Theoretical test of CDF dijet anomaly

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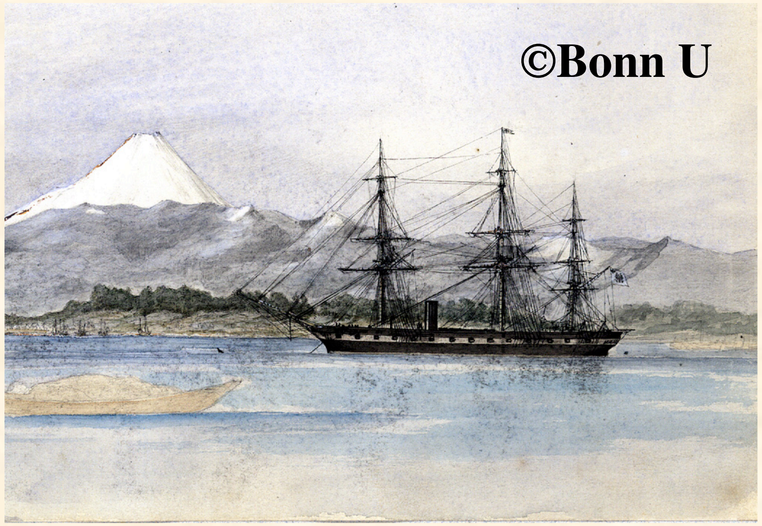
Modern Trends in Quantum Chromodynamics

October 3-5, 2011

DESY, Zeuthen, Germany

October 5, 2011

150 year of friendship between Germany and Japan



Prussia delegation to Japan in 1860

Agreement in Jan. 24, 1861

Meiji restoration (1867)
Many new systems are learned
from Germany
in military, laws, medical sciences, …

日独交流150周年
Jahre Freundschaft
Deutschland – Japan

// 日独交流150周年について // Über 150 Jahre Deutschland – Japan

今月のテーマ
Thema des Monats

日独交流150周年について
Über 150 Jahre Deutschland – Japan

名誉総裁挨拶
Grußwort der Schirmherrn

公式行事認定申請方法
Teilnahme an 150 Jahre D–J

日独関係
Deutsch-Japanische Beziehungen

ドイツで開催される行事
Veranstaltungen in Deutschland

日本で開催される行事
Veranstaltungen in Japan

コンタクト
Kontakt

Japan und das damalige Preußen unterzeichneten am 24. Januar 1861 in Edo (jetztigem Tokyo) einen Freundschafts- und Handelsvertrag. Damit nahm der offizielle Austausch zwischen Japan und Deutschland seinen Anfang. Einige Jahre später wurde ein ähnlicher Vertrag mit den Mitgliedsstaaten des Norddeutschen Bundes abgeschlossen, der schließlich zu Beziehungen mit ganz Deutschland führte.

2011 wird sich der Beginn des Austauschs zwischen unseren beiden Ländern zum 150. Mal jähren. Auch der damalige Premierminister Aso und Bundeskanzlerin Merkel vereinbarten bei Ihrer Zusammenkunft im Mai 2009 in Berlin, 2011 im Rahmen eines Freundschaftsjahres „150 Jahre Japan-Deutschland" dafür zu nutzen, unsere bilateralen Beziehungen weiter auszubauen.

Neben solchen Events, die einen Rückblick auf die bisherigen bilateralen Beziehungen bieten, kommen unter Berücksichtigung des Aspekts der Gestaltung zukunftsgerichteter japanisch-deutscher Beziehungen Veranstaltungen u.a. in den Bereichen Politik, Wirtschaft, Bildung, Wissenschaft und Technologie, Kultur, Gesellschaft und Sport in Frage.

Es steht zu hoffen, dass durch diese Veranstaltungen, die in Japan oder in Deutschland stattfinden, das gegenseitige Verständnis und die Beziehungen zwischen den beiden Ländern weiter vertieft werden.

日本とドイツの交流は、１８６１年１月２４日（万延元年１２月１４日）に江戸で日本と当時のプロイセンが修好通商条約を調印して、始まりました。その後、ドイツ北部連邦諸国との間にも同様の条約が結ばれ、ドイツとの間の全面的な関係に発展していきました。

２０１１年は日独交流が始まって、１５０周年にあたります。２００９年５月に麻生総理大臣（当時）とメルケル首相がベルリンで会談した際にも、この記念すべき年を「日独交流１５０周年」として、これまで幅広い分野において協力・交流が進められてきた両国関係を更に発展させていくために各種の記念事業を行うことで合意しました。

記念事業の対象分野としては、これまでの日独交流を振り返ると共に、未来に向けた日独関係の構築を目指す観点から、政治、経済、教育、科学技術、文化、社会、スポーツ等を含む幅広いものとしたいと思います。日本またはドイツで実施される各種事業をとおし、日本とドイツが相互理解を深め、両国の結びつきが更に深まることを期待しております。

Botschaft von Japan in Deutschland
在ドイツ日本国大使館

21.12.09

There are various activities to celebrate the friendship.

It is very nice to have this workshop on this happy occasion.

Recovering from earthquake

KEK theory: no damage

My office is almost the worst in our KEK theory center.

Activities are normal now in the theory center.

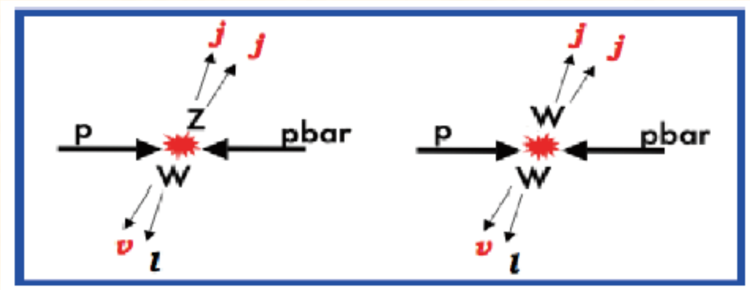
Contents

CDF anomaly of 2011: New discovery or ?

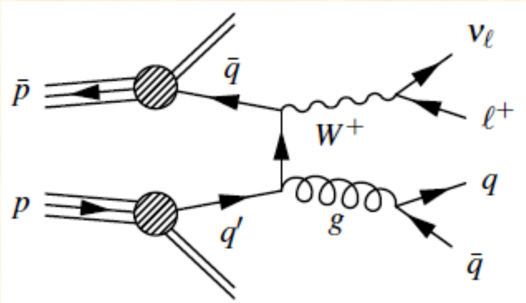
T. Aaltonen et al. (CDF),
Phys. Rev. Lett. 106 (2011) 171801,
[arXiv:1104.0699 (April 4, 2011)]

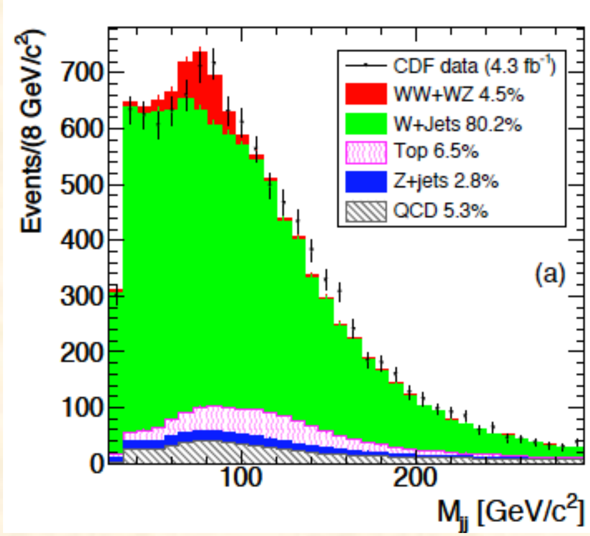
(V. Cavaliere
on April 6, 2011 at Fermilab)

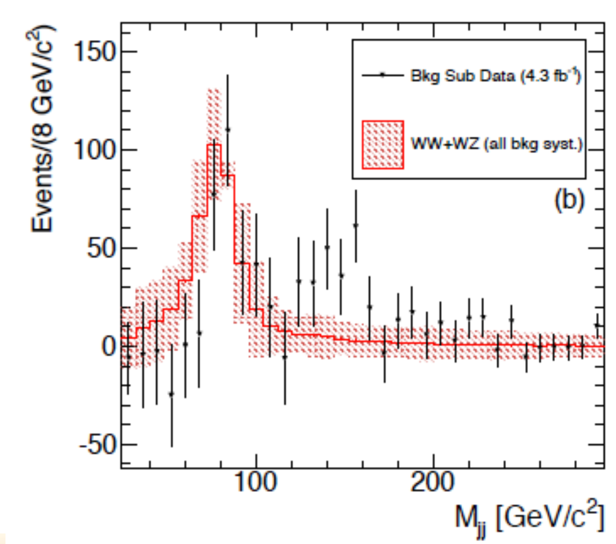
4.3 /fb



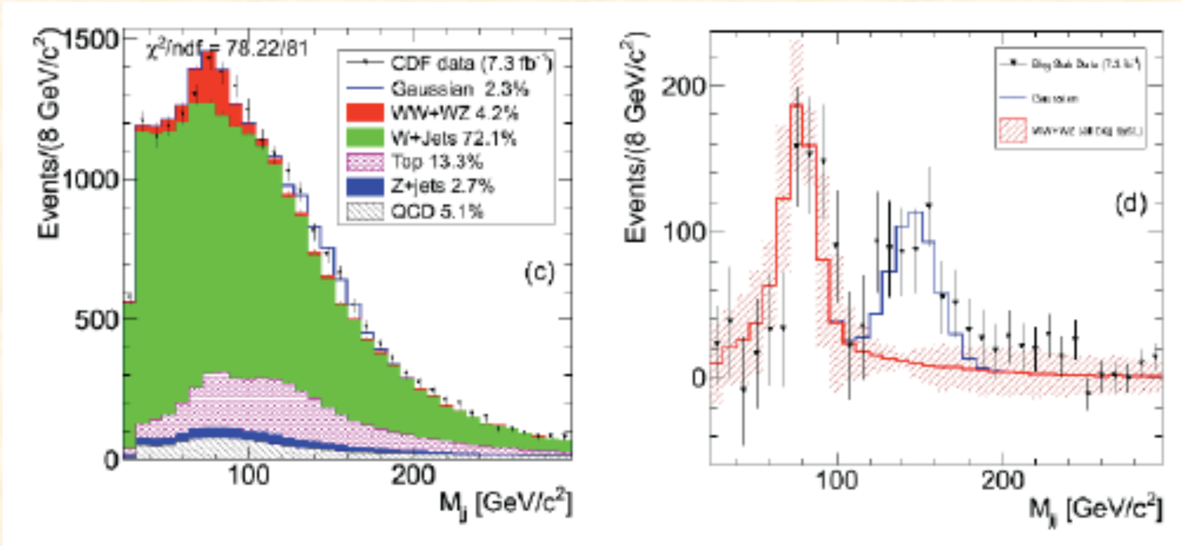
One of subprocesses







May, 2011
7.3 /fb



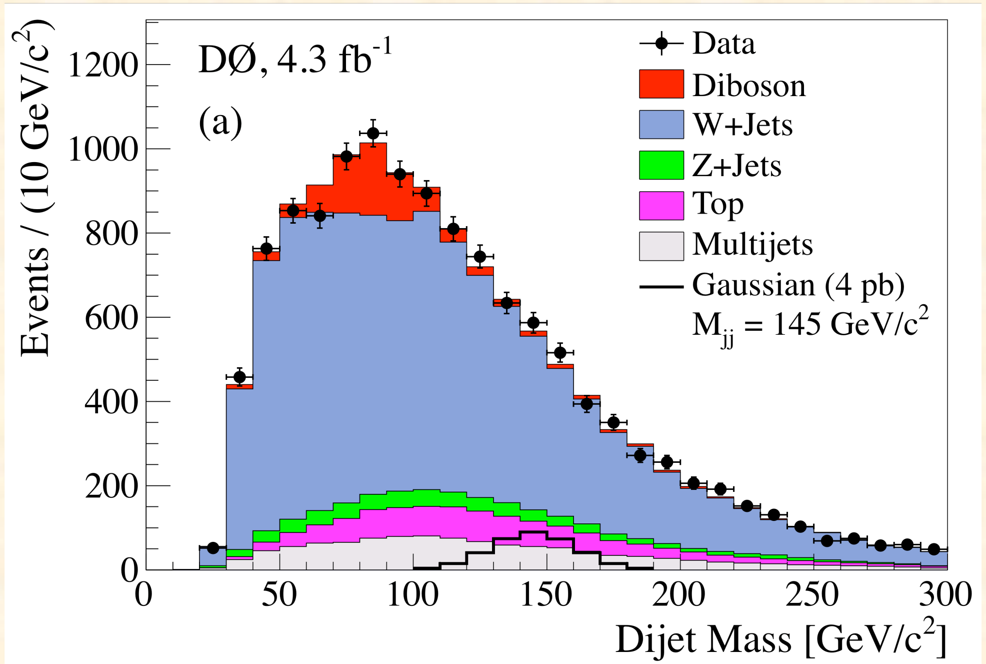
G. Punzi
23th Rencontres de Blois

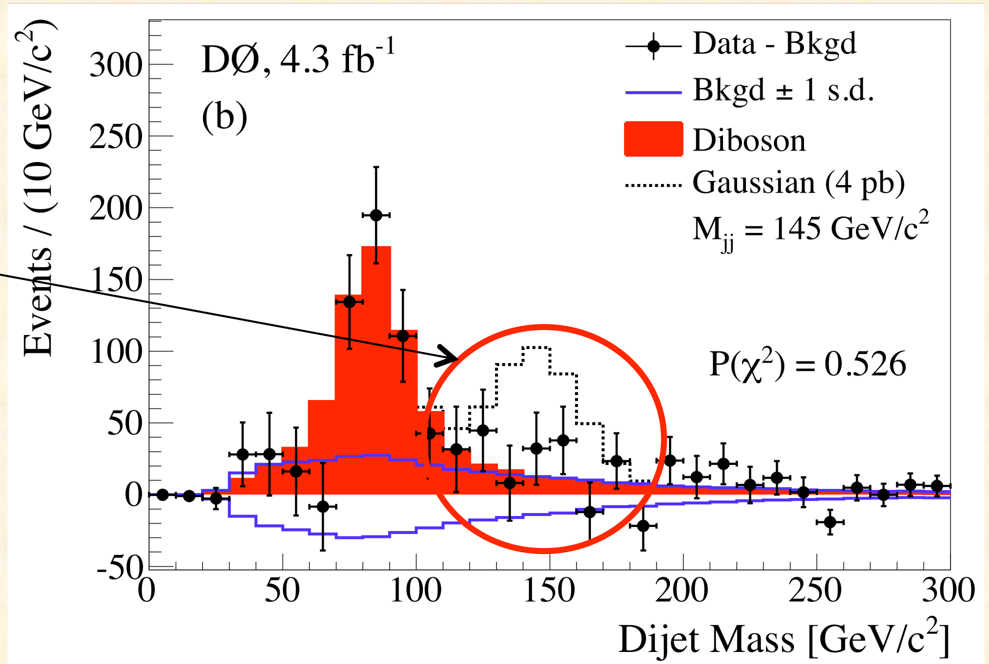
D0 collaboration

June 9, 2011

V. M. Abazov *et al.* (D0 collaboration), Phys. Rev. Lett. 107 (2011) 011804.

CDF-type peak is not observed!





Past experience on the old CDF anomaly in 1996

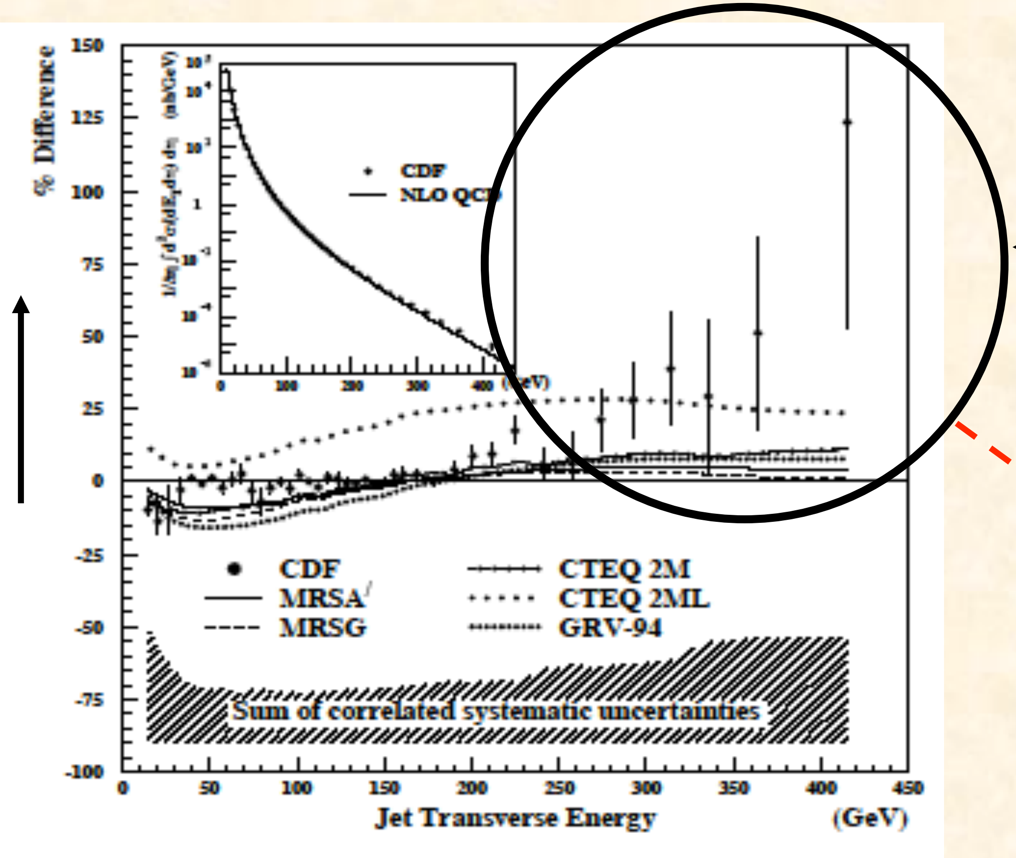
Comparison of theoretical calculations with CDF experimental data.

CDF experiment: PRL, 77 (1996) 438.

$$p+\bar{p}\rightarrow jet+X$$

$$\sqrt{s}=1.8\ \text{TeV},\quad E_T^{jet}=15-400\ \text{GeV}$$

Difference between theory and experiment



Jet transverse energy

Signature of new physics?

Could be explained by a modification of g(x).

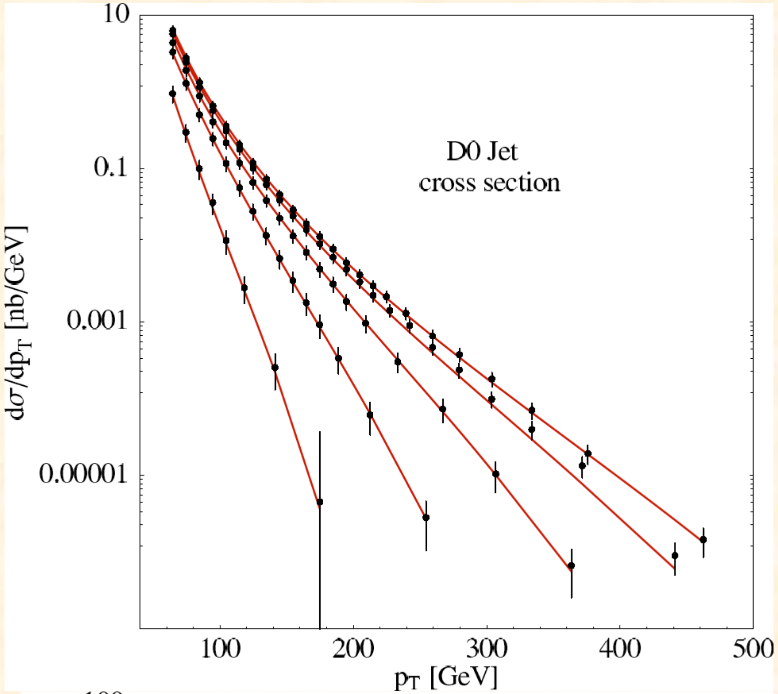
(importance of accurate PDFs)

JET cross sections in 2002

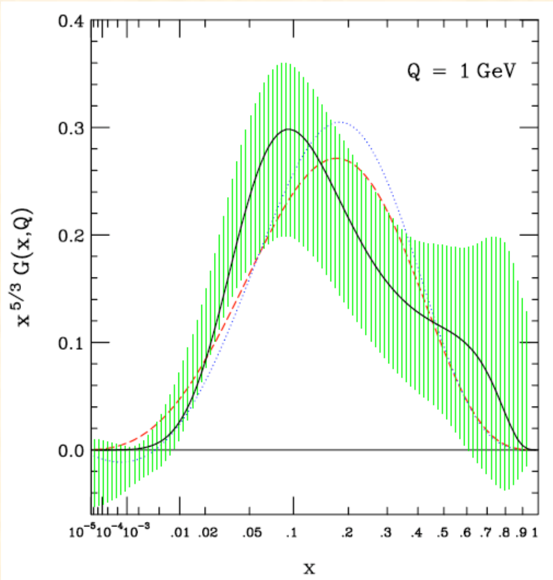
J. Pumplin *et al.* (CTEQ) , JHEP 07 (2002) 012.

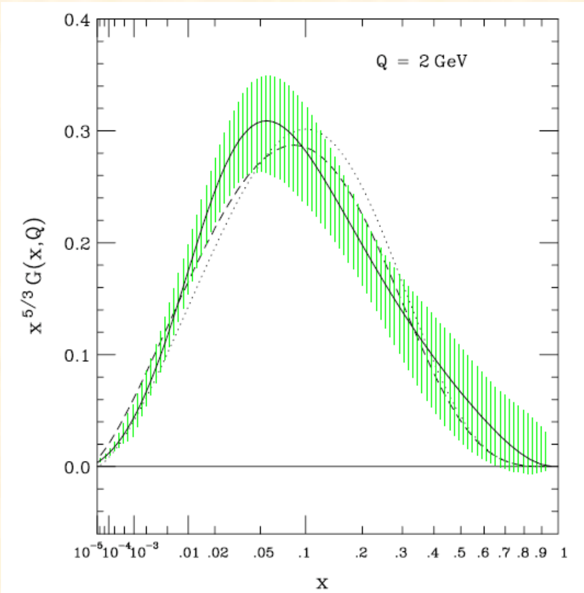
JET cross sections are "explained" by the CTEQ6 PDFs.

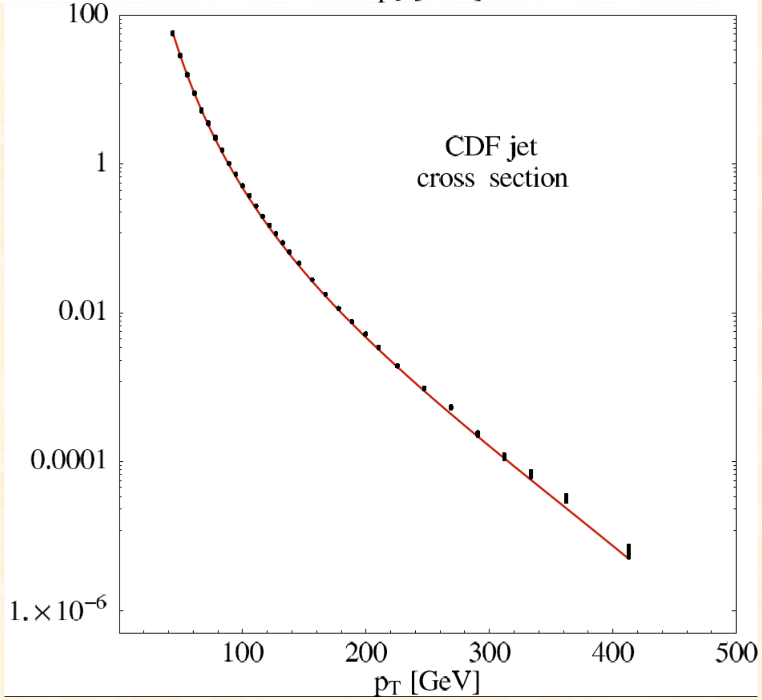
However, it is impossible to predict accurate jet cross sections at large p_T.



——— CTEQ6
- - - - CTEQ5
········ MRS2001

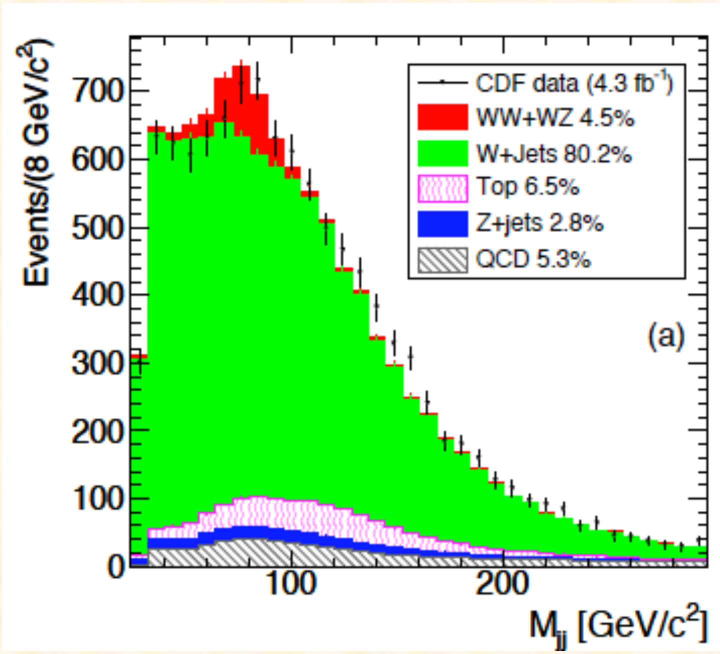


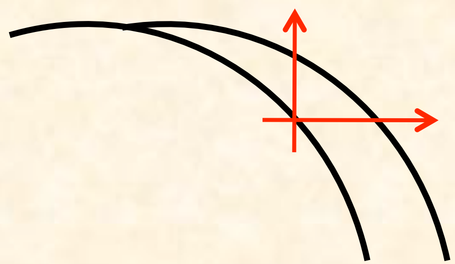




Motivation

Because the CDF finding is in the shoulder region of the cross section, a change of a PDF may explain the anomaly.





Recent works on unpolarized PDFs

ABKM (Alekhin, Blümlein, Klein, Moch)

ABKM-2010, S. Alekhin *et al*., Phys. Rev. D 81 (2010) 014032.

CTEQ (Coordinated Theoretical-Experimental Project on QCD)

CTEQ6.6, P. M. Nadolsky *et al*., Phys. Rev. D 78 (2008) 013004.

CT10, H.-L. Lau *et al*., Phys. Rev. D 82 (2010) 074024.

GJR (Glück, Jimenez-Delgado, Reya)

GJR-2008, M. Gluck *et al*., Eur. Phys. J. C 53 (2008) 355; PRD79 (2009) 074023.

HERA (H1 and ZEUS collaborations)

HERAPDF1.0, F. D. Aaron *et al*., JHEP 01 (2010) 109.

MSTW (Martin, Stirling, Thorne, Watt)

MSTW2008, A. D. Martin *et al*., Eur. Phys. J. C 63 (2009) 189.

Neural Network (Ball, Del Debbio, Forte, Guffanti, Latorre, Rojo, Ubiali)

NNPDF2.0, R. D. Ball *et al*., Nucl. Phys. B 838 (2010) 136.

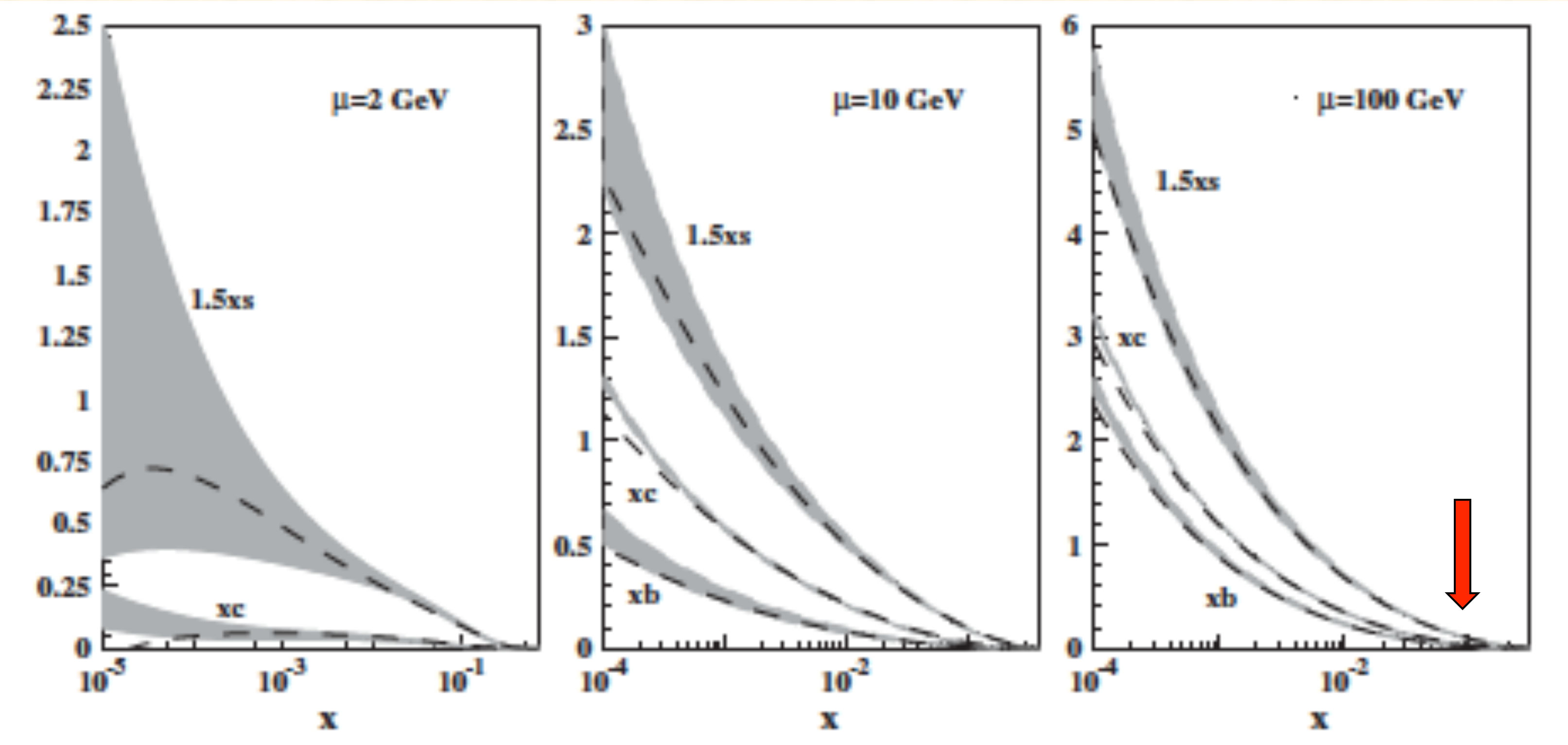
S. Alekhin, J. Blümlein, S. Klein, and S. Moch, Phys. Rev. D 81 (2010) 014032.

Until a few years ago, all the PDF analyses assumed

$$xs(x,Q_0^2) = x\bar{s}(x,Q_0^2) = \kappa \frac{\bar{u}(x,Q_0^2)+\bar{d}(x,Q_0^2)}{2}.$$

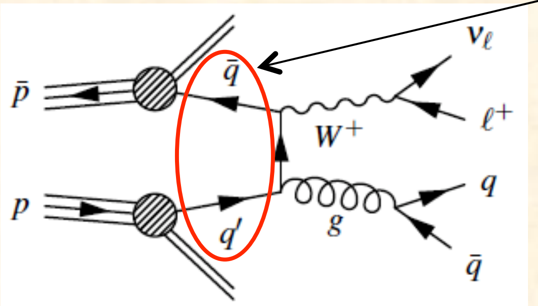
In the ABKM-2010 analysis, an independent functional form is assumed

$$xs(x,Q_0^2) = x\bar{s}(x,Q_0^2) = A_s x^{a_s}(1-x)^{b_s}.$$



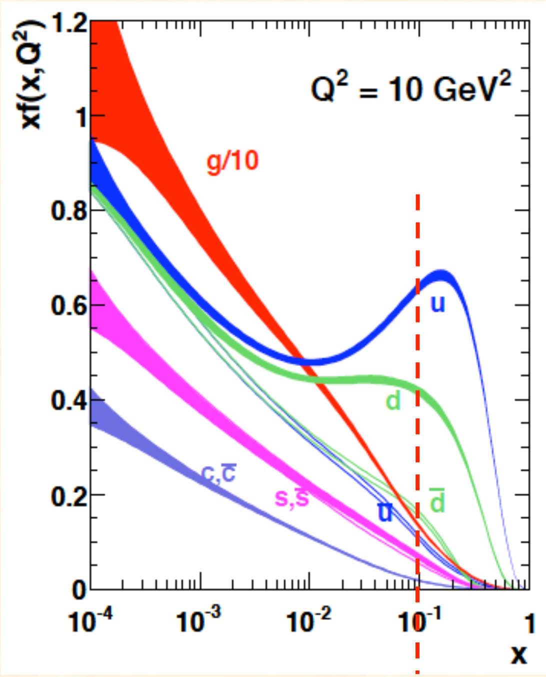
Purpose of our work

One of subprocesses



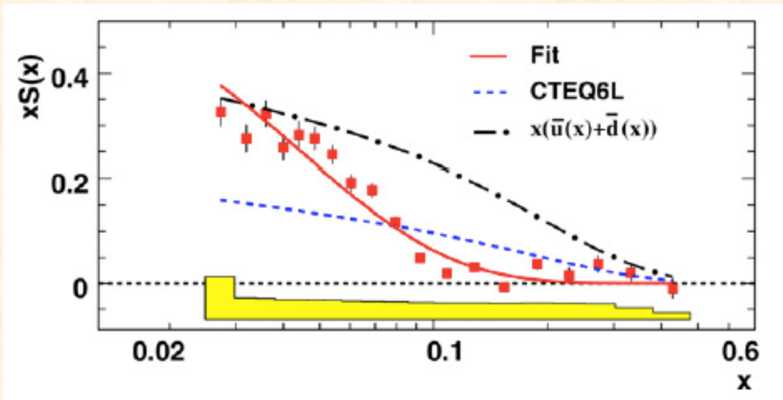
For calculating the cross section,
accurate parton distribution functions (PDFs) need to be supplied.

$\sqrt{s}\,/\,2 = 1.96\,/\,2$ TeV $= 1$ TeV is transferred to
dijets with the energy 140/2 GeV = 70 GeV
$\Rightarrow$ parton momentum fraction x = 70/1000 ~ 0.1



MSTW (2009)

According to the left figure, the PDFs *seem to be* determined well at x ~ 0.1.
$\Rightarrow$ However, this is not the case according to the HERMES collaboration.
The strange-quark distribution $s(x)$ is not determined at all!



A. Airapetian *et al.* (HERMES), Phys. Lett. B 666 (2008) 446.

Our work is to investigate $s(x)$ effects on the CDF ℓ+2j.

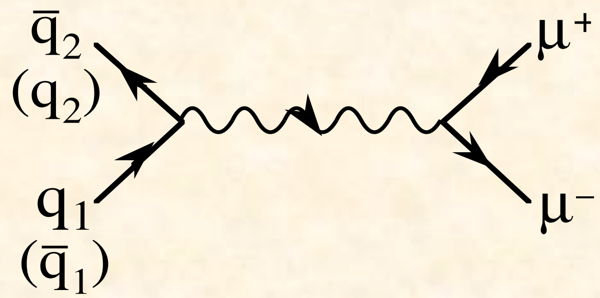
Determination of anti-quark (sea-quark) distributions

e/μ scattering

$$F_2^N = \frac{F_2^p + F_2^n}{2} = \frac{1}{2}\left[\frac{4}{9}x\left(u+\bar{u}+d+\bar{d}\right)+\frac{1}{9}x\left(d+\bar{d}+u+\bar{u}\right)+\frac{2}{9}x\left(s+\bar{s}\right)\right]+(c,b)$$

$$\rightarrow \frac{5}{9}x\left(\bar{u}+\bar{d}\right)+\frac{1}{9}x\left(s+\bar{s}\right)+(c,b) \text{ at small } x$$

Drell-Yan (lepton-pair production)



$$p_1 + p_2 \rightarrow \mu^+\mu^- + X$$

$$d\sigma \propto q(x_1)\,\bar{q}(x_2) + \bar{q}(x_1)\,q(x_2)$$

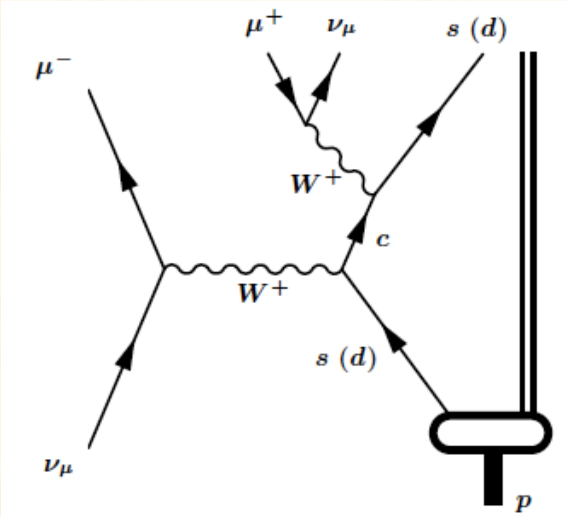
at large $x_F = x_1 - x_2$

projectile target

$$d\sigma \propto q_V(x_1)\,\bar{q}(x_2)$$

$\bar{q}(x_2)$ can be obtained if $q_V(x_1)$ is known.

$s(x)$ from neutrino-induced opposite-sign dimuon events

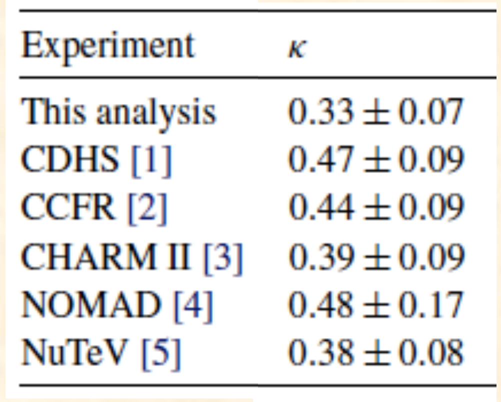


A. Kayis-Topaksu *et al.*, NPB7 98 (2008) 1.
U. Dore, arXiv: 1103.4572 [hep-ex].

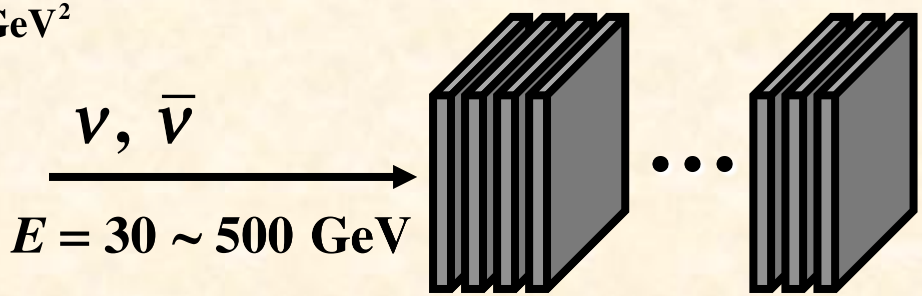
$$\kappa = \frac{\int dx\, x\,[s(x,Q^2)+\bar{s}(x,Q^2)]}{\int dx\, x\,[\bar{u}(x,Q^2)+\bar{d}(x,Q^2)]}$$

$Q^2 = 20\ \mathrm{GeV}^2$

CCFR, NuTeV



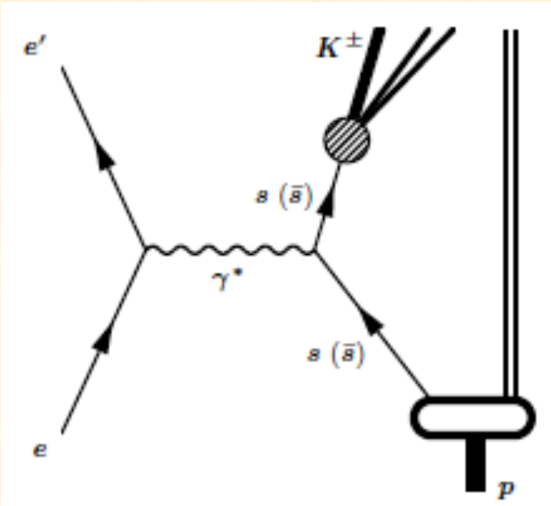
Experiment	κ
This analysis	0.33 ± 0.07
CDHS [1]	0.47 ± 0.09
CCFR [2]	0.44 ± 0.09
CHARM II [3]	0.39 ± 0.09
NOMAD [4]	0.48 ± 0.17
NuTeV [5]	0.38 ± 0.08

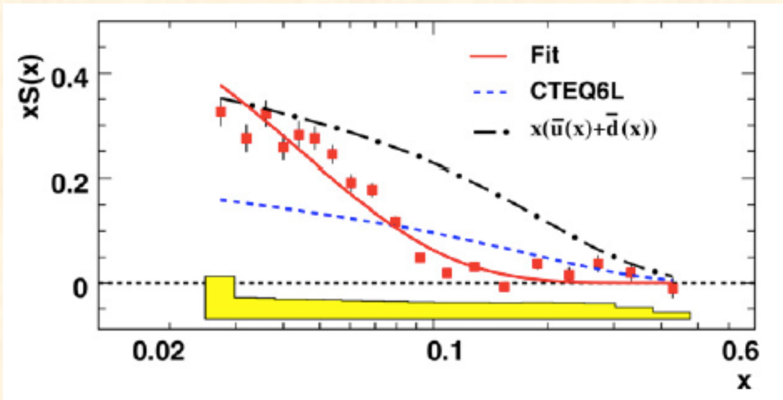


Huge Fe target (690 ton)

Issue: nuclear corrections

HERMES semi-inclusive measurement

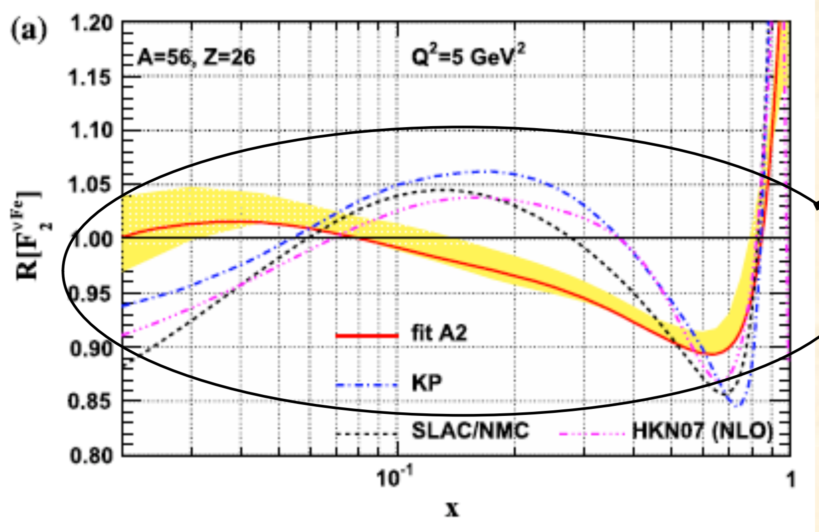




Issue: fragmentation functions

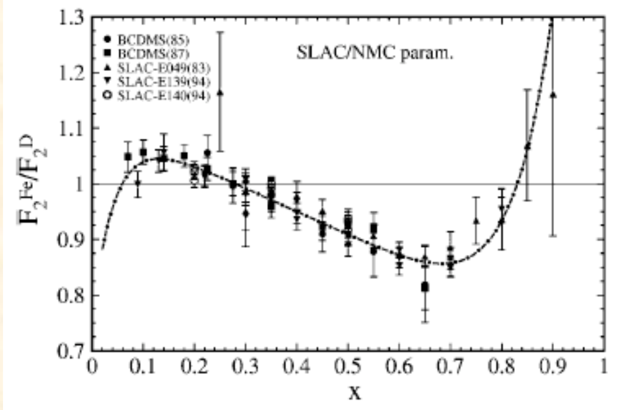
Analysis of SYKMOO-08 (Schienbein *et al.*)

SYKMOO-08 (I. Schienbein *et al.*), PRD 77 (2008) 054013

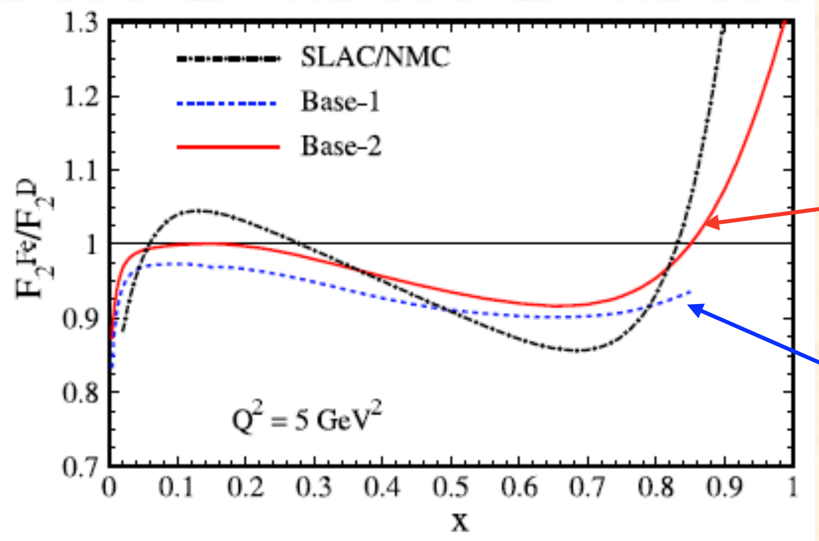


Differences from typical NPDFs.

Charged-lepton scattering



Neutrino scattering



Base-1
- remove CCFR data
- incorporate deuteron corrections

Base-2 corresponds to CTEQ6.1M with s≠sbar
- include CCFR data

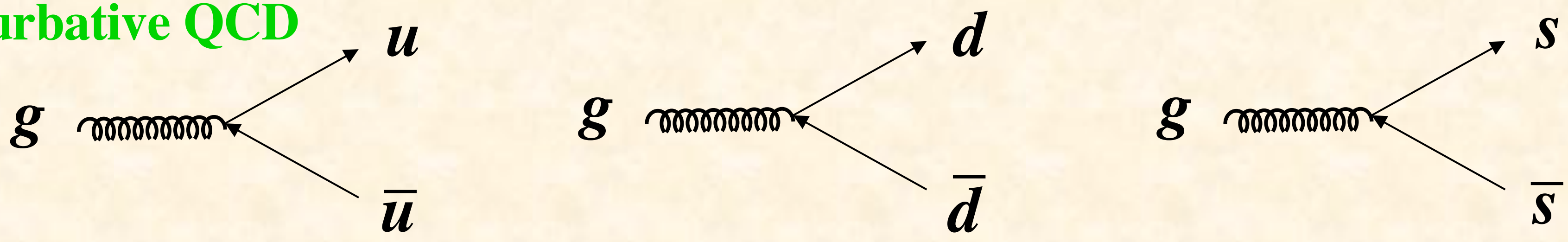
  Charged-lepton correction factors are applied.
- s≠sbar

Base-2: Using current nucleonic PDFs, they (and MRST) obtained very different corrections from charged-lepton data.

Base-1: However, it depends on the analysis method for determining "nucleonic" PDFs.

Flavor dependence of antiquark distributions

Perturbative QCD



Because of $m_u^2,\ m_u^2,\ m_u^2 \ll Q^2$, we expect $\bar{u} = \bar{d} = \bar{s}$ from the antiquark creaction by the gluon splitting $g \to q\bar{q}$ in perturbative QCD.

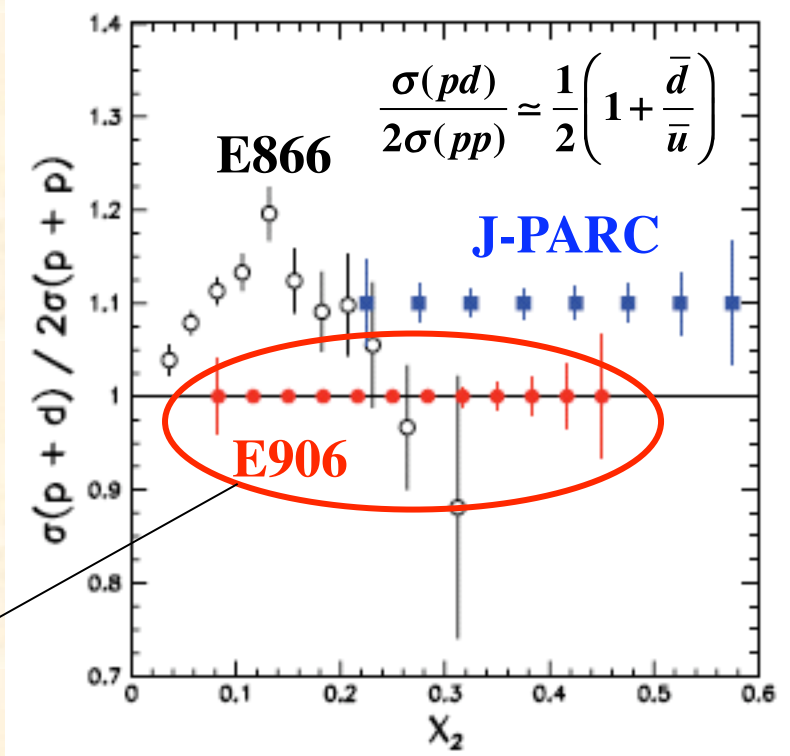
$\Rightarrow$ **Experimentally,** $\dfrac{\bar{s}}{(\bar{u}+\bar{d})/2} \sim 0.4$

$$\frac{\bar{d}}{\bar{u}} = 1 \sim 1.4$$

Non-perturbative mechanism for the asymmetries?

Ref. SK, Phys. Rep. 303 (1998) 183.

Fermilab experiment in progress!



GR@PPA (GRace At Proton-Proton/Antiproton collisions)

http://atlas.kek.jp/physics/nlo-wg/grappa.html

GRACE: mainly for lepton collisions
GR@PPA: GRACE is implemented
for hadron collisions
by including PDF etc.

Lagrangian

↓

GRACE

Feynman rule

↓

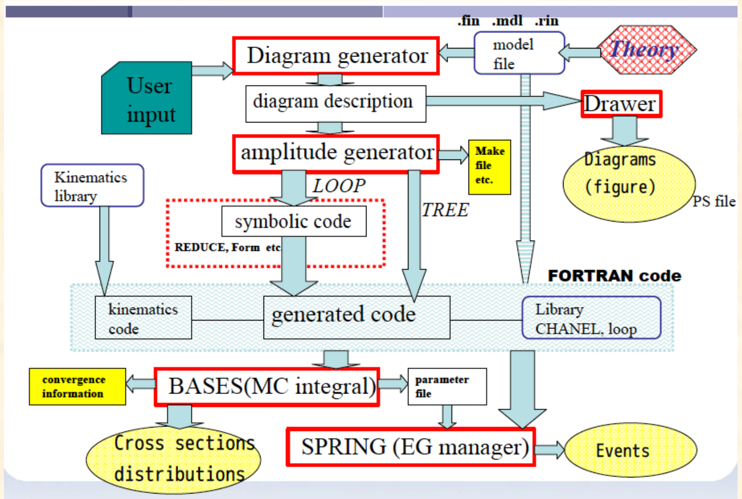
Scattering amplitude

↓

Scattering cross section
(Kinematics, Numerical integrations)

↓

Event generation



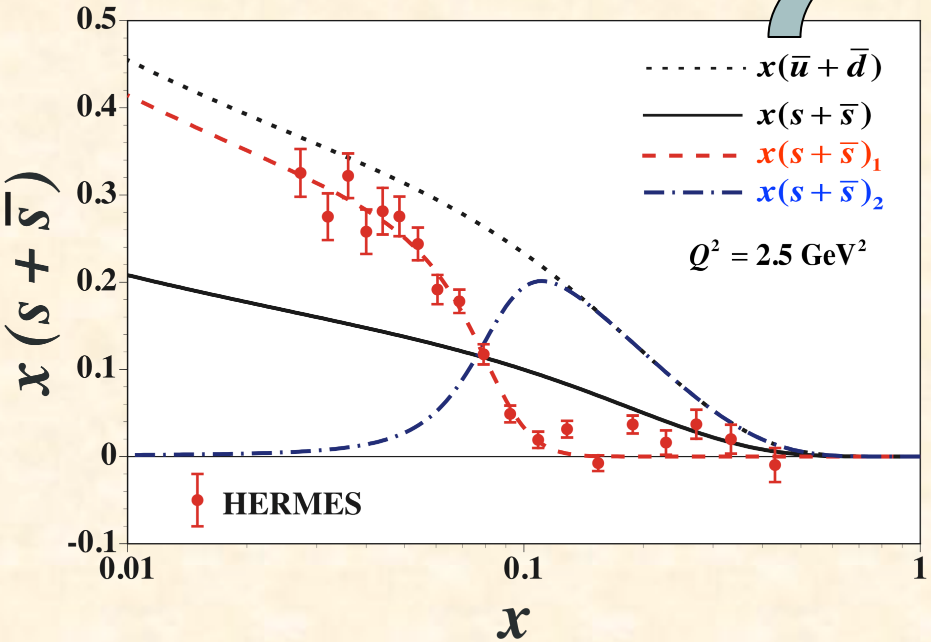
Assumed strange-quark distributions for analyses

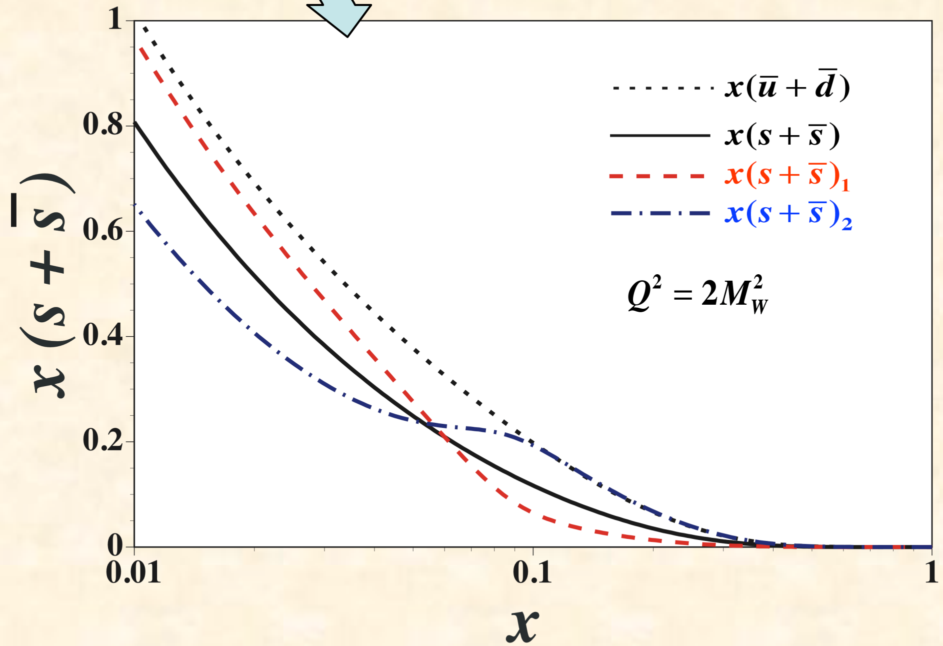
$\left[s(x,Q^2)+\bar{s}(x,Q^2)\right]_i = w_i(x,Q^2)\left[s(x,Q^2)+\bar{s}(x,Q^2)\right]_{\mathrm{CTEQ6L1}}$ $w_i(x,Q^2)$ = weight function to express modification

$Q_0^2 = 2.5\ \mathrm{GeV}^2$ (Average HERMES Q^2)

- $w_1(x,Q_0^2) = 1 - \tanh\left(\dfrac{x-x_0}{\Delta x}\right)$, $x_0 = 0.0796$, $\Delta x = 0.0253$ for explaining HERMES data
- $w_2(x,Q_0^2) = \dfrac{1}{2}\left[1+\tanh\left(\dfrac{x-x_0}{\Delta x}\right)\right]\dfrac{\left[\bar{u}(x,Q_0^2)+\bar{d}(x,Q_0^2)\right]_{\mathrm{CTEQ6L1}}}{\left[s(x,Q_0^2)+\bar{s}(x,Q_0^2)\right]_{\mathrm{CTEQ6L1}}}$

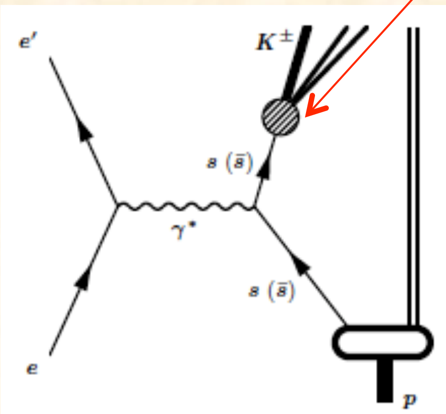
Q^2 evolution from $Q_0^2 = 2.5\ \mathrm{GeV}^2$ to $Q^2 = 2M_W^2$
$(Q^2 = M_W^2 + p_T^2 \sim 2M_W^2)$

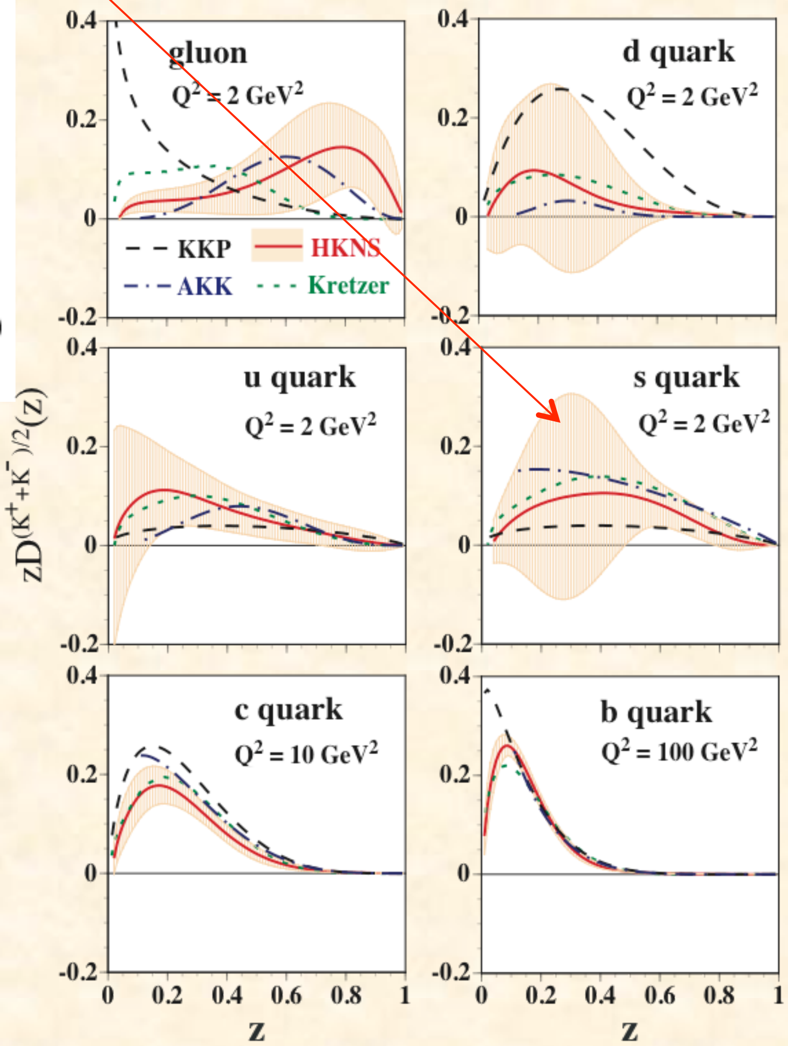


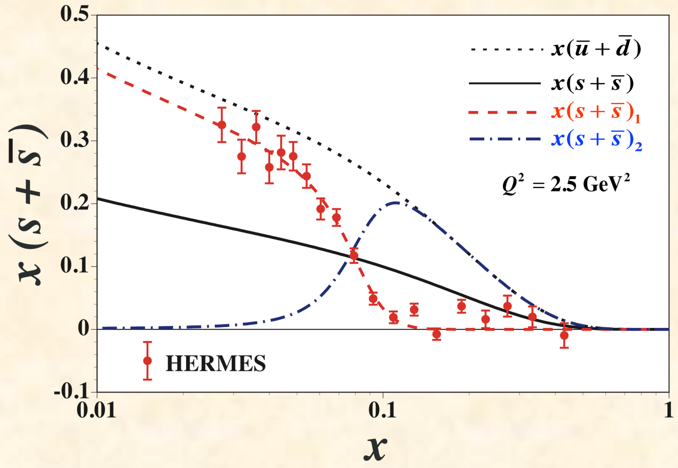


Comments on the $s(x)$ choice I

Issue of fragmentation functions for HERMES $s(x)$





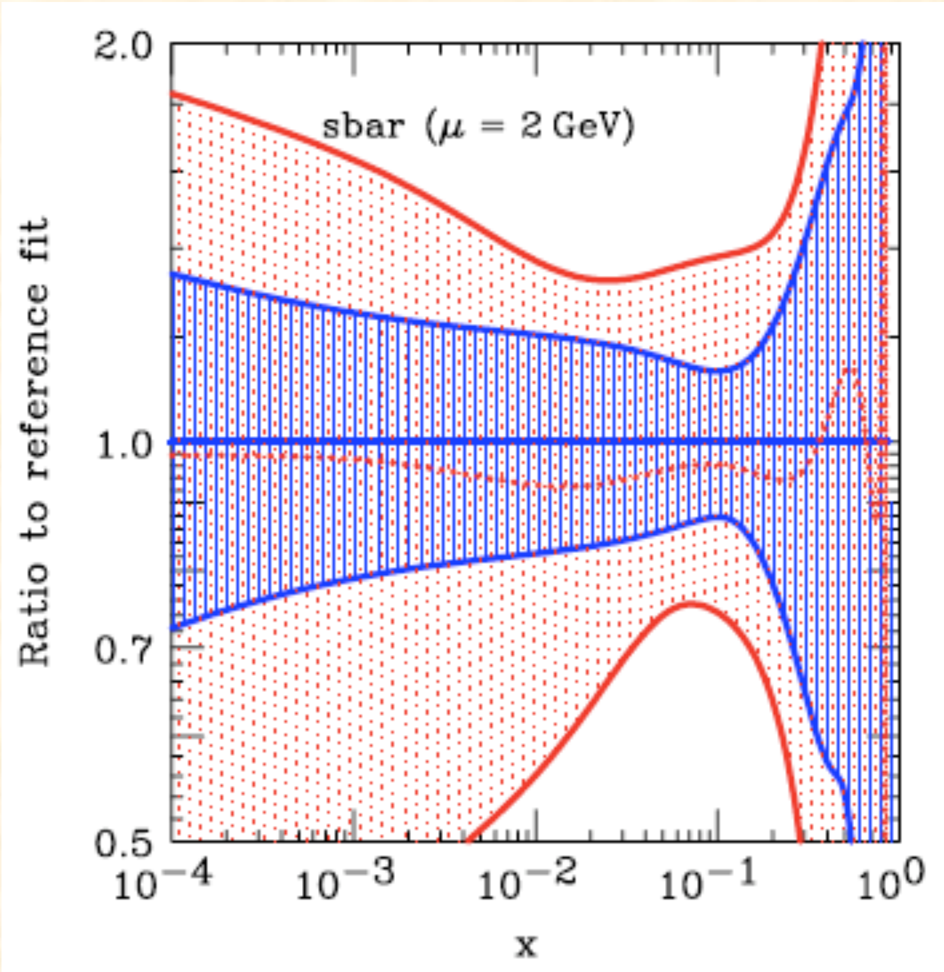


Large uncertainties
in the fragmentation function $D_s^K(x,Q^2)$

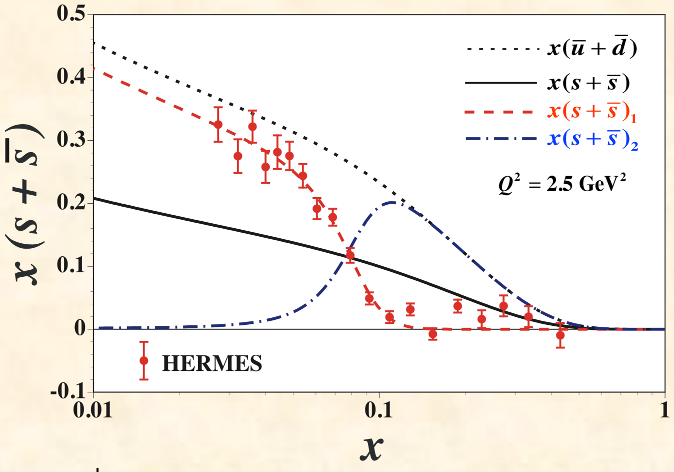
M. Hirai, S. Kumano, T.-H. Nagai,
K. Sudoh, PRD 75 (2007) 094009.

CT10, H.-L. Lai *et al*., Phys. Rev. D 82 (2010) 074024.

Uncertainty range: 0 $\lesssim$ range $\lesssim$ 2 depending on the x region



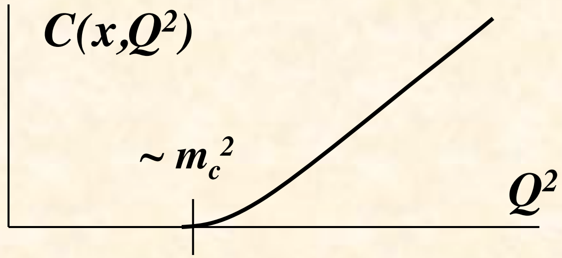
Comments on the $s(x)$ choice II



Large-x distribution of $s(x)$?

Example: Intrinsic charm distribution

- **pQCD (radiatively generated charm)**



The charm distribution is simply generated by Q^2 evolution.

- **Light-cone Fock space picture**

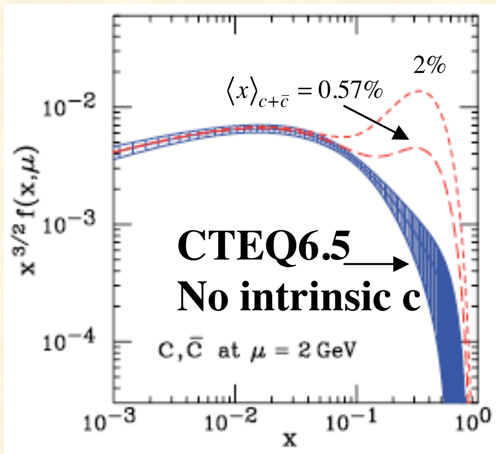
$$|p\rangle = |uud\rangle + \cdots + |uudc\bar{c}\rangle + \cdots$$

Brodsky, Hoyer, Peterson, Sakai (BHPS), PLB93 (1980) 451

- **Meson-cloud picture**

$$p(uud) \to \bar{D}^0(u\bar{c})\Lambda_c^+(udc), \;\; p(uud)J/\psi(c\bar{c})$$

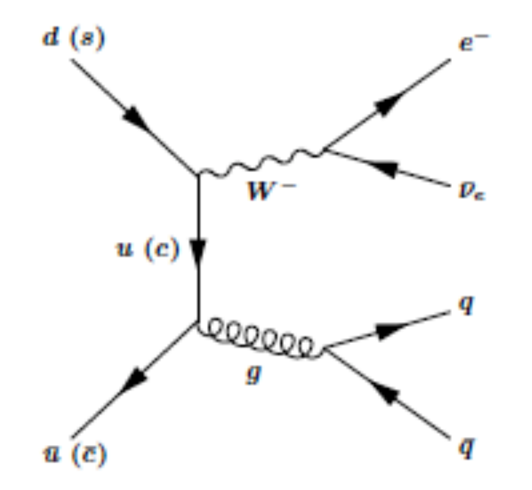
- **Global analysis** CTEQ, PRD75 (2007) 054029



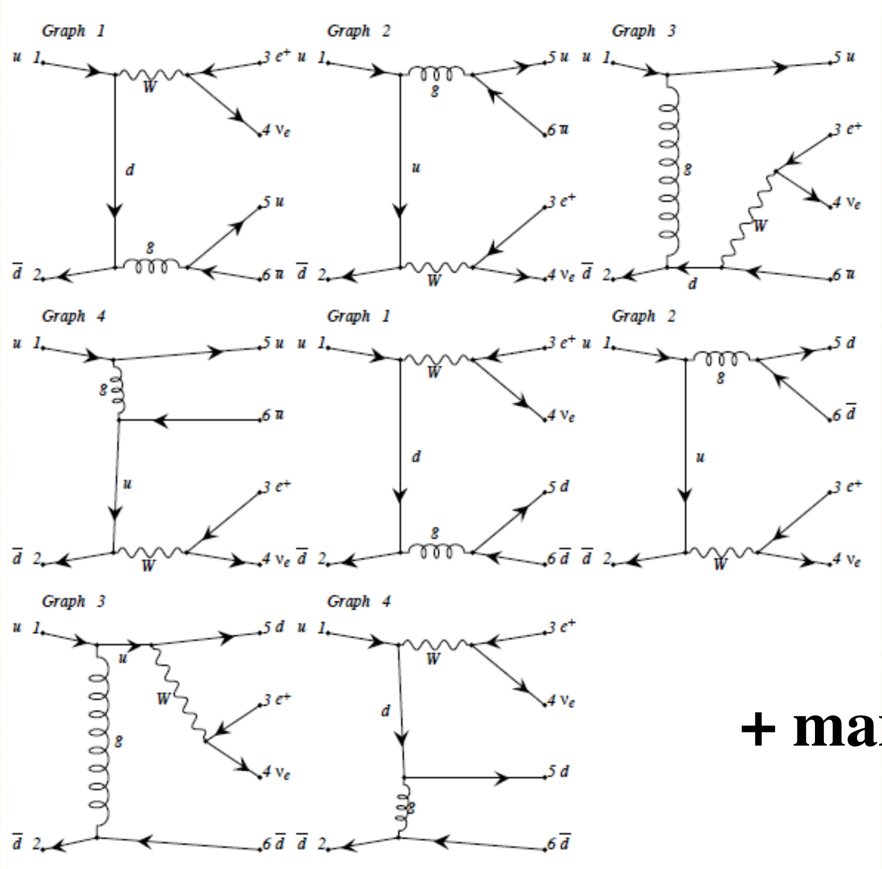
Calculations of GR@PPA

$$p\bar{p} \to \ell^{\pm}\nu_{\ell} + 2\,\text{jets}$$

W+2j



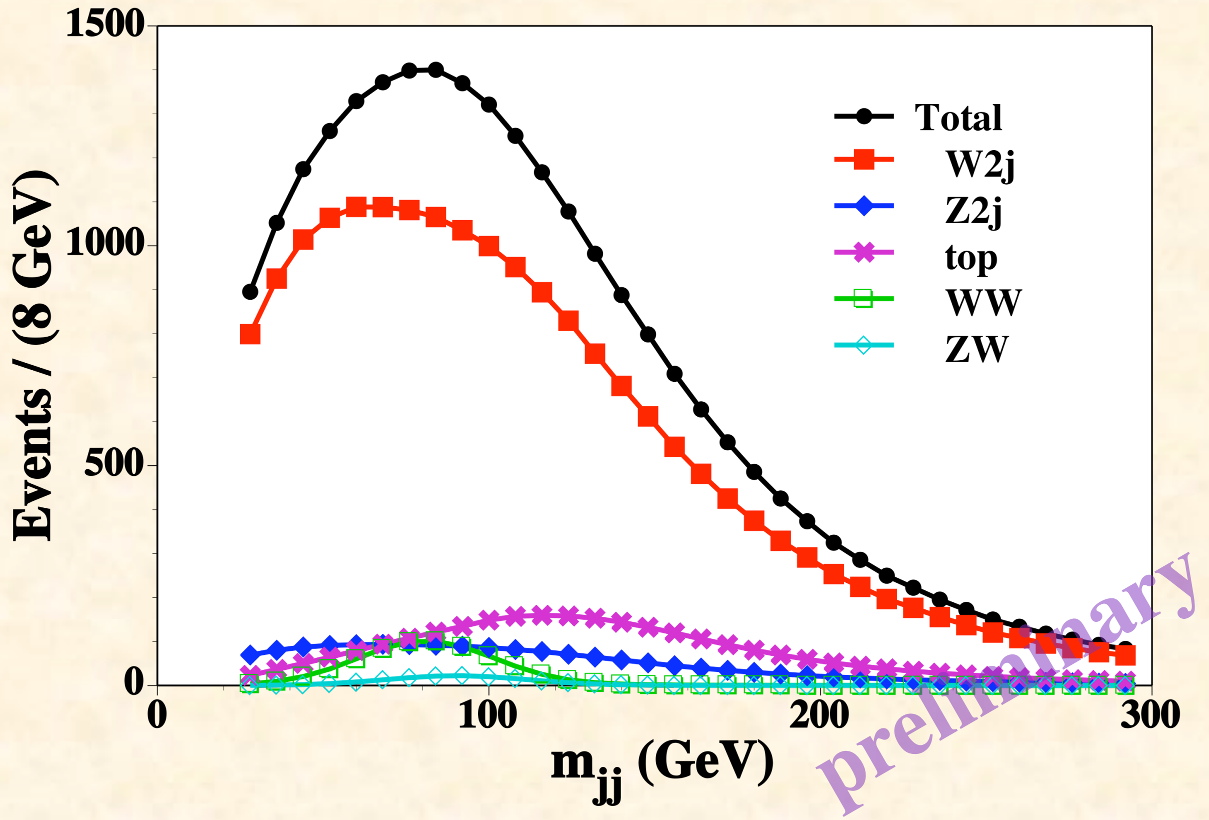
typical process

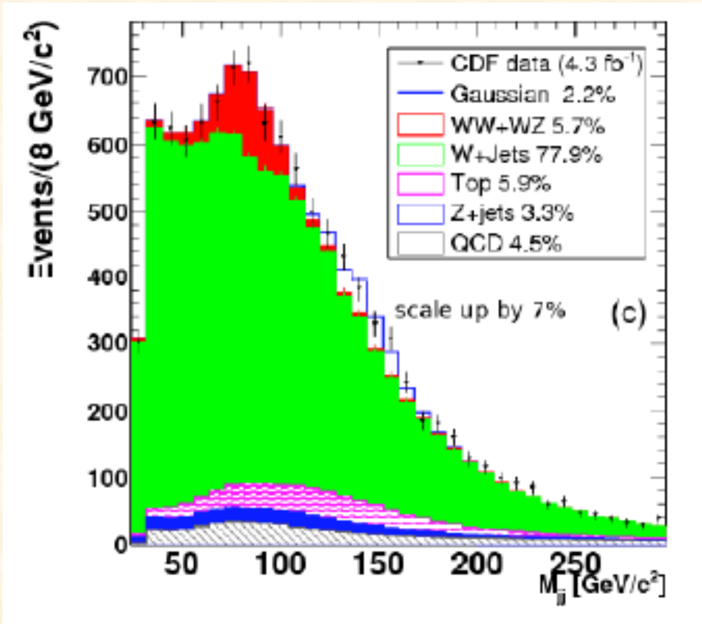


+ many processes …

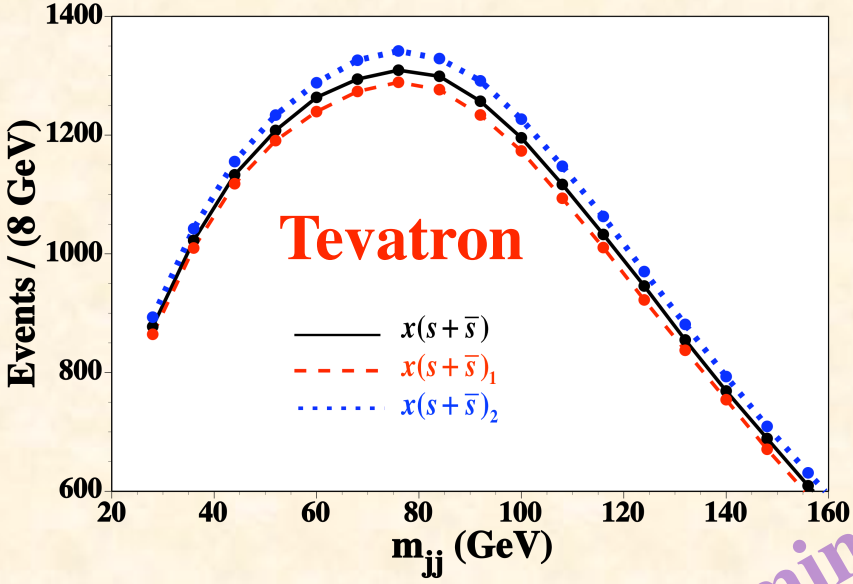
Z+2j, top, WW, ZW

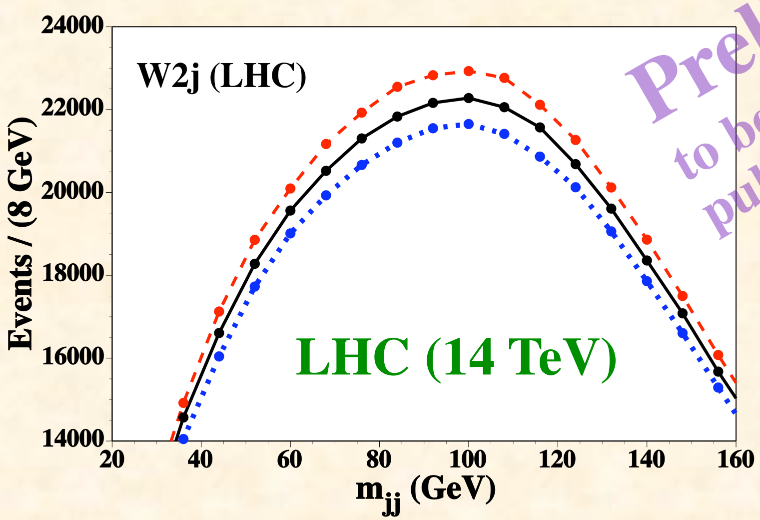
Results on lepton+2jets

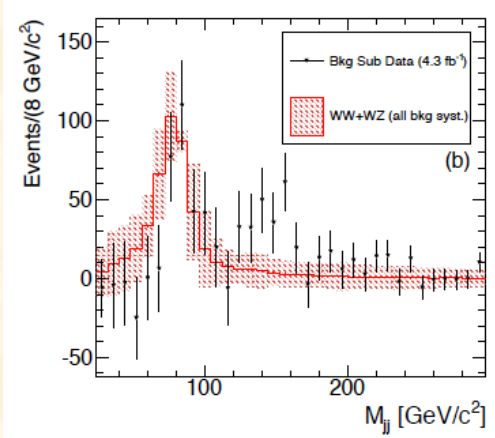


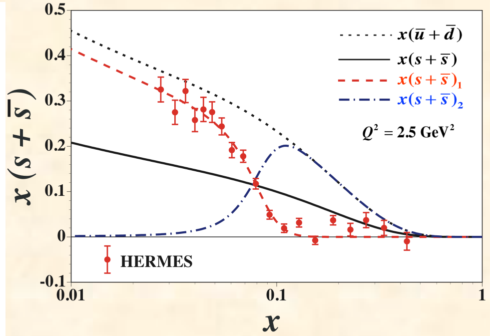


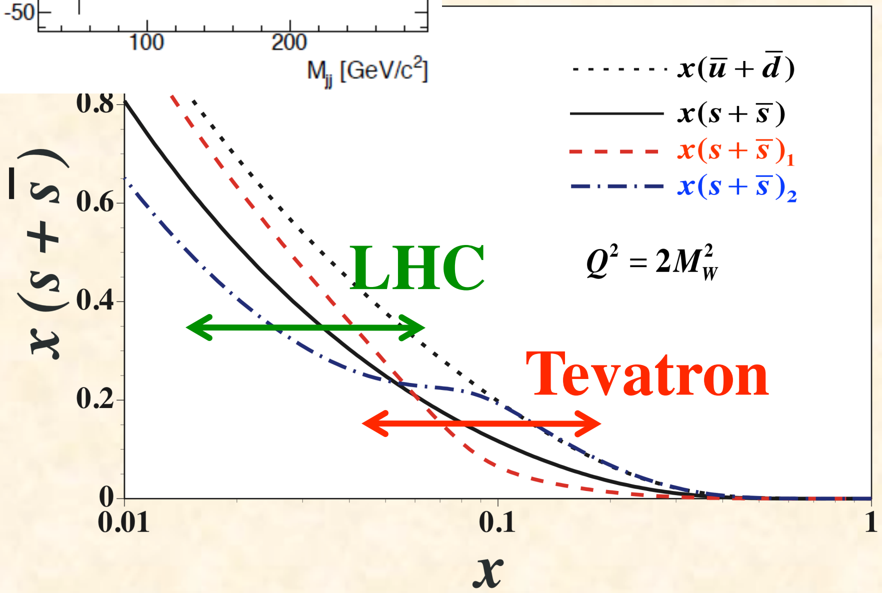
$s(x)$ effects











Preliminary
to be submitted for publication

- $s(x)$ modifications affect the ℓ+2j distribution
- $s(x)$ effects are opposite in LHC due to a different kinematical-x region which affects the ℓ+2j distribution.
- ℓ+2j distribution increases if $s(x)$ is larger at $x \sim 0.1$.

Summary

- Functional form of $s(x)$ is not determined as suggested by HERMES.
- Three types of $s(x)$ are considerd to calculate the ℓ+2j distribution.
    1. global-analysis PDF 2. Hard strange 3. Soft strange
- $s(x)$ modifications affect the ℓ+2j distribution → could partially explain the CDF excess.
- CDF ℓ+2j is sensitive to $s(x)$ at $x \sim 0.1$. → ℓ+2j increases if $s(x)$ is larger at $x \sim 0.1$.
- LHC ℓ+2j is sensitive to $s(x)$ at $x \sim 0.02$. → $s(x)$ effects are opposite in LHC (14 TeV)

If the anomalous distribution is a narrow peak, it is difficult to explain it within the standard model (parton distribution functions). However, the shape of the ℓ+2j distribution could be changed depending on $s(x)$ at $x \sim 0.1$.
→ The CDF excess could (partially) come from PDF effects.

More detailed stduies are needed for x dependence of $s(x)$.

- Theoretical estimates for $s(x)$. Nucleon models, Lattice QCD?
- Experimental investigations on $s(x)$.
  Large uncertainties for the HERMES $s(x) = s \to K$ fragmentation error.
  → Solved by KEK-Belle in the near future.
  Other DIS experiments, RHIC, LHC experiments.
  Nuclear (Fe) corrections in ν reactions
  → Partially solved by Fermilab-Minerνa in the near future. → Wait for ν factory?

The End

The End

Memorial stamp: 150 year of friendship

Memorial stamps from Johannes Blümlein

Thank you for the support from Germany

All the participants

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Werner Vogelsang
Tord Riemann
Johannes Blümlein

The offer to use DESY computing facilities on March 14 (only 3 days after the earthquake)

I hope that the friendship between Germany and Japan will continue forever.