**Motivation**

- photons produced in all stages of the heavy ion collisions → probe the initial state
- "photon puzzle" → find new sources of photons
- goal: saturation physics from photons
- CGC phase → gluon dominated 
  → photons from virtual quarks!
- small coupling compensated by $A^\mu \sim 1/g$ color fields
  → loops as important as trees!

**Amplitude**

- $0$th order in $\rho_p$: $A^\mu$ pure gauge → $\langle p, \lambda | \Omega_{\text{in}} \rangle = 0$
- $1$st order in $\rho_p$: $A^\mu$ develops transverse components
  
  $\langle p, \lambda | \Omega_{\text{in}} \rangle = e_i g_F (p, \lambda) \int d^4 x \int d^4 y e_i F_{\mu\nu}(\alpha) \Omega_{\text{in}}(\alpha) \Omega_{\text{in}}^\dagger(\alpha') \Omega_{\text{in}}(\alpha) A^\mu(x) = e_i g_F (p, \lambda) \int d^4 x \int d^4 y e_i F_{\mu\nu}(\alpha)(p) \Omega_{\text{in}}(\alpha) \Omega_{\text{in}}^\dagger(\alpha') \Omega_{\text{in}}(\alpha) A^\mu(x) \bigg|_{p = 0}$

**Photon multiplicity**

$$dN = \frac{1}{16 \pi (2\pi)^3} \sum_{\lambda} \left| \langle p, \lambda | \Omega_{\text{in}} \rangle \right|^2$$

- color average → Mclerran-Venugopalan model
- proton
  $$\langle \rho_p | (k_{1\perp}^+ | \rho_p^b (k_{2\perp}^+) \rangle = (2\pi)^4 \delta^{ab} g^b g^a \rho_p^2 (k_{1\perp} - k_{2\perp})$$
- nucleus
  $$\langle \rho_n^a | (k_{1\perp}^+ | \rho_n^b (k_{2\perp}^+) \rangle = (2\pi)^4 \delta^{ab} g^b g^a \rho_n^2 (k_{1\perp} - k_{2\perp})$$

- $Q^2_s$: saturation scale

**Summary**

- analytic expression for photon multiplicity in $pA$ within CGC
- leading order → bremsstrahlung, but at high energy gluon content of the proton dominates
  → photon production through quark loop in that limit should resemble more the $AA$ case
- numerical evaluation underway