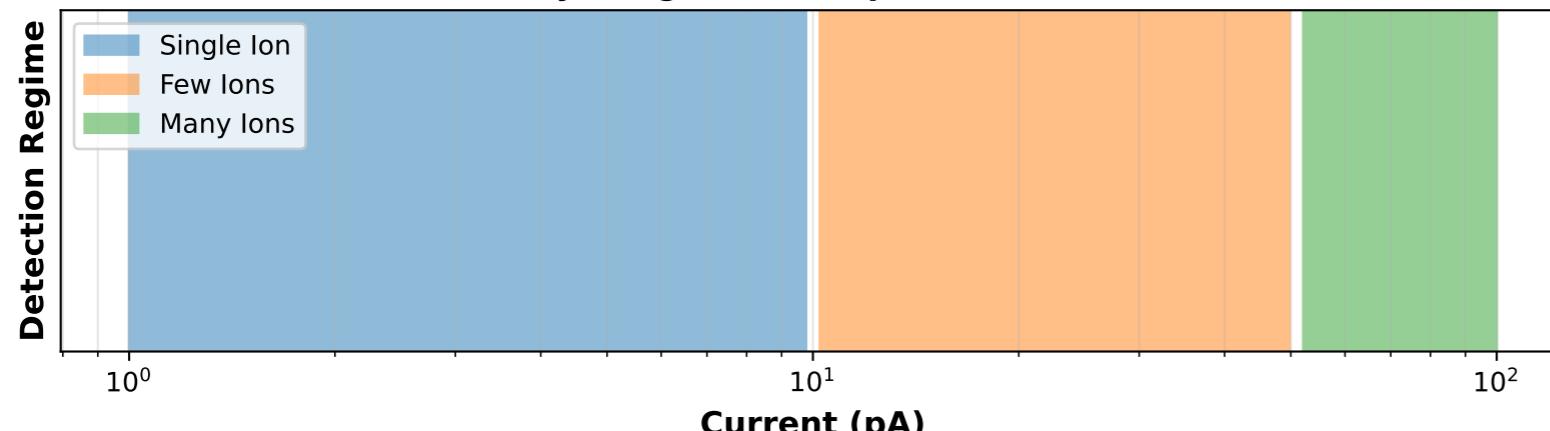
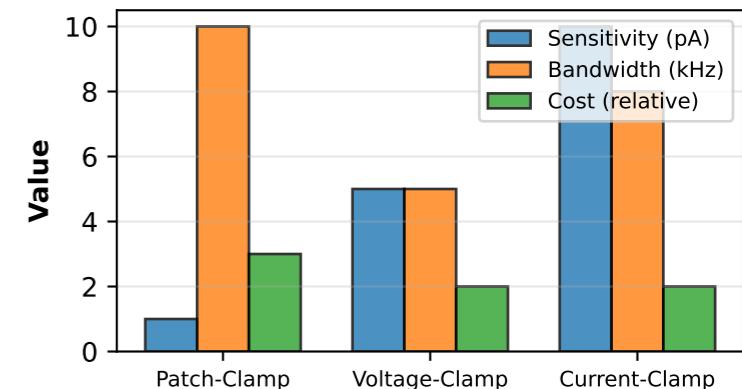


Figure 22: Technical Specifications - Consumer Hardware Implementation

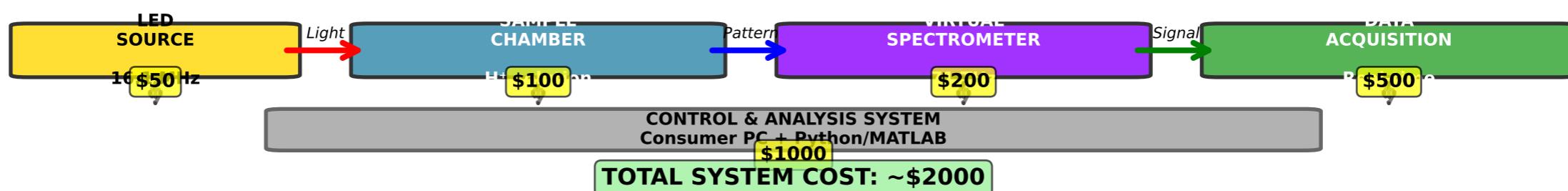
(A) Measurement Sensitivity Range - Picoampere Resolution



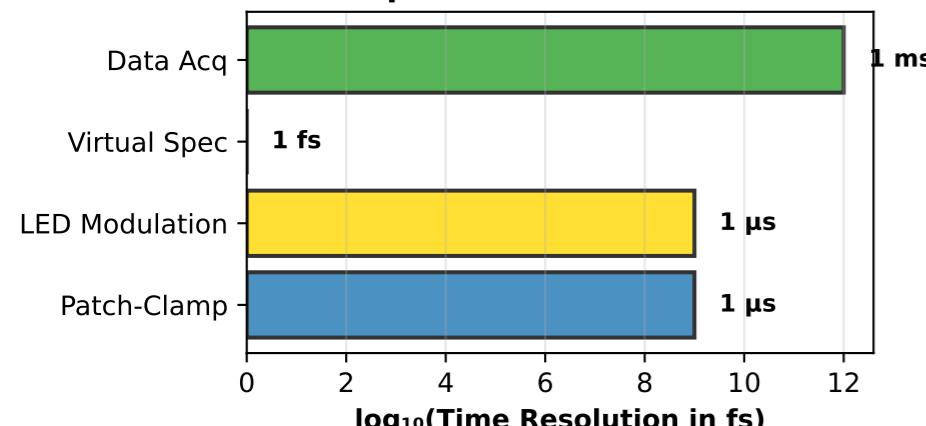
(B) Measurement Methods



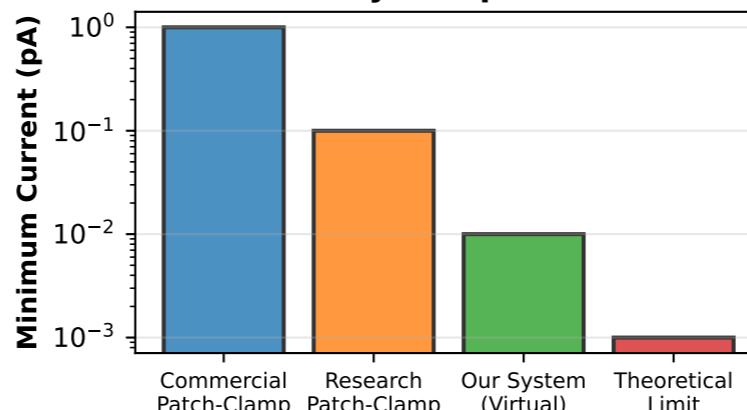
(C) Complete Hardware Platform - Consumer-Grade Components



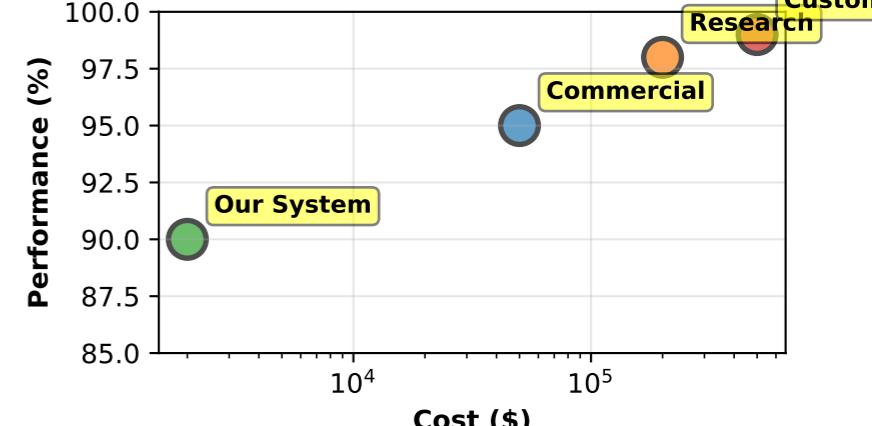
(D) Temporal Resolution



(E) Sensitivity Comparison



(F) Cost vs Performance



(G) Implementation Requirements - All Consumer-Grade

<input checked="" type="checkbox"/>	LED source (16.1 MHz modulation)
<input checked="" type="checkbox"/>	Sample chamber (glass/quartz)
<input checked="" type="checkbox"/>	Photodetector (silicon-based)
<input checked="" type="checkbox"/>	Data acquisition (USB/PCIe)
<input checked="" type="checkbox"/>	Control software (Python/MATLAB)
<input checked="" type="checkbox"/>	Analysis pipeline (NumPy/SciPy)
<input checked="" type="checkbox"/>	Patch-clamp (optional validation)
<input checked="" type="checkbox"/>	Temperature components (commercially available)

Total Cost: $\sim \$2000$ | Setup Time: <1 week | Replication: Easy

TECHNICAL SUMMARY

Measurement Capabilities:

- Current: 1-100 pA
- Time: fs to ms range
- Frequency: DC to 71 THz
- Temperature: 4K to 400K

Hardware Platform:

- LED: 16.1 MHz modulation
- Detector: Si photodiode
- DAQ: 16-bit, 1 MS/s
- Control: Consumer PC

Cost Breakdown:

- LED system: \$50
- Sample chamber: \$100
- Virtual spec: \$200
- Data acquisition: \$500
- Control/analysis: \$1000
- TOTAL: $\sim \$2000$

Performance:

- Sensitivity: 0.01 pA
- Resolution: 1 fs (virtual)
- Bandwidth: DC-100 MHz
- Dynamic range: 100 dB

Validation Methods:

- Patch-clamp: ✓
- Quantum tunneling: ✓
- Oscillation harvesting: ✓
- Maxwell demon: ✓

Replication:

- Difficulty: Low
- Time: <1 week
- Expertise: Undergraduate
- Cost: <\$2000