Fundamental experimental objects

$\Gamma(a_1 \longrightarrow b_1 b_2 \cdots b_n)$: decay width $= 1/\text{lifetime}$

$\sigma(a_1 a_2 \rightarrow b_1 b_2 \cdots b_n)$: cross section

↳ momenta of final state form phase space

Phase space integration element: $(3n-4)$ dim., GeV^{2n-4}

$$dV(P; p_1, \ldots, p_n)$$

$$\equiv (2\pi)^4 \delta^4\left(P - \sum_{i=1}^{n} p_i\right) \cdot \prod_{i=1}^{n} \left\{ \frac{1}{(2\pi)^3} d^4 p_i \, \delta(p_i^2 - m_i^2)\, \theta(p_i^0 > 0) \right\}$$

↑ mom. cons. ↑ mass shell ↑ energy > 0

$$d(\Gamma, \sigma) = \frac{1}{C_{\Gamma,\sigma}} \langle |\mathcal{M}|^2 \rangle \, dV(P, p_1, \ldots, p_n)$$

↳ Sum appropriate states

$\langle |\mathcal{M}|^2 \rangle$ → transition rate, summed/avgd over spins, colours....

$C_{\Gamma,\sigma}$ → "flux" factors

$C_\Gamma = 2m(a_1)$ ⟵ wavefunction normalization

$$C_\sigma = 2m(a_1) \cdot 2m(a_2) \cdot \frac{E(a_2)}{m(a_2)} \cdot \beta(a_2)$$

in a_1 rest frame

$\therefore$ σ is per unit flux

↑ Lorentz contraction

$\approx 2(p_{a_1} + p_{a_2})^2 = 2s$

Scattering in Q.M.

- prepare state at "$t=-\infty$" $\quad |\psi_{in}(t=-\infty)\rangle = |j\rangle$
- time evolution (possible scattering) $\quad \downarrow$

$$|\psi_{in}(t=+\infty)\rangle = S|\psi_{in}(t=-\infty)\rangle$$

- observe resulting system:

  observed to be in state $\quad |\psi_{out}(t=+\infty)\rangle = |f\rangle$

QM: probability amplitude:

$$\langle\psi_{out}(t=+\infty)|\psi_{in}(t=+\infty)\rangle = \langle\psi_{out}(+\infty)|S|\psi_{in}(-\infty)\rangle$$

$\Rightarrow$ an element of the S matrix: $\langle f|S|j\rangle = S_{fj}$

Time evolution is unitary (cons. of probability):

$$SS^{\dagger} = S^{\dagger}S = 1$$

$$S_{fj} = \delta_{fj} + i\,T_{fj}$$

δ_{fj} ← "nothing happens"; T_{fj} ← "something happens"

Consequences of unitarity:

- $|S_{fj}|$ not arbitrarily big $\quad$ Unitarity bounds
- $\mathrm{Im}(T_{kk}) = \frac{1}{2}\sum_n |T_{nk}|^2 \quad$ Optical Theorem

Fundamental picture of quantum mechanics

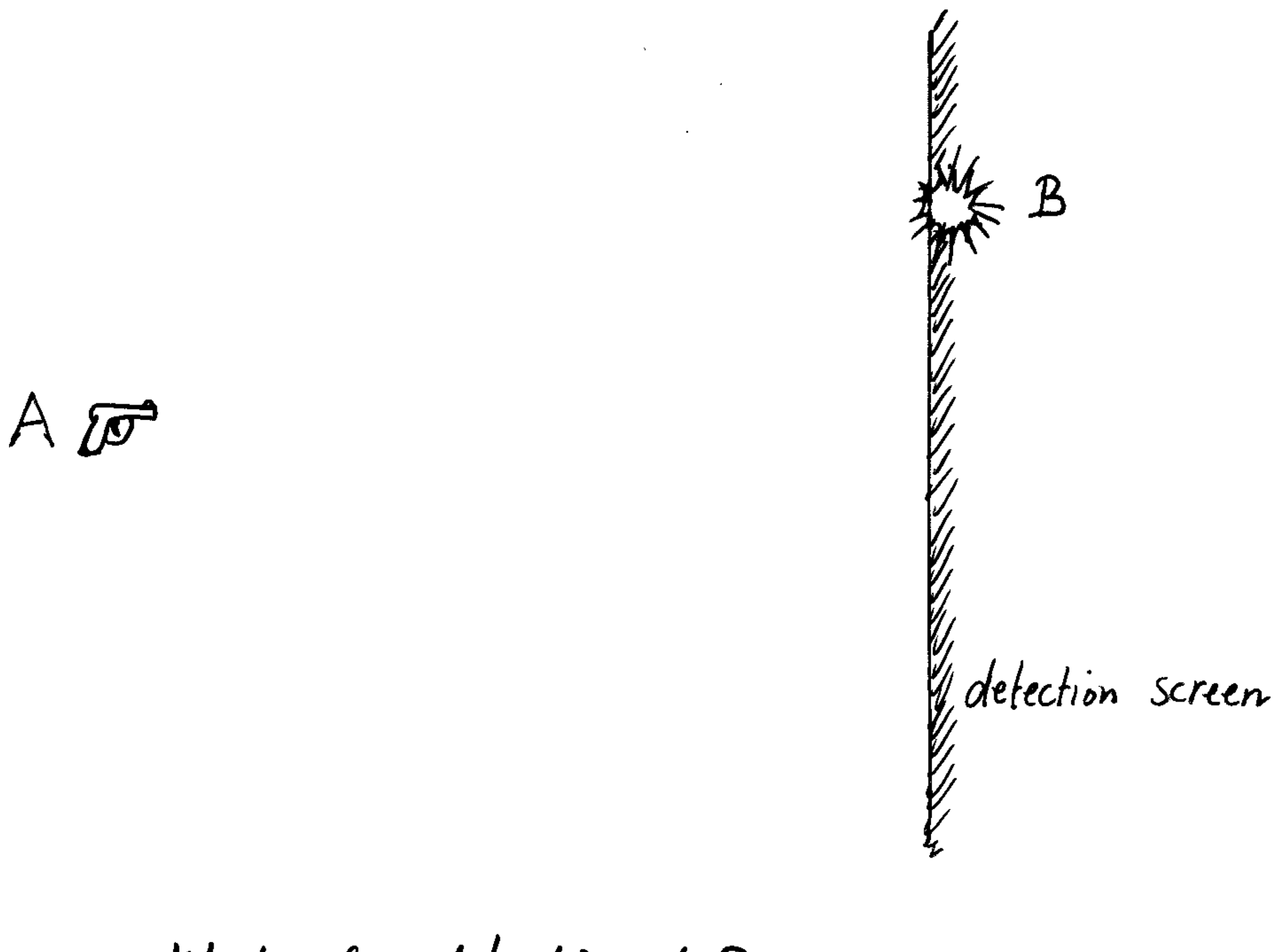
Multislit experiment

Particle emitted at A , observed at B

version # barriers :

slits/barrier :

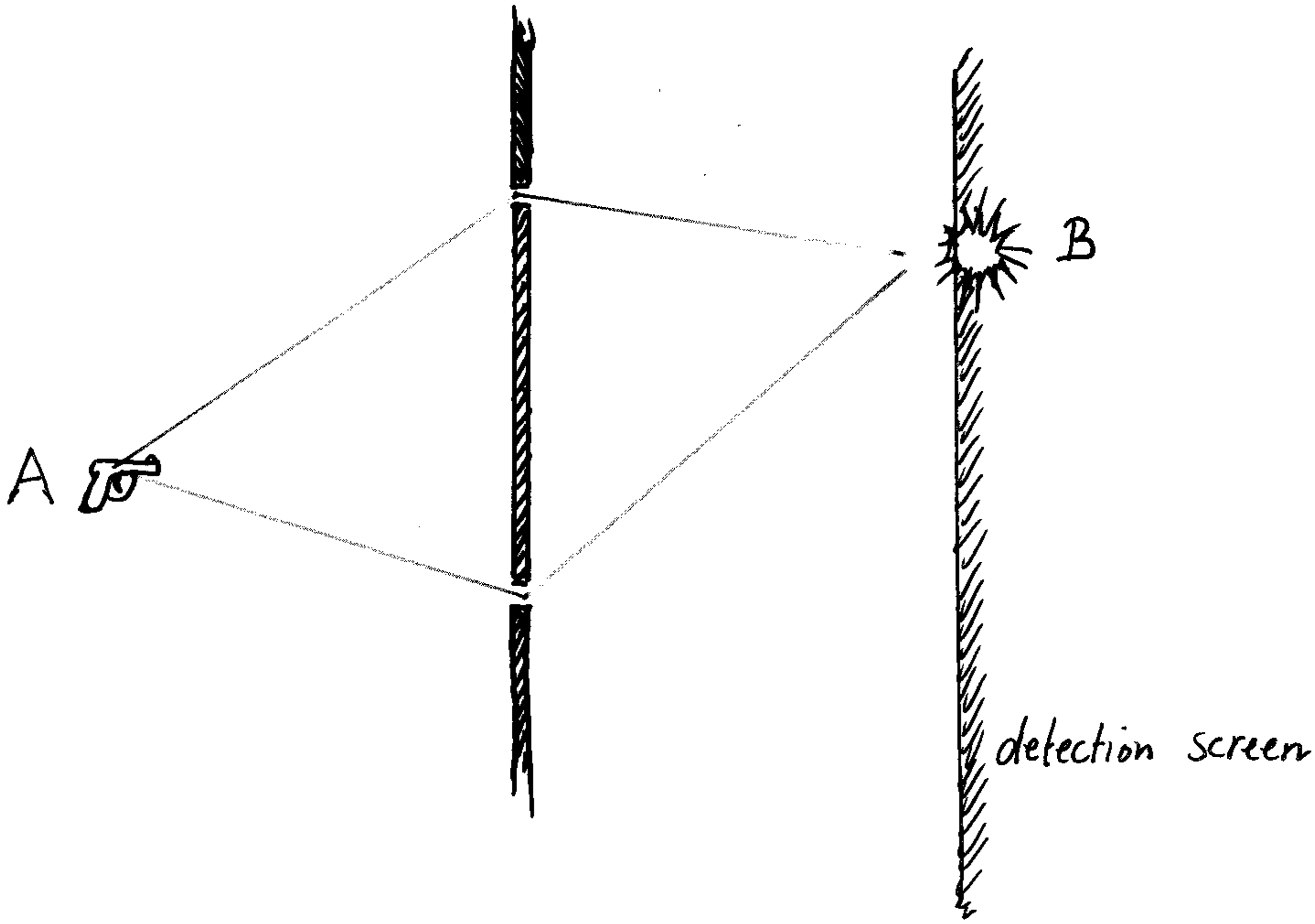
possible paths :



amplitude for detection at B
is sum of contributions of each path

Fundamental picture of quantum mechanics

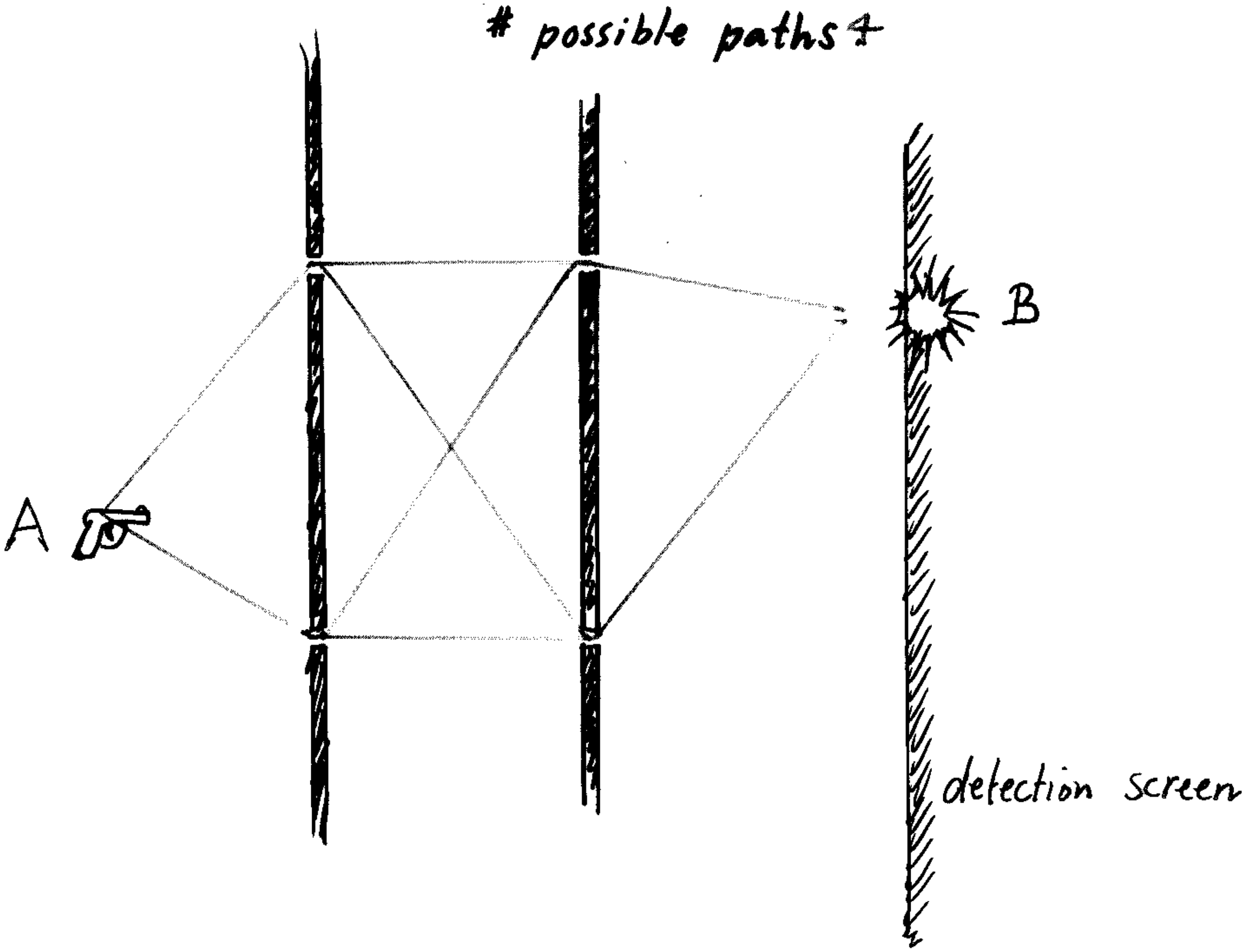
Multislit experiment #1
Particle emitted at A, observed at B
version   # barriers : 1
                 # slits/barrier : 2
                 # possible paths 2



amplitude for detection at B
is sum of contributions of each path

Fundamental picture of quantum mechanics

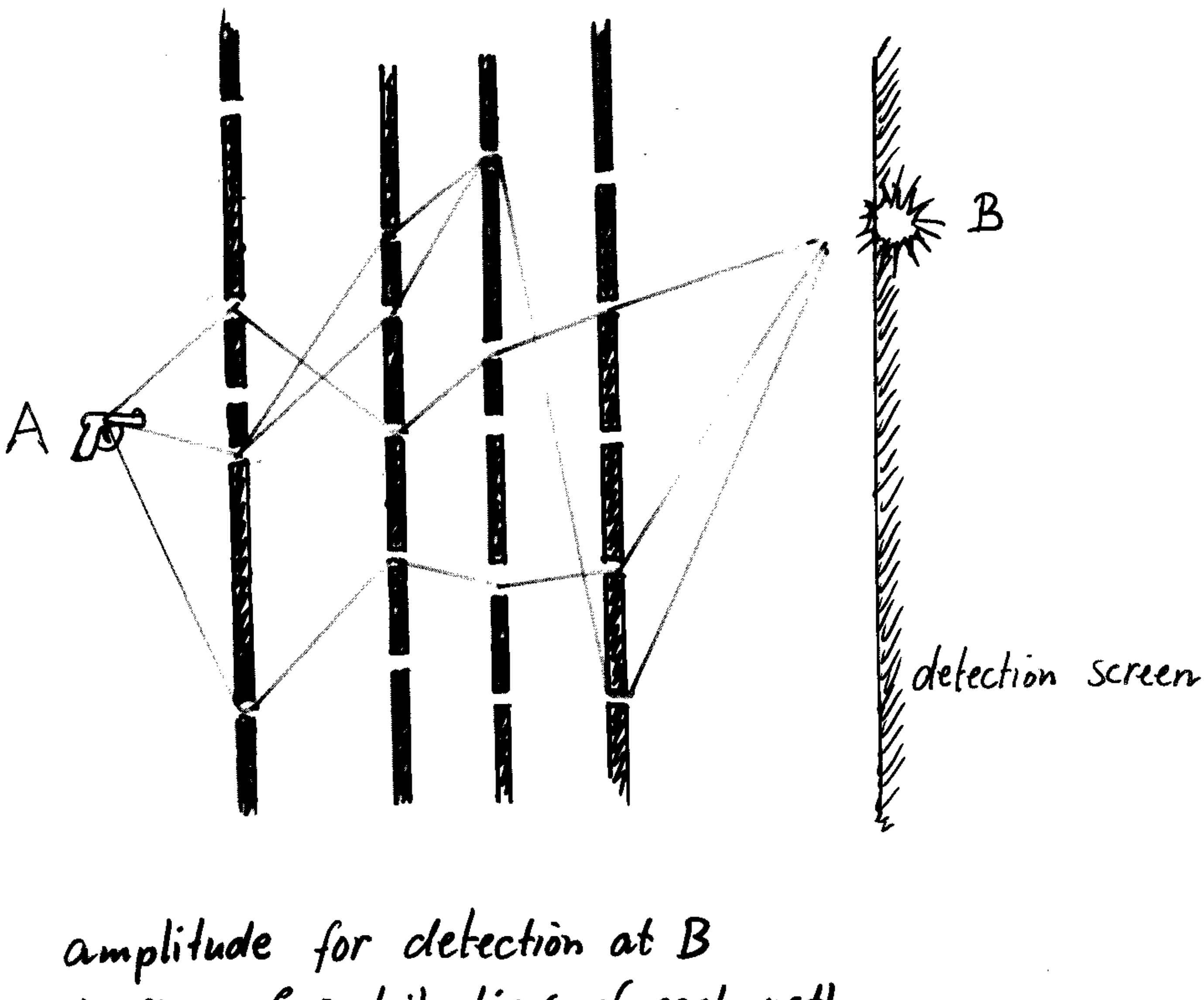
Multislit experiment #2.
Particle emitted at A, observed at B
version
barriers : 2
slits/barrier : 2
possible paths 4



amplitude for detection at B
is sum of contributions of each path

Fundamental picture of quantum mechanics

Multislit experiment #3
Particle emitted at A, observed at B
version
barriers 4
slits/barrier 5
possible paths 625 (not all shown)



amplitude for detection at B
is sum of contributions of each path

Fundamental picture of quantum mechanics

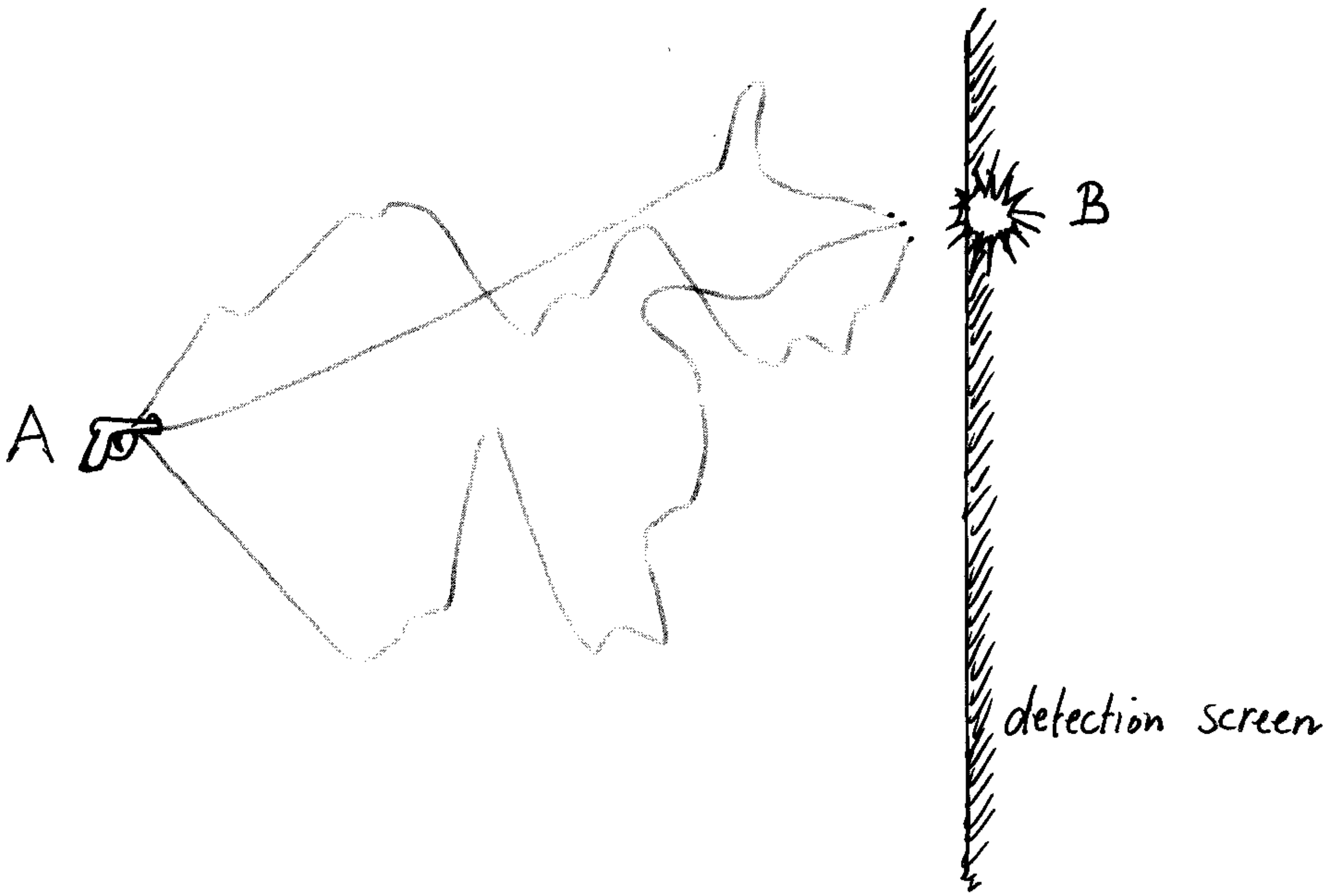
Multislit experiment # ∞

Particle emitted at A, observed at B

version # barriers ∞

\# slits/barrier ∞

\# possible paths ∞^{∞} (not all shown)

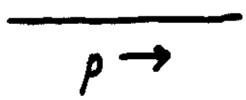


amplitude for detection at B
is sum of contributions of each path (path integral)

Feynman diagrams

- calculational tools to handle "sum over paths"
- made up out of "simple" ingredients:

1) **propagators**



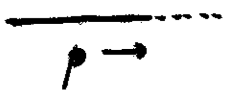
particle moves through spacetime without interacting

2) **vertices**

e.g. 

≥ 2 (usually ≥ 3) particles "meet" at some point: $\propto i(2\pi)^4 \delta^4(\Sigma p)$

3) **external legs**



particle comes in from ∞ or moves out to ∞

- each ingredient $\Leftrightarrow$ well-defined factor in diagram
  Feynman rules
- sum of all diagrams = sum of all possible ways to go from given initial state to observed final state
- vertices $\propto$ coupling constants

often, couplings are "small" e.g. $e = \sqrt{4\pi\alpha} \lesssim 0.3$

→ discard diagrams with many vertices
= perturbation theory

- Choice of Feynman rules $\Leftrightarrow$ choice of theory

choice { restricted by
- Lorentz invariance
- other symmetries
- unitarity

or derived from other postulates

- The full set of Feynman rules

$\Updownarrow$

The Lagrangian density of the theory $\mathcal{L}$

(easier to manipulate than a list of rules e.g. redefinitions of fields etc.)