Budget- and Penalty-oriented EDC System Performance Evaluation

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Outline

- Budget- and penalty-oriented system performance evaluation.
- Performance model: Penalty attributable to DMD before and after equalization.
  - DFE Adaptation Figure-Of-Merit (DFE-AFOM) for channels
- Results: Cambridge Fibers at L=220m and L=300m
  - ISI Power Penalty for unequalized fiber
  - EDC idealized penalty (unequalized ISI+noise enhancement)
  - EDC implementation penalty

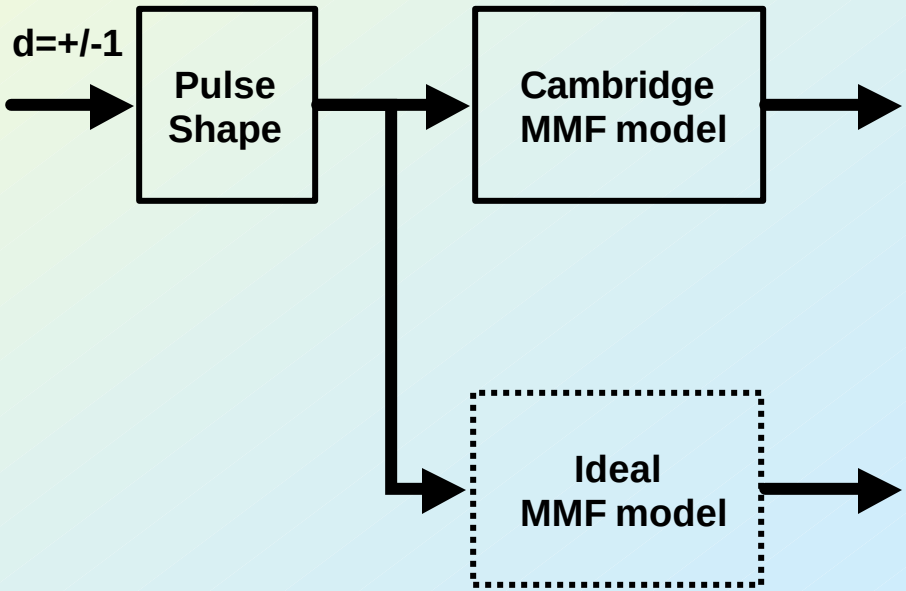
10Gbase-LRM Link Budget

- Link budget is loosely based on 10Gbase-LR
- Carve out un-needed penalty and loss allocations, and assign the slack in the budget to DMD/EDC as a maximum allowable penalty.
  - Current thinking is that there is *about* 6dB left in the budget to spend on EDC.
- EDC idealized penalty: ~4.5dB
- EDC implementation loss: ~1.5dB
  - Circuit implementation loss
  - Static and Dynamic Mis-adaptation loss
  - Implementation complexity limitations (e.g. FFE and FBE number of taps and their precision).
  - CDR static and dynamic sampling error
- *It is likely that the 4.5+1.5 dB split is not entirely accurate.*

Performance Modeling Implications

- The budget-based approach implies a comparison with an ideal fiber (zero differential mode delay) and a launch power of 1 (arbitrary unit).

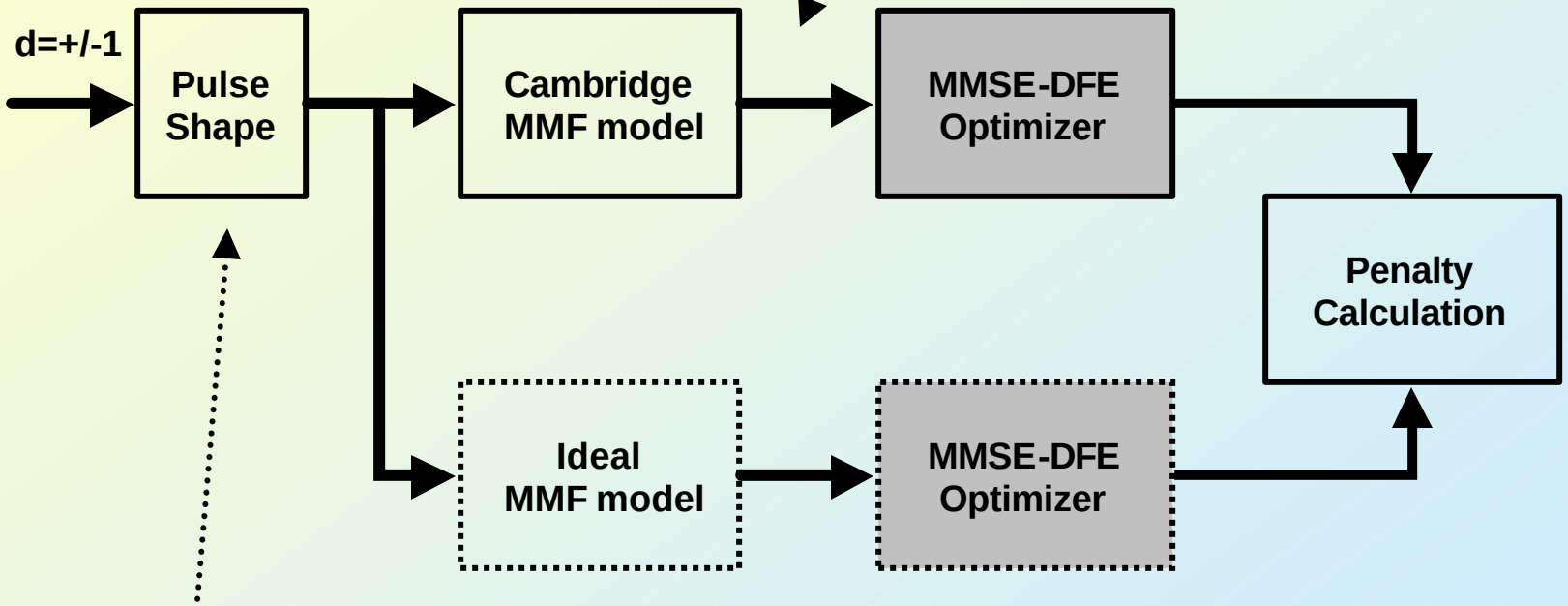
- The objective of the model is to establish the penalties associated with correction and residual of the ISI of the non-ideal fiber.



Budget-Based Power Penalty Model

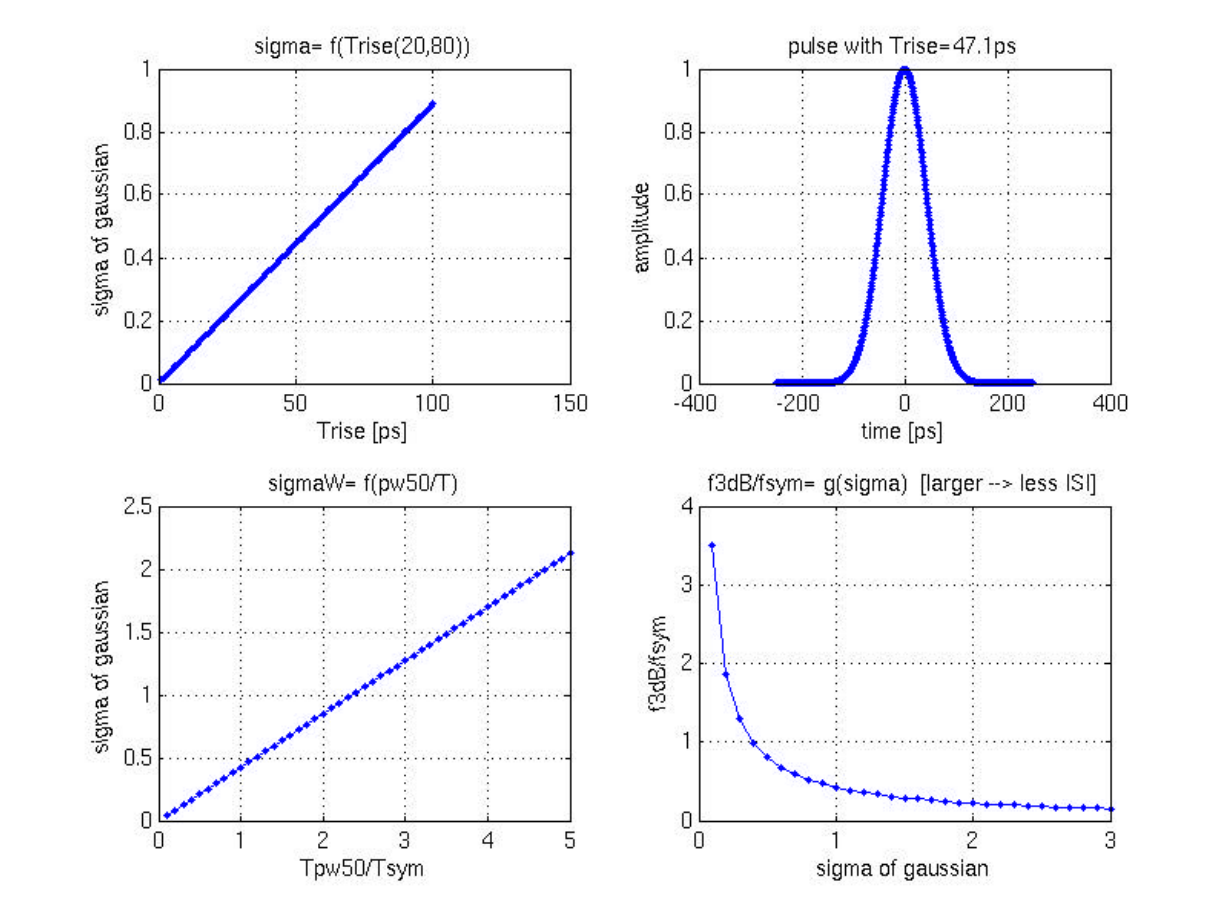
$$h_{ch}(t) = \sum_{k=0}^{N-1} \tilde{h}_{ch}(k) * d(t - t_k)$$

$$h_{pulse}(t) = \sum_{k=0}^{N-1} \tilde{h}_{ch}(k) * p(t - t_k)$$



$$p(t) = K \cdot e^{\frac{-(t/T_0)^2}{2s^2}}$$

Model Input: Back-to-Back Pulse Responses

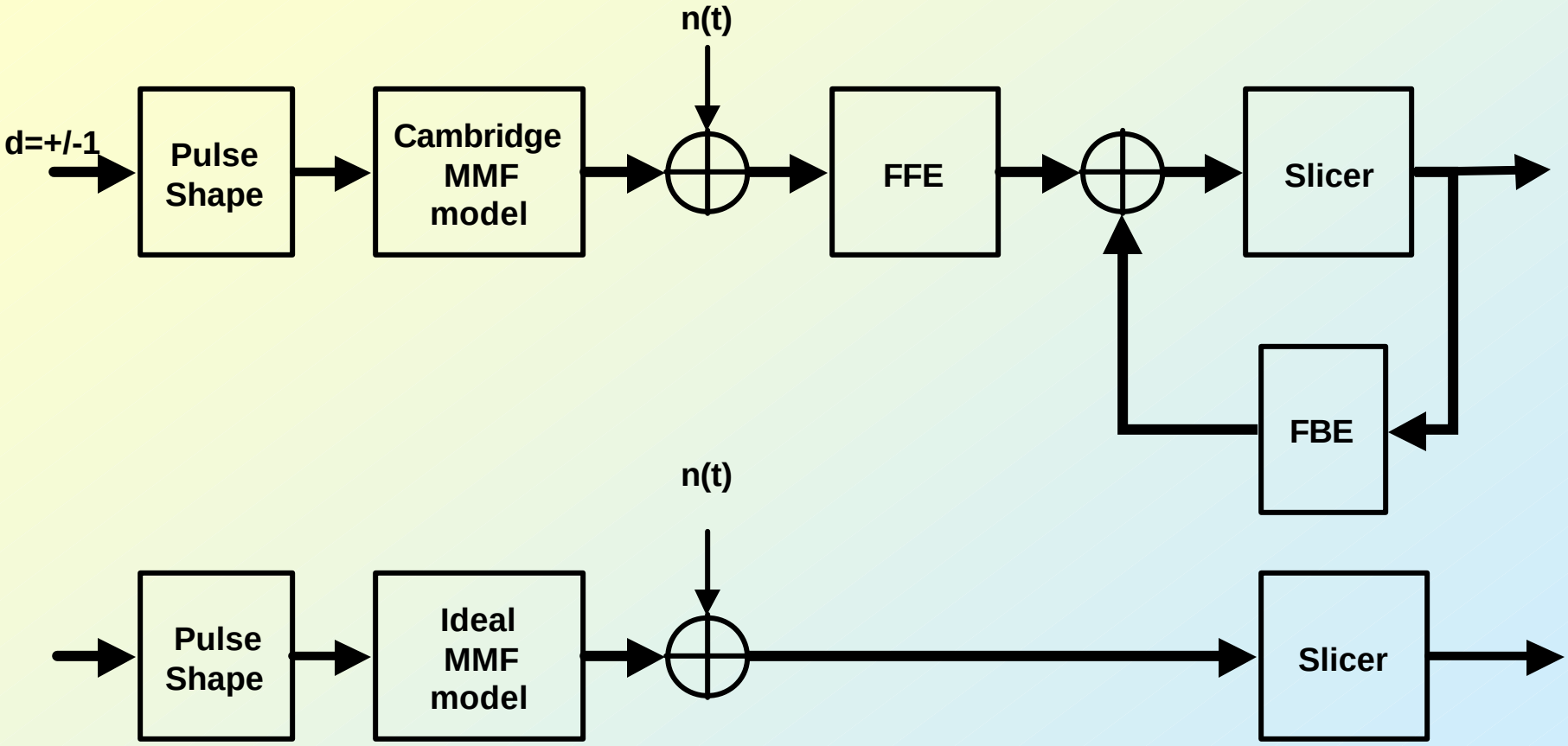


- **Agilent spreadsheet model uses Gaussian pulse with Trise(20-80)=47.1ps, translating into sigma=0.4183, or pw50=100ps.**

Power Penalty Calculation

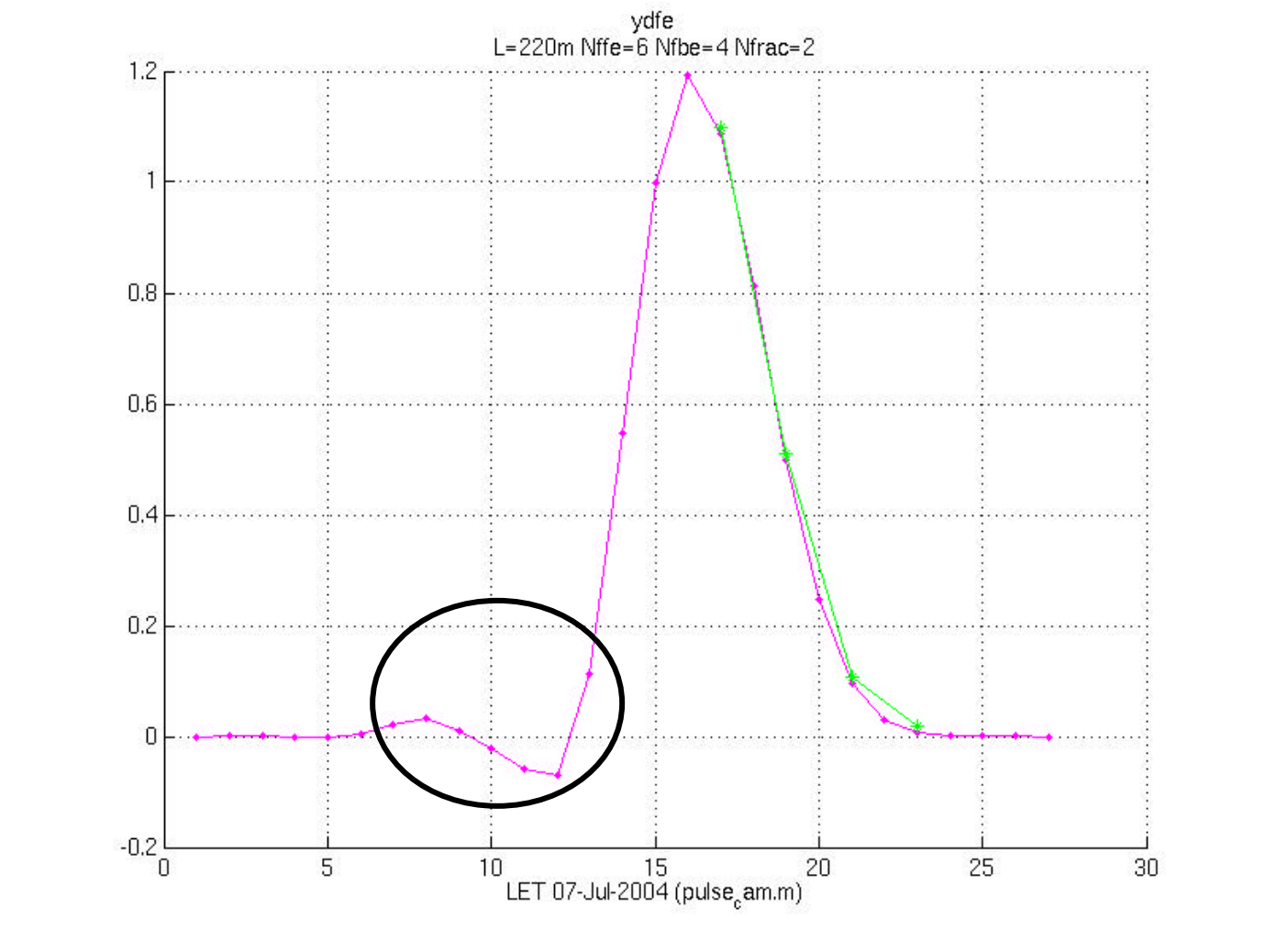
- The power penalty of the EDC *unavoidably* depends on the implementation, for example
  - LE or DFE
  - Nffe and Nfbe (number of taps)
  - Implementation losses
- Idealized models (PIE-L and PIE-D) provide guidance and correspond to unbounded-length equalizers with zero implementation losses.
- Specific lengths considered for implementation are also of great interest.
- Tx or (better) back-to-back pulse shape also matters!

Power Penalty Reference Model



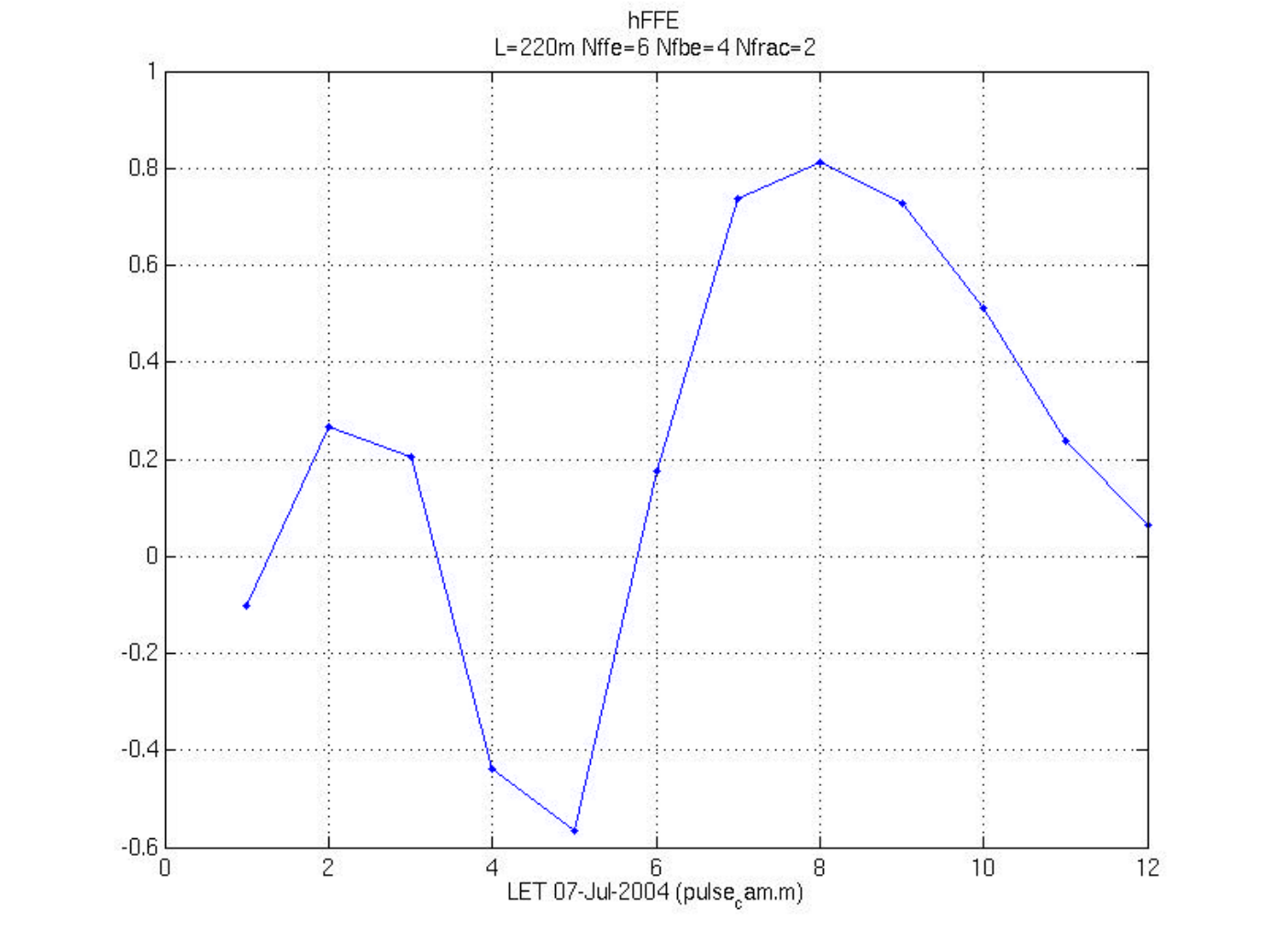
Noise is included only in the sense that we want to evaluate how much the noise is enhanced by the EDC.

Power Penalty : Residual ISI



- **Fiber/launch #163 (nearly the worst case) at L=220m**

Power Penalty : Noise Enhancement



- Fiber/launch #163 (nearly the worst case) at L=220m

Power Penalty Calculations

- The ideal fiber has *by definition* a penalty of 0dB and an rx pulse with cursor amplitude 1.
- A DMD-impaired fiber *with no compensation* has a specific ISI penalty relative to the ideal fiber:

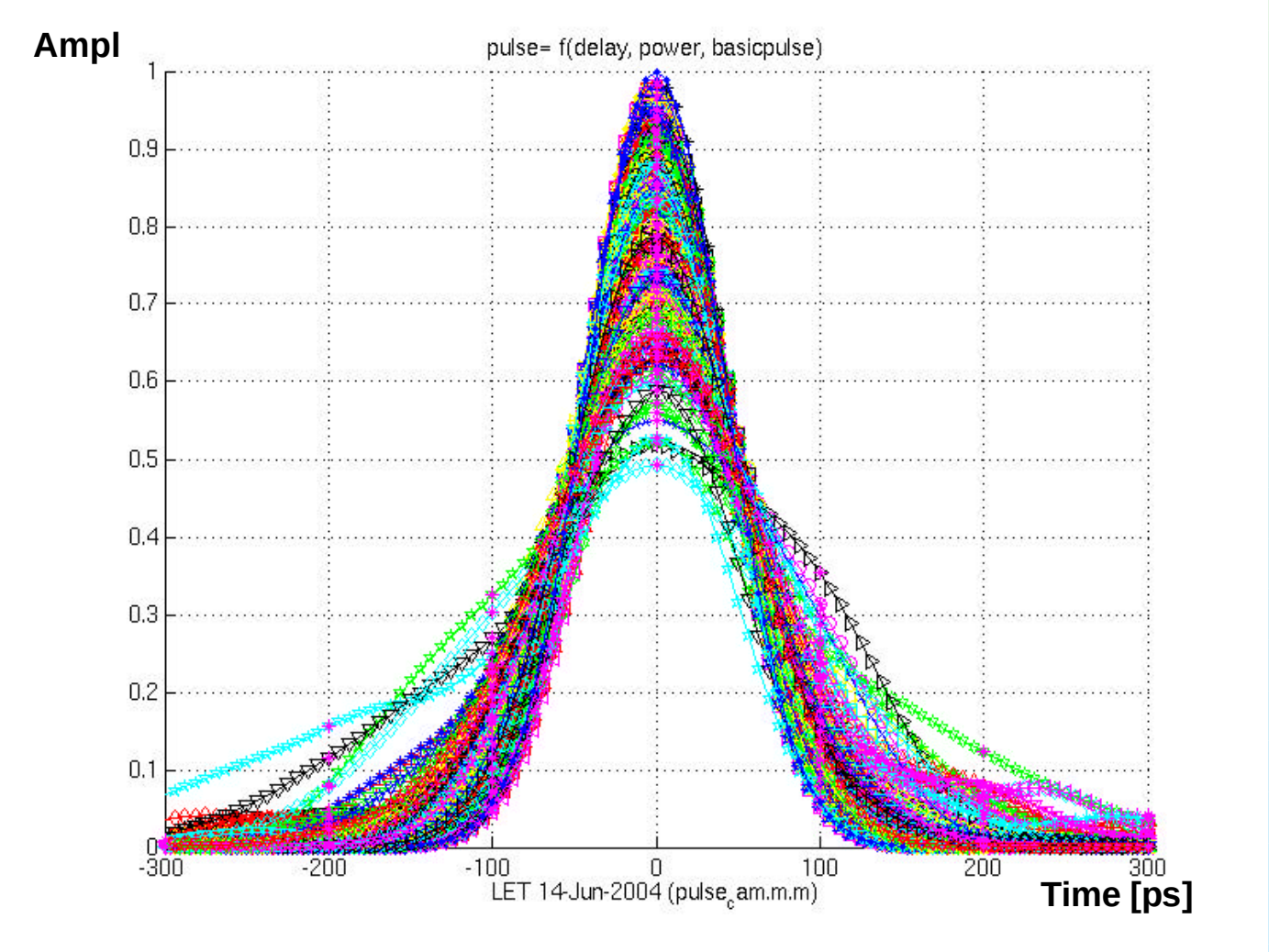
$$\Delta P_{DMD} = \frac{2 \times \left| h_{pulse}(k) \right|_{\max} - \sum_{k=0}^{N-1} \left| h_{pulse}(k) \right|}{1} = 2 \times \left\| h_{pulse} \right\|_{\infty} - \left\| h_{pulse} \right\|_{1}$$

- After MMSE-DFE, the penalty relative to the ideal fiber is comprised of two factors:
  - Residual ISI
  - Noise Enhancement
  - Note: hFFE(n) is scaled so that hcursor=1.

$$\Delta P_{ISI} = \frac{\left| h_{cursor} \right| - \left\| h_{precursor} \right\|_{1}}{\left| h_{cursor} \right|} = 1 - \left\| h_{precursor} \right\|_{1}$$

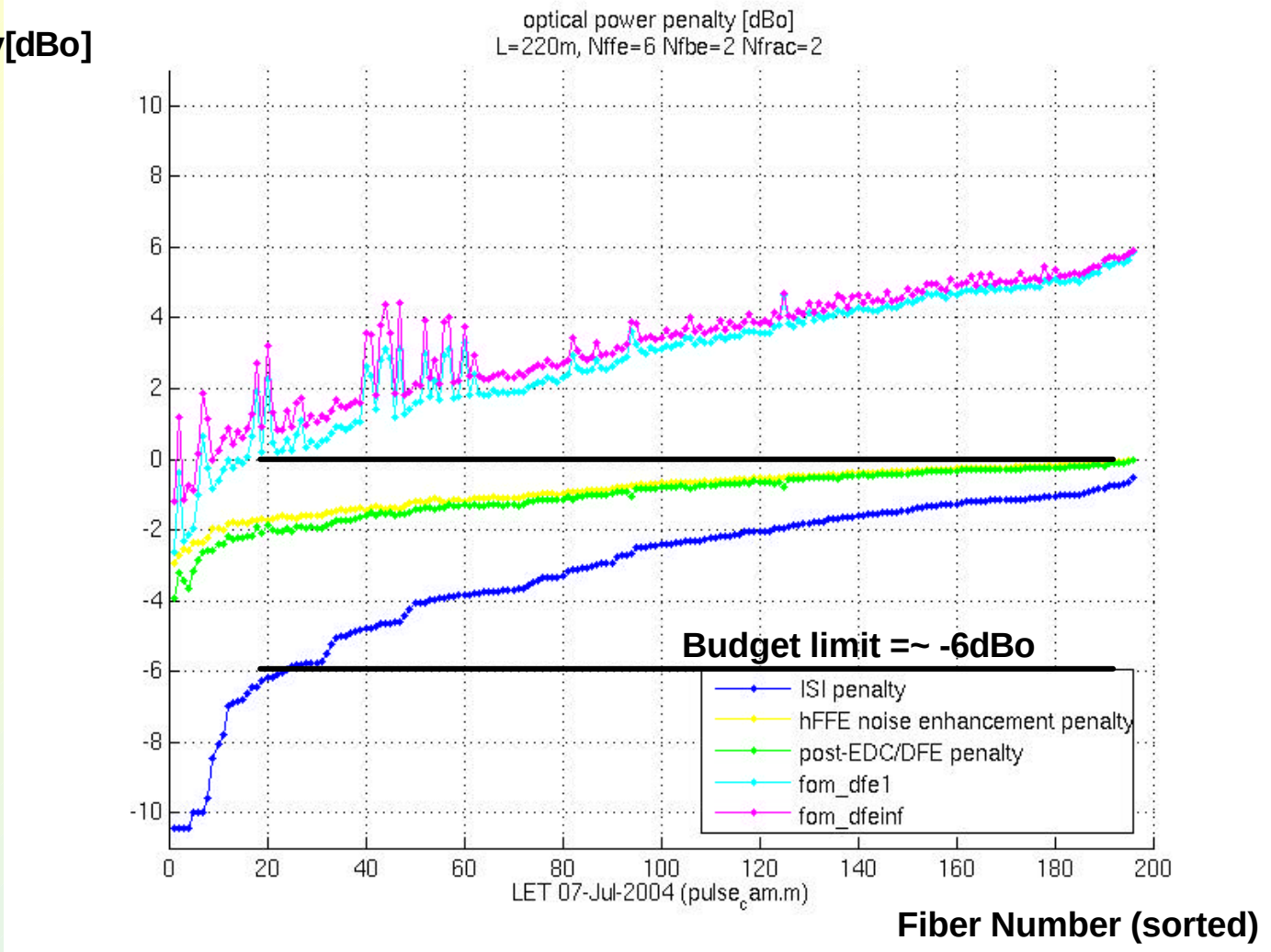
$$\Delta P_{NE} = \frac{\left\| h_{FFE}(n) \right\|_{2}}{1}$$

Cambridge Fiber Model : Pulse responses



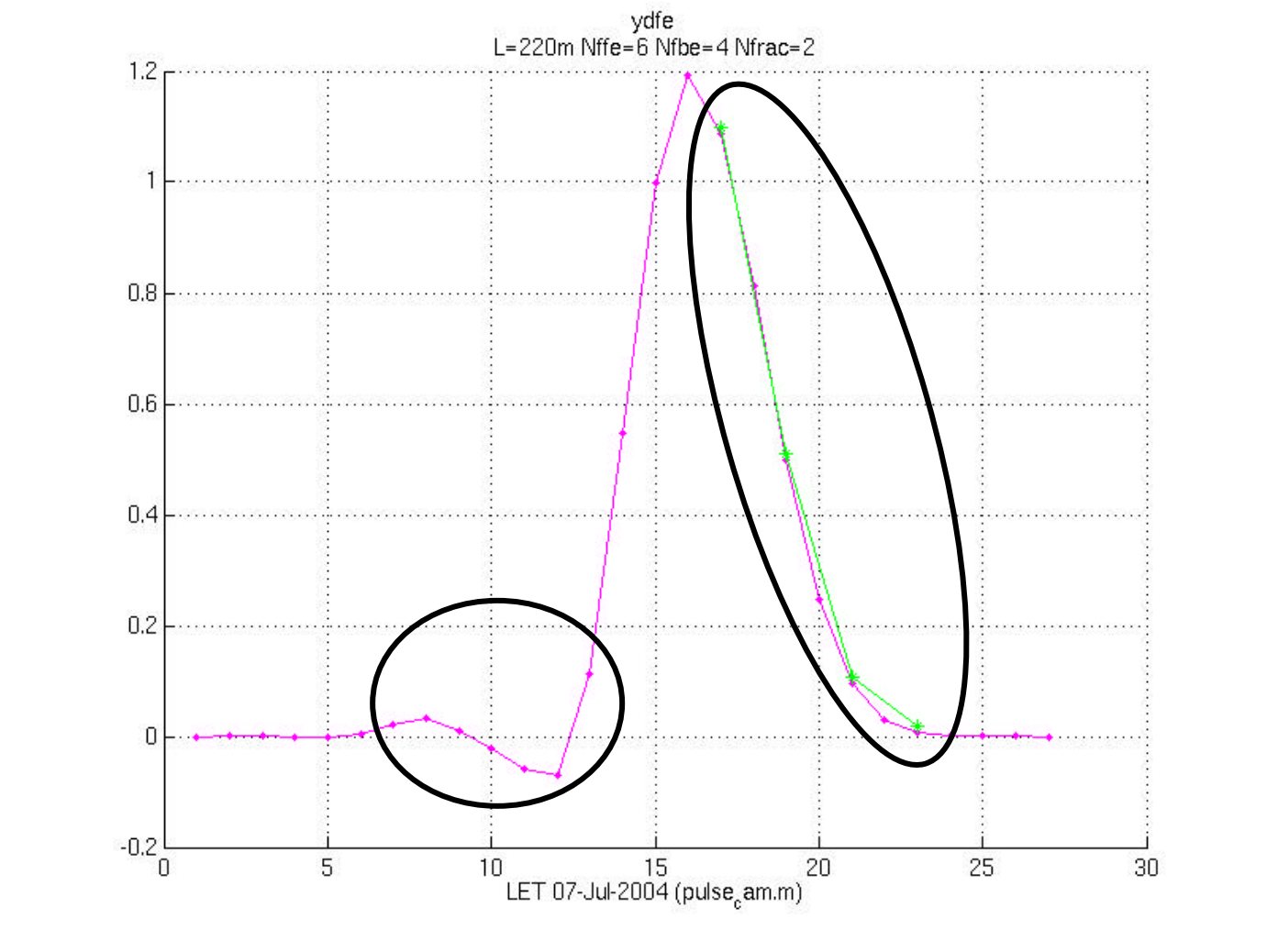
- Cambridge pulses, L=220m, Gaussian, pw50=100ps

Power Penalty : Before and After MMSE-DFE



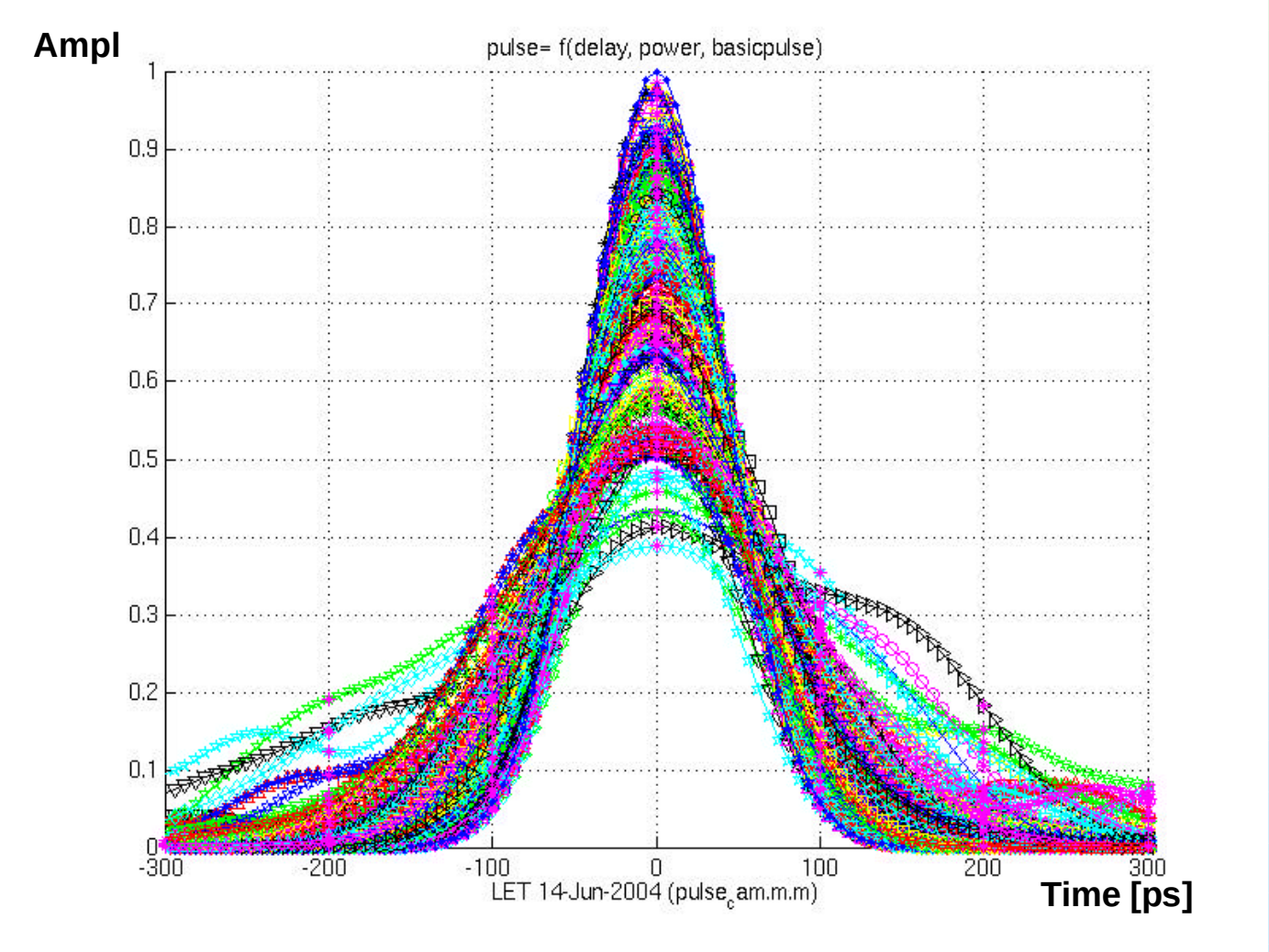
- **DFE-AFOM also shown**

DFE Adaptation Figure of Merit



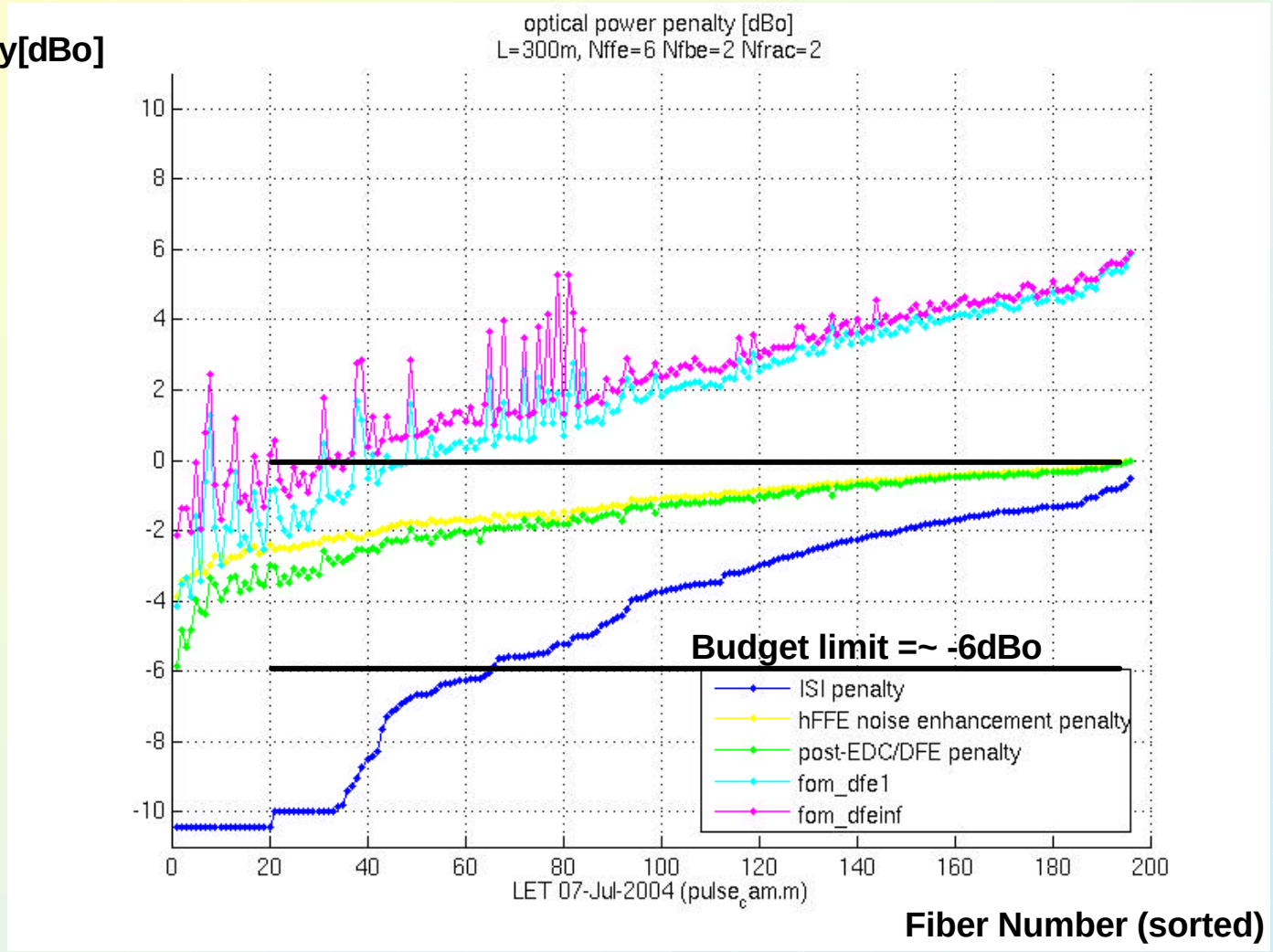
- Fiber/launch #163 (nearly the worst case) at L=220m

Cambridge Fiber Model : Pulse responses



- Cambridge pulses, L=300m, Gaussian, pw50=100ps

Power Penalty : Before and After MMSE-DFE



- DFE-AFOM also shown

Summary

- Budget-oriented analysis quantifies effect of EDC without detailed BER estimation.
- Sorting EDC penalty measures according to the raw ISI penalty provides insight into distribution.
- Consideration of specific implementation choices are an important complement to idealized metrics.
- Results indicate that at least 4dBo of budget is required to cover the Cambridge Model fibers, with ballpark choices of Nffe and Nfbe, net of remaining EDC implementation losses.