Better Hypothesis Testing for MT: Controlling for Optimizer Instability

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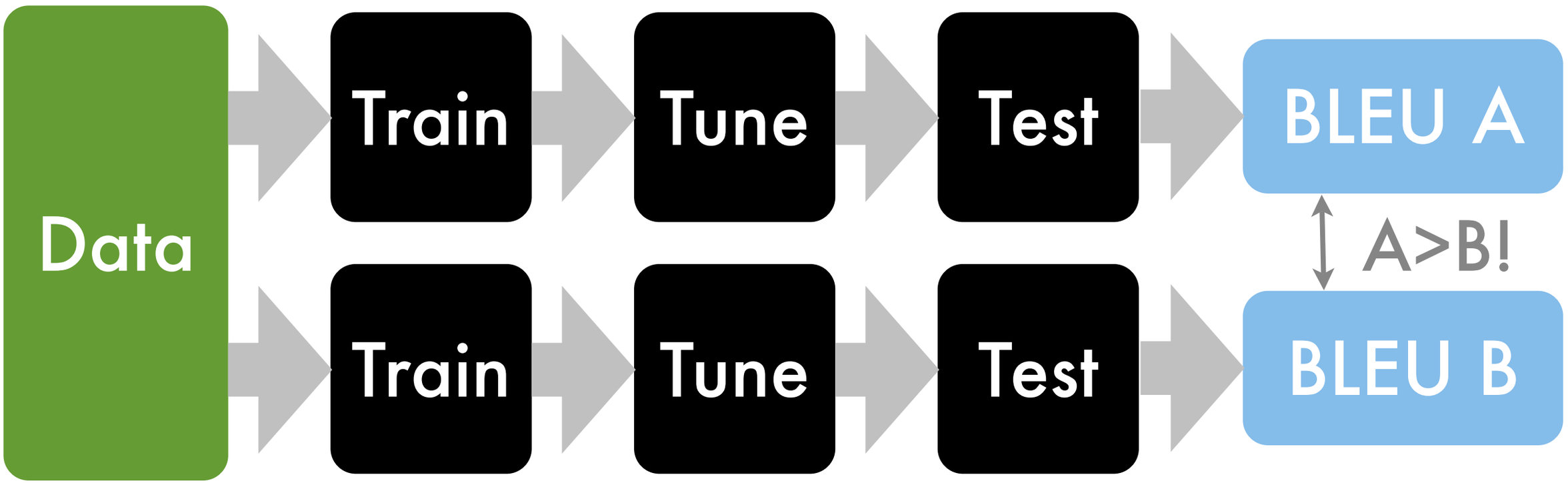
A Tale of 2 BLEU Scores

- Jon runs an experiment: A > B?



A Tale of 2 BLEU Scores

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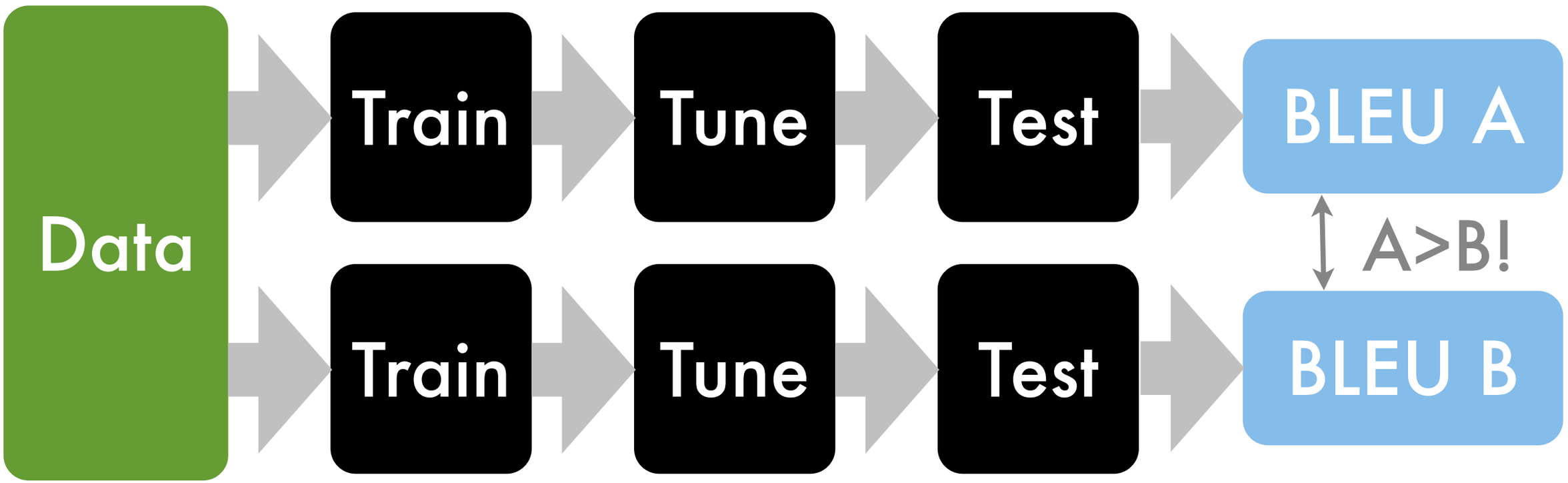
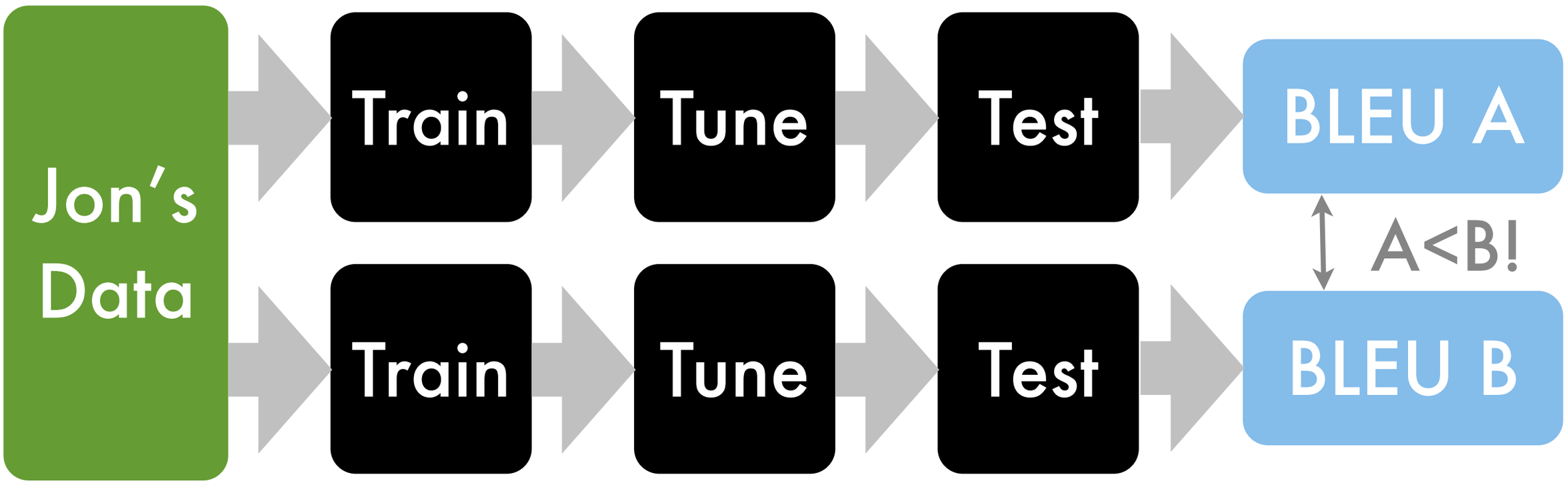


- If BLEU A > BLEU B, we conclude A is better…

…right?

A Tale of 2 BLEU Scores

- Chris repeats Jon's experiment



A Tale of 2 BLEU Scores

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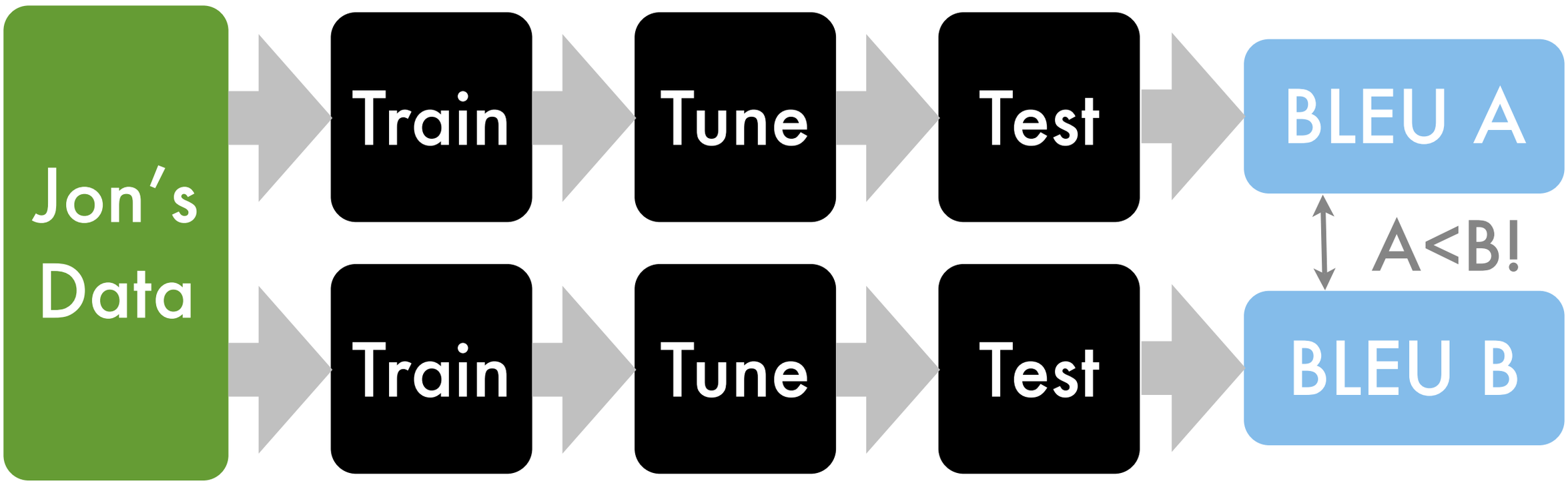

- But Jon found that A > B…
- Who's wrong?

Outline

- Why do these outcomes differ?
- Current practice: Ignore instability
- Experiments: Does instability really matter?
- Recommendation: *Measure* instability
  (software provided @ the link below)

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  - Optimizer initialization
  - Optimizer strategy (MERT, MCMC, MIRA) } Well-known, Not Well-explored → Formalize

Current Practice: Instability

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  - *Single* sample from distribution over weights

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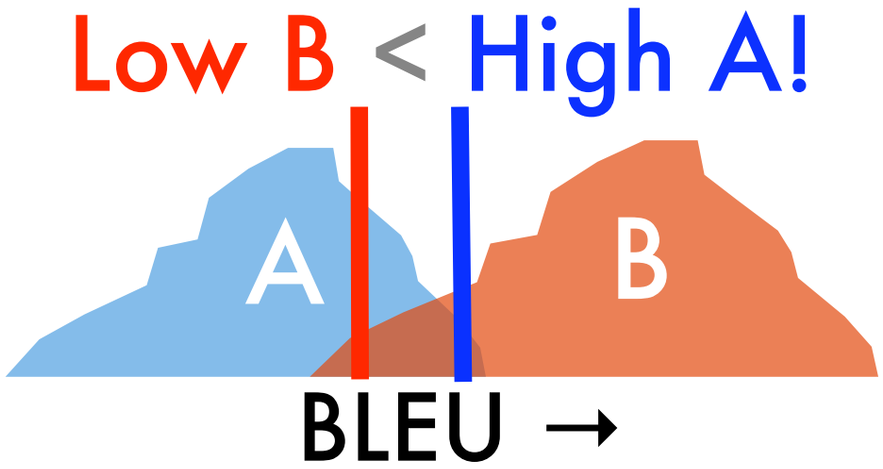

- High baseline (A) + low experimental (B)

Throw away a good idea

Current Practice: Instability

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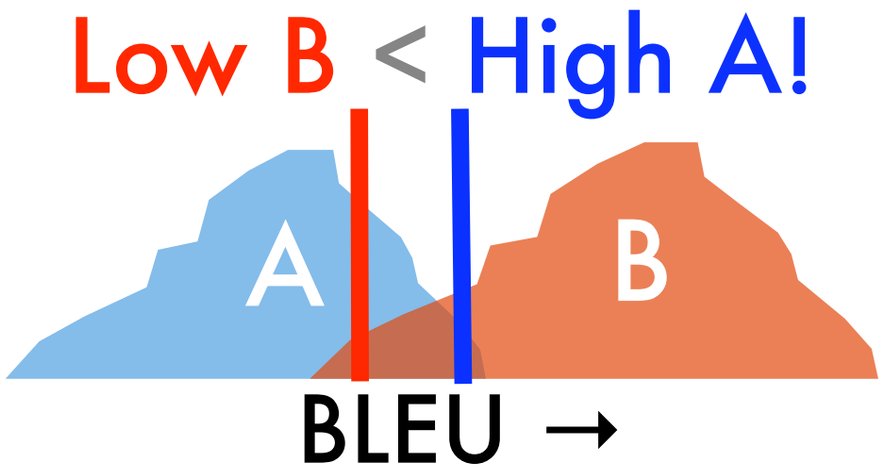
  - *Single* sample from distribution over weights



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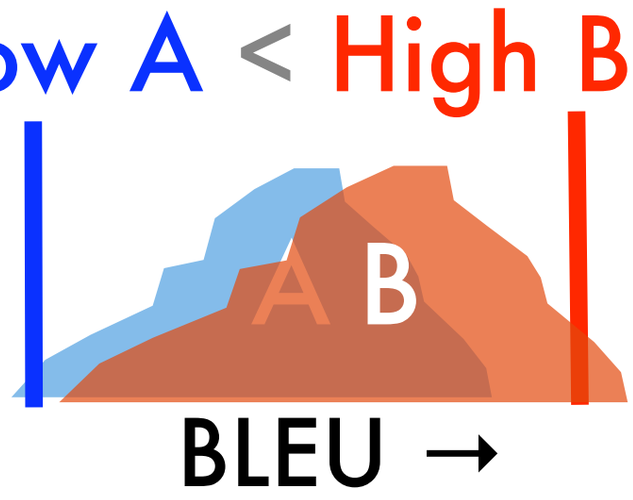
⚠ Throw away a good idea



- Low baseline (A) + high experimental (B)

⚠ Report a spurious improvement

Experiments

- Does this variation really show up?
- Does it affect comparisons to baseline systems?

Single System Variation

System	BLEU Avg			
BTEC Chinese-English				
A	48.4			
B	49.9			
WMT German-English				
A	18.5			
B	18.7			

* See paper for BLEU, METEOR, & TER

Single System Variation

System	BLEU Avg	s_{sel}		
BTEC Chinese-English				
A	48.4	1.6		
B	49.9	1.5		
WMT German-English				
A	18.5	0.3		
B	18.7	0.3		

* See paper for BLEU, METEOR, & TER

- Well-known bootstrap resampling
- Variance over slightly different test sets:

	Sent 1	Sent 1	Sent 1
	Sent 2	Sent 2	Sent 1
	Sent 3	Sent 2	Sent 2
BLEU:	22.0	23.0	24.0
Variance (in BLEU):		1.0	

Single System Variation

System	BLEU Avg	s_{sel}		
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A	48.4	1.6		
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- Run optimizer many times (sampling)
- Run BTEC MERT **300X**
- Run WMT MERT **50X**

Single System Variation

System	BLEU Avg	s_{sel}		
BTEC Chinese-English				
A	48.4	1.6		
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	Opt 1	Opt 2	Opt 3
Corpus BLEU:	22.0	23.0	24.0
Variance (in BLEU):		1.0	

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Single System Variation

System	BLEU Avg	s_{sel}	s_{dev}	
BTEC Chinese-English				
A	48.4	1.6	0.2	
B	49.9	1.5	0.1	
WMT German-English				
A	18.5	0.3	0.0	
B	18.7	0.3	0.0	

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- Optimizer not guaranteed to find global optimum
- Good fit on tuning data
- About the same score (not always same weights)

Single System Variation

System	BLEU Avg	s_{sel}	s_{dev}	s_{test}
BTEC Chinese-English				
A	48.4	1.6	0.2	0.5
B	49.9	1.5	0.1	0.4
WMT German-English				
A	18.5	0.3	0.0	0.1
B	18.7	0.3	0.0	0.2

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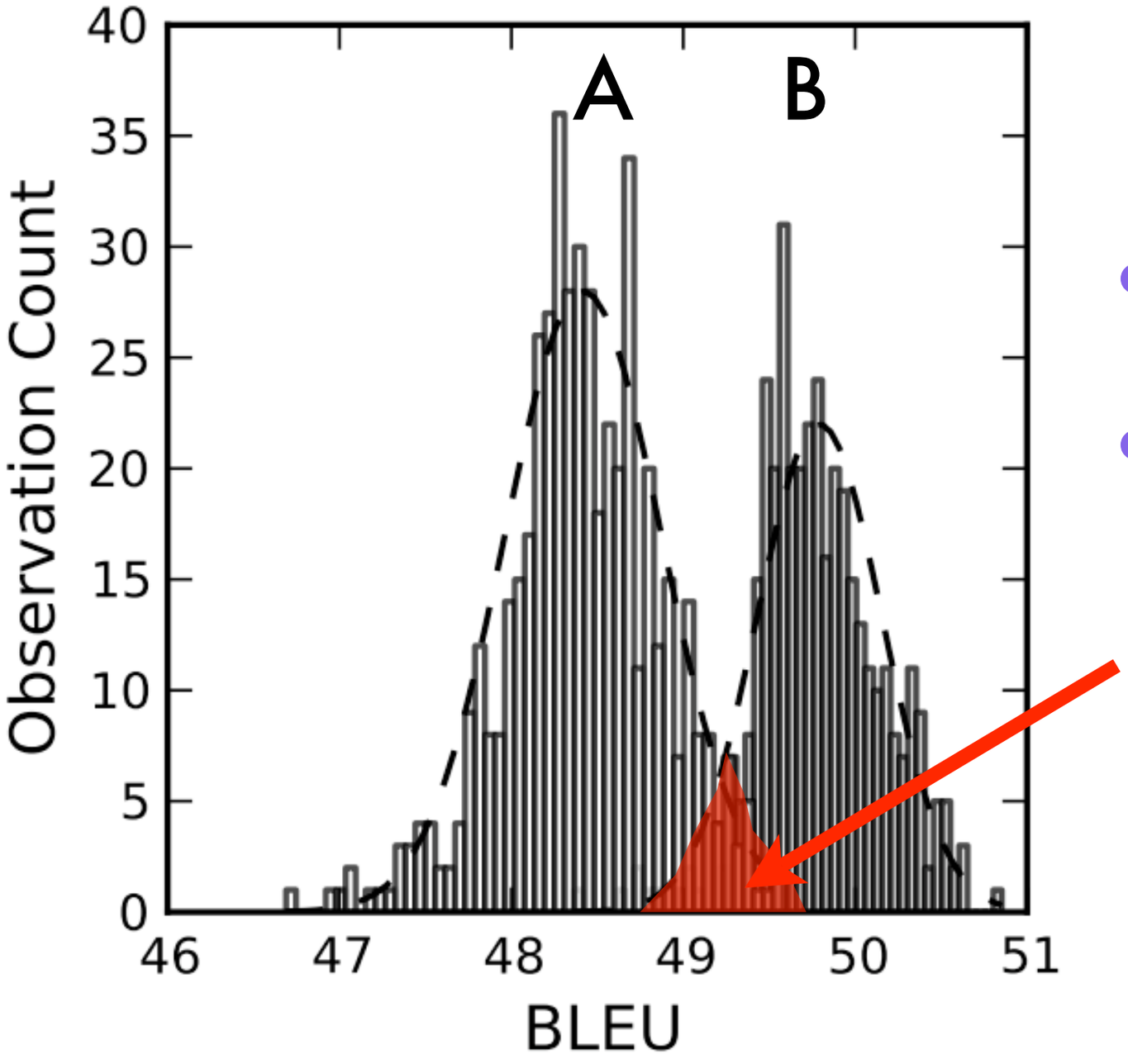
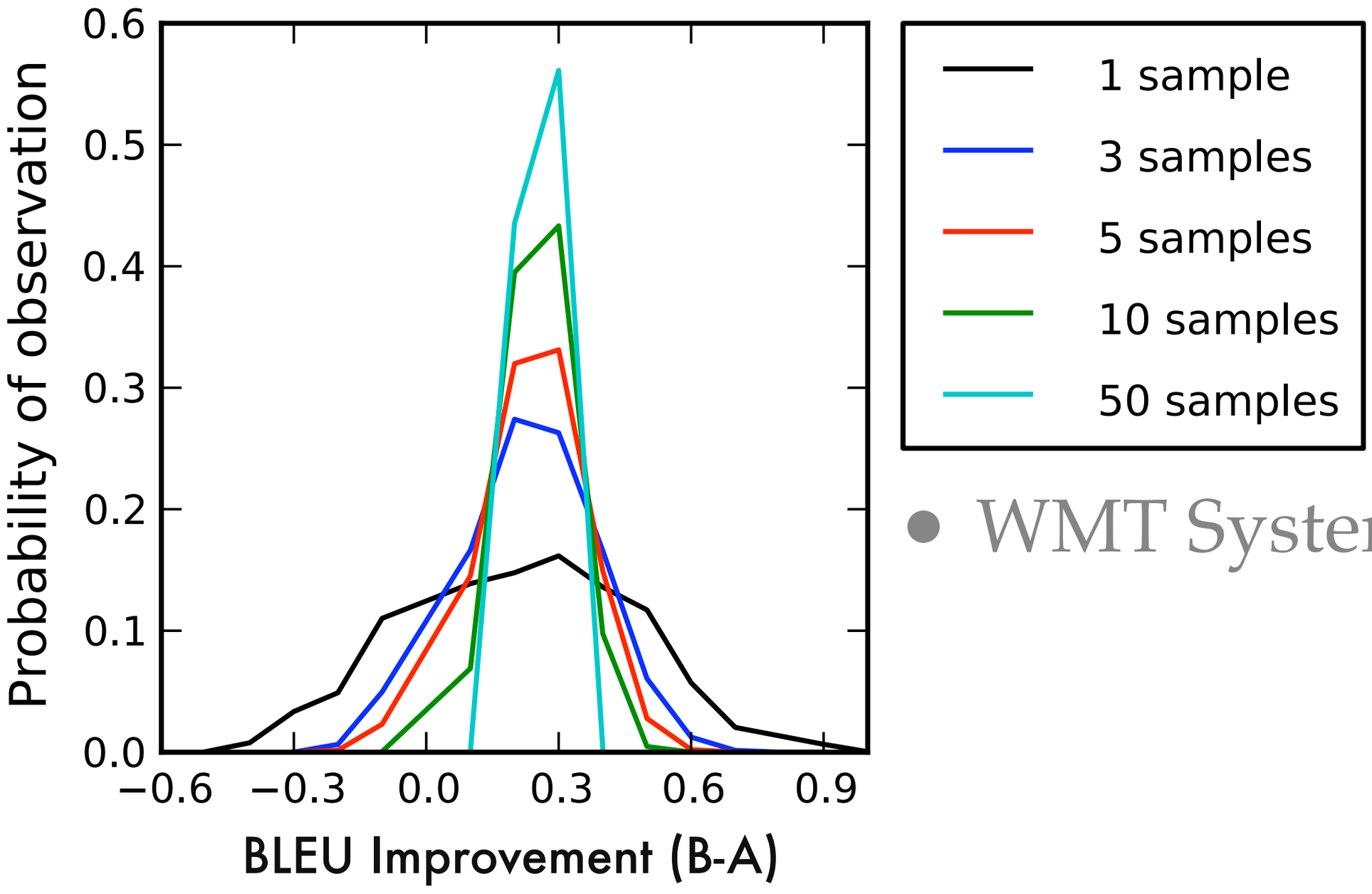
- Optimal weights for tuning may not generalize
- Many weight vectors appear equal on the tuning set, but differentiate on the test set

Two System Variation



- BTEC Systems
- In the overlapping region, we could draw an opposite conclusion

How Many Runs are Needed?



- WMT Systems

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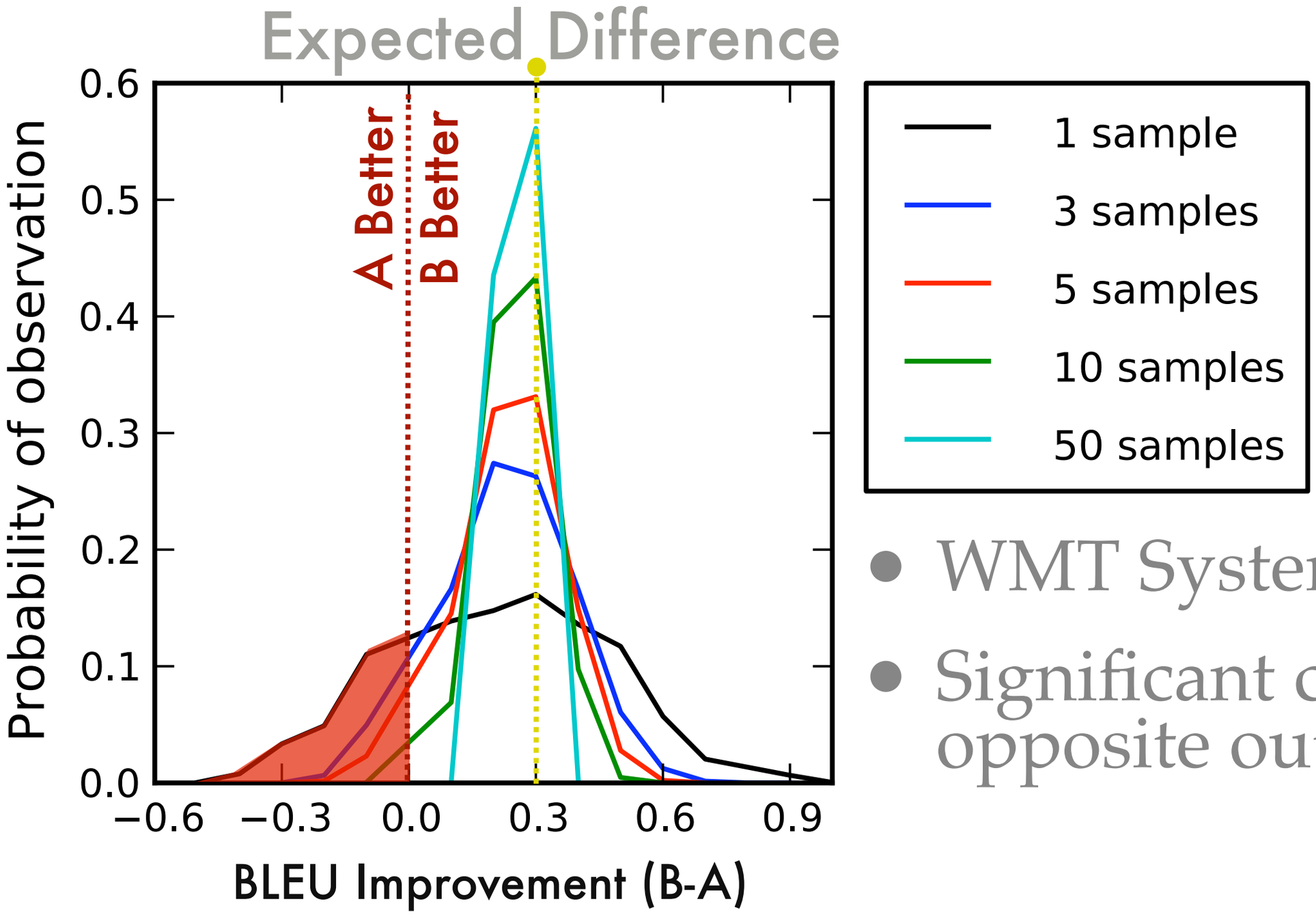
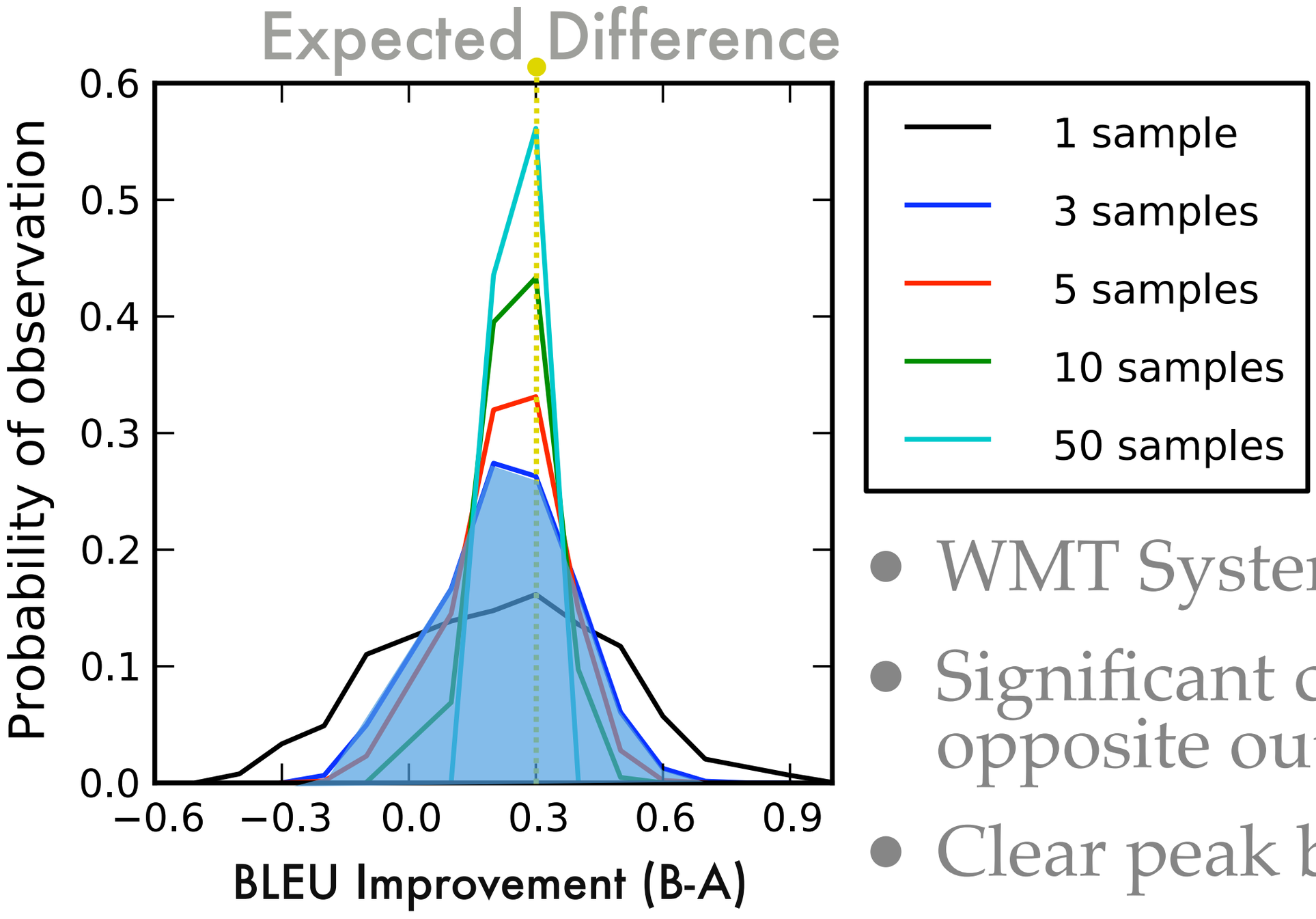


- WMT Systems
- Significant chance of opposite outcome

How Many Runs are Needed?



- WMT Systems
- Significant chance of opposite outcome
- Clear peak by 3

Approximate Randomization

- An approximate permutation significance test

		Set X	Set Y
Optimizer Run 1	Sent 1	Sys A	Sys B
	Sent 2	Sys A	Sys B
	Sent 3	Sys A	Sys B

Observed: A - B = 0.3

Approximate Randomization

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		Set X	Set Y
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	Sent 3	Sys A	Sys B
Optimizer Run 3	Sent 1	Sys A	Sys B
	Sent 2	Sys A	Sys B
	Sent 3	Sys A	Sys B

Observed: A - B = 0.3

Approximate Randomization

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		Set X	Set Y	Observed: A - B = 0.3	
Optimizer Run 1	Sent 1	Sys B	Sys A		
	Sent 2	Sys A	Sys B		
	Sent 3	Sys A	Sys B	Simulated Trials	> 0.3?
Optimizer Run 2	Sent 1	Sys B	Sys A	1) X - Y = 0.2	N
	Sent 2	Sys B	Sys A		
	Sent 3	Sys B	Sys A		
Optimizer Run 3	Sent 1	Sys A	Sys B		
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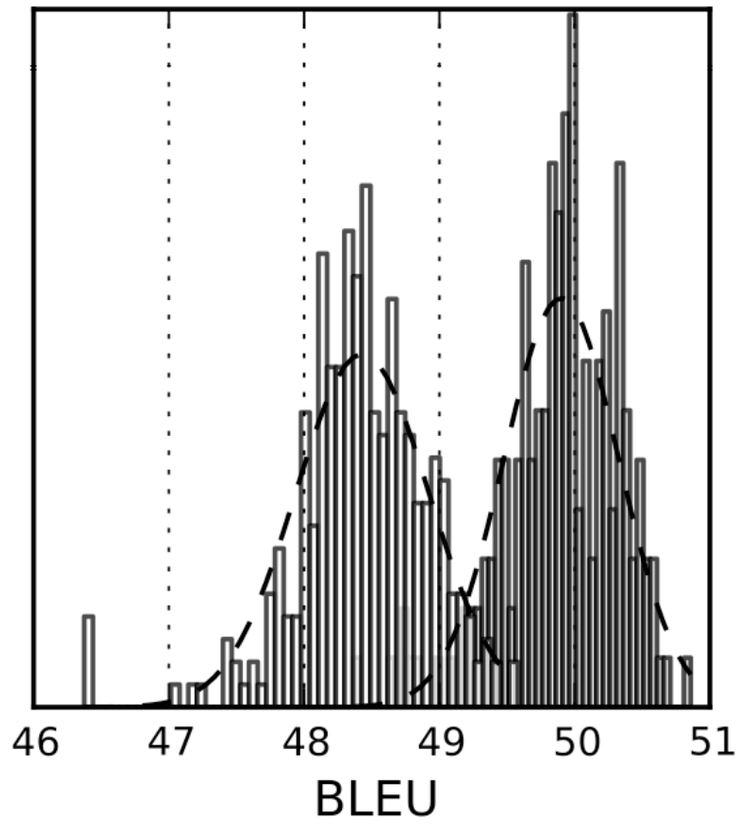
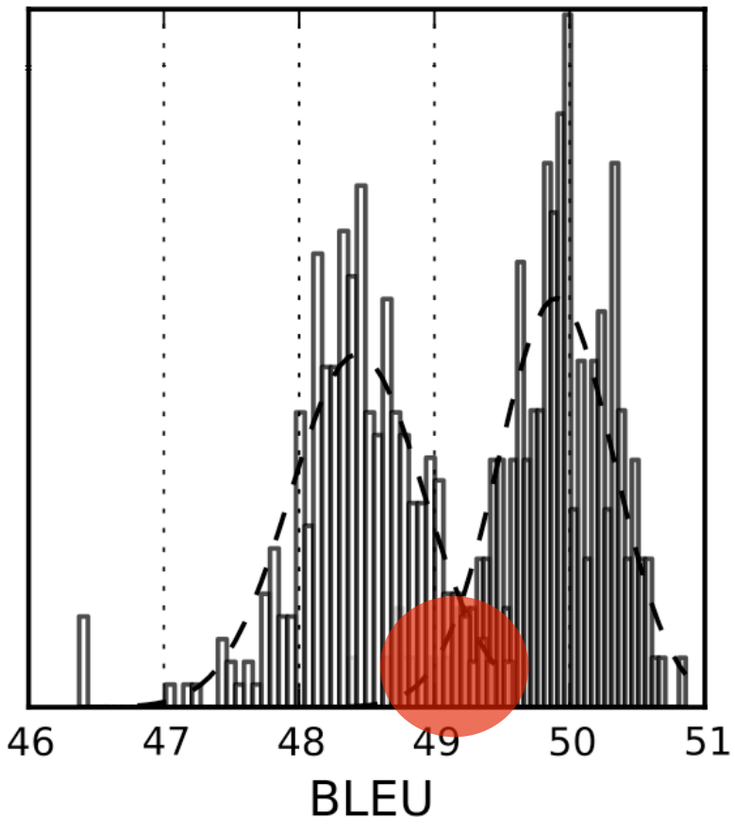
Optimizer Run 3	Sent 1	Sys A	Sys B		
	Sent 2	Sys B	Sys A		
	Sent 3	Sys A	Sys B	*p*-value: *p(by_chance)*	0.67

Sig. Test for Multiple Runs



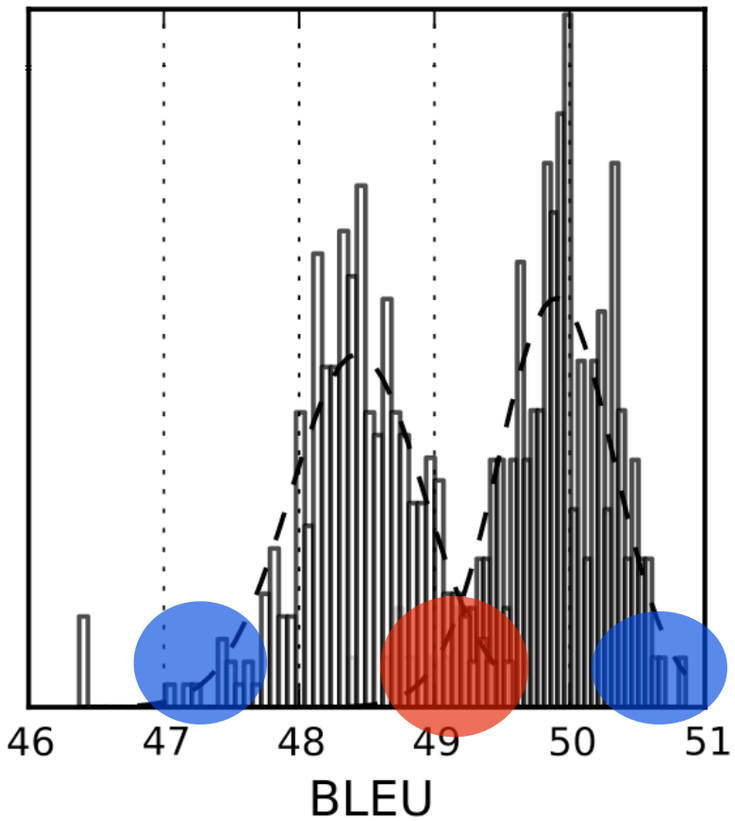
Sig. Test for Multiple Runs

Samples	System A	System B	BTEC *p*-value
1	high	low	0.25



Sig. Test for Multiple Runs

Samples	System A	System B	BTEC *p*-value
1	high	low	0.25
1	low	high	0.0003



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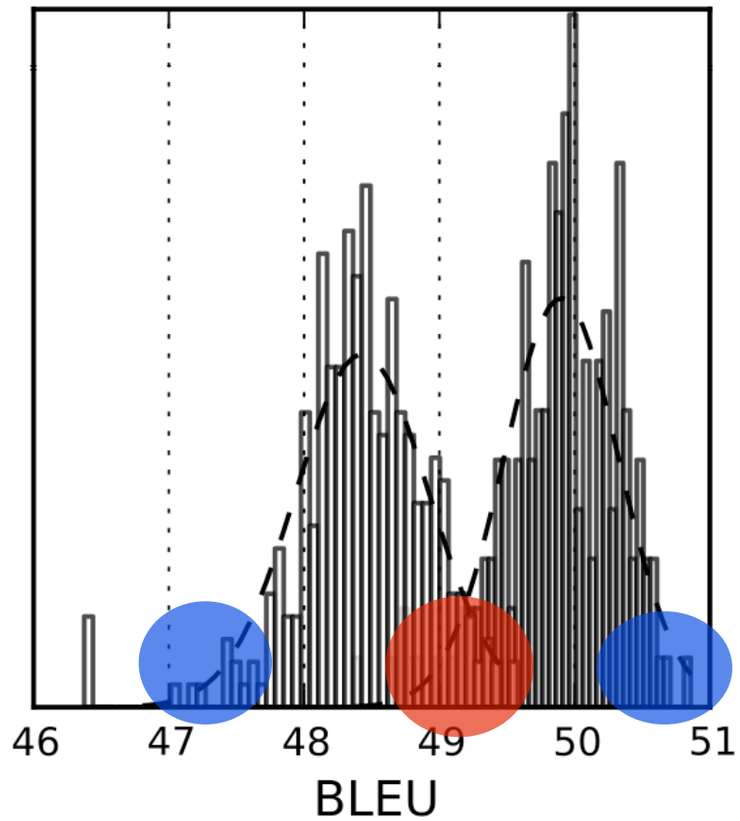
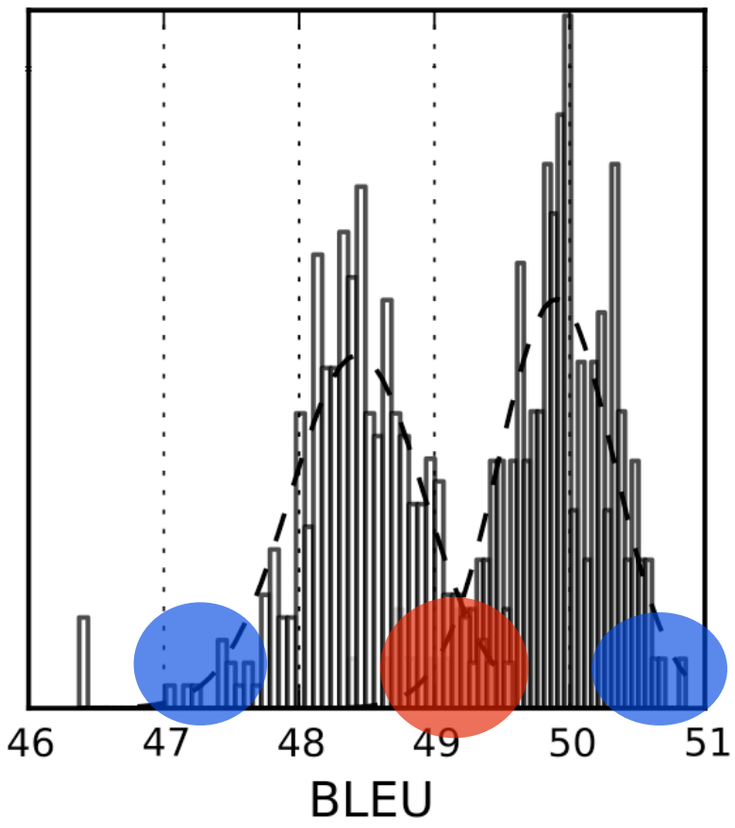


- For small sample sizes, *p*-values vary wildly, even when the true difference is reasonably large

Sig. Test for Multiple Runs

Samples	System A	System B	BTEC *p*-value
1	high	low	0.25
1	low	high	0.0003
			p-value 95% CI
5	random	random	0.001 - 0.034



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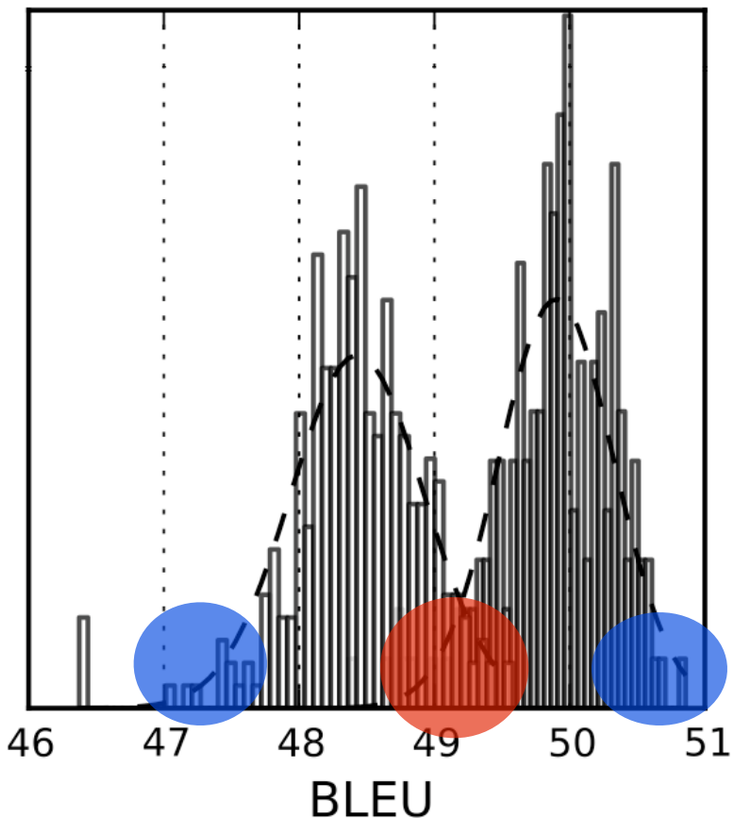
1	low	high	0.0003
			p-value 95% CI
5	random	random	0.001 - 0.034
50	random	random	0.001 - 0.001



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Closing Thoughts

- We can't escape all confounding variables, but reporting bad results is a big gamble
- But single samples are bad, so:

→ Run your optimizer 3^+ times,
decode with each of these weight vectors,
and score the results

→ Report average and variance of these scores

→ Report significance w.r.t. multiple runs

Questions?

- Software at www.github.com/jhclark/multeval
  - BLEU, METEOR, and TER included
- Variance and *p*-values
- Runs within seconds
- Plaintext in. LaTeX out.