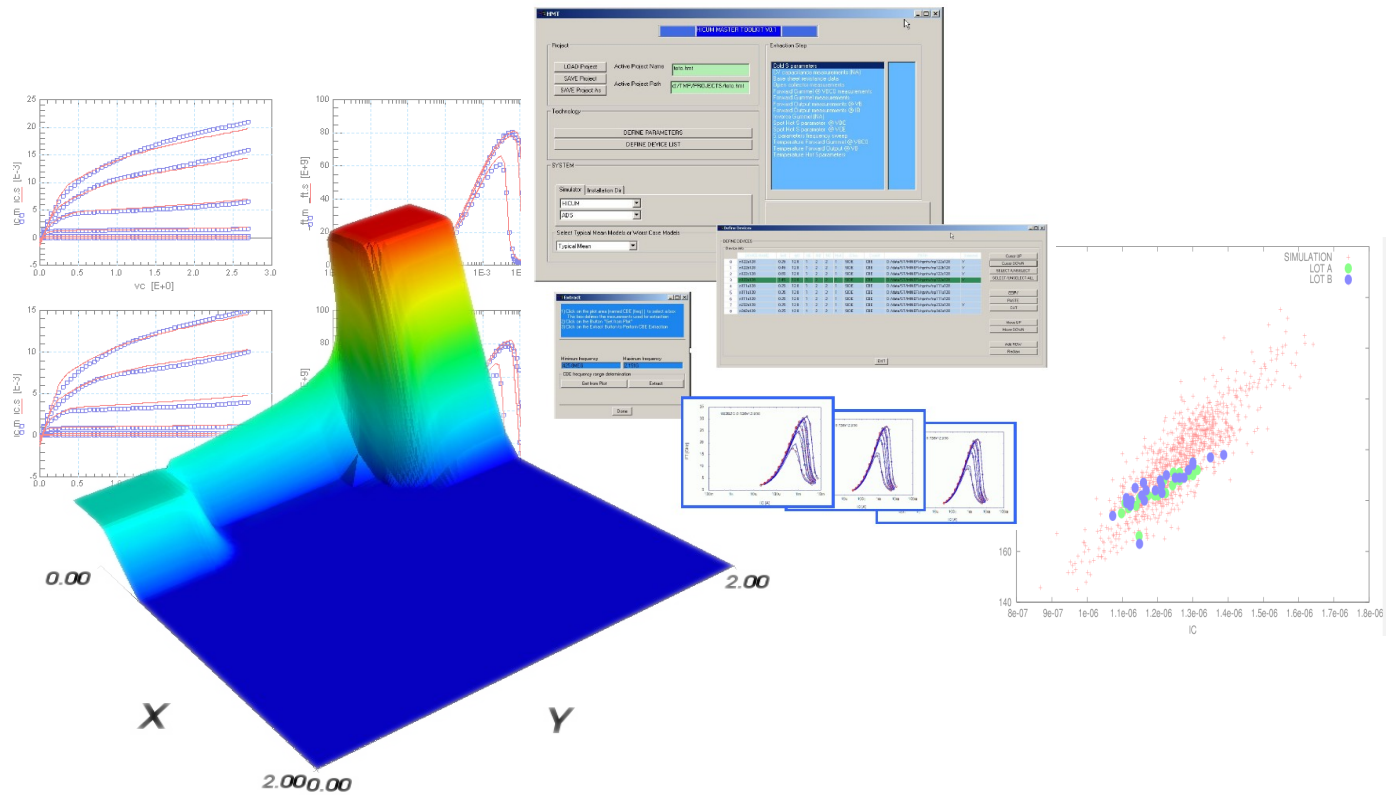


Update of XMOD Activities

HICUM WORKSHOP - Dresden, June 2007

Bertrand ARDOUIN



Current Status: HMT

- ▶ HMT (HiCUM Master Toolkit)/TRADICA:
 - ▶ Mature Solution
 - ▶ Benefit from TRADICA being the HiCUM development tool
 - ▶ HMT can be used as a complete flow (generates model cards)
 - ▶ Standalone TRADICA GUI version can be further used with inputs generated from HMT
 - ▶ Statistics
 - ▶ Other active and passive devices
 - ▶ Transistor sizing (for designers)
 - ▶ Plotting, ...

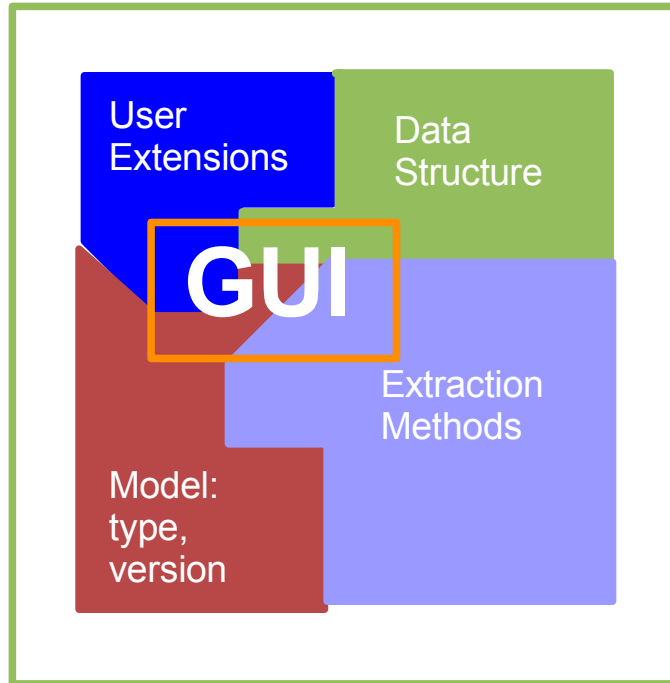
SMACH

▶ SMACH: what's this ?

- ▶ SMACH a scalable and statistical parameter extraction platform fully integrated in ICCAP (no external tool - without TRADICA)
- ▶ SMACH has been designed for **flexibility**
 - ▶ Targets multi-models (HiCUM, VBIC, PSP, MM20), multi-devices (Bipolar, RFCMOS, LDMOS)
- ▶ SMACH has been designed for **maintainability AND user extensions**
- ▶ Extraction Plugin concept

How typical extraction tools are built?

Critical Maintenance area



- ▶ Changing model type or version:
 - ▶ New extractions
 - ▶ New Data Structure
 - ▶ User extensions incompatibilities
 - ▶ Re-check complete architecture
- ▶ Flexibility needs (GUI) interacting with tool core
 - ▶ Complex code mixed with extraction code
 - ▶ Difficulty to upgrade or modify



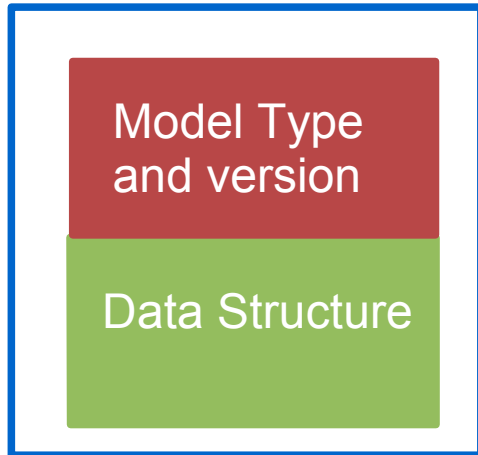
Maintenance is difficult
Usability is reduced

SMACH concept

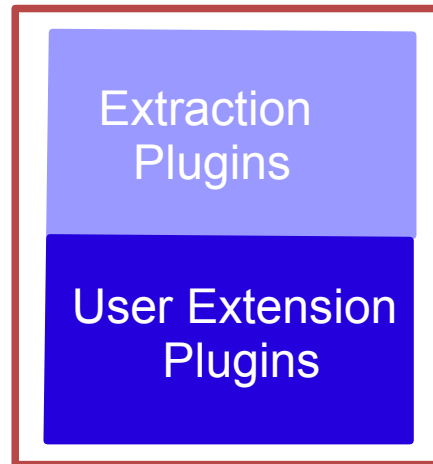
Critical Maintenance area



Generic ICCAP Format



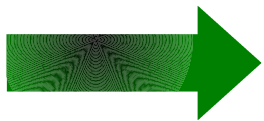
Simplified communication with GUI and Data Structure



- ▶ Each module can be modified without affecting others
 - ▶ MAIN GUI can manage different models, different data structures and different Extraction Plugins
 - ▶ Simple RULES used for communication between modules
 - ▶ Modules can be modified and upgraded without the need to touch the critical maintenance area
 - ▶ Modules are simple

SMACH benefits

- ▶ Plugin based architecture (attach new plugins from the GUI)
- ▶ Simplified parameter extraction flow (via optimizer plugin) done in minutes
- ▶ Optimization, Extraction or mix of both
- ▶ Can maintain top level even in case of user extensions
- ▶ User extension easy (no need to know the architecture)
- ▶ Full scalable and statistical model (in simulator language)
- ▶ Efficient use of new ICCAP plotting capabilities
- ▶ Data gathered in self-contained entities (Test Chips) separate from any code
- ▶ Switch models from the GUI (MOS, Bipolar)



Ideal Tool for evaluation of models before CMC standardization

SMACH: cf Demo

The screenshot displays the SMACH software interface with several key components:

- Available Test Chips in Memory:**
 - DIE_MOS_Demo
 - DIE_SiGe_Demo_Data
 - DIE_MOS_tmp
- Device Selection Policy:**
 - Use Extraction Flow Settings
 - Select from Scaled Devices
 - Select from Fixed Structures
- Scaled Devices:**
 - large
 - small1
 - short1
 - short2
 - short3
- Single Structures:**
 - cox_g_b
 - coverlap_g_sd
 - coverlap_g_sdb
- Extraction Flow:**
 - Extraction Flow Name: Tmp_MOS
 - Version: 1.1
 - TOX
 - VTH0
 - New Extraction Step
- Edit Main Devices Instance parameters:**

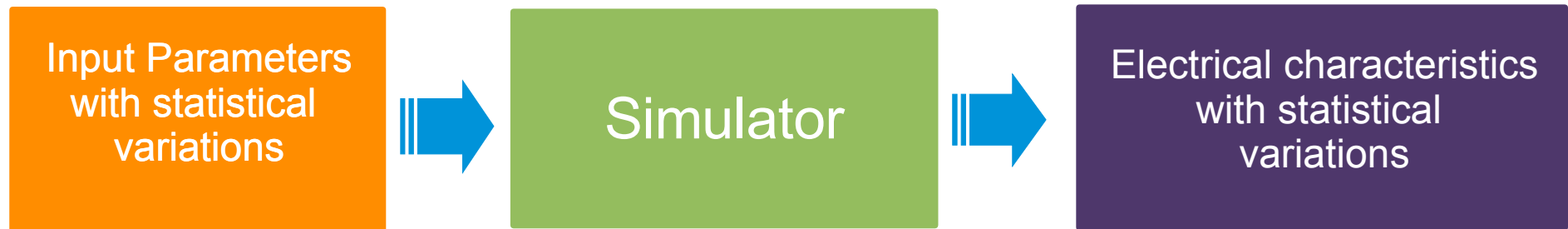
Cell Width	Scaled Devices	L	W	_M	AD	AS	PD	PS
9	large	1E-05	1E-05	1	1.5E-11	1.5E-11	2.3E-05	2.3E-0
	small1	6E-07	8E-07	1	1.2E-12	1.2E-12	4.6E-06	4.6E-0
	short1	6E-07	1E-05	1	1.5E-11	1.5E-11	2.3E-05	2.3E-0
	short2	8E-07	1E-05	1	1.5E-11	1.5E-11	2.3E-05	2.3E-0
	short3	1.2E-06	1E-05	1	1.5E-11	1.5E-11	2.3E-05	2.3E-0
	Fixed Structures	L	W	_M	AD	AS	PD	PS
	cox_g_b	0.00022	8E-05	1	0	0	0	0
	coverlap_g_sd	6E-07	0.00729	1	7.29E-09	7.29E-09	0.01458	0.01458
	coverlap_g_sdb	6E-07	0.00729	1	7.29E-09	7.29E-09	0.01458	0.01458
- Parameters:**

Name	Value
J_BEIS	26.57a
M_BEI	1.000
J_BEPS	0.000
M_BEP	1.000
J_REIS	320.5f
- multi_plot:4:** A grid of plots showing device characteristics for DEV_n122_3_100, DEV_n122_4_100, and DEV_n122_6_100. The plots include:
 - Transfer characteristics: $I_{C,B} [A]$ vs $v_{b,ve} [E+0]$
 - Output characteristics: $I_{C,B} [A]$ vs $v_c [E+0]$
 - Frequency response: $f_{T,B} [Hz]$ vs $f [Hz]$
- Simulation and Plot Management:**
 - Simulate Configured and Enabled Plots
 - Simulate All Visible Plots
 - Reset Simulation
 - Scaled Devices List: DEV_n122_3_100, DEV_n122_4_100, DEV_n122_6_100, DEV_n122_8_100, DEV_n122_3_16, DEV_n122_3_32, DEV_n122_3_64, DEV_n232_3_100, DEV_n342_3_100
 - Setup List: fgamma1_vCB0, fgamma1, fgamma1_sat, Spar_VB, Spar_VC, foutput_vb, foutput_ib, spot_train_bias_fwd, fgamma1_vCB0_T1Z5
 - Plot List: fT_plot, fT_vbe_plot
 - Buttons: APPEND TO PLOT LIST, CLEAR PLOT LIST
 - Single Structures List

Statistical Plugin

- ▶ Theory Presented at HiCUM WS 2006
- ▶ Let us see Practical implementation

What is the principle of Statistical modeling?



▶ Simplest Case: Resistor

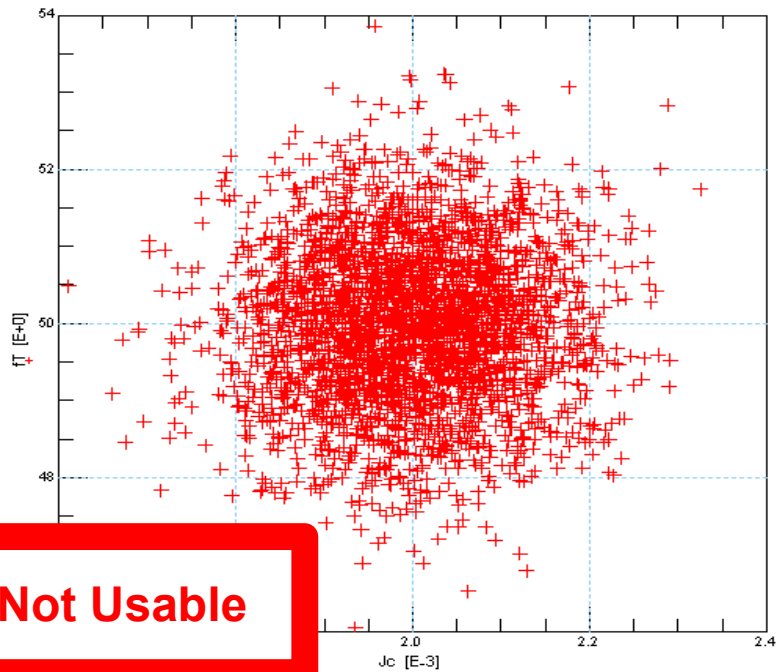
- Measured Statistical variation R is also a model parameter --> Easy
- This is the basis of most EDA Monte Carlo tools

Statistical Plugin

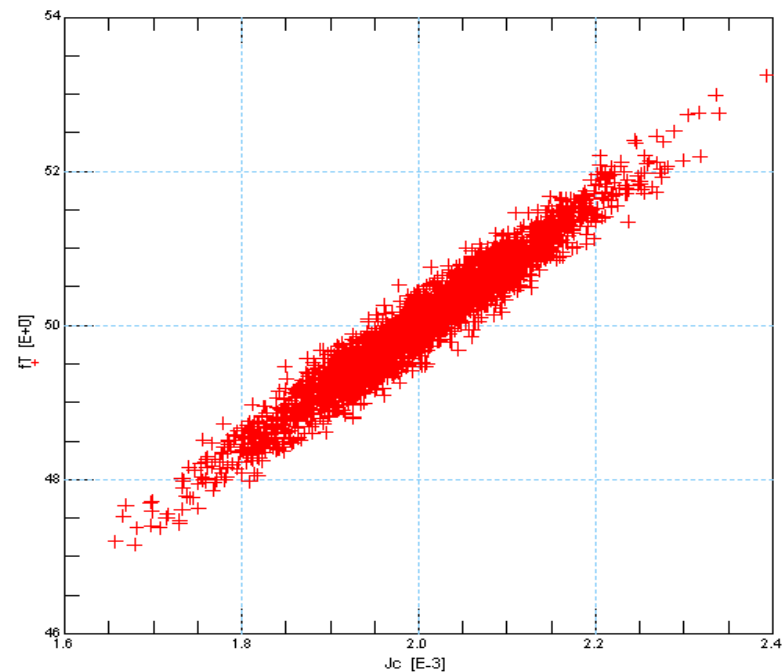
► For Active devices: OPTION 1: use model parameters as inputs

- No idea of model parameters statistical variation (or requires massive parameter extraction + PCA analysis)
- Model parameters are correlated!

Monte Carlo Applied to Model parameters



Real Behavior



Statistical Plugin

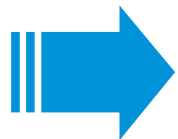
- ▶ For Active devices: OPTION 2: use PCM as inputs
 - One could find relationships between model parameters and PCM
 - Reduces measurement and extraction effort
 - Automatically in Accordance with PCM measurements
 - But PCM are correlated



Statistical Plugin

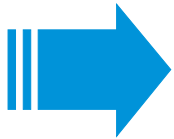
► For Active devices: OPTION 3: use TP as inputs

- One can find relationships between model parameters and TP
- TP are uncorrelated
- Reduces measurement and extraction effort
- But TP statistical variations are unknown!



Re-Simulate PCMs, and adjust TPs variations until fit is obtained
Once Optimization is finished, TPs are KNOWN

- Other Problem: we need to evaluate the statistical spread: this requires several thousand simulation runs
- The above simulations need to be ran again many time (eg, compute Jacobian matrix for the optimizer)

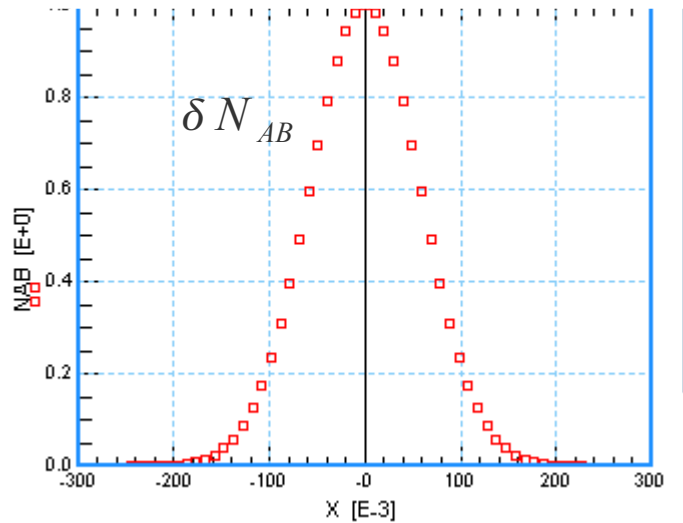


It would require days to be completed (or simply may crash)

Our Implementation Solves this issue by using tricky practical implementation

Definitions

Normalized base doping (NAB)
Statistical distribution.



For a given wafer run, TPs can be expressed as:

$$\frac{N_{AB}^*}{N_{AB}} = 1 + \delta N_{AB}$$

$$\frac{N_{AB}^*}{N_{AB}} = 1 + SIG_{NAB} * PR_{NAB}$$

Ratio of deviation at 1σ (can also be expressed in %)
This value is fixed for a given process

Actual deviation of a given wafer run, in number of σ
This becomes an instance parameter: random number between [-3;+3]

Statistical Plugin

Example of (ADS based) HiCUM scalable & statistical macro model

```

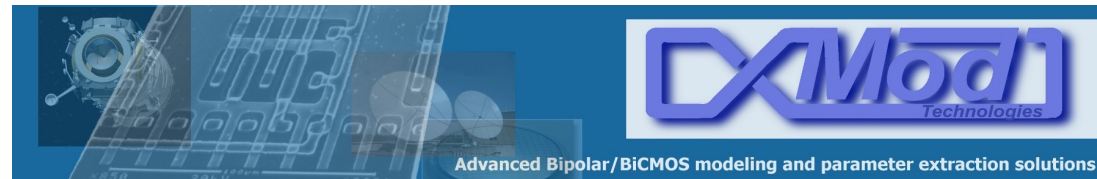
define          SMACH  (C B E S )
parameters     DRAWN_BE0=0.42 DRAWN_LE0=0.84 NE=1 MULT=1 \
\
A_BE0=0.01 A_EG0=0.01 R_EGG=0.01 R_WB=0.01 R_NAB=0.01 R_NDC=0.01 R_WC=0.01 R_NCX=0.01 R_WE=0.01 \
R_NDE=0.01 R_GAIB=0.05 FAC_T0=0.6 FAC_SIC=1.5 \
\
SIG_BE0=0 SIG_EG0=0 SIG_EGG=0 SIG_WB=0 SIG_NAB=0 SIG_NDC=0 SIG_WC=0 \
SIG_NCX=0 SIG_WE=0 SIG_NDE=0 SIG_GAIB=0

;----- PROCESS GEOMETRY -----
b_ov=0.12
w_s=0.1
b_pm=0.1
l_pm=0.1
...
;----- ELECTRICAL specific parameters -----
C_JE10=4.3
C_JC10=4.2
C_JEP0=0.85
C_JCB0=0.1274
...
C_10=3.467E-014
Q_P0=1.5
...
;----- Internal Calculations -----
PBC=(MULT*NE*2*(BBC+LBC))
ASIC=(MULT*NE*(BE0+2*b_sic)*(LE0+2*b_sic))
PSIC=(2*MULT*NE*((BE0+2*b_sic)+(LE0+2*b_sic)))
...

model MAIN HICUM Tnom= 27 \
C10 = (C_10*AE*AE*1e-18*r_AE0*r_AE0* (1+R_EGG*SIG_EGG)*(exp(A_EG0*SIG_EG0))) \
Qp0 = (Q_P0*AE*AE*1e-15*r_AE0*(1+R_WB*SIG_WB)*(1+R_NAB*SIG_NAB)) \
...
Rci0 = ((R_C10/(AE*fcs))*(1+R_WC*SIG_WC)/((1+R_NDC*SIG_NDC))) \
...
end SMACH

```

← Instance Parameters
← 1 σ TP variations (% from nominal) R_x 's
← deviation from nominal (number of σ) SIG_x 's
← geometrical information
← geometry independent parameters
← Intermediate calculations
← Statistical equation
← Scaling equation



Implementation

- ▶ Simulator Linear User Sweeps PAR1 and PAR2 emulates random values for SIG_NAB and SIG_BE0 with Gaussian distributions -> speed up by a factor of 100 to 1000
- ▶ This approximation is justified by real MC simulation once the TP optimization is achieved

The screenshot displays a simulation configuration window with the following settings:

Input	Mode	+ Node	- Node	Unit	Compliance	Sweep Type	Value
ve	V	E	GROUND	SMU E	100.0m	CON	0.000
vb	V	B	GROUND	SMU B	10.00m	CON	0.000

Input	Mode	Param Name	Unit	Sweep Type	Sweep Order	Start	Stop	# of Points	Step Size
PAR1	P	SIG_NAB		LIN	2	-1.495	1.495	7	498.3m
PAR2	P	SIG_BE0		LIN	1	-1.495	1.495	7	498.3m

Output	Mode	High Node	Low Node	Unit	Type
cj	C	B	E	CM	B

Statistical Plugin

► PCM selection, Bias points and geometry definition

The screenshot shows the 'Statistical Modeling' window with the following configuration:

Statistical Modeling
 DC | **DC 2** | DC - CV | DC - CV - RF

PCM Values and Measurement conditions

PCM Name	1 sigma deviation (%)	Measurement Conditions			PCM Structure Geometry						
		Vbe [V]	Vce [V]	Freq [Hz]	BE0 [um]	LE0 [um]	NE [-]	NB [-]	NC [-]	MULT [-]	CONF [-]
<input checked="" type="checkbox"/> IC	17.2	0.7	1		0.4	10	1	1	1	1	0
<input checked="" type="checkbox"/> IB	7.4	0.6	1		0.4	10	1	1	1	1	0
<input checked="" type="checkbox"/> BETA	17	0.8	2		0.4	10	1	1	1	1	0
<input checked="" type="checkbox"/> RSBI0	14				1	20	1	1	1	1	0
<input checked="" type="checkbox"/> RE	7.6				0.4	5	1	1	1	1	0
<input type="checkbox"/> CJEI0	0.2				10	20	1	2	2	50	0
<input type="checkbox"/> CJCI0	0.6				10	20	1	2	2	50	0
<input type="checkbox"/> FT	11.5	0.7	2.5	5e9	0.4	10	1	2	2	1	0

Apply Modifications

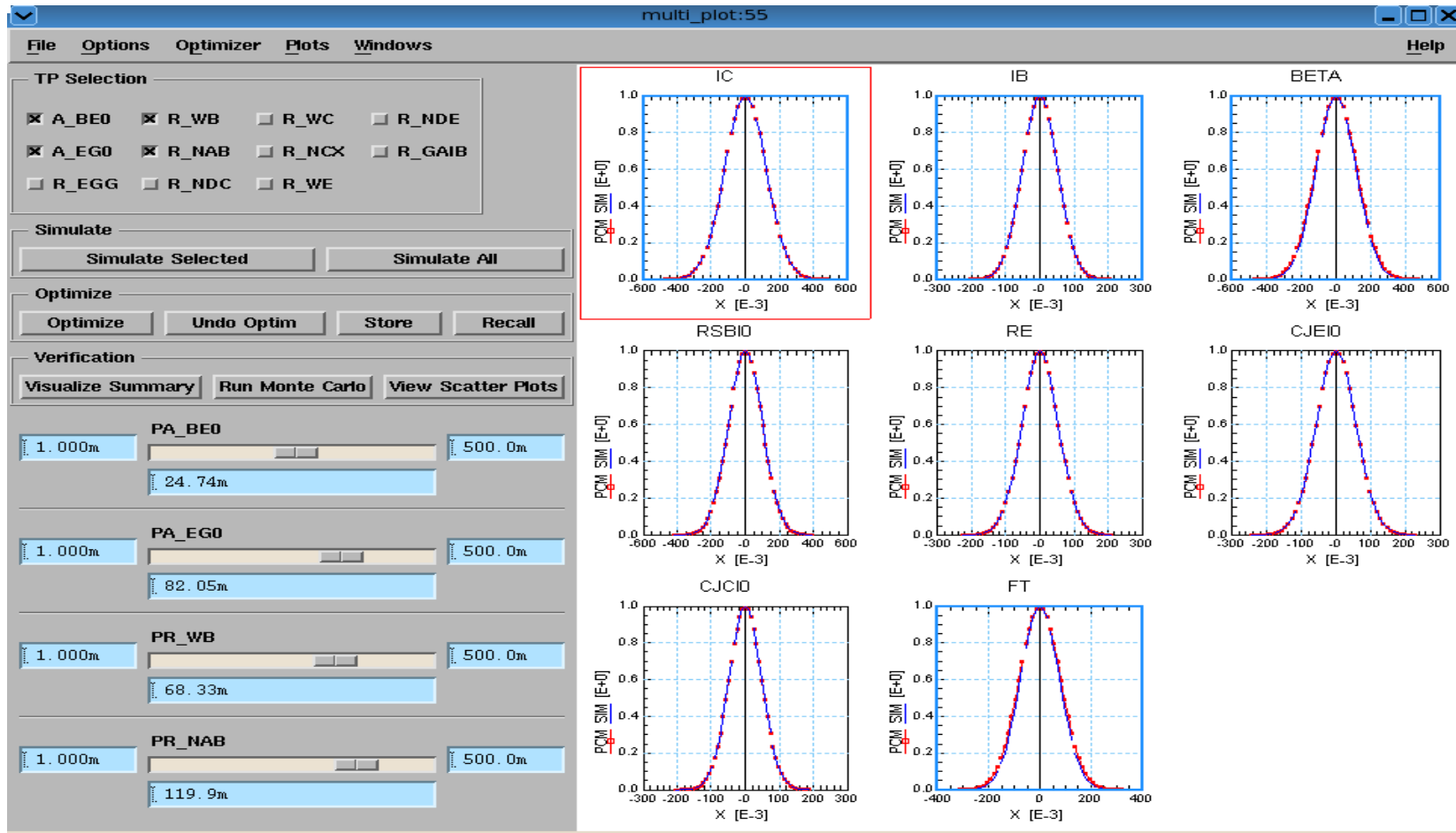
Extraction Strategy

Target PCM	Optimized Parameters
IC	R_NAB, R_WB, A_BE0, A_EG0
IB	R_WE, RNDE, R_GAIB, A_BE0
BETA	R_NAB, RWB, A_EG0, R_WE, RNDE, R_GAIB
RSBI0	R_NAB, RWB, A_BE0
RE	R_WE, RNDE, A_BE0

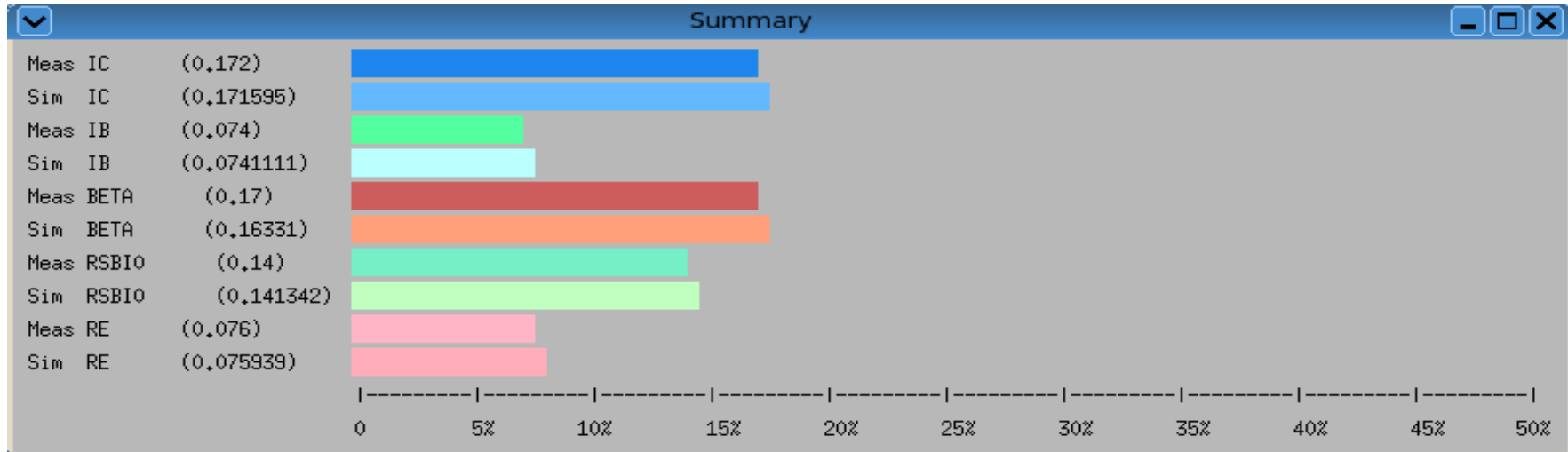
Run Extraction Tool

Statistical Plugin

- ▶ Extraction: TPs are parameters, measured PCMs spread are targets, PCM simulated spread are simulations
- ▶ Done in a few minutes



Statistical Plugin



cf SMACH Demo

HMT Roadmap

HMT	1H 2007	2H 2007	1H 2008	2H 2008
HiCUM v2.1	Blue			
HiCUM v2.21/2.22	Yellow	Green		
HiCUM L0 v1.11	Yellow	Green		
VBIC			Yellow *	

*depends on customer priorities



= High Delay risk

= Medium Delay risk

= Low Delay risk



Already available

SMACH Roadmap

SMACH	1H 2007	2H 2007	1H 2008	2H 2008
HiCUM v2.1	Yellow	White	White	White
HiCUM v2.21/2.22	Yellow	Green	White	White
HiCUM L0 v1.11	Yellow	Yellow	Green	White
VBIC	Yellow	Yellow	Green	White
MM20	Yellow	Green	White	White
Other models (HVEKV, varactors, Inductors)	Yellow	White	White	White

*depends on customer priorities



= Simplified Extraction

= Full set of extraction
plugins