POETIC VI - École Polytechnique

Intrinsic bottom and its impact on heavy new physics at the LHC

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Introduction

- **Heavy quarks parton distribution function** play an important role in several SM and BSM processes
  - b plus jet, associated tW, tH^+
- In the Standard approach, HQ PDF:
  - **DGLAP**$+$ perturbatively calculable boundary condition
- Purely perturbative treatment: $m_c = 1.3$ GeV? $m_b = 4.5$ GeV?
  - Light-cone and meson cloud models predict a **non-perturbative** heavy quark component
- Global analysis for **IC** by CTEQ and Jimenez-Delgado et al. $\Rightarrow$ set *significantly different limits*

Motivations

Our approach

(II) Intrinsic heavy quark evolution can be **decoupled**

- Quantify our approximation

(III) Fill the gap by providing **IB**(IC) PDF

- Well suited because the normalization can be **adjusted freely**

(IV) Study the impact of IC and IB on parton-parton luminosities at the **LHC**

- Assess the impact on SM and NP processes

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II) Evolution of intrinsic heavy quarks

III) Intrinsic bottom PDFs

IV) Parton-parton Luminosities and intrinsic heavy quarks at the LHC 14 TeV

V) Conclusion

Evolution equation

Definition

- $Q_1(x, \mu_0) := Q(x, \mu_0) - Q_0(x, \mu_0)$,
  - in $\overline{\mathrm{MS}}$ (only NLO), $Q_0(x, \mu_0) = 0$ if $\mu_0 = m_Q$
- Any non-zero boundary condition $Q(x, m_Q) \neq 0$ can be attributed to intrinsic component
- Light quark q, heavy quark (c or b) Q, and gluon g

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$$\begin{aligned}
\dot{g} &= P_{gg} \otimes g + P_{gq} \otimes q + P_{gQ} \otimes Q \,, \\
\dot{q} &= P_{qg} \otimes g + P_{qq} \otimes q + P_{qQ} \otimes Q \,, \\
\dot{Q} &= P_{Qg} \otimes g + P_{Qq} \otimes q + P_{QQ} \otimes Q \,.
\end{aligned}$$

- $Q = Q_0 + Q_1$
  - Q_0 is the usual radiatively generated extrinsic heavy quark
  - Q_1 is the **non-perturbative** intrinsic heavy quark

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- $(q, g, Q_0) \Rightarrow$ usual DGLAP eq. without intrinsic
- Q_1 Standalone **non-singlet** evolution equation
  - $\dot{Q}_1 = P_{QQ} \otimes Q_1$.

Sum rule

Full-fledge analysis:

- Modified **sum rule** in global analysis:

$$\int_0^1 \mathrm{d}x \; x \; \left(g + \sum_i (q_i + \bar{q}_i) + Q_0 + \bar{Q}_0 + Q_1 + \bar{Q}_1 \right) = 1 \, .$$

- Allowing for a small **violation** of the sum rule we can completely decouple the analysis of intrincic heavy quarks

$\Rightarrow$
- Can take **any PDF set** for (q, g, Q_0)
- Add the standalone intrinsic heavy quark

- Violation of the sum rule: $\int_0^1 \mathrm{d}x \; x \; (Q_1 + \bar{Q}_1)$

Different matching conditions

BHPS Intrinsic charm:

$$c_1(x) = \bar{c}_1(x) \propto x^2[6x(1+x)\ln x + (1-x)(1+10x+x^2)]$$

- **Normalization** and **precise energy scale** are not specified

- b-quark expected to be **very similar** with **normalization suppressed** $m_c^2/m_b^2 \simeq 0.1$
- Matching scale is "unknown":
  - $b_1(x, m_b) = \frac{m_c^2}{m_b^2} c_1(x, m_c)$
  - $b_1(x, m_c) = \frac{m_c^2}{m_b^2} c_1(x, m_c) \Rightarrow$ our ansatz
- **Remains valid** at all scales
- Note that asymmetric boundary conditions, $c_1(x) \neq \bar{c}_1(x), b_1(x) \neq \bar{b}_1(x)$ could be accomodated (like in meson cloud models)

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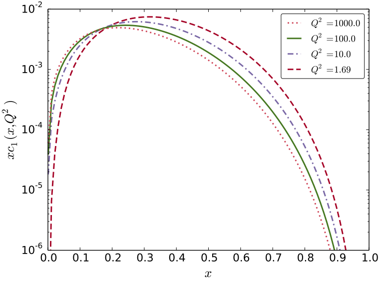
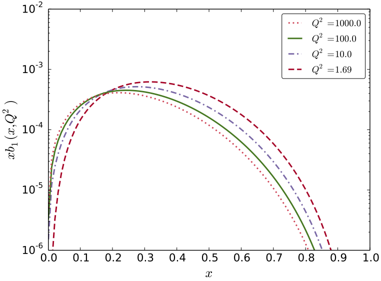
$c_1(x),\ b_1(x)@NLO$

- $b_1(x,m_c) = \frac{m_c^2}{m_b^2} c_1(x,m_c)$, $\int_0^1 c_1(x) = 0.01$, $m_c = 1.3$ GeV, $m_b = 4.5$ GeV





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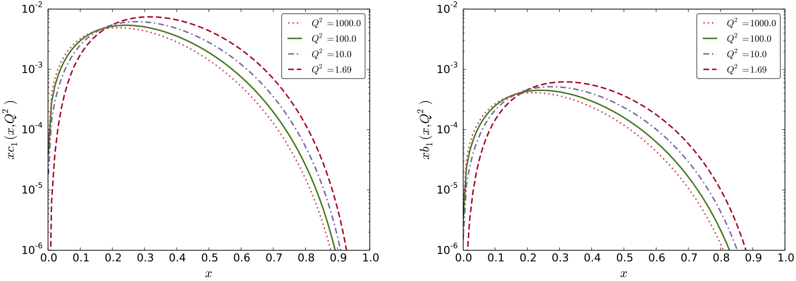

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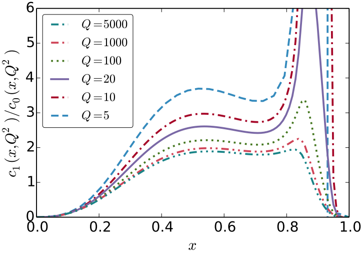
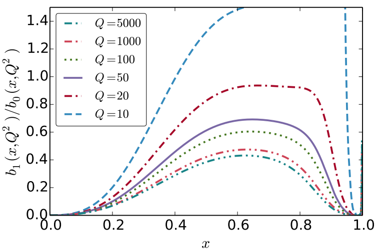
$c_1(x),\ b_1(x)@NLO$

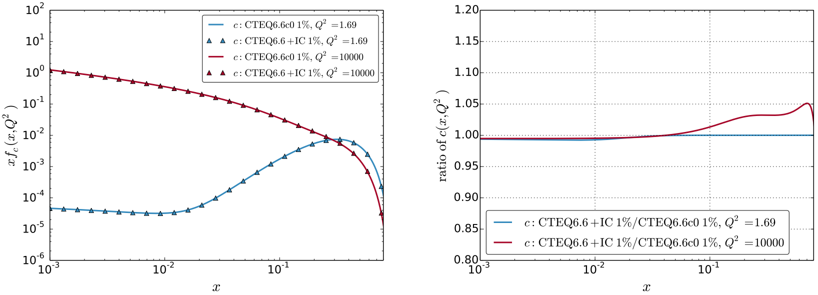
- Modifications in BHPS models are essentially at **large-x**
- IB effects less **pronounced**:
  - Still, observables dominated by b initiated processes could be enhanced by a factor up to ~ 1.6
  - For constraining intrinsic bottom $\Rightarrow$ low Q and high-x e.g. AFTER@LHC





Goodness of the approximation

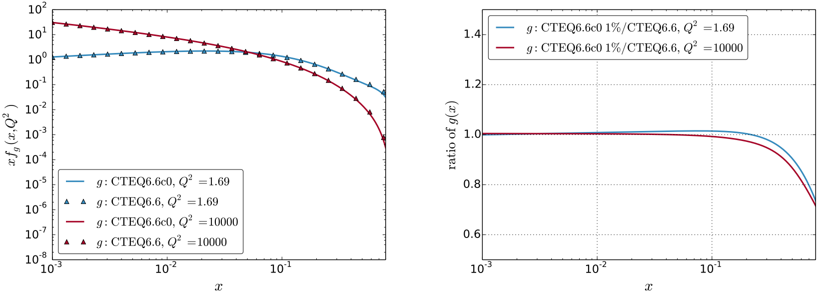
- Comparison of $c_1(x) + \mathrm{CTEQ6.6}$ and $c(x)$ of $\mathrm{CTEQ6.6c0}$ with the **same normalization**
  - $\int_0^1 dx\ c(x)$=0.01
  - $\int_0^1 dx\ x\left[c(x) + \bar{c}(x)\right] = 0.0057$
- Charm-quark with 1% normalization



- The error is under control and reaches at worst 5%.

Goodness of the approximation

- Comparison of $g(x)$ of $\mathrm{CTEQ6.6}$ and $g(x)$ of $\mathrm{CTEQ6.6c0}$ with 1% normalization



- The error is larger at high x but the gluon is very small and the uncertainties large in this region.

Goodness of the approximation

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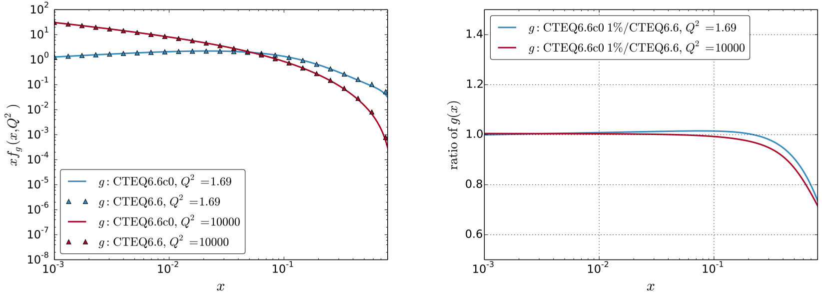

- Also looked at how this affect luminosities
- For **IB** the errors will be 10 times smaller !

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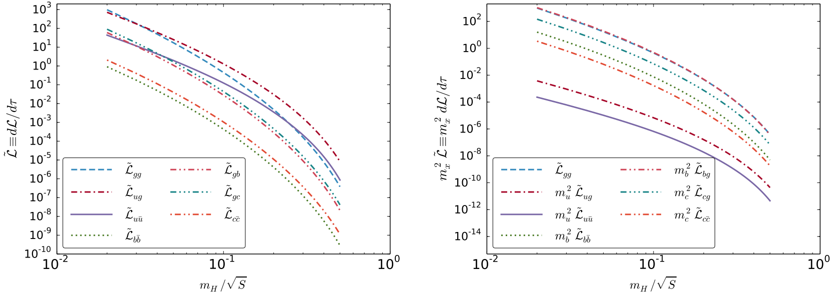
Luminosities @ the LHC14 TeV

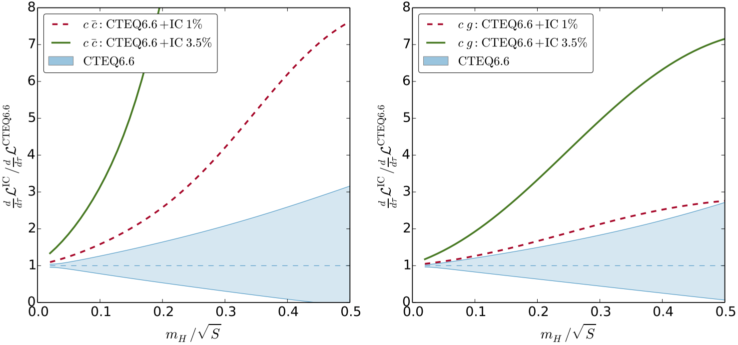
Production of a heavy state

- $\sigma_{pp\to H+X} = \sum_{ij} \int_\tau^1 d\tau \frac{d\mathcal{L}_{ij}}{d\tau} \hat{\sigma}_{ij}(s),\ \sqrt{\tau} = m_H/\sqrt{S}$

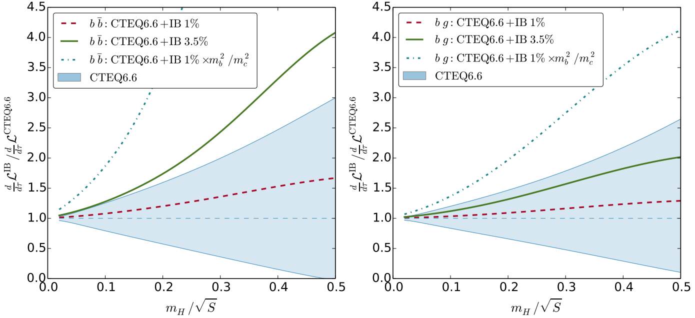


- E.g. a **heavy scalar** with couplings proportional to the **fermion mass**: m_c^2/m_b^2 factor compensated

- $\sqrt{\tau} = m_H/\sqrt{S}$



- The impact of the intrinsic charm is clearly visible and outside the uncertainty band from PDF for both $c\bar{c}$ and cg.



- Also include an *extreme* scenario with the **first moment** of IB at 1%.
- Effects smaller than for IC as expected
- 3.5% normalization is distinguishable

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- Intrinsic heavy quarks can be decoupled⇒ **non-singlet** evolution
  - Can generate matched **IC/IB** distributions for any PDF set **without** re-doing a global analysis ⇒ Produced **IB** set!
  - The normalization can be chosen freely
- The Approximation holds to a very good level for all relevant applications:
  - For **IB**, it is very good
  - For **IC**:
    (i) 1-2% normalization ⇒ error smaller than **PDF uncertainty** at large-x
    (ii) For **larger norms**, the error grows but the effect also such that it can easily be separated from the *without IC case*.
- Need a low Q large-x machine to constrain IB
  - Electron Ion Collider (EIC)
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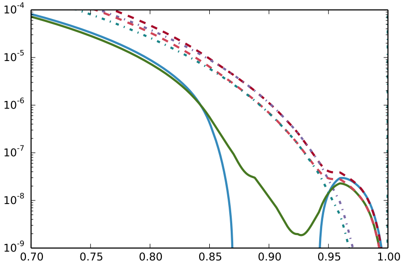
- the c PDF of CTEQ66.c0 goes negative at large-x small Q



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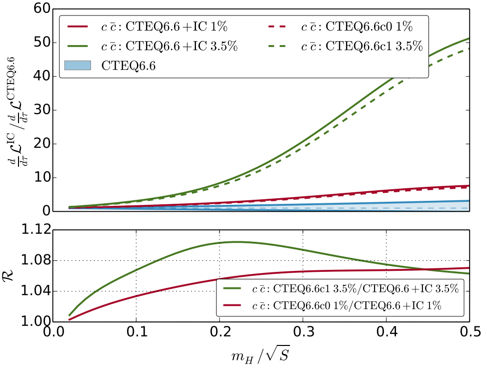
- $\frac{d\mathcal{L}_{ij}}{d\tau}(\tau,\mu) = \frac{1}{1+\delta_{ij}} \int_\tau^1 \frac{dx}{x} \left[f_i(x,\mu) f_j(\tau/x,\mu) + (i \leftrightarrow j) \right]$

- Validity of the approximation on the Luminosities:



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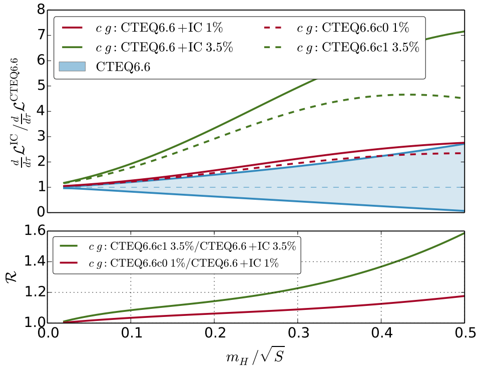
- Validit



- Note that for the intrinsic bottom the error is **smaller**