Infineon

Automotive Power CAD

Statistical Simulation Methodology for a Smart Power Technology

2007, Oct 19th
AK Bipolar 2007 / Munich

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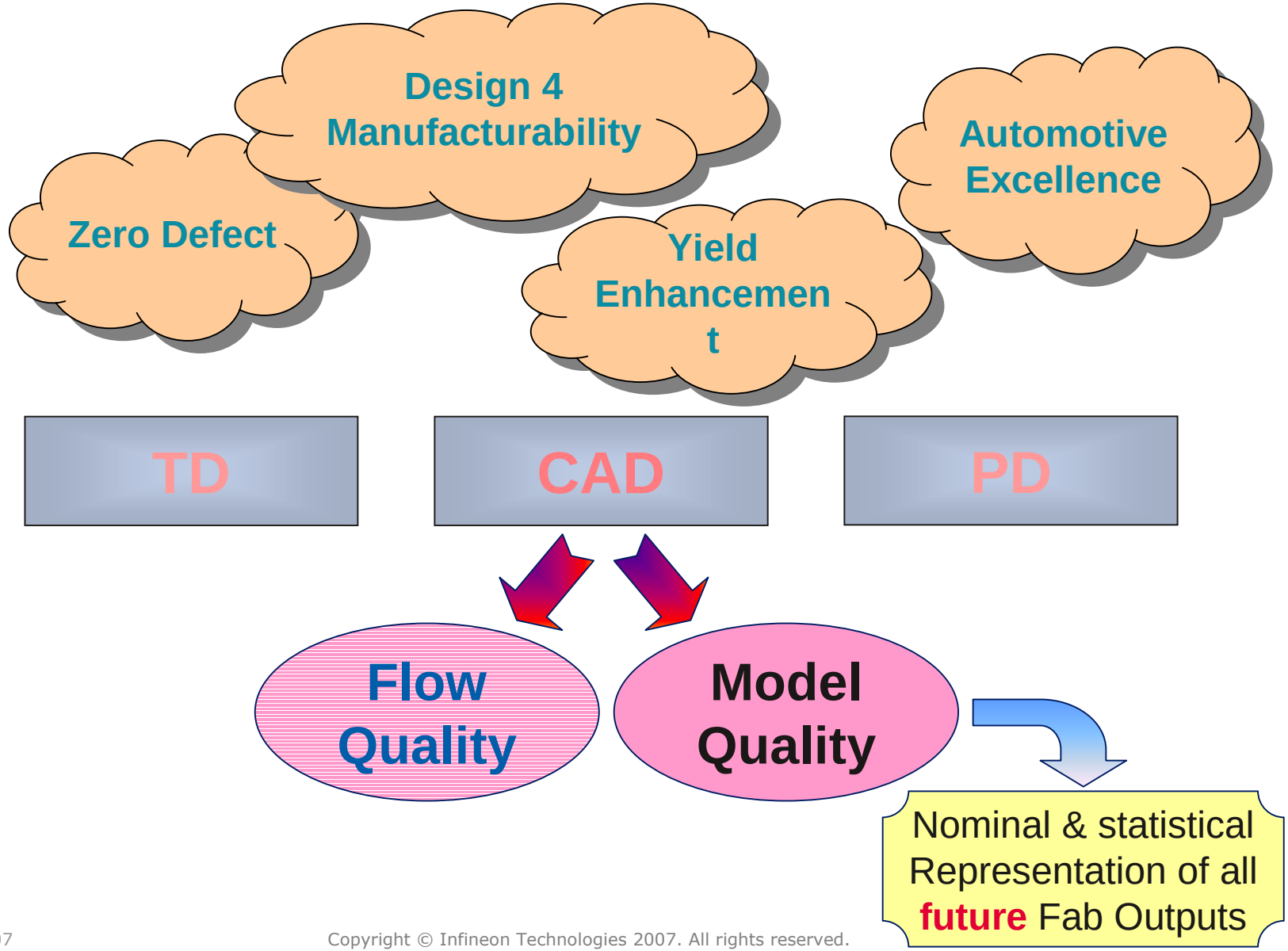
Infineon

Never stop thinking

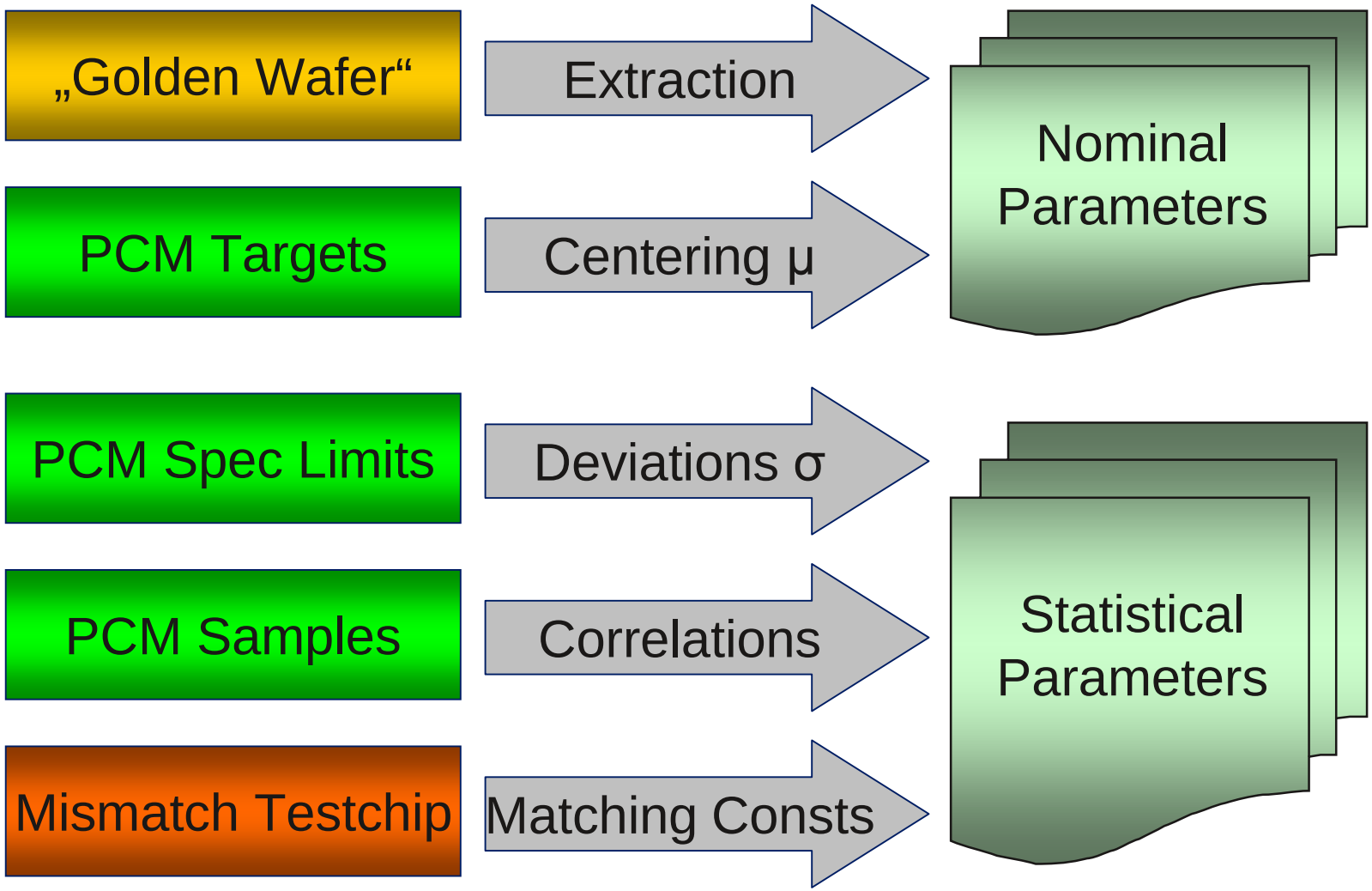
Outline

- Motivation
- Modeling Flow
- Model Quality
- Conclusion

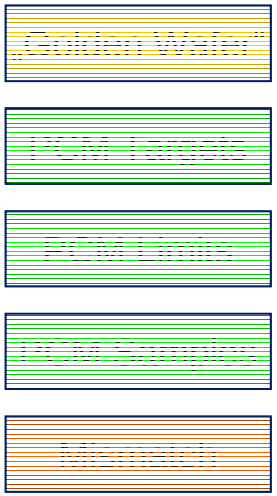
Motivation / Wake-Up

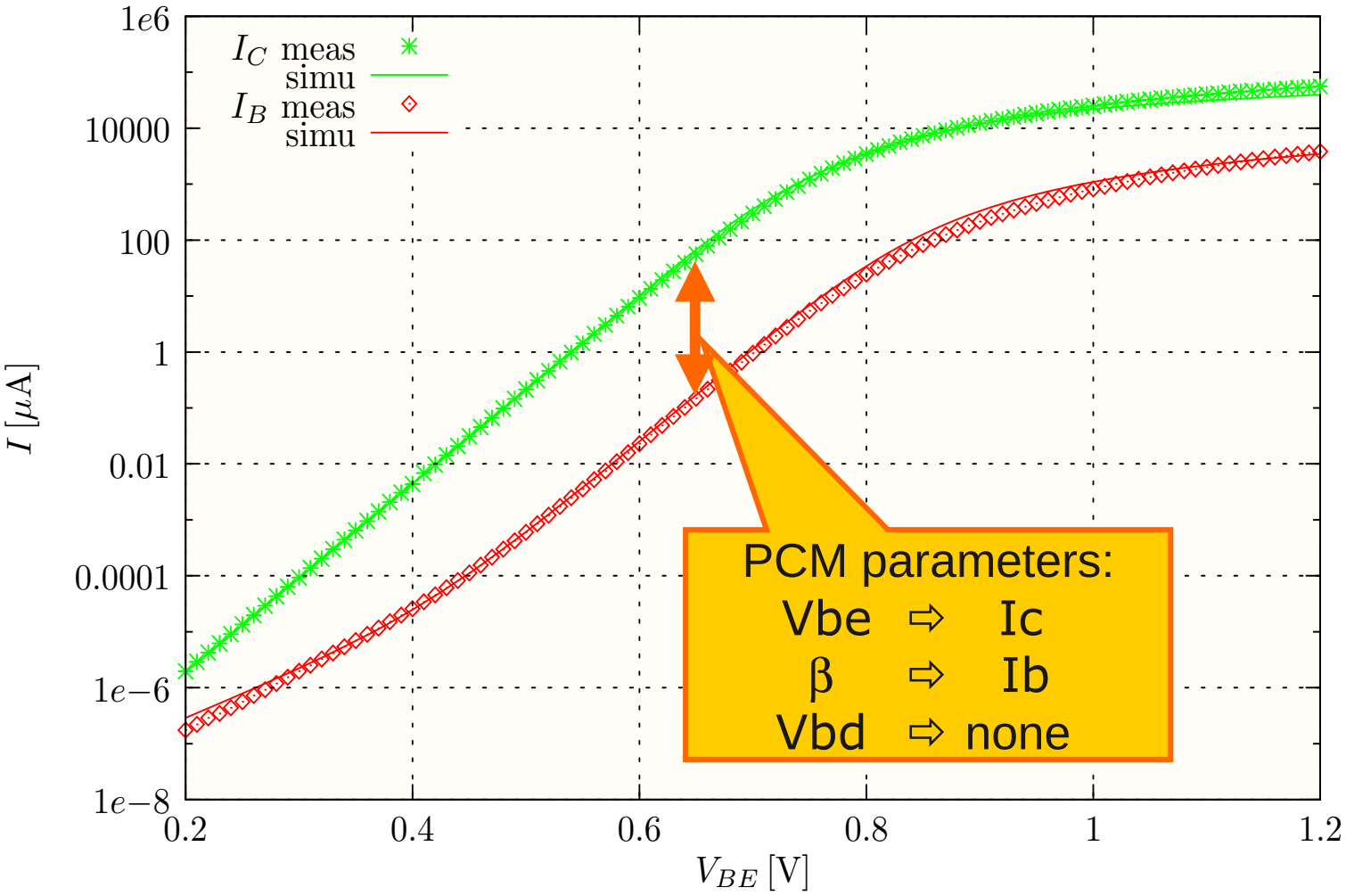


Five Steps Extraction Process of Electrical Parameters



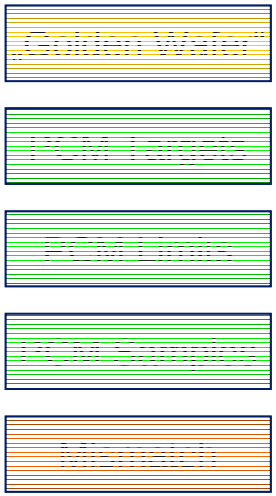
Step 1: Nominal Parameters

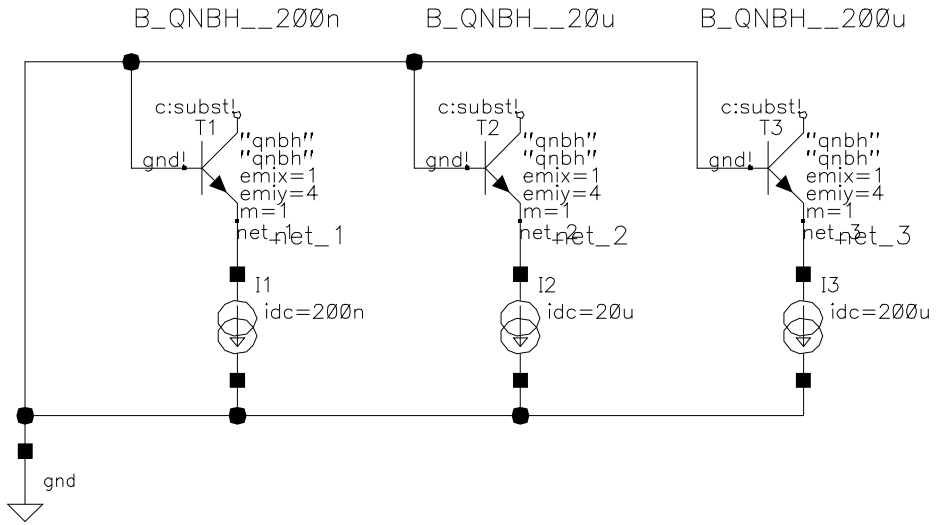


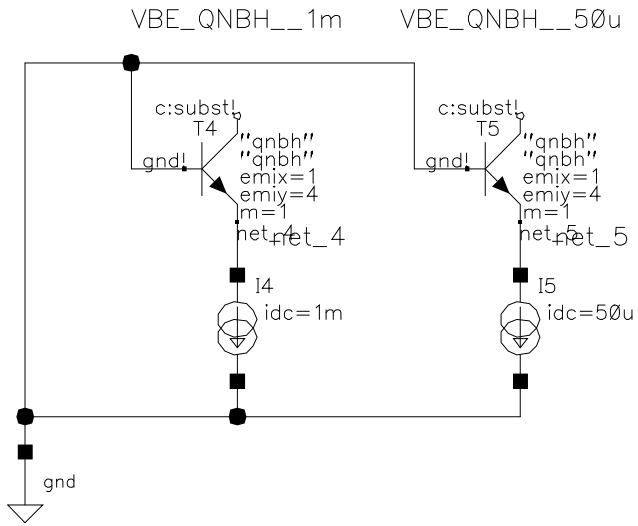


source: ***/EP/***-Docu (Bipolar / Tempsense)

Step 1: Nominal Parameters







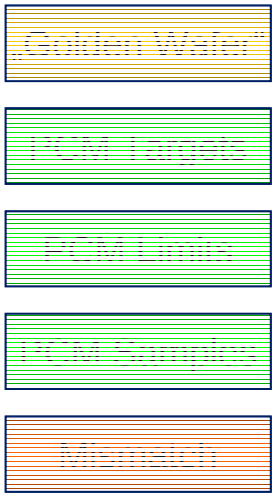
Re-Simulation Schematics

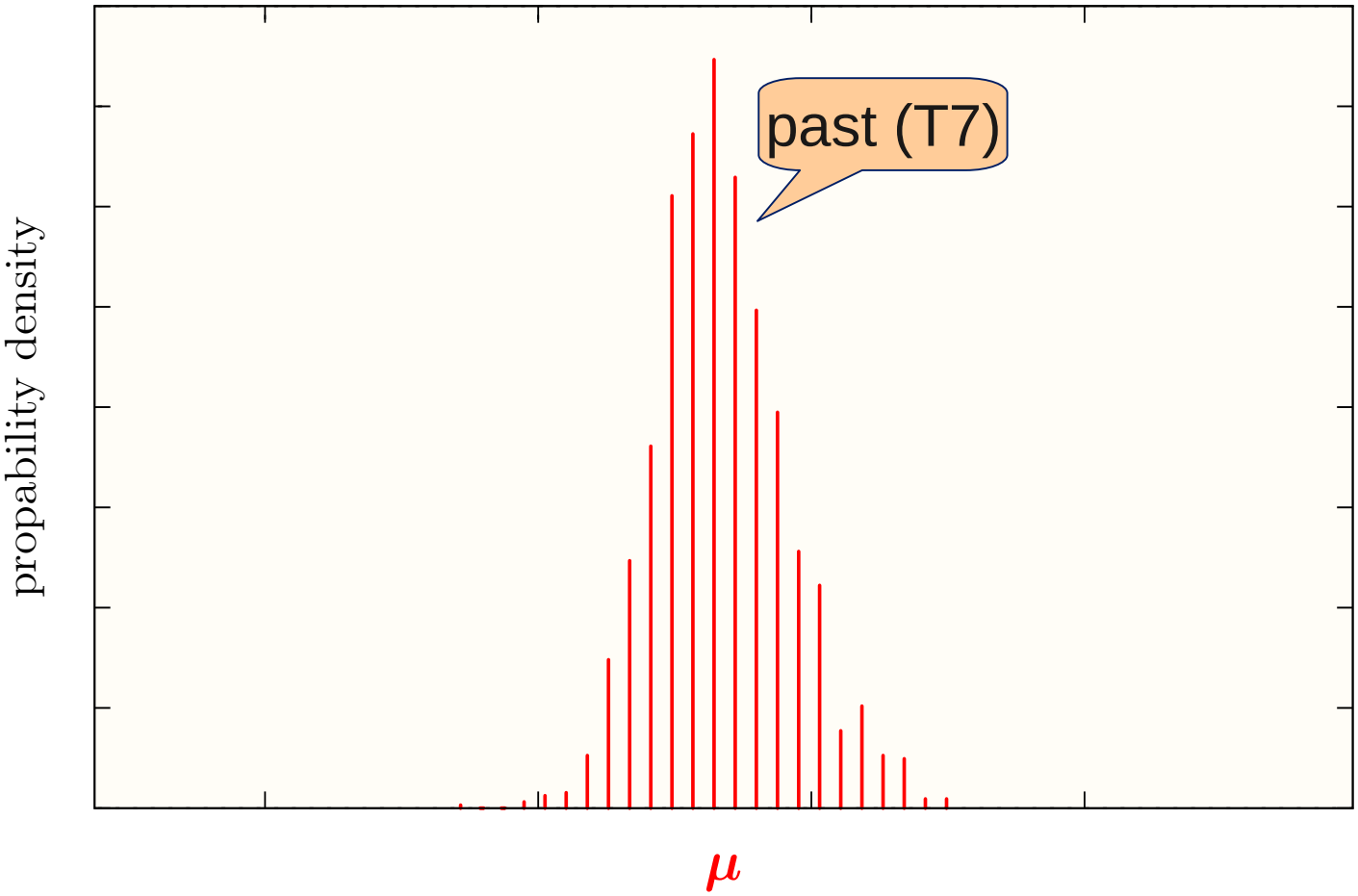
SMART5 PCM:

- 41 of 75 device types covered
- 143 of 194 PCM setups can be re-simulated simultaneously

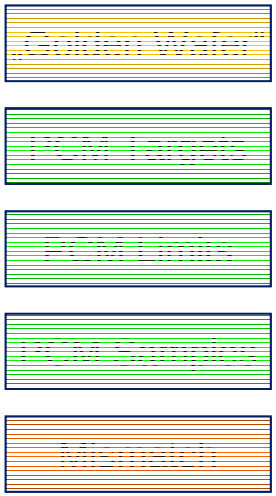
source: ***/PCM/***-Docu (Bipolar)

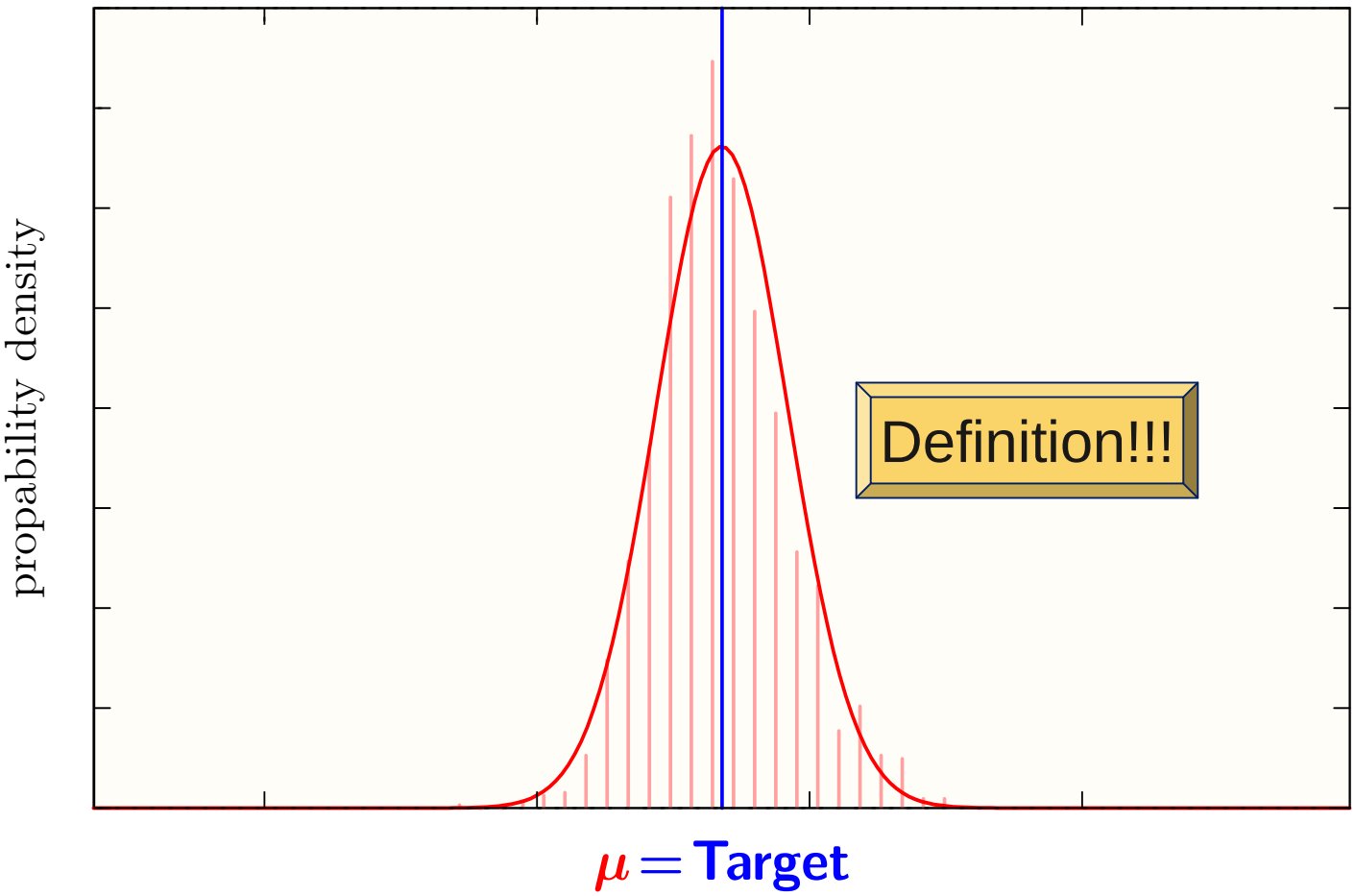
Step 2: Parameter Centering



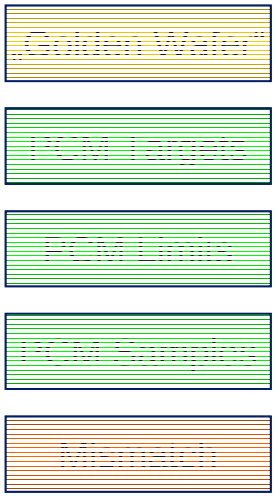


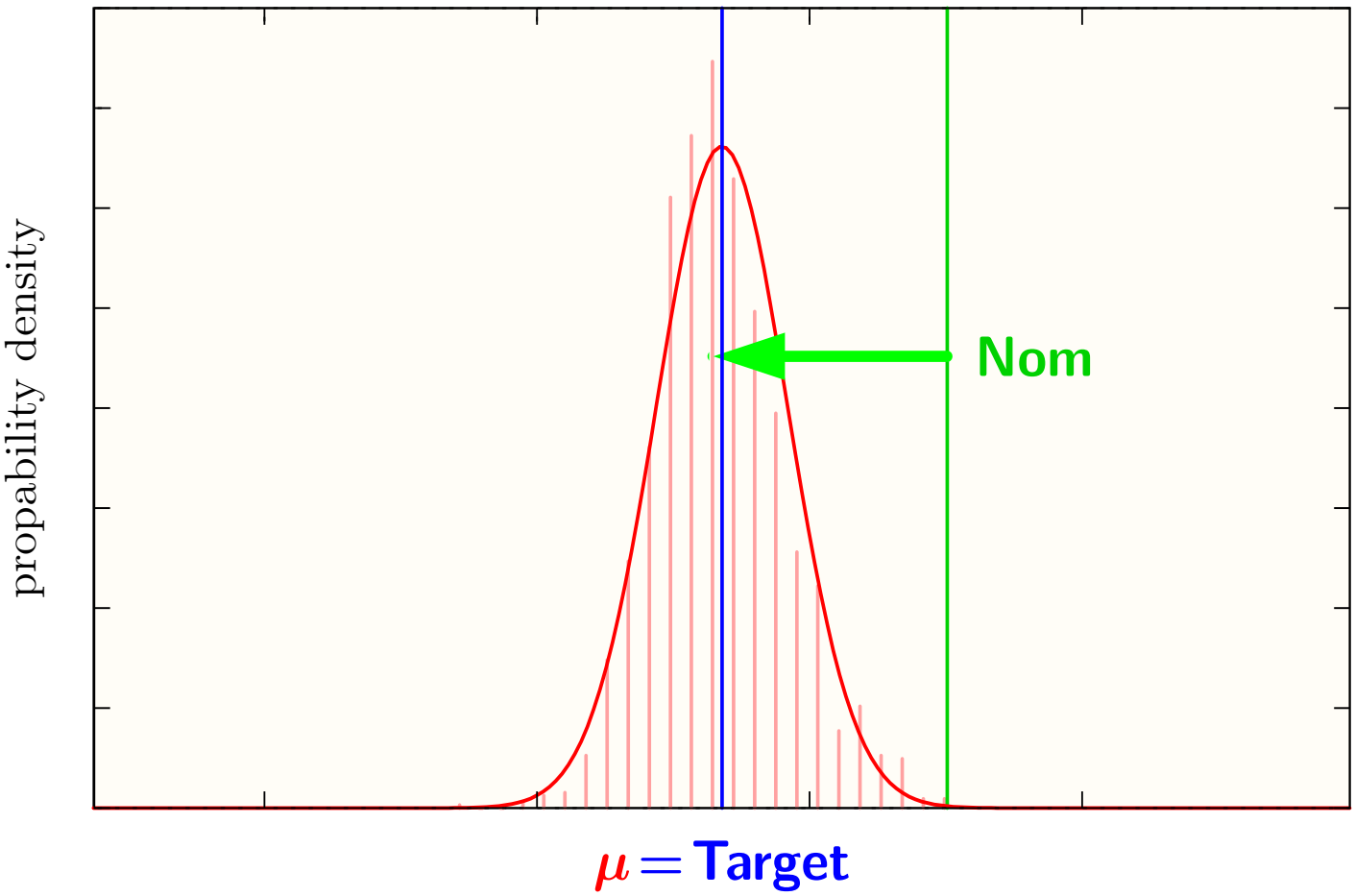
Step 2: Parameter Centering



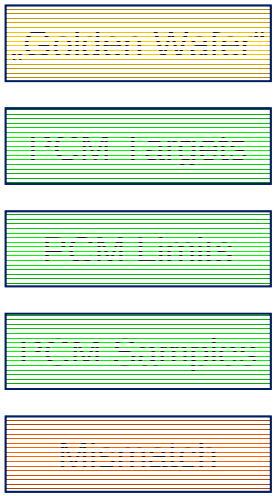


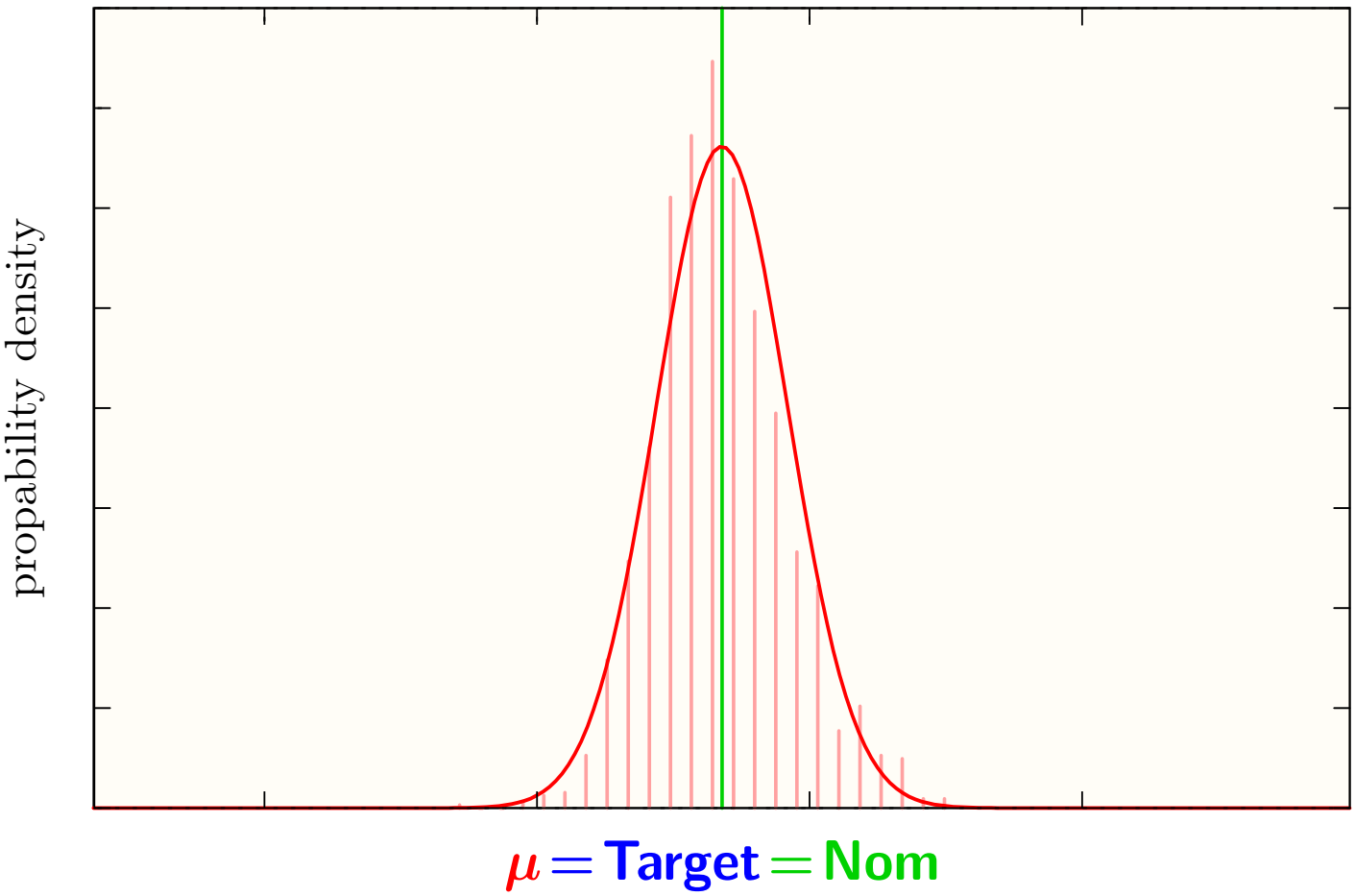
Step 2: Parameter Centering



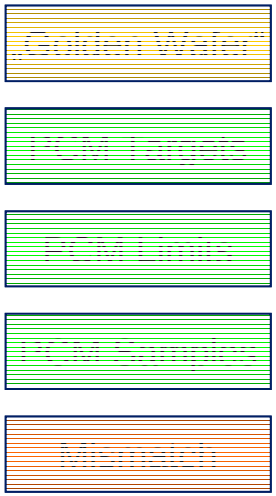


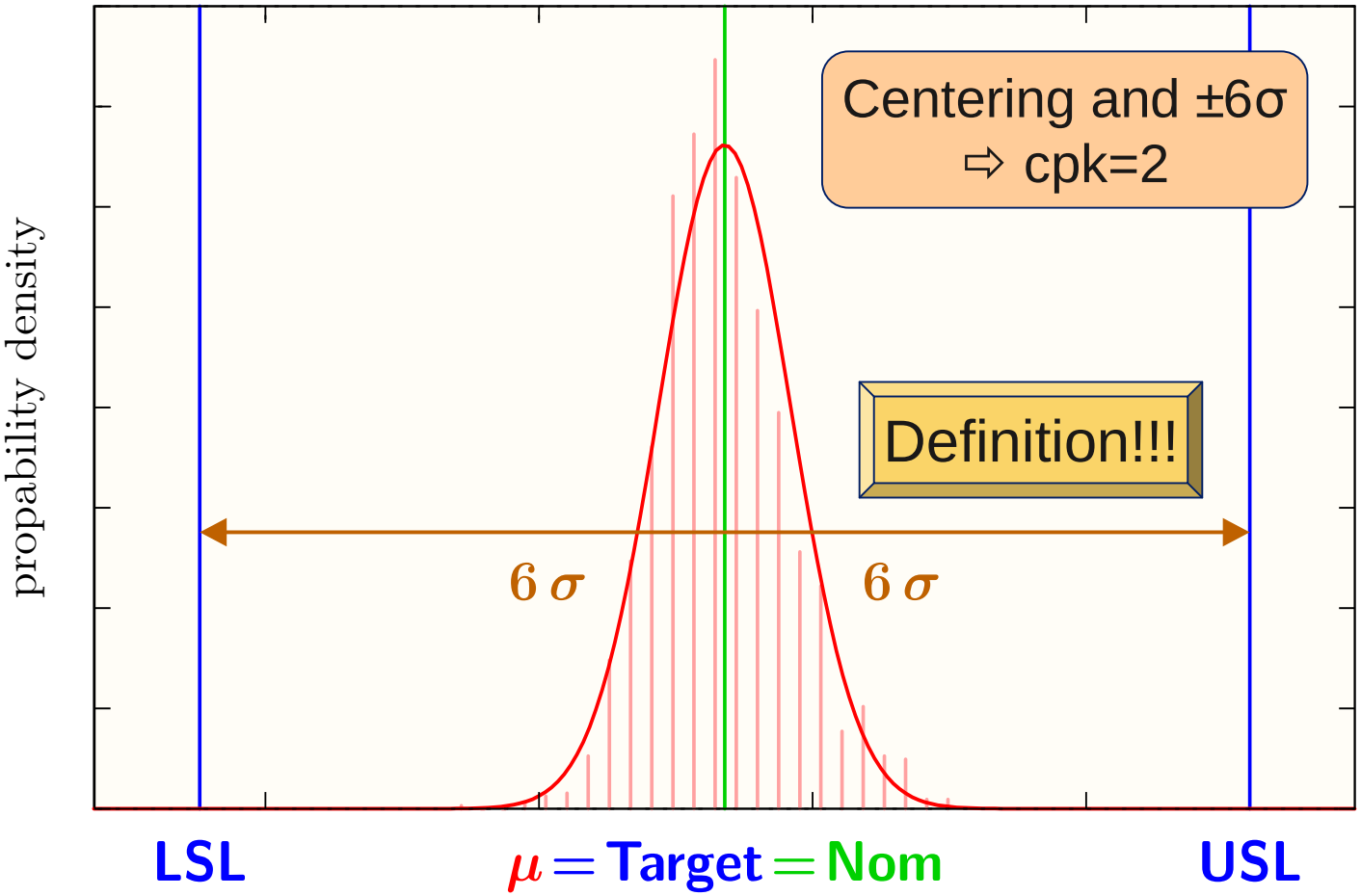
Step 2: Parameter Centering



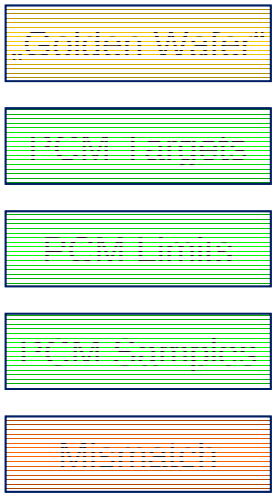


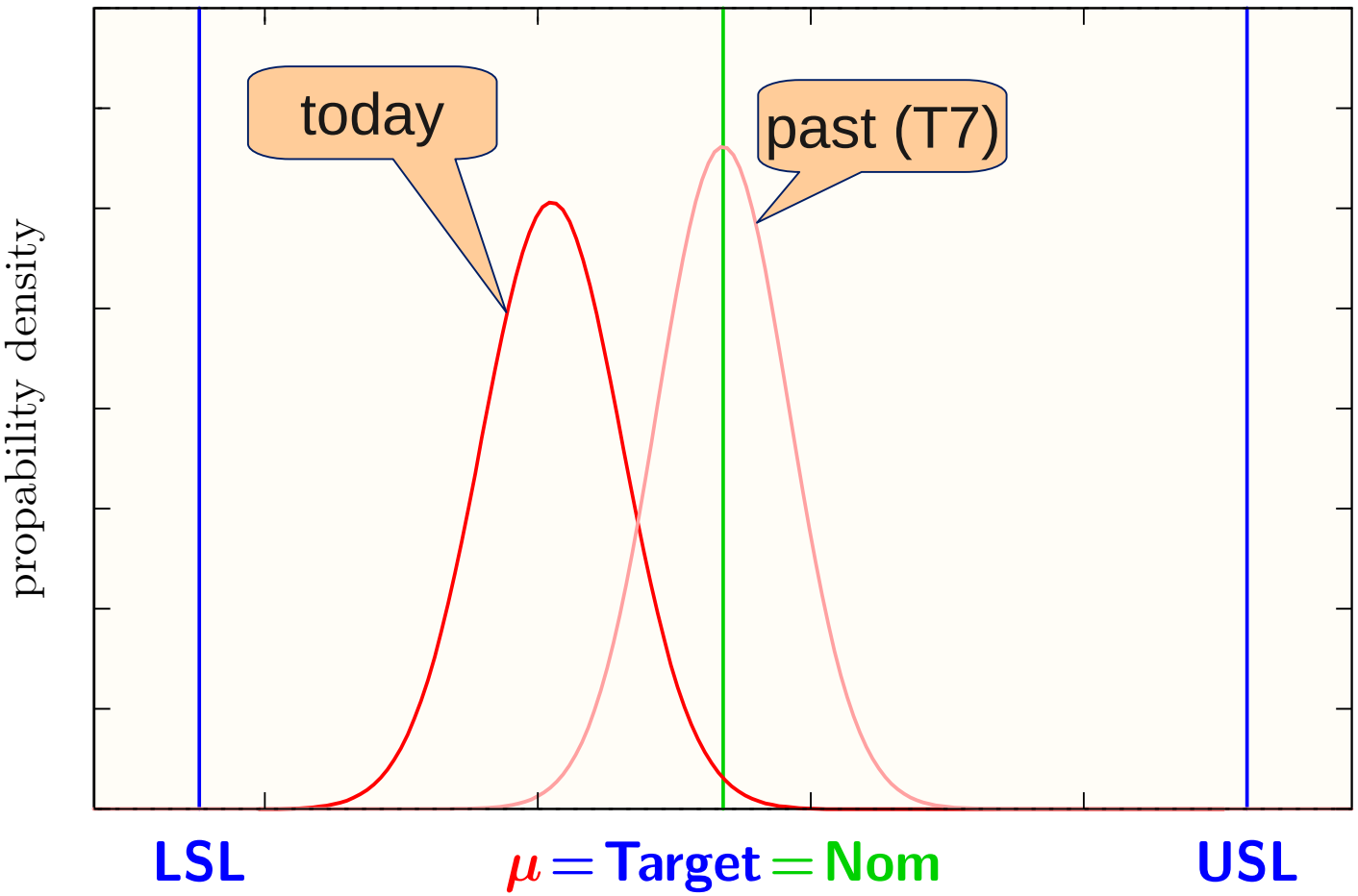
Step 3: Process Deviations



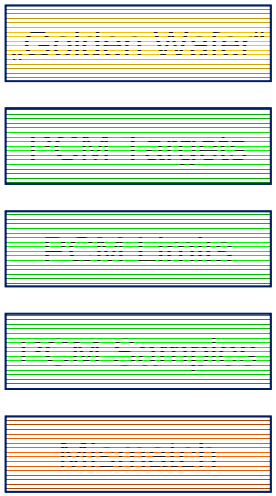


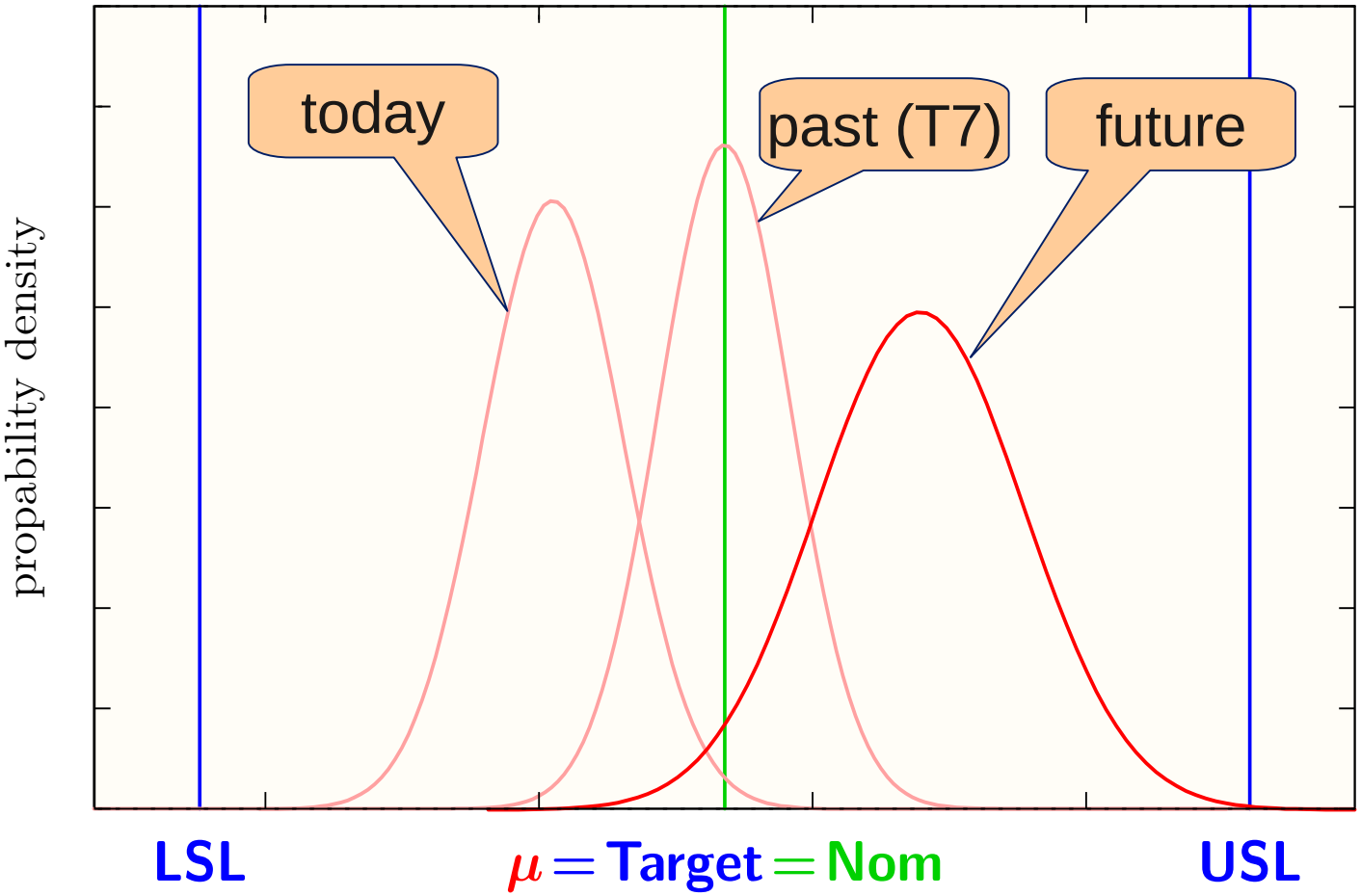
Step 3: Process Deviations



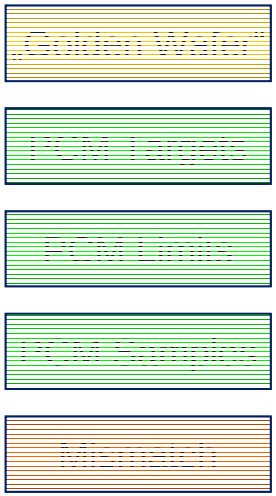


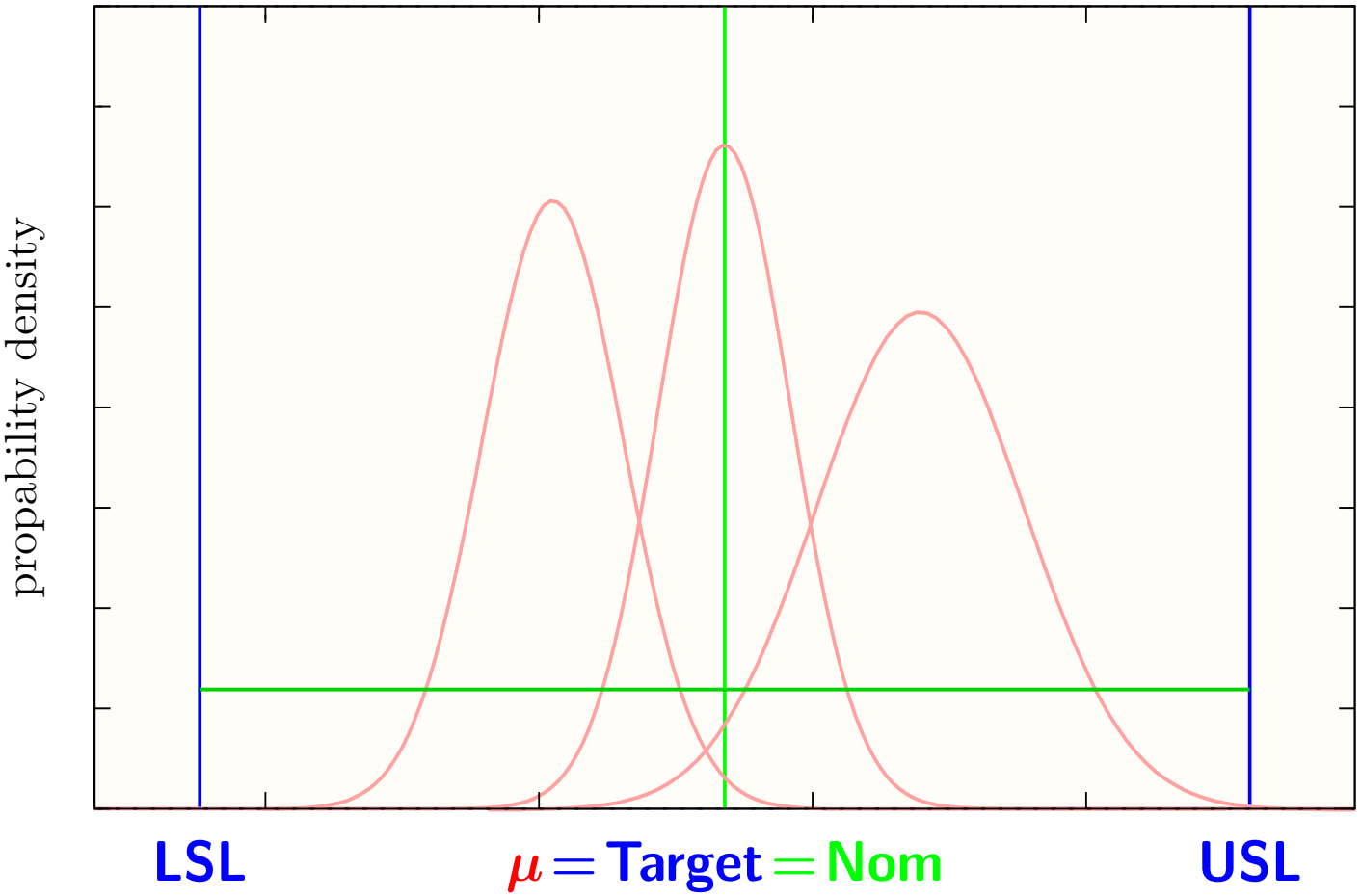
Step 3: Process Deviations



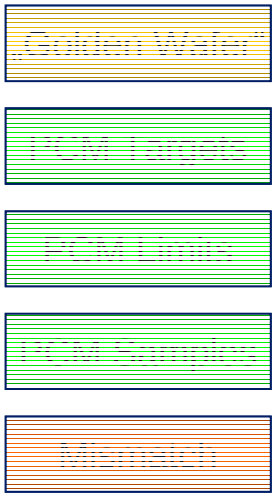


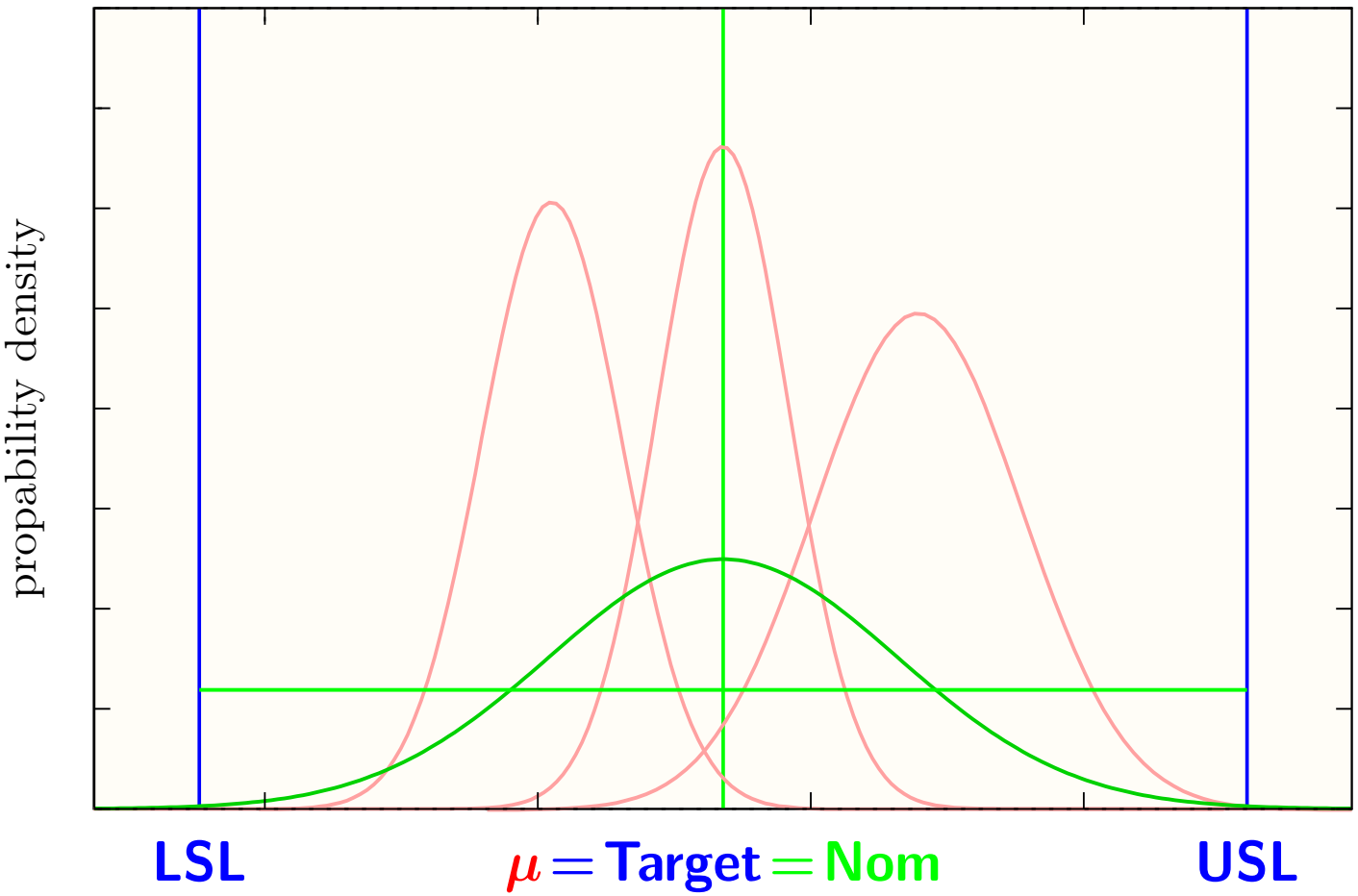
Step 3: Process Deviations



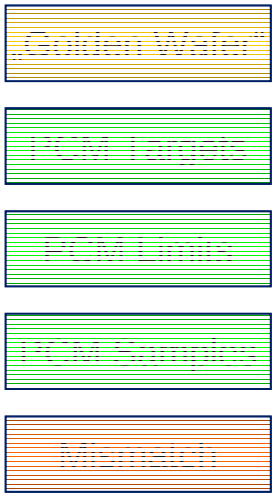


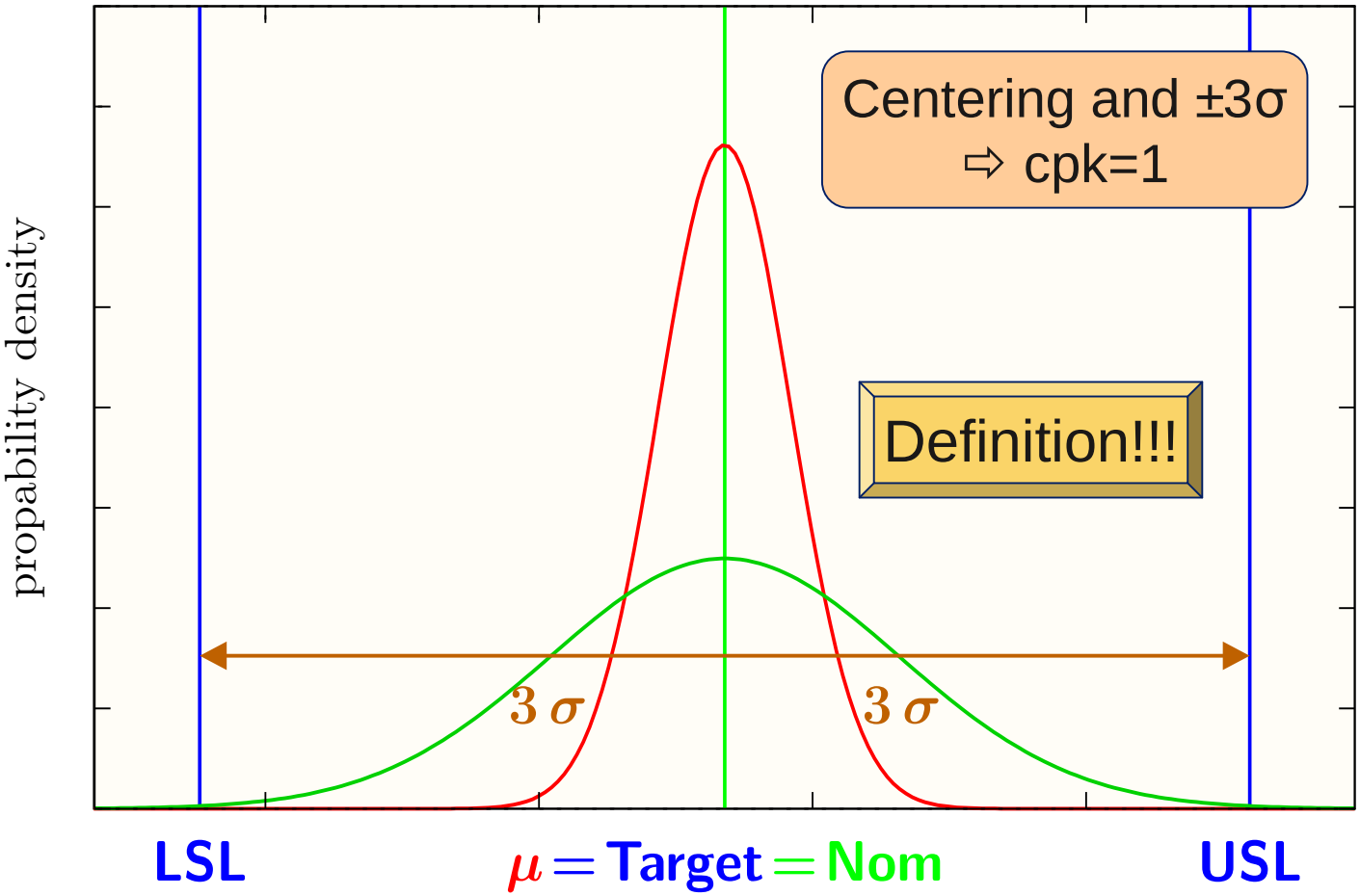
Step 3: Process Deviations





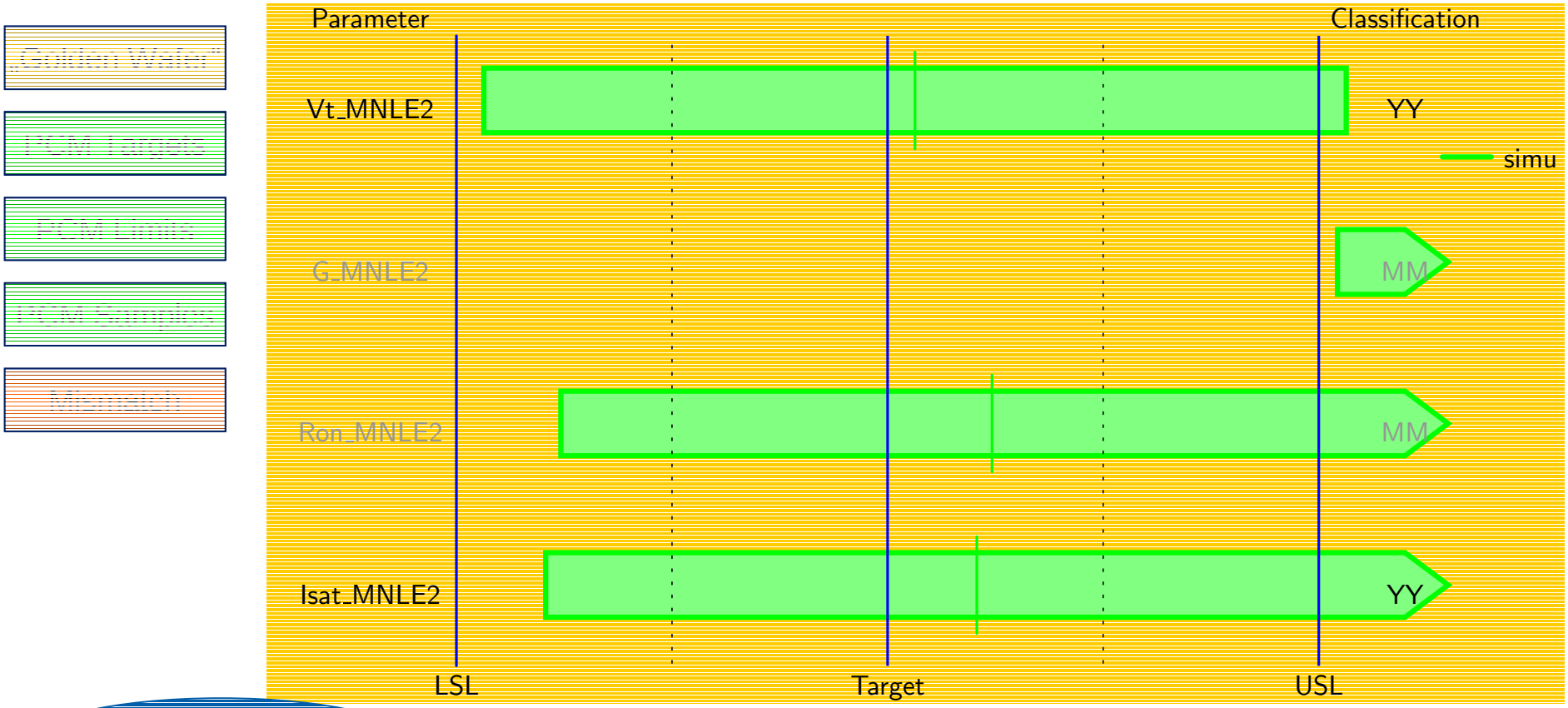
Step 3: Process Deviations





Step 3: Process Deviations

Normalized PCM Window with 3 σ Process Variations

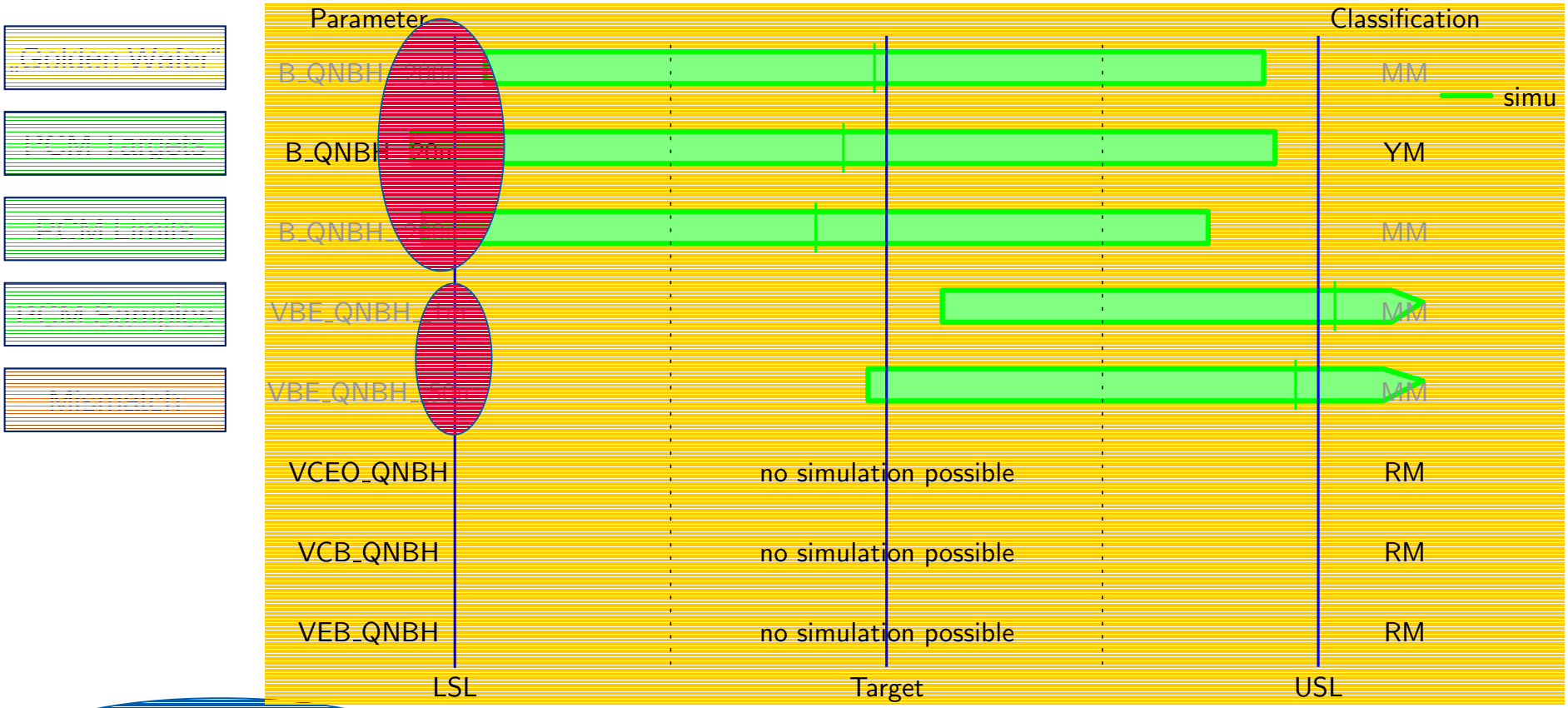


MOSFET

source: ***/MQ/***-Docu (Low Volt NMOS)

Step 3: Process Deviations

Normalized PCM Window with 3 σ Process Variations

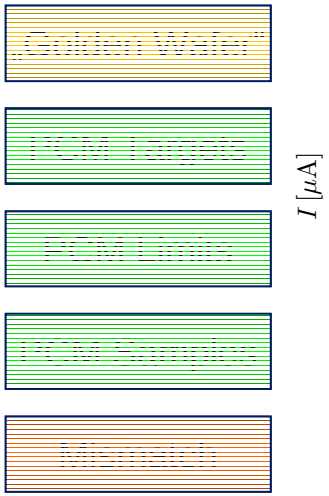


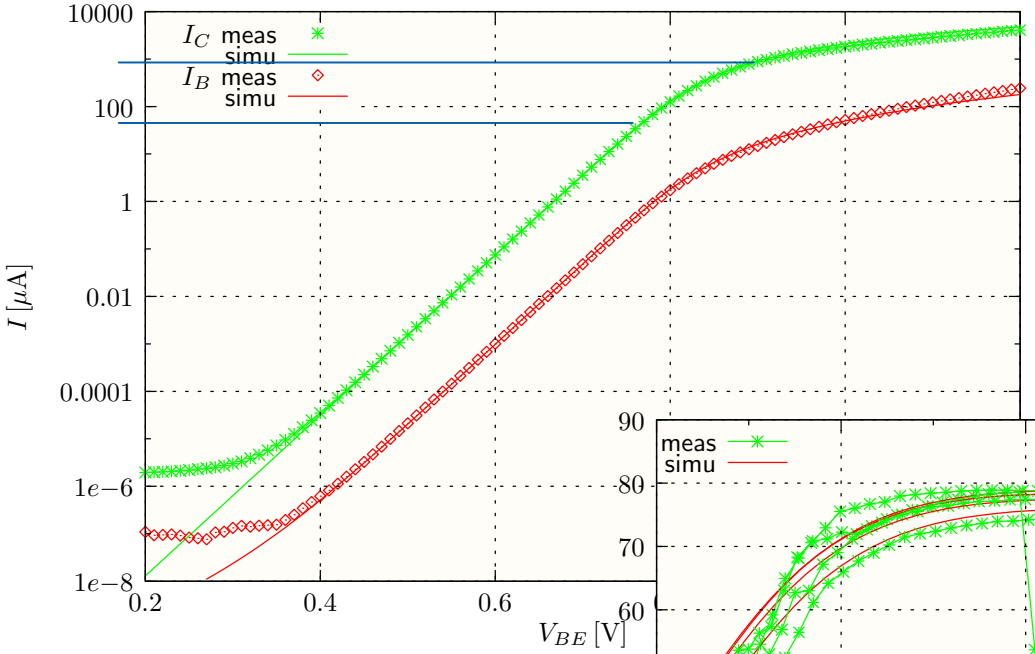
Bipolar

source: ***IMQ/***-Docu (qnbh Bipolar)

Step 3: Process Deviations

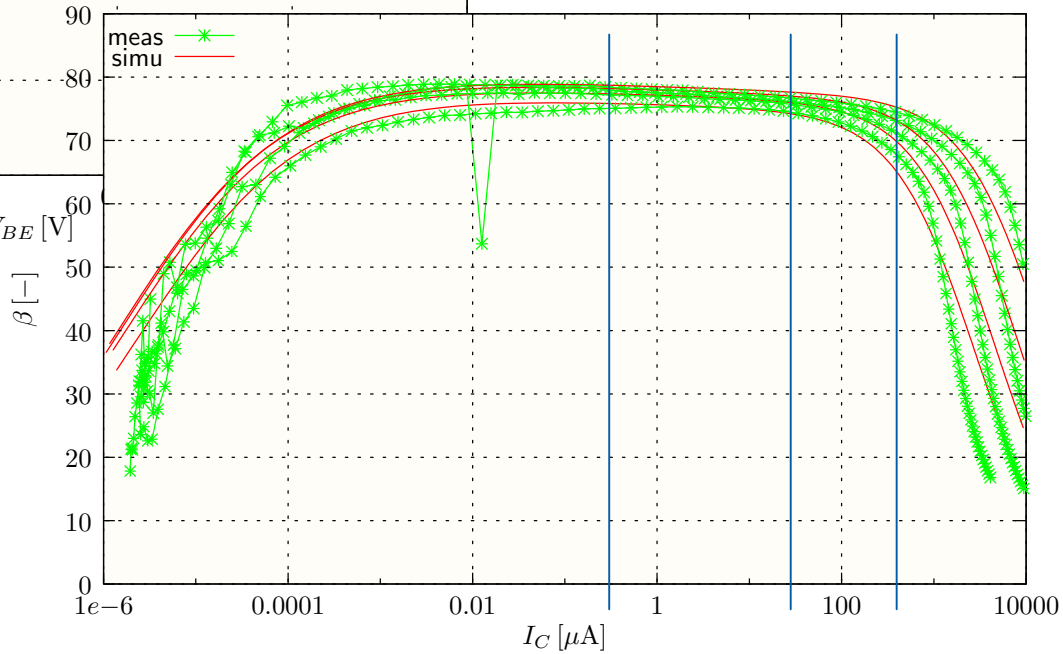
Gummel Poon and beta Plot





Vbe @ Ic=50u, 1m

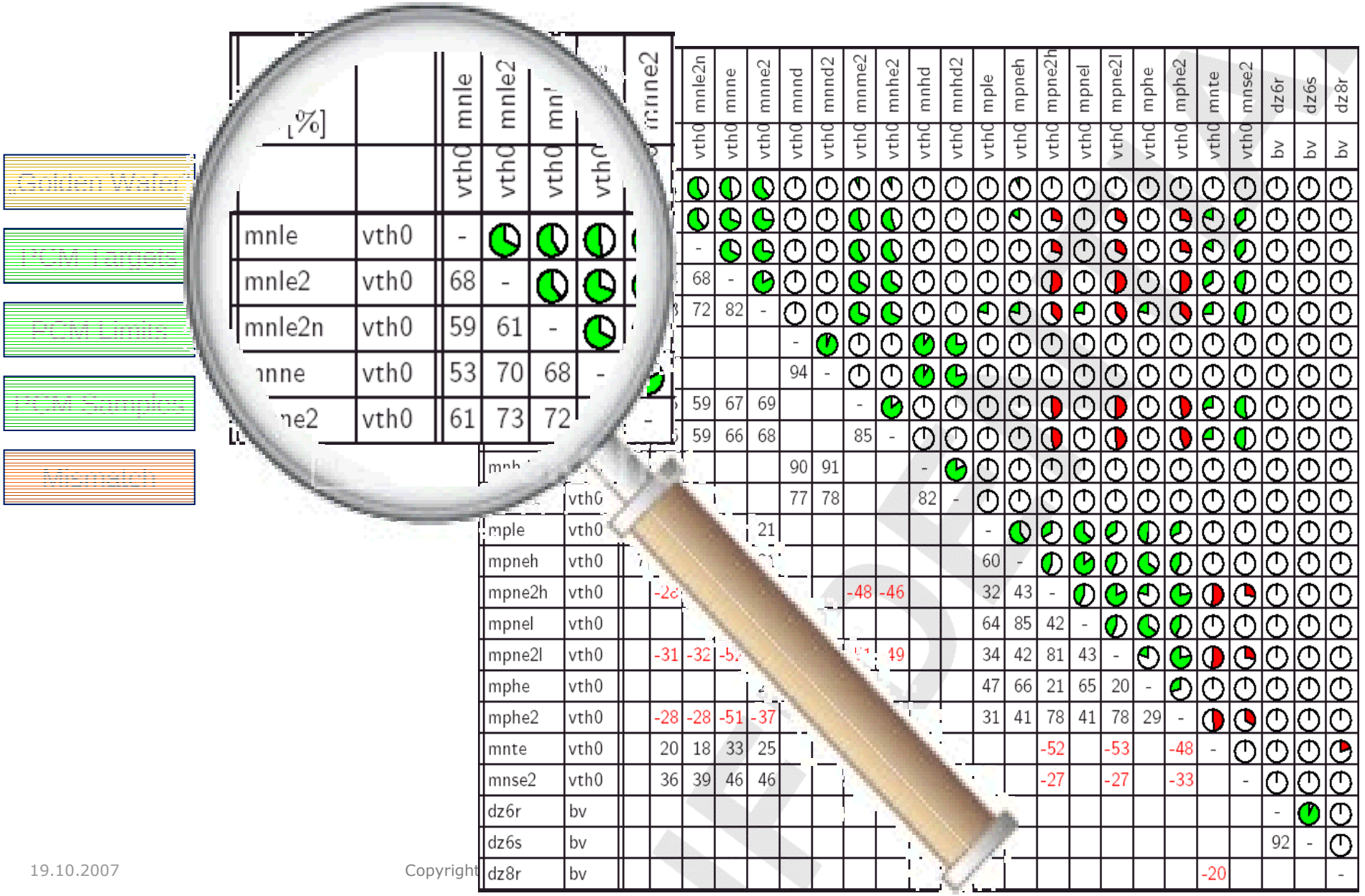
beta @ Ic=200n, 20u, 200u



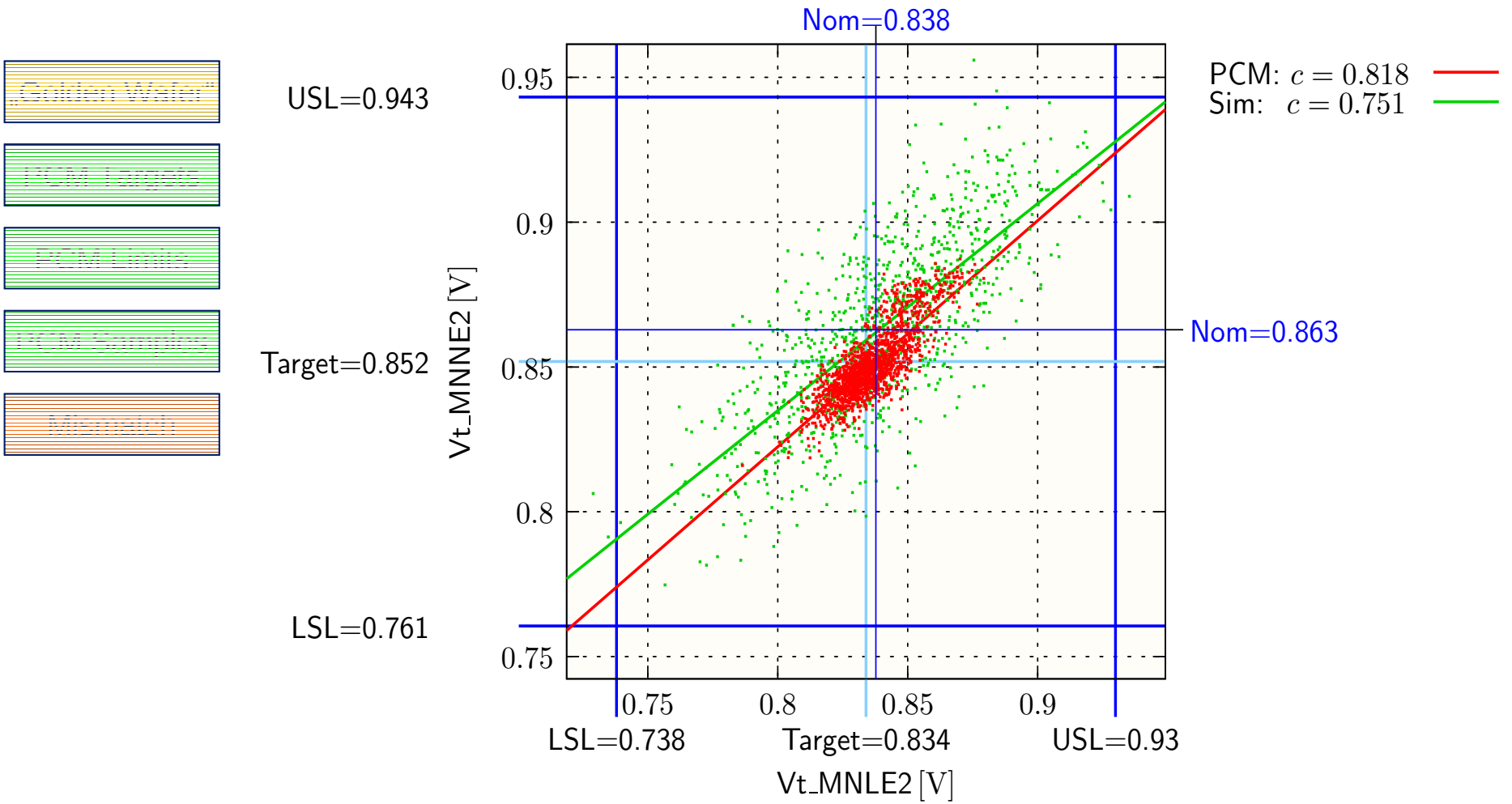
Bipolar

source: ***/EPI***-Docu (qnbh Bipolar)

Step 4: Correlation Table

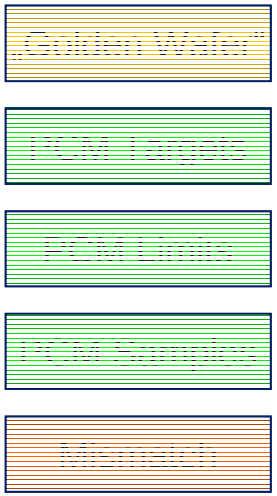


Step 4: Correlations



source: **/PCM/**-Docu

Step 5: Mismatch Parameters

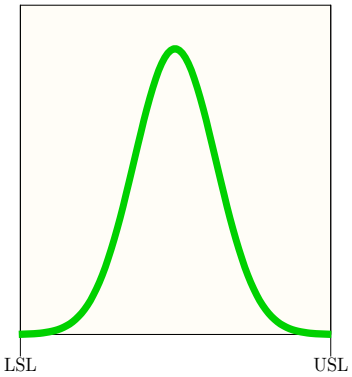
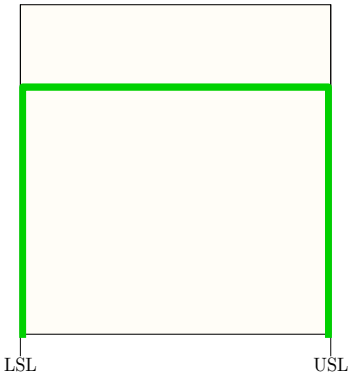


Special Device Pair Measurements on Testchip required

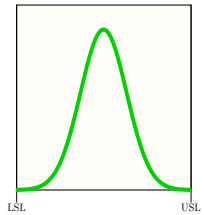
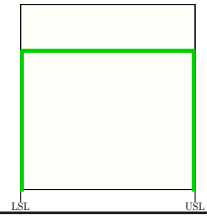
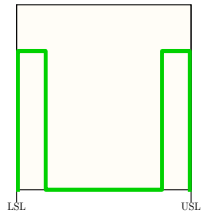
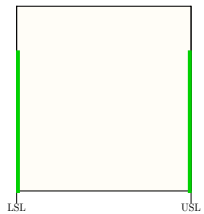
$$\sigma_{mismatch} = \frac{const_{mismatch}}{\sqrt{2\,Area}}$$

- Threshold voltages of MOS transistors
- Current gains of bipolar
- Sheet resistances of poly resistors

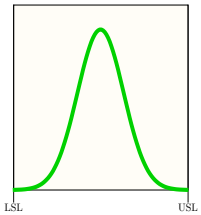
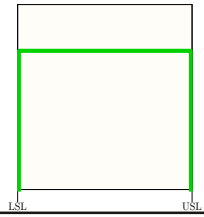
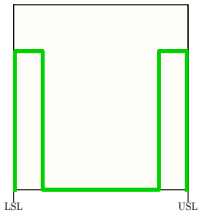
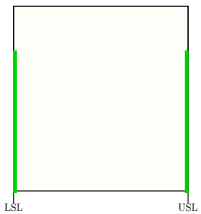
Monte Carlo Sections

	Comment	Distribution
nom	Gaussian distribution of samples *μ = Target = (USL+LSL)/2* *σ = (USL-μ)/3* *= (USL-LSL)/6*	
unif	uniform distribution of samples *μ = Target = (USL+LSL)/2* *σ = (USL-μ)/sqrt(3)* *= σ[nom]*sqrt(3)*	

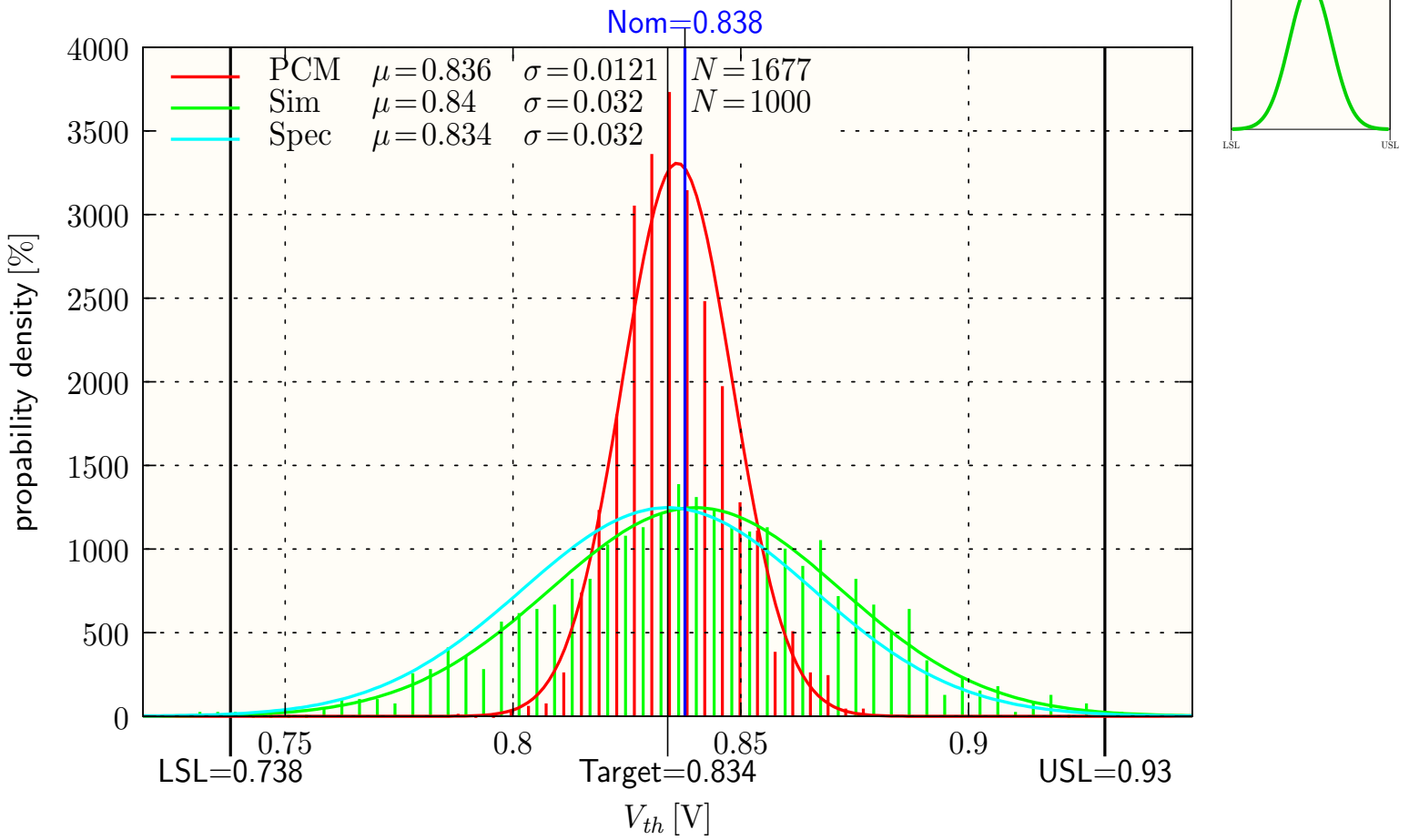
Monte Carlo Sections

	Comment	Distribution
nom	Gaussian distribution of samples *μ = Target = (USL+LSL)/2* *σ = (USL-μ)/3* *= (USL-LSL)/6*	
unif	uniform distribution of samples *μ = Target = (USL+LSL)/2* *σ = (USL-μ)/sqrt(3)* *= σ[nom]*sqrt(3)*	
unif2s3s	uniform distribution of samples within 2σ and 3σ *μ = Target = (USL+LSL)/2* *σ ≈ (USL-μ)*0.84* *= σ[nom]*2.5*	
specLimits	parameters shifted to their Spec Limits (USL or LSL) *μ = Target = (USL+LSL)/2* *σ = USL-μ* *= σ[nom]*3*	

Monte Carlo Sections

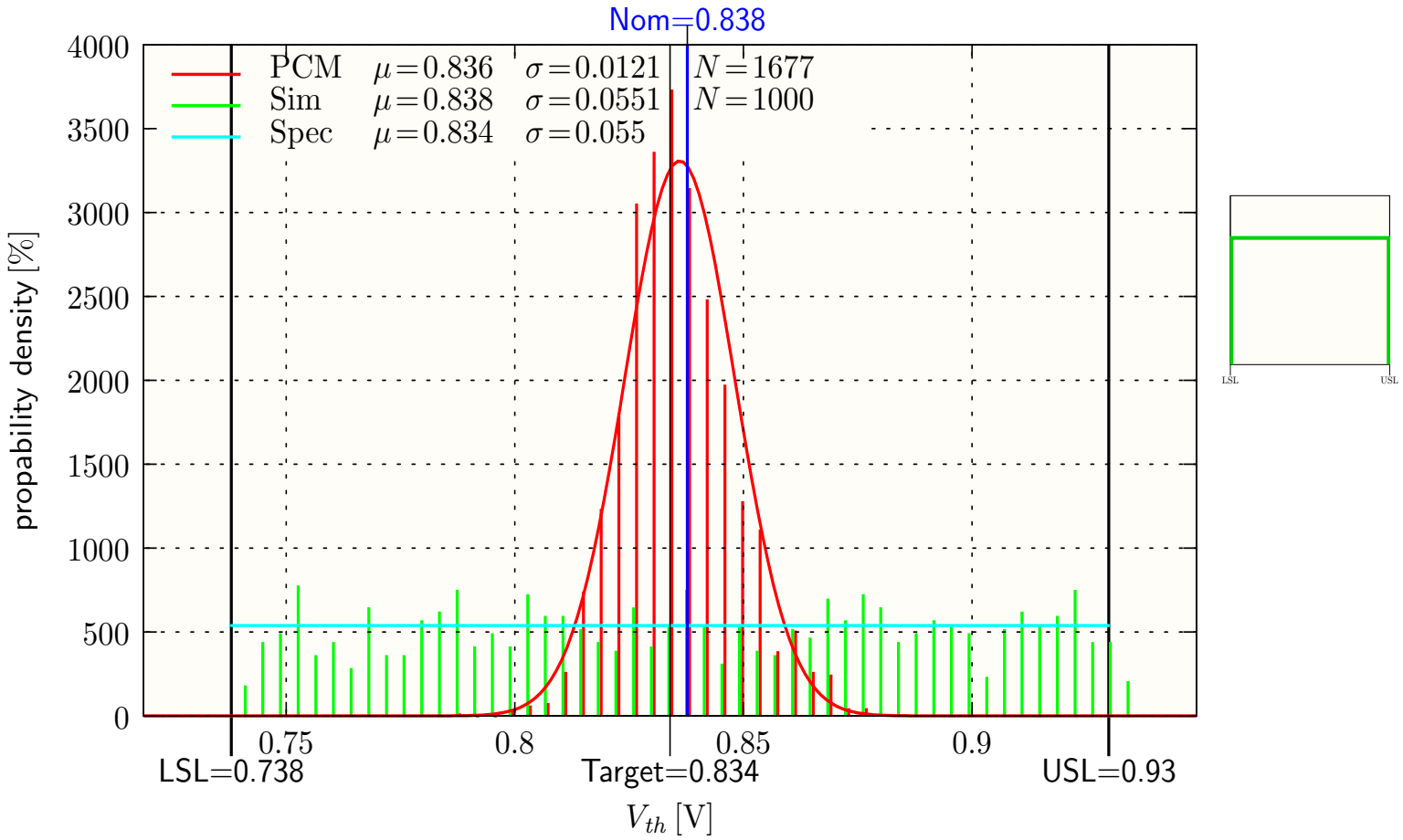
w/ Parasitics	w/o Parasitics	Comment	Distribution
nom	**nom_noPar**	Gaussian distribution of samples *μ = Target = (USL+LSL)/2* *σ = (USL-μ)/3* *= (USL-LSL)/6*	
unif	**unif_noPar**	uniform distribution of samples *μ = Target = (USL+LSL)/2* *σ = (USL-μ)/sqrt(3)* *= σ[nom]*sqrt(3)*	
unif2s3s	**unif2s3s_noPar**	uniform distribution of samples within 2σ and 3σ *μ = Target = (USL+LSL)/2* *σ ≈ (USL-μ)*0.84* *= σ[nom]*2.5*	
specLimits	**specLimits_noPar**	parameters shifted to their Spec Limits (USL or LSL) *μ = Target = (USL+LSL)/2* *σ = USL-μ* *= σ[nom]*3*	

Example 1: PCM Par *Vt_MNLE2* — MC Section *nom*

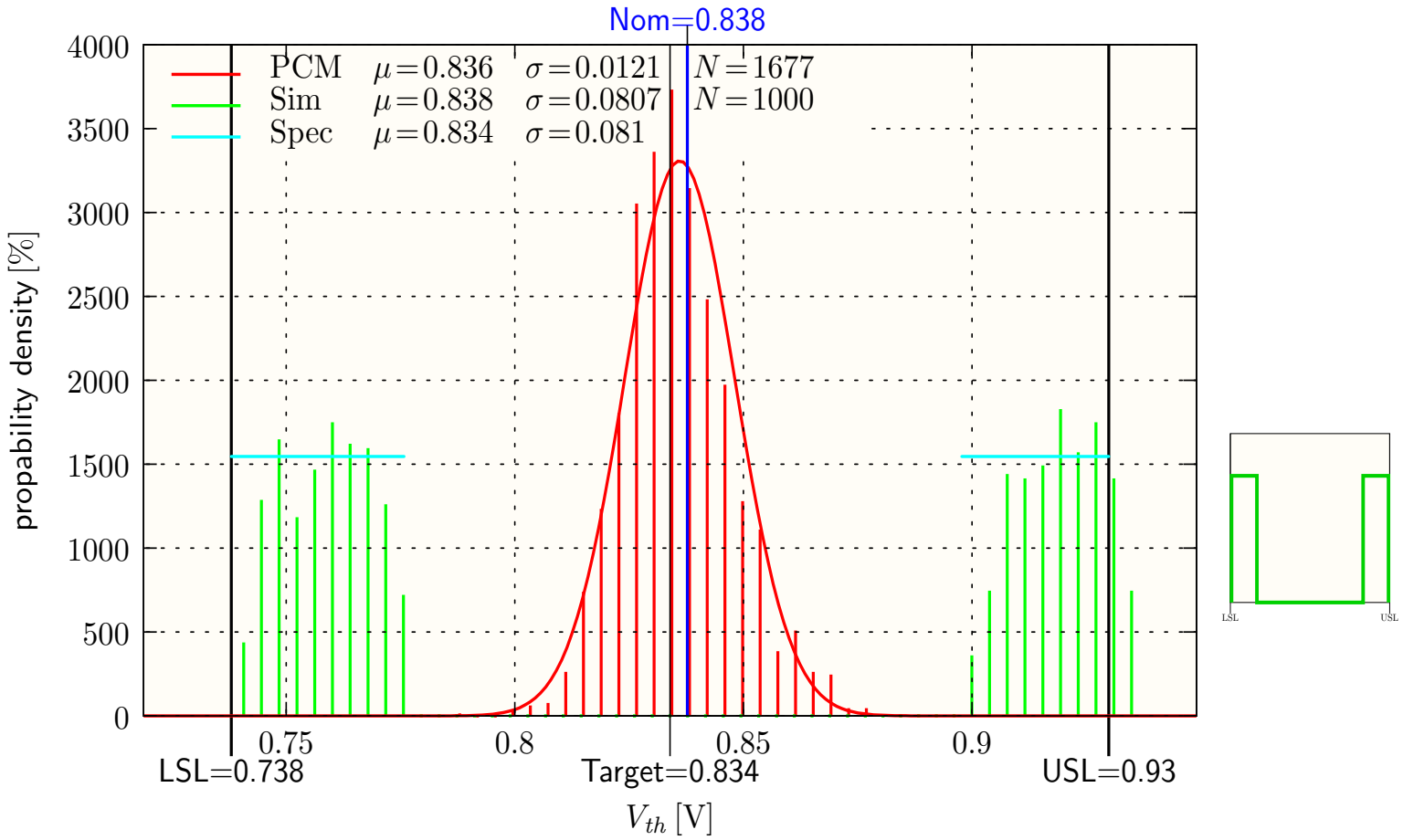


source: **/PCM/**-Docu

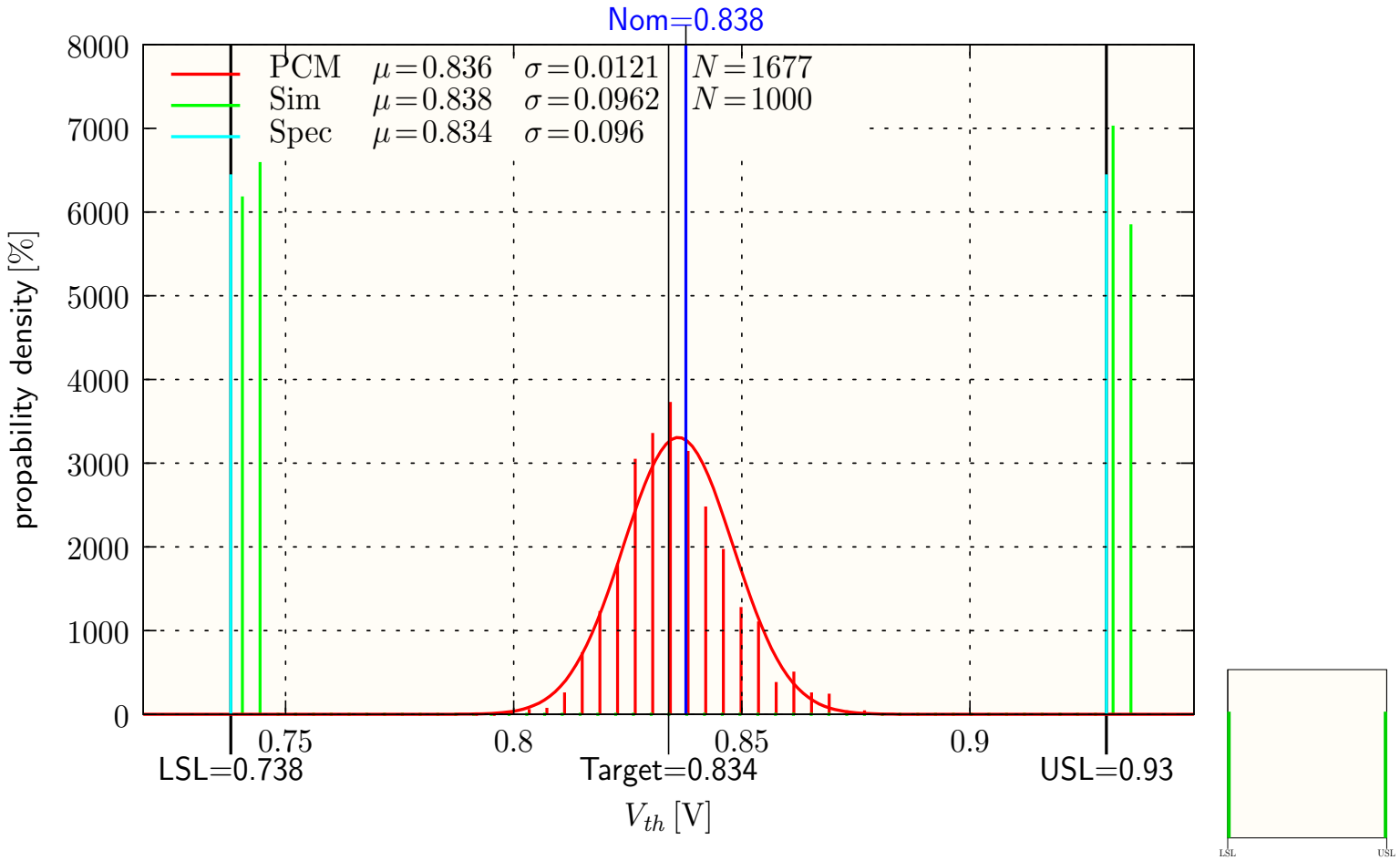
Example 2: PCM Par *Vt_MNLE2* — MC Section *unif*



Example 3: PCM Par *Vt_MNLE2* — MC Section *unif2s3s*



Example 4: PCM Par *Vt_MNLE2* — MC Section *specLimits*



Corner Sections

		Comment
depFast_dmosFast	**depSlow_dmosFast**	depFast: δV_{th}(MNND)=-0.139V δV_{th}(MNND2)=-0.154V dmosFast: δl_{cap}(MNTE, MNSE2)=-0.25μm
depFast_dmosSlow	**depSlow_dmosSlow**	depSlow: δV_{th}(MNND, MNND2)=0.243V dmosSlow: δl_{cap}(MNTE, MNSE2)=0.32μm

There are no universally valid “worst cases” in BCD Technologies
➔Corners have to be defined by Device Team
according to the needs of Product Development!

Corner Sections

		Comment
depFast_dmosFast	**depSlow_dmosFast**	depFast: δV_{th}(MNND)=-0.139V δV_{th}(MNND2)=-0.154V dmosFast: δl_{cap}(MNTE, MNSE2)=-0.25μm
depFast_dmosSlow	**depSlow_dmosSlow**	depSlow: δV_{th}(MNND, MNND2)=0.243V dmosSlow: δl_{cap}(MNTE, MNSE2)=0.32μm
FastFast	**SlowFast**	FastFast: $\delta V_{th}(NMOS)=-3\sigma$ $\delta V_{th}(PMOS)=3\sigma$ $\delta t_{ox}=-3\sigma$ $\delta l_{int}=-3\sigma$ $\delta w_{int}=+3\sigma$ $\delta C_j=-3\sigma$ SlowFast: $\delta V_{th}(NMOS)=3\sigma$ $\delta V_{th}(PMOS)=3\sigma$
FastSlow	**SlowSlow**	SlowSlow: $\delta V_{th}(NMOS)=3\sigma$ $\delta V_{th}(PMOS)=-3\sigma$ $\delta t_{ox}=+3\sigma$ $\delta l_{int}=+3\sigma$ $\delta w_{int}=-3\sigma$ $\delta C_j=+3\sigma$ FastSlow: $\delta V_{th}(NMOS)=-3\sigma$ $\delta V_{th}(PMOS)=-3\sigma$

Model Sections

- 8 Monte Carlo Sections
  - 4 sections with different distributions
  - 4 "no Parasitics" sections (noPar) with neglect of:
    - (substrate) parasitic devices
    - voltage/current/power warnings
    - paramTests (geometry checks)
  - Corresponding *noPar* sections speed up simulation by ≥ 25%.
  - No section toggle required for nominal and Gaussian MC simulation
- 8 Corner Sections
  - 4 corners for NMOS/PMOS speed
  - 4 corners for leakage current of depletion MOS and slew rate of DMOS
  - Performing Monte Carlo analysis issues an error.

Model Quality

- The SMART5 PCM comprises 194 measurements (ASM52).
- 143 of them can be re-simulated.
- PCM evaluations may serve as a **testbench** to quantify the **model quality** (w/o correlation and mismatch).

1. Does the nominal simulation reproduce the PCM Target?
   nom = Target
2. Does the mean value of the Monte Carlo simulation reproduce the nominal value?
   μ = nom
3. Does the standard deviation of the Monte Carlo simulation reproduce one third of the distance between the PCM Upper Spec Limit and the PCM Target (cpk=1)?
   3 σ = USL-Target

Model Quality

PCM Name	Class	Spec			Sim				Nom	
		LSL	Target	USL	μ	$\delta\mu$ [%]	σ	$\delta\sigma$ [%]	nom	δnom [%]
NMOS_N_Logic										
Vt_MNLE2	YY	0.738	0.834	0.93	0.84	0	0.032	0	0.838	0
G_MNLE2	MM	41.2	52	62.7	76.6	0	4.46	24	76.4	47
Ron_MNLE2	MM	2950	3550	4150	3700	0	200	0	3680	4
Isat_MNLE2	YY	250e-6	306e-6	361e-6	317e-6	-1	18.5e-6	0	320e-6	5
Vt_MNLE2N	YY	0.738	0.834	0.931	0.84	0	0.0321	0	0.838	0
G_MNLE2N	MM	44	55.4	66.7	76.5	0	4.5	19	76.4	38
Isat_MNLE2N	YY	267e-6	321e-6	376e-6	319e-6	0	18.1e-6	0	320e-6	0
NMOS_N_Low										
Vt_MNNE	YY	0.905	0.994	1.08	0.985	0	0.0297	0	0.985	-1
G_MNNE	MM	79	91.1	103	119	0	4.66	15	118	30
Ron_MNNE	MM	1580	1770	1960	1730	0	63.4	0	1730	-2
Isat_MNNE	YY	835e-6	966e-6	0.0011	986e-6	-1	43.8e-6	0	992e-6	3
Vt.BE_MNNE	YY	2.3	2.5	2.71	2.48	0	0.0715	4	2.48	-1
Vt_MNNE2	YY	0.761	0.852	0.943	0.864	0	0.0304	0	0.863	1
G_MNNE2	YY	83.6	99.1	115	129	0	5.84	14	130	31
Ron_MNNE2	MM	1470	1690	1900	1650	0	71	0	1650	-2
Isat_MNNE2	YY	904e-6	0.00107	0.00123	0.00106	-1	54.7e-6	0	0.00106	0
Vt.BE_MNNE2	YY	1.99	2.22	2.44	2.21	0	0.0732	-1	2.2	0
DVt_MNNE/2	MM	0.115	0.139	0.162	0.121	0	0.0175	>100	0.122	-12
ID_MNND	YY	18.7e-6	38.5e-6	58.3e-6	42.8e-6	2	12e-6	82	42e-6	9
Vt_MNND	YY	-1.24	-0.967	-0.697	-0.676	0	0.0897	0	-0	

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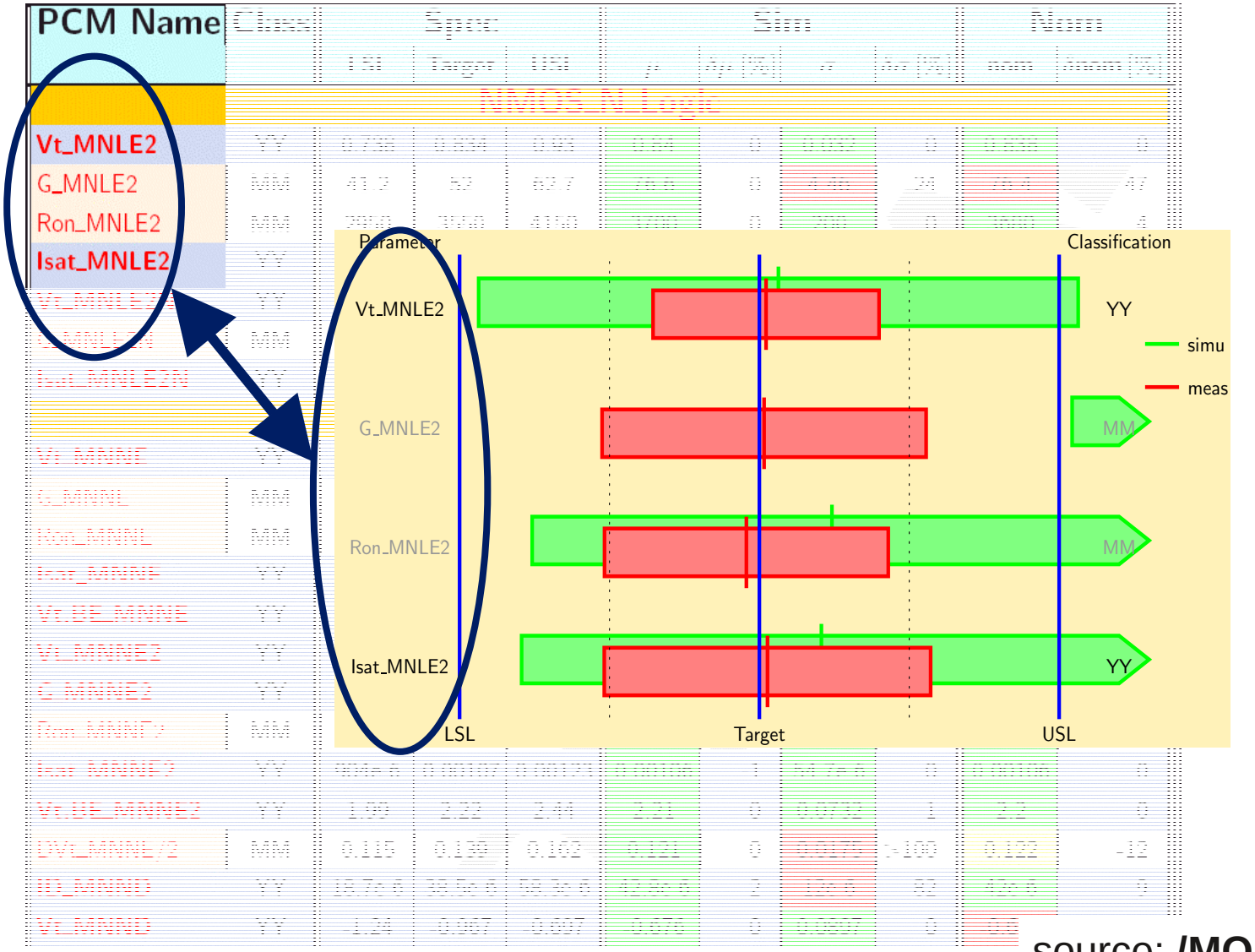
Model Quality



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Conclusion

- PCM: not only Process Monitoring (TD), but also Device Monitoring (CAD)
- Recommended Usage of
  - Monte Carlo Section ***nom*** with ≥100 runs for small circuits
  - Monte Carlo Section ***unif2s3s_noPar*** with ≤100 runs for large circuits
  - Corner Sections only if you know what you are doing (worst-worst case)
- Reproduction of Correlations
  -  Monte Carlo Section ***nom***
  -  Monte Carlo Section ***unif, unif2s3s, specLimits***
  -  Corner Sections
- To be discussed
  - Benefits of Quarterly Monitoring?
  - Device type coverage (SMART5 PCM: 41 of 75 types)?
  - PCM measuring regions?
  - PCM AC and Temp measurements needed?