Non-perturbative momentum dependence of the coupling constant and hadronic models

Pre-DIS Wokshop
QCD Evolution Workshop: from collinear to non collinear case
April 8-9, 2011
JLab

Aurore Courtoy
INFN-Pavia

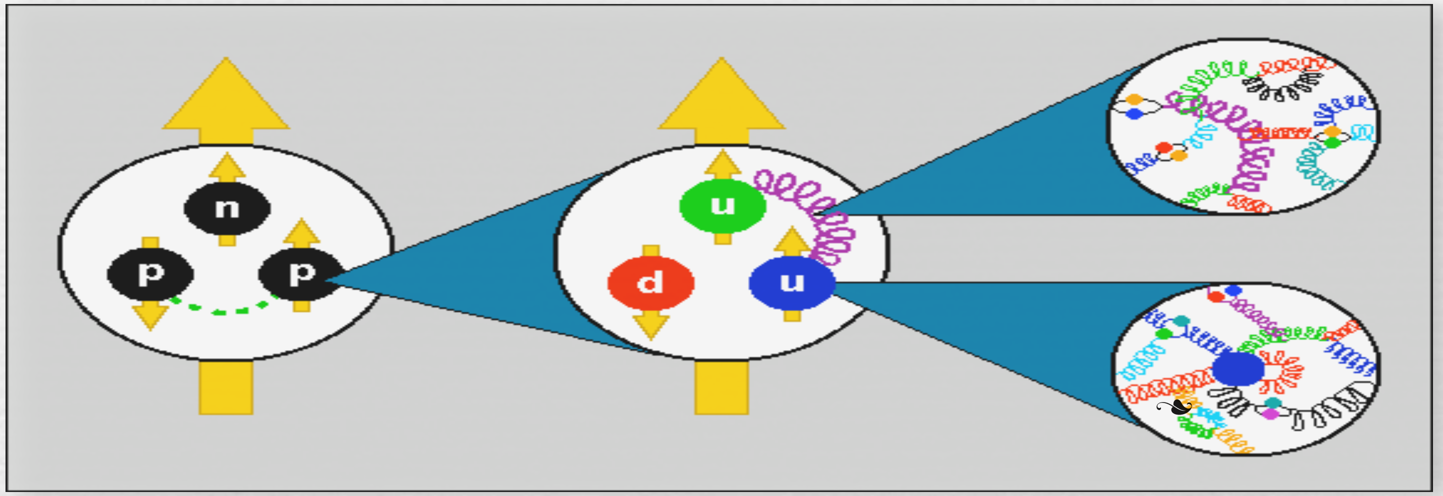
Outline

- Hadronic Models
- Finding the Hadronic Scale
- Rôle of the Coupling Constant: non-perturbative approach
- ‘Non-perturbative evolution’ and final-state interactions

Based on A.C., V. Vento & S. Scopetta, Eur.Phys.J. A47 (2011) 49

Hadronic Physics at Intermediate Energies: Hadronic Models

Hadron ⇔ Constituent quarks ⇔ Current quarks



Nonperturbative vs. Perturbative QCD

Models of Hadron Structure

Renormalization Group Eqs.

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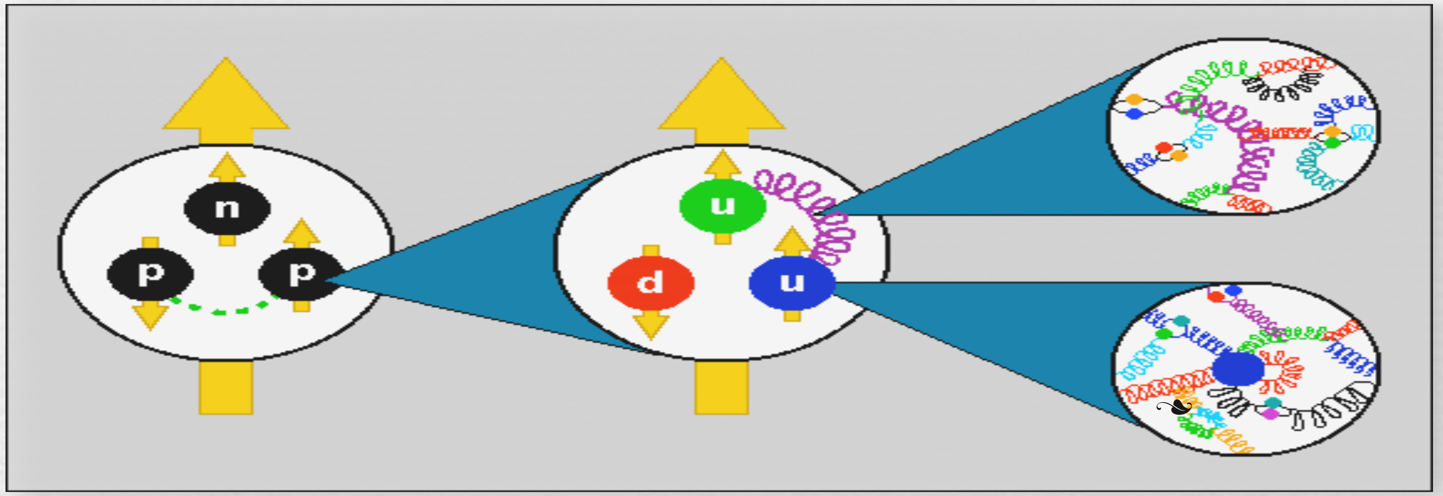

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- calculated in hadronic model
- at scale μ_0
- switch on QCD evolution

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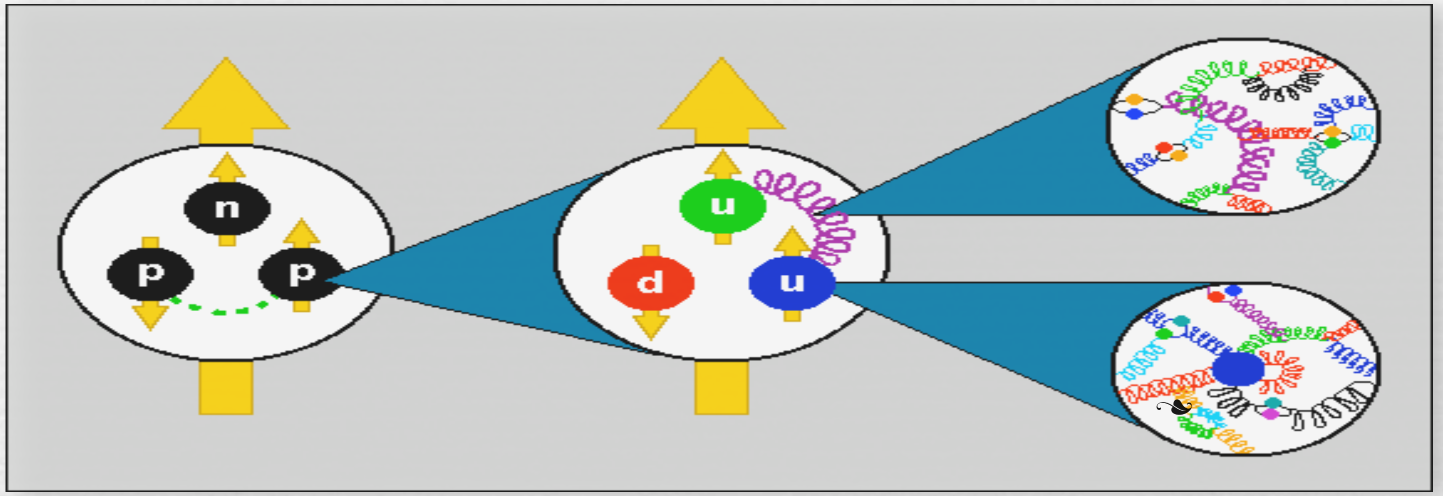

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Hadronic Scale: Standard Approach

There exists a scale at which there is no sea and no gluon:

$$\left\langle (u_v + d_v)\left(\mu_0^2\right)\right\rangle_{n=2} = 1$$

QCD evolution introduces gluons and sea quarks:

e.g. CTEQ parameterization PRD51 :

$$\left\langle (u_v + d_v)\left(Q^2 = 10\,\mathrm{GeV}^2\right)\right\rangle_{n=2} = 0.36$$

Parisi & Petronzio, Phys. Lett. B 62 (1976) 331
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Evolve downward high energy data until 2nd moment=1
Find μ_0^2

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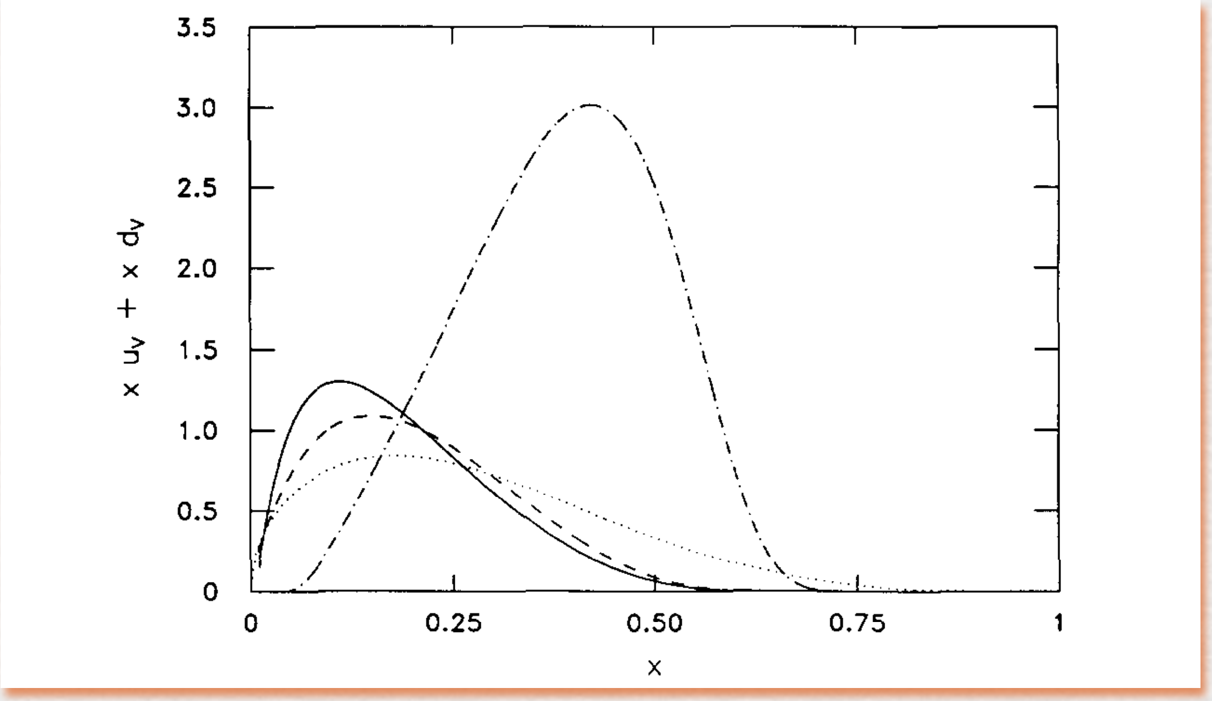
Hadronic Scale: Standard Approach

Models scenarios in MSbar scheme

- quark model
  - $\mu_0^2 = 0.1 GeV^2$
  - $\Lambda_{LO} = .27$ GeV ; $\Lambda_{NLO} = .2$ GeV
  - $\alpha_{sLO} = 4\pi \times .32$; $\alpha_{sNLO} = 4\pi \times .13$
- partonic scenario
  - $\mu_0^2 = 0.2 GeV^2$

e.g. Isgur-Karl model : valence distribution



-·-·-·- IK at μ_0^2
------- LO evolution to Q^2=10 GeV^2
——— NLO evolution to Q^2=10 GeV^2
······· CTEQ parametrization

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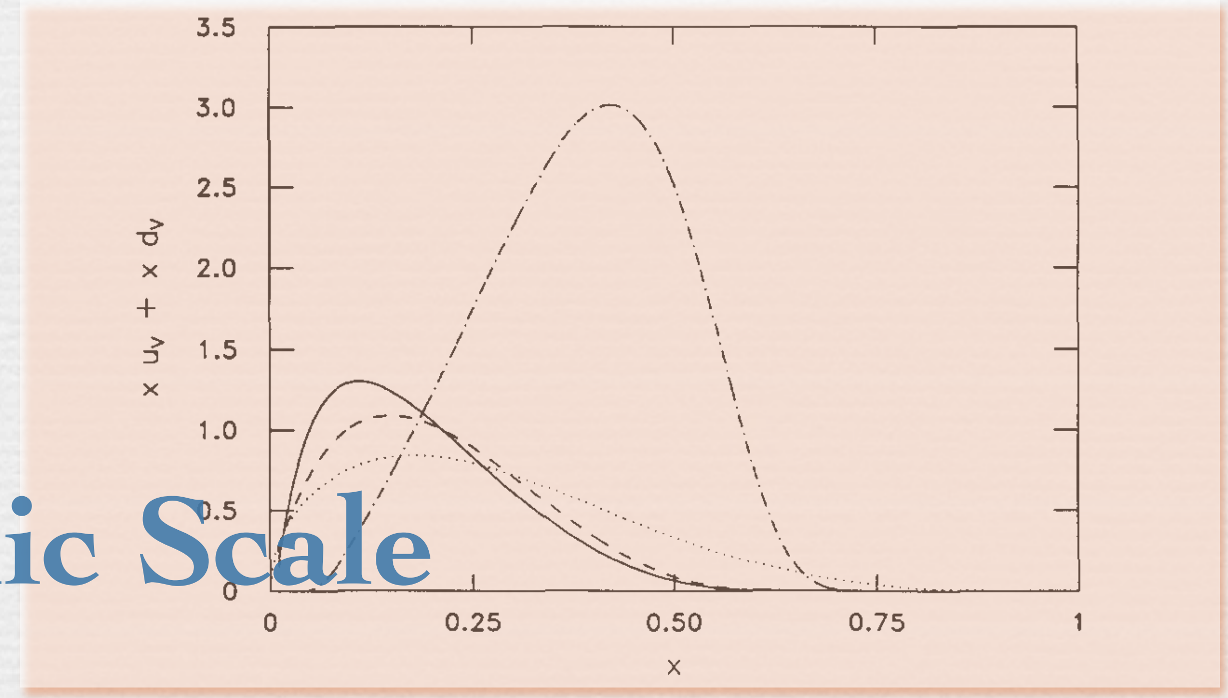
Low Hadronic Scale

e.g. Isgur-Karl model : valence distribution



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‘Perturbative’ Coupling Constant

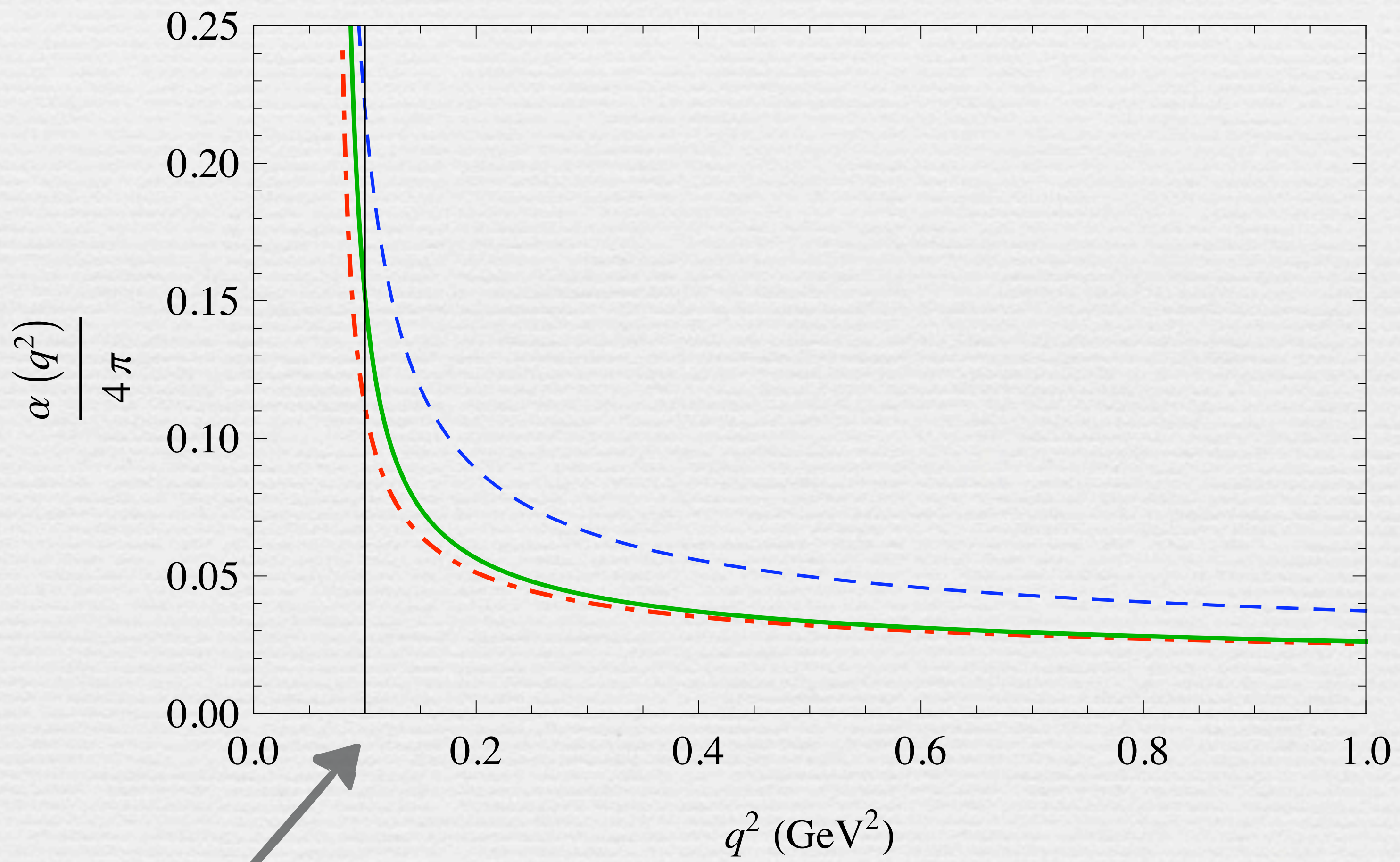
$$\frac{d\,a(Q^2)}{d(\ln\ Q^2)} = \beta_{N^m LO}(\alpha) = \sum_{k=0}^{m} a^{k+2}\beta_k$$

$\overline{MS}$ scheme

LO exact perturbative solution Λ=250 MeV

NLO exact perturbative solution Λ=250 MeV

NNLO exact perturbative solution Λ=250 MeV



Hadronic scale

Infrared Freezing of α_s

Non-perturbative approaches:

- Importance of finite couplings
- Taming the Landau pole

e.g. :

Cornwall, Phys.Rev.D26, 1453 (1982)
Mattingly & Stevenson, Phys.Rev.D49, 437 (1994)
Dokshitzer, Marchesini & Webber, Nucl.Phys.B469 (1996) 93
Cornwall & Papavassiliou, Phys.Rev.Lett.79, 1209 (1997)
Fischer, J. Phys. G32, R 253 (2006)
Alkofer & von Smekal, Phys. Rept. 353, 281 (2001)
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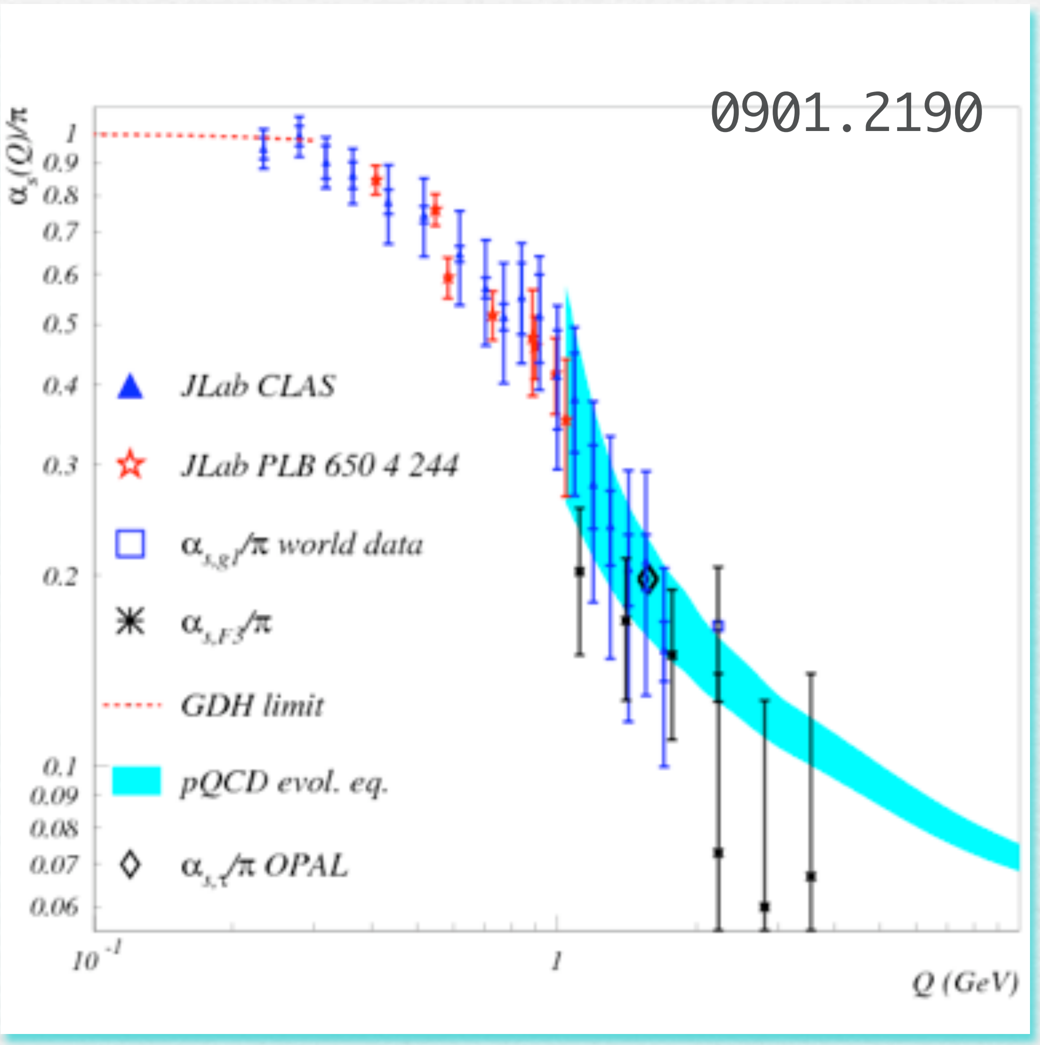
Aguilar, Binosi & Papavassiliou, JHEP 1007, 002 (2010)



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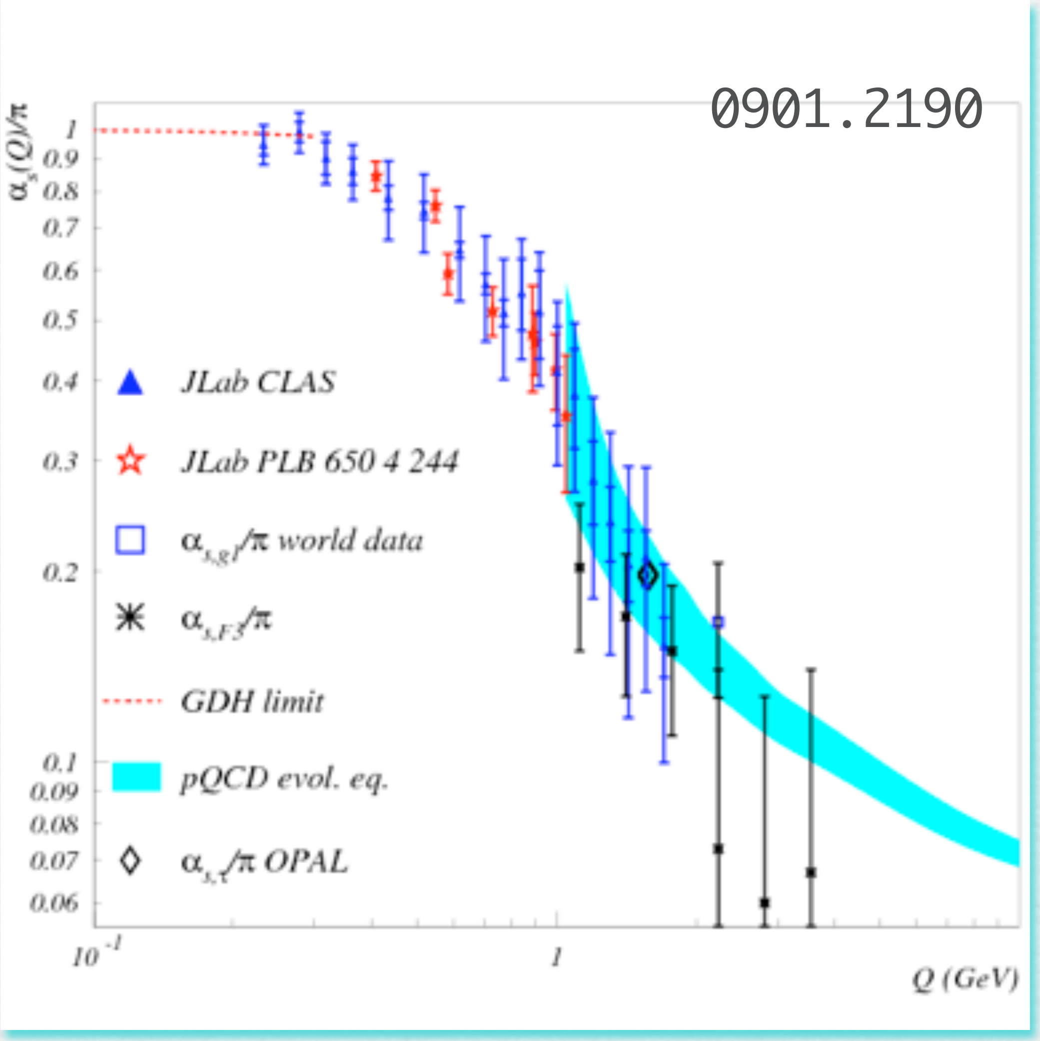


1st step: Qualitative analysis

Implications of IR finite αs in hadronic physics

NP Gluon Propagator: Gluon Mass as IR Regulator

Solving the Schwinger-Dyson eqs ...

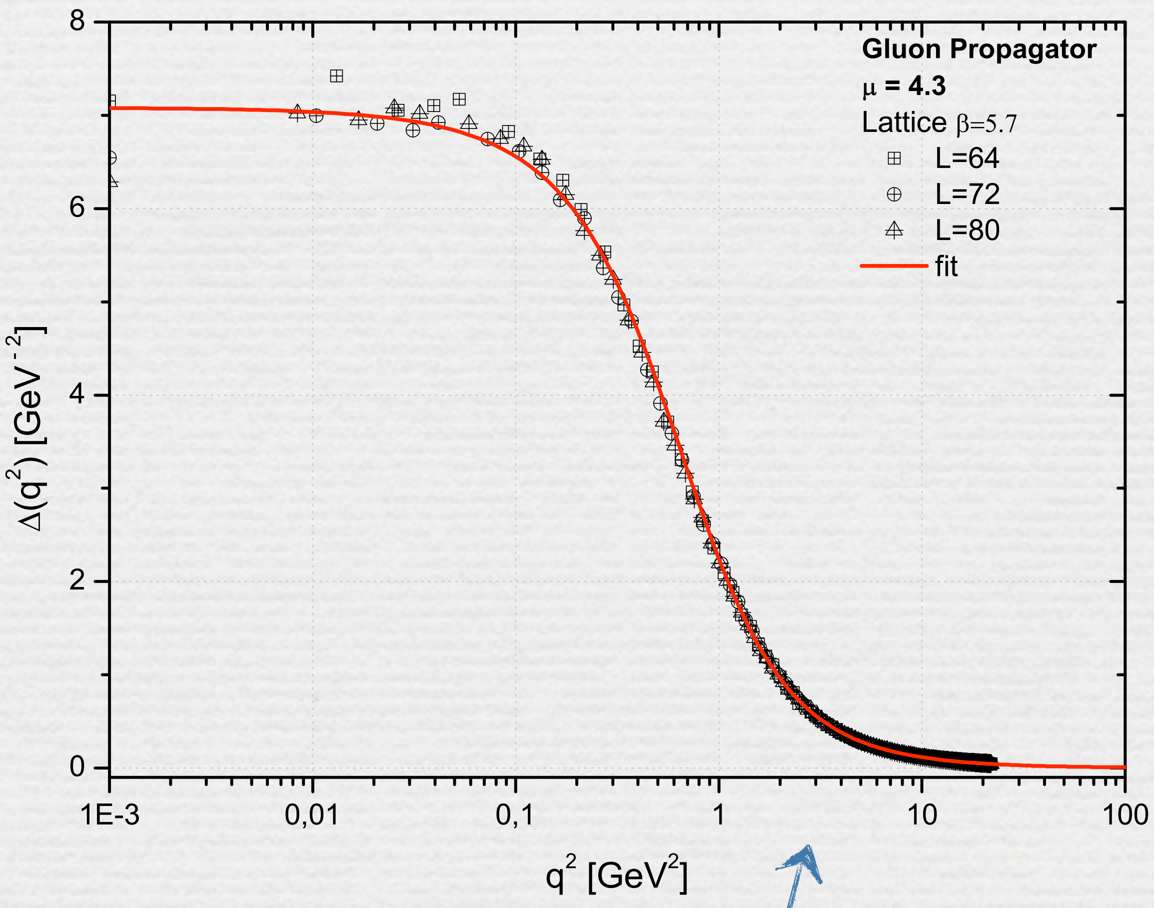
$$\Delta^{-1}(Q^2) = Q^2 + m^2(Q^2)$$

J. M. Cornwall, Phys. Rev. D26, 1453 (1982)
A. C. Aguilar and J. Papavassiliou, JHEP0612, 012 (2006)

$$m^2(Q^2) = m_0^2 \left[\ln\left(\frac{Q^2 + \rho m_0^2}{\Lambda^2}\right) \Big/ \ln\left(\frac{\rho m_0^2}{\Lambda^2}\right) \right]^{-1-\gamma}$$

effective gluon mass
phenomenological estimates

$$m_0 \sim \Lambda - 2\Lambda$$



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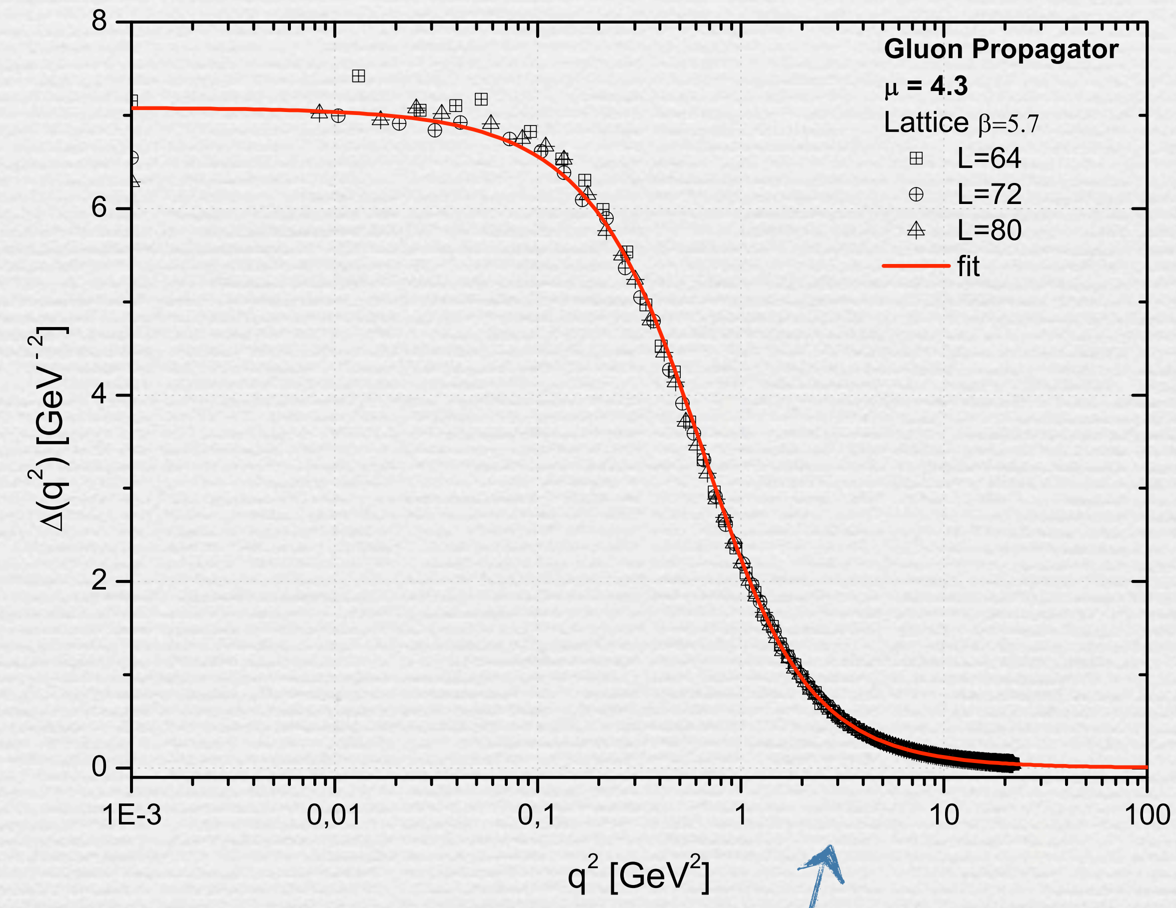

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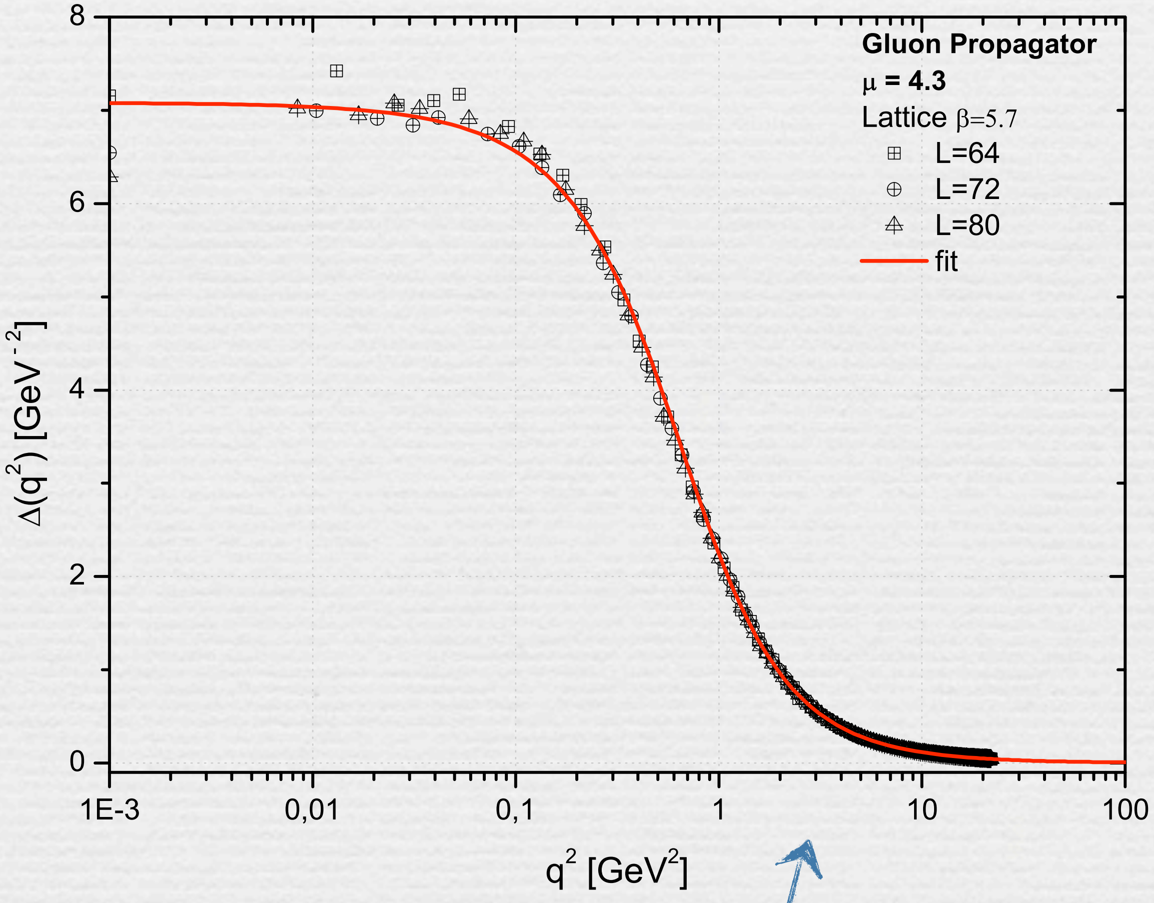
Solution free of Landau pole

Freezes in the IR



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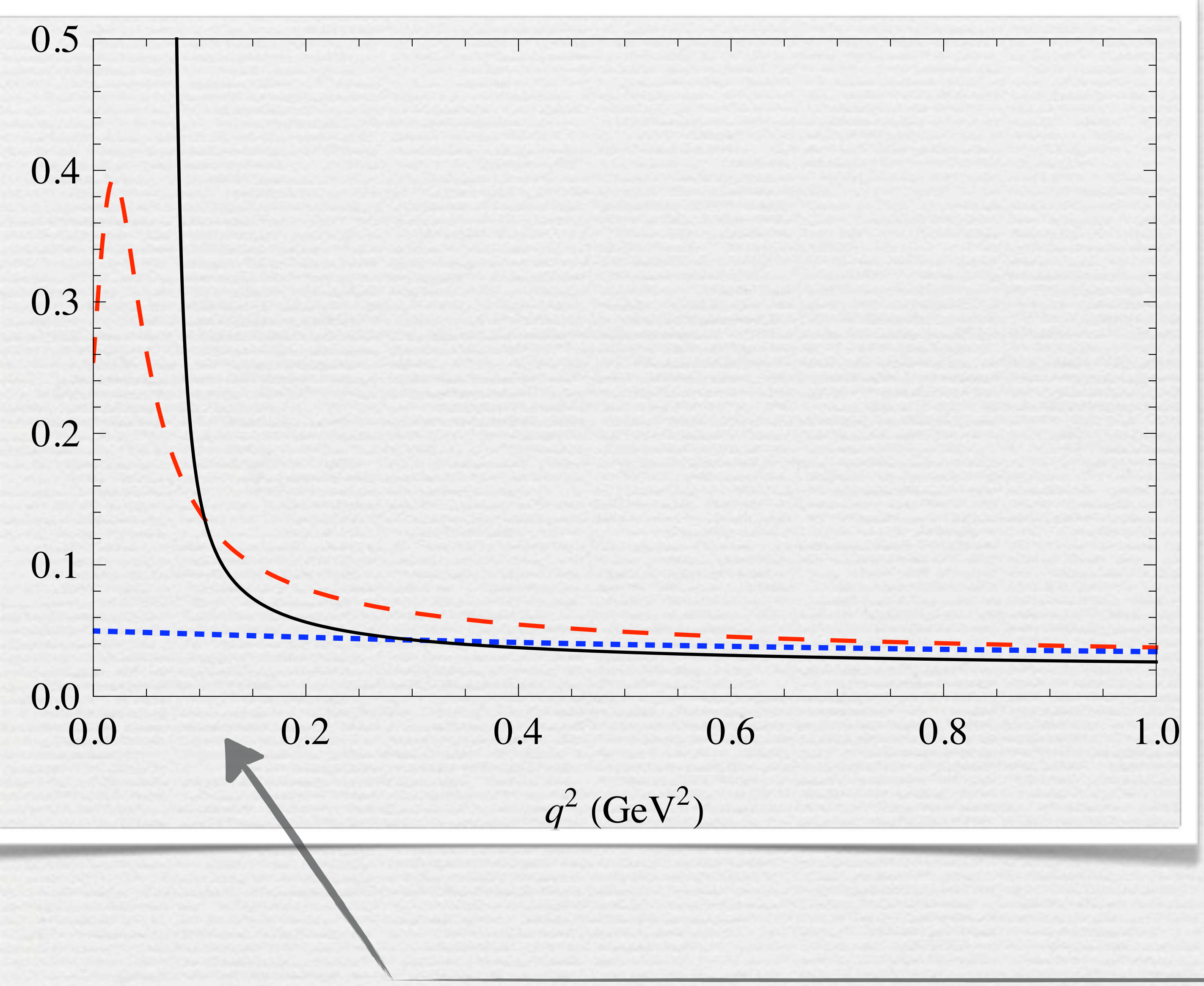
Bogolubsky, Proc. Sci., LAT2007 (2007) 290

NP Momentum-dependence of the Coupling Constant

$$\frac{\alpha_{\rm NP}(Q^2)}{4\pi} = \left[\beta_0 \ln\left(\frac{Q^2+\rho m^2(Q^2)}{\Lambda^2}\right)\right]^{-1}$$



LO perturbative evolution

Λ=250 MeV ; $\overline{MS}$ scheme

Low mass scenario NP coupling constant

m_0=250 MeV ; Λ=250 MeV ; ρ=1.5

High mass scenario NP coupling constant

m_0=500 MeV ; Λ=250 MeV ; ρ=2.

Hadronic scale

Perturbative vs. NP ‘evolution’: Fixing the hadronic scale

2nd moment of f_1

$$\langle q_v(Q^2)\rangle_n = \langle q_v(\mu_0^2)\rangle_n \left(\frac{\alpha(Q^2)}{\alpha(\mu_0^2)}\right)^{d^n_{NS}}$$

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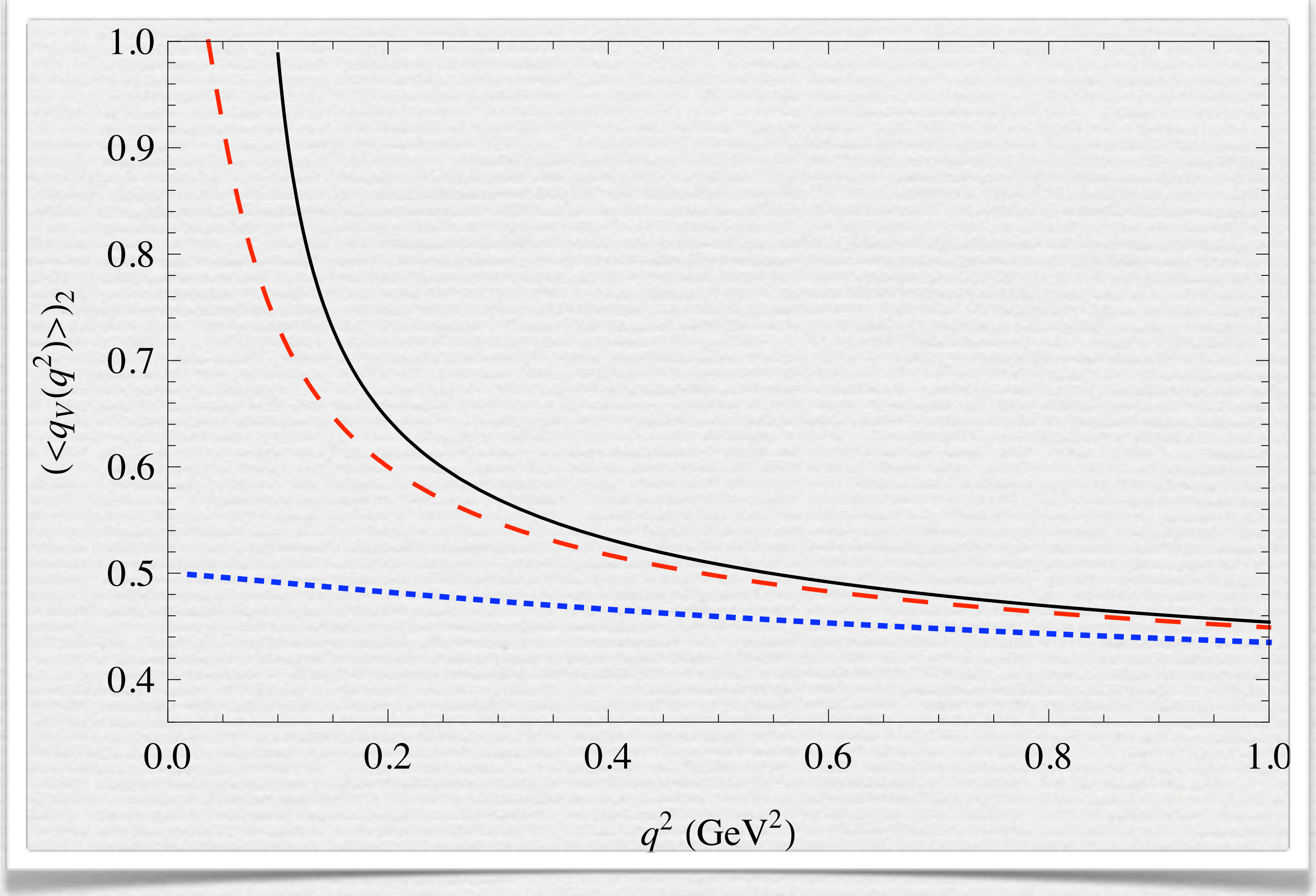

Final State Interactions and NP evolution

T-odd TMDs :

✦ Matrix element of low twist operator

➡

$$
\begin{aligned}
f_{1T}^{\perp q}(x,k_T) &= -\frac{M}{2k_x}\int \frac{d\xi^- d^2\vec{\xi}_T}{(2\pi)^3}\, e^{-i(xp^+\xi^- - \vec{k}_T\cdot\vec{\xi}_T)} \\
&\times \frac{1}{2}\sum_{S_y=-1,1} S_y \,\langle PS_y|\overline{\psi}_q(\xi^-,\vec{\xi}_T)\,\mathcal{L}^\dagger_{\vec{\xi}_T}(\infty,\xi^-)\,\gamma^+\,\mathcal{L}_0(\infty,0)\psi_q(0,0)|PS_y\rangle + \text{h.c.}
\end{aligned}
$$

✦ Importance of gauge link

➡

$$
\mathcal{L}_{\vec{\xi}_T}(\infty,\xi^-) = \mathcal{P}\exp\left(-ig\int_{\xi^-}^{\infty} A^+(\eta^-,\vec{\xi}_T)\,d\eta^-\right)
$$

Final State Interactions and NP evolution

Twofold problem :

- ✦ FSI mimicked by a one-gluon-exchange
  - ➡ gluon propagator

- ✦ Explicit dependence on the coupling constant
  - ➡ relevance of NP scheme for model calculations

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✦ Explicit dependence on the coupling constant

➡ relevance of NP scheme for model calculations

Example :

F. Yuan, PLB 575; AC, VV & SS, PRD79 074001; PRD80 074032

✦ MIT bag model calculation

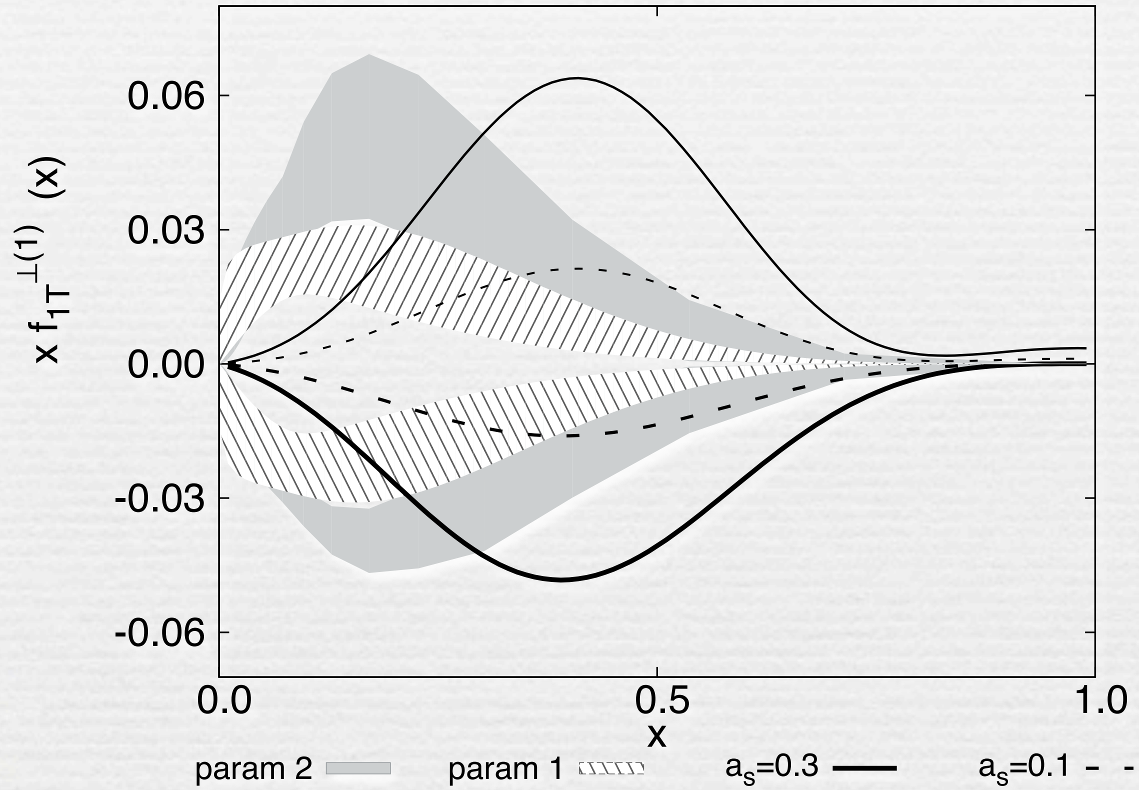
➡ perturbative QCD governs the dynamics inside the confining region

➡ no need for NP gluon propagator

➡ NP scheme → change of hadronic scale

✦ Other model calculations? e.g. L. Gamberg and M. Schlegel, Phys. Lett. B 685 (2010) 95

Sivers & Boer-Mulders functions



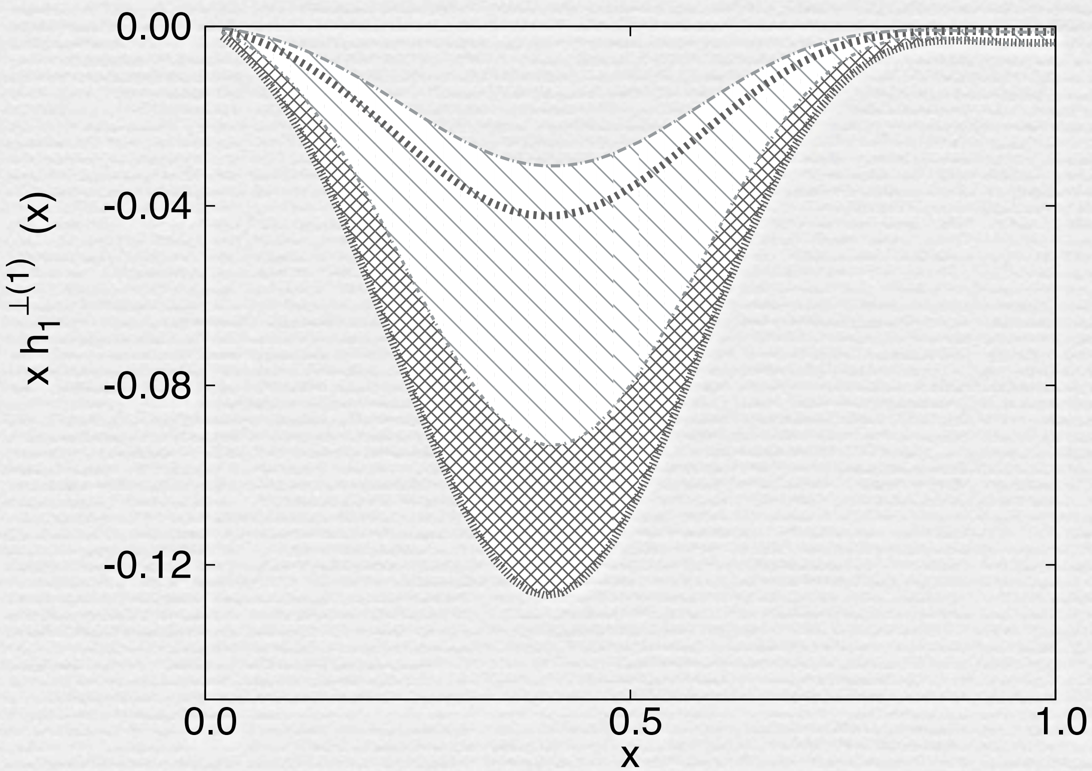
$$0.1 < \frac{\alpha_s(\mu_0^2)}{4\pi} < 0.3$$

dashed $\frac{\alpha_s(\mu_0^2)}{4\pi} = 0.1$

solid $\frac{\alpha_s(\mu_0^2)}{4\pi} = 0.3$

Bag Model:

rescaling of $f_{1T}^{\perp}$ & $h_1^{\perp}$



Conclusions

- **Low hadronic scale validated by IR behavior of α_s**
- Good description of perturbative dynamics by ‘standard scheme’:
  now supported by NP scheme
- Set of parameters needs to be pushed towards ‘pure valence”s hadronic scale:
  NP scheme favors scenarios valence quarks + sea + gluons
- Quantitative analysis:
  would depend on HOW the IR freezing is obtained.
- Impact on Phenomenology:
  Value of coupling constant → *theoretical errorband*
  NP gluon propagator
  QCD evolution equations at low Q^2 ?