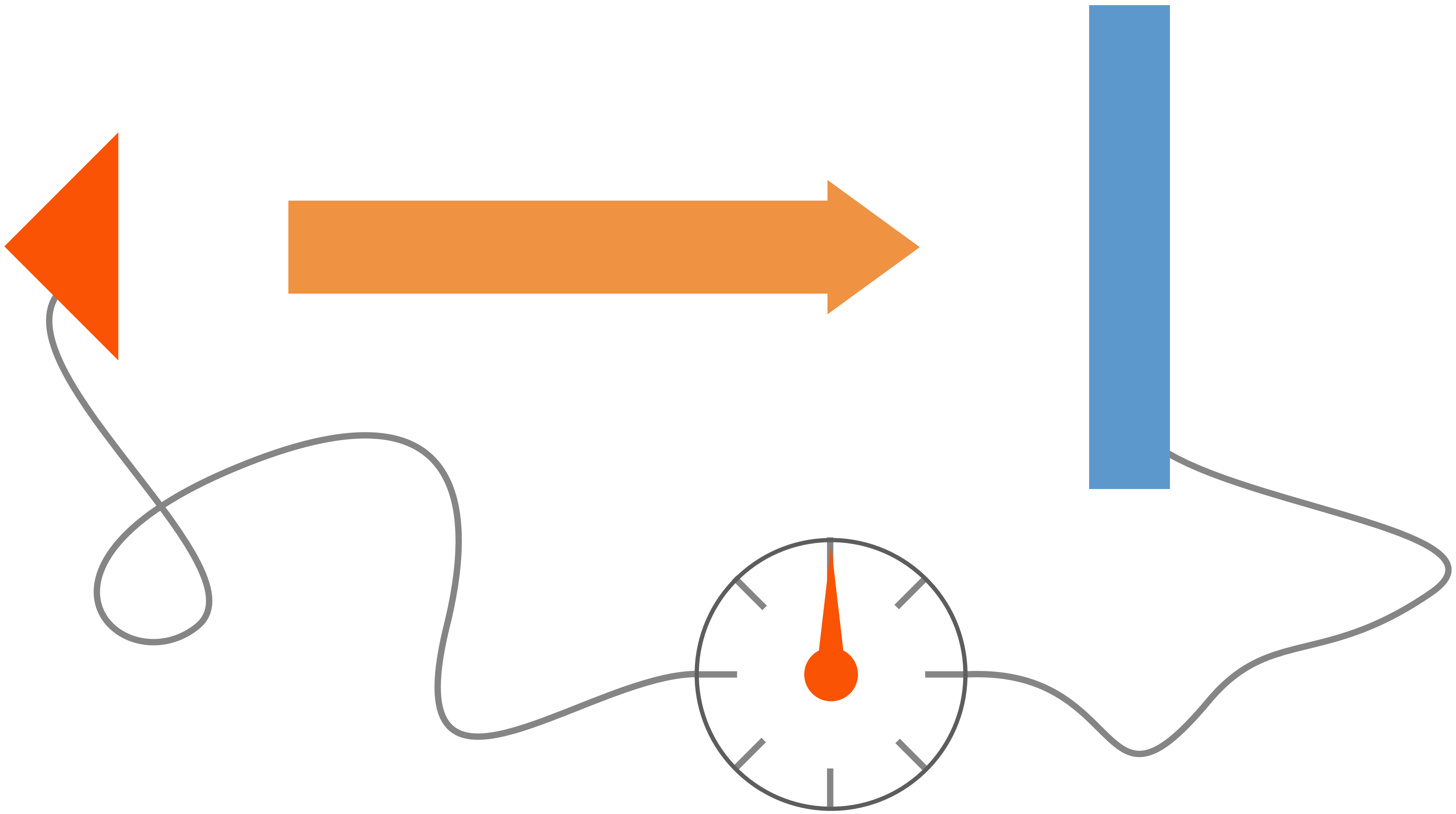
Time Measurement as Test of Quantum Mechanics



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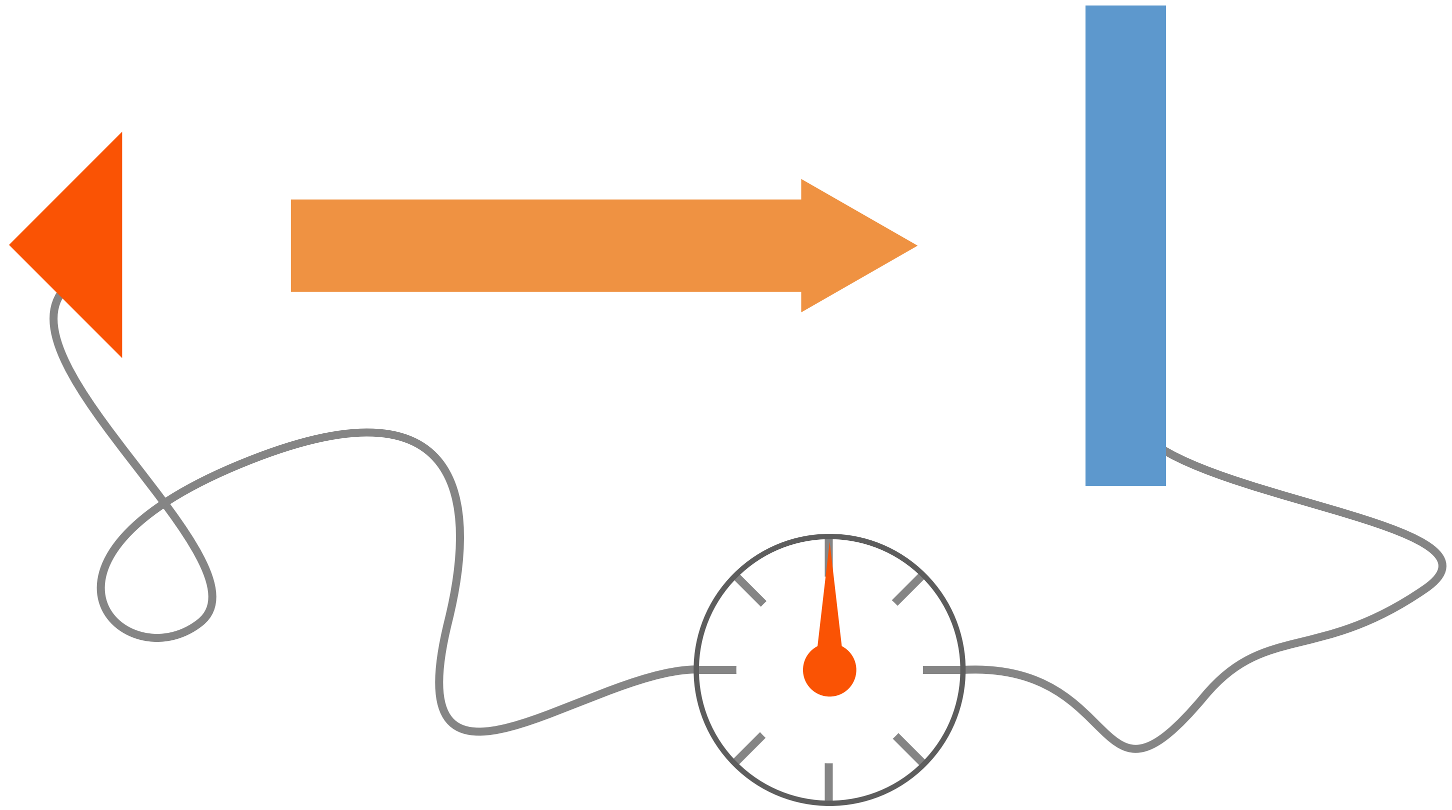
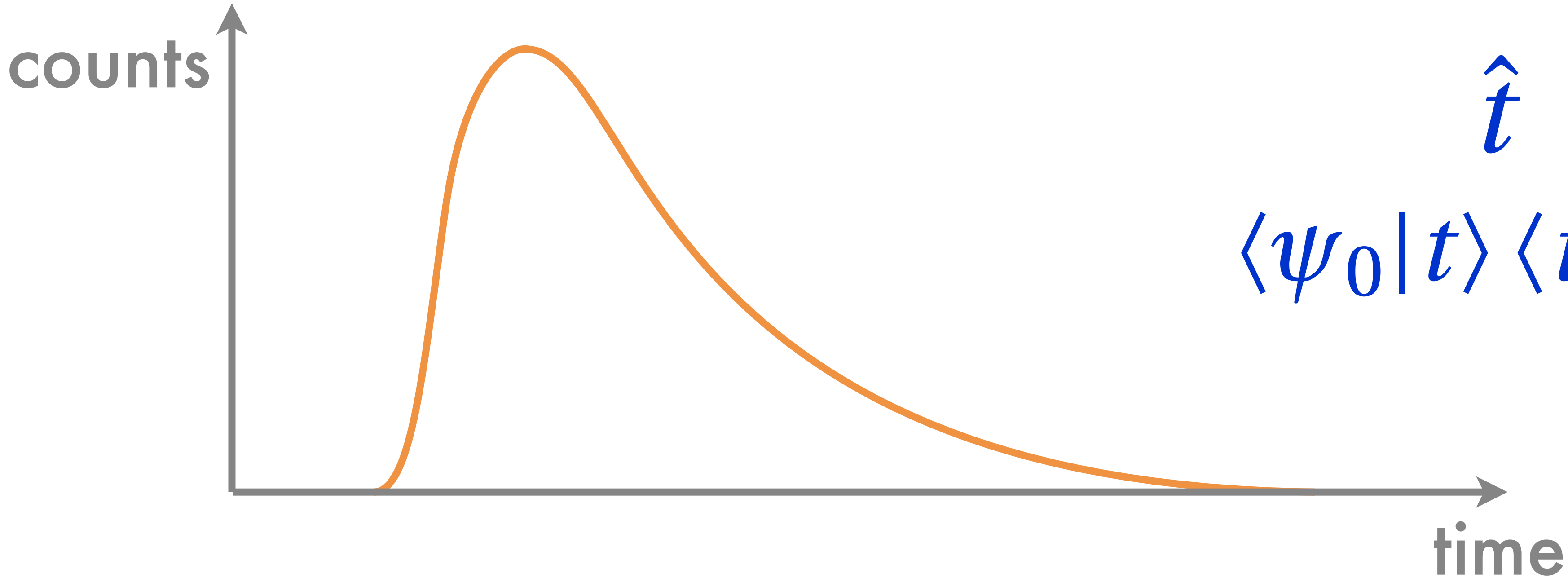
A Time Operator?





$$\hat{t}$$

$$\langle \psi_0 | t \rangle \langle t | \psi_0 \rangle$$

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A Time Operator?

- Schrödinger Equation

$$i\,\underline{\partial_t}\psi(x,t) = -\frac{1}{2}\,\underline{\partial_x^2}\psi(x,t)$$

- Distribution of Measurement Outcomes

$$\langle \psi_{\underline{t}} | a \rangle \langle a | \psi_t \rangle$$

$$t = x/p \quad \Rightarrow \quad 2\,\hat{t} = \hat{x}\,\hat{p}^{-1} + \hat{p}^{-1}\,\hat{x}$$

$$\Rightarrow \quad \Pi_Q(t) = \sum_{\alpha = L,R} \langle \psi_0 | t, \alpha \rangle \langle t, \alpha | \psi_0 \rangle$$

$$L \rightarrow p \geq 0 \qquad R \rightarrow p \leq 0$$

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Is the POVM Helping Us?

$$\langle \psi_t | a \rangle \langle a | \psi_t \rangle$$

- In Quantum Mechanics this structure is fundamental
- In Bohmian Mechanics it is incidental

Does it keep us on the right track,
or does it narrow our view?

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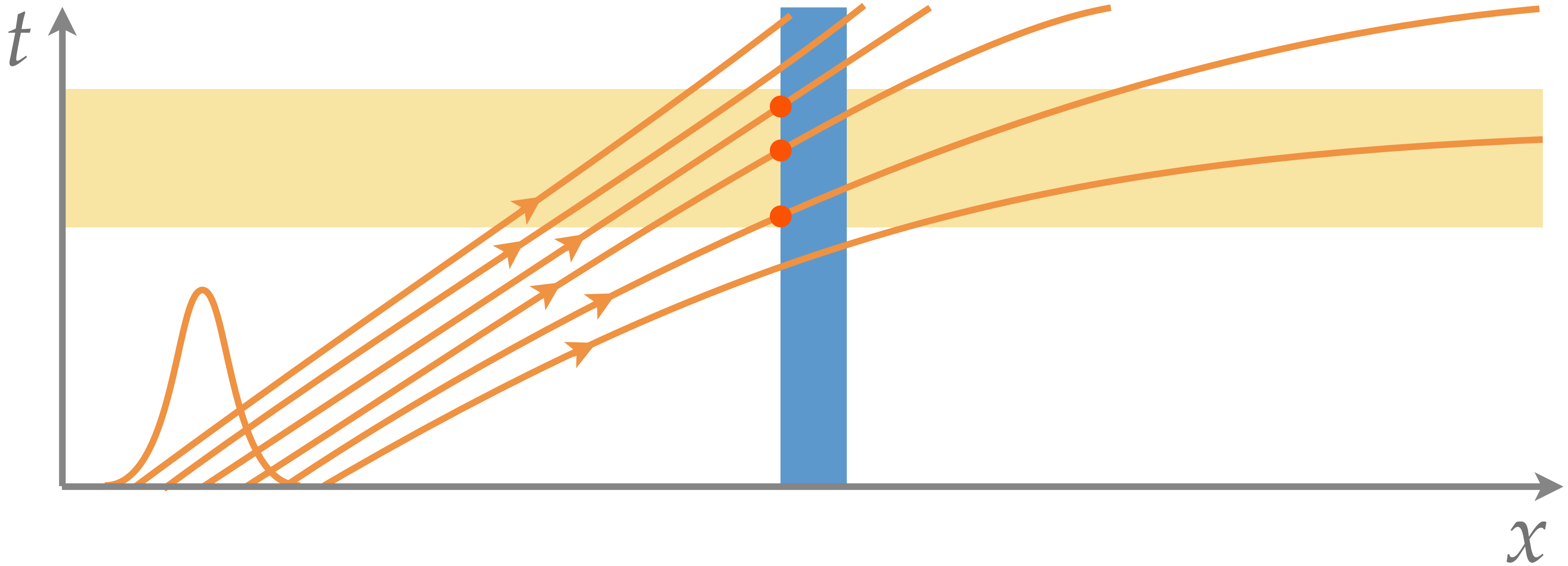
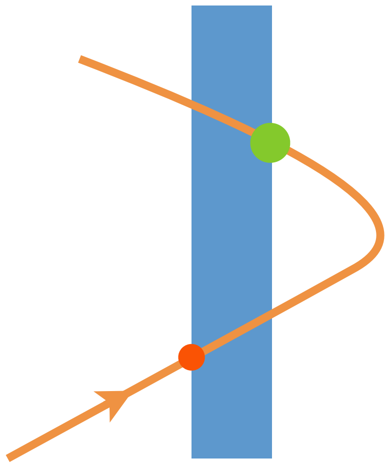
The Bohmian Solution



$$\Pi_B(t) = j_t = \operatorname{Im} \psi_t^* \partial_x \psi_t$$

$$\partial_t \rho_t(x) + \nabla \cdot j_t(x) = 0$$



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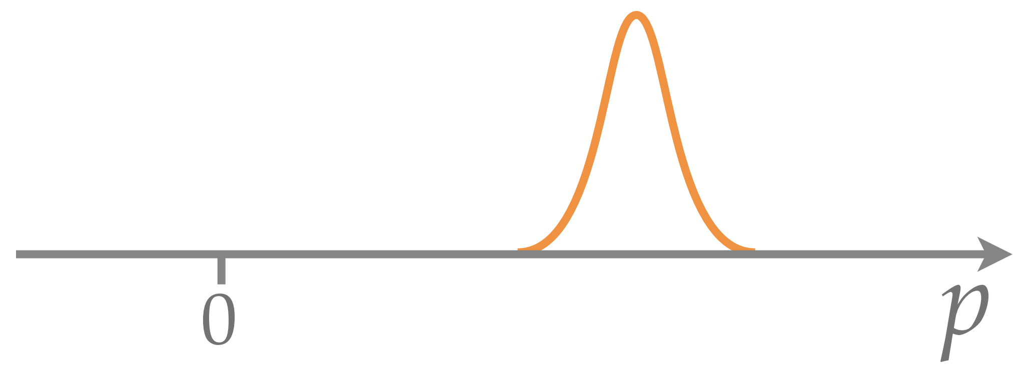
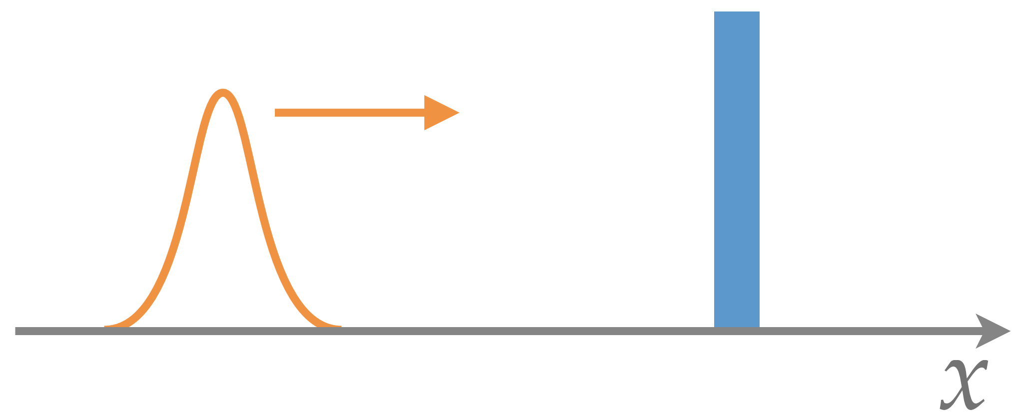
The Comparison

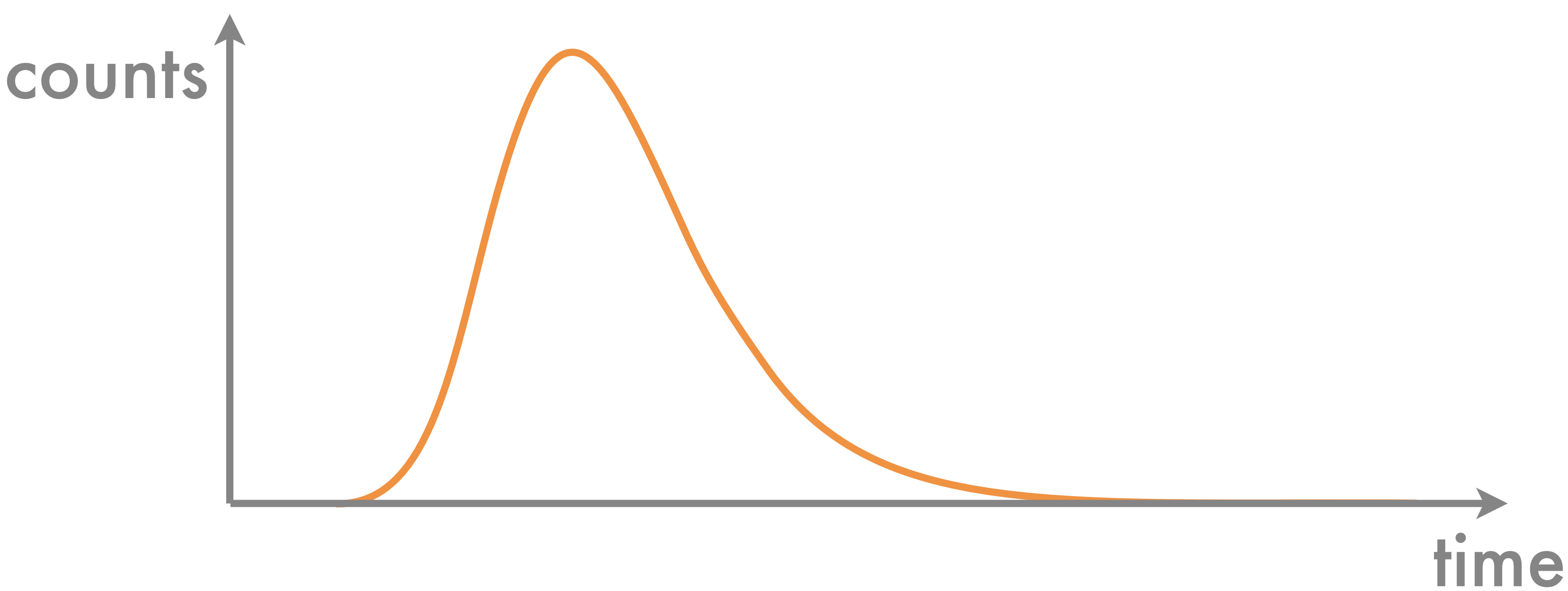
$$\Pi_Q(t) = \sum_{\alpha=L,R} \langle\psi_0|t,\alpha\rangle\,\langle t,\alpha|\psi_0\rangle$$

$p \geq 0$ $\qquad$ $p \leq 0$



$$\Pi_B(t) = j(t) = \mathrm{Im}\,\psi_t^*\partial_x\psi_t$$





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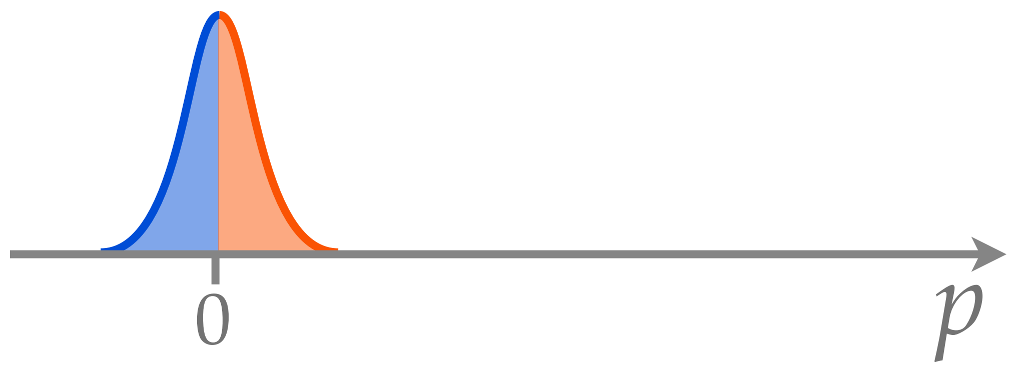
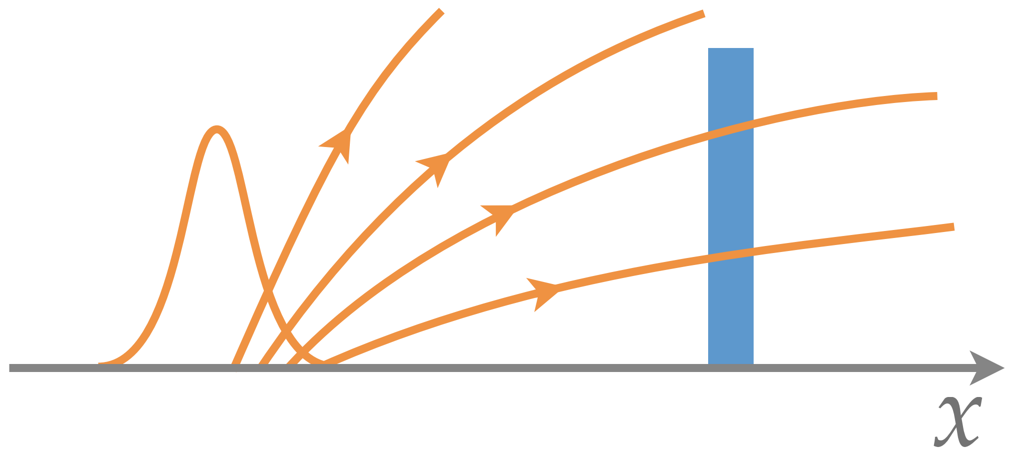
The Comparison

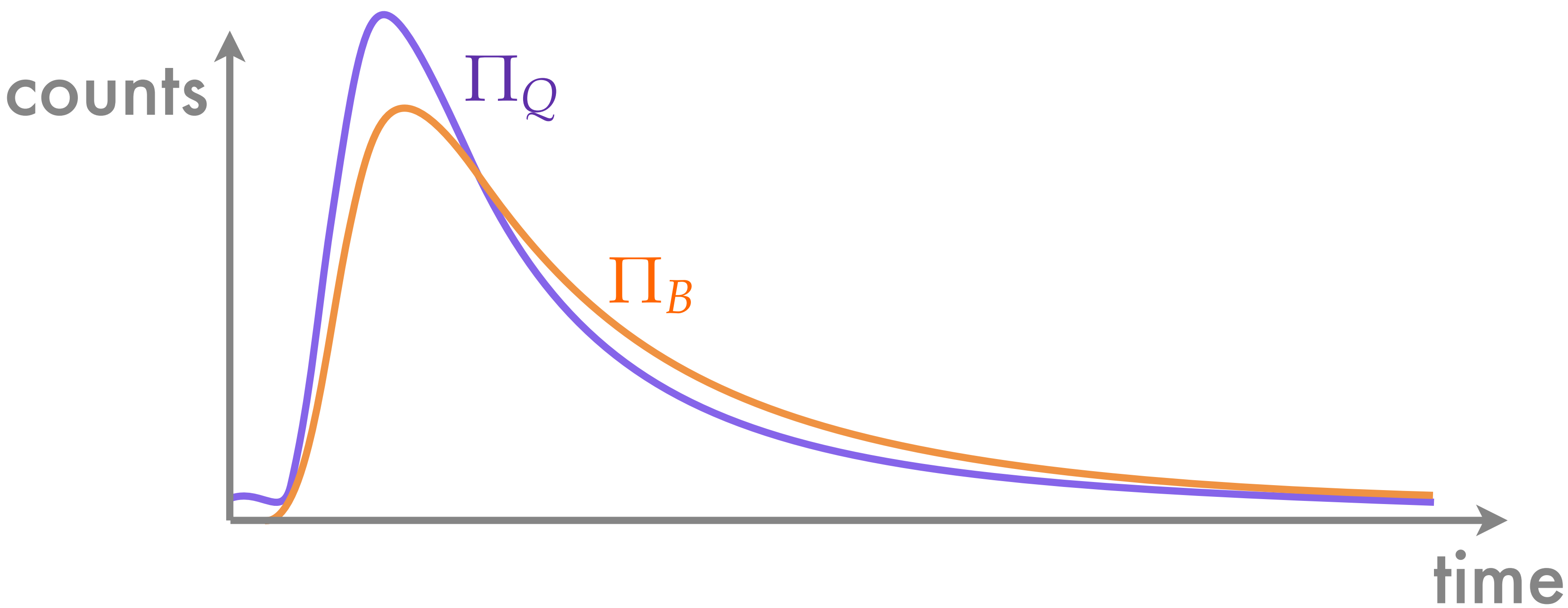
$$\Pi_Q(t) = \sum_{\alpha=L,R} \langle \psi_0 | t, \alpha \rangle \langle t, \alpha | \psi_0 \rangle$$

$p \geq 0$ (for L) $\qquad p \leq 0$ (for R)



$$\Pi_B(t) = j(t) = \operatorname{Im} \psi_t^* \partial_x \psi_t$$





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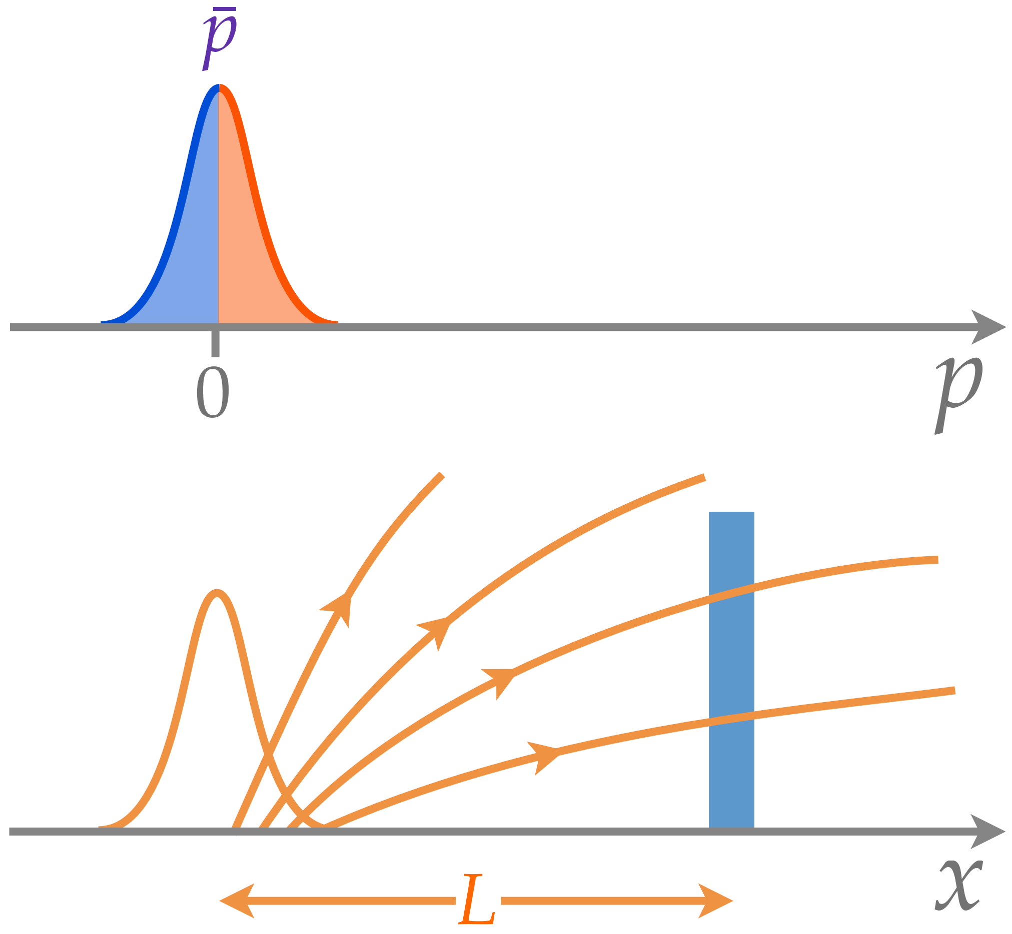
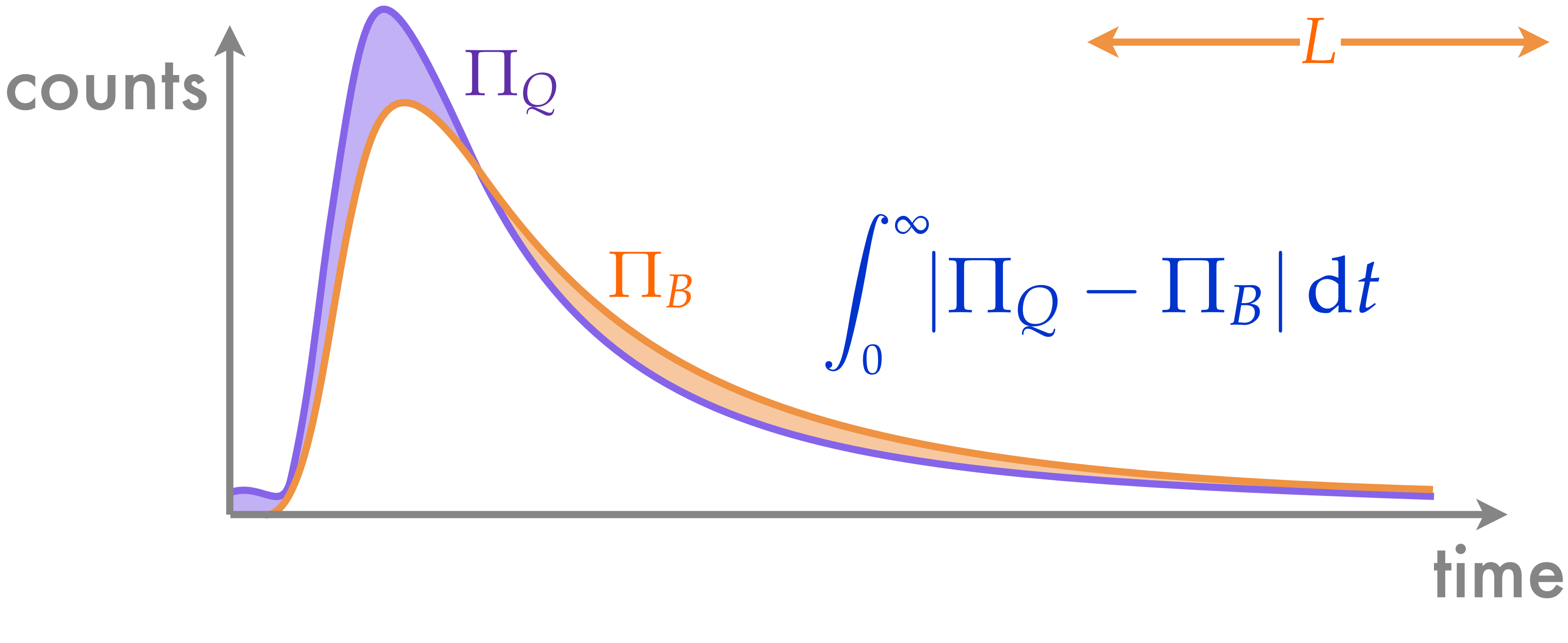
The Comparison

$$\langle \psi_{t} | a \rangle \langle a | \psi_{t} \rangle$$

Does it keep us on the right track, or does it narrow our view?





$$\int_0^\infty |\Pi_Q - \Pi_B| \, \mathrm{d}t$$

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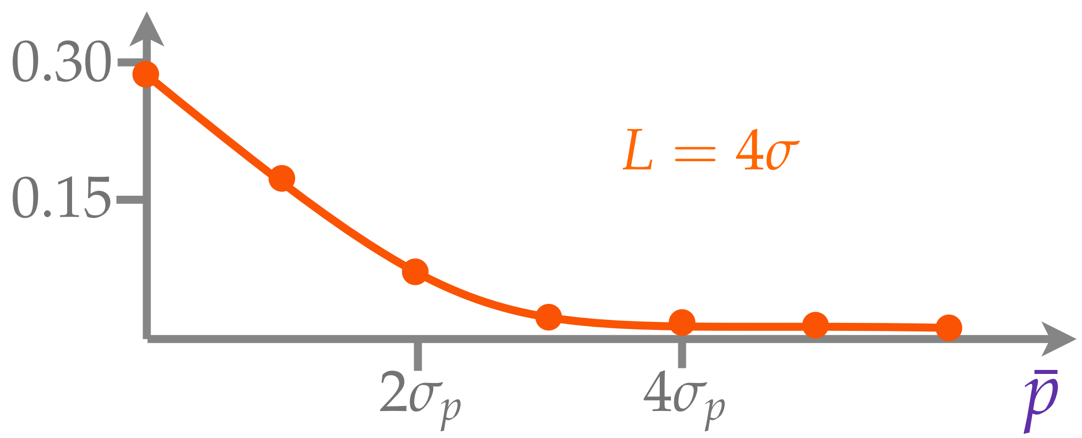
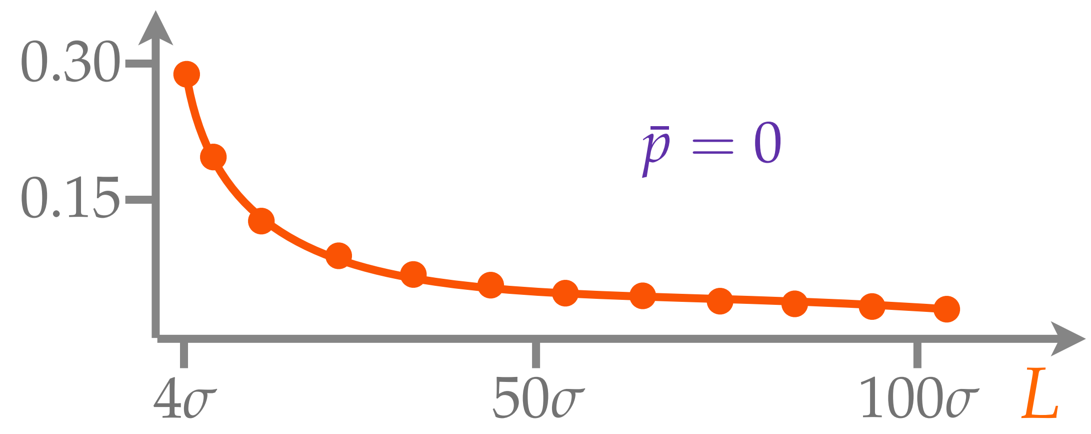
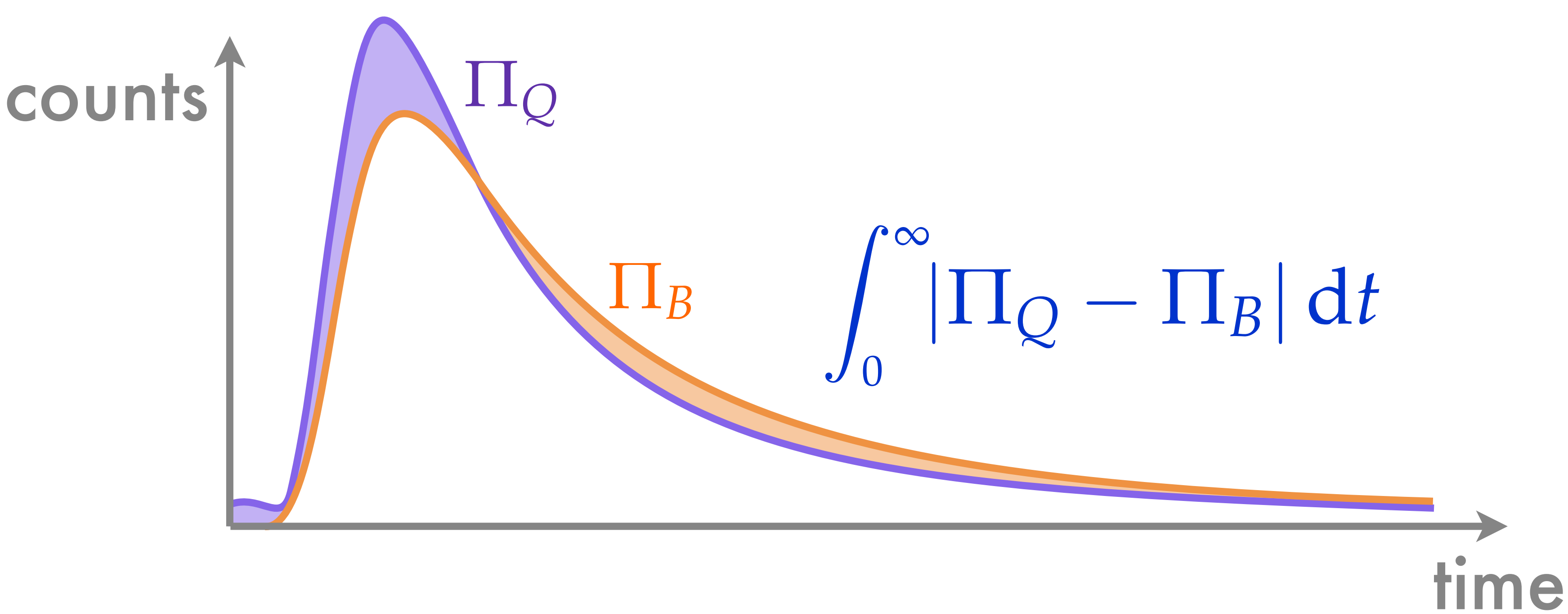
The Comparison





$\sigma \sim \text{Å}$ $\quad L \sim 10\text{Å}$ $\quad \sigma_p = \dfrac{\hbar}{2\sigma} \sim \text{keV}/c$ $\quad \Delta t \approx \dfrac{10 m \sigma L}{\hbar} \sim 10\text{ps}$



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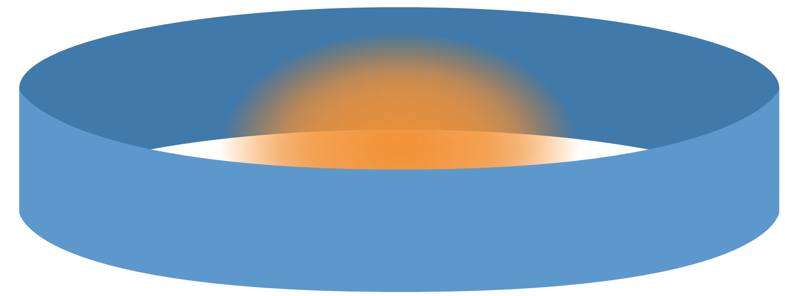
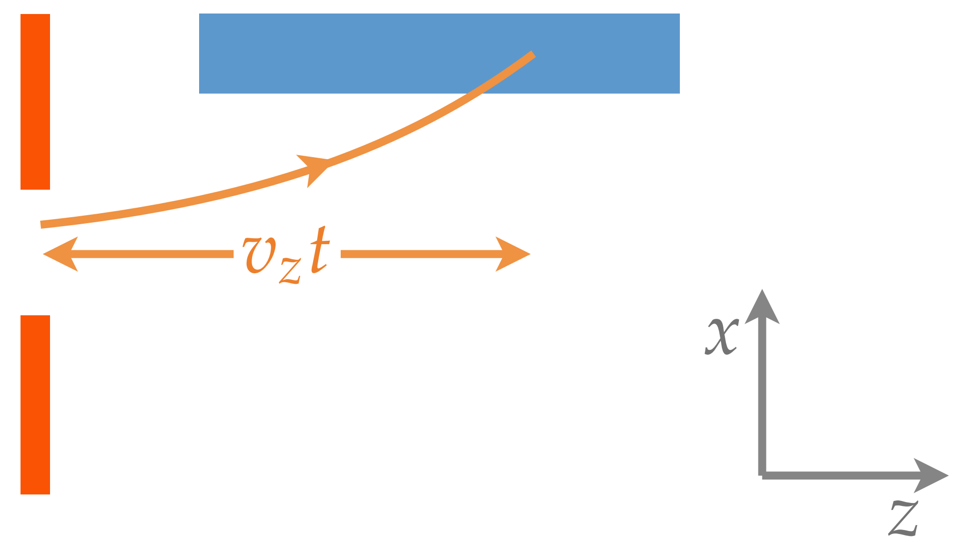
Perspectives…

- Use a Bose-Einstein Condensate



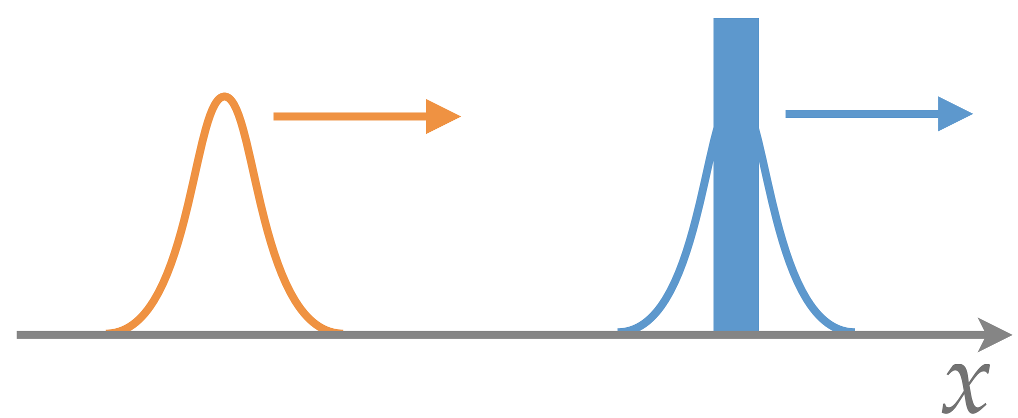
- Look at the transversal motion of a beam after a slit

$$\bar{p}_x \ll \sigma_{px} \qquad \bar{p}_z \gg \sigma_{pz}$$



- Use a particle as detector

$$\bar{p} \gg \sigma_p > \Delta\bar{p}$$



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