HATHOR for Single-Top Predictions

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Outline

Cross section prediction and systematics studies

- Precision of LHC experiments requires accurate theoretical predictions
- Need for systematic studies of theoretical uncertainties:
  PDFs, scale dependencies, . . . (including correlations)
- NLO code exists for many processes in MCFM
  (complete integration of matrix elements and subtraction terms)
- Determining theoretical uncertainties very time-consuming,
  usually many executions neccessary (thus requiring $\mathcal{O}$(days))
- Desirable: fast calculation of total hadronic cross sections
- Already achieved by HATHOR for $t\bar{t}$ production
  [M. Aliev et al, Comput.Phys.Commun.182: 1034-1046,2011]

Factorization

- Make use of

$$\sigma_{\text{had}}(s_{\text{had}}, \mu_F) = \sum_{i,j} \int \mathrm{d}x_1 \mathrm{d}x_2 F_i(x_1, \mu_F) F_j(x_2, \mu_F) \hat{\sigma}(\underbrace{x_1 x_2 s_{\text{had}}}_{\hat{s}}, \mu_F)$$

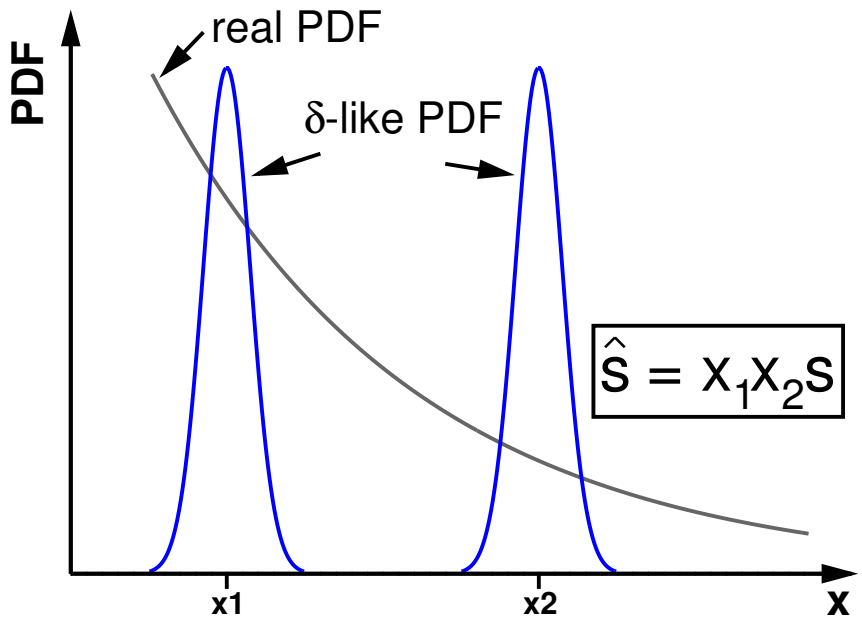
$$\text{with } \hat{\sigma} = \int \mathrm{d}\sigma_{\text{LO}} + \underbrace{\int \mathrm{d}\sigma_{\text{virt}} + \int \mathrm{d}\sigma_{\text{real}} + \int \mathrm{d}\sigma_{\text{fac}}}_{\text{infrared/collinear divergences in each term}}$$

- Integration of real and virtual corrections over different phase spaces $\Rightarrow$ cancelling of divergencies non-trivial
- Code for σ_{had} present in MCFM, but no analytic form of $\hat{\sigma}$
- Modifications of existing program difficult and error-prone
- Need minimal-invasive and process-independent extraction of $\hat{\sigma}$!

Extraction of partonic cross sections

- Idea: use narrow, normalized functions approximating Dirac's δ as PDFs

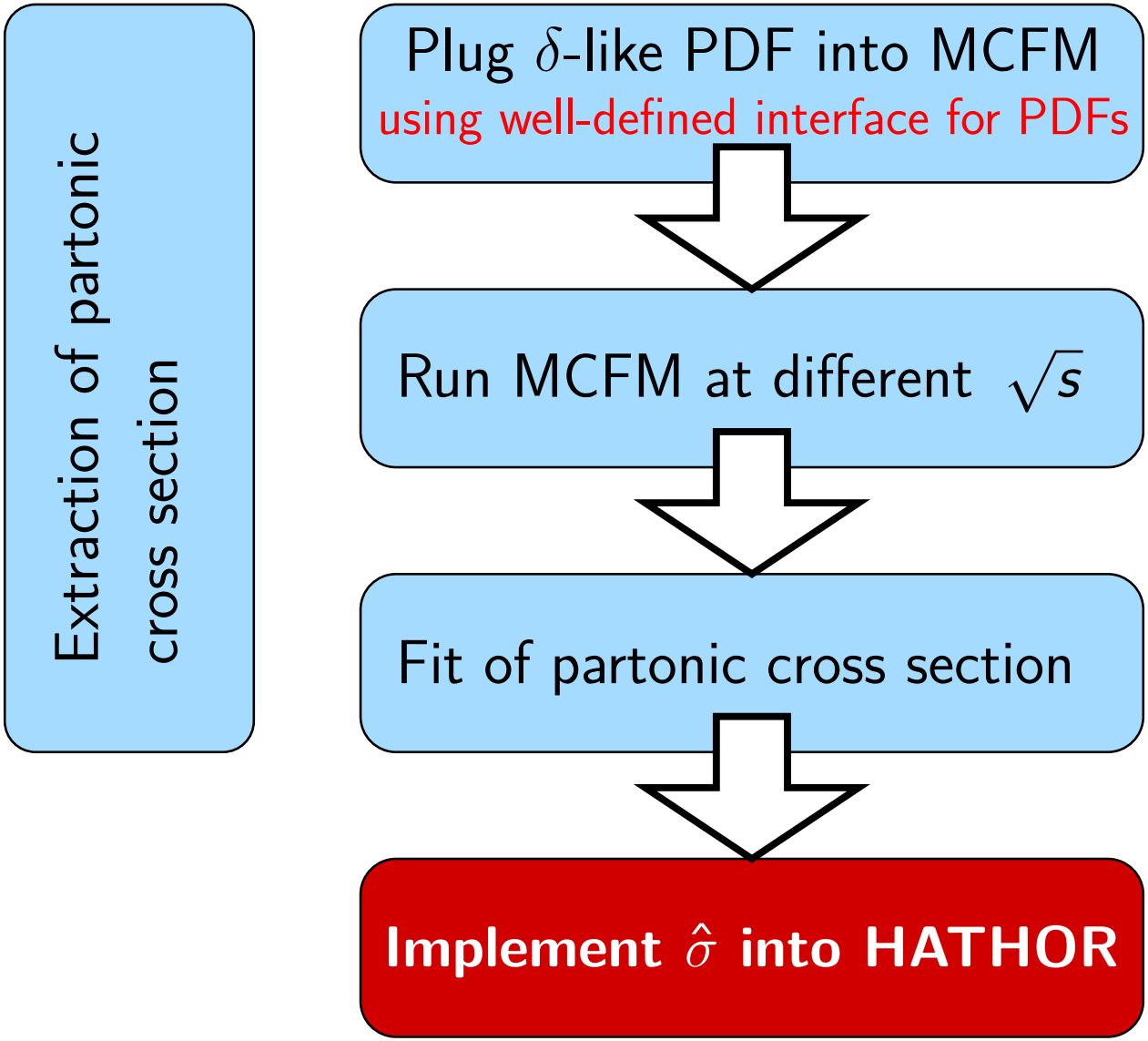
$$F_i(x) = \frac{1}{\sqrt{2\pi}\delta} \exp\left(-\frac{(x-x_0)^2}{2\delta^2}\right)$$



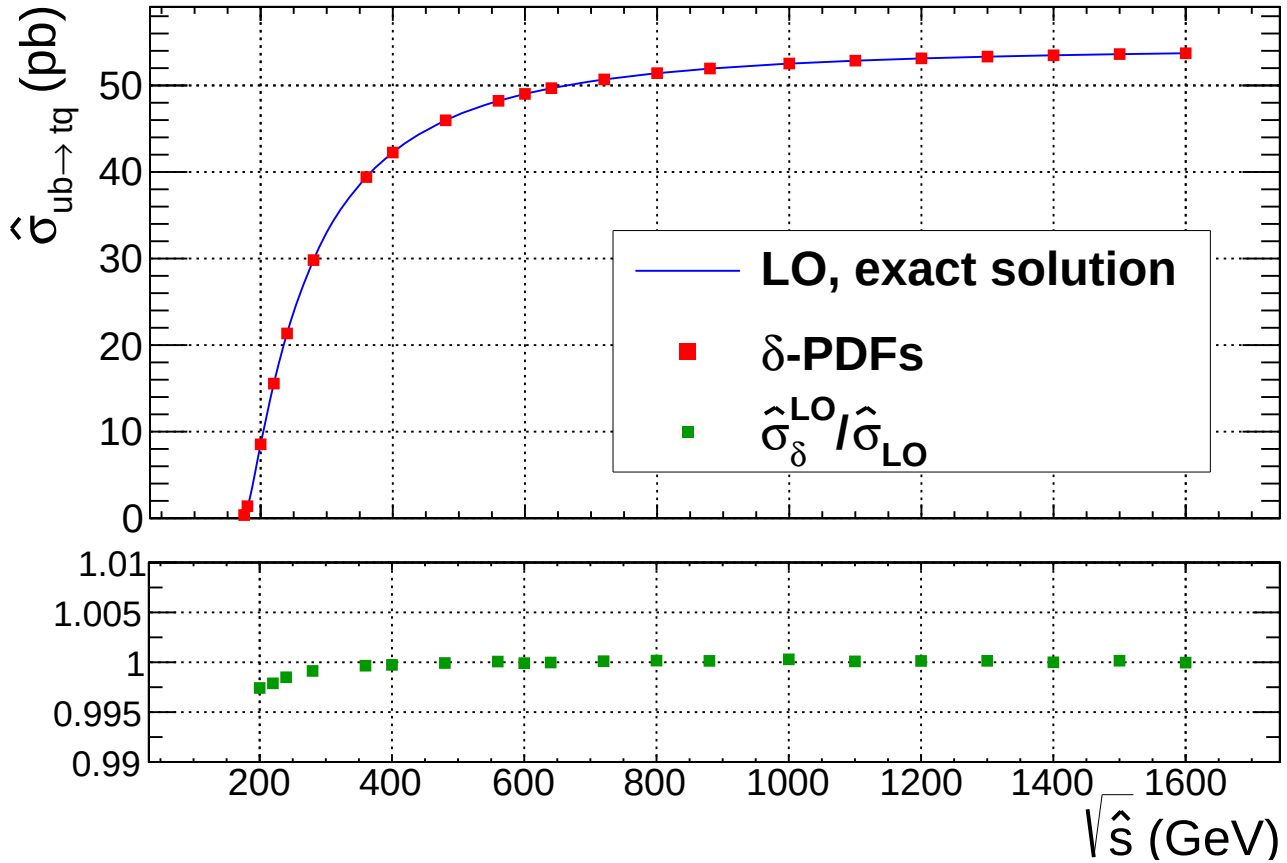
- $\Rightarrow$ Extraction of $\hat{\sigma}(x_1 x_2 s)$ at an arbitrary, fixed place $x_0^2 s$
- Repeat for different values of s and obtain $\hat{\sigma}(s)$
- Choose $\delta = \mathcal{O}(10^{-3})$ for small systematic error

$$\sigma_{\text{had}}(x_0^2 s_{\text{had}}) = \hat{\sigma} + \hat{\sigma}' \underbrace{\left(\bar{x_1}\bar{x_2} - x_0^2\right)}_{=0} s_{\text{had}} + \tfrac{1}{2}\hat{\sigma}'' \underbrace{\overline{\left(x_1 x_2 - x_0^2\right)^2}}_{=2x_0^2\delta^2+\ldots} s_{\text{had}}^2 + \ldots$$

Workflow

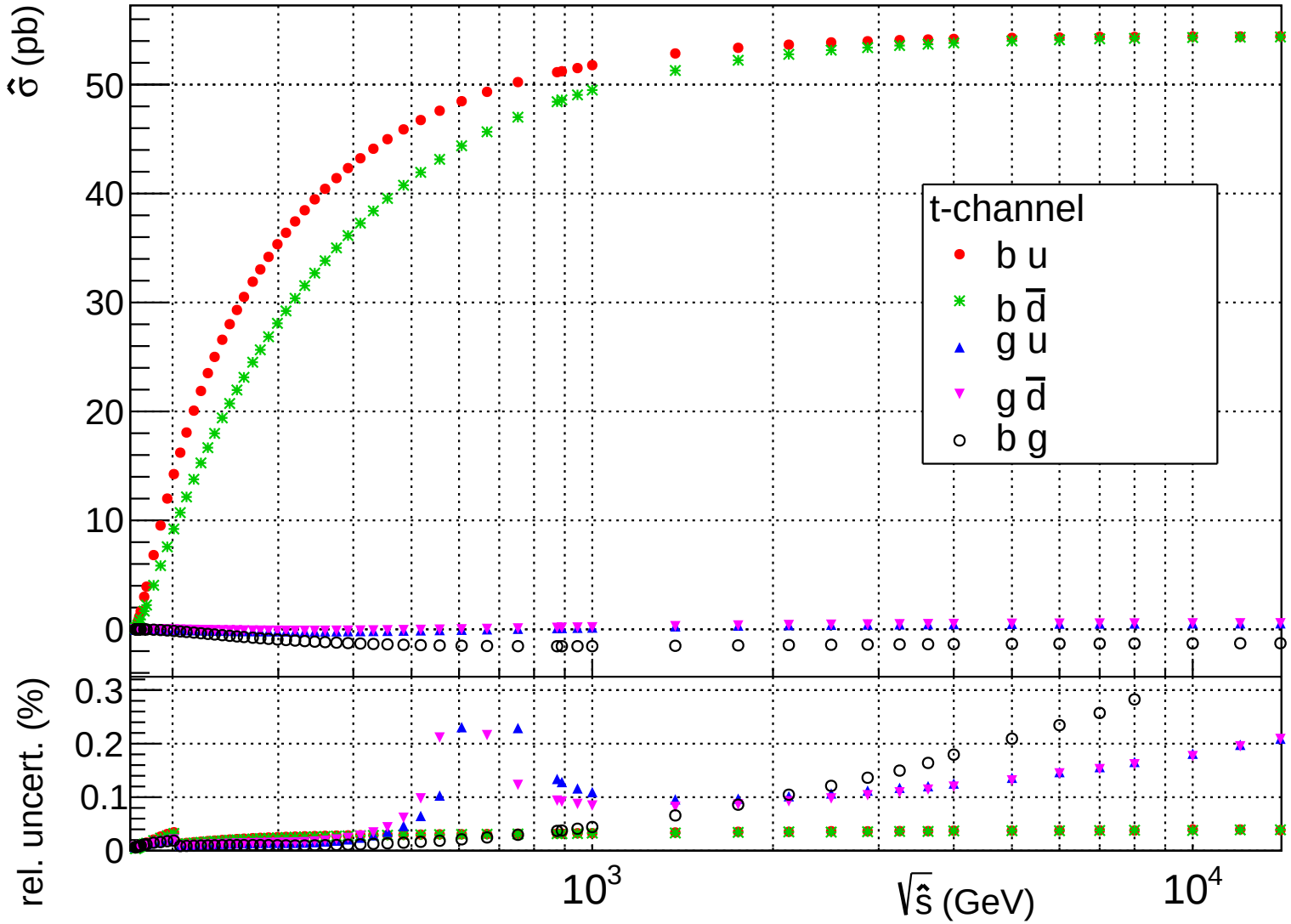

Extraction of partonic cross section
Plug δ-like PDF into MCFM
using well-defined interface for PDFs
Run MCFM at different $\sqrt{s}$
Fit of partonic cross section
Implement $\hat{\sigma}$ into HATHOR

Consistency check in leading order for single-top t-channel



- Compare results in leading order with analytical result ($ub \to tq$)
  $\Rightarrow$ precise extraction possible

NLO results for single-top (t-channel)



- All contributing initial states (in five-flavour scheme)
- Achieved precision of $\mathcal{O}(1\ ‰)$

NLO results for single-top (t-channel)

- NLO correction $\frac{1}{\alpha_s}(\hat{\sigma}_{\text{LO+NLO}} - \hat{\sigma}_{\text{LO}})$ implemented in HATHOR

  $\Rightarrow$ Correction independent of α_s

  $\Rightarrow$ σ_{had} easy to calculate for arbitrary PDFs

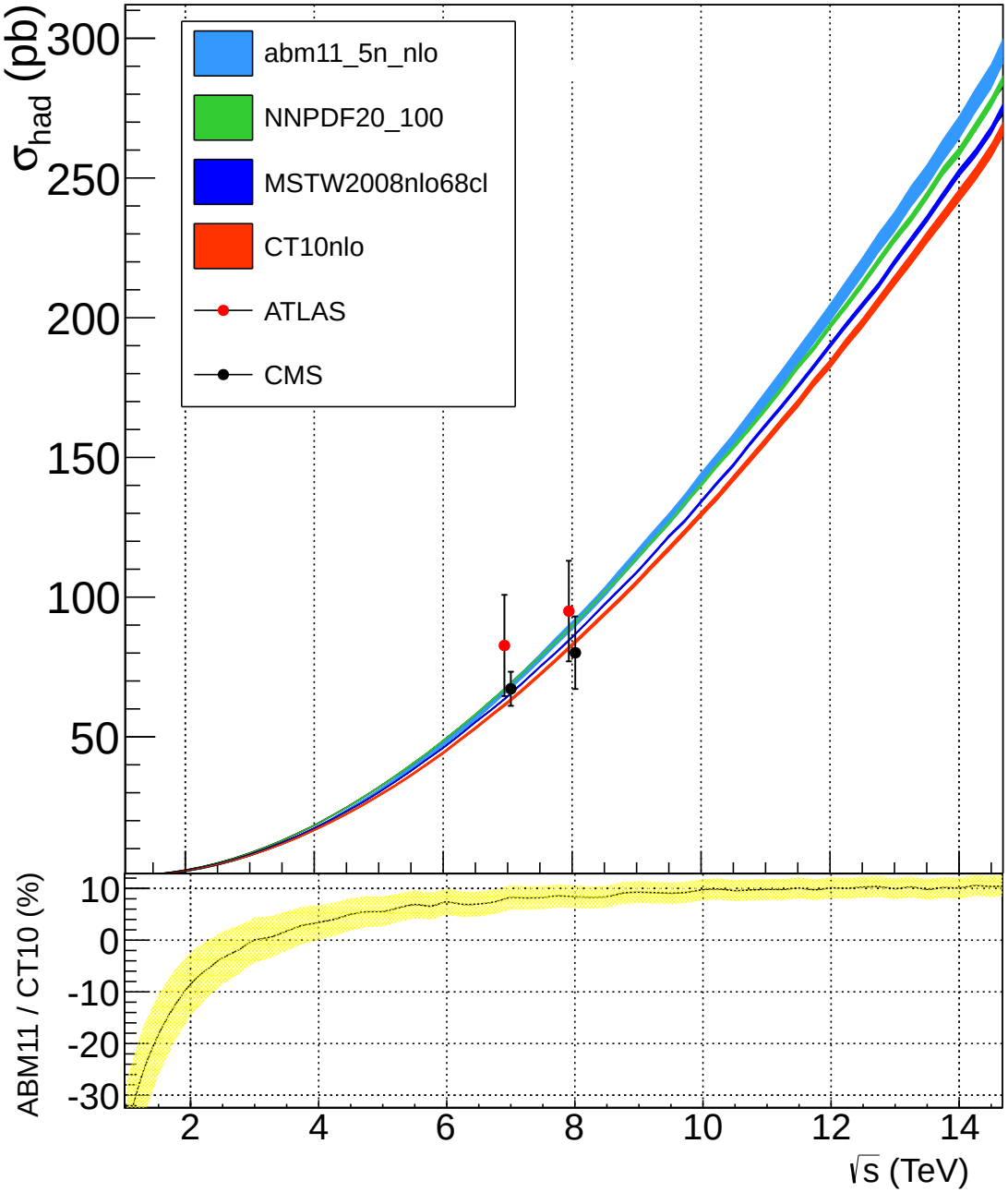
- Verification done by comparison to MCFM (here: MSTW2008nlo)

$\sqrt{s}$	$\mu_r = \mu_f$	σ_{had} (pb)	$1 - \sigma_{\text{had}}/\sigma_{\text{had}}^{\text{MCFM}}$
2 TeV ($\text{p}\bar{\text{p}}$)	m_t	1.0163	0.1%
8 TeV (pp)	m_t	55.212	0.1%
8 TeV (pp)	$2 \cdot m_t$	56.765	0.1%
8 TeV (pp)	$m_t/2$	54.389	0.06%

- Reduced computation time:
  Hathor: $\mathcal{O}(1\text{s})$
  MCFM: $\mathcal{O}(1\text{h})$

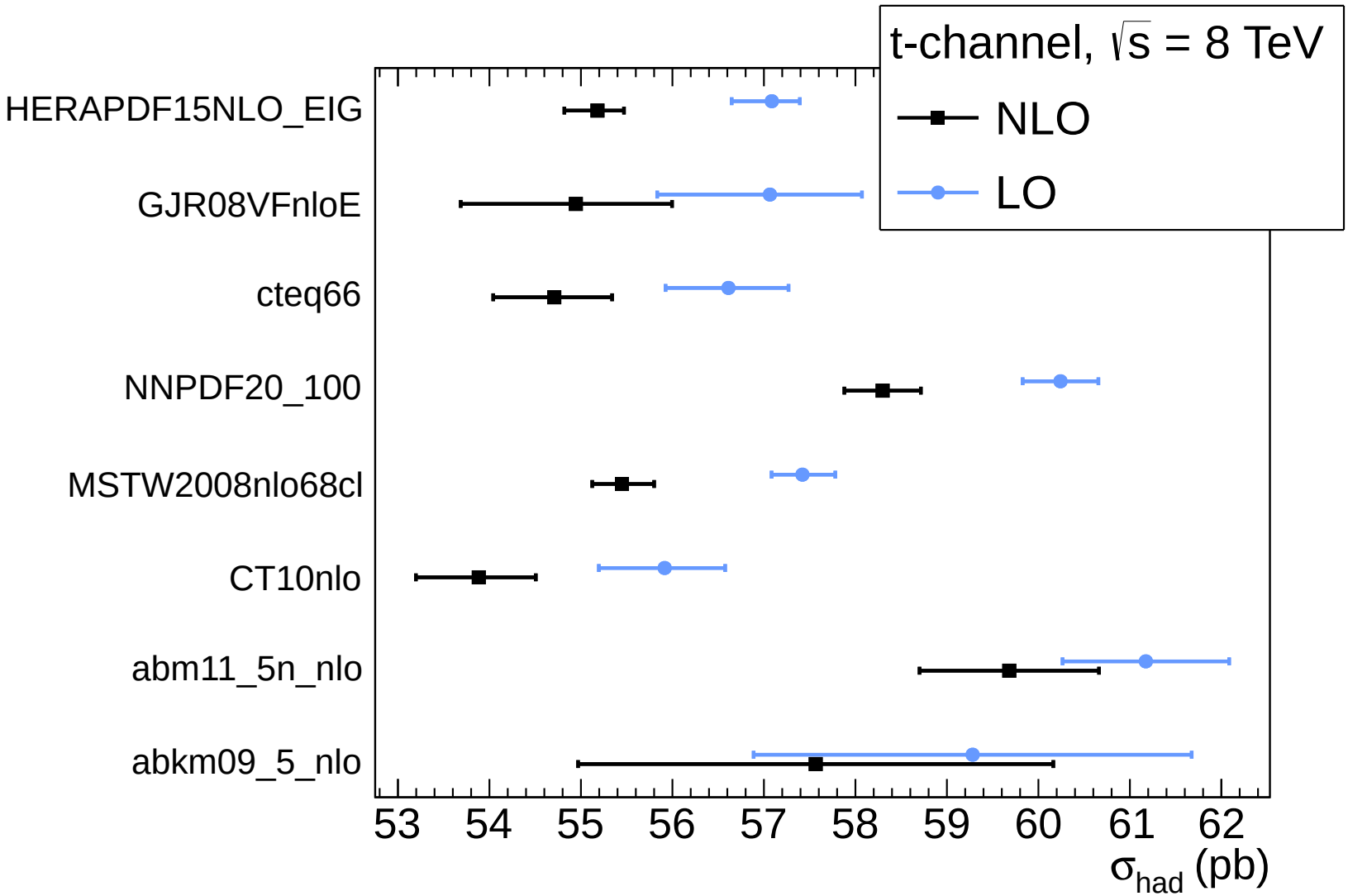
Impact of different PDF sets (obtained using HATHOR)

- Calculation of NLO cross section over wide range of energy
- Compare effect of different PDF sets
- Showing t-channel, pp collider
- At 14 TeV:
  width of single band: 1%
  but overall width is 14%!
- Calculation time: 35min.



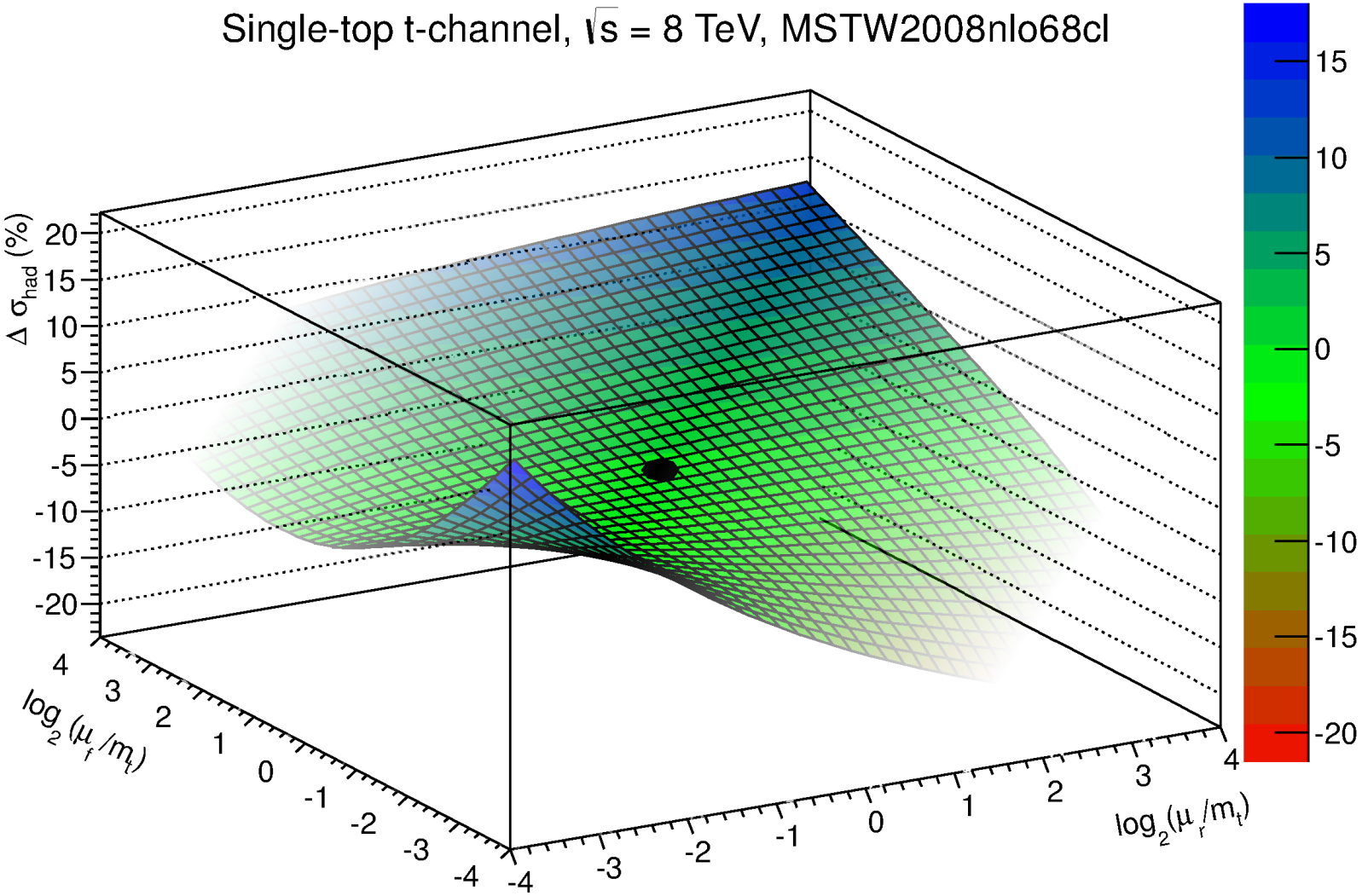
Impact of different PDF sets

- Cross section evaluation together with PDF errors



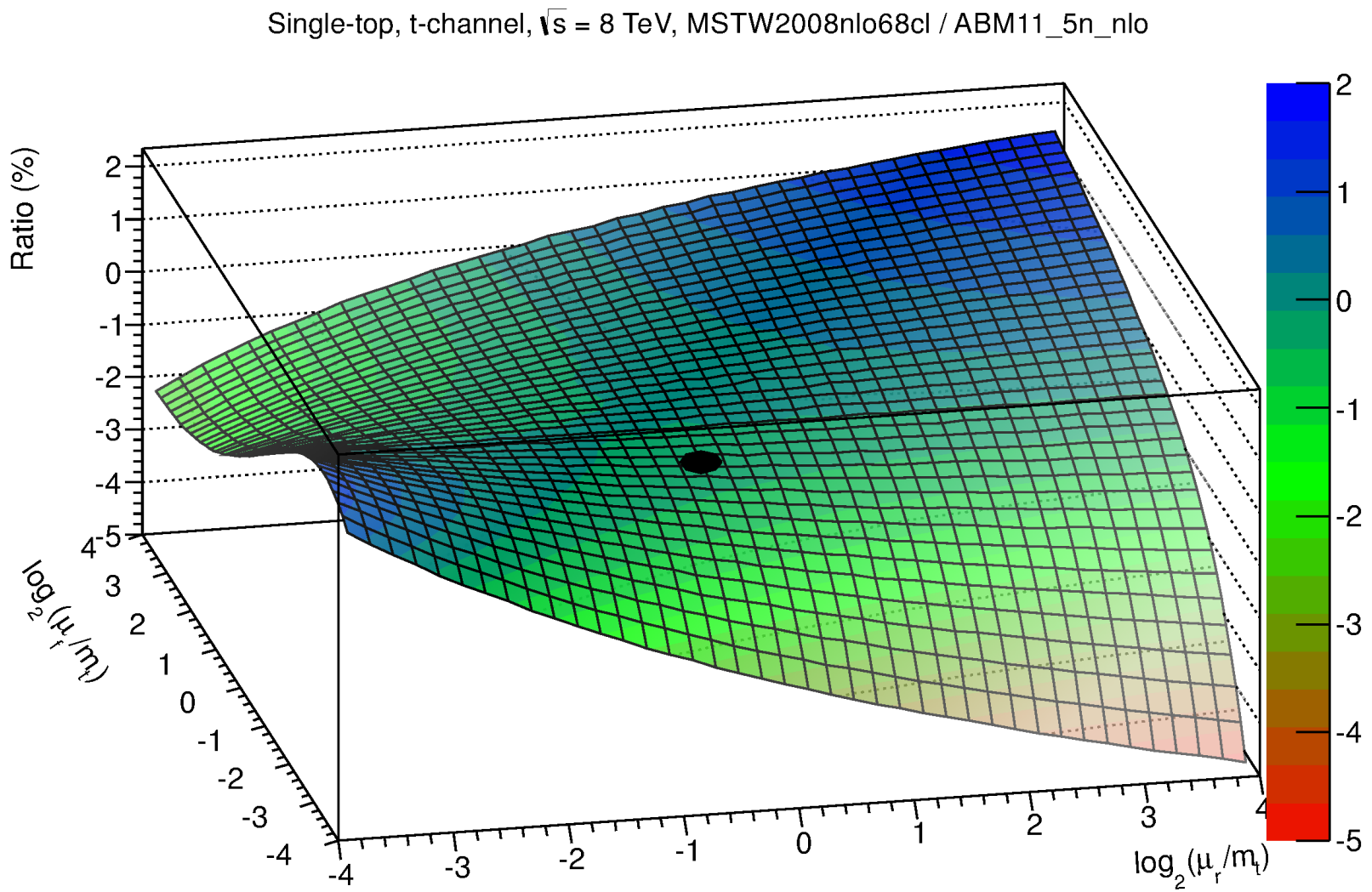
Impact of scale dependency

- Indep. variation of factorization scale μ_f and renormalization scale μ_r



Impact of scale dependency and PDFs

- Indep. variation of factorization scale μ_f and renormalization scale μ_r
- Compare different PDFs depending on scales $\rightarrow$ showing ratio



Summary and Outlook

Summary:

- Extended HATHOR for single-top production at NLO
- Fast computation of t-, s- and Wt-channel cross sections
- Possibility to choose PDFs, μ_r, μ_f, t or $\bar{t}$
- Validation of results by comparison to MCFM
- Application to studies of uncertainties
- Release is imminent

To be done:

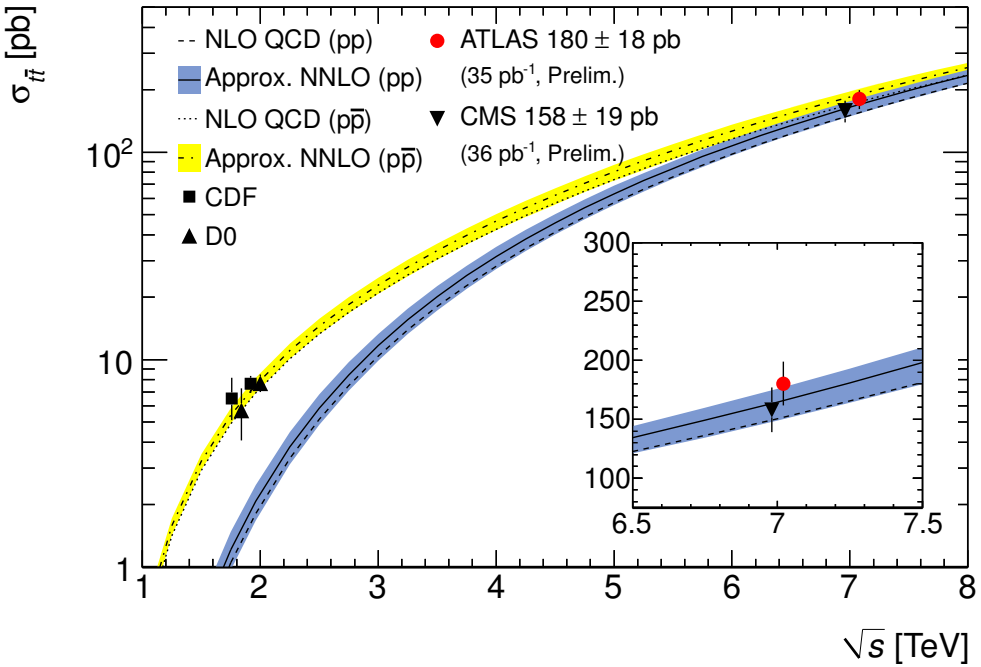
- Addition of approx. NNLO corrections
- Inclusion of m_t dependence
- Allow four-flavor scheme calculations

Backup

Backup

HATHOR for $t\bar{t}$ production

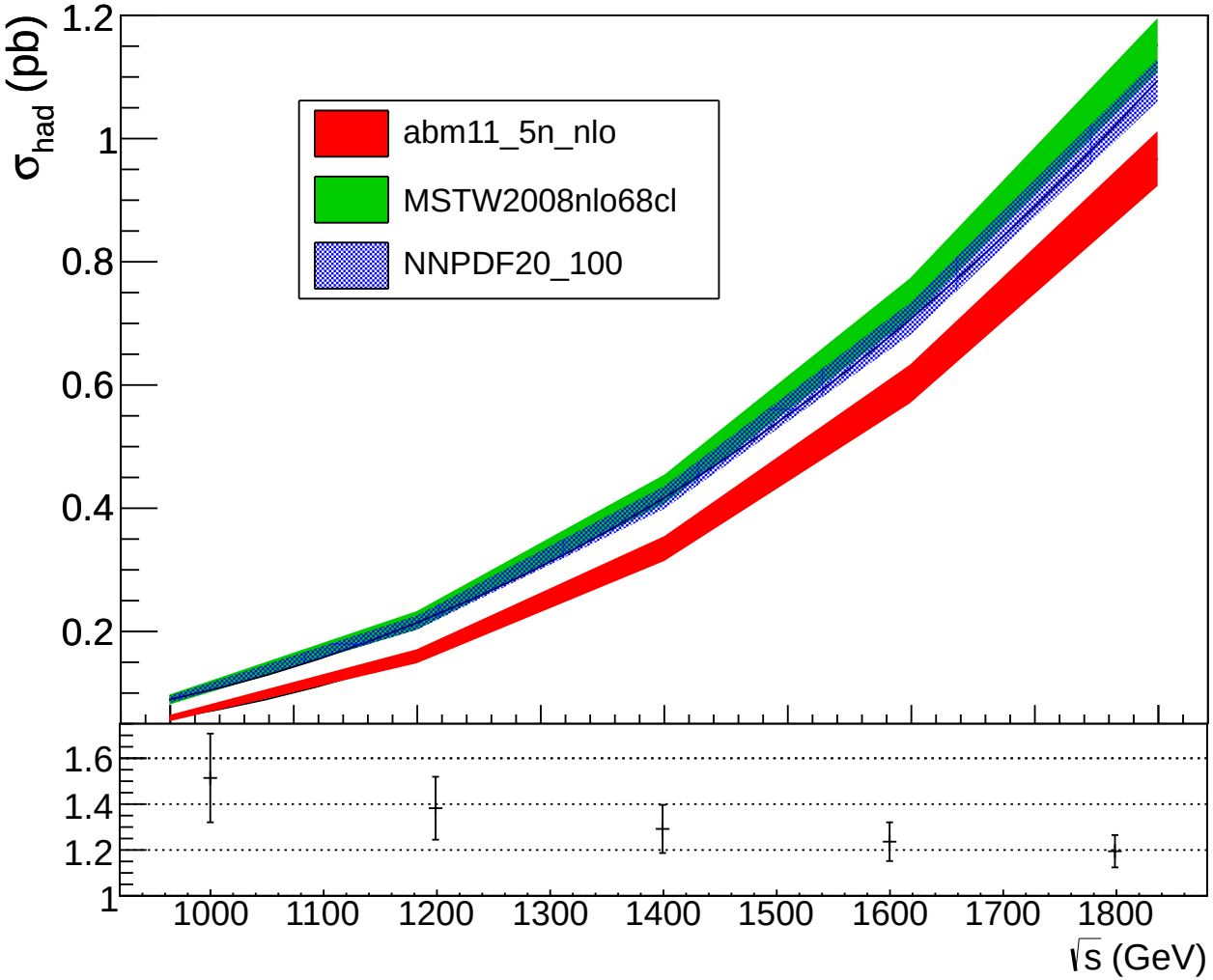
- HATHOR: calculates σ_{had} for $pp \rightarrow t\bar{t} + X$ or $p\bar{p} \rightarrow t\bar{t} + X$
  [M. Aliev et al, Comput.Phys.Commun.182: 1034-1046,2011]
- Integration of partonic cross section and parton density functions
- Combines latest theoretical results - pQCD in approx. NNLO, PDF sets



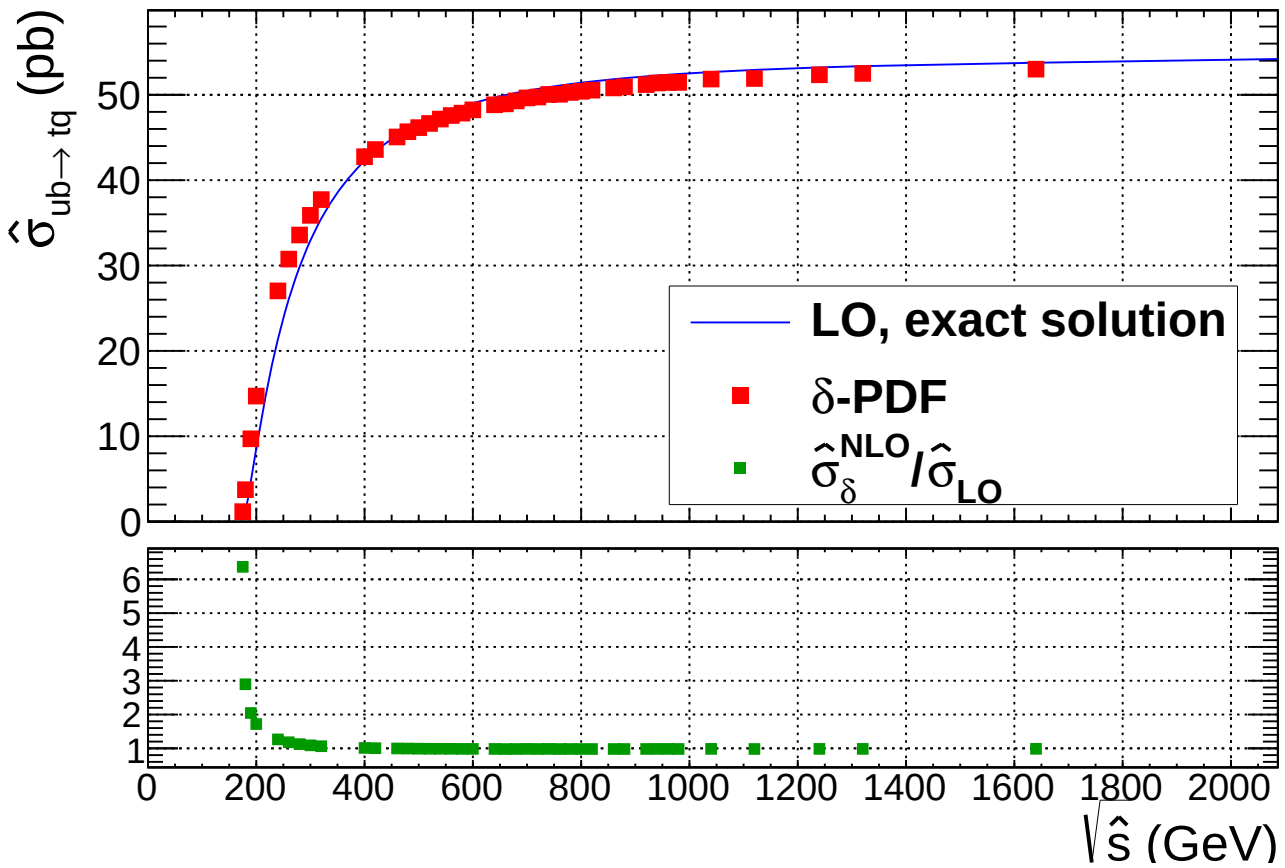
- Flexibility of use - estimation of PDF uncertainties, scale dependencies, various renormalization schemes
- Reference for measurements and further theoretical calculations

Examples: different PDF sets

- calculate cross section over wide energy range
- compare effect of different PDF sets
- plot: t-channel, $p\bar{p}$ collider
- ratio: ABM11 / MSTW2008



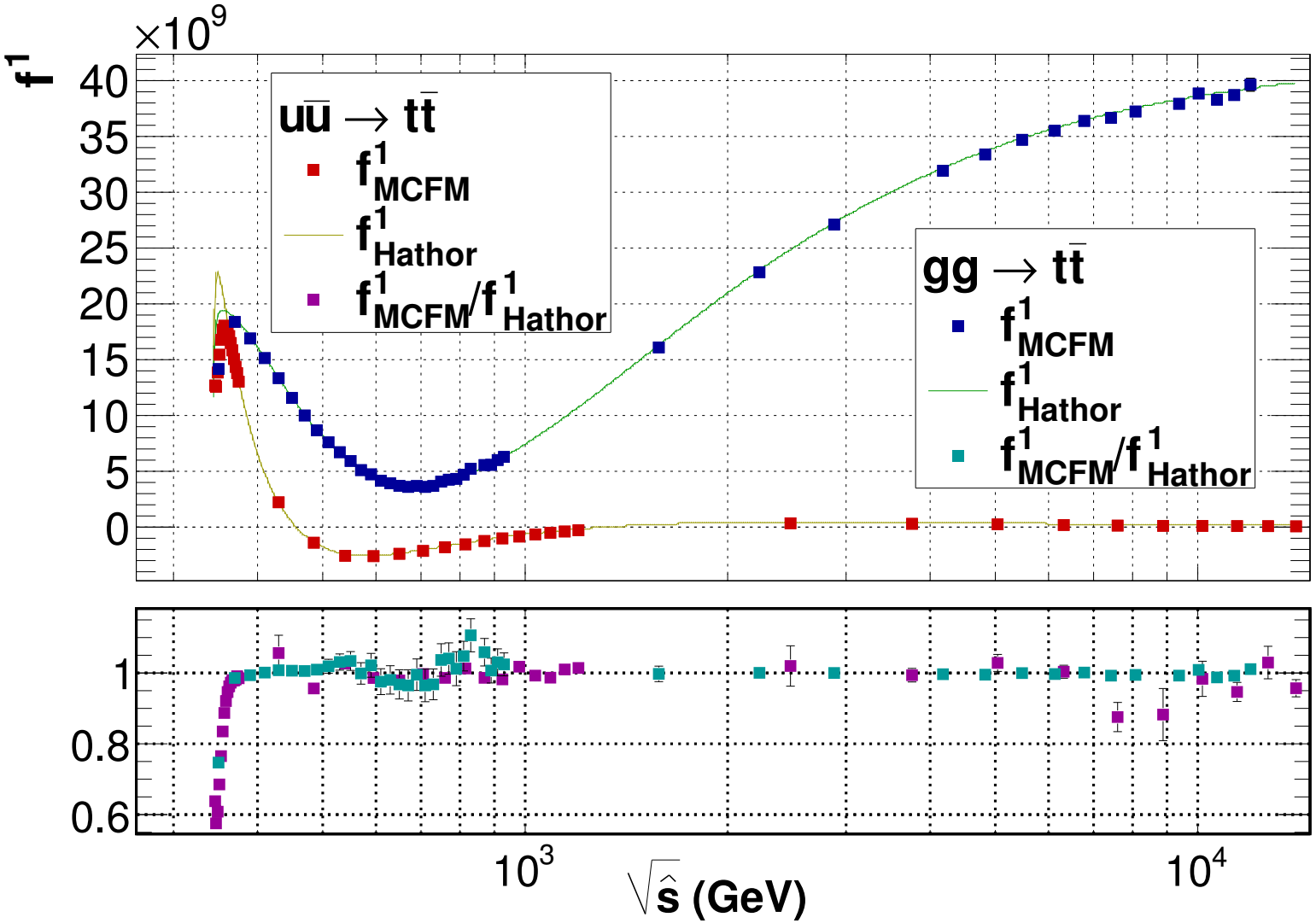
Consistency check in NLO for single-top



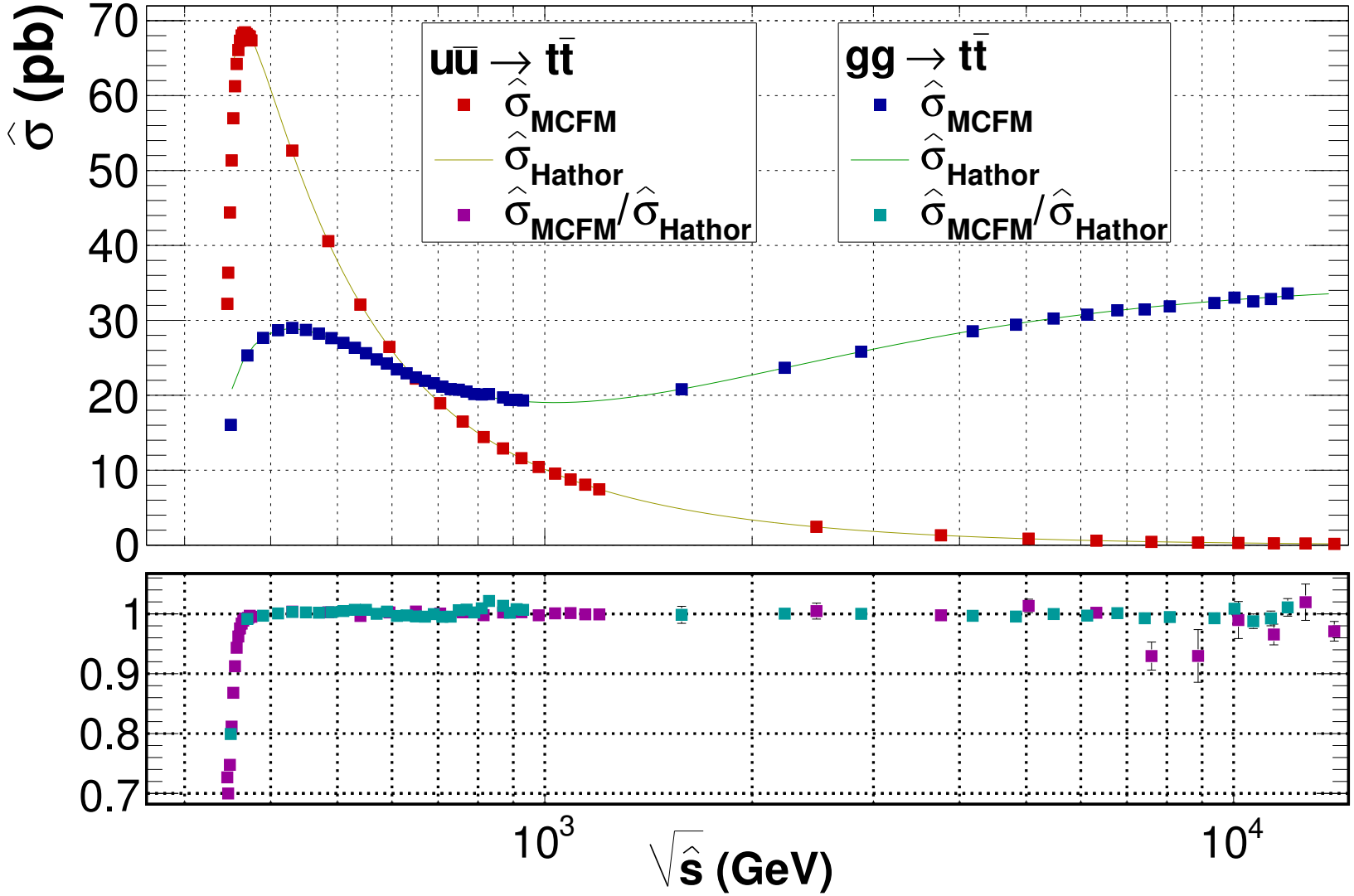
- Small corrections, as expected ($\mathcal{O}(1\%)$)
- Discrepancies close to threshold

Consistency check for $t\bar{t}$-production

- Expand in scaling functions: $\hat{\sigma} = \frac{\alpha_s^2}{m_t^2}\left\{f^0 + 4\pi\alpha_s f^1 + \mathcal{O}(\alpha_s^2)\right\}$
- $\Rightarrow f^1$ depends only on kinematics, not on α_s (input for HATHOR)

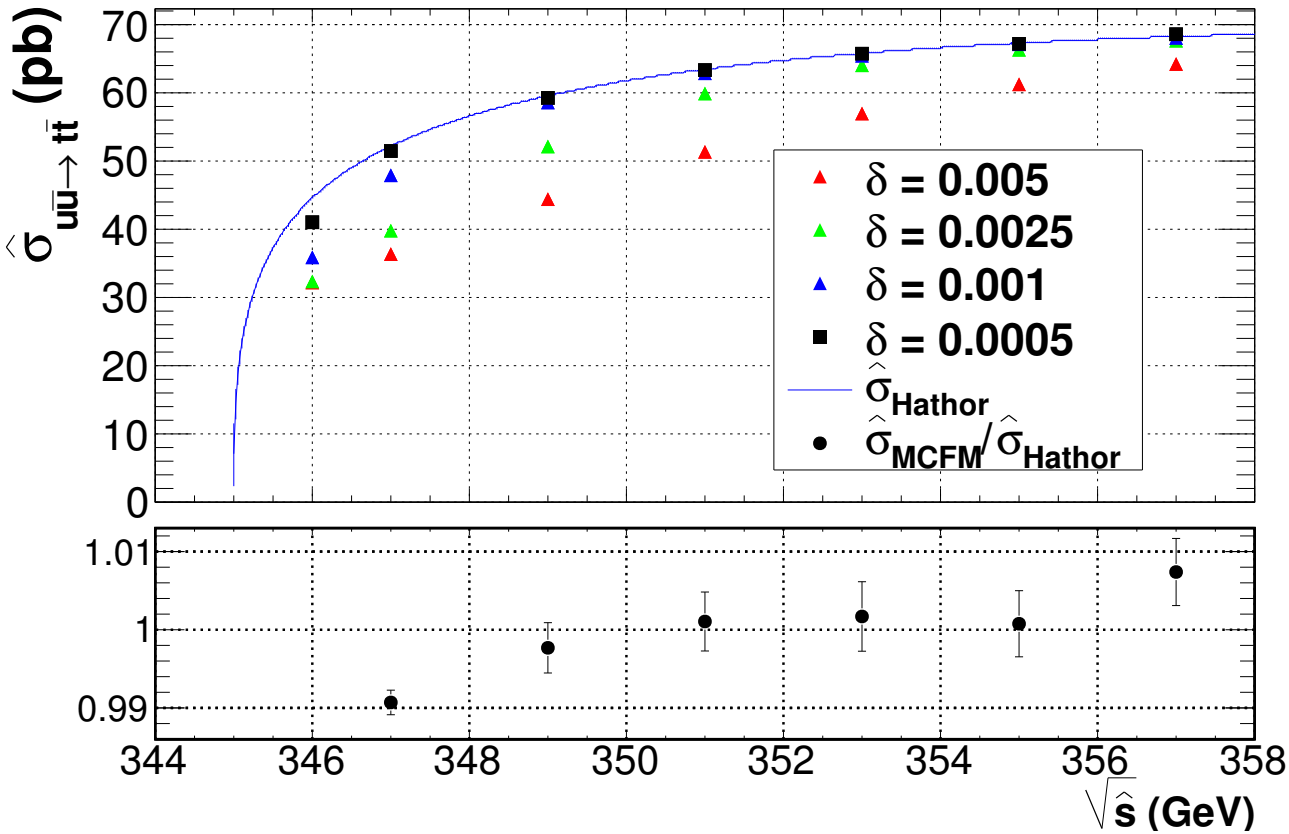


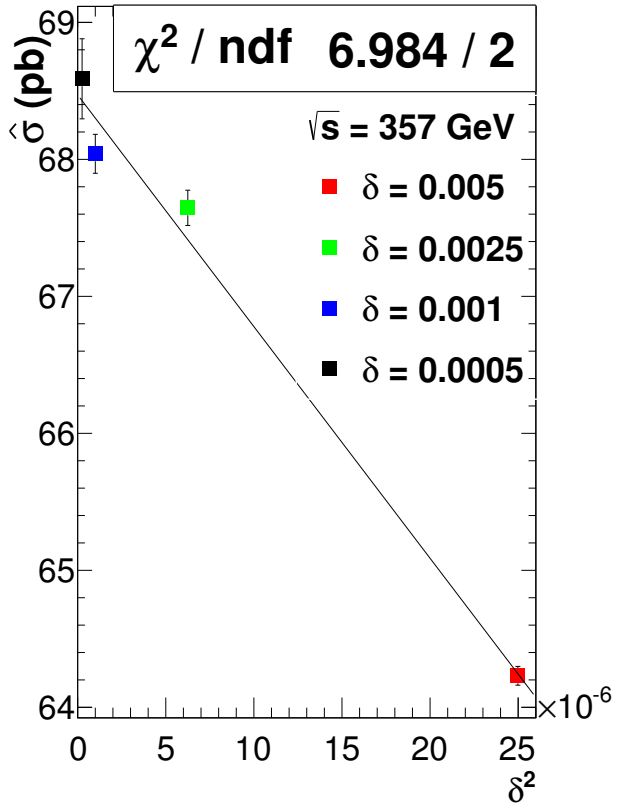
Consistency check for $t\bar{t}$-production



- Good agreement except for discrepancies near threshold ($\sqrt{\hat{s}} \approx 2\, m_t$)

Consistency check for $u\bar{u} \to t\bar{t}$





- Deviations close to the kinematical threshold expected due to

$$\sigma_{had} = \hat{\sigma} + \hat{\sigma}'' x_0^2 s_{had}^2 \delta^2 + \ldots$$

- Improvements achieved $\rightarrow$ works on whole energy range