

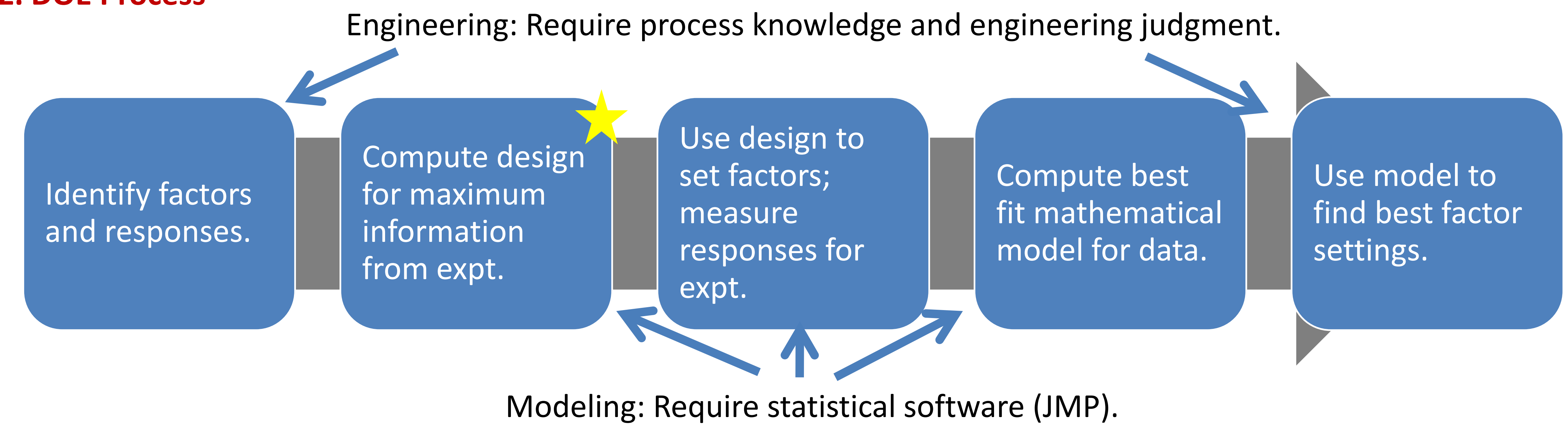
1. Introduction: Why Characterize?

- **Increase process knowledge and improve robustness.**
 - Main effects: Number of factors + range tested.
 - Interactions: Combination of factors changed simultaneously.
- **Use knowledge to continually improve process during product lifecycle.**

Why use Design of Experiments (DOE)?

- **Move from costly and time-consuming trial-and-error searches to elegant and cost-effective statistical methods.**
- **DOE can characterize, predict, and then improve performance.**

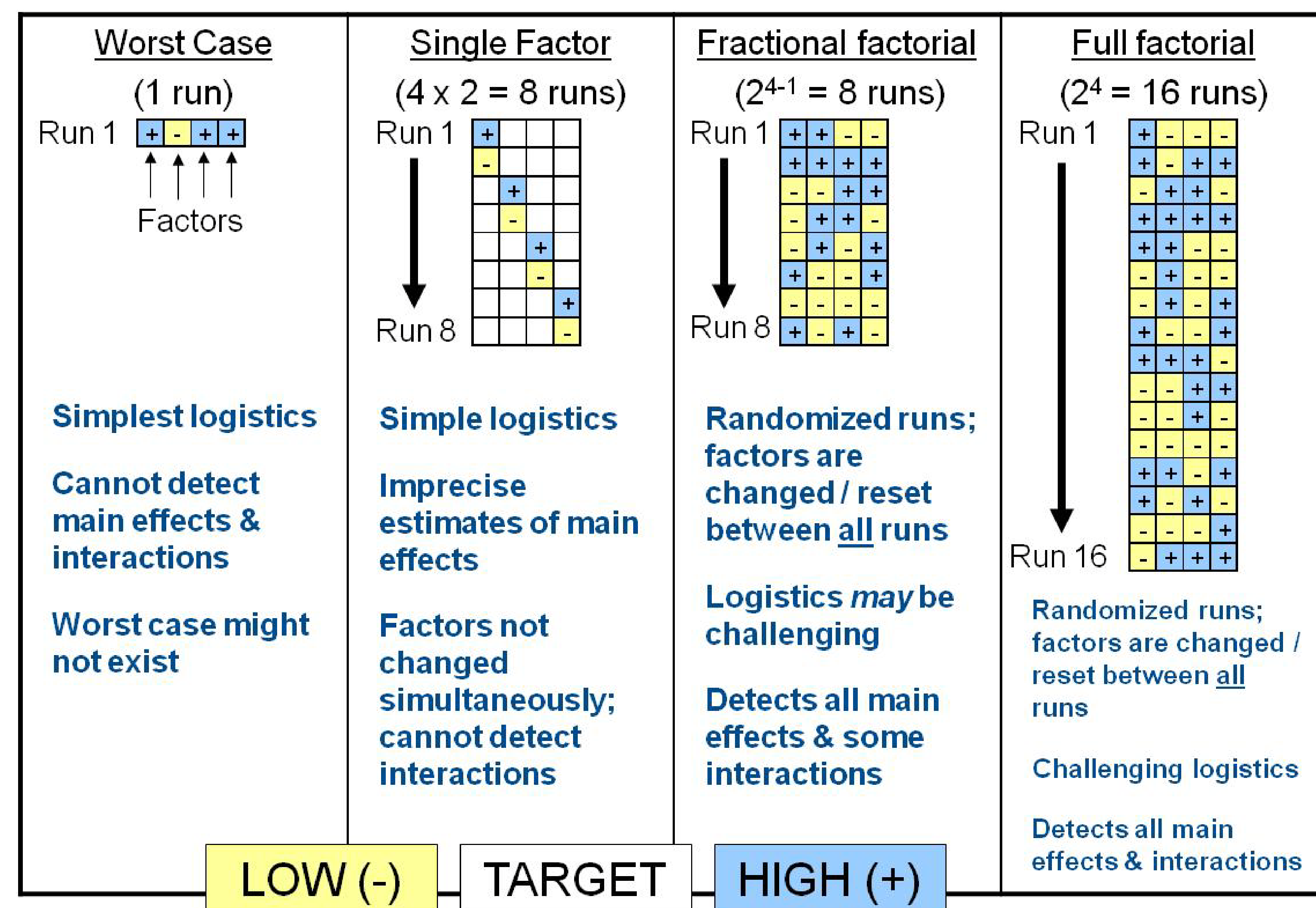
2. DOE Process



3. Challenge: How do we simultaneously change and test many process factors without logistical difficulties?

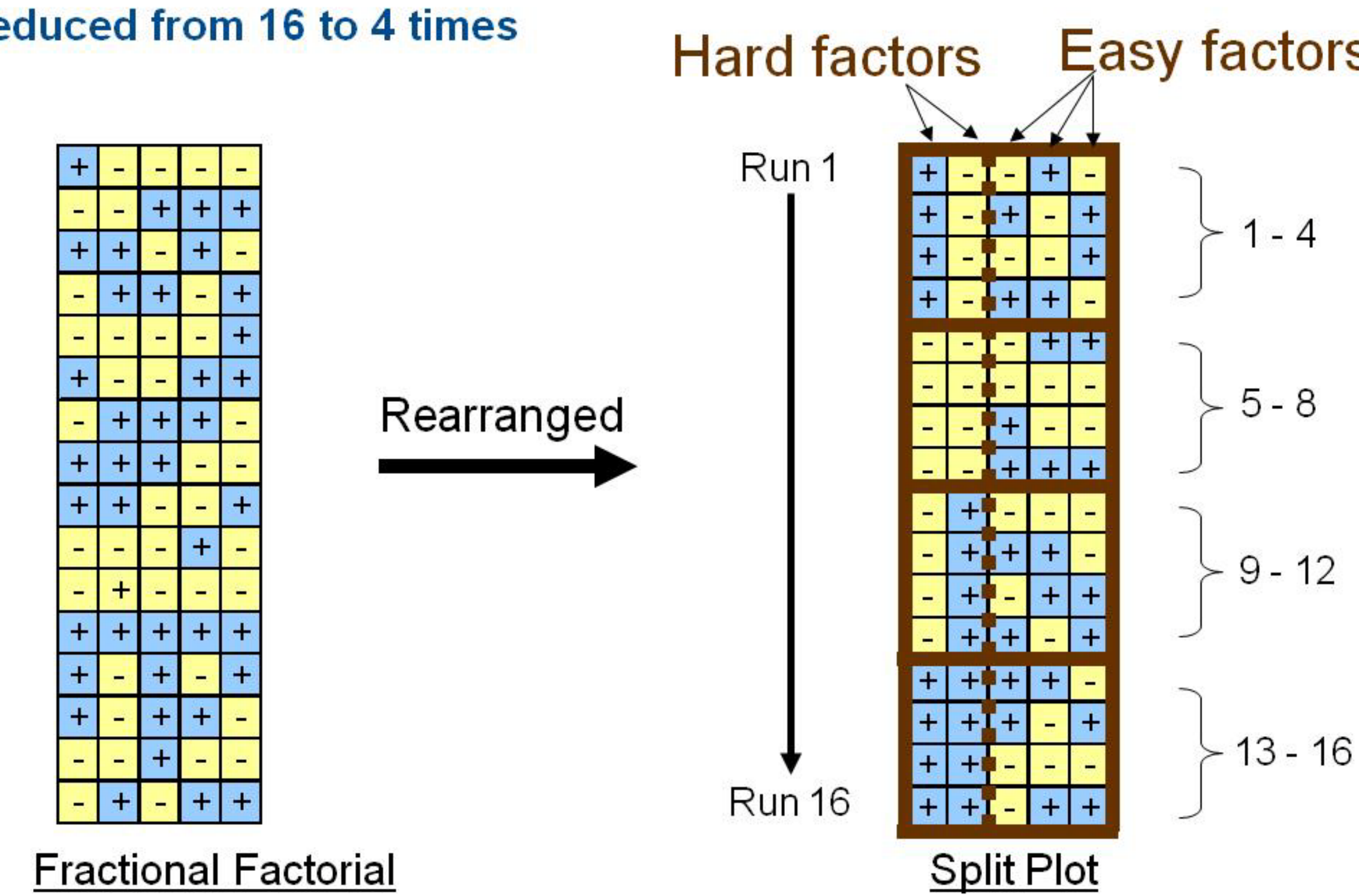
4. “Traditional” Divide and Conquer Approach

- Leverage scientific knowledge and experience with other similar processes and materials.
- Maximize process knowledge and validate the process by testing predicted uncertainties.
- Divide factors into smaller separate experiments using “traditional” designs.



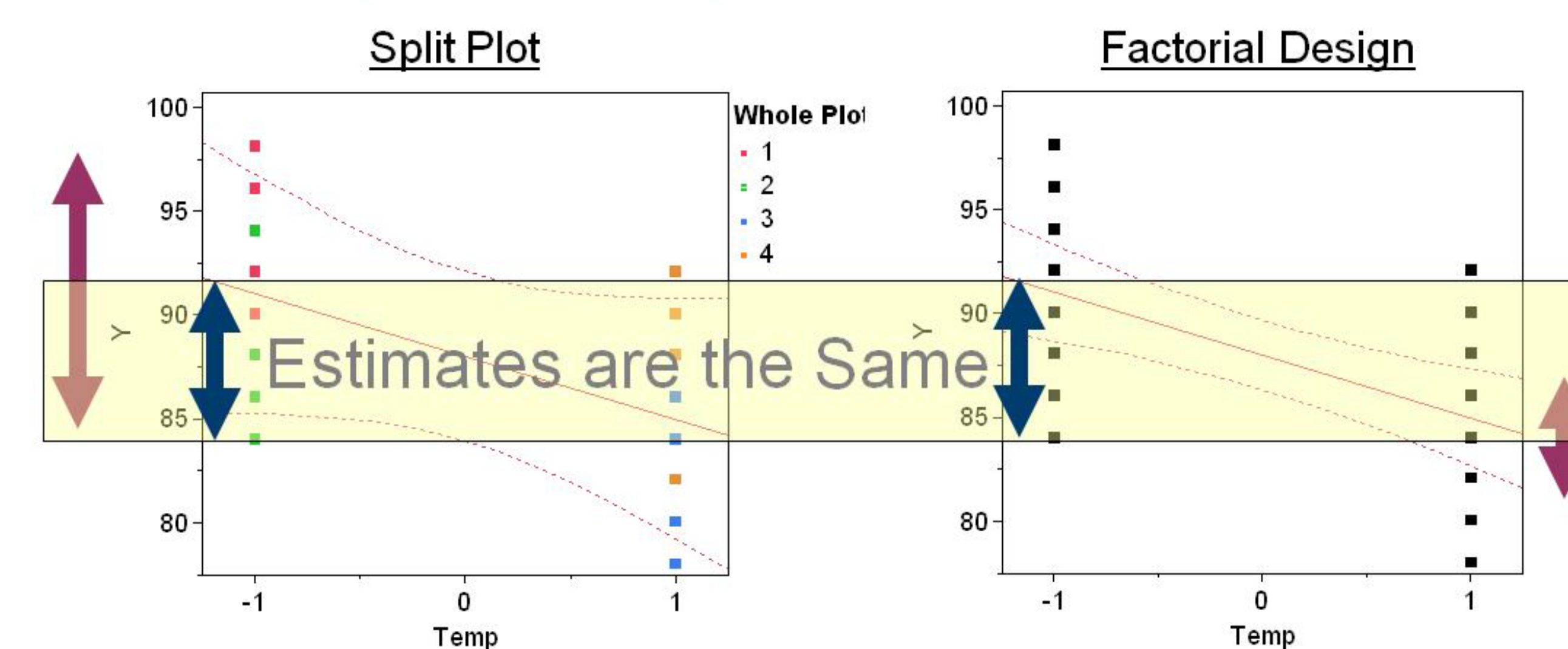
5. Novel Split Plot Approach

Fractional factorial with restricted randomization
Hard factors are changed less often
– Reduced from 16 to 4 times



Split plot estimates are the same as Factorial estimates

Split Plot estimates of hard-to-change factors are less precise
– Hard-to-change factor is changed 4 times instead of 16 times



Factors are categorized by ease of change.

- Easy: Programmable / Automated.
- Hard: Manual.

Hard factors used to create whole plots.

- Easy factors changed b/w all runs.
- Hard factors changed b/w whole plots.

2 sources of variations.

- Run-to-run.
- Whole plot-to-whole plot.

Statistical analysis is more involved.

- Fractional factorial: Standard least squares.
- Split plot: Mixed effect models.

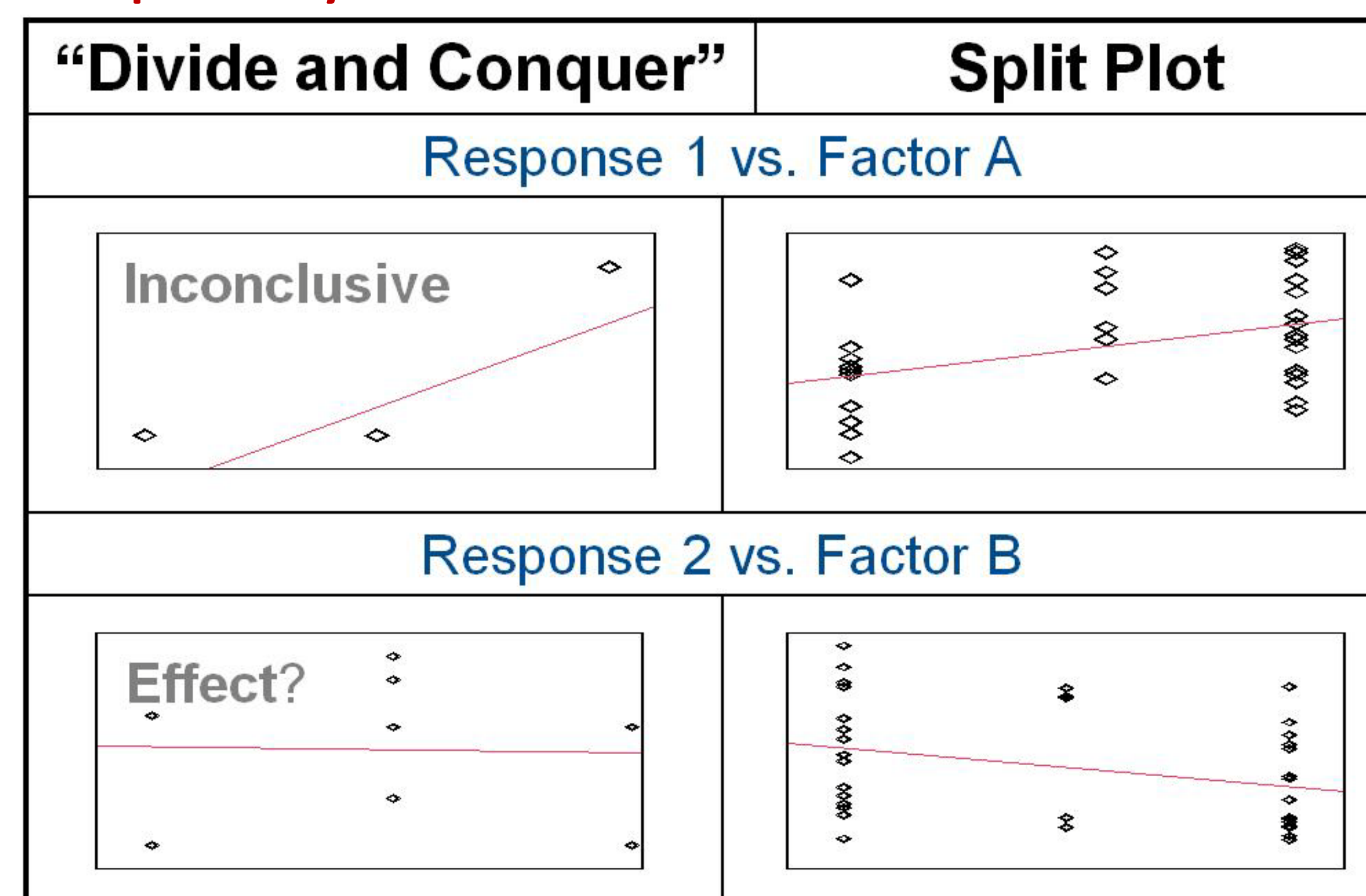
Ignoring the split plot nature and analyzing as a factorial design will lead to erroneous conclusions.

- Hard factors labeled as significant too often.
- Easy factors and interactions labeled as significant not often enough.

6. Application to PV Characterization – Tabling/Stringing

Easy	Hard
Lamp Power	Base-plate Temperature
Heating Time	Flux
Cool-down Time	Cu Thickness
Cool-down Air Flow-rate	Solder Thickness
Preheat Power	
Preheat Time	

Sample Analysis



	E1	E2	E3	E4	E5	E6	H1	H2	H3	H4
1	-	+	-	+	+	-	-	-	+	L1
1	+	+	+	+	+	+	-	-	+	L1
1	+	+	+	+	+	+	-	-	+	L1
1	+	+	+	+	+	+	-	-	+	L1
2	+	+	+	+	+	+	-	-	+	L1
2	+	+	+	+	+	+	-	-	+	L1
2	+	+	+	+	+	+	-	-	+	L1
2	+	+	+	+	+	+	-	-	+	L1
3	+	+	+	+	+	+	-	-	+	L1
3	+	+	+	+	+	+	-	-	+	L1
3	+	+	+	+	+	+	-	-	+	L1
3	+	+	+	+	+	+	-	-	+	L1
4	+	+	+	+	+	+	-	-	+	L1
4	+	+	+	+	+	+	-	-	+	L1
4	+	+	+	+	+	+	-	-	+	L1
4	+	+	+	+	+	+	-	-	+	L1
5	+	+	+	+	+	+	-	-	+	L1
5	+	+	+	+	+	+	-	-	+	L1
5	+	+	+	+	+	+	-	-	+	L1
5	+	+	+	+	+	+	-	-	+	L1
6	+	+	+	+	+	+	-	-	+	L1
6	+	+	+	+	+	+	-	-	+	L1
6	+	+	+	+	+	+	-	-	+	L1
6	+	+	+	+	+	+	-	-	+	L1
7	+	+	+	+	+	+	-	-	+	L1
7	+	+	+	+	+	+	-	-	+	L1
7	+	+	+	+	+	+	-	-	+	L1
7	+	+	+	+	+	+	-	-	+	L1
8	+	+	+	+	+	+	-	-	+	L1
8	+	+	+	+	+	+	-	-	+	L1
8	+	+	+	+	+	+	-	-	+	L1
8	+	+	+	+	+	+	-	-	+	L1
9	+	+	+	+	+	+	-	-	+	L1
9	+	+	+	+	+	+	-	-	+	L1
9	+	+	+	+	+	+	-	-	+	L1
9	+	+	+	+	+	+	-	-	+	L1
10	+	+	+	+	+	+	-	-	+	L1
10	+	+	+	+	+	+	-	-	+	L1
10	+	+	+	+	+	+	-	-	+	L1
10	+	+	+	+	+	+	-	-	+	L1
11	+	+	+	+	+	+	-	-	+	L1
11	+	+	+	+	+	+	-	-	+	L1
11	+	+	+	+	+	+	-	-	+	L1
11	+	+	+	+	+	+	-	-	+	L1
12	+	+	+	+	+	+	-	-	+	L1
12	+	+	+	+	+	+	-	-	+	L1
12	+	+	+	+	+	+	-	-	+	L1
12	+	+	+	+	+	+	-	-	+	L1

7. Conclusions

1. Characterize process over a wide range of conditions.
 - Increase process knowledge.
 - Contribute to process robustness.
2. Testing all factors simultaneously maximizes process knowledge.
 - Does not require prior experience with similar processes.
 - Can detect unpredicted effects.
3. Split plot is an excellent characterization tool.
 - Gained process knowledge
 - Simplified logistics.

Limitations of “Divide and Conquer”

- **Not suitable for novel materials and processes.**
- **Observations from similar processes may not translate exactly to the process being characterized.**
 - May not detect unpredicted effects and interactions.
- **Few replicates at the high and low factor levels.**
 - Detected “effects” may be imprecise and inconclusive.
- **Separate experiments result in small and disjointed design spaces.**
 - No knowledge of process performance when all factors are changed simultaneously.