QCD corrections to the electroweak sphaleron rate

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SM interactions change baryon number

$$\partial_\mu J^\mu_B = \chi \qquad \Rightarrow \qquad \partial_t B \propto \Gamma_{\text{sph}} = \underbrace{\frac{1}{2}\int \mathrm{d}^4x\ \langle\{\chi(x),\chi(0)\}\rangle}_{\text{hot sphaleron rate}}$$

- Important input for primordial baryon asymmetry predictions (baryogenesis, leptogenesis)

$\chi = (\alpha_w/4\pi)\ F\widetilde{F}$ is Chern-Simons charge density / $B = \int \mathrm{d}^3\boldsymbol{x} J^0_B$ is baryon number

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What about other SM interactions?

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Effective theory for $p \sim g_w^2 T$ gauge fields

$$\vec{D} \times \vec{B} = \underbrace{D_t \vec{E}}_{\text{neglect}} + \vec{J} \qquad \vec{J} = g_w \sum_s \int_p \frac{\vec{p}}{|\vec{p}|} \left(f_s(p) - \overline{f}_s(p) \right)$$

s = particle species / f_s, $\overline{f}_s$ = distribution functions (adjoint rep)

- f_s, $\overline{f}_s$ obey Vlasov-Boltzmann equations $\Rightarrow$ Solve to find J

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- f_s, $\overline{f}_s$ obey Vlasov-Boltzmann equations $\Rightarrow$ Solve to find J
- Next-to-leading log (NLL) approximation yields local current

$$J = \sigma E + \zeta \qquad \Rightarrow \qquad \Gamma_{\text{sph}} = \underbrace{(10.0 \pm 0.3)}_{\text{from lattice}} \cdot \frac{2\pi T}{3\sigma} \alpha_w^5 T^4$$

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IR divergencies enhance small-angle scattering

Linearized Vlasov-Boltzmann equation:

$$\underbrace{\cancel{vD\delta f_s}}_{O(g_w^2)} \pm g_w f_F' \, \vec{E}\vec{v} = \underbrace{C_{\text{weak}}[\delta f_s]}_{O(g_w^2 \ln g_w^{-1})}$$

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- Weak collisions are more enhanced but QCD coupling is larger

  ⇒ **Strong interactions potentially important**

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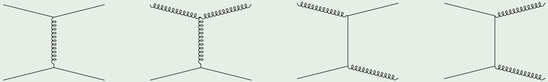
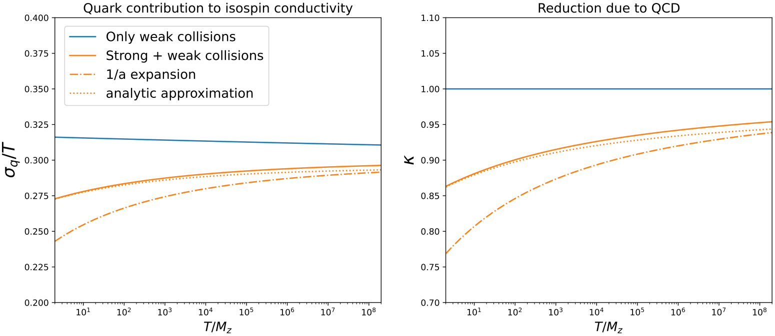
Our work: (1) Compute LL **strong collision term** (Schwinger-Keldysh)



$\Rightarrow$ Single parameter $a \sim \dfrac{g_w^2 \log\left(g_w^{-1}\right)}{g_s^4 \log\left(g_s^{-1}\right)}$ characterizes size

(2) Solve resulting differential equation

Strong scatterings raise sphaleron rate by 6%



- 15% lower quark contribution $\Rightarrow$ 6% overall decrease

σ_q = quark contribution to isospin conductivity / κ = ratio of with and without QCD

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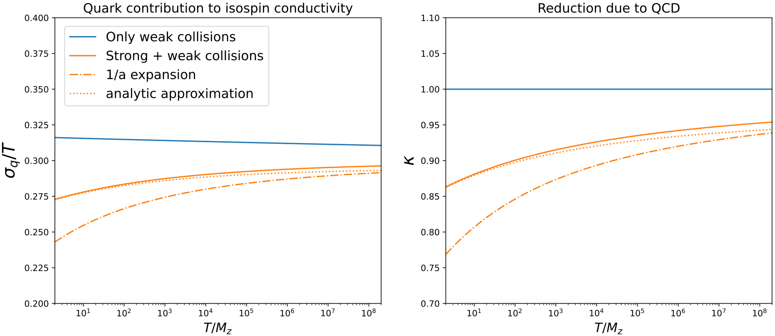

- 15% lower quark contribution ⇒ 6% overall decrease
- Simple analytic approximation:

$$\kappa \equiv \frac{\sigma_q}{\sigma_{q\,\cancel{QCD}}} \approx 0.9767 \cdot \frac{a}{0.2107 + a} \qquad \text{(Error} < 1.5\%\text{)}$$

σ_q = quark contribution to isospin conductivity / κ = ratio of with and without QCD

Conclusions and Outlook

$$\sigma = \underbrace{(\sigma - \sigma_q)_{\cancel{QCD}}}_{\text{from } \ell,\ H,\ W} + \kappa \cdot \sigma_{q\,\cancel{QCD}} \qquad \kappa = 0.9767 \cdot \frac{a}{0.2107 + a}$$

- We computed leading-log QCD corrections to weak-isospin conductivity
  $\Rightarrow$ **6% larger sphaleron rate**

Possible next steps: - Next-to-leading log QCD corrections
- Masses (close to EW crossover)
- Going beyond next-to-leading log (new operators)

Backup slides