Intermediate mass scheme in a global QCD analysis

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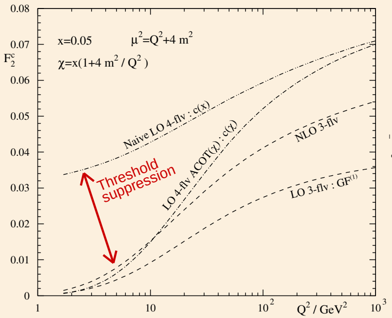
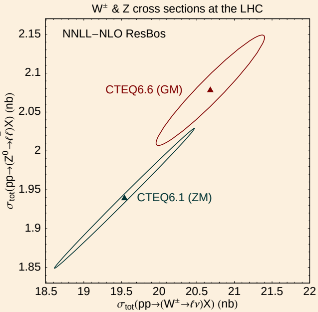
Role of heavy flavors in PDF analyses

General-mass (GM) scheme(s), currently adopted by CTEQ, MSTW and H1 analyses, strive to provide consistent description of c, b scattering both near heavy-quark thresholds and away from them

In 2006 *(CTEQ6.5, hep-ph/0611254)*, it was realized that the GM (and not zero-mass) treatment of c, b mass terms in DIS is essential for predicting precision W, Z, cross sections at the LHC

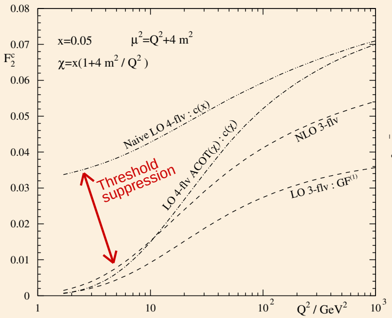


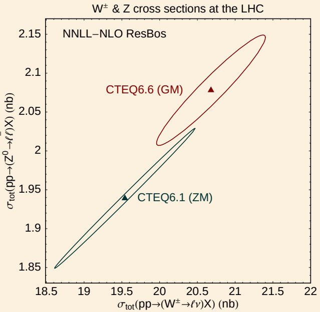


Role of heavy flavors in PDF analyses

At NLO, the dominant mass effect is mostly kinematical; propagates from DIS into W, Z cross sections through changes in $u(x)$, $d(x)$

Thorne and Tung (arXiv:0809.0714): can this kinematical effect be **approximately** introduced in the **widely used** ZM scheme, while preserving ZM hard cross sections?





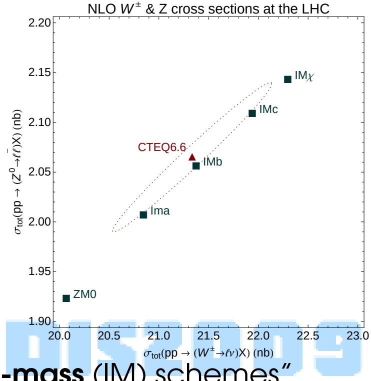
Kinematically improved ZM schemes

At NLO, such schemes were indeed developed (P. N., Tung, arXiv:0903:2667; thanks to R. Thorne for helpful suggestions!)

They depend on a free parameter λ, tuned to approximate either a ZM DIS cross section or a GM DIS cross section

They can be viewed either

- as improved ZM formulations with realistic c, b kinematics; or
- as simplified GM formulations with approximate ZM hard cross sections



We propose to call them "**intermediate-mass** (IM) schemes"

Intermediate-mass scheme: a basic recipe

- Start with PQCD factorization for DIS, in a form applicable both in ZM or GM schemes

$$F_\lambda(x,Q^2) \;=\; \sum_{a,b}\int_\zeta^1 \frac{d\xi}{\xi}\, f_a(\xi,\mu)\, C^a_{b,\lambda}\left(\frac{\zeta}{\xi},\frac{Q}{\mu},\frac{m_i}{\mu},\alpha_s(\mu)\right)$$

- sum over **initial-state** active flavors a **prescribed by the factorization scheme for the PDFs**
- sum over **final-state** quark flavors b **physically produced at the given scattering energy**
- evaluate convolutions over the kinematical range $\zeta \le \xi \le 1$ determined by a **rescaling variable** ζ
- use **zero-mass** Wilson coefficients $C^a_{b,\lambda}$=$C^a_{b,\lambda}\left(\frac{\zeta}{\xi},\frac{Q}{\mu},0,\alpha_s(\mu)\right)$, evaluated at ζ/ξ
- keep $\mu > m_Q$ in heavy-quark channels for all Q, to guarantee applicability of the (subtracted) $\overline{MS}$ expression for $C^a_{b,\lambda}$; e.g., use $\mu=\sqrt{Q^2+m_i^2}$ in $q_i\gamma^*\to q_i$ and $g\gamma^*\to q_i\bar{q}_i$ channels

Rescaling variables in heavy-flavor DIS

Rescaled light-cone variable ζ is a simple way to approximate exact scattering kinematics in processes where the exact momentum conservation is absent

- **General-mass scheme:** dominant heavy-quark mass effects are approximated in LO $c\gamma^* \to c$ (or $sW \to c$) by a **rescaling variable** χ :

$$x = \chi / \left(1 + M_f^2/Q^2\right), \text{ with } M_f^2 = 4m_c^2 \, (m_c^2) \text{ in NC (CC) DIS}$$

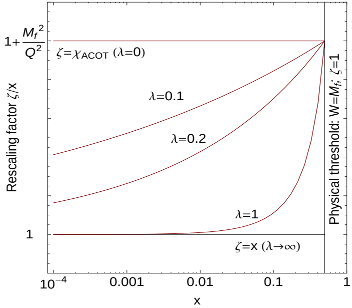
Barnett, Haber, Soper; Tung, Kretzer, Schmidt

- It is natural to try $\zeta = \chi$ both in $c\gamma^* \to c$ and $g\gamma^* \to c\bar{c}$ in the IM scheme; however, it leads to **excessive suppression** of charm scattering in NC DIS at small x (for given Q), where threshold effects should be less pronounced, while the PDF variation is rapid

Generalized rescaling variable ζ

Realistic GM behavior of PDF's is reproduced by a **generalized rescaling variable** $\zeta(\lambda)$:

$$x = \zeta \Big/ \left(1 + \zeta^{\lambda} M_f^2/Q^2\right), \text{ with } 0 \le \lambda \lesssim 1$$



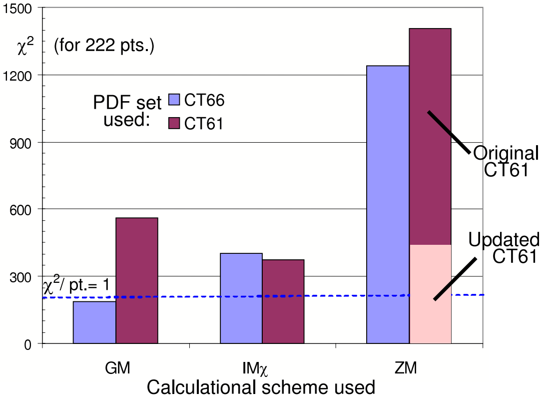
- $\zeta \to 1$ as $W \to M_f^2$
- $\lambda = 0 : \zeta = \chi$ (the ACOT-χ variable)
- $\lambda \gtrsim 1$: $\zeta \approx x$ (no rescaling)
- $\zeta \approx x$ for $Q^2 \gg M_f^2$

Good fits are produced with $0 < \lambda \lesssim 0.5$ both in the IM and GM schemes

The following discussion shows results for ZM, $\lambda = 0.3$ (IMa), $\lambda = 0.15$ (IMb-best IM fit), $\lambda = 0.05$ (IMc), and $\lambda = 0$ (IMχ)

Comparison to c, b SIDIS data from CT6.6 data sample

ZM/GM/IM Wilson coefficients with ZM (CT6.1M) and GM (CT6.6M) PDF's

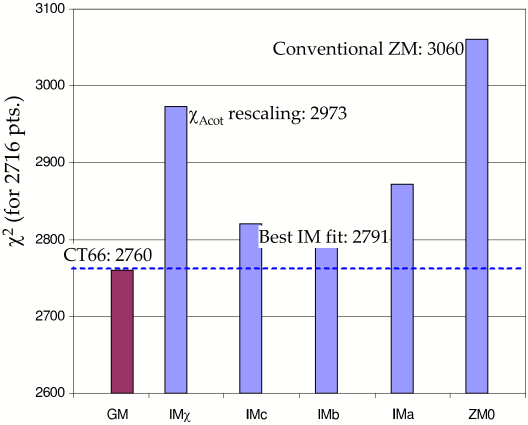


- CT6.1 are refitted including the latest HERA c, b data (χ^2 improved)
- GM+CT6.6 gives the best fit; ZM+CT6.6 the worst
- χ^2 for IM+CT6.6 (IM+CT6.1) is better than ZM+CT6.6 (ZM+6.1)

All IMλ+CT6.x fits produce close χ^2 – only IMχ is shown

IM formulation works!

Comparison to the full CT6.6 data sample



- GM+CT6.6 still gives the best fit; ZM+(new CT6.1) the worst
- Quality of the best IM fit (IMb) approaches that of GM+CT6.6
- Some IM fits ($\lambda = 0.1 - 0.2$) are clearly very good

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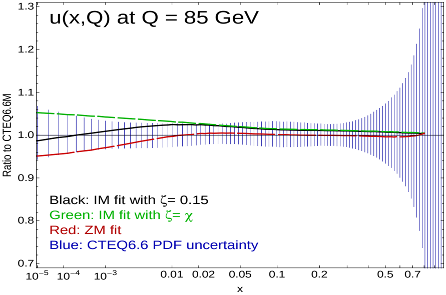
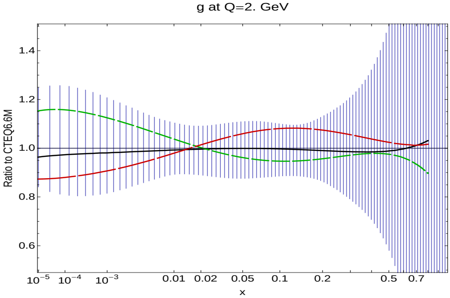
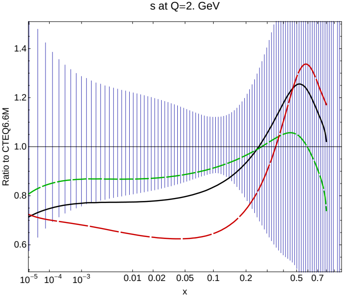
PDFs in GM/IMb/ZM/IMχ formulations



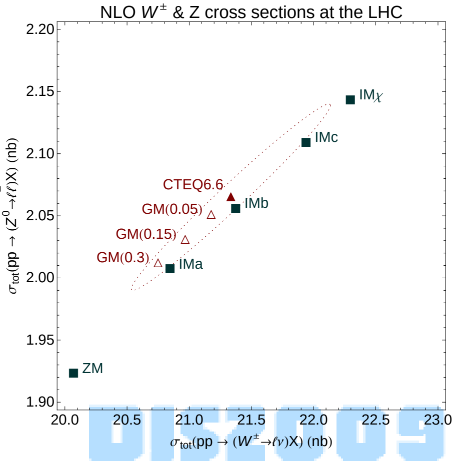




- At $x < 0.01$, ZM u, g are too small compared to GM
- IMχ: u, g are too large
- IMb: u, g are very close to GM
- $s(x, Q)$ (constrained by CC DIS) prefers IMχ rather than IMb

Dependence on the rescaling ζ in W, Z production at the LHC

- IMλ predictions span a wide range between ZM and IMχ
- IM predictions with $\lambda = 0.05 - 0.3$ are compatible with CT6.6M at $\approx 90\%$ c.l.
- ζ variable can be also introduced in the GM scheme; in this case, the standard choice $\zeta = \chi$ (CT6.6, or $\lambda = 0$) gives the best χ^2
- GM PDF's with $\lambda \lesssim 0.3$ agree with CT6.6M within the CT6.6 uncertainty



Conclusions

- The full GM heavy-quark kinematical dependence is approximated well **at NLO** by an **effective** IM scheme with ZM Wilson coefficients and generalized rescaling variable ζ
  - It remains to be seen if this scheme is viable **beyond NLO**
- The IM formulation can be applied to easily implement the leading heavy-quark mass effects in ZM calculations
- Variations in the form of ζ lead to an additional theoretical uncertainty that must be provided with GM predictions

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