Parton Distributions at the FCC:

Synergy of FCC-hh and FCC-he

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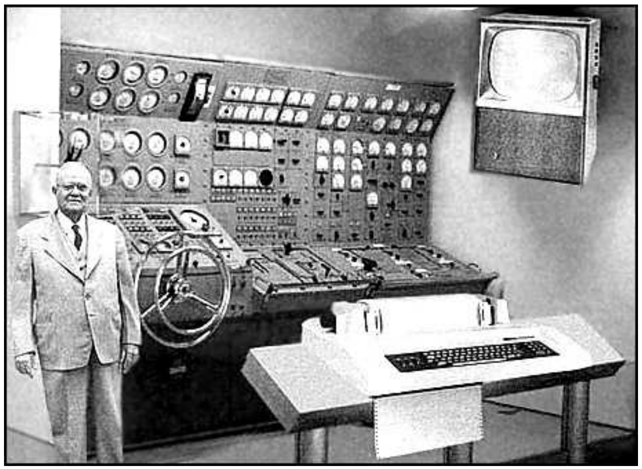
25 March 2015

Now & Then

Things can change a bit over the years

PAST	PRESENT	FUTURE
Tevatron	LHC	FCC



?

Next generation computer

?

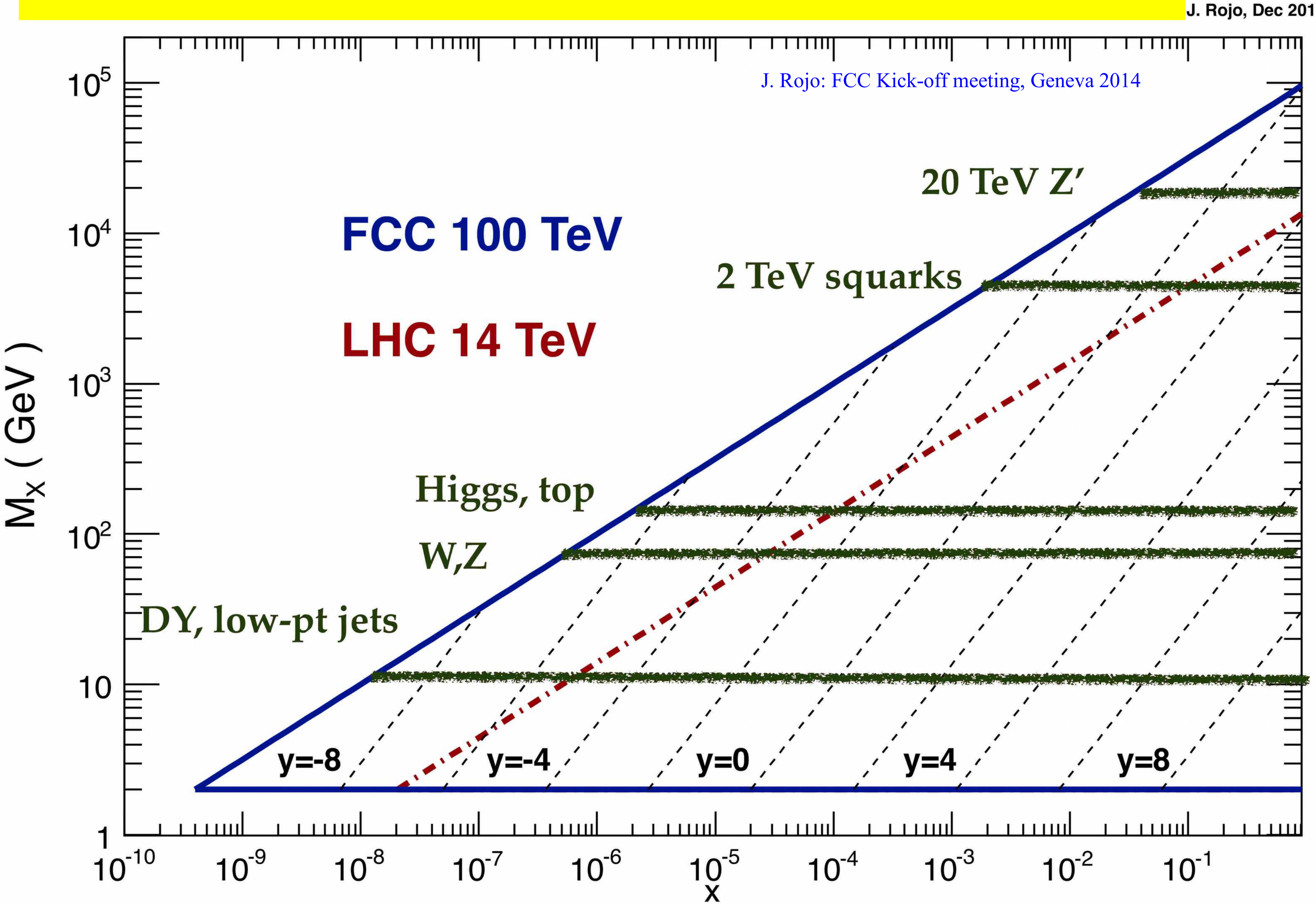
Next generation phone

the same is true for PDFs
FCC is not just a LHC re-do

… with a bit of exaggeration

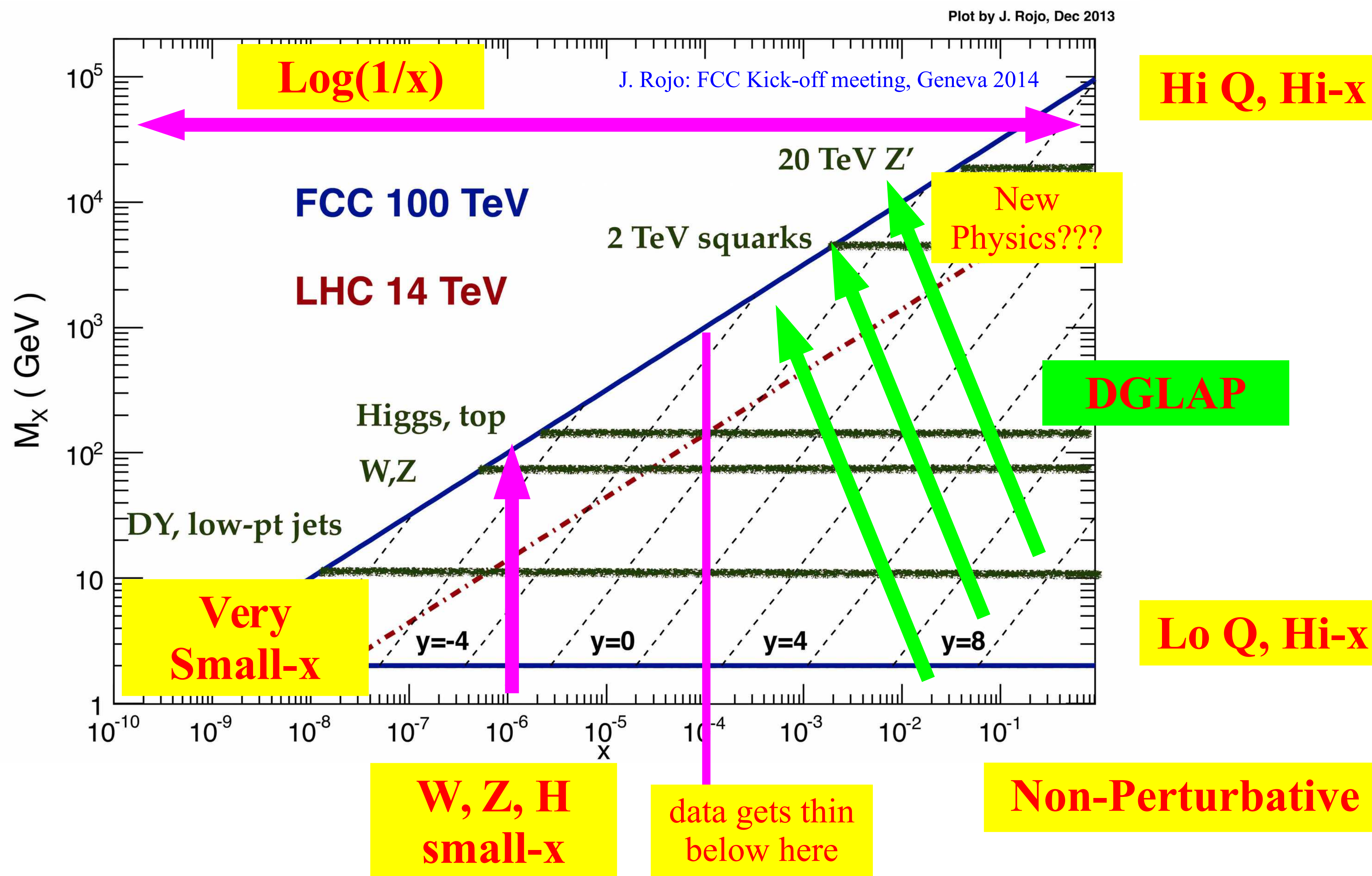
Kinematic Reach of a FCC

Tremendous expanse in $\{x,Q^2\}$ **New Opportunities** **New Challenges**

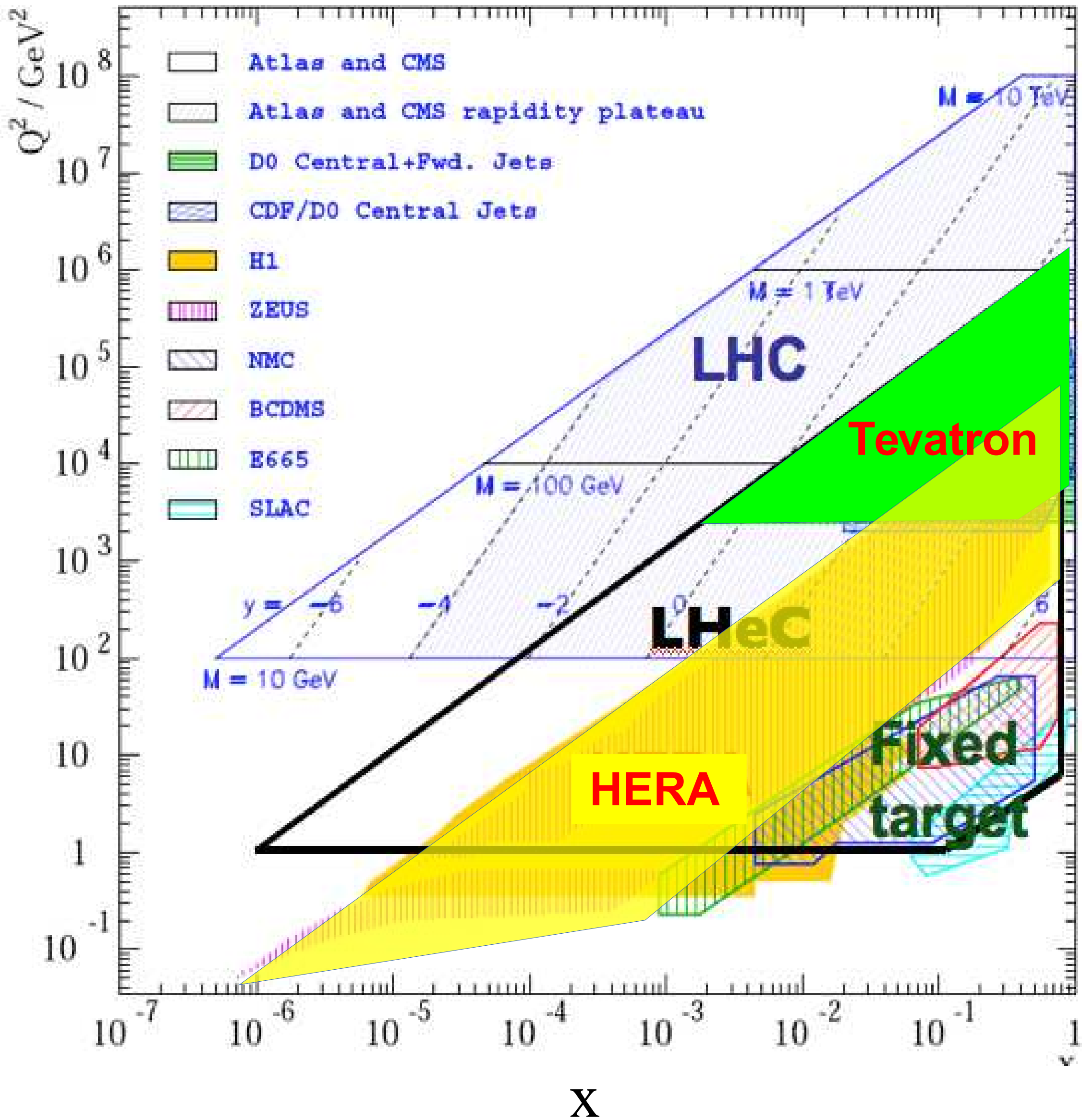


Challenges From a PDF Viewpoint: Predictions rely on accurate PDFs

$$\sigma_{hh\to X} = \boxed{f_{h\to a}} \otimes \widehat{\sigma}_{ab\to X} \otimes \boxed{f_{h\to b}}$$



Kinematic Reach: Combined *hh* & *he*

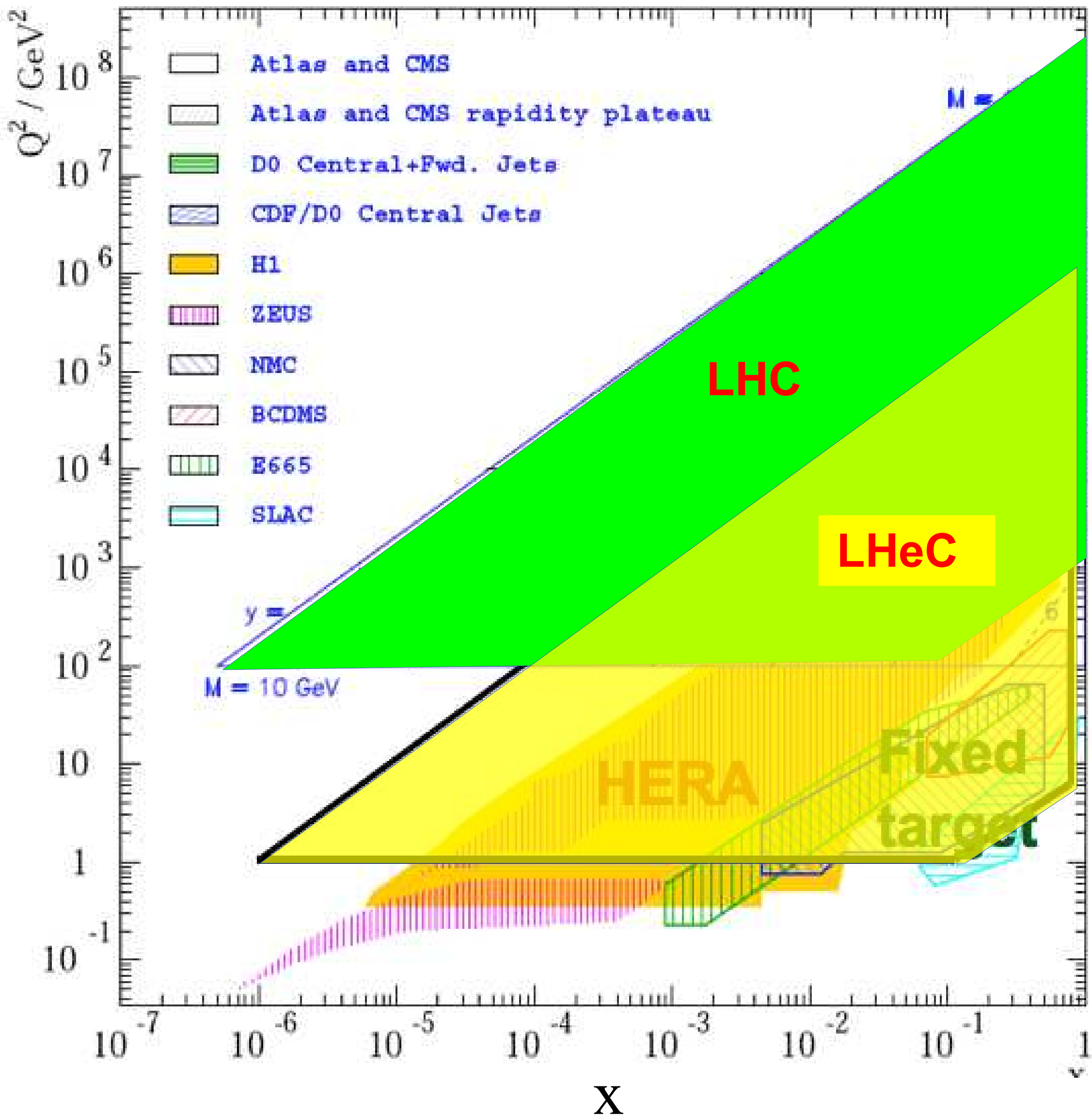


Combination of HERA data with Tevatron was essential to untangle flavor components

Not practical to extract PDFs using ONLY Tevatron data

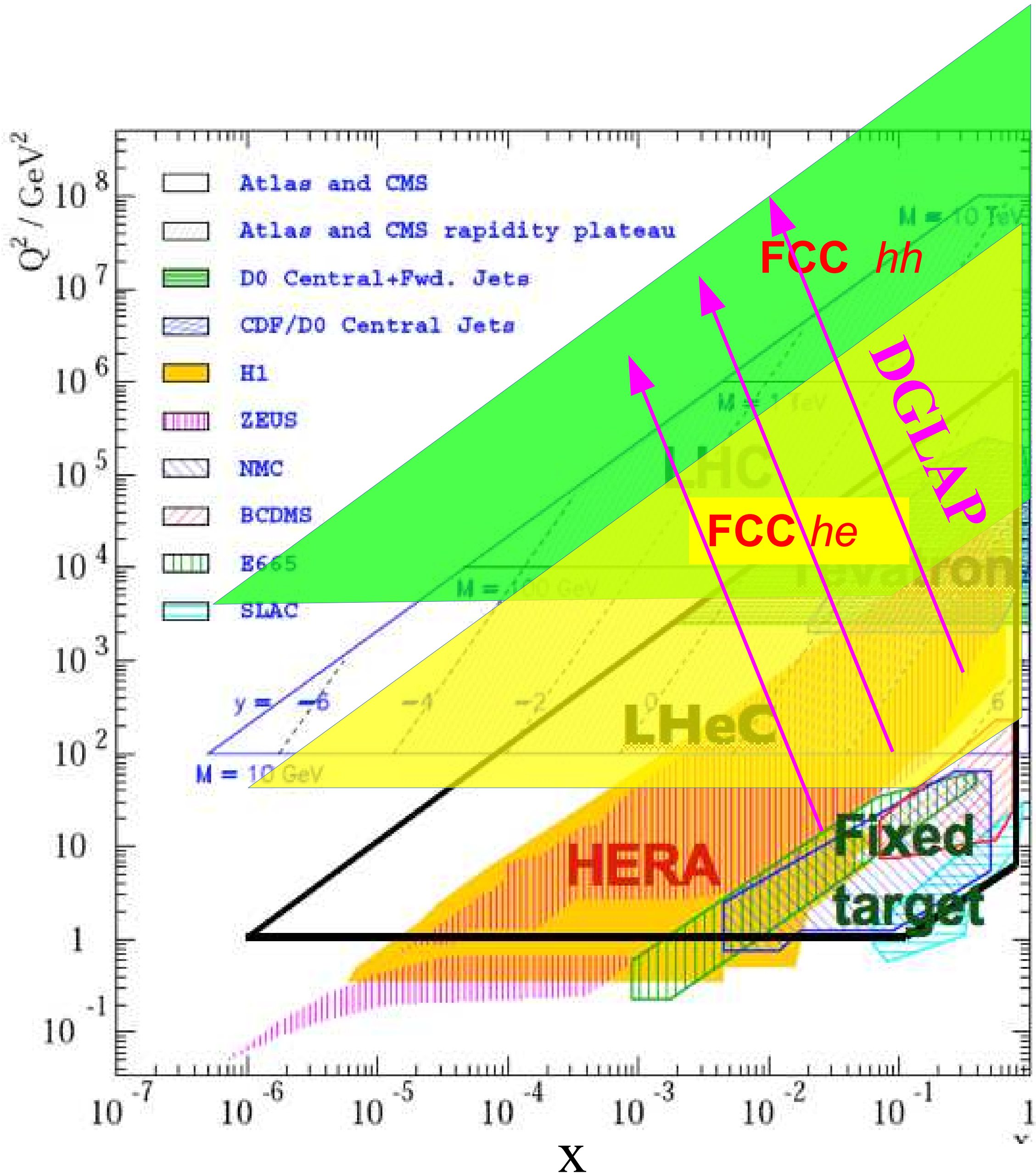
HERA provides criticical constraints, particularly in discovery regions

Kinematic Reach: Combined *hh* & *he*



LHC & LHeC
are complements

Kinematic Reach: Combined *hh* & *he*



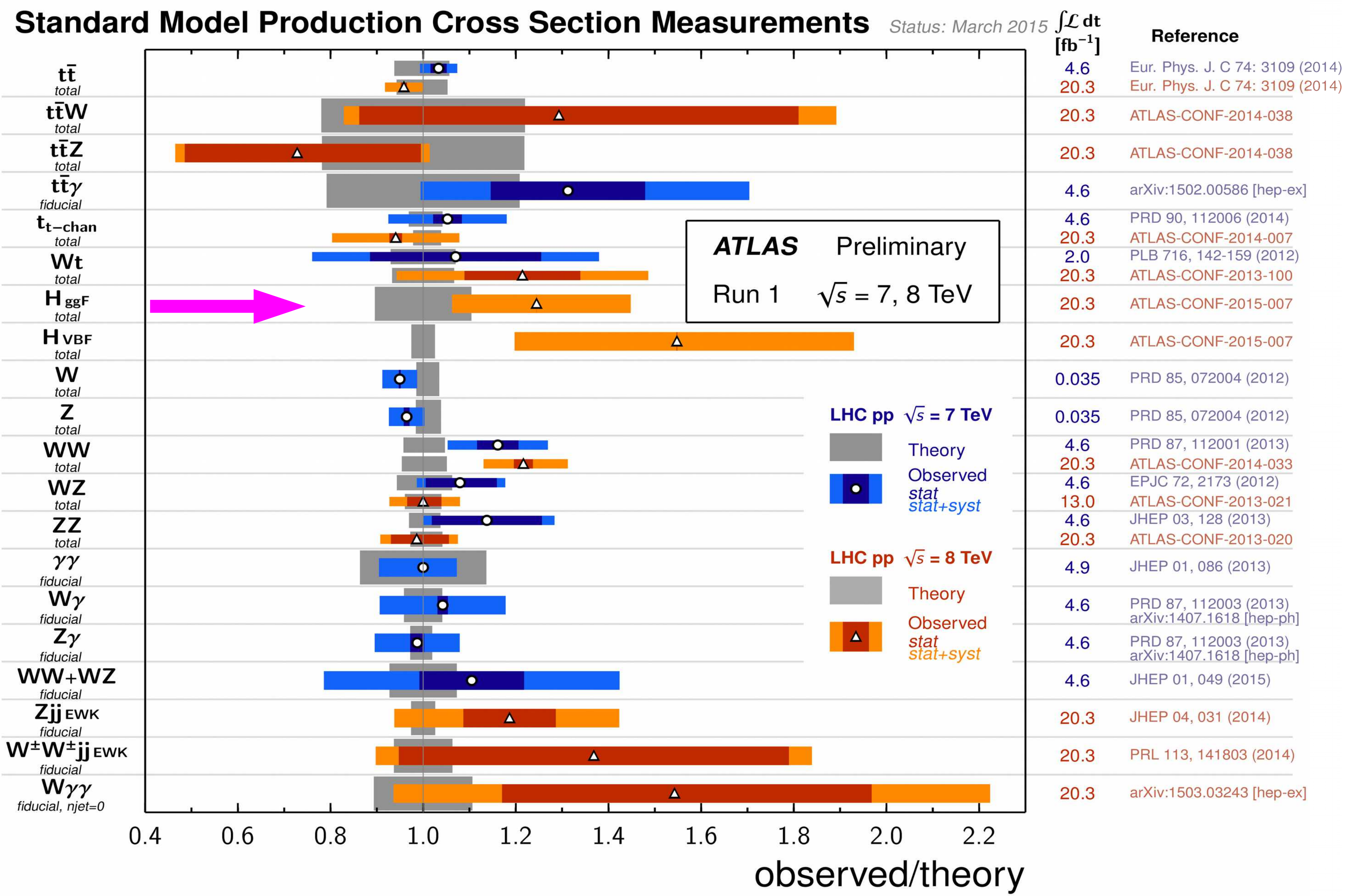
FCC-he
can combine with
FCC-hh
to maximize
discovery potential

FCC hh & he
options provide
complementary
information

DGLAP evolution alone is
not sufficient to constrain
hi-x hi-Q region

Gluon

LHC Results: *Incredible Progress*



Much of theory error from PDFs

Higgs boson gluon-fusion production in $\boxed{N^3LO}$ QCD

Charalampos Anastasiou,[1] Claude Duhr,[2,3,*] Falko Dulat,[1] Franz Herzog,[4] and Bernhard Mistlberger[1]

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[3] *Center for Cosmology, Particle Physics and Phenomenology (CP3), Université Catholique de Louvain, 1348 Louvain-La-Neuve, Belgium*
[4] *Nikhef, Science Park 105, 1098 XG Amsterdam, The Netherlands*

arXiv: 1503.06056v1

(Dated: March 23, 2015)

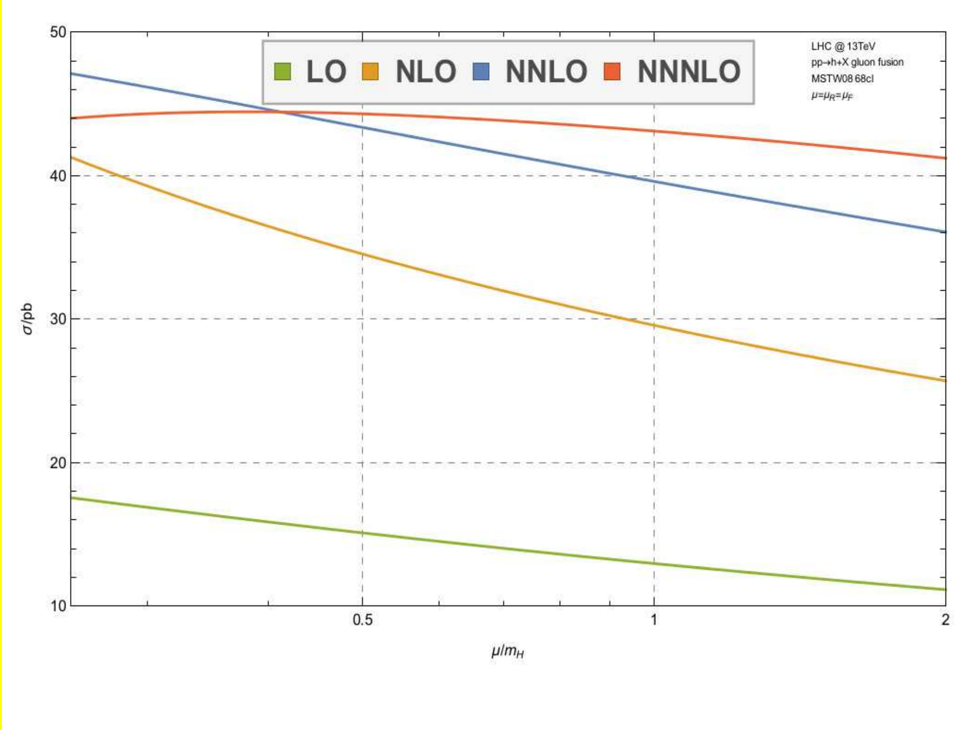
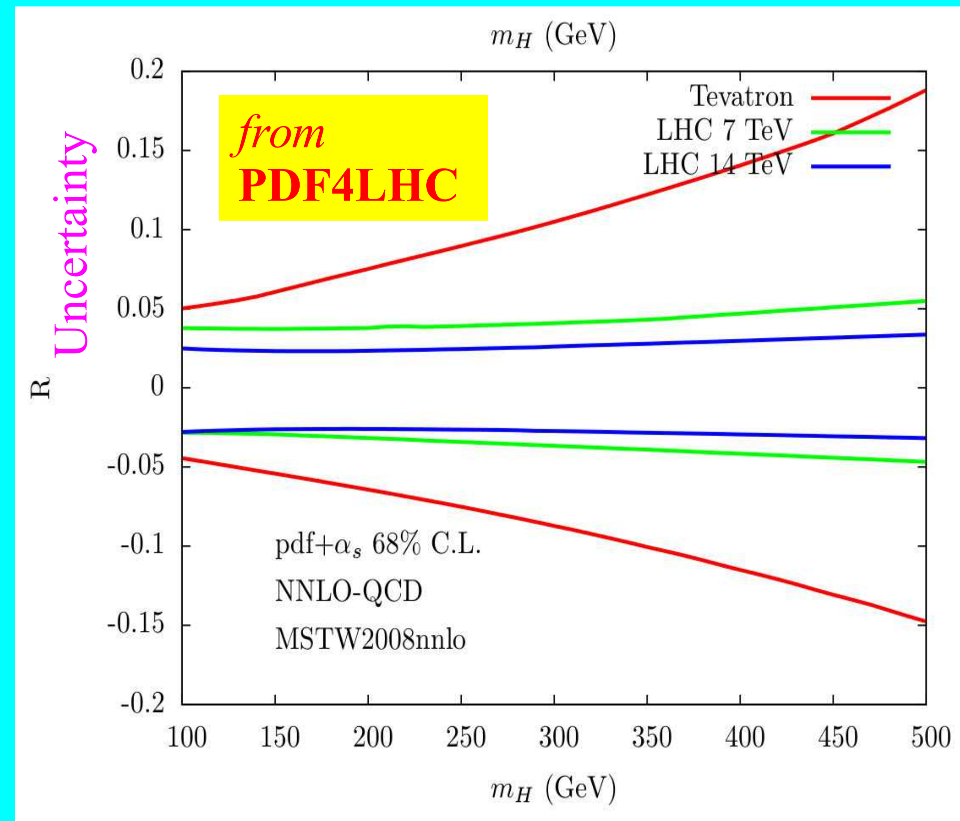
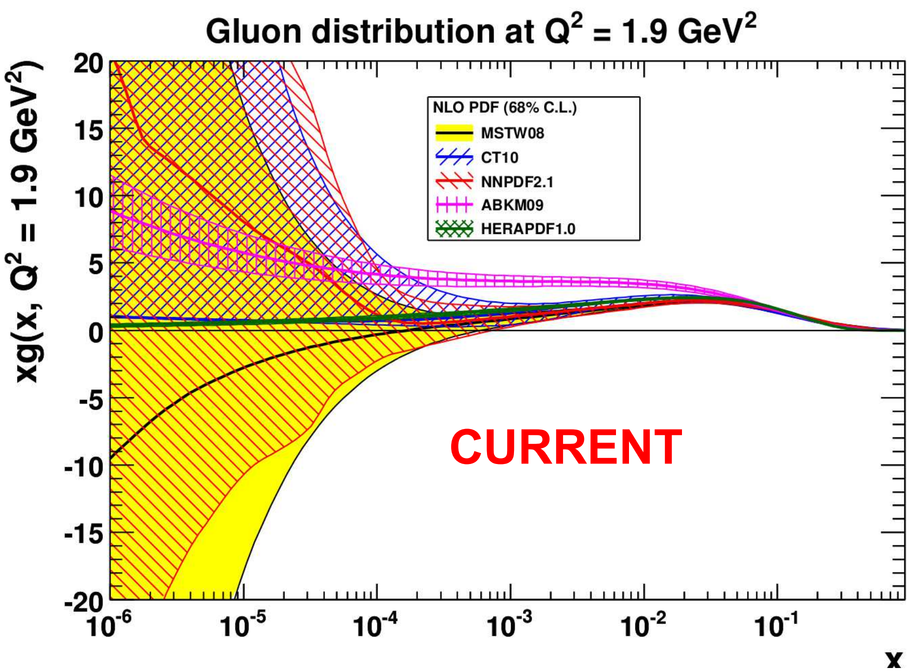


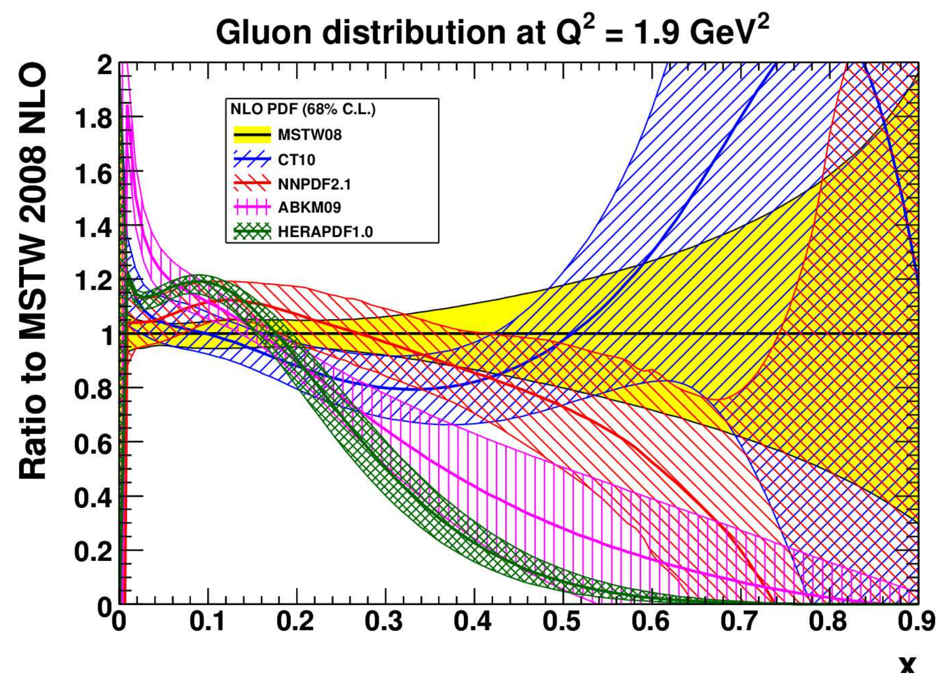
FIG. 2: Scale variation of the gluon fusion cross-section at all perturbative orders through N³LO.

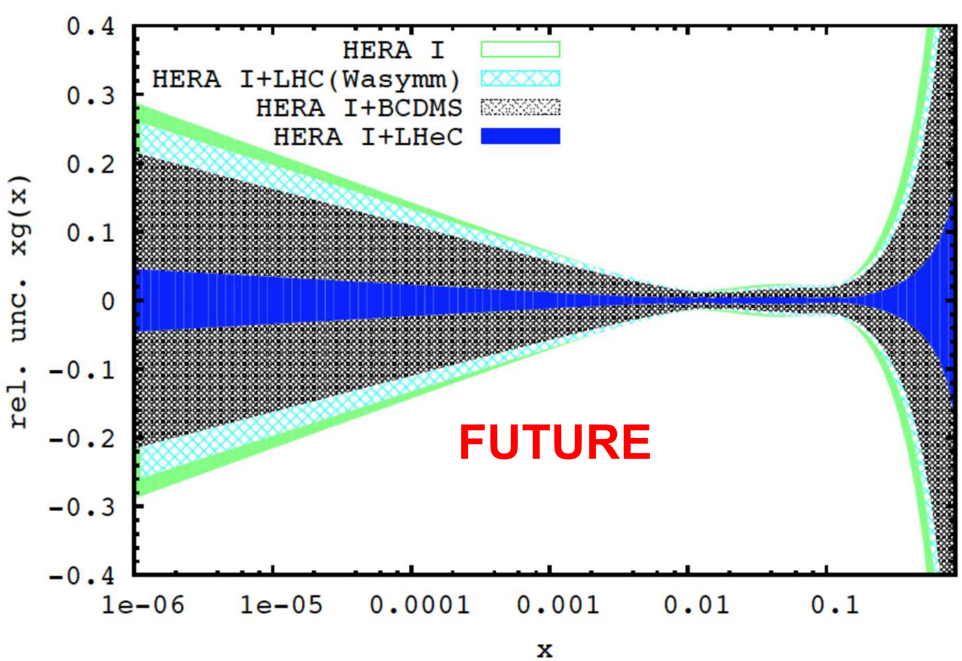


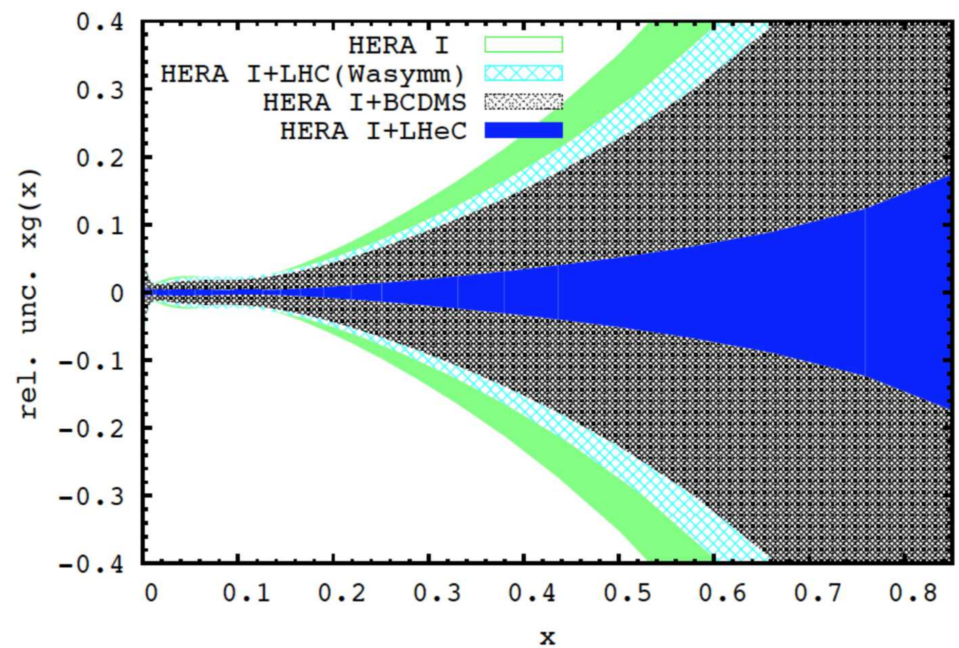
Greatly improved theory uncertainty ~2%; PDFs now dominant ~4%; At Hi-E, Higgs is medium x, but ...

The Gluon PDF Uncertainty: Example from LHeC Study







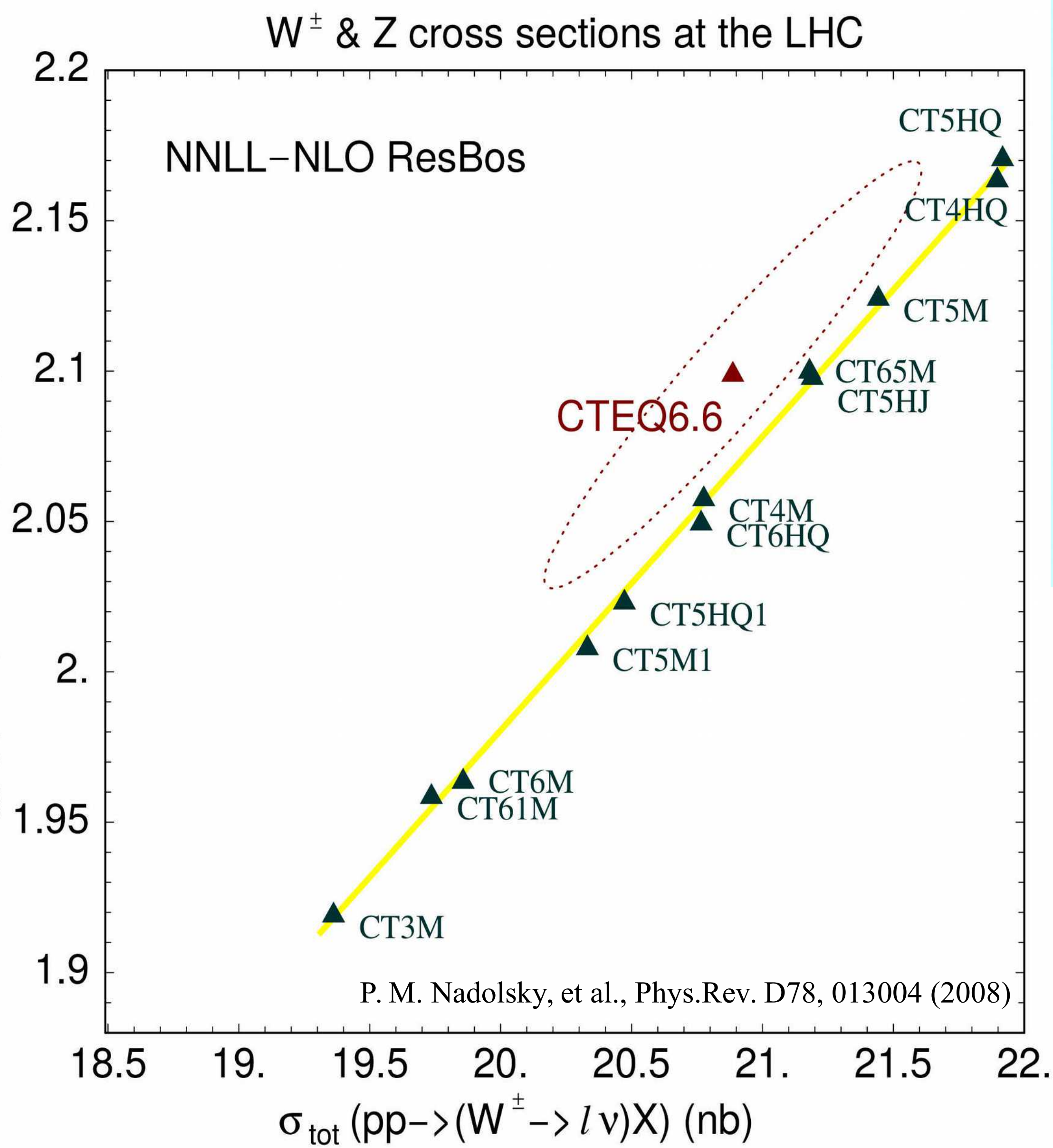


LHeC Study Group arxiv.org/1211.5102
Amanda Cooper-Sarkar: arxiv.org/1310.0662

Useful for new physics processes

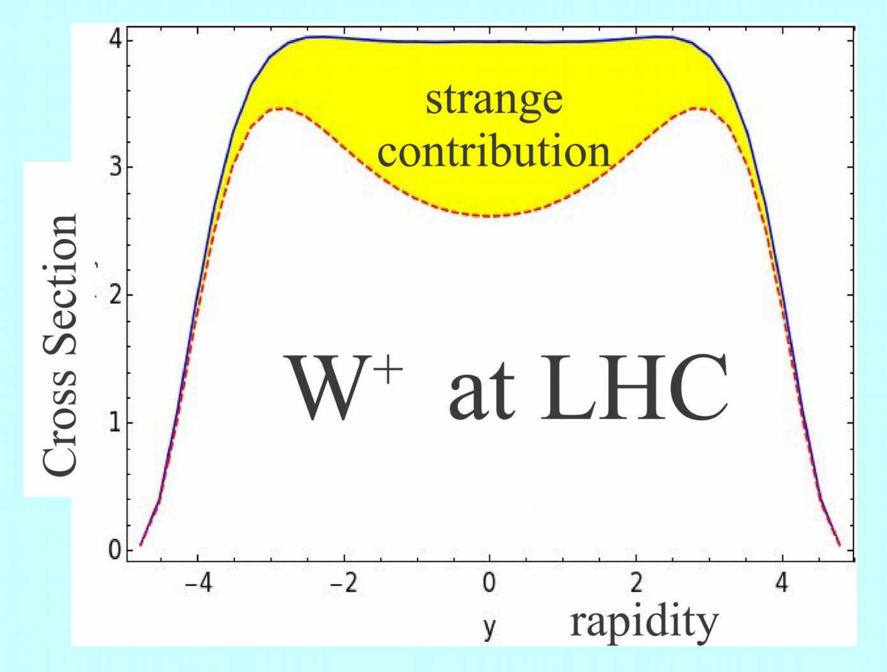
Strange

Surprize: **W & Z decorrelation at the LHC:** *... due to Strange PDF*



Z Cross section

W Cross section



At LHC, flavor composition is very different.

Spoils W/Z Correlations

Impacts M_W extraction

LHC is not just a re-do of the Tevatron

… same for FCC

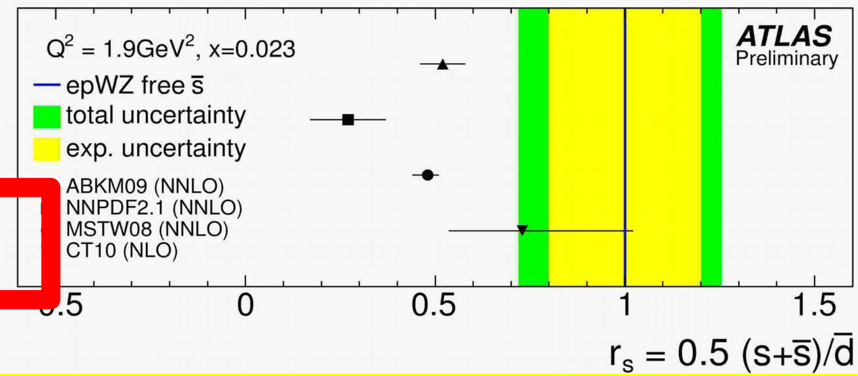
More surprises: W / Z at LHC is Sensitive to Strange

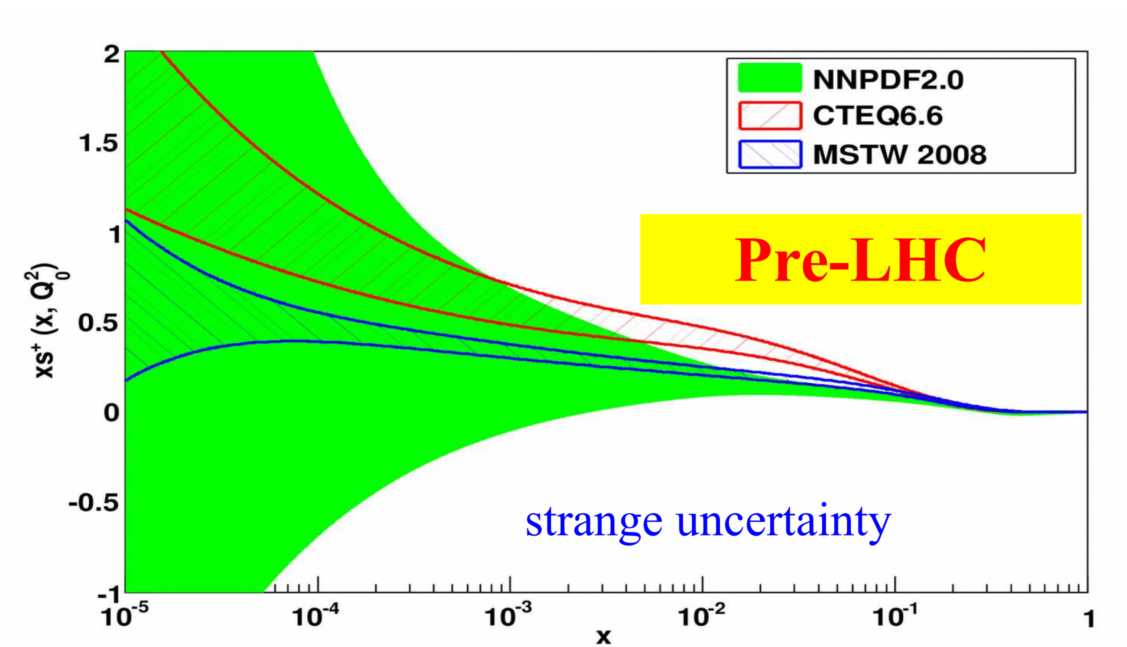
W, Z data sensitivity to strange sea

- ATLAS performed NNLO QCD fit to Z, W^+, W^- + HERA ep DIS cross sections: significant tension for Z observed when suppressing strange by 50% at low scale $1.9\,\mathrm{GeV}^2$

- Fit with free strange sea gives no supression

$$\boxed{r_s = 1.00 \pm 0.20_{\text{exp}}\ {}^{+0.16}_{-0.20}\ \text{sys}}$$





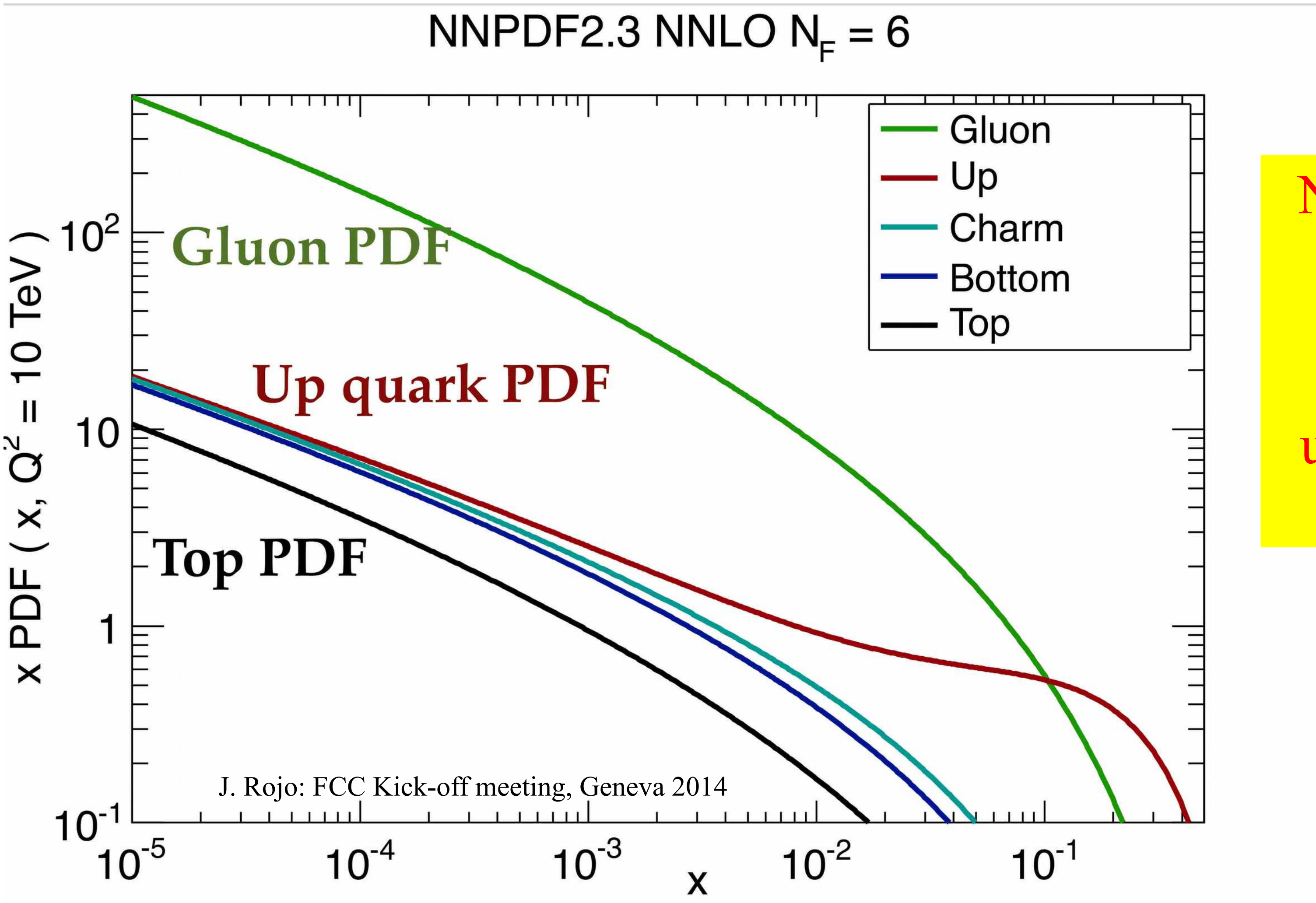
Suggests SU(3) symmetry in contrast to low Q measurements

FCC-he can complement FCC-hh in large-x large-Q region

... speaking of flavor symmetry

Charm Bottom & Top

More surprises: **At Large Q, we have** ***Flavor Democracy***



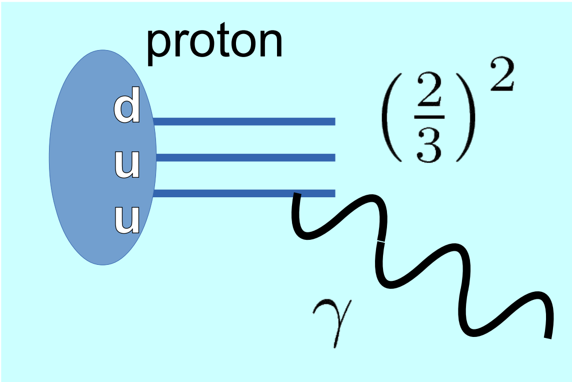
Need to include c, b, and top in PDF

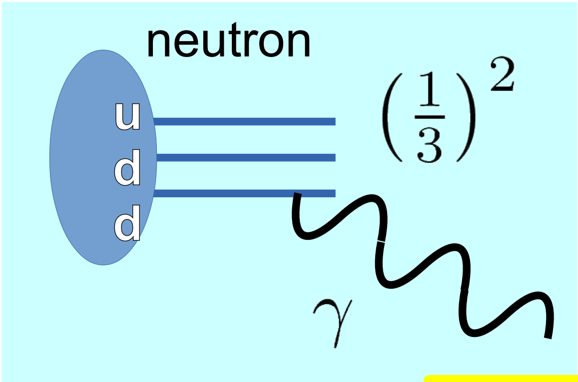
Flavors contribute uniformly at large Q small-x

… beyond issues of FFS and VFS

multi-scale problem: m_H Q

Other issues: Include QED in DGLAP Evolution: Impacts u & d

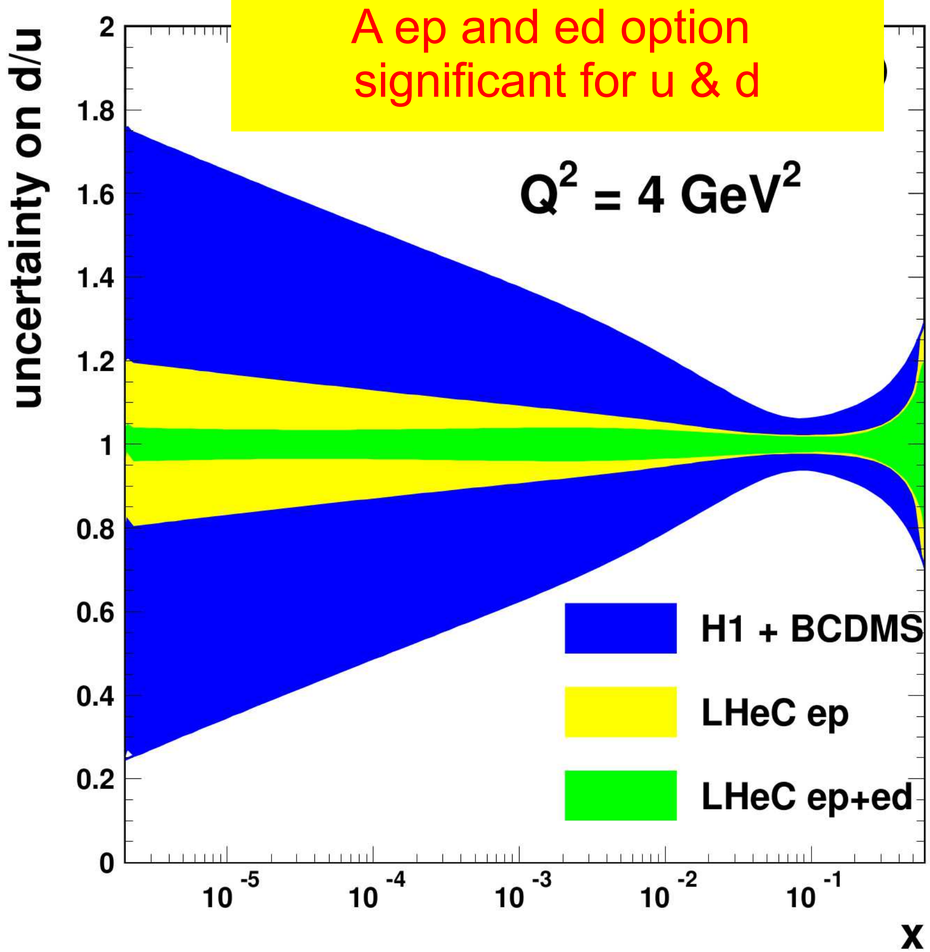


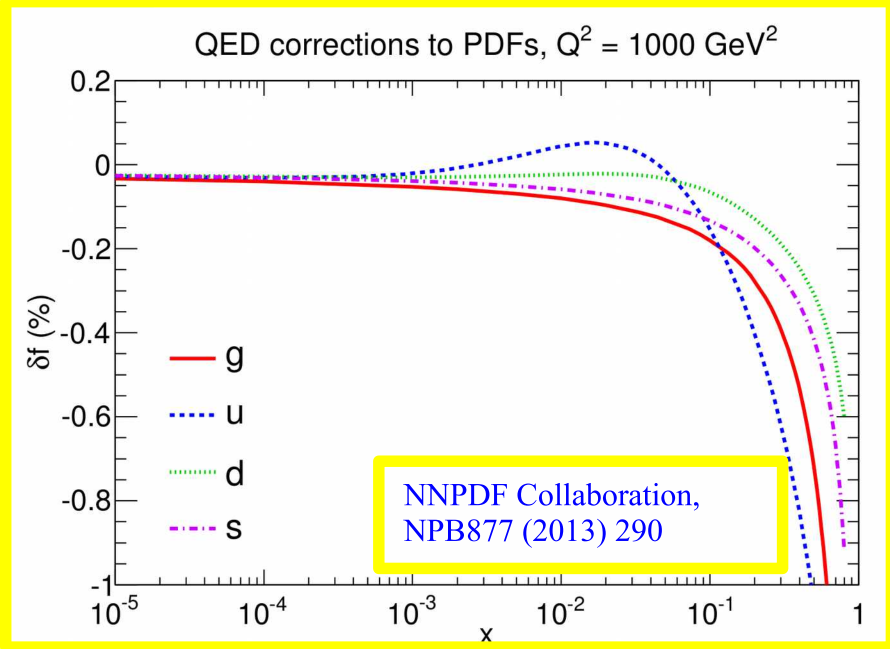


QED Evolution yields Isospin violating terms.

Comparable to NNLO QCD

A ep and ed option significant for u & d





… and beyond:

Need to intoduce PDFs for γ W and Z

Final Thoughts

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: SUSY 2013

ATLAS Preliminar

$\int \mathcal{L}\, dt = (4.6 - 22.9)\ \mathrm{fb}^{-1}$ $\sqrt{s}$ = 7, 8 TeV

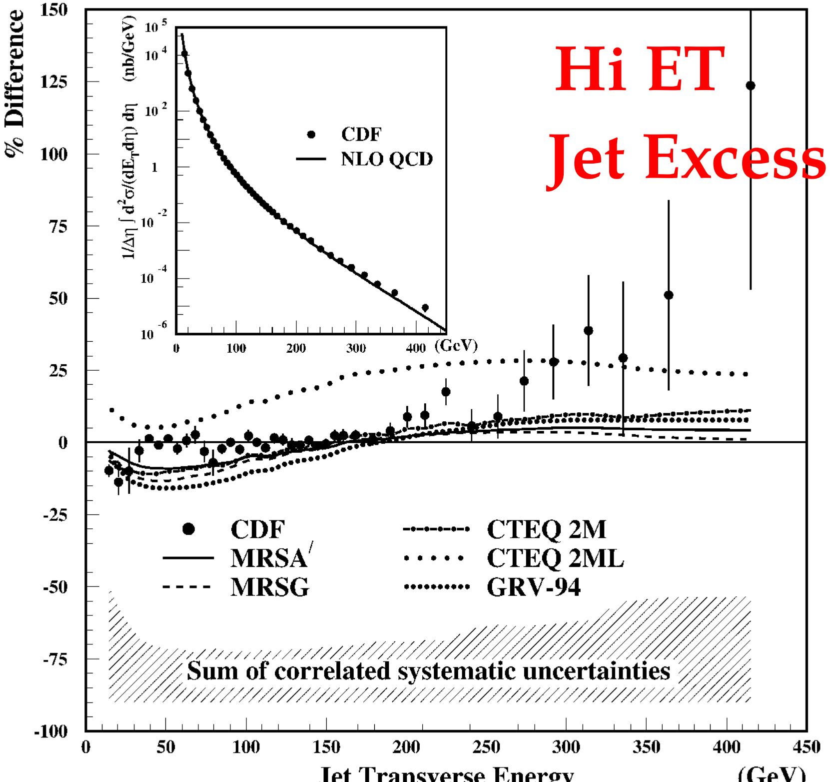
	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt[\mathrm{fb}^{-1}]$		Mass limit		Reference
Inclusive Searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	$\tilde{q}, \tilde{g}$	1.7 TeV	$m(\tilde{q})$=$m(\tilde{g})$	ATLAS-CONF-2013-047
	MSUGRA/CMSSM	1 e, μ	3-6 jets	Yes	20.3	$\tilde{g}$	1.2 TeV	any $m(\tilde{q})$	ATLAS-CONF-2013-062
	MSUGRA/CMSSM	0	7-10 jets	Yes	20.3	$\tilde{g}$	1.1 TeV	any $m(\tilde{q})$	1308.1841
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{q}$	740 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-047
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$	1.3 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-047
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}_1^\pm\to qqW^\pm\tilde{\chi}_1^0$	1 e, μ	3-6 jets	Yes	20.3	$\tilde{g}$	1.18 TeV	$m(\tilde{\chi}_1^0)$<200 GeV, $m(\tilde{\chi}^\pm)$=0.5($m(\tilde{\chi}_1^0)$+$m(\tilde{g})$)	ATLAS-CONF-2013-062
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	2 e, μ	0-3 jets	-	20.3	$\tilde{g}$	1.12 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-089
	GMSB ($\tilde{\ell}$ NLSP)	2 e, μ	2-4 jets	Yes	4.7	$\tilde{g}$	1.24 TeV	tanβ<15	1208.4688
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ	0-2 jets	Yes	20.7	$\tilde{g}$	1.4 TeV	tanβ >18	ATLAS-CONF-2013-026
	GGM (bino NLSP)	2 γ	-	Yes	4.8	$\tilde{g}$	1.07 TeV	$m(\tilde{\chi}_1^0)$>50 GeV	1209.0753
	GGM (wino NLSP)	1 $e, \mu + \gamma$	-	Yes	4.8	$\tilde{g}$	619 GeV	$m(\tilde{\chi}_1^0)$>50 GeV	ATLAS-CONF-2012-144
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	4.8	$\tilde{g}$	900 GeV	$m(\tilde{\chi}_1^0)$>220 GeV	1211.1167
	GGM (higgsino NLSP)	2 e, μ (Z)	0-3 jets	Yes	5.8	$\tilde{g}$	690 GeV	$m(\tilde{H})$>200 GeV	ATLAS-CONF-2012-152
	Gravitino LSP	0	mono-jet	Yes	10.5	$F^{1/2}$ scale	645 GeV	$m(\tilde{g})$>10^{-4} eV	ATLAS-CONF-2012-147
3rd gen. $\tilde{g}$ med.	$\tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	20.1	$\tilde{g}$	1.2 TeV	$m(\tilde{\chi}_1^0)$<600 GeV	ATLAS-CONF-2013-061
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3	$\tilde{g}$	1.1 TeV	$m(\tilde{\chi}_1^0)$ <350 GeV	1308.1841
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e, μ	3 b	Yes	20.1	$\tilde{g}$	1.34 TeV	$m(\tilde{\chi}_1^0)$<400 GeV	ATLAS-CONF-2013-061
	$\tilde{g}\to b\bar{t}\tilde{\chi}_1^+$	0-1 e, μ	3 b	Yes	20.1	$\tilde{g}$	1.3 TeV	$m(\tilde{\chi}_1^0)$<300 GeV	ATLAS-CONF-2013-061
3rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$\tilde{b}_1$	100-620 GeV	$m(\tilde{\chi}_1^0)$<90 GeV	1308.2631
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to t\tilde{\chi}_1^\pm$	2 e, μ (SS)	0-3 b	Yes	20.7	$\tilde{b}_1$	275-430 GeV	$m(\tilde{\chi}_1^\pm)$=2 $m(\tilde{\chi}_1^0)$	ATLAS-CONF-2013-007
	$\tilde{t}_1\tilde{t}_1$(light), $\tilde{t}_1\to b\tilde{\chi}_1^\pm$	1-2 e, μ	1-2 b	Yes	4.7	$\tilde{t}_1$	110-167 GeV	$m(\tilde{\chi}_1^0)$=55 GeV	1208.4305, 1209.2102
	$\tilde{t}_1\tilde{t}_1$(light), $\tilde{t}_1\to Wb\tilde{\chi}_1^0$	2 e, μ	0-2 jets	Yes	20.3	$\tilde{t}_1$	130-220 GeV	$m(\tilde{\chi}_1^0)$ =$m(\tilde{t}_1)$-$m(W)$-50 GeV, $m(\tilde{t}_1)$<<$m(\tilde{\chi}_1^\pm)$	ATLAS-CONF-2013-048
	$\tilde{t}_1\tilde{t}_1$(medium), $\tilde{t}_1\to t\tilde{\chi}_1^0$	2 e, μ	2 jets	Yes	20.3	$\tilde{t}_1$	225-525 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-065
	$\tilde{t}_1\tilde{t}_1$(medium), $\tilde{t}_1\to b\tilde{\chi}_1^\pm$	0	2 b	Yes	20.1	$\tilde{t}_1$	150-580 GeV	$m(\tilde{\chi}_1^0)$<200 GeV, $m(\tilde{\chi}_1^\pm)$-$m(\tilde{\chi}_1^0)$=5 GeV	1308.2631
	$\tilde{t}_1\tilde{t}_1$(heavy), $\tilde{t}_1\to t\tilde{\chi}_1^0$	1 e, μ	1 b	Yes	20.7	$\tilde{t}_1$	200-610 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-037
	$\tilde{t}_1\tilde{t}_1$(heavy), $\tilde{t}_1\to t\tilde{\chi}_1^0$	0	2 b	Yes	20.5	$\tilde{t}_1$	320-660 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-024
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to c\tilde{\chi}_1^0$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$	90-200 GeV	$m(\tilde{t}_1)$-$m(\tilde{\chi}_1^0)$<85 GeV	ATLAS-CONF-2013-068
	$\tilde{t}_1\tilde{t}_1$(natural GMSB)	2 e, μ (Z)	1 b	Yes	20.7	$\tilde{t}_1$	500 GeV	$m(\tilde{\chi}_1^0)$>150 GeV	ATLAS-CONF-2013-025
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1 + Z$	3 e, μ (Z)	1 b	Yes	20.7	$\tilde{t}_2$	271-520 GeV	$m(\tilde{t}_1)$=$m(\tilde{\chi}_1^0)$+180 GeV	ATLAS-CONF-2013-025
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}$, $\tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e, μ	0	Yes	20.3	$\tilde{\ell}$	85-315 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-049
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e, μ	0	Yes	20.3	$\tilde{\chi}_1^\pm$	125-450 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\ell}, \tilde{\nu})$=0.5($m(\tilde{\chi}_1^\pm)$+$m(\tilde{\chi}_1^0)$)	ATLAS-CONF-2013-049
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	20.7	$\tilde{\chi}_1^\pm$	180-330 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\tau}, \tilde{\nu})$=0.5($m(\tilde{\chi}_1^\pm)$+$m(\tilde{\chi}_1^0)$)	ATLAS-CONF-2013-028
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu)$, $\ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e, μ	0	Yes	20.7	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$	600 GeV	$m(\tilde{\chi}_1^\pm)$=$m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell}, \tilde{\nu})$=0.5($m(\tilde{\chi}_1^\pm)$+$m(\tilde{\chi}_1^0)$)	ATLAS-CONF-2013-035
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$	3 e, μ	0	Yes	20.7	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$	315 GeV	$m(\tilde{\chi}_1^\pm)$=$m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, sleptons decoupled	ATLAS-CONF-2013-035
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 h\tilde{\chi}_1^0$	1 e, μ	2 b	Yes	20.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$	285 GeV	$m(\tilde{\chi}_1^\pm)$=$m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, sleptons decoupled	ATLAS-CONF-2013-093
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}_1^\pm$	270 GeV	$m(\tilde{\chi}_1^\pm)$-$m(\tilde{\chi}_1^0)$=160 MeV, $\tau(\tilde{\chi}_1^\pm)$=0.2 ns	ATLAS-CONF-2013-069
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	22.9	$\tilde{g}$	832 GeV	$m(\tilde{\chi}_1^0)$=100 GeV, 10 μs<$\tau(\tilde{g})$<1000 s	ATLAS-CONF-2013-057
	GMSB, stable $\tilde{\tau}$, $\tilde{\chi}_1^0\to\tilde{\tau}(\tilde{e}, \tilde{\mu})+\tau(e, \mu)$	1-2 μ	-	-	15.9	$\tilde{\chi}_1^0$	475 GeV	10<tanβ<50	ATLAS-CONF-2013-058
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	4.7	$\tilde{\chi}_1^0$	230 GeV	0.4<$\tau(\tilde{\chi}_1^0)$<2 ns	1304.6310
	$\tilde{q}\tilde{q}$, $\tilde{\chi}_1^0\to qq\mu$ (RPV)	1 μ, displ. vtx	-	-	20.3	$\tilde{q}$	1.0 TeV	1.5 <$c\tau$<156 mm, BR(μ)=1, $m(\tilde{\chi}_1^0)$=108 GeV	ATLAS-CONF-2013-092
RPV	LFV $pp\to\tilde{\nu}_\tau + X$, $\tilde{\nu}_\tau\to e + \mu$	2 e, μ	-	-	4.6	$\tilde{\nu}_\tau$	1.61 TeV	λ'_{311}=0.10, λ_{132}=0.05	1212.1272
	LFV $pp\to\tilde{\nu}_\tau + X$, $\tilde{\nu}_\tau\to e(\mu) + \tau$	1 $e, \mu + \tau$	-	-	4.6	$\tilde{\nu}_\tau$	1.1 TeV	λ'_{311}=0.10, $\lambda_{1(2)33}$=0.05	1212.1272
	Bilinear RPV CMSSM	1 e, μ	7 jets	Yes	4.7	$\tilde{q}, \tilde{g}$	1.2 TeV	$m(\tilde{q})$=$m(\tilde{g})$, $c\tau_{LSP}$<1 mm	ATLAS-CONF-2012-140
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e, μ	-	Yes	20.7	$\tilde{\chi}_1^\pm$	760 GeV	$m(\tilde{\chi}_1^0)$>300 GeV, λ_{121}>0	ATLAS-CONF-2013-036
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 $e, \mu + \tau$	-	Yes	20.7	$\tilde{\chi}_1^\pm$	350 GeV	$m(\tilde{\chi}_1^0)$>80 GeV, λ_{133}>0	ATLAS-CONF-2013-036
	$\tilde{g}\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$	916 GeV	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2013-091
	$\tilde{g}\to\tilde{t}_1 t$, $\tilde{t}_1\to bs$	2 e, μ (SS)	0-3 b	Yes	20.7	$\tilde{g}$	880 GeV		ATLAS-CONF-2013-007
Other	Scalar gluon pair, sgluon$\to q\bar{q}$	0	4 jets	-	4.6	sgluon	100-287 GeV	incl. limit from 1110.2693	1210.4826
	Scalar gluon pair, sgluon$\to t\bar{t}$	2 e, μ (SS)	1 b	Yes	14.3	sgluon	800 GeV		ATLAS-CONF-2013-051
	WIMP interaction (D5, Dirac χ)	0	mono-jet	Yes	10.5	M* scale	704 GeV	$m(\chi)$<80 GeV, limit of<687 GeV for D8	ATLAS-CONF-2012-147

10^{-1} 1 **Mass scale [TeV]**

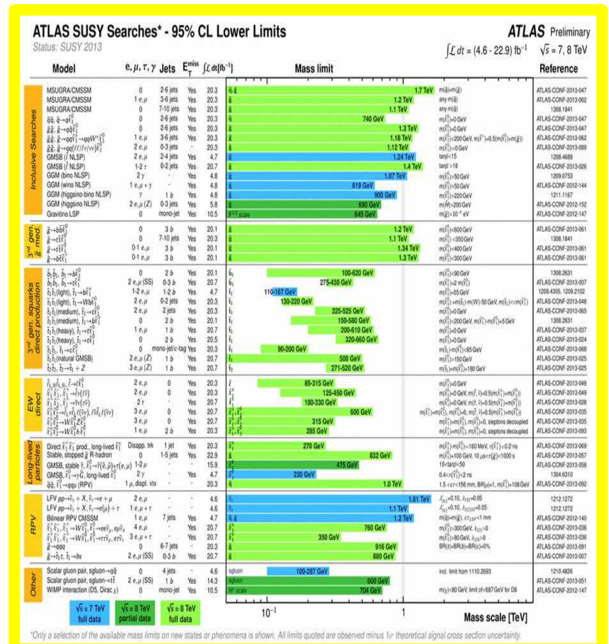
$\sqrt{s}$ = 7 TeV full data | $\sqrt{s}$ = 8 TeV partial data | $\sqrt{s}$ = 8 TeV full data

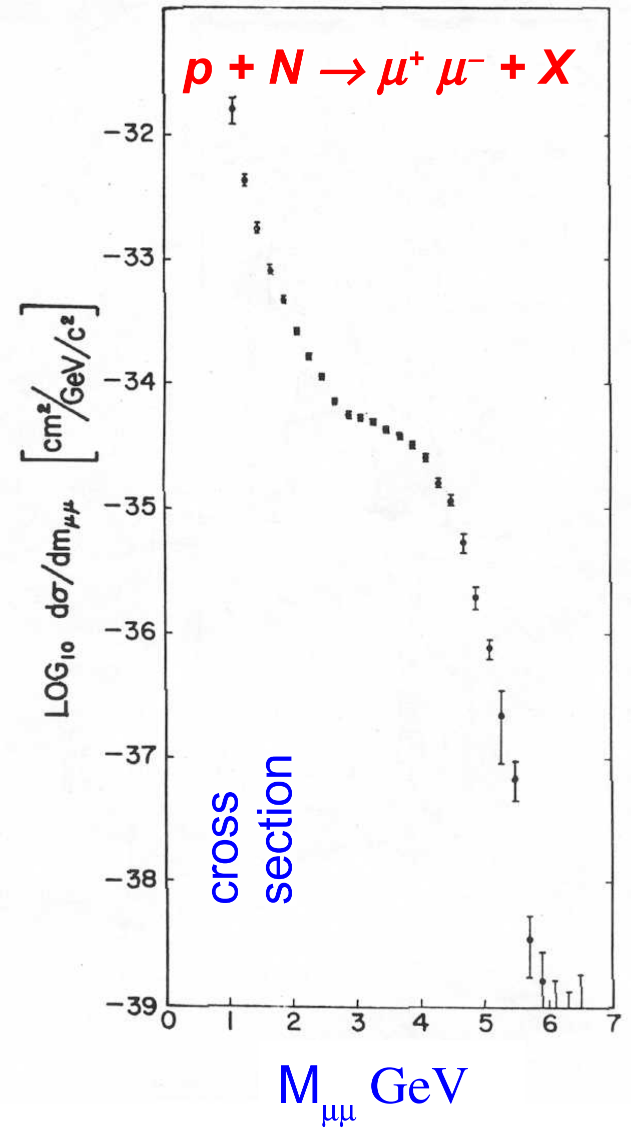
*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

What can improved PDFs do for you: … to think about



CDF Collaboration, PRL 77, 438 (1996)





Just because we can absorb it into the PDFs doesn't mean we should

We need to calibrate new physics searches

Parton Distributions and the FCC Project

Photo credit: http://justinsomnia.org/

<u>FCC Program:</u>

⇒ tremendous reach for New Physics Searches

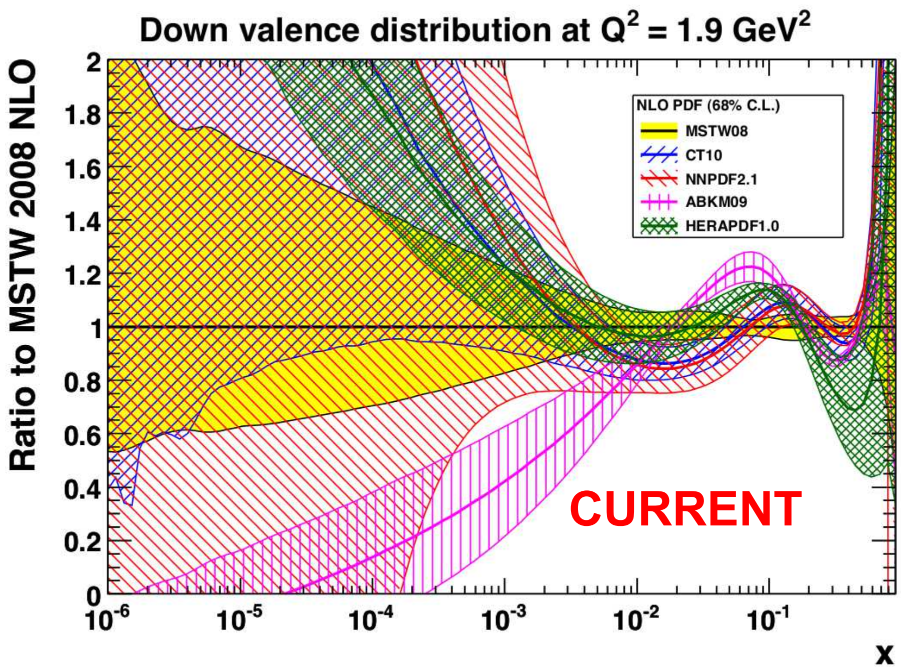
⇒ new opportunities *<u>and</u>* challenges

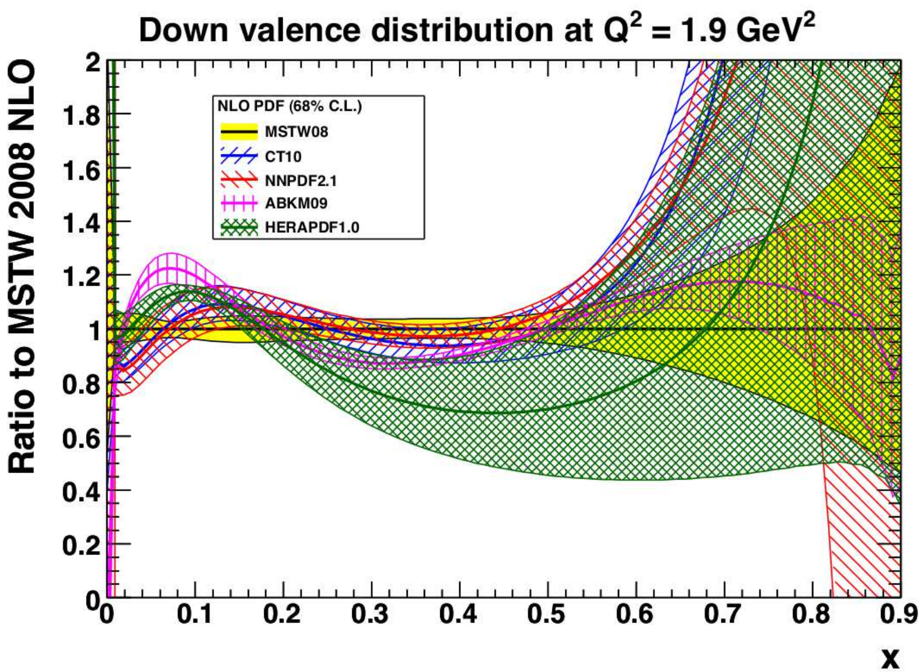
<u>FCC-*he* Option:</u> Complement FCC-*hh*

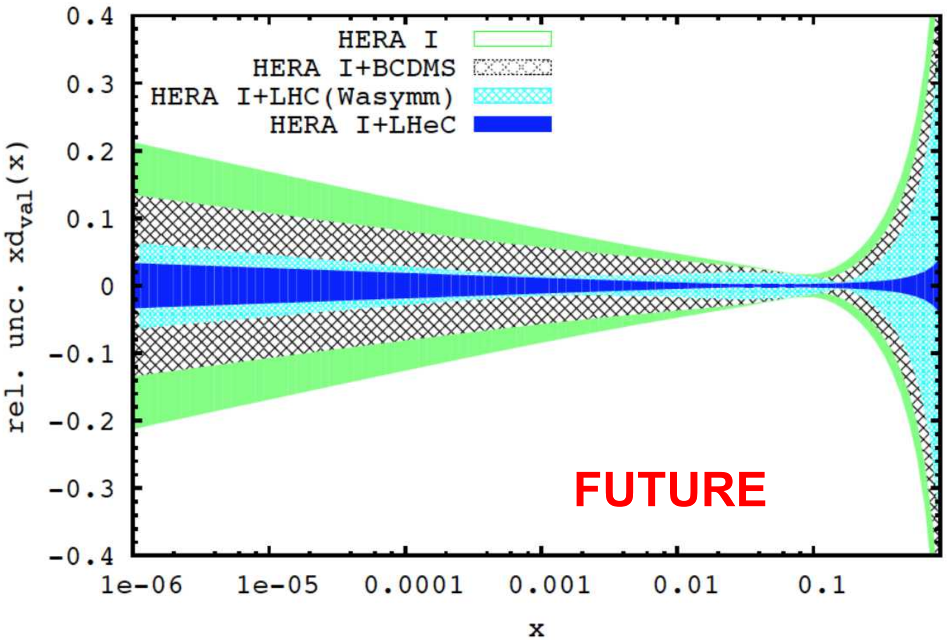
Maximize discovery potential at highest energy

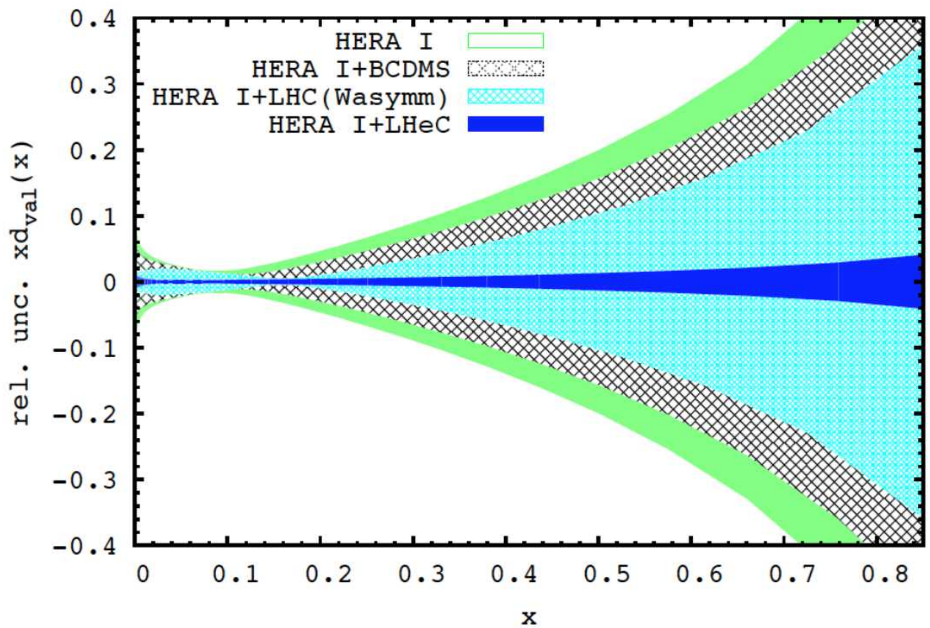
Study QCD extremes in $\{x,Q^2\}$ plane

Up and Down Distributions





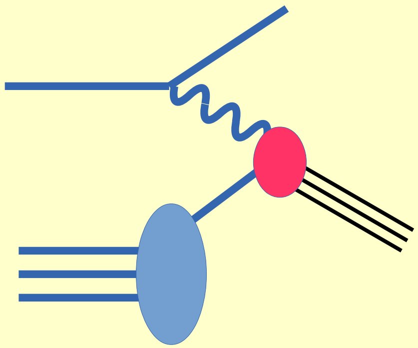




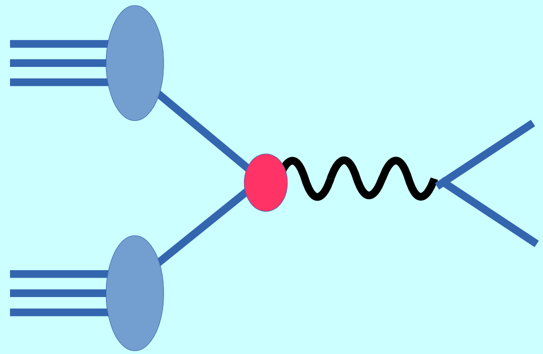
Useful for hi-mass searches

LHeC Study Group arxiv.org/1211.5102
Amanda Cooper-Sarkar: arxiv.org/1310.0662

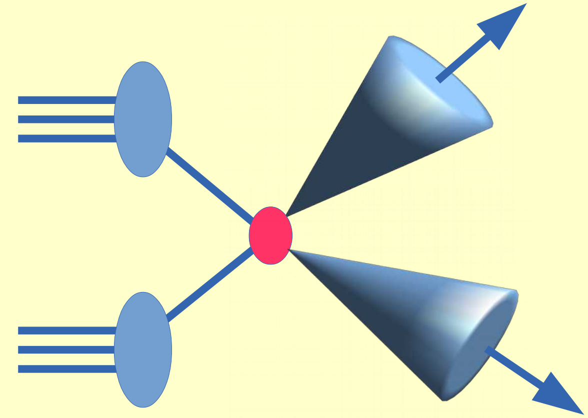
PDF Flavor Differentiation: *A difficult problem*



DIS Production



Drell-Yan



Jet Production

$$F_2^{\nu} \sim [d + s + \bar{u} + \bar{c}]$$

$$F_2^{\bar{\nu}} \sim \left[\bar{d} + \bar{s} + u + c\right]$$

$$F_3^{\nu} = 2\,[d + s - \bar{u} - \bar{c}]$$

$$F_3^{\bar{\nu}} = 2\left[u + c - \bar{d} - \bar{s}\right]$$

$$\begin{aligned} F_2^{\ell^\pm} &\sim \left(\tfrac{1}{3}\right)^2 [d + s] \\ &+ \left(\tfrac{2}{3}\right)^2 [u + c] \end{aligned}$$

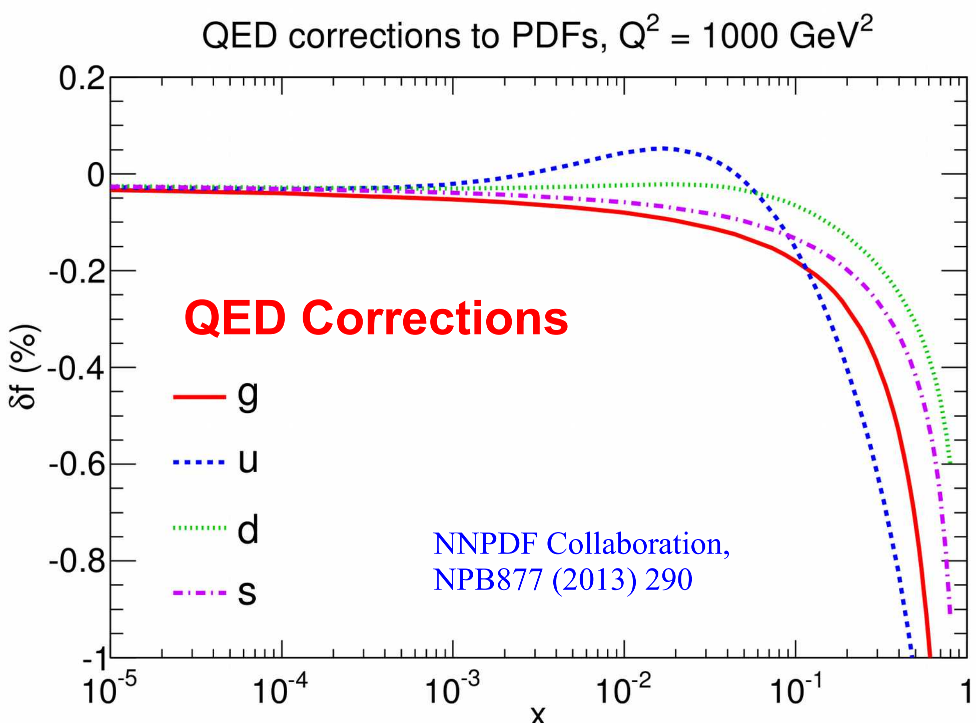
The DIS combinations have historically been particularly useful

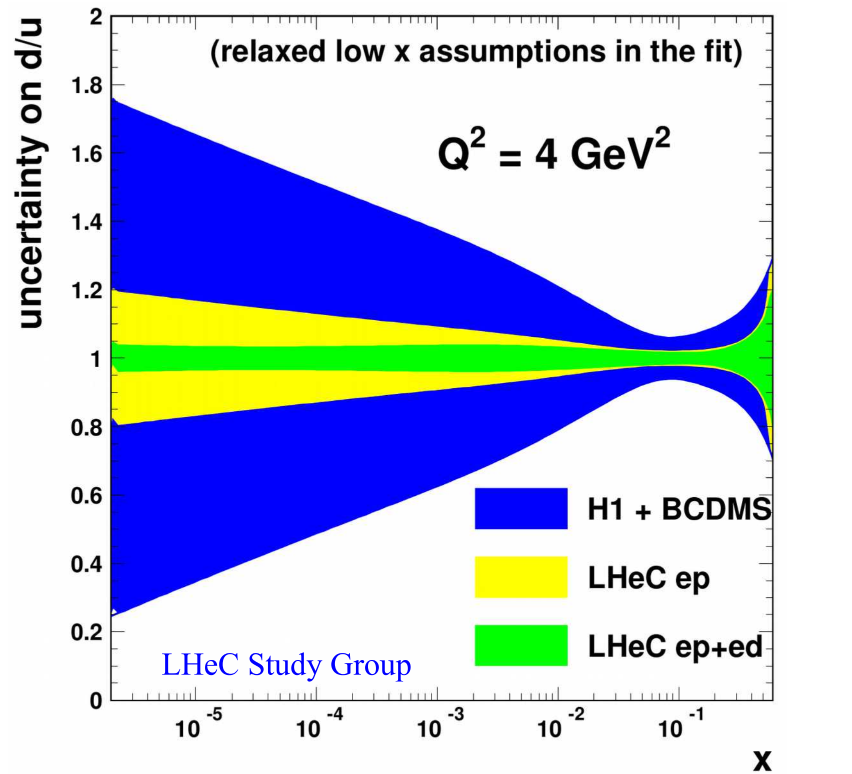
<u>Different</u> linear combinations – key for flavor differentiation

The n-DIS data typically use heavy targets, and this requires the application of ***<u>nuclear corrections</u>***

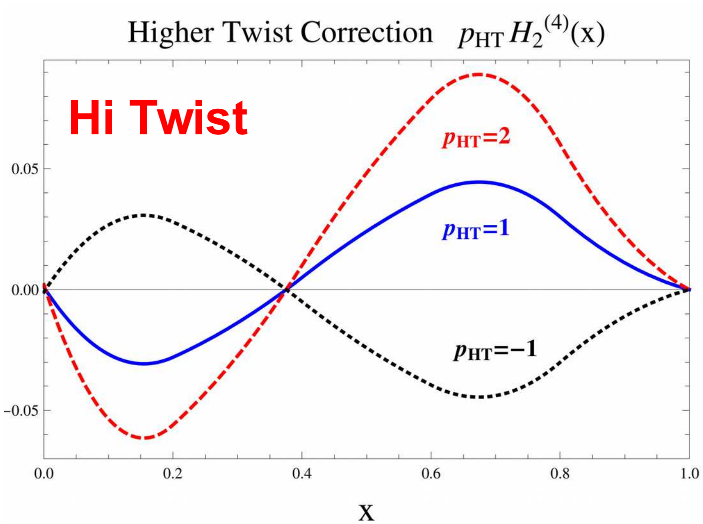
see next talk: *Heavy Ion Physics in e-A and p/A-A,* ***Nestor Armesto Perez***

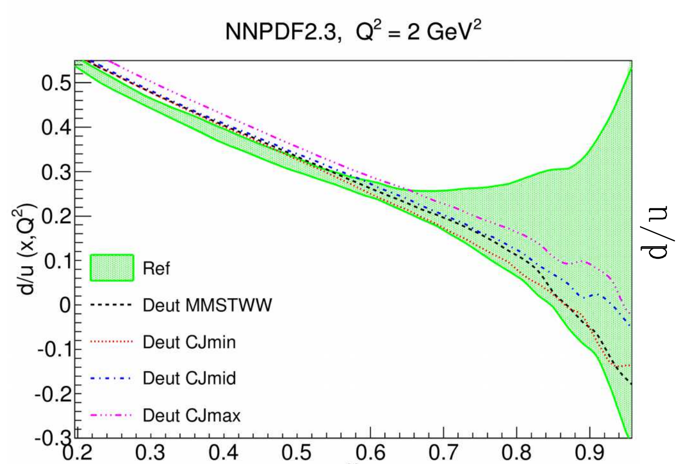
Isospin Symmetry Violation, Higher Twist, Nuclear Corrections ...

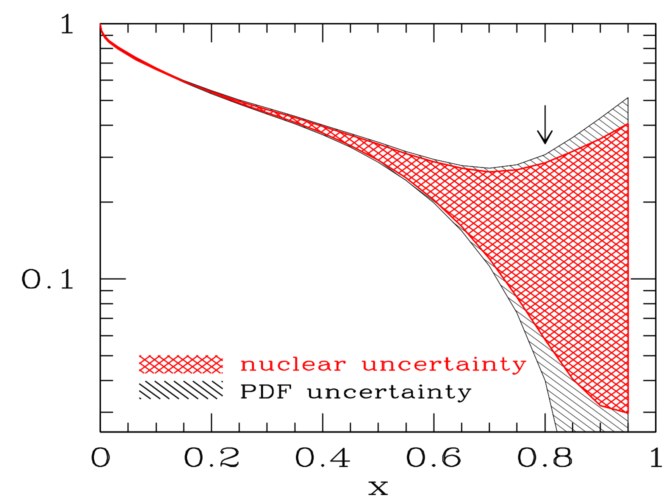




Nuclear Corrections or Parameterization???







The NNPDF Collaboration, PLB723 (2013) 330

CTEQ-CJ: Phys.Rev. D84 (2011) 014008

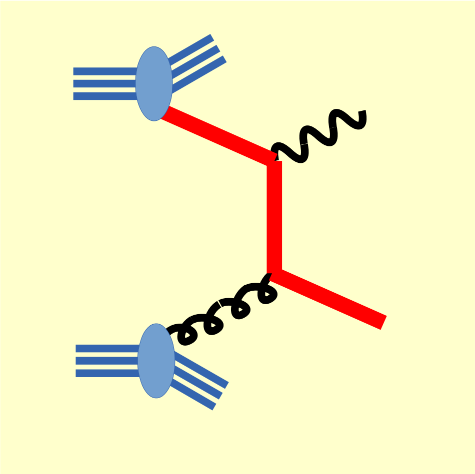
… what about the

Heavy Quarks

c & b

Extrinsic & Intrinsic

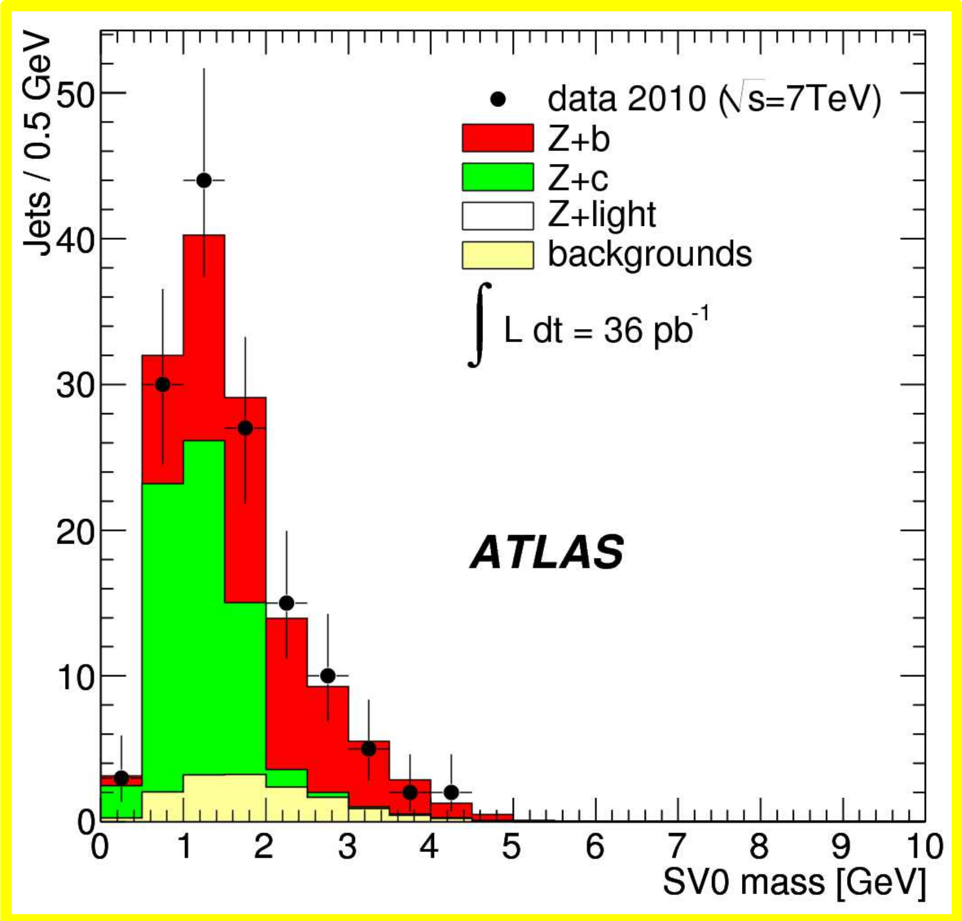
Heavy Quarks at the LHC

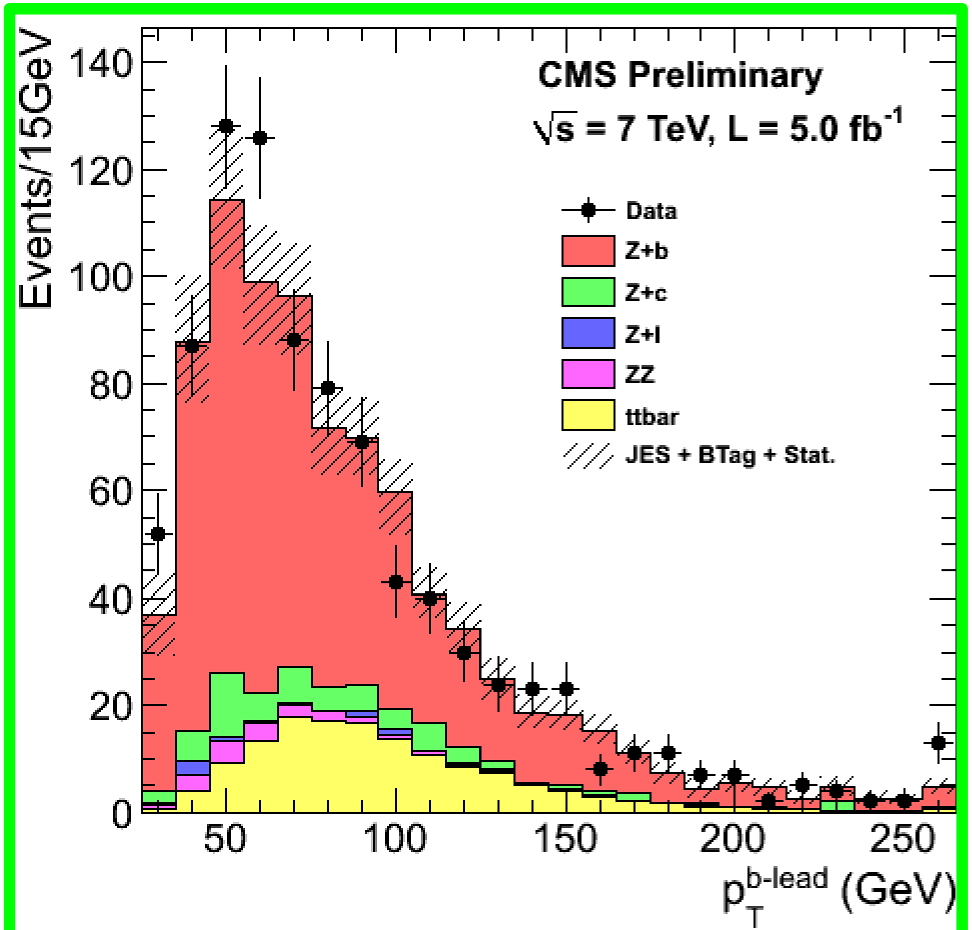


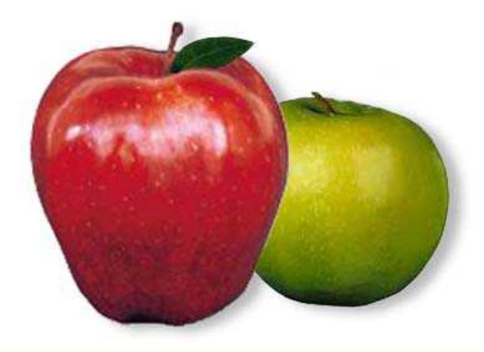
$$c\ g \to c\ \gamma, Z$$
$$b\ g \to b\ \gamma, Z$$

$$s\ g \to cW$$
$$c\ g \to bW$$

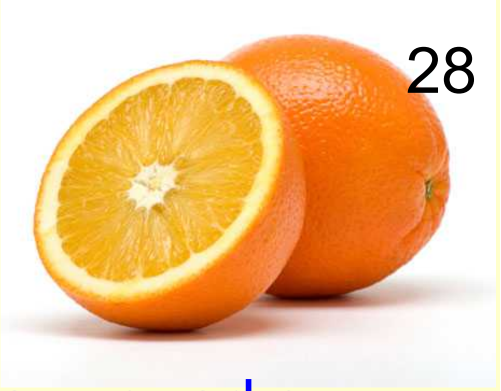
Much higher scales
Sensitive to $\alpha \ln(m/Q)$ resummation







Les Houches Comparative Studies



Excellent progress in addressing how to compute heavy quarks

The Cast:

ACOT & S-ACOT Codes
Used in CTEQ4HQ, 5HQ, 6HQ

Aivazis, Collins, Olness, Tung, Phys.Rev.D50:3102-3118,1994.

S-ACOT
CTEQ 6.5 & 6.6

Tung, Lai, Belyaev, Pumplin, Stump, Yuan, JHEP 0702:053,2007.
Nadolsky, Tung, Phys.Rev.D79:113014,2009.

Thorne-Roberts (TR')
MSTW Fits

Thorne, Phys.Rev.D73:054019,2006.

FONLL:
Used in NNPDF Fits

Forte, Laenen, Nason, Rojo, Nucl.Phys.B834:116-162,2010.

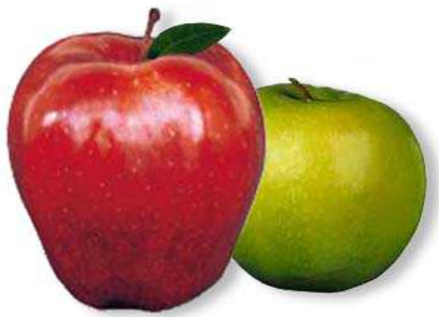
ABKM:

Blumlein, Klein, Moch
Phys.Rev.D81:014032,2010

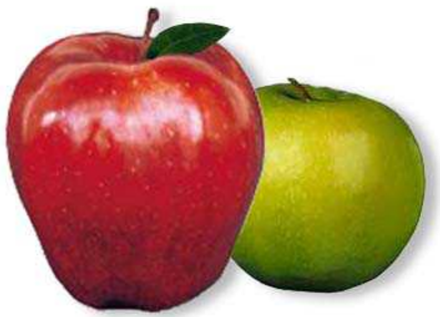
Work is continuing

Many of the above incorporated in HERA-Fitter

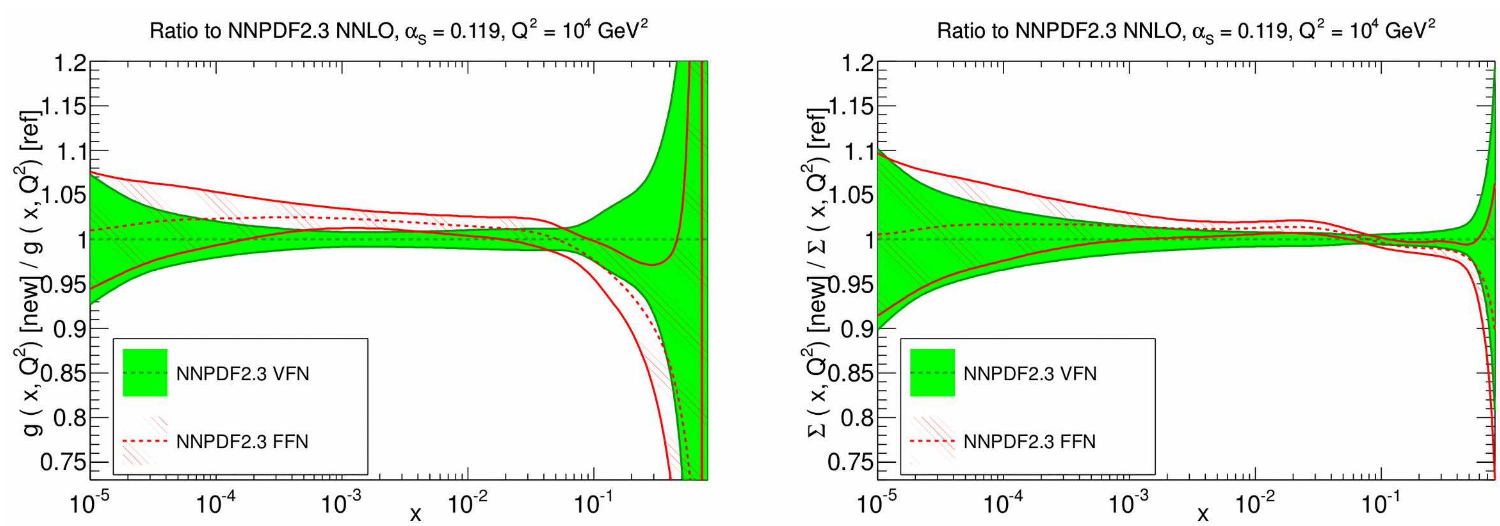
Les Houches Report.
J. Rojo, et al., arXiv:1003.1241 [hep-ph]



Compare VFN & FFN Schemes



Resum: $\alpha \ln(m/Q)$



$$\Delta\chi^2 \equiv \chi^2_{FFN} - \chi^2_{VFN} \quad > 0$$

$x_{\rm min}$	$x_{\rm max}$	$Q^2_{\rm min}$ (GeV)	$Q^2_{\rm max}$ (GeV)	$\Delta\chi^2$ (DIS)	$N_{\rm dat}^{\rm DIS}$	$\Delta\chi^2$ (HERA-I)	$N_{\rm dat}^{\rm hera-I}$
$4 \cdot 10^{-5}$	1	3	10^6	72.2	2936	77.1	592
$4 \cdot 10^{-5}$	0.1	3	10^6	87.1	1055	67.8	405
$4 \cdot 10^{-5}$	0.01	3	10^6	40.9	422	17.8	202
$4 \cdot 10^{-5}$	1	10	10^6	53.6	2109	76.4	537
$4 \cdot 10^{-5}$	1	100	10^6	91.4	620	97.7	412
$4 \cdot 10^{-5}$	0.1	10	10^6	84.9	583	67.4	350
$4 \cdot 10^{-5}$	0.1	100	10^6	87.7	321	87.1	227

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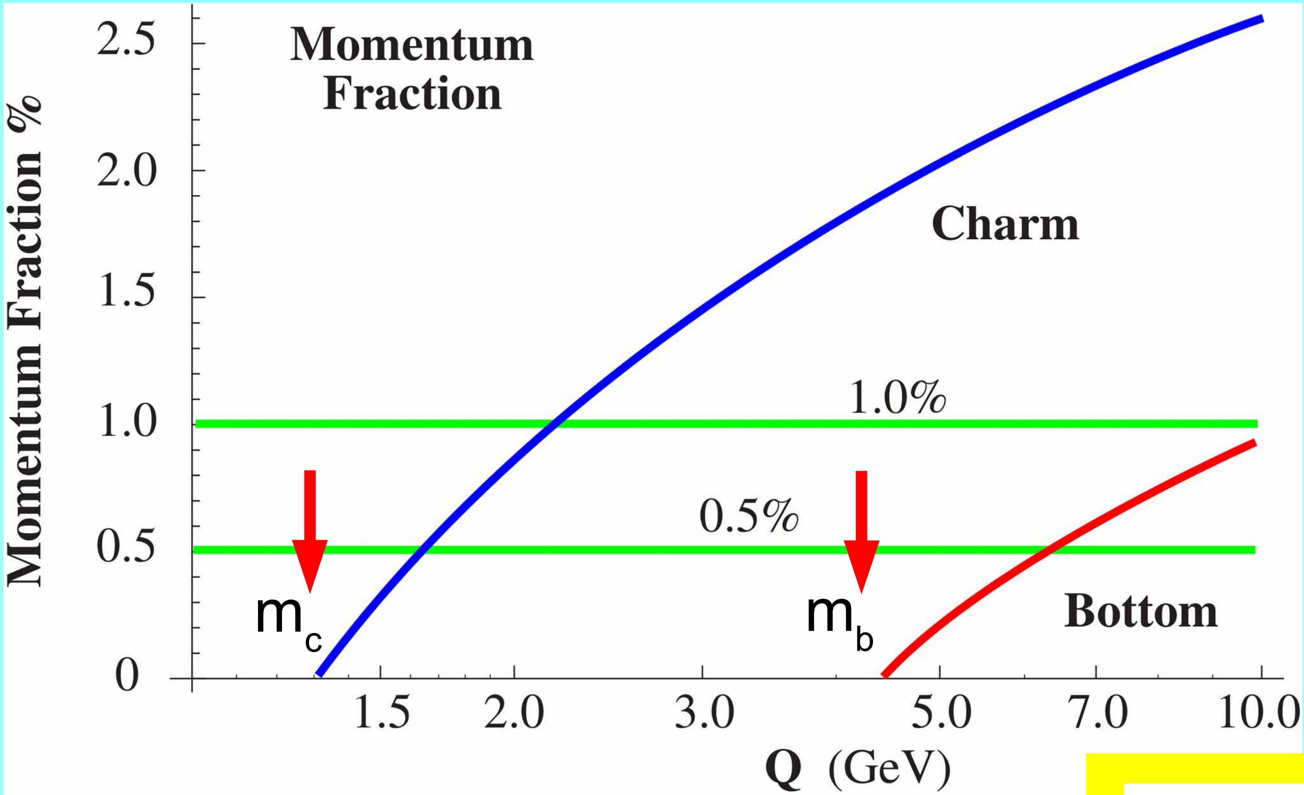
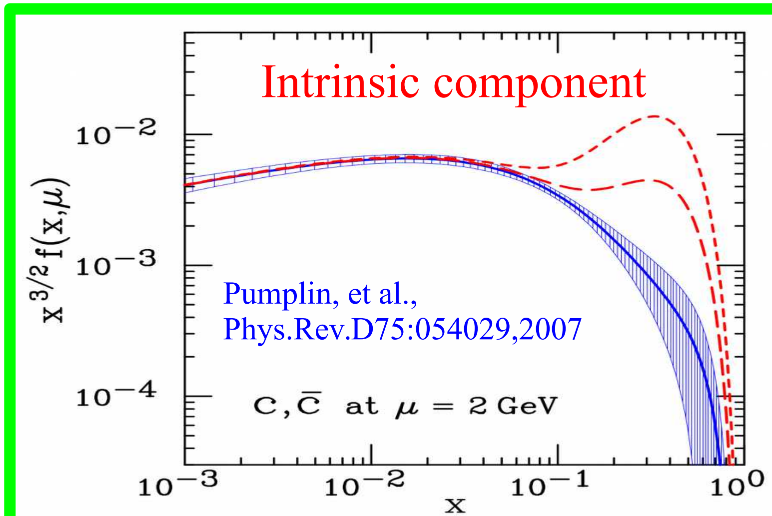
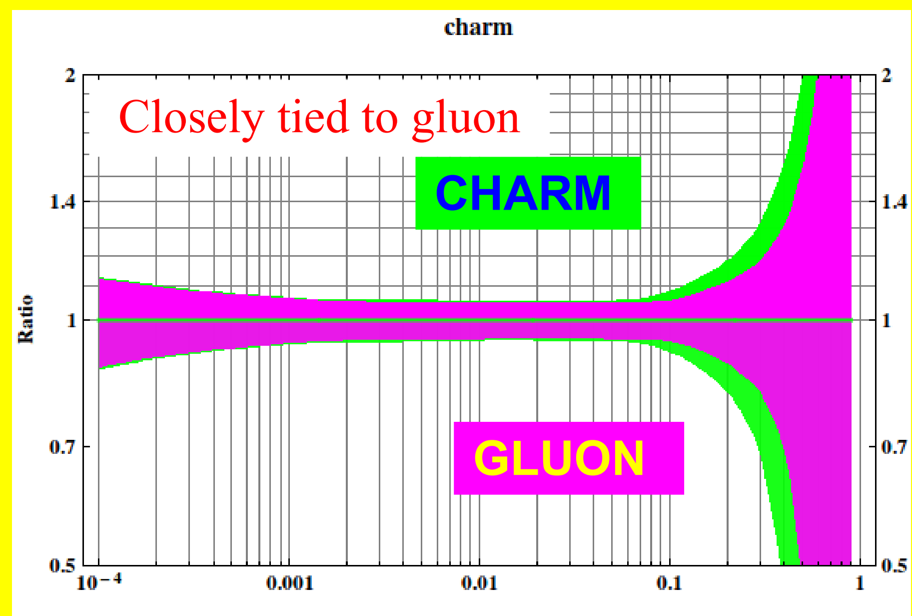
Uncertainties in c(x) and b(x)

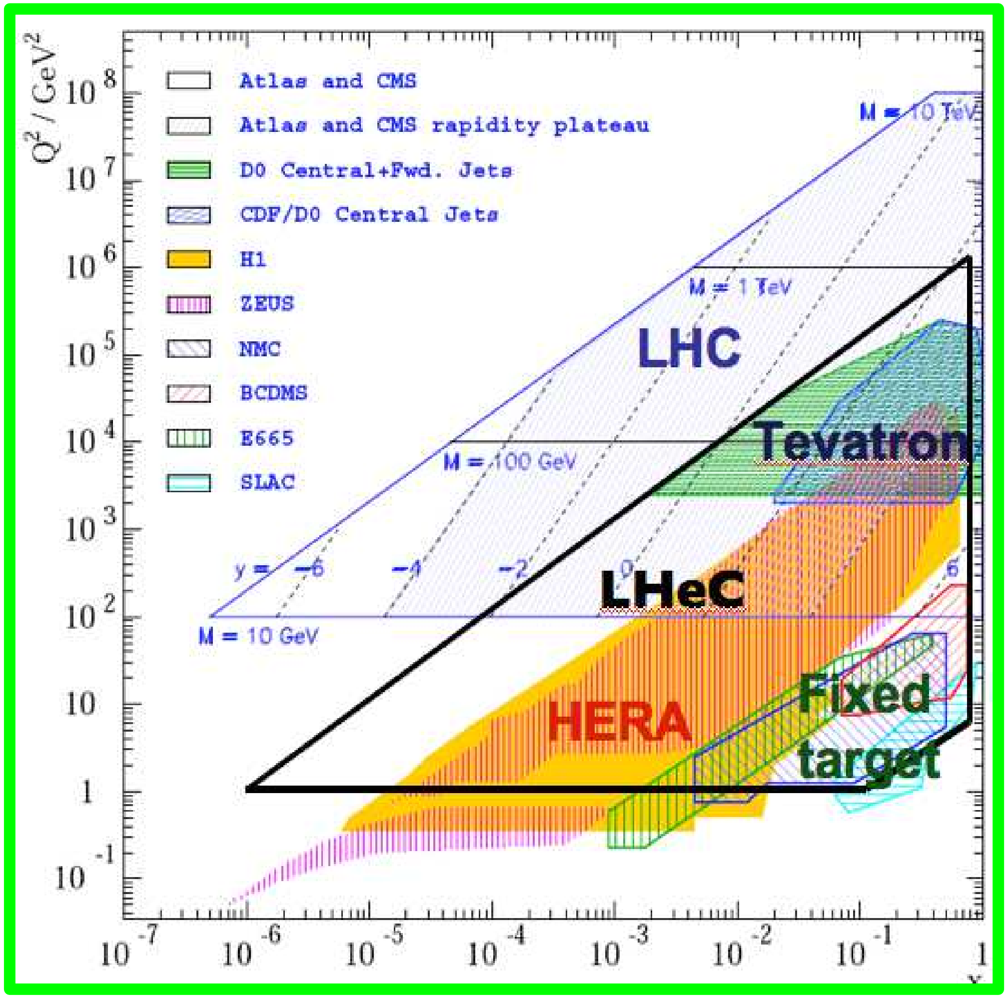


Controlled by m_Q and gluon PDF





Kinematic Reach of LheC: Extremes of QCD



DGLAP:	$\ln(Q^2)$
HQ:	$\ln(m^2/Q^2)$
BFKL:	$\ln(1/x)$