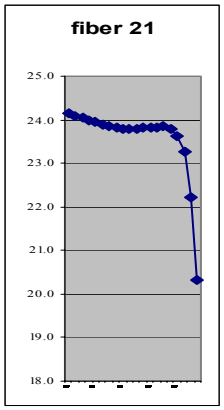
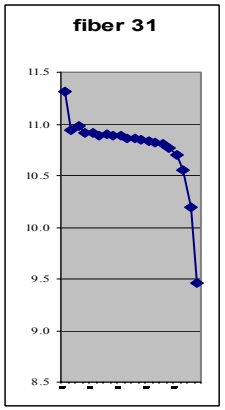
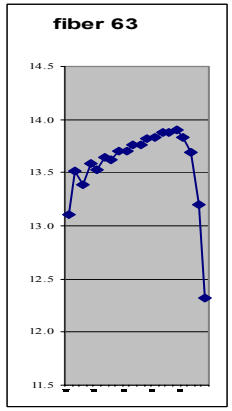
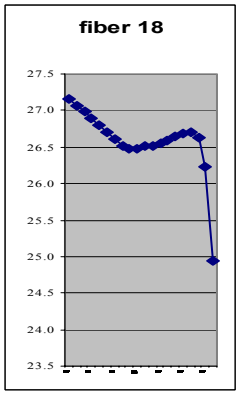
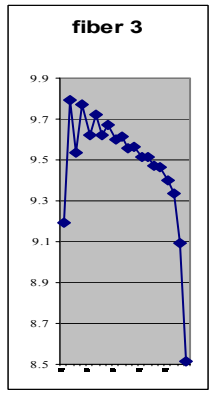
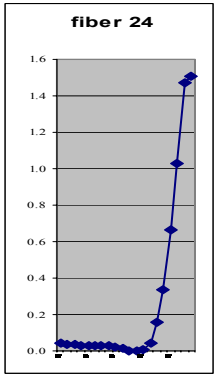
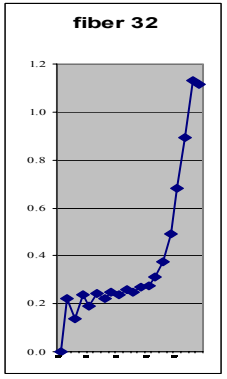
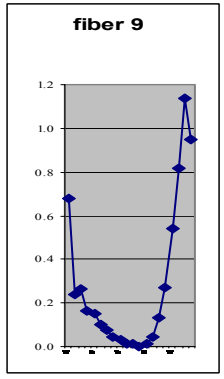
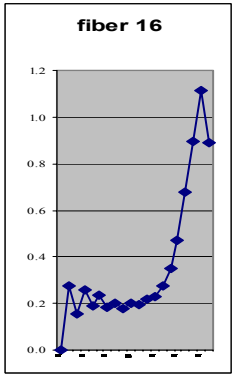
Multimode Fiber Model Issues

From TIA FO-4.1.2
To IEEE 802.3aq

July 2004

Cambridge Delay Structure Types

Number of occurrences

10	19	23	10	3
				
				
Flat low & mid. Poor high order.	Moderate low & mid. Poor high order. Monotonic.	Moderate low & mid. Poor high order. Low and high order overlap (U shape).	S or Z shape (non-monotonic). Poor high order.	Variable low order. Poor high order.

Shared Traits

- DMD magnitude dominated by high order modes, even though these plots ignore two highest mode groups
- Two classes of low order mode behavior for split fundamental mode cases:
  - Leading fundamental followed by alternating higher order delays (e.g. fibers 16, 32, 63)
  - Lagging fundamental followed by non-alternating higher order delays (e.g. fibers 9, 19)

Some Possible Index Perturbation Deficiencies

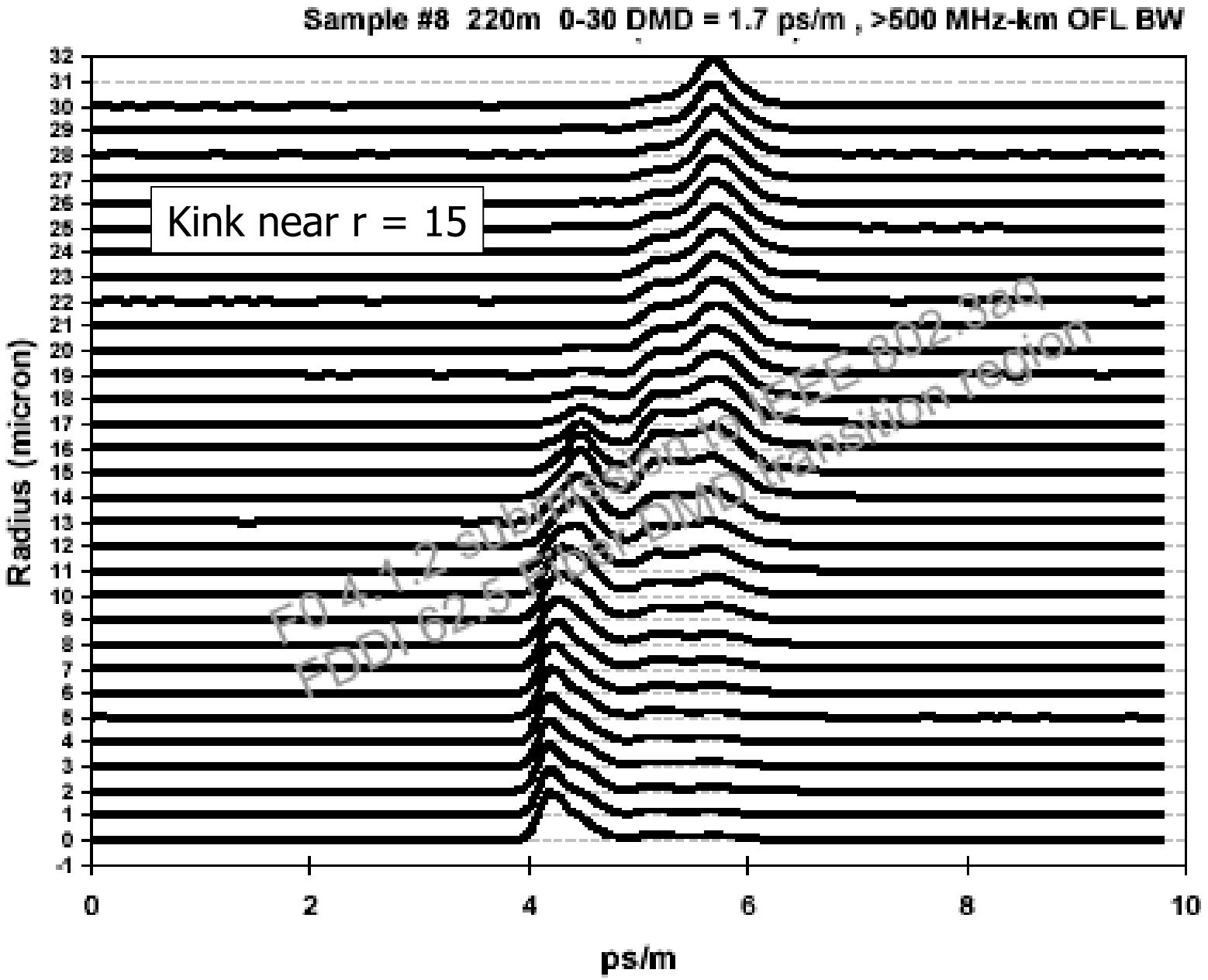
1. variation in the radial width of perturbations at the core center,
2. central perturbation complexity such as index peaks surrounding a dip,
3. central defect in otherwise near-perfect profile,
4. mid-radial α (power-law) shifts occurring at a variety of radial positions,
5. multiple α shifts along the mid-radial region,
6. abrupt changes in α over a very short radial interval ("kinks") occurring at various mid-radial positions

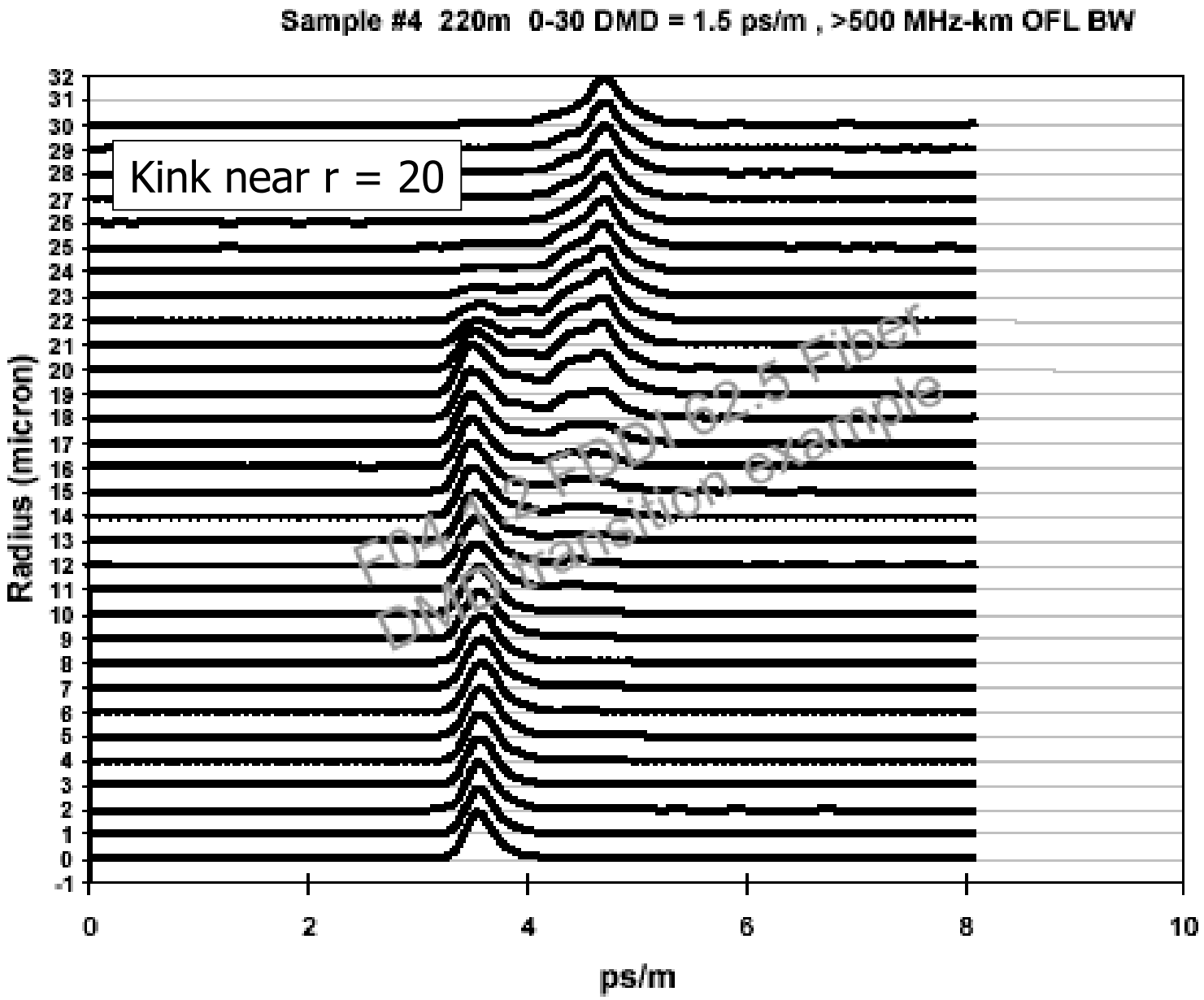
DMD Manifestations of Index Perturbation Deficiencies

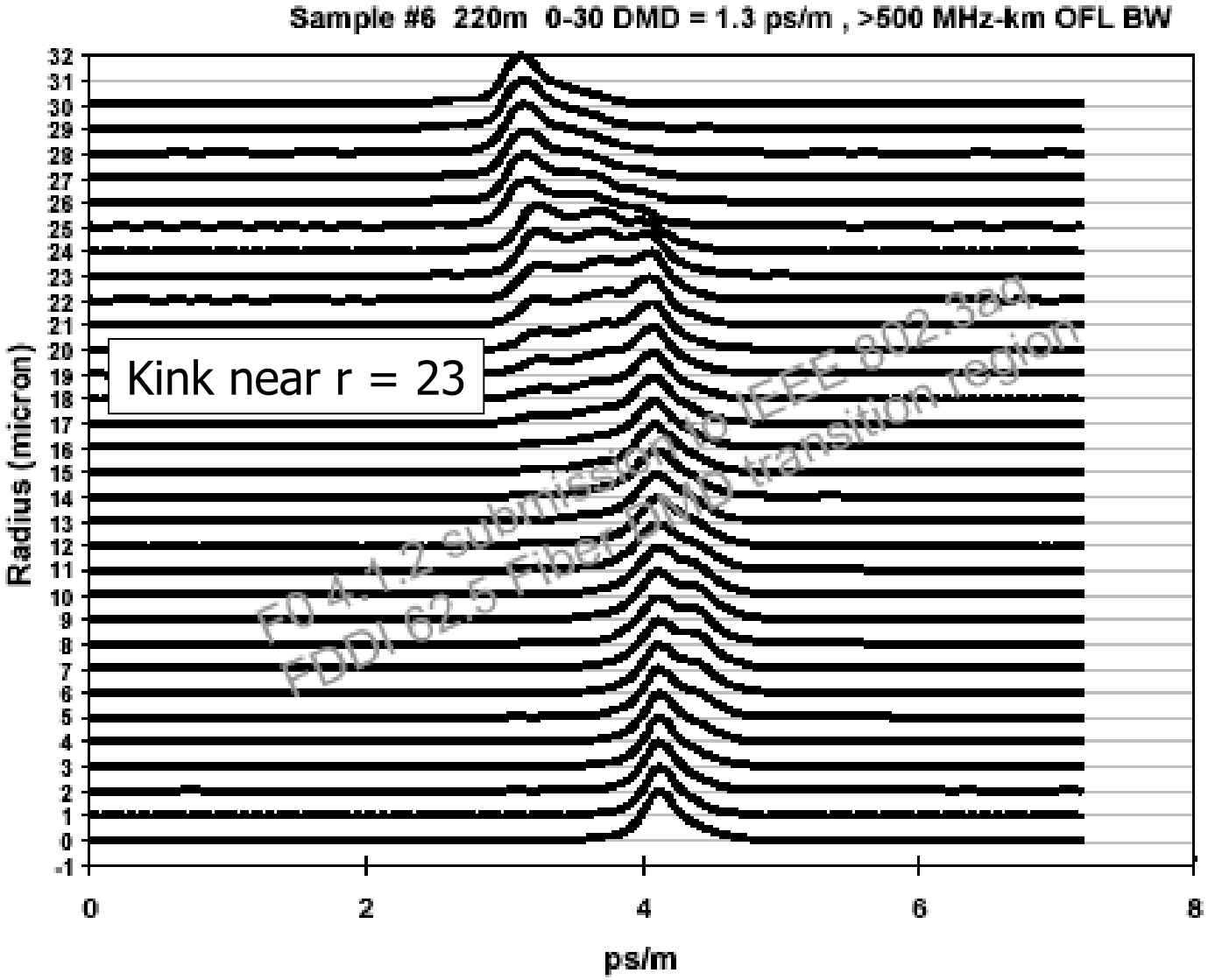
- 1 & 2 appear as low order mode group splitting in variety of ways.
- 3 has DMD dominated by low order mode splitting.
- 4 shows a change of delay slope at various radial positions.
- 5 has at least three slope changes.
- 6 shows a discontinuity in mode group delay that can occur even between otherwise well equalized collections of adjacent mode groups.

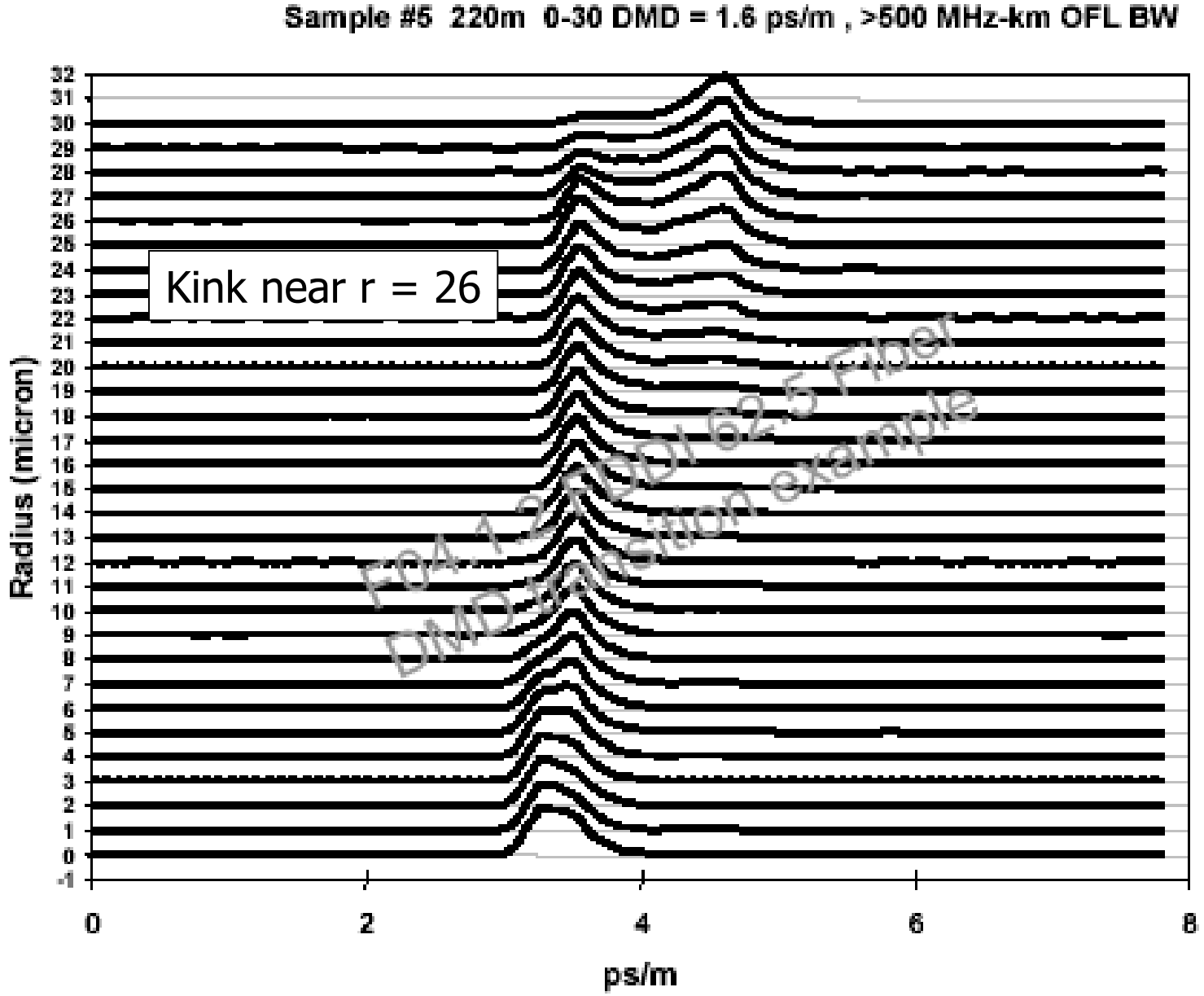
Measured DMD Examples

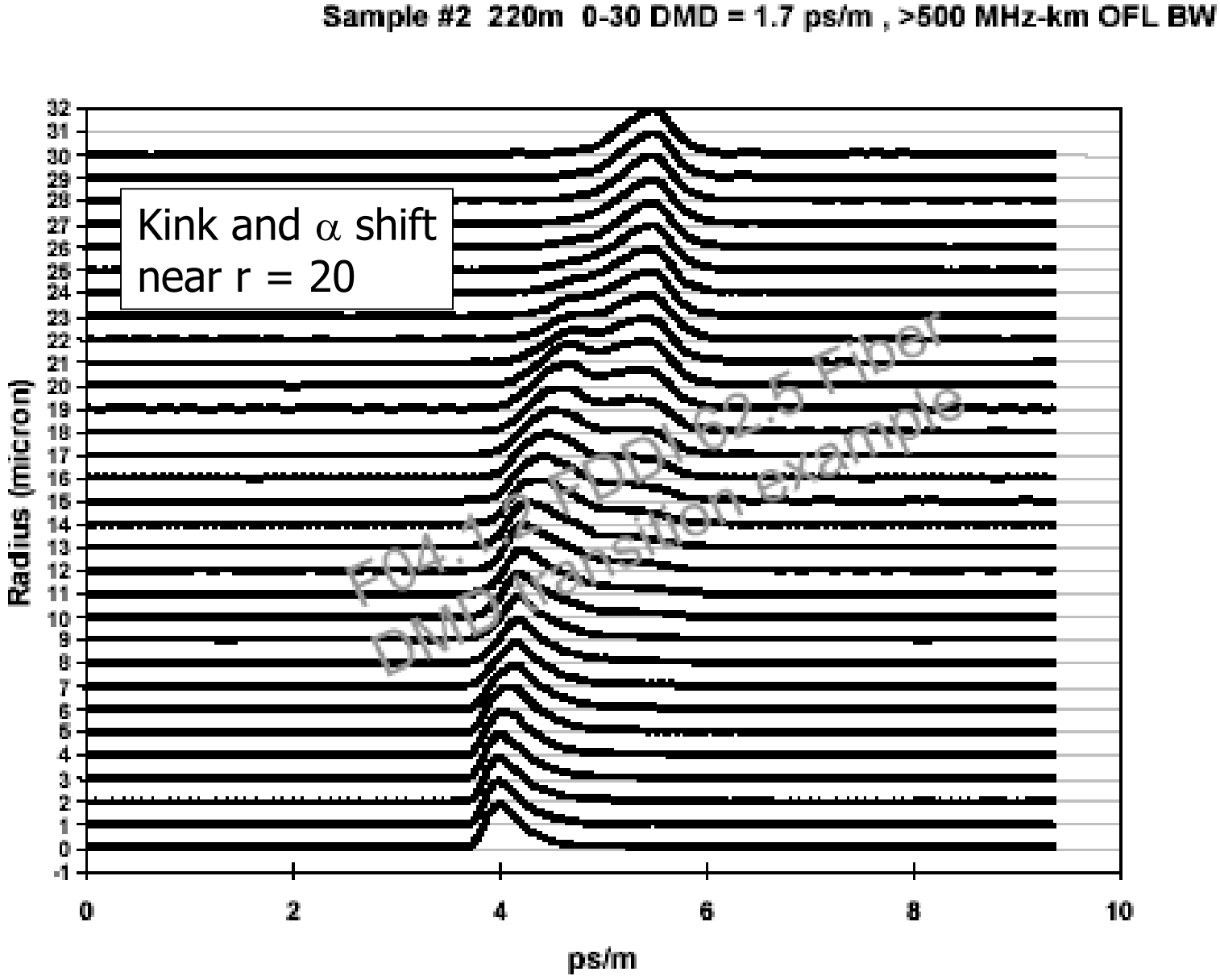
- Three manufacturers
- DMD for 62.5 μm fibers @ 1300 nm
- All fibers rated > 500 MHz-km OFL BW
- Interesting features described to illustrate under represented perturbations
- DMDs represent structural variations produced by fiber manufacturing processes and present in the installed base
- DMD magnitudes not representative of the 98 to 99th percentile of the installed base
  - Significantly higher DMD values seen for middle-aged to old fibers as evidenced by the MBI and national labs fibers

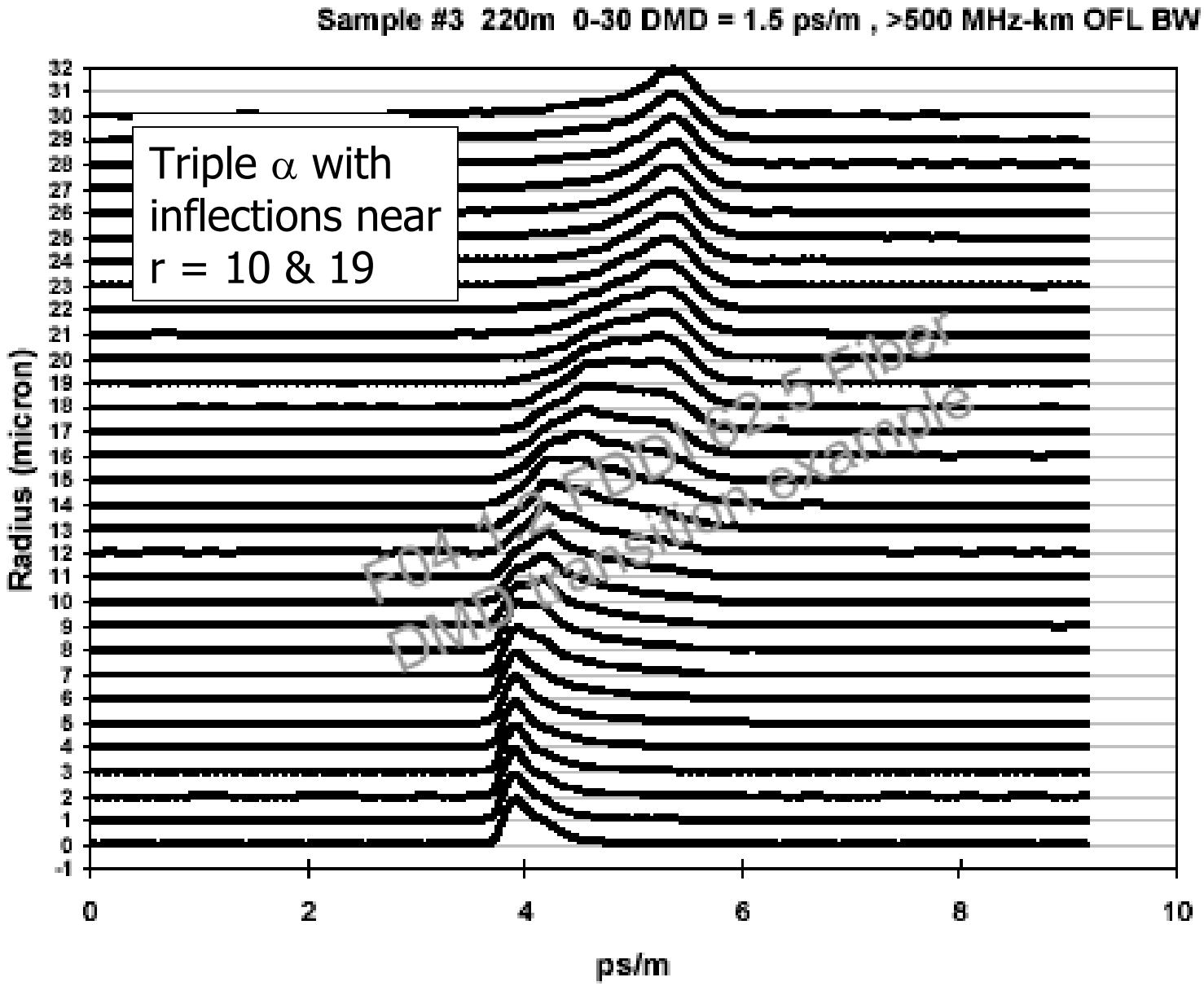

Sample #8 220m 0-30 DMD = 1.7 ps/m , >500 MHz-km OFL BW
Kink near r = 15
Radius (micron)
ps/m
0
2
4
6
8
10

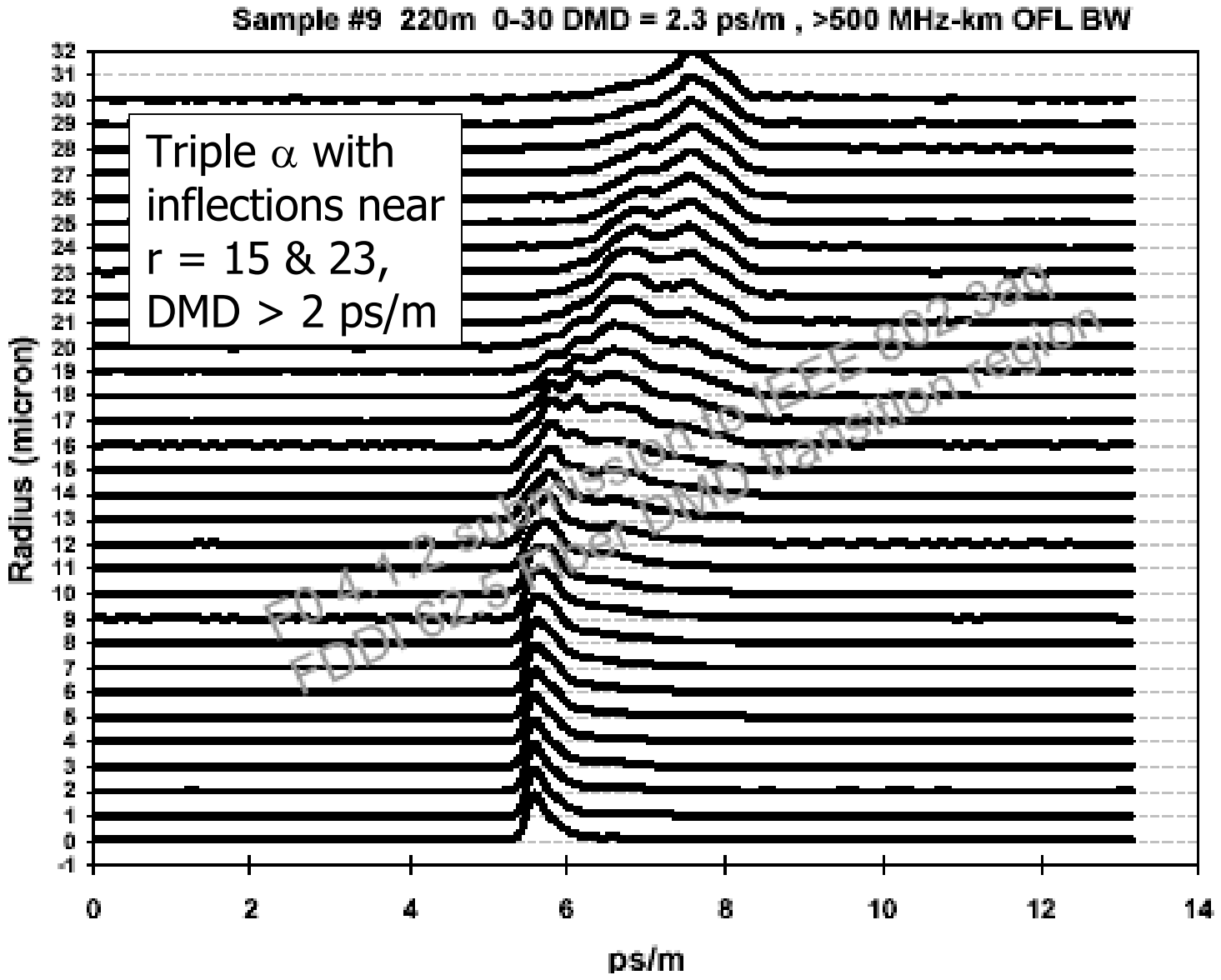

Sample #4 220m 0-30 DMD = 1.5 ps/m , >500 MHz-km OFL BW
Kink near r = 20
Radius (micron)
ps/m
0
2
4
6
8
10
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32

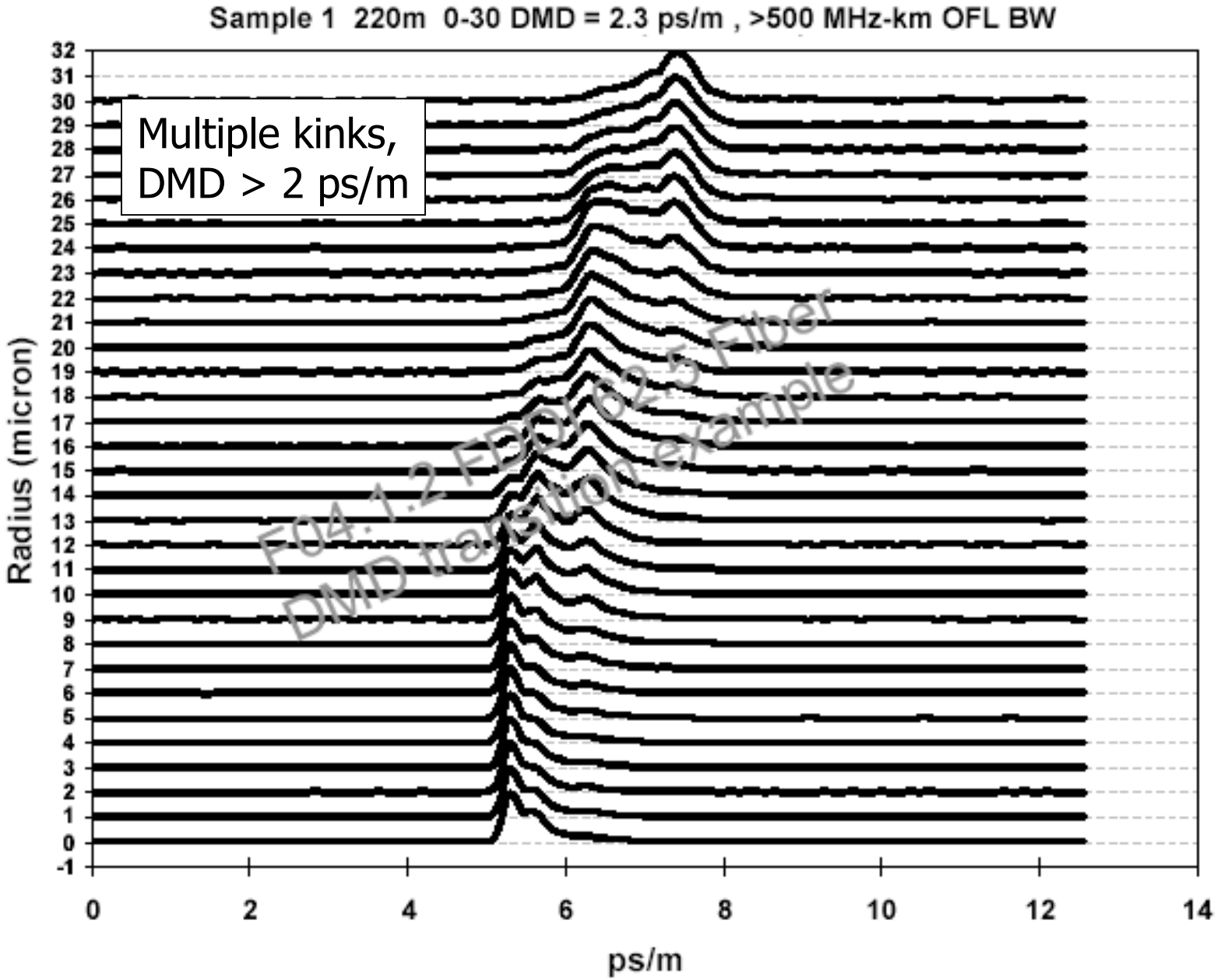

Sample #6 220m 0-30 DMD = 1.3 ps/m , >500 MHz-km OFL BW
Radius (micron)
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
0
2
4
6
8
ps/m
Kink near r = 23
r0.4-1.7 submitted to IEEE 802.3aq
FDDI 62.5 Fiber MMF transition region

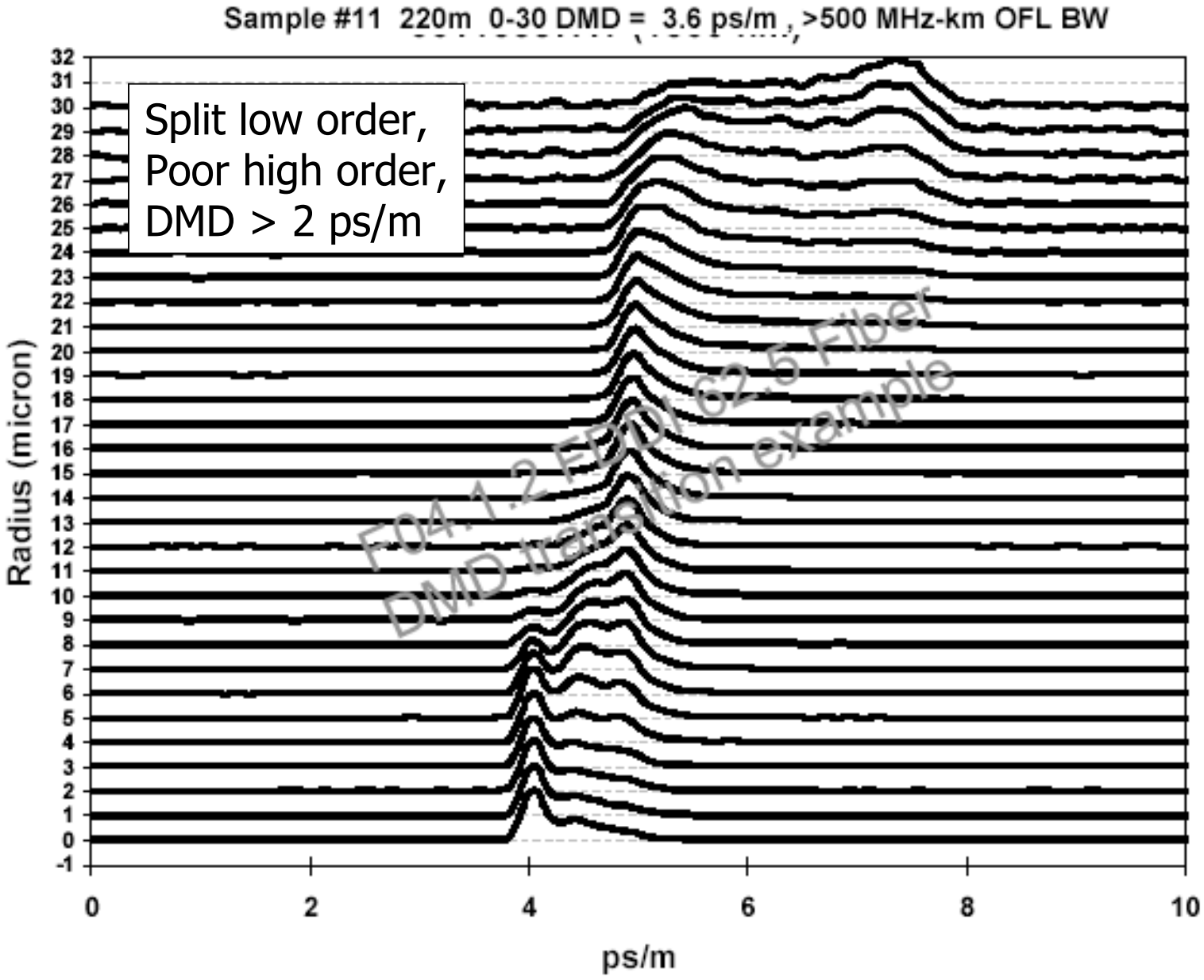

Sample #5 220m 0-30 DMD = 1.6 ps/m , >500 MHz-km OFL BW
Kink near r = 26
FOA 1.2 TIA/EIA 62.5 Fiber
DMD Illustration example
Radius (micron)
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
0
2
4
6
8
ps/m

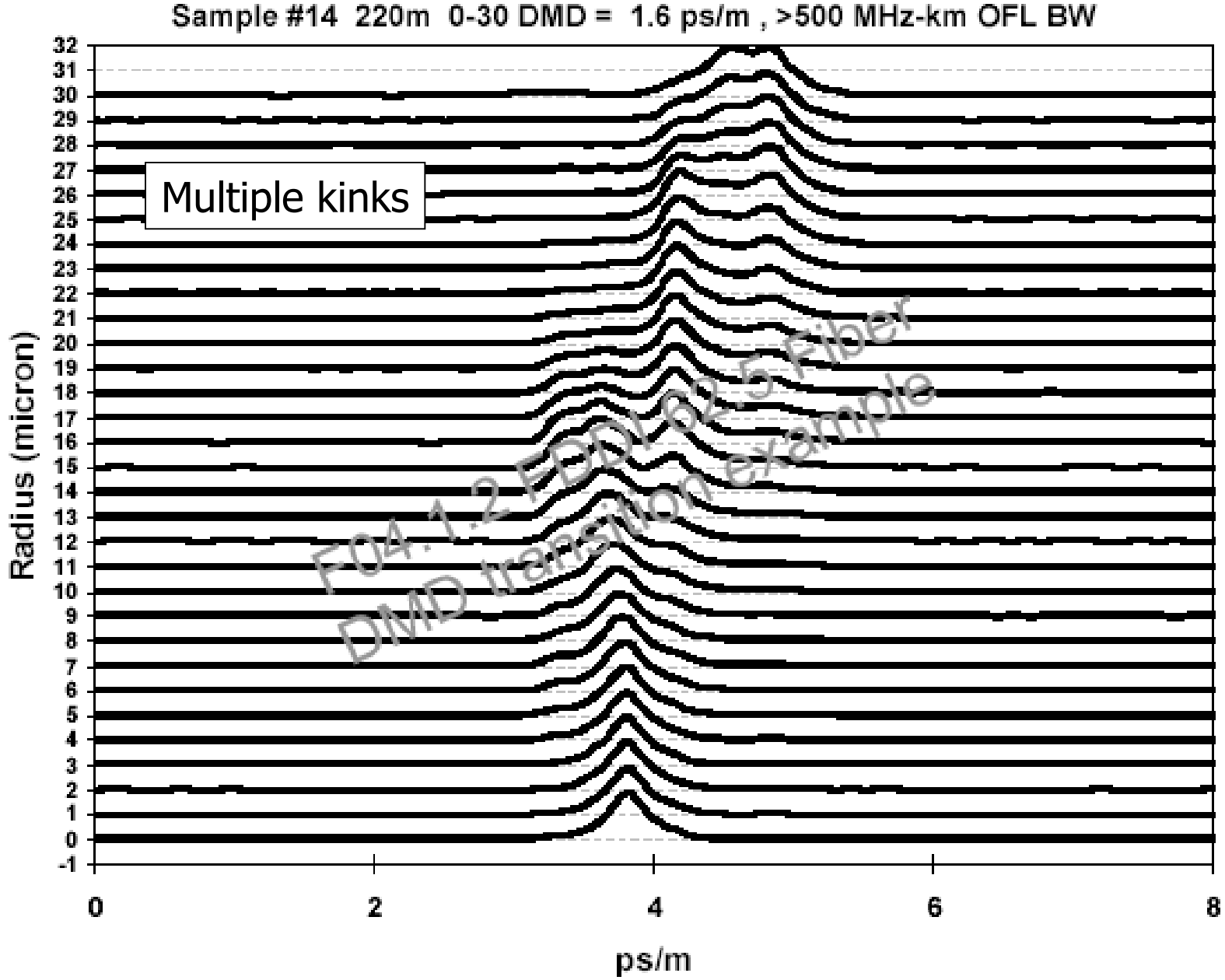

Sample #2 220m 0-30 DMD = 1.7 ps/m , >500 MHz-km OFL BW
Kink and α shift
near r = 20
Radius (micron)
ps/m
0
2
4
6
8
10

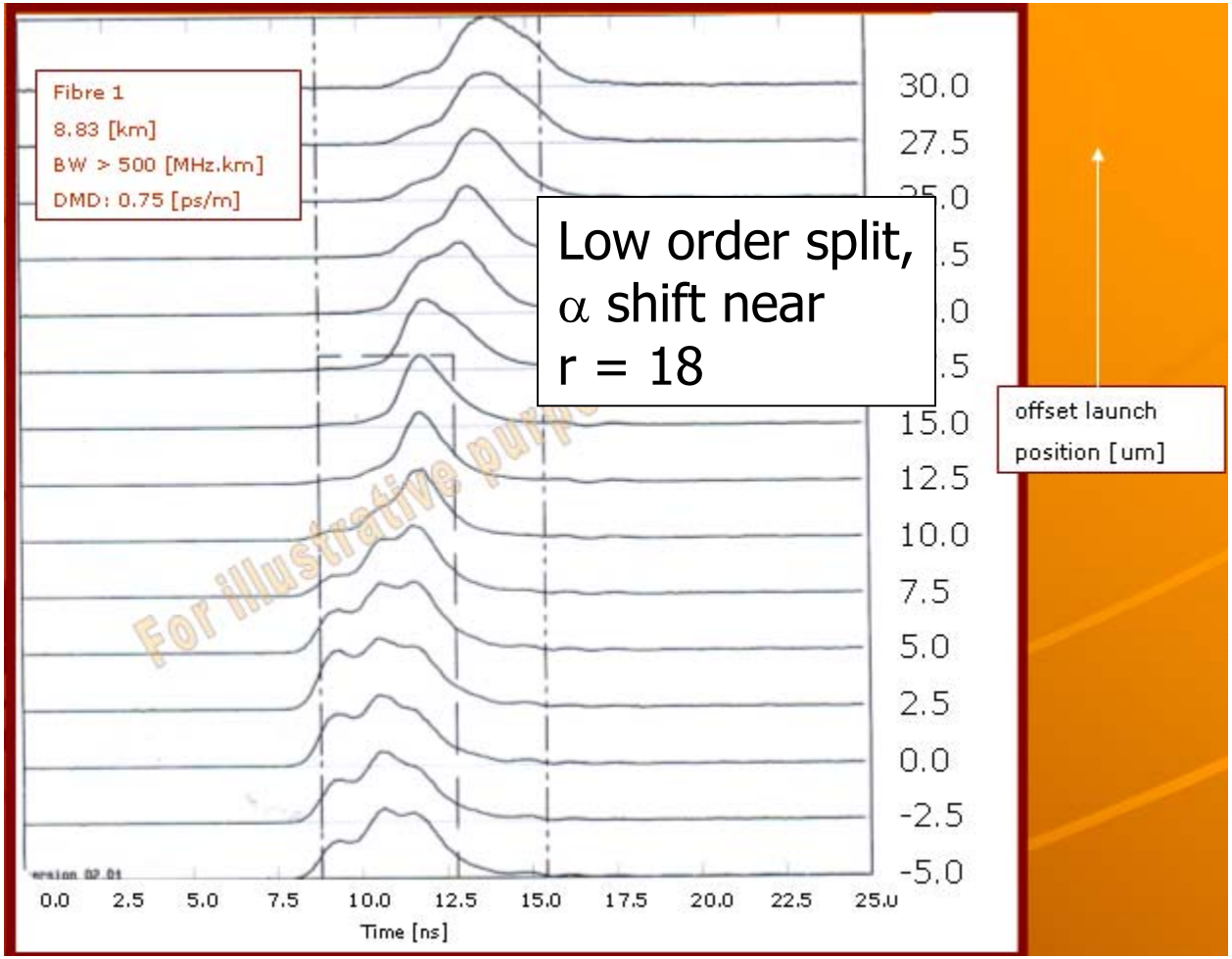

Sample #3 220m 0-30 DMD = 1.5 ps/m , >500 MHz-km OFL BW
Triple α with inflections near r = 10 & 19
Radius (micron)
ps/m
0
2
4
6
8
10
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
FO4-1 FDD 62.5 Fiber
DMD transition example

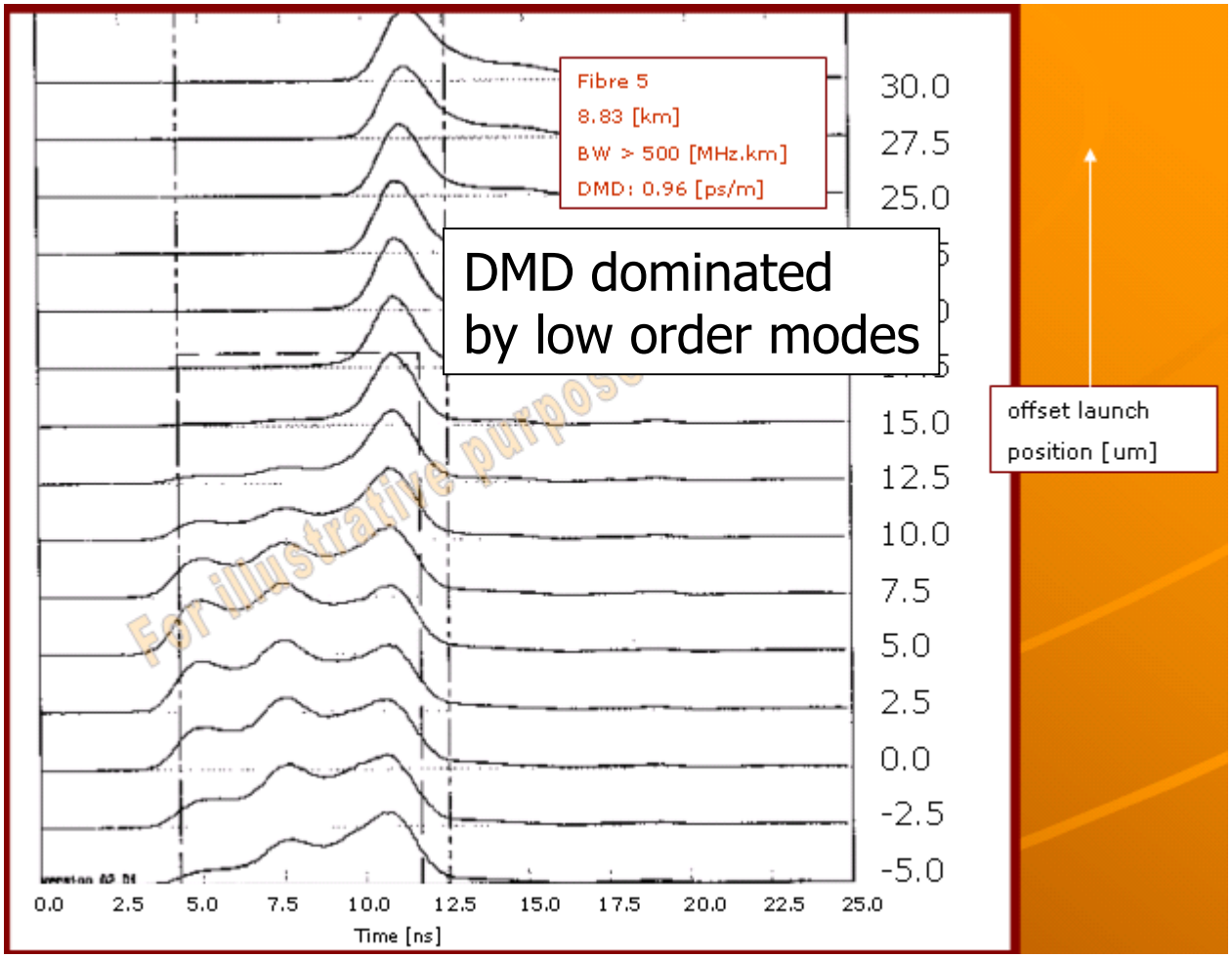

Sample #9 220m 0-30 DMD = 2.3 ps/m , >500 MHz-km OFL BW
Triple α with inflections near r = 15 & 23, DMD > 2 ps/m
Radius (micron)
ps/m
0
2
4
6
8
10
12
14

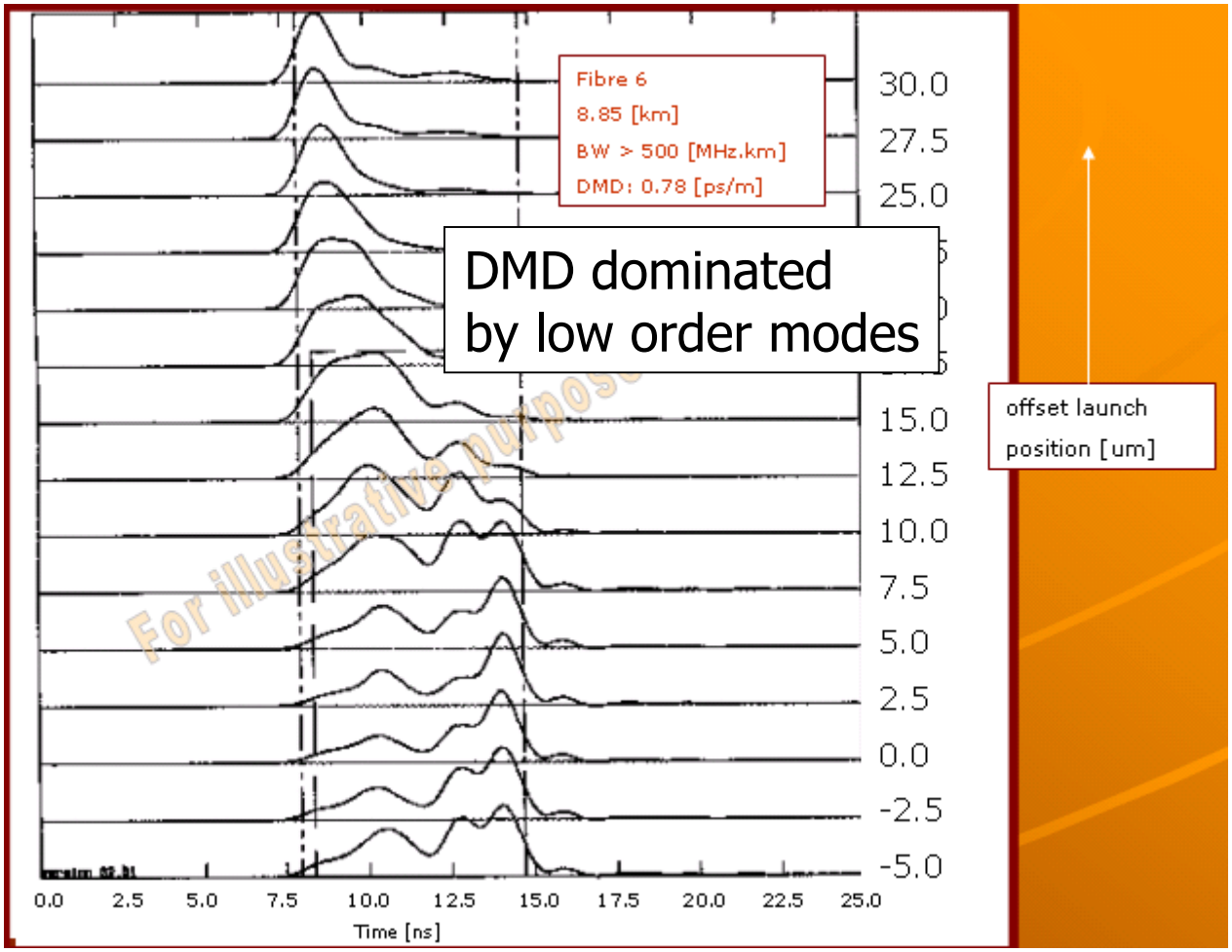

Sample 1 220m 0-30 DMD = 2.3 ps/m , >500 MHz-km OFL BW
Multiple kinks,
DMD > 2 ps/m
F04.1.2 FBGRIN2.5 Fiber
DMD transition example
Radius (micron)
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
0
2
4
6
8
10
12
14
ps/m

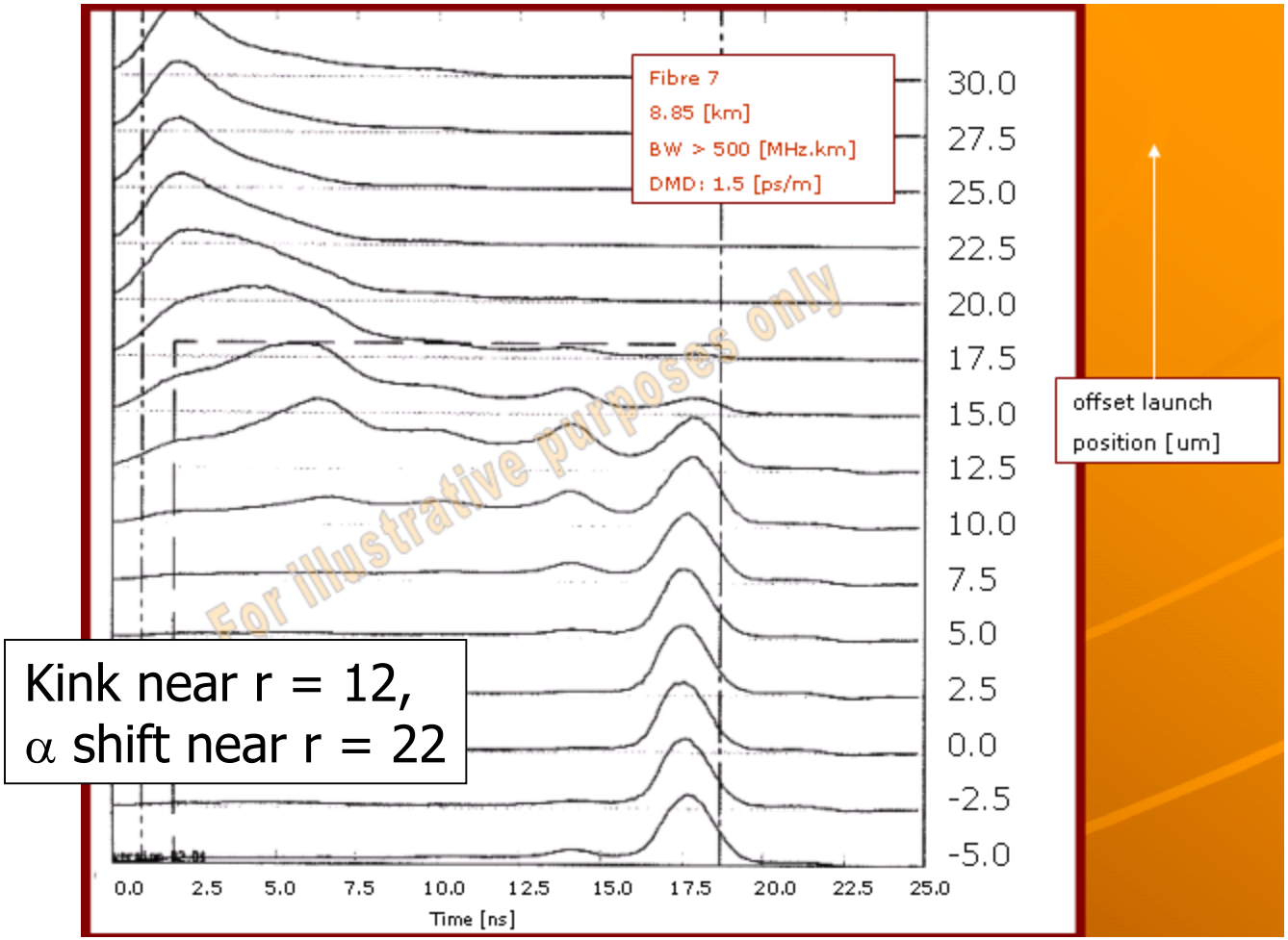

Sample #11 220m 0-30 DMD = 3.6 ps/m , >500 MHz-km OFL BW
Split low order,
Poor high order,
DMD > 2 ps/m
F04.1.2 FBGA 62.5 Fiber
DMD Illustration example
Radius (micron)
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
0
2
4
6
8
10
ps/m


Sample #14 220m 0-30 DMD = 1.6 ps/m , >500 MHz-km OFL BW
Multiple kinks
F04.1.2 FDDI 62.5 Fiber
DMD transition example
Radius (micron)
ps/m
0
2
4
6
8
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1


Fibre 1
8.83 [km]
BW > 500 [MHz.km]
DMD: 0.75 [ps/m]
Low order split,
α shift near
r = 18
offset launch
position [um]
30.0
27.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
-2.5
-5.0
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5
25.0
Time [ns]

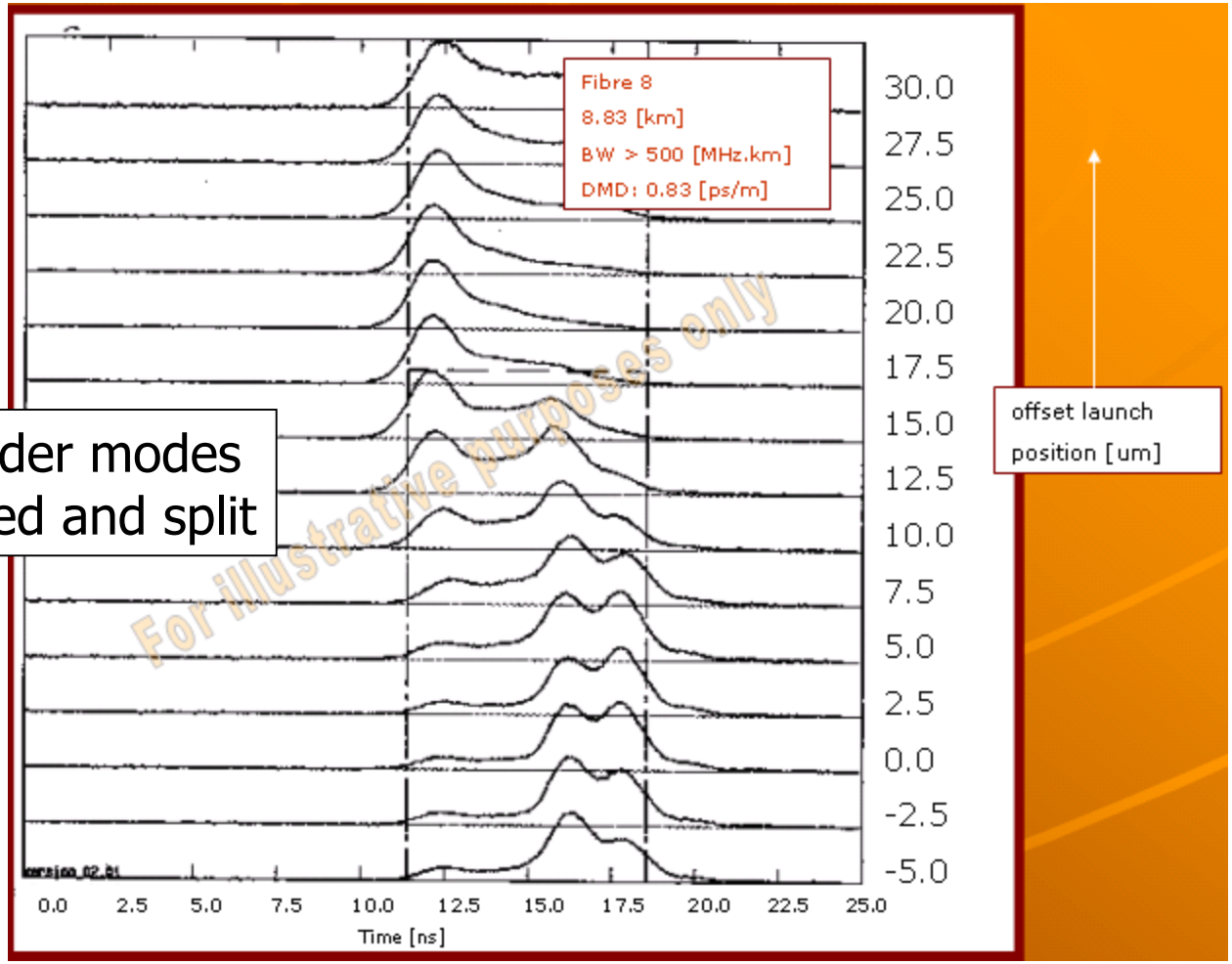

Fibre 5
8.83 [km]
BW > 500 [MHz.km]
DMD: 0.96 [ps/m]
DMD dominated
by low order modes
For illustrative purpose
30.0
27.5
25.0
15.0
12.5
10.0
7.5
5.0
2.5
0.0
-2.5
-5.0
offset launch
position [um]
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5
25.0
Time [ns]


Fibre 6
8.85 [km]
BW > 500 [MHz.km]
DMD: 0.78 [ps/m]
DMD dominated
by low order modes
For illustrative purpos
30.0
27.5
25.0
15.0
12.5
10.0
7.5
5.0
2.5
0.0
-2.5
-5.0
offset launch
position [um]
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5
25.0
Time [ns]

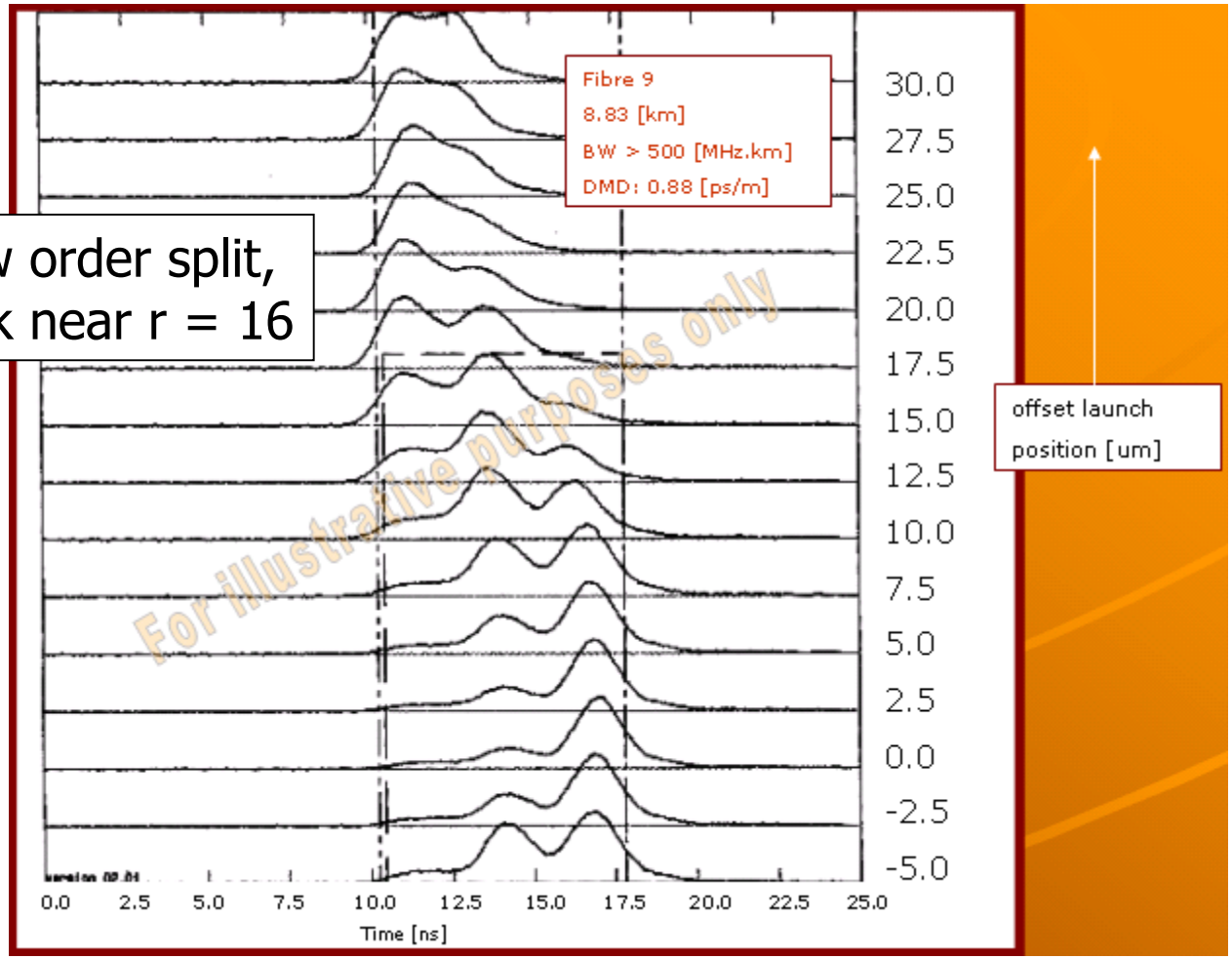


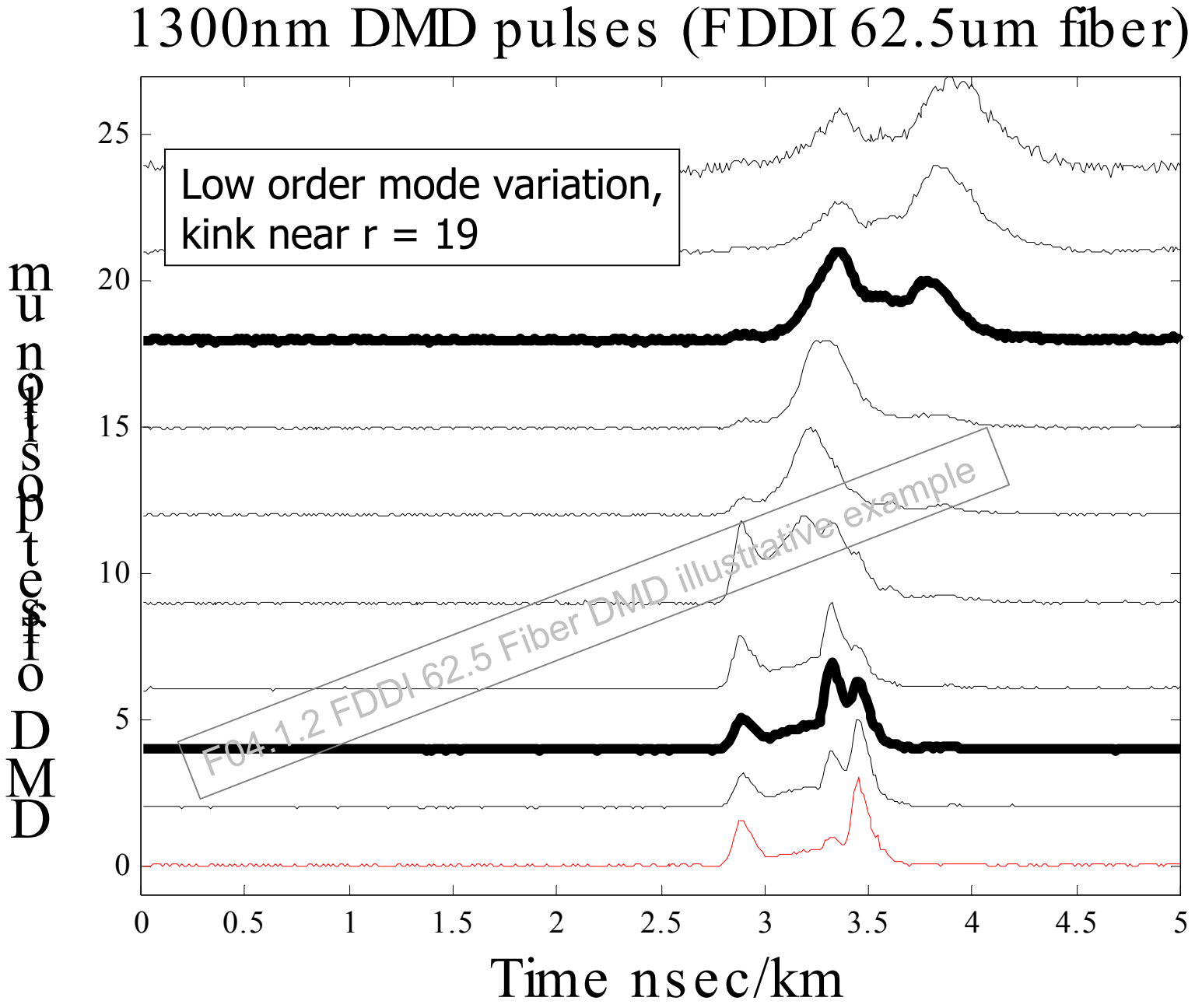
Kink near r = 12,
α shift near r = 22

low order modes grouped and split

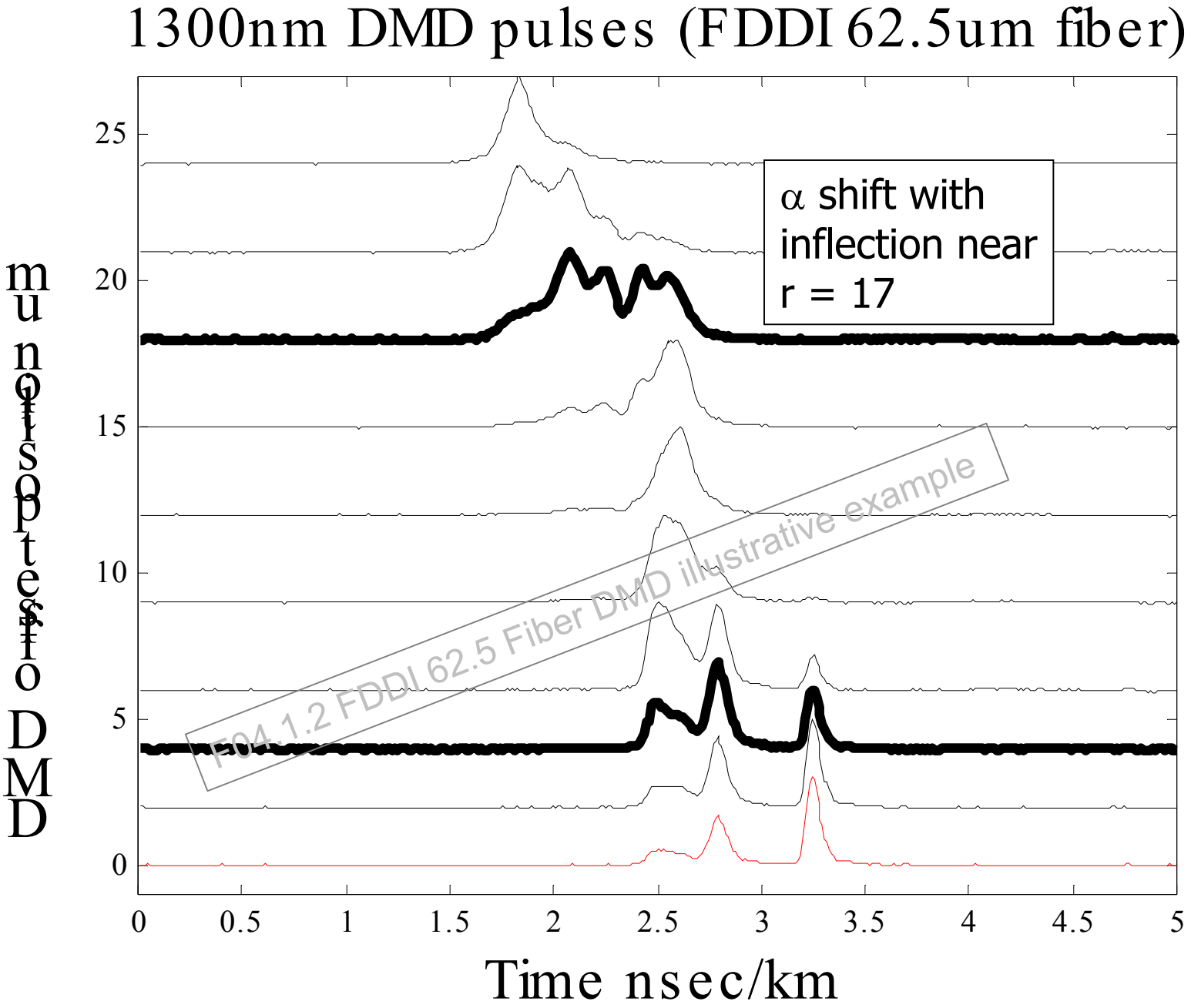


Low order split,
kink near r = 16

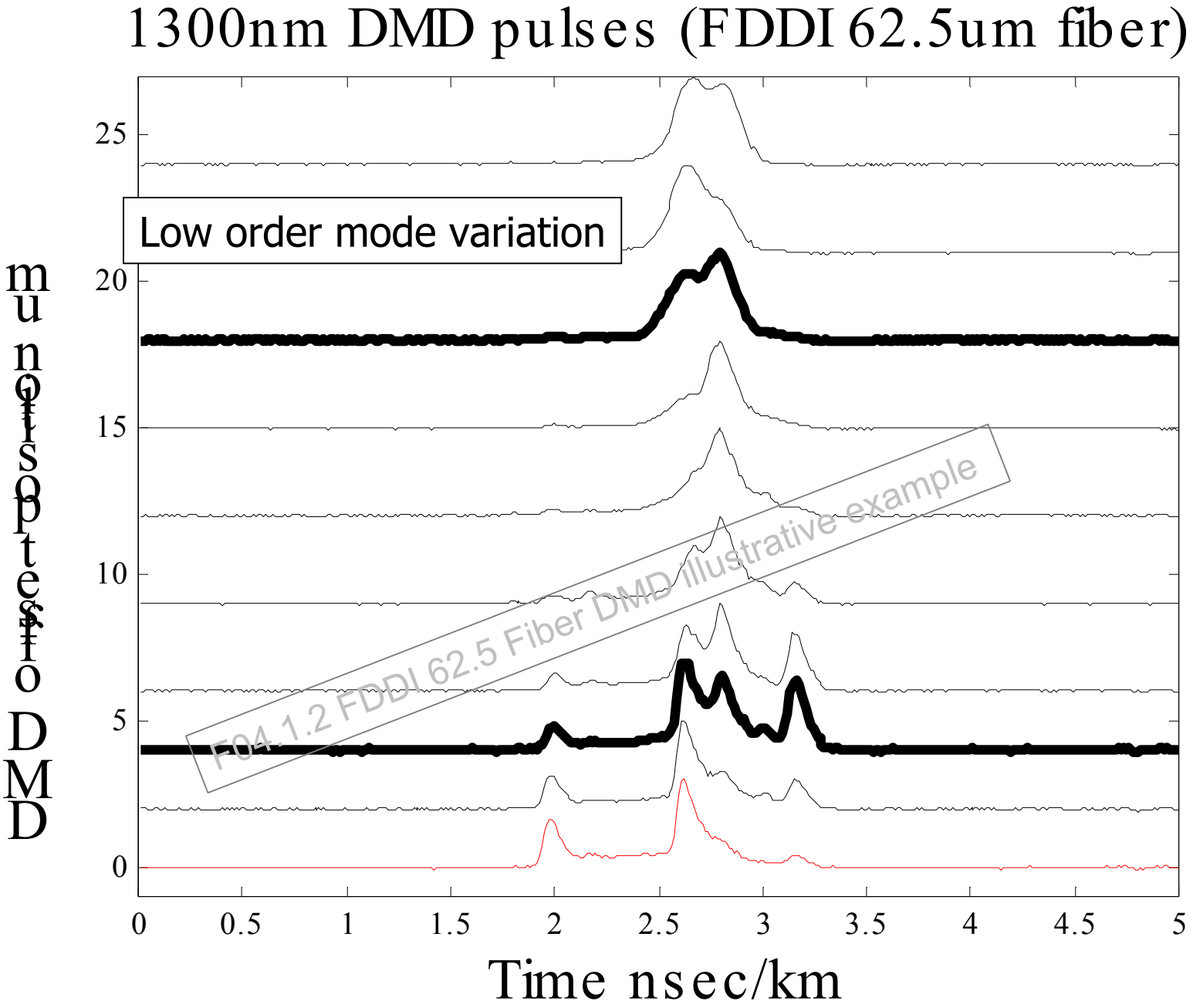




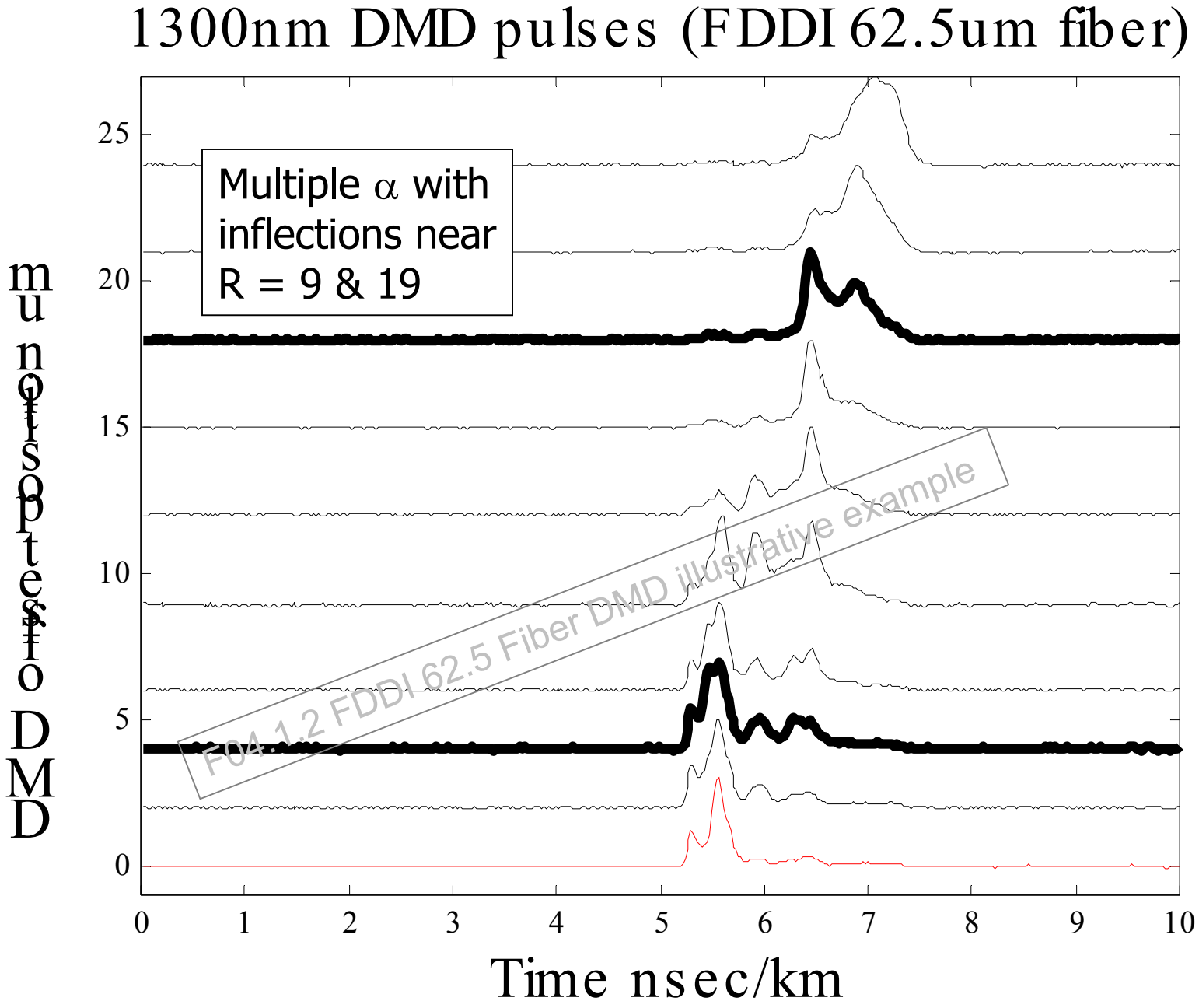
Sample 41 8860m



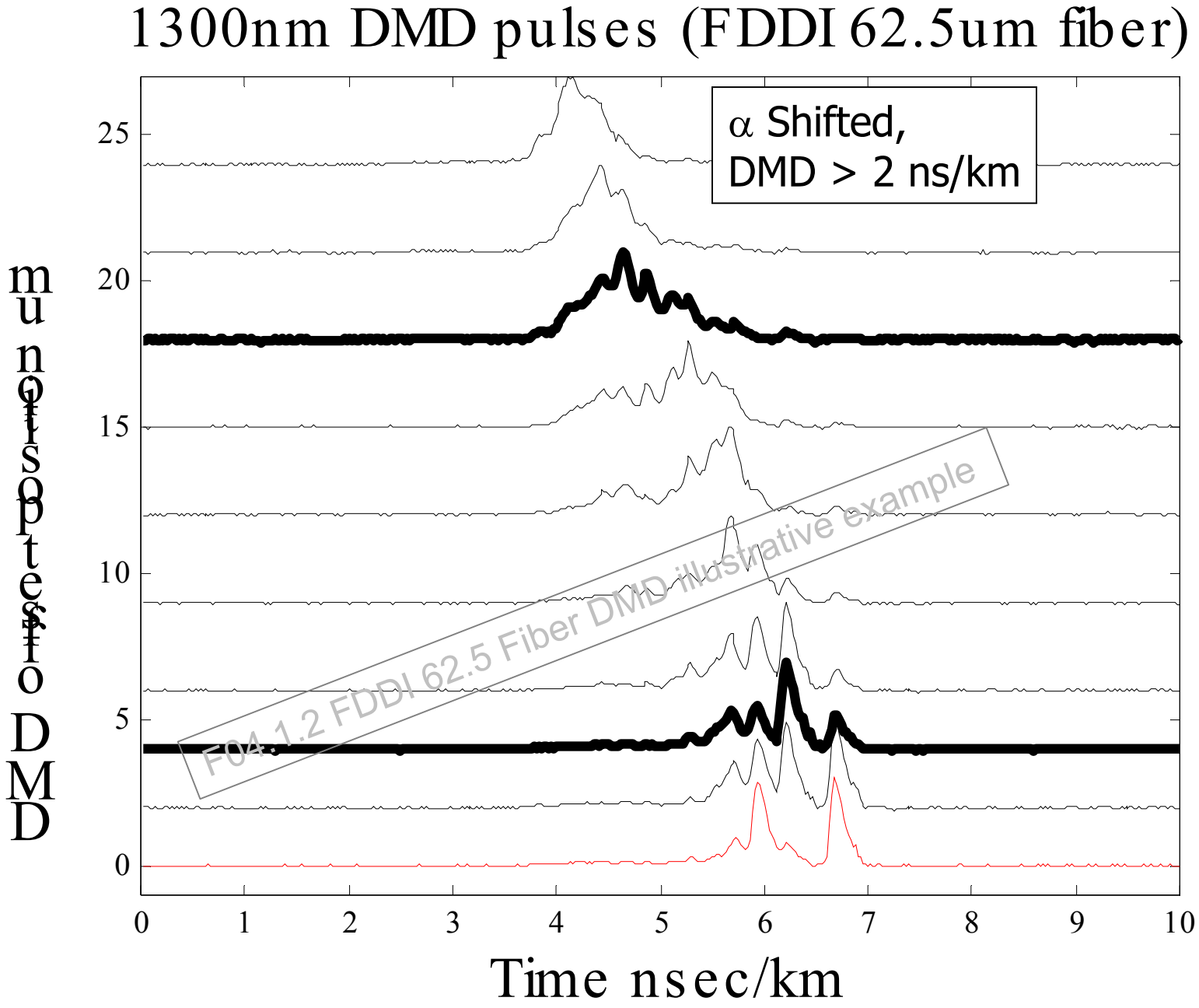
Sample 43 8860m



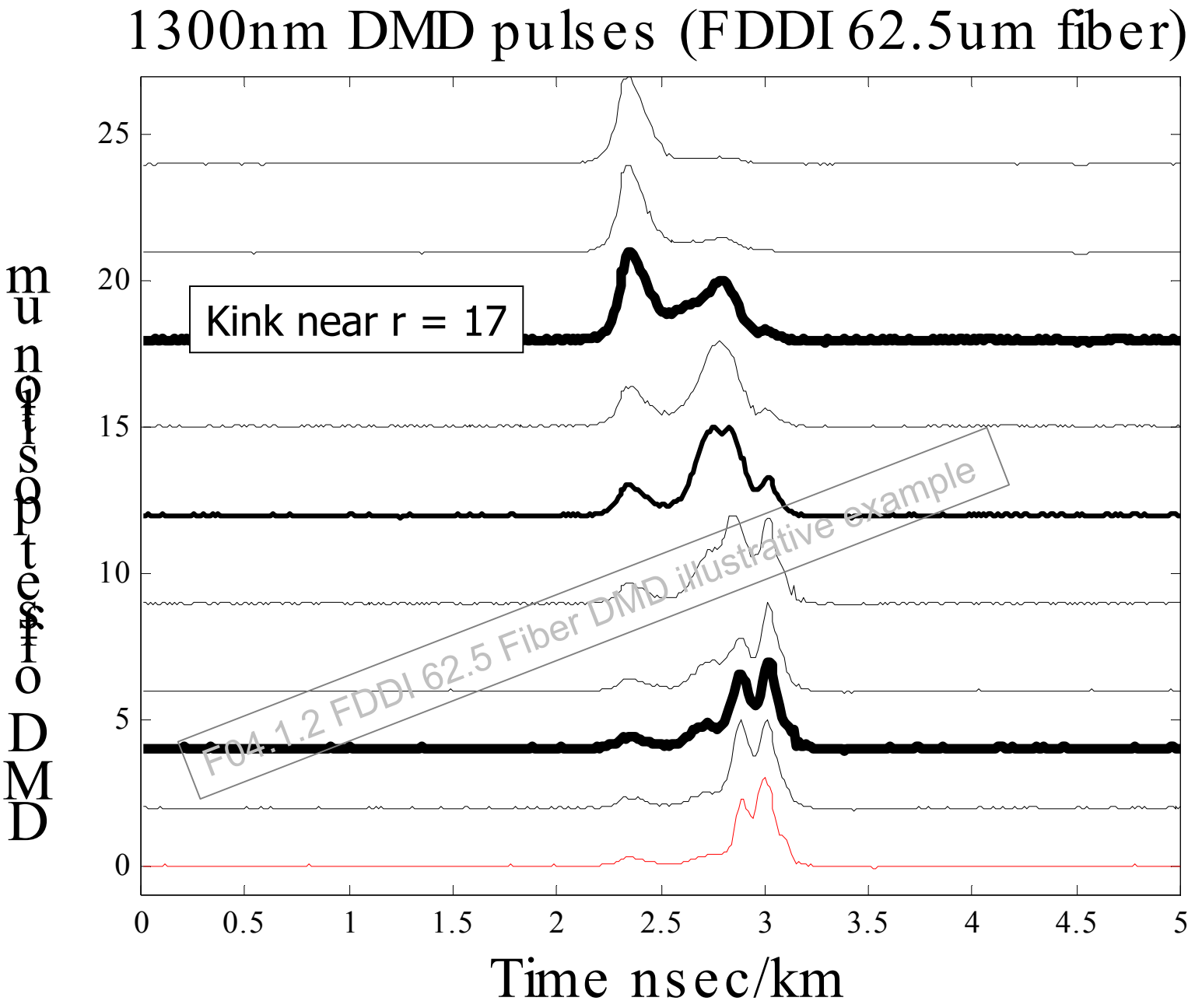
Sample 44 8859m



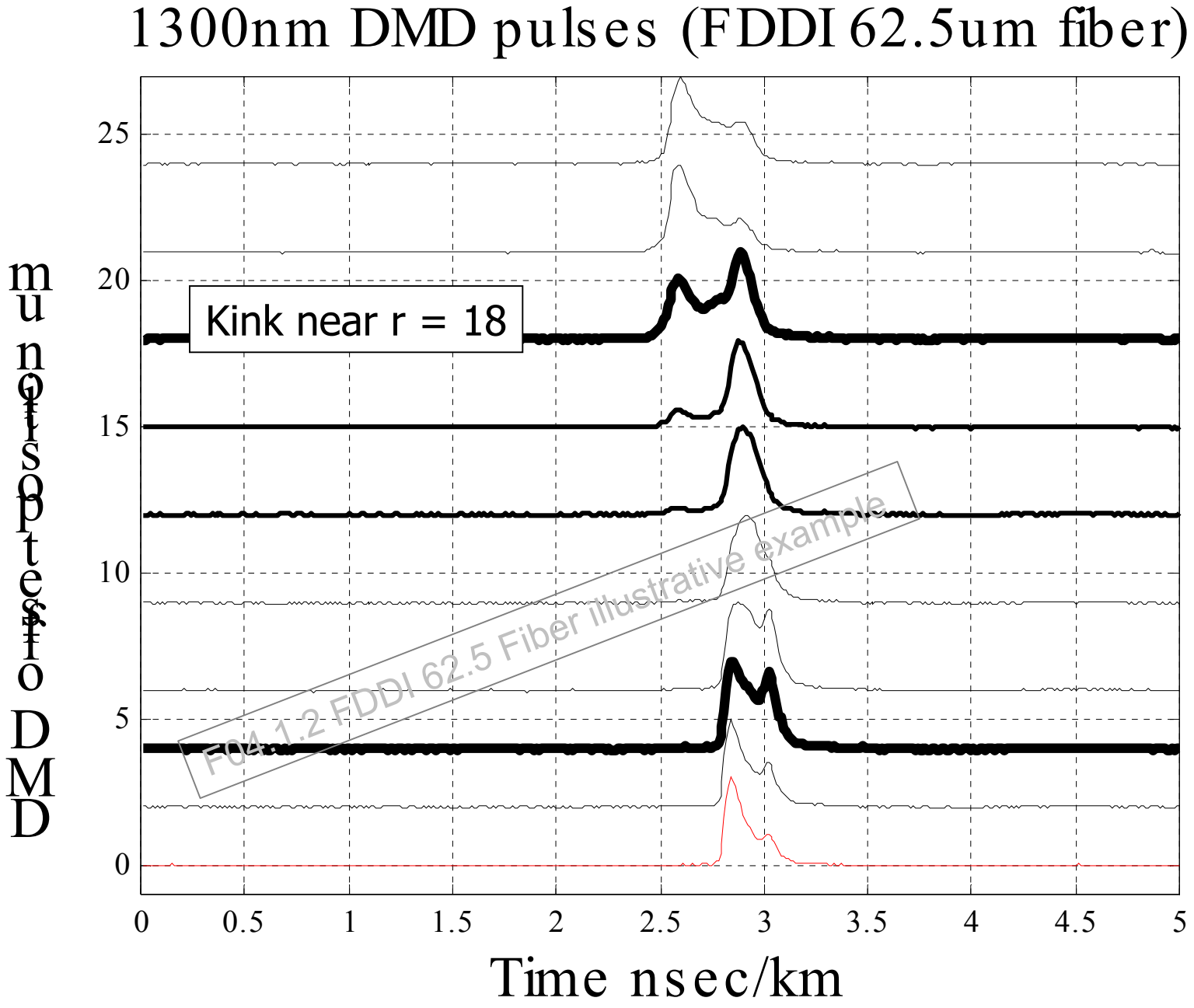
Sample 45 4460m



Sample 47 4459m



Sample 48 8860m



Sample 49 8860m

Recommendations to Enhance Cambridge Model

- Extract group delays from these DMD plots
- Include representative delay sets in model if not already present
- Re-examine present core-clad perturbations
  - Magnitude of high order DMD overly dominant
- Scale all delay sets to 500 MHz-km OFL BW without limiting DMD to 2 ps/m
  - Scaling uniformly may not produce delay sets representative of observed fibers
  - Examine other scaling approaches, such as scaling as a function of local index delta

Recommendations for Overall Modeling Effort

- Use two models as cross check for each fiber type
  - Cambridge “worst-case”
  - FO-4.1.2 Monte Carlo
- Enhance the Cambridge fiber set
  - Modify 62.5 μm set
  - Create 50 μm equivalent set
- Enhance FO-4.1.2 fiber set
  - Modify 50 μm set for 1300 nm (done) and FDDI grade
  - Create 62.5 μm equivalent set
- Resolve discrepancies
  - Converge on common model, or
  - Pass/fail criterion for two models