The coupling constant in NP QFT

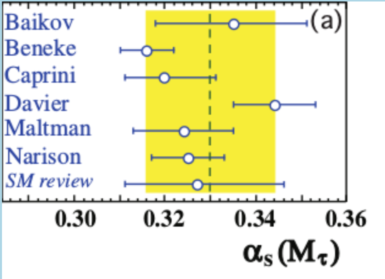
Alberto Ramos <alberto.ramos@cern.ch>

Computing $\alpha_s(M_Z)$

- Take some experimental observable $O(\mu; p) = A(p)\alpha_{MS}(\mu) + B(p)\alpha^2_{MS}(\mu) + \dots$
- Determine $\alpha_{MS}(\mu)$ by comparing experiment and theory computation.
- Straightforward in QED

$$g_e - 2 : \alpha_{em} = 7.297\,352\,5698(24) \times 10^{-3}$$
$$\text{recoil} : \alpha_{em} = 7.297\,352\,585(48) \times 10^{-3}$$

- But not in strongly interacting theories



- $g^2 \sim 4$ non-perturbative effects: renormalons, hadronization, ...
- Use perturbative $\beta-$function to run to M_Z.

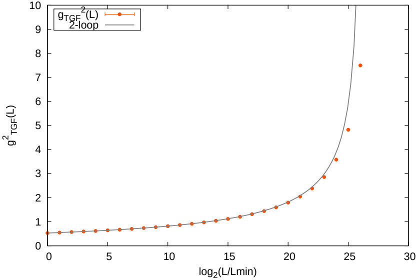
$$\tau : \alpha_s(M_Z) = 0.1198(15)$$
$$e^+e^- : \alpha_s(M_Z) = 0.1172(37)$$
$$DIS : \alpha_s(M_Z) = 0.1154(20)$$

- Basic question: When is safe to use perturbation theory? For sure at $\mu = 100\mathrm{GeV}$!

Running coupling from the lattice: Finite size scaling

Many ways to determine α_s on the lattice, but one of them (Finite size scaling) is able to match with perturbation theory at an arbitrary scale (modulo grants for computer time).

- Determine non-perturbatively how much changes $g^2(\mu)$ when $\mu \to 2\mu$.
- Repeat recursively as many times as you want.



- Example: $SU(2)$ Yang-Mills theory.
- Scale in units of lattice size $\mu = 1/L$.
- Non-perturbative running coupling. Renormalization scale changes by 10^8.
- Use new tool: Gradient (Wilson flow) to define the strong coupling $g^2_{GF}(\mu)$.

Running coupling from the lattice: Finite size scaling

Precise determination of α_s

On-going project with the ALPHA collaboration:

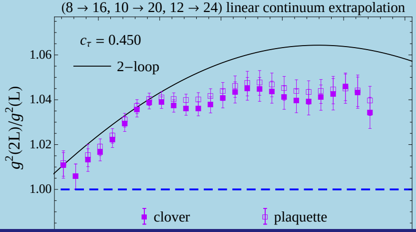
- **[Patrick Fritzsch (Madrid)]**,
- **[Tomasz Korzec, Ulli Wolff (HU)]**,
- **[Mattia delabrida, Hubert Simma, Rainer Sommer (DESY-Zeuthen)]**

Need CLS (very large collaboration) for "scale setting" (determine how much is L in [fm]).

Is $SU(3)$ with $N_f = 12$ flavours IR conformal?

Using existing data to compute the more precise gradient-flow coupling.

- **[C.J. Lin, Kenji Ogawa (Taiwan)]**
- **[Hiroshi Ohki (Japan)]**
- **[Eigo Shintani (Mainz)]**



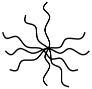
Lattice people hate discovering "new physics"

S = Standard model + Quantum Gravity

At low energies ($\ll M_{\rm pl}$)
$\langle O \rangle = \langle O \rangle_{SM} + \mathcal{O}(1/M_{\rm pl})$

We simulate

$S = \sum_{x,\mu\neq\nu} \mathrm{Tr}(1 - U_\mu(x)U_\nu(x+\mu)\cdots)$



Multi gluon interactions:
6,8,10,12,... gluon vertices.
at energy scales $1/a$

⟹ UNIVERSALITY
(Symmetries, dimensions, ...)

We obtain QCD

$S = -\frac{1}{2}\int \mathrm{Tr}\,(F_{\mu\nu}F_{\mu\nu}) + \ldots$

At low energies ($\ll 1/a$)
$\langle O \rangle_{\rm latt} = \langle O \rangle_{\rm QCD} + \mathcal{O}(a^2)$

- A lot of freedom on what we simulate. Cook taking into account:
  - Symmetry. Specially chiral symmetry (fermions a là Wilson, clover, Domain Wal,...).
  - Improvement. Minimize "new physics" (cutoff effects). (Symanzik improvement program).
- Even more freedom for "Gradient flow" quantities (i.e. coupling, EM tensor,...). Good choice following Symanzik program **[S. Sint (Dublin)]**.
  - Non-perturbative $\mathcal{O}(a^2)$ improvement of the integration of the flow equations.
  - Non-perturbative $\mathcal{O}(a^2)$ improved choice of observables for a definition of the coupling.