Parton-hadron duality and the extraction of α_S

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Open Questions in Parton Hadron Duality

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March 13th, 2015

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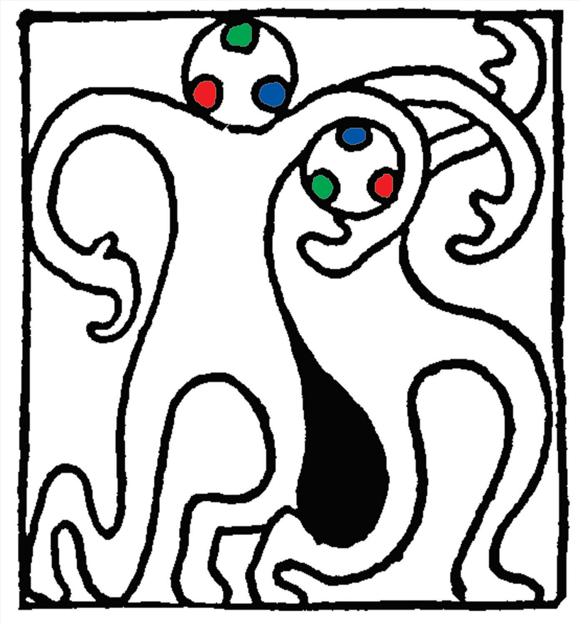
Friday, March 13, 2015



Topics:

Unpolarized & polarized eN inclusive experiments
Semi-inclusive experiments
Duality in Nuclei
Veneziano model
QCD sum rules
Perturbative QCD Large x resummation

Organizers:

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Image adapted from *The Burgess Nonsense Book*, Gelett Burgess, New York: Frederick A. Stokes Company, 1901, p. 59.

- Review DGLAP evolution at large Bjorken x
    - z-dependent scale gives rise to “large Bjorken x evolution”
- Interplay of TMCs, Large Bjorken x evolution, HigherTwists
- Nuclear corrections at large Bjorken x
- Conclusions/Outlook for the 12 GeV program and beyond…

Open question: how to continue pQCD curve? What defines the pQCD curve?

S.L., R. Ent, C.Keppel, I. Niculescu, PRL 2000

- ✓ Fix the order of the analysis, e.g. NLO and extend pQCD curve to low W^2
- ✓ Corrections arise that are more important than at low x_{Bj} and that are responsible for duality

→ TMCs

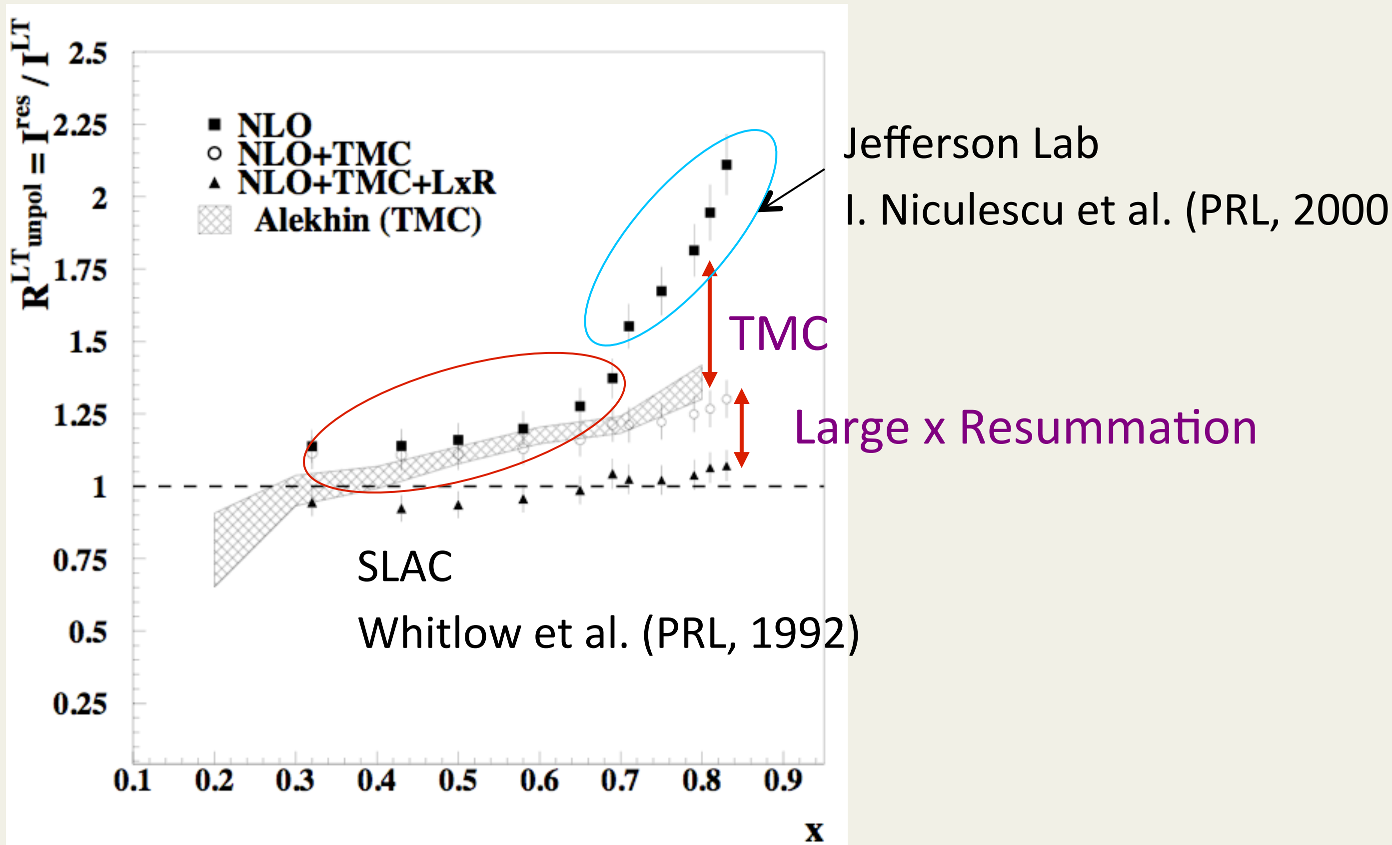
→ Large x structure of PQCD evolution equations

→ NNLO and higher…

→ Higher Twists

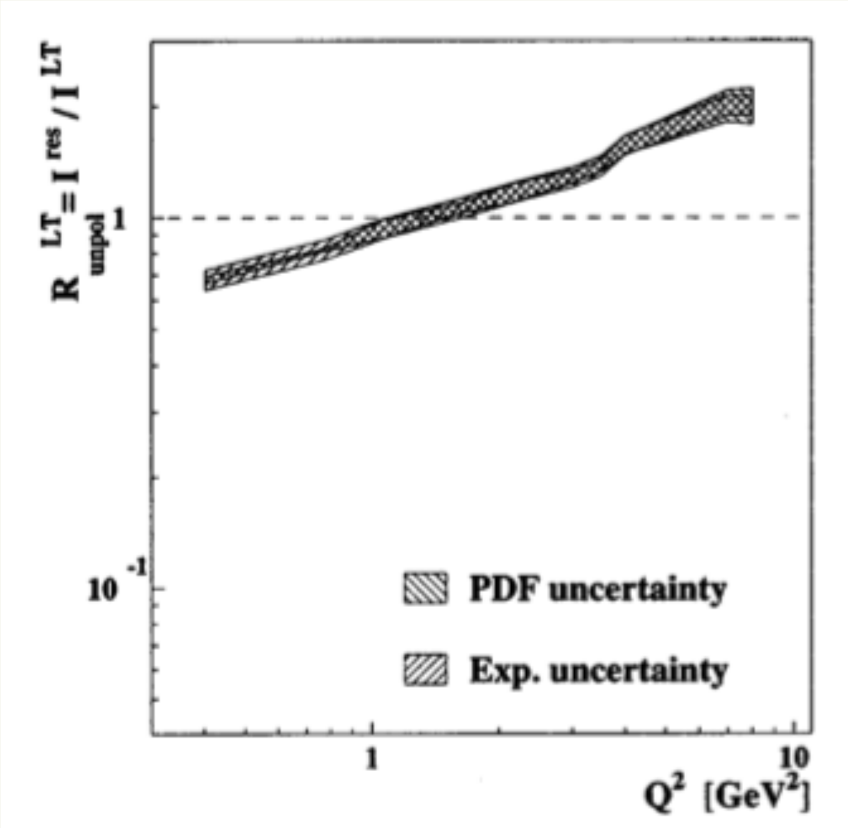
→ Nuclear corrections (for neutron)

$$R = \frac{I^{exp}}{I^{theory}} = \frac{\int_{x_{min}}^{x_{max}} F_2^{exp}(x,Q^2)}{\int_{x_{min}}^{x_{max}} F_2^{theory}(x,Q^2)}$$

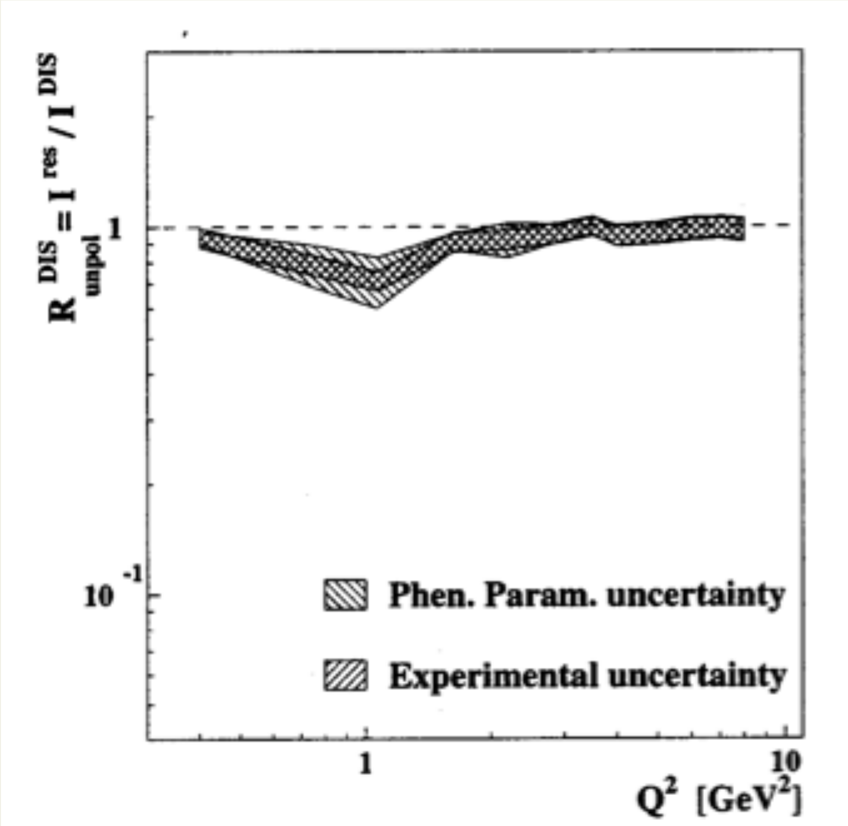


Unpolarized Jlab+SLAC data

Bianchi, Fantoni, S.L. (PRD, 2004)



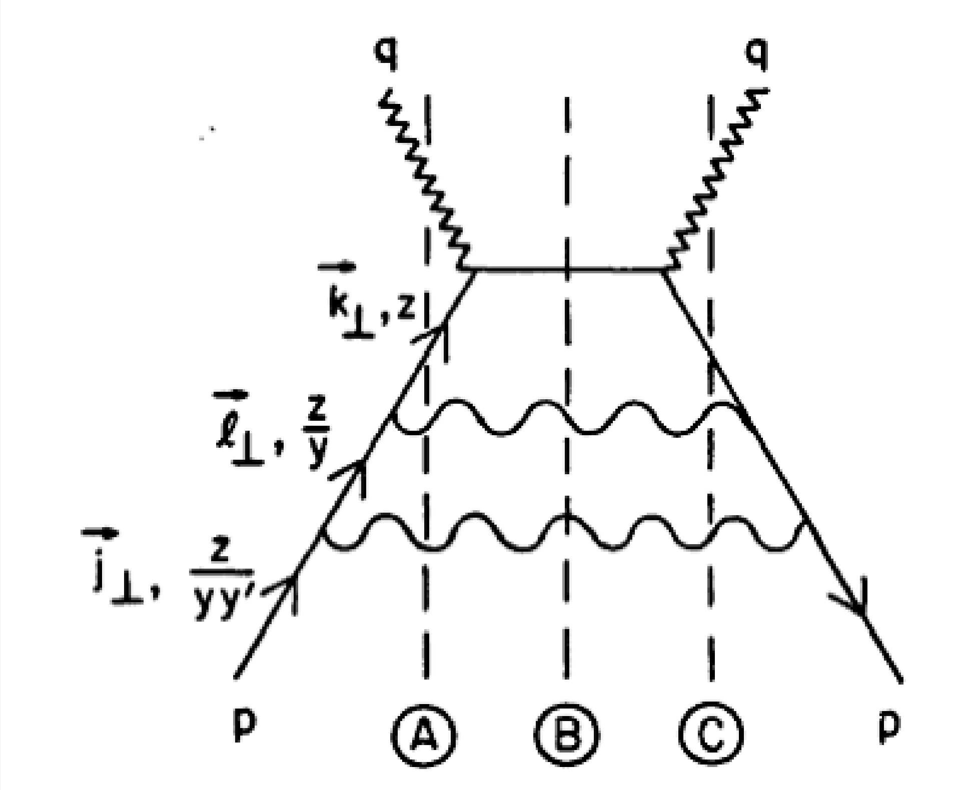
Envelope of all PDFs available at the time



Ratio to phenomenological parameterization by Abramowicz et al. with “non conventional” Q^2 dependence

Large x_{Bj} evolution

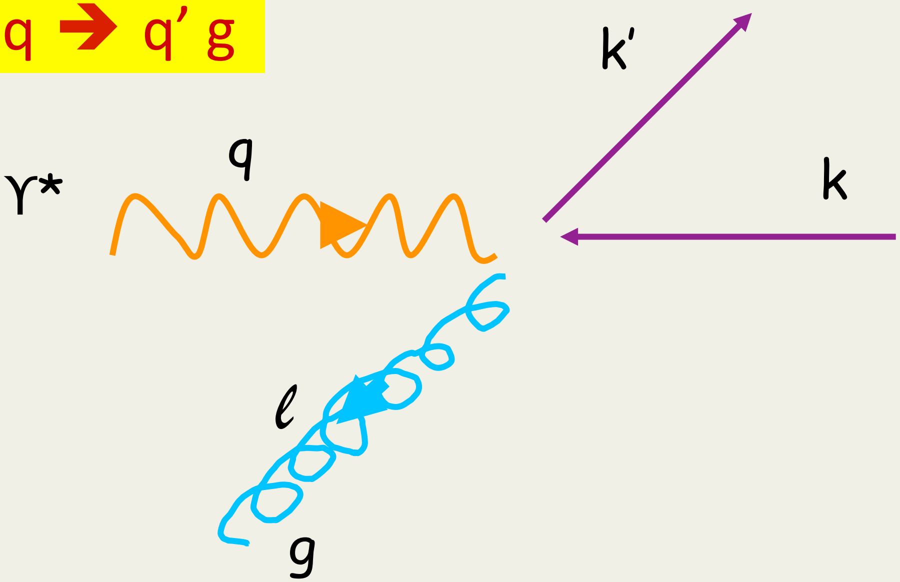
(S. Brodsky, SLAC lectures (1979), D. Amati et al., NPB(1980), R. Roberts, Z.Phys.C (1998)



$\alpha_S = \alpha_S(k^2)$ at each vertex

$$\alpha_S(Q^2) = \frac{4\pi}{\beta_0 \ln(Q^2/\Lambda^2_{QCD})}$$

γ*q → q' g



$$\hat{s} = (q+k)^2 = 4k'^2$$ Invariant mass!

$$\hat{t} = (k-k')^2 = -2qk'(1-\cos\theta)$$

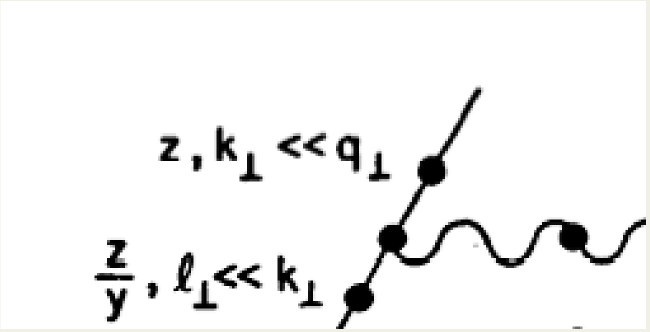
$$\hat{u} = (q-k')^2 = -2qk'(1+\cos\theta)$$

$$k_T^2 = \frac{\hat{s}\,(-\hat{t}\,)\hat{u}}{\hat{s}\,(\hat{s}+Q^2\,)} = \frac{\hat{s}\sin^2\theta}{4} \qquad (k_T^{MAX})^2 = \frac{\hat{s}}{4}$$

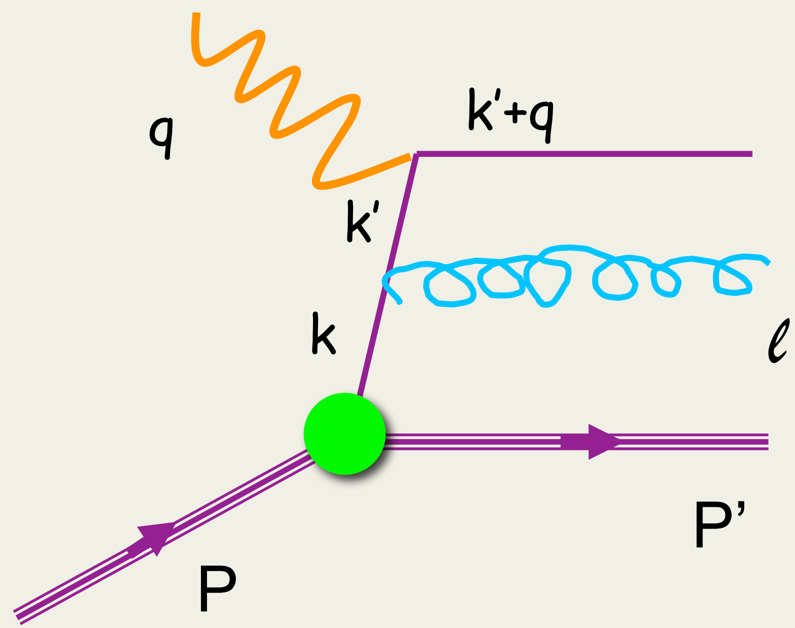
In terms of LC variables

$k = (k^+ = zP^+, k^- = P^- - \ell^-, k_T)$

$$\rightarrow \quad (k_T^{MAX})^2 = \frac{Q^2(1-z)}{4z}$$



$\gamma^* P \rightarrow q' \, g \, X$

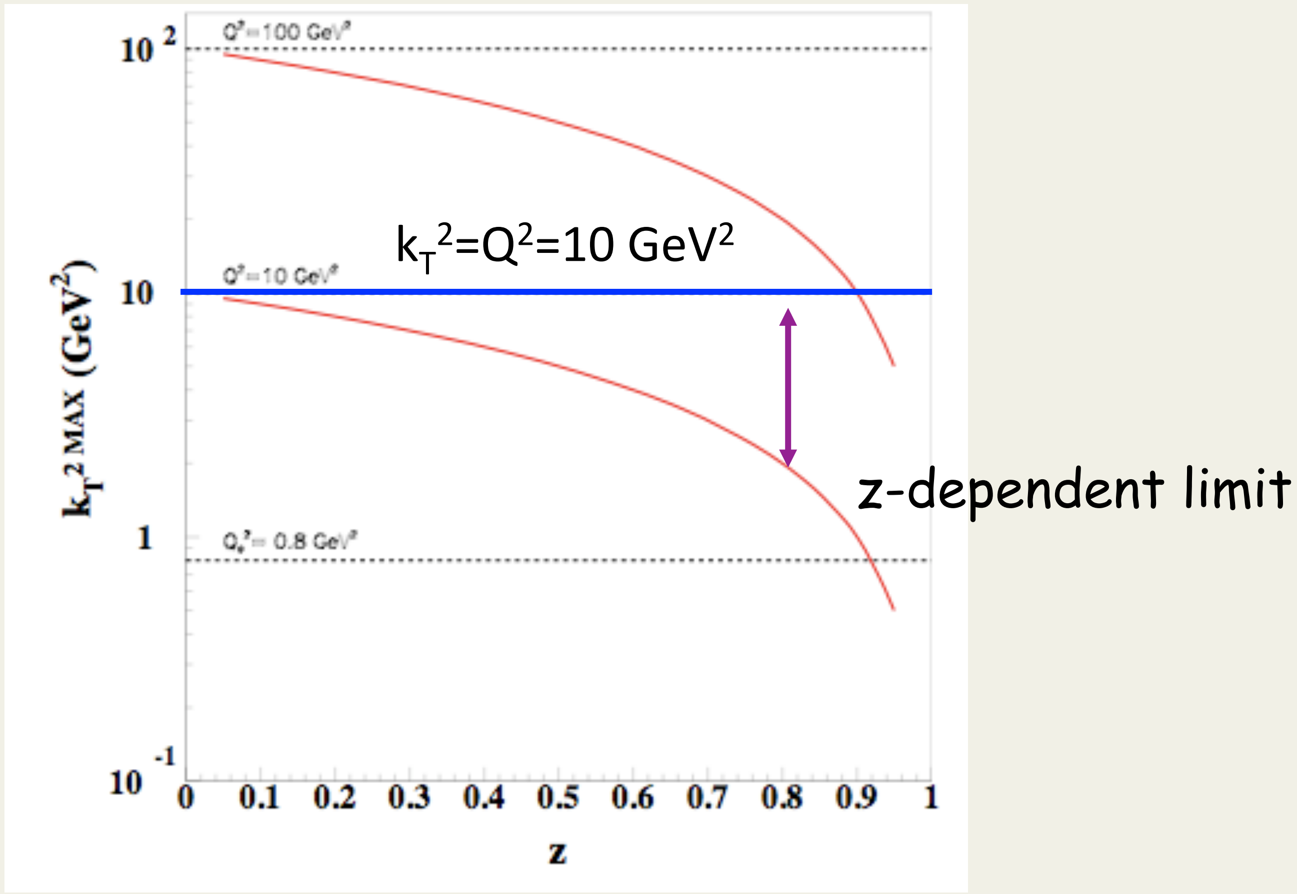


$$q(x,Q^2) = \int_x^1 \frac{dz}{z} \int_{\mu^2}^{Q^2 \frac{1-z}{4z}} dk_T^2 \, \alpha_S(k_T^2) P_{qq}(z) \, q\left(\frac{x}{z}, k_T^2\right)$$

Disregarding z-dependence in k_T integration limit

$$\frac{dq(x,Q^2)}{d\ln Q^2} = \frac{\alpha_S(Q^2)}{2\pi} \int_x^1 \frac{dz}{z} P_{qq}(z) \, q\left(\frac{x}{z}, Q^2\right)$$

Effect on pQCD evolution



As a consequence…

$$\alpha_S(Q^2) \rightarrow \alpha_S[Q^2(1-z)] \approx \alpha_S(Q^2) - \frac{1}{2}\beta_0 \underline{\ln(1-z)} \left(\alpha_S(Q^2)\right)^2$$

This takes care of the large log term in the Wilson coefficient f.
(NLO, MS-bar)

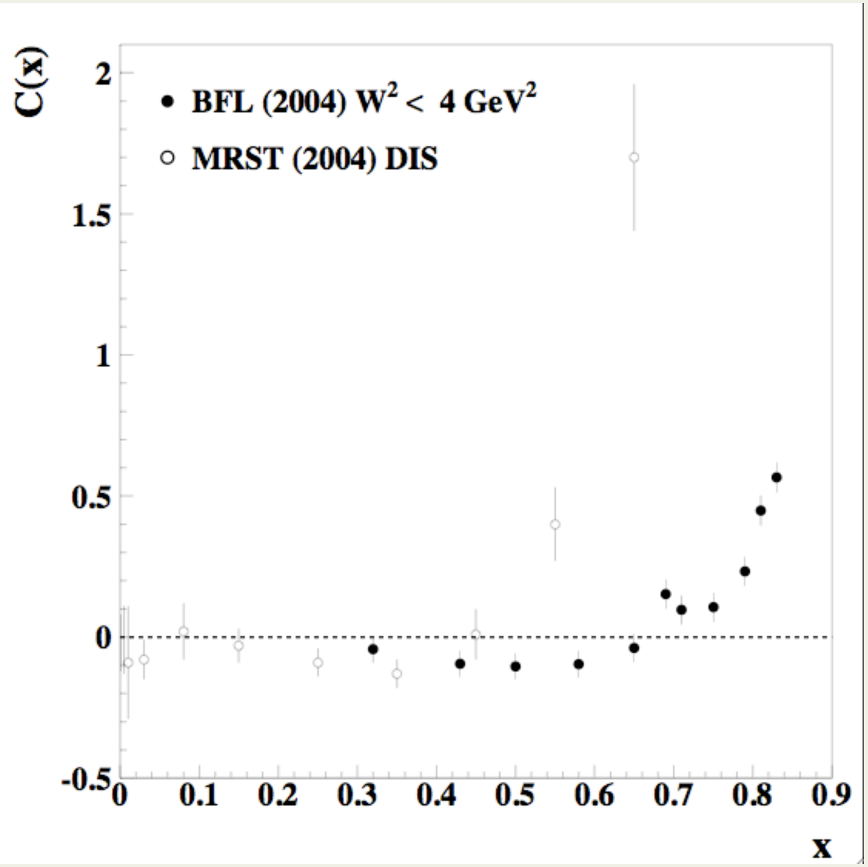
$$F_2^{NS}(x,Q^2) = \frac{\alpha_s}{2\pi} \sum_q \int_x^1 dz\, \underline{C_{NS}(z)}\, q_{NS}(x/z, Q^2), \tag{24}$$

$$C_{NS}(z) = \delta(1-z) + \left\{ C_F \left(\frac{1+z^2}{1-z}\right)_+ \left[\ln\left(\frac{1-z}{z}\right) - \frac{3}{2}\right] + \frac{1}{2}(9z+5) \right\}$$

The scale that allows one to annihilate the effect of the large ln(1-z) terms at large x at NLO is the invariant mass, W^2

Equivalent to a resummation of these terms up to NLO

In Bianchi, Fantoni, S.L., we used this to extract the genuine HTs

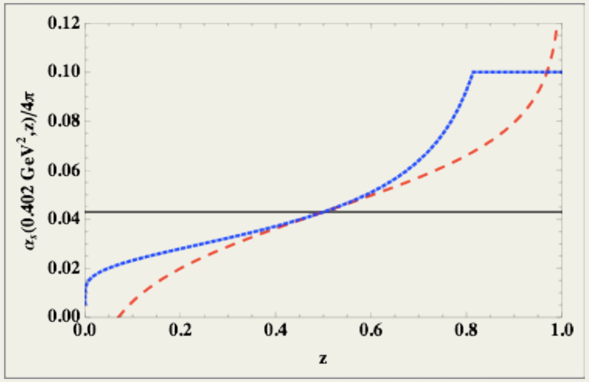


$$F_2^{exp}=F_{PQCD}(1+C(x)/Q^2)$$

In Courtoy, S.L., we used this to extract α_s in the infrared region

[Courtoy & Liuti, 1208.5636]

Parametrize the realization of duality



$$\widetilde{W}^2(z_{\max}) = Q^2(1 - z_{\max})/z_{\max}$$

- Freeze α_s by imposing a z_{max} :

- Changes the behavior of the coefficient function $x \to 1$

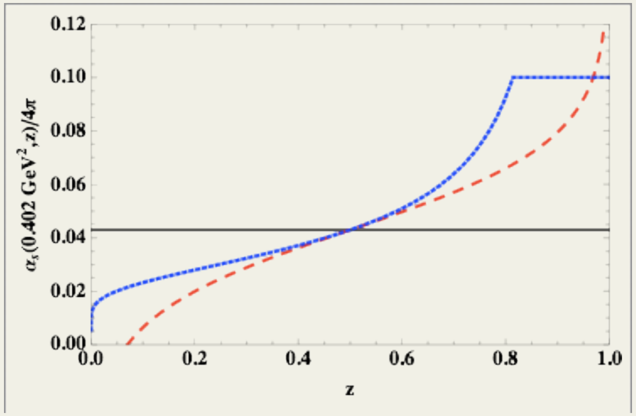
- **Realization of duality depends on z_{max} :**

$$R^{\exp/\mathrm{th}}(z_{\max}, Q^2) = \frac{\int_{x_{\min}}^{x_{\max}} dx\, F_2^{\exp}(x, Q^2)}{\int_{x_{\min}}^{x_{\max}} dx\, F_2^{NS,\mathrm{Resum}}(x, z_{\max}, Q^2)} = \frac{I^{\exp}}{I^{\mathrm{Resum}}} = 1$$

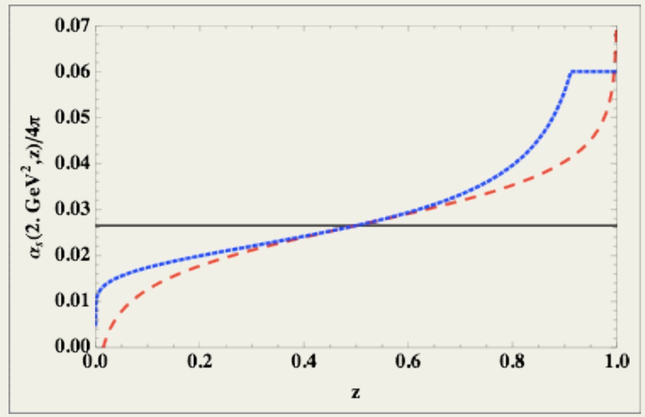
- **Adjust z_{max} according to the data**

[Courtoy & Liuti, 1208.5636]

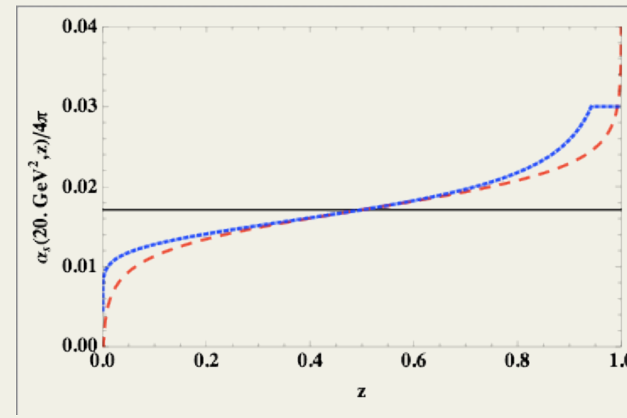
Q^2=0.4 GeV^2



Q^2=2 GeV^2



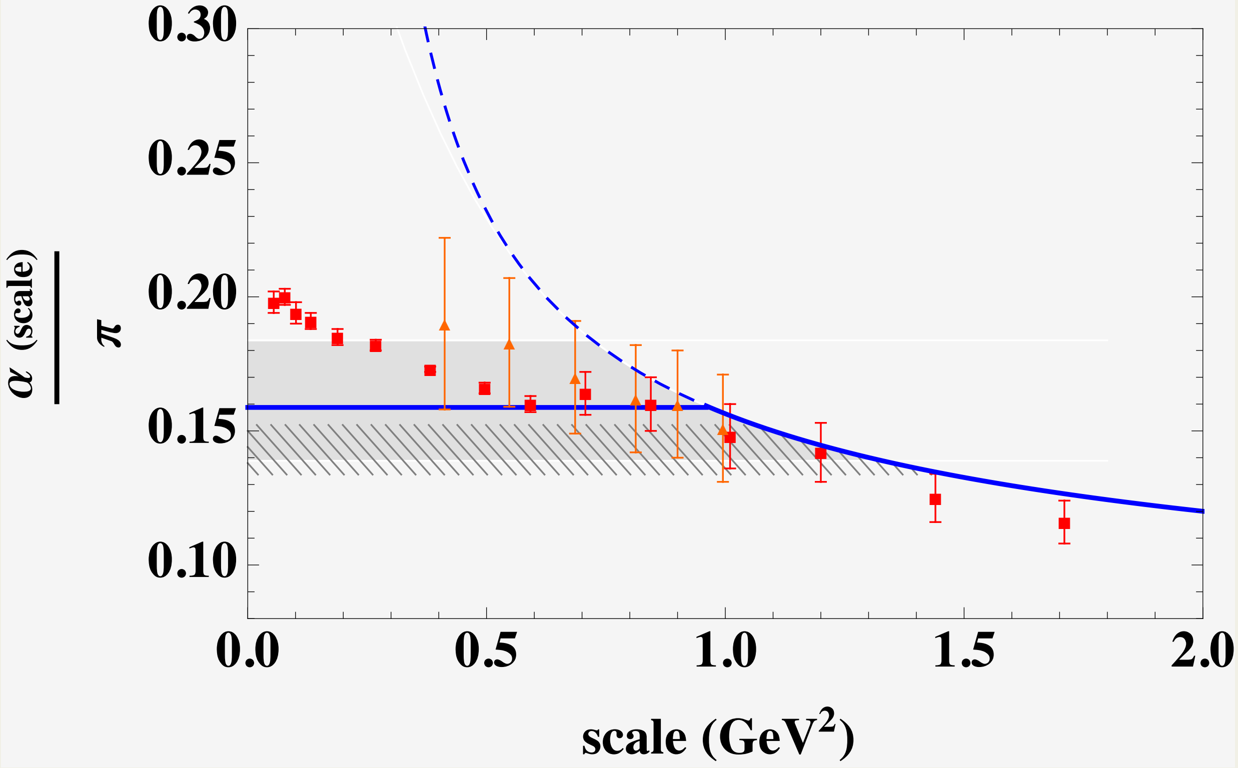
Q^2=20 GeV^2



- $\alpha_s(Q^2)$;
- an expansion of $\alpha_s(\tilde{W}^2)$ in $\ln((1-z)/z)$, to NLO,

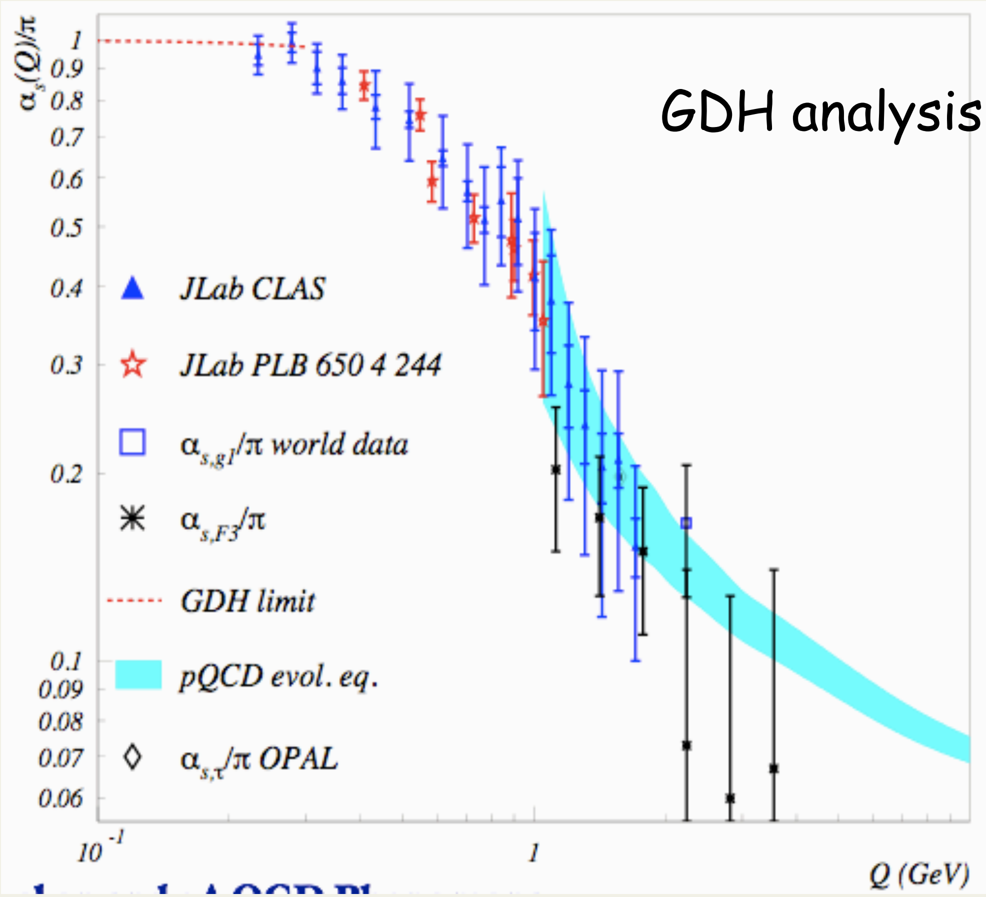
$$\alpha_s(\tilde{W}^2) = \alpha_s(Q^2) - \frac{\beta_0}{4\pi} \ln\left(\frac{1-z}{z}\right) \alpha_s^2(Q^2)$$

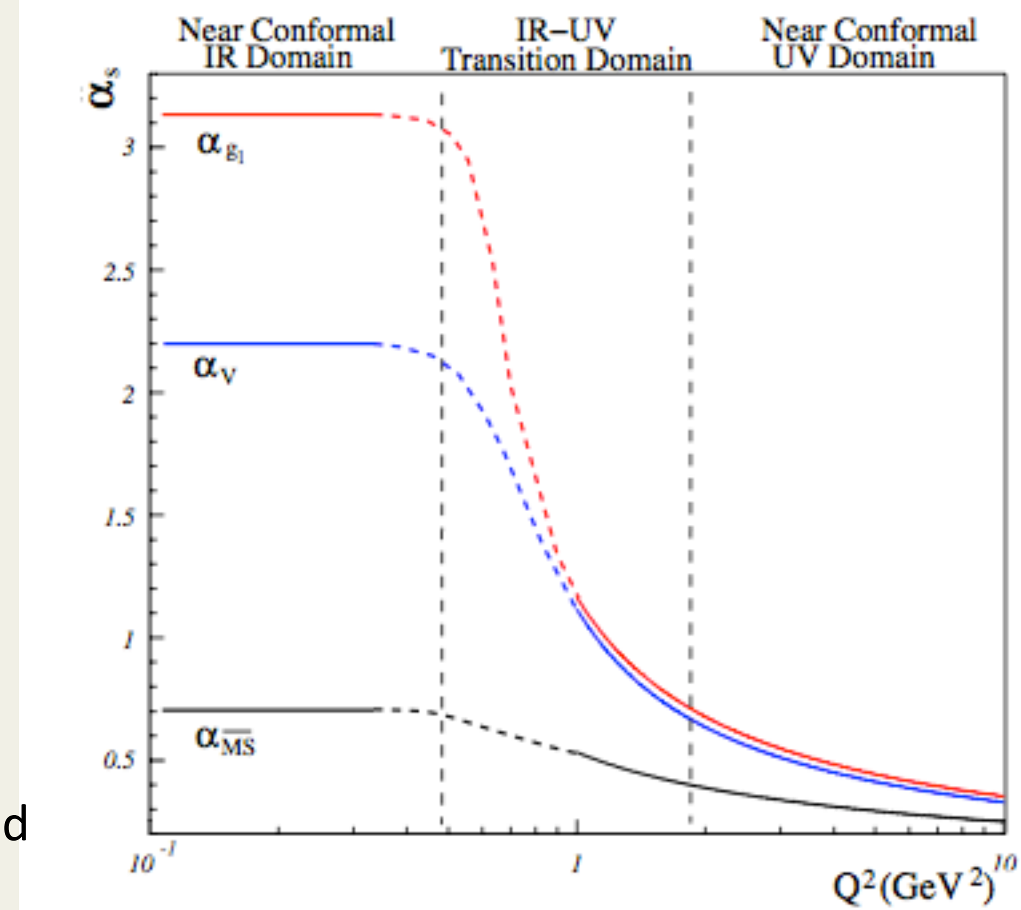
- the complete z dependence of $\alpha_s(\tilde{W}^2)$ **cut**



0.30
0.25
0.20
0.15
0.10
0.0
0.5
1.0
1.5
2.0
α (scale) / π
scale (GeV²)

This agrees with extraction by Burkert, Chen, Deur, Korsch





provided the right scheme is defined

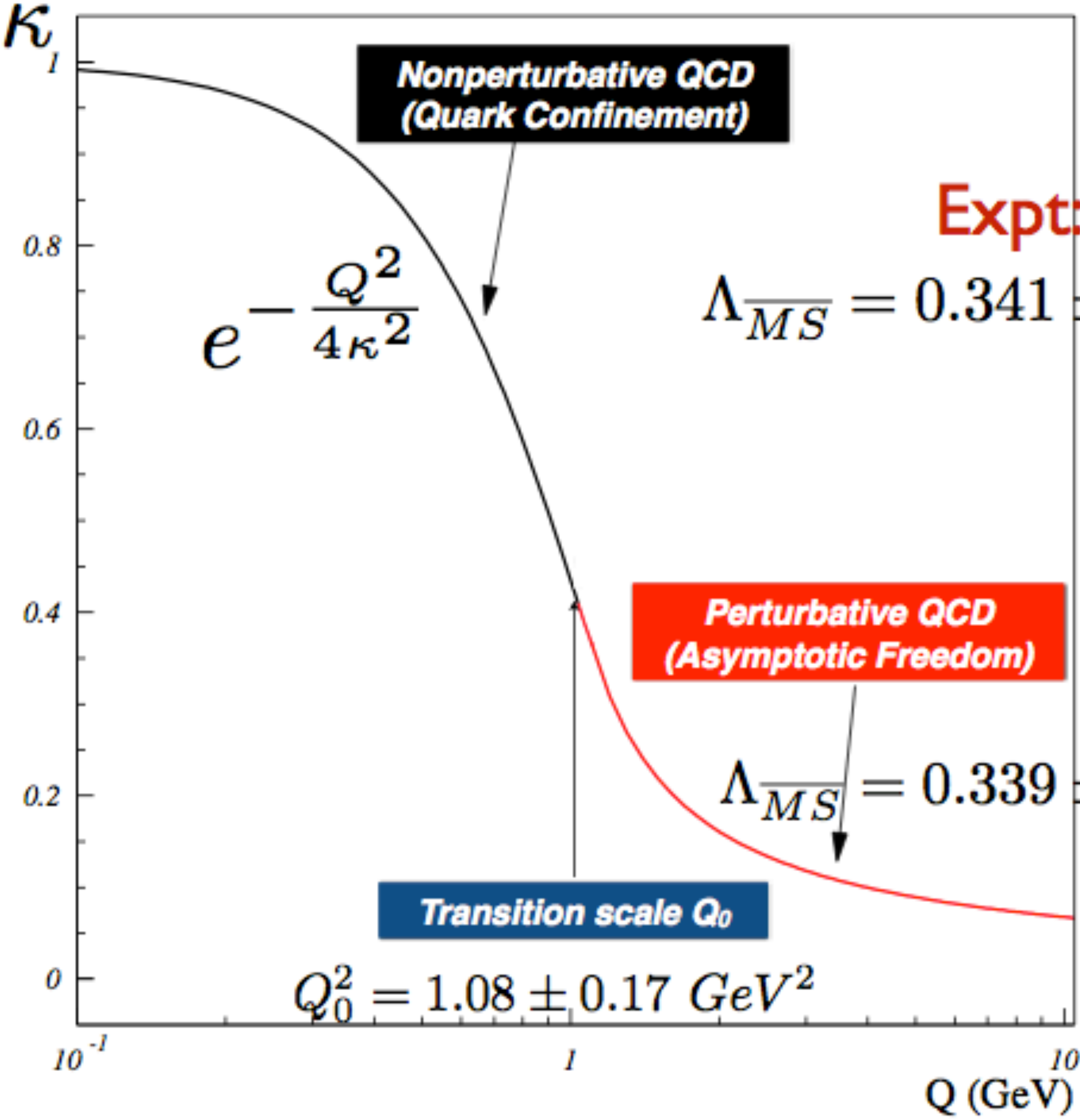
$$m_\rho = \sqrt{2}\kappa$$

$$m_p = 2\kappa$$

All-Scale QCD Coupling

Deur, de Tèramond, sjb

$$\frac{\alpha^s_{g_1}(Q^2)}{\pi}$$

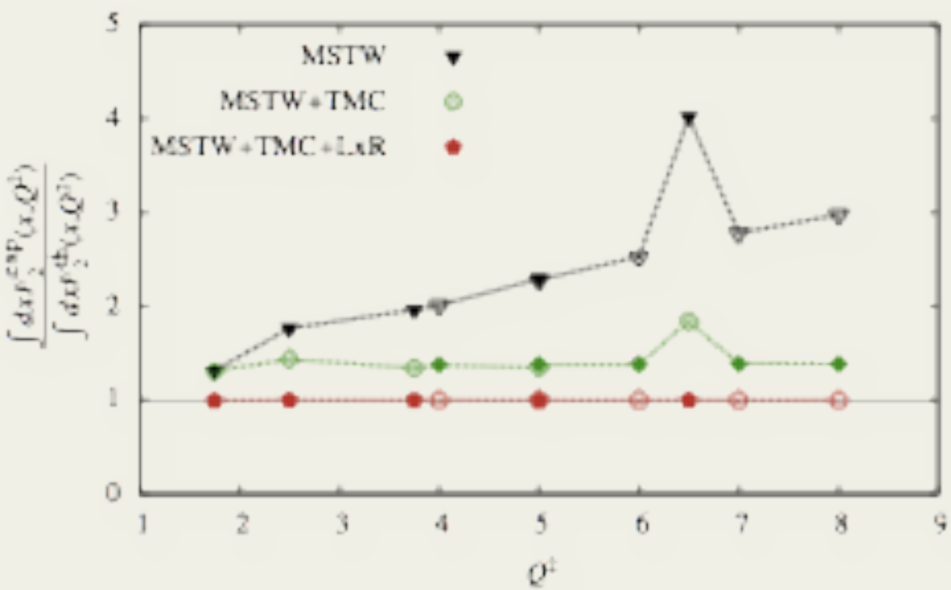


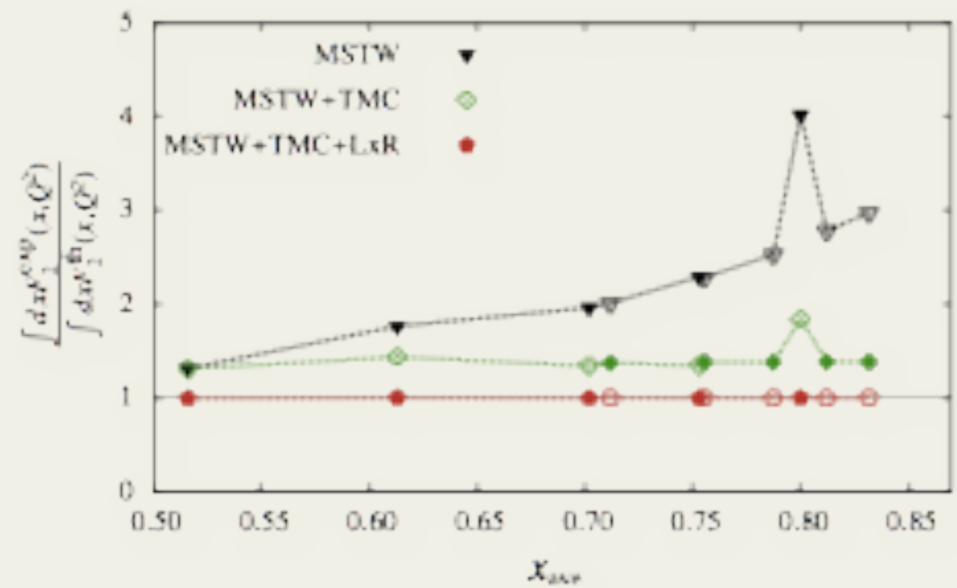
Expt:

$$\Lambda_{\overline{MS}} = 0.341 \pm 0.024\ GeV$$

$$\Lambda_{\overline{MS}} = 0.339 \pm 0.016\ GeV$$

$$\lambda \equiv \kappa^2$$





JLab data

SLAC data

Phys.Lett. B282

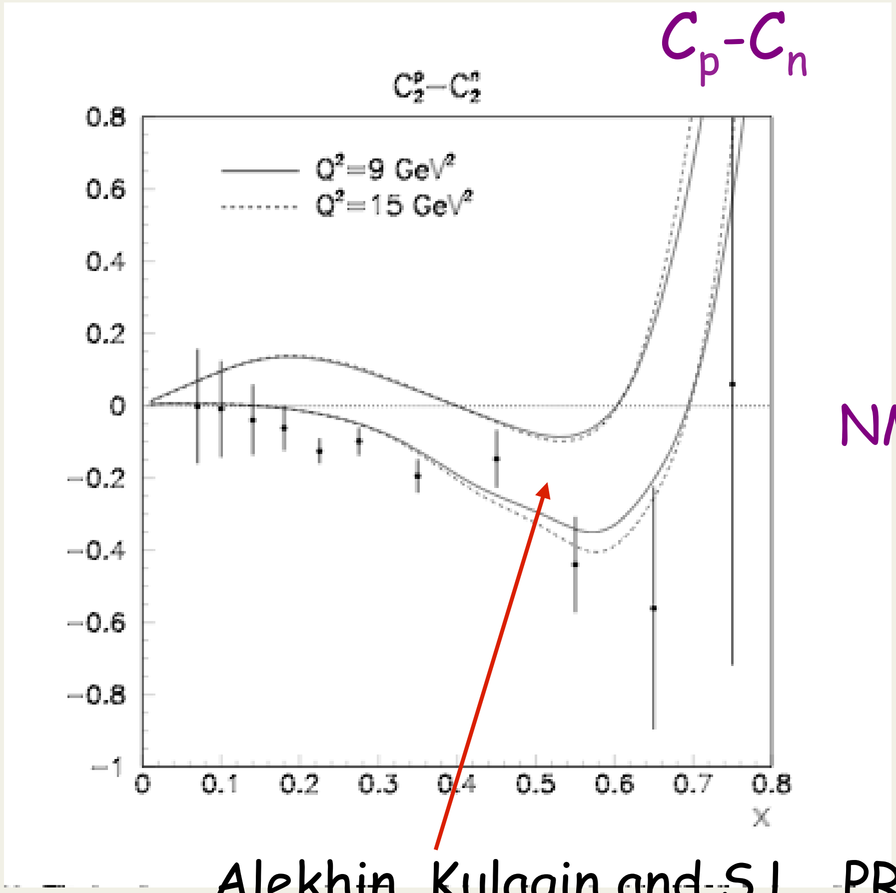
Q^2 [GeV^2]	$I^{exp}(Q^2)$	$I^{(0),DIS}(Q^2)$	$I^{(0),DIS+TMC}(Q^2)$	$I^{Resum}(z_{max}, Q^2)$	z_{max}
1.75	6.994×10^{-2}	5.316×10^{-2}	5.345×10^{-2}	7.025×10^{-2}	0.63
2.5	4.881×10^{-2}	2.765×10^{-2}	3.393×10^{-2}	4.872×10^{-2}	0.745
3.75	2.356×10^{-2}	1.201×10^{-2}	1.756×10^{-2}	2.359×10^{-2}	0.76
5.	1.267×10^{-2}	0.553×10^{-2}	0.942×10^{-2}	1.270×10^{-2}	0.79
6.5	0.685×10^{-2}	0.170×10^{-2}	0.372×10^{-2}	0.683×10^{-2}	0.9
4.	2.045×10^{-2}	1.017×10^{-2}	1.487×10^{-2}	2.041×10^{-2}	0.79
5.	1.255×10^{-2}	0.550×10^{-2}	0.909×10^{-2}	1.255×10^{-2}	0.811
6.	0.802×10^{-2}	0.317×10^{-2}	0.581×10^{-2}	0.803×10^{-2}	0.825
7.	0.531×10^{-2}	0.191×10^{-2}	0.383×10^{-2}	0.532×10^{-2}	0.837
8.	0.363×10^{-2}	0.122×10^{-2}	0.262×10^{-2}	0.363×10^{-2}	0.845

?

$$\alpha_s\left(Q^2\frac{(1-z)}{z}\right)$$

One open question on HT analysis:

✔ Are HTs isospin dependent? Deviations from PQCD effects



NMC data

Alekhin, Kulagin and S.L., PRD (2003)

Conclusions

- The resonance region is described in terms of there are two independent scales, W^2 and Q^2
- PQCD evolution is governed by W^2
- This has consequences on:
  - The extraction of genuine twist 4 terms
  - The extraction of α_s in the infrared region