Quantum Parton Showers

KAVLI IPMU
Masahito Yamazaki
THE UNIVERSITY OF TOKYO

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So Chigusa (Berkeley) + MY, arXiv: 2204.12500 [hep-ph]
Christian W. Bauer, So Chigusa + MY [In Progress]
also Bauer, de Jong, Nachman, Provasoli (2019),⋯

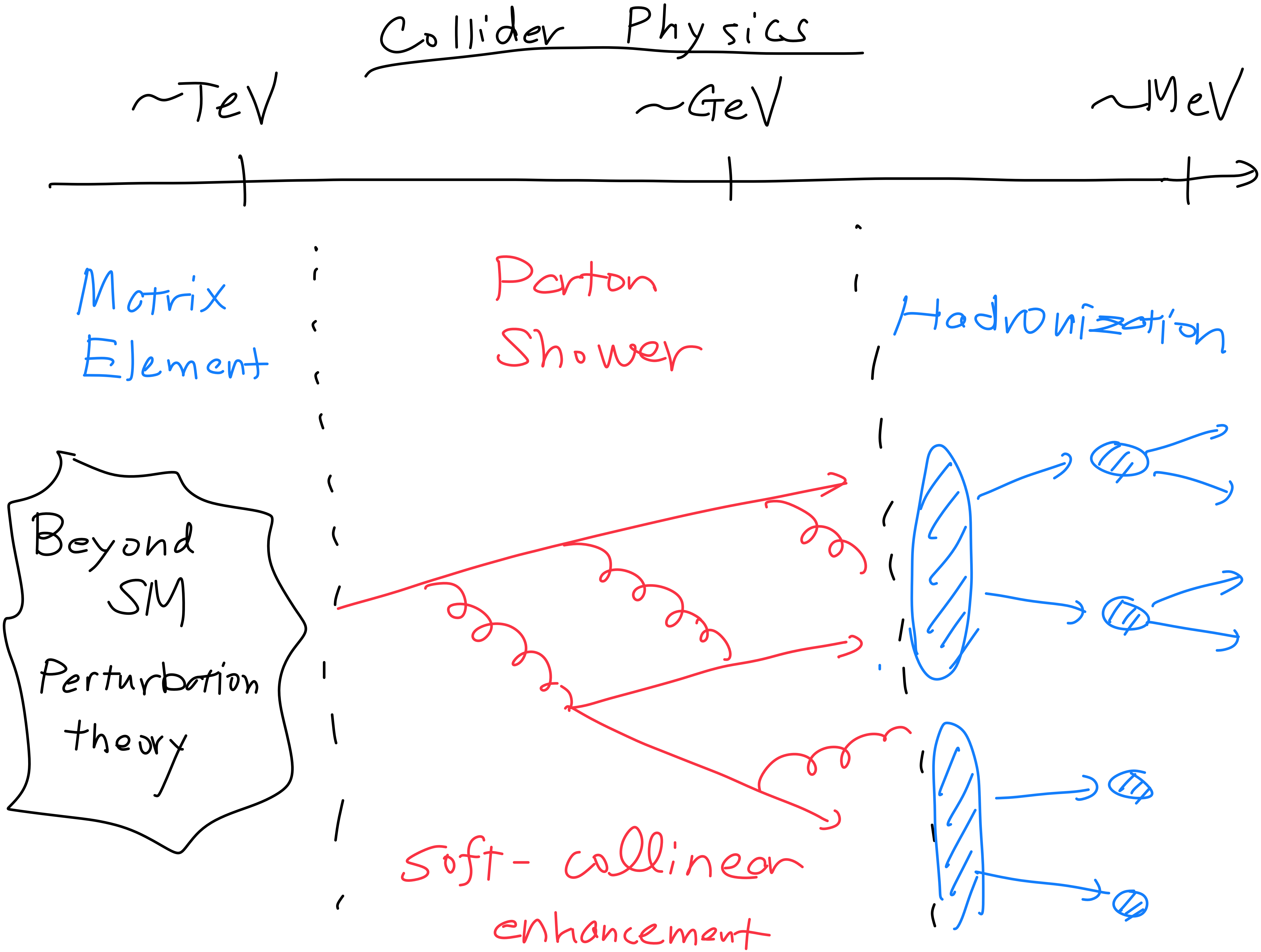
Wish List

* quantum effects important
  (interference, entanglement, ...)

* small-scale problem $\subset$ full-scale problem

* quantum / classical hybrid

* simplified model + extra layers
  + general lessons?


Collider Physics
~TeV
~GeV
~MeV
Matrix Element
Parton Shower
Hadronization
Beyond SM
Perturbation theory
soft-collinear enhancement

Simplified Model

fermion $\chi_{i=1\sim N_f}$ (N_f flavors)

photon $U(1)$ A'_μ

$$\mathcal{L}_{dark} = \sum_i \overline{\chi_i}(i\partial\!\!\!/ - m_{\chi_i})\chi_i + \sum_{ij} g'_{ij}\,\overline{\chi_i}\,A\!\!\!/'\,\chi_j$$

$$- \frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} - \frac{1}{2}m_{A'}^2 A'_\mu A'_\mu$$

Simplified Model

dark fermion $\chi_{i=1\sim N_f}$ (N_f flavors)

dark photon $U(1)$ A'_μ

$$\mathcal{L}_{dark} = \sum_i \overline{\chi_i} (i\partial\!\!\!/ - m_{\chi_i}) \chi_i + \sum_{ij} g'_{ij} \overline{\chi_i} A\!\!\!/' \chi_j - \frac{1}{4} F'_{\mu\nu} F'^{\mu\nu} - \frac{1}{2} m_{A'}^2 A'_\mu A'_\mu$$

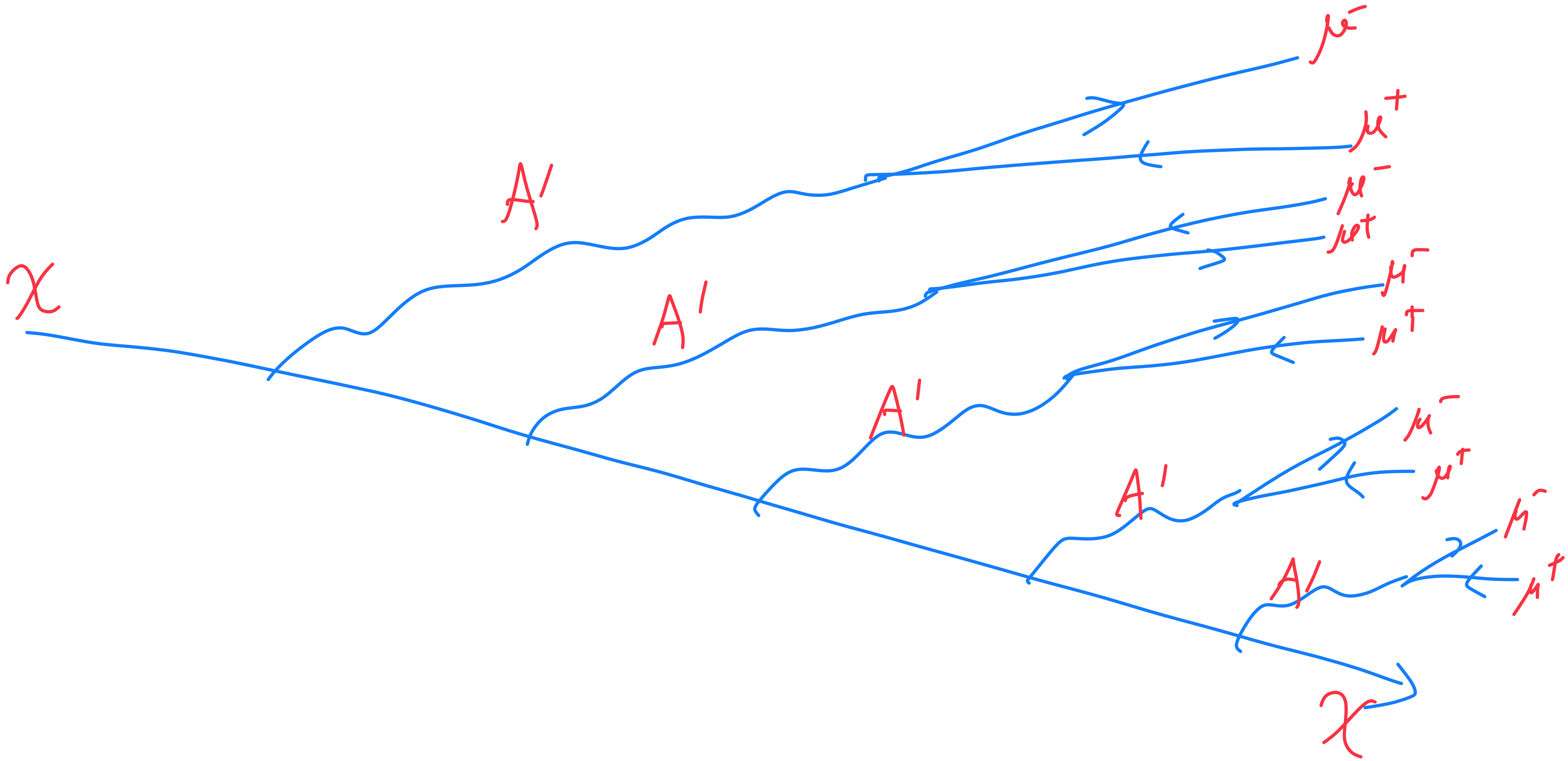
※ dark sector model [many papers]

mediator for dark-matter self-interactions

↑

cosmology

Dark Sector Jets

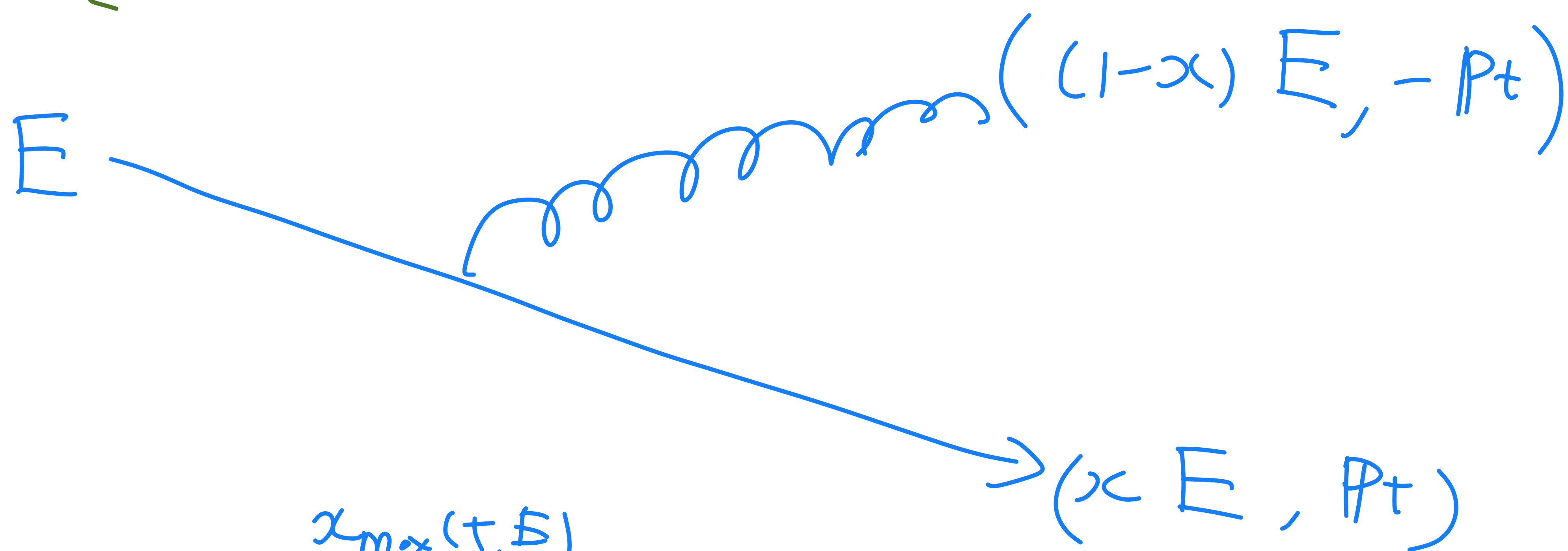


dramatic event e.g. @ HL-LHC

[many papers]

Standard : classical Monte Carlo

[many programs, e.g. Pythia, Herwig, Sherpa, ...]



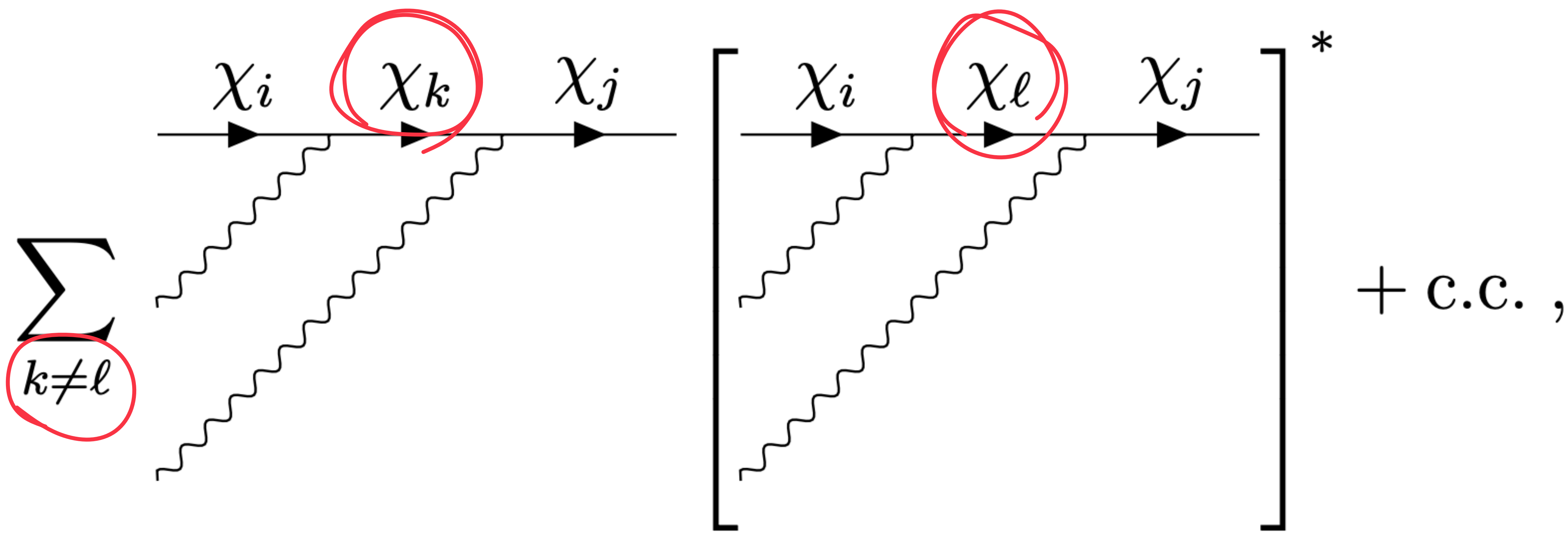
$$R(t) = \int_{x_{min}(t,E)}^{x_{max}(t,E)} dx \, \frac{g^2}{8\pi} \frac{1}{t} P_{\chi\to\chi}(x, t)$$

x: energy fraction

t: virtuality $\longleftrightarrow p_T$

$$P_{\chi\to\chi} = \frac{1+x^2}{1-x} - \frac{2(m_\chi^2 + m_{A'}^2)}{t}$$

Quantum interference between flavors ($N_f > 1$)

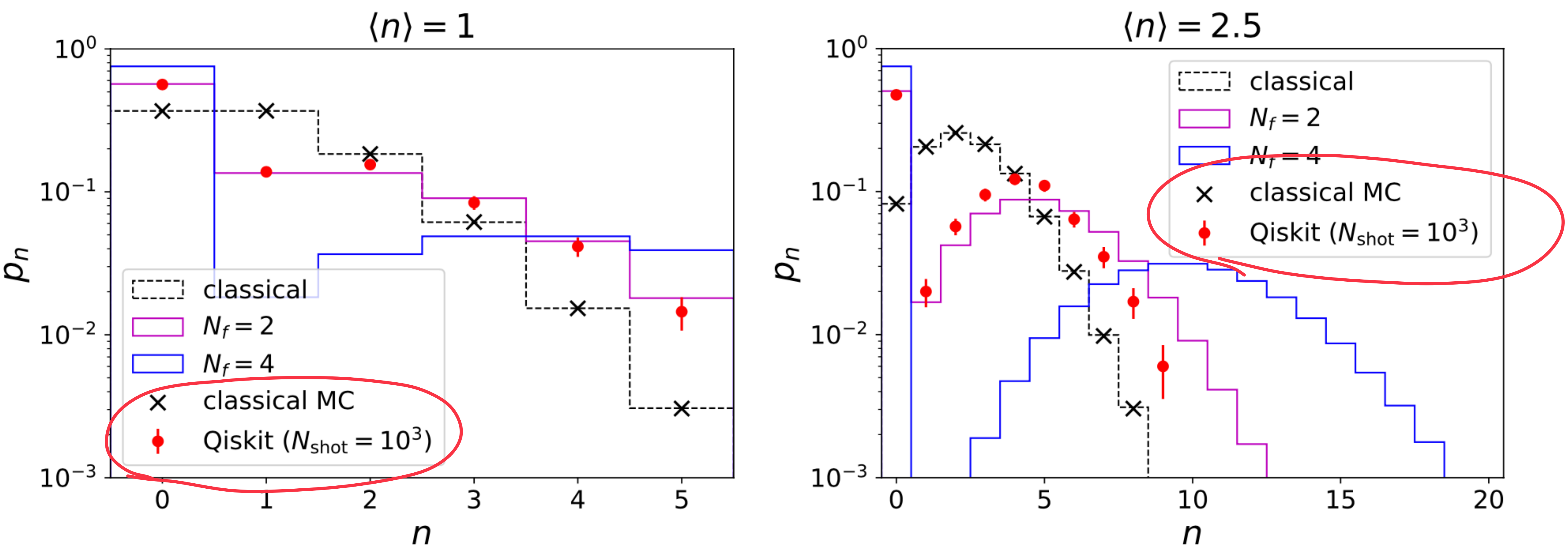


Not in classical Monte Carlo

(except in large N_c approximation)

Results (in simplified analysis)

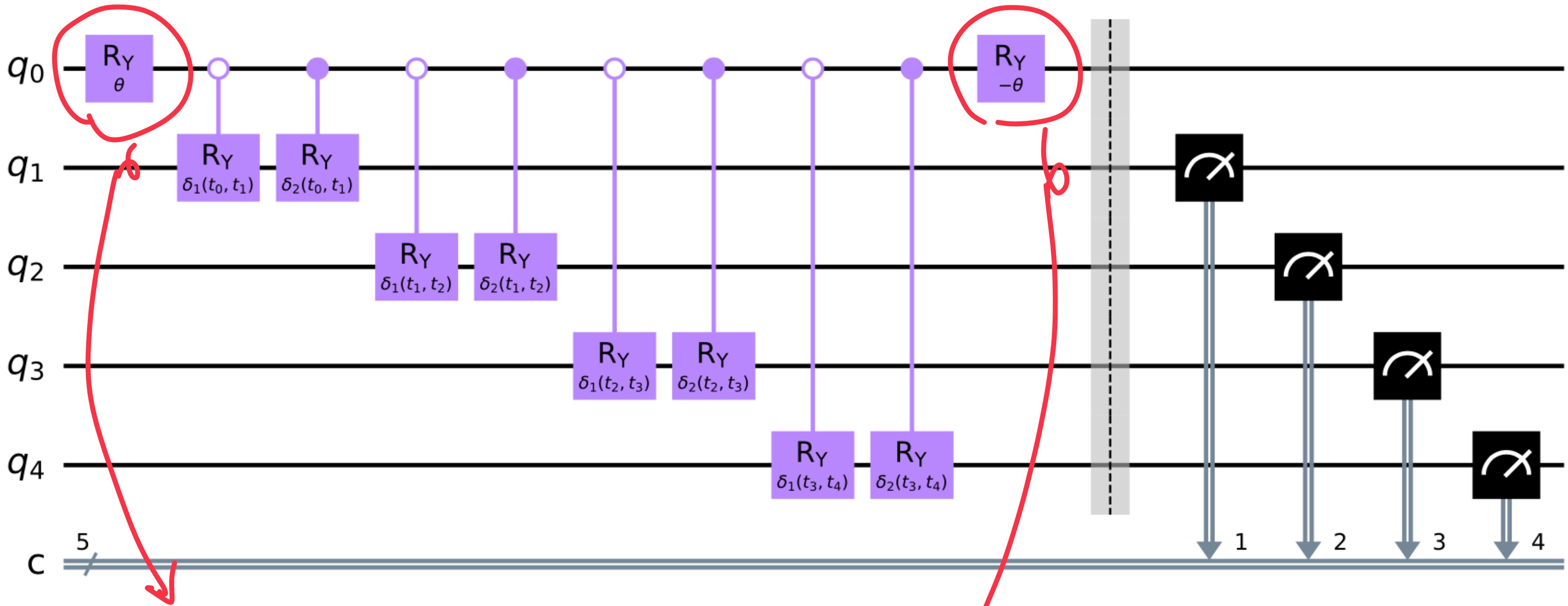
[Chigusa-MY '22]



huge enhancement

for n (# emissions) large!

$N_f = 2, \quad N_{step} = 4$

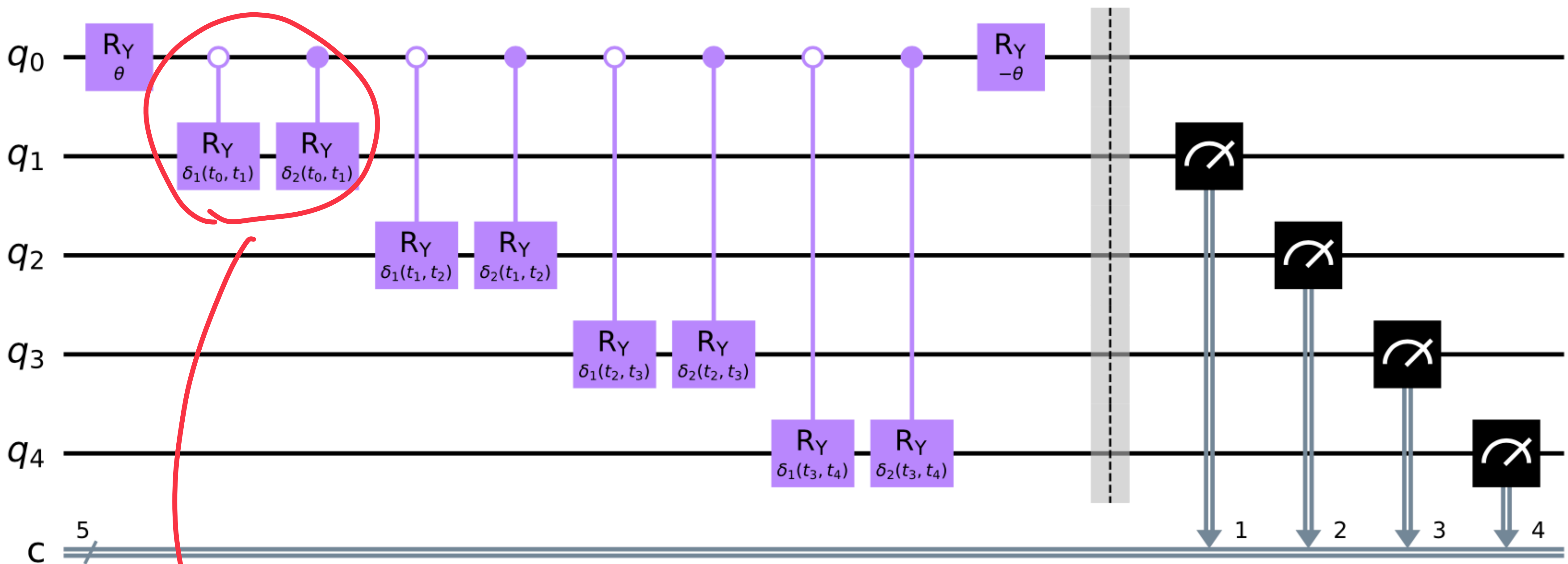


rotate the state into gauge-diagonal basis

$$\begin{pmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{pmatrix} = R_Y(\theta)^{\dagger} \begin{pmatrix} g_1' & 0 \\ 0 & g_2' \end{pmatrix} R_Y(\theta)$$

$$R_Y(\theta) = \begin{pmatrix} \cos\frac{\theta}{2} & -\sin\theta/2 \\ \sin\frac{\theta}{2} & \cos\theta/2 \end{pmatrix}$$

$N_f = 2, \quad N_{step} = 4$



depending on the q_0

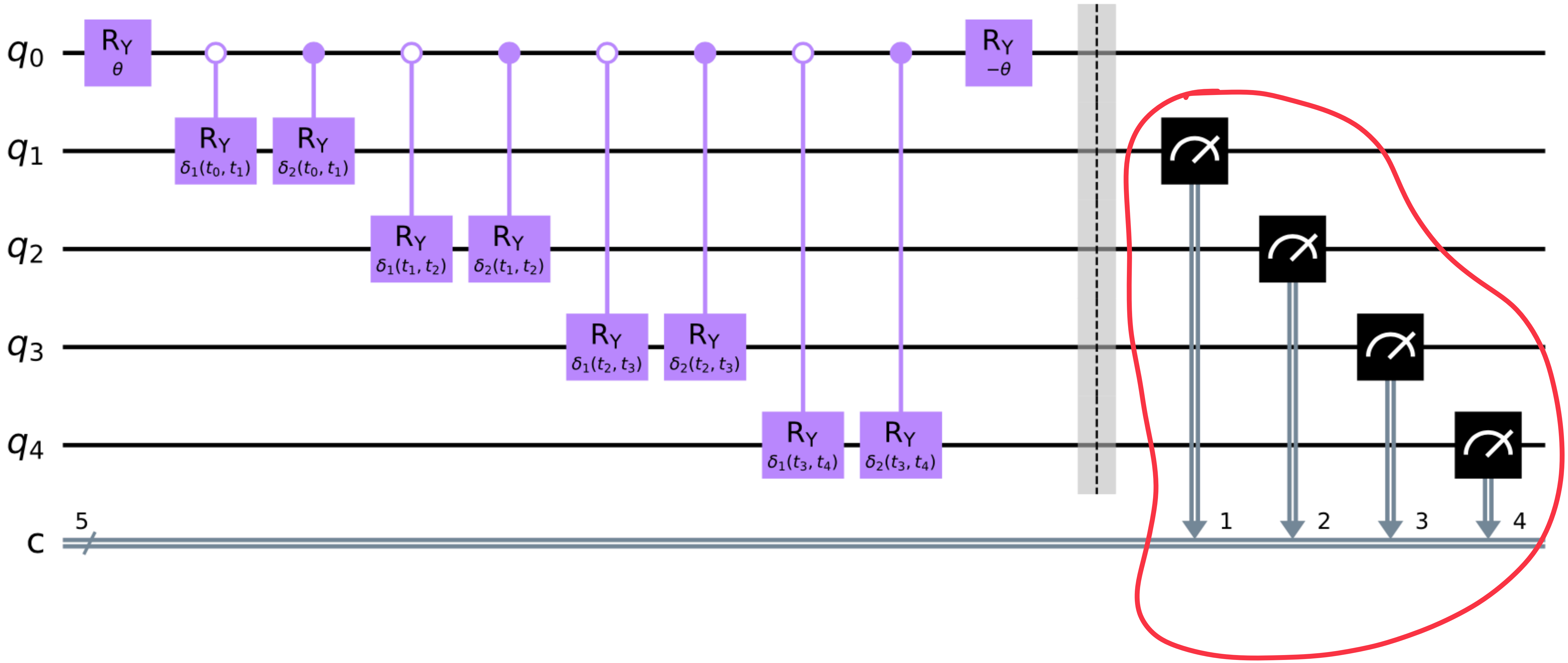
we emit particles

with different probabilities

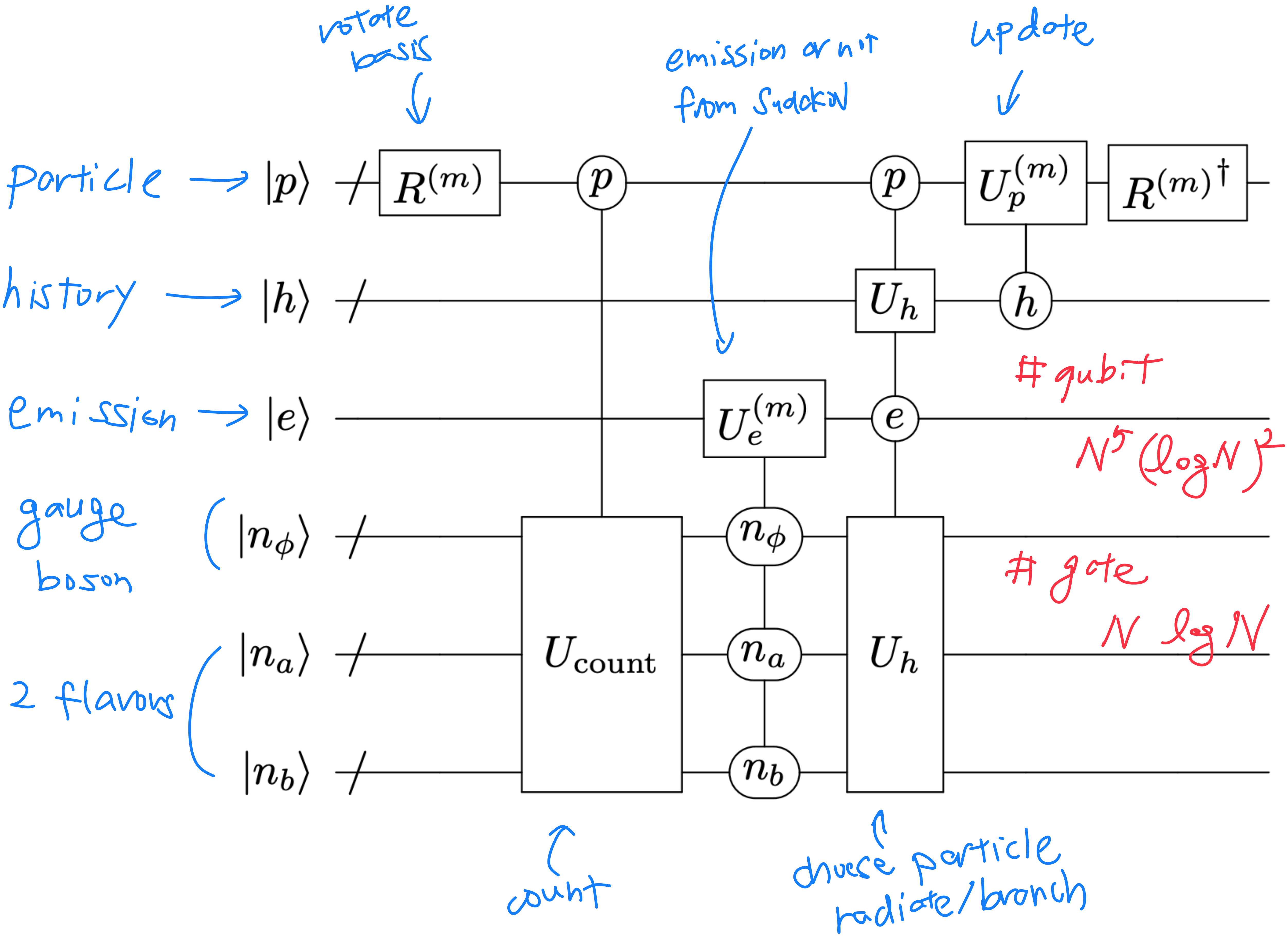
$$\tan\frac{\delta_i}{2} = \sqrt{\frac{1-\Delta_i}{\Delta_i}}$$

$$\Delta_i = \exp\left[-N_f \int R(t)\right]$$

$N_f = 2, \quad N_{step} = 4$



measure # of γ'



[Bauer – de Jong – Nachman – Provasoli '19]

In Progress (Bauer + Chigusa + MY)

- incorporate kinematics, RG-flow

  quantum-classical hybrid
  [Bauer-Chigusa-MY]

- incorporate veto algorithm

  mid-circuit measurement

  [cf. Deliyannis-Sud-Chamaki-Webb-Mack-Bauer-Nachman ('22)]

- more serious model building

  simulations on quantum hardware

General Lessons?

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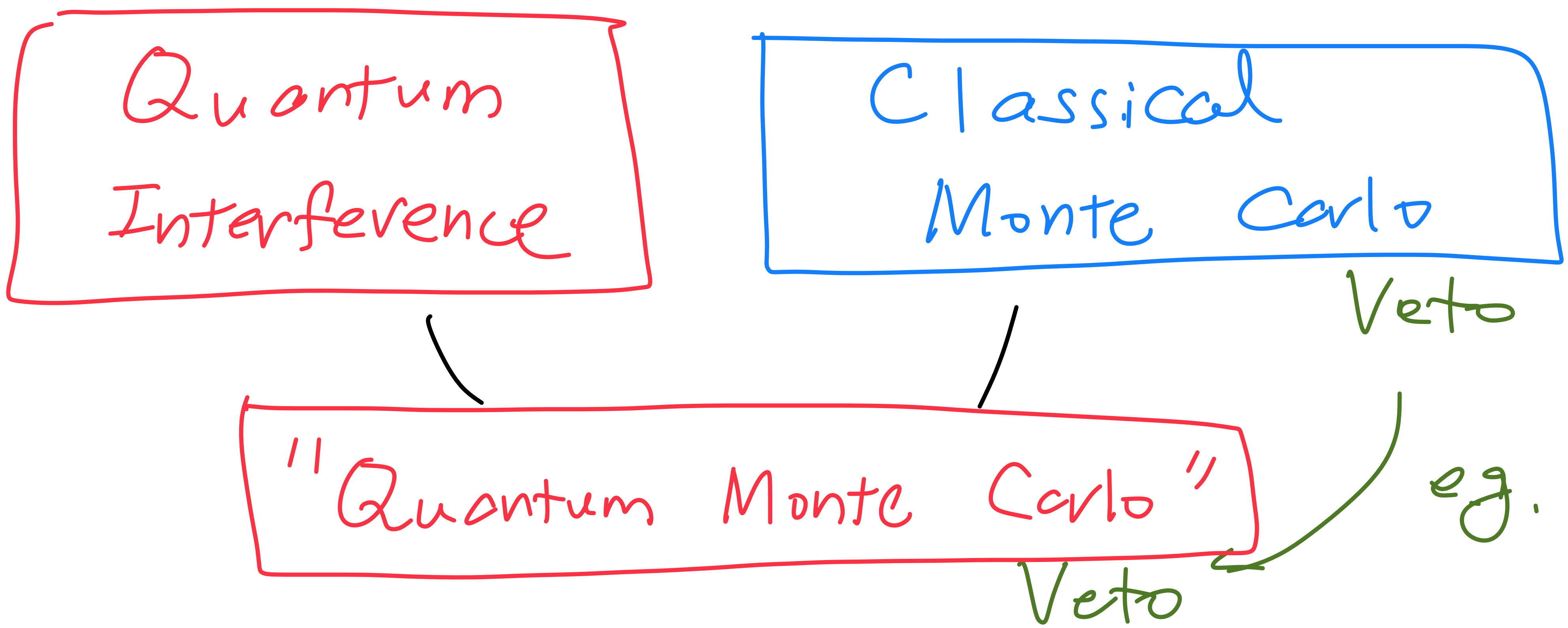

* Separation of energy scales

EFT, renormalization-group, . . .