Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: More on 4ab preambles: apEval results and recommendations
Date Submitted: 15 September, 2022
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Abstract: This document provides recommendations on the preamble selection and performance comparison of different preamble sequences

Purpose: To converge on a common framework to evaluate the new codes being proposed in 802.15.4ab

PAR Objective	Proposed Solution (how addressed)
Safeguards so that the high throughput data use cases will not cause significant disruption to low duty-cycle ranging use cases	
Interference mitigation techniques to support higher density and higher traffic use cases	Proposed sequences offer flexible multi-user interference mitigation
Other coexistence improvement	
Backward compatibility with enhanced ranging capable devices (ERDEVs)	
Improved link budget and/or reduced air-time	
Additional channels and operating frequencies	
Improvements to accuracy / precision / reliability and interoperability for high-integrity ranging	
Reduced complexity and power consumption	Proposed sequences allows efficient construction
Hybrid operation with narrowband signaling to assist UWB	
Enhanced native discovery and connection setup mechanisms	
Sensing capabilities to support presence detection and environment mapping	
Low-power low-latency streaming	
Higher data-rate streaming allowing at least 50 Mbit/s of throughput	
Support for peer-to-peer, peer-to-multi-peer, and station-to-infrastructure protocols	
Infrastructure synchronization mechanisms	

Introduction

- 802.15.4z supports 32 preamble codes, based on Ipatov sequences
  - Ipatov 31 (8 codes), Ipatov 91 (8 codes), Ipatov 127 (16 codes)
- Need to expand the preambles to support more emerging use cases for UWB, and expanding UWB ecosystem
- New Preamble codes for 4ab and performance comparison
  - Golay codes [1], CZC codes [2], m-sequences [3] were proposed for 4ab
  - Contributions in July meeting ([4, 5]) comparing the cross-correlation of two sequences
  - A framework to evaluate the cross-correlation performance of family of codes [6]
- We provide updates to framework, cross-correlation comparison results, and recommendations on preambles for MMS

apEval (4ab preamble Evaluation) Framework - (recap)

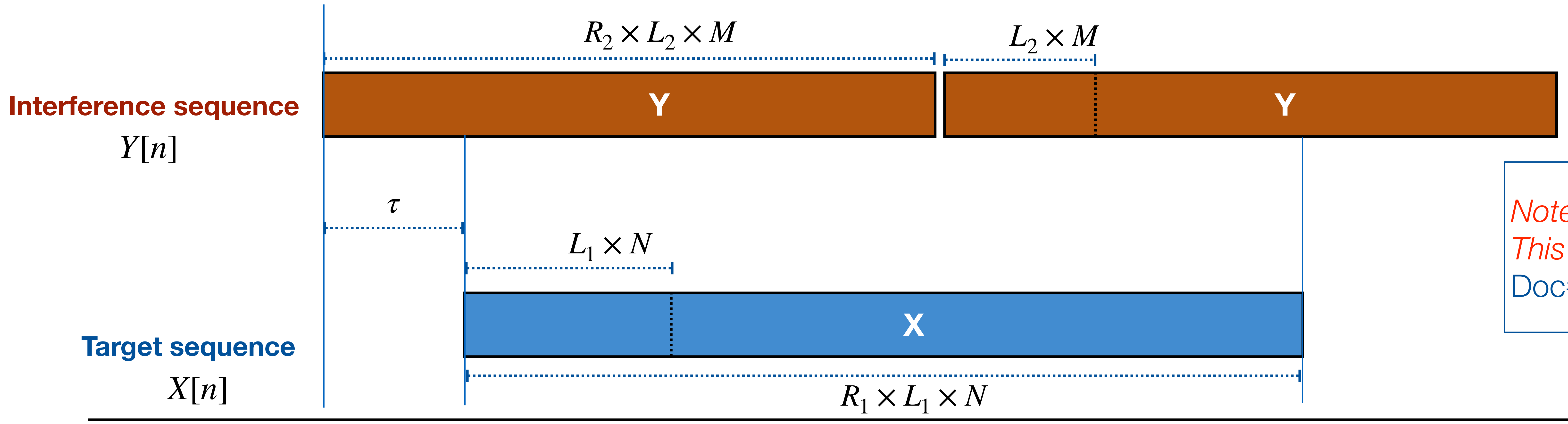
- The framework characterizes the cross-correlation between two sets of codes, through montecarlo simulations
  - Set1: **target codes**
    - Could be Golay codes, m-sequences, CZC sequences, any other new 4ab preamble codes
  - Set2: **interfering codes**
    - Could be Ipatov 127 (or) Ipatov 91 (or) the target codes (or) the union of all of these

- Other input parameters to the framework
  - PSR (R), Gap (G), STS/Data collision prob (p), spreading factor (L), Max CFO (Δf_{max})

- Output: measure of cross-correlation between Target codes (Set1) and the Interference codes (Set2)
  - **90-percentile CDF of the cross-correlation**

apEval cross-correlation metric (update)

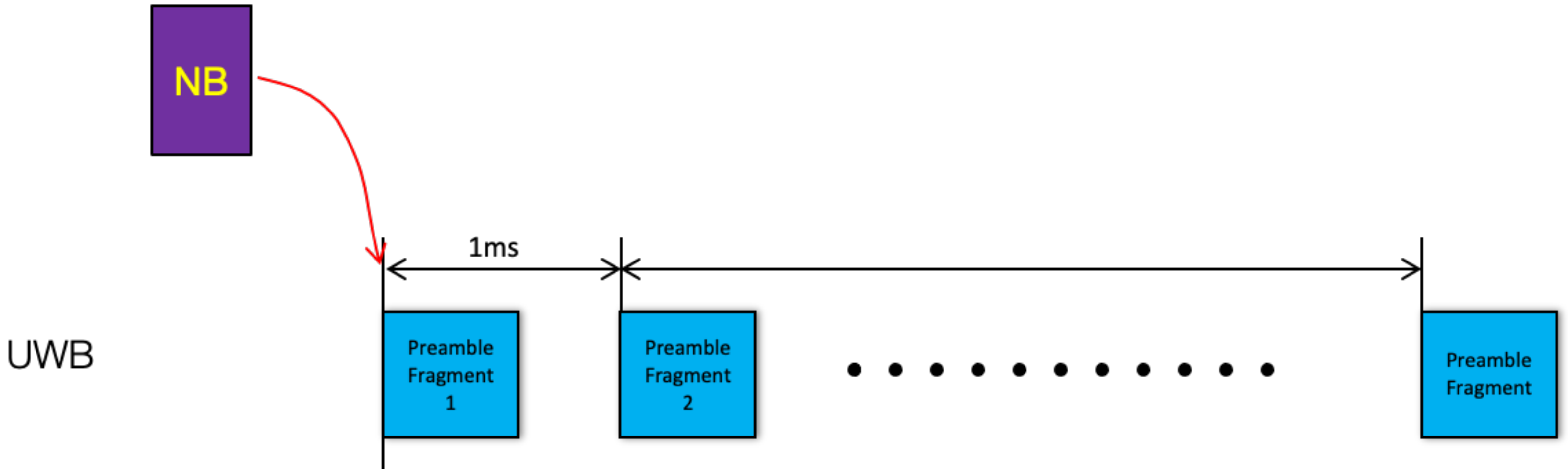
- Cross-Correlation Metric (Updated)
  - Let N denote the length of x, the length of x' is $L_1 \times N$, the length of the **target sequence** $X[n]$ is $R_1 \times L_1 \times N$
  - Let M denote the length of y, the length of y' is $L_2 \times M$, the length of the **interference sequence** $Y[n]$ is $R_2 \times L_2 \times M$
  - Normalized Cross-Correlation metric is computed in dB scale as
    - $\max_{\tau \in [0, R_2 L_2 M - 1]} \phi[\tau]$
      - where $\phi[\tau] := 20 \log_{10} \left| \frac{\sum_{n=0}^{R_1 L_1 N-1} Y[\text{mod}(n+\tau, R_2 L_2 M)] \cdot X[n]}{\sum_{n=0}^{R_1 L_1 N-1} X[n]^2} \right| + \Delta$
      - Δ is the scaling factor to account for power difference in symbols x and y (Δ = 0 by default)
      - Note: the range of τ to find the max of $\phi[\tau]$ could be reduced to $[0, L_2 M - 1]$ when $Y[n]$ is periodic with period M
        - This will be the case when $\Delta f = 0$. When $\Delta f \neq 0$, the range needs to be $[0, R_2 L_2 M - 1]$



Note:
This change is reflected in updated simulation code available in
Doc#: 15-22-0447-02-04ab-apEval_framework.m

Preamble sequences

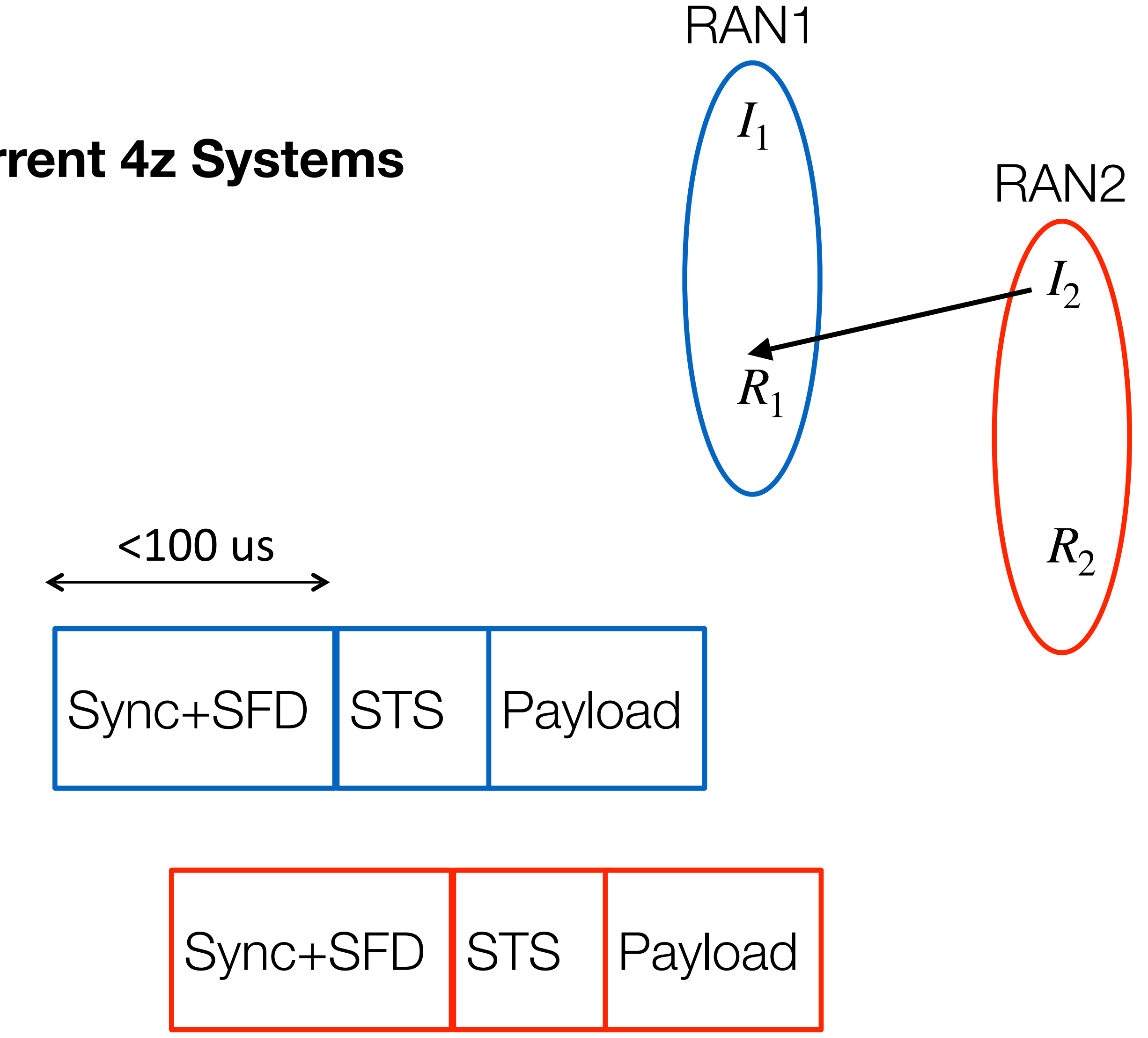
- Need to differentiate preambles for MMS combining and Packet acquisition
- Preamble codes for **packet acquisition**
  - Large ZACZ, and good cross-correlation over **short accumulation** is desirable
- Preamble codes for **MMS combining**



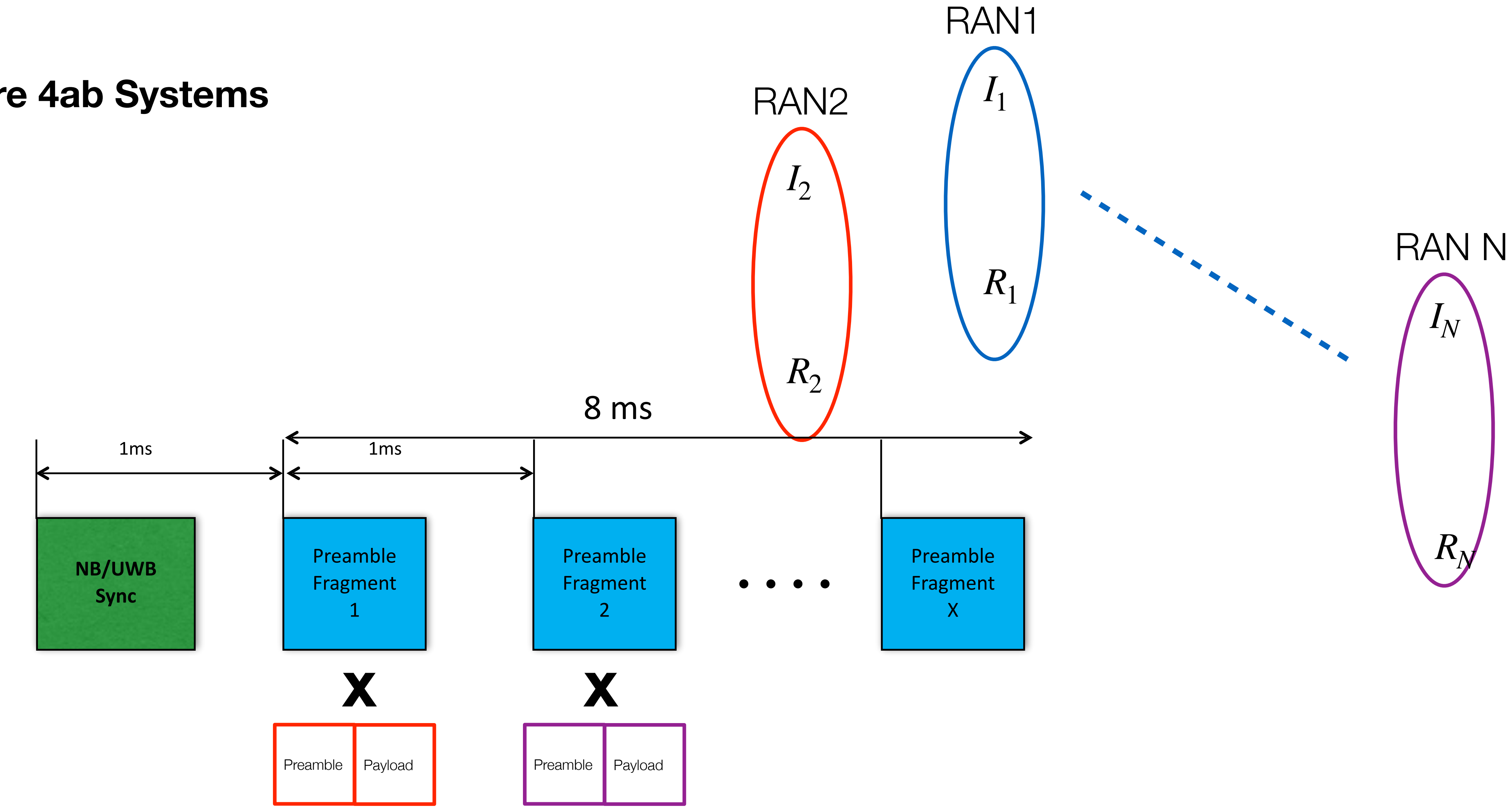
  - Initial timing and CFO provided by NB (in NBA-MMS)
  - ZACZ of channel delay spread is sufficient, to enable clean CIR estimation
  - Good cross-correlation over **long accumulation** is desirable
    - Preamble codes with different periodicity suits well for this purpose
  - Desirable to have large set of preamble codes to enable several parallel operation of RANs

Preamble for MMS: way forward recommendations (1)

Current 4z Systems



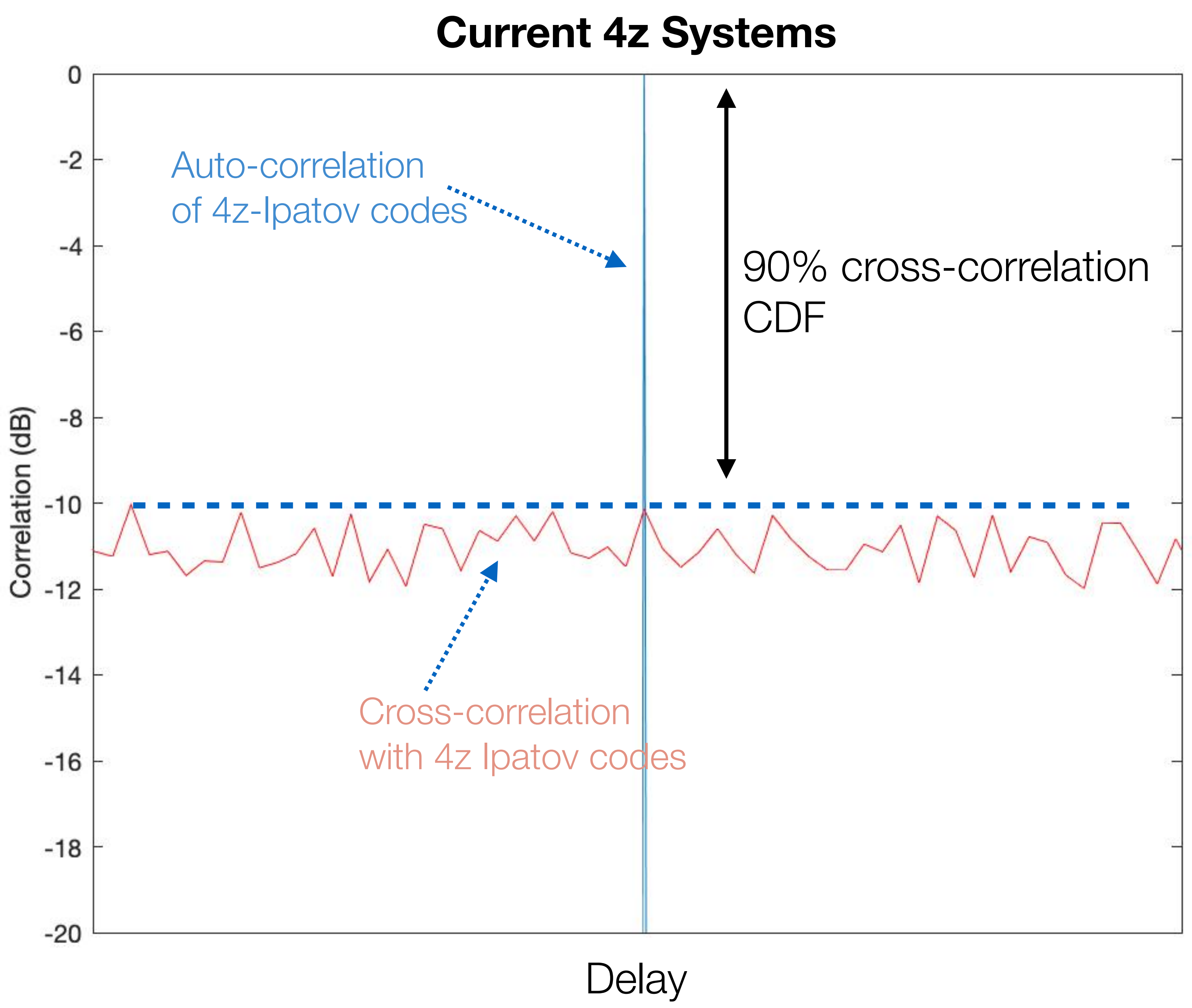
Future 4ab Systems

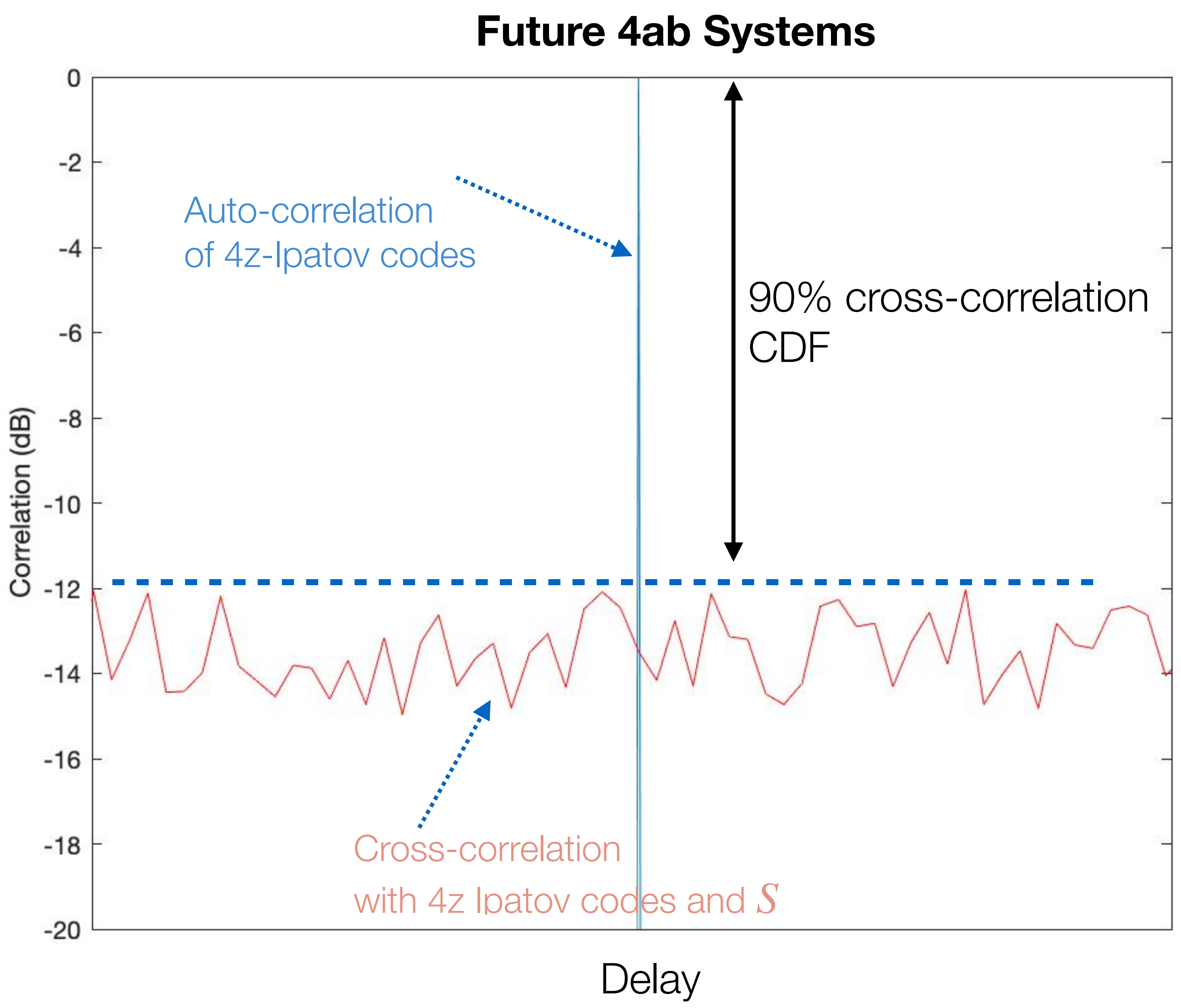


- Recommend to define 64 new preamble codes for MMS preamble fragments
  - Large code set enables parallel operation of several RANs
  - Reduces the chances of collisions of packets with same preamble code
    - MMS preamble are more susceptible to collisions, due to longer air-time (up to 8 ms of preamble fragments)
  - Code set size constrained by welch bound on achievable cross-correlation
- Codes with a flexibility to add Gaps further increases the overall preamble set

Preamble for MMS: way forward recommendations (2)

- Recommend to characterize the impact to the legacy 4z Ipatov systems
  - New preamble codes (set S) should not hurt the performance of legacy 4z preamble code acquisition
    - 90% Cross-correlation level should not get worse with the addition of new codes

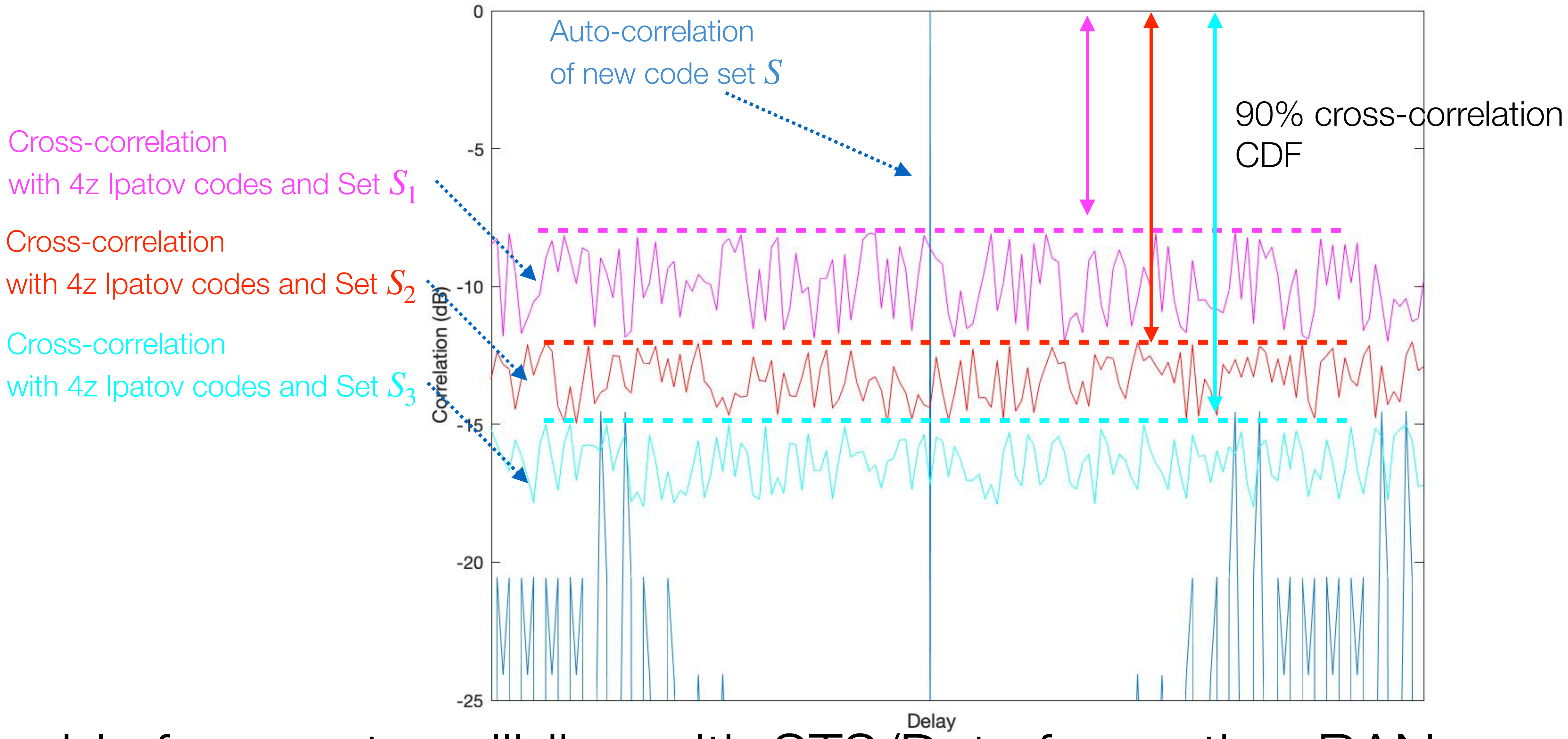




- Representative test scenarios
  - Target codes = {Ipatov 91}, Long accumulation with $R = 40$
  - Target codes = {Ipatov 127}, Long accumulation with $R = 40$
  - Target codes = {Ipatov 91}, Short accumulation with $R = 4$
  - Target codes = {Ipatov 127}, Short accumulation with $R = 4$

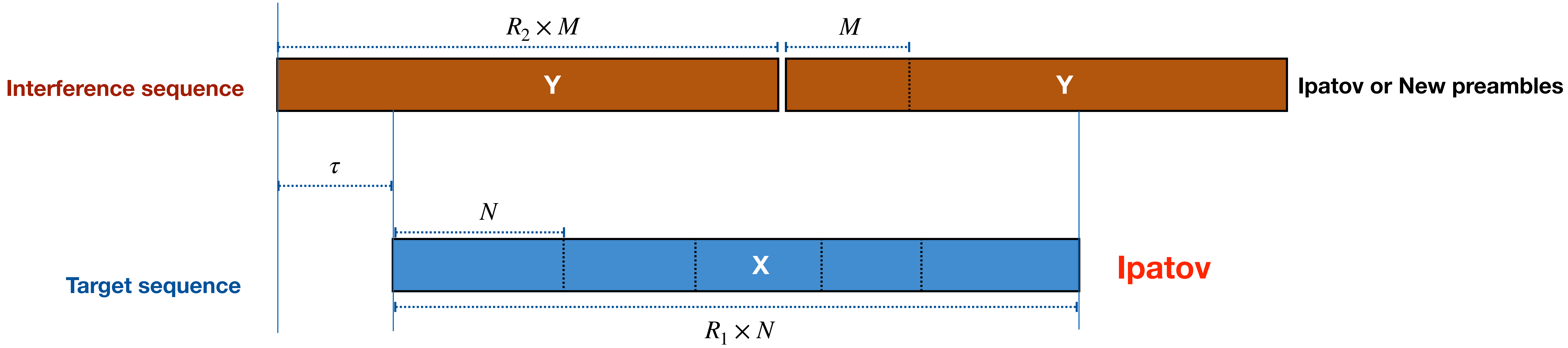
Preamble for MMS: way forward recommendations (3)

- Recommend to characterize the performance of new code set S, using long accumulation (R=40) and CFO = 0
  - Preamble fragment collision with preambles from other RAN
    - Recommend to pick the codes that provide the best 90% cross-correlation level at CFO = 0



  - Preamble fragments colliding with STS/Data from other RAN
    - Recommend to evaluate preamble code set (say S) cross-correlation with random polarity pulses (STS)
    - 90% cross-correlation CDF should not exceed a pre-determined threshold η

New codes impact on legacy 4z preamble acquisition



$R_1 = 4$ Short Accumulation

$R_1 = 40$ Long Accumulation

Cross-correlation comparison of new preamble code sets

New preamble codes impact on legacy 4z preamble code acquisition

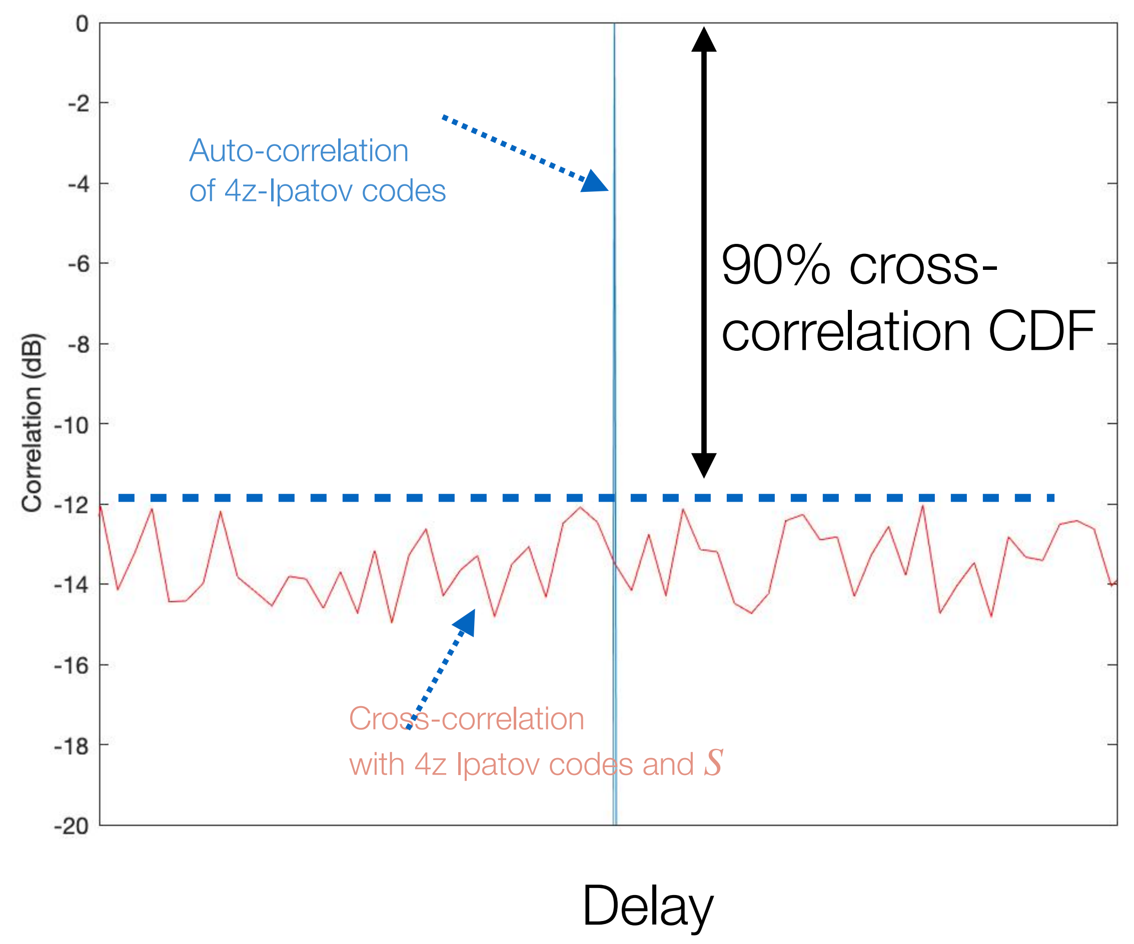
Target codes = {Ipatov 91 (or) Ipatov 127}
Interfering codes = {Ipatov 91, Ipatov 127, New preamble codes}

4z preamble acquisition using short accumulation (R = 4)

	Legacy cross-correlation	With added Golay 64+64 (64 codes)	With added m127-sequences (6 codes)	With added CZC 64x2 codes (8 codes)	With added CZC 64+64 codes (64 codes)
Target codes = Ipatov91	**-10.56 dB**	-14.32 dB	-10.56 dB	-10.56 dB	-14.52 dB
Target codes = Ipatov127	**-10.10 dB**	-14.54 dB	-10.10 dB	-10.10 dB	-14.54 dB

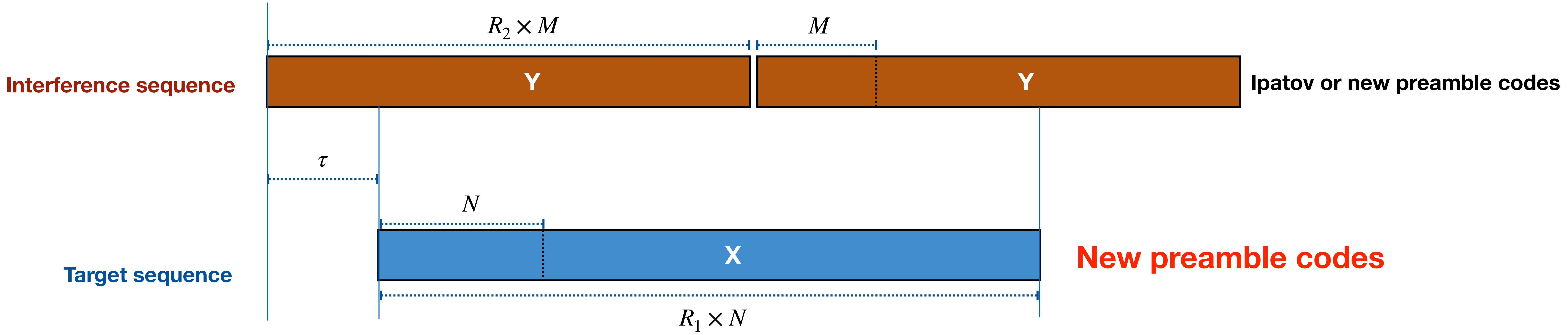
4z preamble acquisition using long accumulation (R = 40)

	Legacy cross-correlation	With added Golay 64+64 (64 codes)	With added m127-sequences (6 codes)	With added CZC 2x64 codes (8 codes)	With added CZC 64+64 codes (64 codes)
Target codes = Ipatov91	**-10.56 dB**	-26.12 dB	-10.56 dB	-10.56 dB	-26.20 dB
Target codes = Ipatov127	**-10.10 dB**	-14.54 dB	-10.10 dB	-10.10 dB	-14.54 dB



- All the proposed new preamble sequences do not hurt the legacy 4z preamble code acquisition
- Detailed CDF curves in the appendix (Slides 19-22)

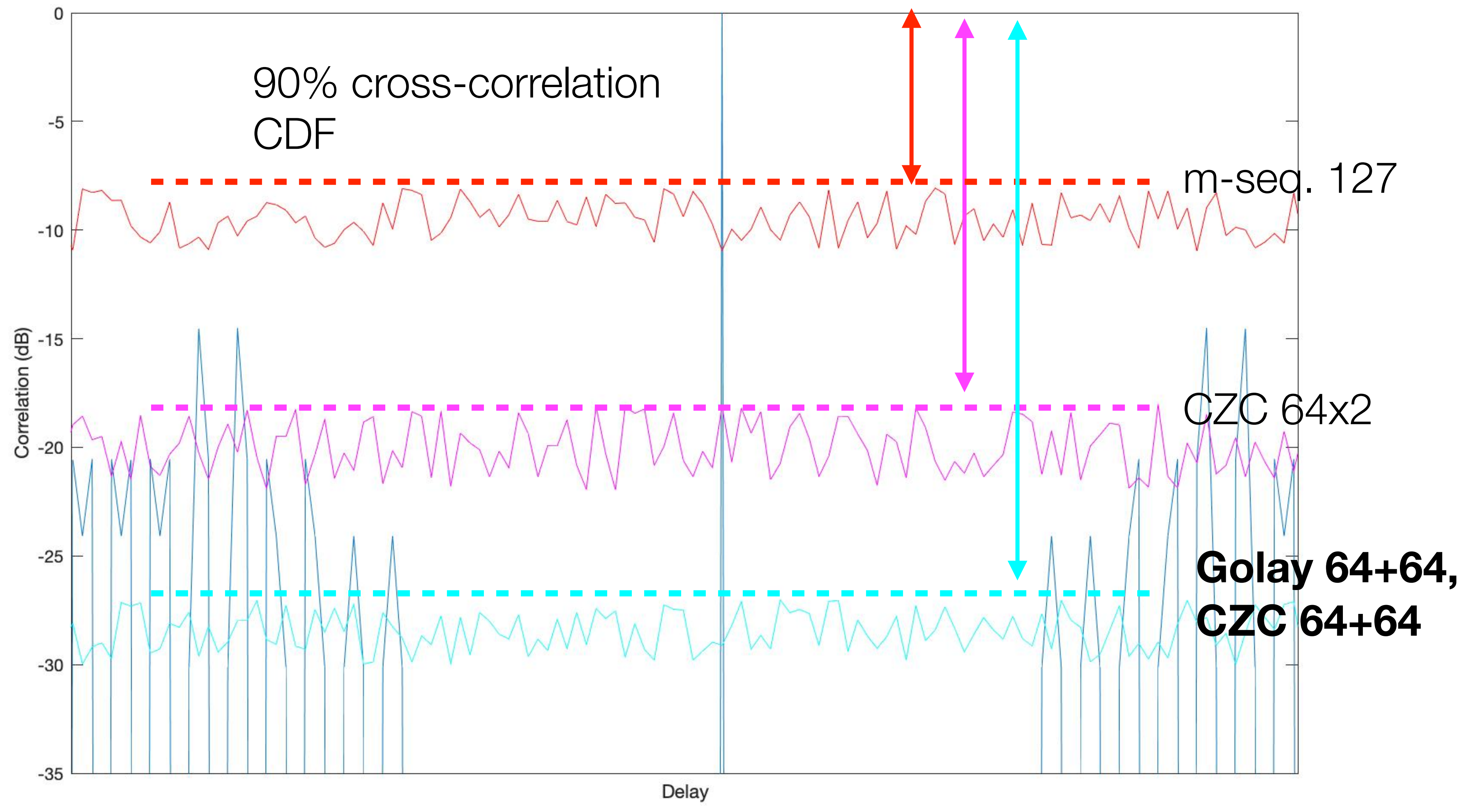
Performance of new preamble codes for MMS



Cross-correlation comparison of new preamble codes for MMS

Cross-correlation with long accumulation (R=40)

Target codes = {New preamble codes}
Interfering codes = {Ipatov 91, Ipatov 127, New preamble codes}

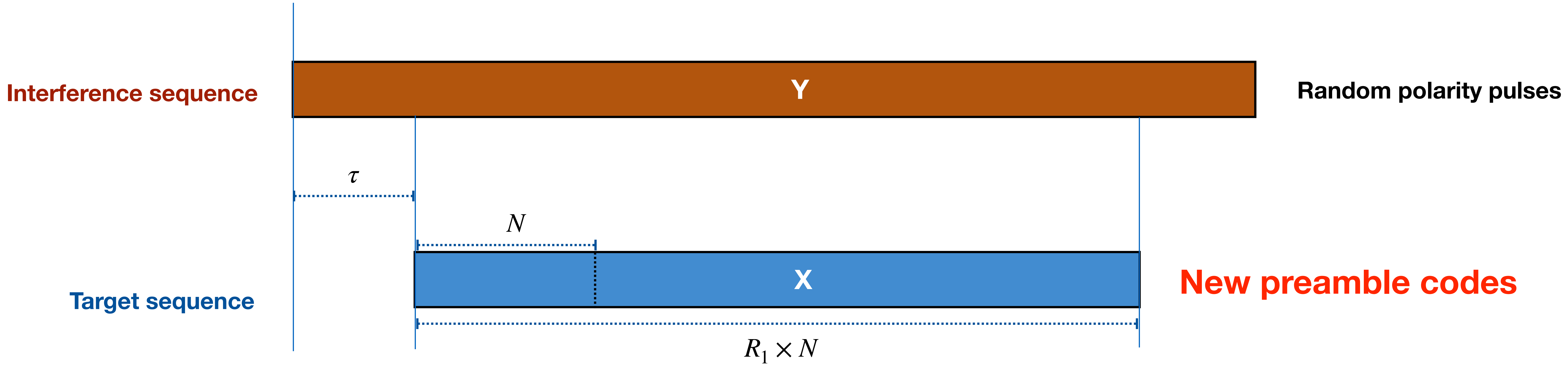


Cross-correlation with long accumulation (R = 40), STS/Data collision prob. = 0

	Target codes = Ipatov 91 (8 codes)	Target codes = Ipatov 127 (16 codes)	Target codes = Golay 64+64, Gap Of 1 chip *(64 codes)*	Target codes = m127-sequences (6 codes)	Target codes = m255-sequences (8 codes)	Target codes = CZC 64x2, Gap of 1 chip (8 codes)	Target codes = CZC 64+64, Gap of 1 chip (64 codes)
90% cross-correlation	-10.56 dB	-10.10 dB	**-27.56 dB**	-8.47 dB	-14.68 dB	-18.80 dB	**-27.40 dB**
50% cross-correlation (For reference)	-28.19 dB	-16.12 dB	-32.06 dB	-17.40 dB	-34.40 dB	-31.76 dB	-30.62 dB

- Golay 64+64 and CZC 64+64 codes provides the best correlation with long accumulation
  - Both are from **complimentary sets of size 2**
  - Inserting gaps to sequences provides different periodicity, thereby providing the combining gain in reducing cross-correlation
- Detailed CDF curves in the appendix (Slide 24)

Performance of new preamble codes for MMS



Cross-correlation comparison of new preamble codes for MMS

Long correlation with Radom polarity pulses

Target codes = {Ipatov 91 (or) Ipatov 127 (or) New preamble codes}
Interfering codes = {Random polarity pulses}

Cross-correlation with long accumulation (R = 40), STS/Data collision prob. = 1

	Target codes = Ipatov 91 (8 codes)	Target codes = Ipatov 127 (16 codes)	Target codes = Golay 64+64 (64 codes)	Target codes = m127-sequences (6 codes)	Target codes = CZC 64x2 (8 codes)	Target codes = CZC 64+64 (64 codes)
90% cross-correlation	**-23.48 dB**	**-24.86 dB**	-25.56 dB	-24.92 dB	-24.87 dB	-24.93 dB
50% cross-correlation	-24.61 dB	-26.04 dB	-26.66 dB	-26.16 dB	-26.09 dB	-26.02 dB

- All the new preamble code sets have similar or slightly better cross-correlation with Random pulses than the 4z Ipatov codes
- Detailed CDF curves in the appendix (Slide 26)

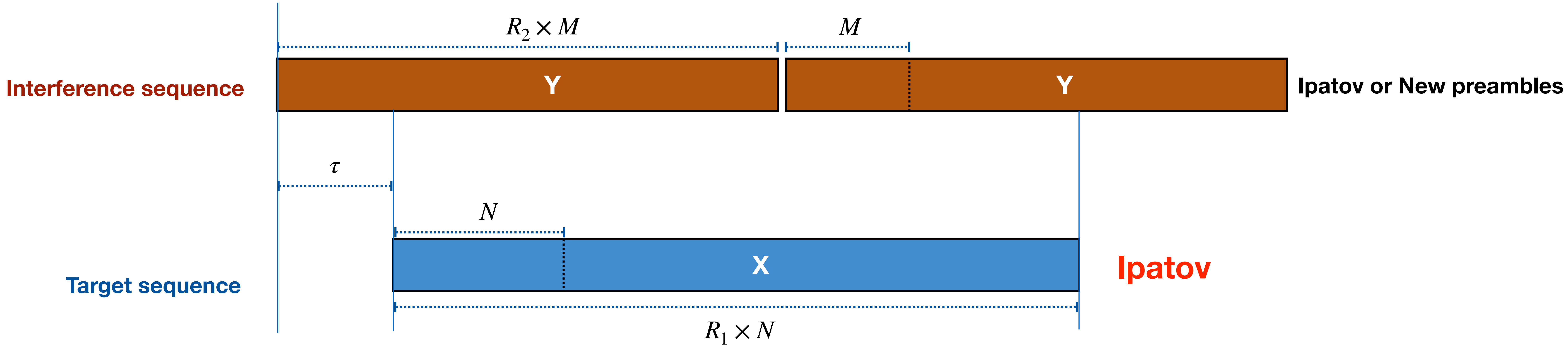
Concluding Remarks

- Observation:
  - Preambles for NBA-MMS and initial packet acquisition necessitate different requirements
    - Initial packet acquisition —> good cross-correlation over short accumulation
    - NBA-MMS —> good cross-correlation over long accumulation + a larger set of available sequences
- Way forward:
  1. For NBA-MMS, N preamble sequences based on complimentary sets of size 2 are introduced
     - N >= 64
     - Best cross-correlation suppression with zero relative CFO
     - Further improved cross-correlation suppression as relative CFO gets larger
     - Designed with periodicity division multiple access in mind through flexible and natural insertion of gaps
  2. For initial packet acquisition, select among {legacy Ipatov, additional Ipatov, m-sequences, complementary set sequences} by November meeting
     - Complexity, auto-correlation, cross-correlation over short accumulation etc.

References

- [1] 15-22-0243-00-04ab, “golay-complementary-sequences-preamble-construction-for-uwb-ranging-beyond-4z-ipatov”, Xiliang Luo, et.al.
- [2] 15-22-0178-00-04ab, “a-novel-channel-sounding-sequence”, Michael McLaughlin, et.al.
- [3] 15-21-0377-02-04ab, “preamble-codes-for-data-communications, Carlos Aldana, et.al.
- [4] 15-22-0390-00-04ab, “discussion-on-preamble-sequence-options-for-detection-and-channel-estimation”, Pooria Pakrooh, et.al.
- [5] 15-22-0267-01-04ab, “preamble-only-packet-for-uwb”, Chenchen Liu, et.al.
- [6] 15-22-0446-01-04ab, “Simulation Framework for Recommending Preambles for 4ab”, Vinod Kristem, et.al.

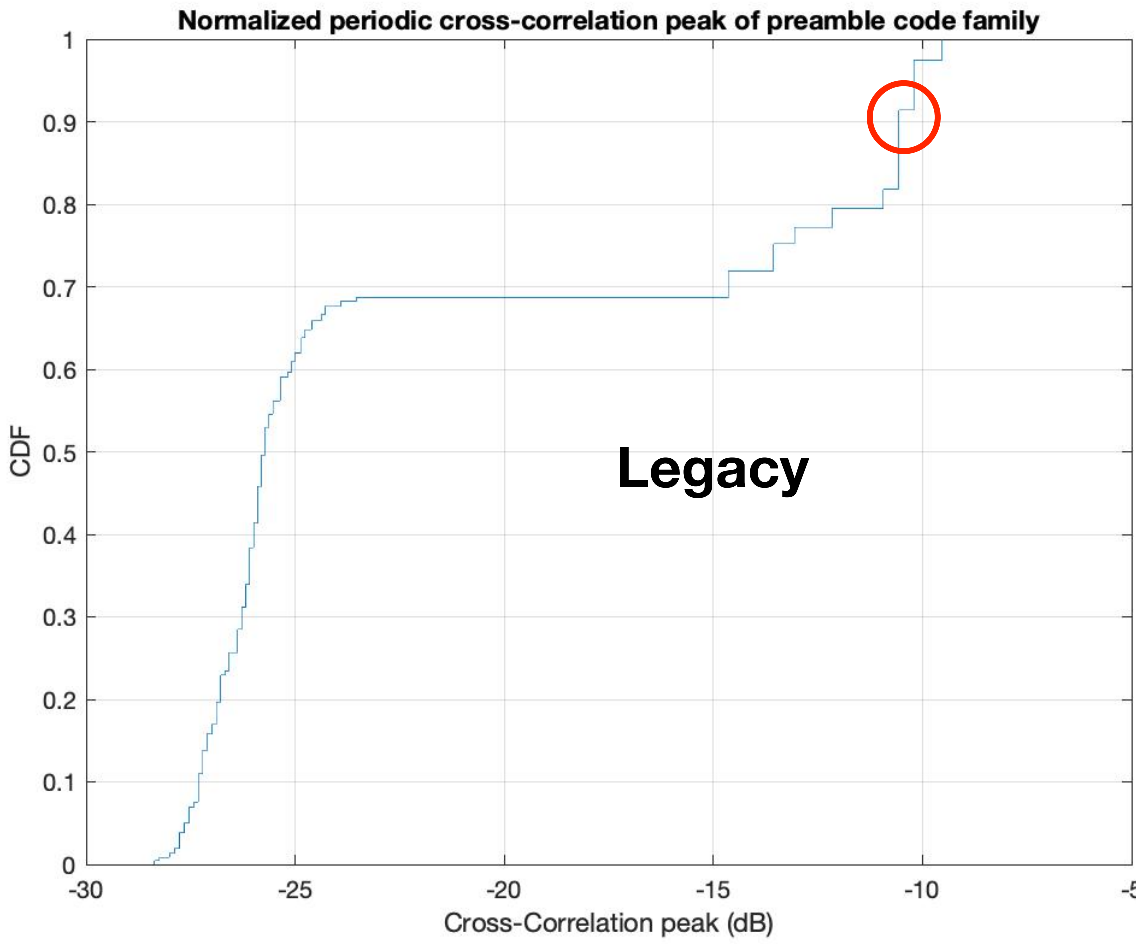
New codes impact on legacy 4z preamble acquisition



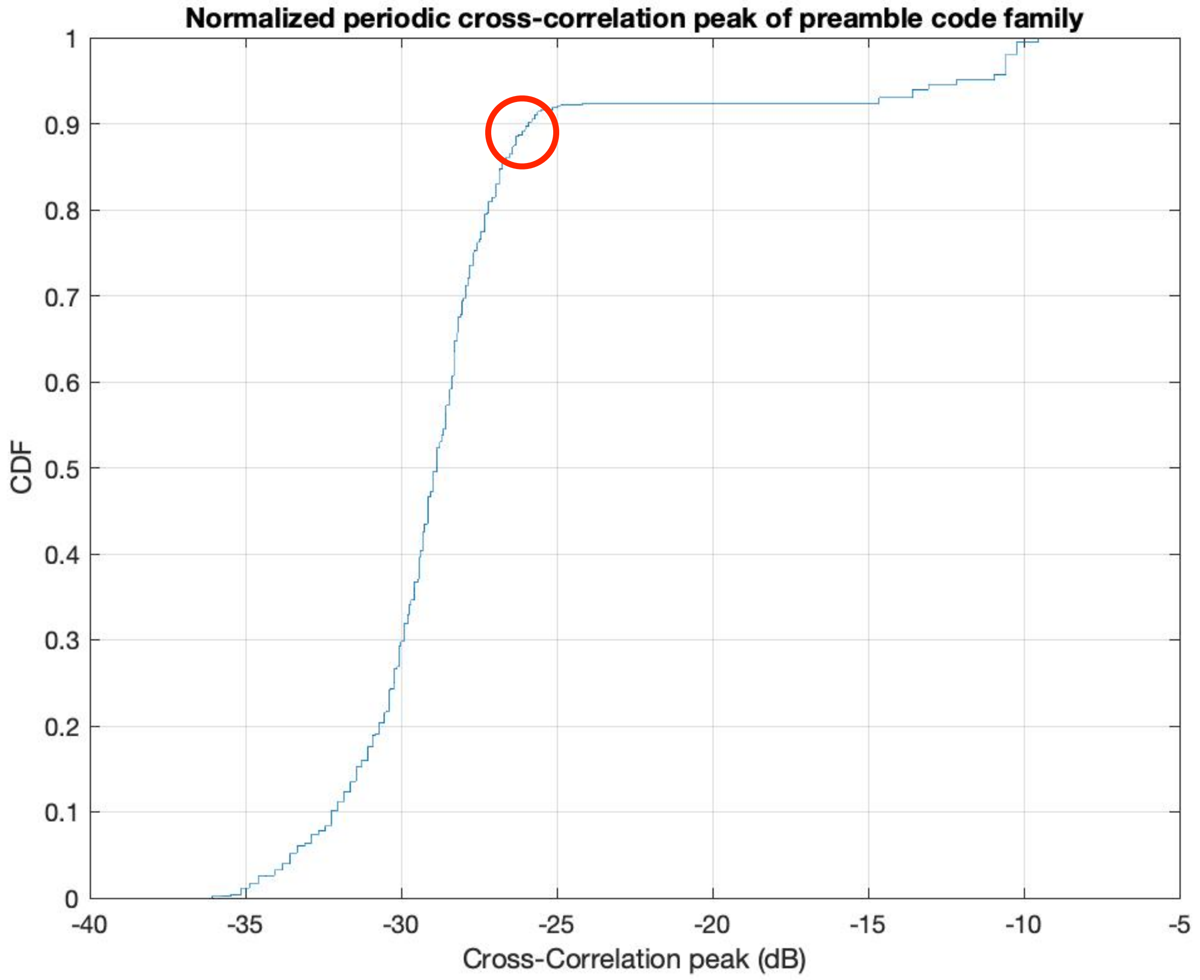
Impact on Legacy Ipatov 91 (R_1,R_2=40, Δf_{max}=0, p=0, L_1,L_2 = 4)

Long-Term Correlation w/ PSR=40

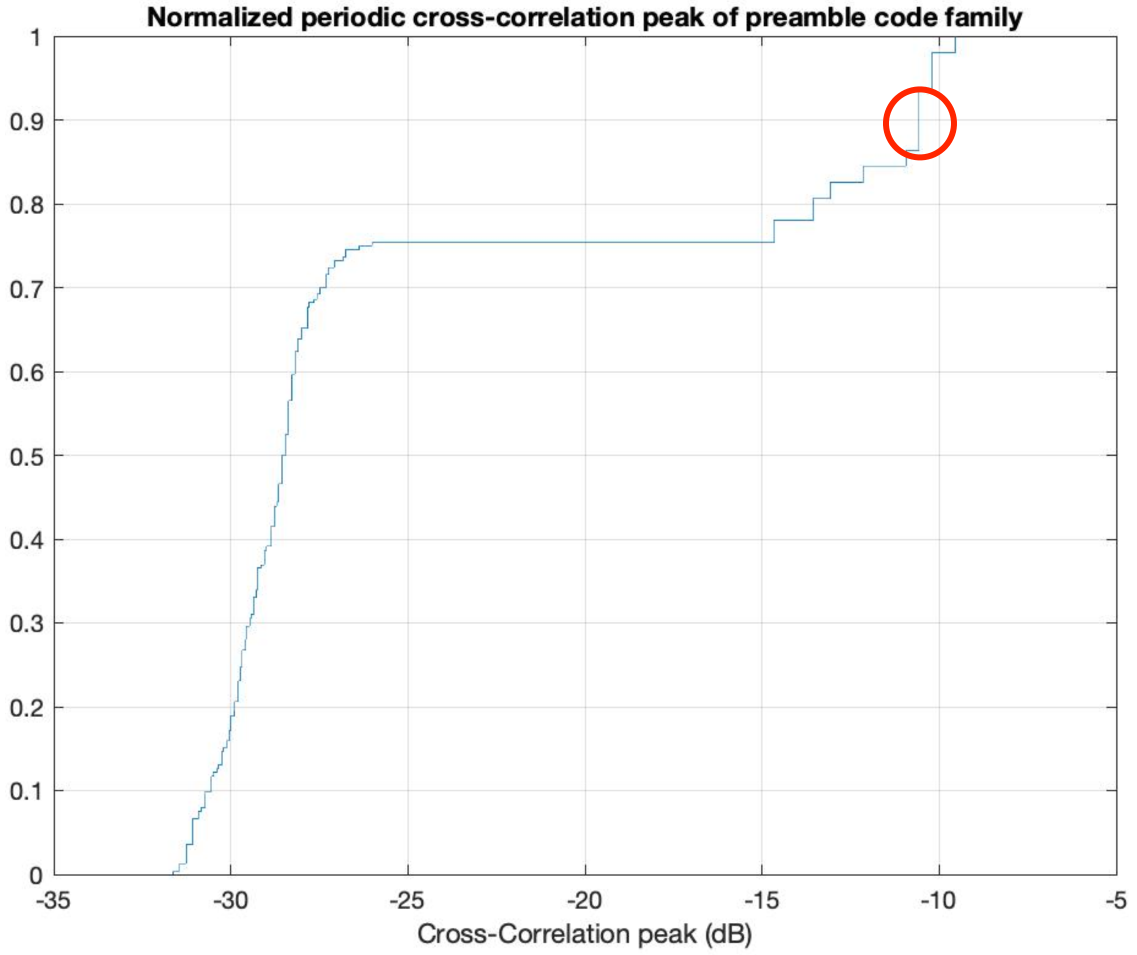
Target codes = {Ipatov 91}
Interfering codes = {Ipatov 91, Ipatov 127}



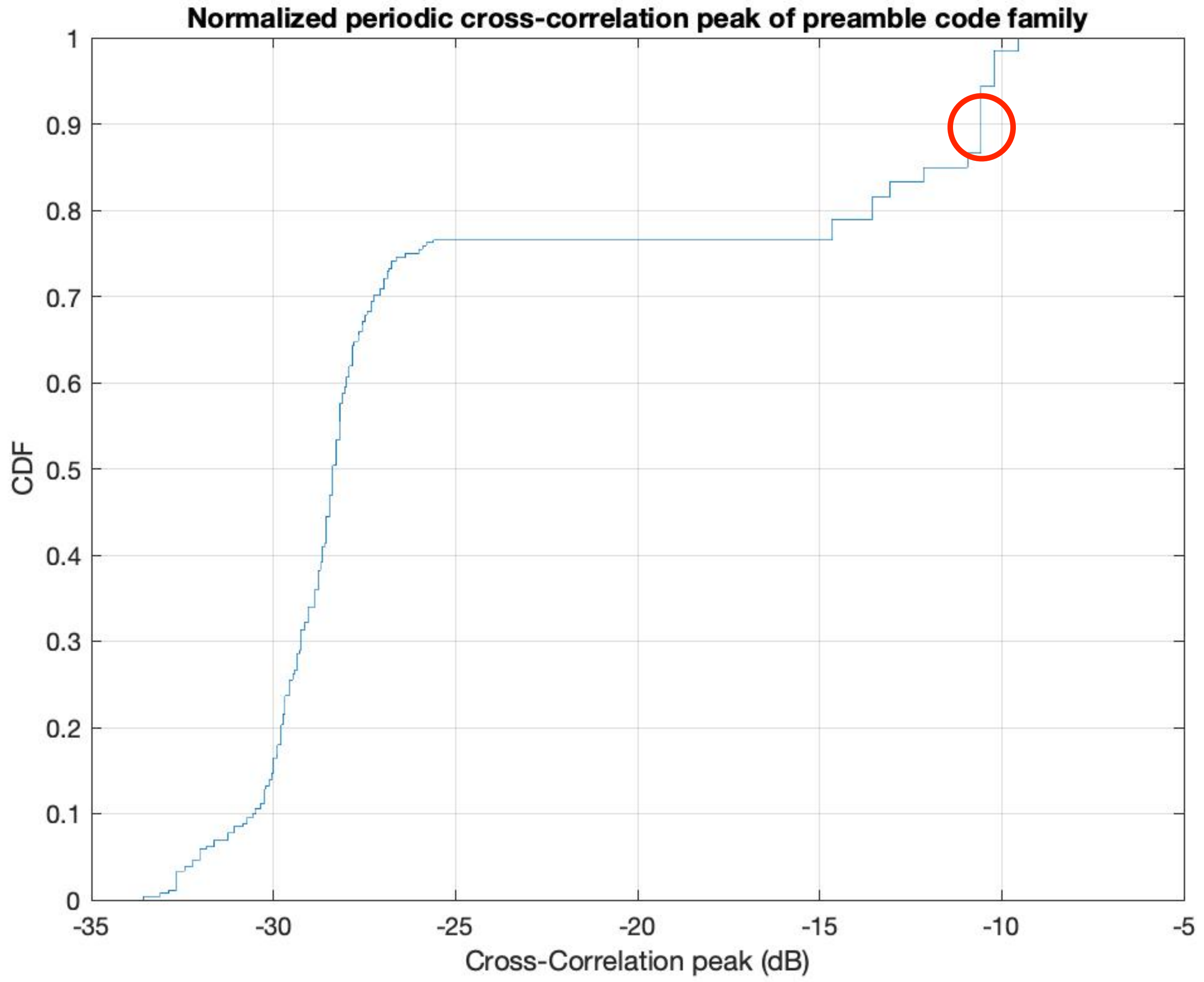
Target codes = {Ipatov 91}
Interfering codes = {Ipatov 91, Ipatov 127, **Golay 64+64**}



Target codes = {Ipatov 91}
Interfering codes = {Ipatov 91, Ipatov 127, **m-seq 127**}



Target codes = {Ipatov 91}
Interfering codes = {Ipatov 91, Ipatov 127, **CZC 64x2**}

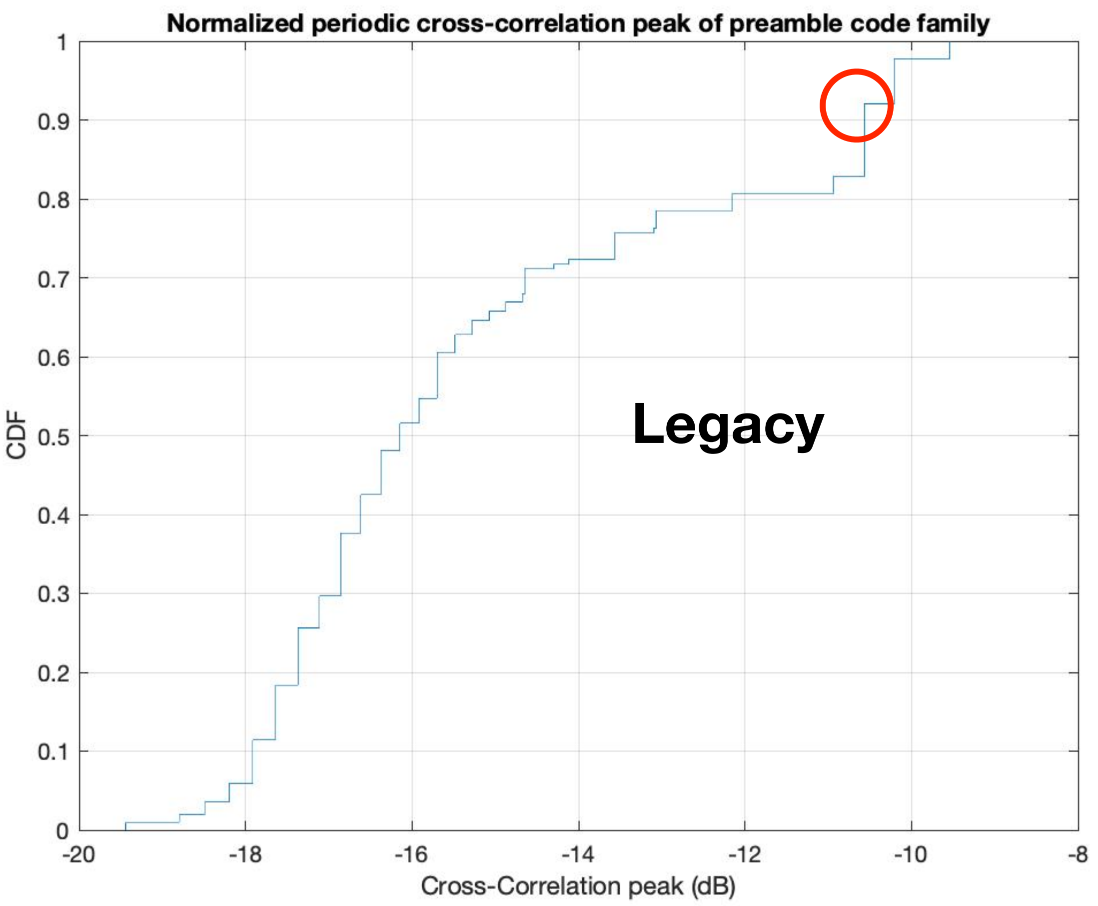


- Adding the new preamble codes to the 4z-Ipatov family, does not make legacy long cross-correlation worse

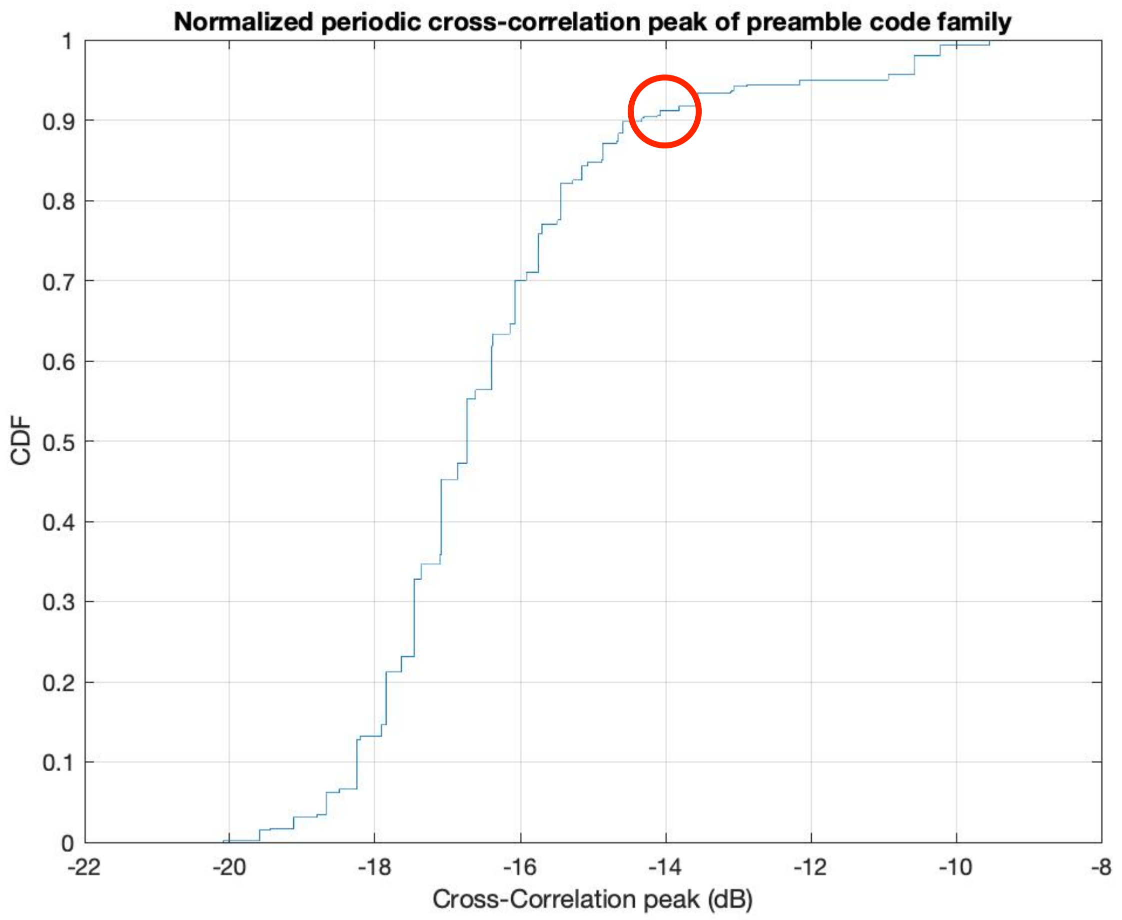
Impact on Legacy Ipatov 91 (R_1,R_2=4, Δf_{max}=0, p=0, L_1,L_2 = 4)

Short-Term Correlation w/ PSR=4

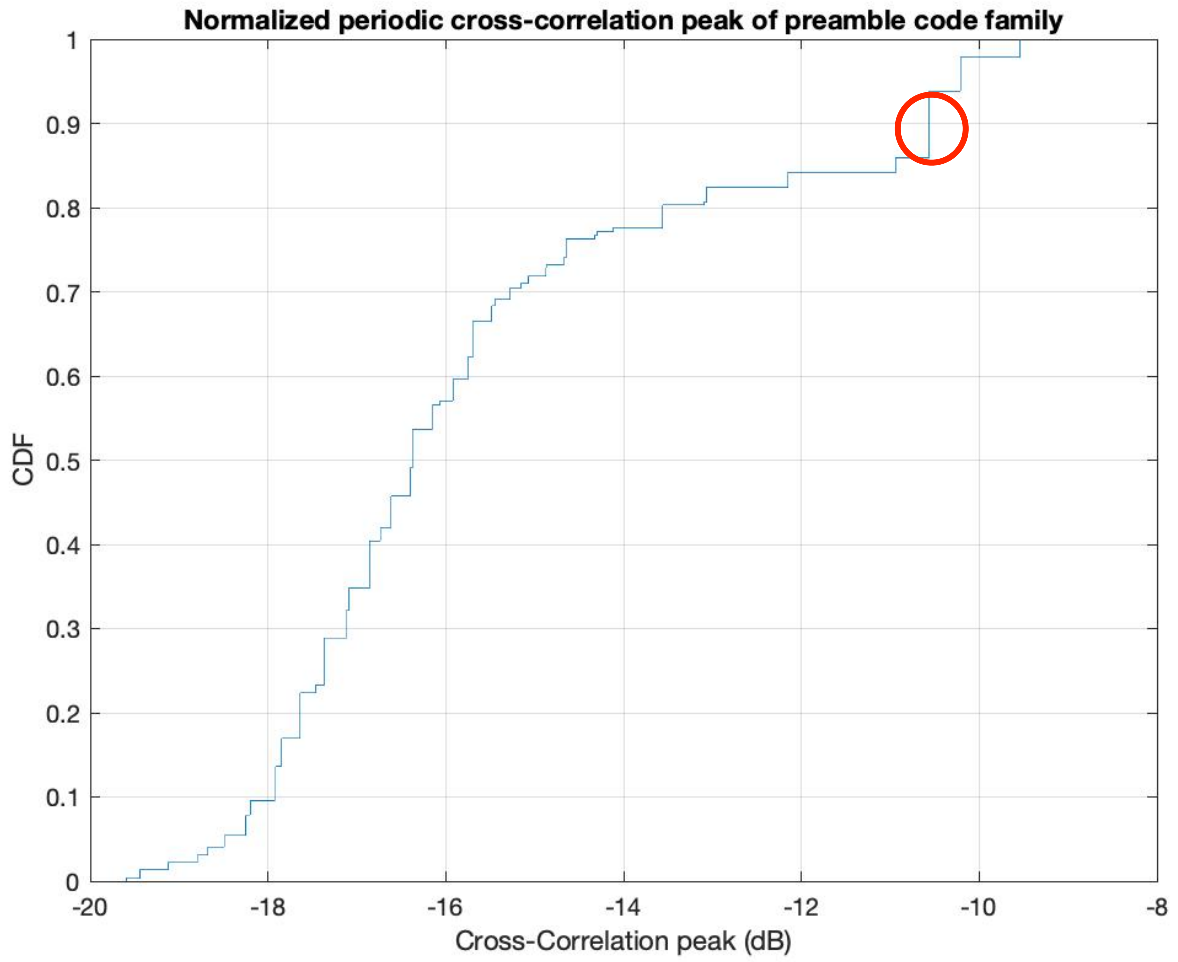
Target codes = {Ipatov 91}
Interfering codes = {Ipatov 91, Ipatov 127}



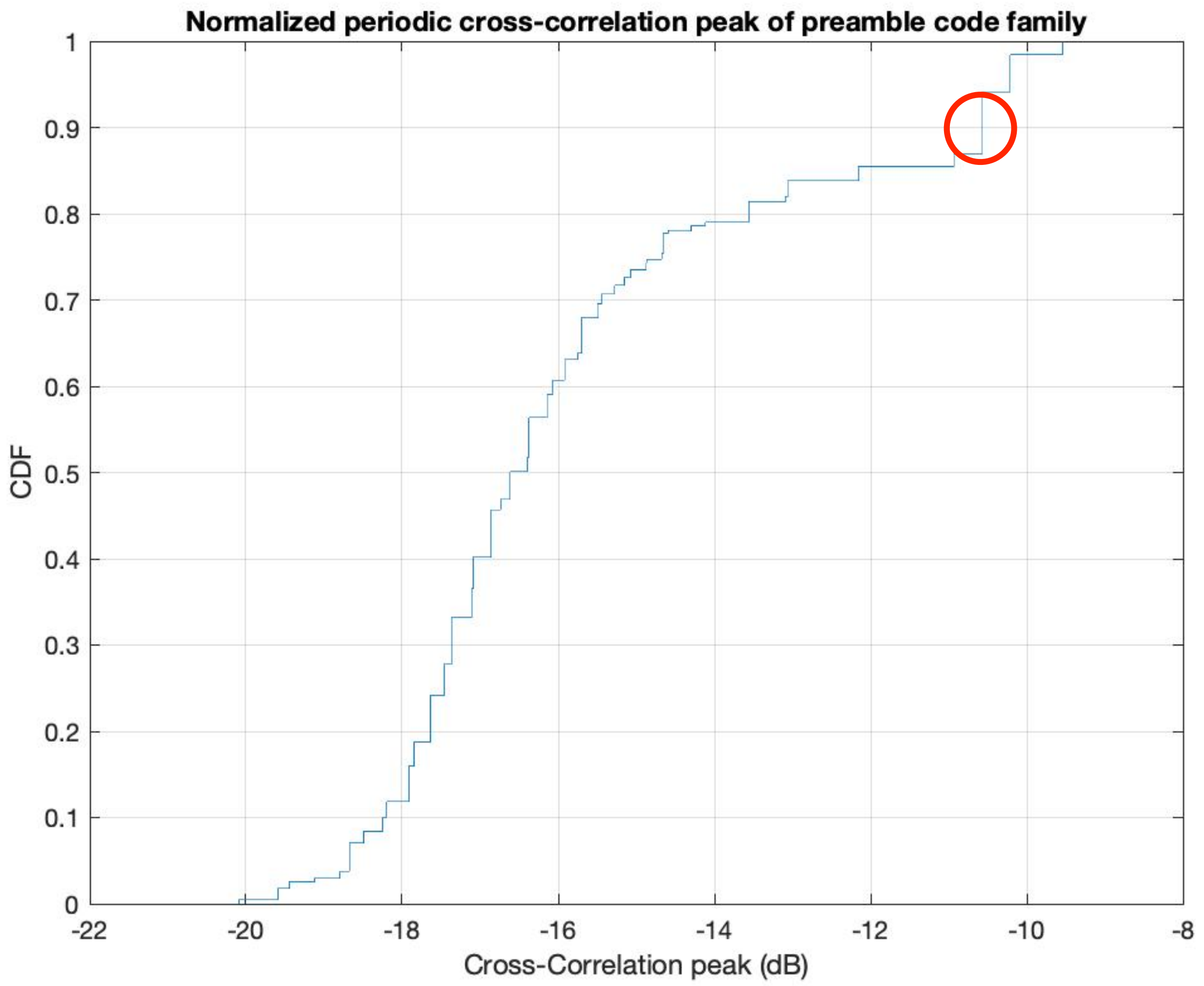
Target codes = {Ipatov 91}
Interfering codes = {Ipatov 91, Ipatov 127, **Golay 64+64**}



Target codes = {Ipatov 91}
Interfering codes = {Ipatov 91, Ipatov 127, **m-seq 127**}



Target codes = {Ipatov 91}
Interfering codes = {Ipatov 91, Ipatov 127, **CZC 64x2**}

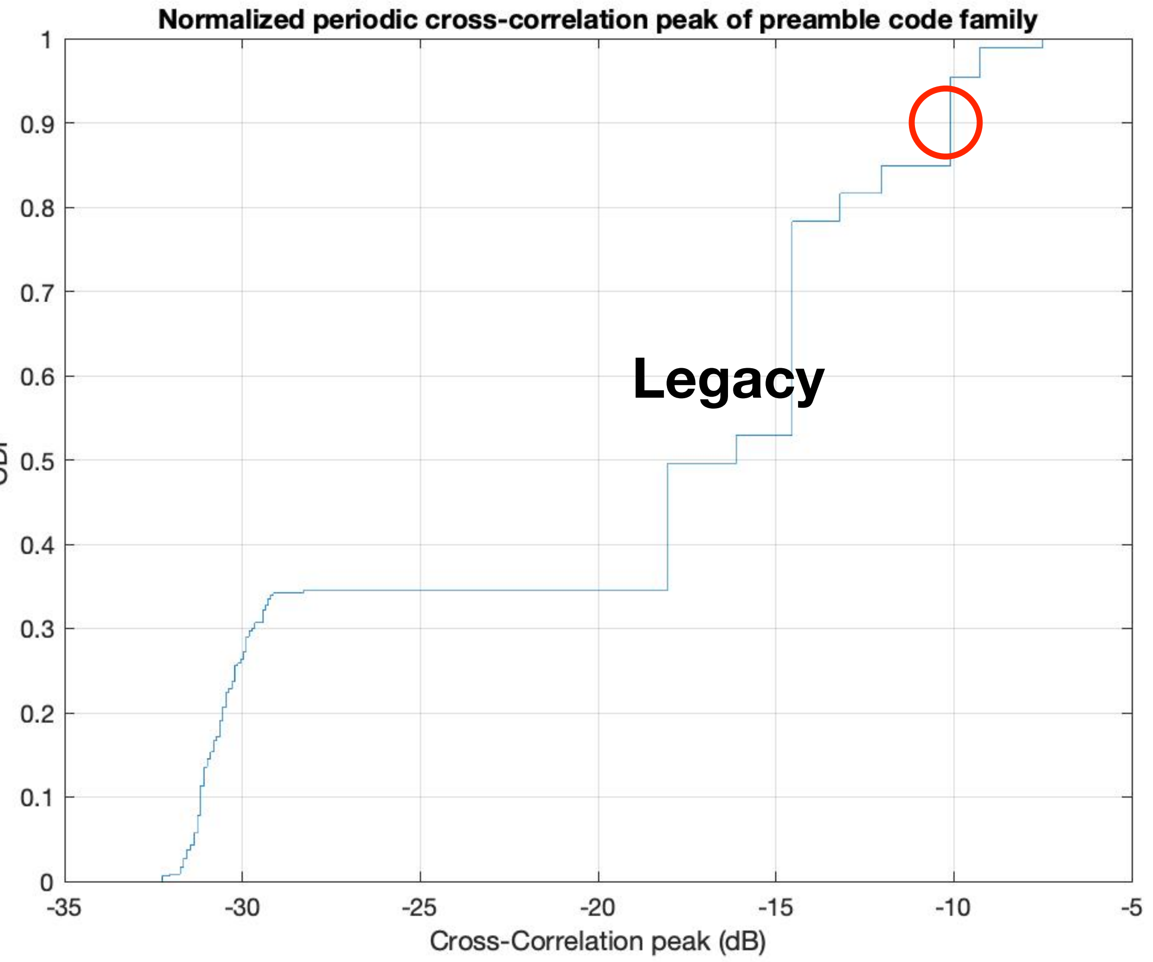


- Adding the new preamble codes to the 4z-Ipatov family, does not make legacy short cross-correlation worse

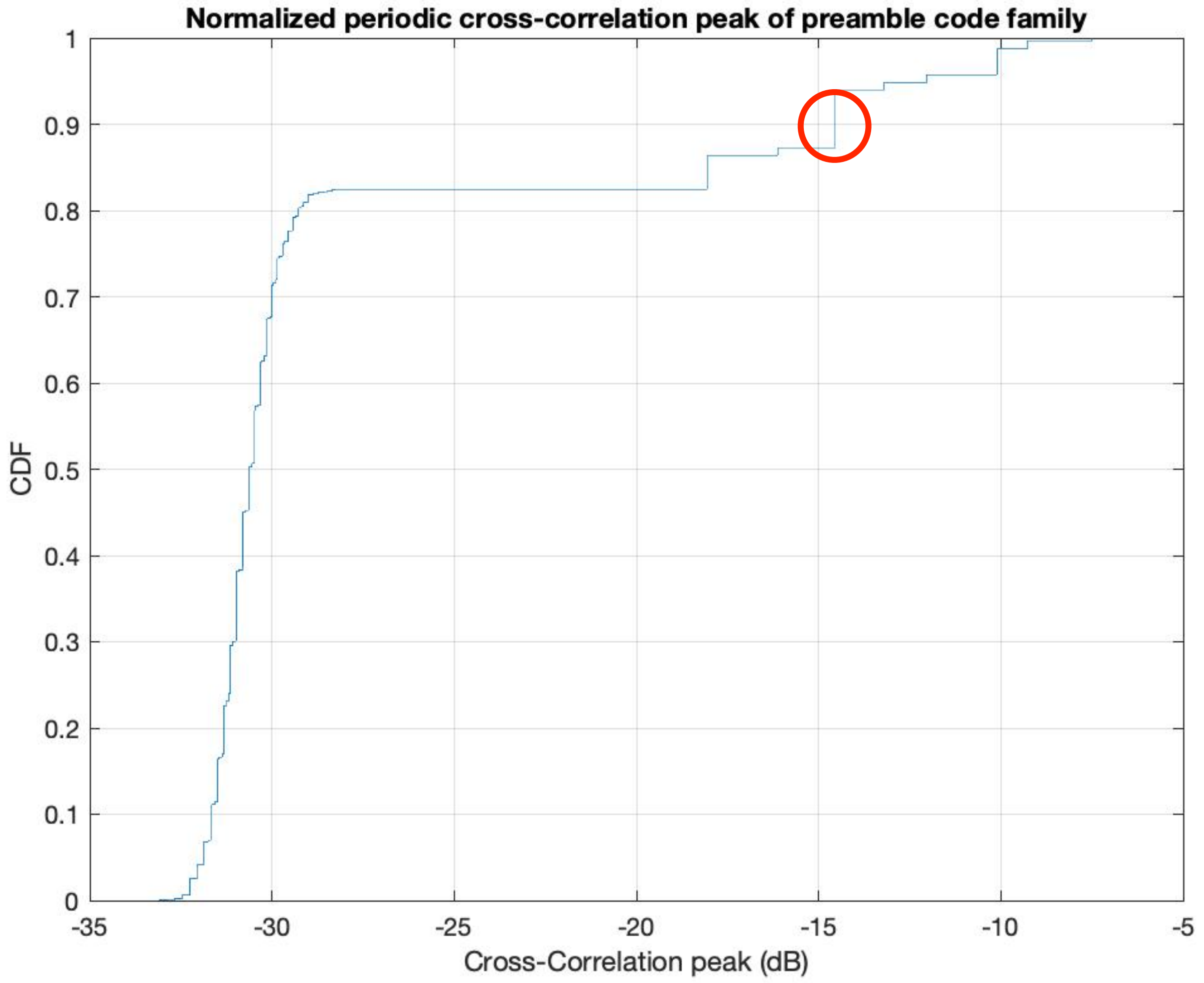
Impact on Legacy Ipatov 127 ($R_1,R_2=40$, $\Delta f_{max}=0$, $p=0$, $L_1,L_2 = 4$)

Long-Term Correlation w/ PSR=40

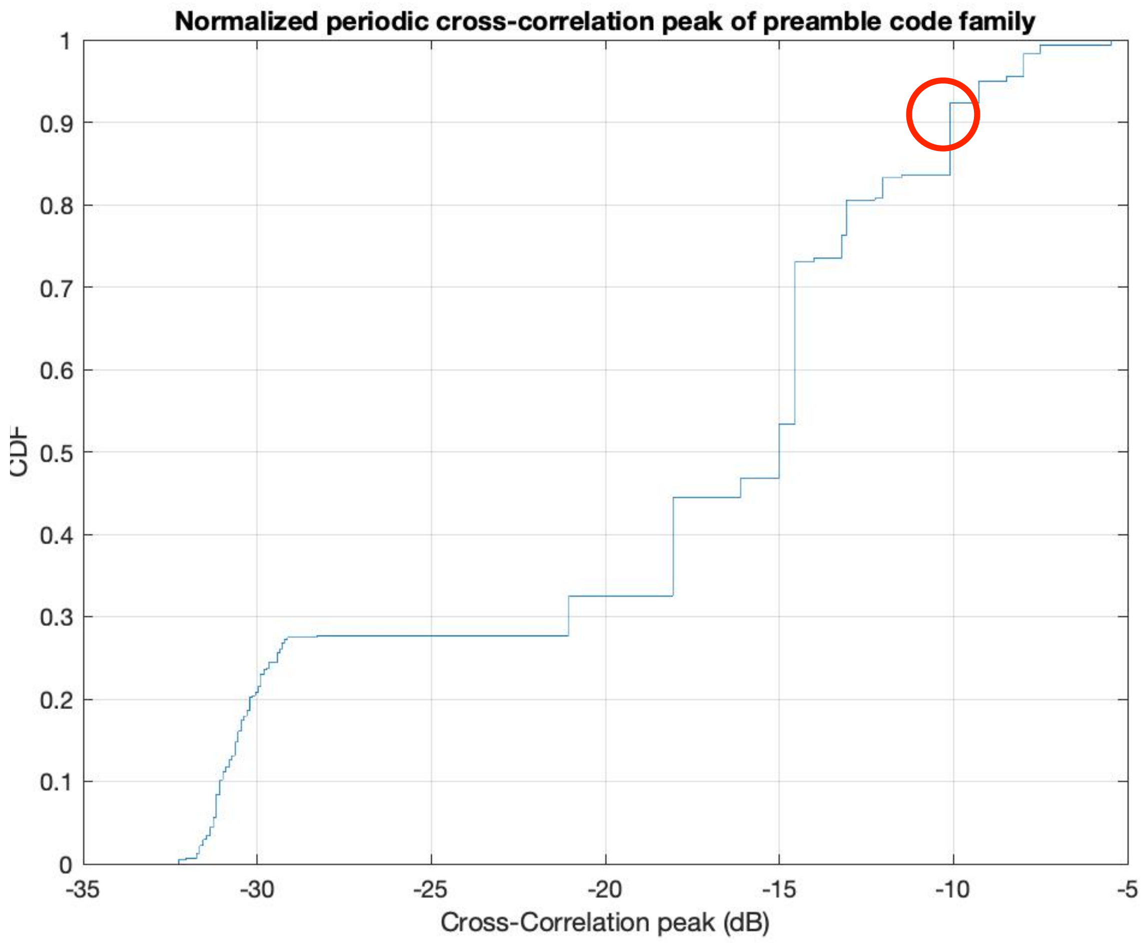
Target codes = {Ipatov 127}
Interfering codes = {Ipatov 91, Ipatov 127}



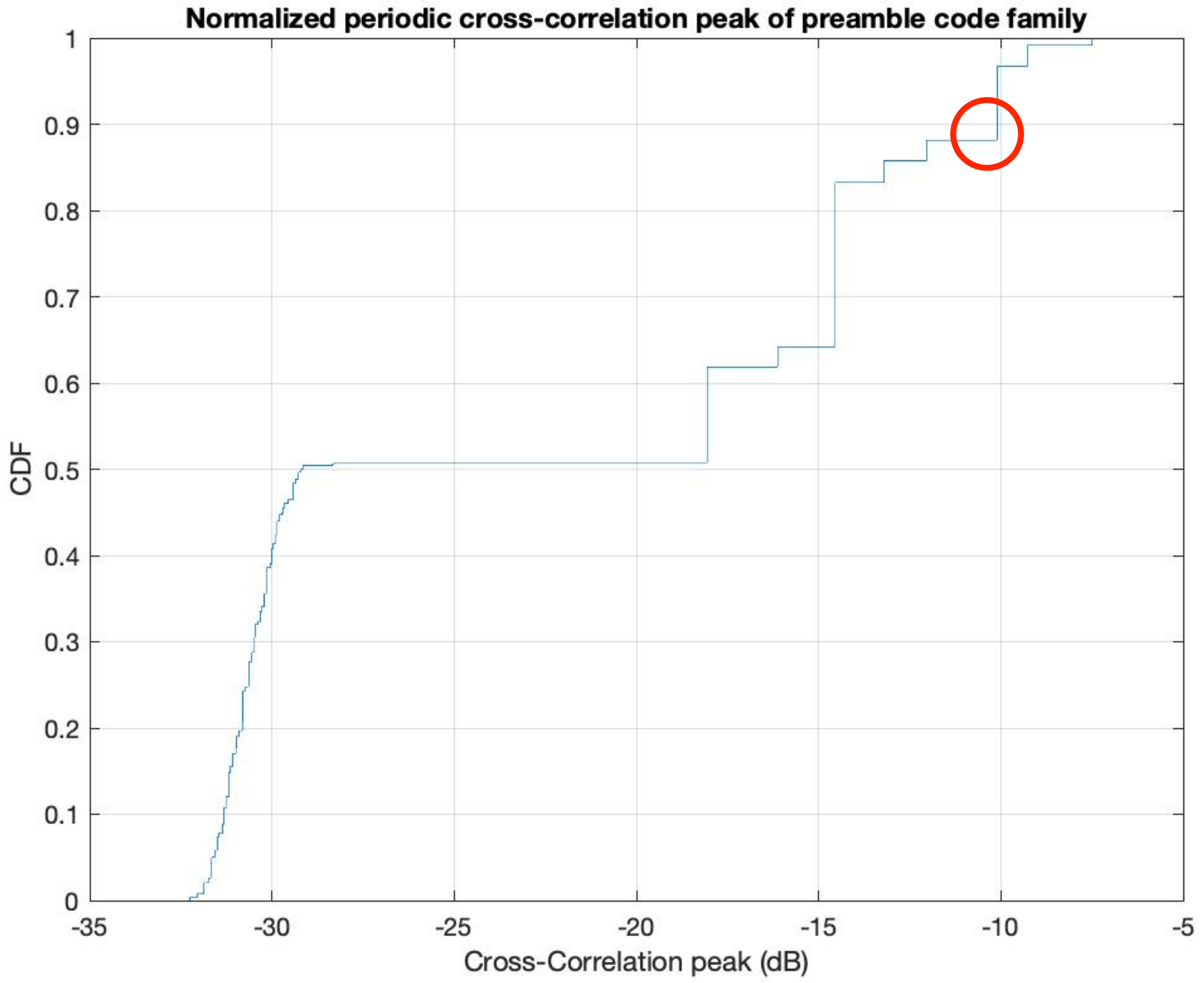
Target codes = {Ipatov 127}
Interfering codes = {Ipatov 91, Ipatov 127, **Golay 64+64**}



Target codes = {Ipatov 127}
Interfering codes = {Ipatov 91, Ipatov 127, **m-seq 127**}



Target codes = {Ipatov 127}
Interfering codes = {Ipatov 91, Ipatov 127, **CZC 64x2**}

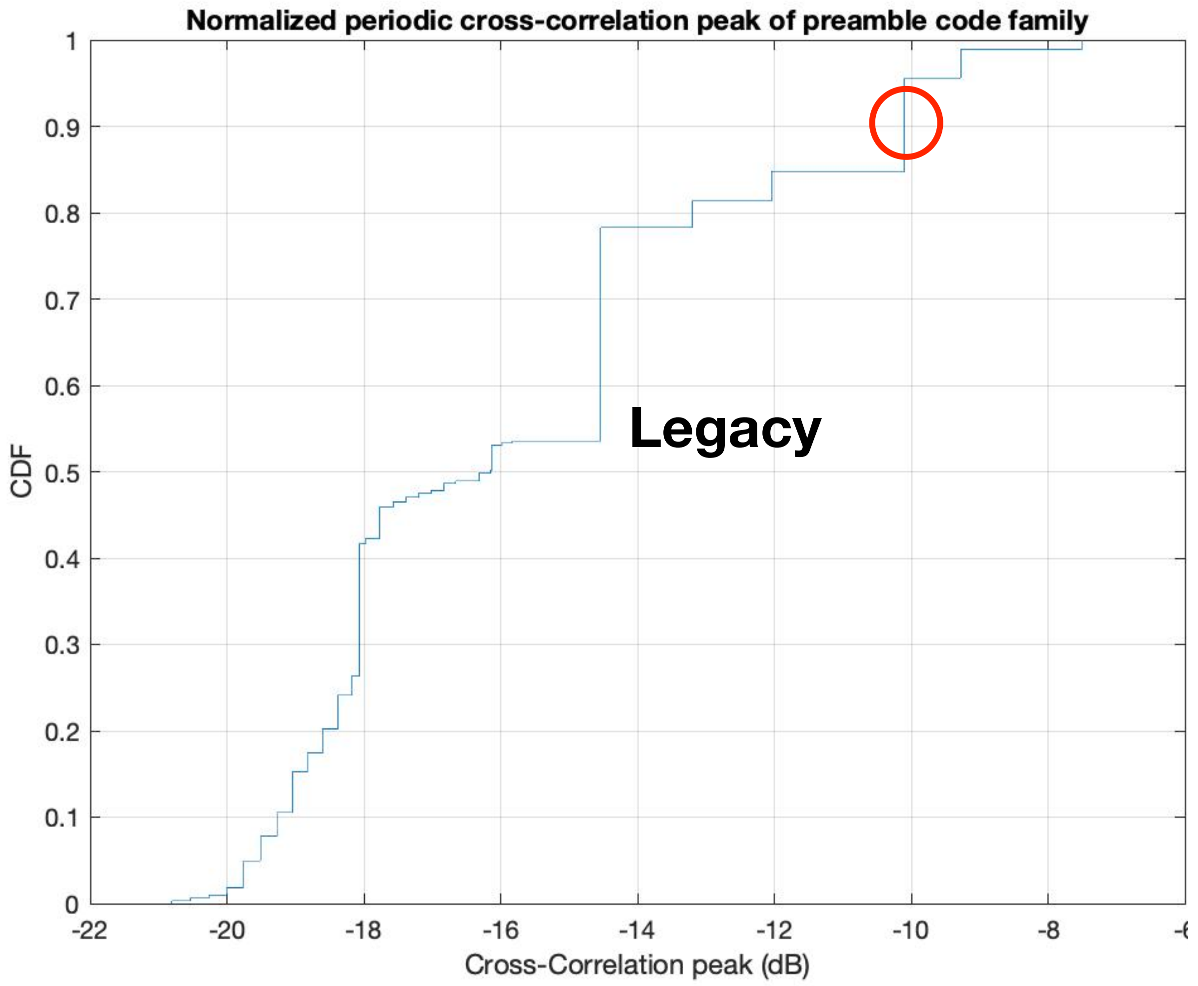


- Adding the new preamble codes to the 4z-Ipatov family, does not make legacy long cross-correlation worse

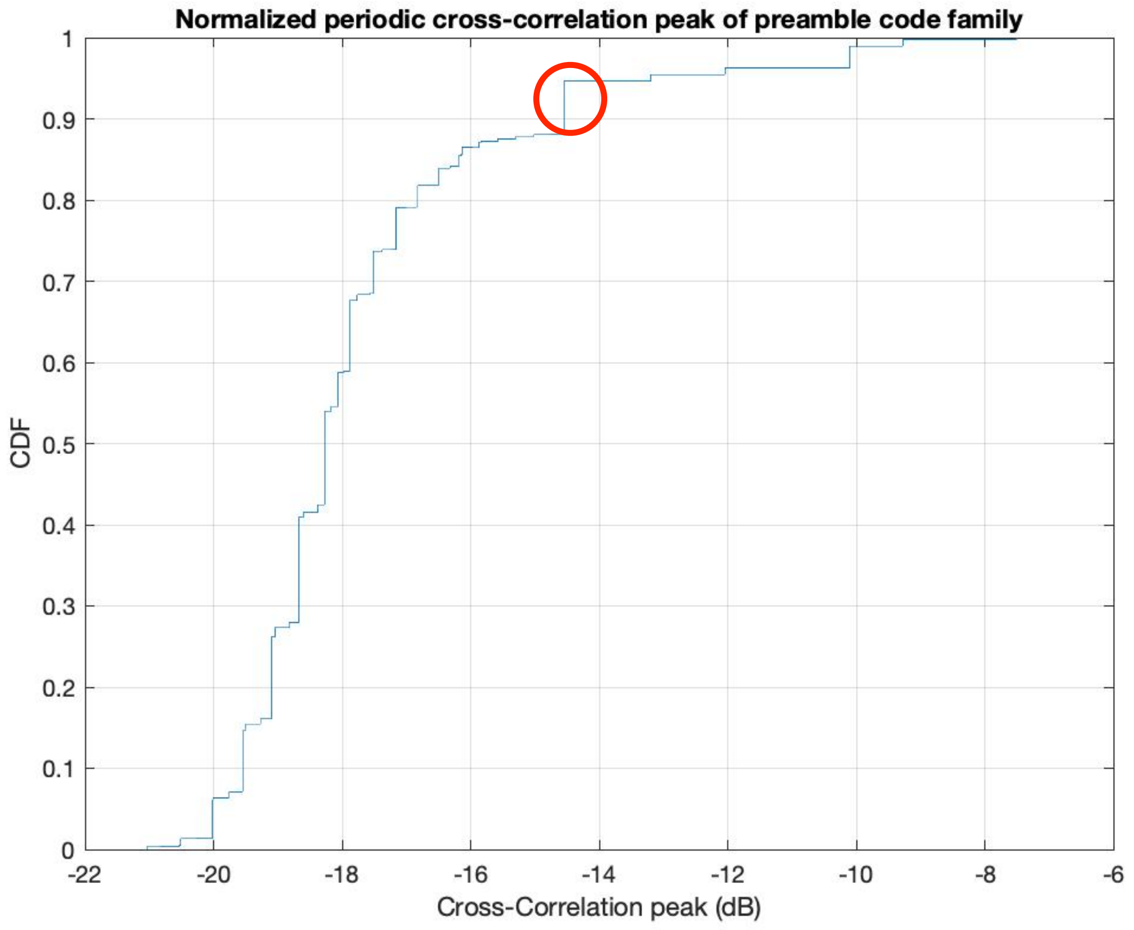
Impact on Legacy Ipatov 127 (R_1,R_2=4, Δf_{max}=0, p=0, L_1,L_2 = 4)

Short-Term Correlation w/ PSR=4

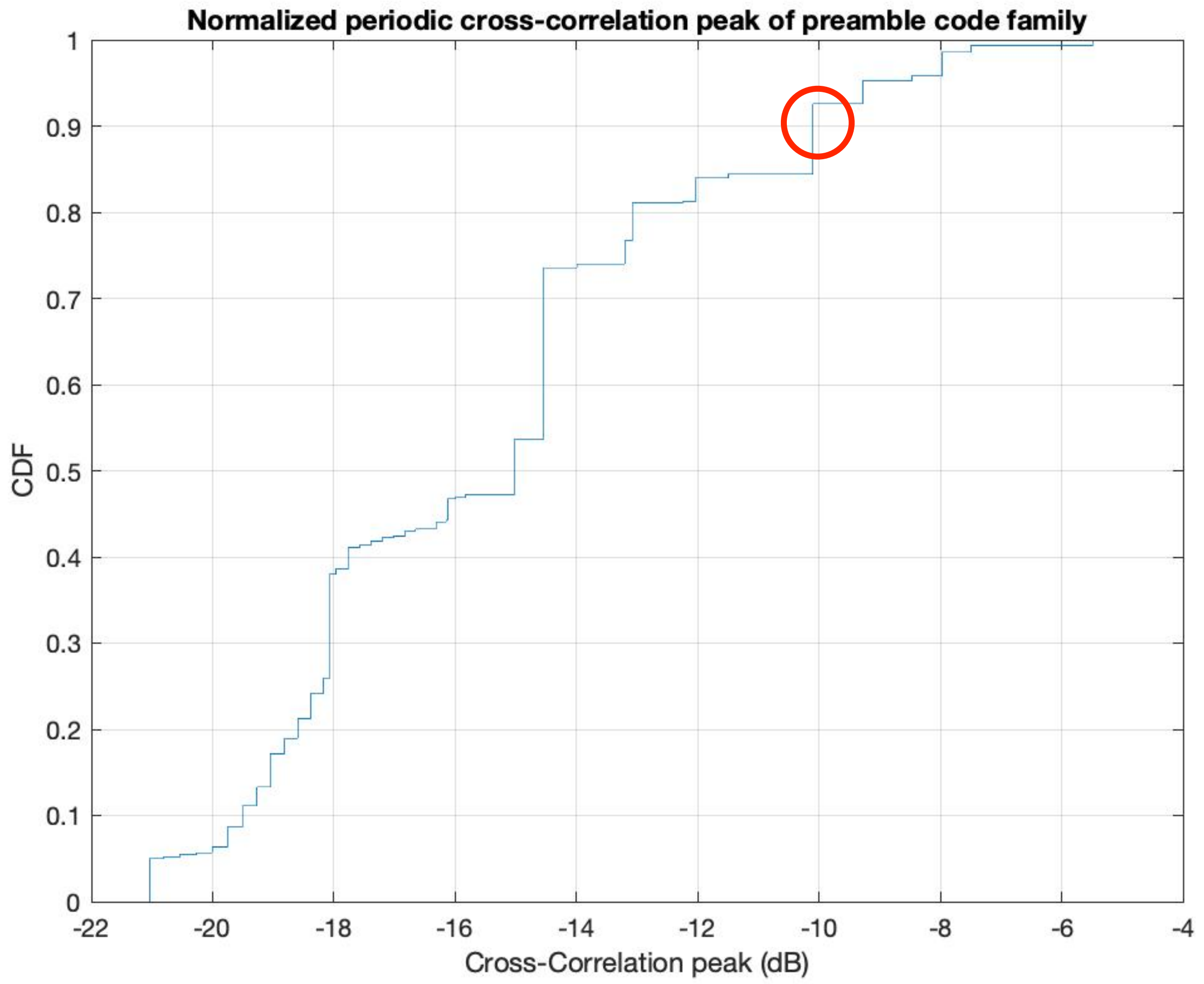
Target codes = {Ipatov 127}
Interfering codes = {Ipatov 91, Ipatov 127}



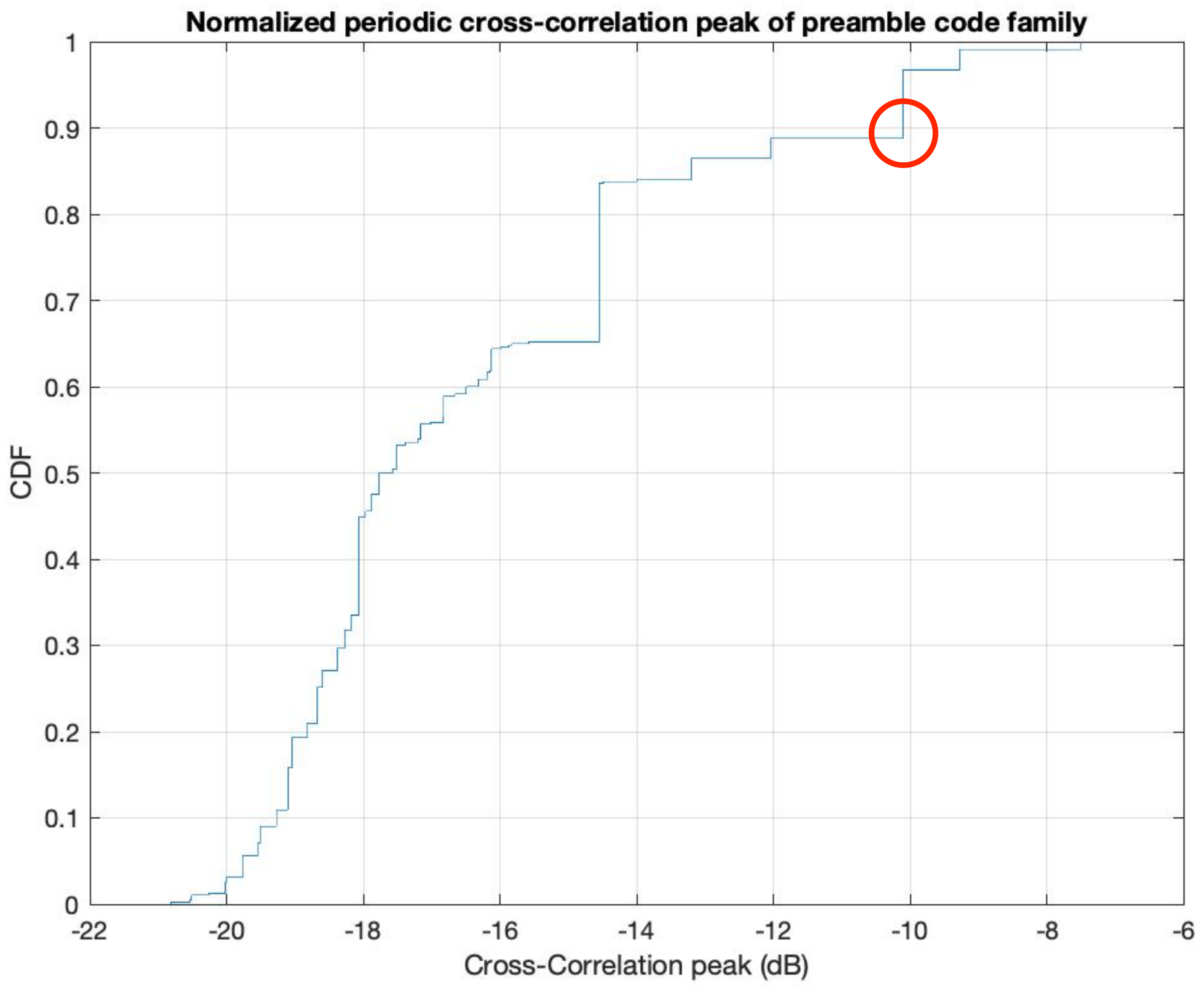
Target codes = {Ipatov 127}
Interfering codes = {Ipatov 91, Ipatov 127, **Golay 64+64**}



Target codes = {Ipatov 127}
Interfering codes = {Ipatov 91, Ipatov 127, **m-seq 127**}

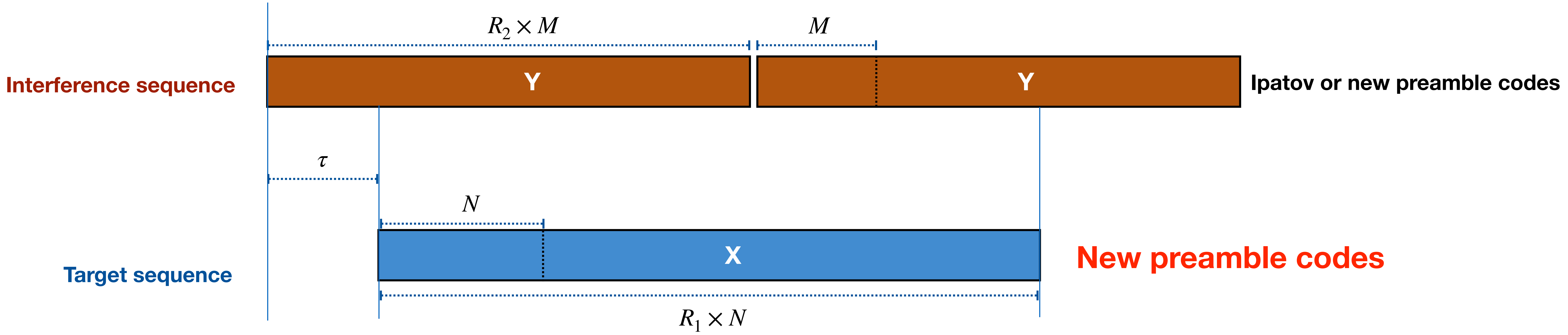


Target codes = {Ipatov 127}
Interfering codes = {Ipatov 91, Ipatov 127, **CZC 64x2**}



- Adding the new preamble codes to the 4z-Ipatov family, does not make legacy short cross-correlation worse

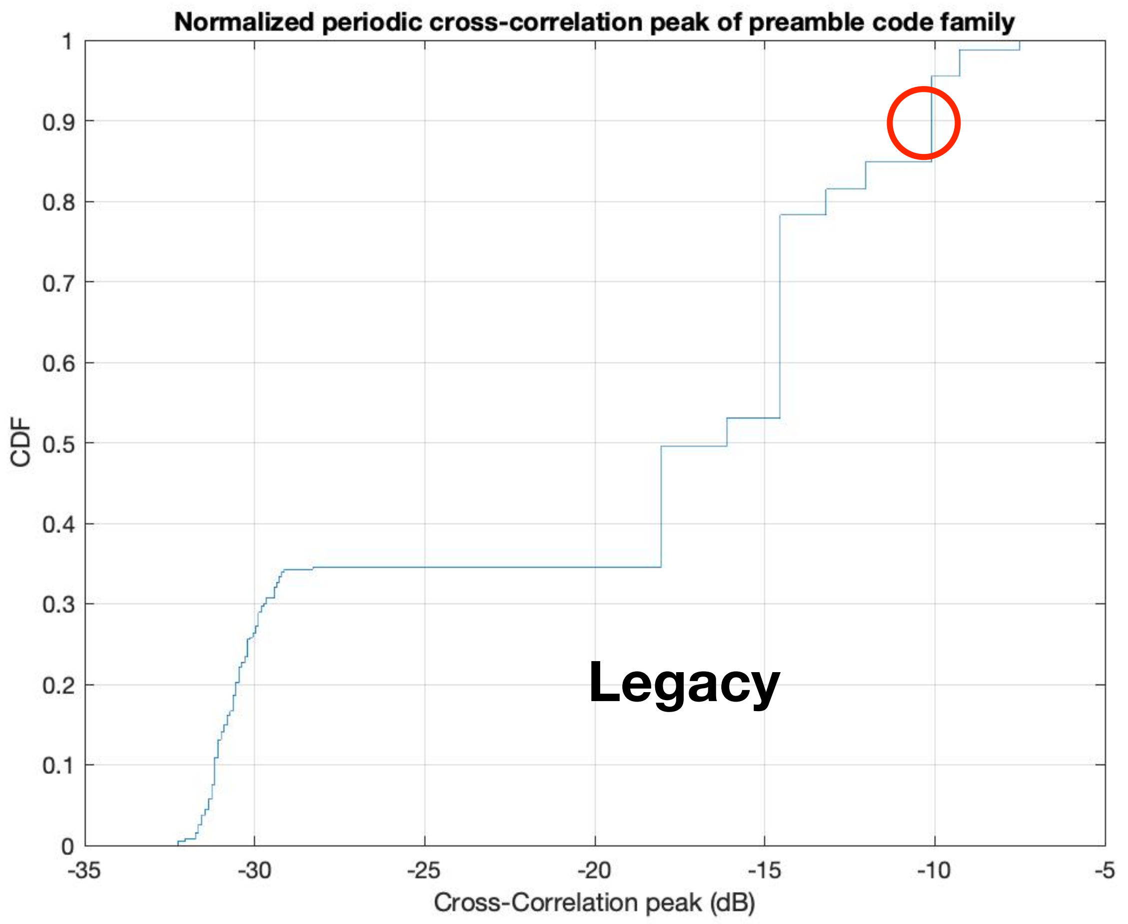
Performance of new preamble codes for MMS



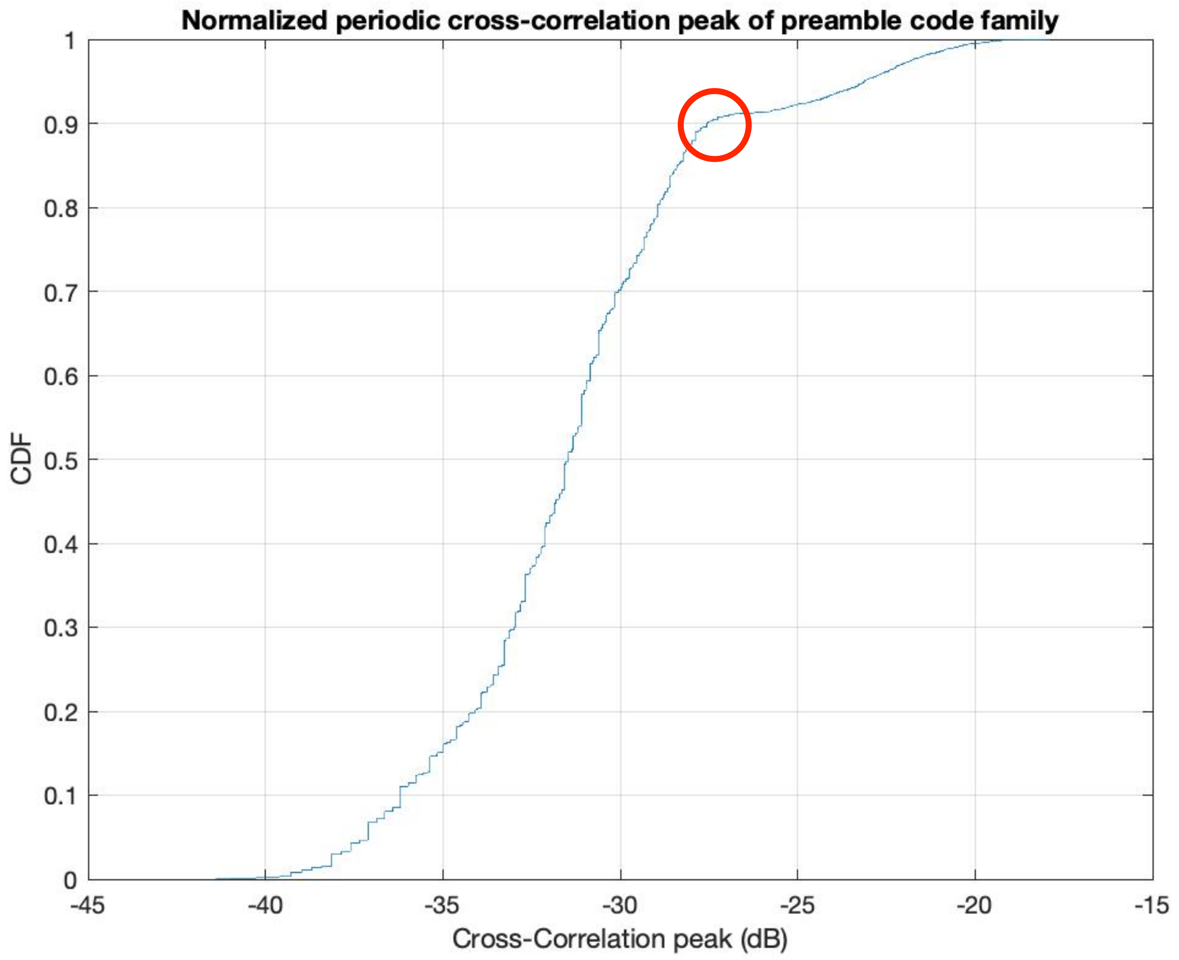
Performance of new preamble codes for MMS (R_1,R_2=40, Δf_{max}=0, p=0, L_1,L_2 = 4)

Long-Term Correlation w/ PSR=40: Gap of 1 chips in Target Sequence X (for Golay and CZC)

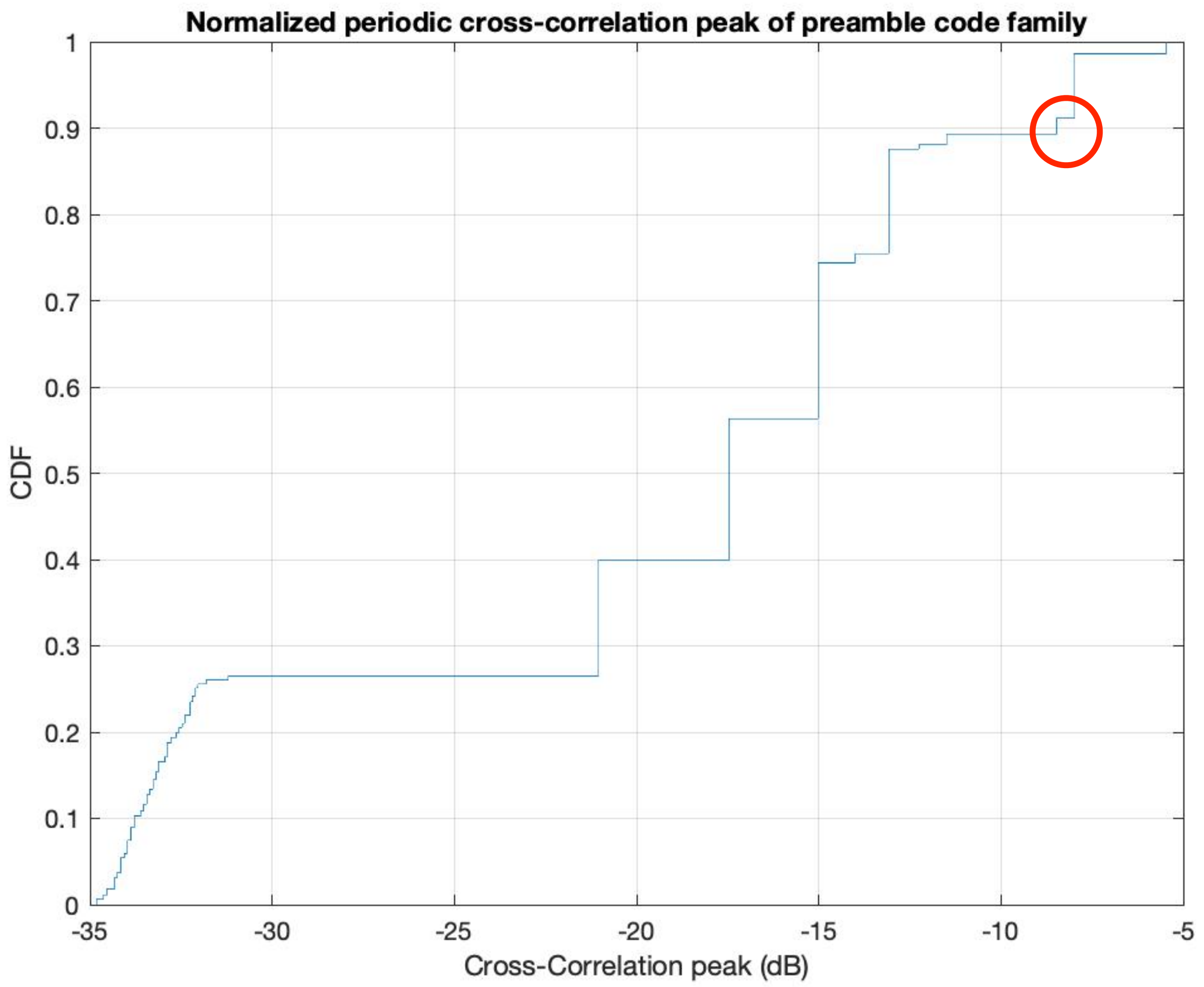
Target codes = {Ipatov 127}
Interfering codes = {Ipatov 91, Ipatov 127}



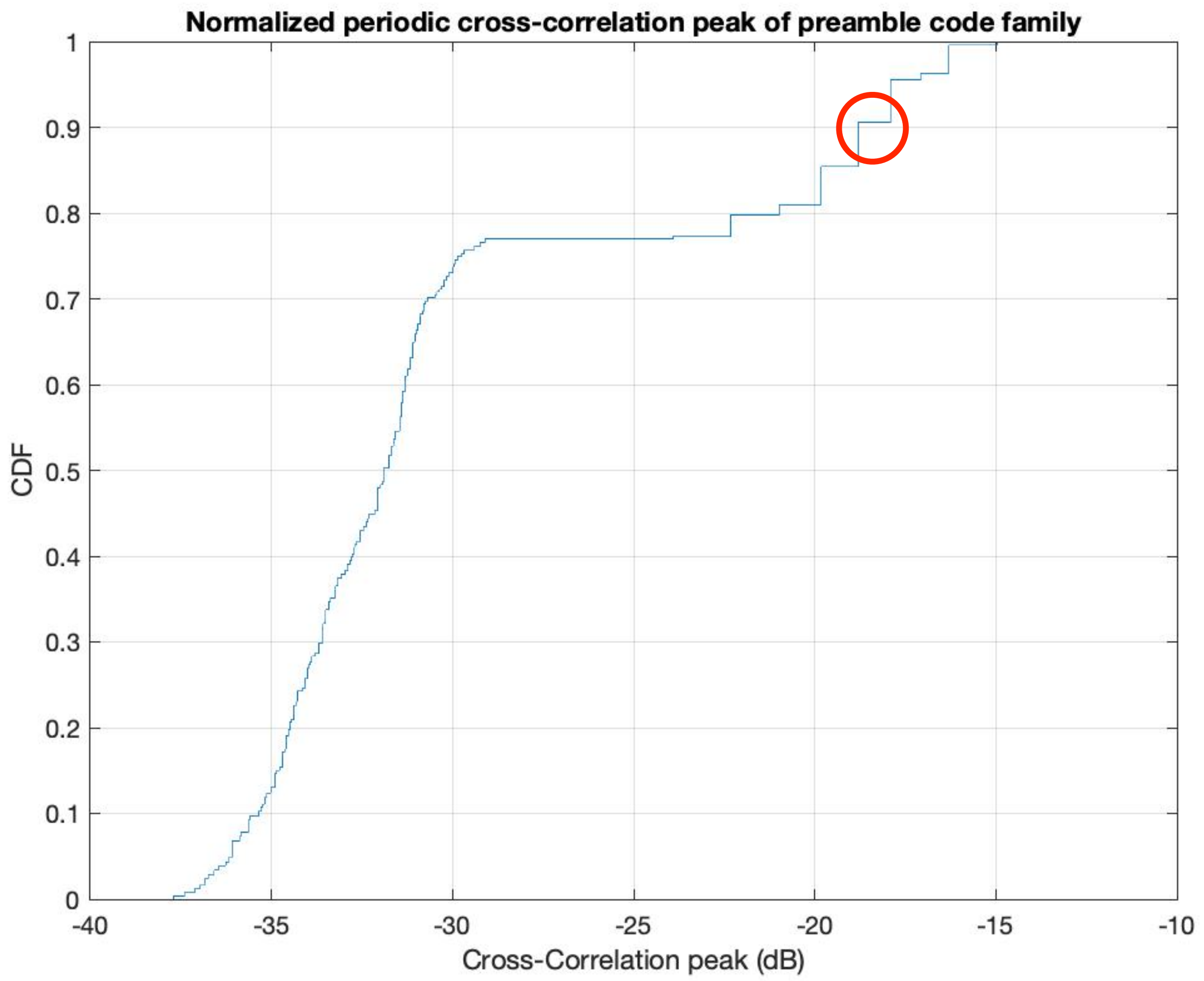
Target codes = {**Golay 64+64**}
Interfering codes = {Ipatov 91, Ipatov 127, Golay 64+64}



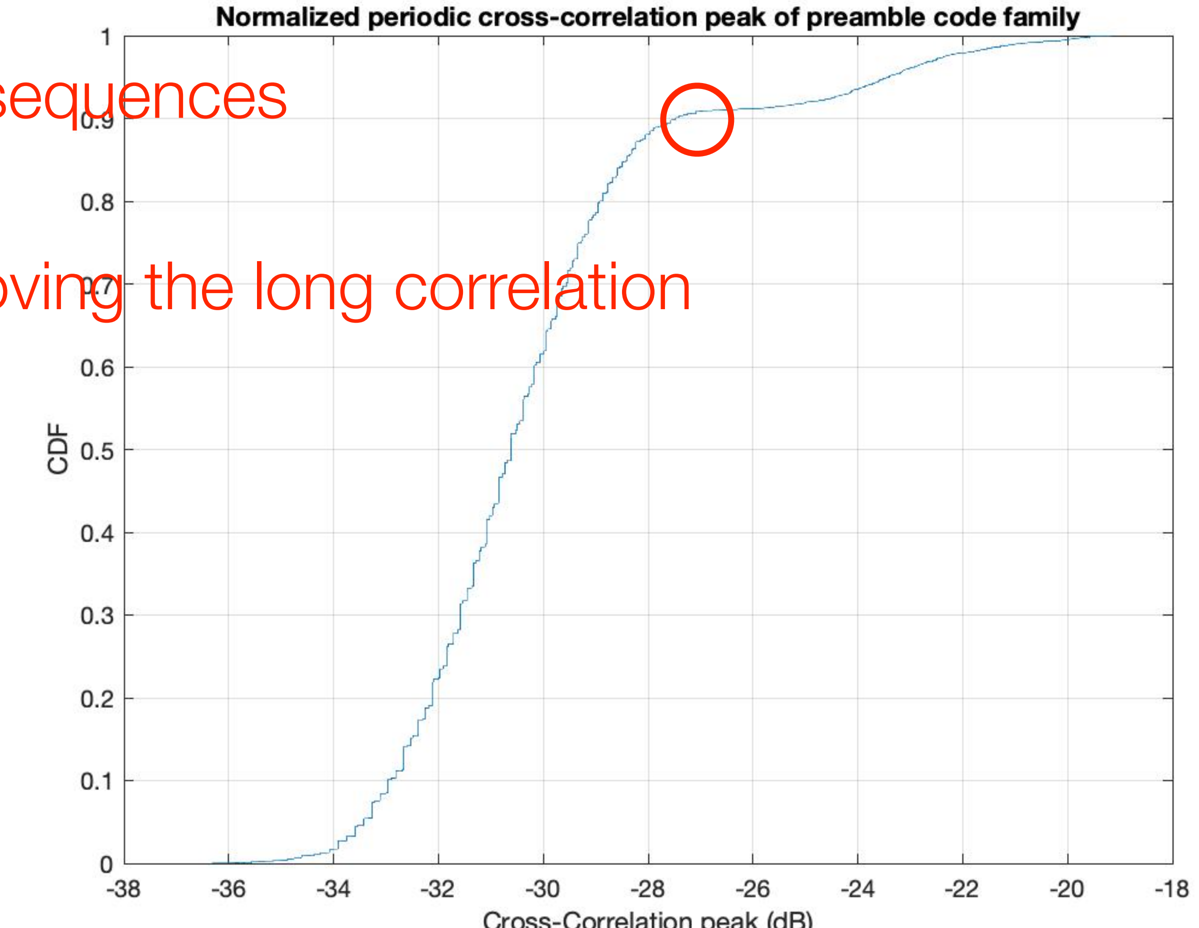
Target codes = {**m-seq 127**}
Interfering codes = {Ipatov 91, Ipatov 127, m-seq 127}



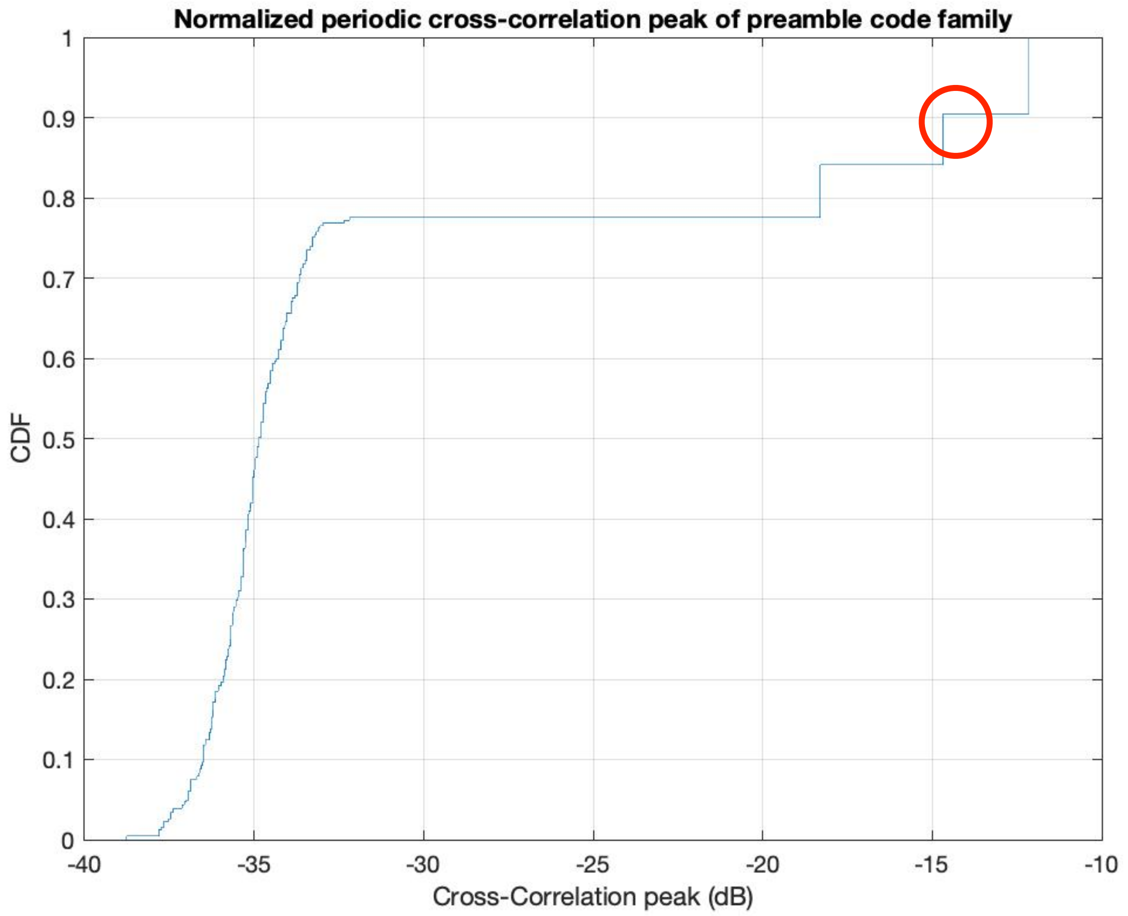
Target codes = {**CZC 64x2**}
Interfering codes = {Ipatov 91, Ipatov 127, CZC 64x2}



Target codes = {**CZC 64+64**}
Interfering codes = {Ipatov 91, Ipatov 127, CZC 64+64}

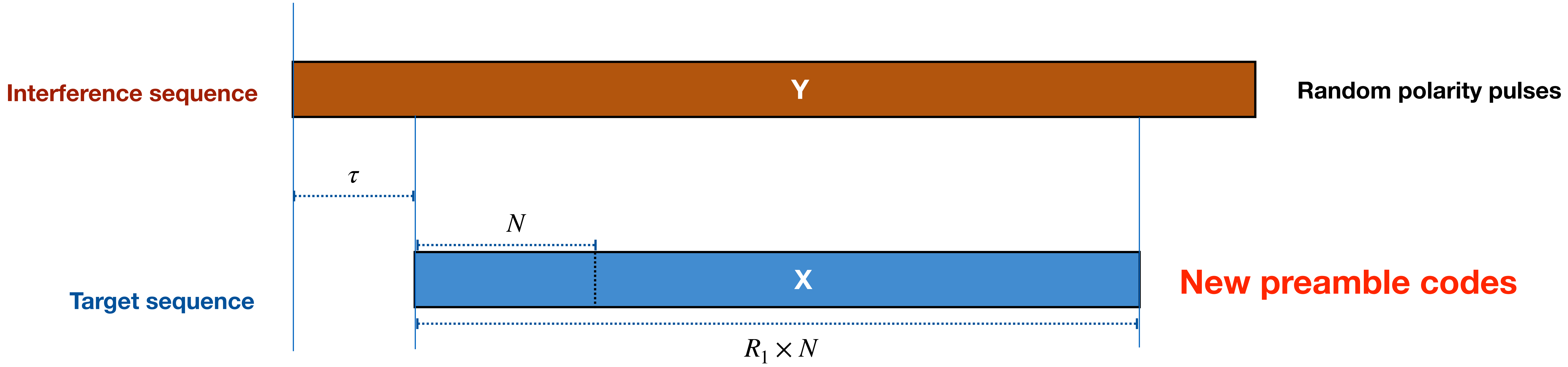


Target codes = {**m-seq 255**}
Interfering codes = {Ipatov 91, Ipatov 127, m-seq 255}



- Golay 64+64 code set has the lowest 90% cross-correlation among the different sequences
  - 16 dB better than the legacy cross-correlation
  - Golay with gaps creates different periodic to different sequences, thereby improving the long correlation

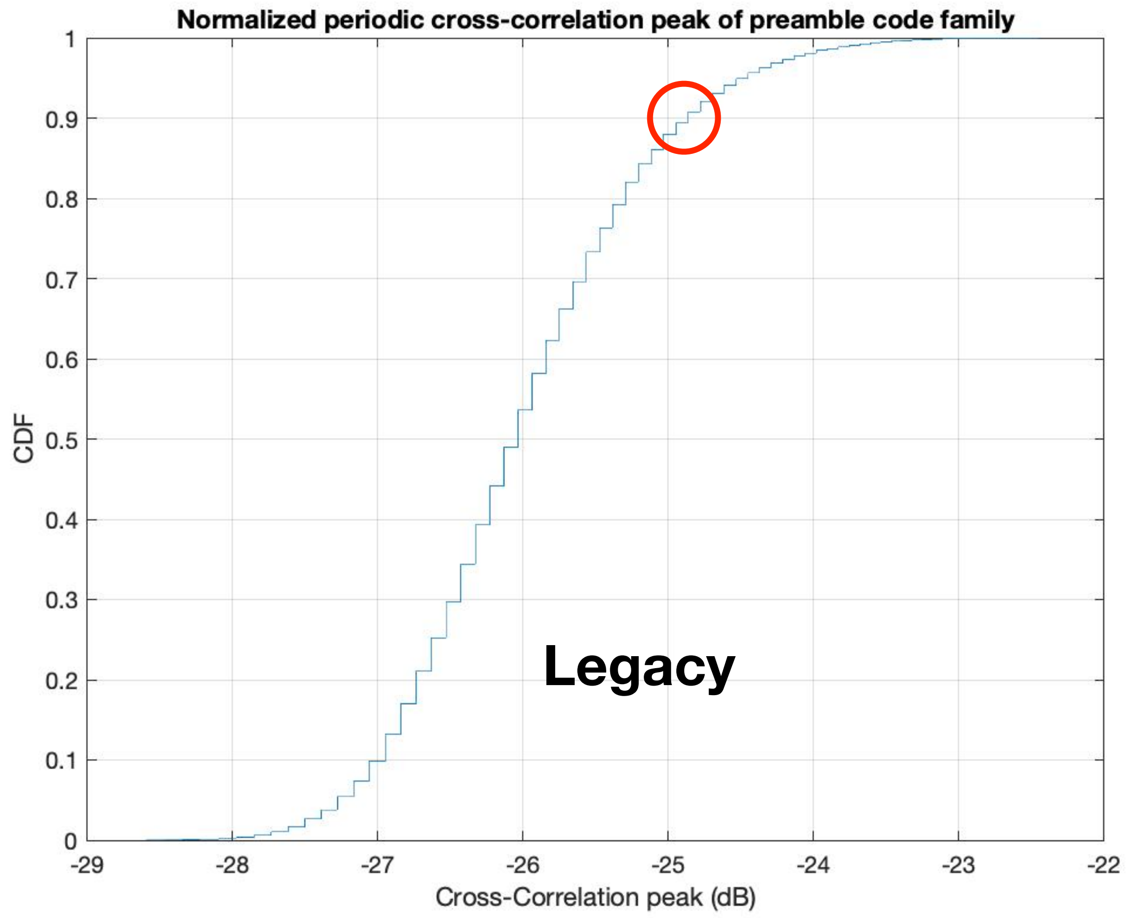
Performance of new preamble codes for MMS



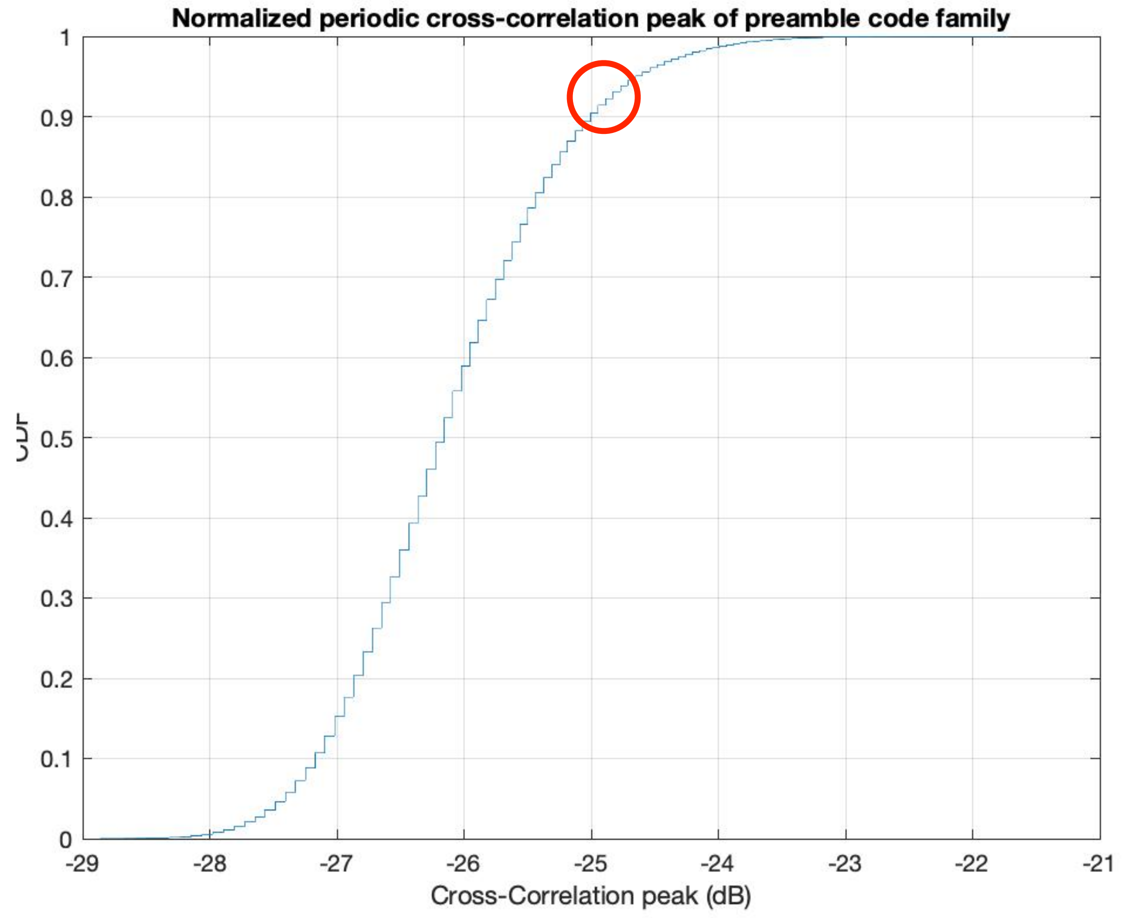
Performance of new preamble codes for MMS (R_1,R_2=40, Δf_{max}=0, p=1, L_1,L_2 = 4)

Long-Term Correlation with random polarity pulses

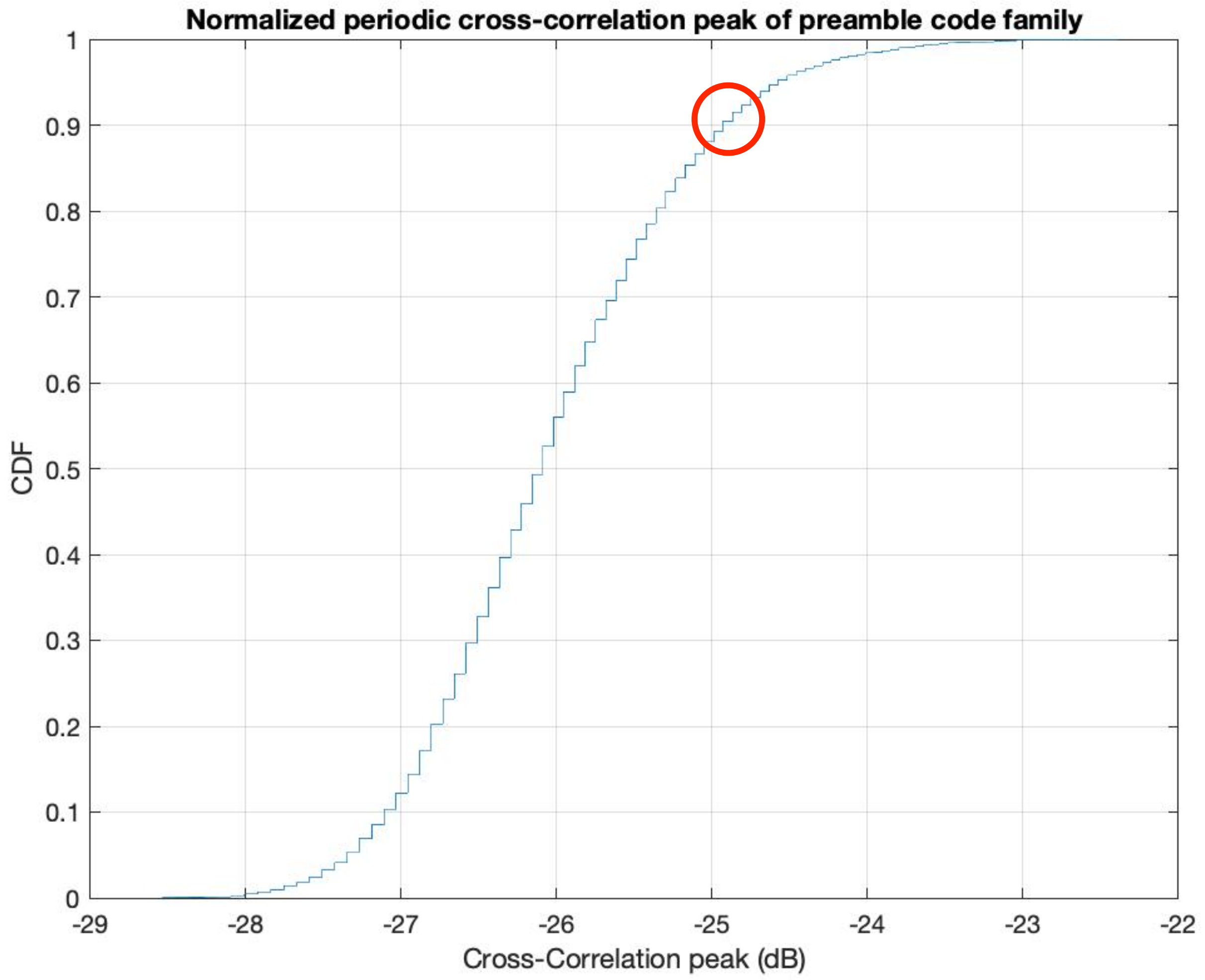
Target codes = {Ipatov 127}
Interfering codes = {Random polarity pulses}



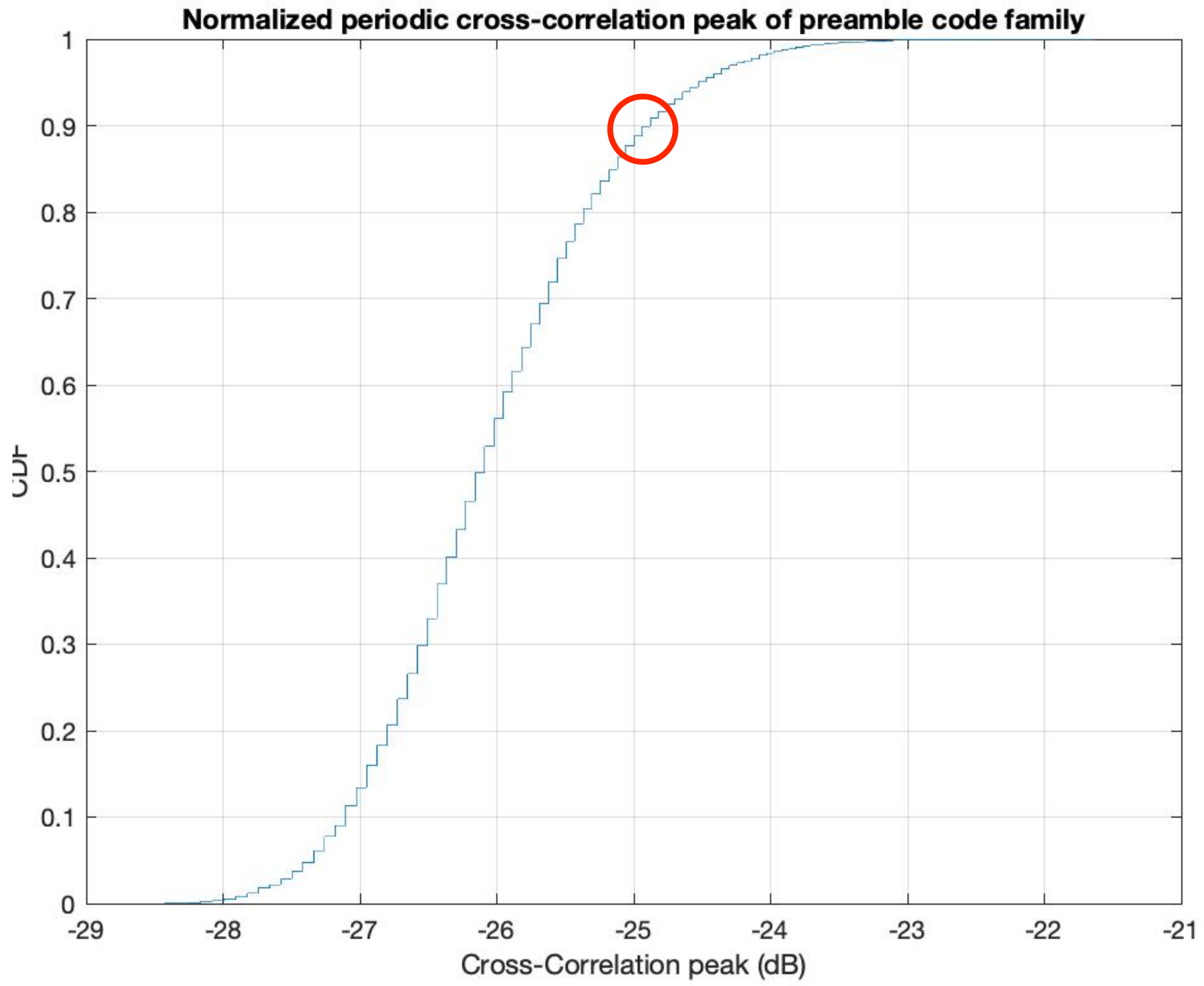
Target codes = {**Golay 64+64**}
Interfering codes = {Random polarity pulses}



Target codes = {**m-seq 127**}
Interfering codes = {Random polarity pulses}



Target codes = {**CZC 64x2**}
Interfering codes = {Random polarity pulses}



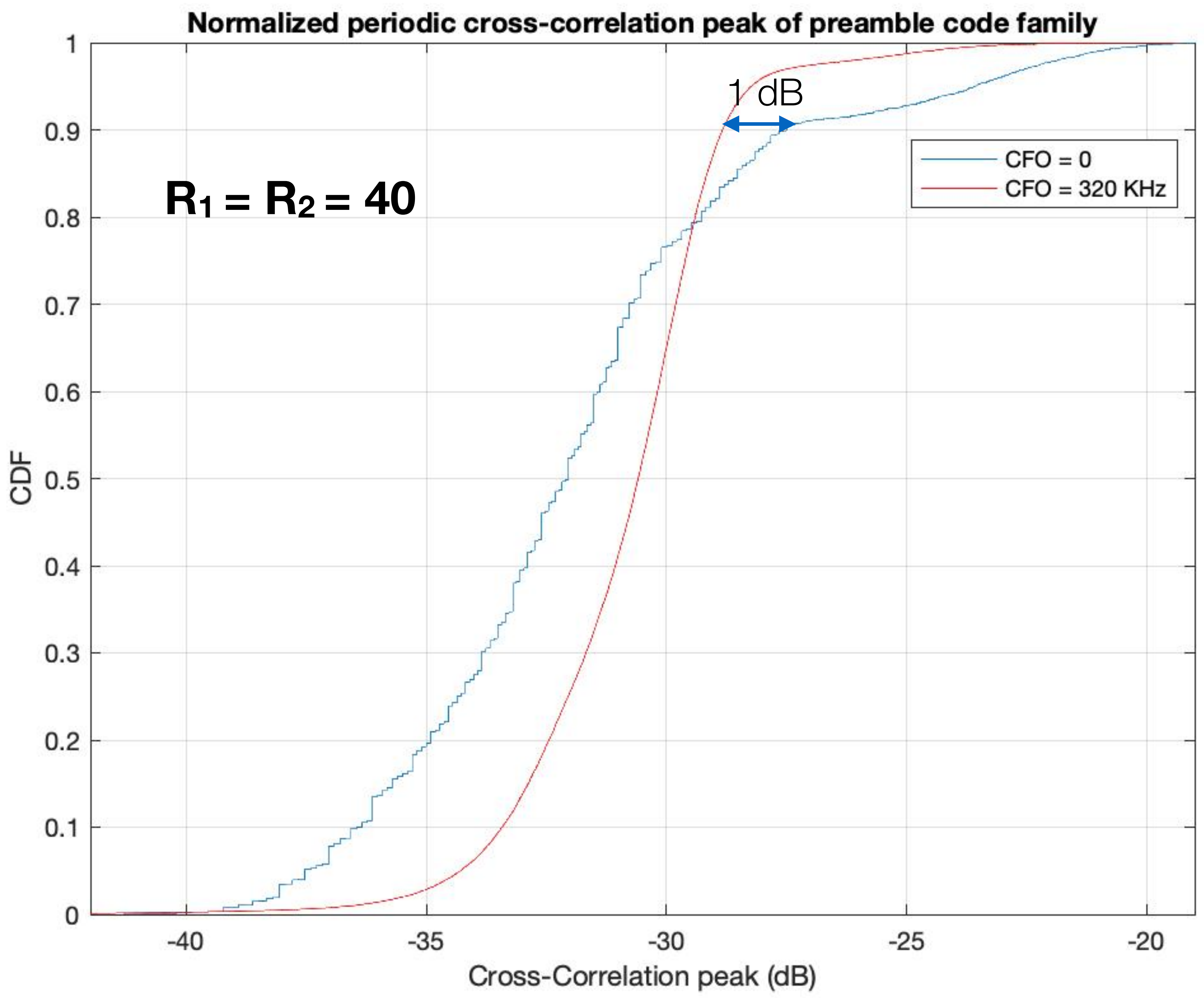
- All the new preamble sequences has similar or slightly better cross-correlation with Random pulses than the 4z Ipatov codes

Additional miscellaneous Results

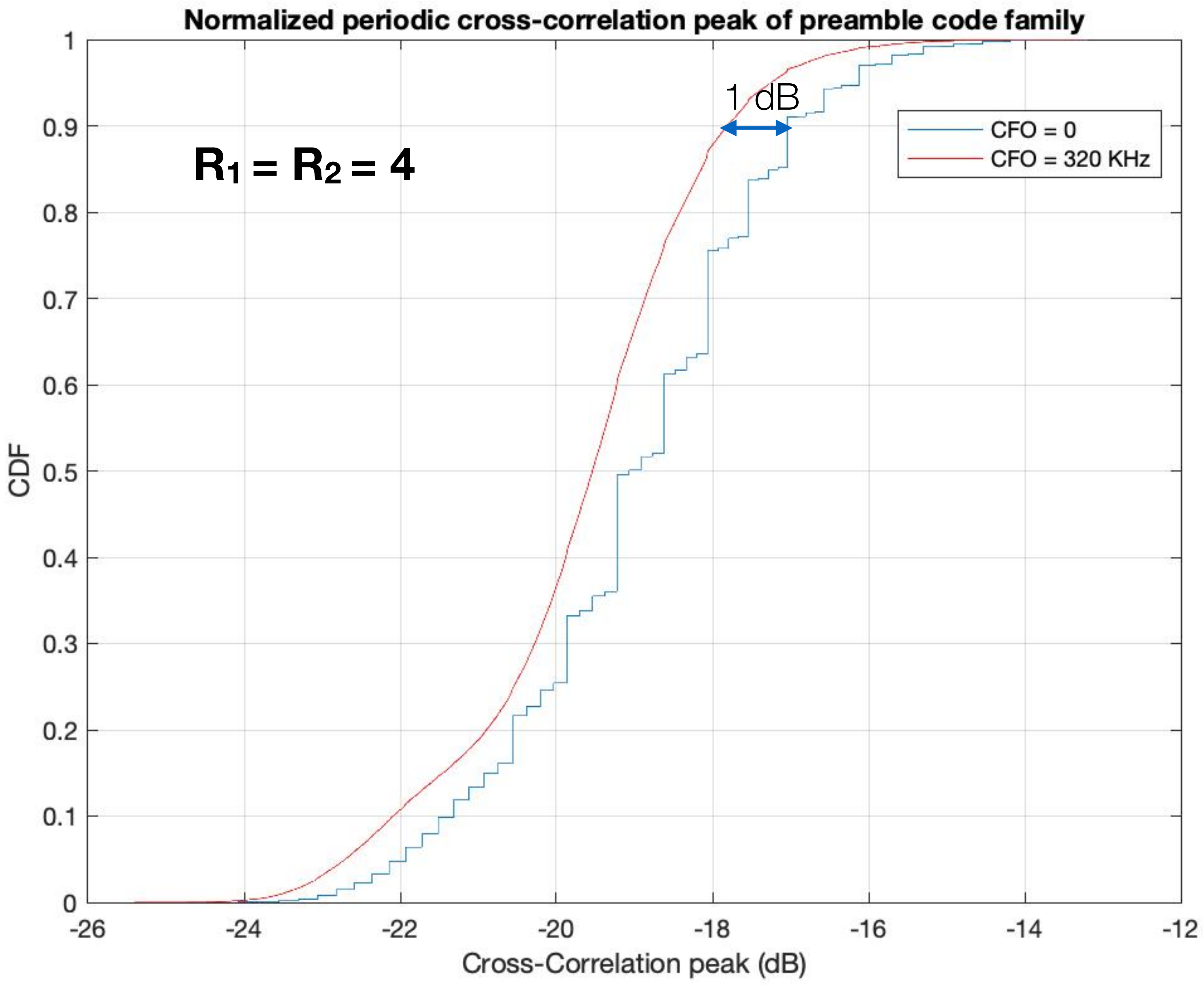
Results for Golay Pair, with CFO (Δf_{max}=320 KHz, p=0, L_1,L_2 = 4)

Gap=1 in Target Sequence X

Target codes = {Golay 64+64: 64 codes}
Interfering codes = {Ipatov 91, Ipatov 127, Golay 64+64}



Target codes = {Golay 64+64: 64 codes}
Interfering codes = {Ipatov 91, Ipatov 127, Golay 64+64}

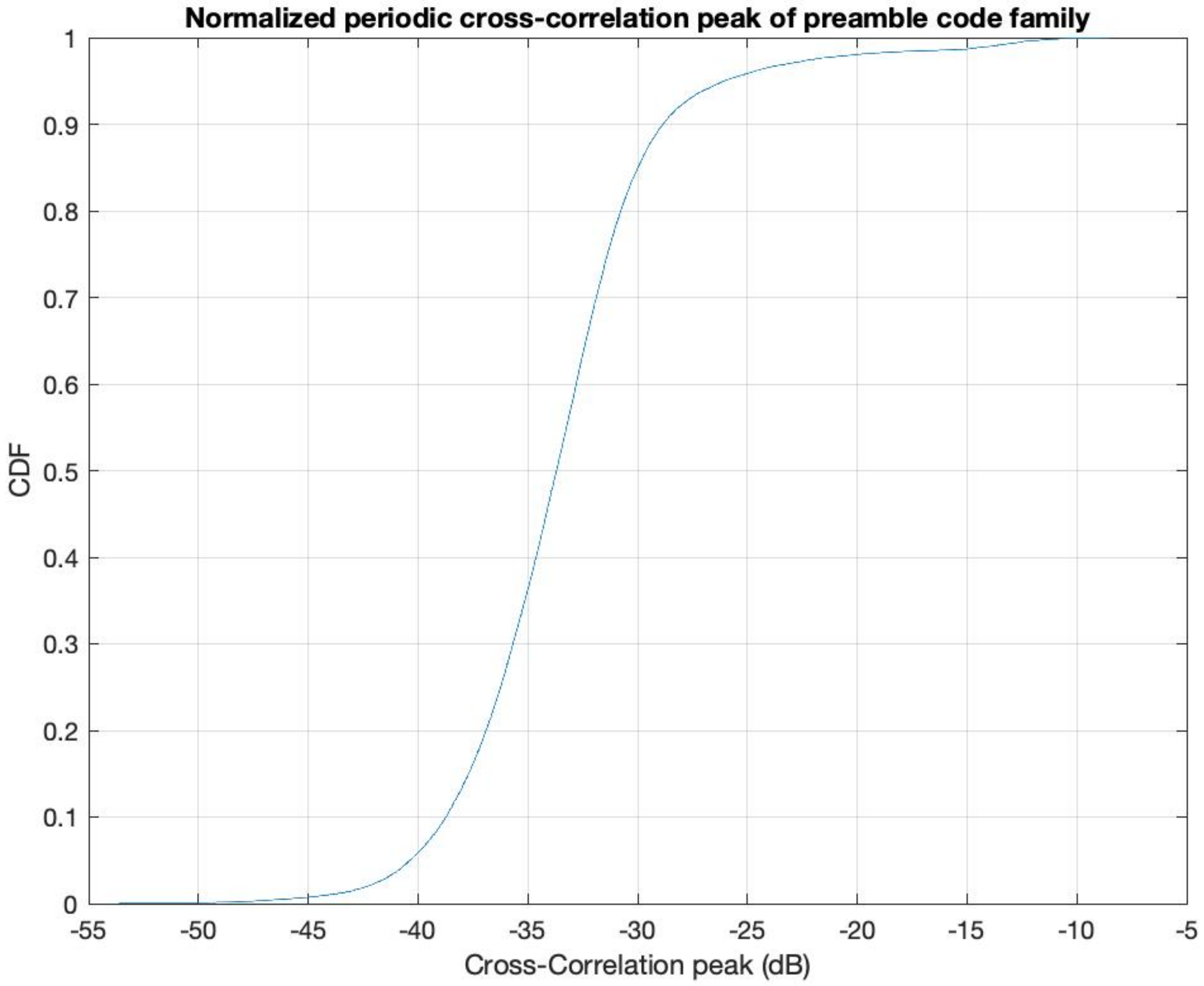


- CFO makes the cross-correlation better
  - 1 dB lower cross-correlation at 90% CDF

Results for Golay Pair, with random gap (p=0, L=4, R=40)

Gap=0 in Target Sequence X, Random gap for interference Golay code

Target codes = {Golay 64+64: 64 codes}
Interfering codes = {Ipatov 91, Ipatov 127, Golay 64+64 with random gap}

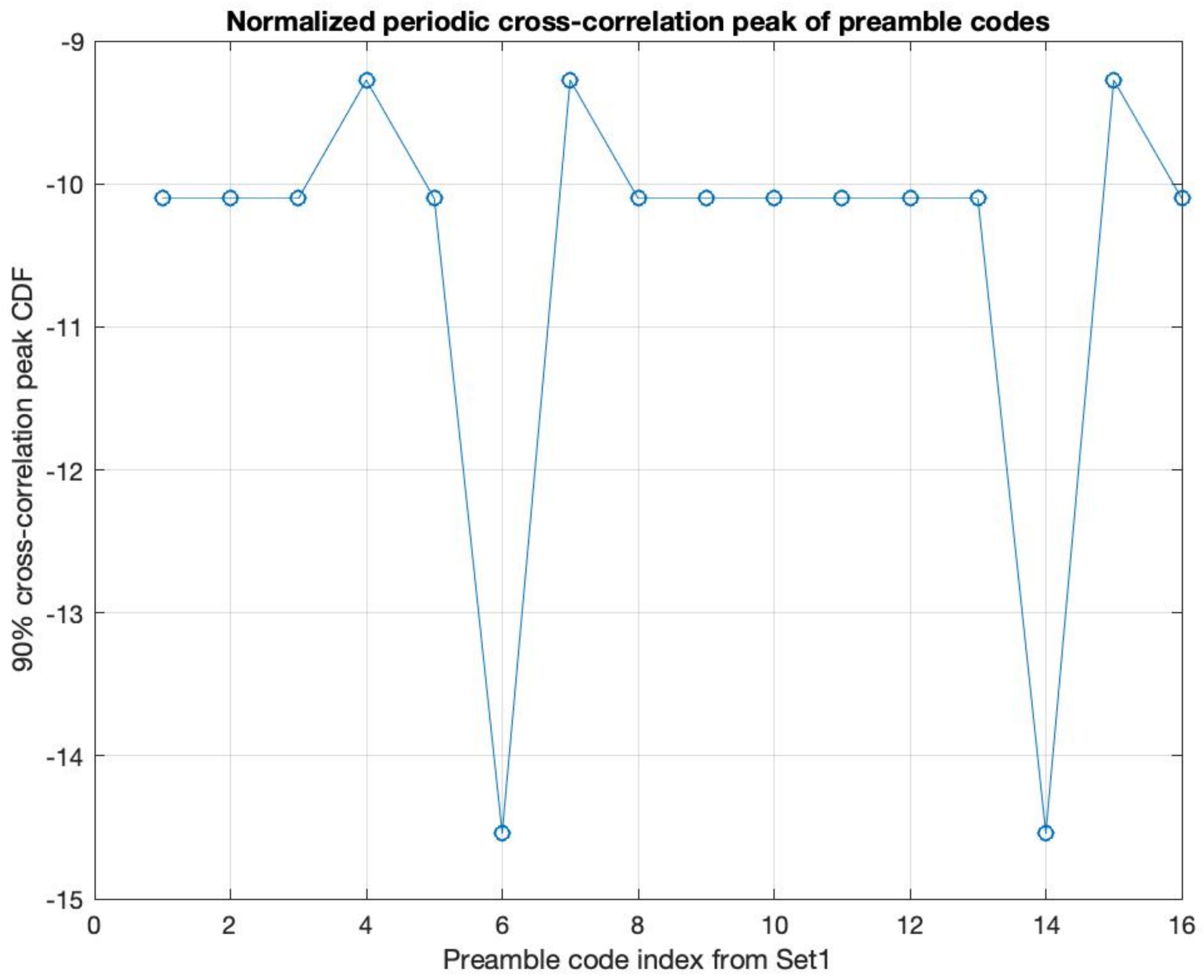


- 90% Cross-correlation CDF at -28 dB
    - Significantly better than best cross-correlation of -18 dB with Ipatov sequences

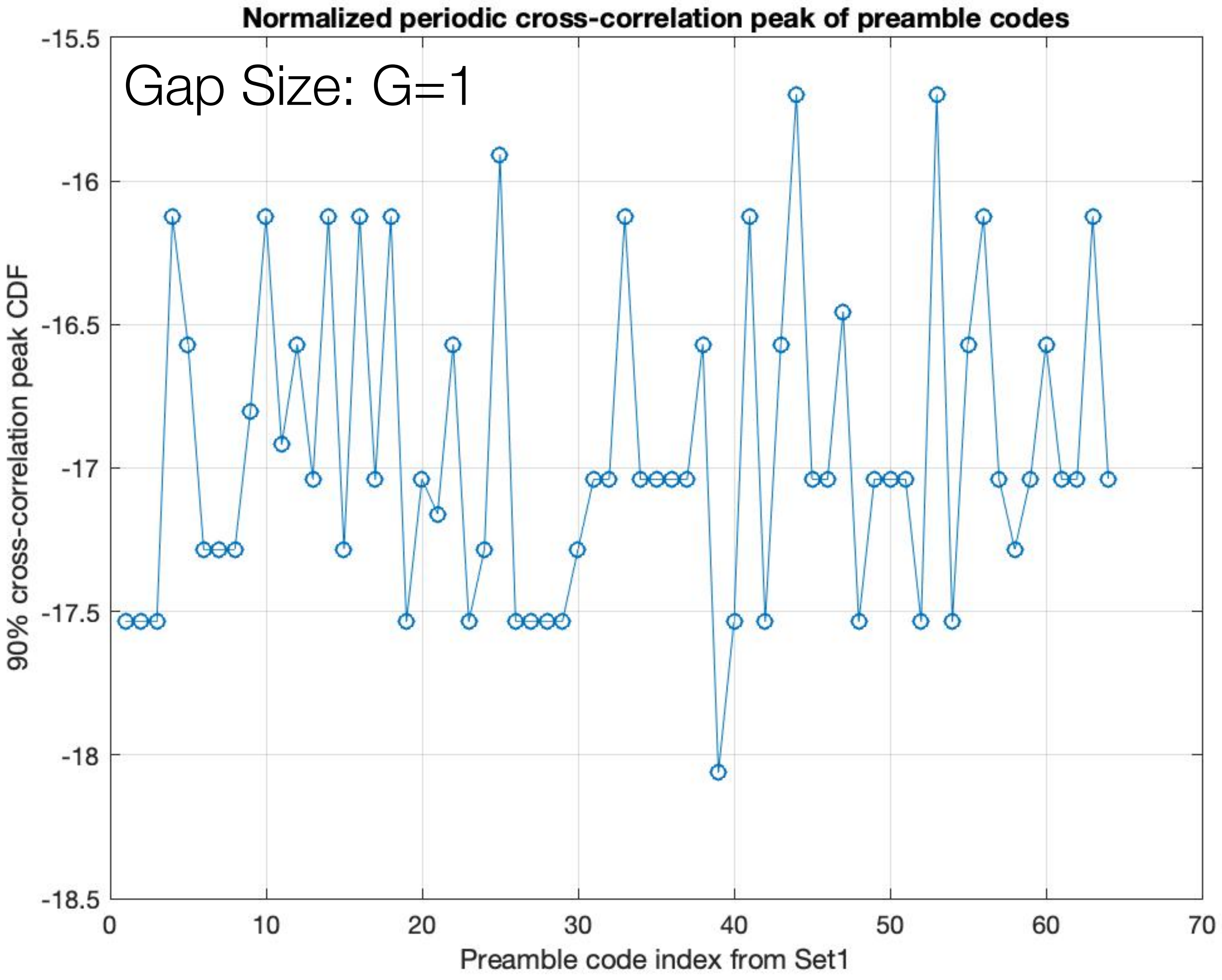
90% Cross-correlation Results for individual sequences (R_1,R_2=4, Δf_{max}=0, p=0, L_1,L_2 = 4)

Short-Term Correlation w/ PSR=4: Gap=1 in Target Sequence X

Target codes = {Ipatov 127: 16 codes}
Interfering codes = {Ipatov 91, Ipatov 127}



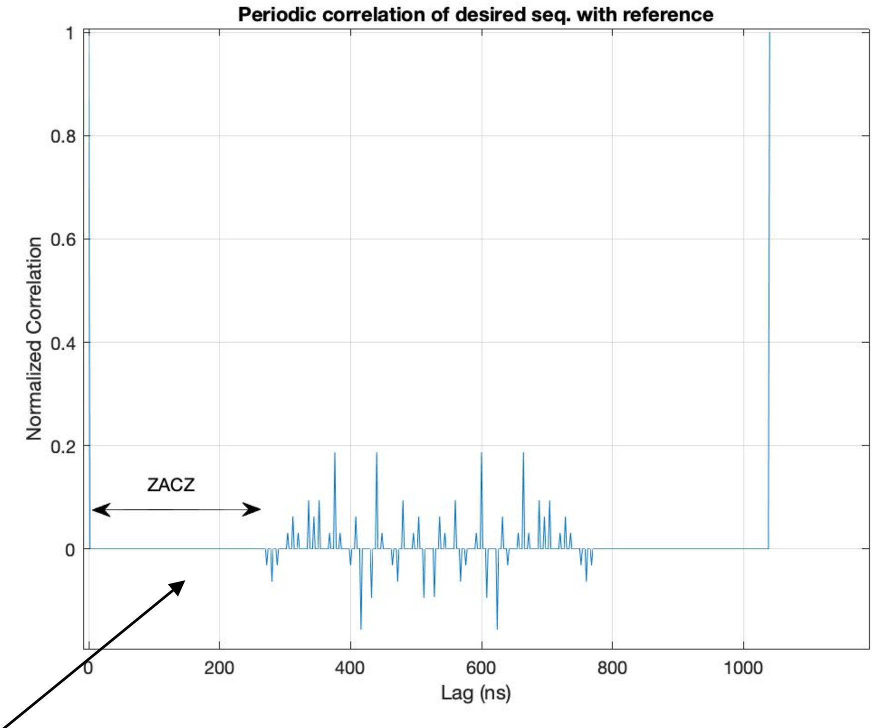
Target codes = {Golay 64+64: 64 codes}
Interfering codes = {Ipatov 91, Ipatov 127, Golay 64+64}

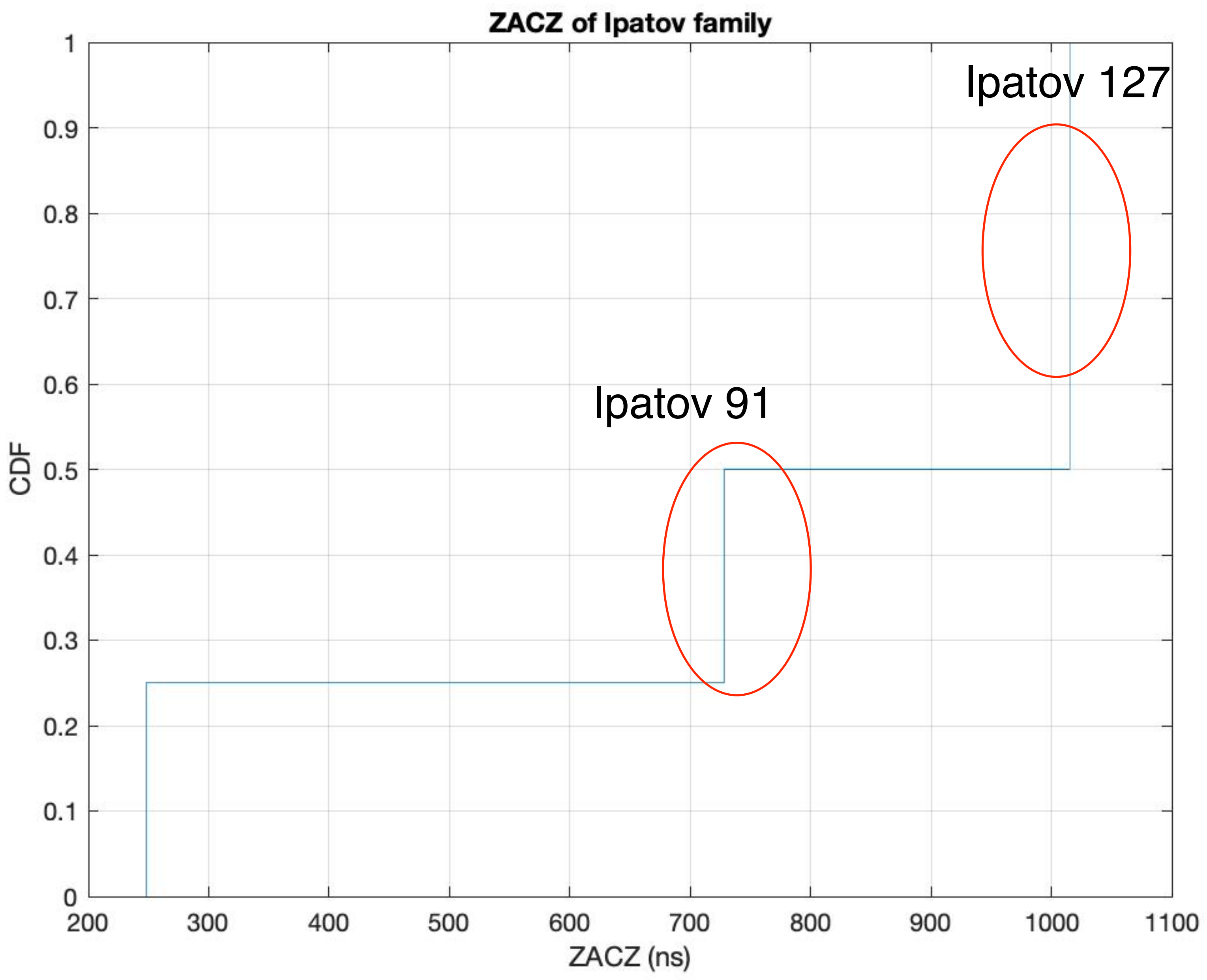


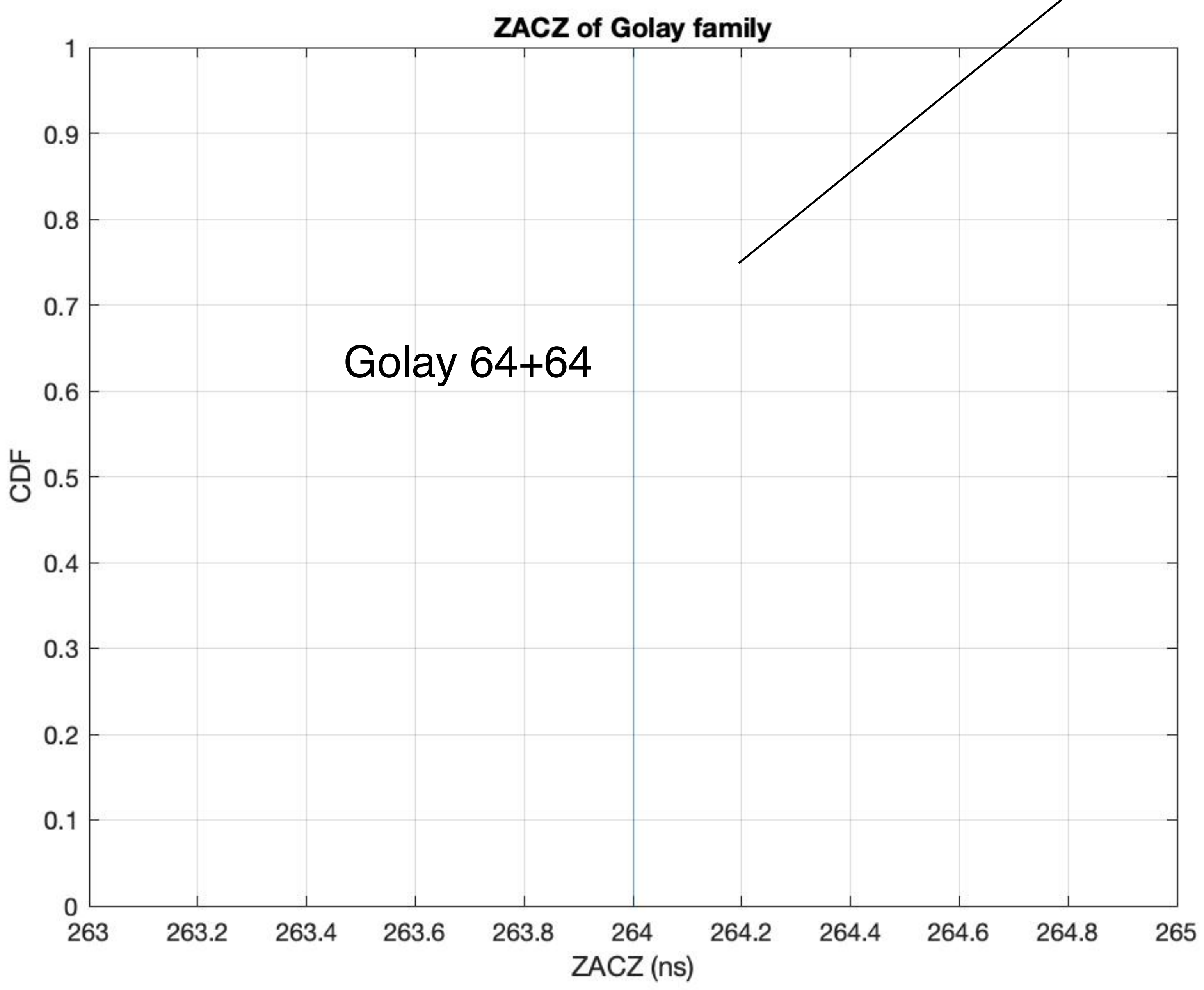
- All the 64 sequences from Golay set has similar 90% Cross-correlation CDF
  - All sequences have better 90% cross-correlation than Ipatov 127 set

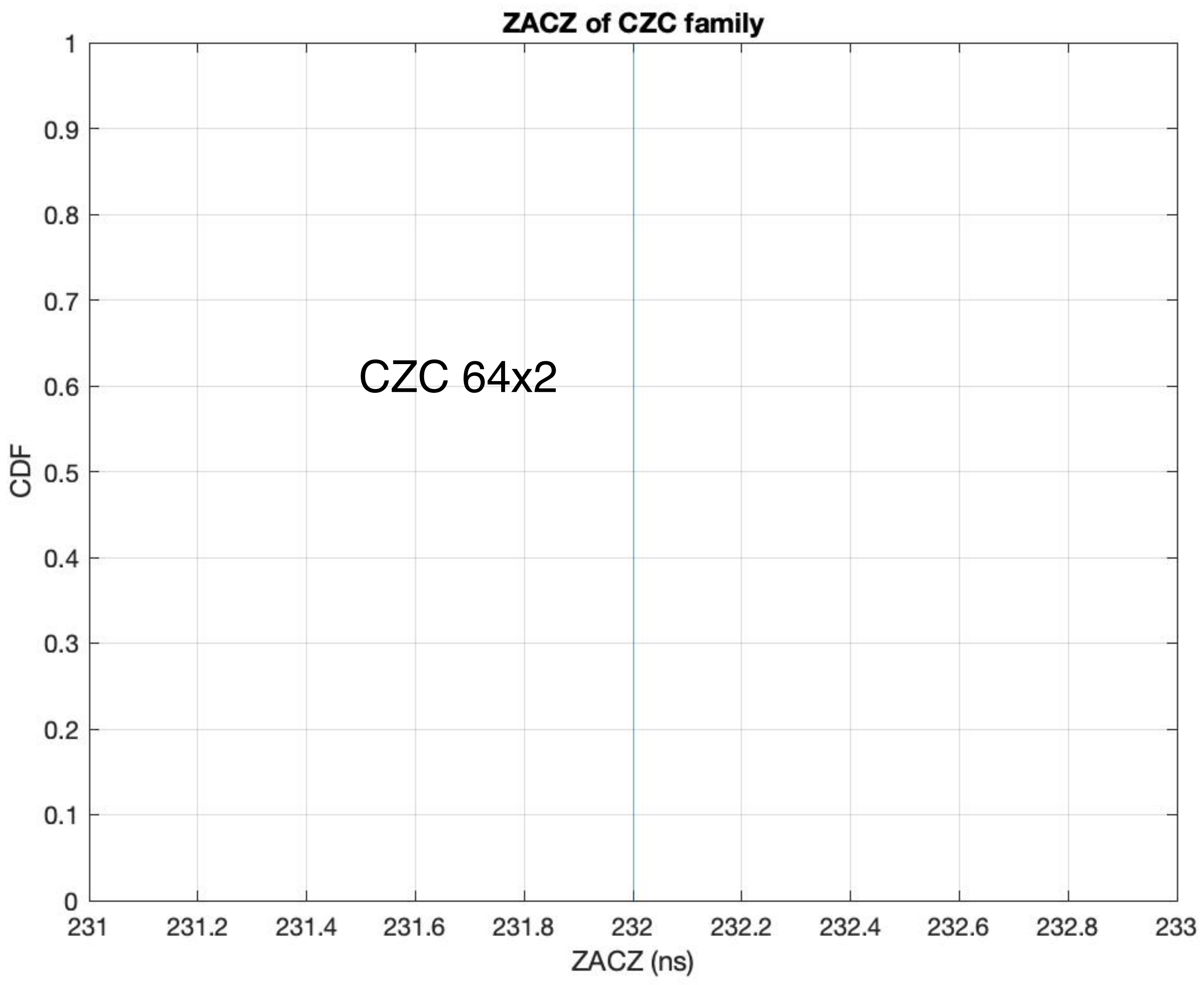
ZACZ of different preamble sequences

Spreading = 4, No gaps







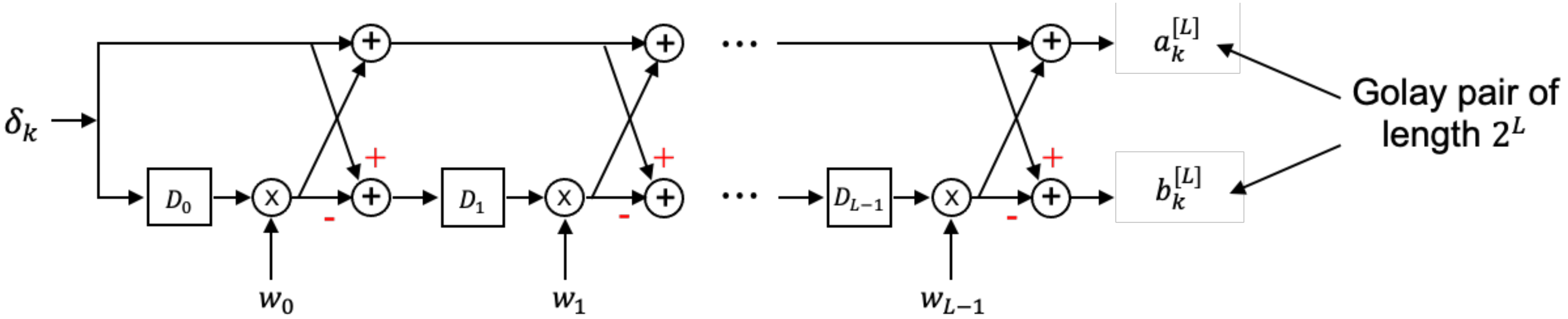


- Ipatov provides the largest ZACZ for the same symbol length
- ZACZ with Golay 64+64 is 264 ns, which is larger than channel delay spread of most propagation scenarios
  - ZACZ further increases with gaps, linearly with gap size

More Information on Proposed (64, 64) Golay Pairs

Golay Generator from Seeds

Seed and Delay Vector Definitions

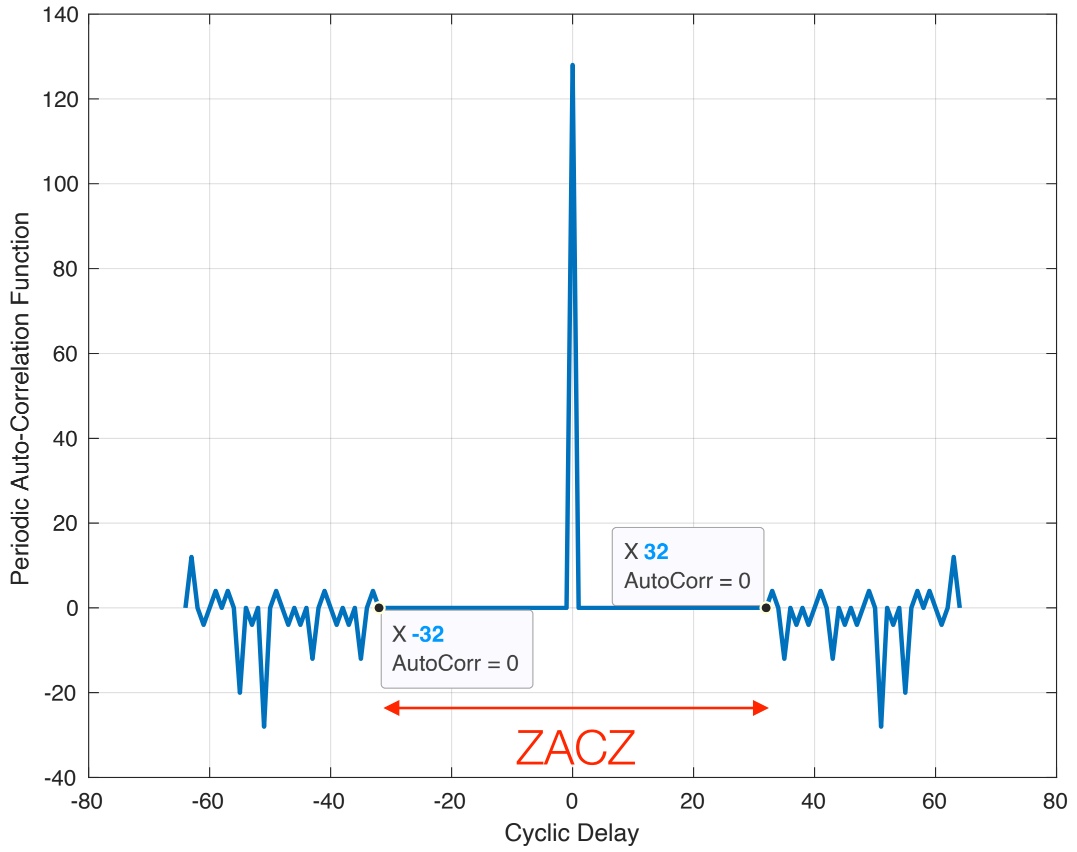


- $L = 6$
- Delay Vector:
  - $\mathbf{D} := [D_0, D_1, \ldots, D_{L-1}]$
  - $D_k \in \{2^0, 2^1, \ldots, 2^{L-1}\}, \forall k \in [0, L-1]$
- Weight Vector:
  - Seed $:= \sum_{i=0}^{L-1} \frac{1+w_i}{2} 2^i$

Golay Generator from Seeds

Seed and Delay Vector Configurations for 64 Golay (64, 64) Pairs

```
Seq. 1: Seed=40;  delay=[1   2  16   8   4  32];
Seq. 2: Seed=27;  delay=[2   1  16   8   4  32];
Seq. 3: Seed=7;   delay=[4   1  16   8   2  32];
Seq. 4: Seed=39;  delay=[1   8   4  16   2  32];
Seq. 5: Seed=61;  delay=[8   1  16   2   4  32];
Seq. 6: Seed=37;  delay=[4   1   2  16   8  32];
Seq. 7: Seed=63;  delay=[16   1   2   8   4  32];
Seq. 8: Seed=3;   delay=[4   2  16   8   1  32];
Seq. 9: Seed=58;  delay=[16   2   4   1   8  32];
Seq. 10: Seed=40; delay=[4   2  16   1   8  32];
Seq. 11: Seed=22; delay=[4   8   2   1  16  32];
Seq. 12: Seed=30; delay=[16   4   2   1   8  32];
Seq. 13: Seed=21; delay=[8   4  16   1   2  32];
Seq. 14: Seed=0;  delay=[4   2   1   8  16  32];
Seq. 15: Seed=47; delay=[4   8  16   2   1  32];
Seq. 16: Seed=59; delay=[2   8   1  16   4  32];
Seq. 17: Seed=42; delay=[1   2   8   4  16  32];
Seq. 18: Seed=61; delay=[1   8   2   4  16  32];
Seq. 19: Seed=52; delay=[1   4   8  16   2  32];
Seq. 20: Seed=47; delay=[1   4  16   2   8  32];
Seq. 21: Seed=58; delay=[16   8   1   2   4  32];
Seq. 22: Seed=39; delay=[8   1   4   2  16  32];
Seq. 23: Seed=53; delay=[8   4   2  16   1  32];
Seq. 24: Seed=50; delay=[2  16   8   4   1  32];
Seq. 25: Seed=52; delay=[1   8   2  16   4  32];
Seq. 26: Seed=9;  delay=[16   2   8   1   4  32];
Seq. 27: Seed=8;  delay=[16   1   2   8   4  32];
Seq. 28: Seed=9;  delay=[16   8   4   1   2  32];
Seq. 29: Seed=54; delay=[1   2  16   4   8  32];
Seq. 30: Seed=63; delay=[16   4   2   1   8  32];
Seq. 31: Seed=53; delay=[2  16   1   8   4  32];
Seq. 32: Seed=27; delay=[4  16   8   1   2  32];
Seq. 33: Seed=61; delay=[8   4   1   2  16  32];
Seq. 34: Seed=33; delay=[4  16   1   2   8  32];
Seq. 35: Seed=11; delay=[1   8   2   4  16  32];
Seq. 36: Seed=38; delay=[2   1   8   4  16  32];
Seq. 37: Seed=35; delay=[8   4  16   1   2  32];
Seq. 38: Seed=17; delay=[1   2   4  16   8  32];
Seq. 39: Seed=46; delay=[8   1   2  16   4  32];
Seq. 40: Seed=37; delay=[8  16   4   2   1  32];
Seq. 41: Seed=16; delay=[1  16   8   4   2  32];
Seq. 42: Seed=27; delay=[8   4   1  16   2  32];
Seq. 43: Seed=42; delay=[16   1   8   2   4  32];
Seq. 44: Seed=0;  delay=[1  16   8   4   2  32];
Seq. 45: Seed=8;  delay=[2  16   4   1   8  32];
Seq. 46: Seed=49; delay=[16   1   8   4   2  32];
Seq. 47: Seed=11; delay=[1  16   8   2   4  32];
Seq. 48: Seed=27; delay=[4   2   8  16   1  32];
Seq. 49: Seed=7;  delay=[8   4  16   1   2  32];
Seq. 50: Seed=62; delay=[2   8   1   4  16  32];
Seq. 51: Seed=36; delay=[2   8   4   1  16  32];
Seq. 52: Seed=15; delay=[2  16   8   1   4  32];
Seq. 53: Seed=30; delay=[1   8   4  16   2  32];
Seq. 54: Seed=11; delay=[2   4   8  16   1  32];
Seq. 55: Seed=61; delay=[2   4  16   1   8  32];
Seq. 56: Seed=54; delay=[2   4   8   1  16  32];
Seq. 57: Seed=1;  delay=[2   1   4  16   8  32];
Seq. 58: Seed=27; delay=[1   2  16   4   8  32];
Seq. 59: Seed=13; delay=[16   2   8   1   4  32];
Seq. 60: Seed=44; delay=[8   4   1   2  16  32];
Seq. 61: Seed=35; delay=[8   2   1   4  16  32];
Seq. 62: Seed=61; delay=[4   2   1   8  16  32];
Seq. 63: Seed=28; delay=[1   8   2   4  16  32];
Seq. 64: Seed=39; delay=[2   1   8  16   4  32];
```



Note: corresponding sequences are also available in the shared codes for apEval: Doc#: 15-22-0447-01-04ab-apEval_framework.m

- Each of the recommended Golay pair exhibits a ZACZ of 2x32 as illustrated in the top right figure (before spreading, in the absence a gap)