arXiv:1203.1290

Strange Quark PDF Uncertainty and its Implications for W/Z Production at the LHC

A. Kusina[1], T. Stavreva[2], S. Berge[3], F. I. Olness[1], I. Schienbein[2], K. Kovařík[4], T. Ježo[2], J. Y. Yu[1,2], K. Park[1]

[1]Southern Methodist University, Dallas, TX 75275, USA

[2]Laboratoire de Physique Subatomique et de Cosmologie, Université Joseph Fourier/CNRS-IN2P3/INPG, 53 Avenue des Martyrs, 38026 Grenoble, France

[3]Institute for Physics (WA THEP), Johannes Gutenberg-Universität, D-55099 Mainz, Germany

[4]Institute for Theoretical Physics, Karlsruhe Institute of Technology, Karlsruhe, D-76128, Germany

Light Cone 2012, 8-13 July 2012, Krakow

Motivations

- One of the most important source of uncertainties in the LHC are parton distribution functions (PDFs).
- Especially s-quark and heavy flavor PDFs are poorly constrained.
- PDFs uncertainties affect nearly all observables in particular benchmark processes used for calibration of Higgs boson and "new physics" searches.
- Here we concentrate on s-quark PDF and its impact on W/Z boson production

Extracting s-quark PDF

Predominant information on strange used to come from difference of NC and CC DIS F_2 structure function (at LO neglecting charm)

$$\Delta F_2 = \frac{5}{18} F_2^{CC} - F_2^{NC} \sim \frac{x}{6}[s(x) + \bar{s}(x)]$$

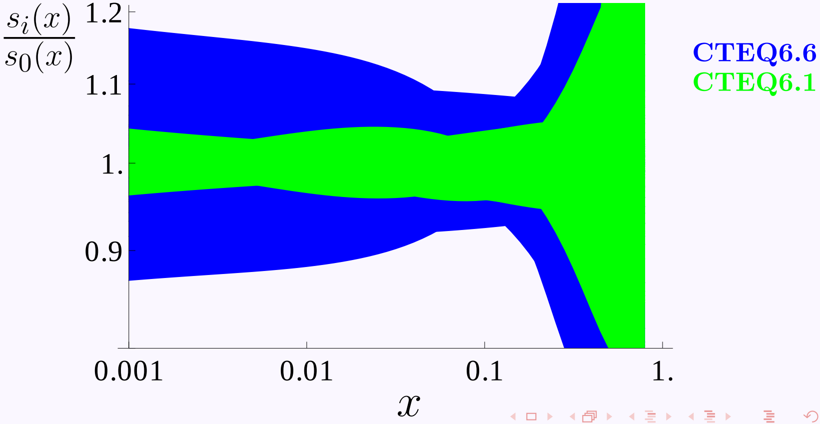
s is small compared to u and d PDFs $\rightarrow$ large uncertainties $\rightarrow$ it was assumed (CTEQ6.1, CTEQ6.5)

$$s(x) = \bar{s}(x) \sim \kappa \, \frac{\bar{u}(x) + \bar{d}(x)}{2}, \qquad \kappa = \frac{1}{2}$$

$\rightarrow$ underestimation of s PDF uncertainty, as $\bar{u}$, $\bar{d}$ are much better constrained.

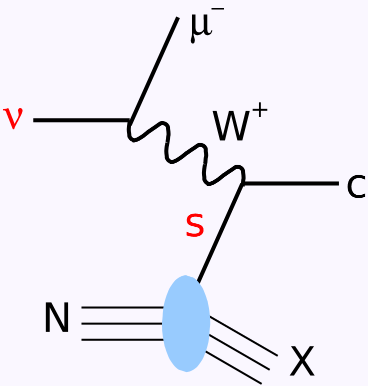
Extracting s-quark PDF

Starting with CTEQ6.6 (2008, `arXiv:0802.0007`) neutrino-nucleon dimuon data was included in the global fits → more direct constrain of strange quark → allow to fit s PDF independently of $\bar{u}$, $\bar{d}$ sea.



Constraints of s-PDF – CCFR and NuTeV

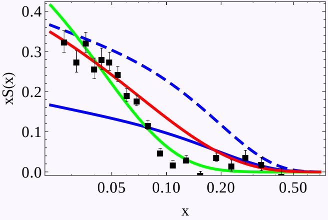
Neutrino induced dimuon production ($\nu N \to \mu^+\mu^- X$) proceeds primarily through the Cabibbo favored $s \to c$ or $\bar{s} \to \bar{c}$ subprocess.



direct information on s and $\bar{s}$ (contrary to ΔF_2)

Other possible constraints of s-PDF

- **HERMES:** strange PDF via charged kaon production in positron-deuteron DIS



- $S(x) = s(x) + \bar{s}(x)$
- $S(x)$ suppressed for $x \gtrsim 0.1$
- Hermes data is not included dynamically in global analyses

- **CHORUS:** measured neutrino structure functions F_2, xF_3, R in collisions of sign selected neutrinos and anti-neutrinos with a lead target $\rightarrow$ results consistent with NuTeV
- **NOMAD:** high statistic neutrino-induced charm dimuon production – direct probe of the s-quark PDF $\rightarrow$ data analysis is continuing

Other possible constraints of s-PDF

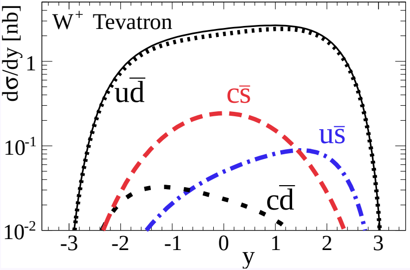
- **MINERνA:** neutrino DIS on a variety of targets (plastic, helium, carbon, water, iron, and lead) – 2010 finished construction and started data collection $\rightarrow$ allow to understand better nuclear corrections $\rightarrow$ lower uncertainties
- **CDF & D0:** measured Wc final states in $p\bar{p}$ collisions (at LO 90% produced via $sg \rightarrow W^- + c$)
  - direct probe of s PDF
  - no nuclear corrections
  - different kinematic region then fixed-target neutrino experiments

  Current data ($1fb^{-1}$) in agreement with today PDF analyses.
- **ATLAS** measured rapidity distributions for $Z \rightarrow l^+l^-$, $W^+ \rightarrow l^+\nu_l$ and $W^- \rightarrow l^-\bar{\nu}_l$; **CMS** rapidity distributions for $Z \rightarrow l^+l^-$, and $W + c$ production sensitive to s; **LHCb** W charge asymmetry ($\sim 35pb^{-1}$ 2010 data)

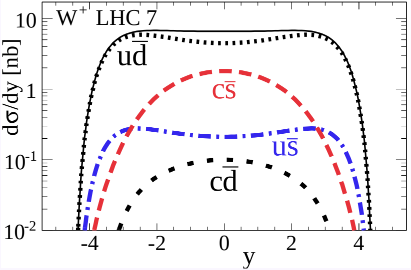
Impact of s-quark on W/Z production at LHC

W^+ production at LO ($d\sigma/dy$)

Tevatron



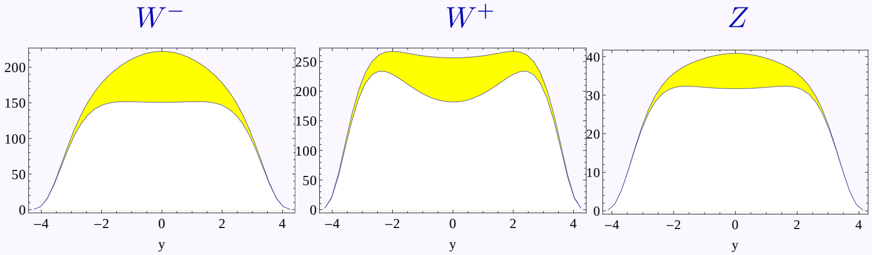
LHC



- s initiated processes at Tevatron were negligible
- at LHC they contribute substantially

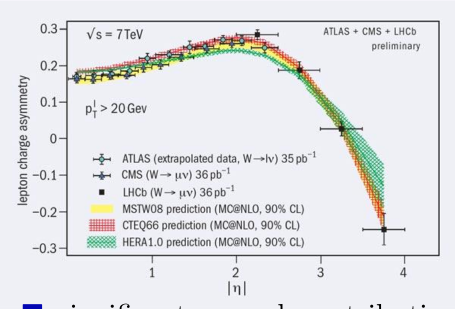
s contribution to W/Z cross-section at LHC at NNLO with VRAP ($d\sigma^2/dM/dy$ at $M = m_{W/Z}$)

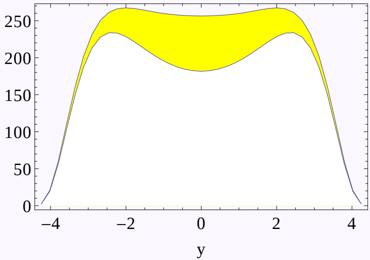
hep-ph/0312266



- significant s-quark contribution $\rightarrow$ need to constrain s-PDF to have accurate predictions for LHC
- single peak (s) vs. double peak (u, d) distributions
  $\rightarrow$ shape measurements of W/Z rapidity distributions
  $\rightarrow$ information about relative s and u, d contributions

s contribution to W/Z cross-section at LHC at NNLO with VRAP ($d\sigma^2/dM/dy$ at $M = m_{W/Z}$)

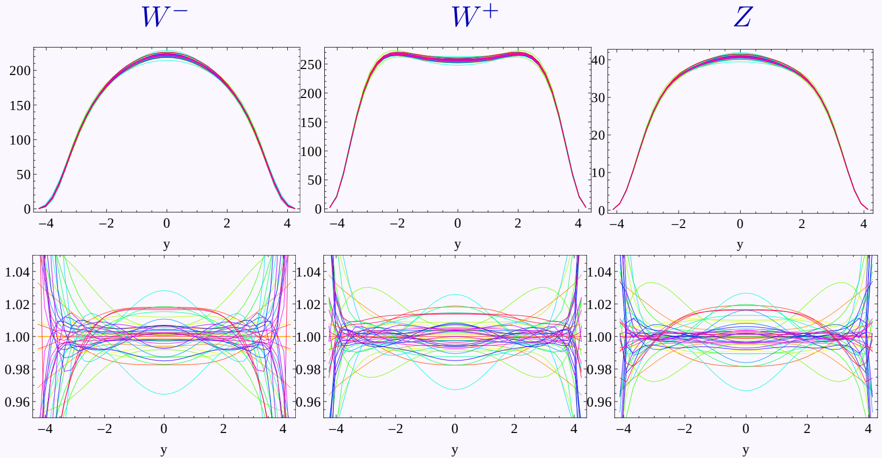




- significant s-quark contribution → need to constrain s-PDF to have accurate predictions for LHC
- single peak (s) vs. double peak (u, d) distributions
  → shape measurements of W/Z rapidity distributions
  → information about relative s and u, d contributions

Uncertainty due to PDFs

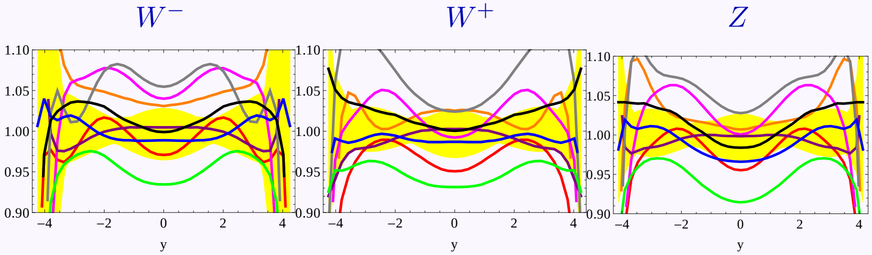
$d\sigma^2/dM/dy$ at LHC for CTEQ6.6 error PDFs ($M = m_{W/Z}$)



$[d\sigma(W/Z)]/[d\sigma(W/Z)]_0$

- uncertainty $\pm 3\%$

$d\sigma^2/dM/dy$ at LHC for different PDFs vs. CTEQ6.6 error set ($M = m_{W/Z}$)

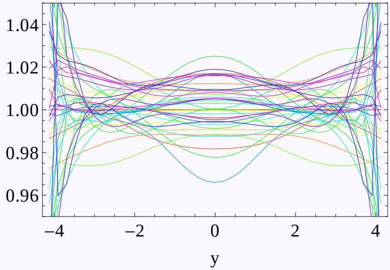


- CTEQ6.6 (yellow band) $\sim \pm 3\%$ uncertainity
- spread of different PDFs $\sim \pm 8\%$
  $\rightarrow$ error sets don't account all uncertainties
- should use errors in quadrature

CTEQ6.6
CT10
CTEQ6.5
CTEQ6.1
HERAPDF10
MSTW2008
NNPDF
ABKM09
MRST2004

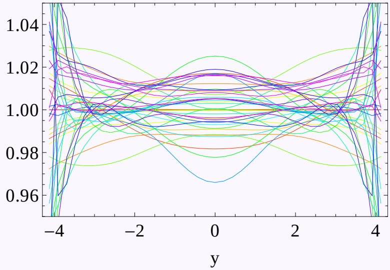
Correlations in W and Z proccesses

Correlations of the W/Z rapidity distributions for CTEQ6.5 (hep-ph/0611254)

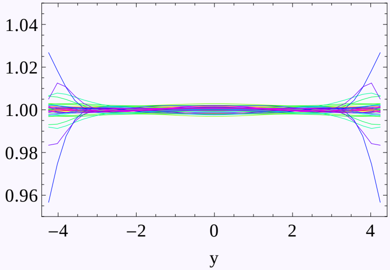


$[d\sigma(W^+)]/[d\sigma(W^+)]_0$

Correlations of the W/Z rapidity distributions for CTEQ6.5 (hep-ph/0611254)



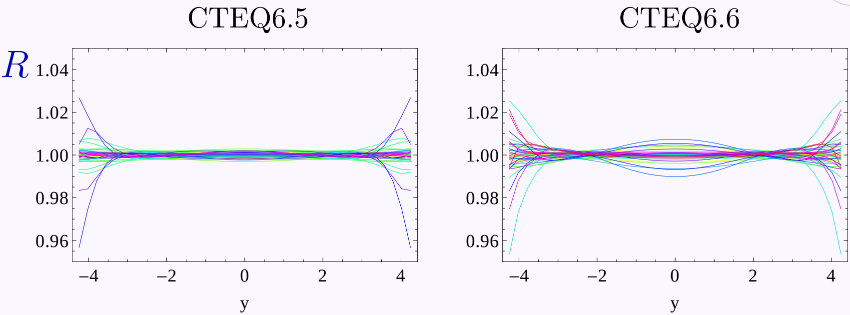
$$[d\sigma(W^+)]/[d\sigma(W^+)]_0$$



$$R = \left[\frac{d\sigma(W^+ + W^-)}{d\sigma(Z)}\right] / \left[\frac{d\sigma(W^+ + W^-)}{d\sigma(Z)}\right]_0$$

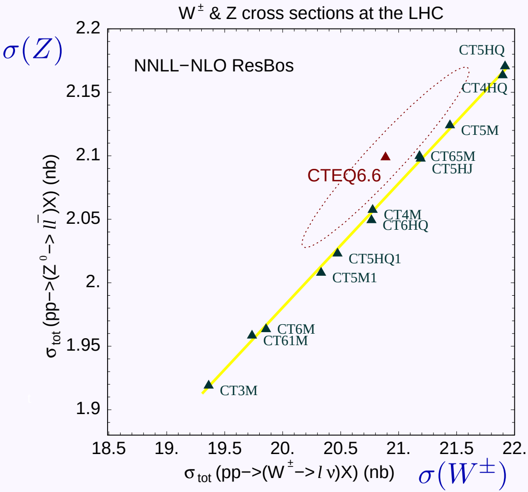
- errors for double ratios are order of magnitude smaller then for single ratios! $\rightarrow$ W and Z processes are highly correlated
- it is used for precision measurements (W mass) to calibrate W with help of Z boson
  - it works to the extent that W and Z production is correlated

Correlations of the W/Z rapidity distributions



- In case of CTEQ6.5 $W^{\pm}$ and Z processes are strongly correlated.
- This effect is much smaller for CTEQ6.6 PDFs.
- It is driven by independent treatment of s-quark PDF!
  - CTEQ6.5: $s = \bar{s} = \frac{1}{2}\frac{\bar{u}+\bar{d}}{2}$
  - CTEQ6.6: s independent from $\bar{u}$, $\bar{d}$

Correlations of the W/Z rapidity distributions



Nadolsky et al.
arXiv:0802.0007

- Once again freedom of the strange quark PDF is reflected in the freedom of $W^{\pm}$ and Z cross-sections.

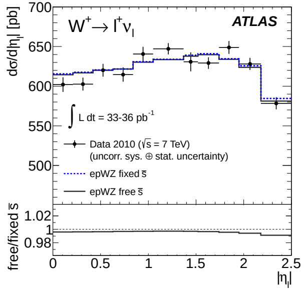
Summary

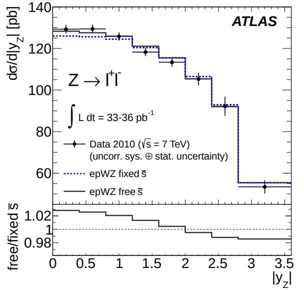
- s quark is poorly constrained, particularly in the low x region sensitive to W/Z production at the LHC
- new/updated data can help reducing s PDF uncertainty
  - NOMAD
  - MINERνA
  - CDF, D0
- W/Z measurements at the LHC can be an input for global PDF analyses
  - shape measurement of rapidity distribution – relative measure of strange and valence PDFs
- doing precision measurements at LHC one needs to remember that proper s-PDF treatment decorelates W and Z processes.

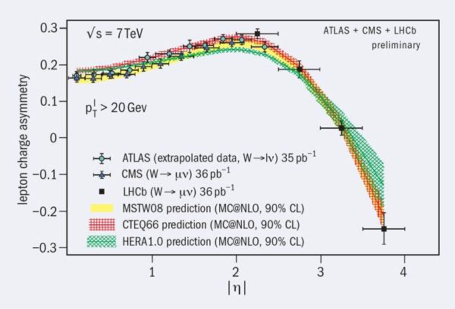
BACKUP SLIDES

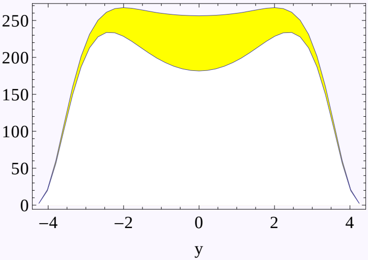
W/Z measurements at LHC

arXiv:1203.4051









ATLAS strange measurement

ATLAS has used W/Z production to infer constraints on the strange quark distribution, they measured (arXiv:1203.4051)

$$r_s = 0.5(s + \bar{s})/\bar{d} = 1.00^{+0.25}_{-0.28}$$

at $Q^2 = 1.9$ GeV^2 and $x = 0.023$

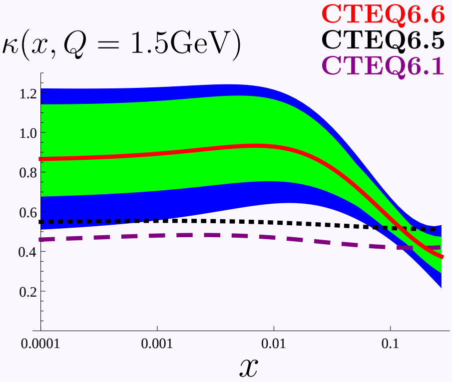
CMS Wc final states measurement

CMS maesured ratios of cross-sections using $36pb^{-1}$ of data (CMS-PAS-EWK-11-013)

$$R_c^{\pm} = \frac{\sigma(W^+\bar{c})}{\sigma(W^-c)} = 0.92 \pm 0.19(stat.) \pm 0.04(sys.)$$

see also: Stirling, Vryonidou, arXiv:1203.6781

Strange Quark Uncertainty



$$\kappa(x,Q) = \frac{s(x,Q)}{[\bar{u}(x,Q) + \bar{d}(x,Q)]/2}$$

Exact SU(3): $\bar{u} = \bar{d} = \bar{s}$ and $\kappa(x,Q) \sim 1$

$$\Delta X = \frac{1}{2}\sqrt{\sum_{i=1}^{N_p} \left[X(S_i^+) - X(S_i^-)\right]^2}$$