Design and deployment of a prototype multicomponent DAS sensor

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Acknowledgments

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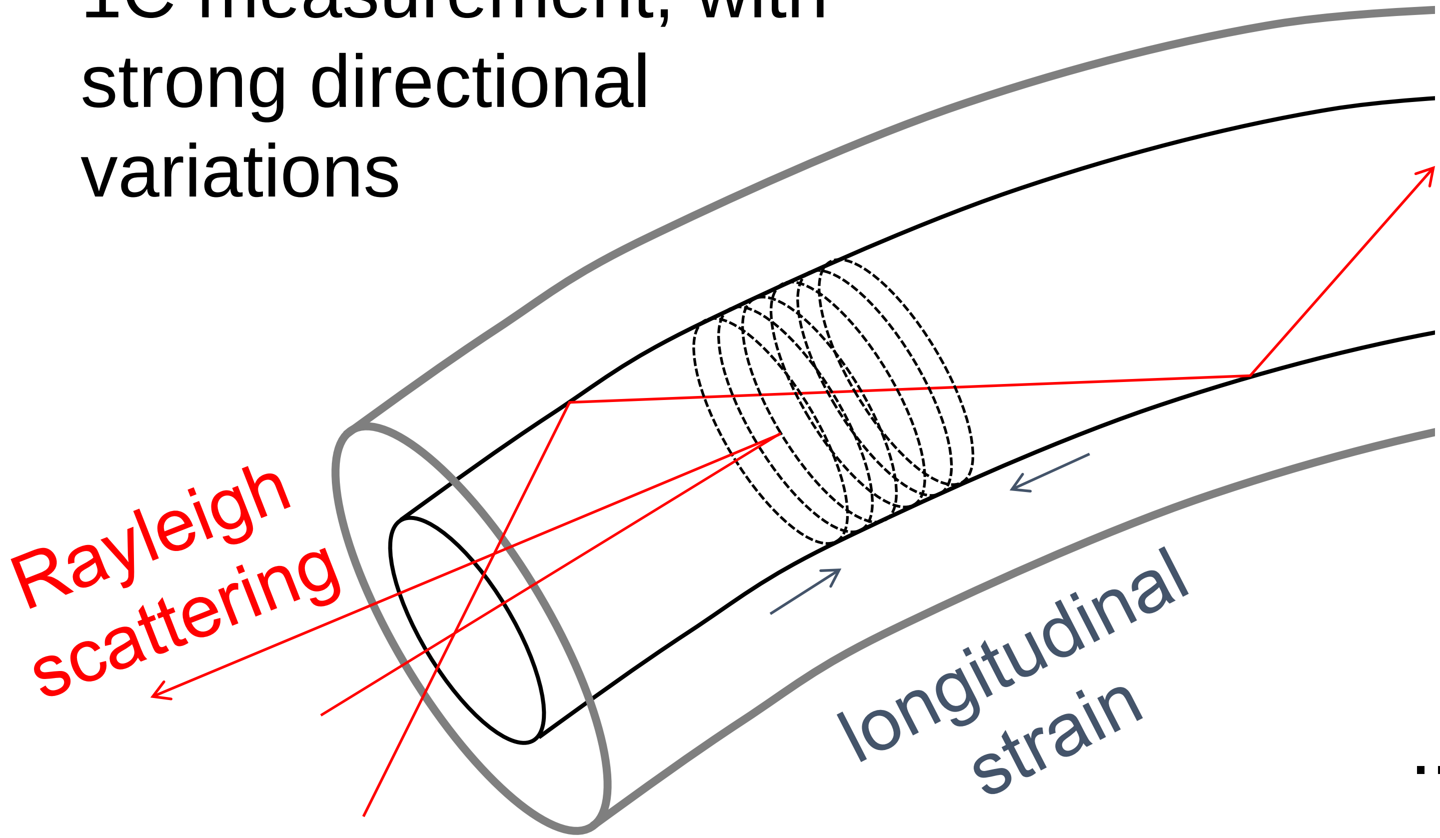
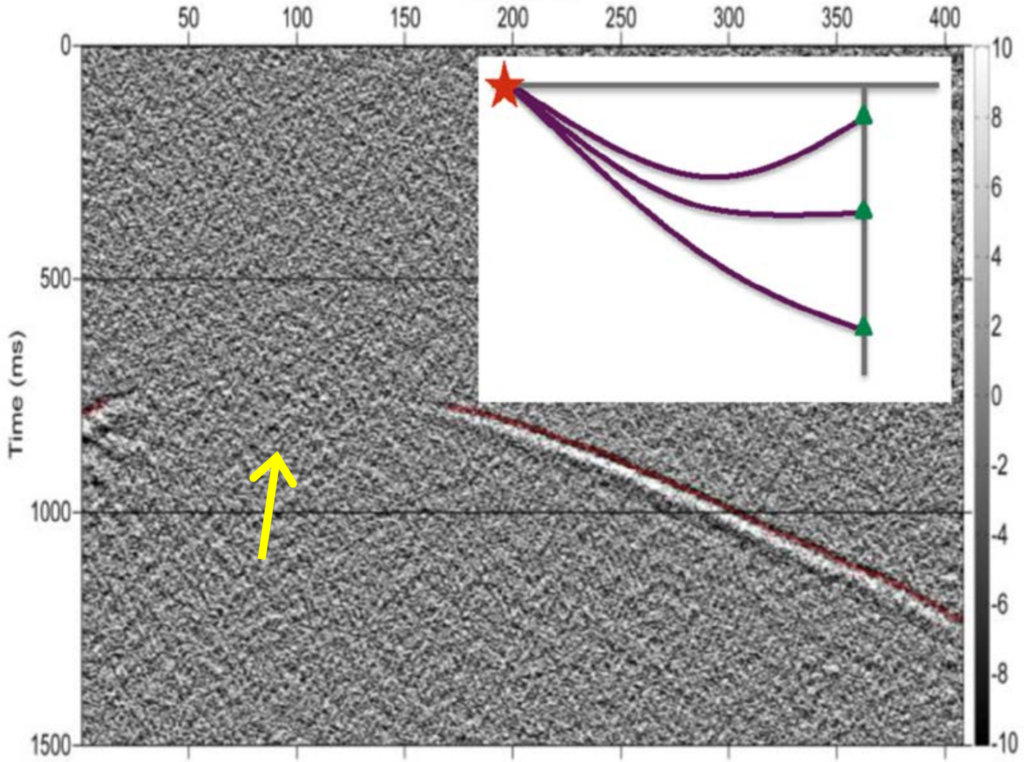
CMC RESEARCH INSTITUTES

Halliburton, LBNL

Motivation: DAS directionality

DAS is a fundamentally 1C measurement, with strong directional variations



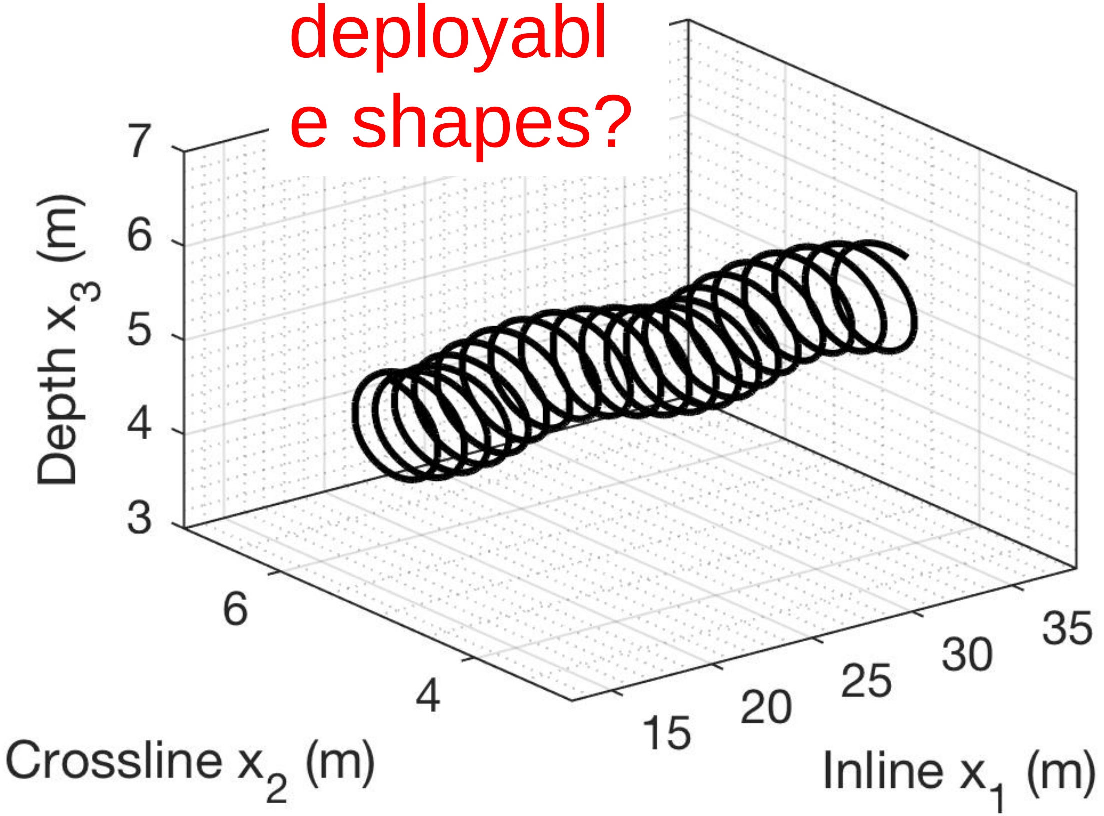


Mateeva et al., 2014

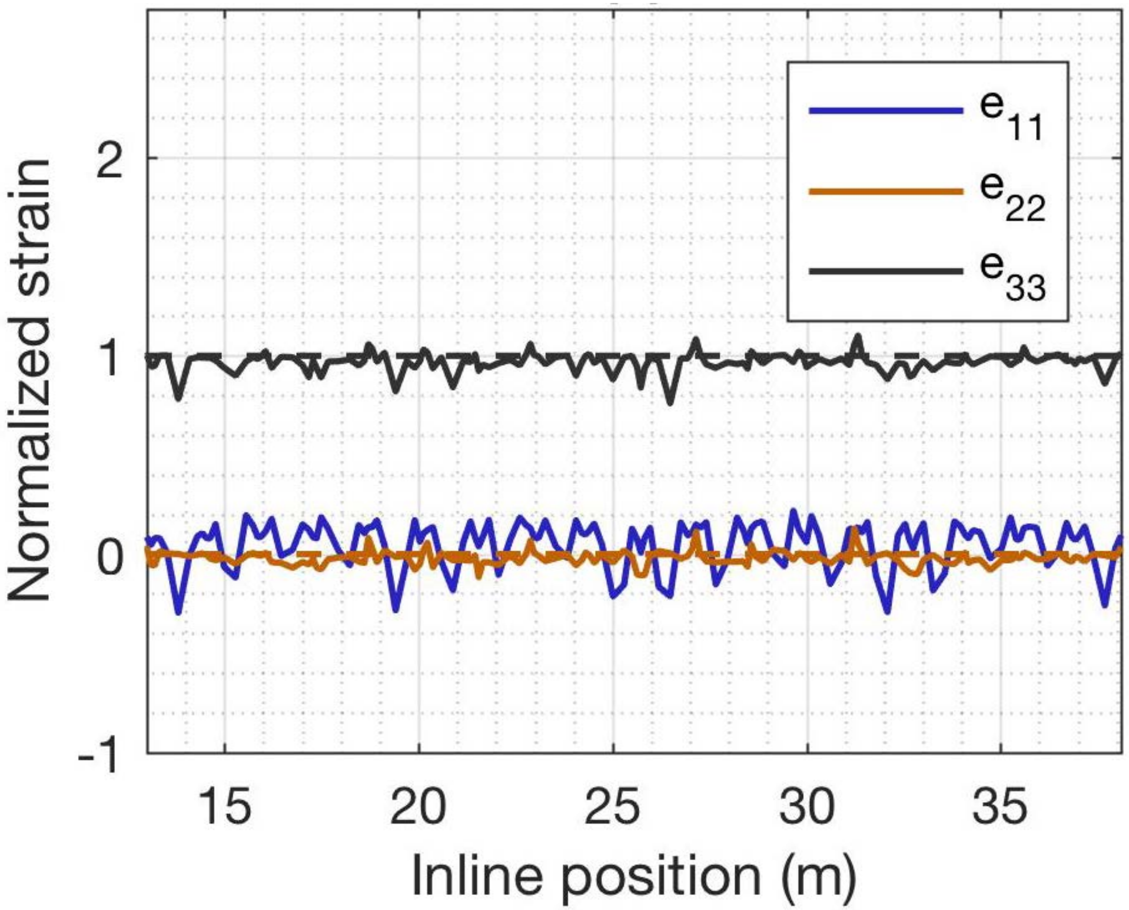
...leading to, e.g., the issue of P-wave broadside insensitivity

Motivation: DAS directionality

Practical, deployabl e shapes?



Intervals consistent with field gauge lengths?



Deployment

Partners

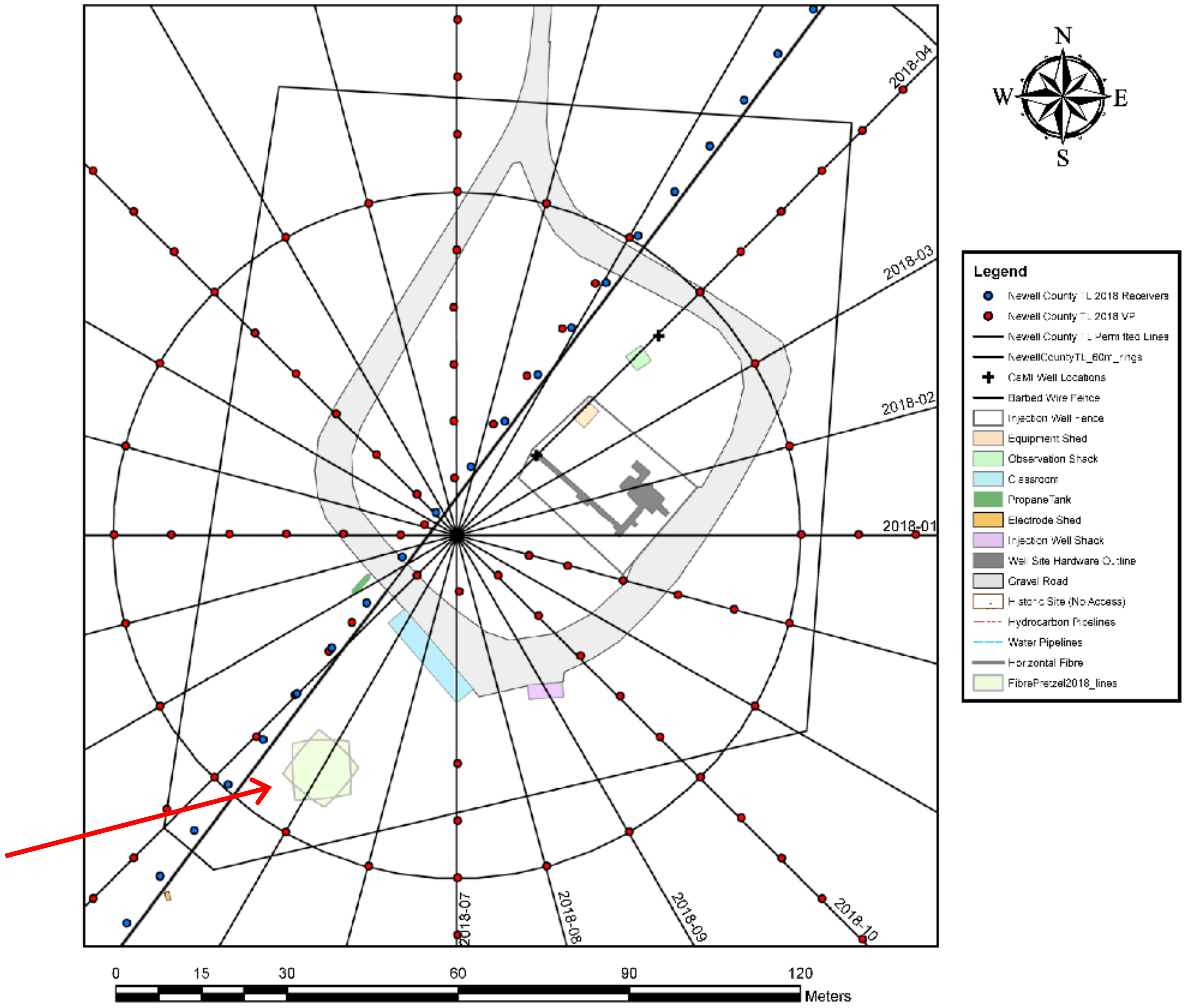
Halliburton

CaMI-FRS

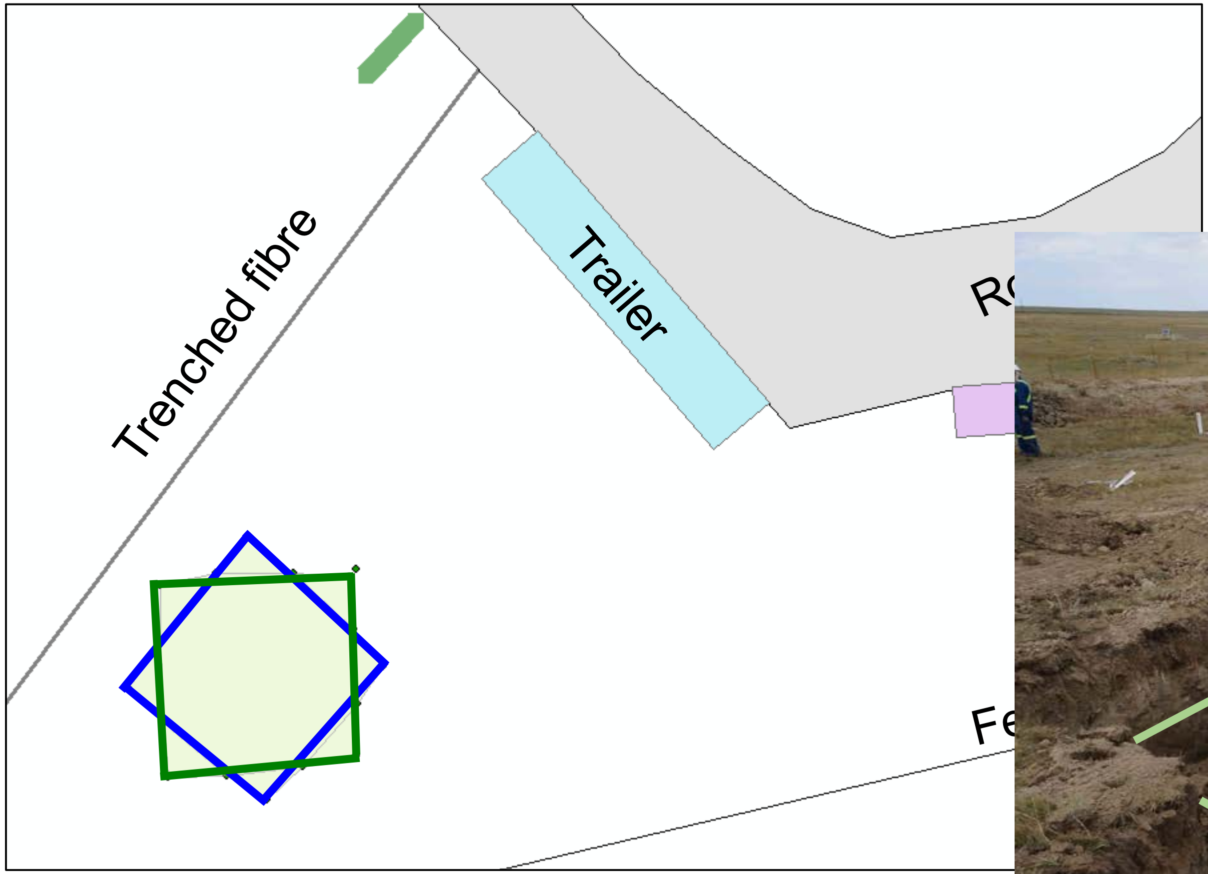
Objectives

- Directionality characterization
- Multicomponent DAS sensing feasibility
- Gauge length v directionality

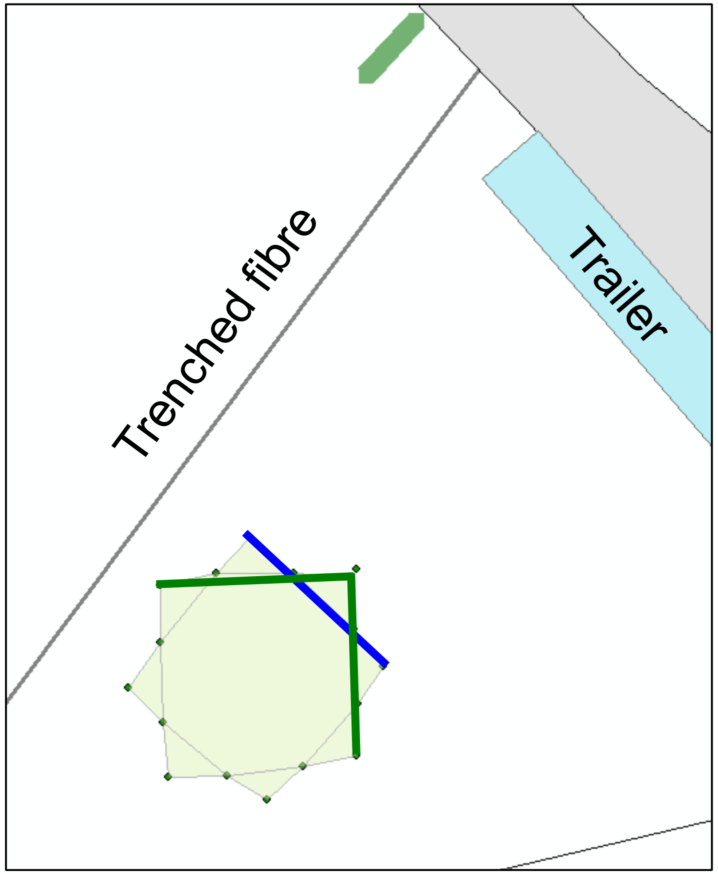
Newell County 2018 TL



Deployment



Deployment



Within each square:

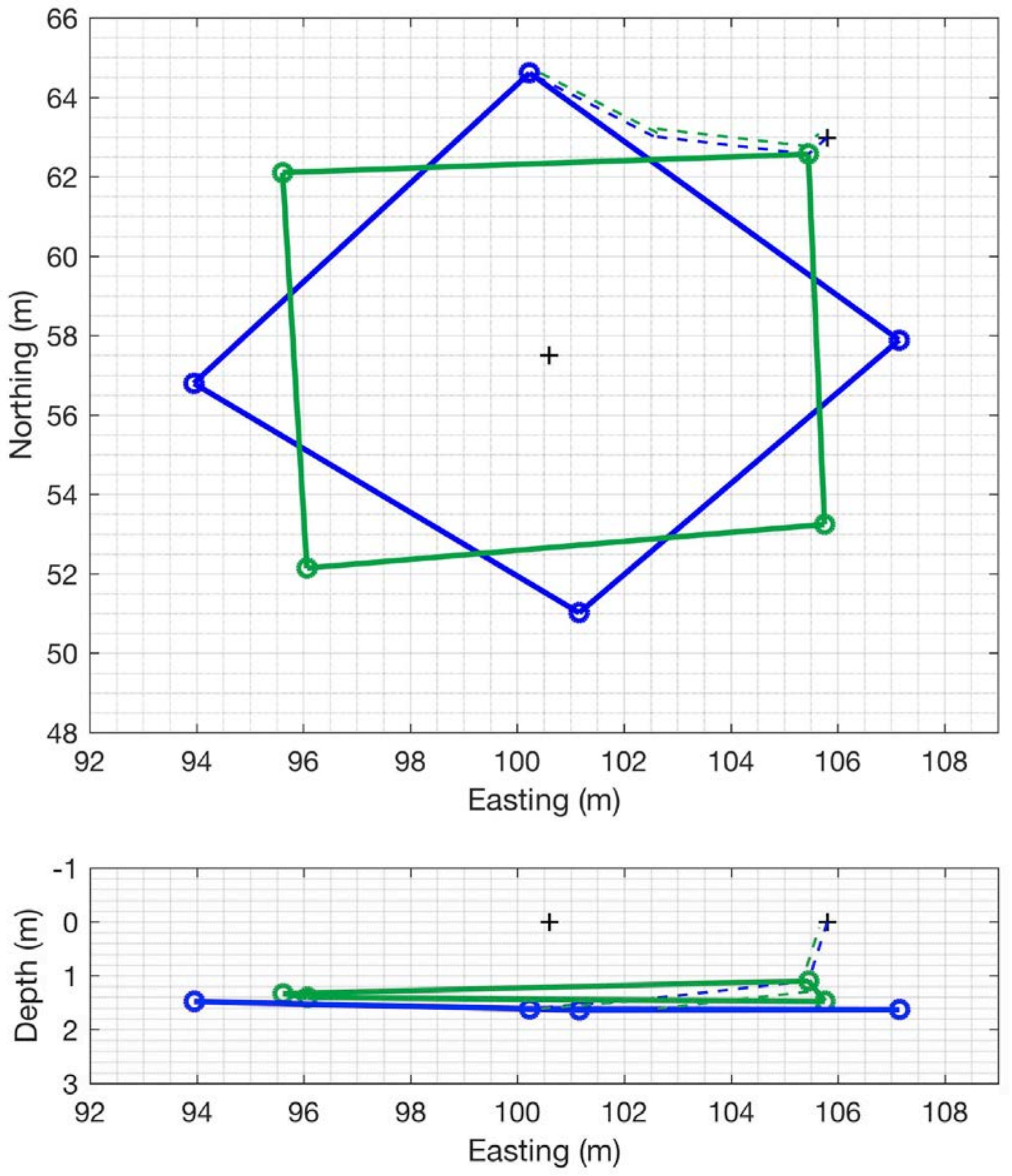
- 2 wraps straight fibre
- 2 wraps HWC

Each segment 10m (1-10 gauge lengths)

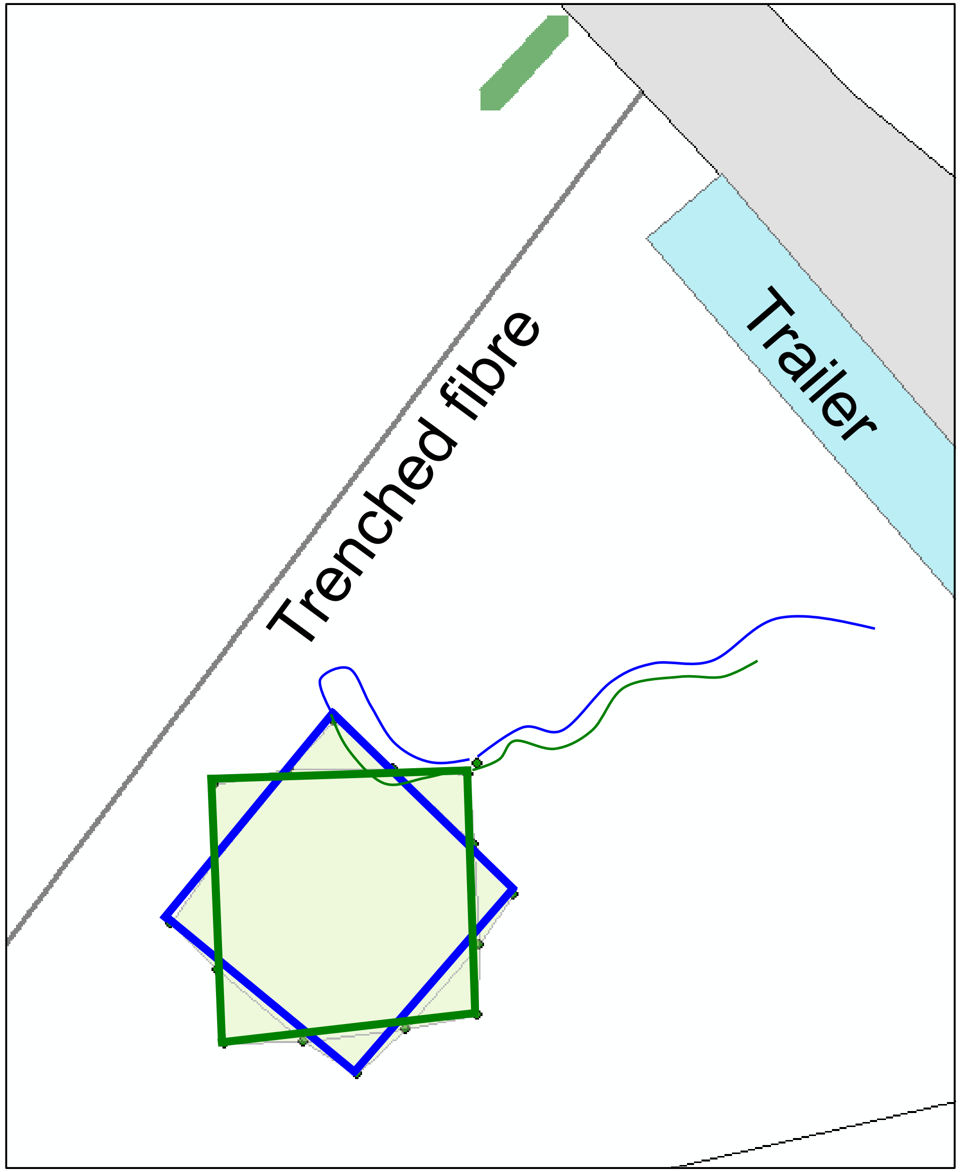
Segments between 1.4m to 1.8m depth.

Each corner & x-over points RTK GPS.

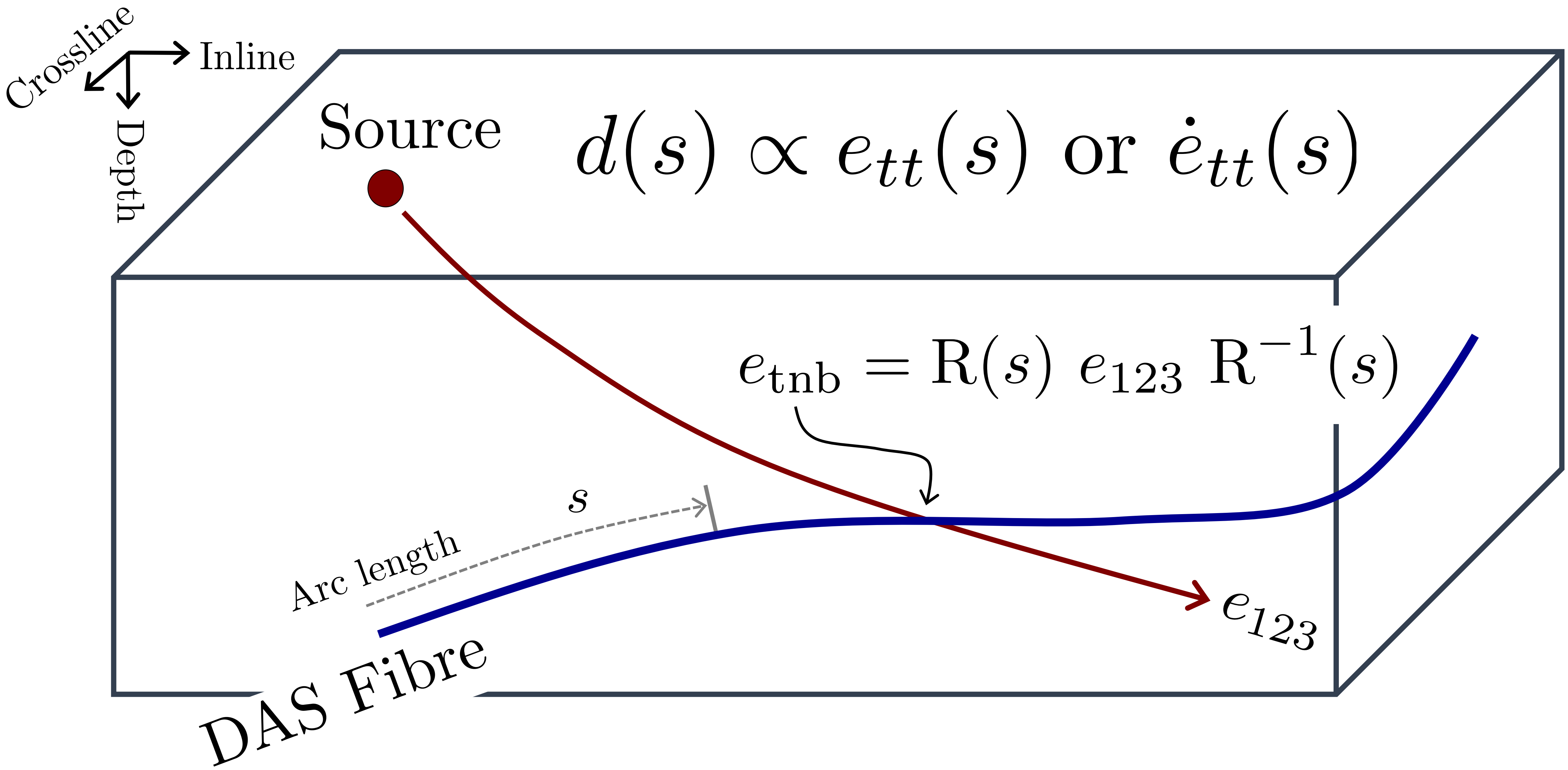
Geometry



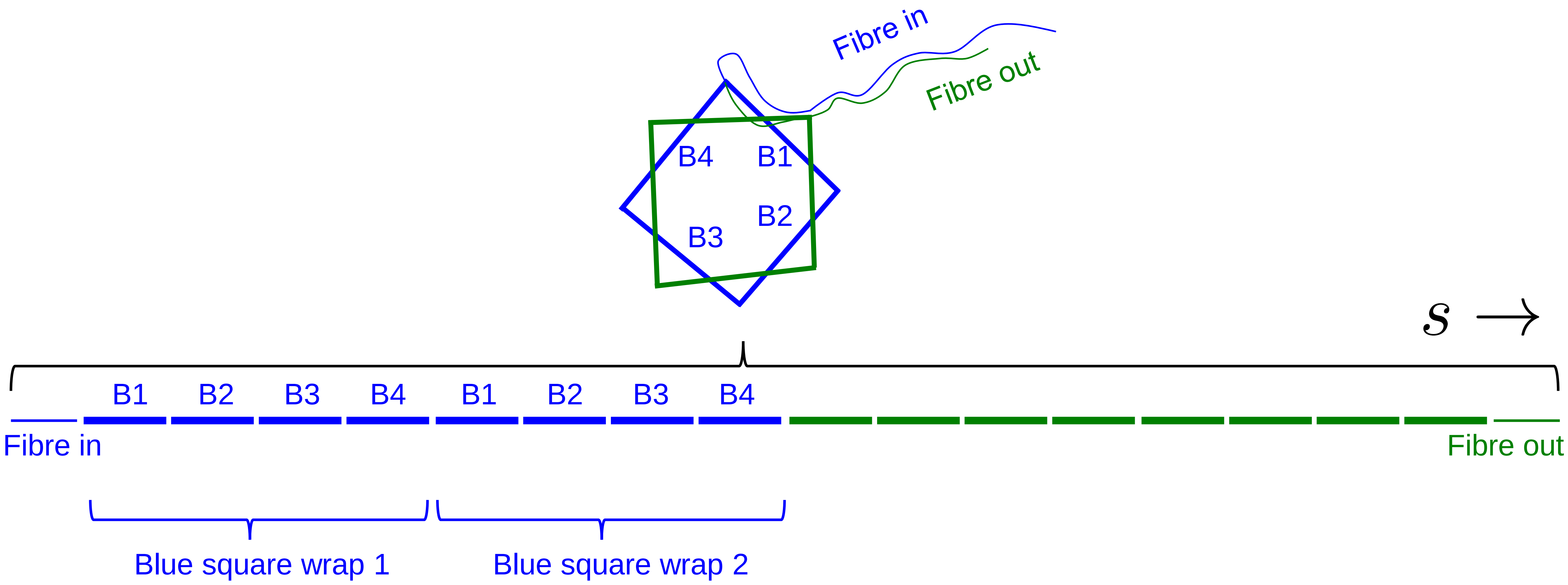
66
64
62
60
58
56
54
52
50
48
Northing (m)
92
94
96
98
100
102
104
106
108
Easting (m)
-1
0
1
2
3
Depth (m)
92
94
96
98
100
102
104
106
108
Easting (m)



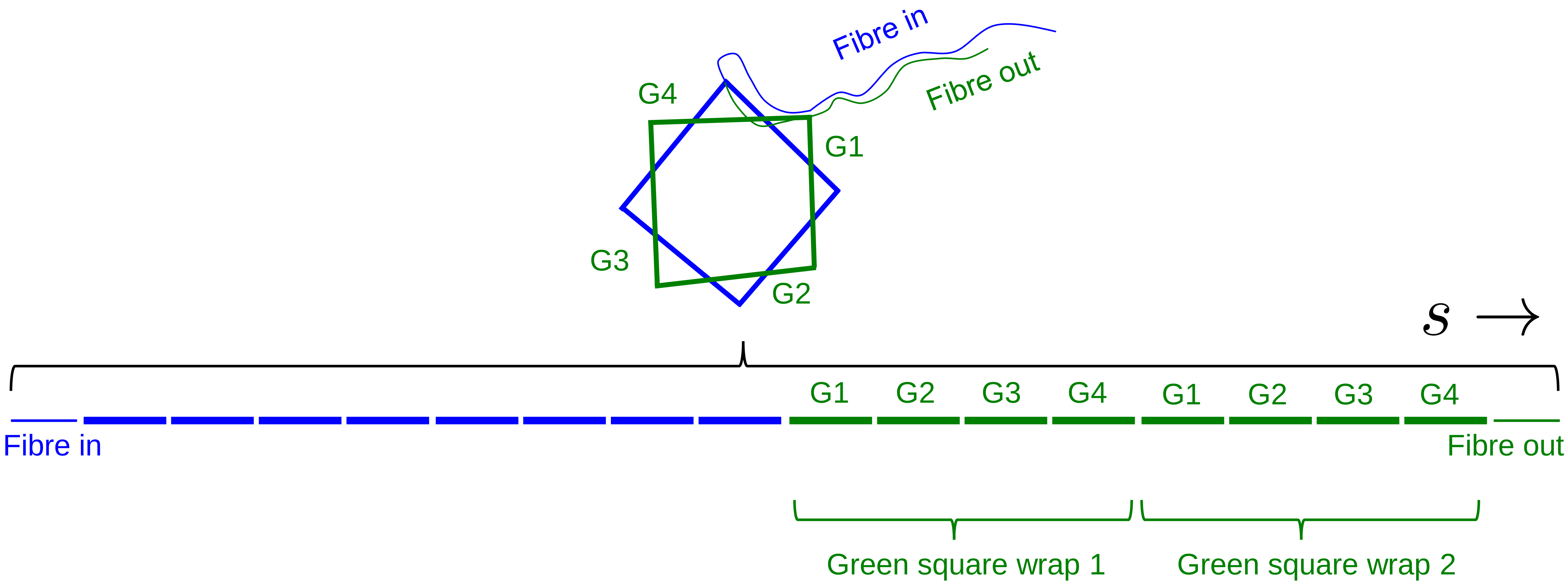
Trenched fibre
Trailer


Crossline
Inline
Depth
Source
$d(s) \propto e_{tt}(s)$ or $\dot{e}_{tt}(s)$
$e_{\mathrm{tnb}} = \mathrm{R}(s)\; e_{123}\; \mathrm{R}^{-1}(s)$
s
Arc length
e_{123}
DAS Fibre

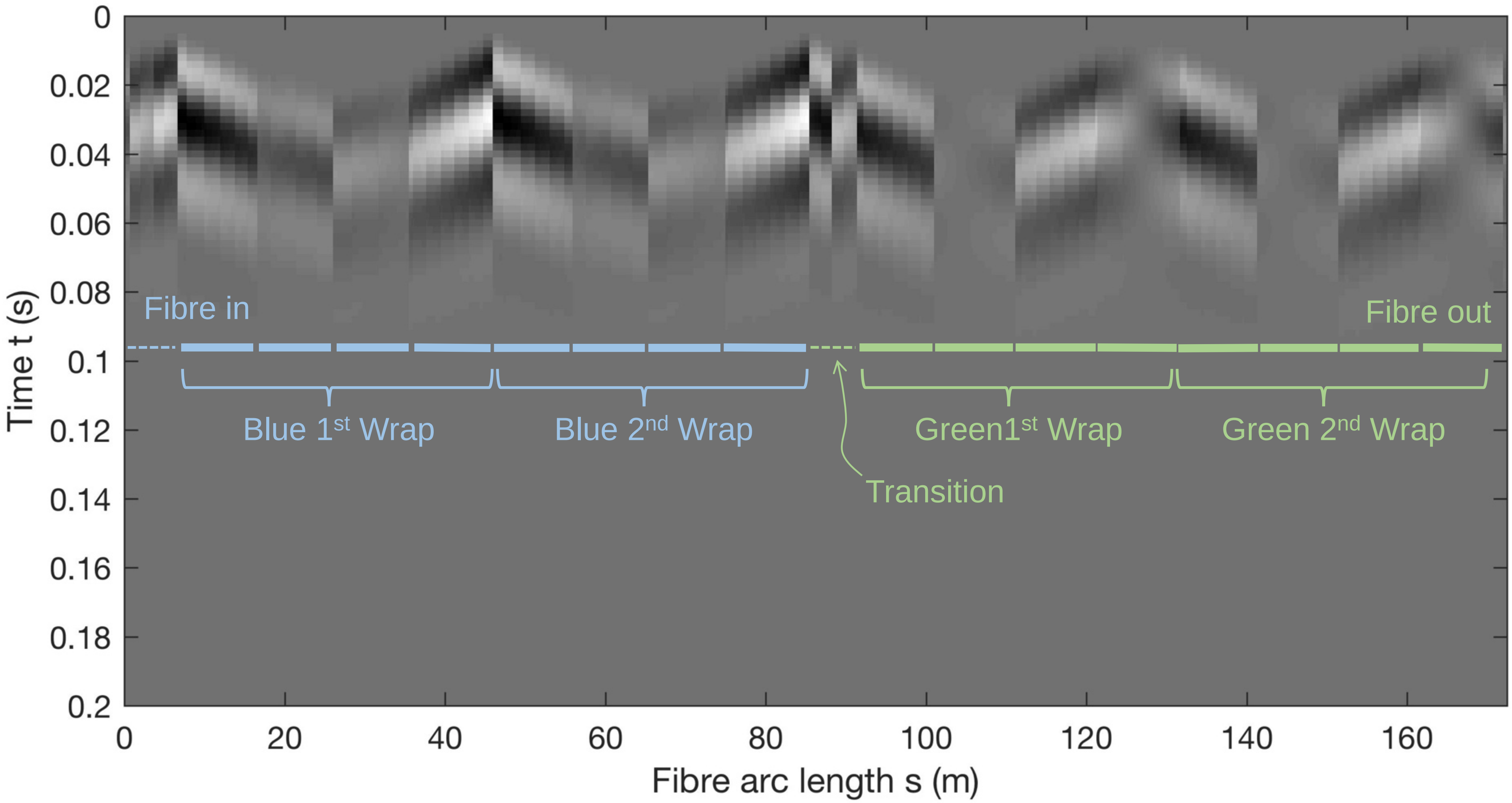
Synthetics



Fibre in
Fibre out
B4
B1
B2
B3
$s \longrightarrow$
B1 B2 B3 B4 B1 B2 B3 B4
Fibre in
Fibre out
Blue square wrap 1
Blue square wrap 2

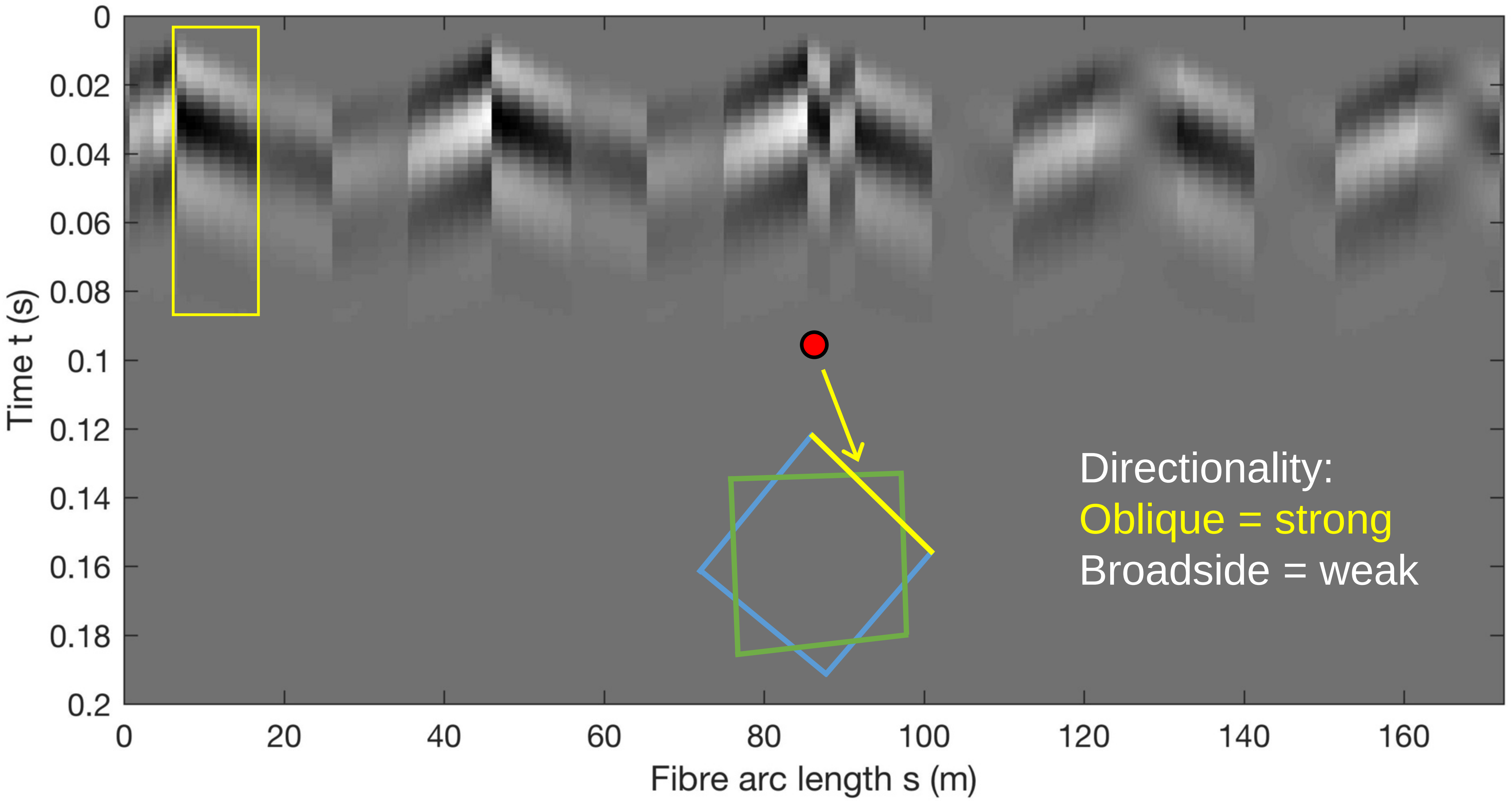

Fibre in
Fibre out
G4
G1
G3
G2
s →
G1
G2
G3
G4
G1
G2
G3
G4
Fibre in
Fibre out
Green square wrap 1
Green square wrap 2

Synthetics

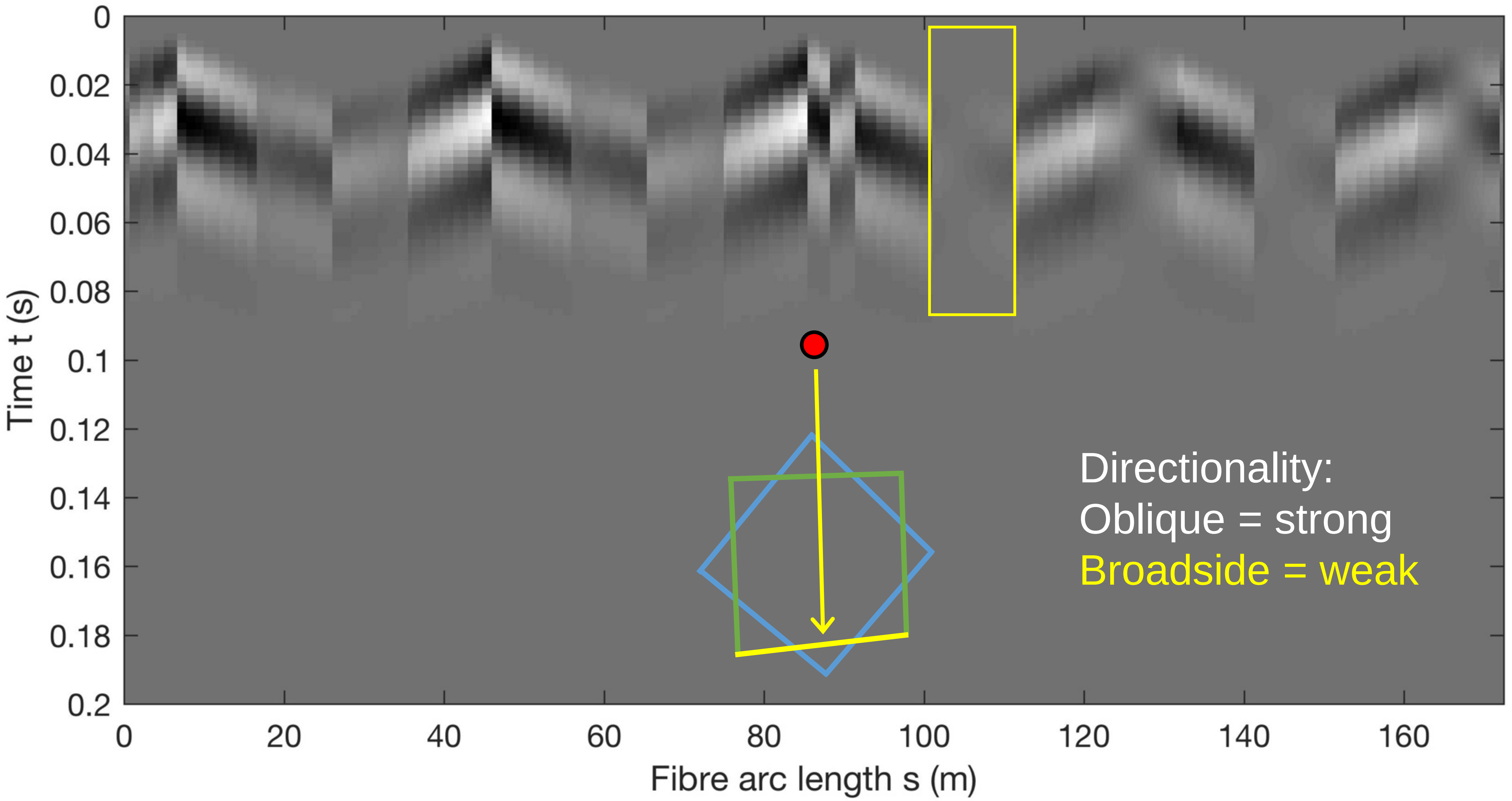


Fibre in
Fibre out
Blue 1st Wrap
Blue 2nd Wrap
Green1st Wrap
Green 2nd Wrap
Transition
Time t (s)
Fibre arc length s (m)
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0
20
40
60
80
100
120
140
160

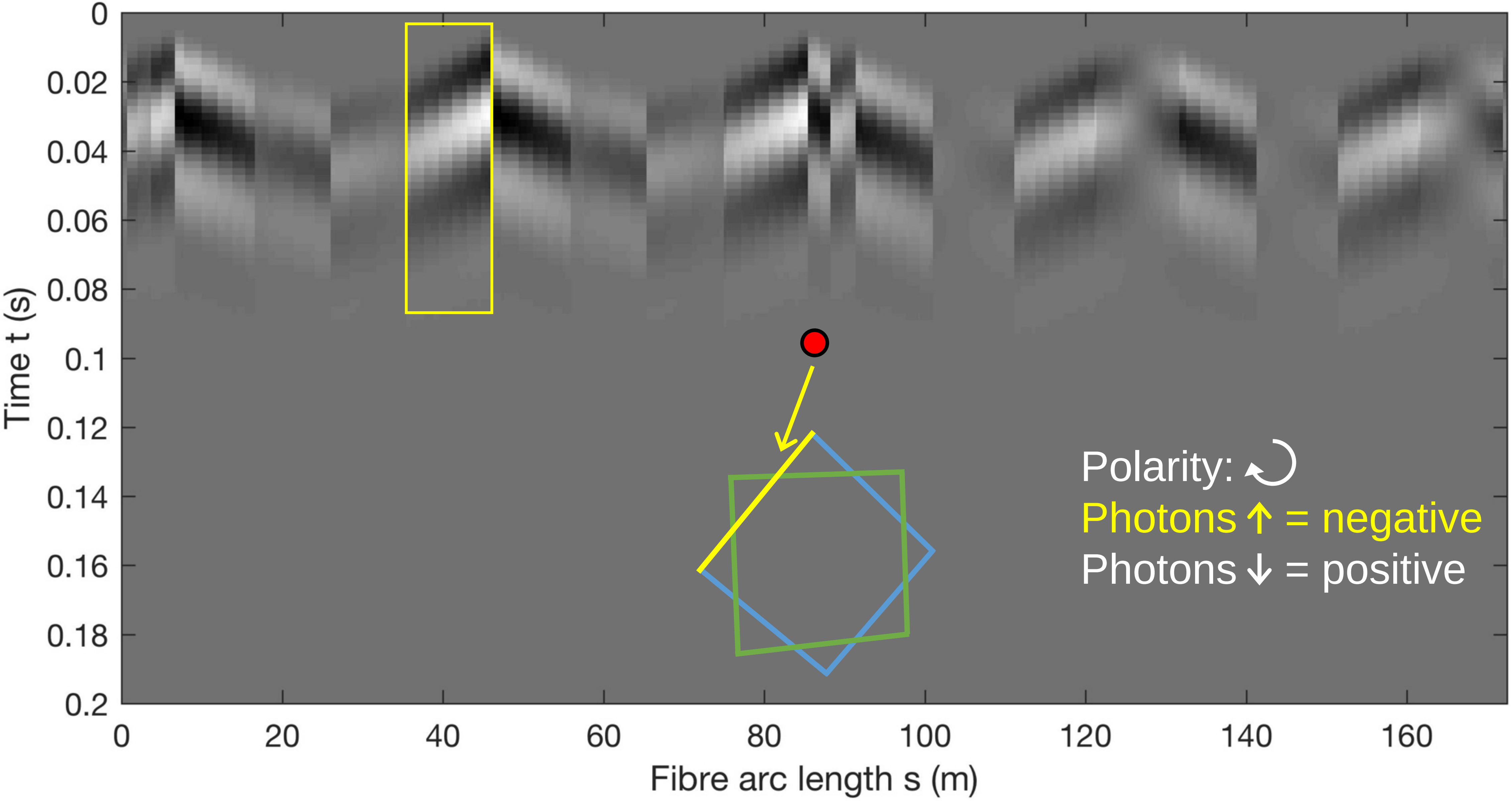
Directionality



Directionality

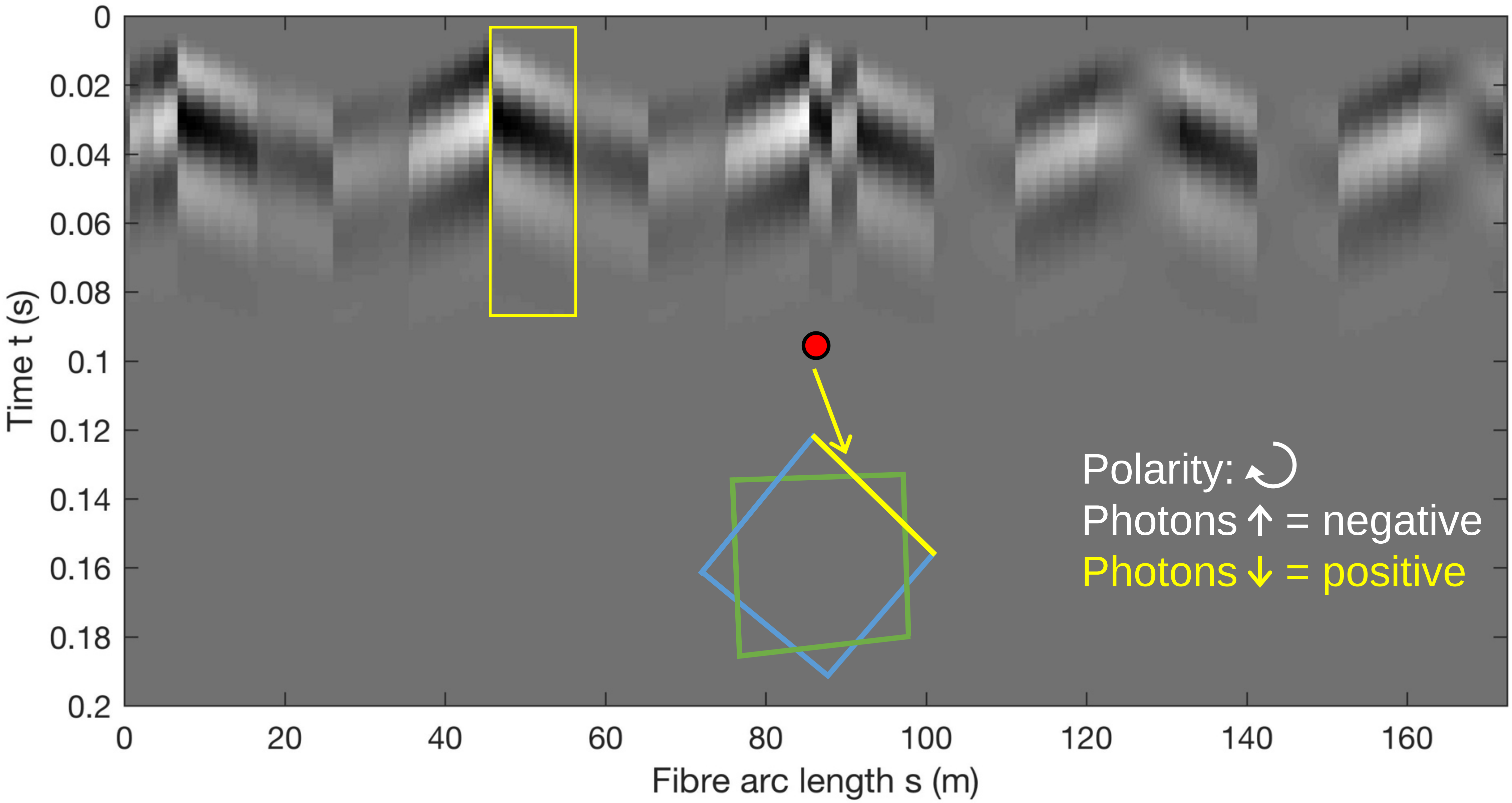


Polarity



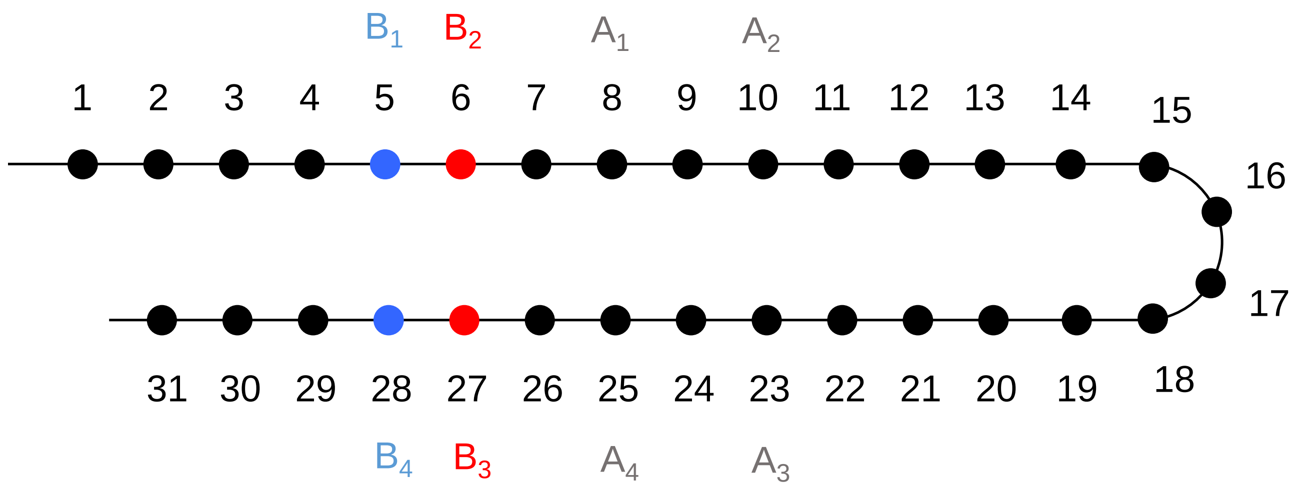
Time t (s)
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0
20
40
60
80
100
120
140
160
Fibre arc length s (m)
Polarity:
Photons ↑ = negative
Photons ↓ = positive

Polarity



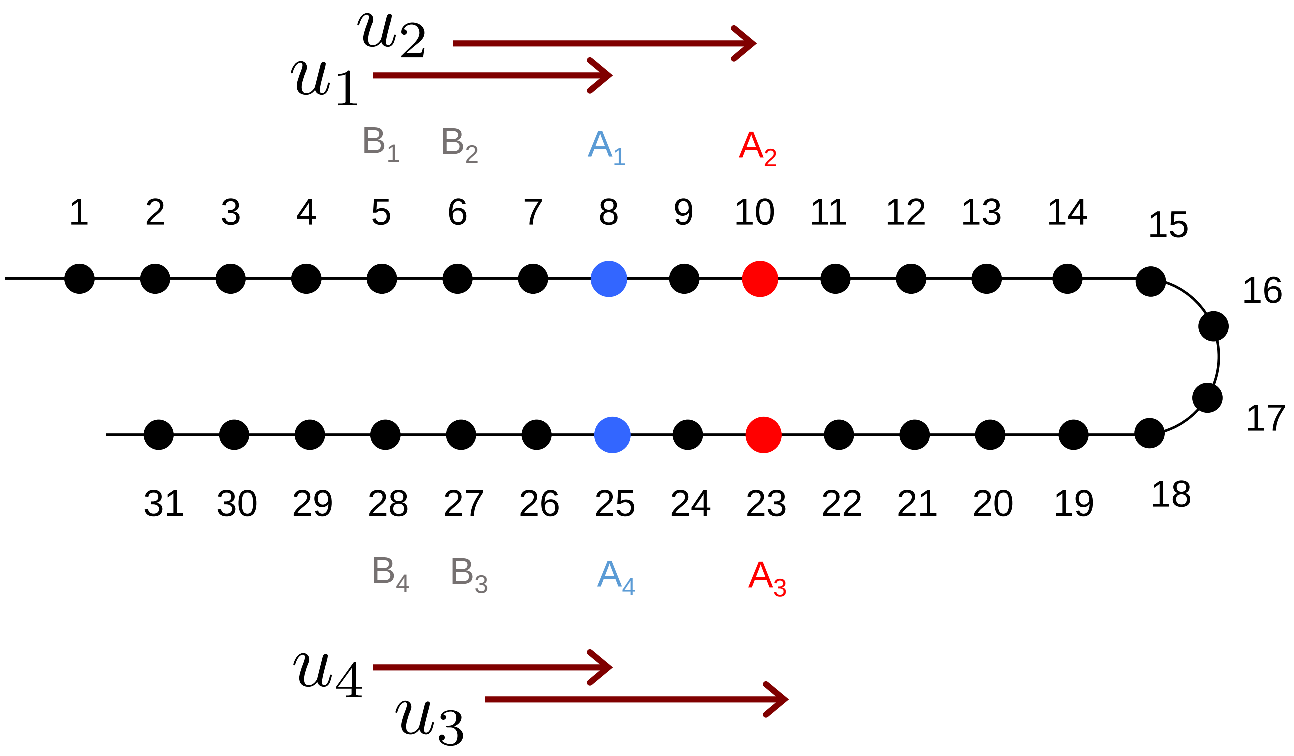
Time t (s)
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0
20
40
60
80
100
120
140
160
Fibre arc length s (m)
Polarity:
Photons ↑ = negative
Photons ↓ = positive

Polarity



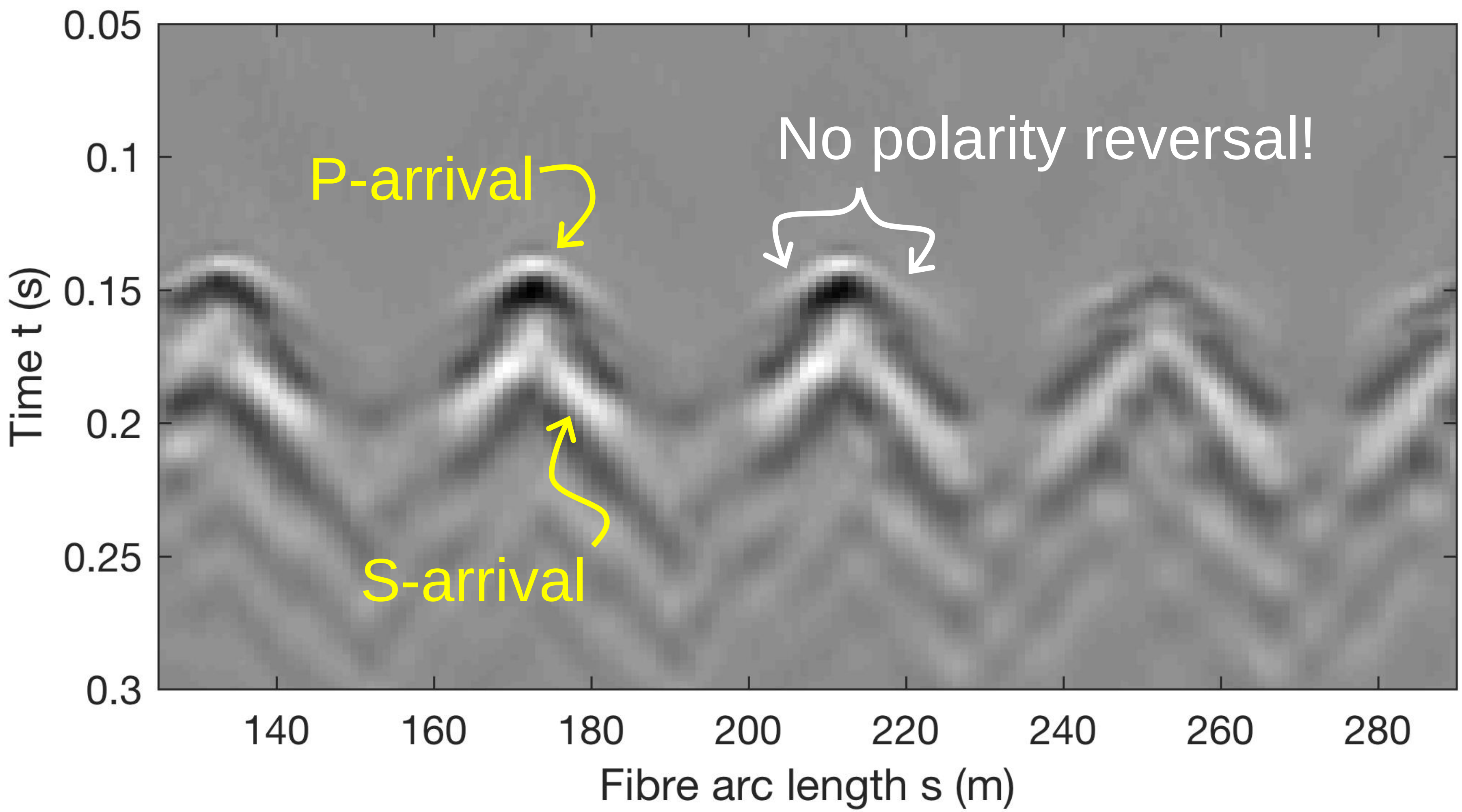
$$e_H \approx \frac{u_2 - u_1}{B_2 - B_1} = \frac{4-3}{6-5} = 1 \qquad e_L \approx \frac{u_4 - u_3}{B_4 - B_3} = \frac{-3-(-4)}{28-27} = 1$$

Polarity



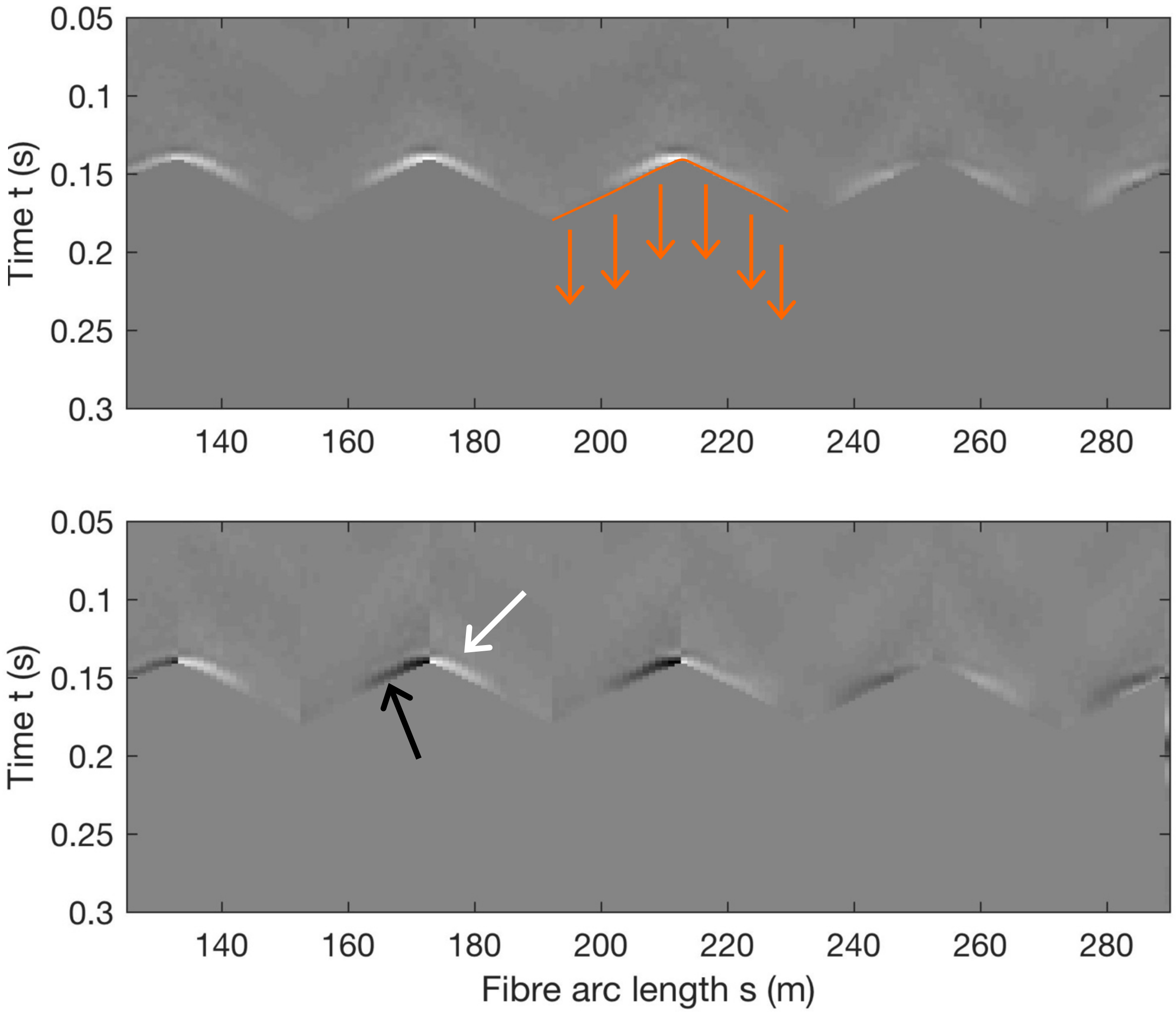
$$e_H \approx \frac{u_2 - u_1}{B_2 - B_1} = \frac{4-3}{6-5} = 1 \qquad e_L \approx \frac{u_4 - u_3}{B_4 - B_3} = \frac{-3-(-4)}{28-27} = 1$$

Field data



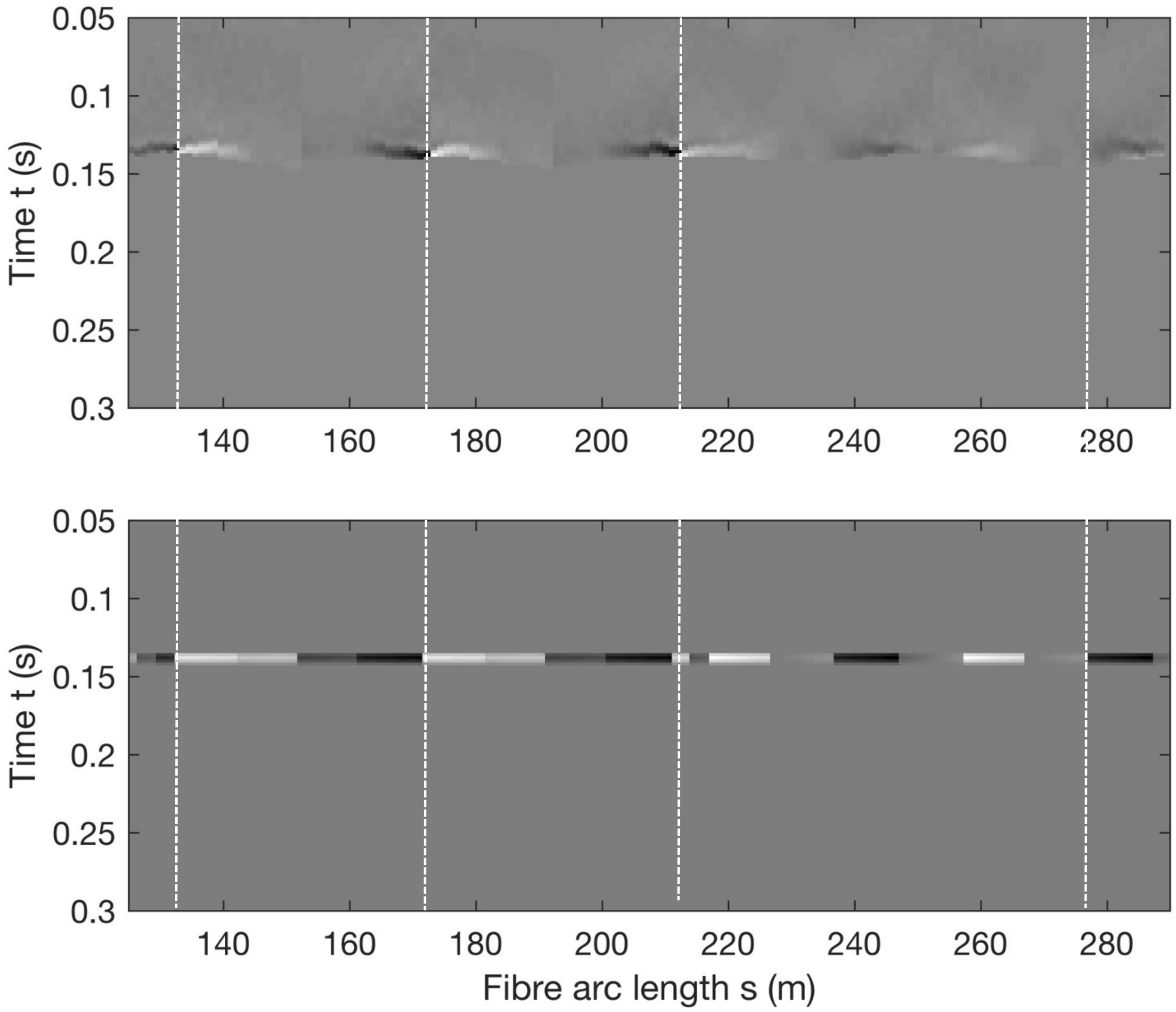
VP2 (25m N)
Vibroseis 10-150Hz
Halliburton Interrogator
Channel spacing 1.02m
Gauge length 5m

Field data



1. Mute to emphasize first arrival P-wave
2. Artificially re-introduce polarity based on source-fibre geometry

Field data

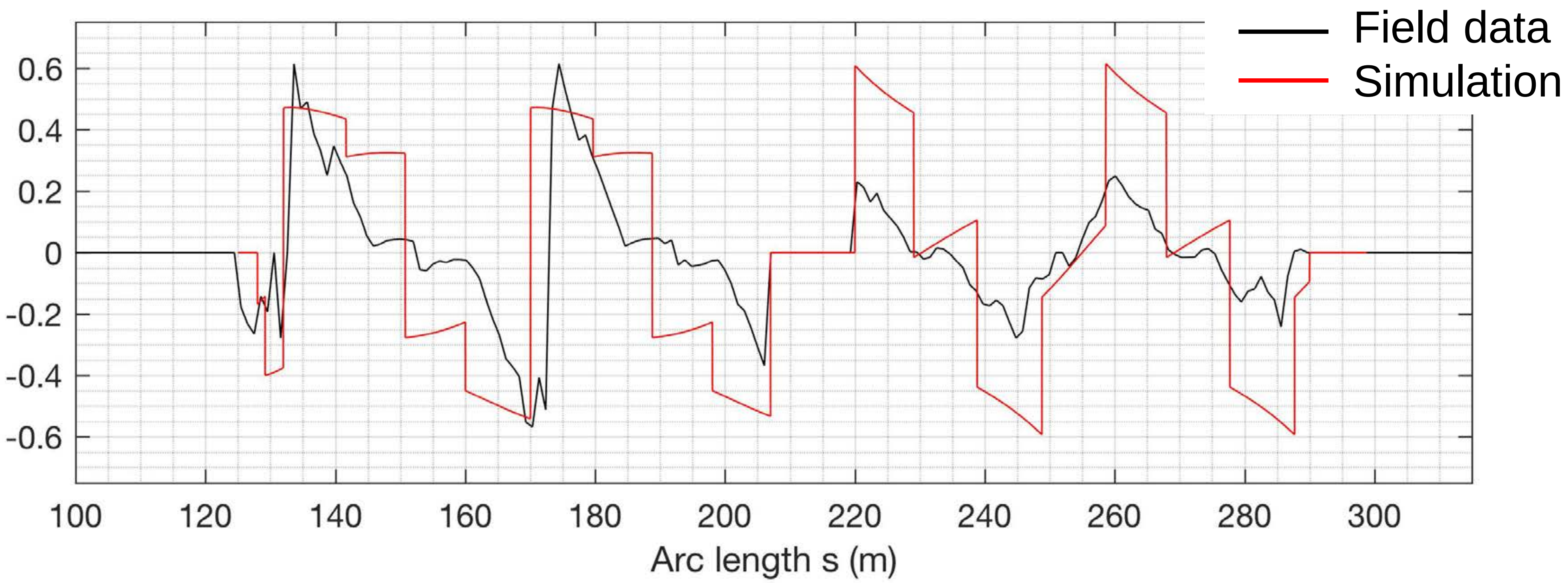


3. Correct moveout within fibre array

4. Compare against simulation from fibre geometry measurements & P-wave strain

Field data

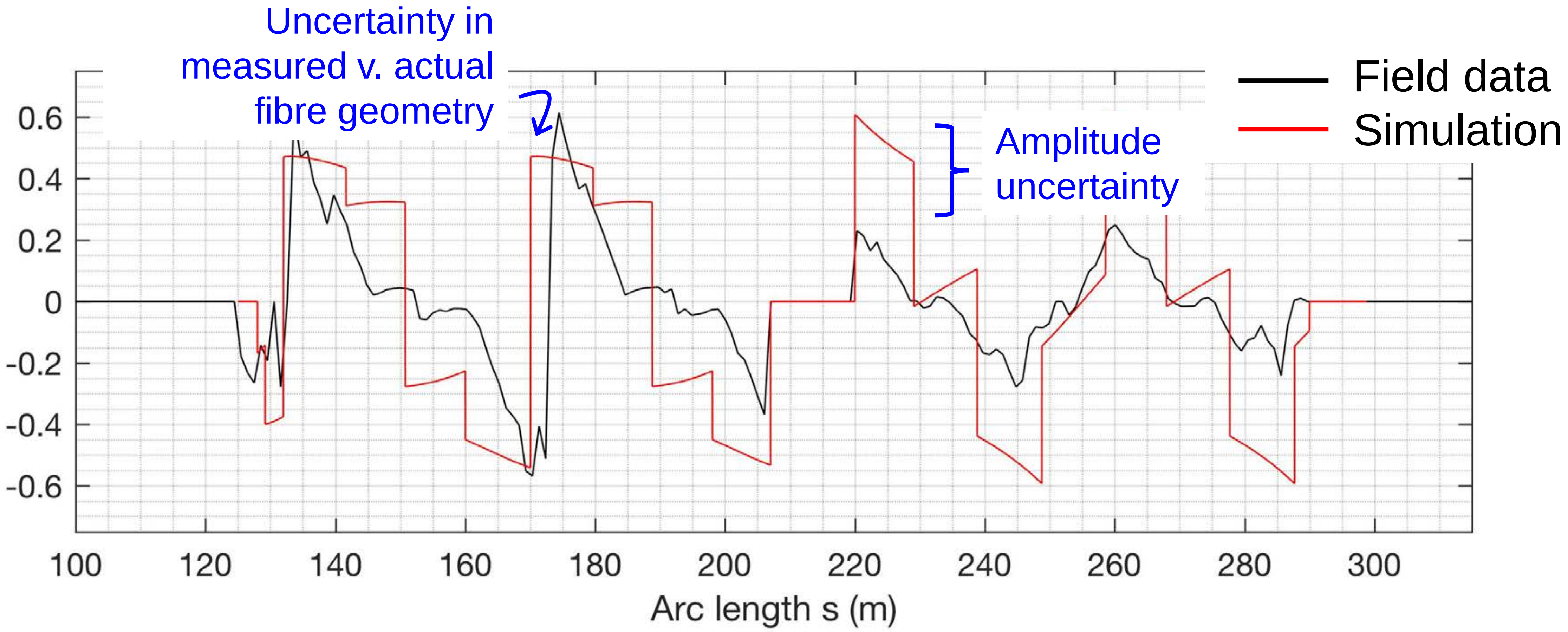
Raw data / fixed time
t = ~ 0.14s



Field data

Clear agreement between measured and simulated directionality in amplitudes. Caution:

Raw data / fixed time
t = ~ 0.14s



Strain estimation

$$\mathbf{e} = \begin{bmatrix} e_{WW} & e_{WN} & e_{WD} \\ \cdot & e_{NN} & e_{ND} \\ \cdot & \cdot & e_{DD} \end{bmatrix}$$

← What we want

What we have →

$$\begin{bmatrix} e_{tt}(s_1) \\ e_{tt}(s_2) \\ \vdots \\ e_{tt}(s_M) \end{bmatrix} = \mathbf{L} \begin{bmatrix} e_{WW} \\ e_{WN} \\ e_{WD} \\ e_{NN} \\ e_{ND} \\ e_{DD} \end{bmatrix}$$

Strain estimation

$$\mathbf{L} = \begin{bmatrix} \lambda_{WW}^{1} & 2\lambda_{WN}^{1} & 2\lambda_{WD}^{1} & \lambda_{NN}^{1} & 2\lambda_{ND}^{1} & \lambda_{DD}^{1} \\ \lambda_{WW}^{2} & 2\lambda_{WN}^{2} & 2\lambda_{WD}^{2} & \lambda_{NN}^{2} & 2\lambda_{ND}^{2} & \lambda_{DD}^{2} \\ & & \vdots & & & \\ \lambda_{WW}^{M} & 2\lambda_{WN}^{M} & 2\lambda_{WD}^{M} & \lambda_{NN}^{M} & 2\lambda_{ND}^{M} & \lambda_{DD}^{M} \end{bmatrix}$$

$$\lambda_{ij}^{k} = \left(\hat{\mathbf{t}}(s_k) \cdot \hat{\mathbf{i}} \right) \left(\hat{\mathbf{t}}(s_k) \cdot \hat{\mathbf{j}} \right)$$

Strain estimation

$$\mathbf{L} = \begin{bmatrix} \lambda^1_{WW} & 2\lambda^1_{WN} & 2\lambda^1_{WD} & \lambda^1_{NN} & 2\lambda^1_{ND} & \lambda^1_{DD} \\ \lambda^2_{WW} & 2\lambda^2_{WN} & 2\lambda^2_{WD} & \lambda^2_{NN} & 2\lambda^2_{ND} & \lambda^2_{DD} \\ & & \vdots & & & \\ \lambda^M_{WW} & 2\lambda^M_{WN} & 2\lambda^M_{WD} & \lambda^M_{NN} & 2\lambda^M_{ND} & \lambda^M_{DD} \end{bmatrix}$$

All zeros: our loop has no 10m segments in the depth direction! $L^T L$ will have no inverse.

Strain estimation

$$\begin{bmatrix} e_{WW} \\ e_{WN} \\ e_{NN} \end{bmatrix} \approx \left(\mathbf{L}_r^T \mathbf{L}_r + \alpha \mathbf{I}\right)^{-1} \mathbf{L}_r^T \begin{bmatrix} e_{tt}(s_1) \\ e_{tt}(s_2) \\ \vdots \\ e_{tt}(s_N) \end{bmatrix}$$

$$\mathbf{L}_r = \begin{bmatrix} \lambda_{WW}^1 & 2\lambda_{WN}^1 & \lambda_{NN}^1 \\ \lambda_{WW}^2 & 2\lambda_{WN}^2 & \lambda_{NN}^2 \\ & \vdots & \\ \lambda_{WW}^M & 2\lambda_{WN}^M & \lambda_{NN}^M \end{bmatrix}$$

Strain estimation

$$\mathbf{e} = \begin{bmatrix} e_{WW} & e_{WN} & e_{WD} \\ \cdot & e_{NN} & e_{ND} \\ \cdot & \cdot & e_{DD} \end{bmatrix} = \begin{bmatrix} 0 & 0 & e_{WD} \\ \cdot & 1 & e_{ND} \\ \cdot & \cdot & e_{DD} \end{bmatrix}$$

$$\mathbf{e}_{\text{synth}} = \begin{bmatrix} 0.13 & 0.03 & e_{WD} \\ \cdot & 0.74 & e_{ND} \\ \cdot & \cdot & e_{DD} \end{bmatrix}$$

Strain estimation

$$\mathbf{e} = \begin{bmatrix} e_{WW} & e_{WN} & e_{WD} \\ \cdot & e_{NN} & e_{ND} \\ \cdot & \cdot & e_{DD} \end{bmatrix} = \begin{bmatrix} 0 & 0 & e_{WD} \\ \cdot & 1 & e_{ND} \\ \cdot & \cdot & e_{DD} \end{bmatrix}$$

$$\mathbf{e}_{\text{field}} = \begin{bmatrix} 0.04 & 0.11 & e_{WD} \\ \cdot & 0.26 & e_{ND} \\ \cdot & \cdot & e_{DD} \end{bmatrix}$$

Conclusions

Multicomponent DAS sensing: yes! In the sense that:

- directional-dependent amplitudes are clear in field data
- partial directional coverage can provide parts of the strain tensor
- a large “sensor” can manage 10m gauge lengths

Multicomponent DAS sensing: maybe! in the sense that:

- 10m gauge lengths enforce difficult preprocessing
- coupling will be critical; repeated shots close to fibre were used