Quantum Veto Parton Shower

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To appear w/

Cristian W. Bauer
(Berkeley)

So Chigusa
(Berkeley)

(Also Chigusa + MY 2204.12500
Bauer + de Jong + Nachman + Provasoli 1904.03196)

Today:

Quantum Veto Parton Shower

veto algorithm

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quantum / classical
hybrid

high energy problem

veto algorithm

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Quantum Veto Parton Shower

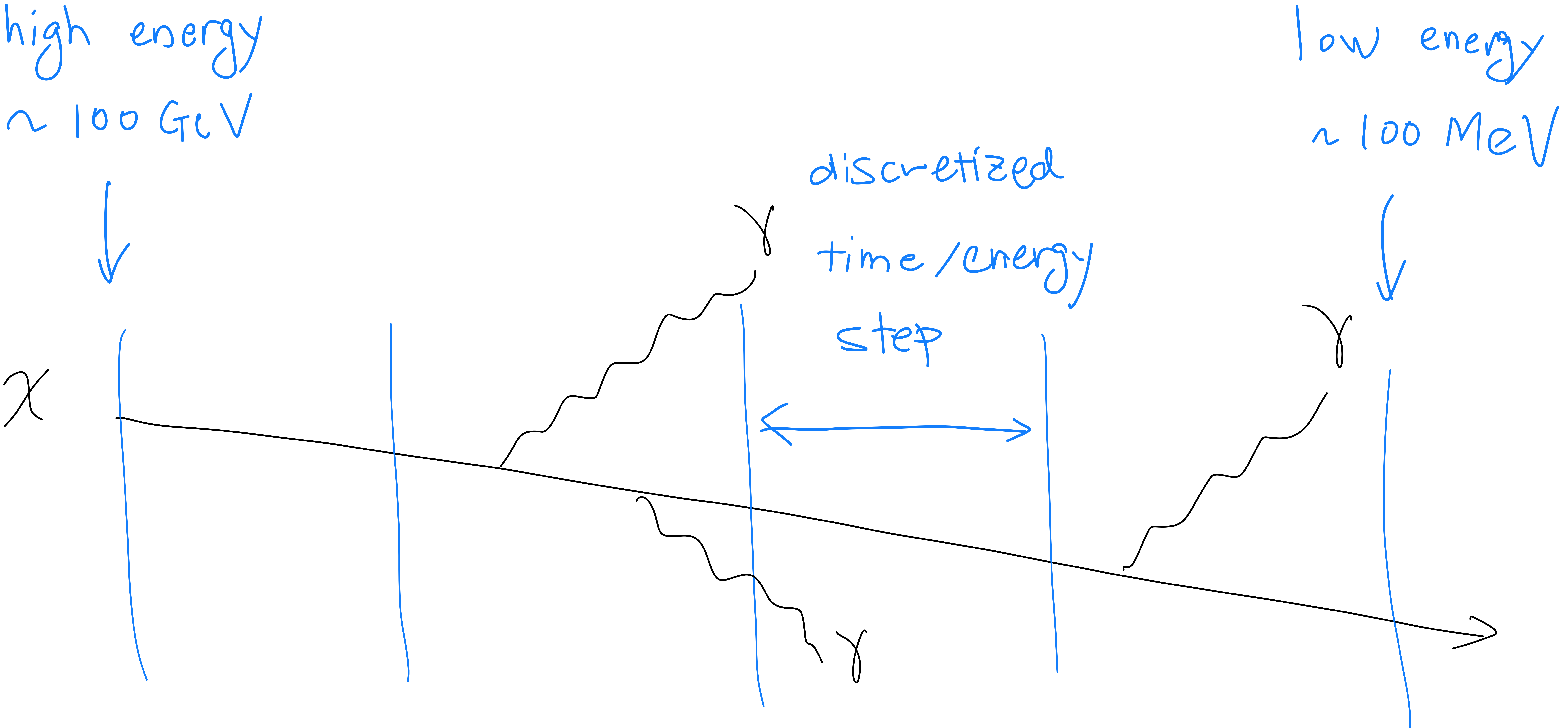
quantum/classical hybrid

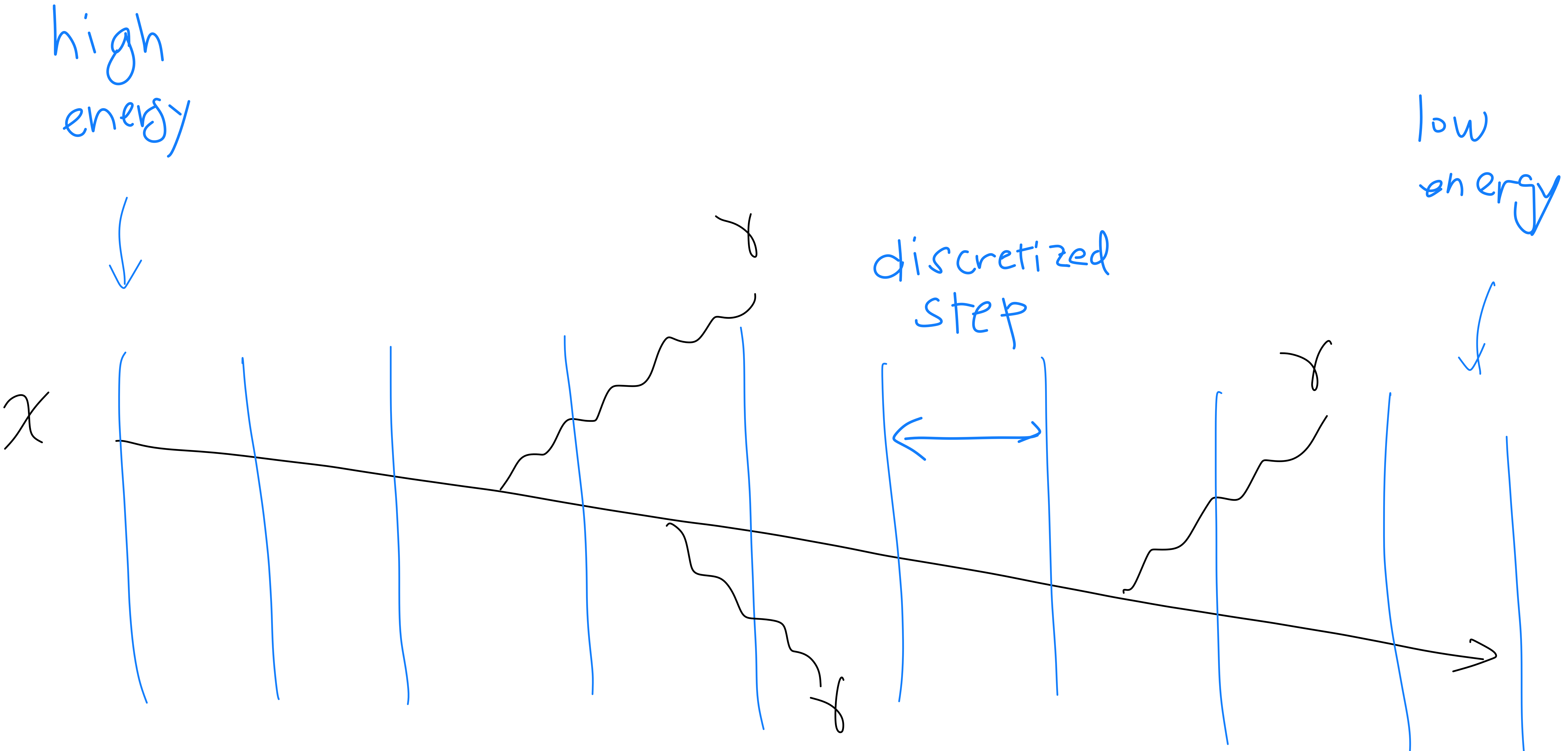
high energy problem

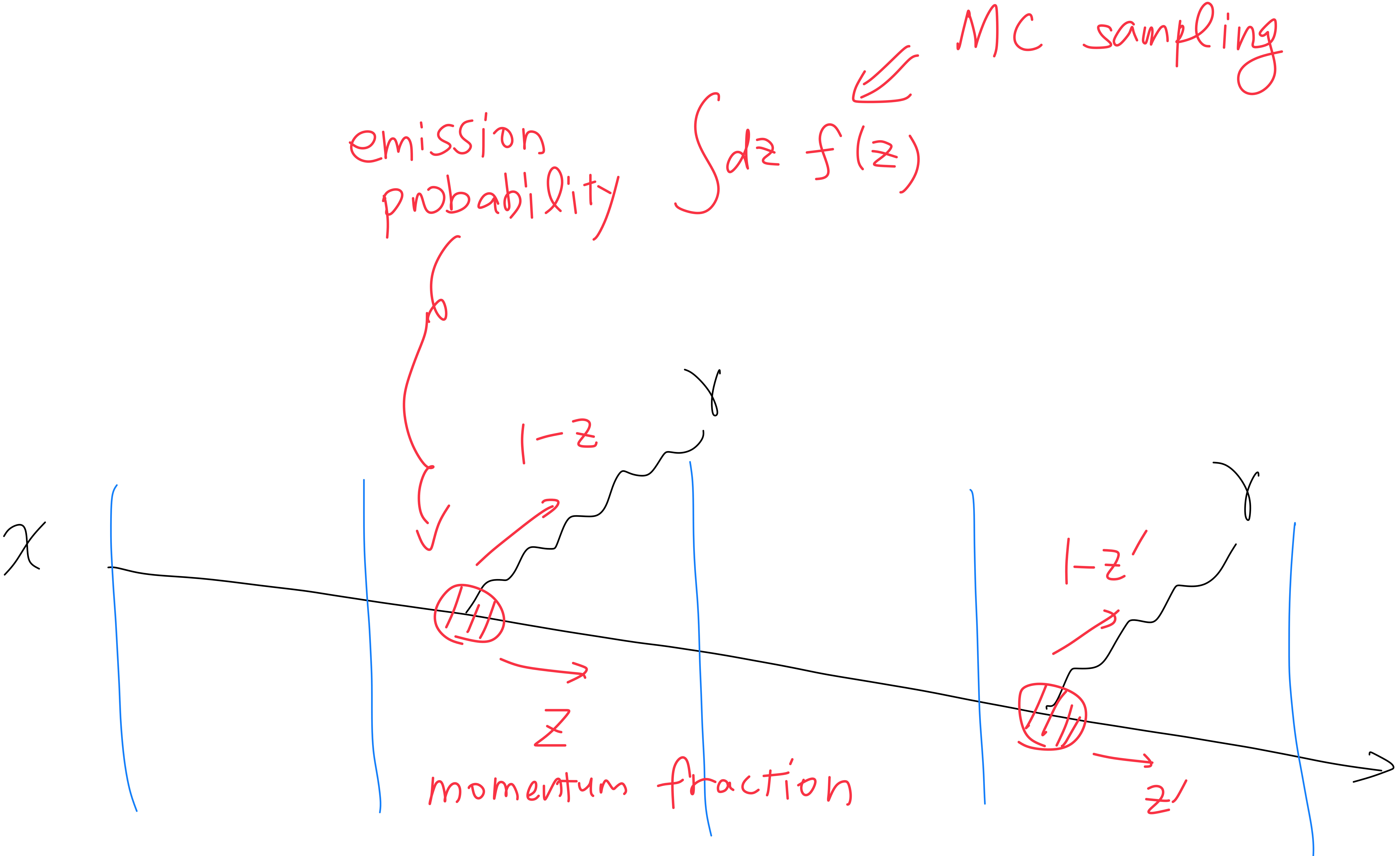
General Applicability to Quantum Monte Carlo!?

Porton Shower


"dark photon"
emission
γ
χ
γ
"dark
fermion"
γ


high energy
~ 100 GeV
low energy
~ 100 MeV
discretized
time/energy
step
χ
γ
γ
γ


high energy
low energy
discretized step
χ
γ
γ
γ



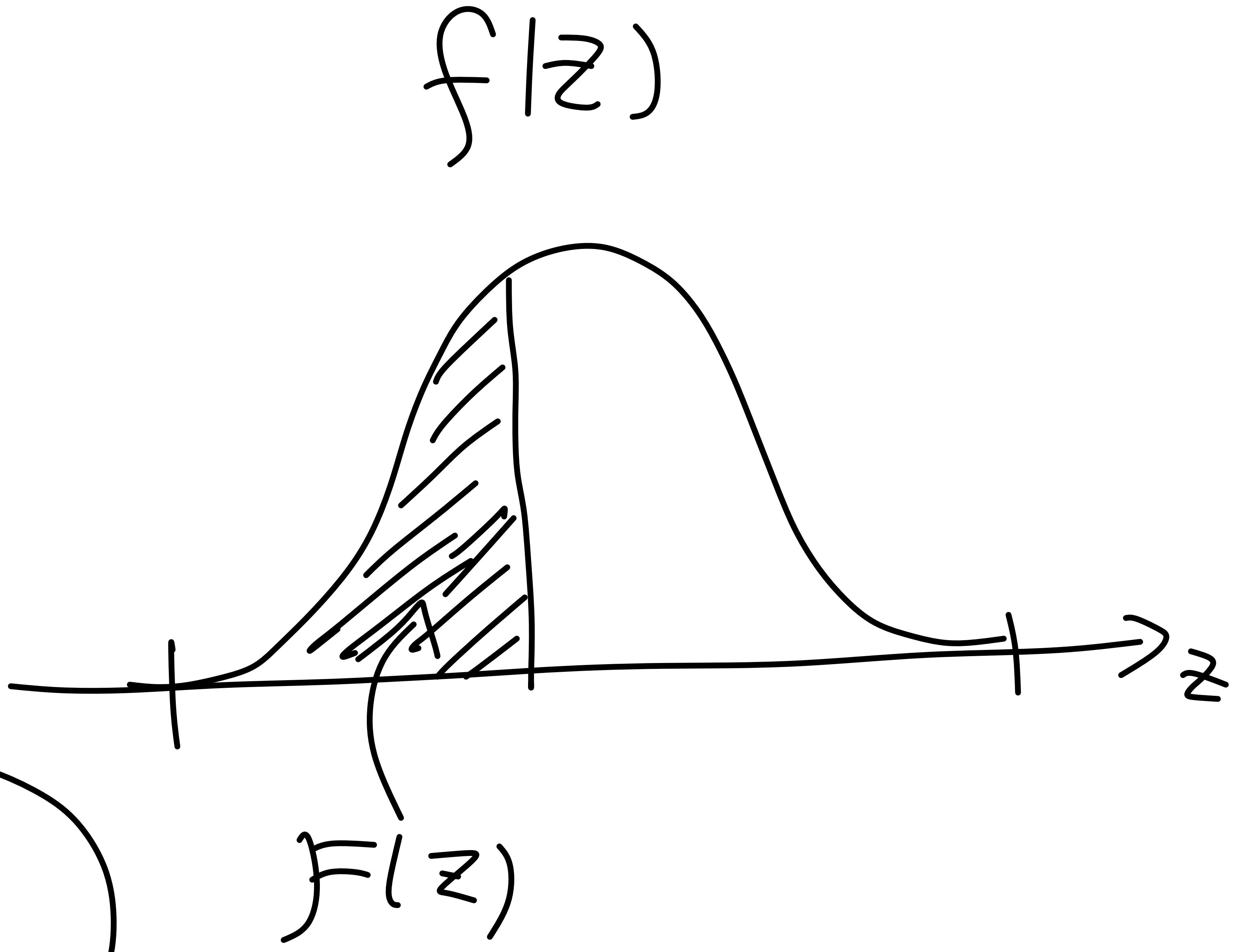
MC sampling
$\int dz\, f(z)$
emission probability
γ
$1-z$
χ
z
momentum fraction
γ
$1-z'$
z'

MC sampling

emission probability $\int dz\, f(z)$

Sample z by

$$z = F^{-1}(\underbrace{R}_{\text{uniform distribution}})$$

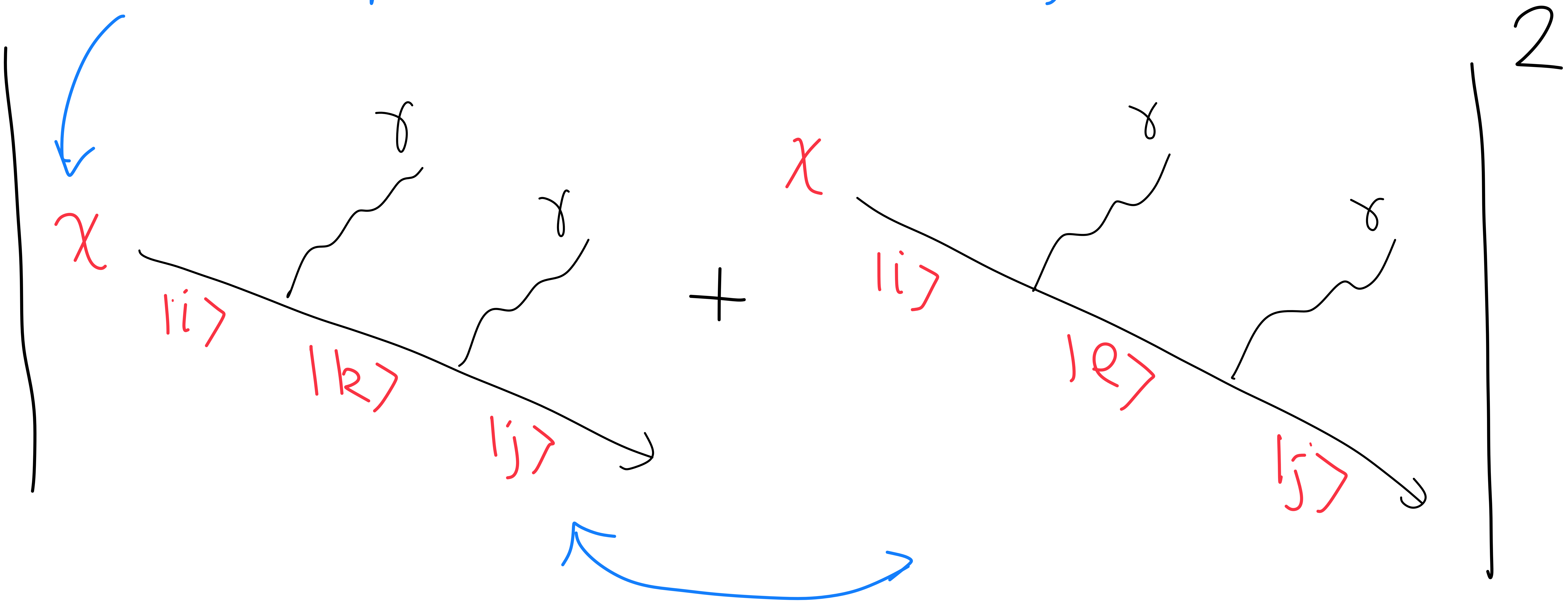


$$F(z) := \int^{z} dz'\, f(z') \quad \text{s.t.} \quad f(z)\,dz = dR$$

Quantum Parton Shower

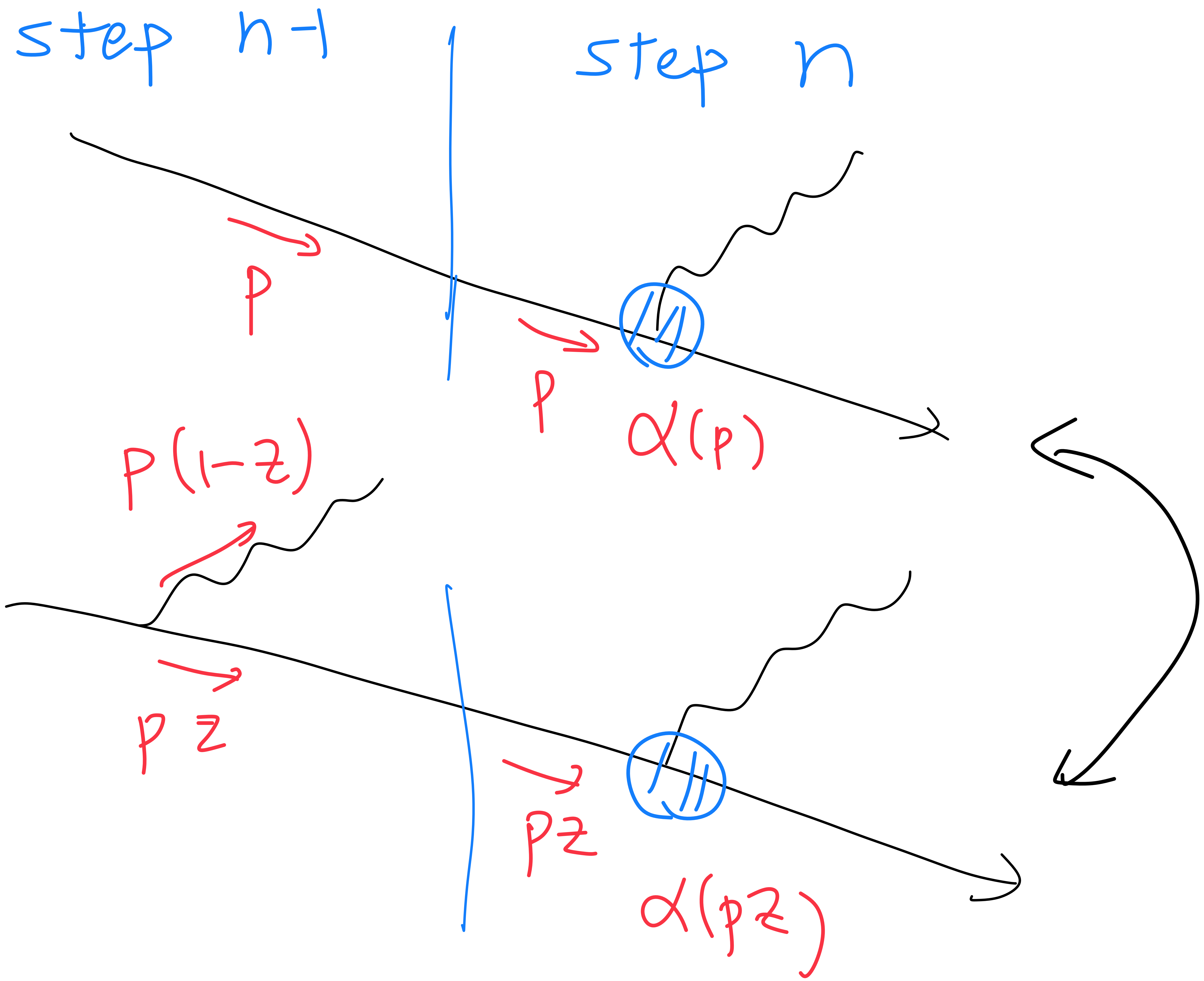
quantum interference

* multiple quantum states (flavors)



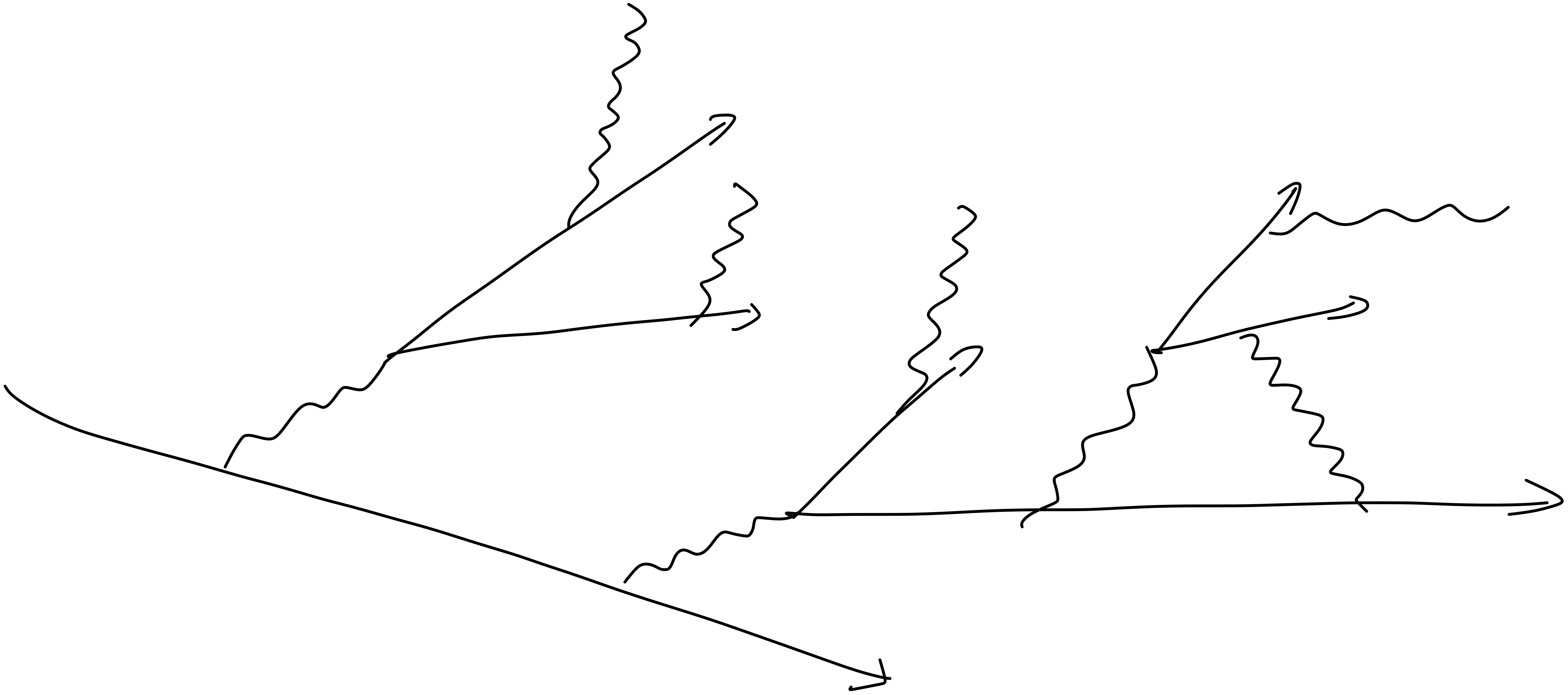
cross term w/ $k \neq l$

kinematics: requires quantum/classical hybrid



differences in history matters

emission history is complicated in general



Toy Model

$$\left(\begin{array}{l} * \text{ quantum state } \quad |q\rangle \\ * \text{ classical data } \quad \mathbb{C} \end{array} \right)$$

history

$$\left(\begin{array}{l} \text{parameter } \quad z \\ \text{from prob. dist.} \\ \qquad f(q, \mathbb{C}, z) \ll 1 \end{array} \right)$$

$$f_{tot}(q, \mathbb{C}) = \int dz \; f(q, \mathbb{C}, z) \leftarrow \text{emission}$$

$$f_{no}(q, \mathbb{C}) = 1 - f_{tot}(q, \mathbb{C}) \leftarrow \text{no emission}$$

$$\begin{pmatrix} * \text{ quantum state } |\mathbb{q}\rangle \\ * \text{ classical data } \mathbb{C} \end{pmatrix}$$

history

$$\Big\downarrow$$

$$\begin{pmatrix} \text{parameter } z \\ \text{from prob. dist.} \\ f(\mathbb{q}, \mathbb{C}, z) \ll 1 \end{pmatrix} \rightsquigarrow \begin{pmatrix} \text{sample } z \text{ from} \\ p(\mathbb{C}, z) = \sum_{\mathbb{q}} \alpha_{\mathbb{q}}^2 f(\mathbb{q}, \mathbb{C}, z) \end{pmatrix}$$

exponentially-many terms !

$$f_{tot}(\mathbb{q}, \mathbb{C}) = \int dz \, f(\mathbb{q}, \mathbb{C}, z) \leftarrow \text{emission}$$

$$f_{no}(\mathbb{q}, \mathbb{C}) = 1 - f_{tot}(\mathbb{q}, \mathbb{C}) \leftarrow \text{no emission}$$

* quantum state $|q\rangle$
* classical data $\mathcal{C}$

history

inverse needed for

$$P(\mathcal{C}, z) = \underbrace{\int^{z} dz' \, p(\mathcal{C}, z')}_{\text{sum of prob. dist.}}$$

parameter z from prob. dist.

$$f(q, \mathcal{C}, z) \ll 1$$

sample z from

$$p(\mathcal{C}, z) = \sum_{q} \alpha_q^2 f(q, \mathcal{C}, z)$$

exponentially-many terms!

$$f_{tot}(q, \mathcal{C}) = \int dz \, f(q, \mathcal{C}, z) \quad \leftarrow \text{emission}$$

$$f_{no}(q, \mathcal{C}) = 1 - f_{tot}(q, \mathcal{C}) \quad \leftarrow \text{no emission}$$

Quantum Veto Algorithm

$$f^{\text{over}}(\mathbb{C}, z) \geq f(\P, \mathbb{C}, z) \quad \forall \P$$

Quantum Veto Algorithm

$$f^{over}(\Phi, z) \geq f(q, \Phi, z) \quad \forall q$$

replace $p(\Phi, z) = \sum_q \alpha_q^2 f(q, \Phi, z)$

by $P_{over}(\Phi, z) = \sum_q \alpha_q^2 f_{over}(\Phi, z)$

$$= f_{over}(\Phi, Z)$$

w/ simple $\int P_{over}(\Phi, z)\, dz$

Veto Algorithm

$$f^{over}(\mathfrak{a}, z) \geq f(q, \mathfrak{a}, z) \quad \forall q$$

replace $p(\mathfrak{a}, z) = \sum_q \alpha_q^2 f(q, \mathfrak{a}, z)$

by $P_{over}(\mathfrak{a}, z) = \sum_q \alpha_q^2 f_{over}(\mathfrak{a}, z)$

$= f_{over}(\mathfrak{a}, z)$

w/ simple $\int P_{over}(\mathfrak{a}, z)\, dz$

Veto

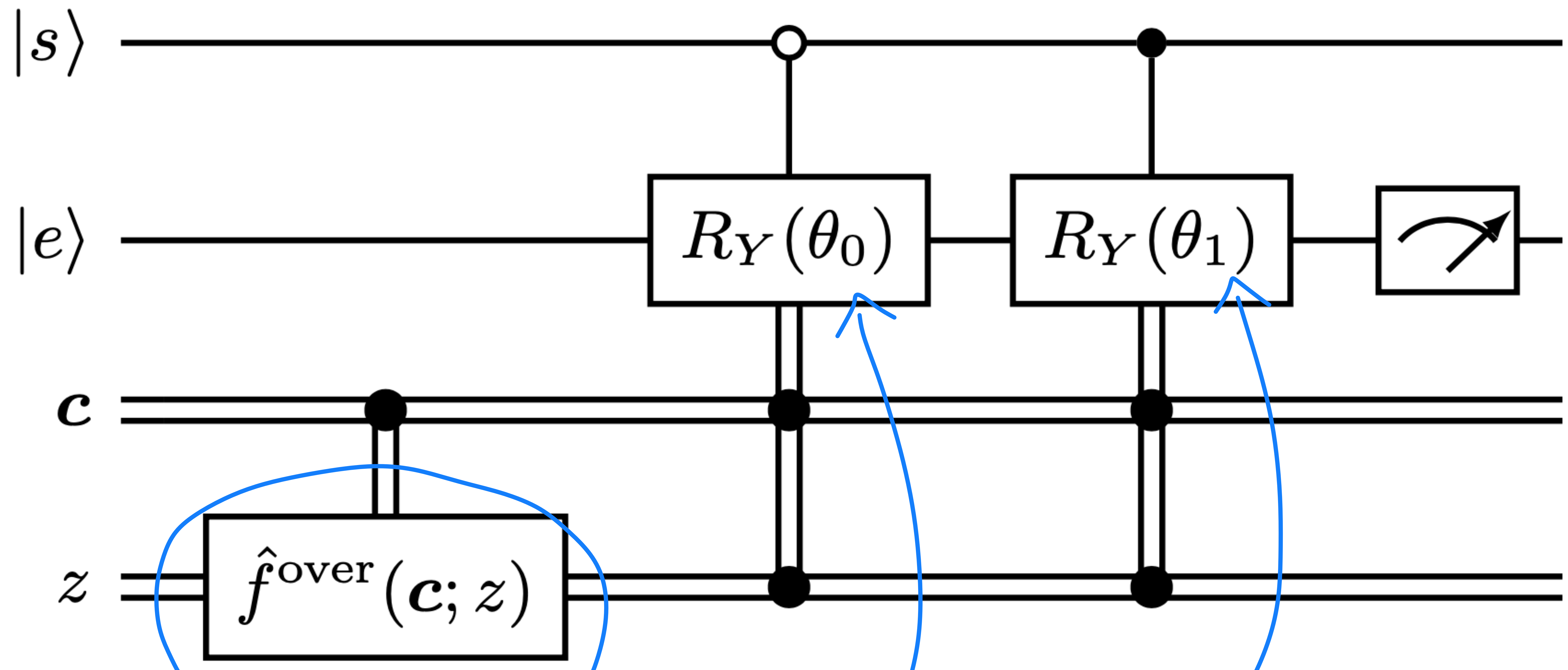
reject if

$$\frac{f(q, \mathfrak{a}, z)}{f_{over}(\mathfrak{a}, z)} < \underset{[0,1]}{R}$$

Quantum Circuit Implementation

state
$\alpha_0|0\rangle + \alpha_1|1\rangle$

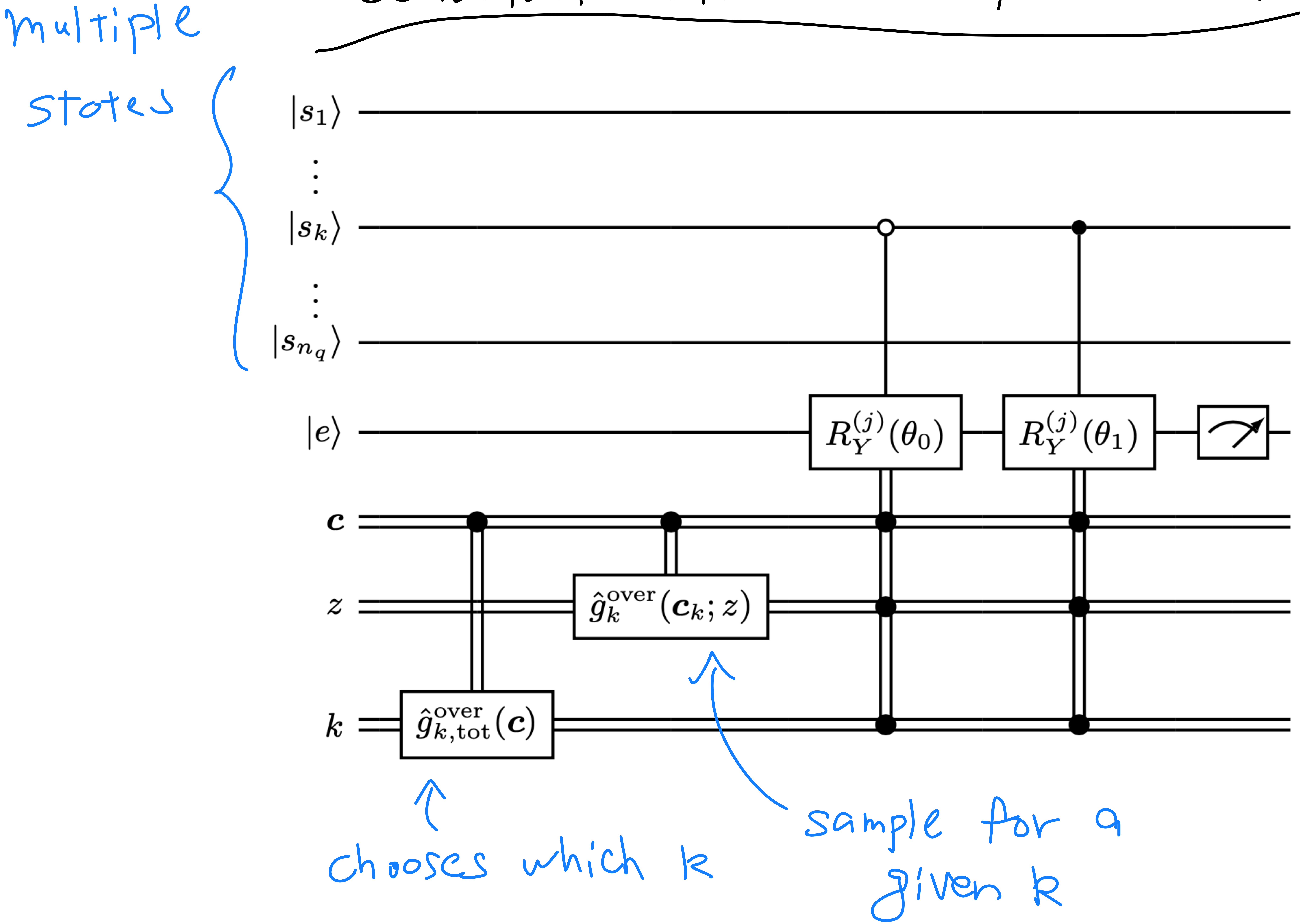
emission



$$\left(\theta_q = 2 \arcsin \sqrt{\frac{f(q, c, z)}{\hat{f}_{over}(c, z)}} \right)$$

↑ normalized fover

Quantum Circuit Implementation



* We can show:

  Quantum Circuit gives correct ρ if $f \ll 1$

* multiple MC steps / multiple q-state works

* can be upgraded to full Quantum PS

* if ψ is a product state

classically simulated, with error $\sim N_{step}$

$$|S\rangle = \bigotimes_{k} \left(\sum_{q_k=0,1} \alpha_{k,q_k} |q_k\rangle \right)$$

$$p_k(z;c) = \sum_{q_k=0,1} |\alpha_{k,q_k}|^2 f(q_k, c_k; z)$$

only 2 terms

Summary

* Quantum Veto Algorithm for
  Quantum Parton Shower

* Much more efficient than previous algorithms
  sometimes classically simulated

Q : More examples for

Quantum Vetos in MC ?