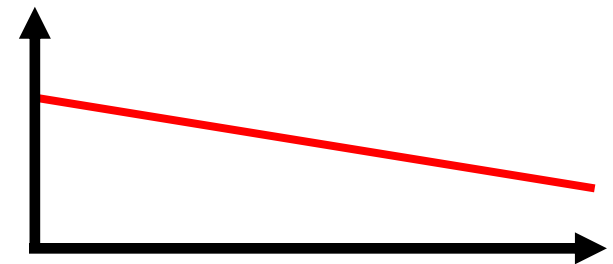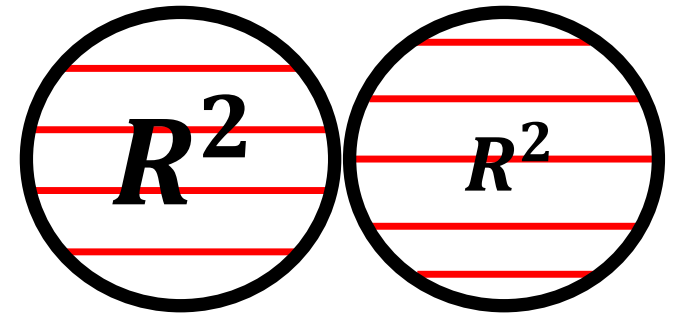
Error due to axial asymmetry

Benefits Of More Paths
- Swirl Cancellation

Two paths crossed per chord with path angles of equal magnitude but opposite sign

Swirl causes an equal and opposite effect on each path *if both paths are at the same height*

The average of the two paths gives the true axial velocity measurement for the chord

A few manufacturers now producing this design with 4 chords

Modelling Asymmetric Swirl
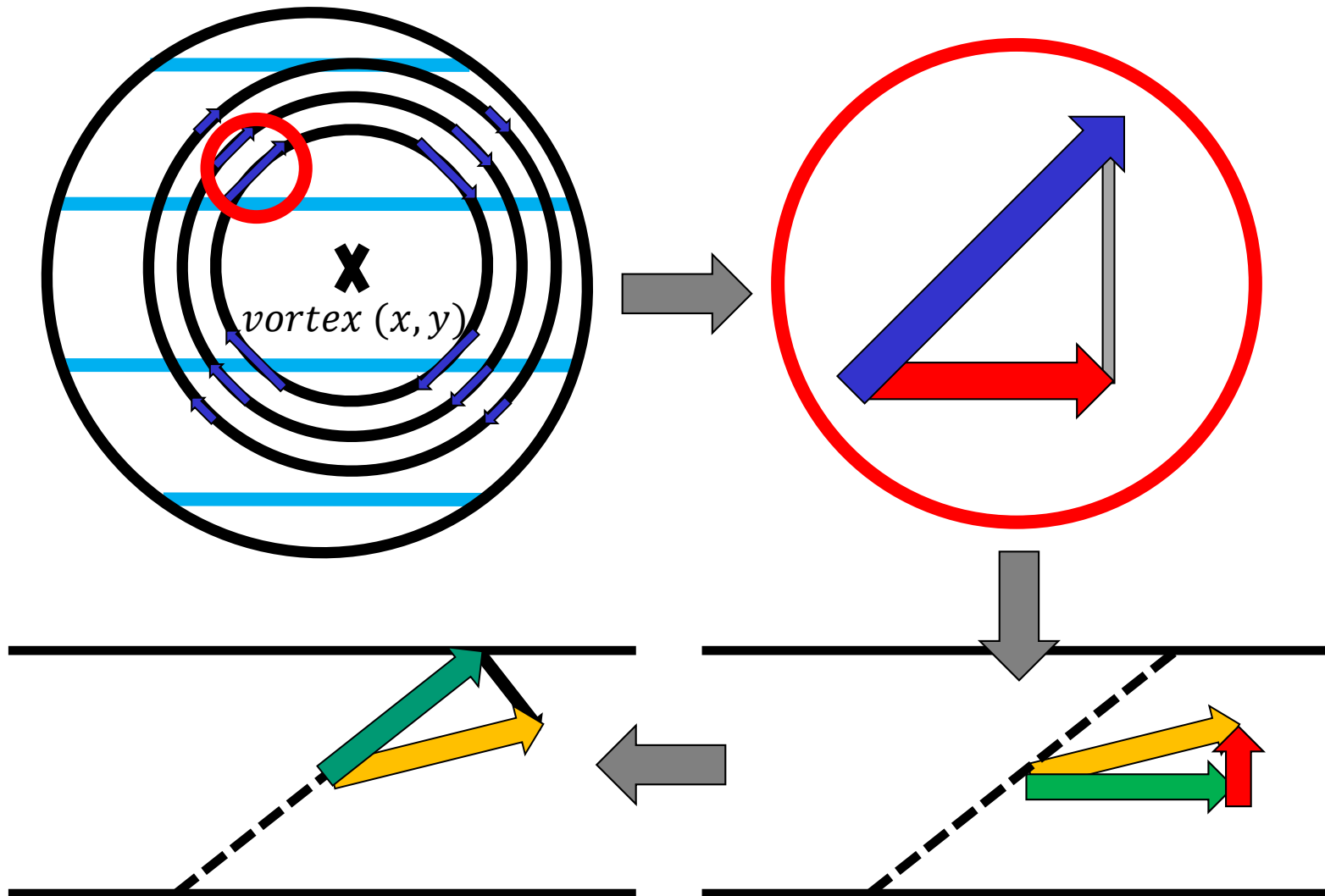
Benefits Of Modelling

Develops understanding and allows meter designs to be tested and compared against one another
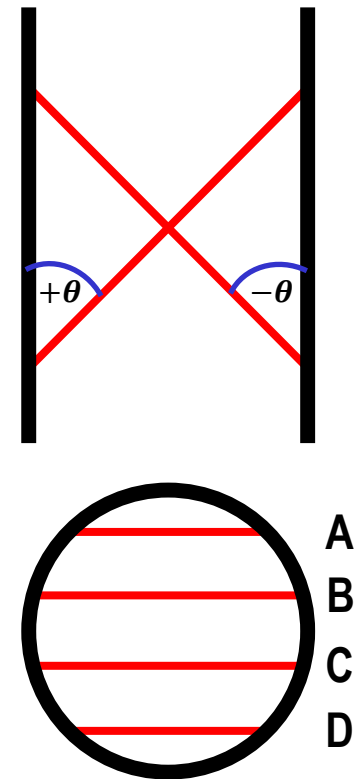
Can test for diagnostic correlations with different designs

Demonstrated the difficulty presently faced in the field with an unknown combination of swirl and asymmetry

Presently estimation of the error magnitude is difficult from diagnostics alone

Why is it so difficult?

Interference With Diagnostics - Parallel Chord

$y = 45.353x - 48.86$
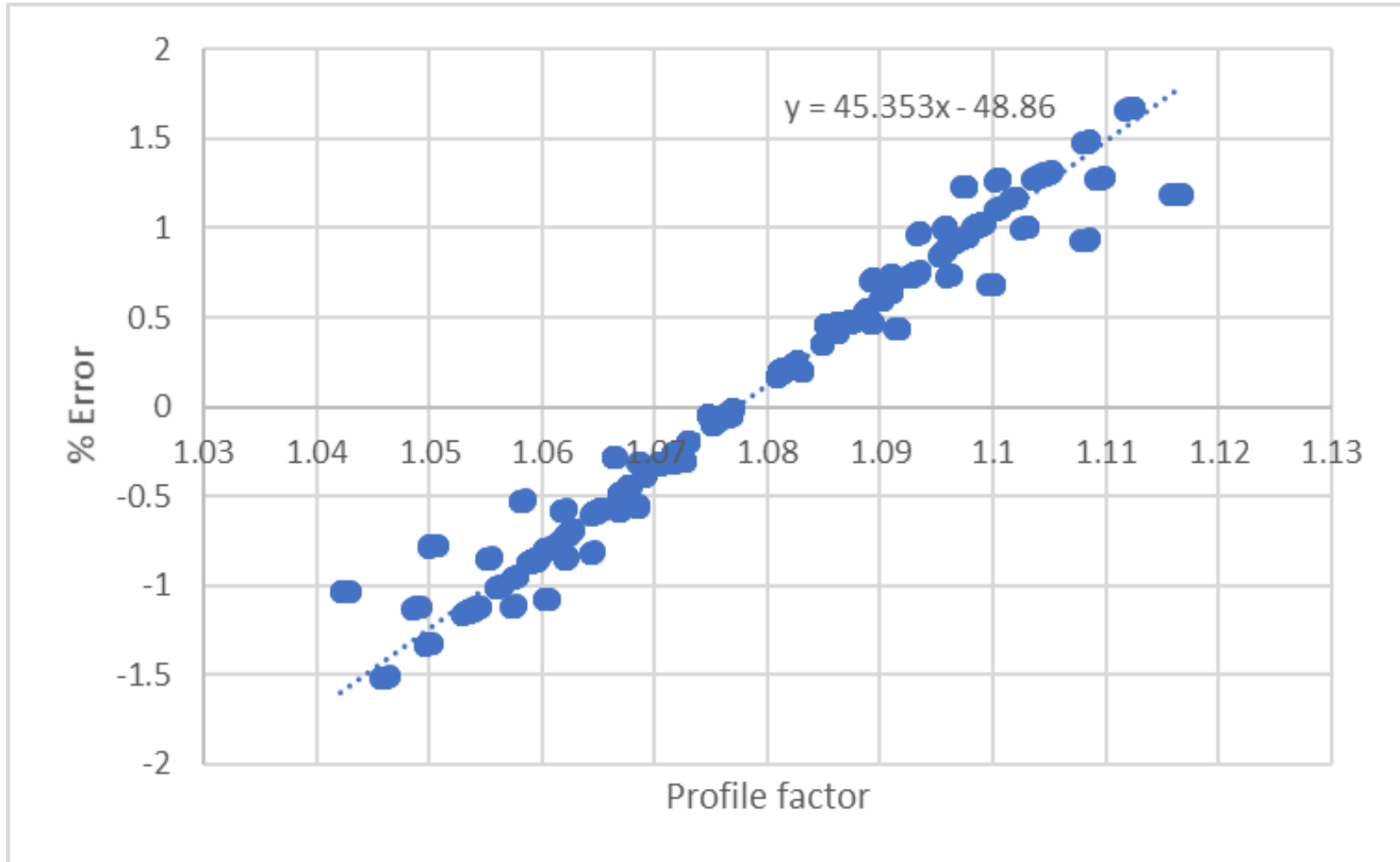
Sensitive to changes in profile factor caused by swirl

Interference With Diagnostics - Crossed Chord

Less sensitive to changes in profile factor caused by swirl

Interference With Diagnostics
- 4 Chords In Axial Asymmetry

North Sea
FLOW
Measurement Workshop
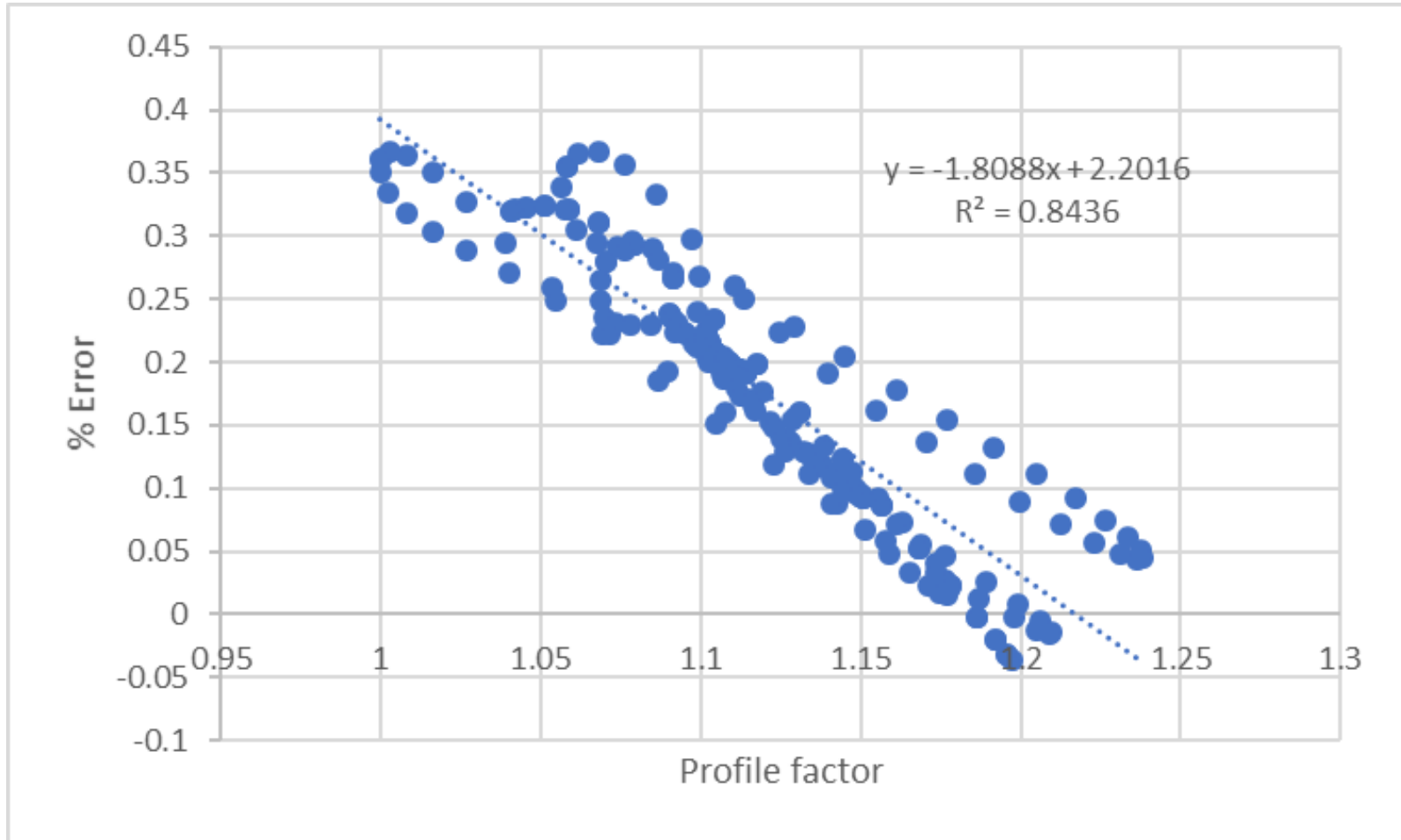
Far less sensitive to changes in profile factor caused by asymmetry

Interference With Diagnostics

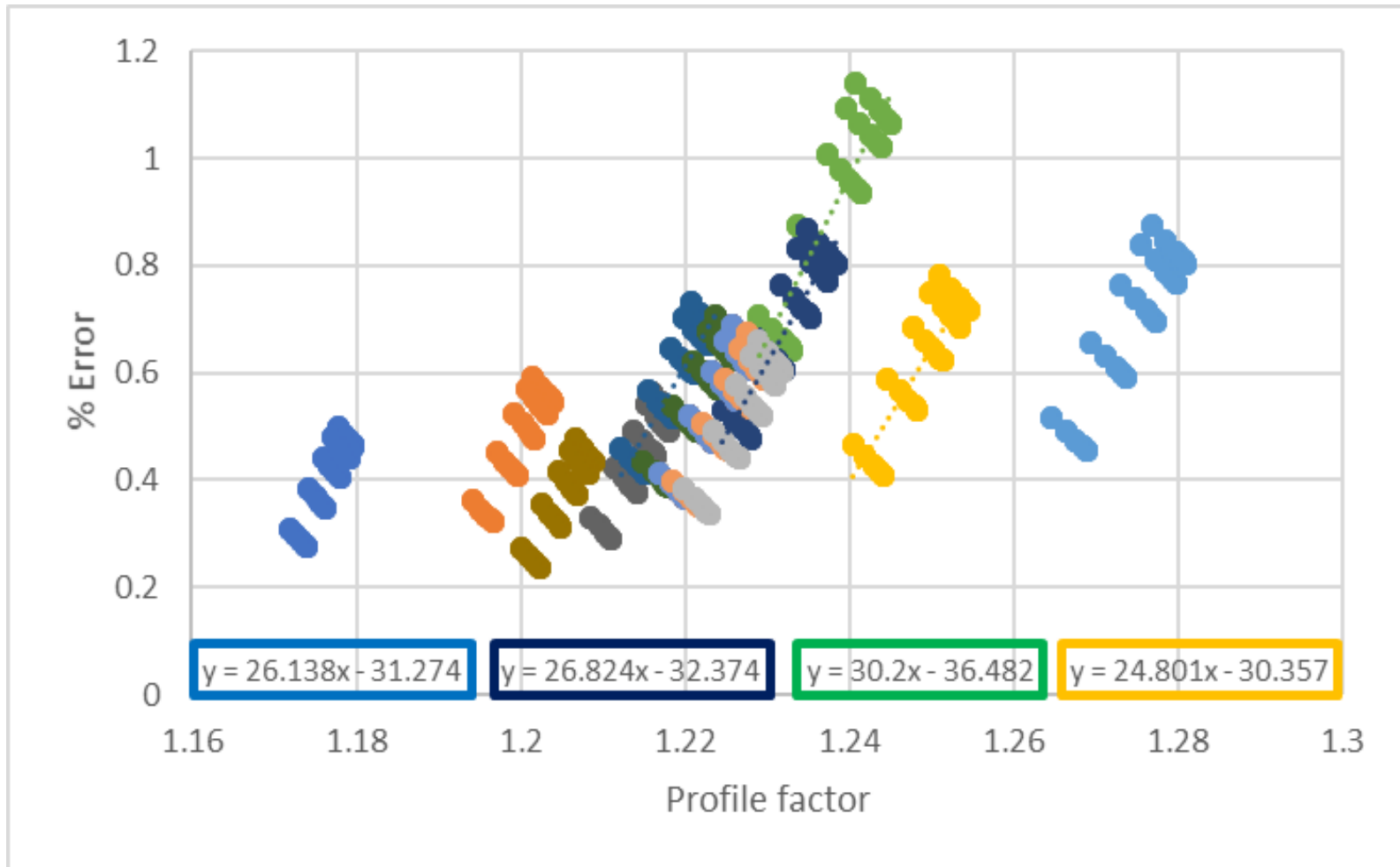Swirl and axial asymmetry change our usual velocity profile diagnostics - profile factor and asymmetry ratio

A change in profile factor caused by swirl has a larger effect on the measurement than the same change caused by axial asymmetry

Difficult to visibly separate swirl from axial asymmetry using diagnostics with some designs

Example – Axial Asymmetry

Profile factor 1.07
Symmetry 0.95
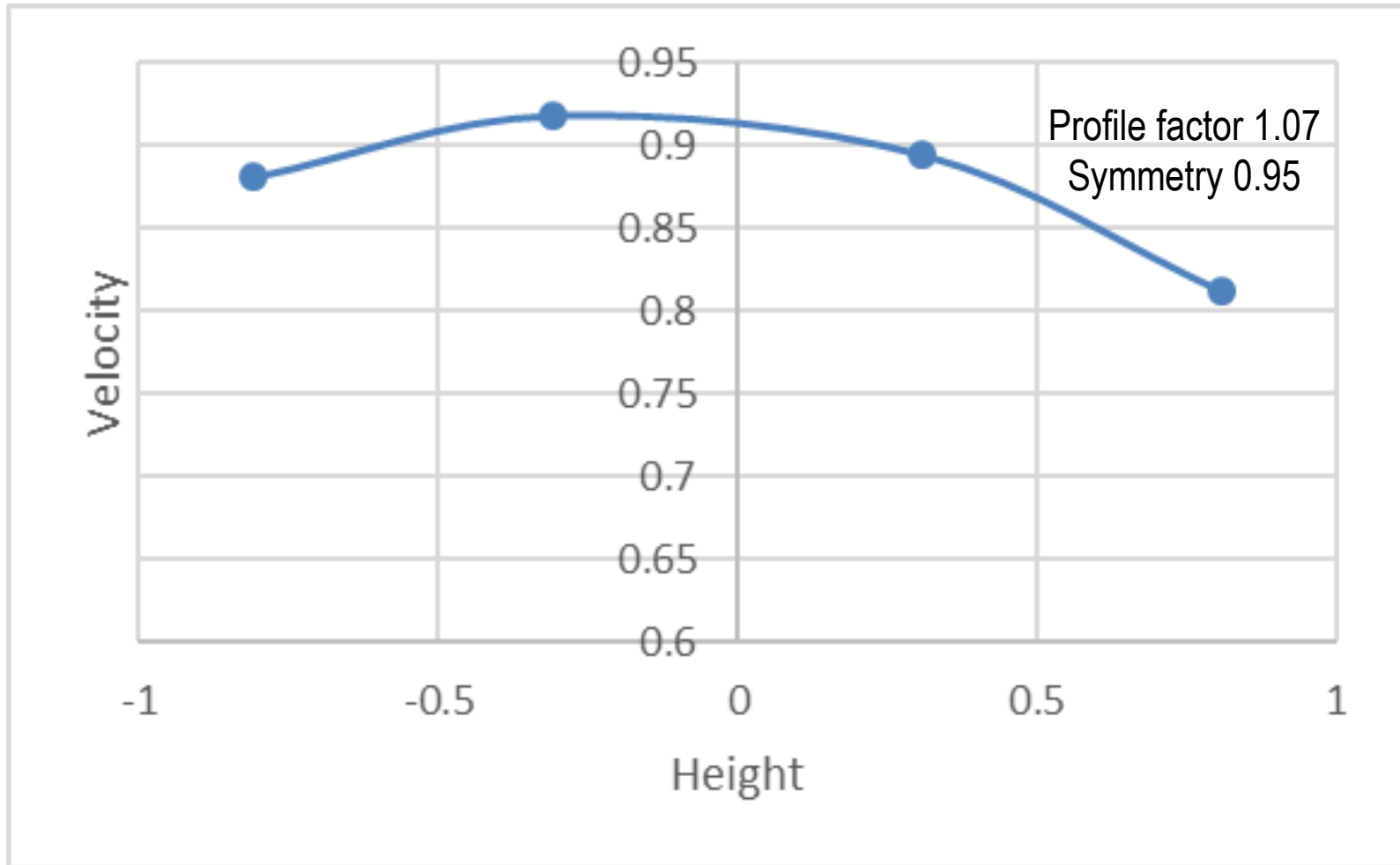
Base case – an error δ will likely be present due to the asymmetry

Example – Axial Asymmetry With Superimposed Swirl
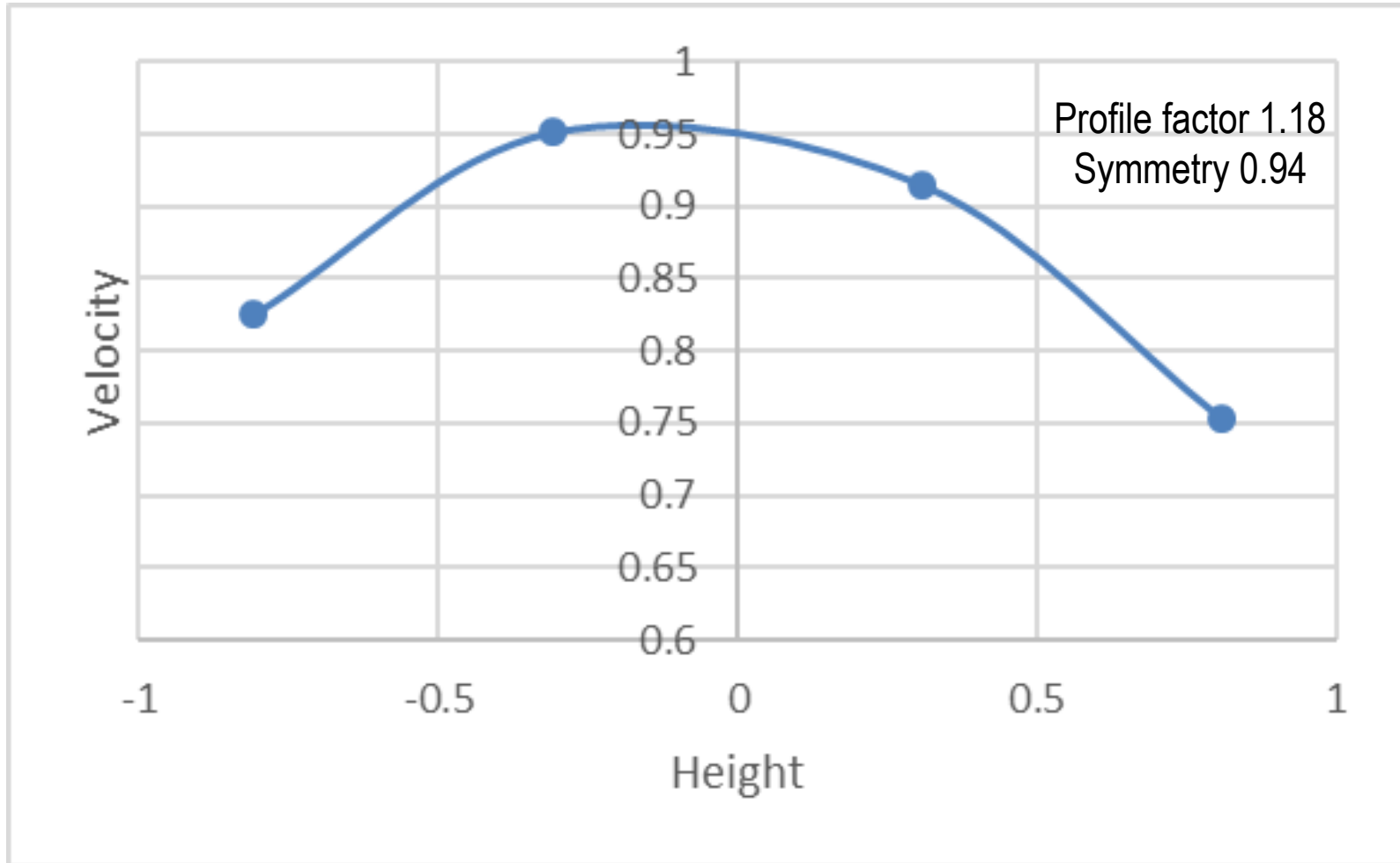
Profile factor 1.18
Symmetry 0.94

Parallel crossed chord: error % = δ + 0.4

Example – Axial Asymmetry With Superimposed Swirl

Profile factor 1.06
Symmetry 1.04
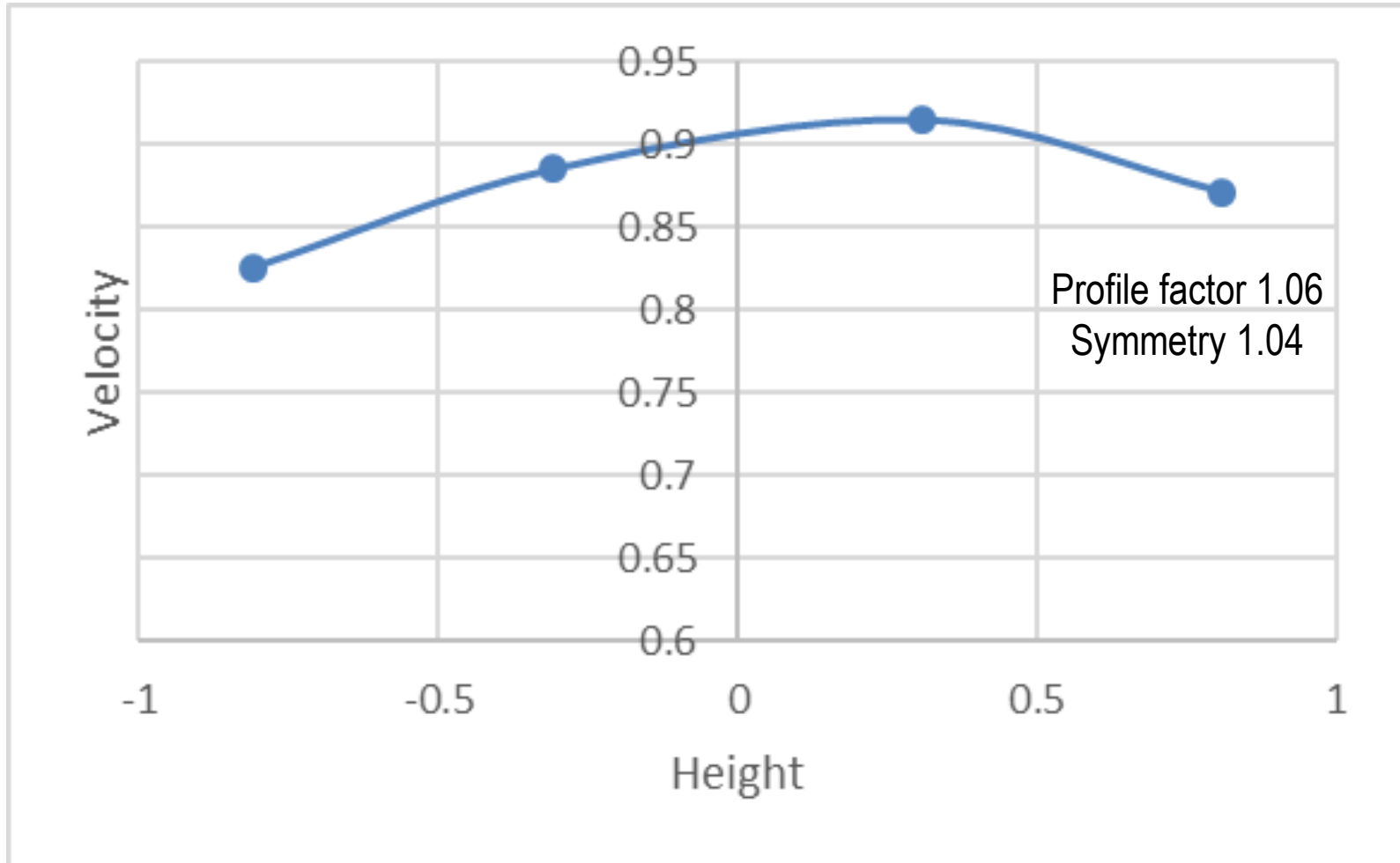
Parallel chord: error % = δ - 0.5

Example – Axial Asymmetry With Superimposed Swirl
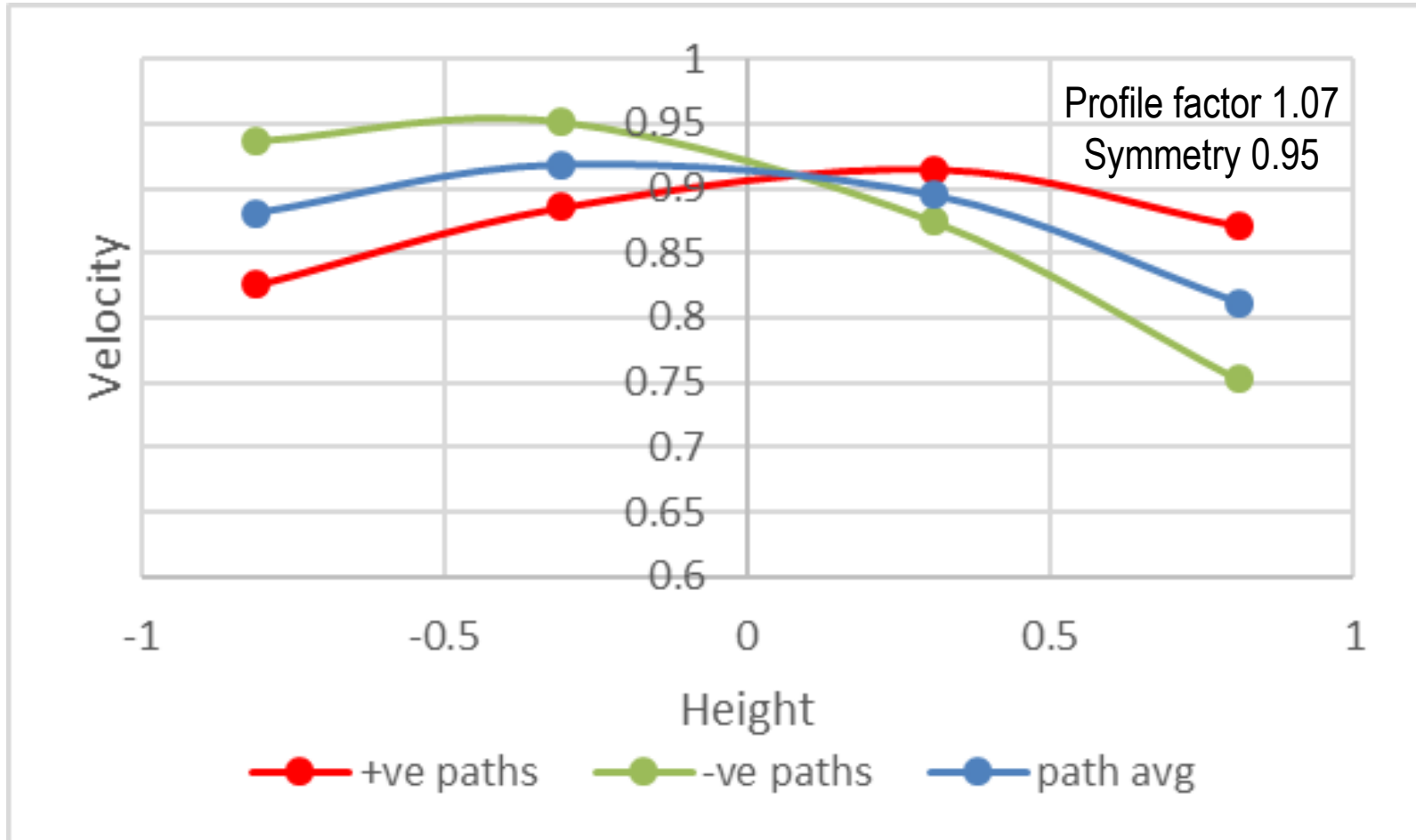
In-plane crossed chord: error % = δ

The true underlying axial profile has been recovered

In-Plane Crossed Chord - Advantages

True swirl cancellation results in reduced upstream straight length requirements, no need for flow conditioner, smaller footprint, *lower cost*

No flow conditioner means no chance of it becoming blocked, *lower risk*

Simplified interpretation of the diagnostics – *interference effects of swirl are removed*

Potentially easier correction for axial asymmetry effects by diagnostic corrections – no interference

Potentially *larger permissible changes in profile factor and asymmetry ratio permitted* before investigative action required

In-Plane Crossed Chord – Final Points

Still affected by axial asymmetry. Magnitude of effect will depend on number of chords and the diagnostic based corrections in use

Still need to monitor for changes in profile factor and asymmetry ratio between calibration facility and site

Installation effect test data (e.g. ISO-17089 or OIML R137) should be released to help users decide permissible changes in diagnostics

More Chords or Diagnostic Based Corrections?

If used for correcting axial asymmetry diagnostic corrections and more chords are two different ways of achieving the same thing

Diagnostic corrections that are kept confidential make it difficult for users to model meter performance (to justify correcting an installation)

More chords reduces the reliance on confidential correlations *that we need for todays high performing meters*

Shouldn't we therefore aspire to develop chordal meters with more than 4 chords?

Summary

4 chords is not optimal – more chords reduces any error from axial asymmetry and potentially reduces reliance on confidential corrections

4 paths is not optimal – more paths can be used for swirl cancellation

We know why a profile factor correlation for correcting for the effects of axial asymmetry appears to work and what the limitations are

Possible reason for why we are struggling to relate a change in diagnostics to a change in error has been given

The in-plane crossed chord design has superb potential for cost savings through smaller footprint and no flow conditioning
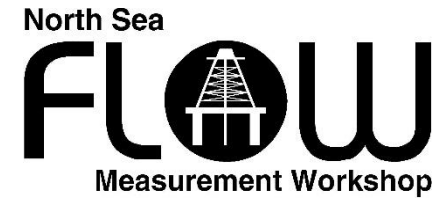
Acknowledgements

Dr Gregor Brown

Douglas Griffin

Steve Peterson

Phil Stockton

Thanks for listening

Questions?