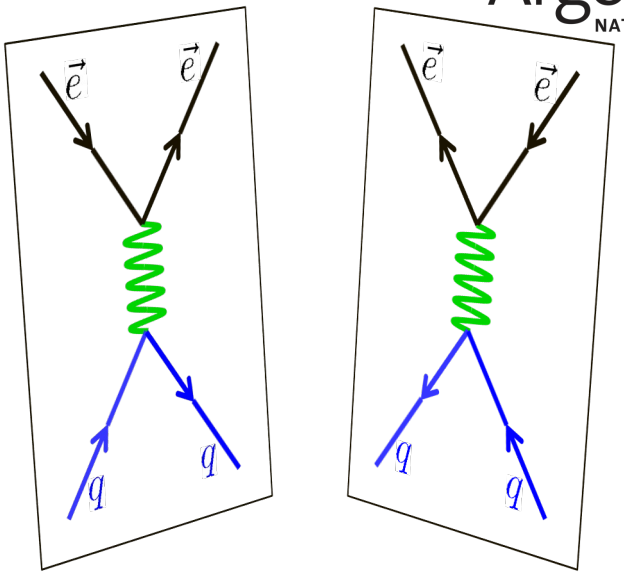
Parton Distributions and PVDIS in SoLID



Paul E Reimer
19 June 2024
Argonne National Laboratory
Lemont, IL

The question is not about parton distribution uncertainties in 2024, but rather what these uncertainties will be in 203x.

This work was partially supported under grant DE-AC02-06CH11357 from the US Department of Energy, Office of Nuclear Physics

PVDIS Measurement

$$\sigma^l \propto \left|\mathcal{M}_\gamma + \mathcal{M}^l_{PV}\right|^2 \qquad \sigma^r \propto \left|\mathcal{M}_\gamma + \mathcal{M}^r_{PV}\right|^2$$

$$A^{PV}_{LR} = \frac{\sigma^l - \sigma^r}{\sigma^l + \sigma^r} \approx \frac{\mathcal{M}^l_{PV} - \mathcal{M}^r_{PV}}{\mathcal{M}_\gamma}$$

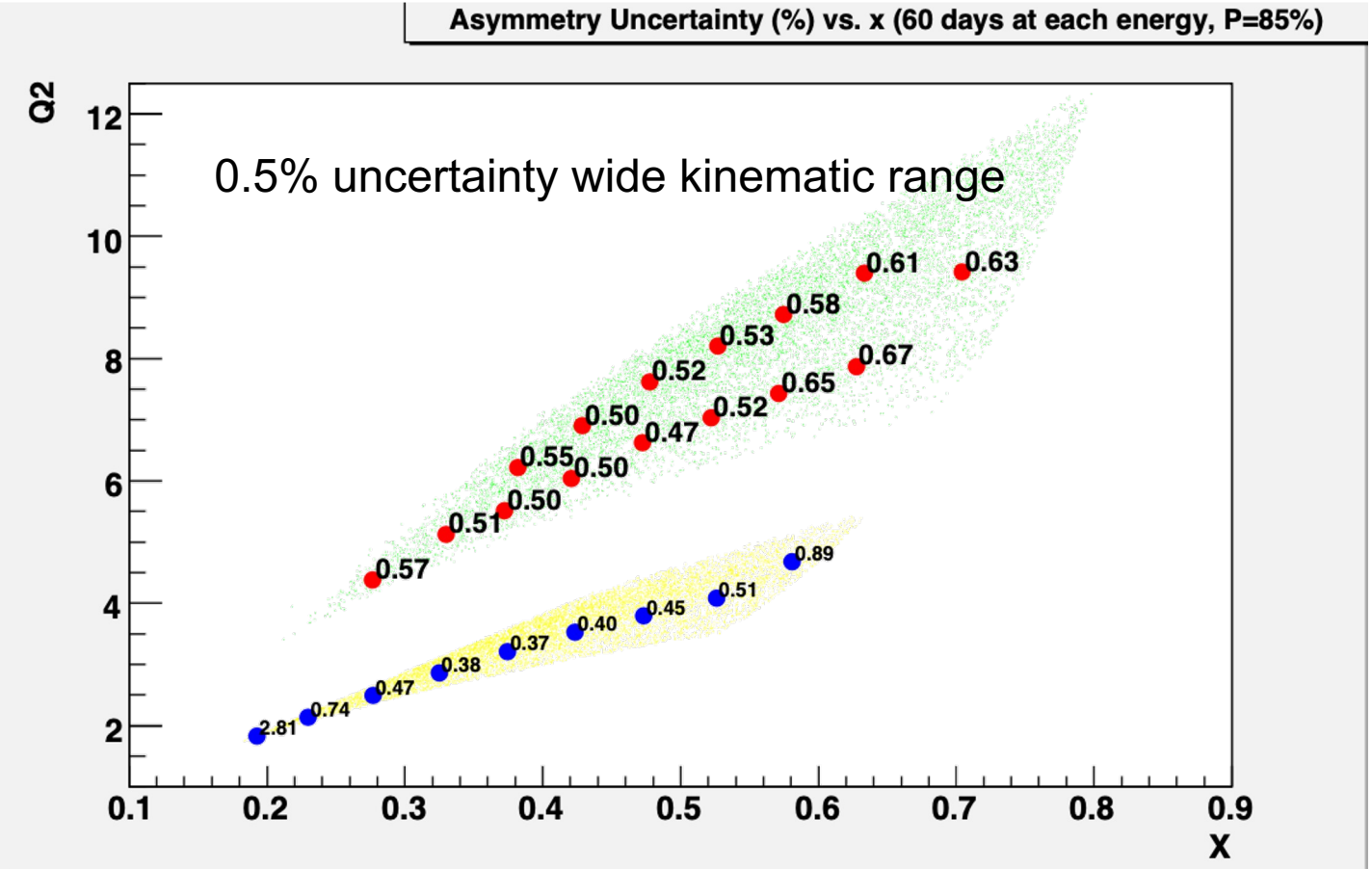
$$\approx -\left(\frac{3G_F Q^2}{2\sqrt{2}\pi\alpha}\right)\frac{2C_{1u} - C_{1d}\left(1+R_s\right) + Y\left(2C_{2u} - C_{2d}\right)R_v}{5 + R_s}$$

$$R_s\left(x\right) = 2\frac{s\left(x\right) + \bar{s}\left(x\right)}{u\left(x\right) + d\left(x\right)} \xrightarrow{x\to 11} 0$$

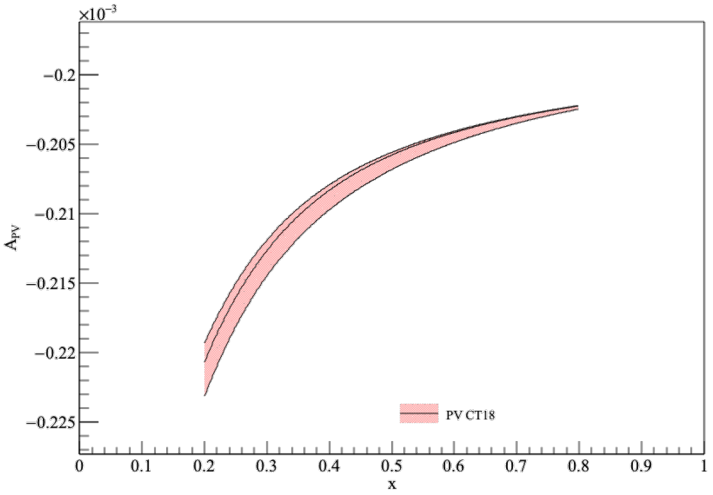
$$R_v\left(x\right) = \frac{u_v\left(x\right) + d_v\left(x\right)}{u\left(x\right) + d\left(x\right)} \xrightarrow{x\to 1} 1$$

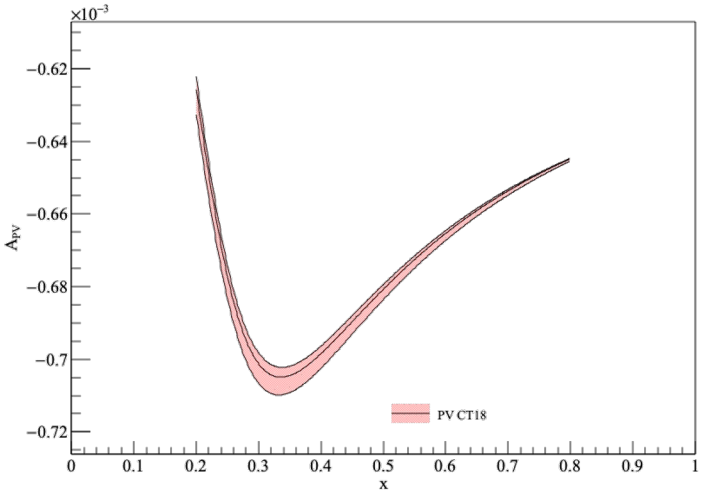
Half full or
half empty

SoLID PVDIS Asymmetry Uncertainty



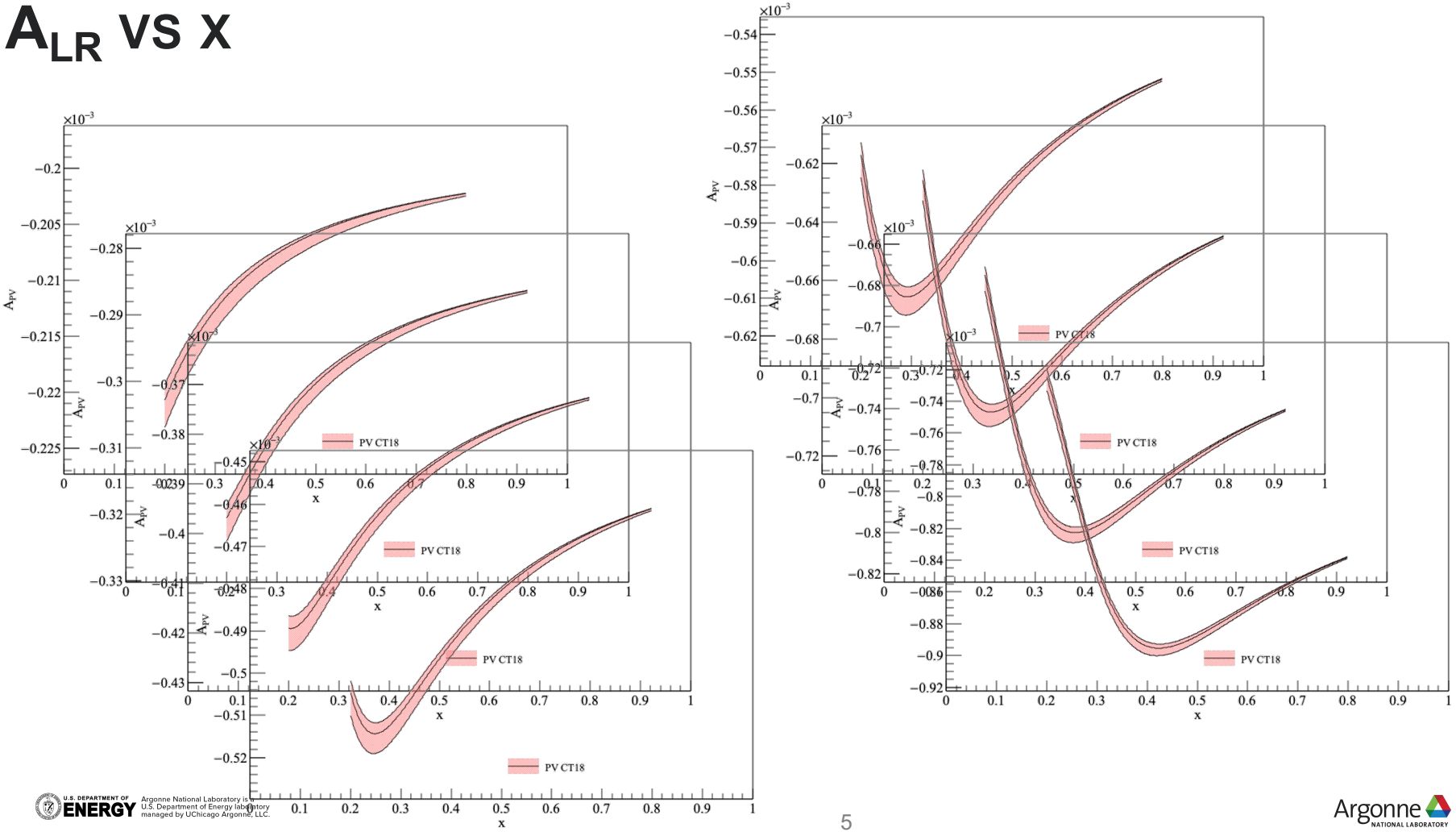
A_{LR} vs x



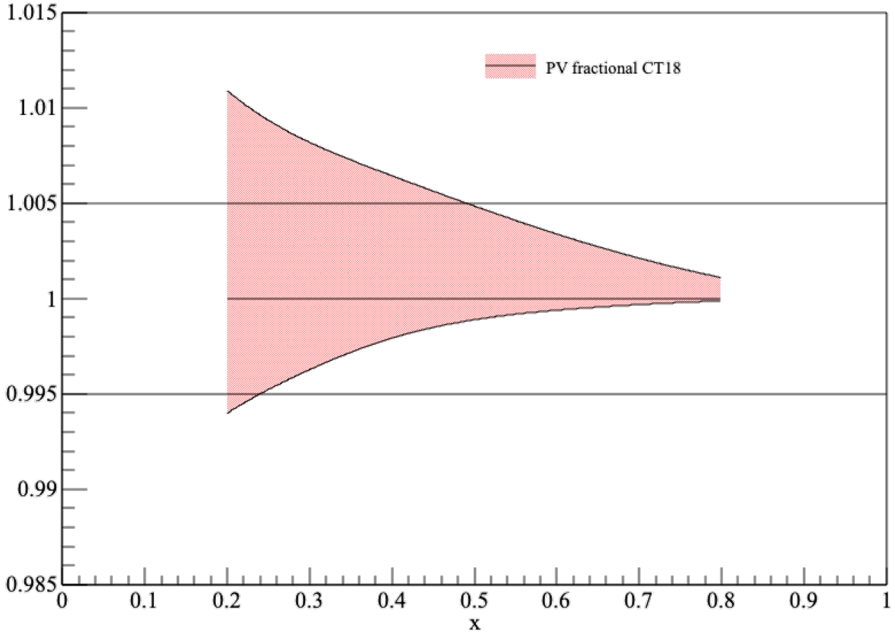


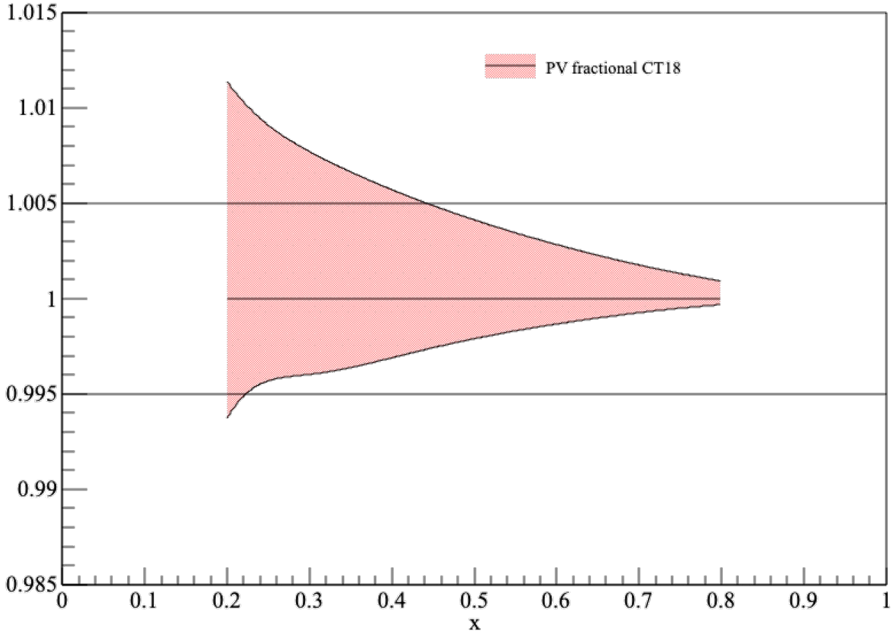
Calculate A_{LR} and associated PDF uncertainties for 2 Q^2 bins, 11 GeV beam

A_{LR} vs x



A_{LR} vs x (Percentage Uncertainty)

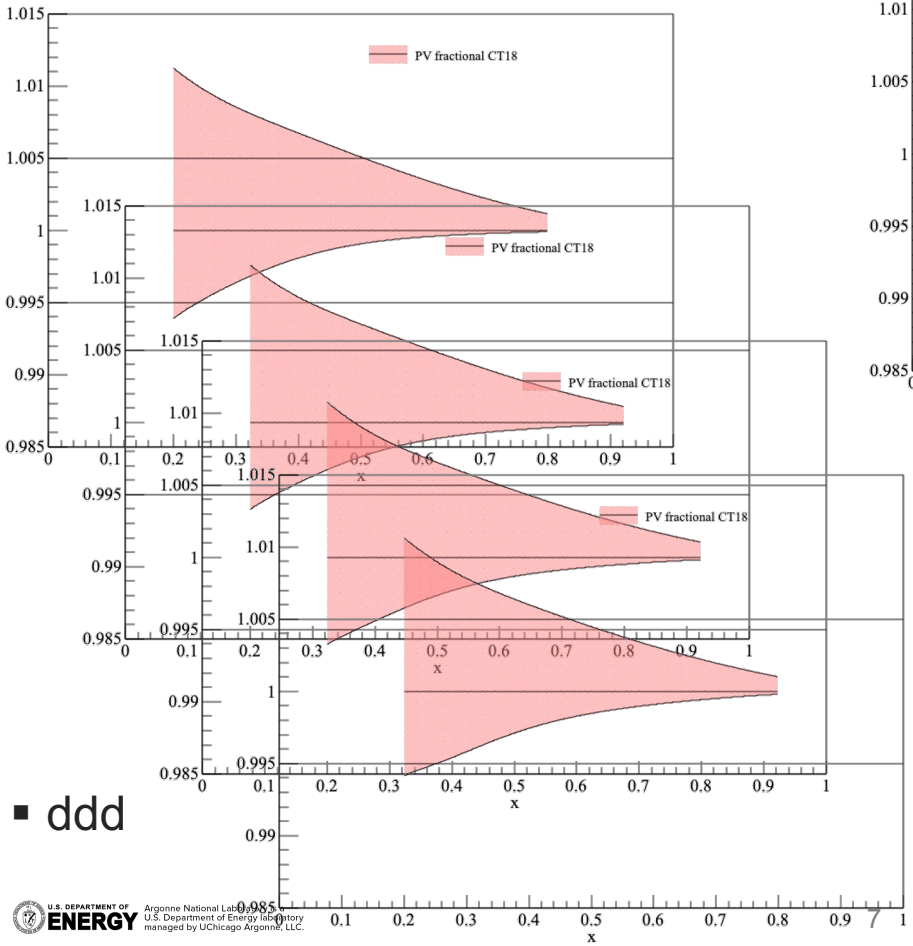


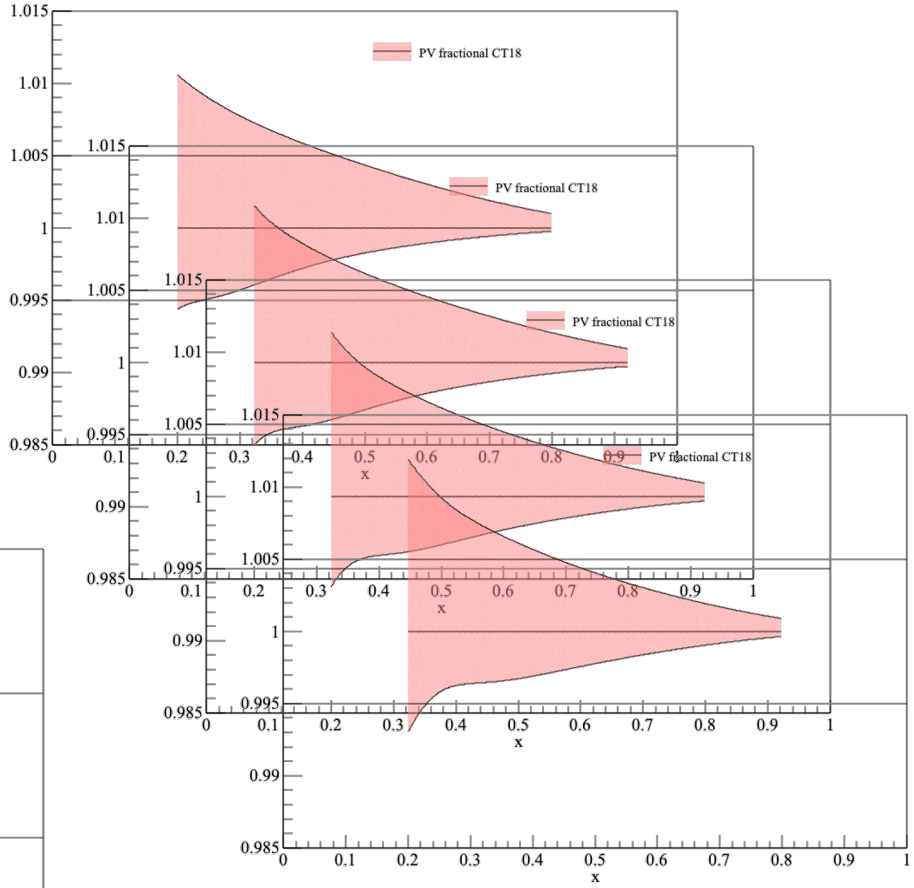


Uncertainties at high-x < 0.5%

In general uncertainties < 1%

A_{LR} vs x





- ddd

R_S AND R_V VS X

$$A_{\mathrm{PV}}^{\mathrm{DIS}} = -\left(\frac{3G_F Q^2}{2\sqrt{2}\pi\alpha}\right)\frac{2C_{1\mathrm{u}} - C_{1\mathrm{d}}\left(1+R_s\right) + Y\left(2C_{2\mathrm{u}} - C_{2\mathrm{d}}\right)R_v}{5+R_s}$$

$$0.85 \lesssim R_v\left(x,Q^2\right) = \frac{u_v\left(x,Q^2\right)+d_v\left(x,Q^2\right)}{u\left(x,Q^2\right)+d\left(x,Q^2\right)} \leq 1$$

$$0.34 \lesssim Y \lesssim 1.0 \quad \text{and} \quad \left(2C_{2u} - C_{2d}\right) \approx 0.038$$

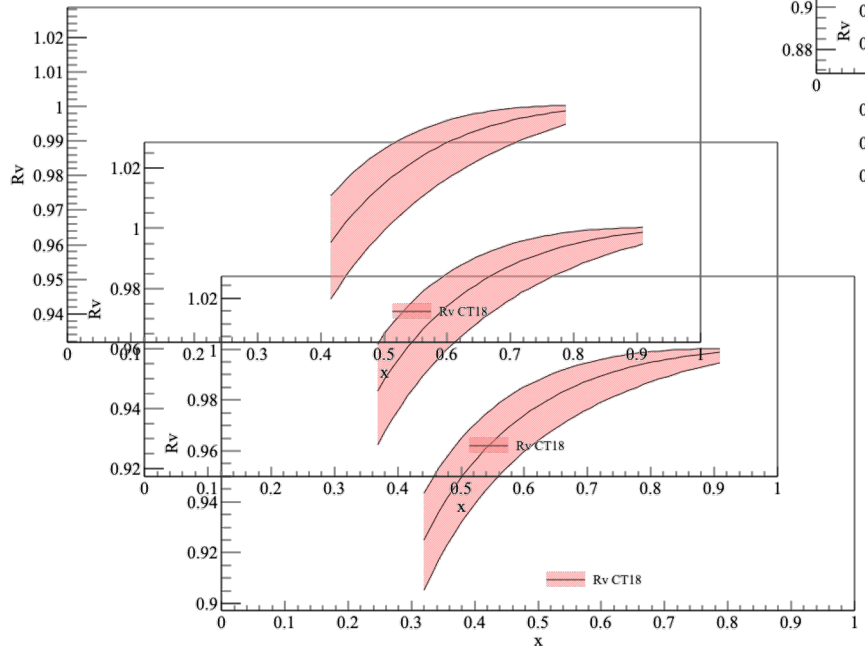
That is, in terms of

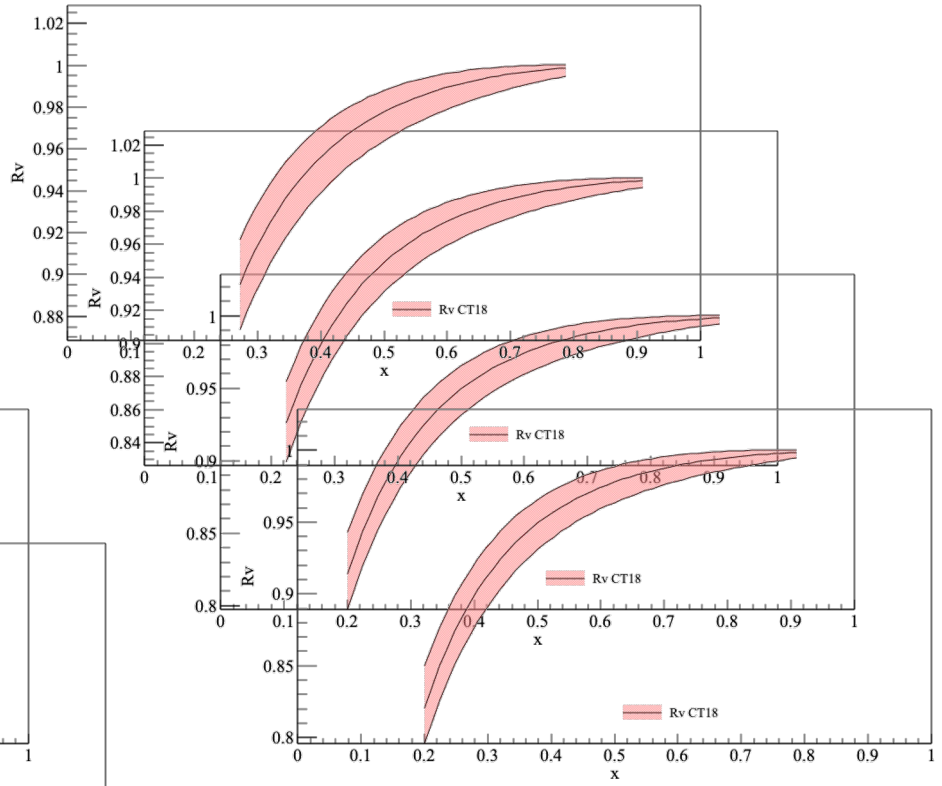
- $\delta A_{PV}, \delta R_v$ will have little impact
- $\delta\left(2C_{2u} - C_{2d}\right), \delta R_v$ is still important

R_V vs x

$\delta R_v \leq 2.5\%$ at low-x

$\delta R_v \leq 0.5\%$ at high-x





R_S AND R_V VS X

$$A_{\mathrm{PV}}^{\mathrm{DIS}} = -\left(\frac{3G_F Q^2}{2\sqrt{2}\pi\alpha}\right)\frac{2C_{1\mathrm{u}} - C_{1\mathrm{d}}\left(1+R_s\right) + Y\left(2C_{2\mathrm{u}} - C_{2\mathrm{d}}\right)R_v}{5+R_s}$$

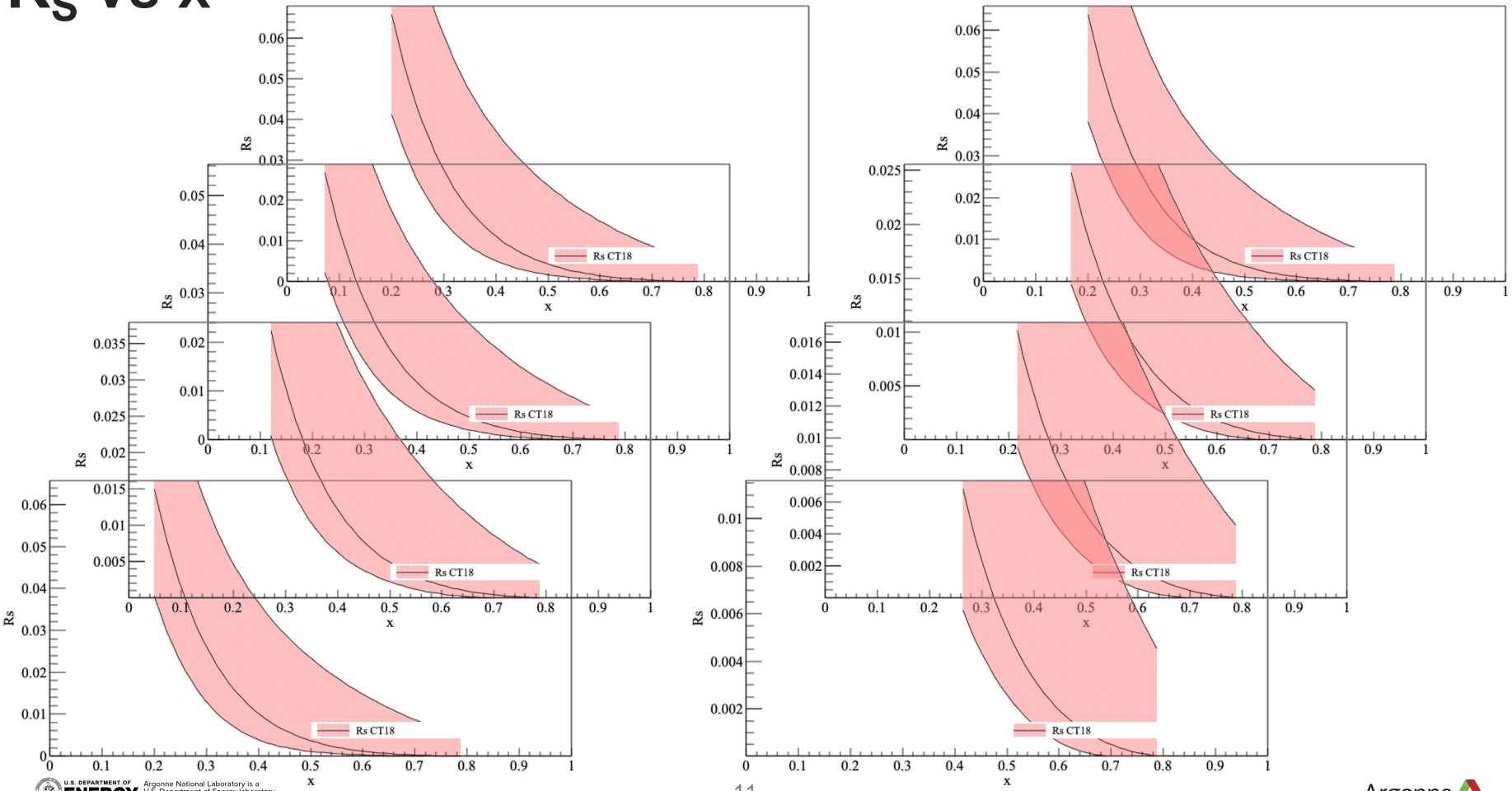
$$0 \leq R_s\left(x,Q^2\right) = 2\frac{s\left(x,Q^2\right)+\bar{s}\left(x,Q^2\right)}{u\left(x,Q^2\right)+d\left(x,Q^2\right)} \lesssim 0.05$$

$$C_{1d} \approx 0.35$$

That is, in terms of

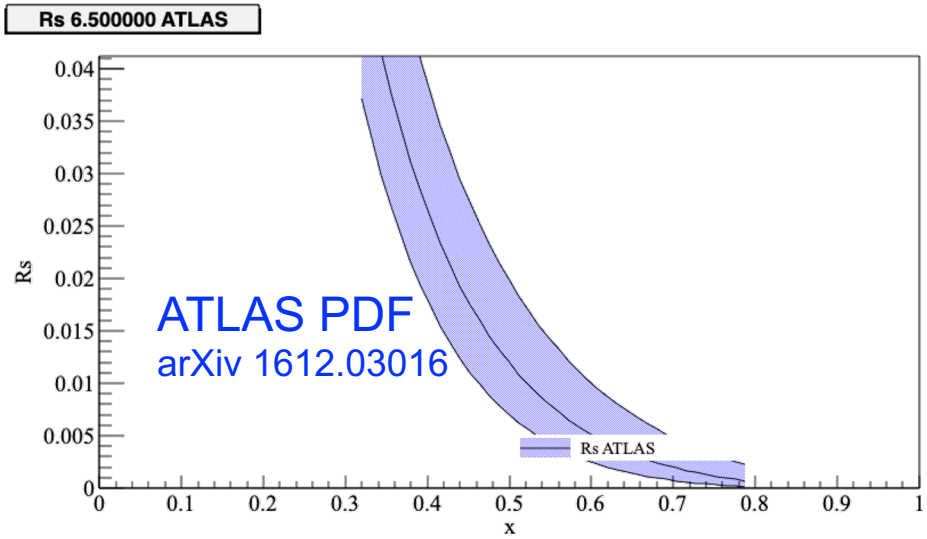
- $\delta A_{PV}, \delta R_s$ will have little impact
- $\delta\left(2C_{2u} - C_{2d}\right), \delta R_s$ is still important

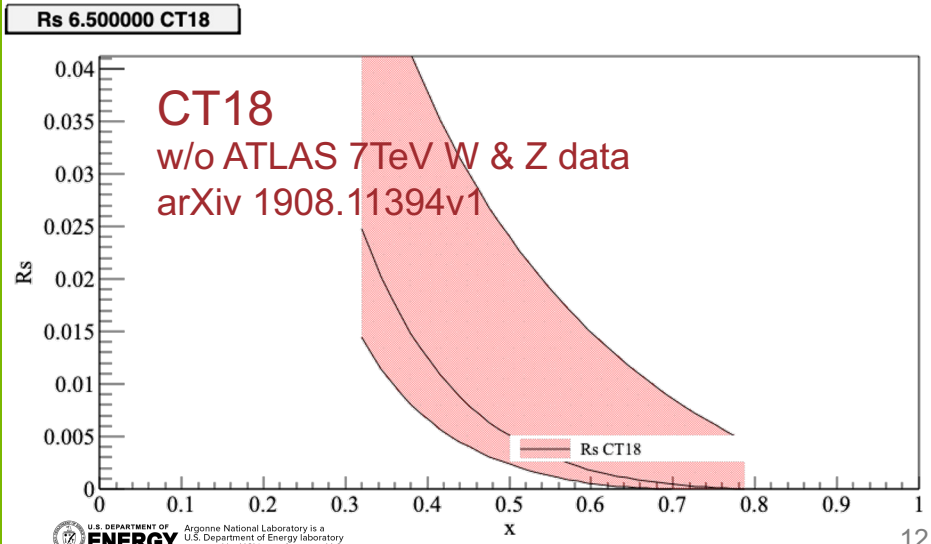
R_S vs x



R_S vs x

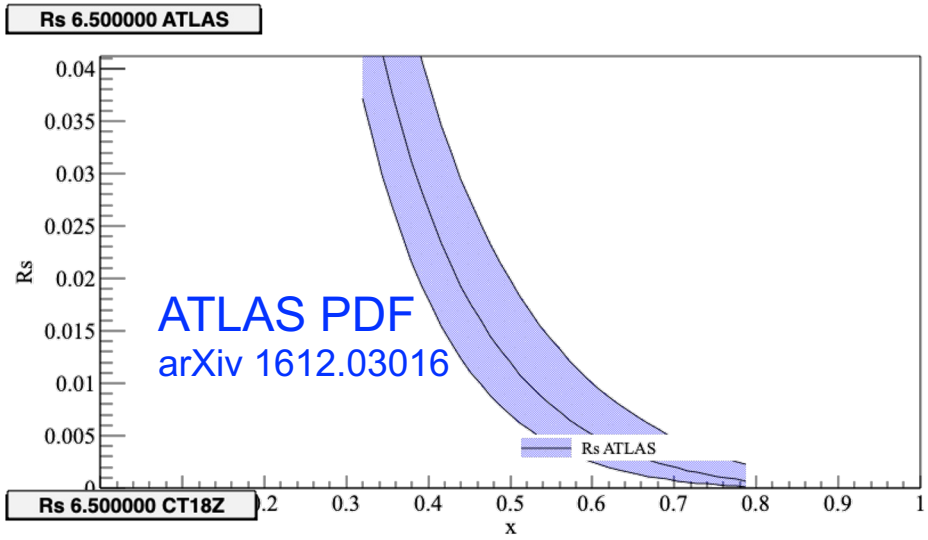
Primary difference is the treatment of ATLAS 7 TeV W & Z measurements

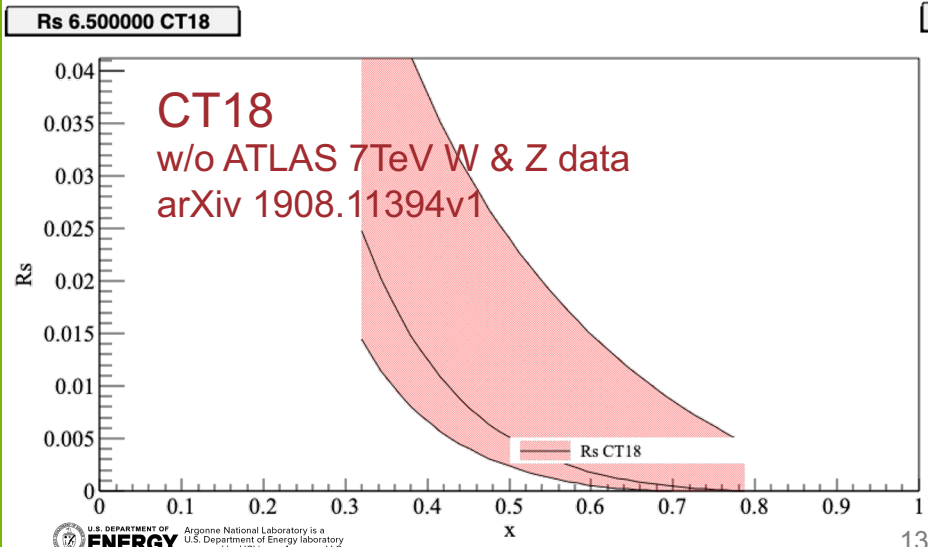


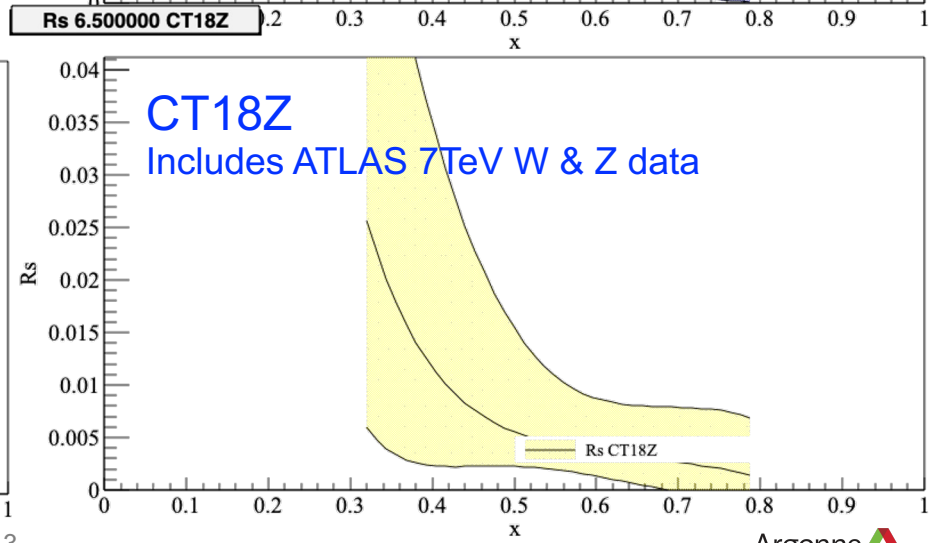


R_S vs x

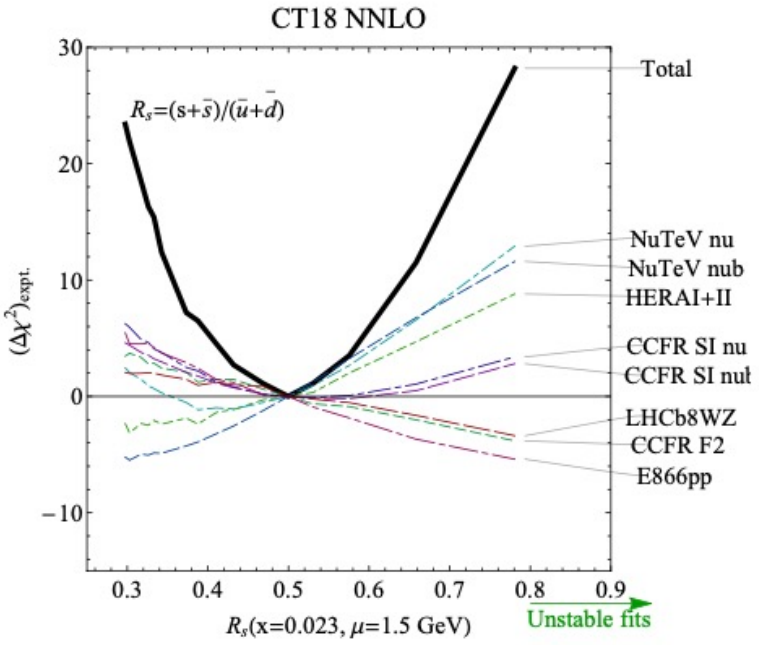
Primary difference is the treatment of ATLAS 7 TeV W & Z measurements

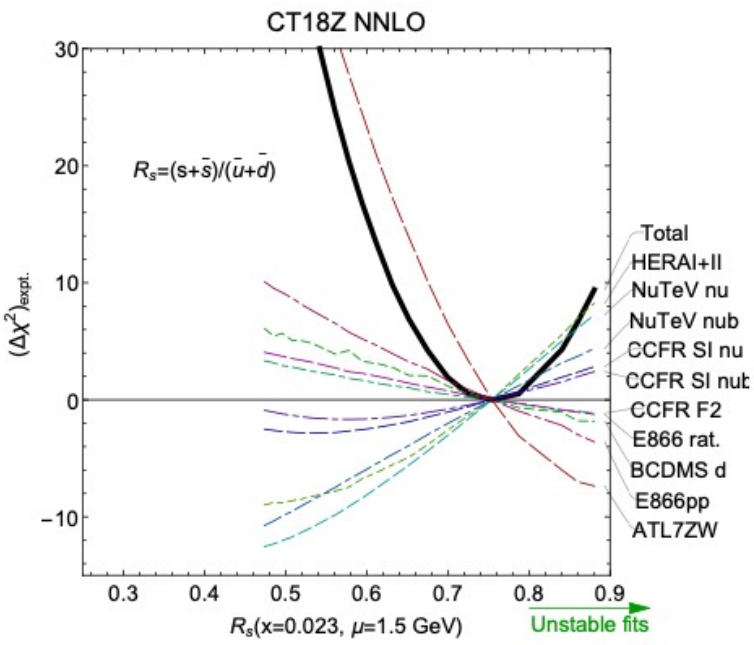






CT18NLO CT18ZNLO LEGRANGE MULTIPLIER SCAN





NEW ATLAS W & Z DATA

ATLAS, arXiv **2404**.06204, submitted to EPJC.

PDF set	$W^- \to \ell^- \nu$	$W^+ \to \ell^+ \nu$	$Z \to \ell\ell$
	$\sigma_{\text{fid}}(\sqrt{s} = 5.02\,\text{TeV})$ [pb]		
Data	1384 ± 16	2228 ± 25	333.0 ± 4.1
CT18	$1360 \pm 10\,(\text{scale})\,^{+30}_{-40}\,(\text{PDF})$	$2200 \pm 10\,(\text{scale})\,^{+40}_{-70}\,(\text{PDF})$	$320 \pm 1\,(\text{scale})\,^{+5}_{-9}\,(\text{PDF})$
MSHT20	$1351\,^{+5}_{-6}\,(\text{scale})\,^{+22}_{-23}\,(\text{PDF})$	$2180 \pm 10\,(\text{scale})\,^{+30}_{-40}\,(\text{PDF})$	$324 \pm 1\,(\text{scale})\,^{+4}_{-5}\,(\text{PDF})$
NNPDF31	$1381 \pm 6\,(\text{scale}) \pm 16\,(\text{PDF})$	$2232\,^{+8}_{-9}\,(\text{scale}) \pm 25\,(\text{PDF})$	$329 \pm 1\,(\text{scale}) \pm 4\,(\text{PDF})$
	$\sigma_{\text{fid}}(\sqrt{s} = 13\,\text{TeV})$ [pb]		
Data	3486 ± 38	4571 ± 49	780.3 ± 10.4
CT18	$3410\,^{+40}_{-20}\,(\text{scale})\,^{+60}_{-100}\,(\text{PDF})$	$4460\,^{+40}_{-30}\,(\text{scale})\,^{+80}_{-130}\,(\text{PDF})$	$748\,^{+5}_{-4}\,(\text{scale})\,^{+18}_{-25}\,(\text{PDF})$
MSHT20	$3400\,^{+40}_{-20}\,(\text{scale})\,^{+40}_{-60}\,(\text{PDF})$	$4460\,^{+40}_{-30}\,(\text{scale})\,^{+60}_{-70}\,(\text{PDF})$	$763\,^{+6}_{-4}\,(\text{scale})\,^{+9}_{-12}\,(\text{PDF})$
NNPDF31	$3450\,^{+40}_{-20}\,(\text{scale}) \pm 30\,(\text{PDF})$	$4510\,^{+40}_{-30}\,(\text{scale}) \pm 40\,(\text{PDF})$	$769\,^{+6}_{-4}\,(\text{scale}) \pm 7\,(\text{PDF})$

NEW CMS W & Z DATA

CMS, http://cds.cern.ch/record/2868090 **(2023)**

$\sqrt{s} = 5.02$ TeV

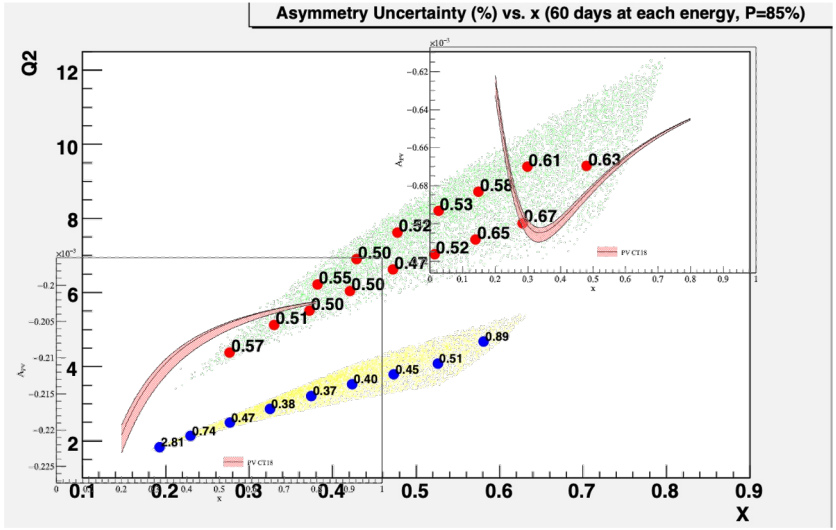
	Data	NNPDF3.1	NNPDF4.0	CT18	MSHT20
$W^+ \to \ell^+\nu$	$2476 \pm 2_{\text{stat}} \pm 8_{\text{syst}} \pm 47_{\text{lum}}$	2476^{+24}_{-24}	2513^{+18}_{-18}	2431^{+41}_{-41}	2421^{+28}_{-28}
$W^- \to \ell^-\bar{\nu}$	$1525 \pm 2_{\text{stat}} \pm 5_{\text{syst}} \pm 29_{\text{lum}}$	1519^{+18}_{-18}	1543^{+9}_{-9}	1505^{+25}_{-25}	1490^{+18}_{-18}
$W^\pm \to \ell^\pm\nu$	$4001 \pm 3_{\text{stat}} \pm 10_{\text{syst}} \pm 76_{\text{lum}}$	3995^{+38}_{-38}	4056^{+22}_{-22}	3936^{+64}_{-64}	3911^{+46}_{-46}
$Z \to \ell^+\ell^-$	$319.9 \pm 0.9_{\text{stat}} \pm 1.2_{\text{syst}} \pm 6.2_{\text{lum}}$	$319.5^{+3.7}_{-3.7}$	$325.2^{+1.8}_{-1.8}$	$310.2^{+4.9}_{-4.9}$	$314.0^{+3.5}_{-3.5}$
W^+/W^-	$1.623 \pm 0.003_{\text{stat}} \pm 0.007_{\text{syst}}$	$1.631^{+0.016}_{-0.016}$	$1.628^{+0.013}_{-0.013}$	$1.615^{+0.014}_{-0.014}$	$1.625^{+0.008}_{-0.008}$
$W^\pm/Z$	$12.51 \pm 0.04_{\text{stat}} \pm 0.03_{\text{syst}}$	$12.51^{+0.12}_{-0.12}$	$12.47^{+0.08}_{-0.08}$	$12.69^{+0.13}_{-0.13}$	$12.46^{+0.05}_{-0.05}$

$\sqrt{s} = 13$ TeV

	Data	NNPDF3.1	NNPDF4.0	CT18	MSHT20
$W^+ \to \ell^+\nu$	$5318 \pm 4_{\text{stat}} \pm 18_{\text{syst}} \pm 86_{\text{lum}}$	5061^{+62}_{-62}	5118^{+45}_{-45}	5003^{+89}_{-89}	4991^{+57}_{-57}
$W^- \to \ell^-\bar{\nu}$	$4039 \pm 4_{\text{stat}} \pm 14_{\text{syst}} \pm 66_{\text{lum}}$	3871^{+45}_{-45}	3930^{+28}_{-28}	3783^{+65}_{-65}	3816^{+43}_{-43}
$W^\pm \to \ell^\pm\nu$	$9360 \pm 10_{\text{stat}} \pm 30_{\text{syst}} \pm 160_{\text{lum}}$	8930^{+90}_{-90}	9050^{+60}_{-60}	8790^{+150}_{-150}	8810^{+100}_{-100}
$Z \to \ell^+\ell^-$	$775 \pm 2_{\text{stat}} \pm 3_{\text{syst}} \pm 13_{\text{lum}}$	743^{+18}_{-18}	754^{+6}_{-6}	719^{+16}_{-16}	734^{+8}_{-8}
W^+/W^-	$1.317 \pm 0.002_{\text{stat}} \pm 0.005_{\text{syst}}$	$1.307^{+0.017}_{-0.017}$	$1.302^{+0.012}_{-0.012}$	$1.322^{+0.013}_{-0.013}$	$1.308^{+0.009}_{-0.009}$
$W^\pm/Z$	$12.08 \pm 0.03_{\text{stat}} \pm 0.03_{\text{syst}}$	$12.02^{+0.28}_{-0.28}$	$12.00^{+0.11}_{-0.11}$	$12.21^{+0.16}_{-0.16}$	$12.00^{+0.07}_{-0.07}$

SUMMARY: PDF UNCERTAINTIES

- Under control at high-x
- $\delta R_v(x) = \frac{u_v(x)+d_v(x)}{u(x)+d(x)}$ small
- $\delta R_s(x) = \frac{s(x)+\bar{s}(x)}{u(x)+d(x)}$ new data
- Lattice contributions



The question is not about parton distribution uncertainties in 2024, but rather what these uncertainties will be in 203x.

PDF uncertainties appear to be under control
We can sing like Cicadias!