Beyond I&D:
Prelude to an Information Theory of the Future

Towards a strong converse for the quantum capacity (of degradable channels)

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- in preparation -

Outline

1. Quantum channel capacity

2. LSD capacity formula and weak converse

3. Strong converse - and why you would care

4. Additivity for degradable channels

5. "Semi-strong" converse and proof ideas

6. Open question(s)...

1. Quantum channel capacity

Channel = cptp map $\mathcal{N}: L(A) \longrightarrow L(B)$.

Stinespring: $\mathcal{N}(\rho) = \mathrm{Tr}_E \, V \rho V^\dagger$,

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$\mathcal{N}$ is degradable if there exists a cptp map $\mathcal{D}$ s.t. $\widehat{\mathcal{N}} = \mathcal{D} \circ \mathcal{N}$.

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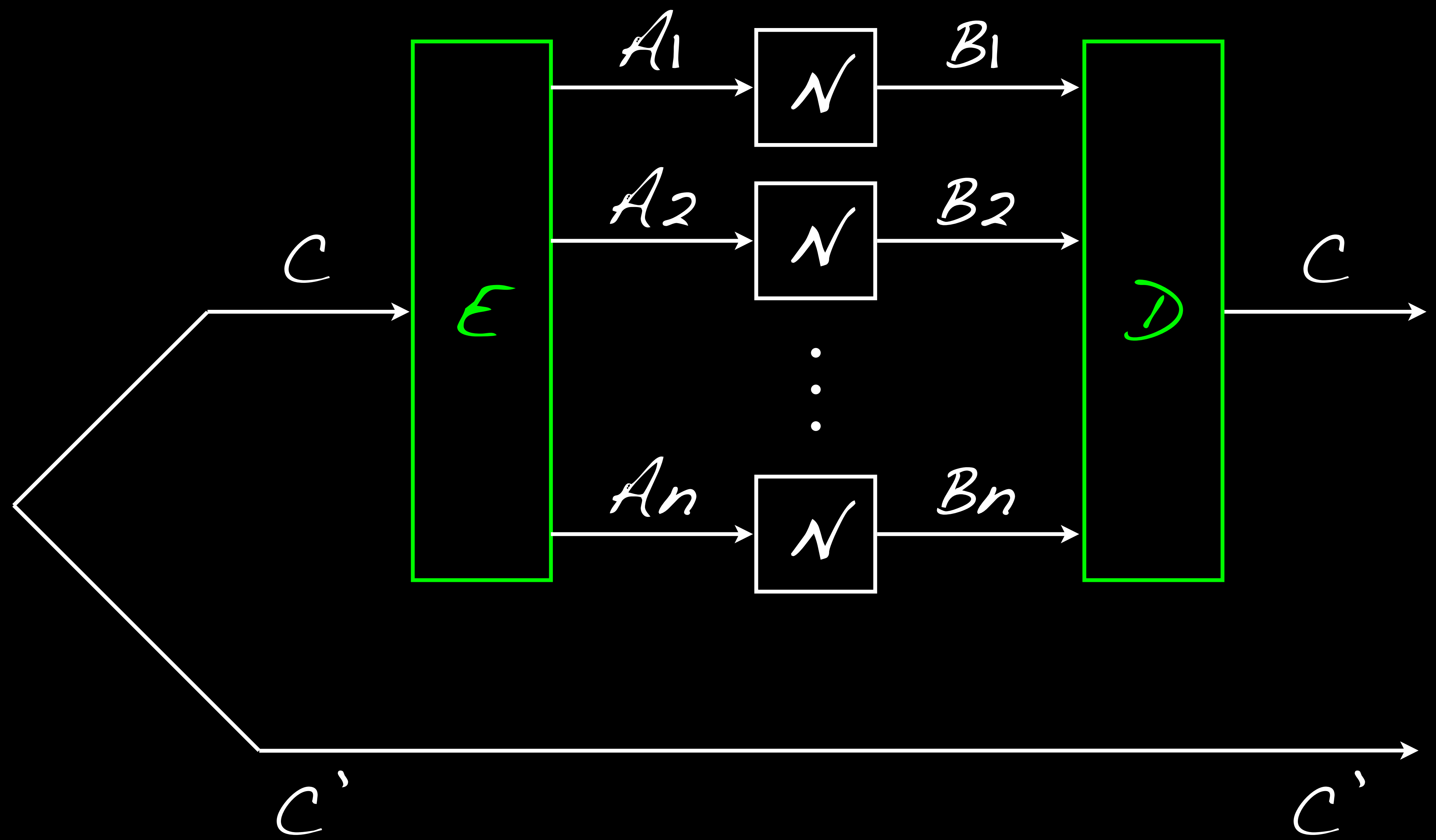
Note: Both are equivalent to the trace distance $\|\rho-\sigma\|_1$.

With cptp en- and decoding operations $\mathcal{E}, \mathcal{D}$:



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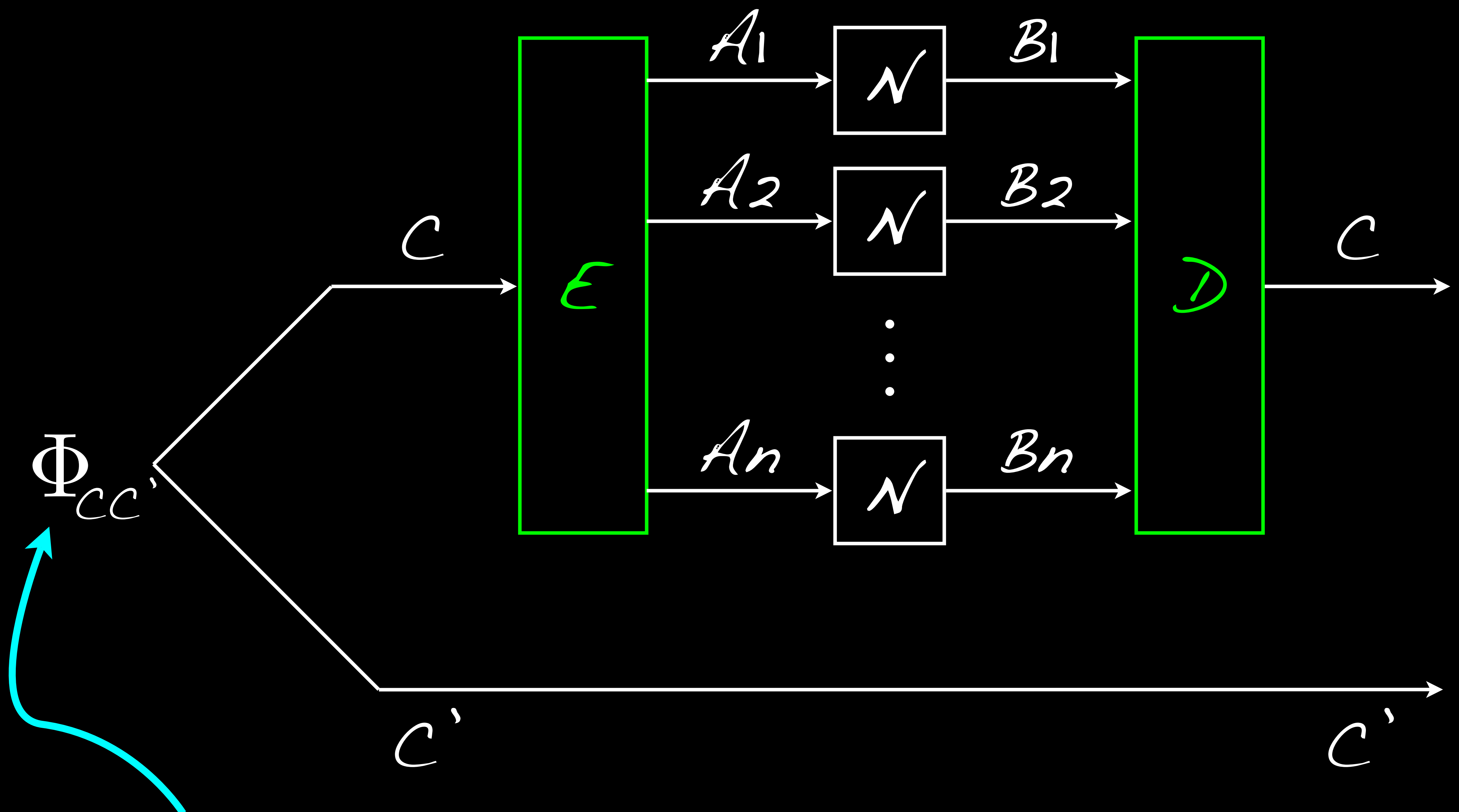

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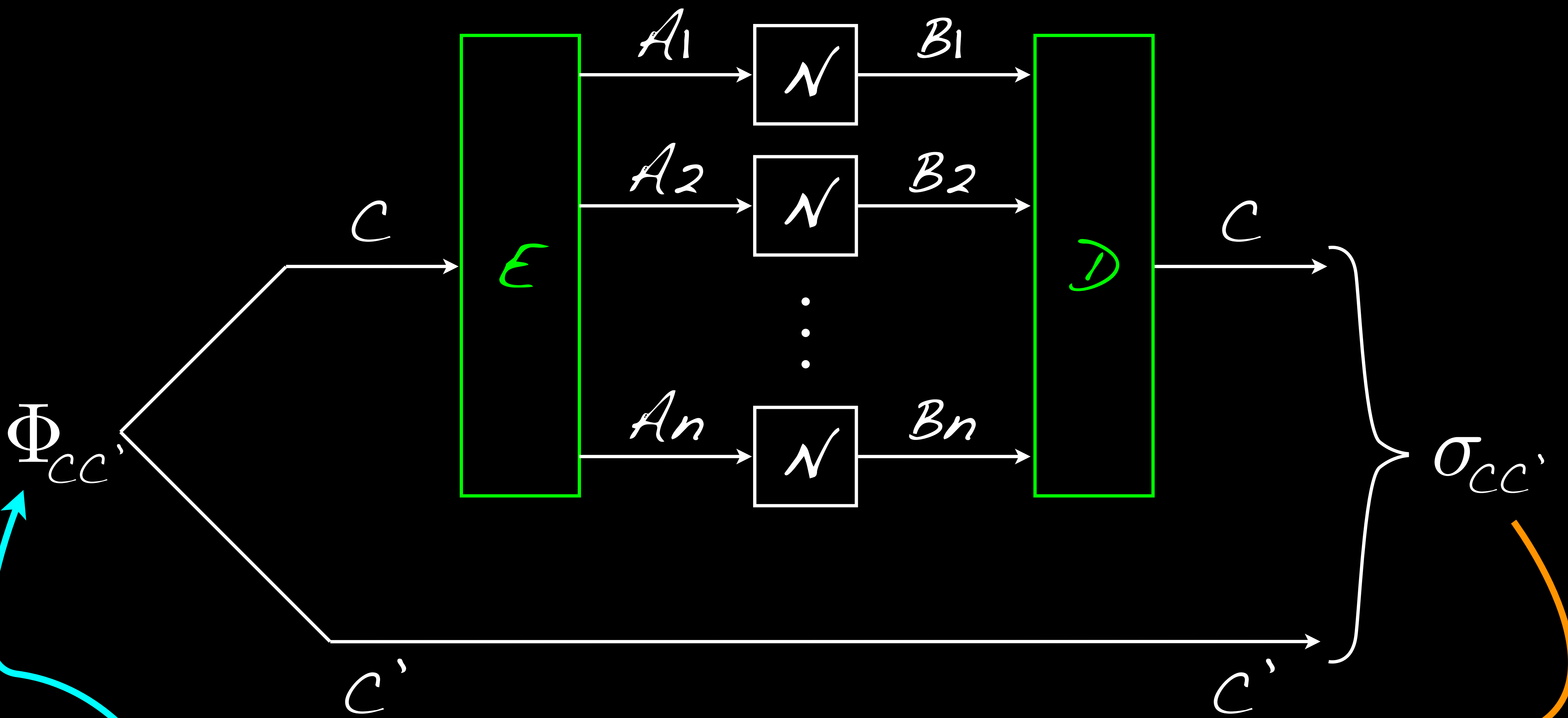

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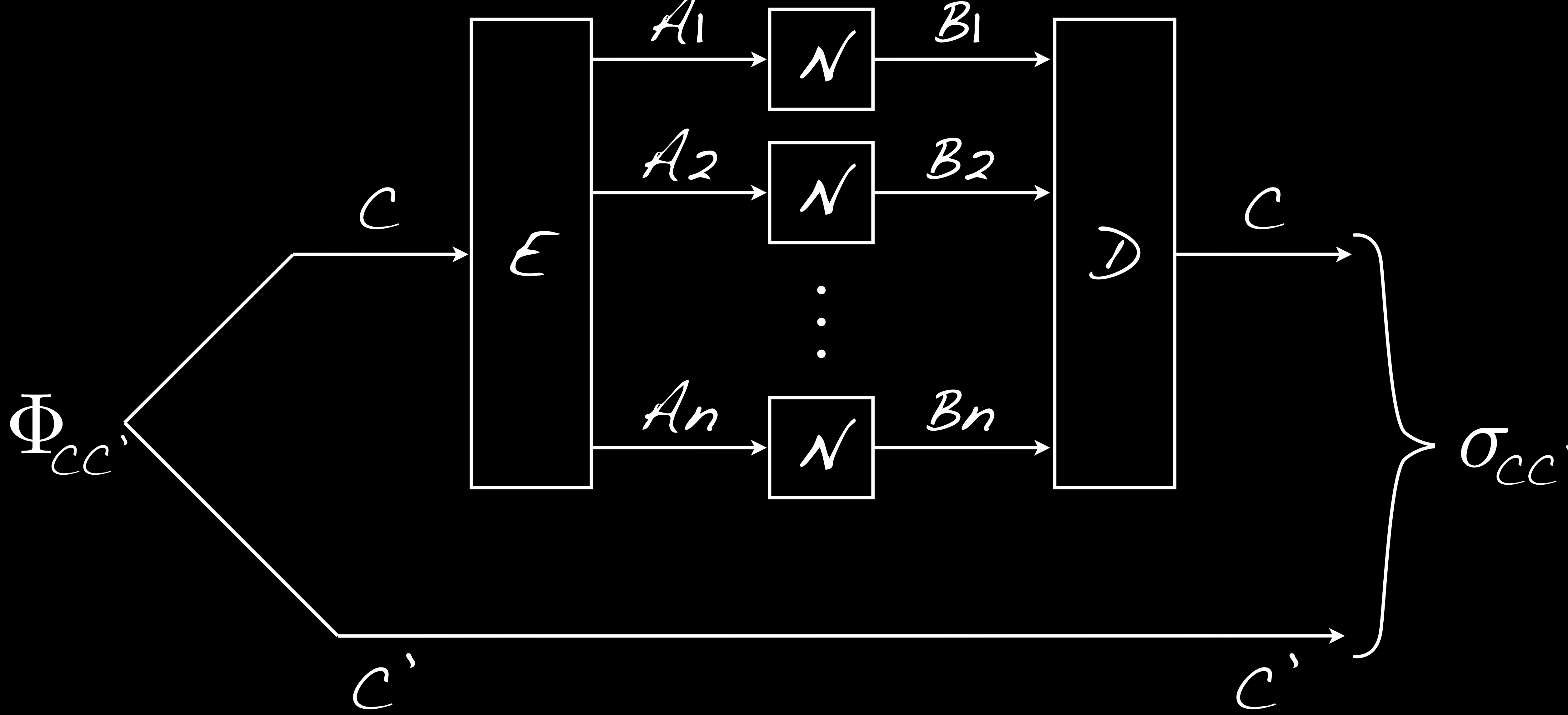
Approximates input:

$P(\Phi, \sigma) \leq \epsilon$.



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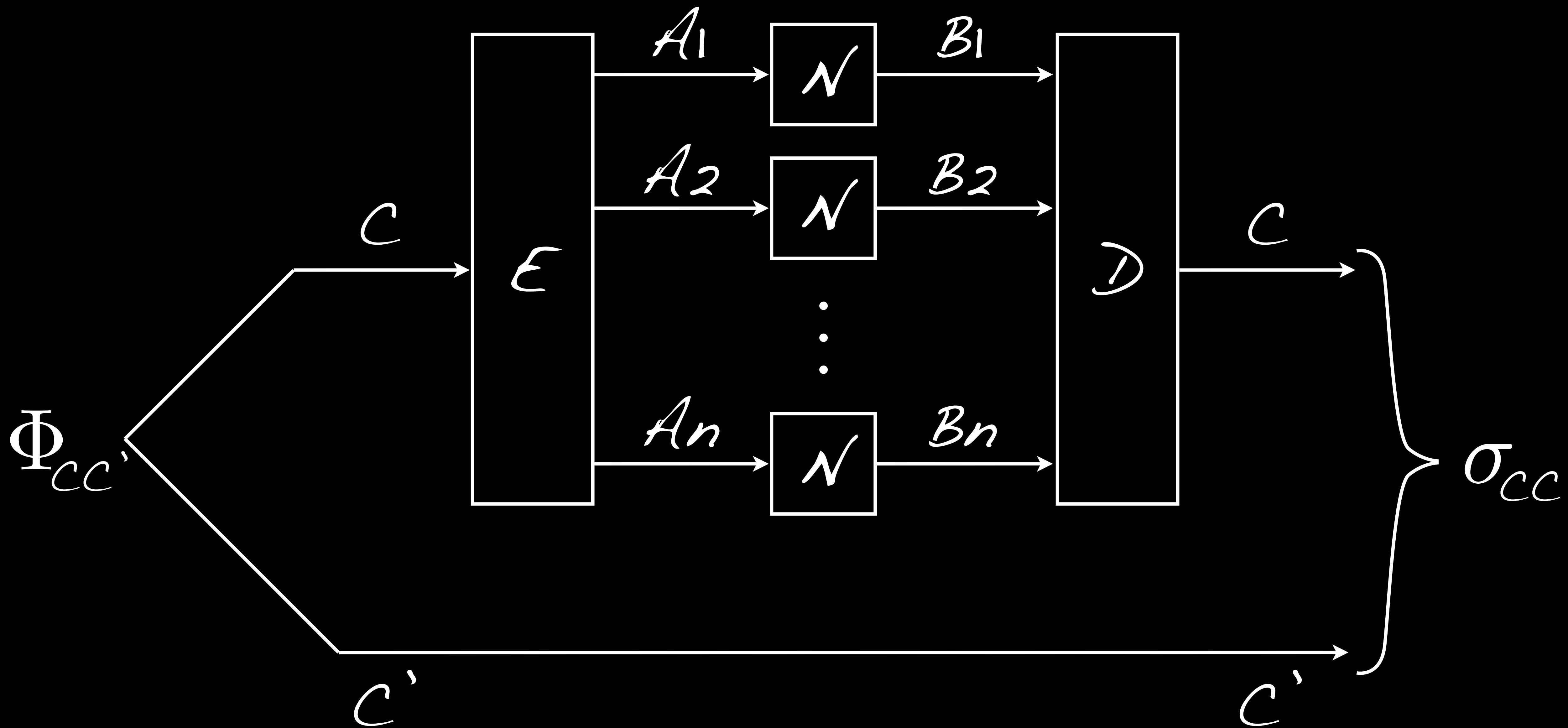

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[Cf. D. Kretschmann & R.F. Werner, NJP 6:26 (2004).]

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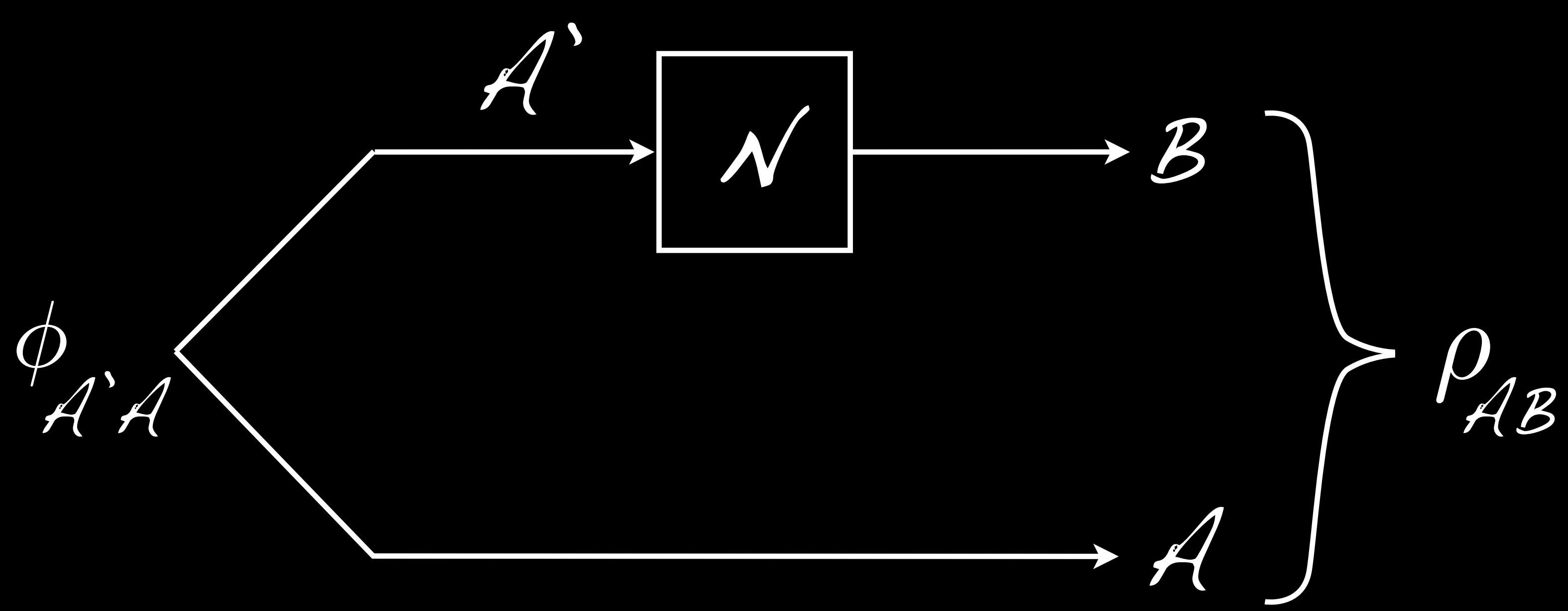

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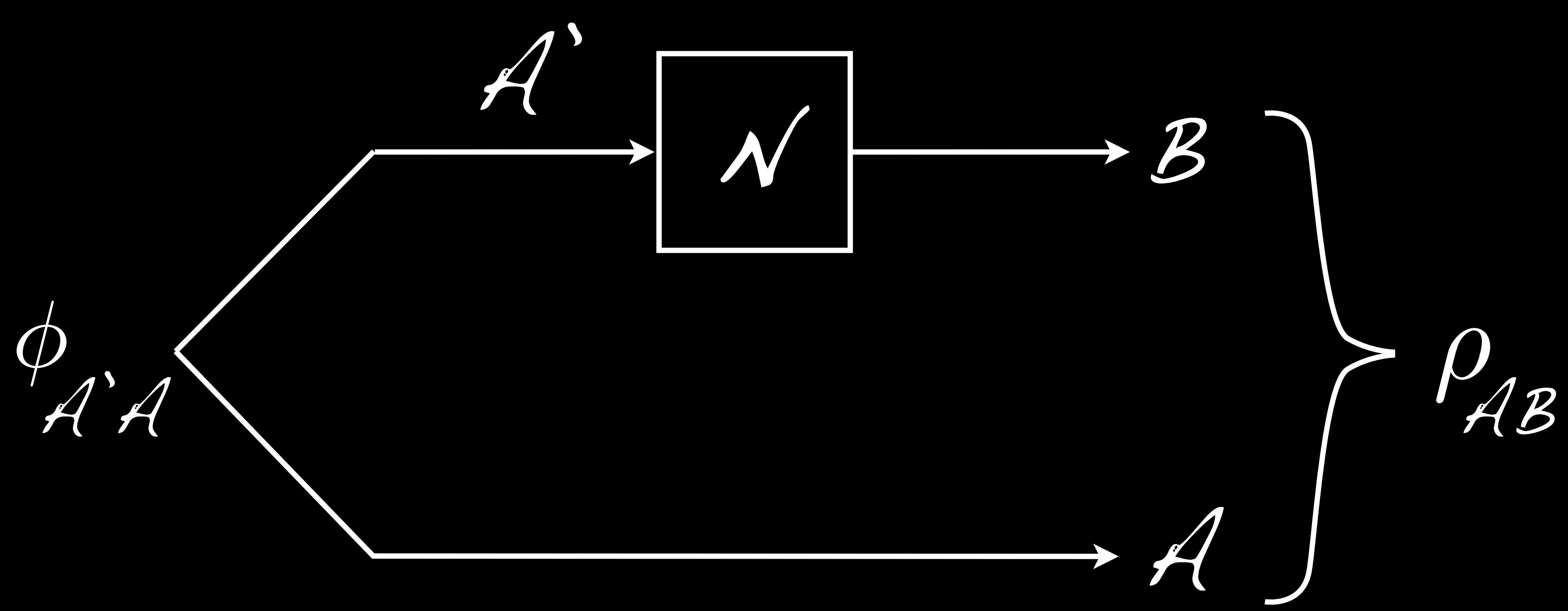

$I(A\rangle B) = -S(A|B)$

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Note: For rates $R = \frac{k}{n} < Q(\mathcal{N})$, i.e. below the capacity, the LSD (random) coding theorem guarantees error exponentially small in n!

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The strong converse – in the sense of Wolfowitz [Ill. J. Math. 1:591 (1957)] –, is the statement that there is no rate-error trade-off. Viz., for rates R above the capacity, the error converges to 1.

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- Entanglement-assisted capacity [Bennett et al., 0912.5537]

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Applications: E.g. bounded/noisy storage quantum cryptography...

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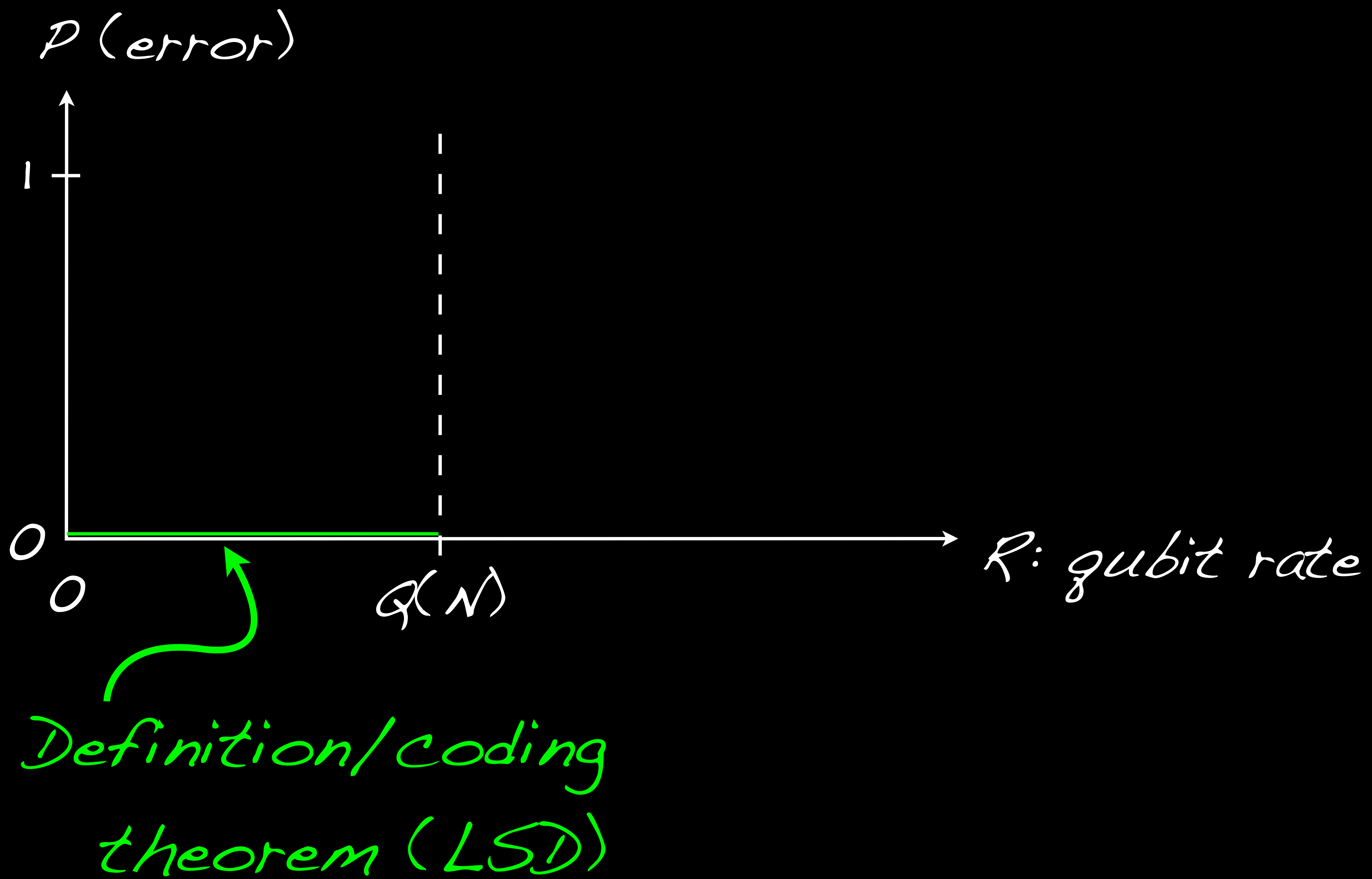

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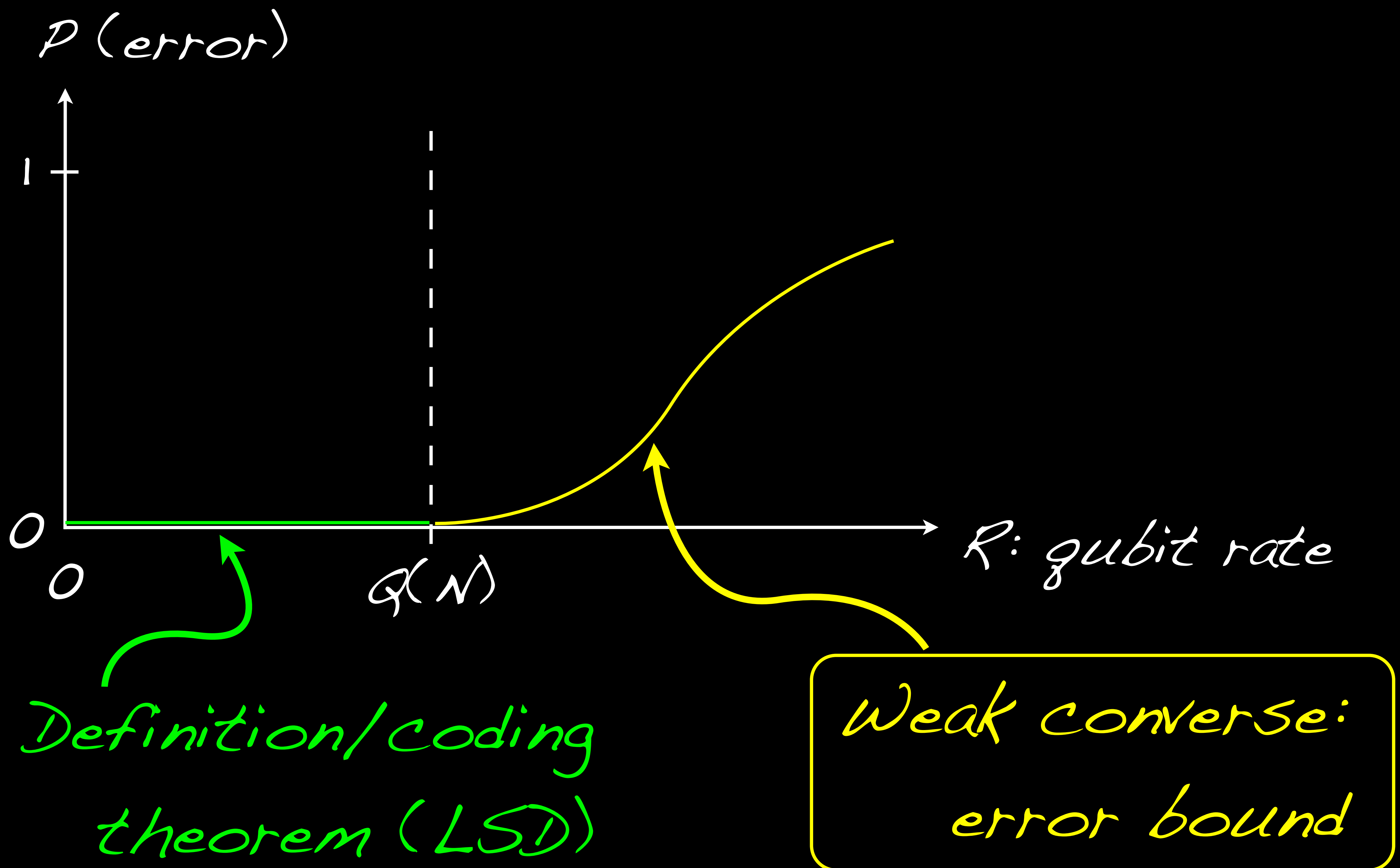

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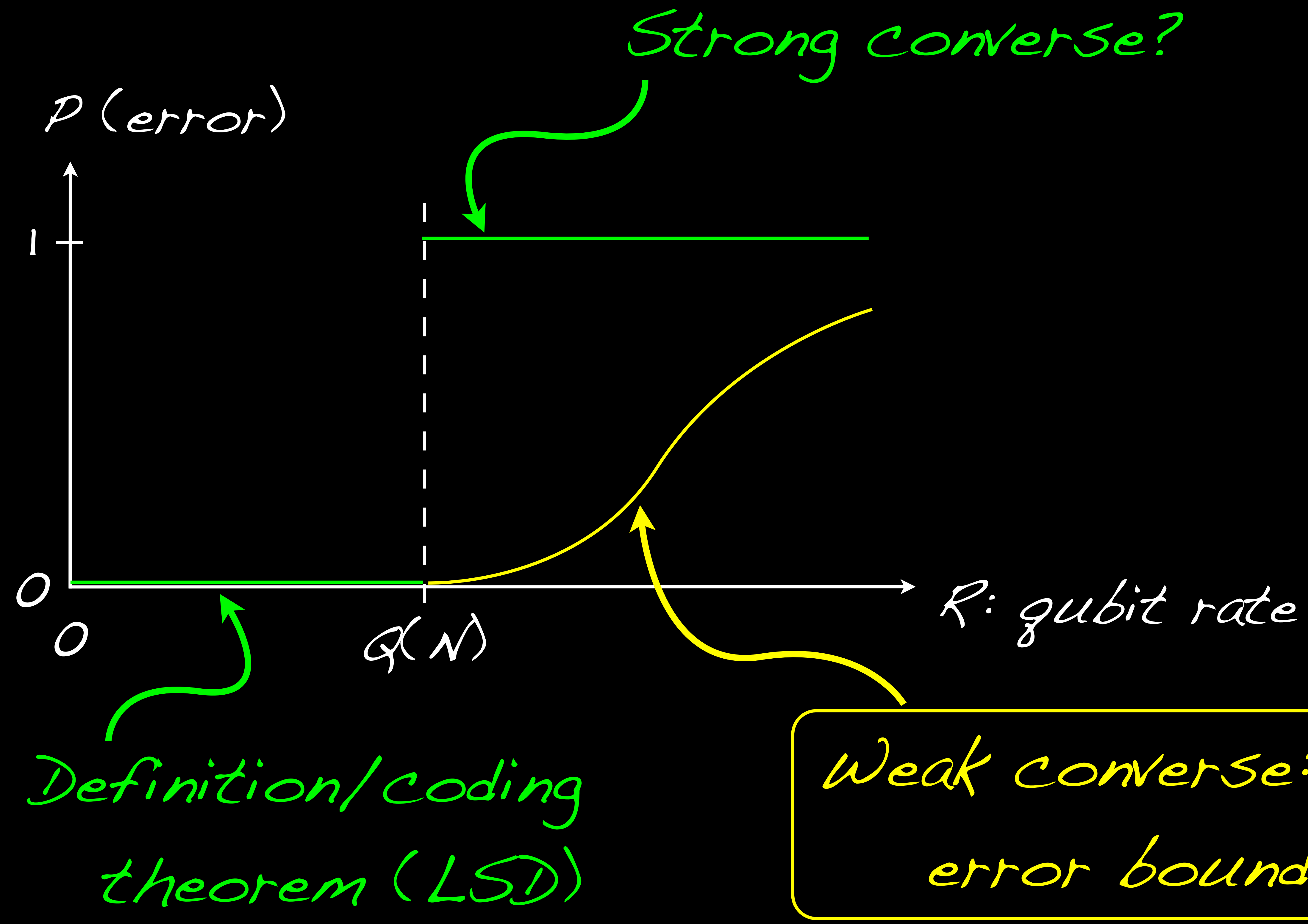
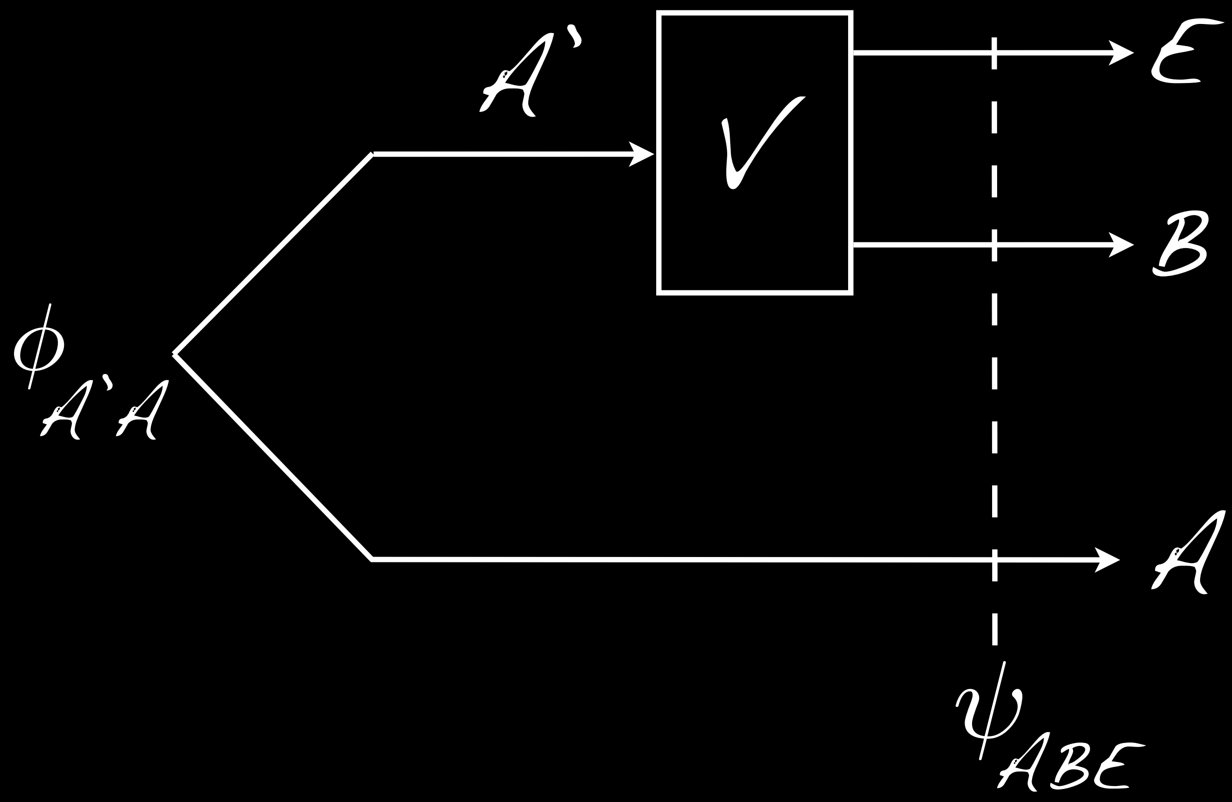


4. Additivity for degradable channels

[Devetak/Shor, CMP 2004; quant-ph/0311131]



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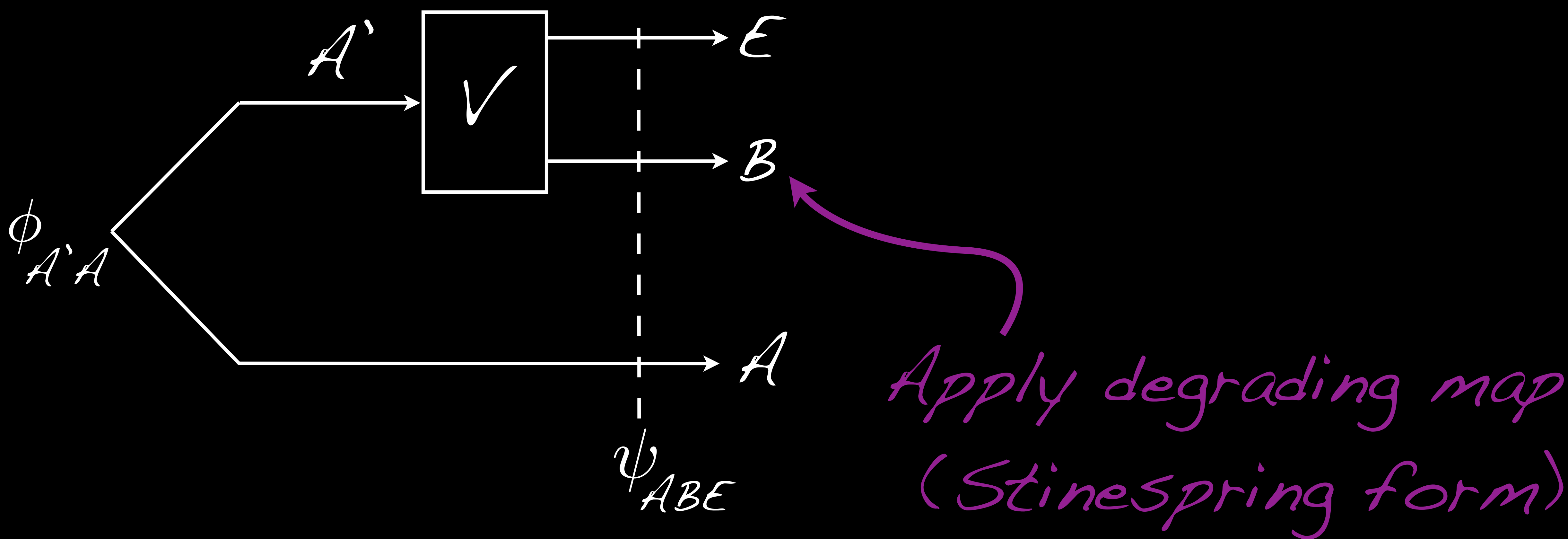

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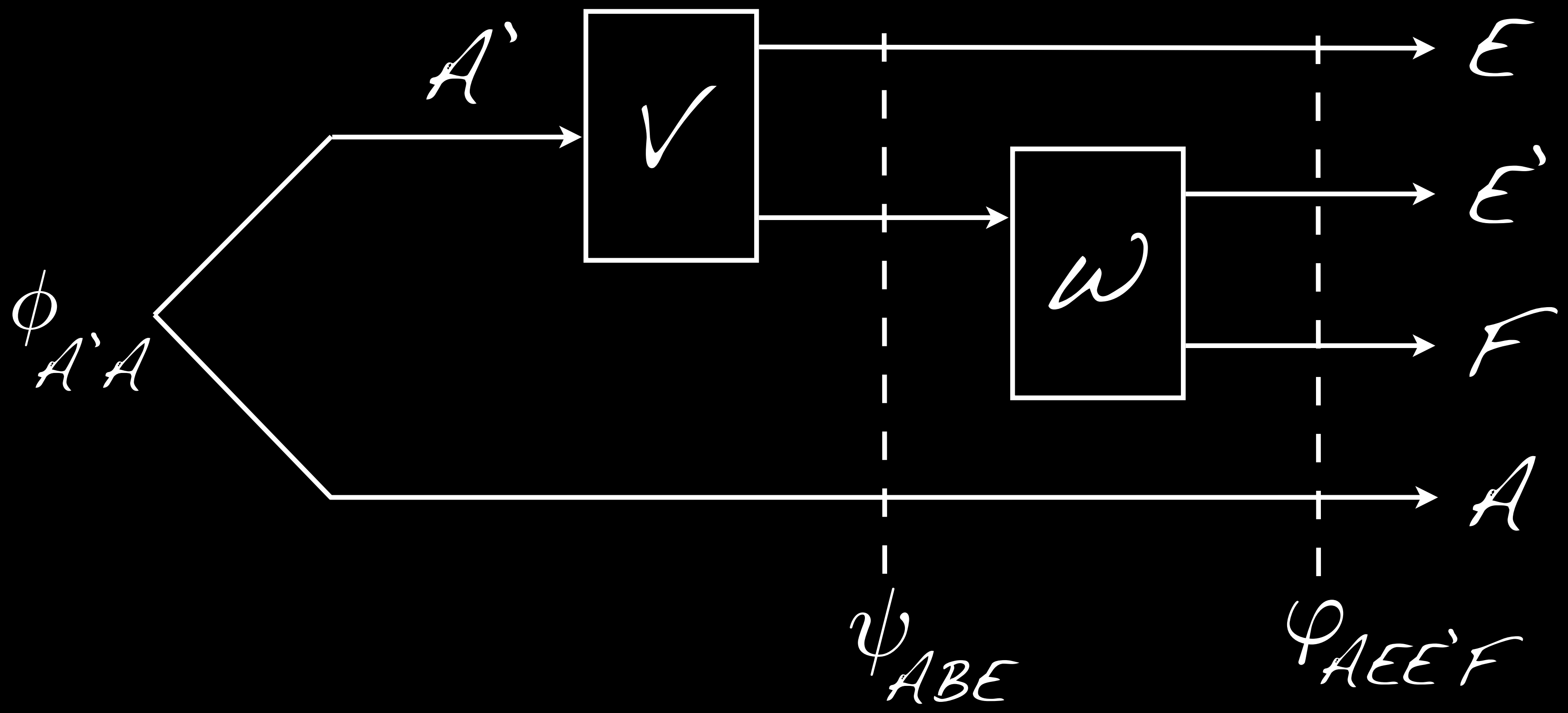

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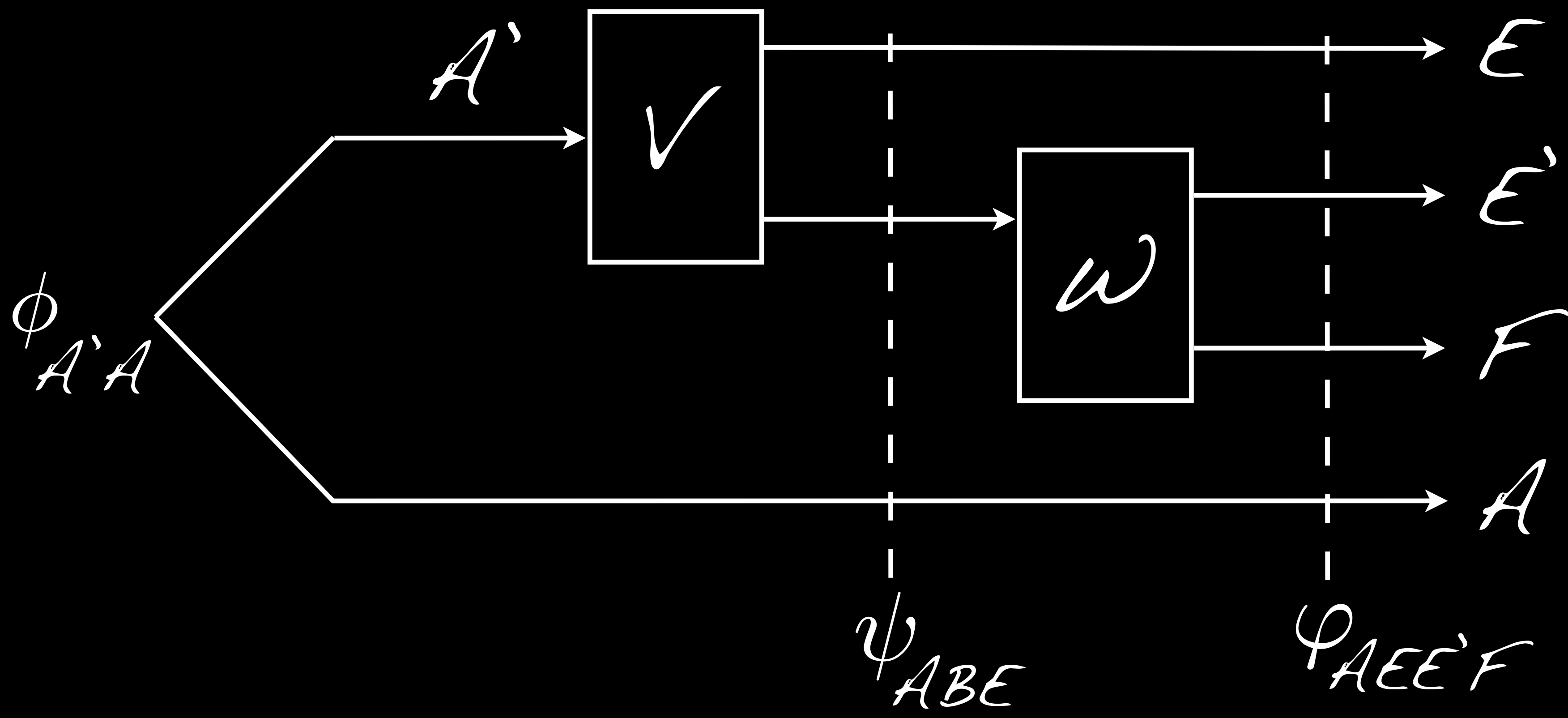

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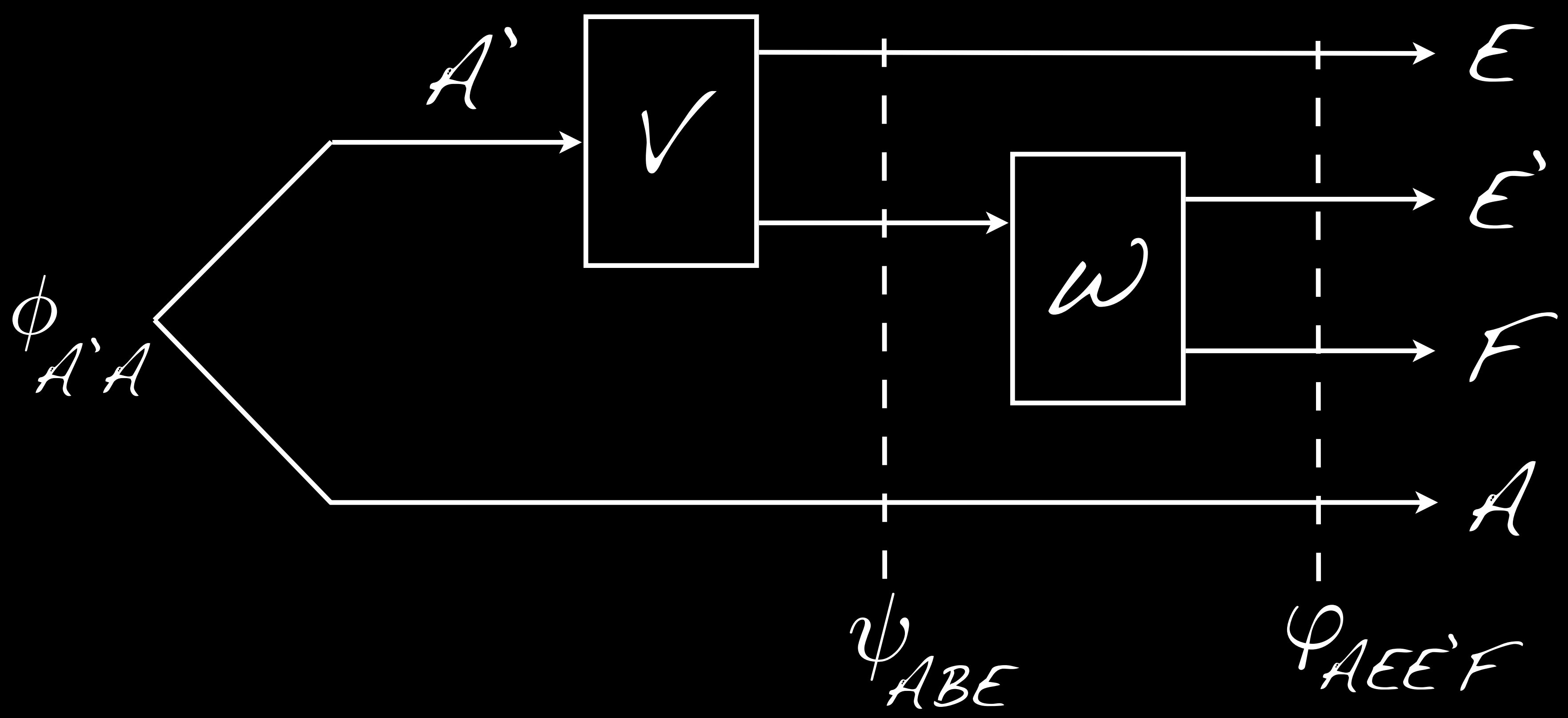

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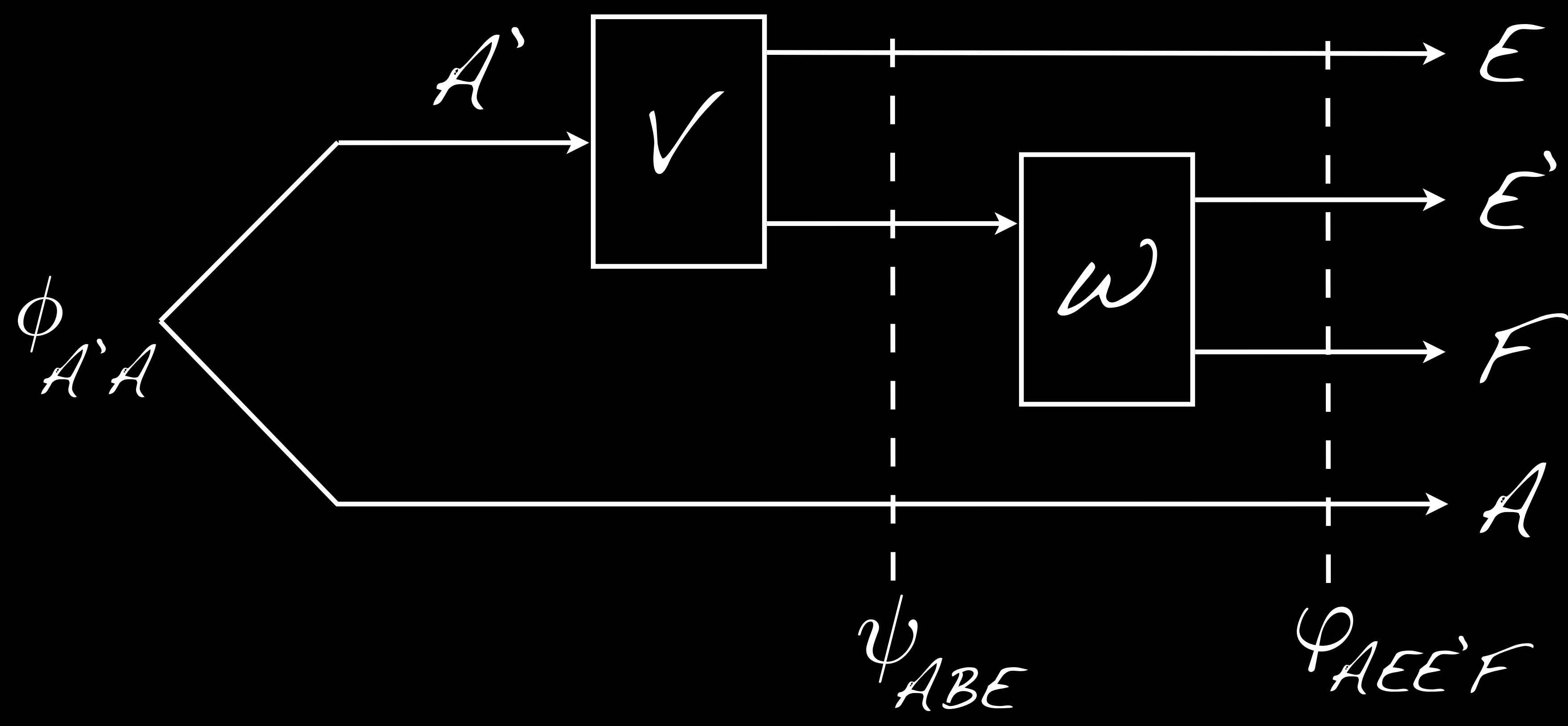

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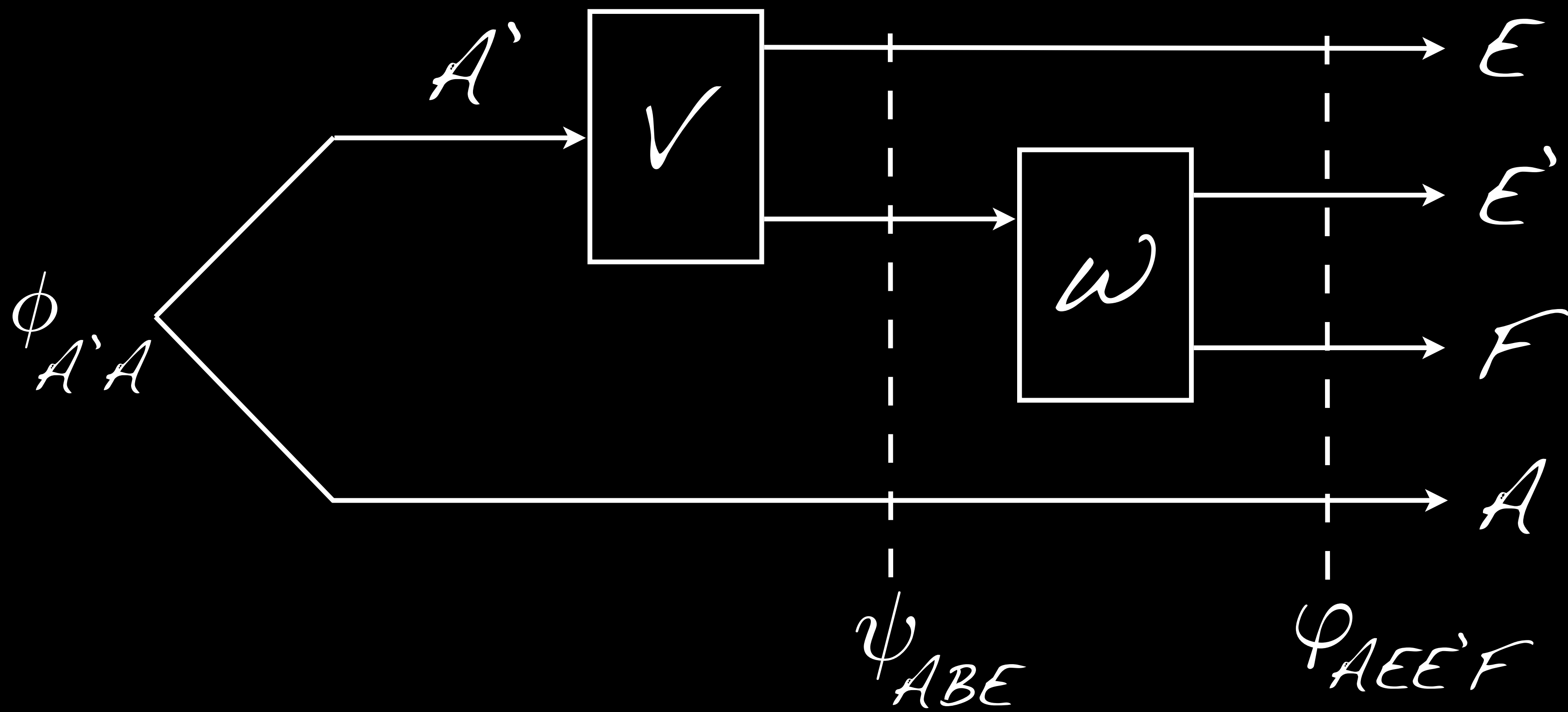

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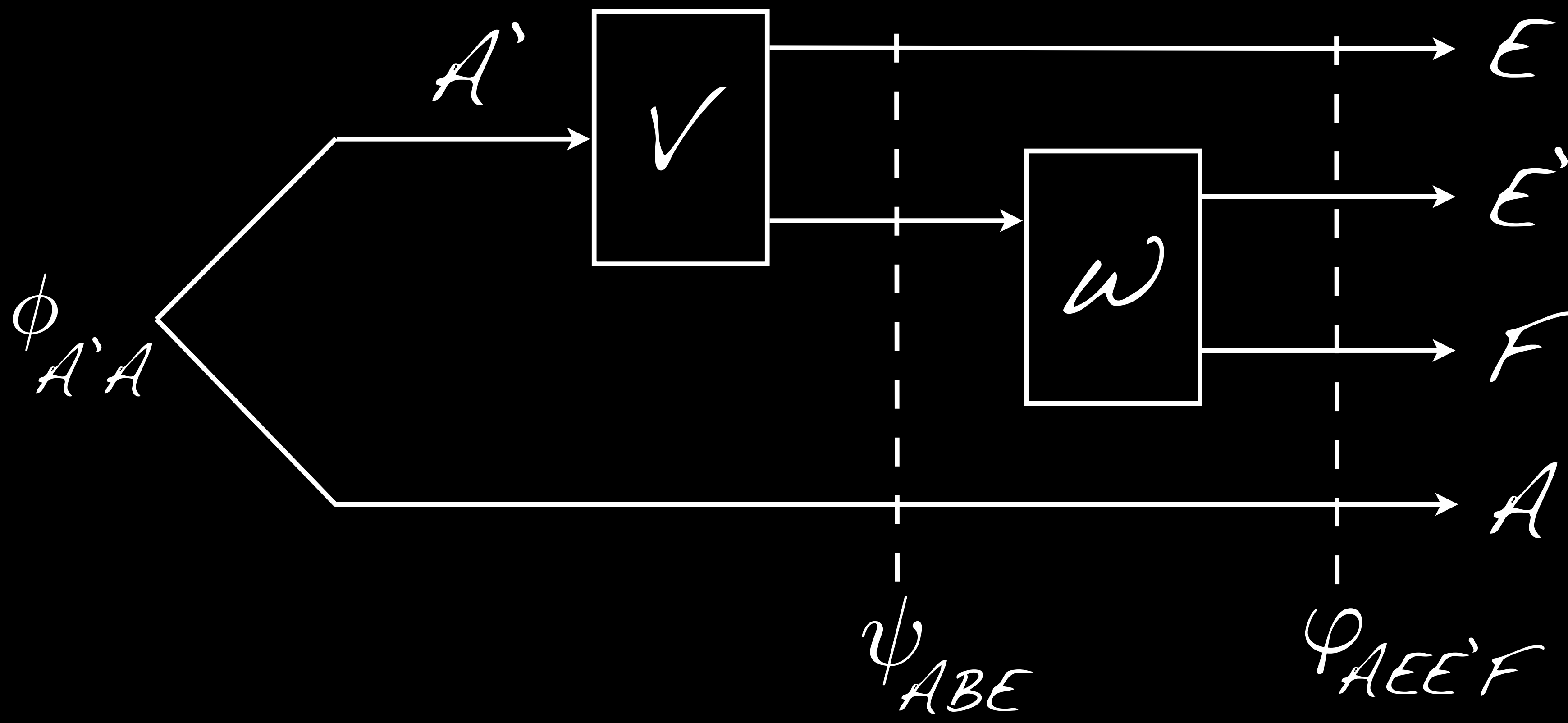

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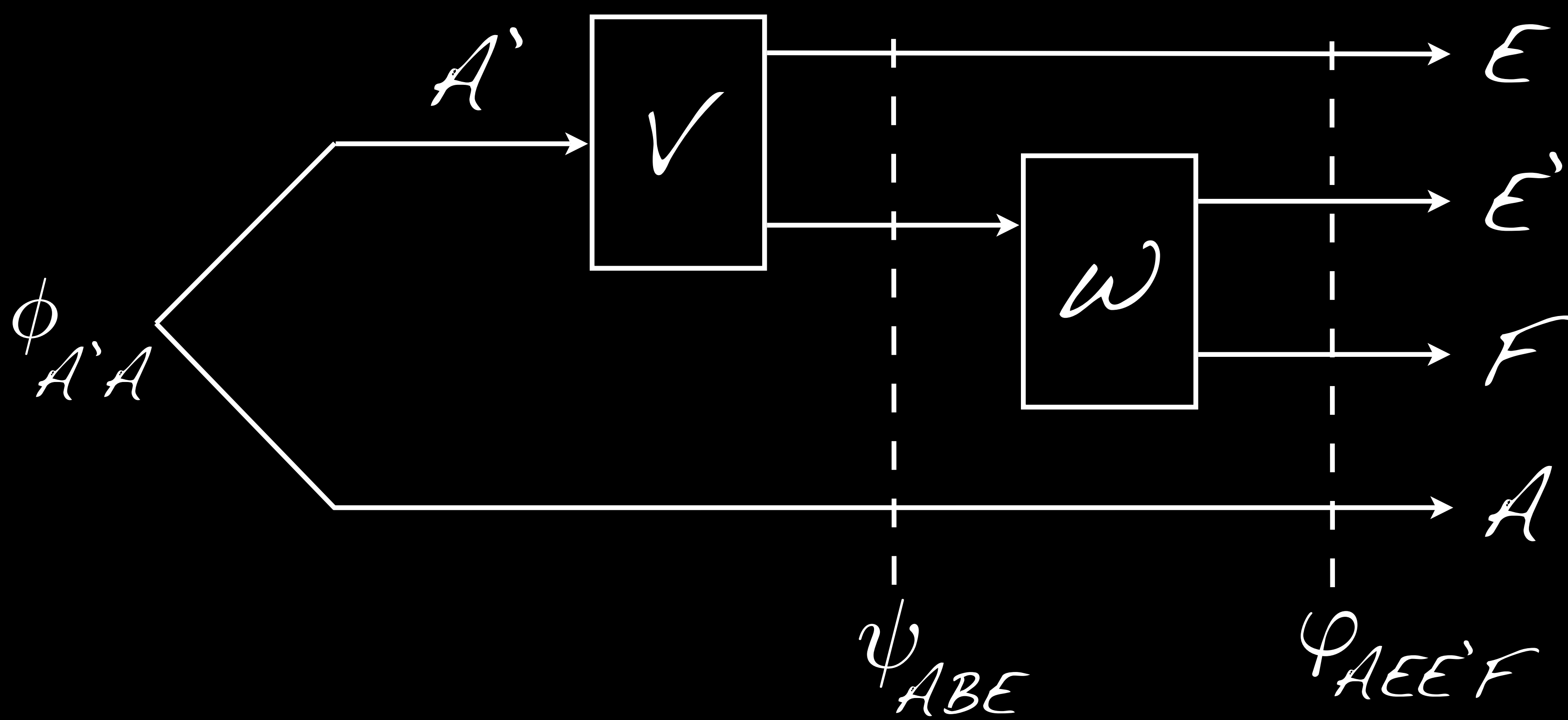

$$I(A\rangle B) = -S(A|B) = -S(A|E'F)$$
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$I(A\rangle B)_{\psi} = S(F|E')_{\varphi}$ for one channel use.

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For two degradable channels:

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$$\leq S(F_1|E_1'E_2') + S(F_2|E_1'E_2')$$
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G. Smith (0705.3838): Also private classical capacity, $P(N) = Q(N) = Q^{(1)}(N)$.

5. Results & proof ideas

Previous [via E. Rains, IEEE-IT 47(7): 2921-2933 (2001) - thanks to R. Koenig!]: If N is PPT entanglement-binding, then of course $Q(N)=0$, and strong converse holds (with error converging exponentially to 1).

5. Results & proof ideas

Previous [via E. Rains, IEEE-IT 47(7): 2921-2933 (2001) - thanks to R. Koenig!]: If N is PPT entanglement-binding, then of course $Q(N)=0$, and strong converse holds (with error converging exponentially to 1).

Note: Already for symmetric (degradable & anti-degradable) channels - for which also $Q(N)=0$ - not clear at all.

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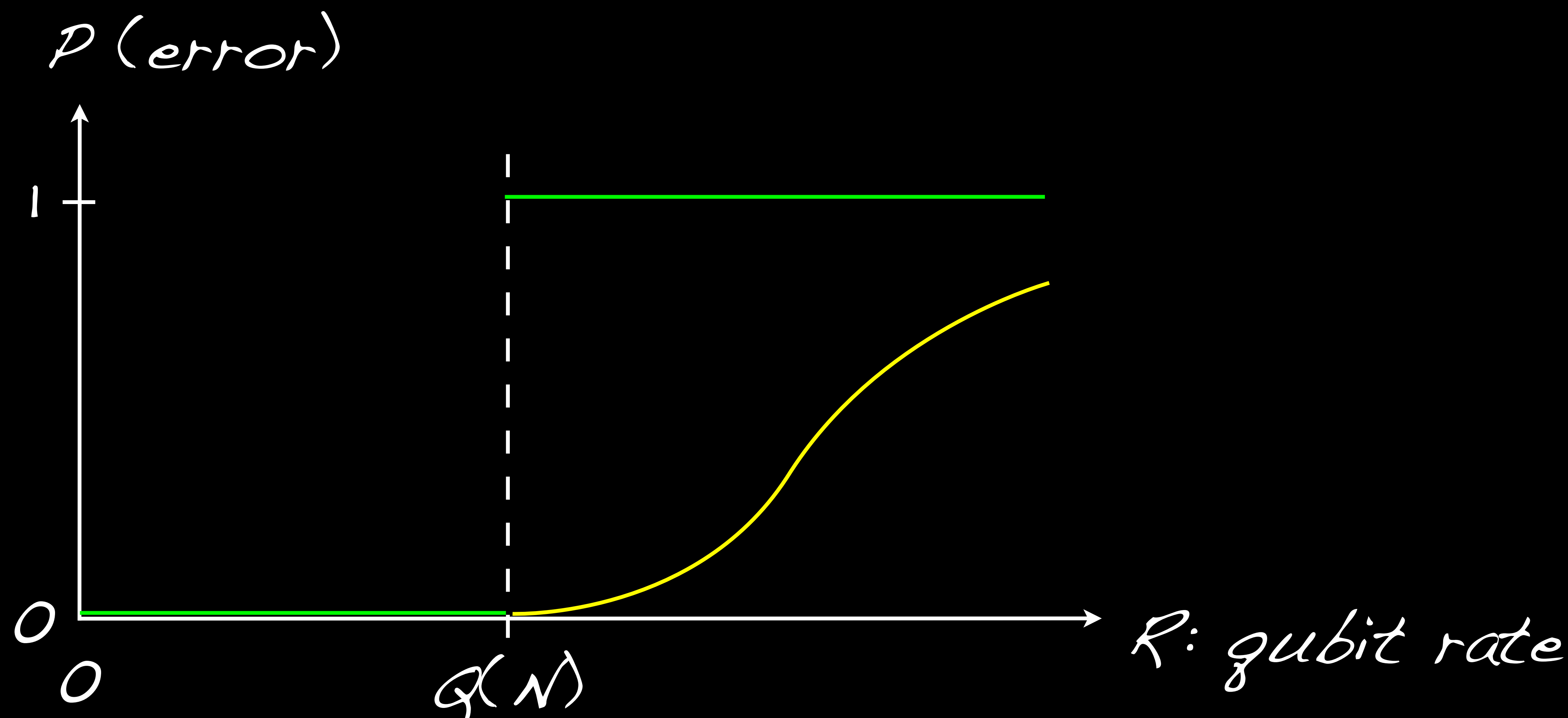

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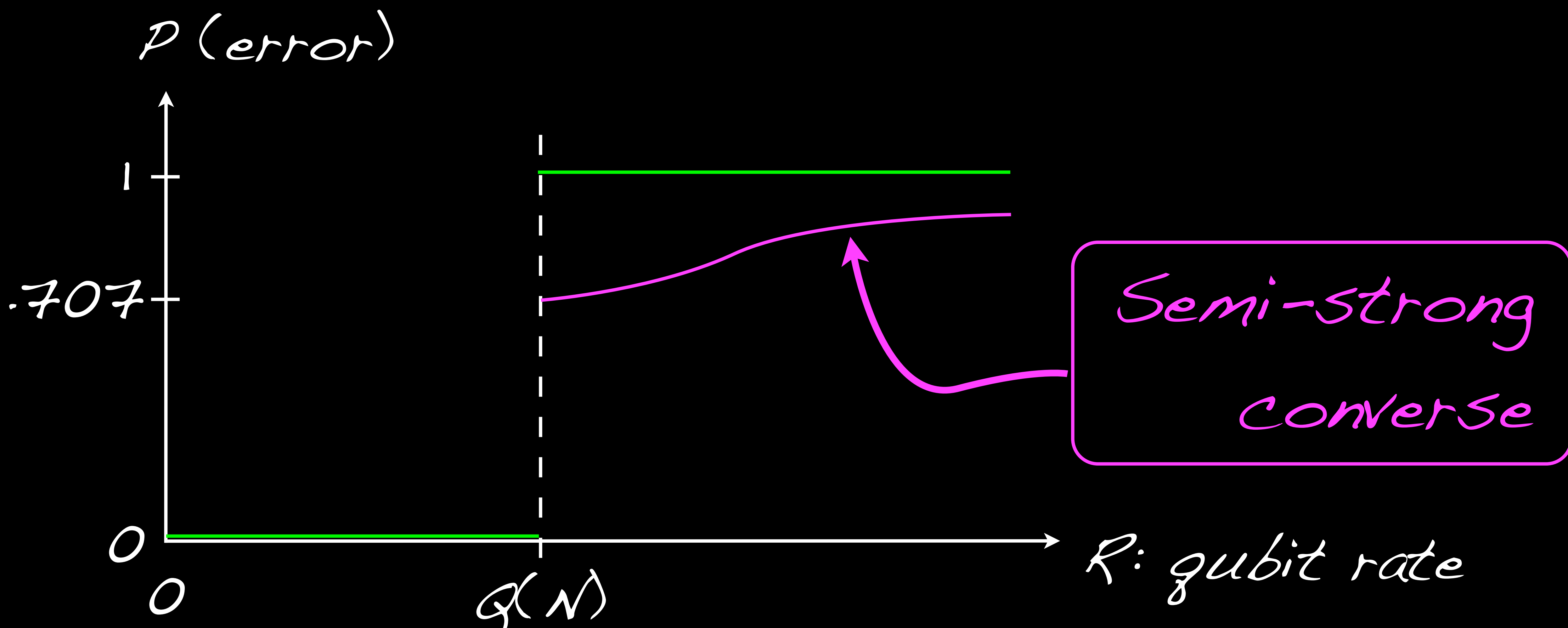

Ideas: (smooth) min-entropies,
symmetrisation, de Finetti theorem,
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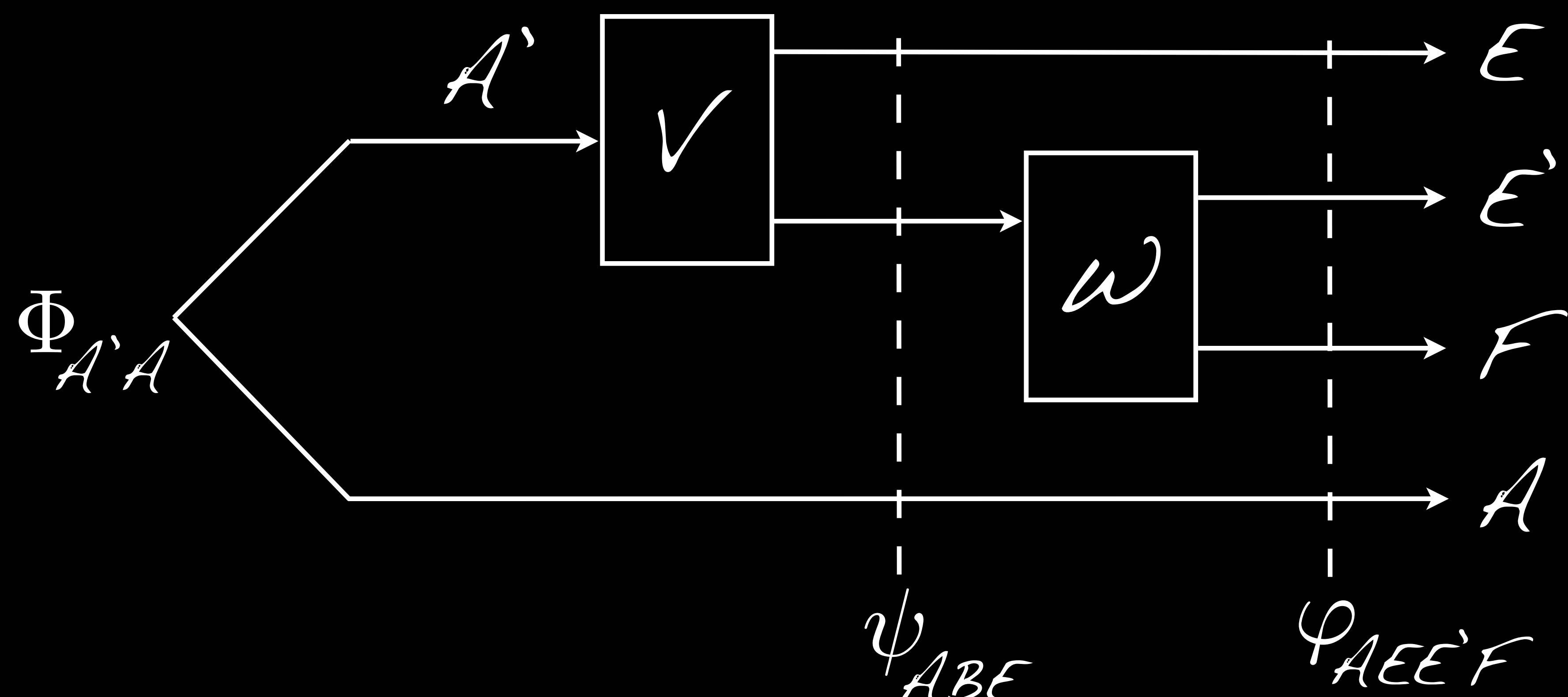
1) Use code - for simplicity subspace - with maximally entangled state Φ of k qubits:



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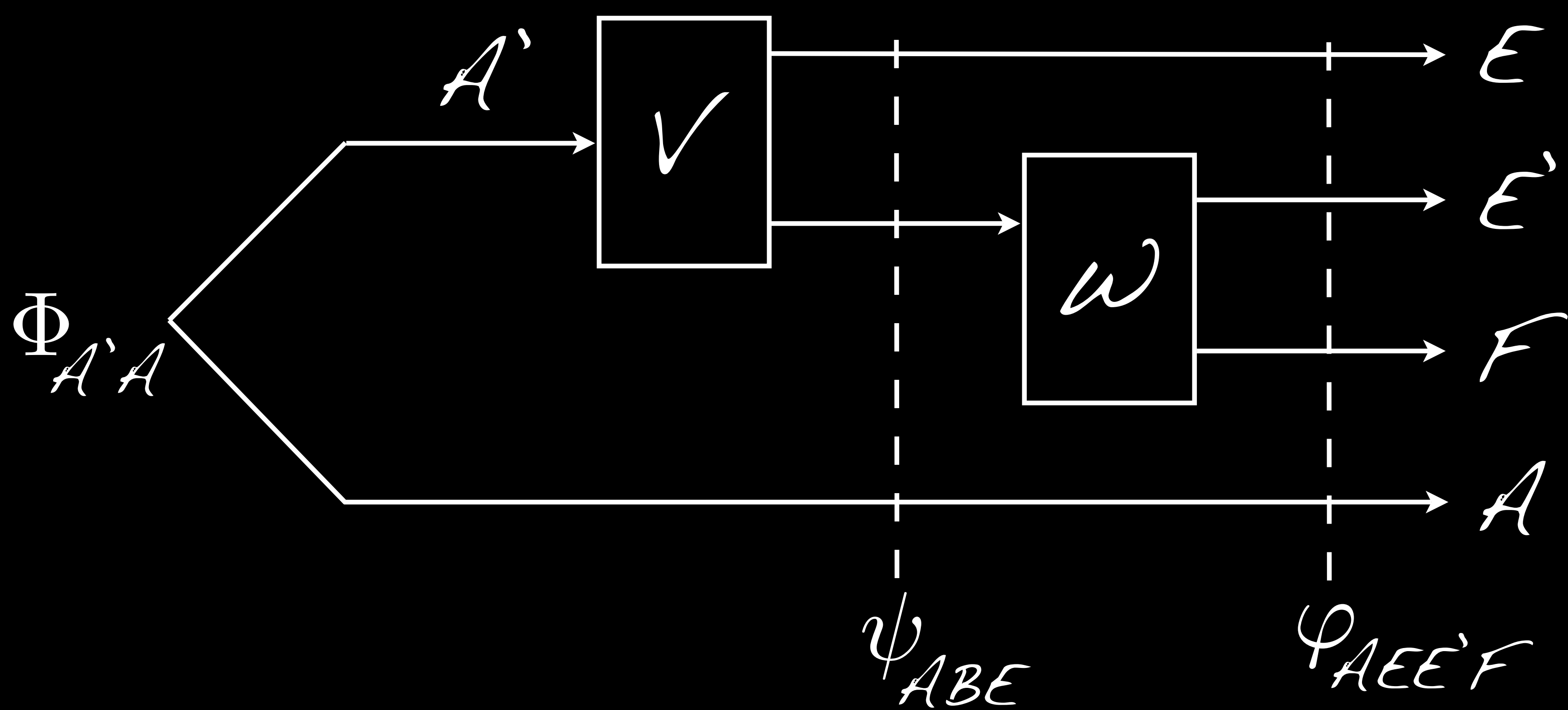

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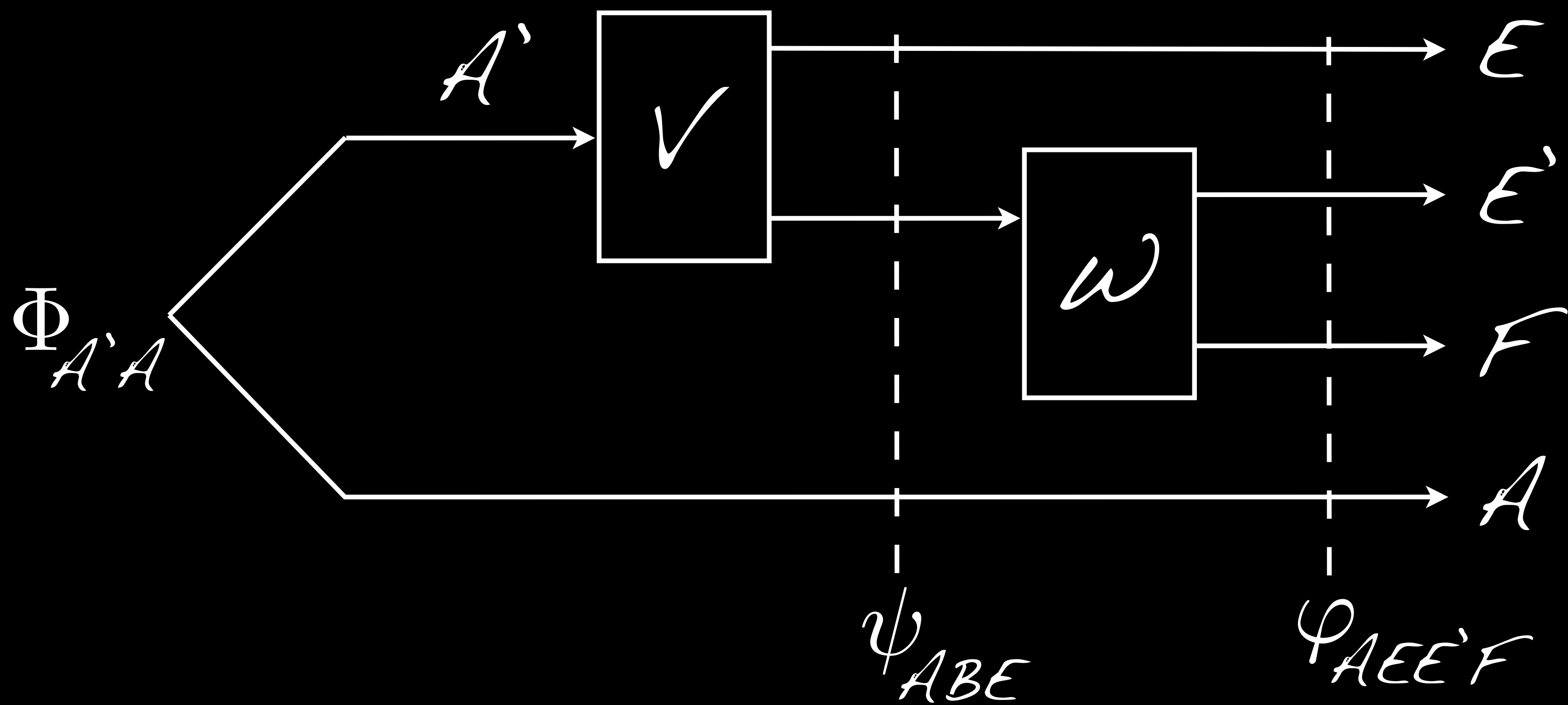

$$k \leq H_{min}^{\epsilon}(A|E)$$

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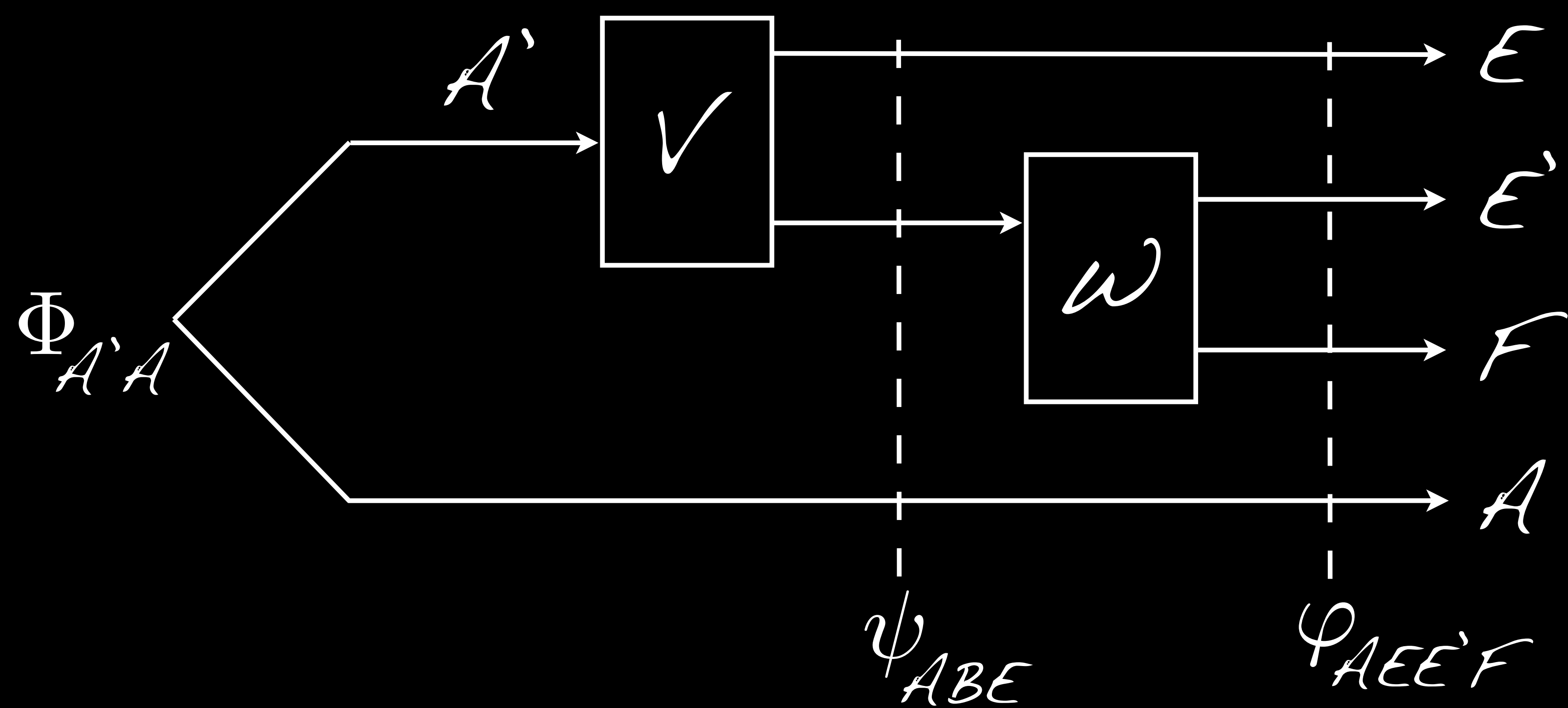

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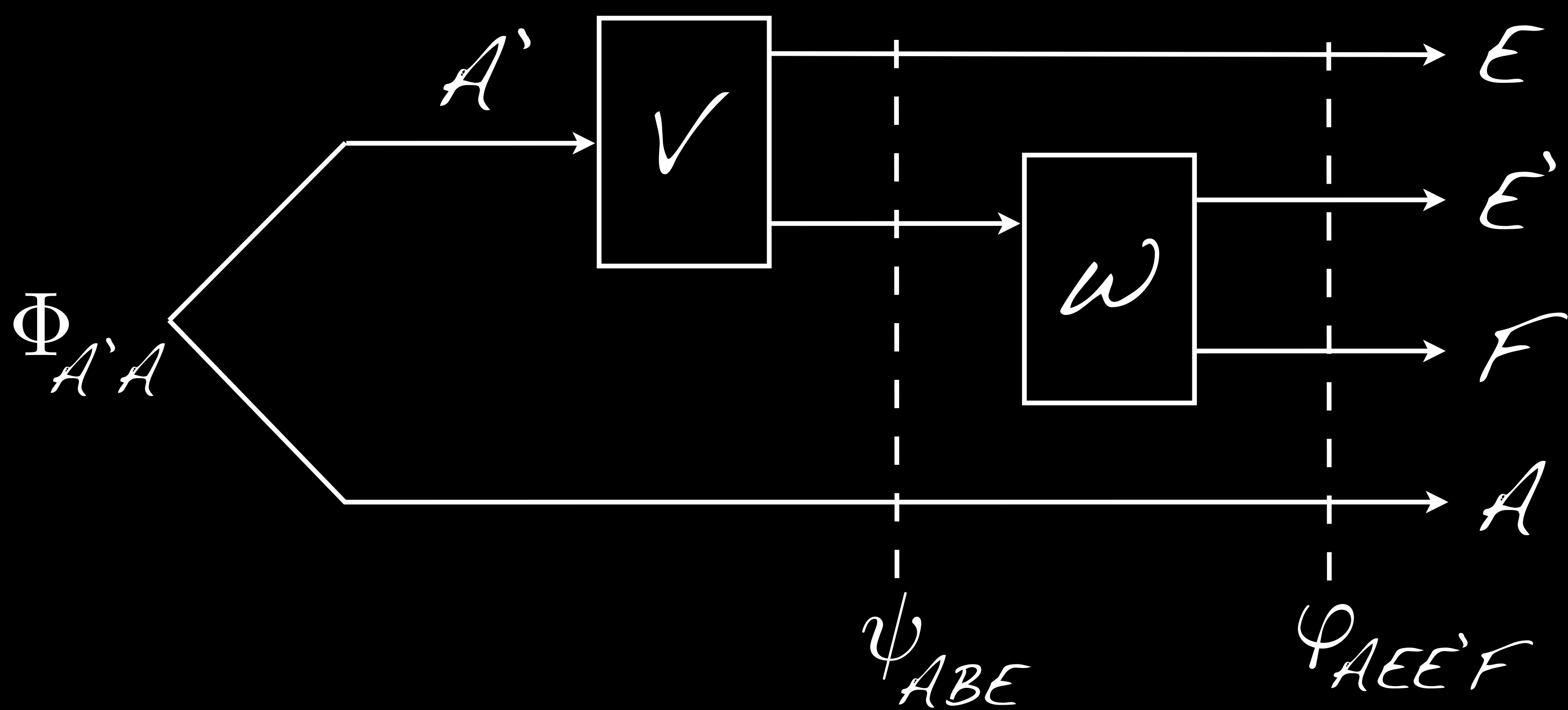

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[For min-entropy calculus, consult
R. Renner, PhD thesis, quant-ph/0512258
& M. Tomamichel, PhD thesis, arXiv:1203.2142]

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[Cf. also Buscemi/Datta, IEEE-IT 56(3), 2010; Datta/Hsieh, 1103.1135]

$$k \leq H^{\epsilon}_{min}(A|E)$$

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Note: If we knew that for n channel uses, the maximum min-entropy is attained on a tensor product input, we'd be done by AEP (= asymptotic equipartition property)...

$$
\begin{aligned}
k &\leq H_{min}^{\epsilon}(A|E) \\
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...if $\delta < 0.707$, by inequality H_{min} vs. H_{max}, and using symmetry between E and E'...

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W.r.t. a permutation symmetric input state and $\lambda' = \lambda/\sqrt{2}$

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3) By exponential de Finetti theorem [R. Renner, PhD thesis, quant-ph/0512258]:

$$k \leq \max_{\rho_A} H_{max}^{\lambda''}(F^{n}|E'^{n})_{\rho^{\otimes n}} + o(n)$$

4) By AEP (asymptotic equipartition property) [M. Tomamichel, arXiv:1203.2142]:

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- Proved "semi-strong" converse for the quantum capacity of degradable channels; similar statement possible for private classical capacity...
- Can we get an honest strong converse? (Bottleneck are symmetric channels: the current error threshold is that of a 50% erasure channel.)
- Indeed: Strong converse for degradable channels if it holds for symmetric ch.

- Sharma/Warsi (arXiv:1205.1712) propose a different methodology, based on certain generalised divergences. They can't prove a strong converse, but if an additivity problem could be solved for some channels (degradable?), it would follow..
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- How to prove strong converses without additivity? Note that neither Q nor $Q^{(1)}$ are additive! Similar for other capacities...