Charm as a probe for strangeness at the EIC

...

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... in collaboration with

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Details: arXiv:2006.12520

Thanks for substantial input
from my friends & colleagues

C T E Q

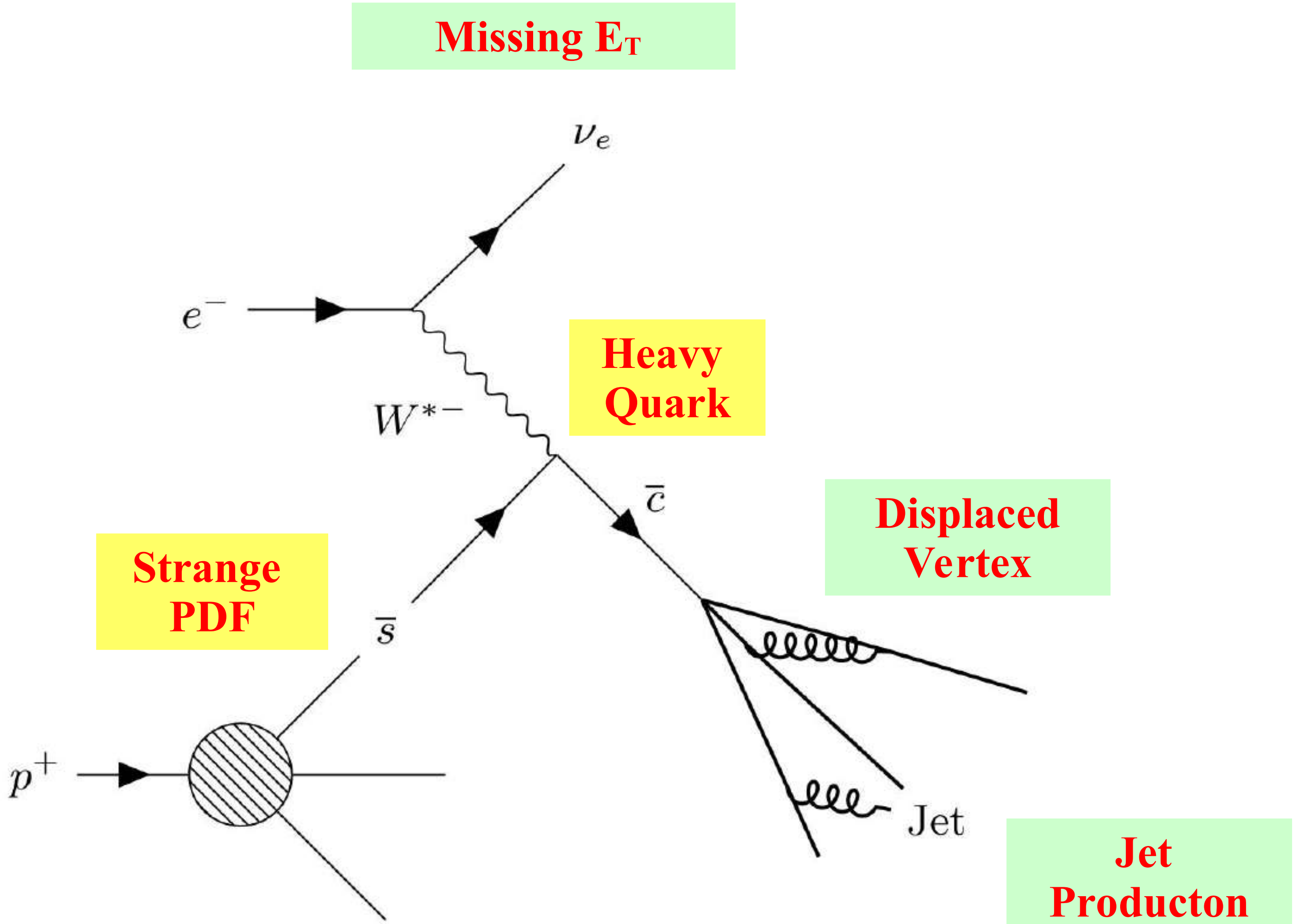
xFitter

nCTEQ
nuclear parton distribution functions

EIC opportunities for Snowmass

29 January 2021

Charged Current DIS Charm Jet Production at the EIC



CC-DIS, 10GeVx275GeV, $Q^2 > 100\text{GeV}^2$

Heavy Quark Mass: *Multi-Scale Problems are Challenging*

Two-Loop Total Cross Section e^+e^-: One Scale

$$\sigma(Q^2)=\sigma_0\left\{1+\frac{\alpha_s(Q^2)}{4\pi}(3C_F)+\left[\frac{\alpha_s(Q^2)}{4\pi}\right]^2\left[-C_F^2\left[\frac{3}{2}\right]+C_FC_A\left[\frac{123}{2}-44\zeta(3)\right]+C_FTn_f(-22+16\zeta(3))\right]\right.$$

Two-Loop Drell-Yan Cross Section: Two Scales

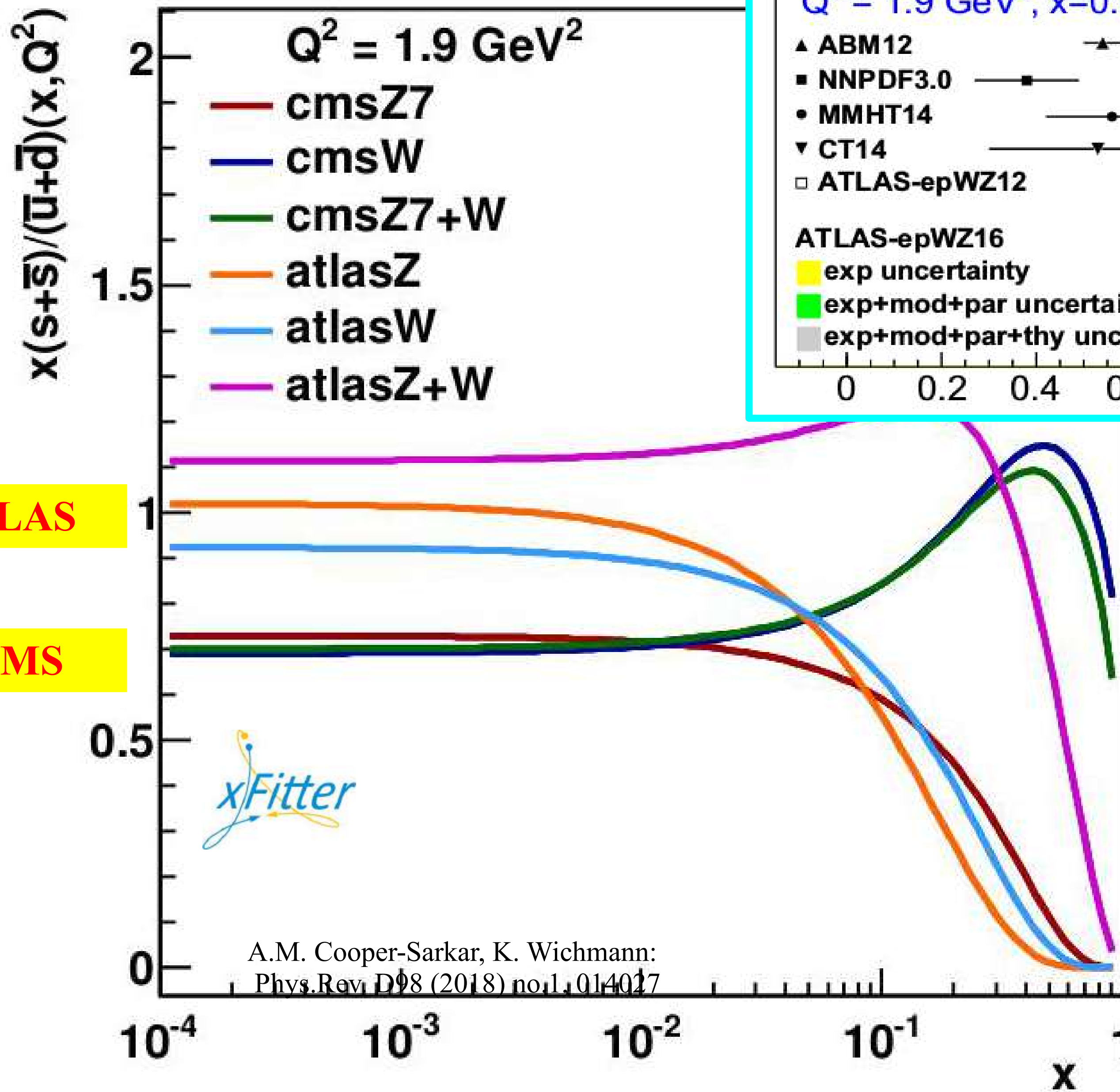
$$\begin{aligned}
H_{q\bar{q}}^{(2),S+V}(z)=\left[\frac{\alpha_s}{4\pi}\right]^2\delta(1-z)\Bigg\{&C_AC_F\left[\left[\tfrac{193}{3}-24\zeta(3)\right]\ln\left[\frac{Q^2}{M^2}\right]-11\ln^2\left[\frac{Q^2}{M^2}\right]-\tfrac{12}{5}\zeta(2)^2+\tfrac{592}{9}\zeta(2)+28\zeta(3)-\tfrac{1535}{12}\right]\\
&+C_F^2\left[[18-32\zeta(2)]\ln^2\left[\frac{Q^2}{M^2}\right]+[24\zeta(2)+176\zeta(3)-93]\ln\left[\frac{Q^2}{M^2}\right]\right.\\
&\left.+\tfrac{8}{5}\zeta(2)^2-70\zeta(2)-60\zeta(3)+\tfrac{511}{4}\right]\\
&+n_fC_F\left[2\ln^2\left[\frac{Q^2}{M^2}\right]-\tfrac{34}{3}\ln\left[\frac{Q^2}{M^2}\right]+8\zeta(3)-\tfrac{112}{9}\zeta(2)+\tfrac{127}{6}\right]\Bigg\}\\
&+C_AC_F\left[-\tfrac{44}{3}\mathcal{D}_0(z)\ln^2\left[\frac{Q^2}{M^2}\right]+\{[\tfrac{536}{9}-16\zeta(2)]\mathcal{D}_0(z)-\tfrac{176}{3}\mathcal{D}_1(z)\}\ln\left[\frac{Q^2}{M^2}\right]\right.\\
&\left.-\tfrac{176}{3}\mathcal{D}_2(z)+[\tfrac{1072}{9}-32\zeta(2)]\mathcal{D}_1(z)+[56\zeta(3)+\tfrac{176}{3}\zeta(2)-\tfrac{1616}{27}]\mathcal{D}_0(z)\right]\\
&+C_F^2\left[[64\mathcal{D}_1(z)+48\mathcal{D}_0(z)]\ln^2\left[\frac{Q^2}{M^2}\right]+\{192\mathcal{D}_2(z)+96\mathcal{D}_1(z)-[128+64\zeta(2)]\mathcal{D}_0(z)\}\ln\left[\frac{Q^2}{M^2}\right]\right.\\
&\left.+128\mathcal{D}_3(z)-(128\zeta(2)+256)\mathcal{D}_1(z)+256\zeta(3)\mathcal{D}_0(z)\right]\\
&+n_fC_F\left[\tfrac{8}{3}\mathcal{D}_0(z)\ln^2\left[\frac{Q^2}{M^2}\right]+[\tfrac{32}{3}\mathcal{D}_1(z)-\tfrac{80}{9}\mathcal{D}_0(z)]\ln\left[\frac{Q^2}{M^2}\right]+\tfrac{32}{3}\mathcal{D}_2(z)-\tfrac{160}{9}\mathcal{D}_1(z)+[\tfrac{224}{27}-\tfrac{32}{3}\zeta(2)]\mathcal{D}_0(z)\right].
\end{aligned}$$

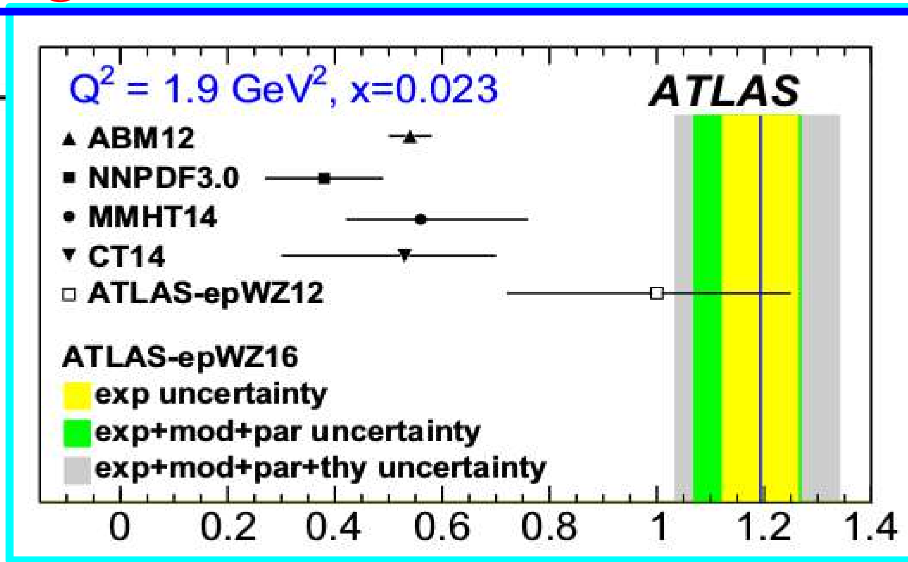
Ref: CTEQ Handbook

Strange PDF: *relatively large uncertainties*

ATLAS

CMS



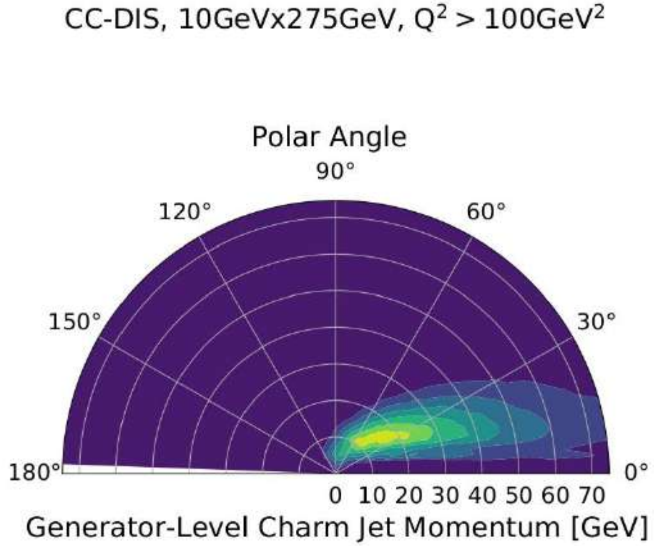


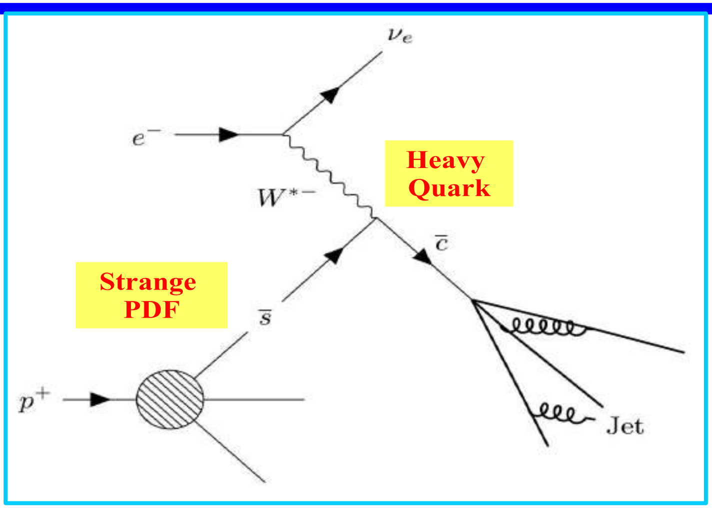
$$R_s = \frac{s+\bar{s}}{\bar{u}+\bar{d}}$$

Additionally, consider charged current νN DIS: nuclear target corrections (Fe, Pb)

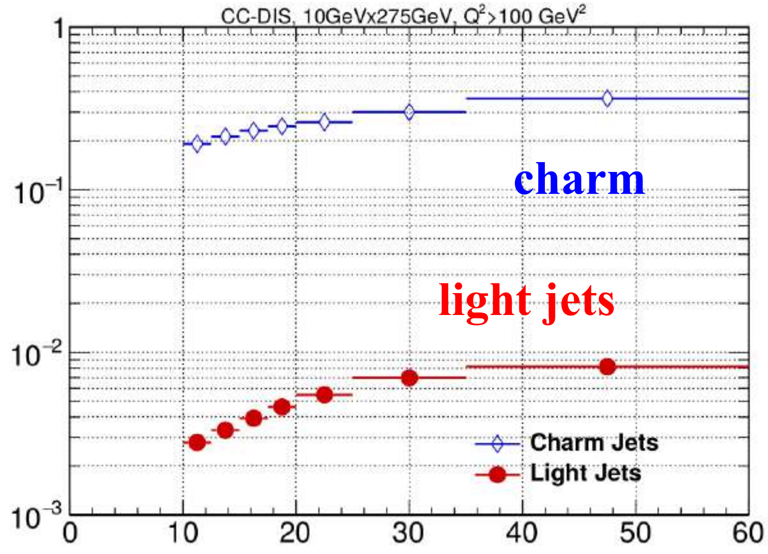
Charm Jet Production: *Pythia with parameterized detector simulation*

Charm Jet Angular Distribution

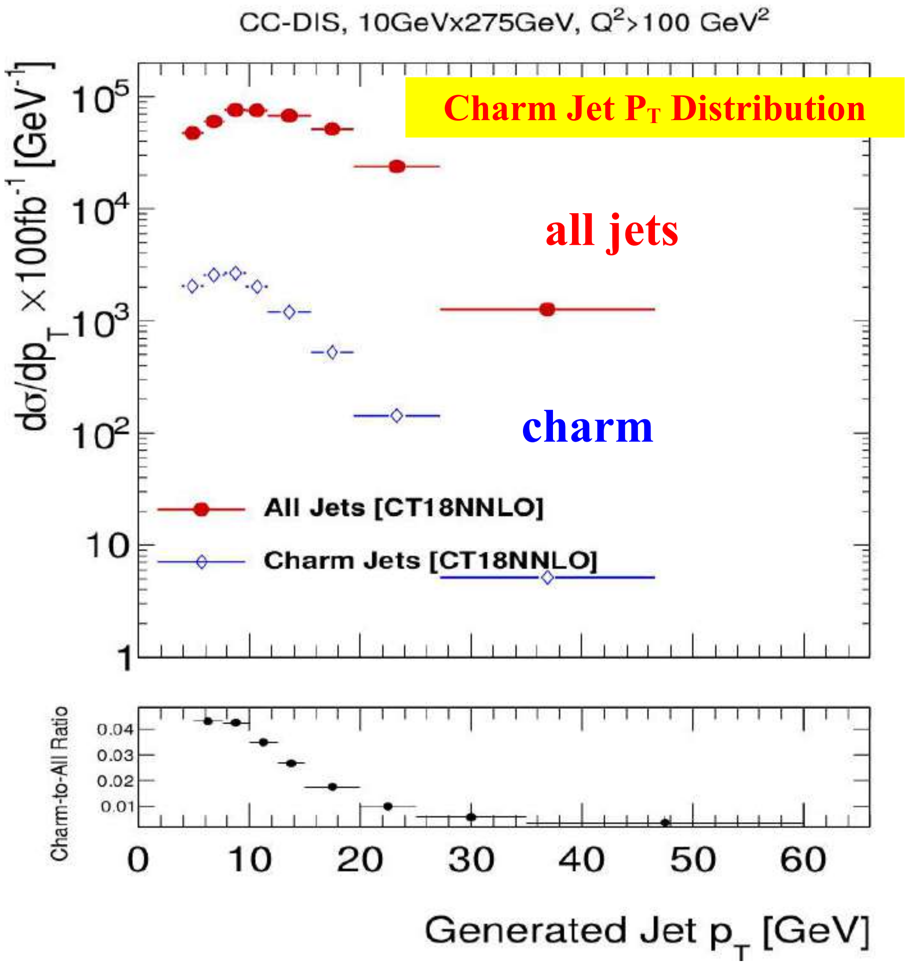




Jet Tagging Efficiency



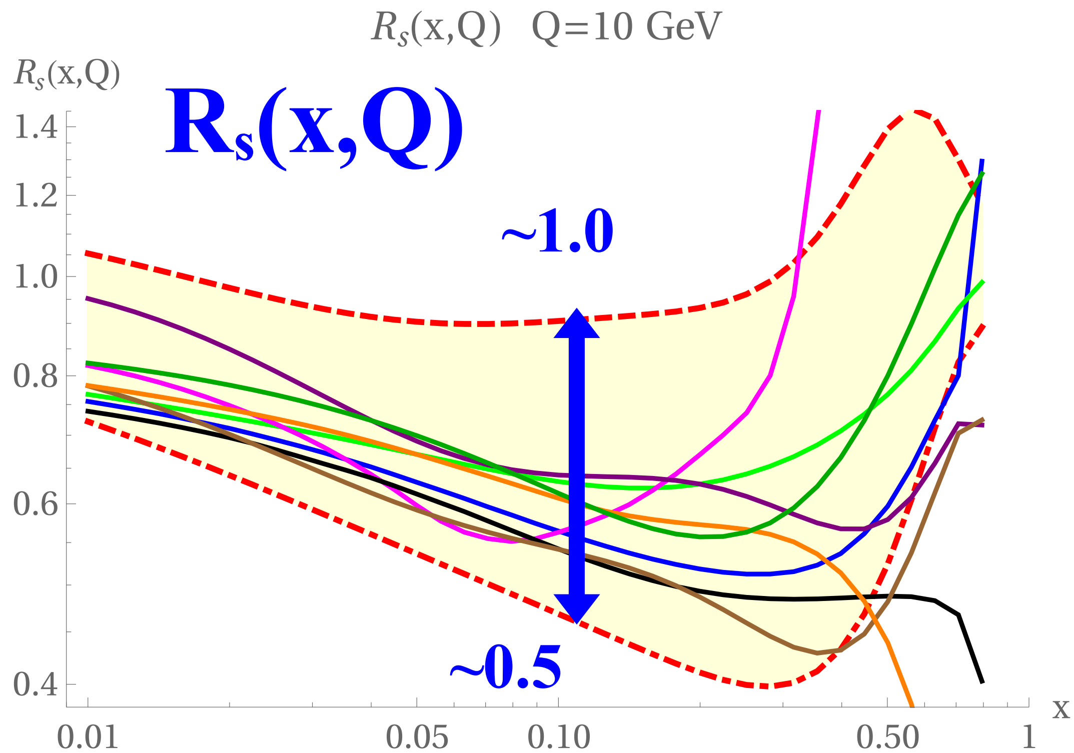
Charm Jet P_T Distribution

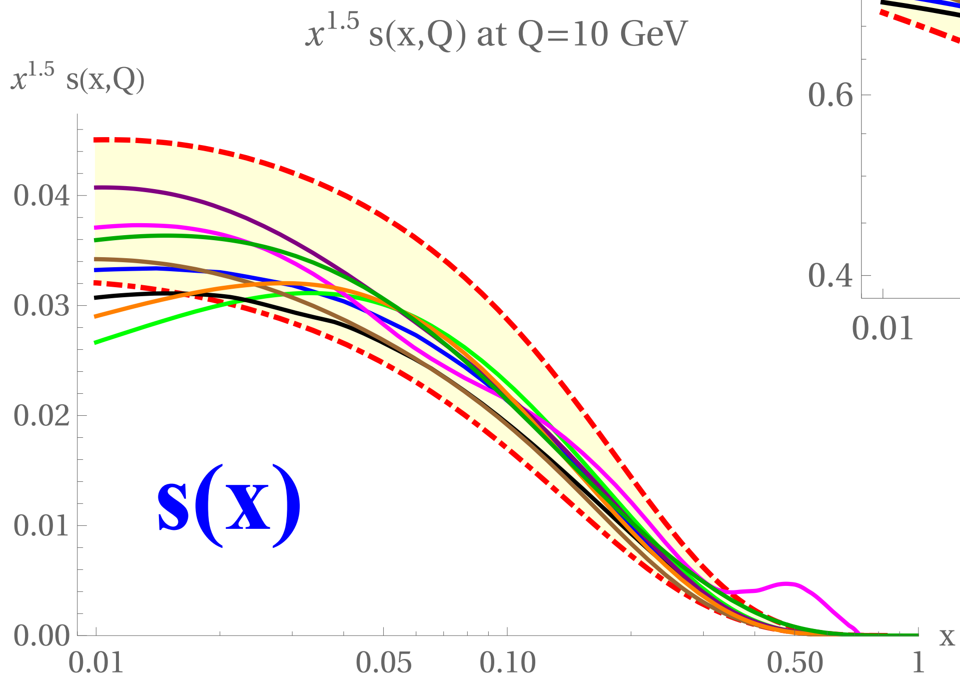


High-impact parameter track-counting approach is essential

Strange PDF: *Relatively Large Uncertainty*

$$R_s = \frac{s+\bar{s}}{\bar{u}+\bar{d}}$$

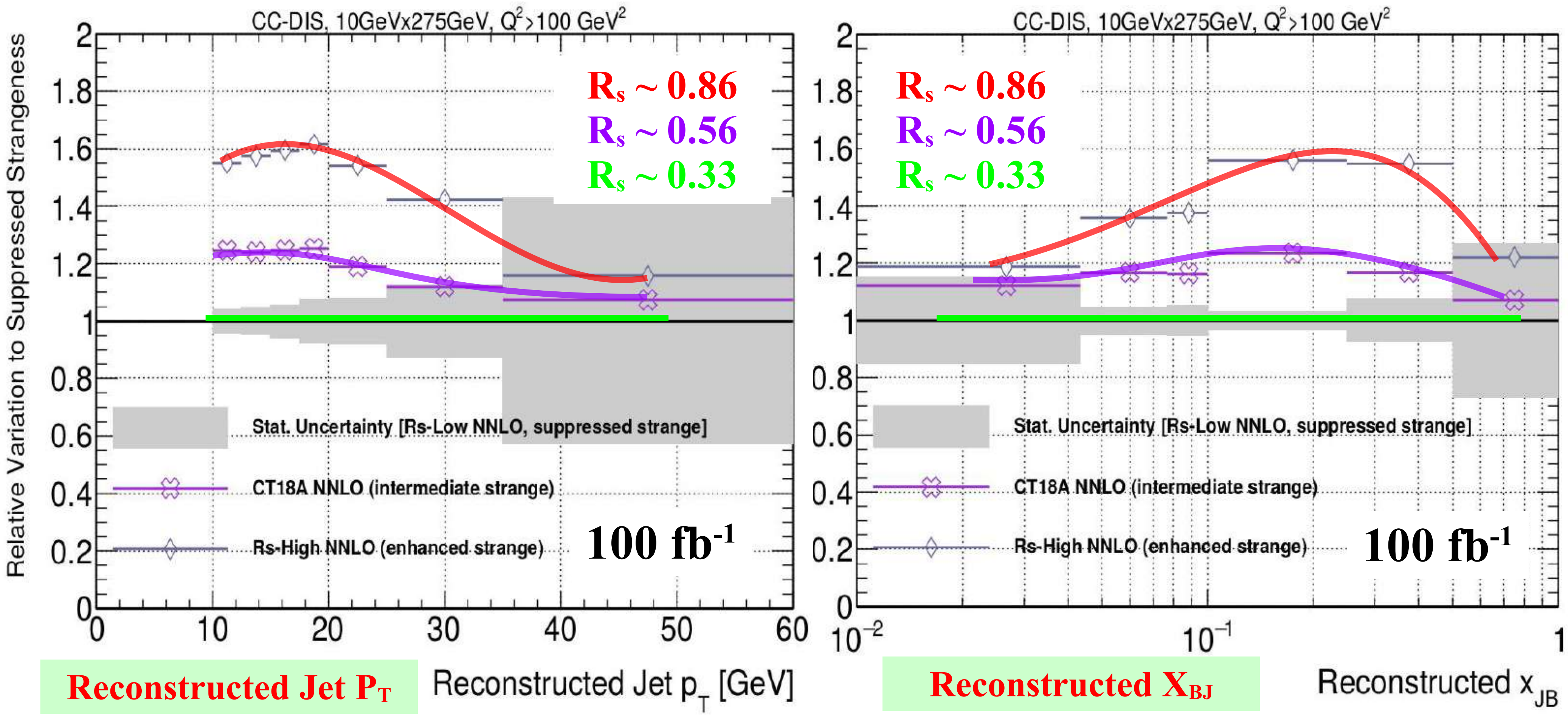




PDF Set	$\kappa(Q) = \int R_s(x,Q)$	color
Rs-Low	0.37	red
CJ15nlo	0.43 $\pm$0.01	black
CT18NNLO	0.44 $^{+0.15}_{-0.11}$	brown
MSTW2008nnlo68cl	0.48 $^{+0.02}_{-0.03}$	blue
EPPS16_CT14nlo_Pb208	0.49 $^{+0.21}_{-0.19}$	orange
nCTEQ15FullNuc_208_82	0.50 $\pm$0.01	light green
HERAPDF20_NLO_VAR	0.57 $^{+0.19}_{-0.42}$	green
NNPDF31_nnlo_as_0118	0.59 $^{+0.30}_{-0.30}$	magenta
CT18A NNLO	0.63 $^{+0.23}_{-0.16}$	purple
Rs-High	0.96	red

Can the EIC Resolve the range of strange PDFs

Yes, ability of the EIC study heavy quarks and address strange PDF is excellent



EIC an ideal QCD Laboratory

"EIC would unlock scientific mysteries" *NAP Report*

Ideally suited to " ... glean the fundamental insights into QCD"

"QCD is our most perfect physical theory" *Frank Wilczek*

Extras

Tracking resolution		
$[-1.0, 1.0]$	$0.5\% \oplus 0.05\% \times p$	
$1.0 < \lvert\eta\rvert < 2.5$	$1.0\% \oplus 0.05\% \times p$	
$2.5 < \lvert\eta\rvert < 3.5$	$2.0\% \oplus 0.01\% \times p$	
Track Impact Parameter Resolution		
Parameter	Resolution [μm]	
d_0	20	
z_0	20	
Charged Particle Tracking Efficiency [%]		
η	$p_\mathrm{T} = [0.1, 1.0]$ GeV	$p_\mathrm{T} > 1.0$ GeV
$[-3.5, -2.5]$	95	97
$[-2.5, -1.5]$	96	98
$[-1.5, 1.5]$	97	99
$[1.5, 2.5]$	96	98
$[2.5, 3.5]$	95	97
Electromagnetic Calorimeter ($E > 0.2$ GeV)		
η	Resolution [%]	
$[-4.0, -2.0]$	$\sqrt{E} \times (2.0) \oplus E \times (1.0)$	
$[-2.0, -1.0]$	$\sqrt{E} \times (7.0) \oplus E \times (1.0)$	
$[-1.0, 1.0]$	$\sqrt{E} \times (10.0) \oplus E \times (1.0)$	
$[1.0, 4.0]$	$\sqrt{E} \times (12.0) \oplus E \times (2.0)$	
Hadronic Calorimeter ($E > 0.4$ GeV)		
η	Resolution [%]	
$[-4.0, -1.0]$	$\sqrt{E} \times (50.0) \oplus E \times (10.0)$	
$[-1.0, 1.0]$	$\sqrt{E} \times (100.0) \oplus E \times (10.0)$	
$[1.0, 4.0]$	$\sqrt{E} \times (50.0) \oplus E \times (10.0)$	
PID performance		
$K^\pm$, $\pi^\pm$	$\geq 3\sigma$ separation in the range	
$[-4.0, -1.0]$	up to 10 GeV	
$[-1.0, 1.0]$	up to 6 GeV	
$[1.0, 4.0]$	up to 50 GeV	
$e^\pm$, $\pi^\pm$	$\geq 2.4\sigma$ separation (rejection factor 50)	
$\mu^\pm$, $\pi^\pm$	$\geq 2\sigma$ separation	

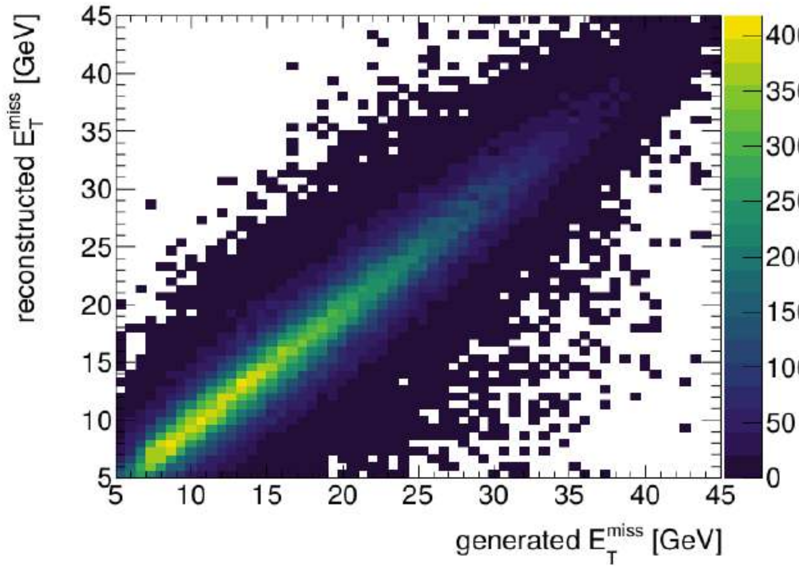


Figure 4. Missing-transverse energy ($E_T^{\rm miss}$) response matrix for charged-current DIS events. The missing energy is reconstructed using DELPHES particle-flow objects.

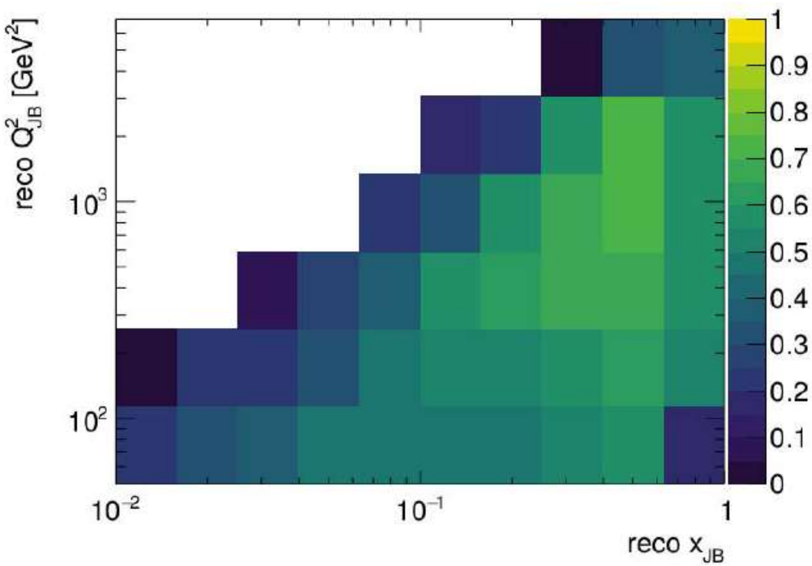


Figure 5. Bin survival probability obtained using the Jacquet-Blondel method in charged-current DIS events.

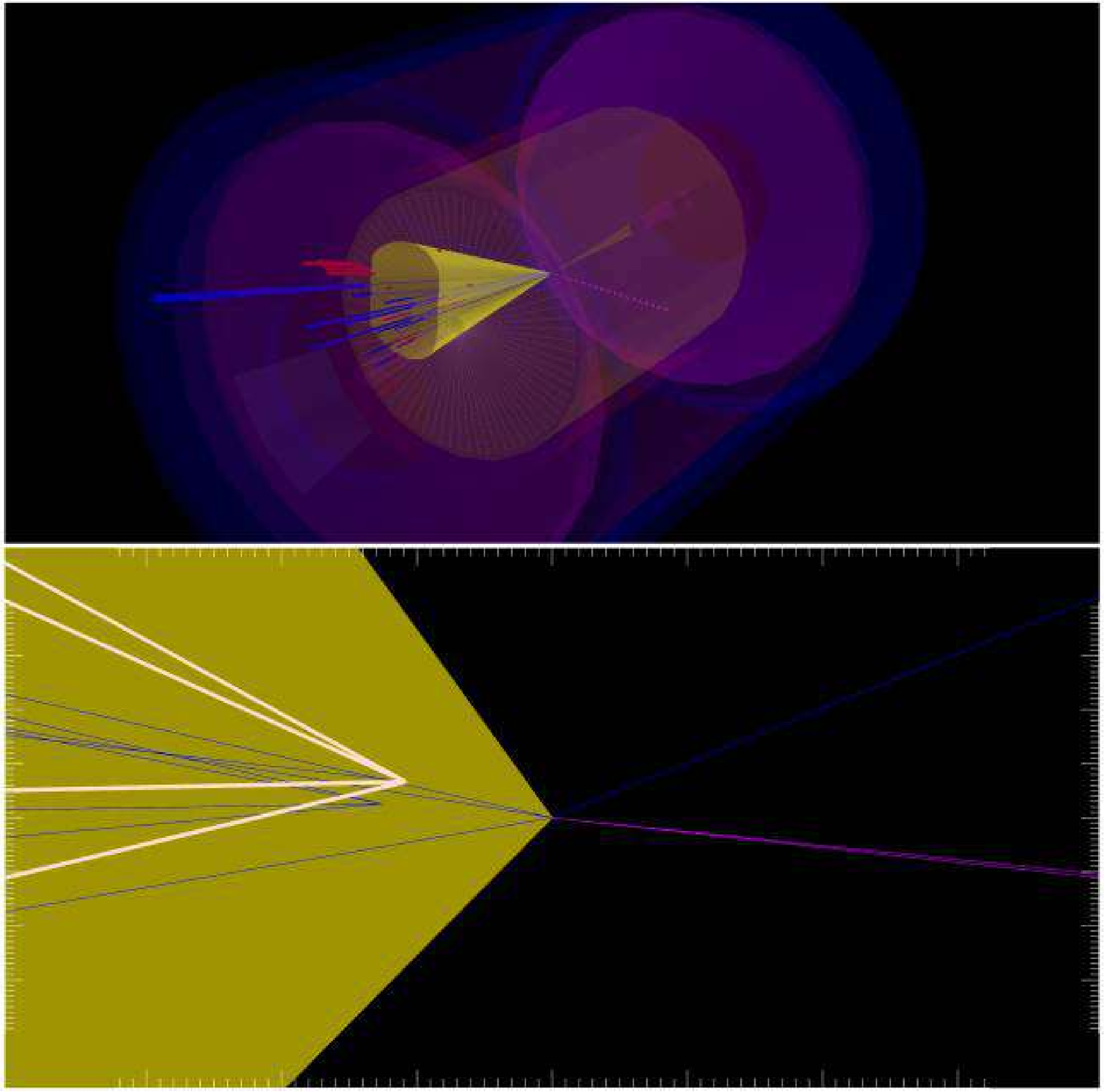


Figure 7. A pair of event displays of a single CC DIS event simulated with PYTHIA8 and reconstructed with DELPHES. A reconstructed jet is represented as a yellow cone; blue bars are hadronic calorimeter energy deposits, and red bars are electromagnetic calorimeter energy deposits. Tracks are indicated by blue lines; the yellow-highlighted tracks originate from a displaced decay vertex. The zoomed-in view (bottom) shows these tracks and vertices.

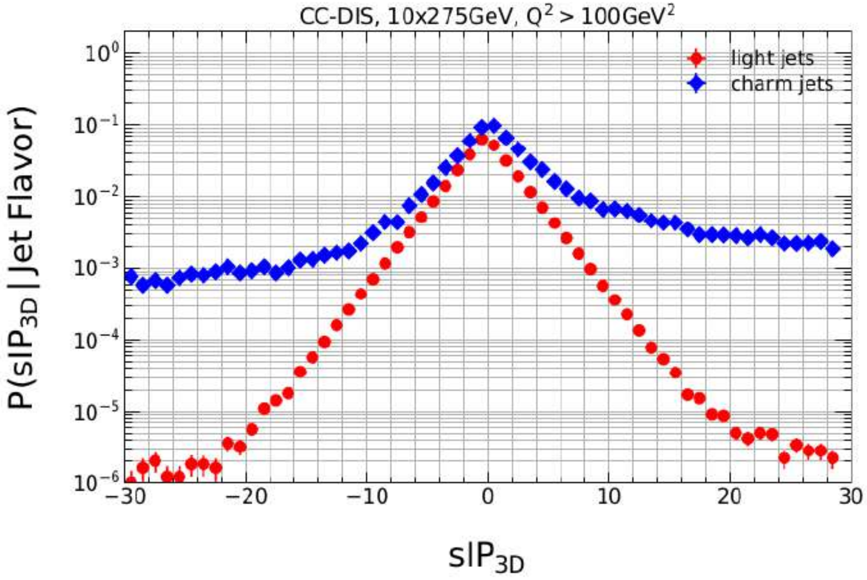
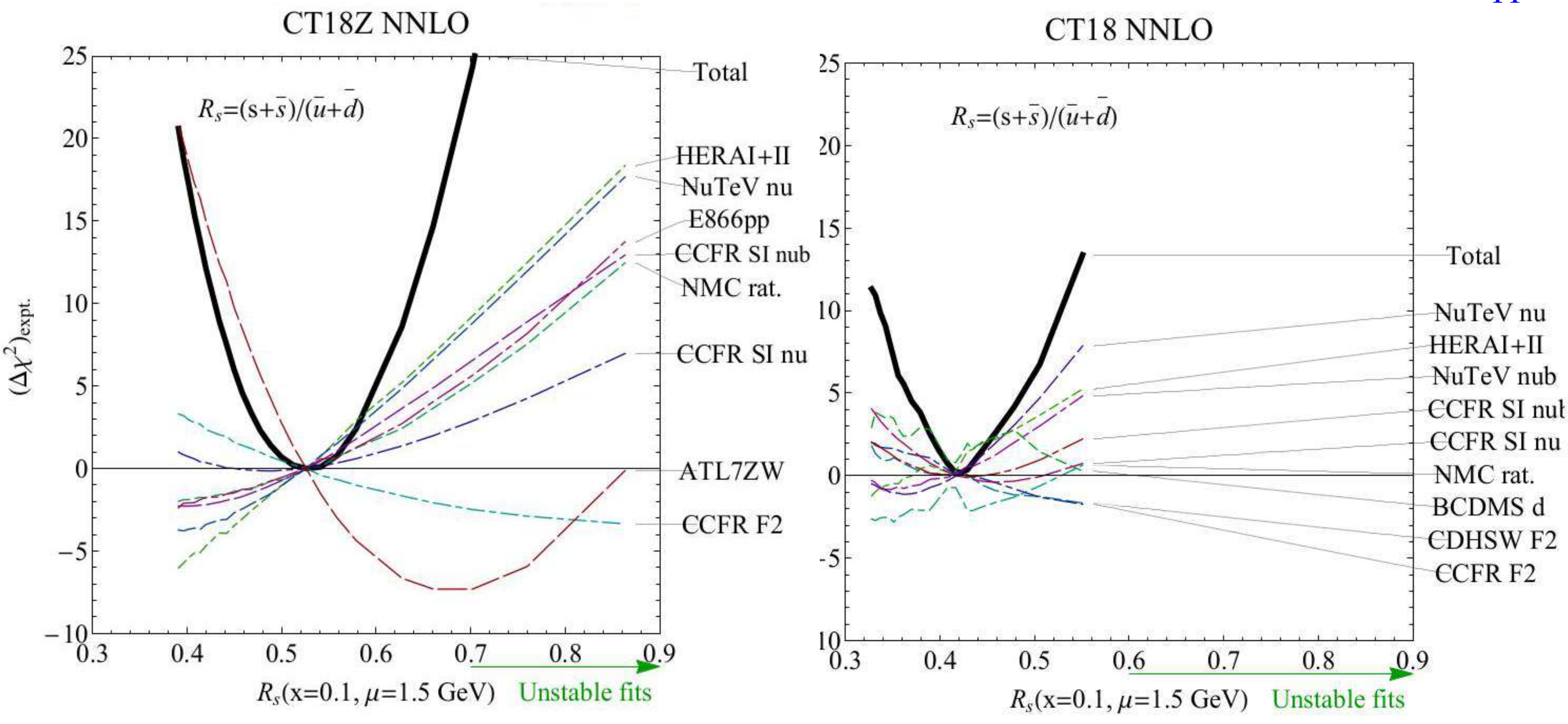


Figure 6. Signed impact parameter significance, sIP_{3D}, probability distribution for light and charm jets.



Rs-Low NNLO
Suppressed Strange
$$\begin{cases} R_s(0.1, 1.5) = 0.325 \\ \kappa(Q=1.5) = 0.37 \end{cases}$$

CT18A NNLO
Intermediate Strange
$$\begin{cases} R_s(0.1, 1.5) = 0.552 \\ \kappa(Q=1.5) = 0.63 \end{cases}$$

Rs-High NNLO
Enhanced Strange
$$\begin{cases} R_s(0.1, 1.5) = 0.863 \\ \kappa(Q=1.5) = 0.96 \end{cases}$$

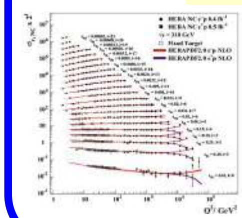
xFitter

PROTON NUCLEON MESON

www.xFitter.org

Sample data files:
- **LHC:** ATLAS, CMS, LHCb
- **Tevatron:** CDF, D0
- **HERA:** H1, ZEUS, Combined
- **Fixed Target:** …
- **User Supplied:** ...

Experimental Data



Data: HERA, Tevatron, LHC, fixed target experiments

Processes:
Inclusive DIS, Jets, Drell-Yan,
Diffraction, Top production
W and Z production

Theory Calculations

HQ Schemes:	MSTW, NNPDF, ABM, ACOT
Jets, W, Z:	FastNLO, ApplGrid
Top:	Hathor
Evolution:	QCDNUM, APFEL, k_T
Other:	NNPDF reweighting TMDs, Dipole Model, ...

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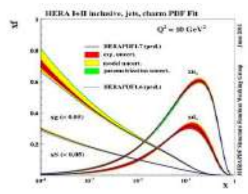


Parton Distribution Functions: PDF, Updf, TMD

$\alpha_S(M_Z)$, m_c, m_b, m_t ...

Theoretical Cross Sections

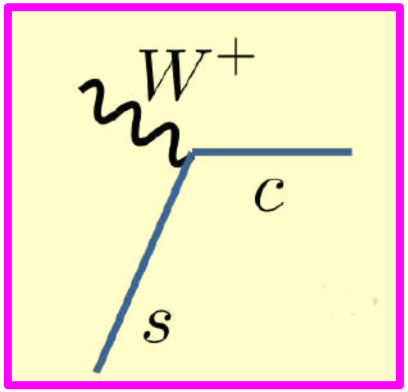
Comparisons to other PDFs (LHAPDF)

extensions include nuclear PDFs

Features & Recent Updates:
- Photon PDF & QED
- Pole & MS-bar masses
- Profiling and Re-Weighting
- Heavy Quark Variable Treshold
- Improvements in χ^2 and correlations
- TMD PDFs (uPDFs)
- *... and many other*

xFitter 2.0.1
Old Fashioned

Charged Current Charm Production Constrains Strange PDF

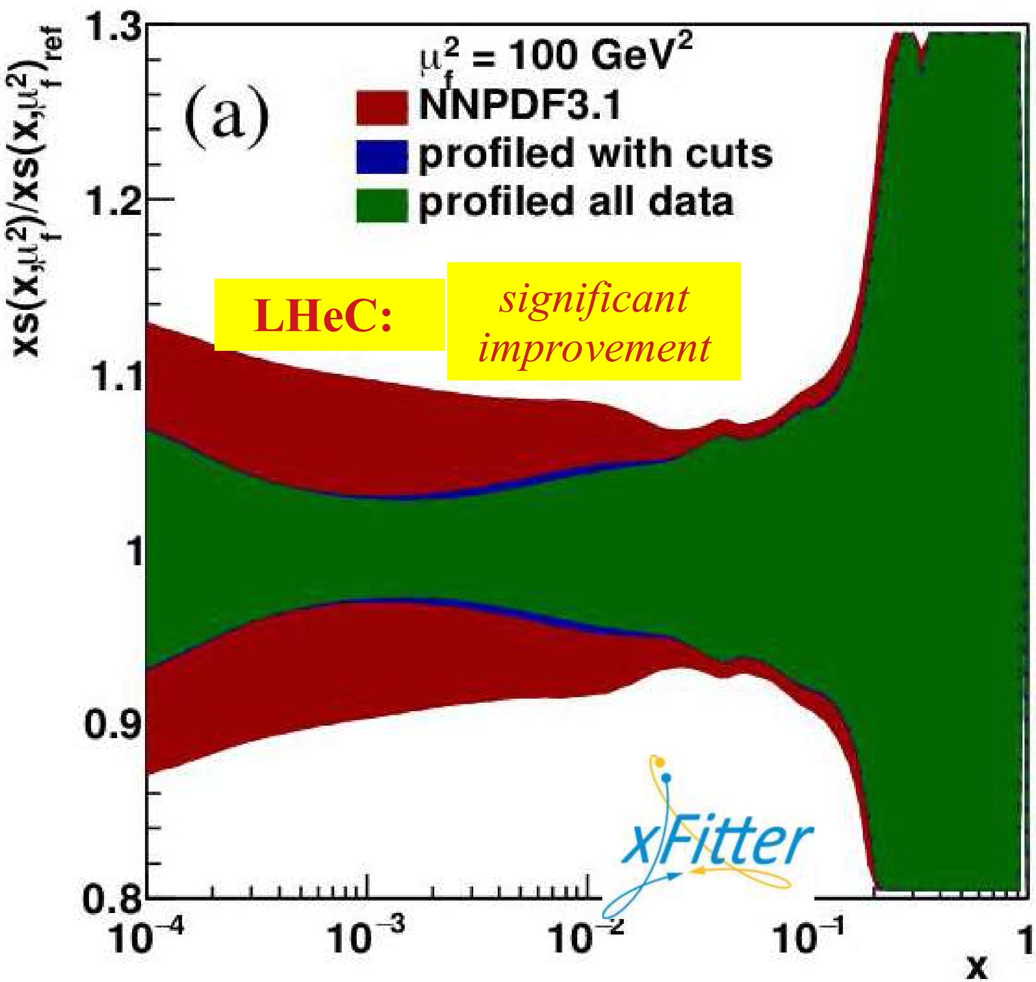


Probing the strange content of the proton with charm production in charged current at LHeC

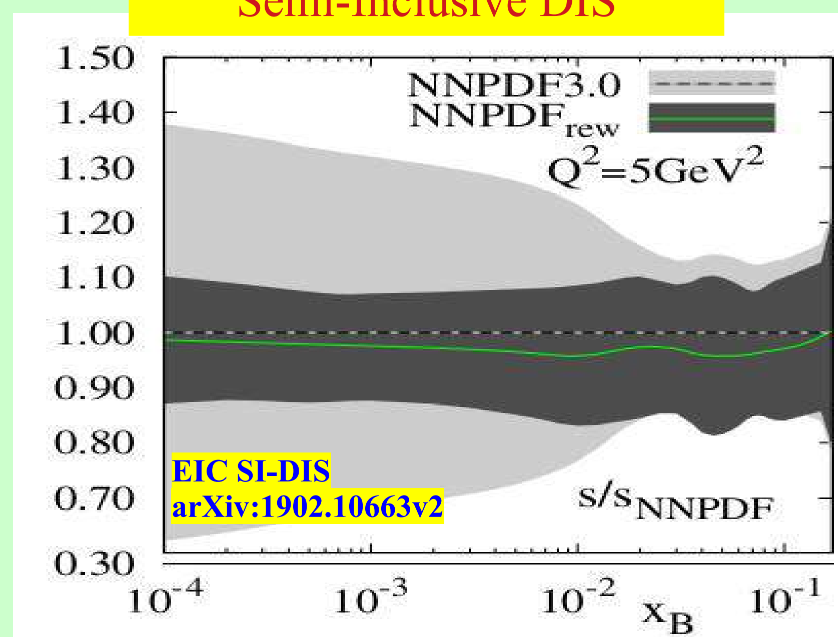
xFitter Developers' team: Hamed Abdolmaleki[1], Valerio Bertone[2], Daniel Britzger[3], Stefano Camarda[4], Amanda Cooper-Sarkar[5], Achim Geiser[6], Francesco Giuli[7], Alexander Glazov[6], Agnieszka Luszczak[8], Ivan Novikov[9], Fred Olness[10], Andrey Sapronov[9], Oleksandr Zenaiev[11]

xFitter Developers' Team;
arXiv:1907.01014 [hep-ph]

xFitter:
Docker & Singularity images available
details in extra slides



Potential EIC improvement
Semi-Inclusive DIS



See also: R.A. Khalek, S. Bailey, J.Gao, L. Harland-Lang, J. Rojo, arXiv:1906.10127 [hep-ph] *w/ additional channels*

... how can we nail this!
would also elucidate LHC issues