

# Bipolar Transistor Modeling: Present and Future Trend

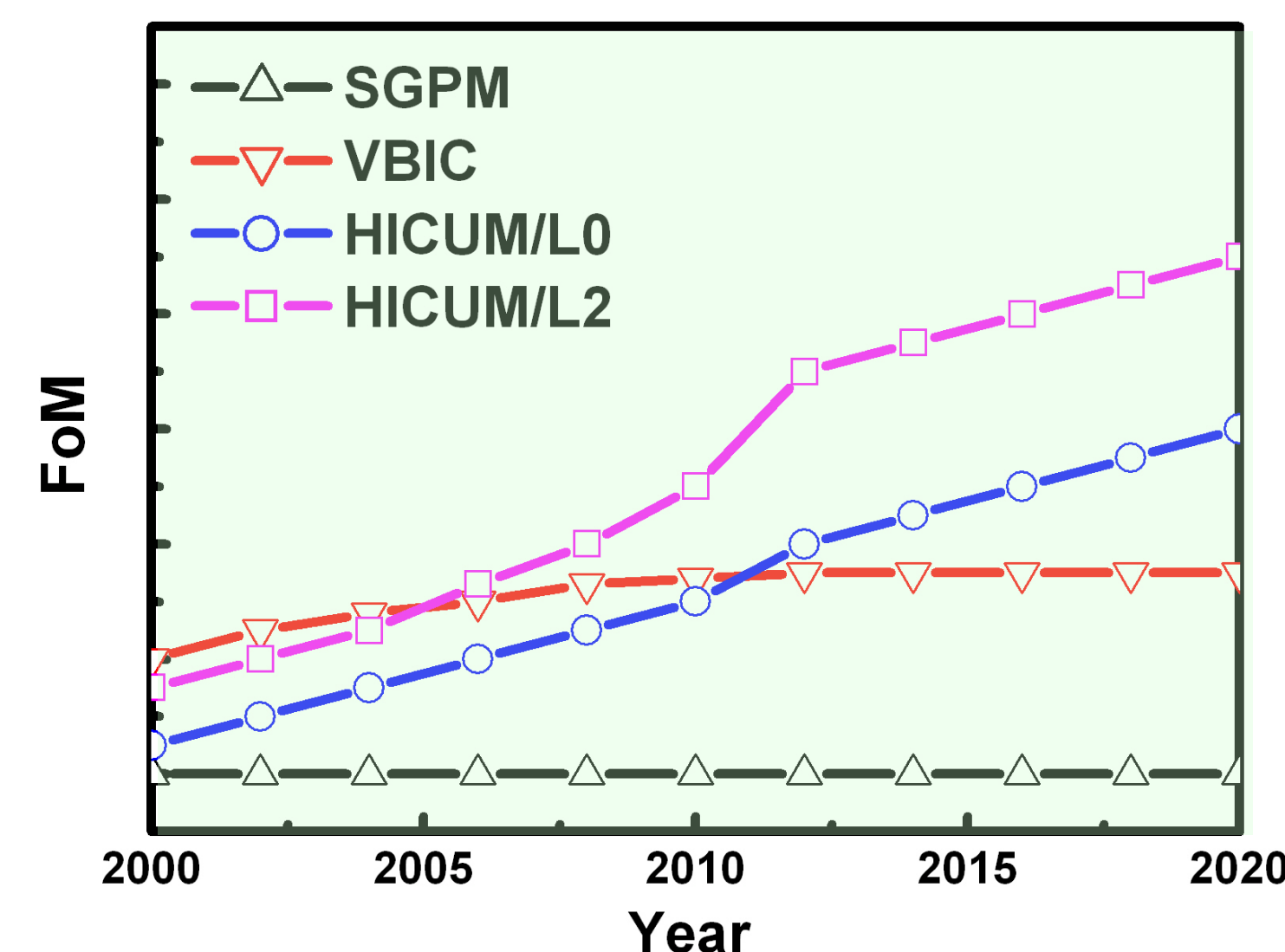
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## Introduction

Model applicability or sustenance in industry depends on higher values of newly proposed figure of merit (FoM)

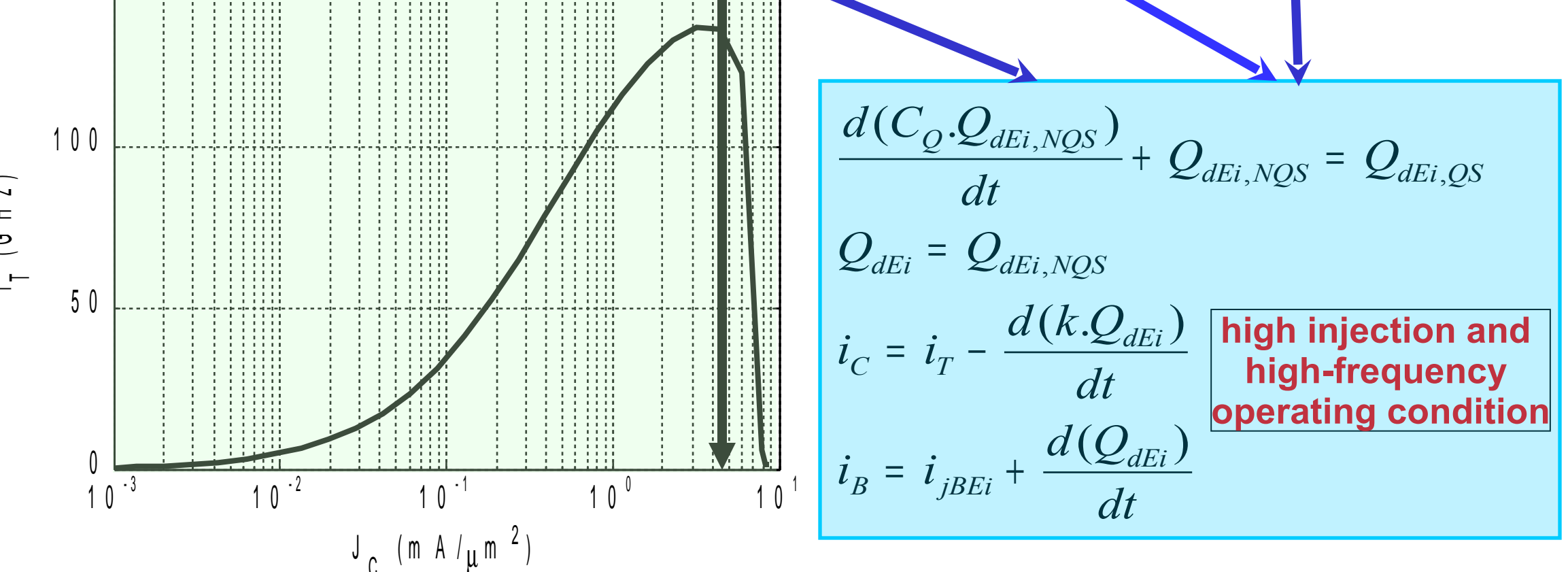
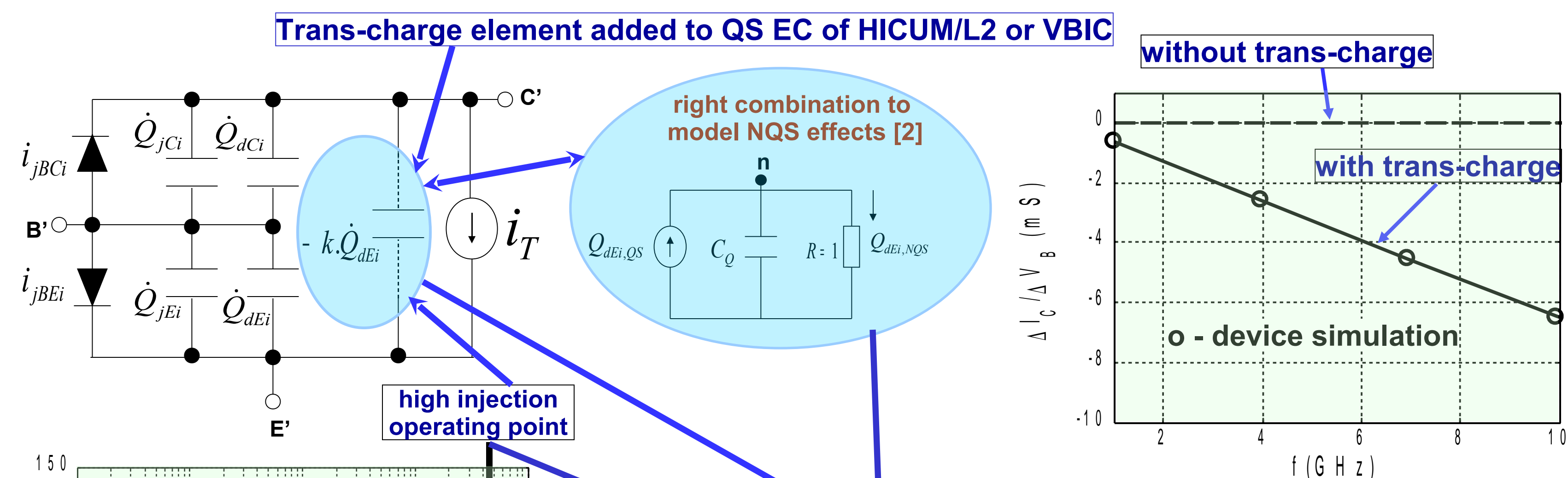
$$FoM = \frac{B}{T} + \frac{A}{E} + \frac{V}{L}$$

**B** = (physical) basis of the model  
**T** = (simulation) time, function (EC node count, complexity in model equations, convergence)  
**A** = (model) accuracy  
**E** = (parameter extraction) effort to achieve highest possible accuracy  
**V** = (public domain availability and quality of) verilog-A model code  
**L** = (time to) learn the model via documentation and model code  
**T** does not include any speed improvement by efficient processor or algorithm of simulator



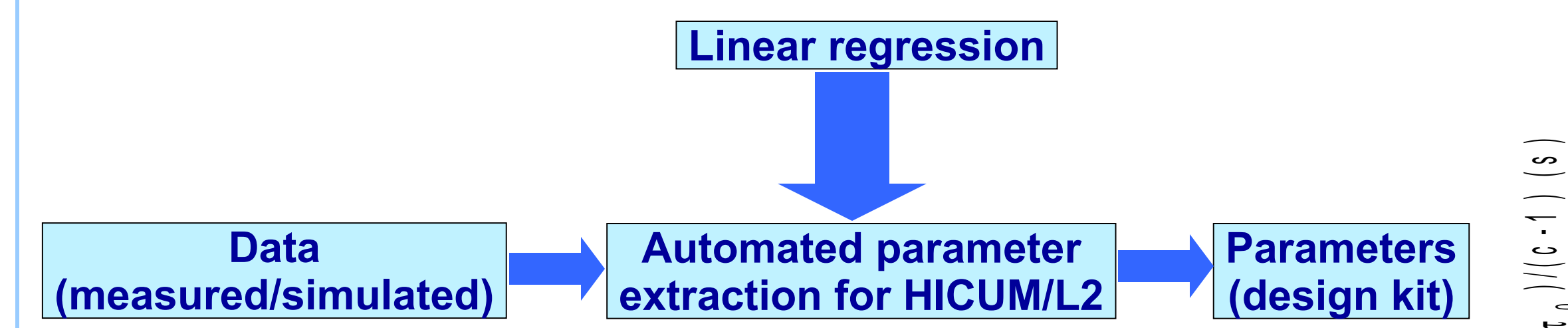
- Modeling new physical effects improves **B** value subsidizing the subsequent high value of **T**
- Although **A** depends on **B**, higher **E** value improves the value of **A**
- Pain in learning and using a complicated but accurate model results into high **L** value, effect which can be reduced by availability of high **V**
- Active research on a model improves **B**, **A**, **V**, and simultaneously reduces **L**, **E** and possibly keeps **T** at constant value
- Saturation of SGPM curve is caused by almost zero follow-up research
- Slight improvement in VBIC curve is caused by few research documents mainly on implementation and very good quality verilog-A code, however, the curve is saturating unless some smarter extraction strategy is adopted
- Active research on HICUM keeps both the curves rising steadily; a steeper rise in recent years is expected via the reduction of **L** [1], **E** (smarter extraction strategy), **T** (reducing node count in NQS model), increasing **B** (better QS model), and **V** (improving verilog-A code quality) without compromising **A**.

## Modeling



- Intrinsic transistor EC looks similar for VBIC or HICUM/L2 although the element formulations are different especially for  $i_T$  and  $Q_{dEi}$
- At high injection region effect of minority charge partitioning is visible in QS domain
- Additional single-node RC circuit is sufficient to model both input and output NQS effects, unlike four extra nodes required in two LCR networks modeling the same effects if VBIC or HICUM/L2 conventional QS EC is used without trans-charge element [2]

## Parameter Extraction



### extraction of low current transit time parameters of HICUM

$$\tau_f(V_{B'E'})|_{V_{B'C'}} = \frac{1}{2\pi f_T} - (R_{Cx} + R_E)C_{jCi} - \frac{C_{jEi} + C_{jCi}}{g_m}$$

$$\tau_{f0} = \min(\tau_f)$$

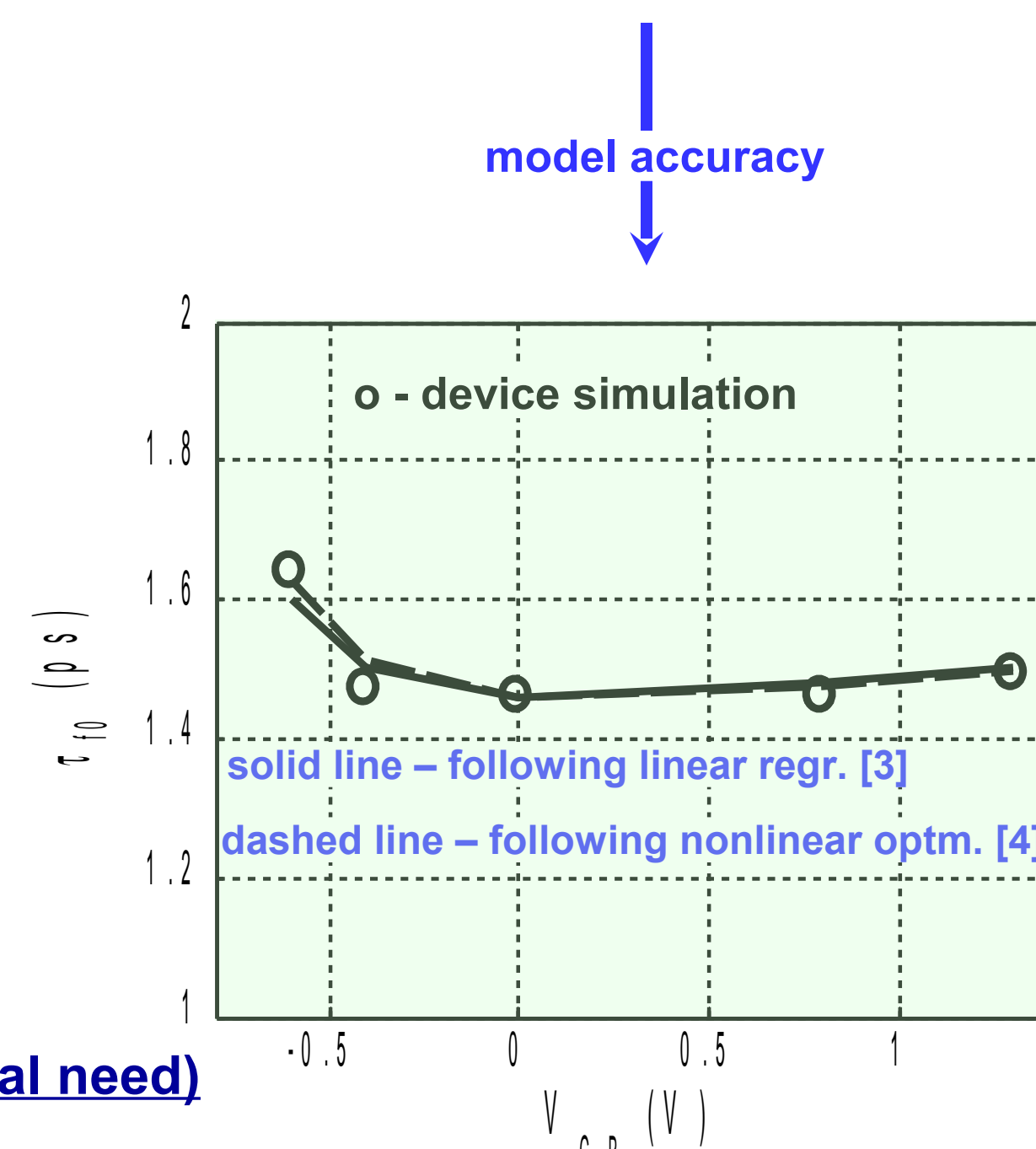
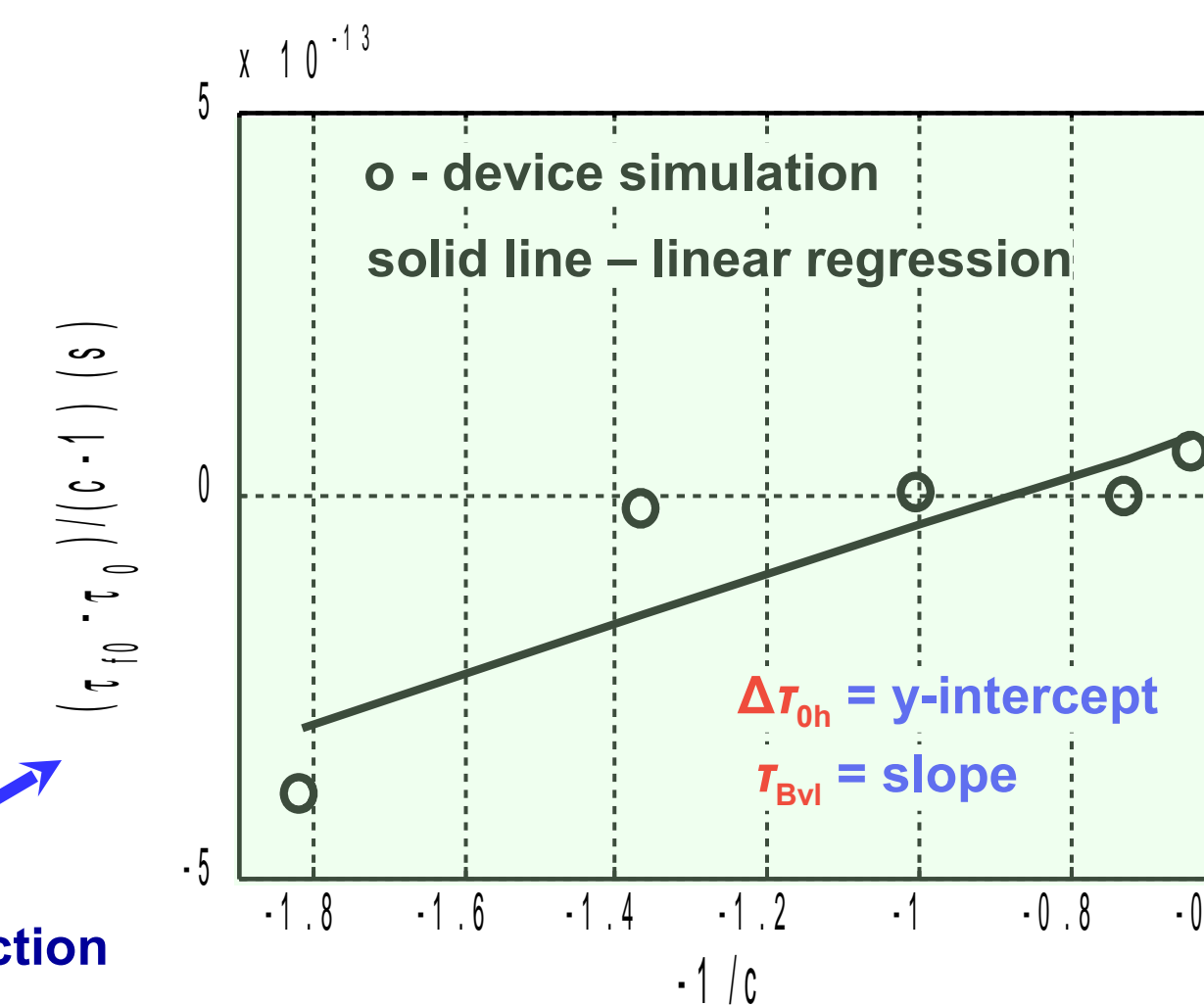
$$\tau_0 = \tau_{f0}(V_{B'C'} = 0)$$

$$c = \frac{C_{jCi0}}{C_{jCi}}$$

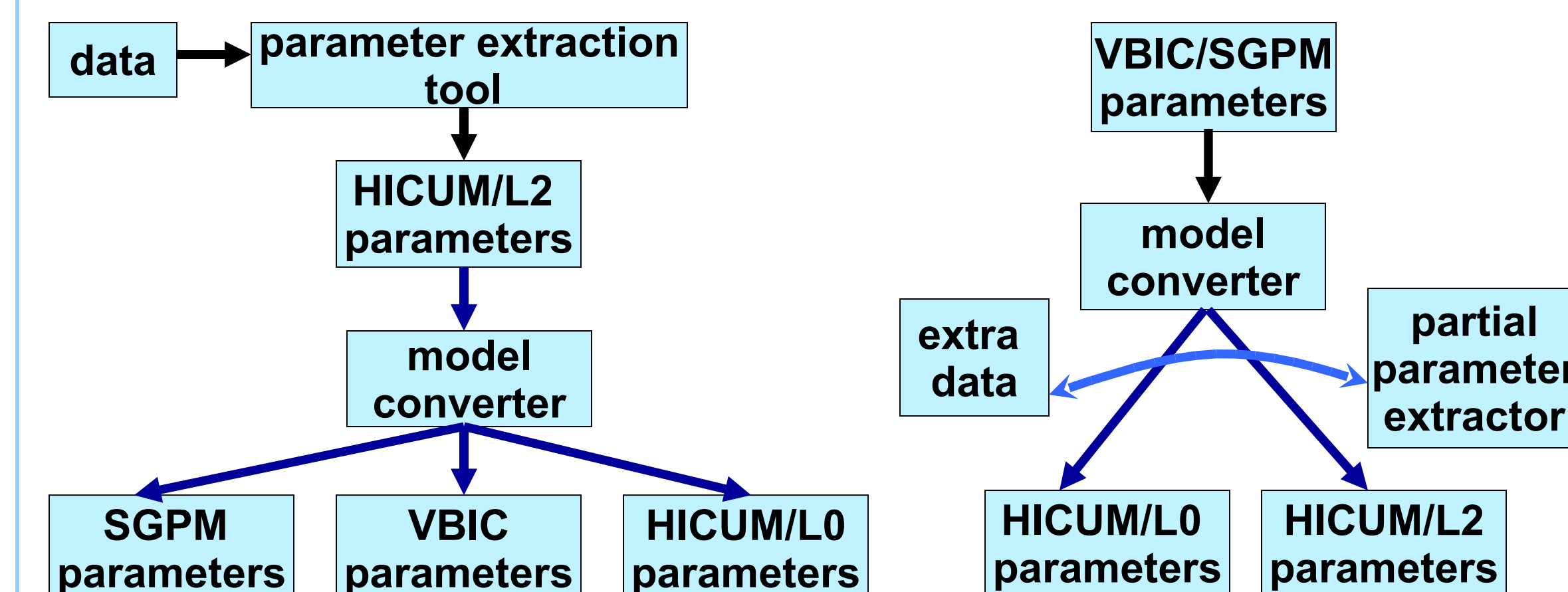
$$\frac{\tau_{f0} - \tau_0}{c - 1} = \Delta\tau_{0h} + \tau_{BvI} \left( -\frac{1}{c} \right)$$

available data:  $C_{jEi}, C_{jCi}, g_m, f_T$

already extracted parameters:  $R_{Cx}, R_E, C_{jCi0}$



- Hardly compromises on model accuracy (**A**) but slightly reduce the extraction effort (**E**)
  - Linear regression is faster and eliminates the use of computationally complex optimization loop, or any non-physical initial guess for parameter values
  - Even smarter extraction technique is required to reduce **E** further
- Smarter extraction strategy-I Smarter extraction strategy-II (industrial need)



## References

[1] Michael Schröter and Anjan Chakravorty, "Compact Hierarchical Bipolar Transistor Modeling with HICUM," World Scientific, International Series Advances in Solid State Electronics and Technology (ASSET), to be published in Oct., 2010.

[2] J. Jacob, A. DasGupta, M. Schroter, A. Chakravorty, "Modeling Non-Quasi-Static Effects in SiGe HBTs", IEEE Trans. Electron Devices, pp. 1559-1566, 2010.

[3] P. K. Holla, D. Enbasekar, S. Kailash, Swagata K., A. Chakravorty, "HIPAX: Simple, Accurate and Automated Parameter Extraction for HICUM/L2", pp. 168, IWPSD, 2009.

[4] D. Berger and D. Céli, "HICUM Parameter Extraction Methodology for a Single Transistor Geometry", Proc. IEEE BCTM, pp. 116-119, 2002.

## Summary

- In general, the goal is to try for increasing **B**, **A**, **V** and reducing **T**, **E**, **L**
- Trans-charge-based model improves **A** (as well as **B**) in high-injection QS operation; and the trans-charge based NQS model reduces **T** (by reducing the node count)
- Linear technique for parameter extraction reduces **E**
- Smarter extraction strategies reduce **E** value; strategy-I uses extraction tool for extracting only HICUM/L2 (having highest **B** value) parameter set; other sets (with lower **B** values) are found using model converters
- Since design houses wish to use HICUM models, the existing PDKs (with SGPM/VBIC parameters) are required to be converted resulting into strategy-II (industrial need); few extra data set and partial parameter extractor must be additionally used due to lower **B** values of SGPM/VBIC