Cross section benchmarks for 7 TeV LHC

— ABKM report —

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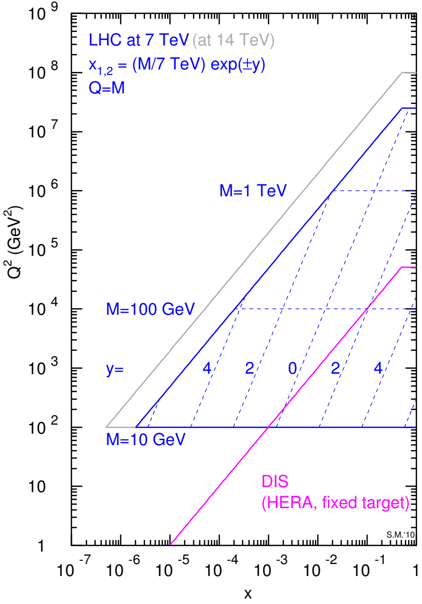
PDF4LHC meeting - CERN

26 March 2010

MOTIVATIONS



Facts:

- ✓ First attempt @ $7\ \mathrm{TeV}$ collisions scheduled for 30 March
- ✓ LHC will run @ $7\ \mathrm{TeV}$ for the next $\approx\ 2$ years, up to $1 fb^{-1}$
- ✓ For SM cross section this corresponds to $\approx\ \frac{1}{4}$ rate with respect to run @ $14\ \mathrm{TeV}$
- ✓ Parton kinematics restricted to larger effective $< x >= \frac{M}{\sqrt{S}}$
- ✓ For light mass states less phase space available
- ✓ Limited discovery reach suggests accurate SM benchmark
- ✓ Larger pdf uncertainties at low x's

ABKM PARTON DENSITIES

- Light quarks
  $m_u, m_d << \Lambda_{QCD}, m_s < \Lambda_{QCD}$
- Neglect quark masses in calculations of hard scattering processes
- Mass singularities absorbed into PDF's, scale dependent evolving u, d, s, g

- Heavy quarks $m_c, m_b, m_t >> \Lambda_{QCD}$
- Explicitly include quark masses in calculations
- No mass singularities, no scale dependent c, b, t PDF's
- Large logs $\log(\frac{Q^2}{m^2})$ when $Q^2 >> m^2$ spoil PT

VFN schemes interpolate between the two approaches, smooth matching between two distinct theories required

In the ABKM set:

✓ PDF fit and NNLO DGLAP evolution performed in the $n_f = 3$ fixed-flavour scheme

✓ PDF sets in $n_f = 4$ or $n_f = 5$ flavour-schemes derived through NNLO evolution and NNLO boundary conditions at the scales m_c, m_b

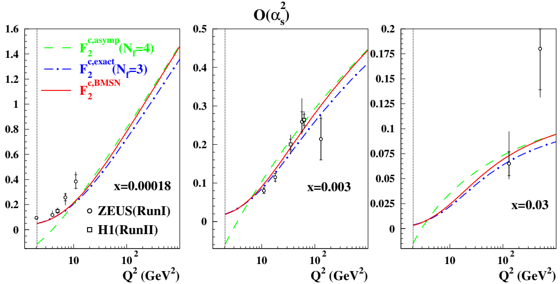
✓ Strong coupling constant α_S fitted at $n_f = 3$ flavours and evolved to

$$\alpha_S^{\overline{\text{MS}}}(n_f = 5, M_z) = 0.1135 \pm 0.0014$$

Accuracy $\approx 1.5\%$

Data considered in the fit

- ✓ Inclusive neutral current DIS world data at HERA collider and fixed-target experiments
  - $F_2^{c,BMSN}(4,x,Q^2) = F_2^{c,exact}(3,x,Q^2) + F_2^{c,asymp}(4,x,Q^2) - F_2^{c,asymp}(3,x,Q^2)$ considered in analysis, with corrections up to $\mathcal{O}(\alpha_S^2)$ included:

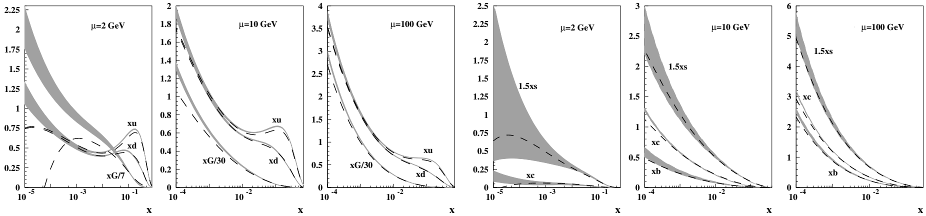


  - For F_2^b and F_L only $n_f = 3$ fixed-flavour scheme considered.
- ✓ Neutrino-nucleon DIS di-muon data CCFR/NuTeV
  - Analysis in $n_f = 3$ fixed-flavour scheme, including NLO QCD corrections
- ✓ Fixed target Drell-Yan data
  - Analysis in $n_f = 5$ fixed-flavour scheme, obtained with NNLO matching conditions
  - NNLO QCD corrections of partonic x-sec included
- ✓ No Tevatron data included

✓ PDF initial parametrization at $Q_0^2 = 9\ \mathrm{GeV}^2$ in terms of 22 parameters

$$
\begin{aligned}
x\,q_V(x,Q_0^2) &= \frac{2\delta_{qu}+\delta_{qd}}{N_q^V} x^{a_q}(1-x)^{b_q} x^{P_{q,V}(x)}, \quad P_{q,V} = \gamma_{1,q}x + \gamma_{2,q}x^2, \quad q = u,d\,, \\
x\,G(x,Q_0^2) &= A_G x^{a_G}(1-x)^{b_G} x^{P_G(x)}, \quad P_G = \gamma_{1,G}x\,, \\
x\,u_S(x,Q_0^2) &= x\,\bar{u}_S(x,Q_0^2) = A_u x^{a_{us}}(1-x)^{b_{us}} x^{P_{u,s}(x)}, \quad P_{u,s} = \gamma_{1,us}x\,, \\
x\,\Delta(x,Q_0^2) &= x\,d_S(x,Q_0^2) - x\,u_S(x,Q_0^2) = A_\Delta x^{a_\Delta}(1-x)^{b_\Delta} x^{P_\Delta(x)}, \quad P_\Delta = \gamma_{1,\Delta}x\,, \\
x\,s(x,Q_0^2) &= x\,\bar{s}(x,Q_0^2) = A_s x^{a_s}(1-x)^{b_s}
\end{aligned}
$$

✓ $\alpha_S(n_f = 3, 3\ \mathrm{GeV})$, $m_c(\pm 0.1)$ and $m_b(\pm 0.5)$ are 3 additional fit parameters



✓ $n_f = 4\ (\mu = 2\mathrm{GeV})$ and $n_f = 5\ (\mu = 10, 100\mathrm{GeV})$ results, with 1σ symmetric uncertainties, compared to MSTW08 (dashed)

SM STANDARD CANDLES: W, Z PRODUCTION

- NNLO corrections reduce theory uncertainties to a few %, enabling their use to monitor collider luminosity

- For a pp collider $W^+(\approx u\bar{d}), W^-(\approx \bar{u}d), Z(\approx u\bar{u}, d\bar{d})$ sensible at valence/sea PDF's, combined with non-resonant DY data allow flavour separation

- PDF benchmarking exercise using a common x-sec integrator:
  - ✓ All processes evaluated at NLO with MCFM version 5.7
  - ✓ Massless calculation in the $n_f = 5$ flavour $\overline{\mathrm{MS}}$ scheme
  - ✓ pp collisions at $\sqrt{S} = 7$ TeV LHC
  - ✓ Results for best fit prediction and $\pm 68\%$ C.L. (or $\pm 90\%$ C.L.) when provided
  - ✓ Observables under inspection:
    - ⋆ W^+, W^-, Z total x-sec
    - ⋆ W^+, W^-, Z rapidity distribution in the range $|y| \leq 4$
    - ⋆ $A_W(y) = \frac{\frac{d\sigma^{\mathrm{W}^+}}{dy} - \frac{d\sigma^{\mathrm{W}^-}}{dy}}{\frac{d\sigma^{\mathrm{W}^+}}{dy} + \frac{d\sigma^{\mathrm{W}^-}}{dy}}$ production asymmetry

EXERCISE: W, Z PRODUCTION

- ✓ Calculations performed in zero-width approximation
- ✓ Z/γ interference included, $M^2_{\ell^+\ell^-} > 1\mathrm{GeV}^2$ to avoid photon pole
- ✓ EW parameter taken from PDG 2009:
  - Masses $M_Z = 91.188$ GeV, $\quad M_W = 80.398$ GeV
  - Total widths $\Gamma_Z = 2.4952$ GeV, $\quad \Gamma_W = 2.1054$ GeV
  - Branching ratios $Br(Z \to \ell^+\ell^-) = 0.03366, \quad Br(W \to \ell\nu_\ell) = 0.1080$
  - $G_F = 0.11663710^{-4}$ GeV^{-2}
  - CKM matrix elements, unitary assumed

$$
\begin{array}{lll}
V_{ud} = 0.97419, & V_{us} = 0.22570, & V_{ub} = 0.00359 \\
V_{cd} = 0.22560, & V_{cs} = 0.97334, & V_{cb} = 0.04150
\end{array}
$$

PDF BENCHMARKING

PDF sets considered in comparison:

✓ ABKM09 $n_f = 5$ flavour sets NNLO — `abkm09_5_nnlo.LHgrid`

best prediction + 25 error sets, Symmetric errors at 68% C.L.

✓ MSTW08 $n_f = 5$ flavours NNLO — `MSTW2008nnlo68cl.LHgrid`, `MSTW2008nnlo90cl.LHgrid`

best prediction + 40 error sets, Asymmetric errors at 68% and 90% C.L.

✓ CTEQ6.6 $n_f = 5$ flavours NLO — `cteq66.LHgrid`

best prediction + 44 error sets, Asymmetric errors at 90% C.L.

✓ HERAPDF 1.0 $n_f = 5$ flavours NLO — `HERAPDF10_EIG.LHgrid`

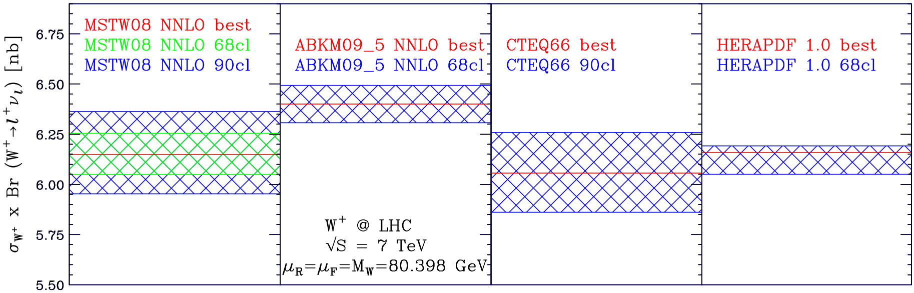
best prediction + 20 error sets, Asymmetric errors at 68% C.L.

$$\Delta X^{\pm}_{max} = \sqrt{\sum_{i=1}^{N} (X_i - X_0)^2}$$

$$\Delta X^{+}_{max} = \sqrt{\sum_{i=1}^{N} [max(X_i^+ - X_0, X_i^- - X_0, 0)]^2}$$

$$\Delta X^{-}_{max} = \sqrt{\sum_{i=1}^{N} [max(X_0 - X_i^+, X_0 - X_i^-, 0)]^2}$$

RESULTS: W^+ TOTAL



- ✓ Maximum $\approx 4\%$ shift in central value
- ✓ Major discrepancy in ABKM set
- ✓ Fixed renormalization μ_R and factorization μ_F scales
- ✓ PDF uncertainties comparable in size (at the same C.L.)
- ✓ asymmetric uncertainties hardly visible (with the exception of HERAPDF 1.0, but only asymmetric experimental errors considered, no model/param. variations)

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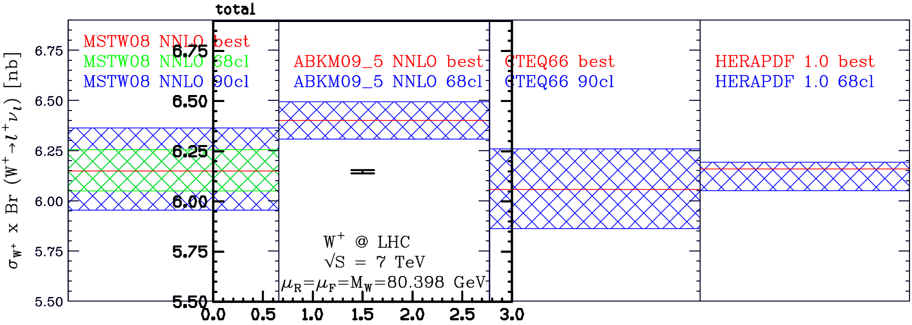

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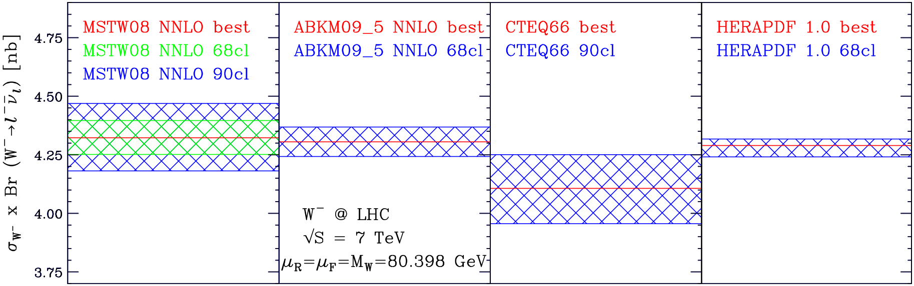
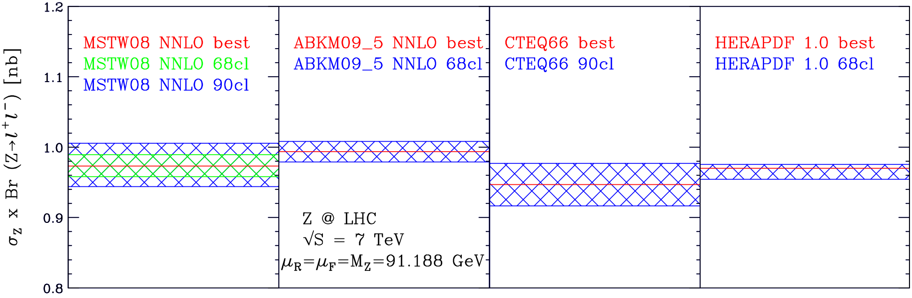
- ✓ Integration errors negligible (same scales on the plots)

RESULTS: W^- TOTAL



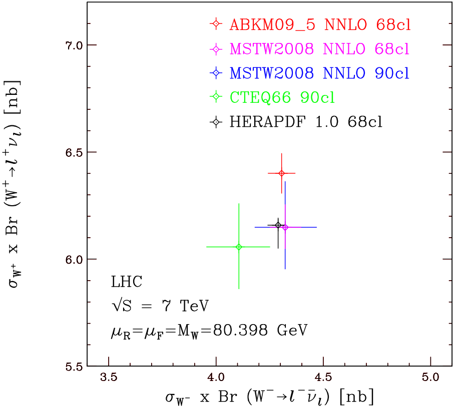
- ✓ Maximum $\approx 5\%$ shift in central value
- ✓ Major discrepancy in CTEQ66 set
- ✓ Fixed renormalization μ_R and factorization μ_F scales
- ✓ PDF uncertainties comparable in size (at the same C.L.)
- ✓ Asymmetric uncertainties hardly visible (with the exception of HERAPDF 1.0, but only asymmetric experimental errors included, no model/param. variations)

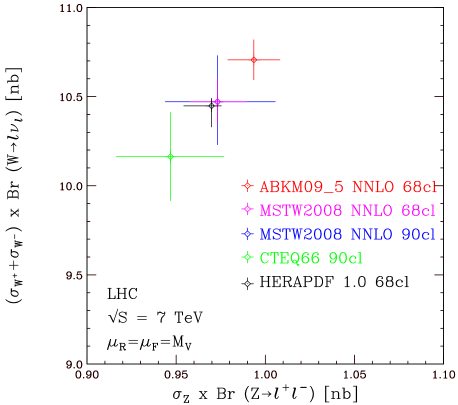
Results: Z total



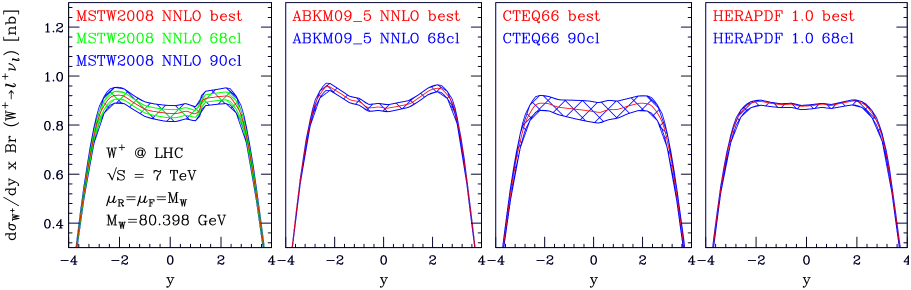
- ✓ Maximum $\approx 5\%$ shift in central value
- ✓ PDF uncertainties comparable in size (at the same C.L)
- ✓ Asymmetric uncertainties hardly visible (with the exception of HERAPDF 1.0, but only asymmetric experimental errors included, no model/param. variations)

RESULTS: W, Z TOTAL



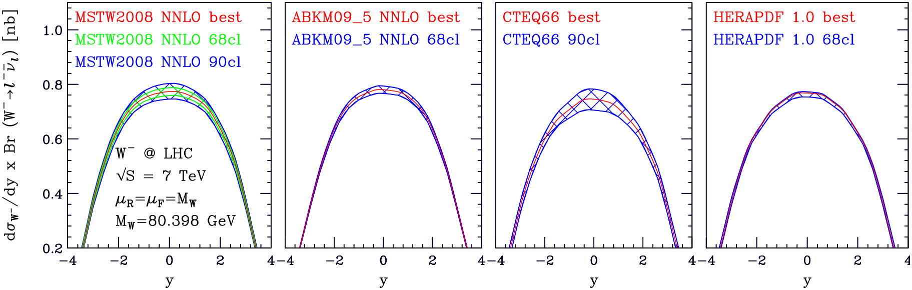


RESULTS: W^+ RAPIDITY



- ✓ Results inside PDF uncertainties
- ✓ Shape seems strongly affected by higher-order contributions
- ✓ Asymmetric uncertainties hardly visible (with the exception of HERAPDF 1.0, but only asymmetric experimental errors included, no model/param. variations)
- ✓ Integration errors negligible

Results: W^- rapidity



- ✓ Results inside PDF uncertainties
- ✓ Shape not affected by higher-order evolution
- ✓ Asymmetric uncertainties hardly visible (with the exception of HERAPDF 1.0, but only asymmetric experimental errors included, no model/param. variations)
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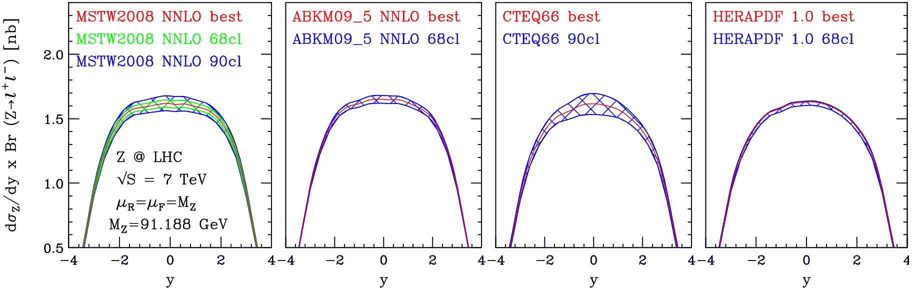
RESULTS: Z RAPIDITY



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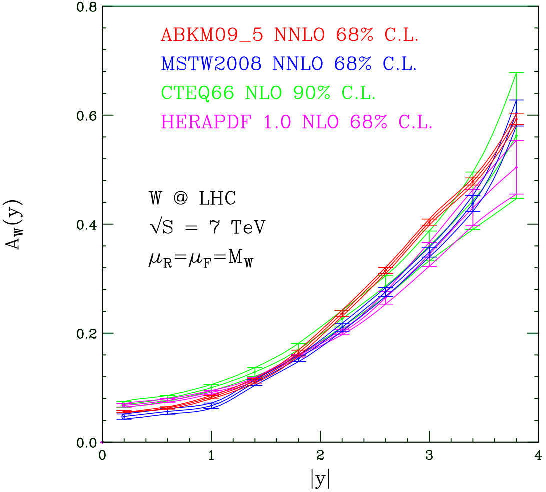
RESULTS: A_W ASYMMETRY

$$A_W(y) = \frac{\frac{d\sigma^{W^+}}{dy} - \frac{d\sigma^{W^-}}{dy}}{\frac{d\sigma^{W^+}}{dy} + \frac{d\sigma^{W^-}}{dy}}$$

- ✓ $A_W(y) = A_W(-y)$ for CP in pp collisions
- ✓ Symmetric errors obtained sampling bin-by-bin over different members

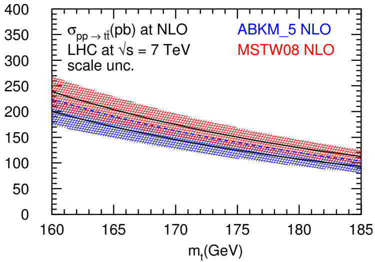
$$\Delta A_W^{\pm} = \sqrt{\sum_{i=1}^{N}(A_W^i - A_W^0)^2}$$

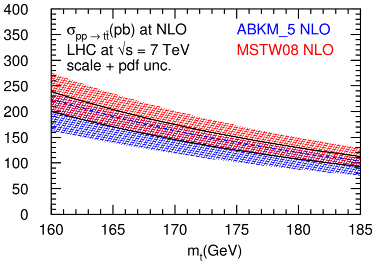
- ✓ Asymmetric errors symmetrized $N \to N/2$, $A^i \to (A^i + A^{i+1})/2$
- ✓ Sensitive to contribution from $c-$quark PDF



$t\bar{t}$ PRODUCTION

- ✓ Mainly due to $q\bar{q} \to t\bar{t}$ subprocess at the TeVatron, $gg \to t\bar{t}$ at LHC
- ✓ NLO and approx. NNLO (ArXiv:0906.5273) results with scale unc. $\mu \to 2\mu, \mu/2$ and combined pdf and scale unc.





- ✓ Difference between the ABKM/MSTW sets at NNLO well outside the PDF uncertainty
- ✓ This issue is due to sizeable difference of the gluon PDFs for low x values and can only be settled with first LHC data.

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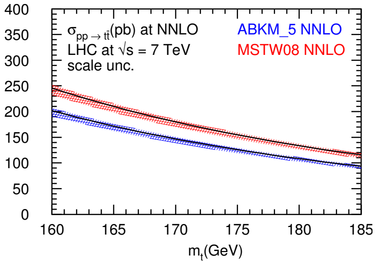

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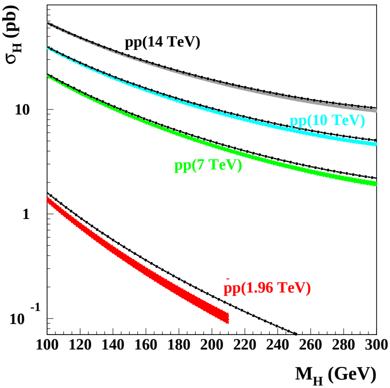
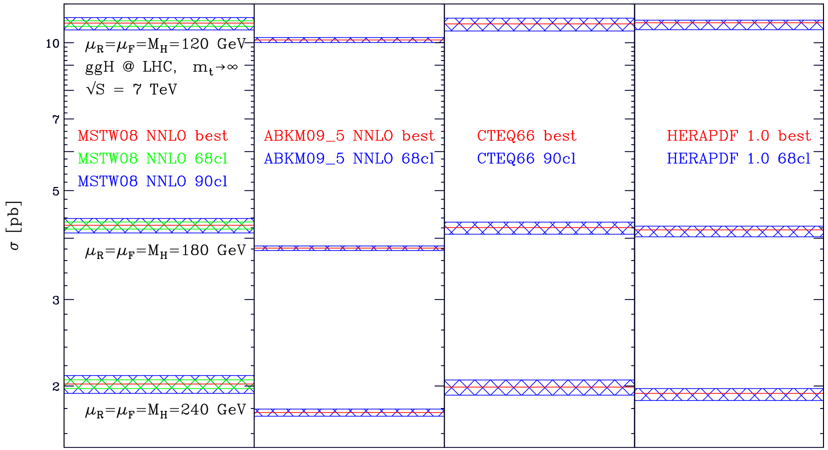
- Only $gg \to H$ gluon fusion considered
- Results in ABKM 0902.2766
- obtained with V. Ravindran, J. Smith and W.L van Neerven, Nucl.Phys. B 665 (2003) 325
- NNLO calculation, $m_t \to \infty$ approx.
- MSTW2008 / ABKM09 comparison, with ABKM09 pdf uncertainties
- Sizeable differences over a wide range for Higgs boson mass



HIGGS BOSON PRODUCTION

✓ MCFM 5.7 NLO comparison, $m_t \to \infty$, zero Higgs width approx.



✓ ABKM differs $\approx 10 - 15\%$, well outside PDF uncertainties, ascribed again to different g pdf's

CONCLUSIONS

- ✓ Fair agreement (even if at the border of uncertainty bands in some cases) between different PDF sets for SM standard candles W, Z in both total x-sec and rapidity distributions.
- ✓ Discrepancies found in W asimmetry under investigation
- ✓ ABKM set shows quite large differences for gluon driven processes: $gg \to H$, $gg \to t\bar{t}$
- ✓ First LHC data may resolve the issue, giving more constraints on gluon PDF
- ✓ Better to obtain it also from analisys of independent processes $W + j, Z + j$

Thank you for your attention