Heavy Quark Theory Approaches for PDF Analysis

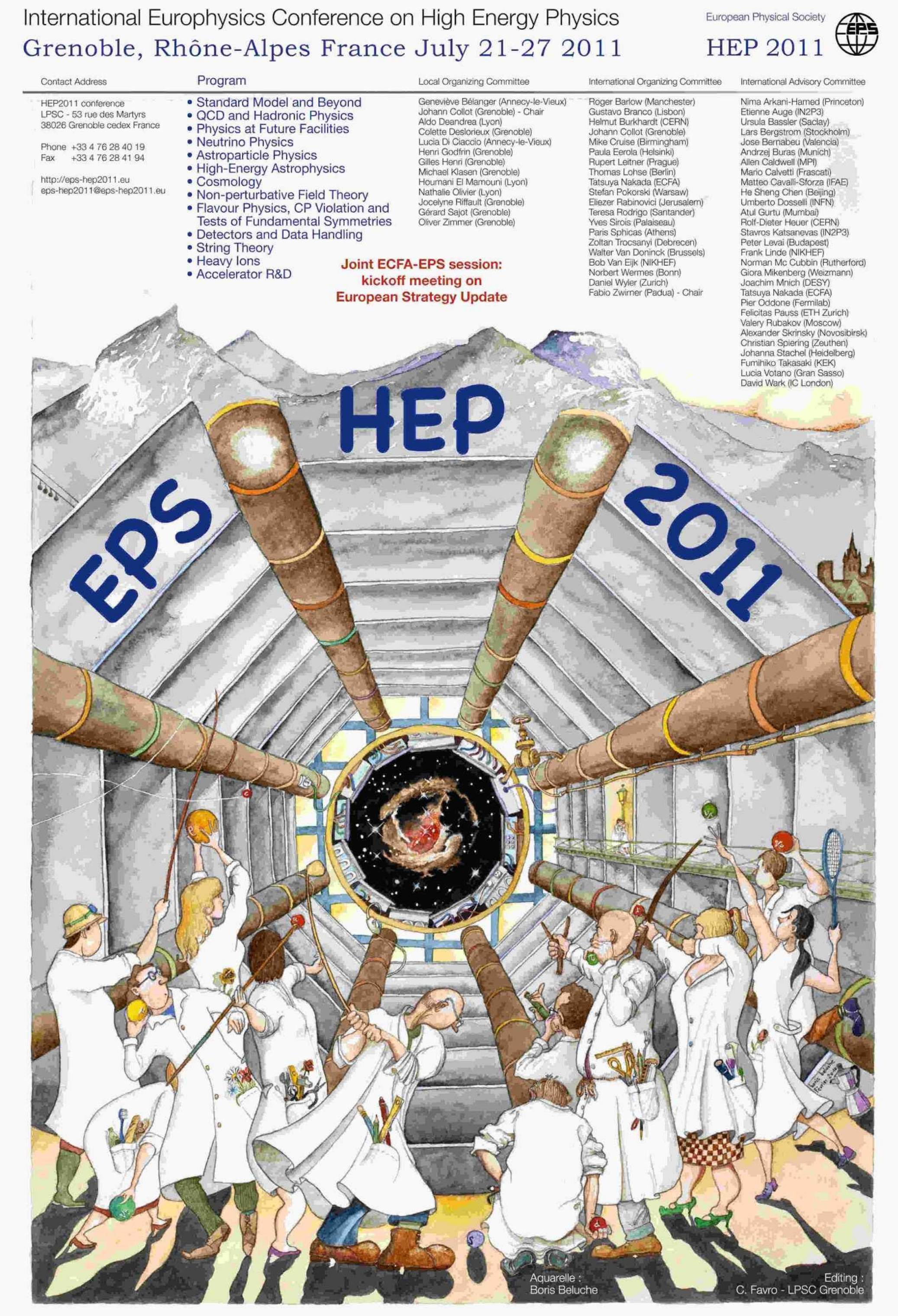
… a new perspective in the LHC era

Earth,
as viewed from
Ringberg castle

Fred Olness

SMU

Ringberg Workshop
26 September 2011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European Physical Society
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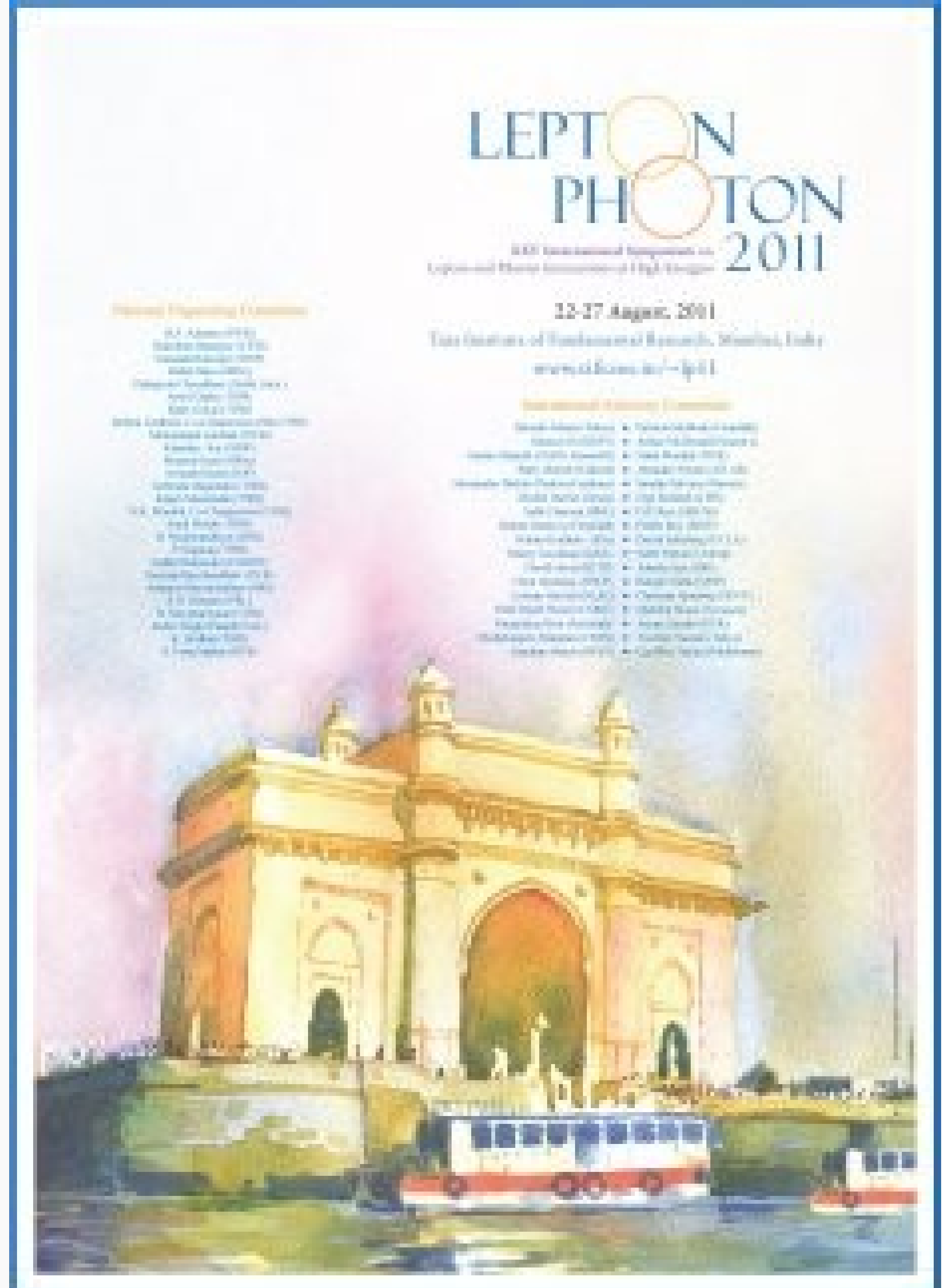
LEPTON PHOTON 2011
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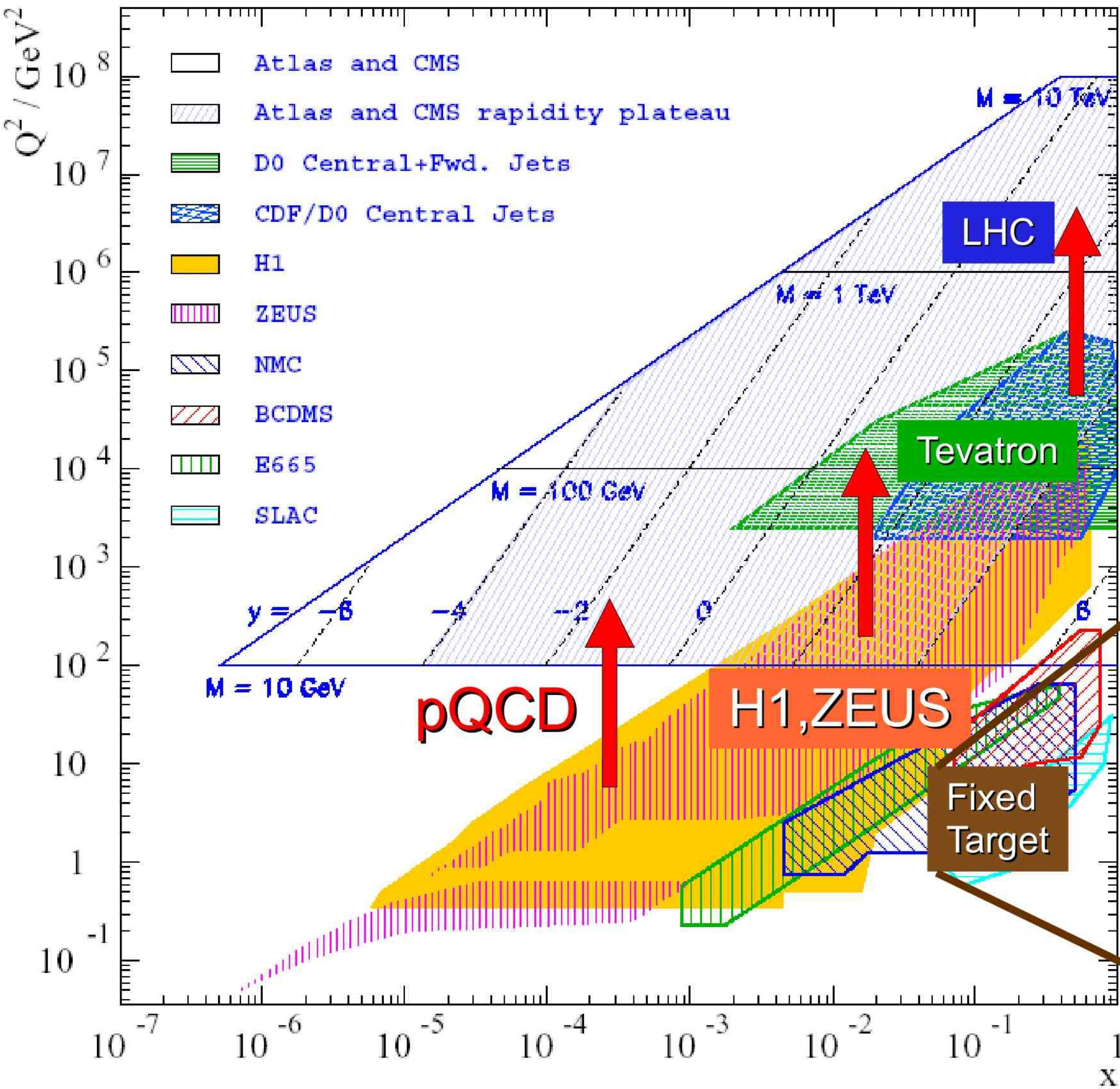
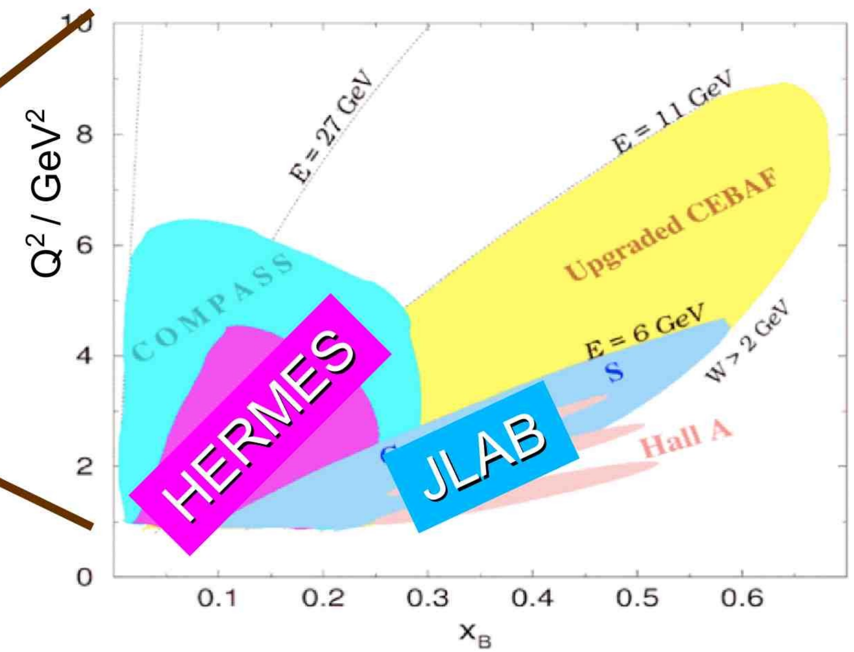
Kinematics

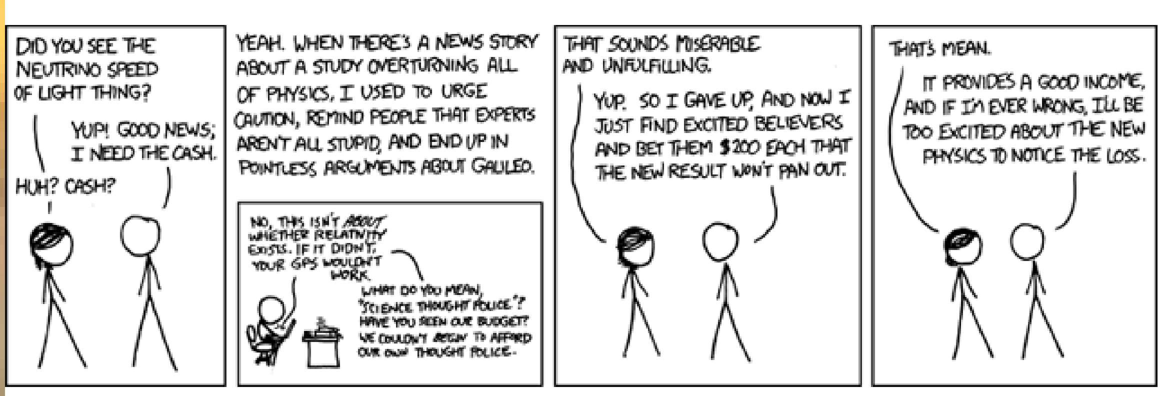


- H1, ZEUS: large coverage in x und Q^2
- HERMES, JLAB: access to large x and low Q^2
- pQCD (DGLAP) predicts Q^2 dependence



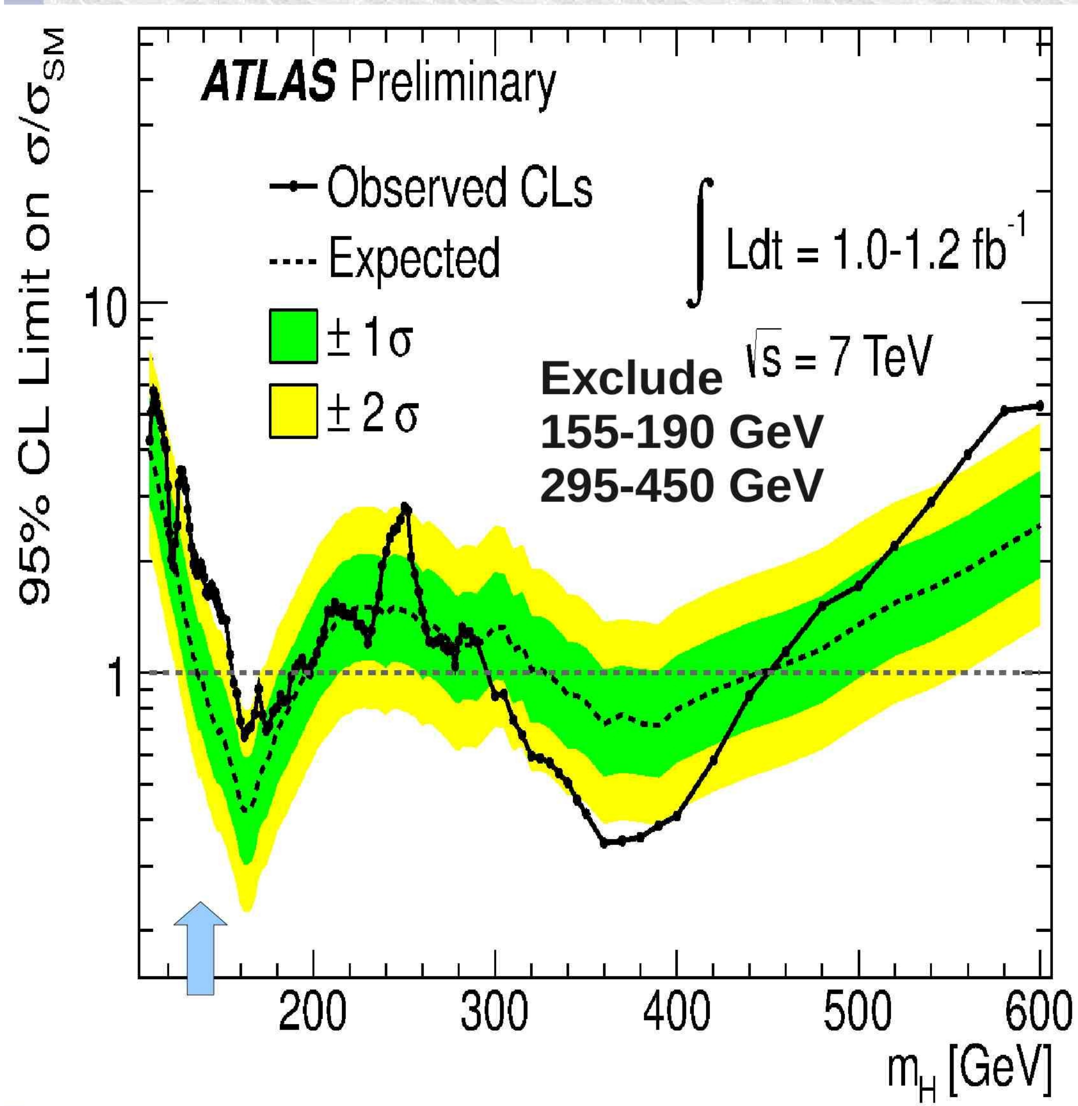
Higgs Production

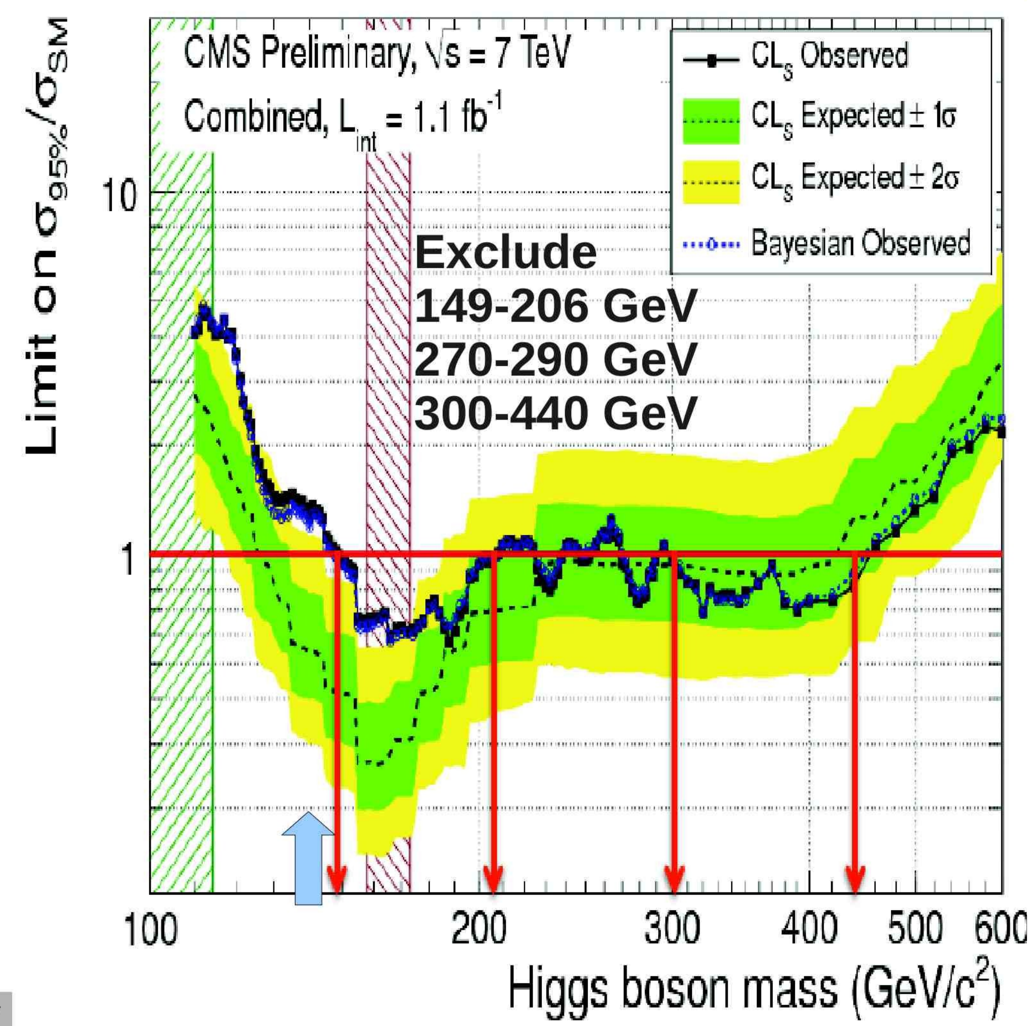
… no lose theorems...



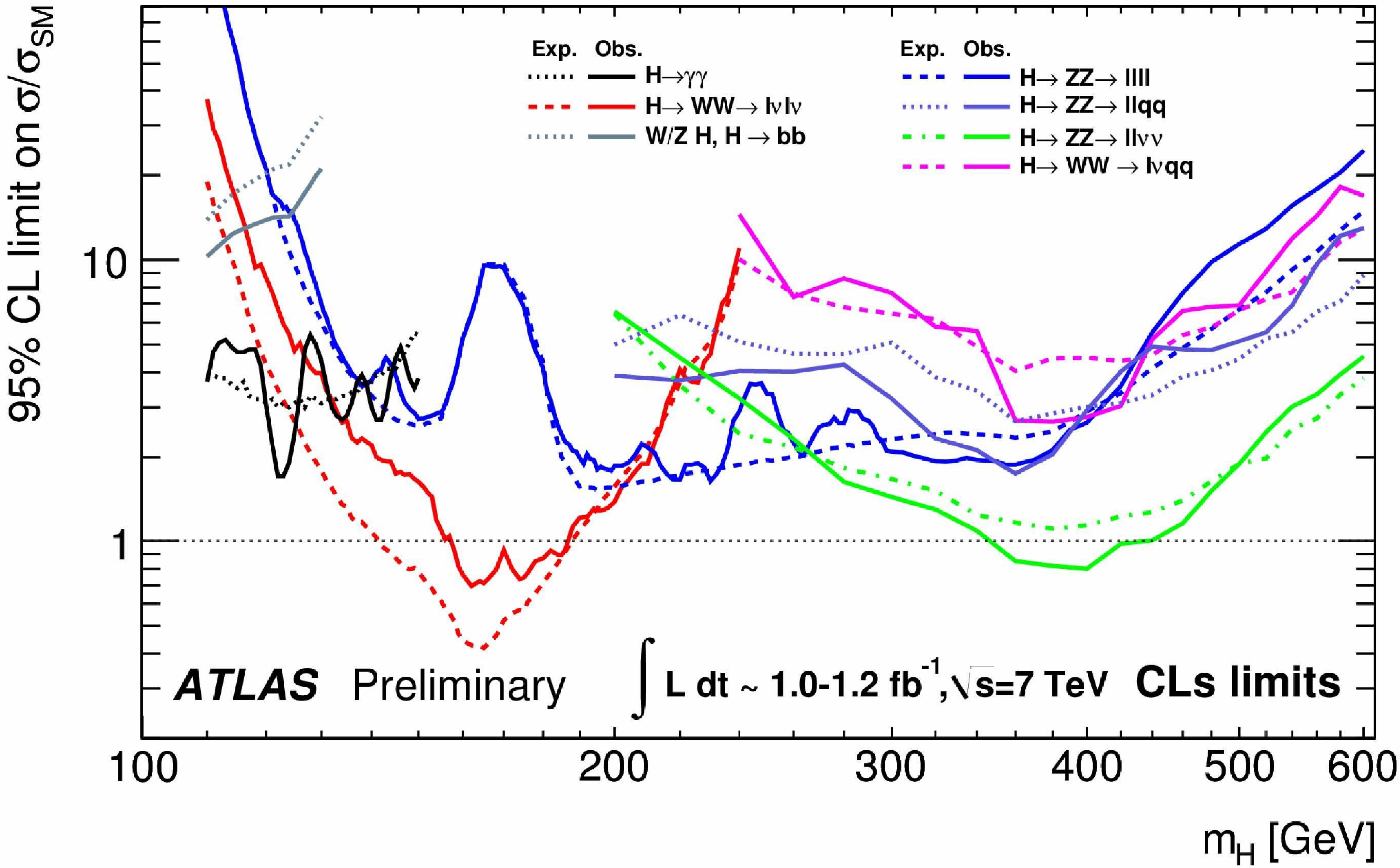
ATLAS & CMS limits

Sensitivities differ in detail
But on average similar



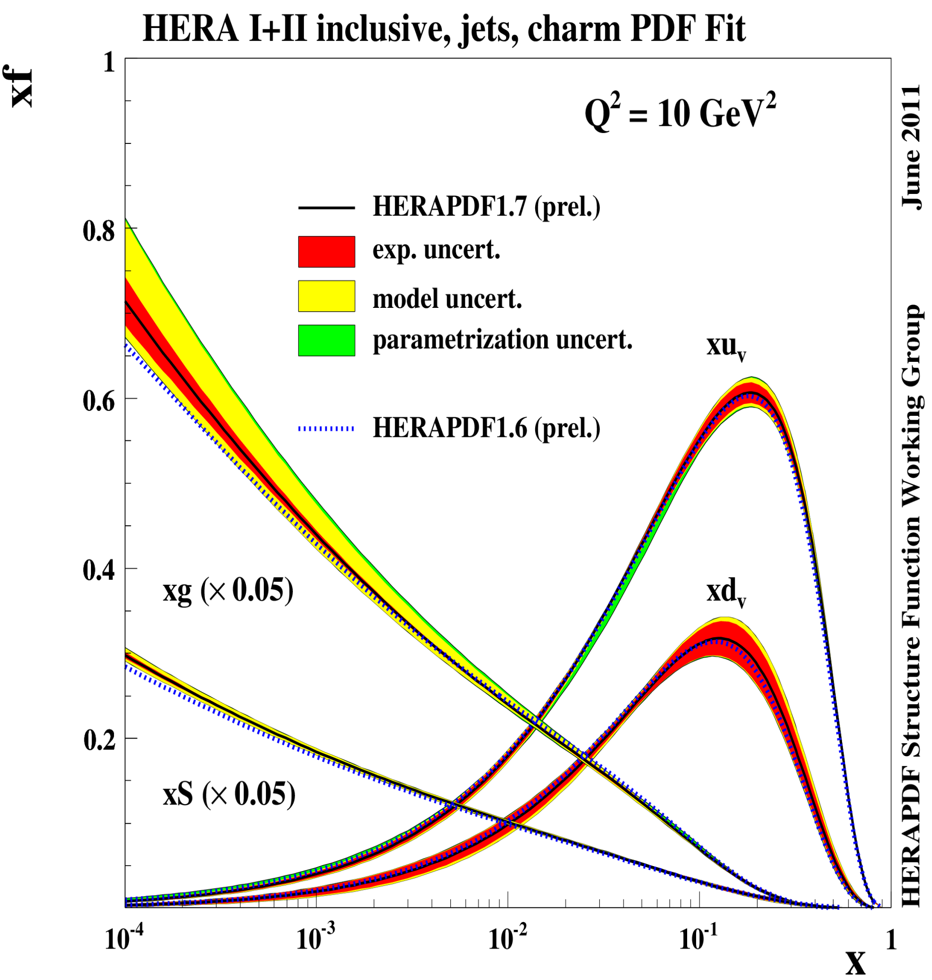


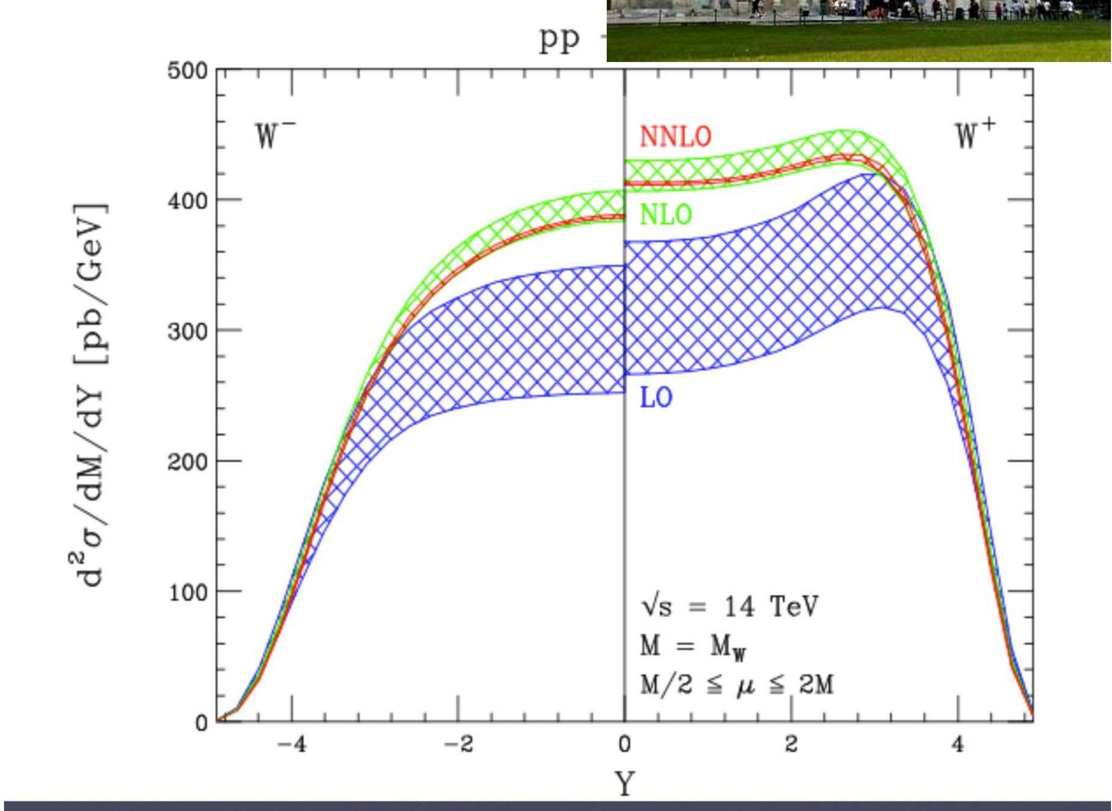
Channels reviewed (ATLAS)



FOUNDATIONS

PDFs are certainly one of the foundations that our search for "new physics" is built upon

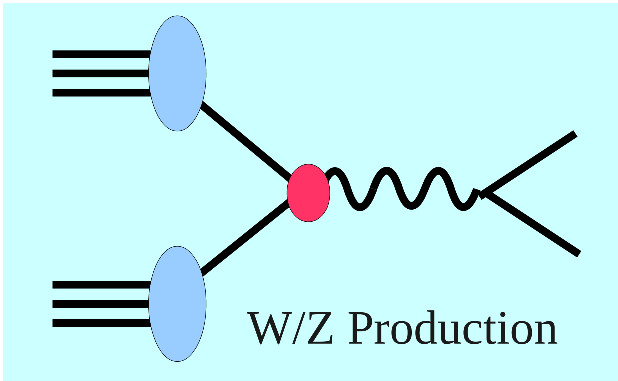


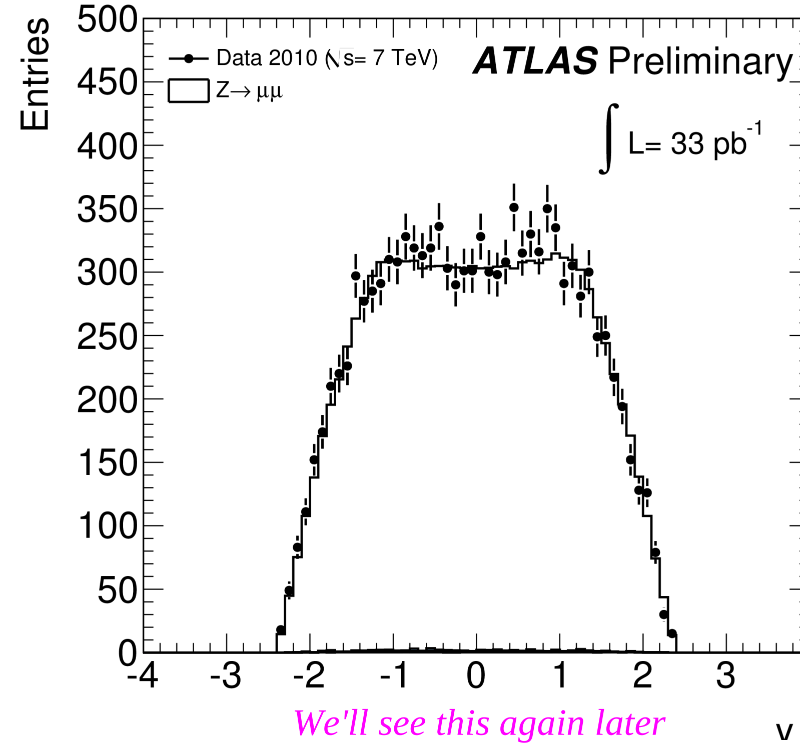


W/Z Production

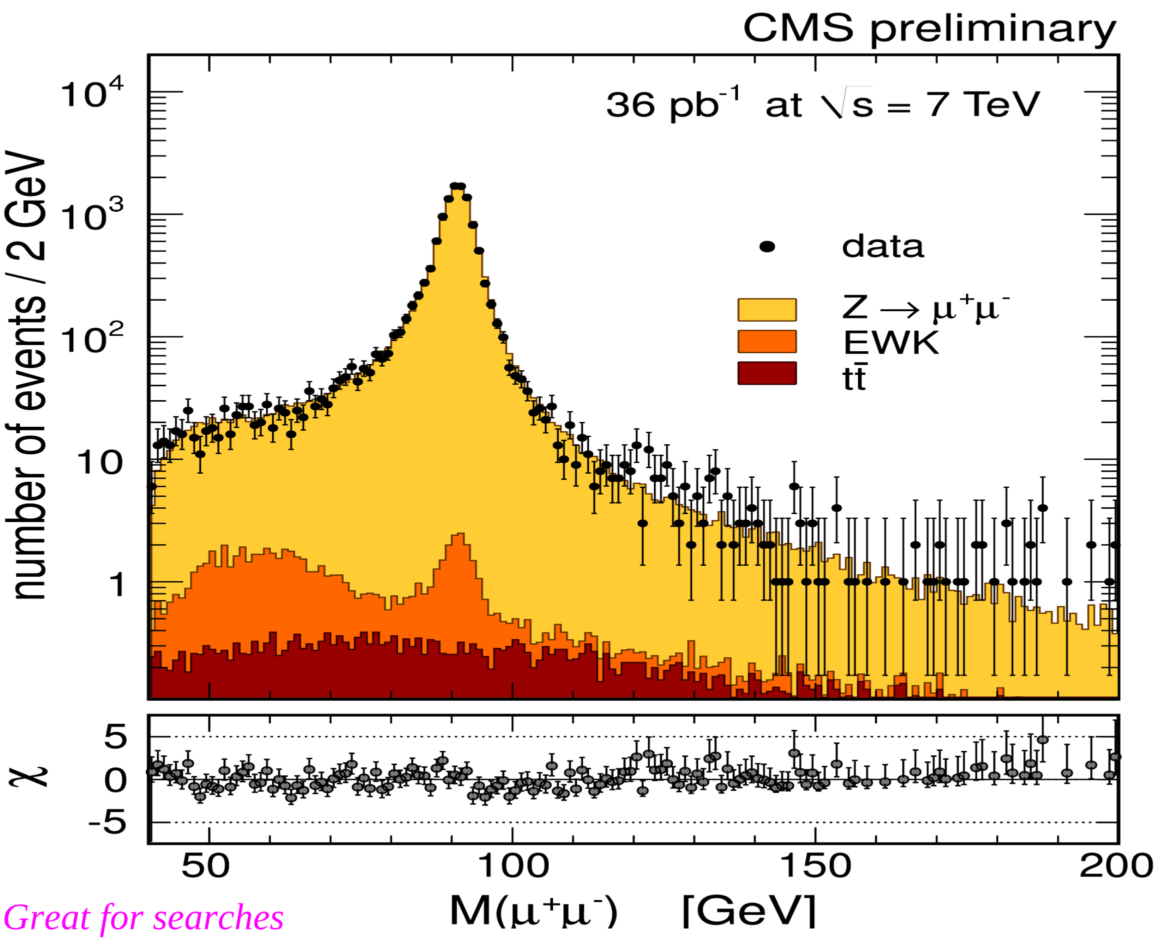
“Benchmark Calculations”

LHC W/Z PRODUCTION

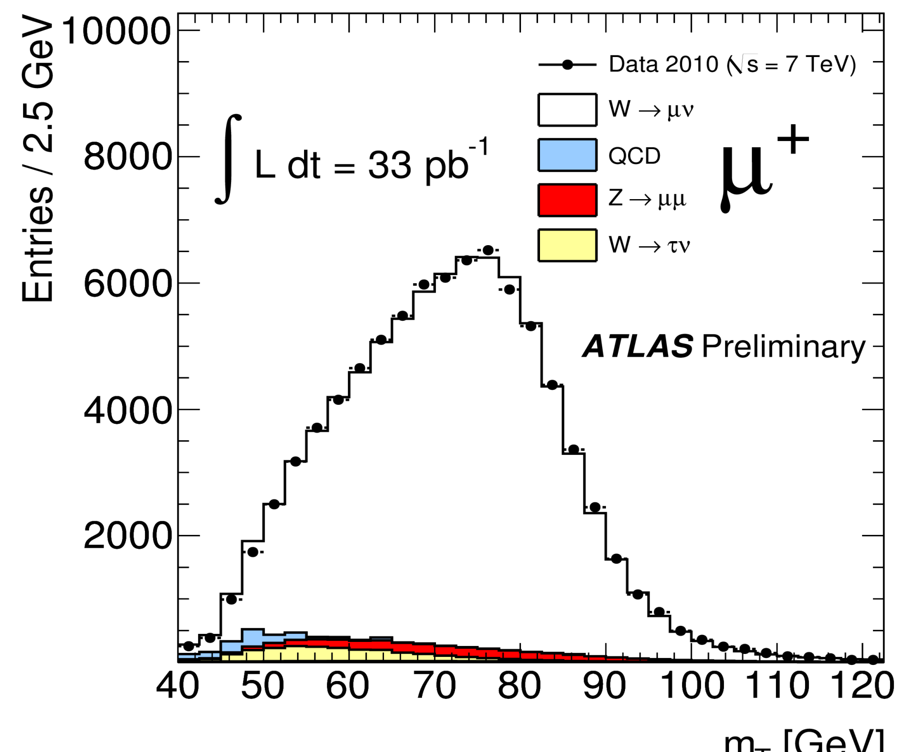




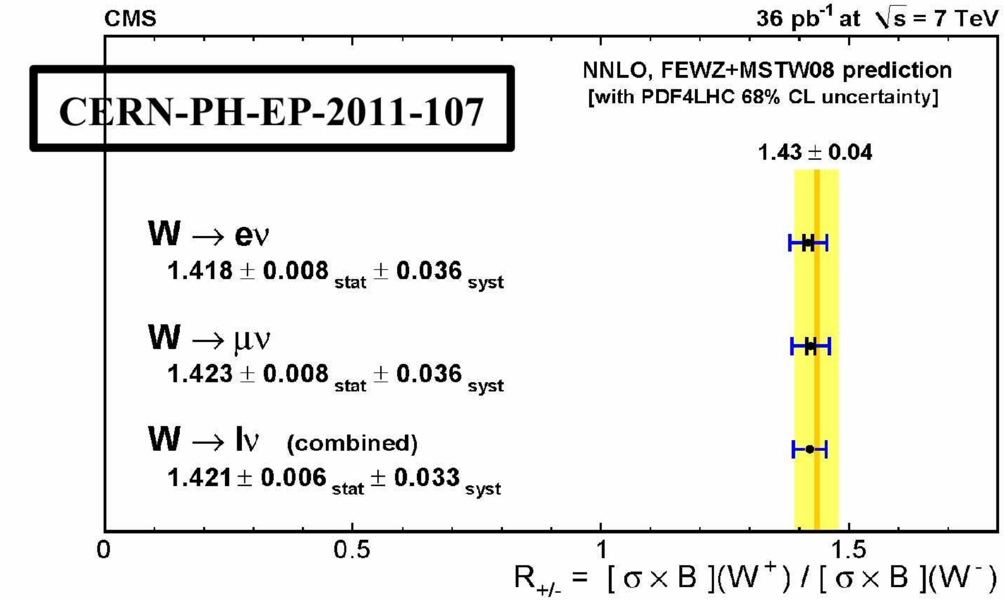
We'll see this again later

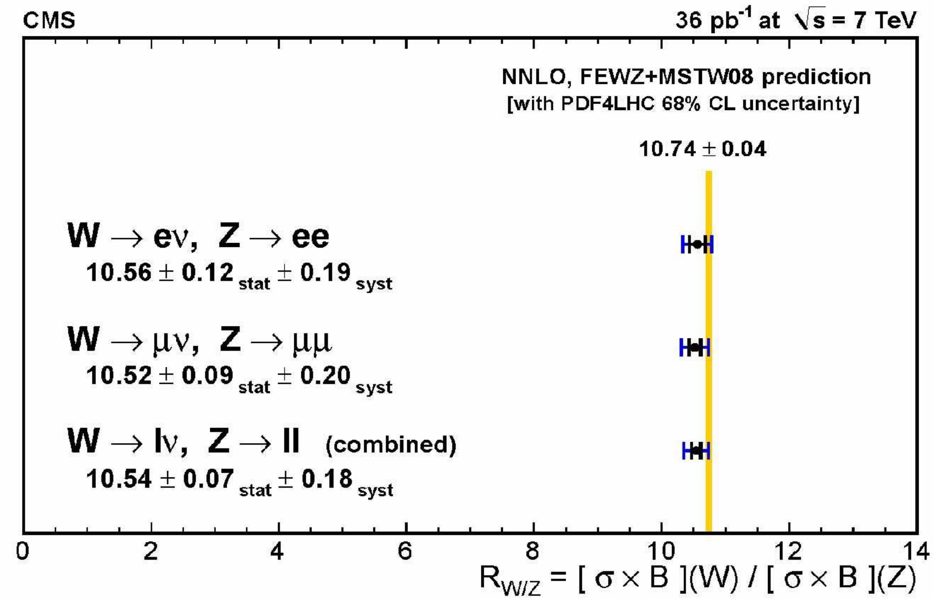


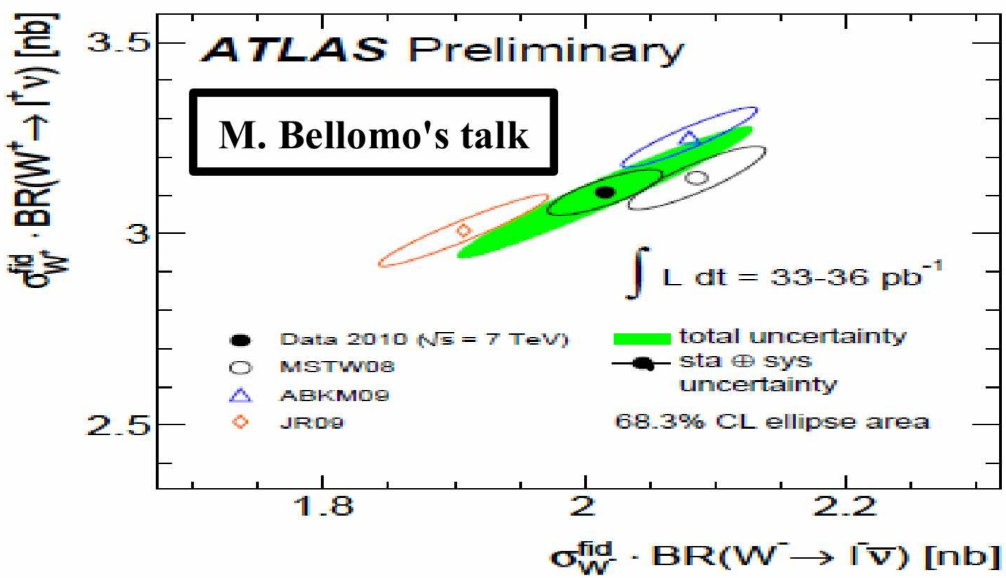
Great for searches

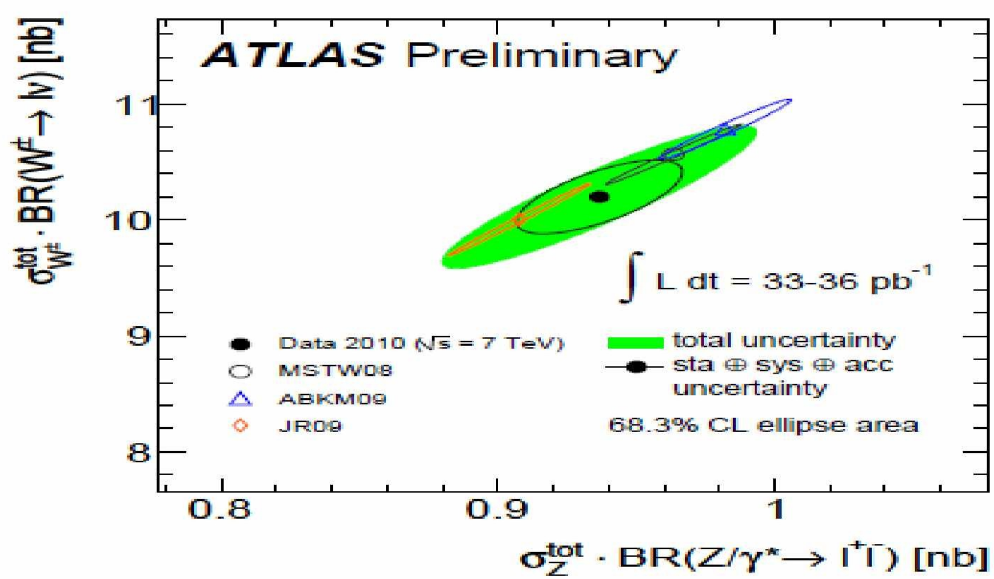


LHC W+/W- and W/Z ratios









W+/W-: potential to constrain PDF uncertainties

W/Z: stringent test of theoretical expectations

W/Z Production

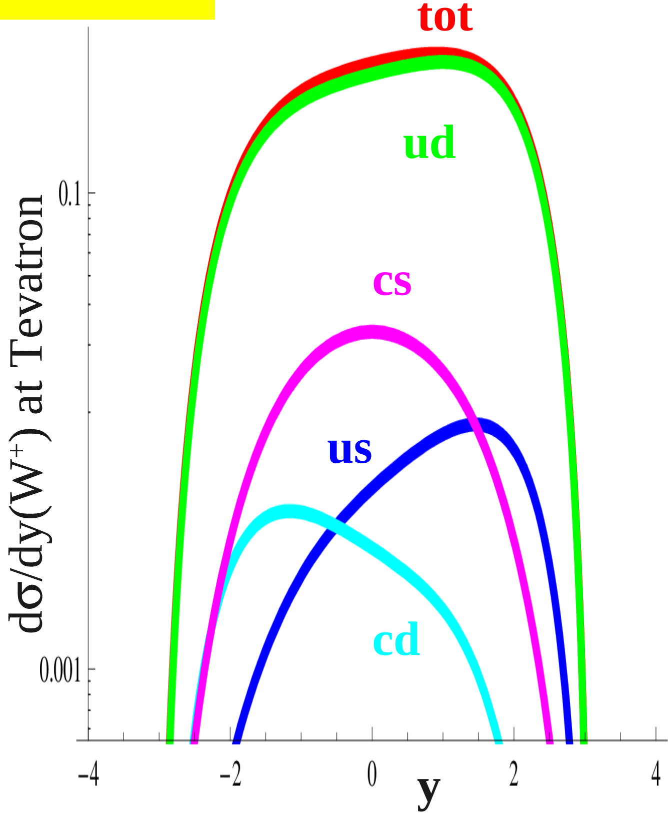
On the theoretical side …

… and what's this got to do with heavy quarks...

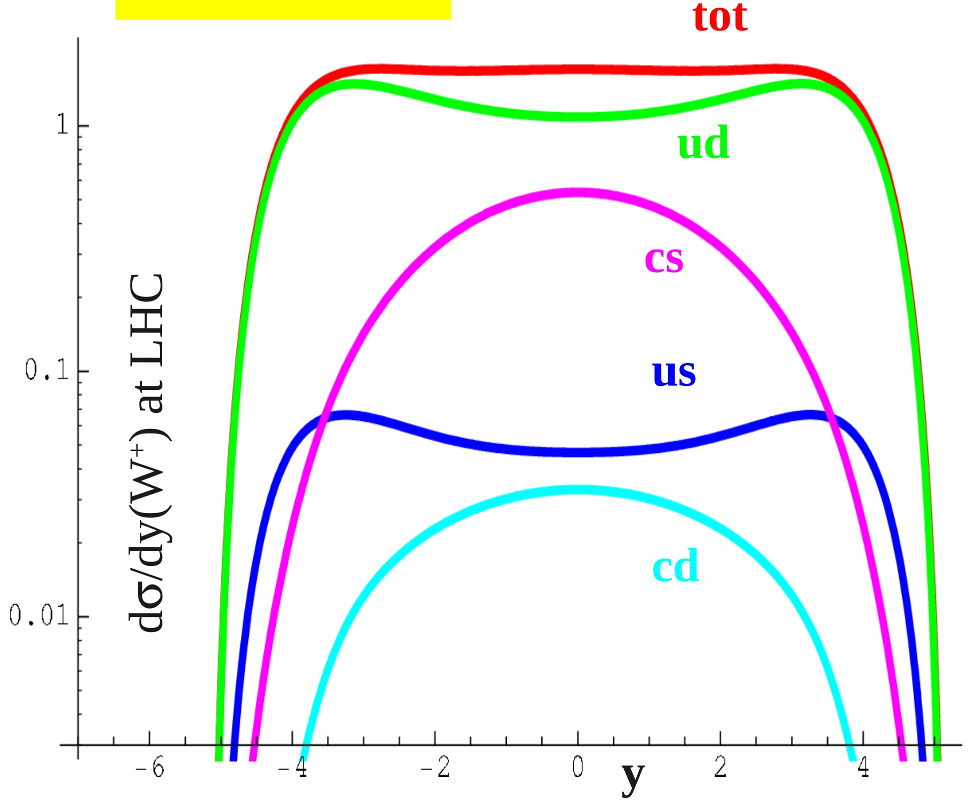
W Production at LHC: A Benchmark Cross Section

Heavy quark PDFs are essential ingredient

Tevatron

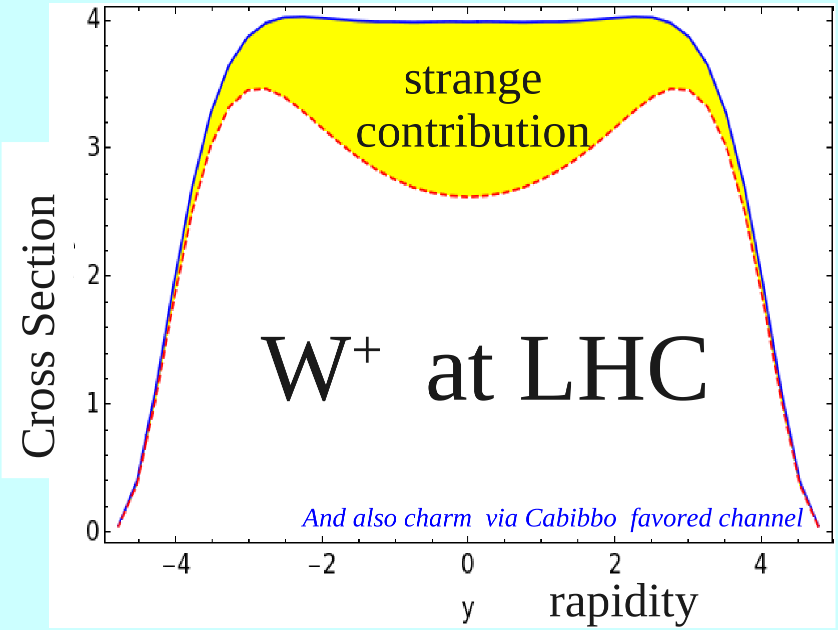


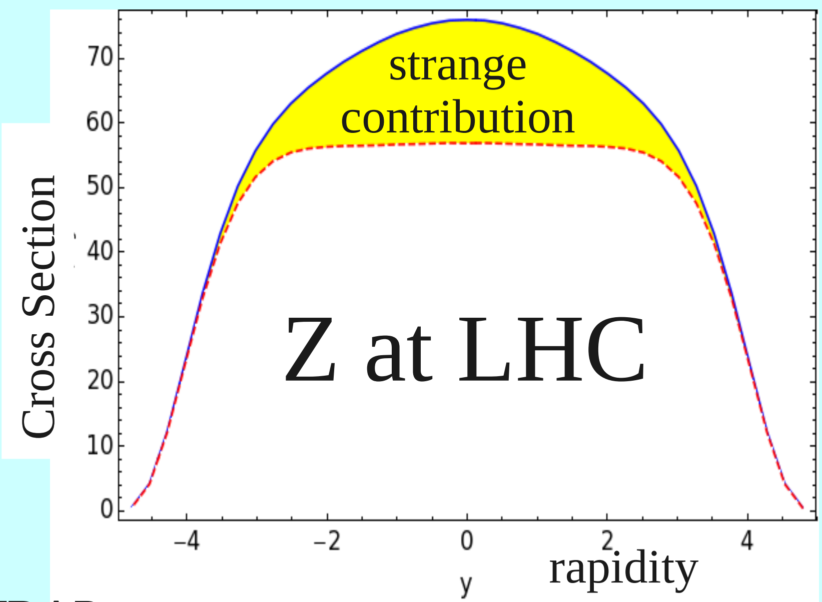
LHC



Heavy Quark components play an increasingly important role at the LHC

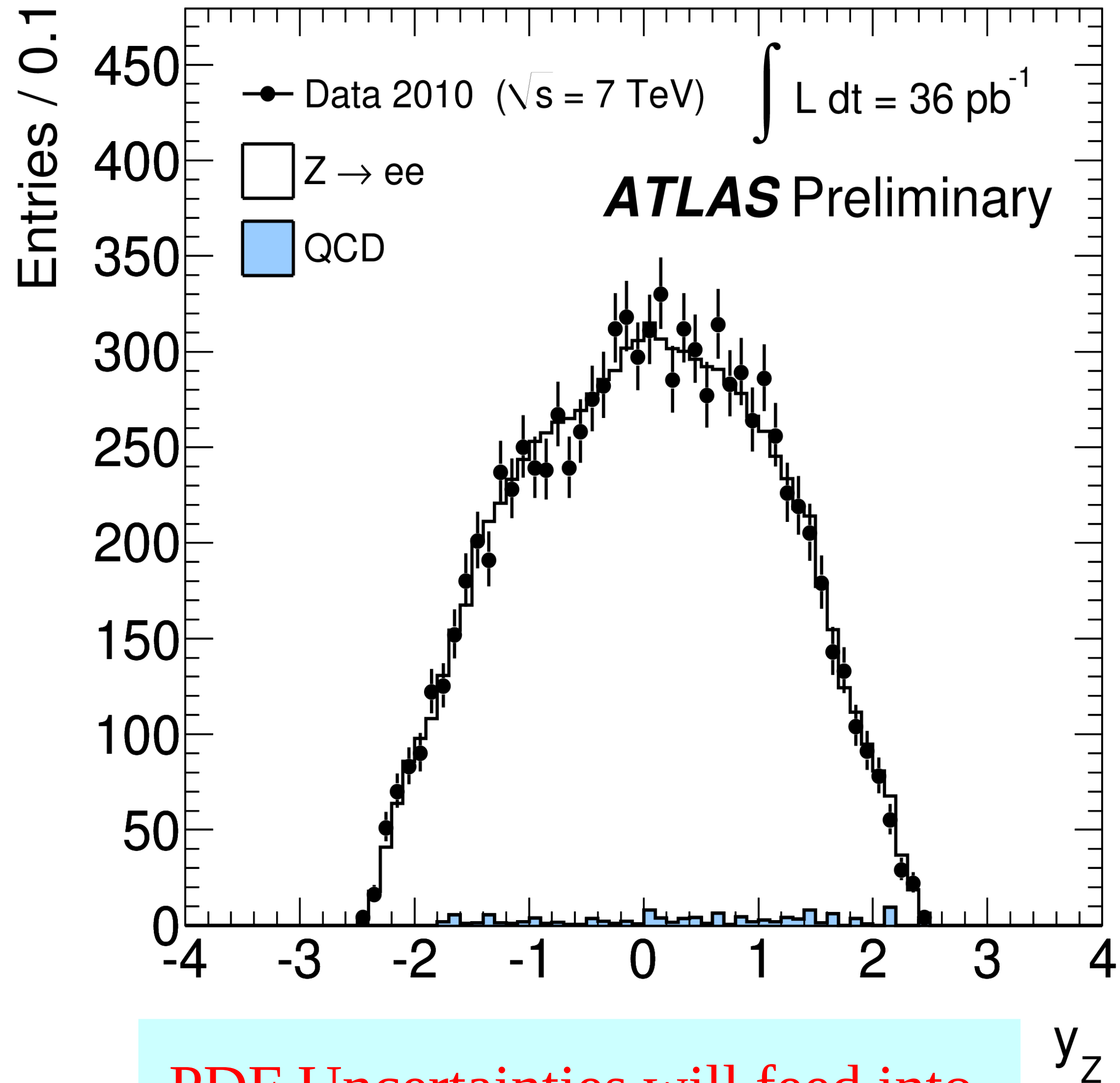
PDF Uncertainties ⇒ S(x) PDF ⇒ W/Z at LHC





VRAP Code

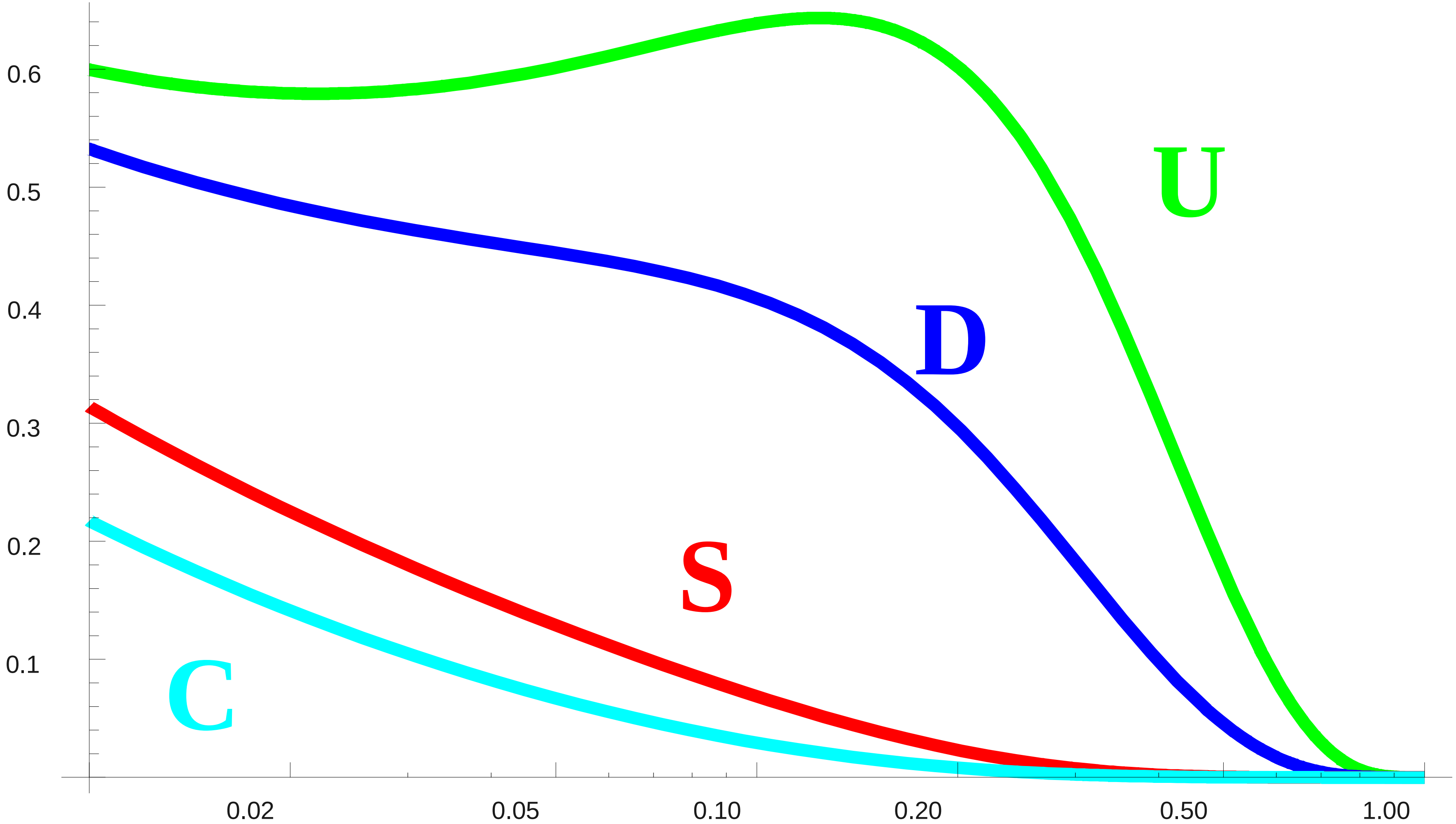
Anastasiou, Dixon, Melnikov, Petriello, Phys.Rev.D69:094008,2004.



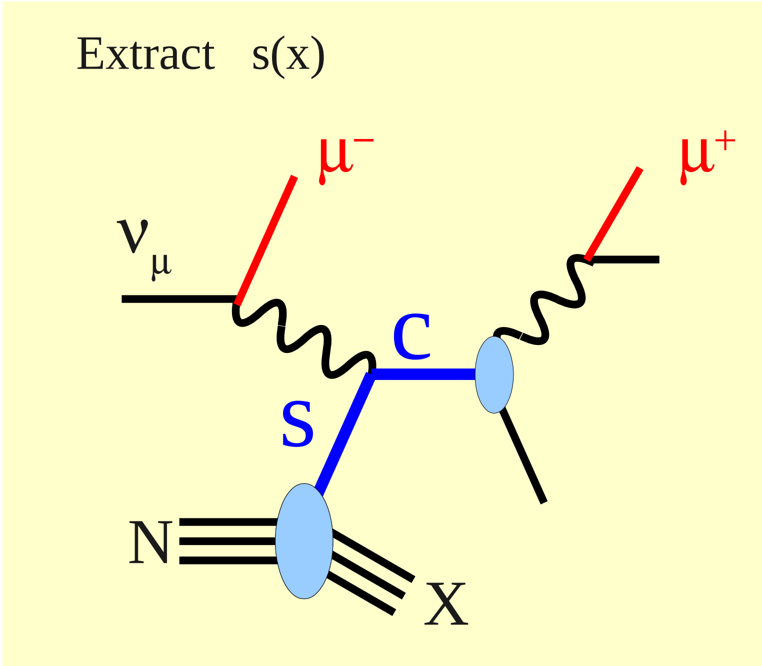
PDF Uncertainties will feed into LHC "Benchmark" processes

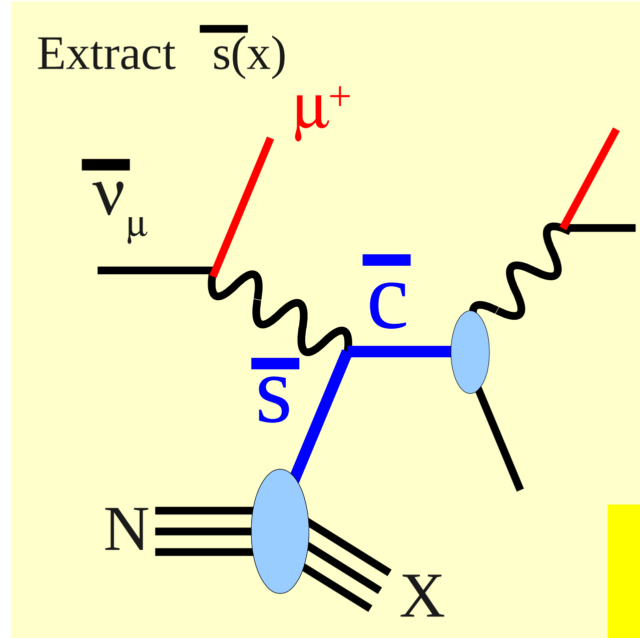
Comparison with new NNPDF sets: Les Houches 2009

What constrains the Strange???



Di-muon production ⇒ Extract s(x) Parton Distribution



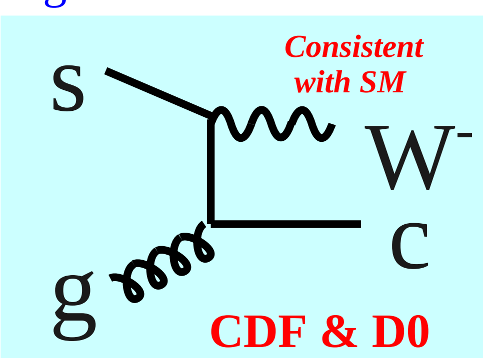


Depends on nuclear corrections

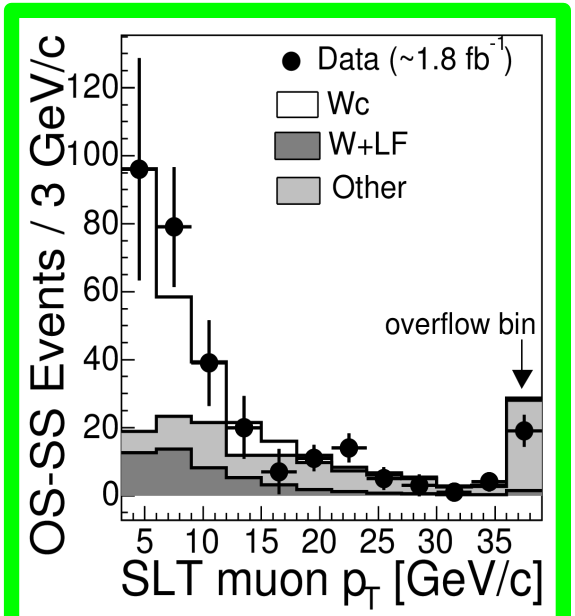
$s(x)$ and $\bar{s}(x)$ are essential in extraction of $\sin\theta_W$

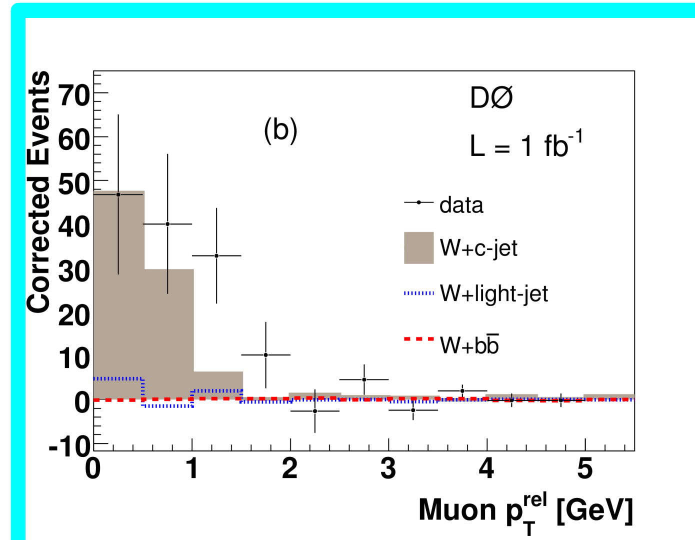
Used in CTEQ6 Fits

s g→Wc at the Tevatron



CDF: PRL 100:091803,2008.
D0: PLB666:23,2008.





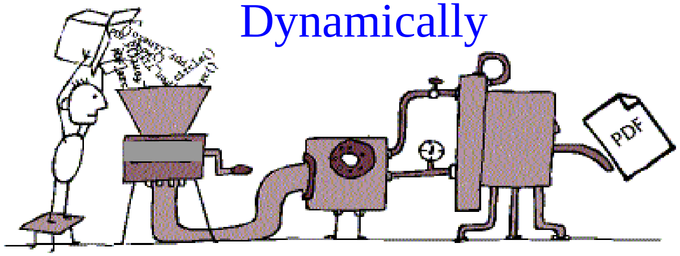
Also a challenge at LHC

Nuclear Corrections

???

Traditional Input to Global PDF Fit

Include Nuclear Dimension Dynamically



Start with Neutrino data on heavy targets (Fe, Pb, ...)

Nuclear Correction

"Corrected" data for isoscalar

Isospin Symmetry

"Corrected" data for proton

Nuclear Correction "Frozen"

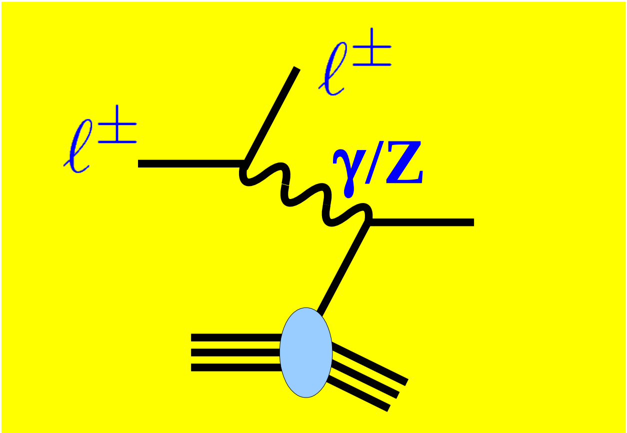
Global PDF Fit

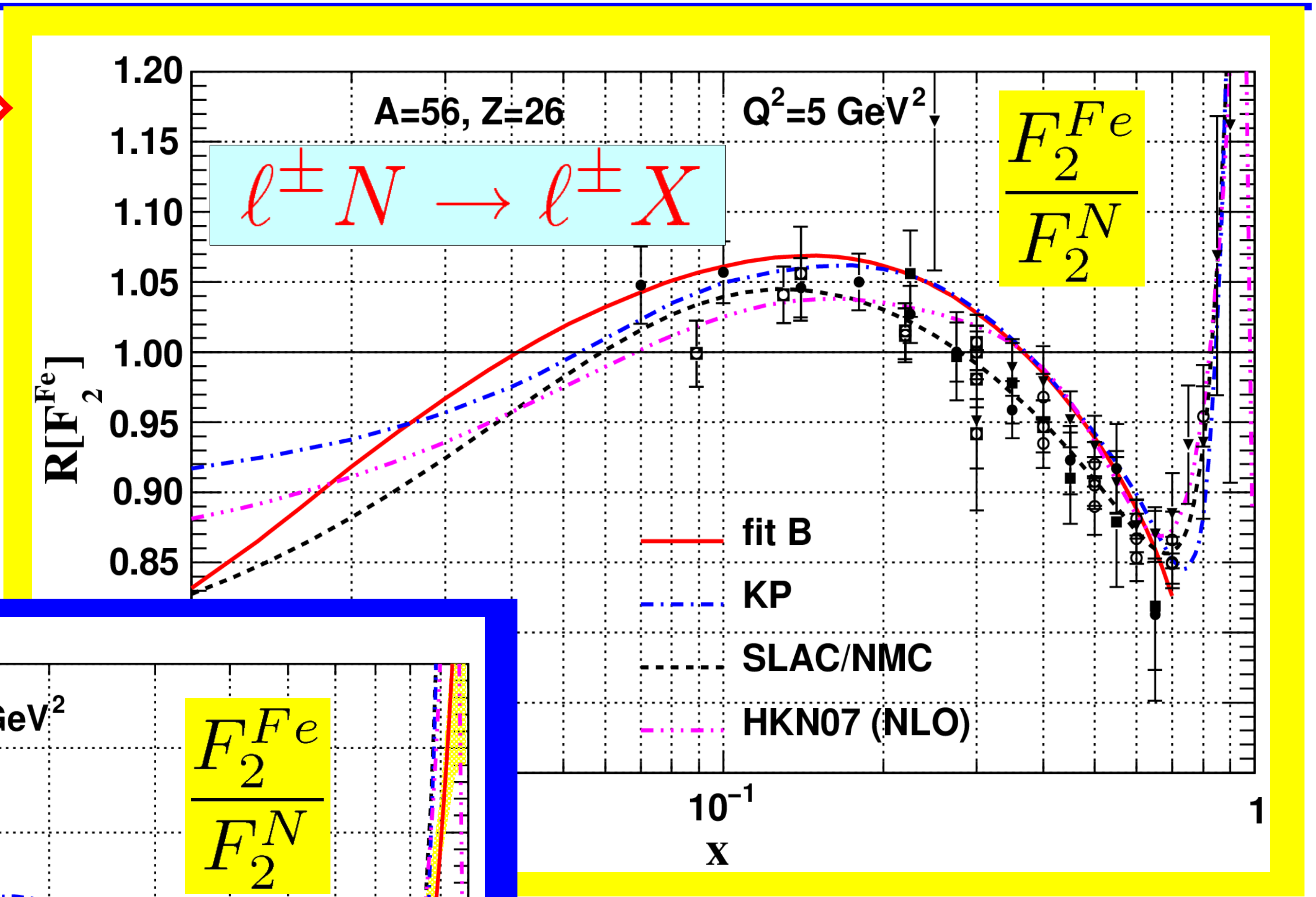
No Feedback!!!

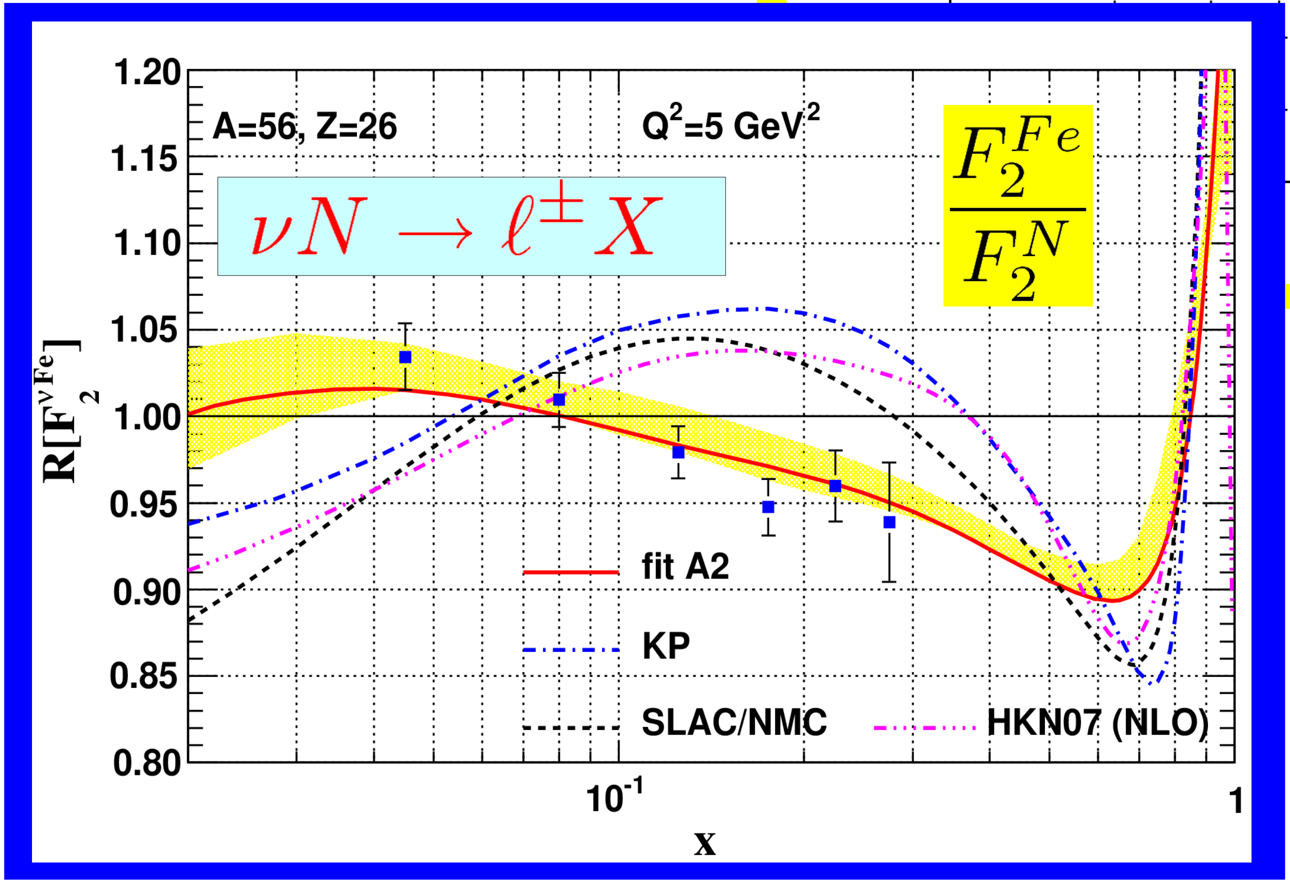
Oooooops!

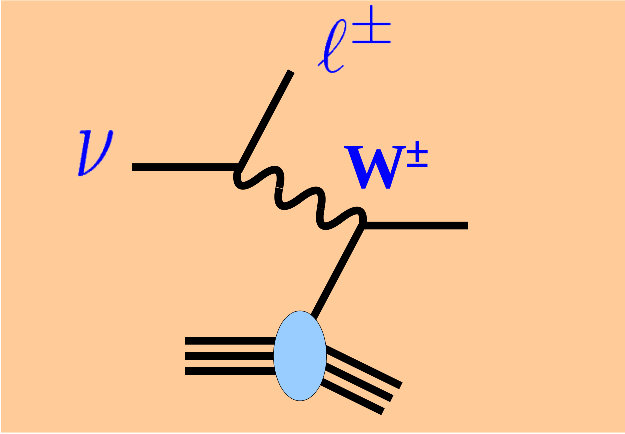
Nuclear Corrections: Compare Neutrino and Charged Lepton DIS

Charged Lepton DIS ⇒









⇐ Neutrino DIS

nCTEQ Nuclear PDF's

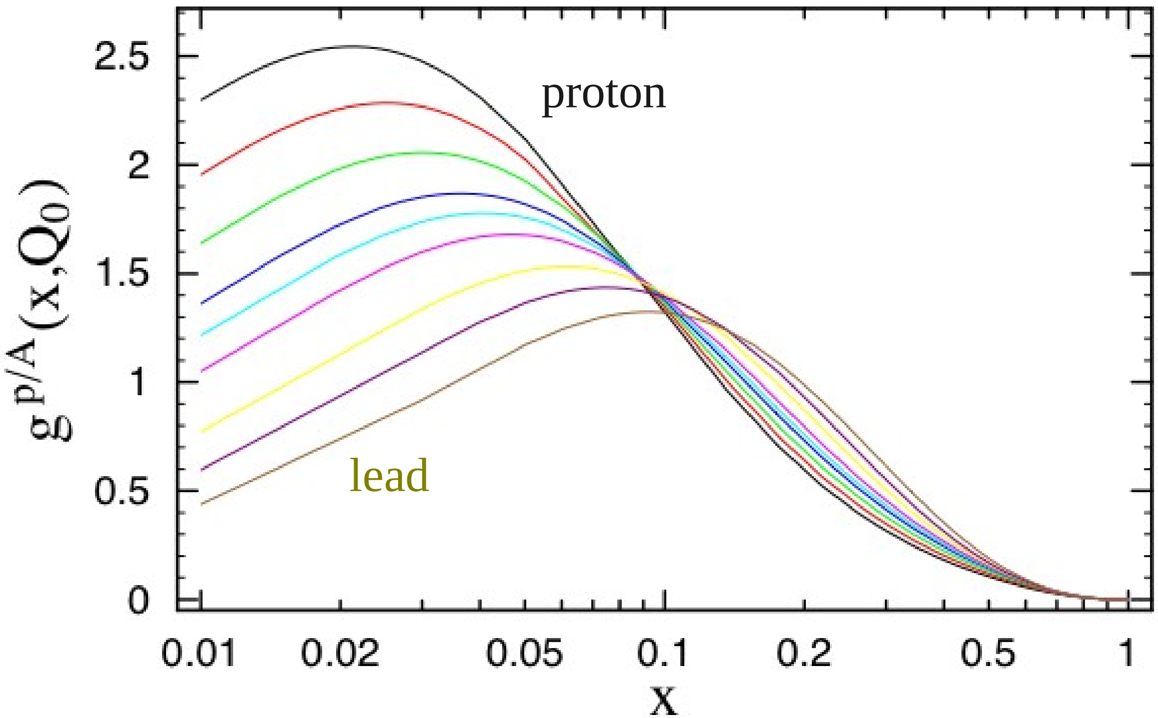
- ✔ CTEQ style global fit extended
  handle various nuclear targets
- ✔ CTEQ Data + nuclear DIS & DY
  [~15 targets; ~2000+ data]
- ✔ A-dependence modeled;
  NLO fits work well

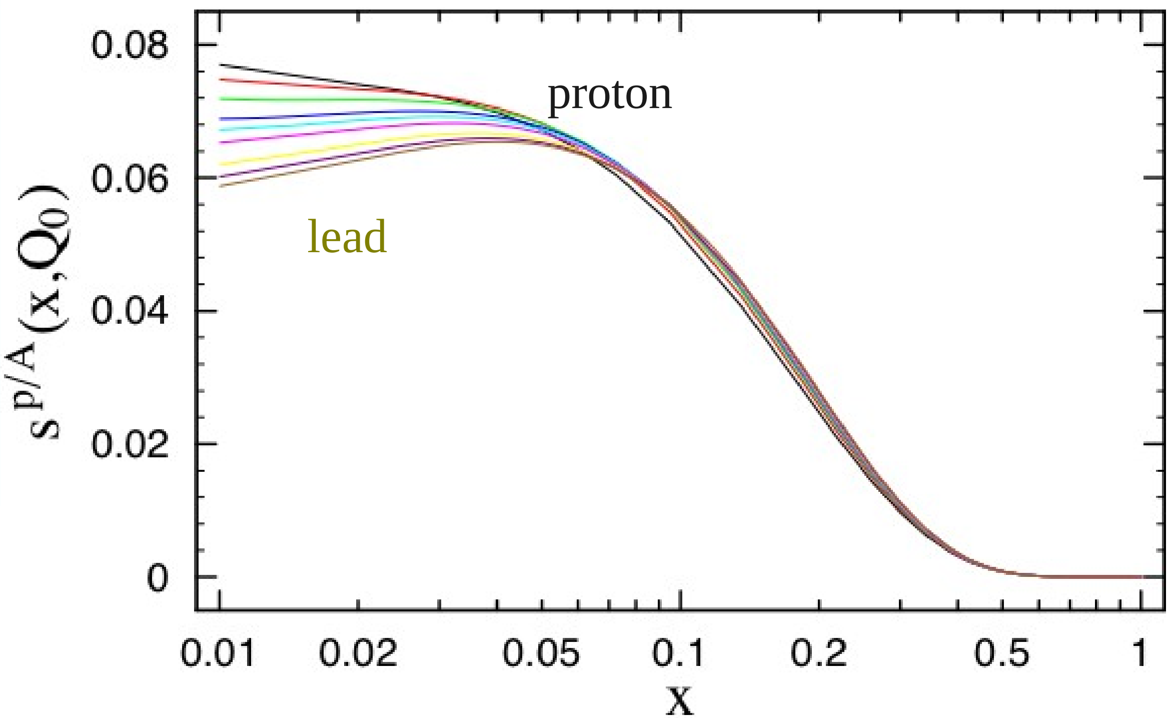
A-Dependent PDFs

$$xf(x) = x^{a_1}(1-x)^{a_2}e^{a_3 x}(1+e^{a_4}x)^{a_5}$$

$$a_i \to a_i(A)$$

$$a_k = a_{k,0} + a_{k,1}\left(1 - A^{-a_{k,2}}\right)$$





Nuclear PDFs from neutrino deep inelastic scattering.
I. Schienbein, J.Y. Yu, C. Keppel, J.G. Morfin,
F. Olness, J.F. Owens. Phys.Rev.D77:054013,2008.

Nuclear CTEQ parton distribution functions - Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://projects.hepforge.org/ncteq/

The CTEQ Meta-Page | Nuclear CTEQ parton distri...

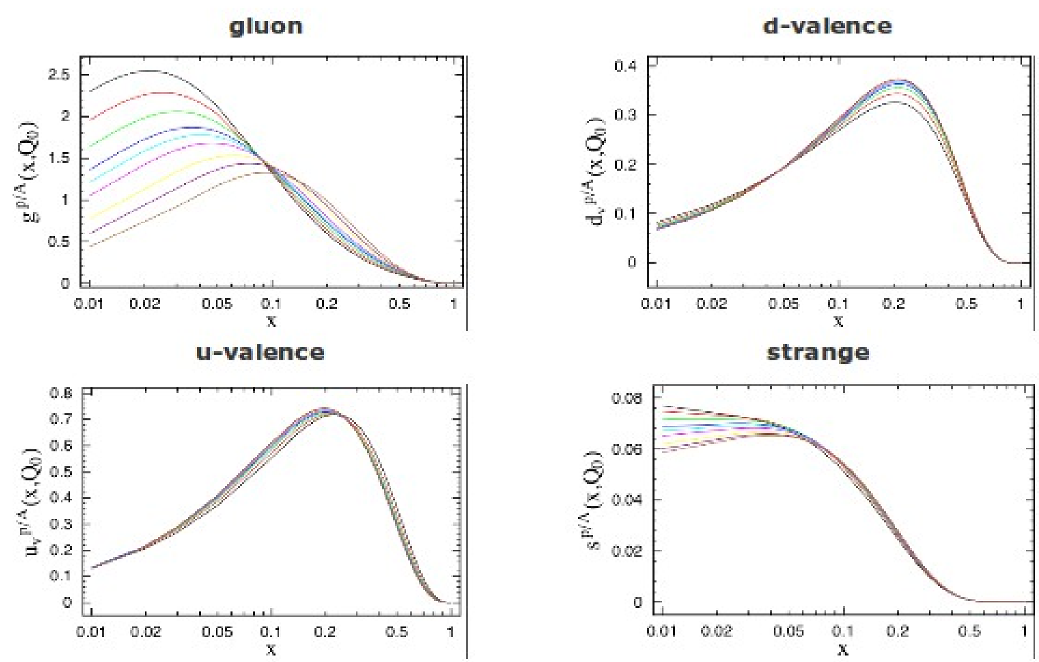
nCTEQ Go! hosted by **CEDAR HepForge**

nCTEQ

nuclear parton distribution functions

- Home
- PDF grids & code
- Papers & Talks
- Subversion
- Tracker
- Wiki

nCTEQ project is an extension of the CTEQ collaborative effort to determine parton distribution functions inside of a free proton. It generalizes the free-proton PDF framework to determine densities of partons in bound protons (hence nCTEQ which stands for nuclear CTEQ). More details on the framework and the first results can be found in arXiv:09072357 [hep-ph].
The effects of the nuclear environement on the parton densities can be shown as modified parton densities



where all black curves stand for free proton PDF and red, green, blue, cyan, pink, yellow, magenta and brown curves show PDF in protons bound in nuclei - from deuterium (red) to lead (brown).

Done

K Kovarik,
I. Schienbein,
J.Y. Yu,
T. Stavreva,
T Jezo,
C. Keppel,
J.G. Morfin,
F. Olness,
J.F. Owens.

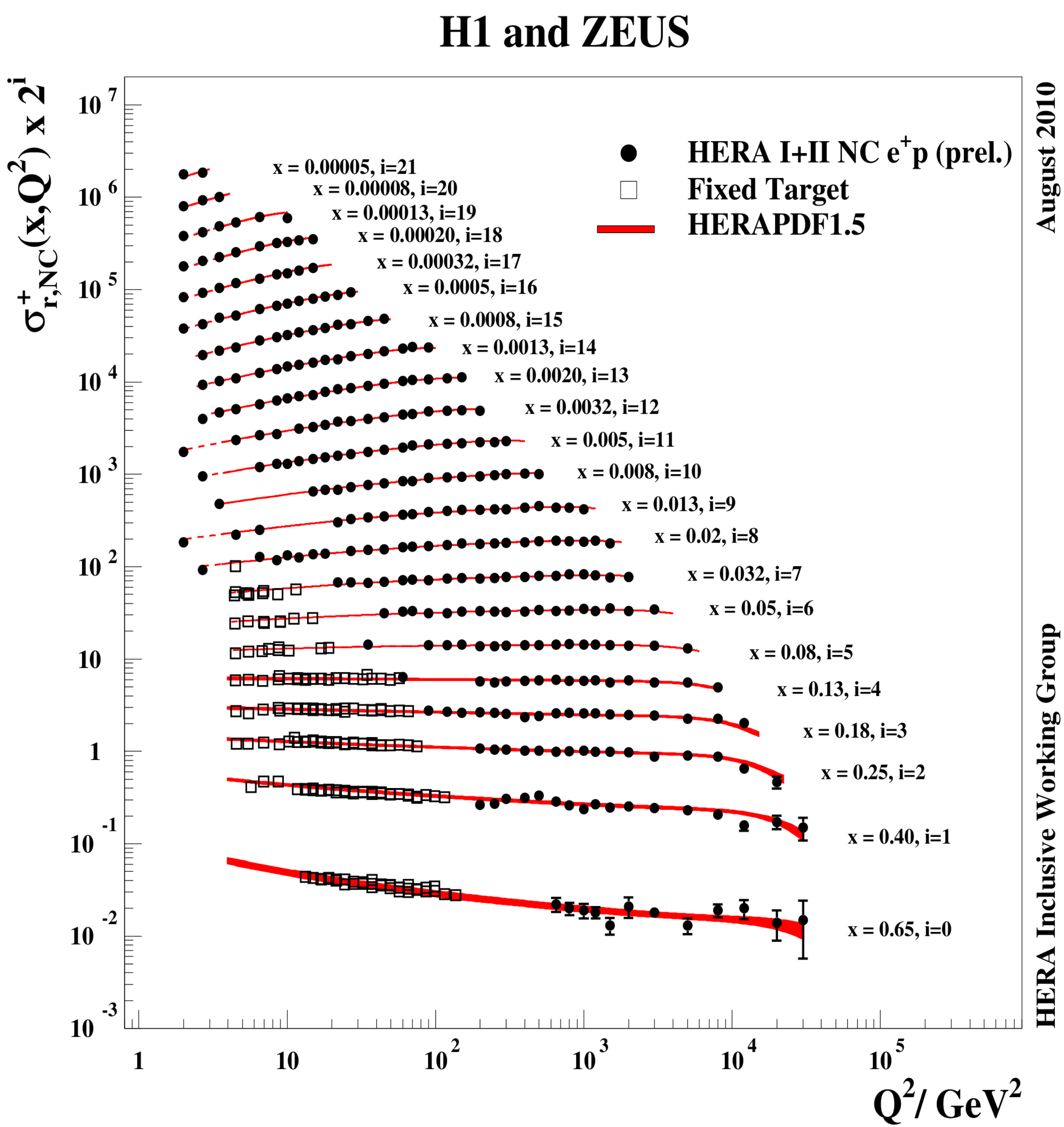
… what about the

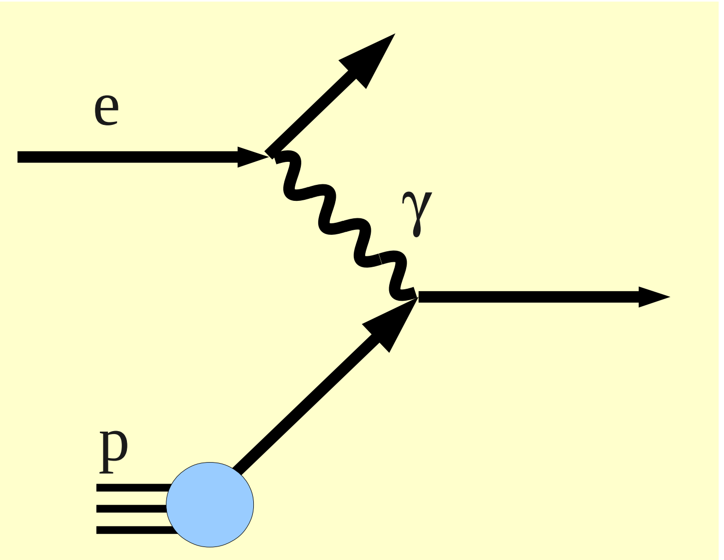
Heavy Quarks

c & b

Extrinsic & Intrinsic

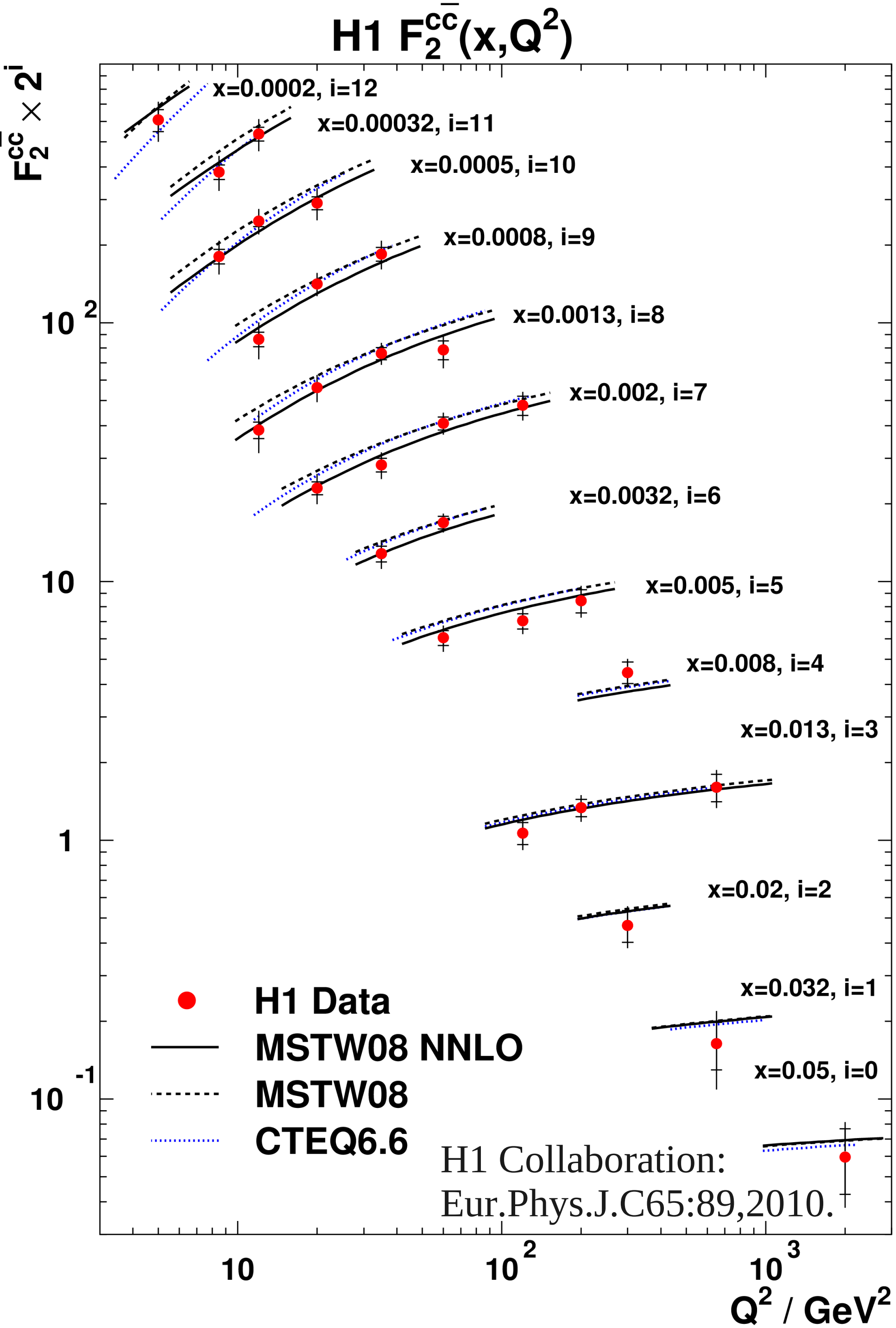
F2 from HERA: Essential ingredient for PDF analysis



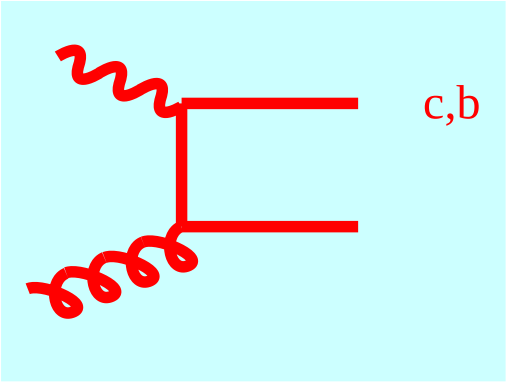


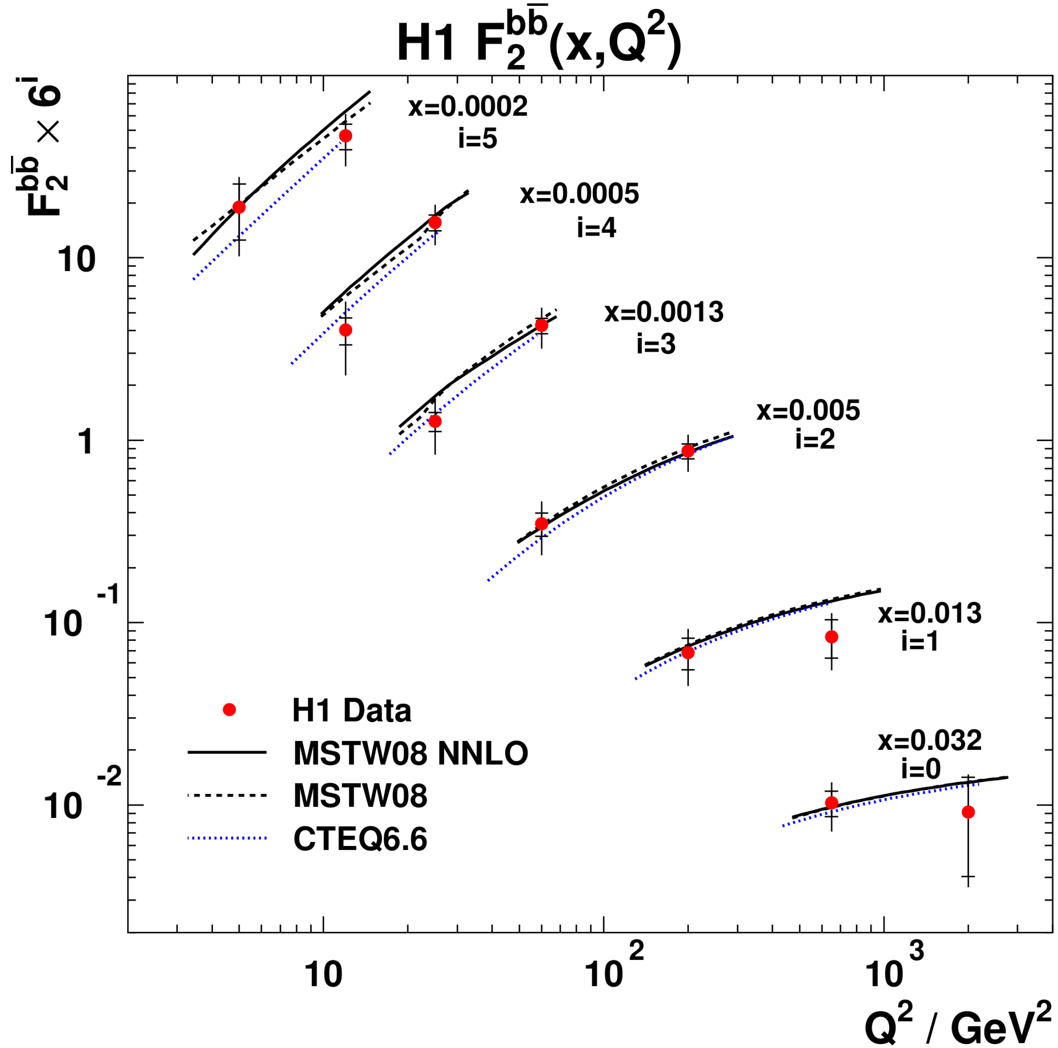
$$F_2^{ep} \sim \frac{4}{9}(u+\bar{u}+c+\bar{c}) + \frac{1}{9}(d+\bar{d}+s+\bar{s})$$

Heavy Flavor Components will play prominent role at LHC



c & b tied to gluon PDFs

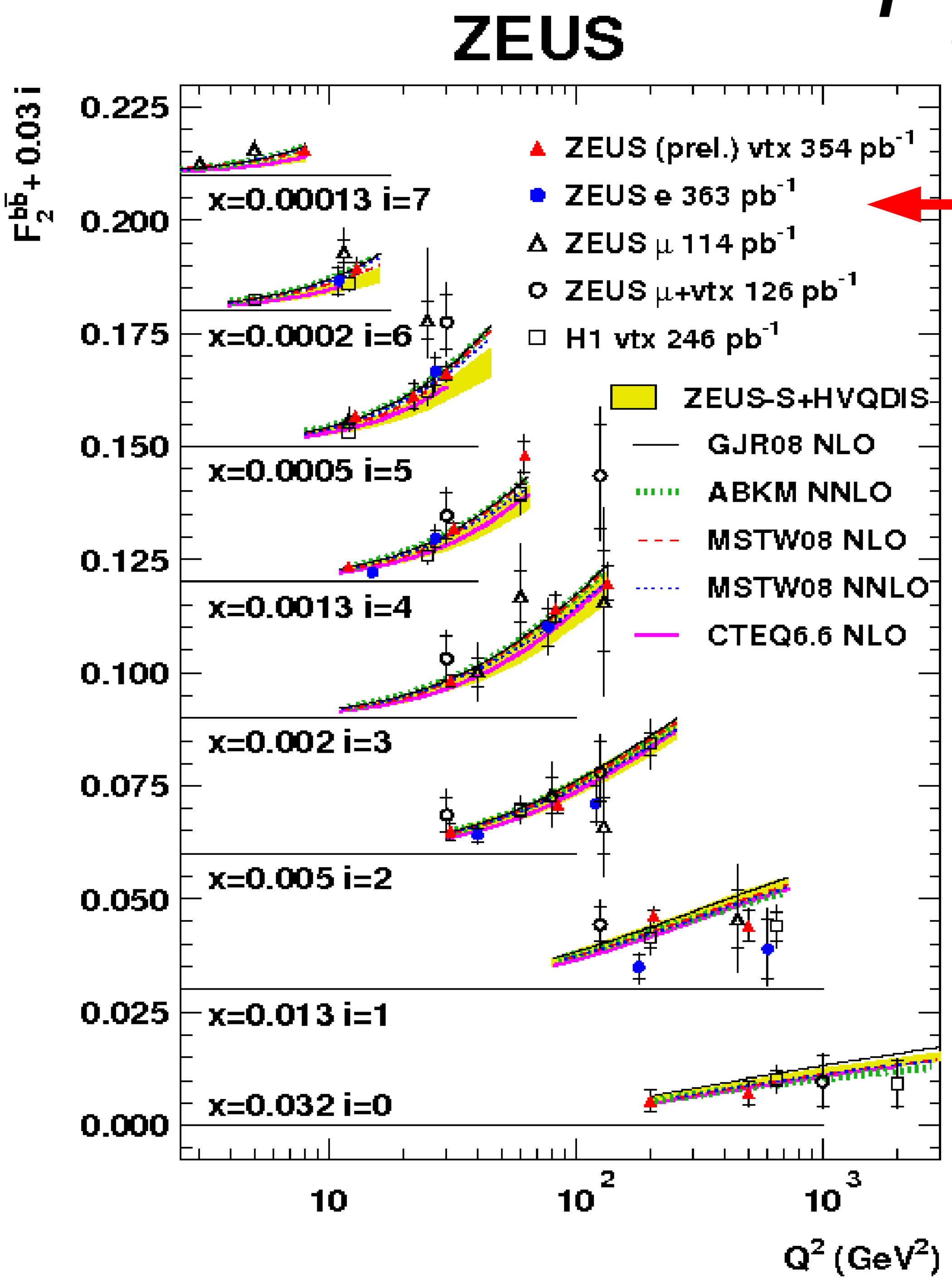




$F_2^{b\bar{b}}$

DIS 2011

XIX International Workshop on Deep Inelastic Scattering and Related Subjects



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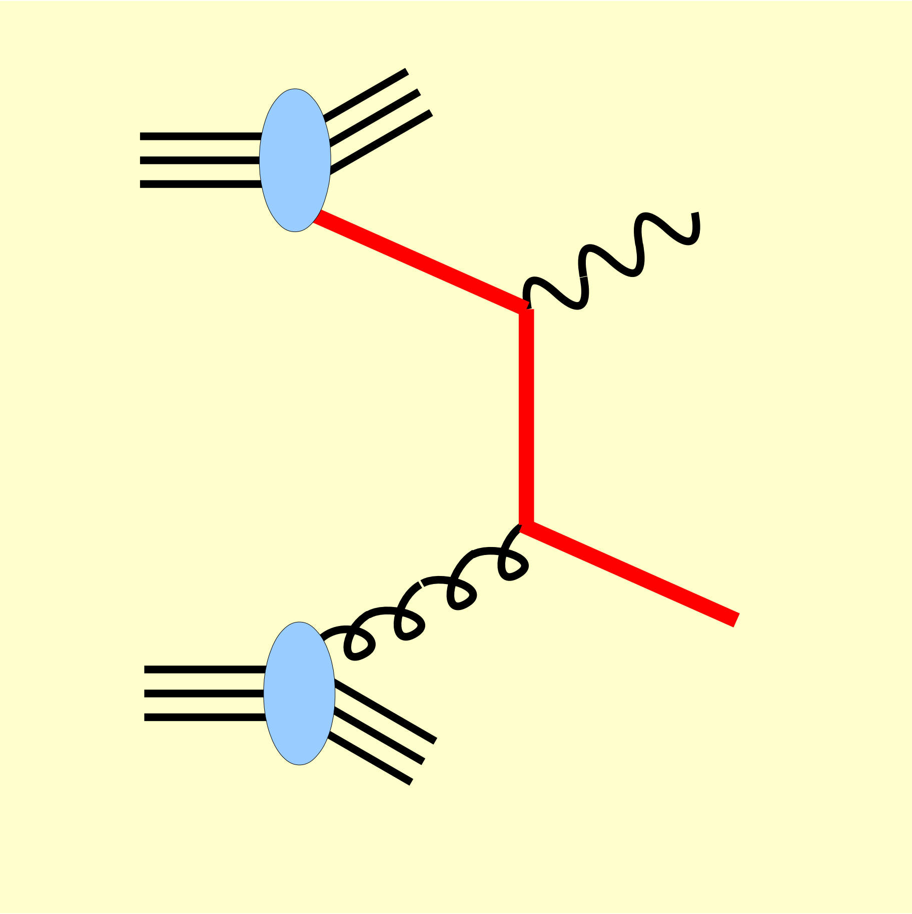
Ramoona Shehzadi

HF prod in DIS
electron channel

Vladyslav Libov

HF prod in DIS w/ inclusive
secondary vertex

Alternate Access Heavy Flavor Components



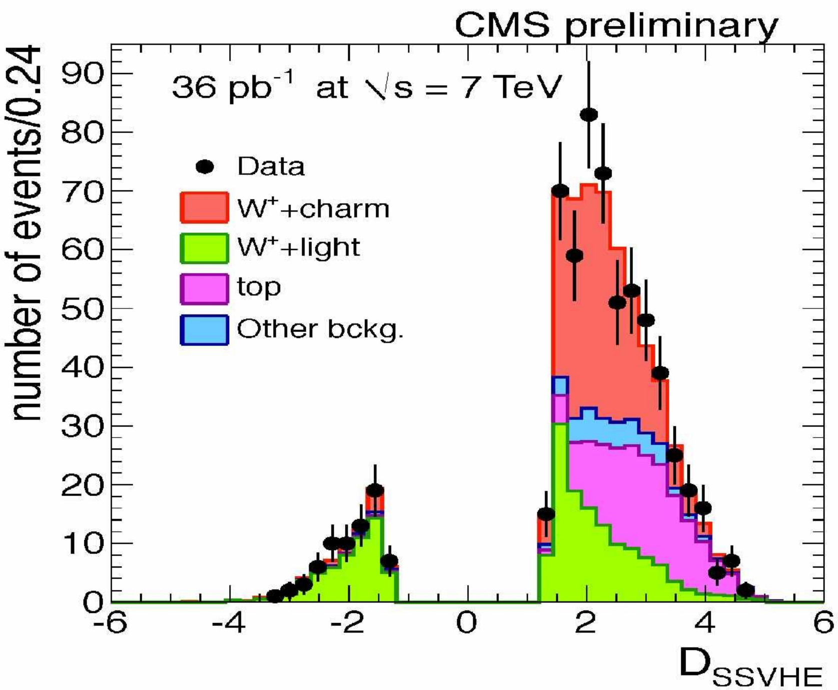
$c\, g \rightarrow c\, \gamma$

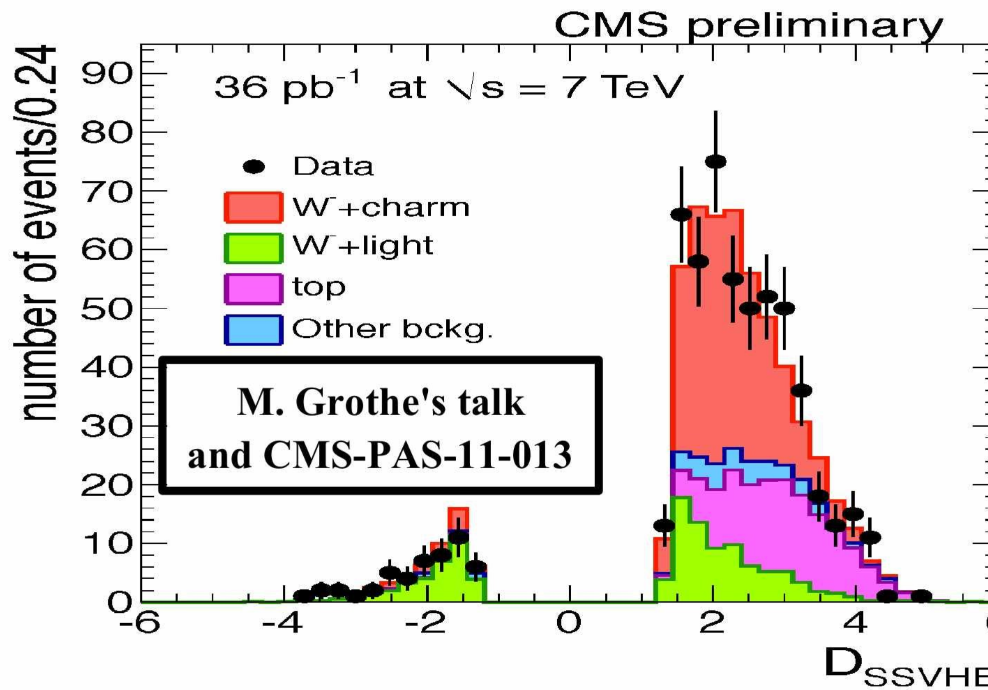
$b\, g \rightarrow b\, \gamma$

$s\, g \rightarrow c\, W$

$c\, g \rightarrow b\, W$

First LHC results on W+charm (CMS)





- Sensitive to strange quark PDFs (process dominated by s+g → W + charm):
  - PDF uncertainties from the second quark generation are a potential source of uncertainty for the W mass measurement at the LHC
  - Data-driven control of light-quark and top backgrounds
  - Enormous margin for improvement (only 2010 statistics used), new method (secondary vertex tagging), complementary to the one employed until now at Tevatron (semileptonic charm decay tagging):

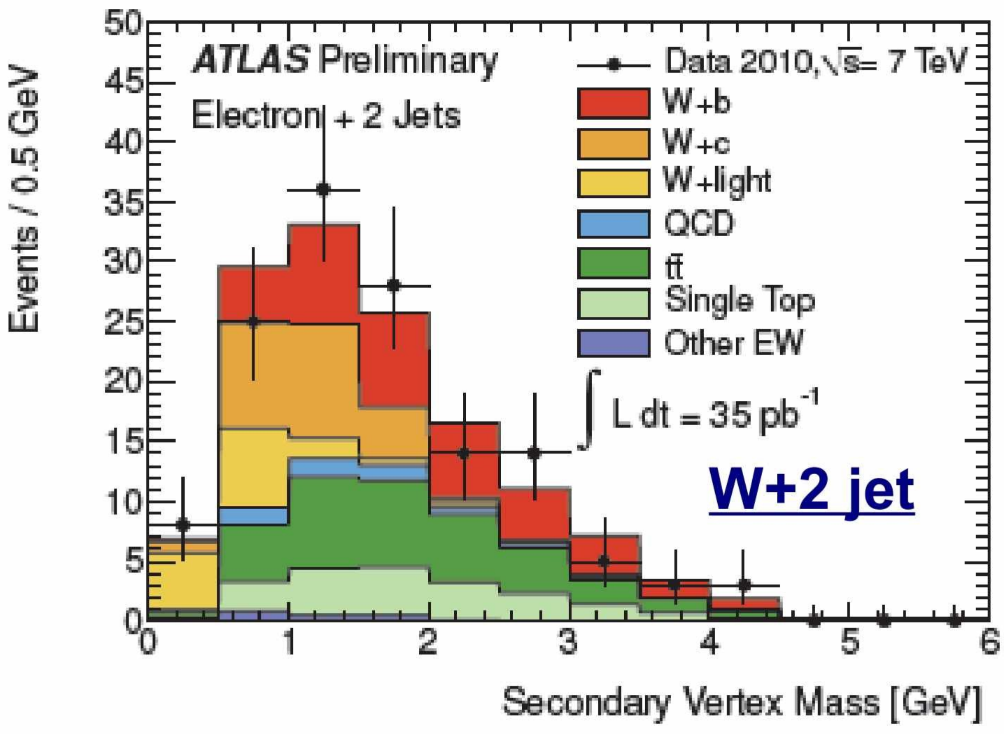
$$\underline{For \quad p_T^{jet} > 20 \quad GeV, |\eta^{jet}| < 2.1}:$$

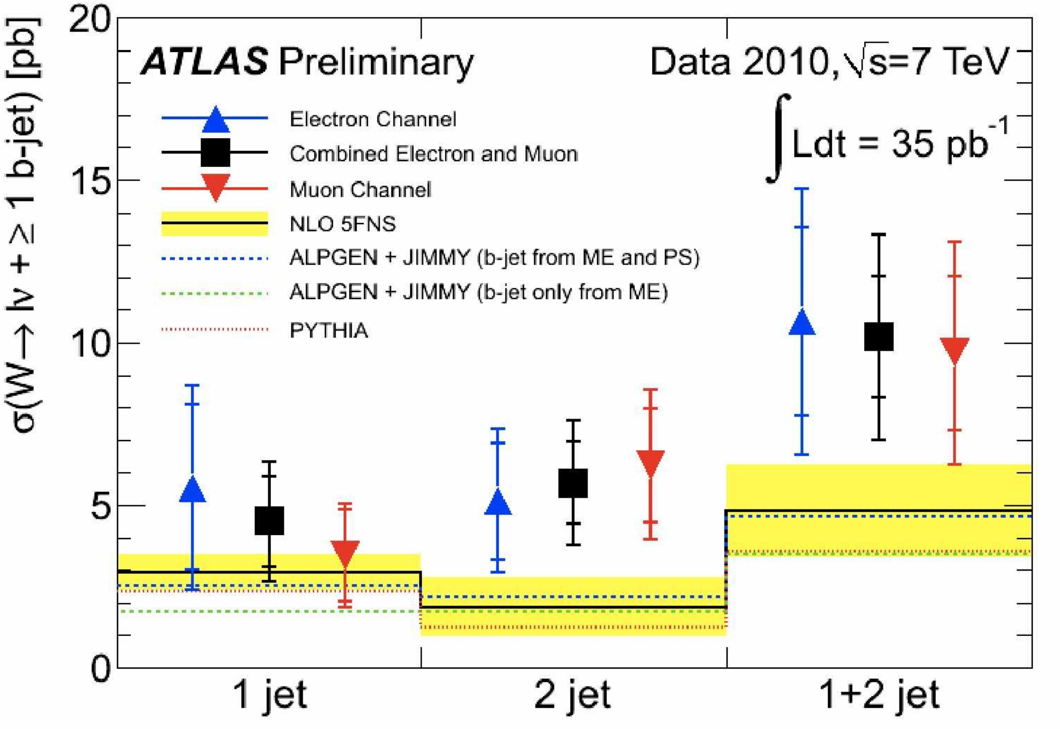
$$\frac{\sigma(W^+ + charm)}{\sigma(W^- + charm)} = 0.92 \pm 0.19(stat.) \pm 0.04(syst.); \quad \frac{\sigma(W + charm)}{\sigma(W + jets)} = 0.142 \pm 0.015(stat.) \pm 0.024(syst.)$$

First LHC W+b results (ATLAS)

- **Important background for Higgs searches: W+H (H → $b\bar{b}$) at low Higgs masses. Also a background for $t\bar{t}$ and single-top measurements**
- **W+b excess over expectations published by CDF**

A. Messina's talk

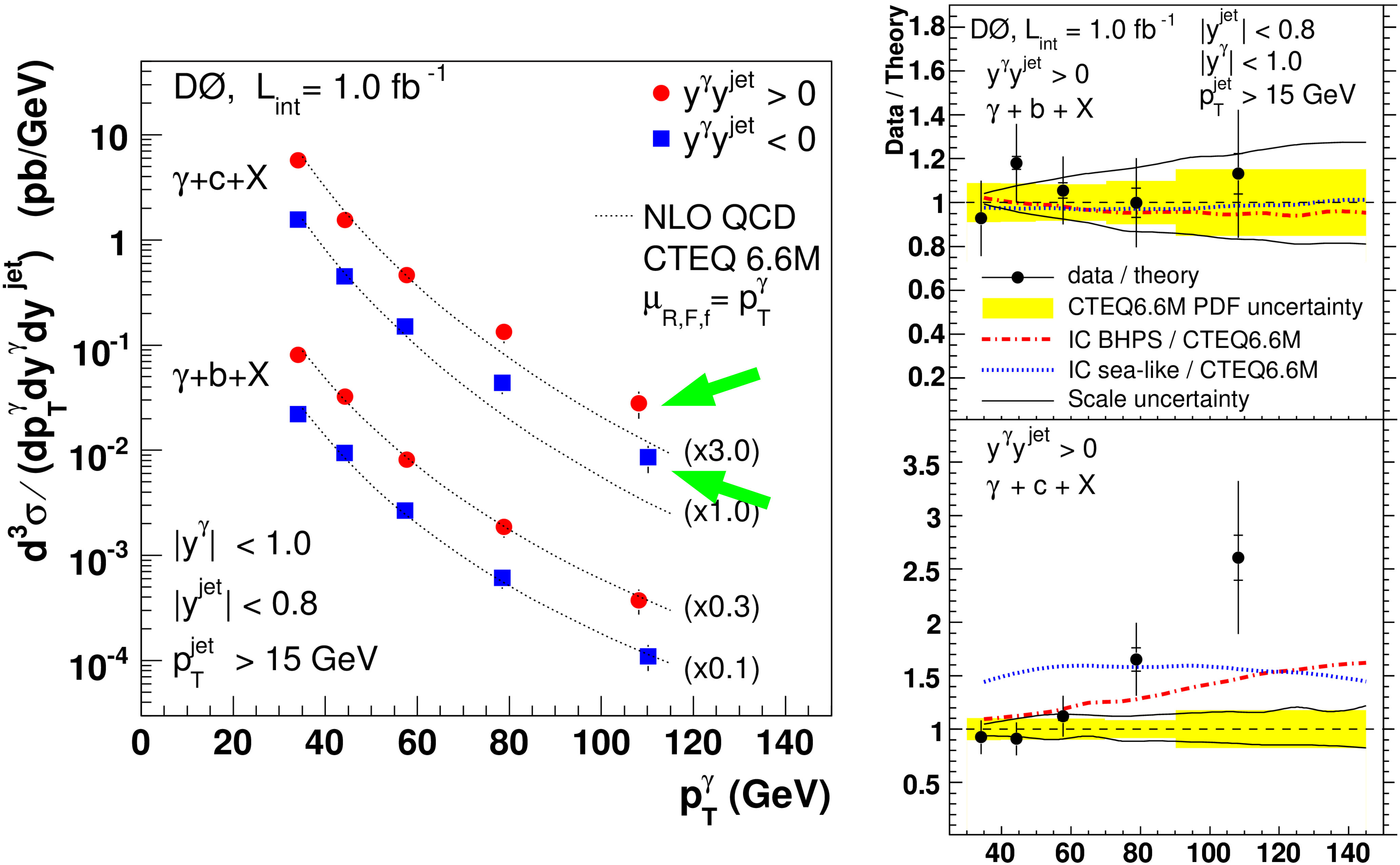




- **Significant decay length (>5.85 σ), fit to the reconstructed mass at secondary vertex**
- **Challenging analysis: it requires significant reduction and control of top backgrounds and W+charm. Analysis performed independently for 1 and 2 b-tags in the event**

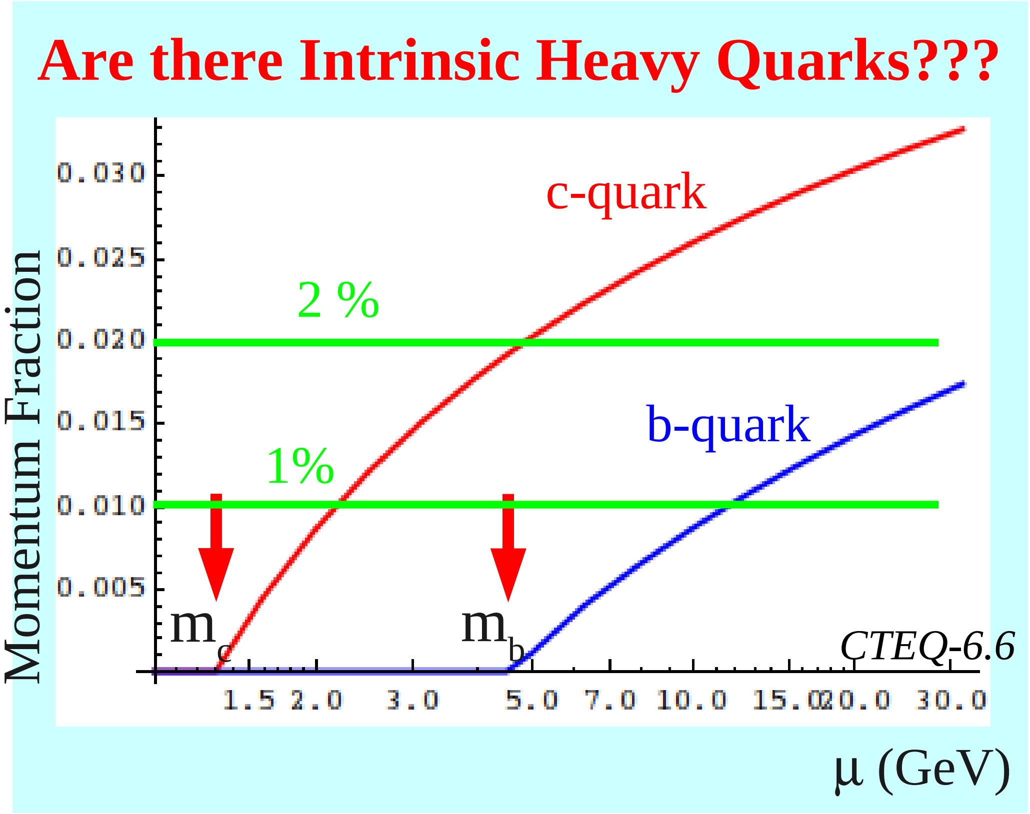
Agreement with theoretical predictions at the 1.5 σ level

Heavy Quarks at the Tevatron



D. Duggan (D0) arXiv:0906.0136

Are there Intrinsic Heavy Quarks???   Do they matter???

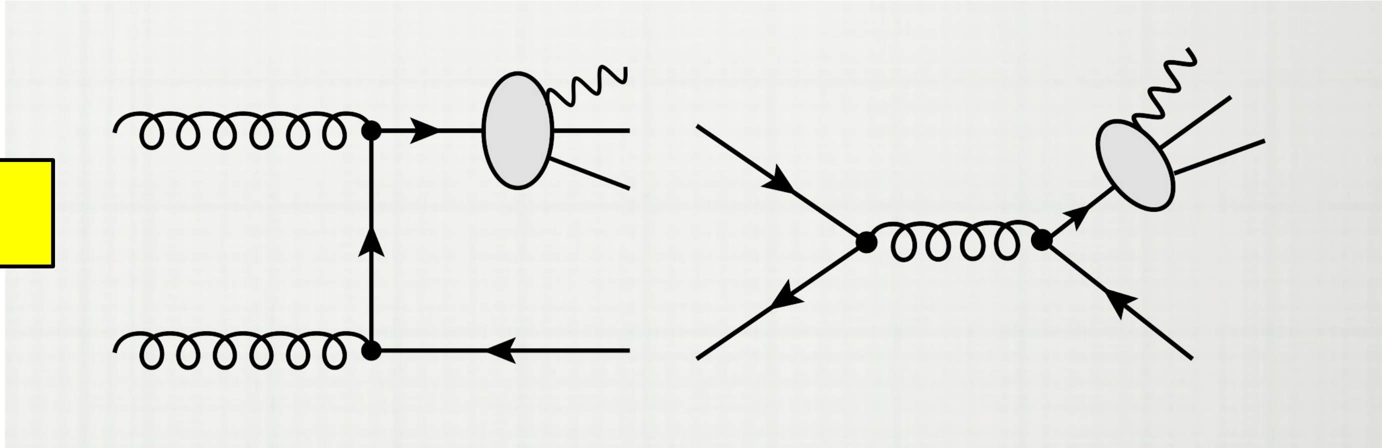


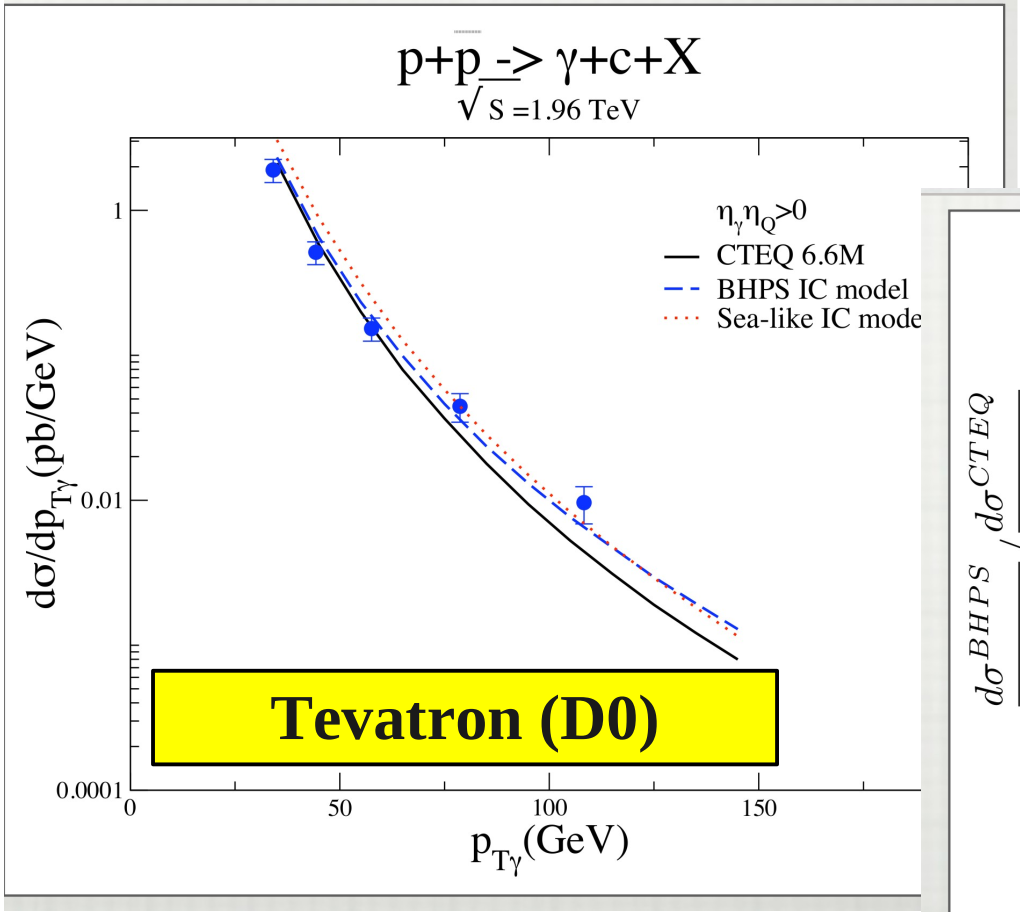
* Most sensitive near threshold
* What happens if we allow the evolution to determine charm?

Zero:	No intrinsic charm
Positive:	Intrinsic charm
Negative:	Inconsistent

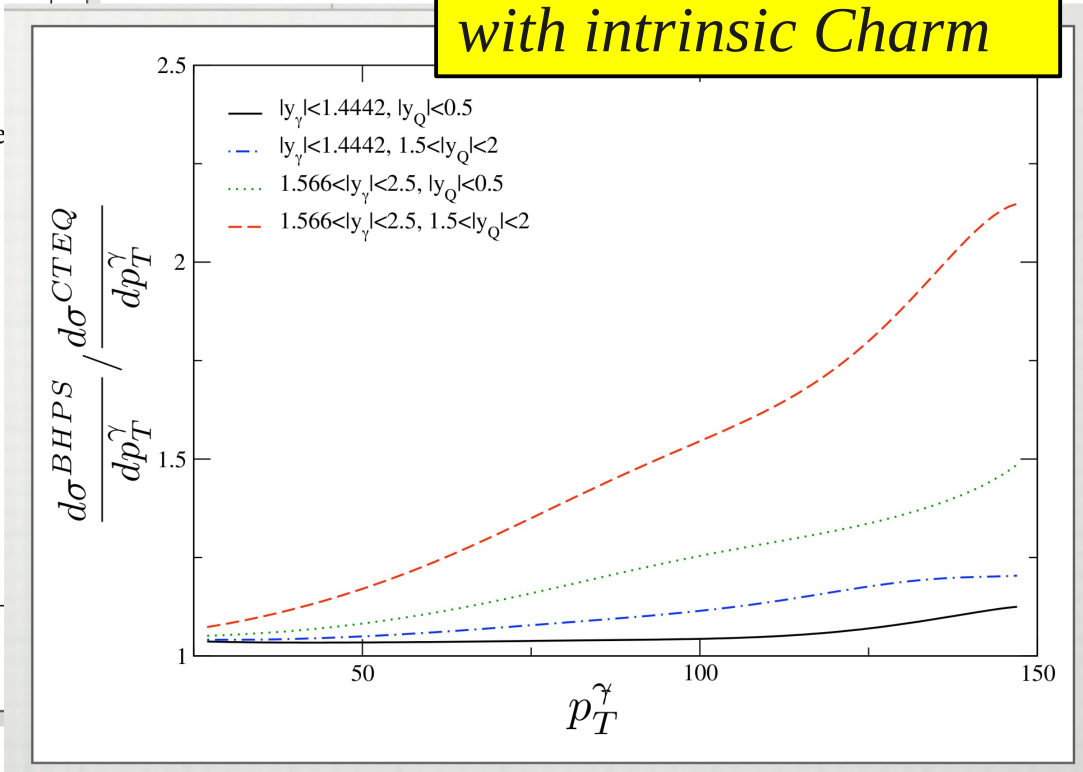
Karol Kovarik

γ+HQ prod. in pp & pA





Tevatron (D0)



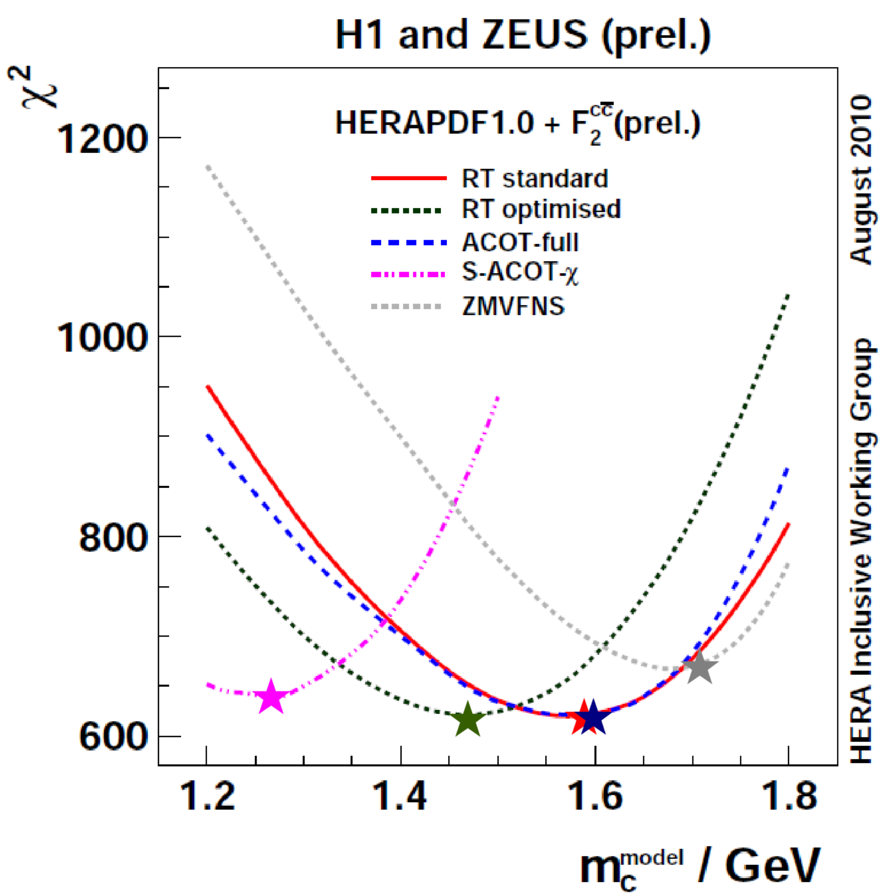
LHC (CMS)
with intrinsic Charm

The role of the quark masses

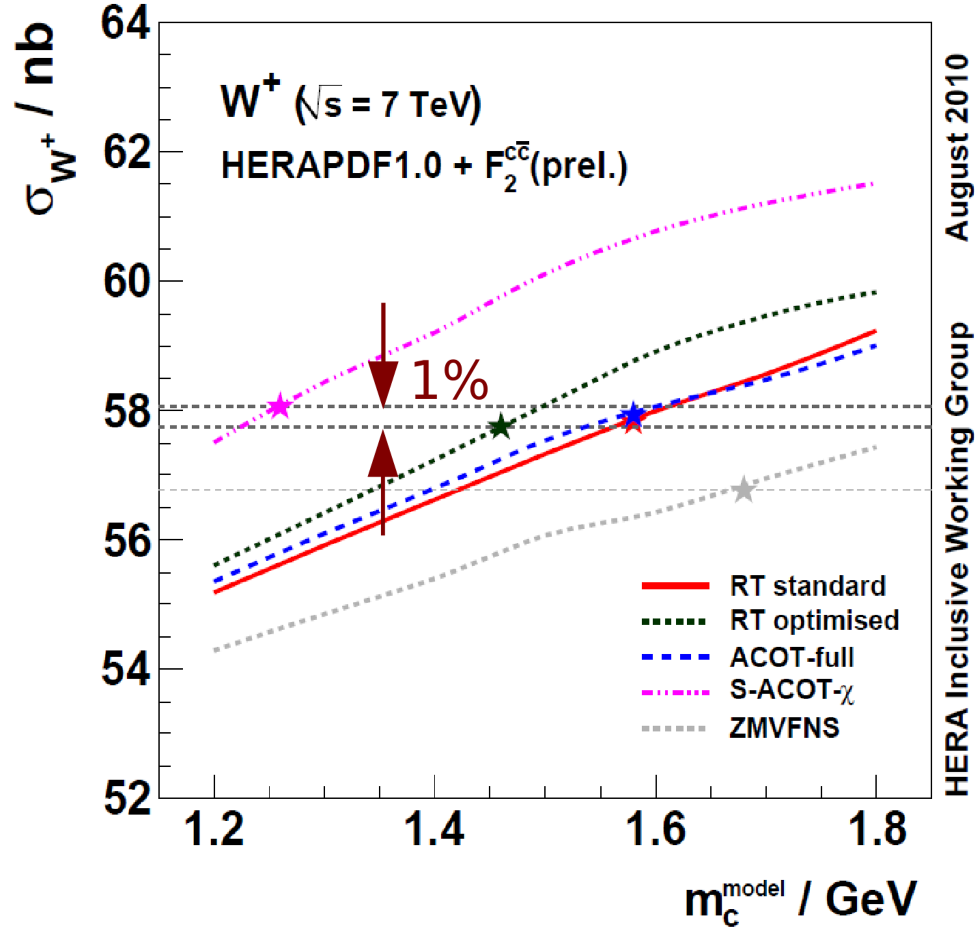
Constraints on PDFs from HERA Charm Data

Ringaile Placakyte

Inclusive ep data + F_2^{cc} for different HQ schemes



Impact of mc on W σ at LHC



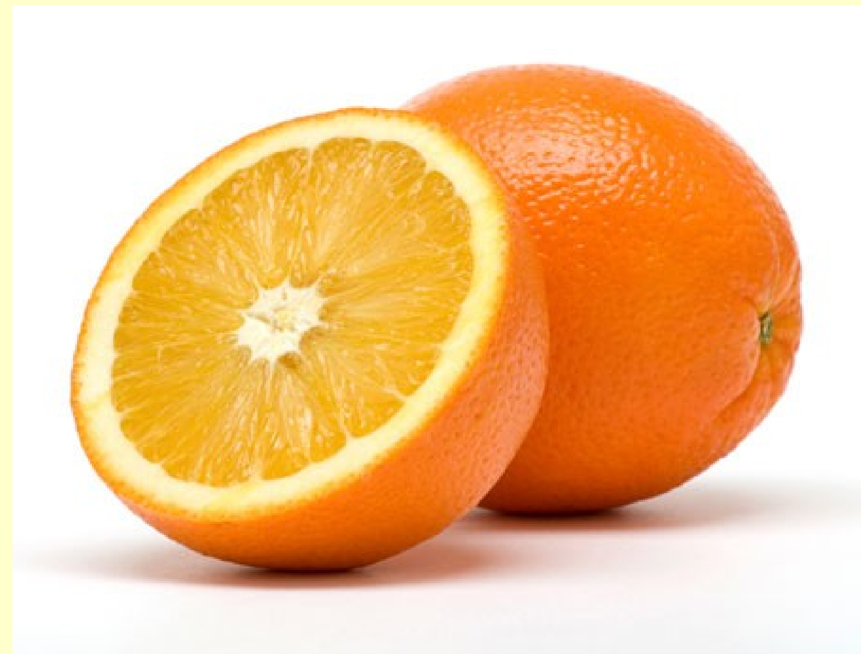
Different HQ schemes have different optimal m_c^{model}

What is the proper treatment of masses???

2009 Les Houches Comparative Studies

The SM and NLO Multileg Working Group: Summary report.

e-Print: arXiv:1003.1241 [hep-ph]



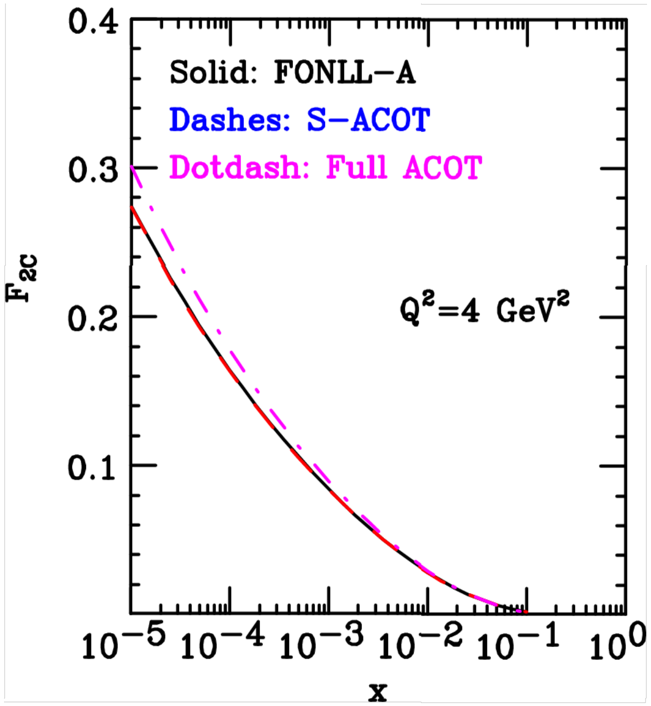
Physics at TeV Colliders

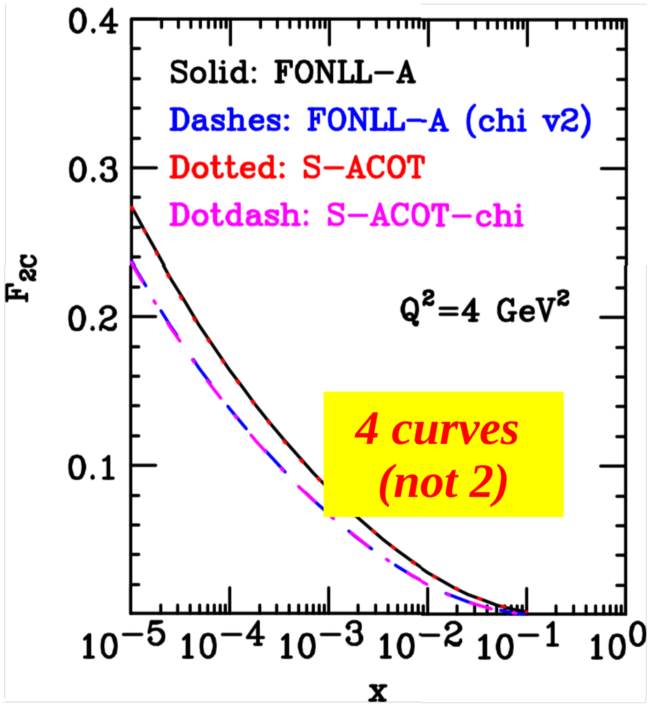
Les Houches 8-26 June 2009

LES HOUCHES

centre de physique

Les Houches Comparative Study





ACOT & S-ACOT essentially identical

... scheme differences are higher order

FONNL & S-ACOT

Numerically similar

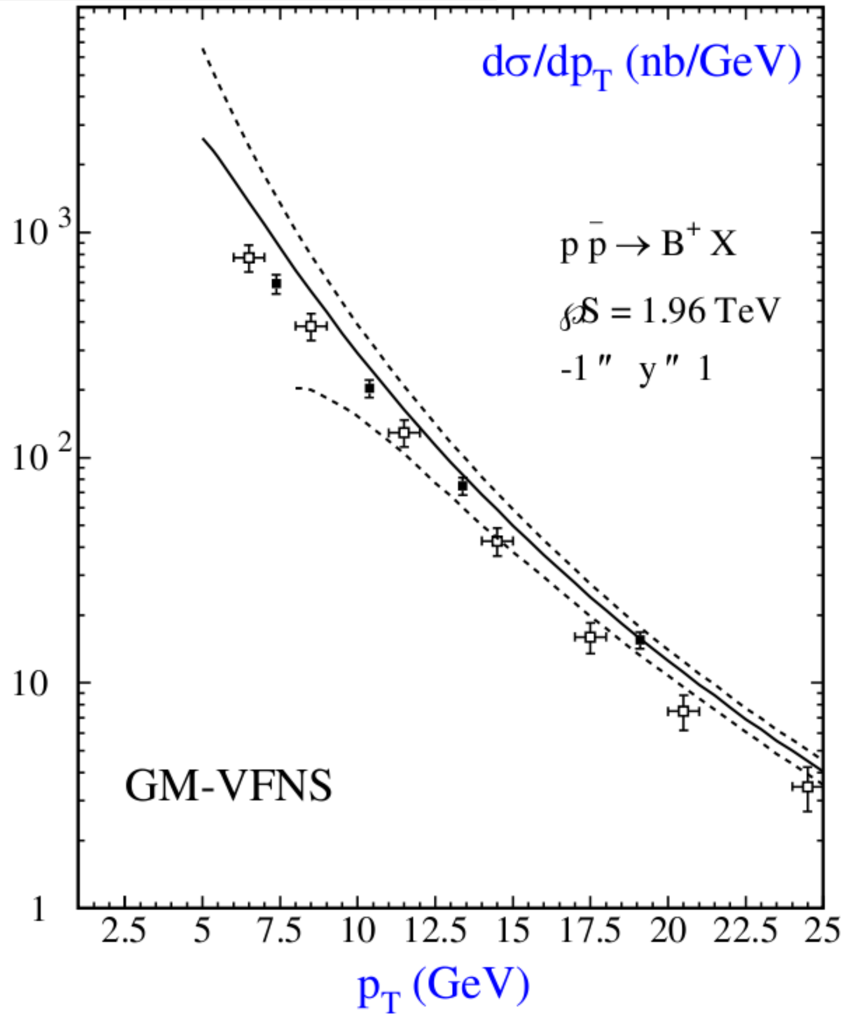
The SM and NLO Multileg Working Group: Summary report.

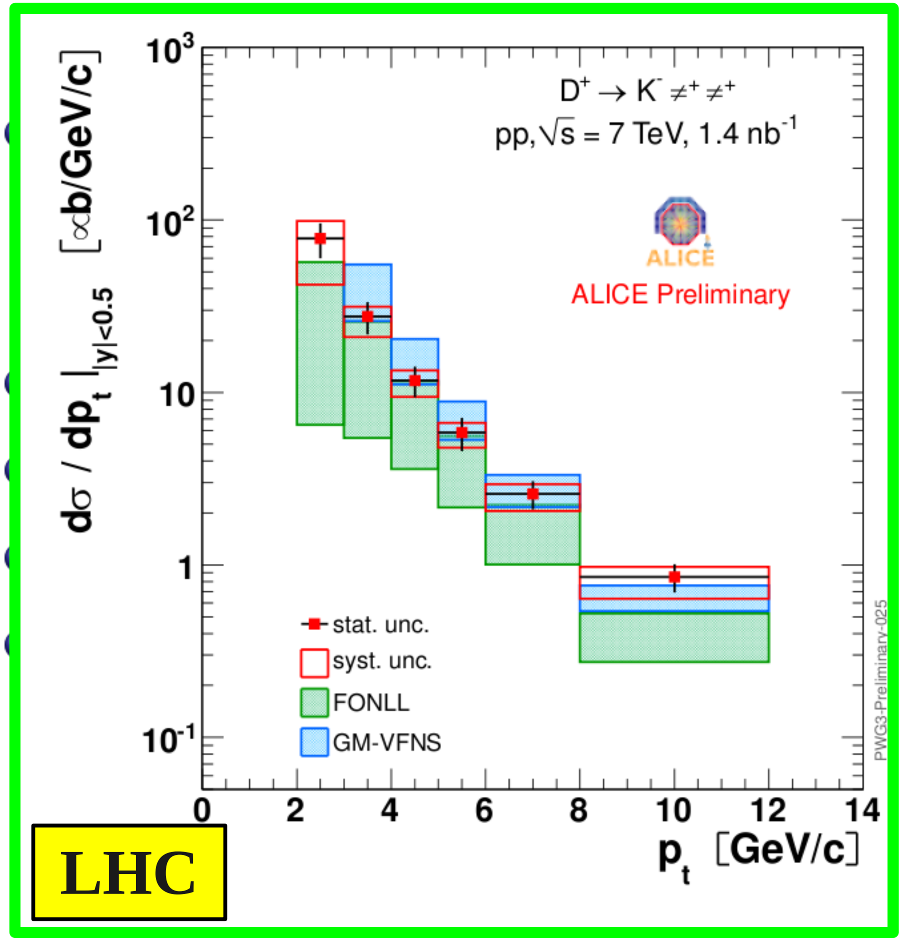
J. Rojo, et al., e-Print: arXiv:1003.1241 [hep-ph]

GM-VFNS prediction vs. CDF II [1,2]

DIS 2011
XIX International Workshop on Deep Inelastic Scattering and Related Subjects

Tevatron





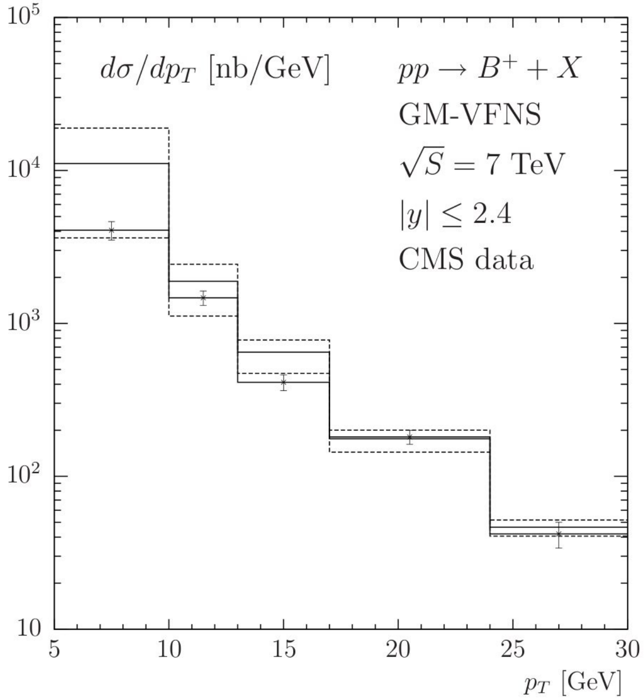
GM-VFNS
-Reduces to MS-bar
- No “parameters”
- Good agreement w/ C & B

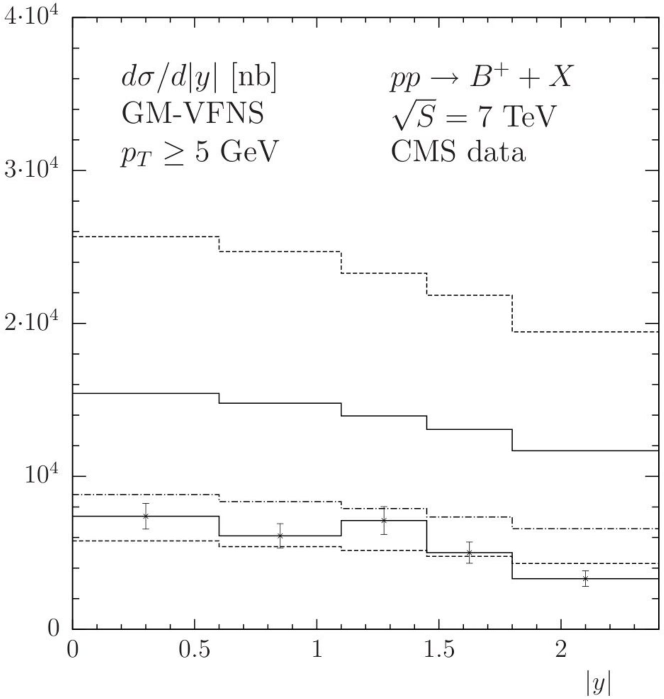
[1] CDF, PRD71(2005)032001

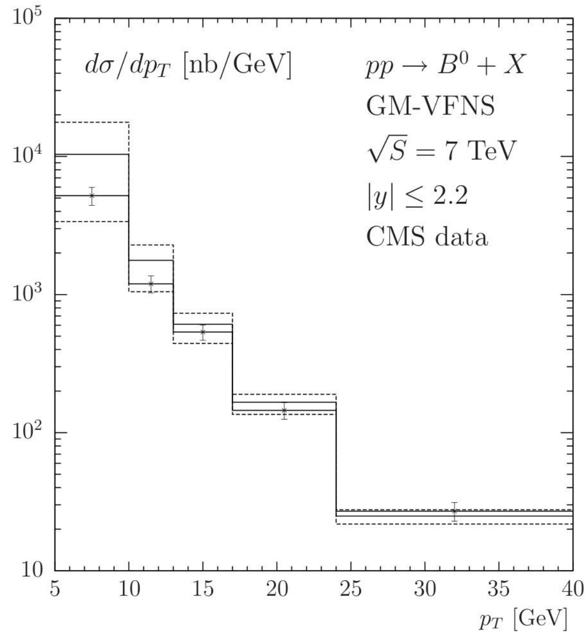
[2] CDF, PRD75(2007)012010

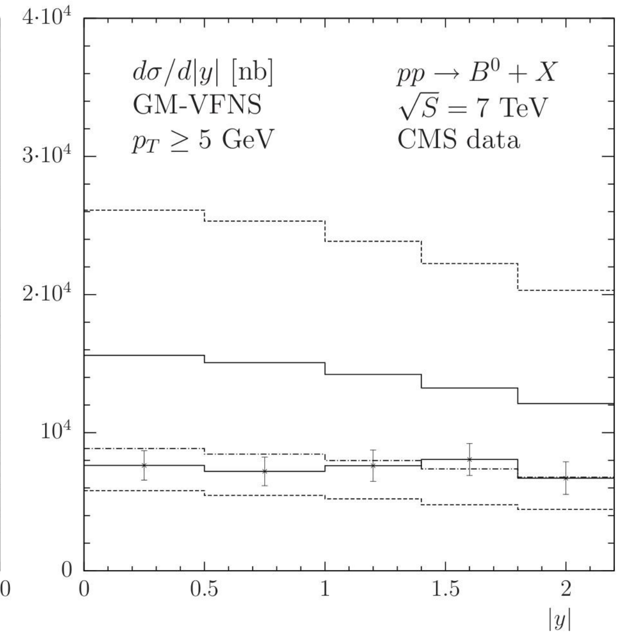
Bernd Kniehl

GM-VFN Scheme at LHC: B-production



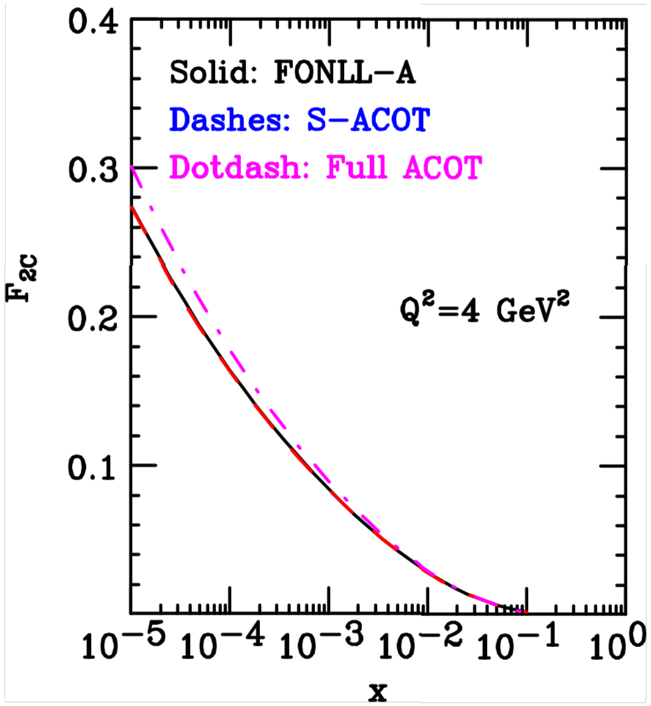


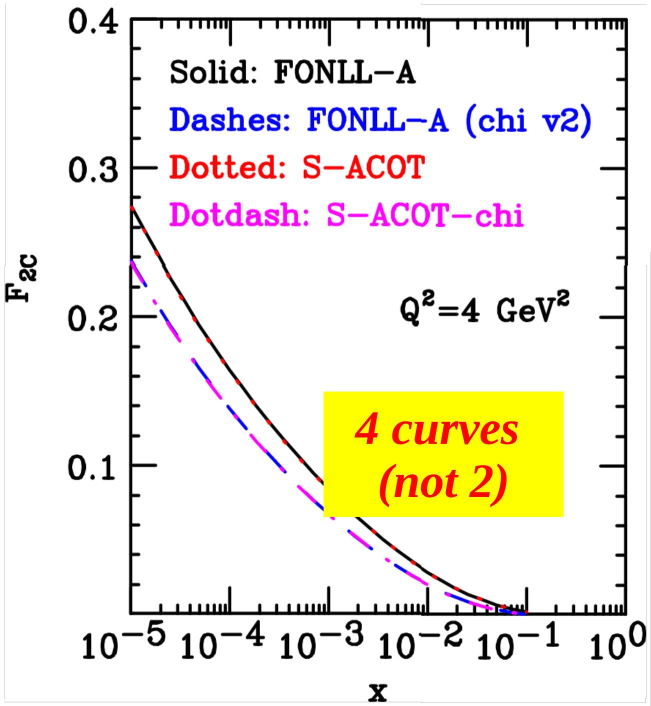


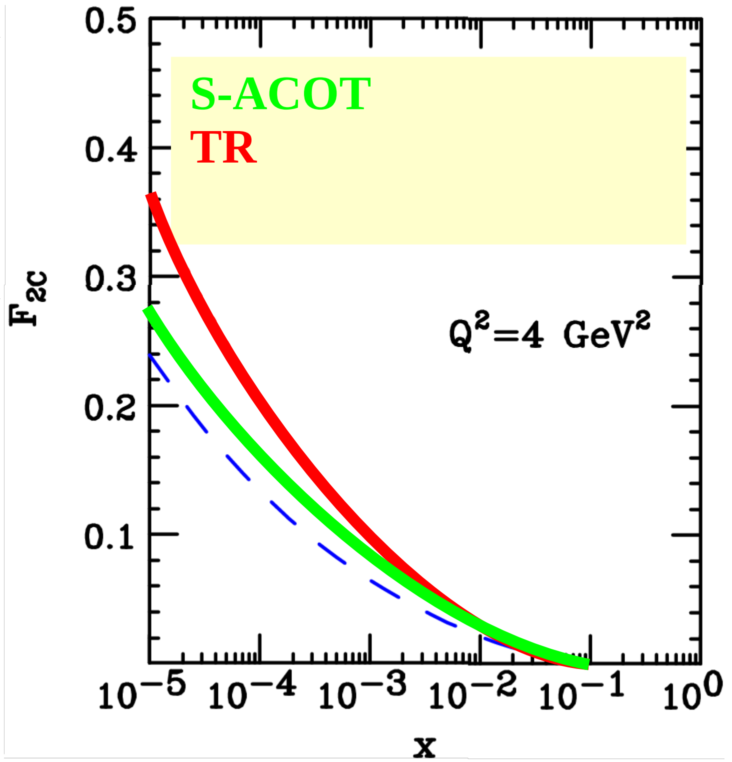


B-Meson Production at the LHC in the GM-VFN Scheme
B. A. Kniehl, G. Kramer, I. Schienbein, H. Spiesberger
arXiv:1109.2472v1 [hep-ph]

Les Houches Comparative Study







ACOT & S-ACOT essentially identical

... scheme differences are higher order

FONNL & S-ACOT

Numerically similar

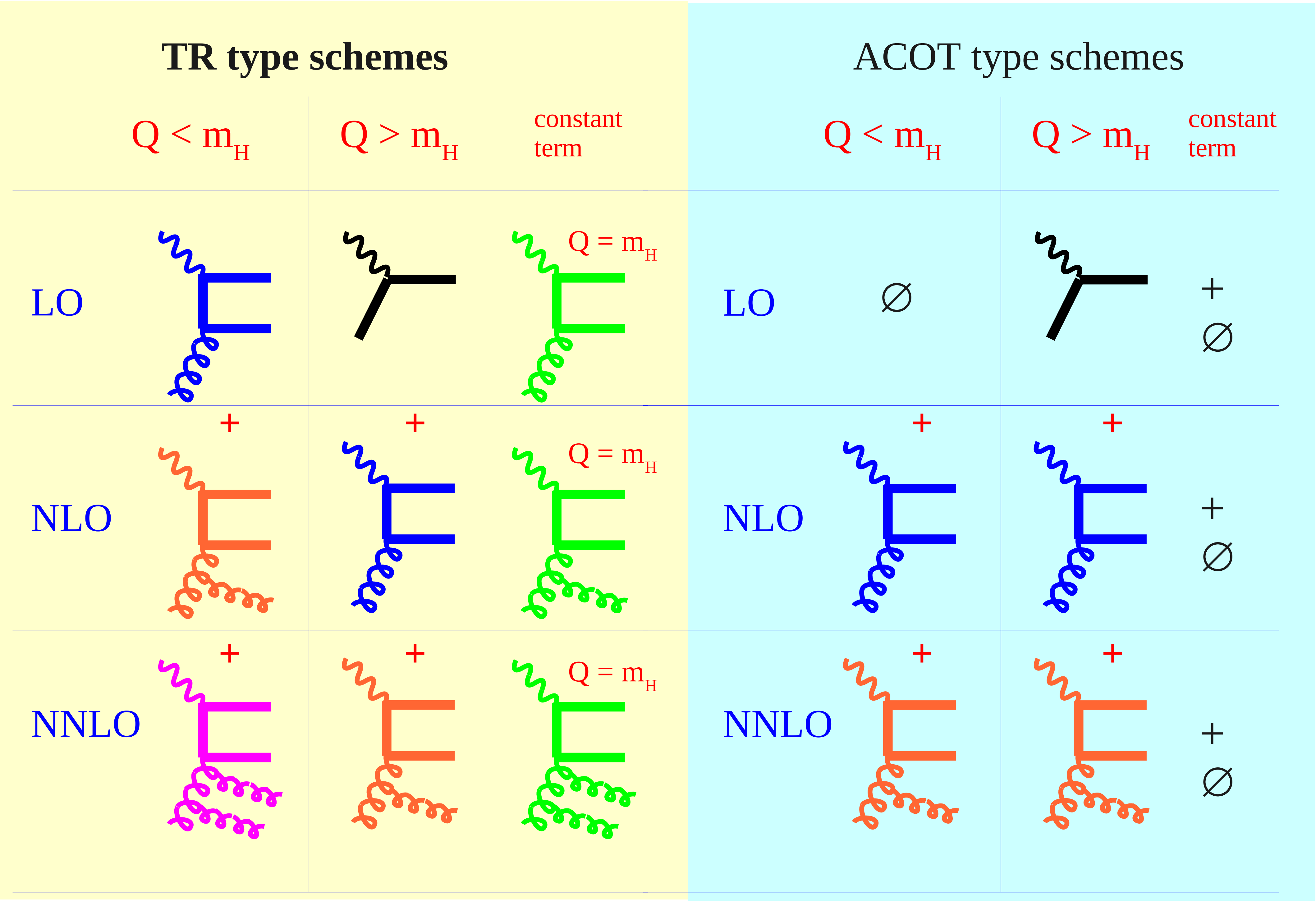
MSTW09

We can quantify <u>theoretical</u> scheme diffferences

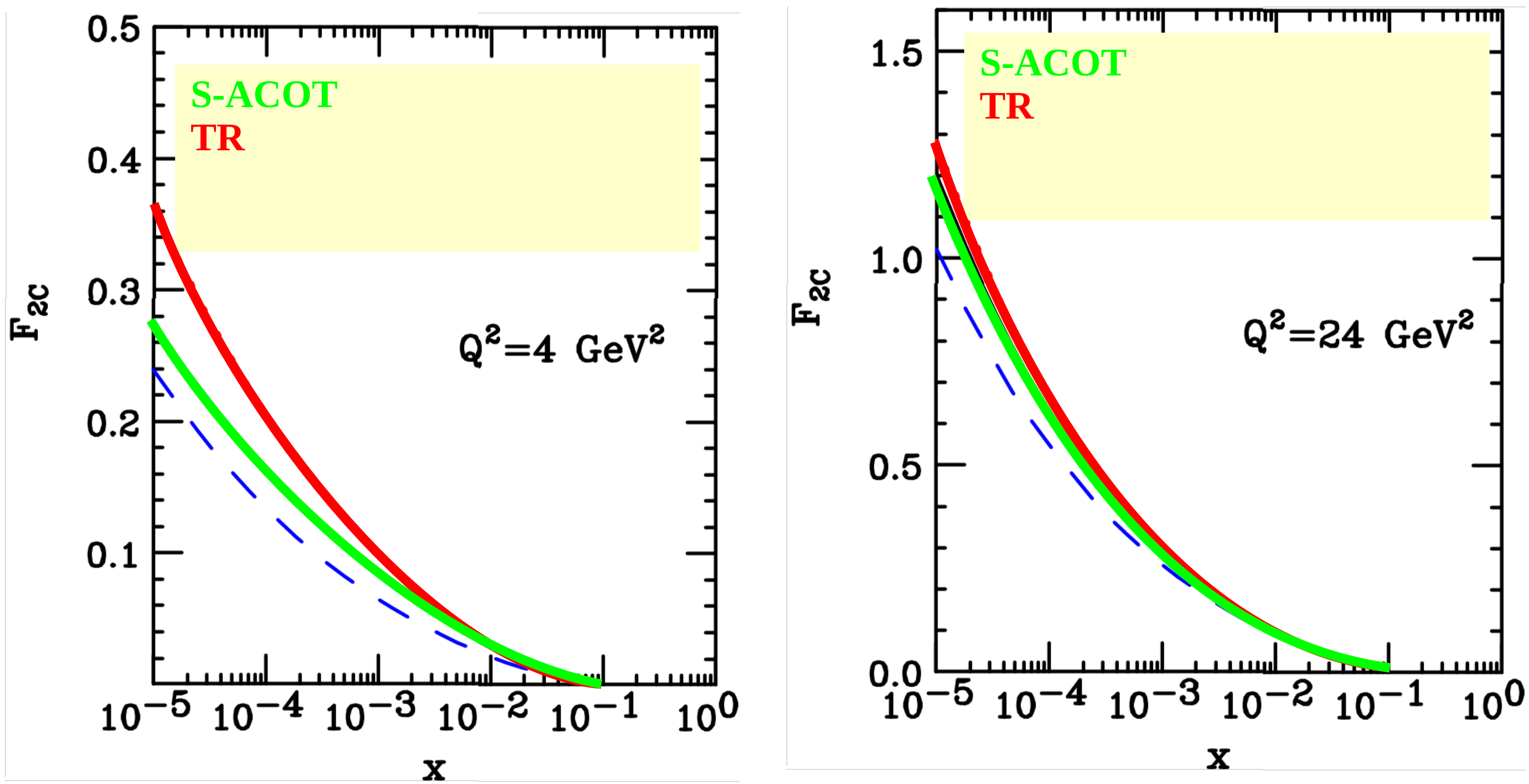
The SM and NLO Multileg Working Group: Summary report.

J. Rojo, et al., e-Print: arXiv:1003.1241 [hep-ph]

Schematic Summary of ACOT & TR Schemes



Comparison of ACOT & TR Schemes



Different schemes ⇒ Different PDFs ⇒ yet consistent σ

Differences reduce at:

1) higher Q,
2) higher order

If experiments are sensitive, time to compute to higher order

F
L

Why is F_L so special ???

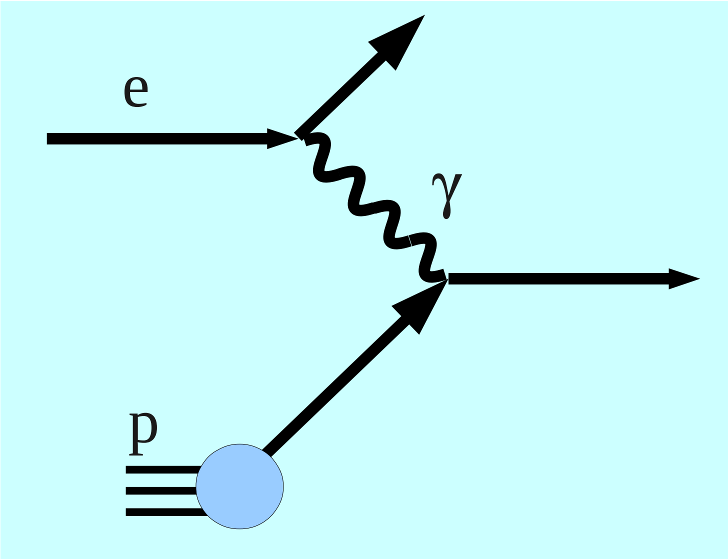
$$\frac{d\sigma^{\nu\,DIS}}{dx\,dy} = (1-y)^2\,\bar{q}(x) + (1-y)\,\phi(x) + q(x)$$

$$\frac{d\sigma^{\nu\,DIS}}{dx\,dy} = (1-y)^2\,F_+(x) + (1-y)\,F_0(x) + F_-(x)$$

$$F_0 = \frac{F_2}{2x} - F_1$$

$$F_0 = 0 \quad \Longrightarrow \quad F_2 = 2xF_1$$

Callan-Gross

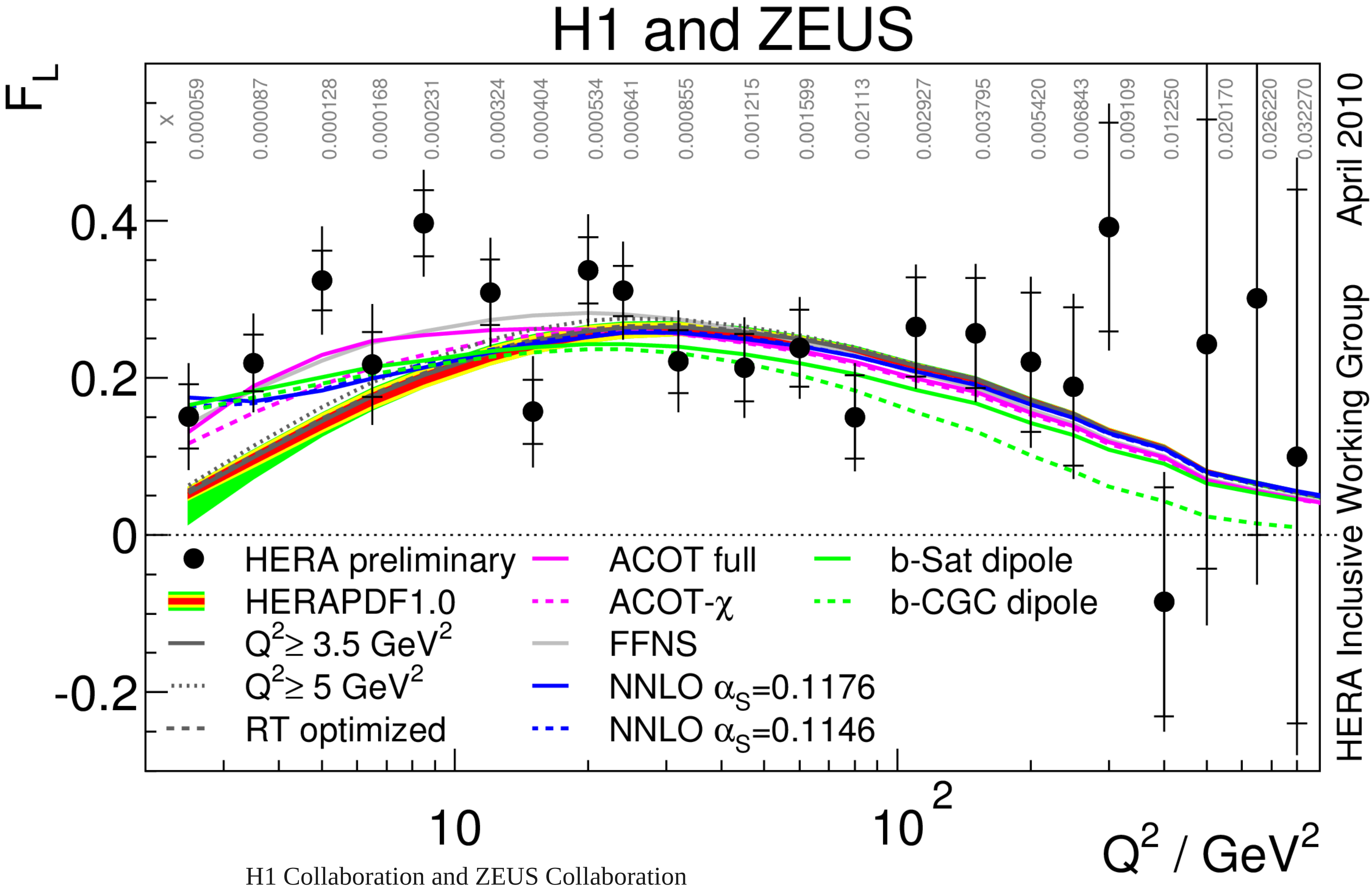


$$F_L \sim \frac{m^2}{Q^2}\,q(x) + \alpha_S\,\{c_g \otimes g(x) + c_q \otimes q(x)\}$$

Masses are importan

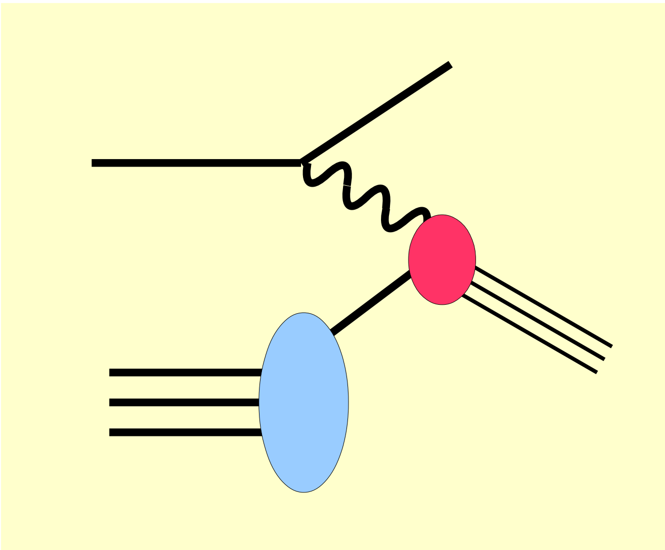
Higher Orders are important

New F_L Measurements: New Perspective

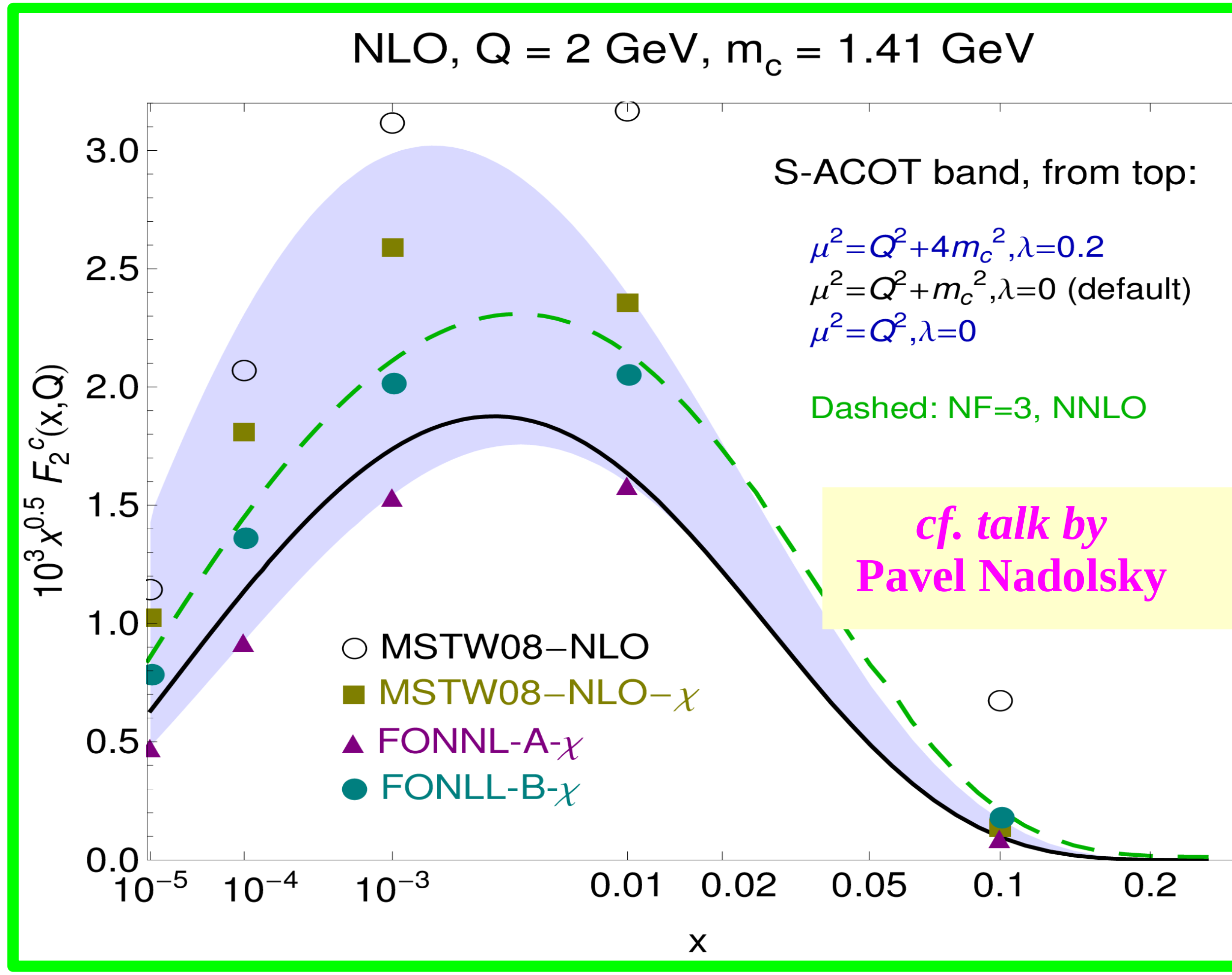


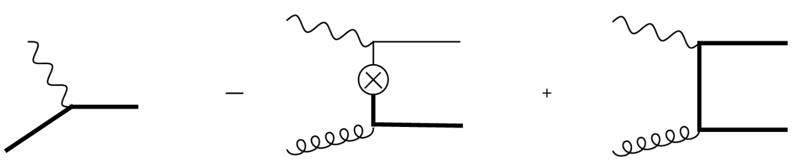
H1 Collaboration and ZEUS Collaboration

Step toward NNLO CTEQ



DIS Production



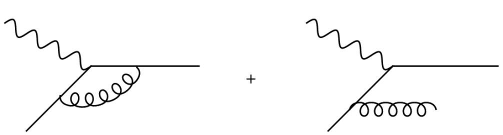


NLO Subtraction

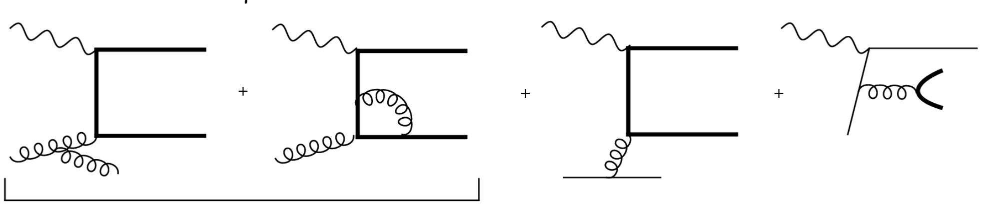
NLO γ* g

ACOT I: Phys.Rev.D50:3085−3101,1994

ACOT II: Phys.Rev.D50:3102−3118,1994



NLO γ* c

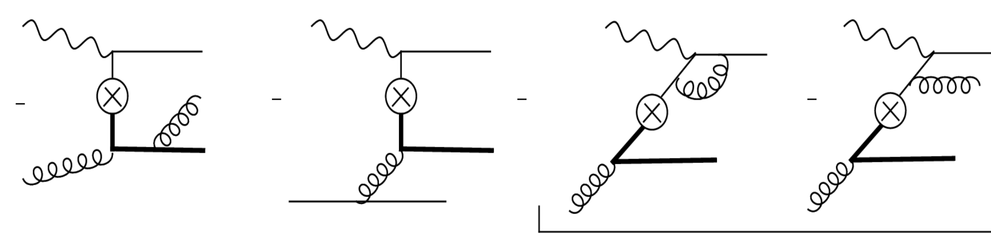


NNLO: γ* g

NNLO: γ* Σ

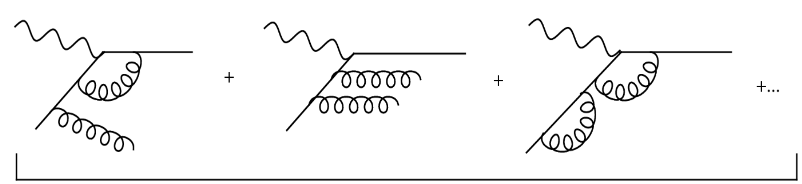
NNLO: γ* q NS

Riemersma et. al. Phys.Lett. B347 (1995)



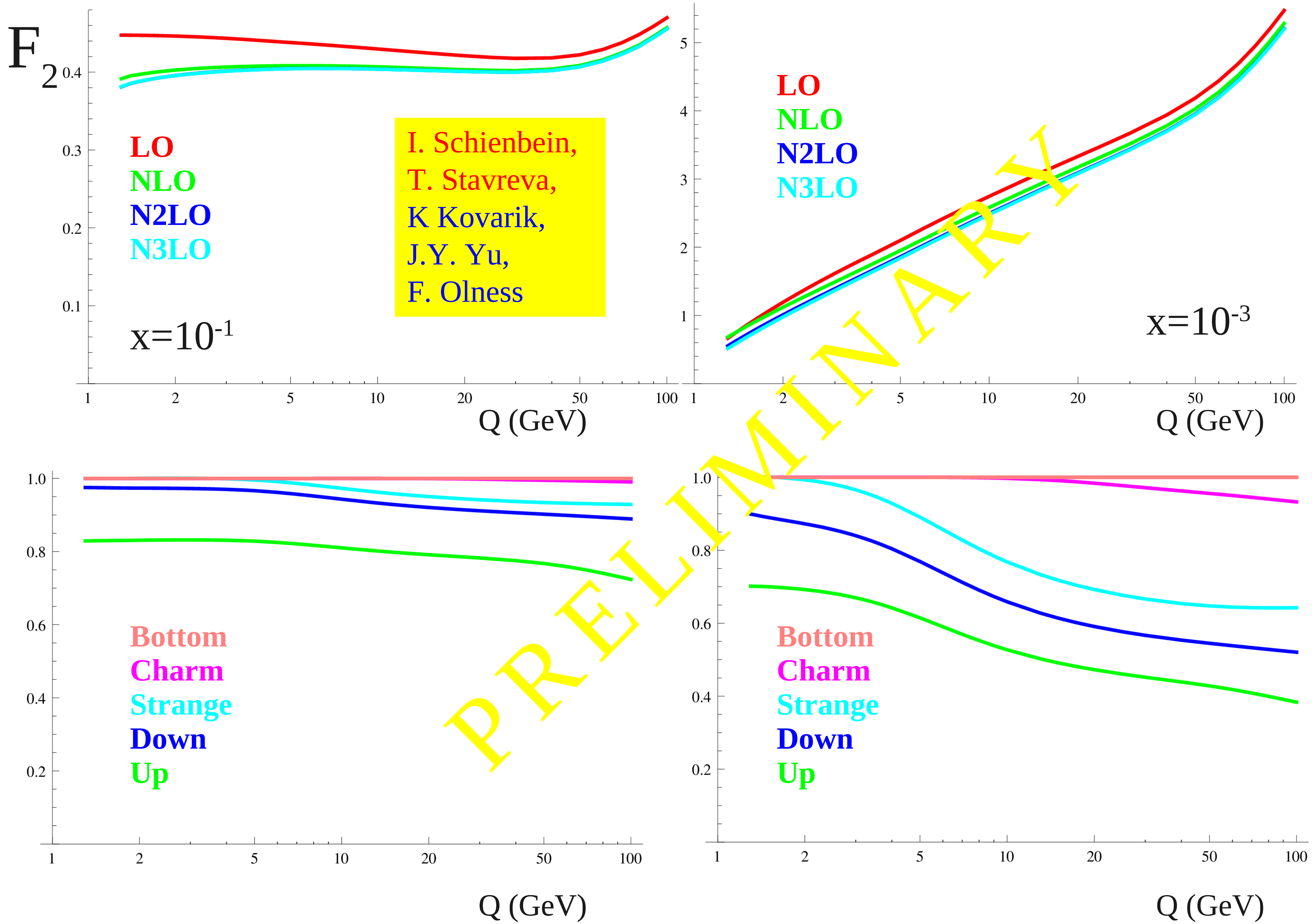
NNLO Subtractions

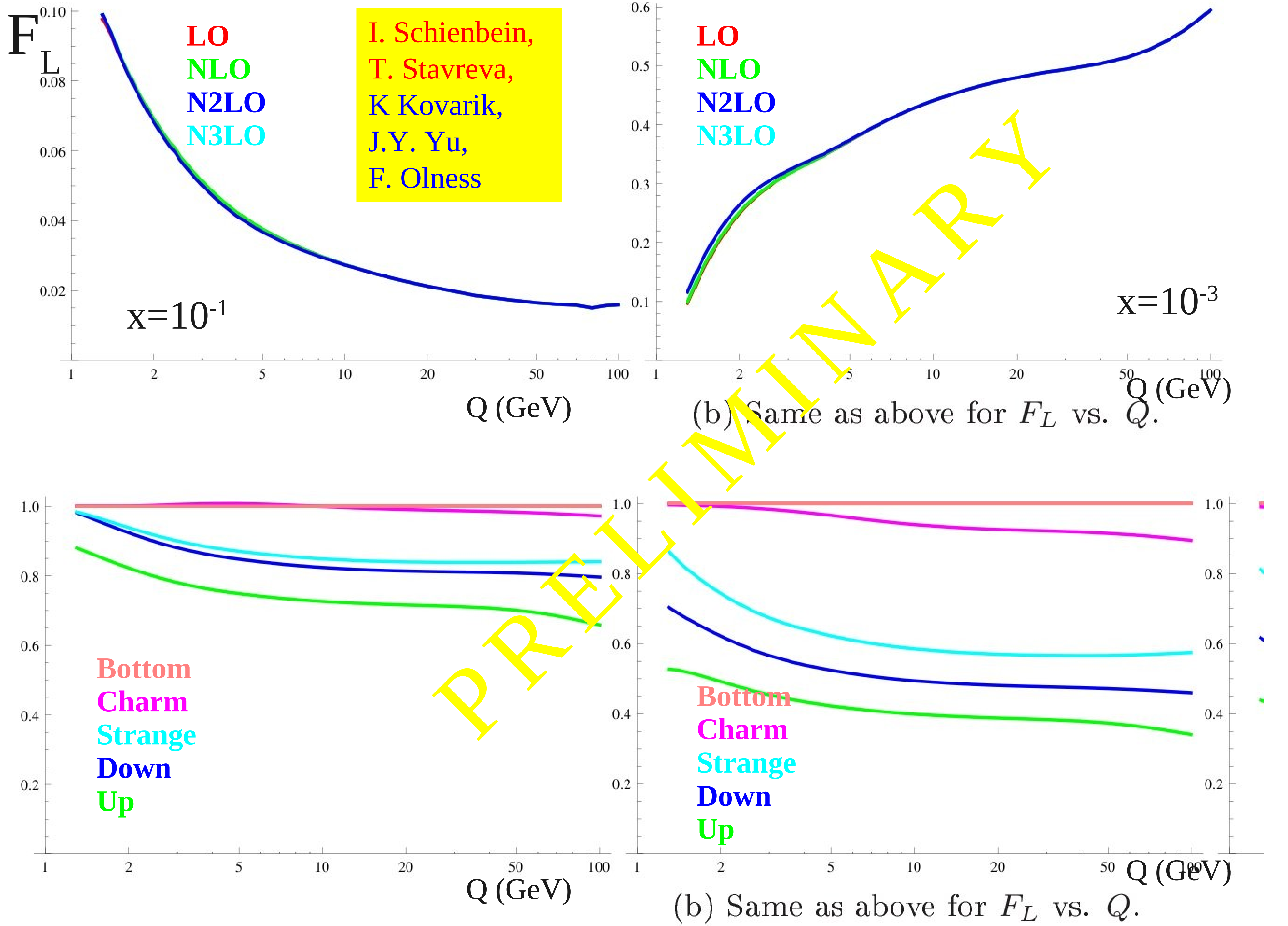
Buza, Matiounine, Smith, Van Neerven, Eur. Phys. J. C 1998



NNLO γ* c

Moch, Vermaseren and Vogt, Nucl.Phys.B724, 2005

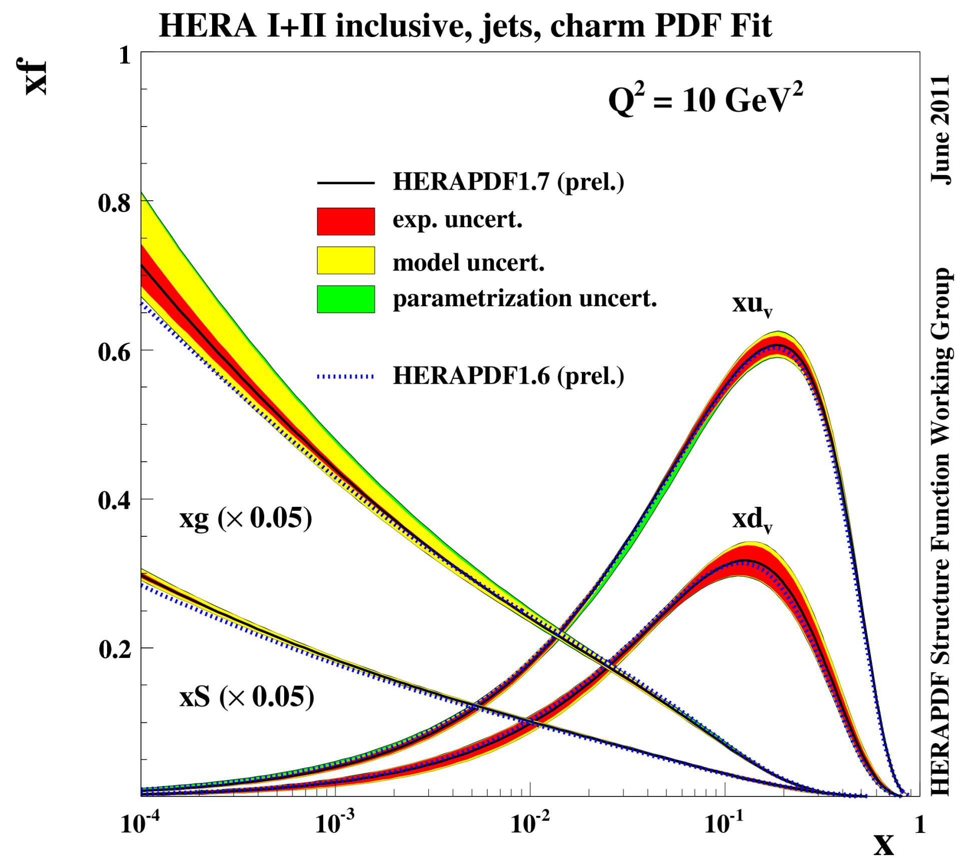

F2
LO
NLO
N2LO
N3LO
I. Schienbein,
T. Stavreva,
K Kovarik,
J.Y. Yu,
F. Olness
x=10-1
Q (GeV)
LO
NLO
N2LO
N3LO
x=10-3
Q (GeV)
PRELIMINARY
Bottom
Charm
Strange
Down
Up
Q (GeV)
Bottom
Charm
Strange
Down
Up
Q (GeV)



F_L
LO
NLO
N2LO
N3LO
I. Schienbein,
T. Stavreva,
K Kovarik,
J.Y. Yu,
F. Olness
x=10^-1
Q (GeV)
x=10^-3
Q (GeV)
(b) Same as above for F_L vs. Q.
PRELIMINARY
Bottom
Charm
Strange
Down
Up
Q (GeV)
Bottom
Charm
Strange
Down
Up
Q (GeV)
(b) Same as above for F_L vs. Q.

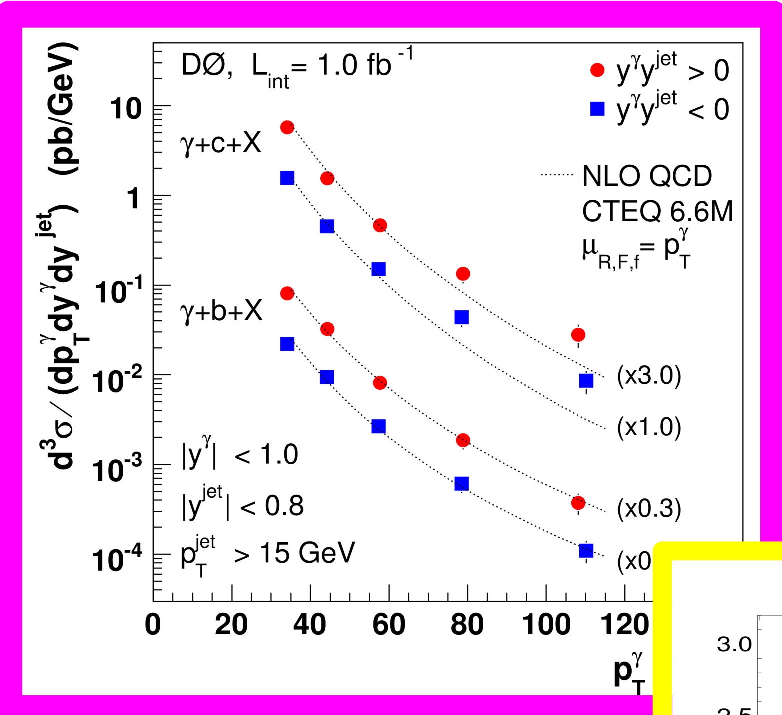
Search for "new physics" requires dependable foundation

Ability to discover
"New Physics"
is dependent on distinguishing
"Old Physics"

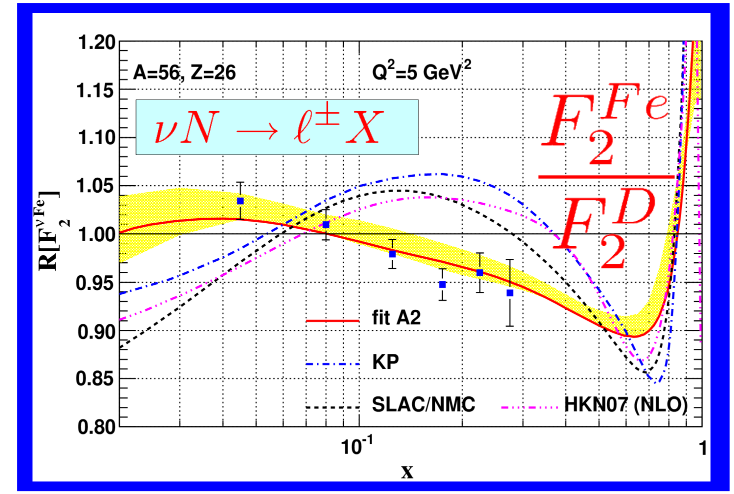


As experimental precision has increased, we need to be concerned about the details

The Challenges

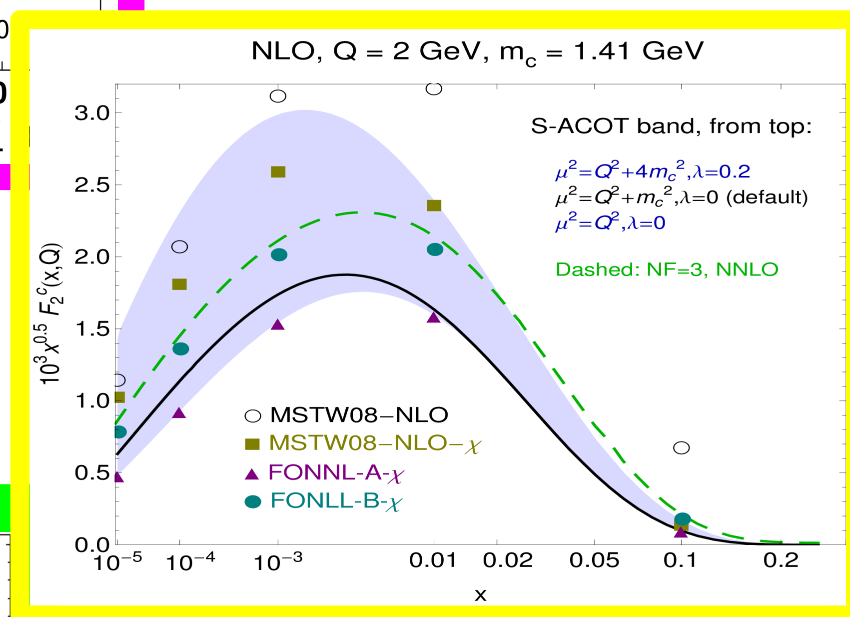


Charm+γ at Tevatron



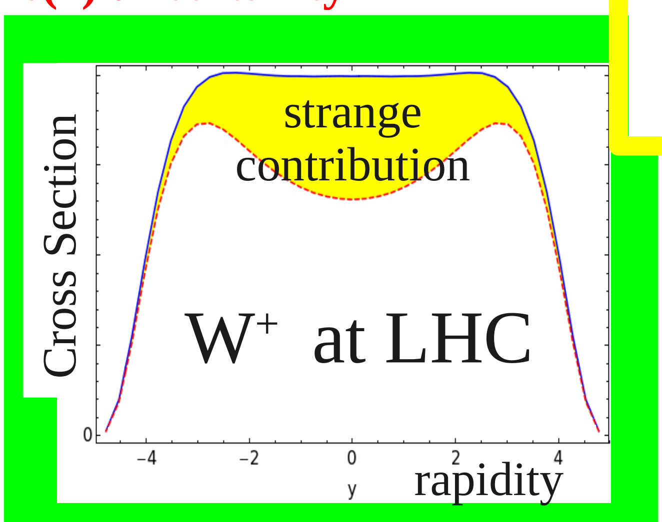
S-ACOT at NNLO

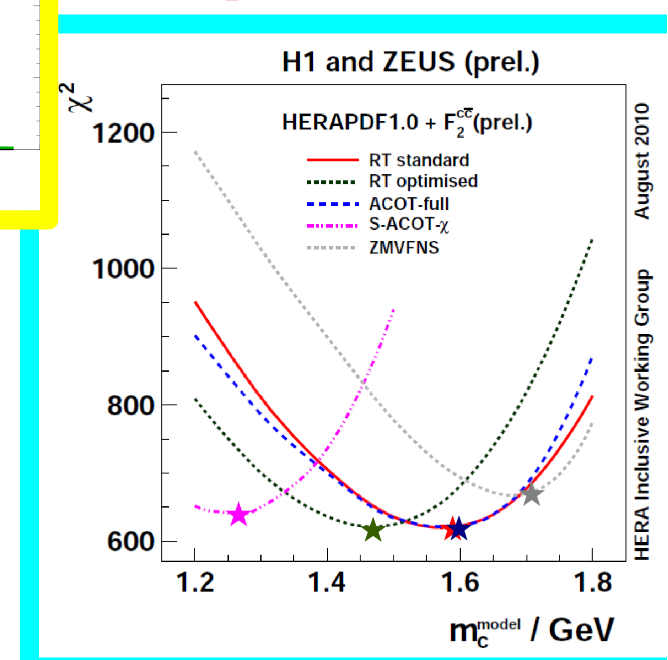
Nuclear Modifications limit PDFs



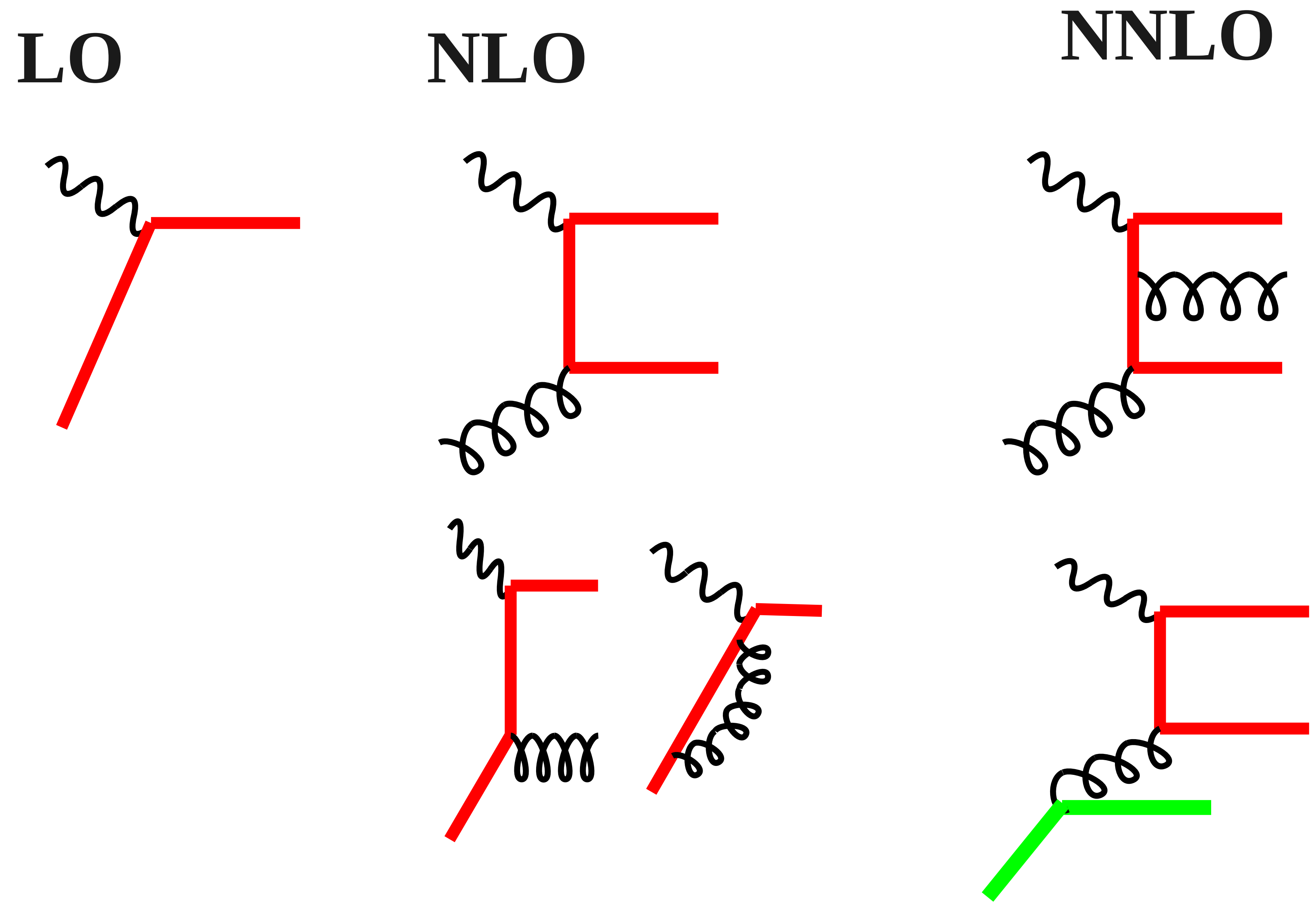
Interpretation of mass

s(x) uncertainty



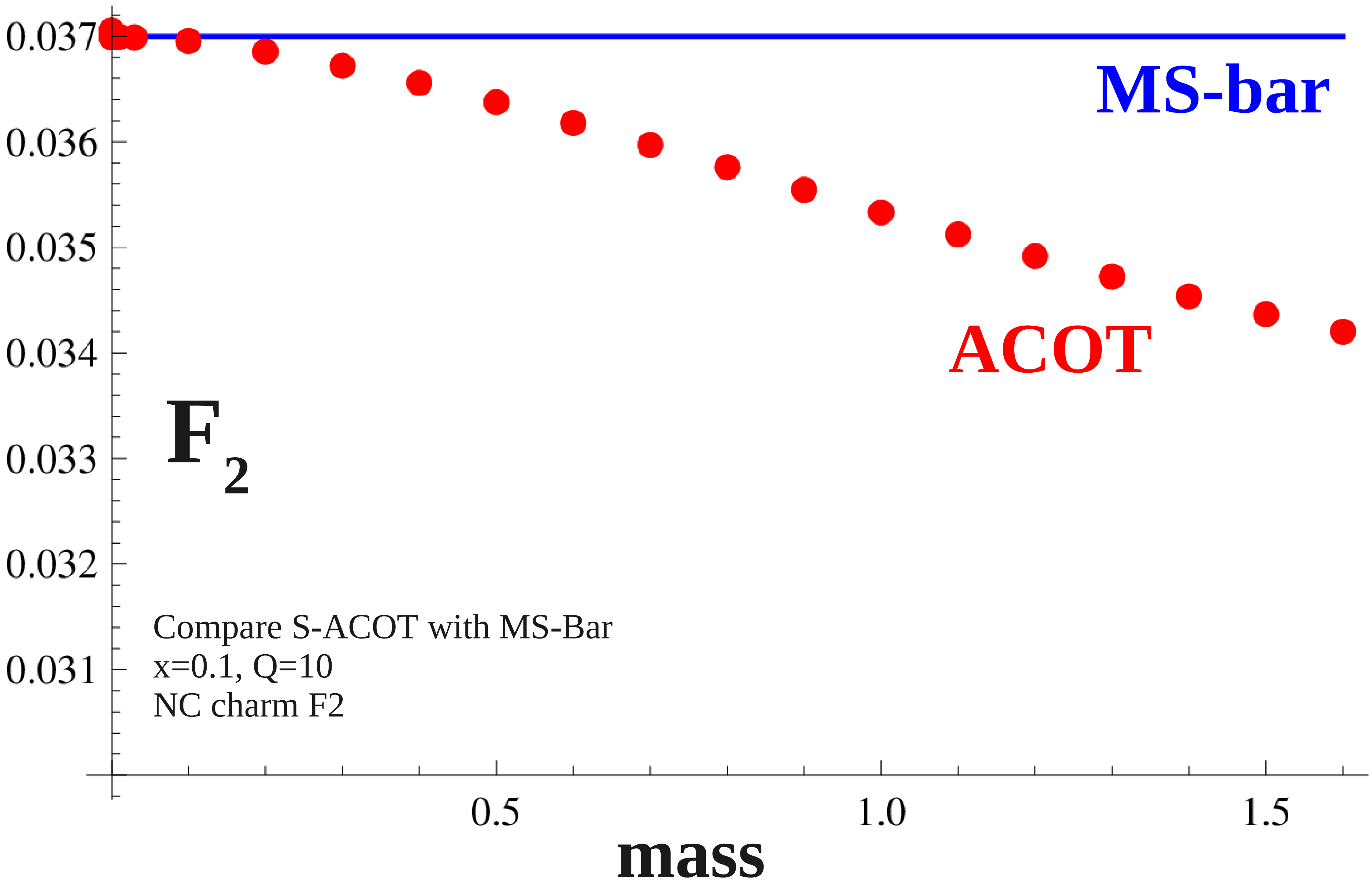


Backup

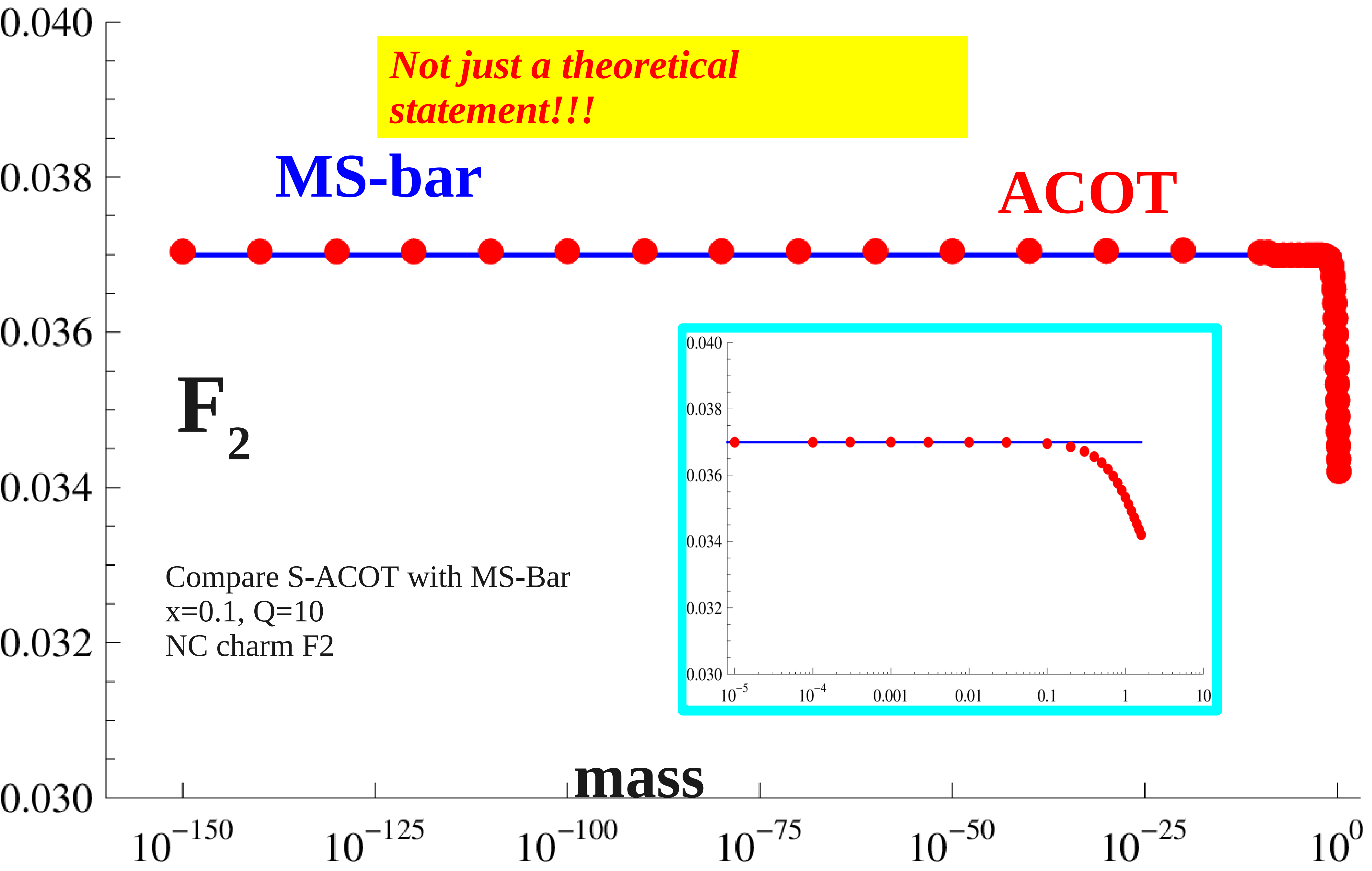


$$F_{123} \sim q(x) \otimes C_q^0 + \alpha_S \left\{ g(x) \otimes C_g^1 + q(x) \otimes C_q^1 \right\}$$

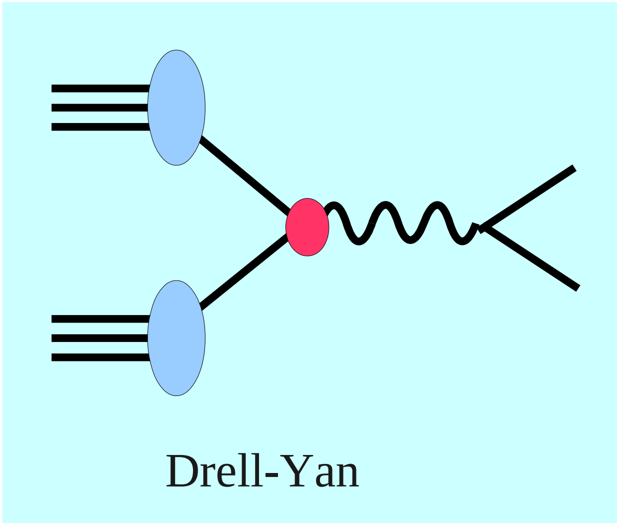
ACOT m→ 0 limit yields MS-Bar: *No finite renormalization*

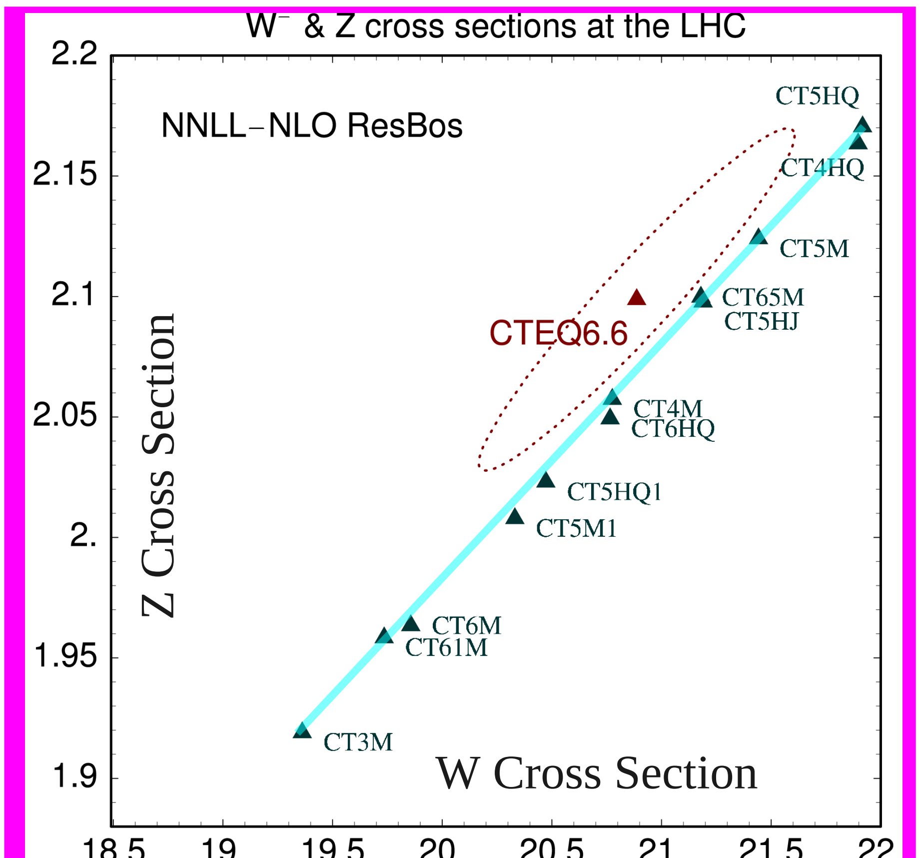


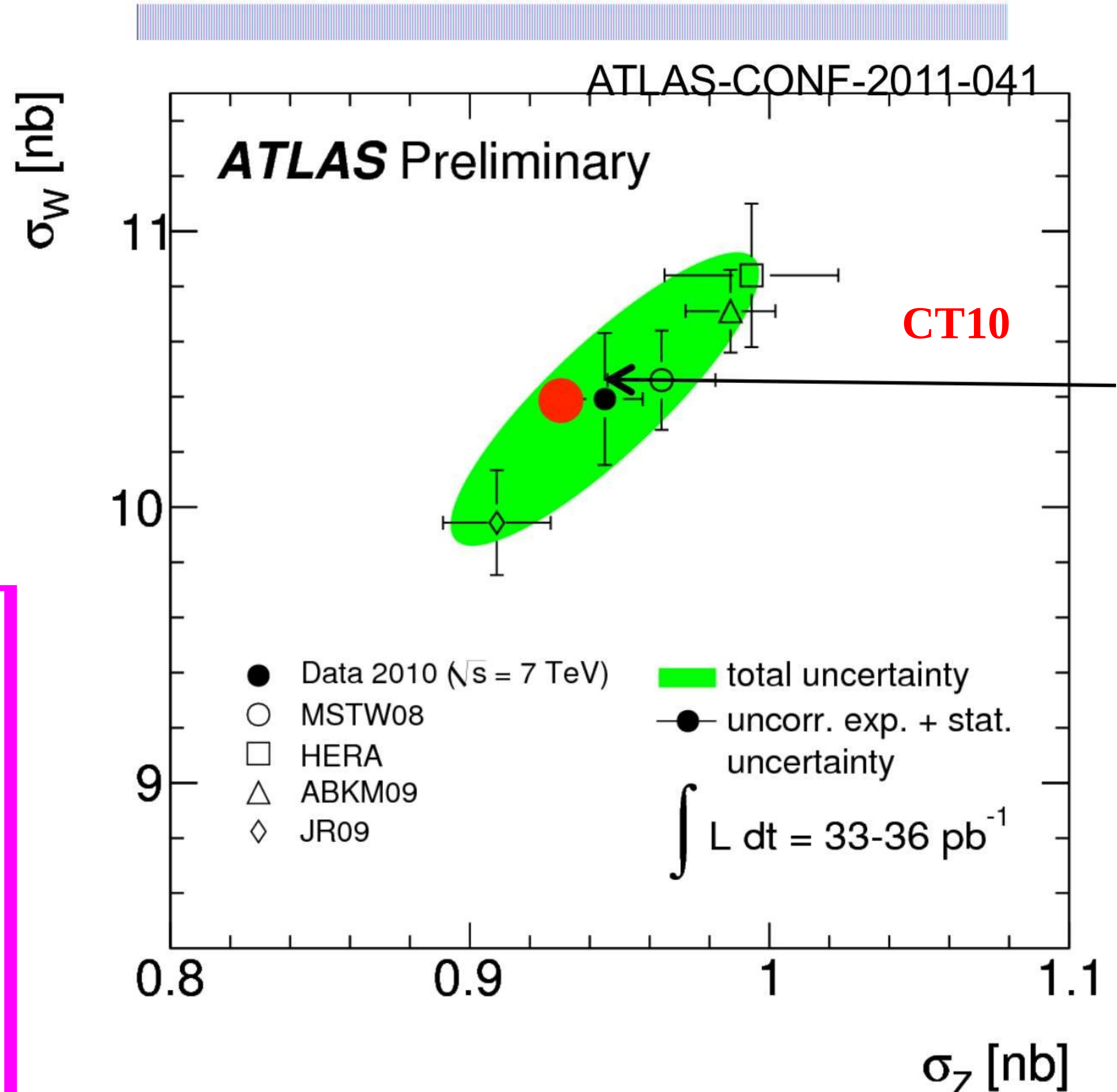
ACOT m→ 0 limit yields MS-Bar: *No finite renormalization*



W/Z PRODUCTION

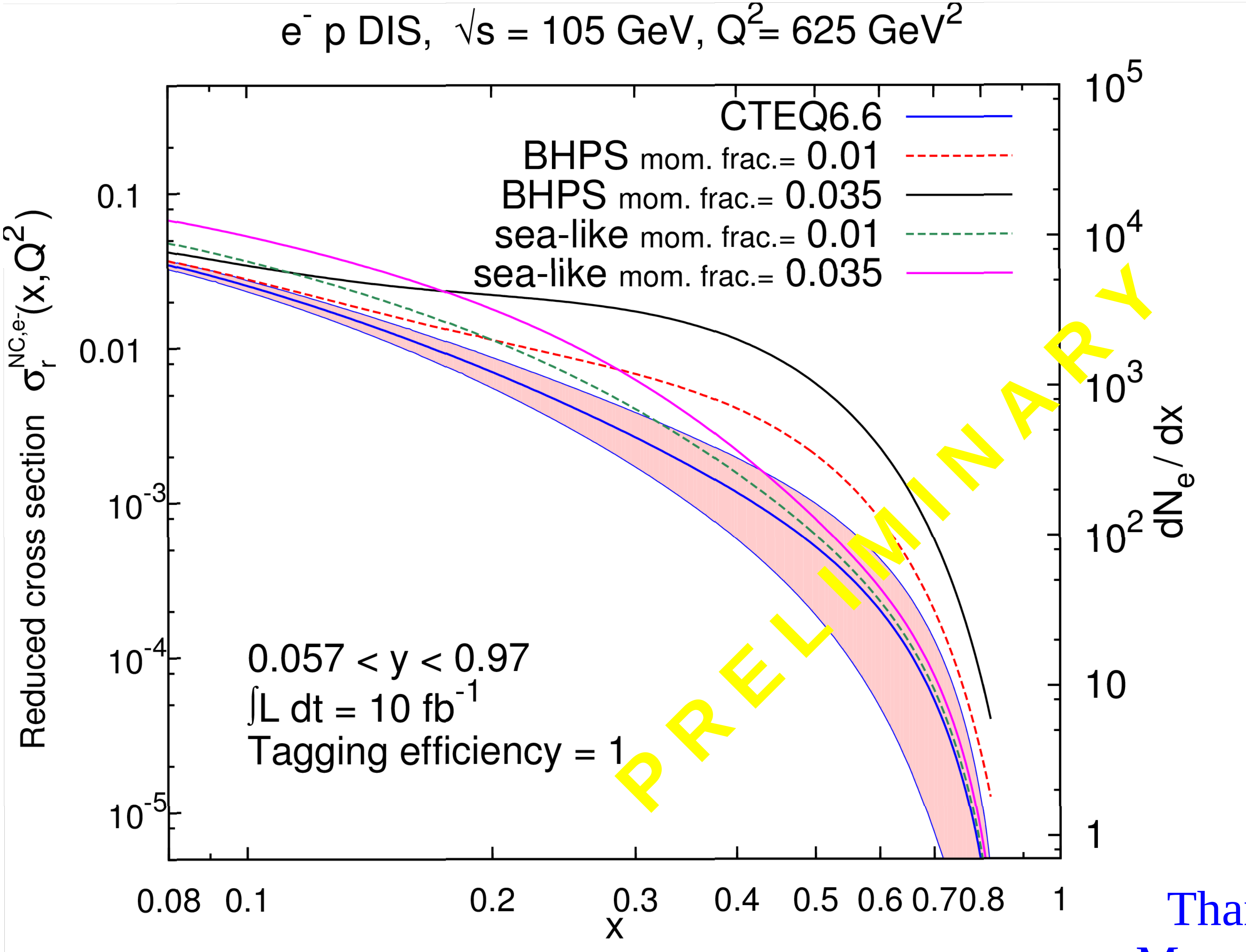






ATLAS W/Z cross section ratio in good agreement with NNLO predictions from the PDF groups shown

Sample Cross Section for an Electron Ion Collider



Thanks to Marco Guzzi for this calculation

Sample Cross Section for an Electron Ion Collider