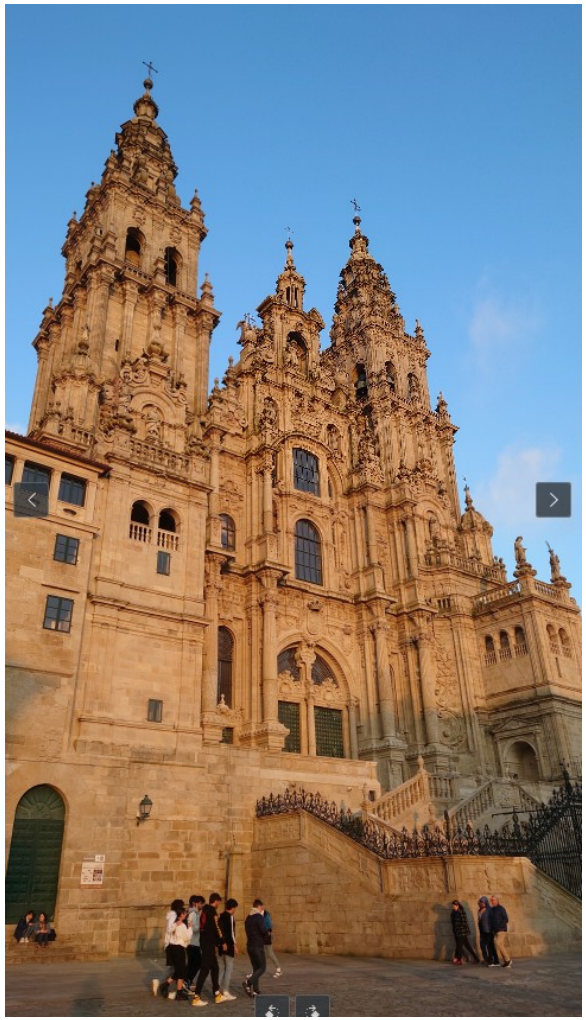
Summary WG1

Tom Cridge, Klaus Rabbertz, Barak Schmookler



WG1 Summary

WG1 - Structure Functions and Parton Densities

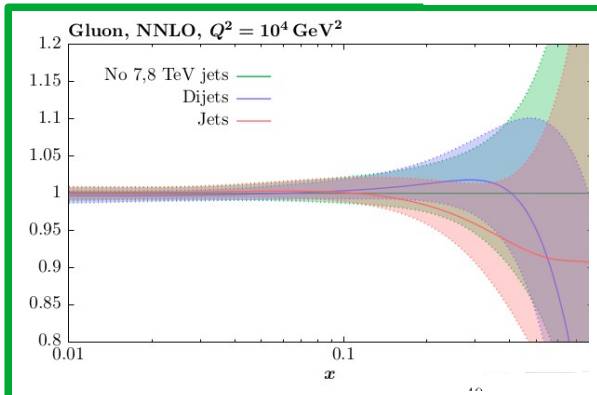
>130 abstracts, ~50 talks (13 online), ~20 hours

Sessions on global PDFs, nuclear PDFs, TMDs, Experiments, Tools, Theoretical developments and many other topics….

Tough task to summarise in 25 minutes!

Global PDFs – more data...

L. Harland - Lang MSHT20

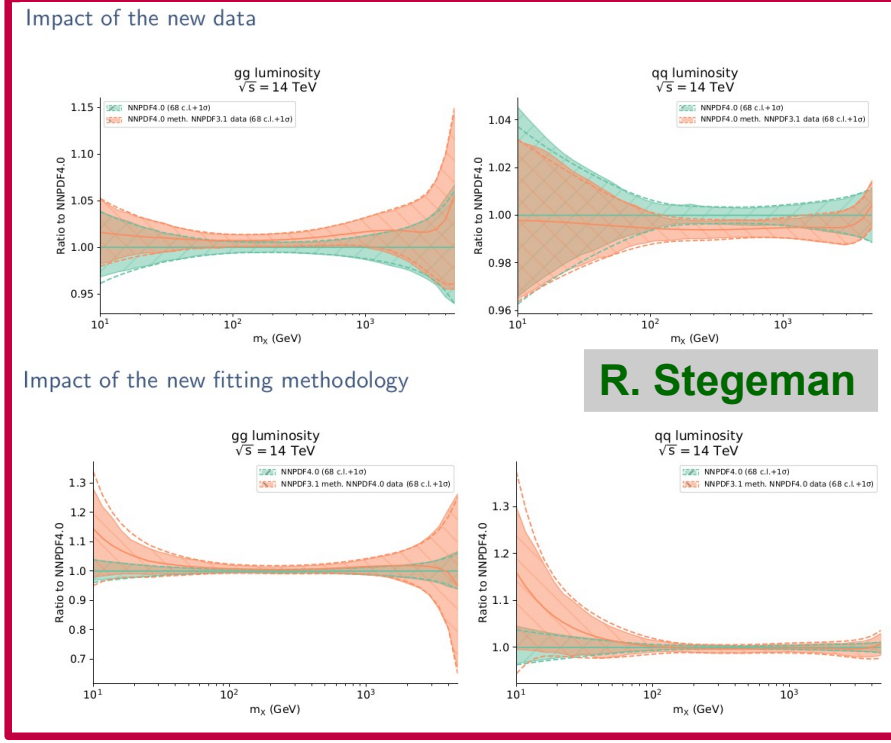


	$N_{\rm pts}$	NLO	NNLO
ATLAS 7 TeV jets	140	1.69	1.53
ATLAS 8 TeV jets	171	2.37	1.45
CMS 7 TeV jets	158	1.38	1.22
CMS 8 TeV jets	174	1.65	1.80
Total Jets	643	1.78	1.50

	$N_{\rm pts}$	NLO	NNLO
ATLAS 7 TeV dijets	90	1.10	1.05
CMS 7 TeV dijets	54	1.71	1.43
CMS 8 TeV dijets	122	5.30	1.04
Total Dijets	266	3.15	1.12

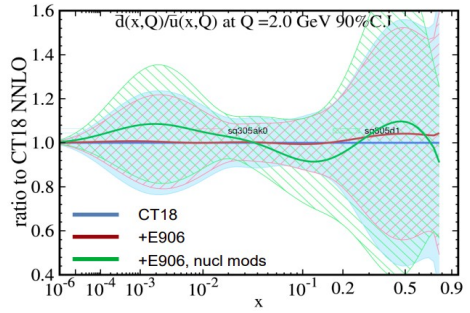
- Lots of data updates/studies.
- Ever-growing list of datasets included.
- NNLO now required for good fit quality for precise LHC data.

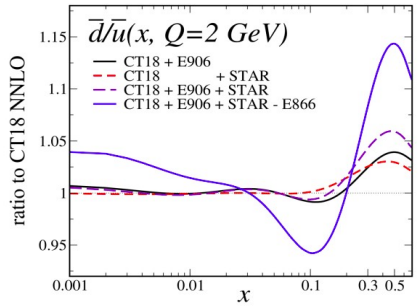
NNPDF4.0



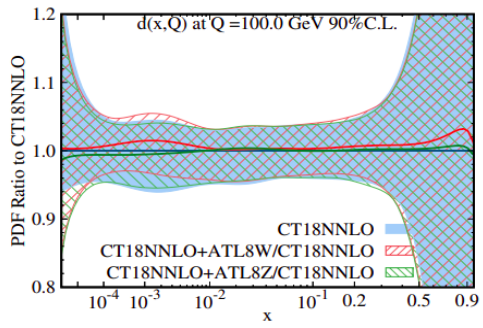
R. Stegeman

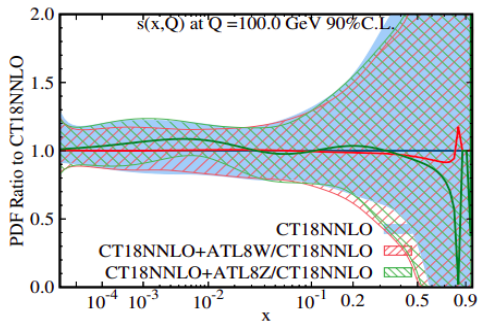
CT18





P. Nadolsky, K. Xie

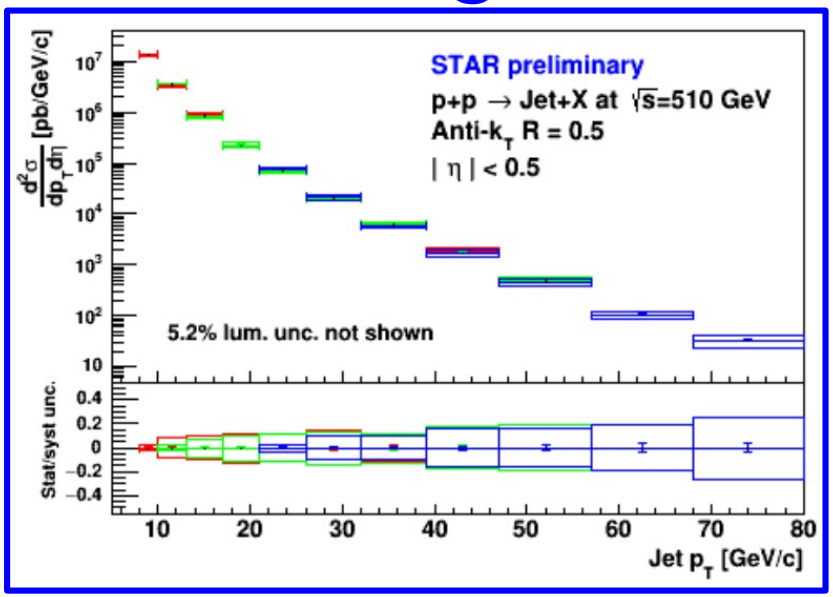




New food 4 (PDF) thought

D. Kalinkin

New jet p_T measurements STAR @ 200 & 510 GeV



HERA+CMS jets 13 TeV: PDF+α_s

T. Mäkelä

$$\alpha_S = 0.1170 \pm 0.0014(\text{fit}) \pm 0.0007(\text{model}) \pm 0.0008(\text{scale}) \pm 0.0001(\text{param.})$$

NNLO

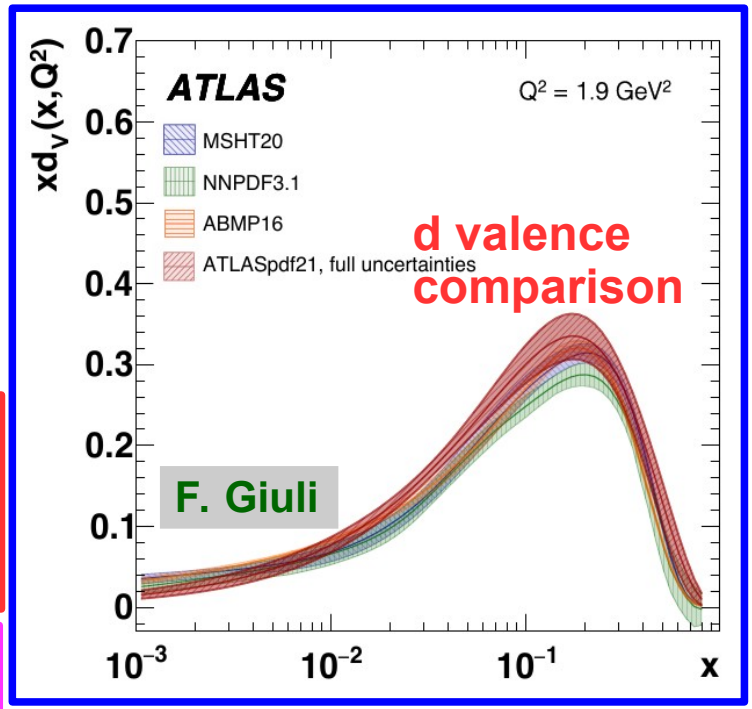
HERAPDF2.0Jets @ NNLO: PDF+α_s

K. Wichmann

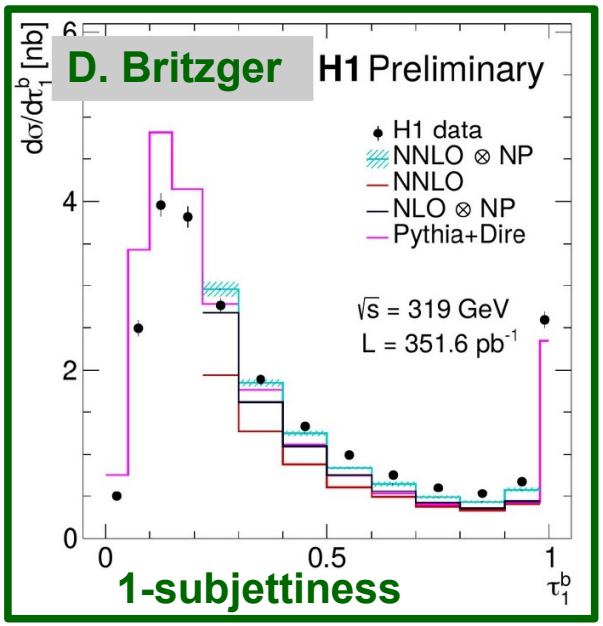
$$\alpha_s = 0.1156 \pm 0.0011(\text{exp}) \pm 0.0029(\text{scale}) {}^{+0.0001}_{-0.0002}(\text{mod} + \text{par})$$

NNLO

ATLAS combined PDF fit incl. V, J, V+J, ttbar data ~ 15 datasets

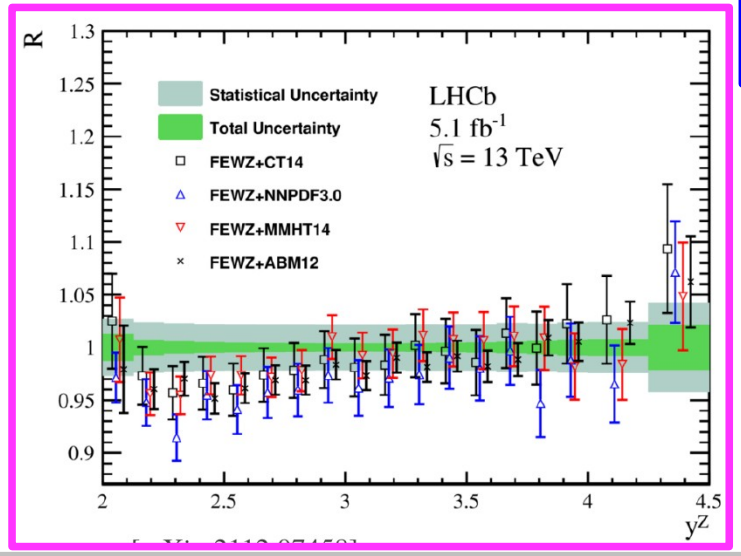


D. Britzger



New ideas

H1 Data re-ana-lysed

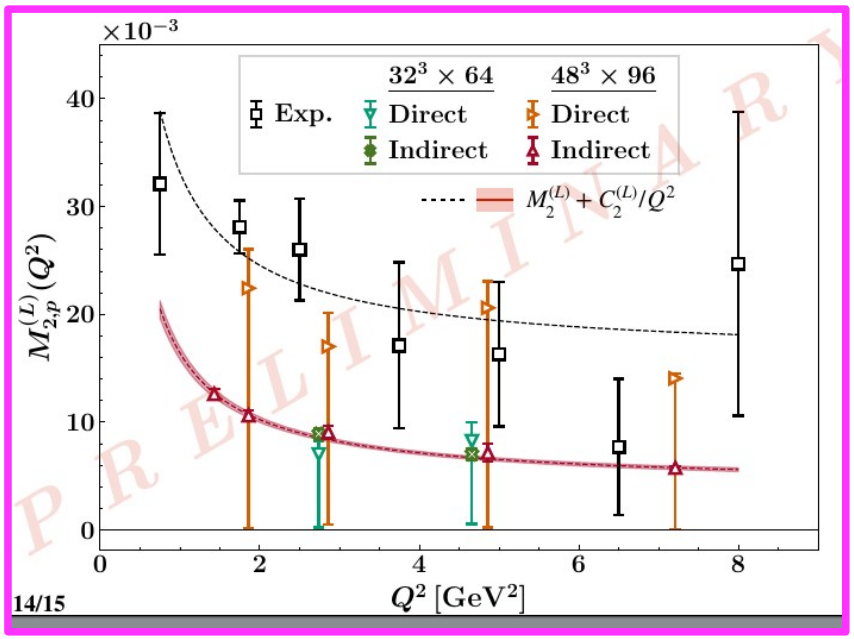


M. Xu

LHCb measures forward rapidities for PDF fits, e.g. Z boson rapidity y_Z 2.0 – 4.5

FEWZ underestimates low y_Z

Lattice PDF news

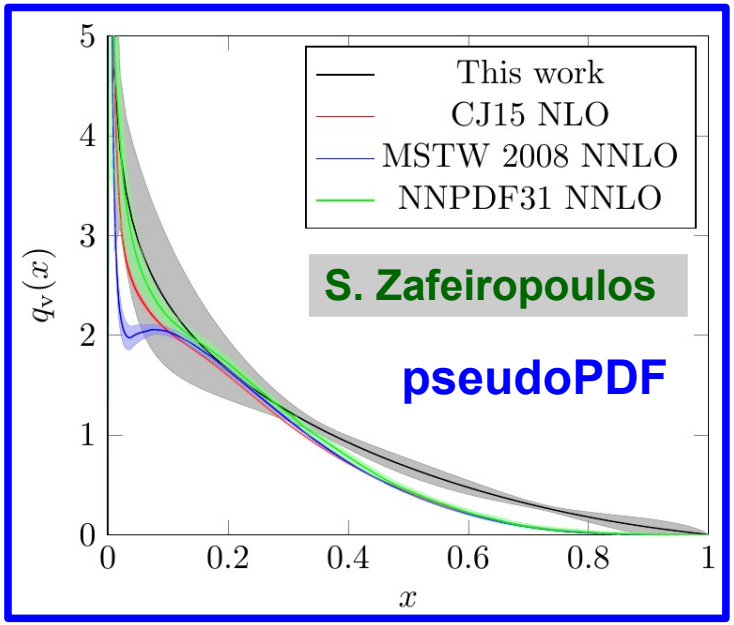


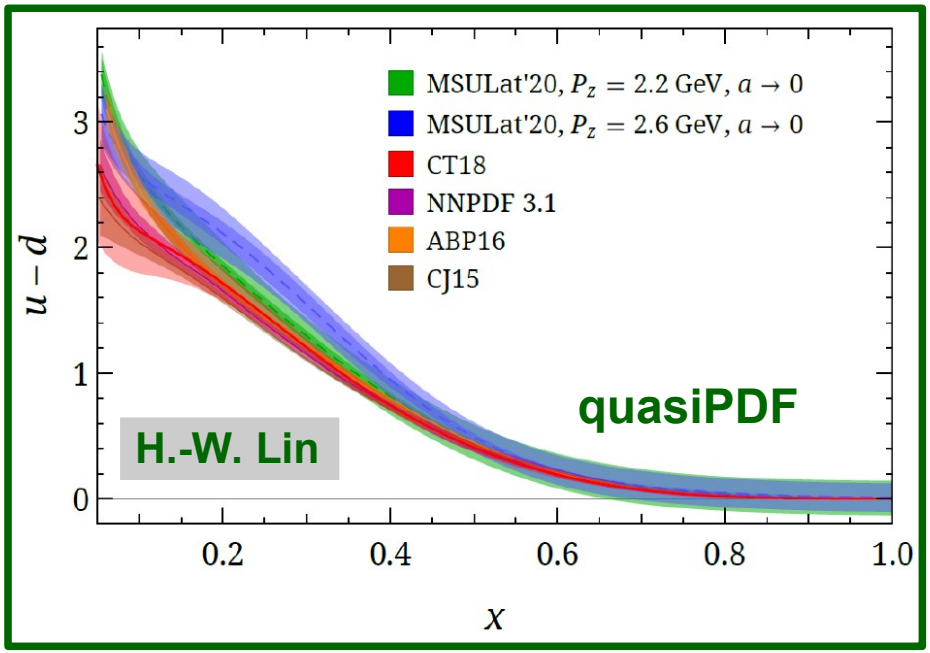
Technique of forward Compton amplitude

K. Utku Can

Allow for 1st time study of moments of F_L

Interplay with pheno PDFs studied within NNPDF; comparison with nucleon valence PDF

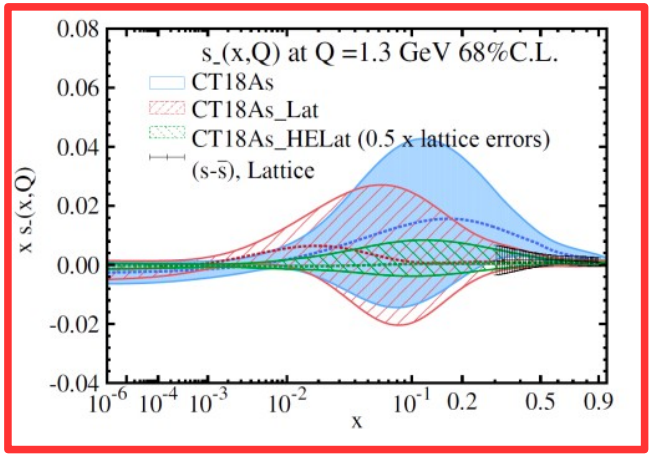




Comparisons to pheno PDFs Here: u - d

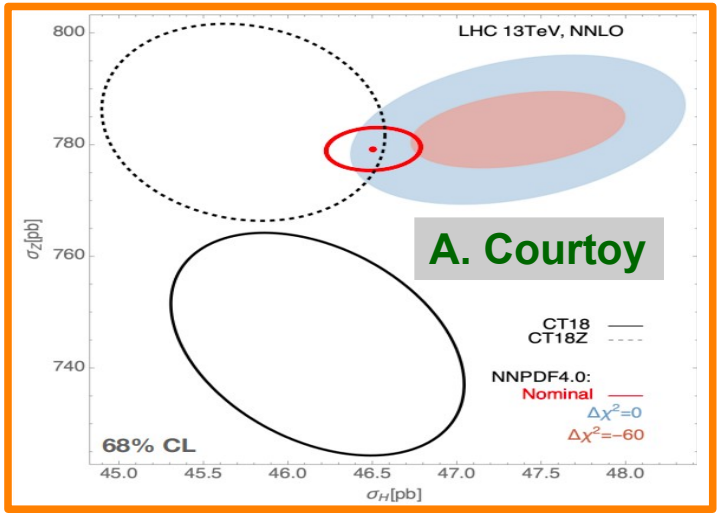
Exciting era of PDFs from lattice QCD; more studies of systematics needed

Lattice constraint on s asymmetry

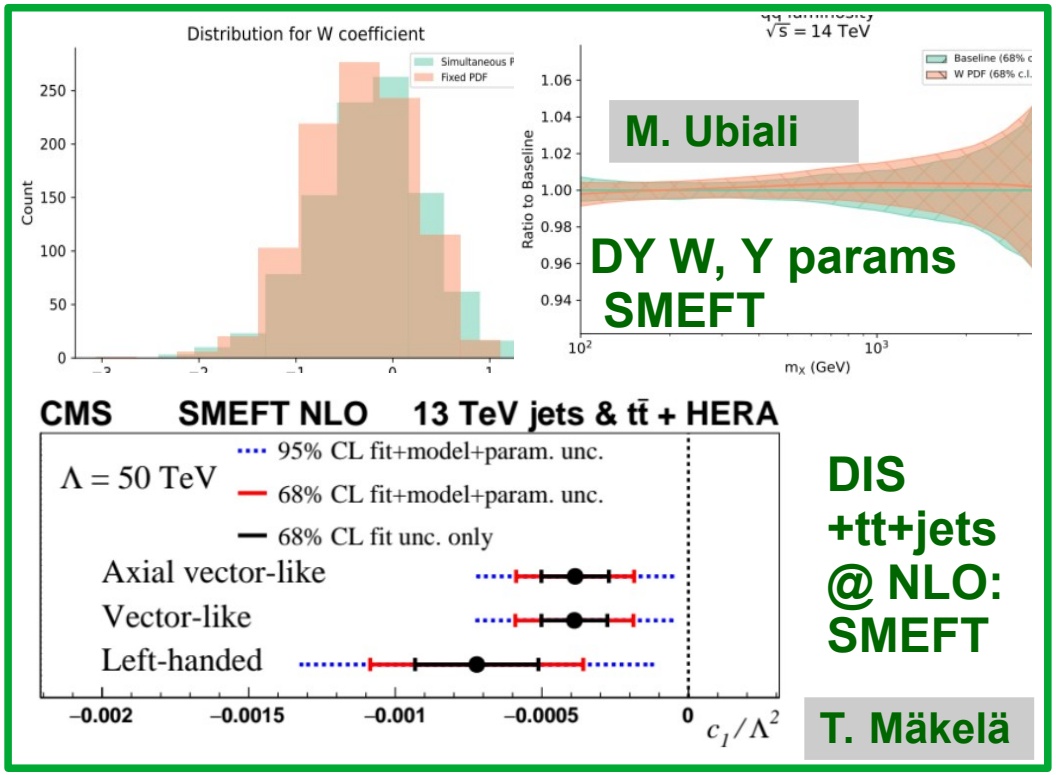


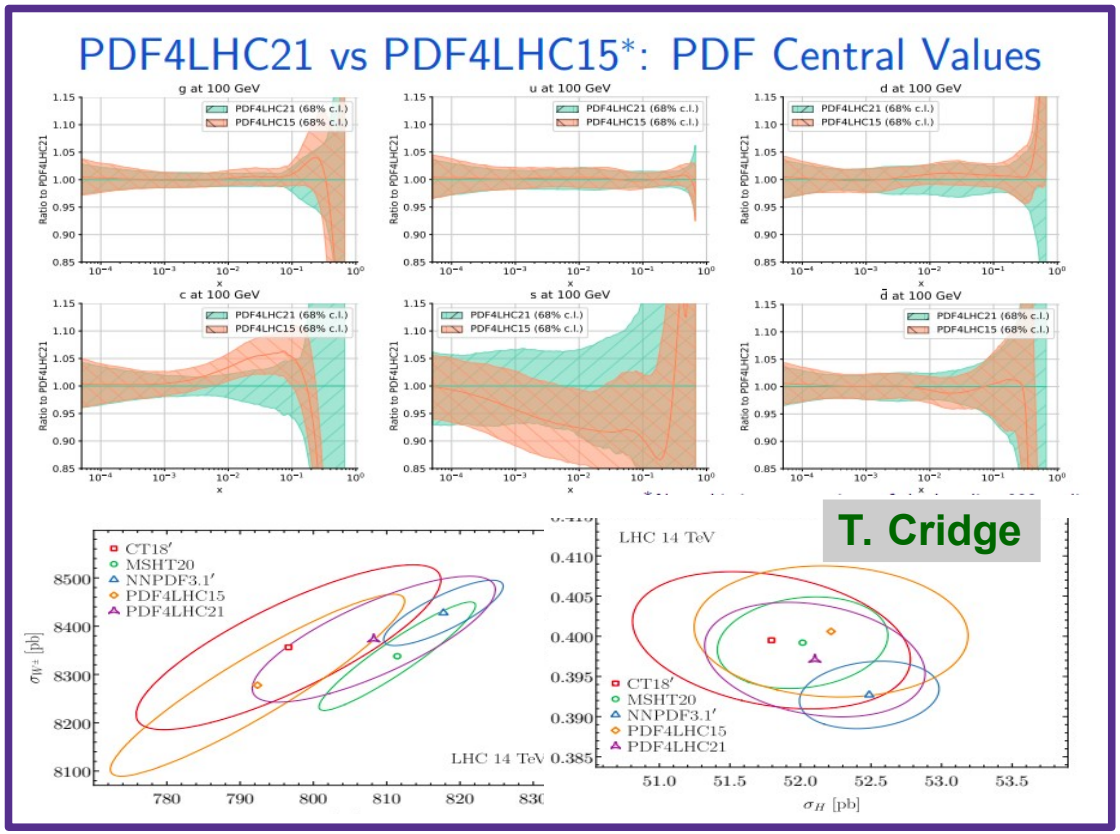
P. Nadolsky H.- W. Lin

PDFs – new developments



- New studies on:
  - PDF uncertainties
  - Fits to PDFs + SMEFT parameters
- PDF4LHC21 combined CT18, NNPDF3.1.1, MSHT20 PDF set.

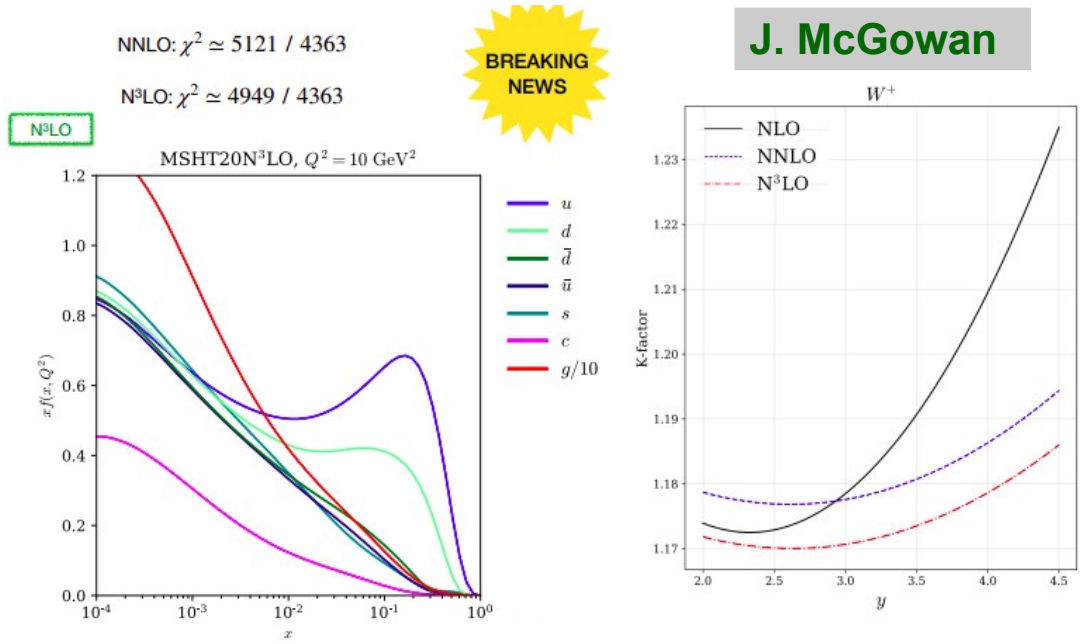




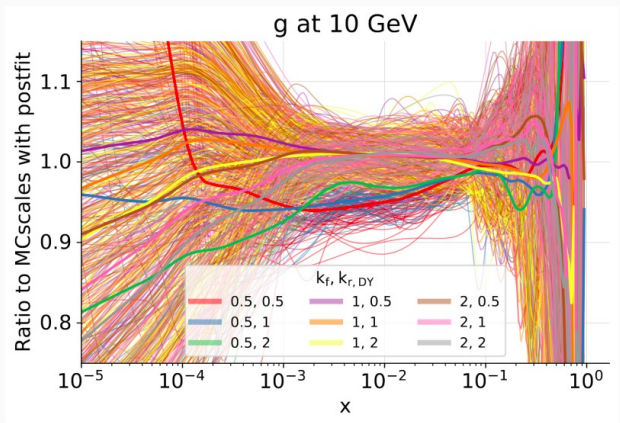
Global PDFs – theory uncertainties

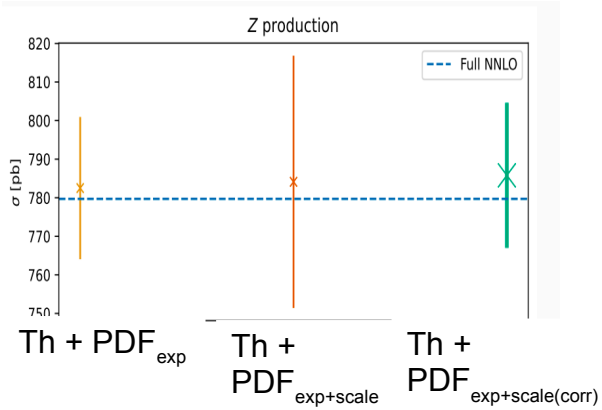
MSHT20

J. McGowan



- Approximate N3LO PDFs → MSHT, including theoretical uncertainties, first attempt.
- NNPDF – using scale variations for theory uncertainties.
- Bonvini – Bayesian inference for MHOUs in PDF fits.

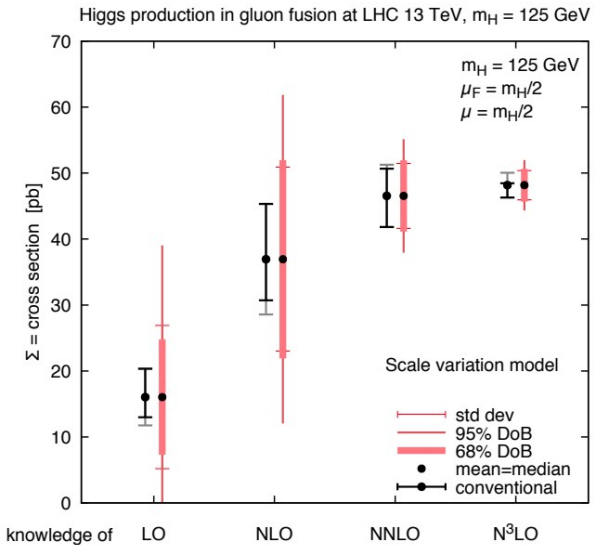




NNPDF4.0

Z. Kassabov

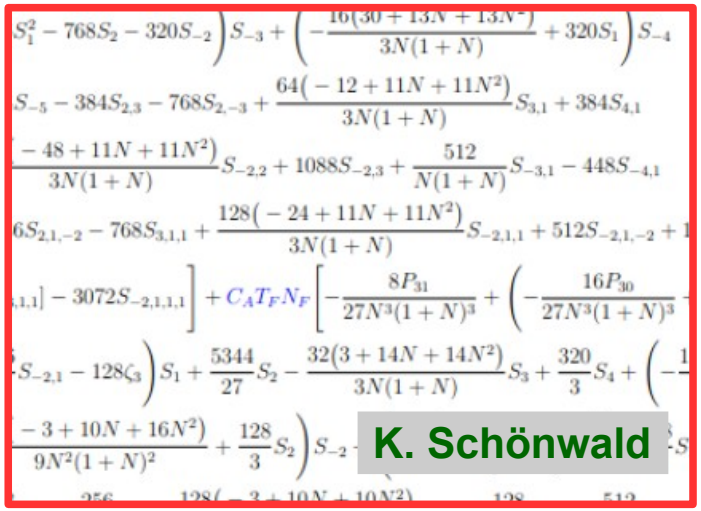
M. Bonvini



Bayesian Inference -

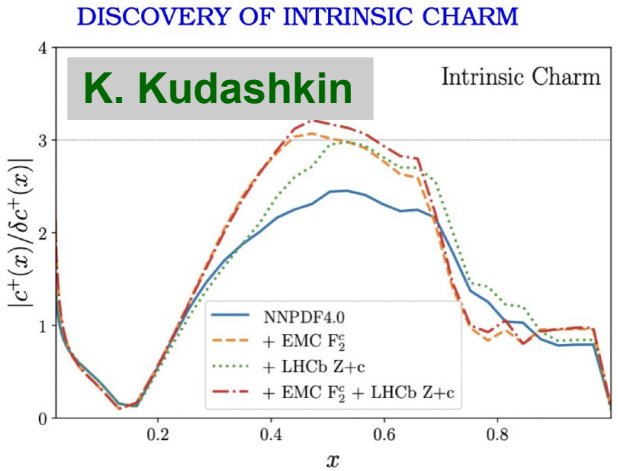
New features for DIS theory

New: 3-loop transversity anomalous dimensions: other 3-loop a.d. recovered.

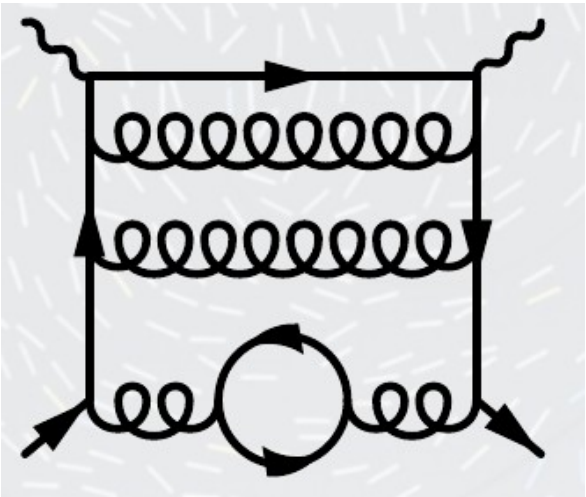


K. Schönwald

Planned to use method for 4-loop quantities.



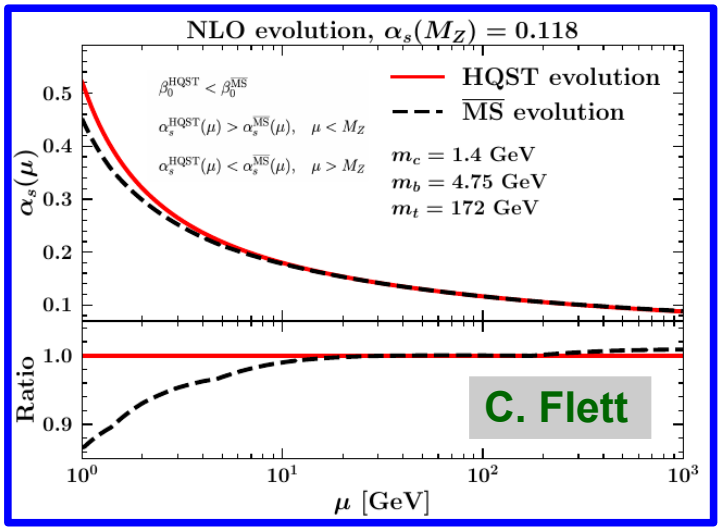
Test new method with Mellin moments for DIS 3-loop Wilson coefficients.



1500 Mellin moments generated for n_f^2 term to derive 4-loop DIS Wilson coefficients.

A. Pelloni

Implement physical mass scheme on HQ in DIS into xFitter



Allows smooth transition over MS_{bar} thresholds Study impact vs. Ms_{bar}, 1st at NLO, HQ in DIS

Progress on NNLO to intrinsic structure functions

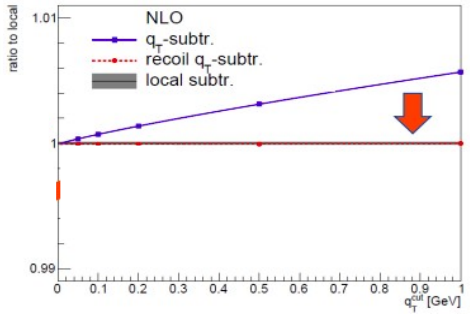
Last missing piece to charm structure function; on its way to last PDF matching coefficient at NNLO

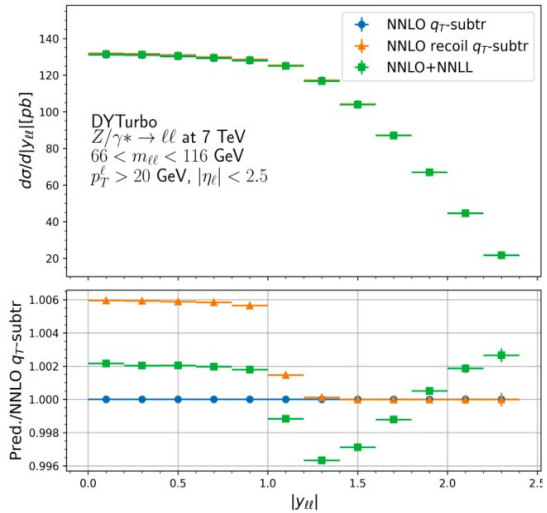
PDFs – qT, resummations, theory

- Increasing precision → we have to be more careful.
- Symmetric lepton fiducial cuts induce linear qT dependence. Related to subtraction scheme.
- Difference of exact and perturbative solutions to RGE → account for it using new scale.
- Approximate MHOUs using resummed expressions.

Linear power corrections and qT resummation for DY

A. Guida

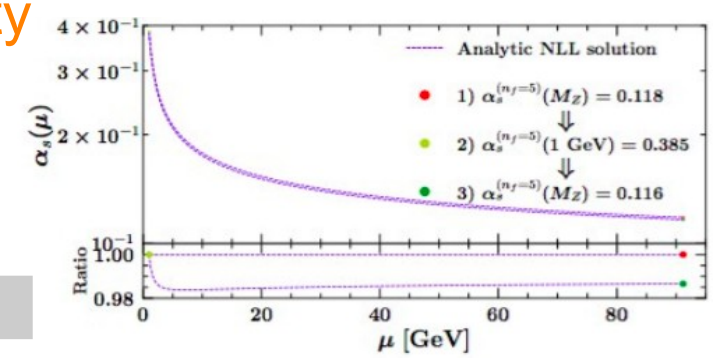




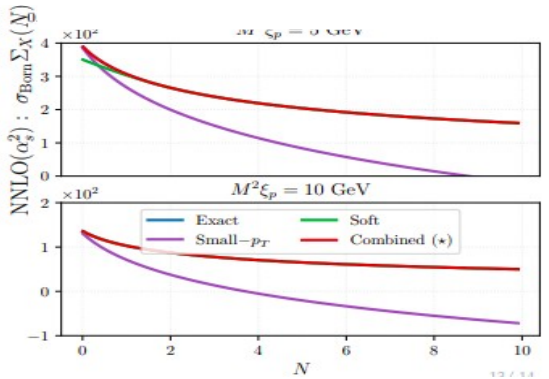
PDF	Total χ^2 (ndf=61)		
	NNLO q_T subtr.	NNLO recoil q_T-subtr	NNLO+NLL
CT18ANNLO68	96	84	74
MSHT20nnlo	111	87	79
NNPDF31	91	84	71
NNPDF40nnlo	89	83	69

Hysteresis – introduce "emergent resummation scale" to evaluate uncertainty

F. Hautmann



Threshold + small-pT resummations: approx N3LO Higgs pT



T. Rabemananjara

$$\frac{d\sigma^{[m]}_{DY,\star}}{dp_T^2} = T(N,\xi_p)\frac{d\sigma^{[m]}_{DY,TH}}{dp_T^2} + (1 - T(N,\xi_p))\frac{d\sigma^{[m]}_{DY,p_T}}{dp_T^2}$$

TMDPDFs

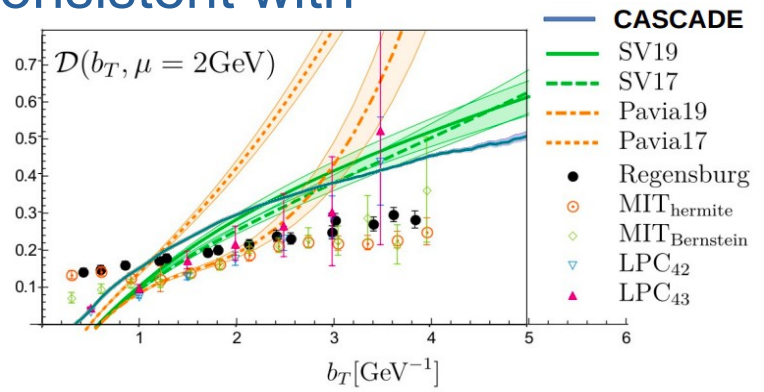
- Increasing interest transverse momentum dependent PDFs.
- Add Hera jets and CMS DY to PB-TMD fit, good agreement with collinear PDFs.
- PB-TMD fit with dynamical resolution scale zmax.
- Method to extract CS-kernel from Monte Carlo and PB-TMDs.

A. Bermúdez Martínez

$$\Delta(b; Q \to (\mu_0, \zeta_0)) = \int_P \left(\gamma_F(\mu, \zeta) \frac{d\mu}{\mu} - \mathcal{D}(b, \mu) \frac{d\zeta}{\zeta} \right),$$

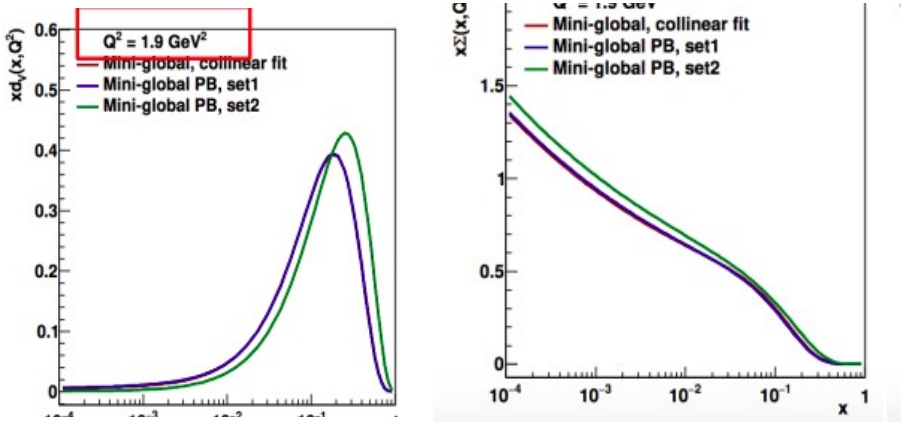
Collins-Soper kernel

CASCADE MC to determine CS kernel consistent with perturbative calculations at small b and lattice at large b.

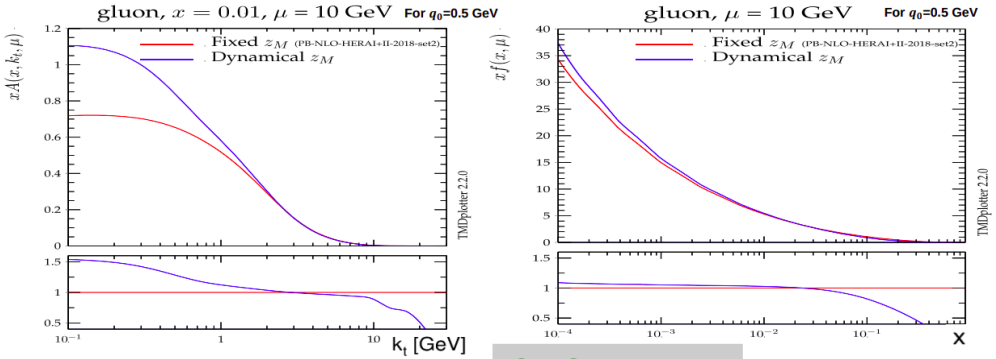


Mini-global PB-TMD fits

K. Wichmann



First such PB-TMD fits, good χ^2/N for HERA data, impacts kT and x dependence



S. Sadeghi

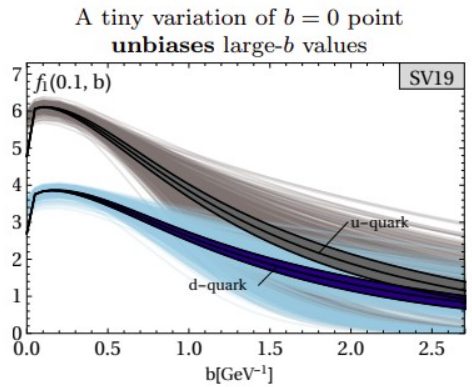
TMDPDFs/Light Front

- Increasing interest transverse momentum dependent PDFs.
- PDF bias and flavour dependence in TMDPDFs.
- Alternatively can use Basis Light Front Quantisation (BLFQ) framework for (TMD)PDFs.
- Used for Light meson PDFs, mass spectrum, Pion EM form factor, GPDs, strangeonia, etc….

A. Vladimirov

$$f(x,b) = C(x,b) \otimes q(x) f_{\rm NP}(x,b)$$

TMDs matched to PDFs at b→ 0. Remove PDF bias by fitting each replica with its own non-perturbative function.

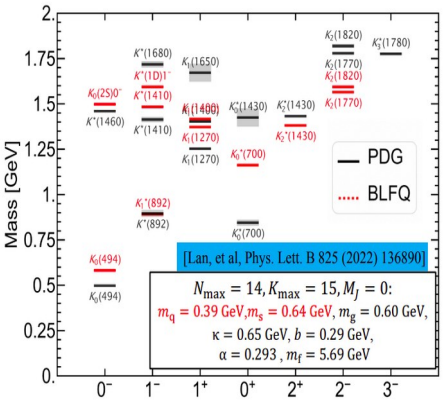


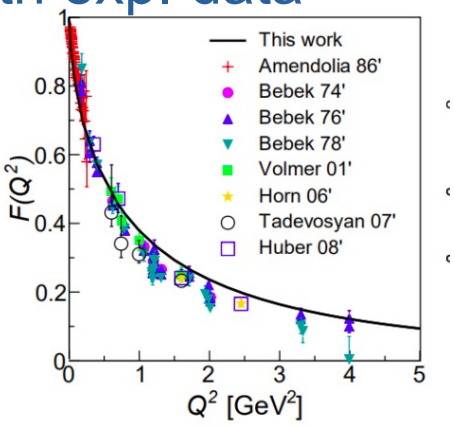
2-parameter flavour-dependent f_{NP}

$$f_{NP}(x,b) = \exp\left(-\frac{\lambda_1(1-x)+\lambda_2 x}{\sqrt{1+\lambda_0 x^2 \mathbf{b}^2}}\mathbf{b}^2\right)$$

J. Lan

Agreement of Pion EMFF with exp. data

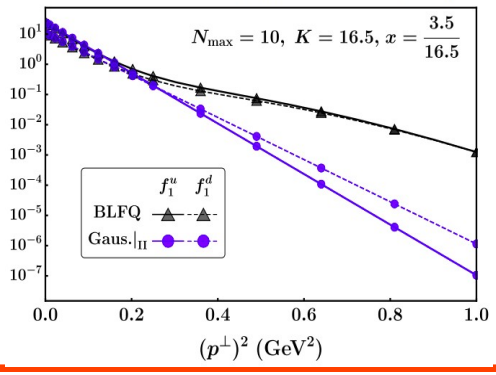




Proton TMDs
- Also examined related factor
- Strong x and flavour dependence, falls slower than Gaussian
- Compared also proton and Lambda(c) TMDs.

H. Zhi

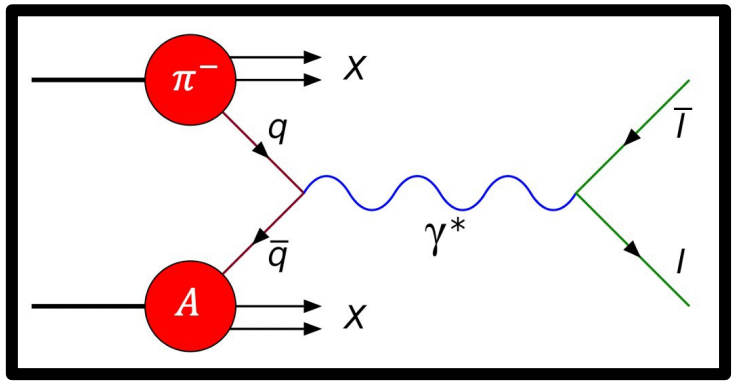
$$\langle (p^\perp)^2 \rangle_f^q(x) = \frac{\int d^2p^\perp (p^\perp)^2 f^q_{\rm BLFQ}(x,(p^\perp)^2)}{\int d^2p^\perp f^q_{\rm BLFQ}(x,(p^\perp)^2)}$$

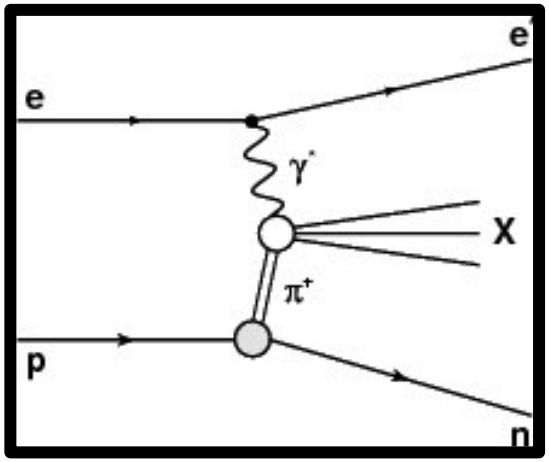


Pion PDFs

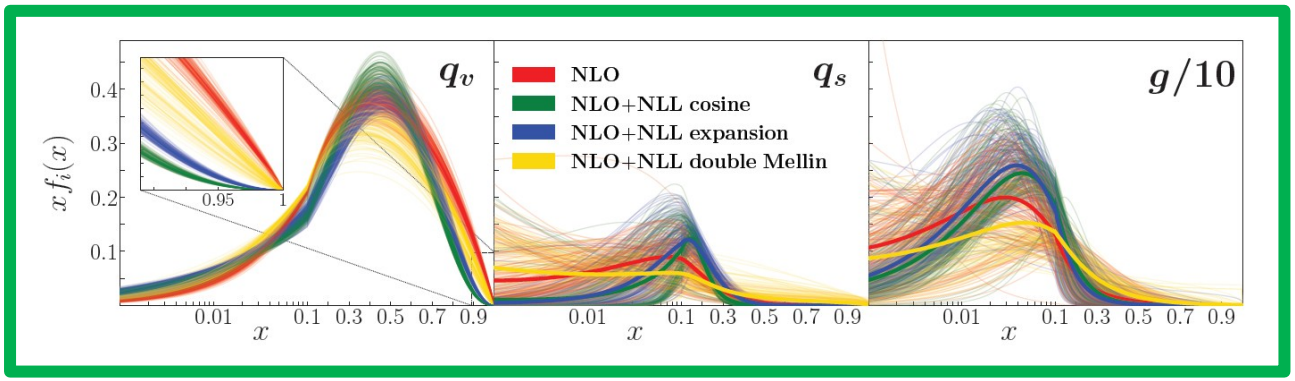
- JAM: Global QCD analysis – **Patrick Barry**
  - Pion PDFs with threshold resummation
- Pion PDFs – **K. Raya & J. Rodríguez-Quintero**
  - Emergence of both pion and proton PDFs
- JAM: Experimental and Lattice pion PDFs – **Patrick Barry**
  - Comparison and complementarity of experimental and lattice pion PDFs
- Pion PDFs in Minkowski space – **Wayne de Paula**
  - Calculation of the PDFs, charge radius and Electromagnetic Form Factor

Pion PDFs in JAM!

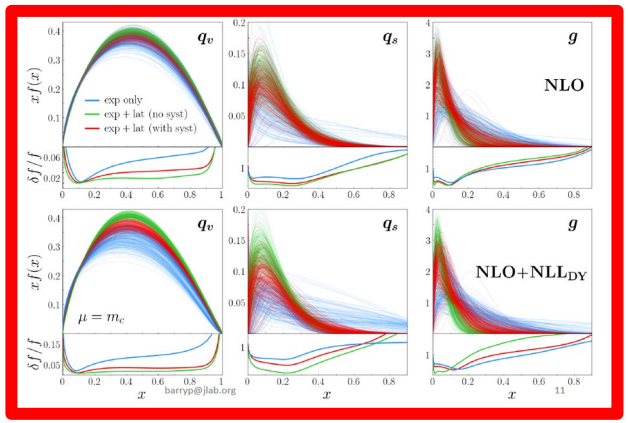




Pion PDFs with threshold resummation



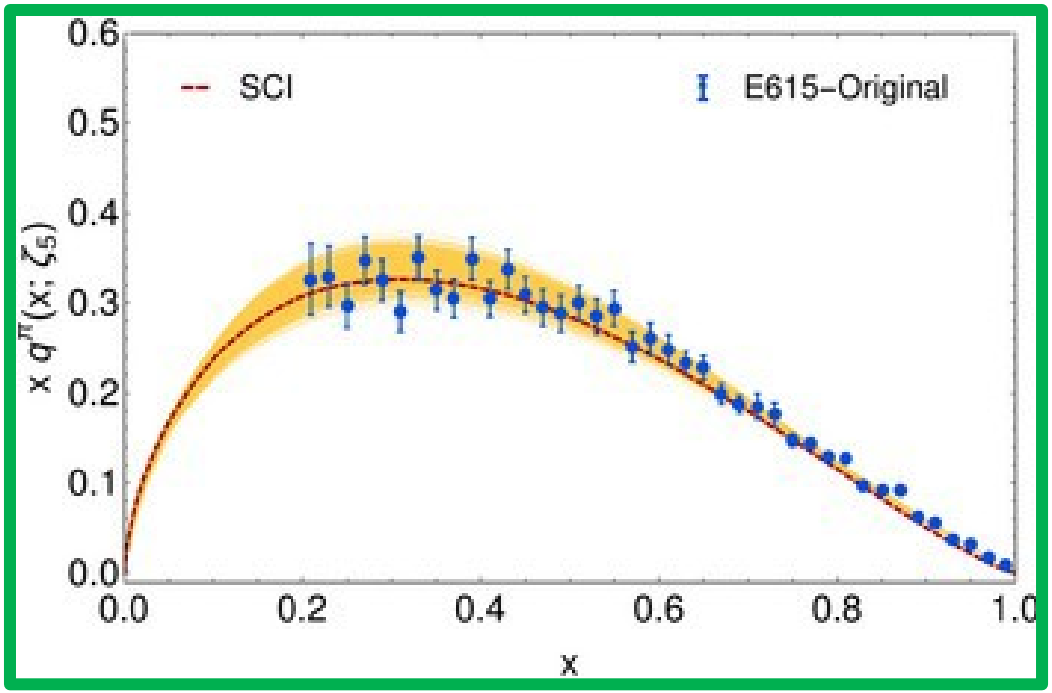
Inclusion of lattice results



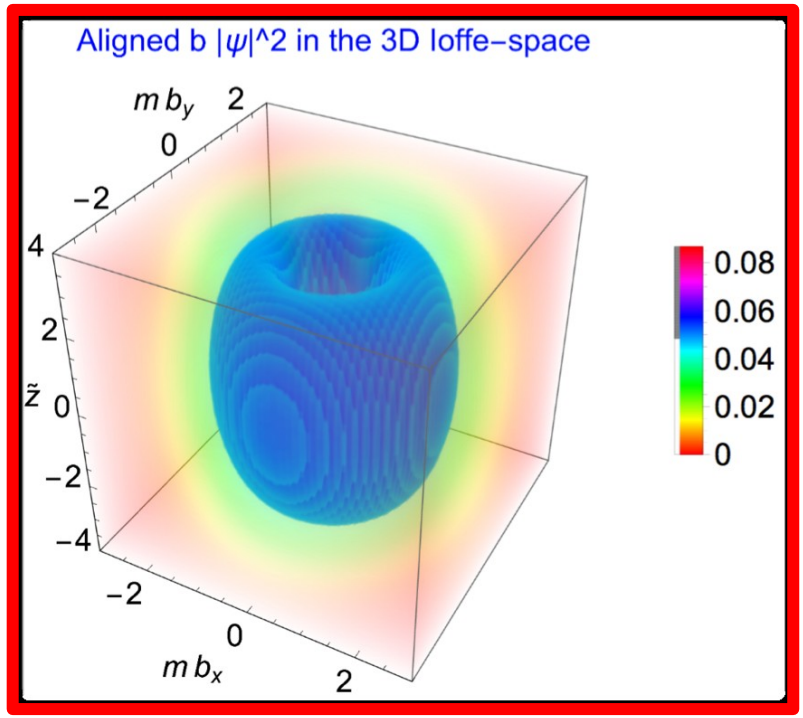
- Threshold resummation does not give a universal value of the high-x exponent. Some improvement when lattice results are also included.

Pion PDFs (cont.)!

Emergence of pion PDFs



Pion PDFs in Minkowski space



- Pion experimental data is parameterized and then evolved down to hadronic scale, as is lattice calculation.
- Evolved analysis favors Continuum Schwinger Methods (CSM) results.

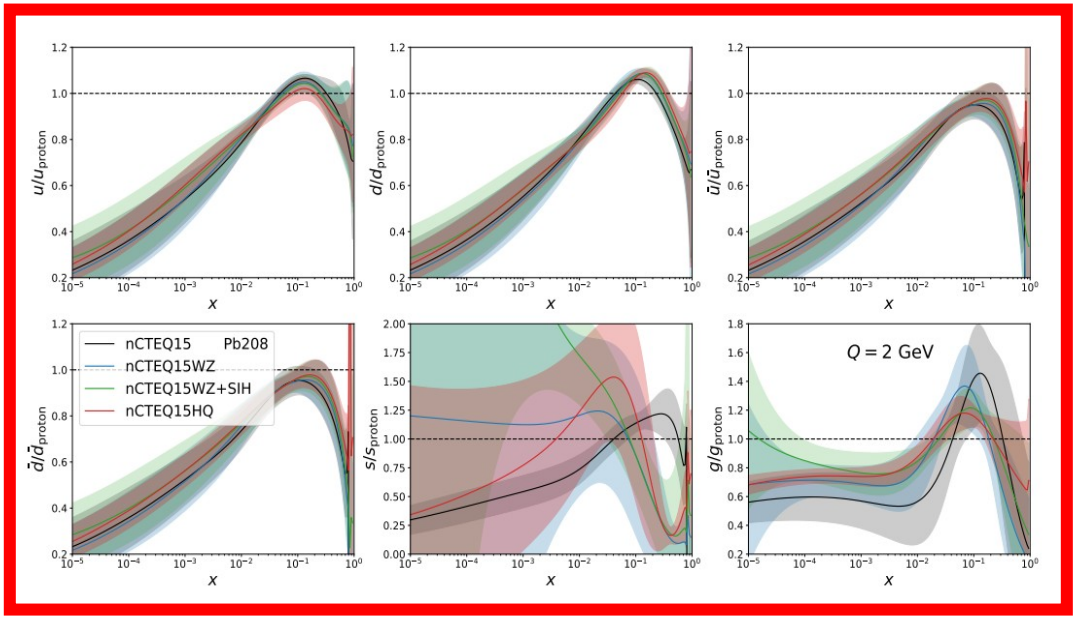
- Constructed 3D image of pion in configuration space.
- Valence probability is on the order of 70% -- beyond valence contributions are important.

Nuclear PDF analyses

- nCTEQ – **Pit Duwentaster & Khoirul Faiq Muzakka**
  - Global analyses including HQ and Quarkonium data or neutrino DIS data
- EPPS21 – **Petja Paakkinen**
  - New fit including LHC and JLab data
- TUJU21 – **Ilkka Helenius**
  - Update of TUJU19 to include EW-boson production in LHC
- nNNPDF3.0 – **Tommaso Giani**
  - Modification of parton structure in heavy nuclei
- KP Model – **Roberto Petti**
  - Modification of bound nucleons at high-x
- Short Range Correlations (SRC) based fit – **Alexander Kusina**
  - New fit using simple SRC modelled fit of nPDFs

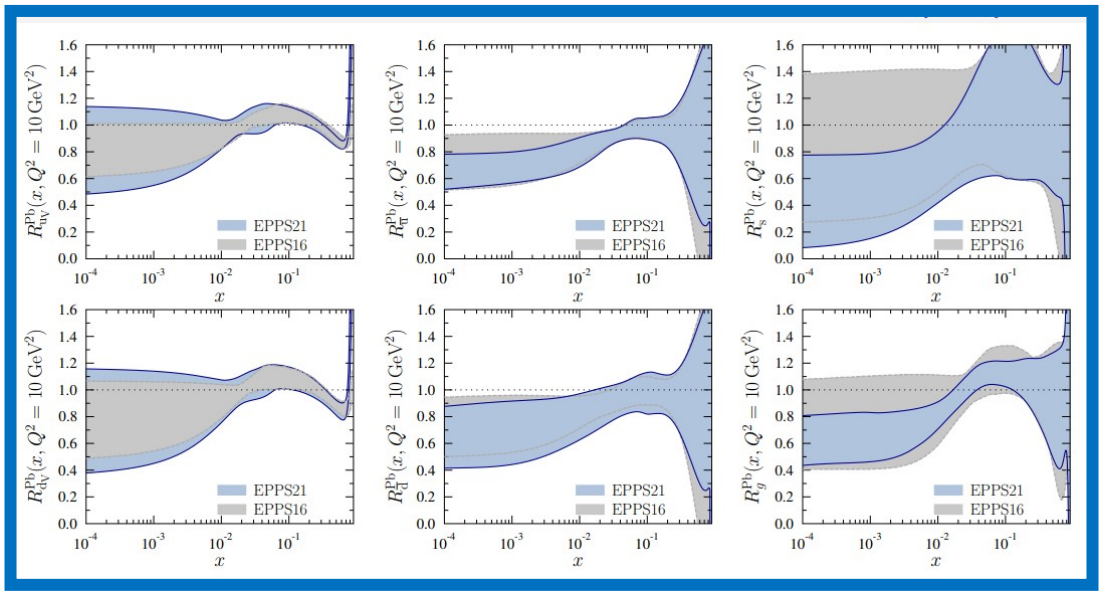
New constraints on nPDFs!

nCTEQ15HQ PDFs



- Strong new constraints on the gluon PDF, particularly at low x
- Additional fits with neutrino DIS performed to constrain strange quark uncertainty

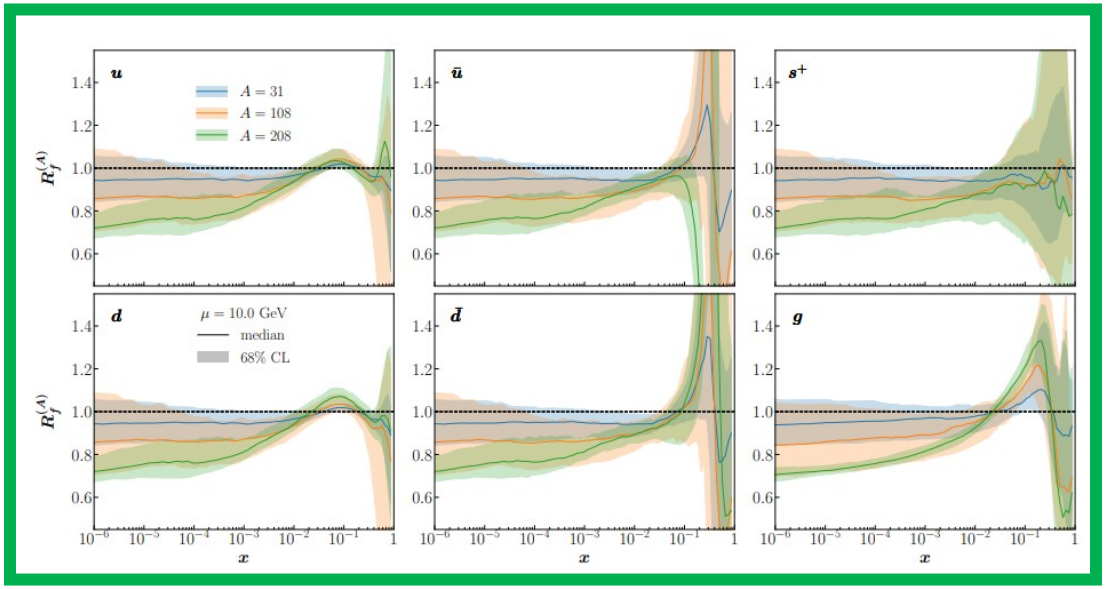
EPPS21



- Fit includes new nuclear data from LHC and JLab
- Strong constraints on gluon modification for in lead nucleus. Better control of gluon (anti-)shadowing

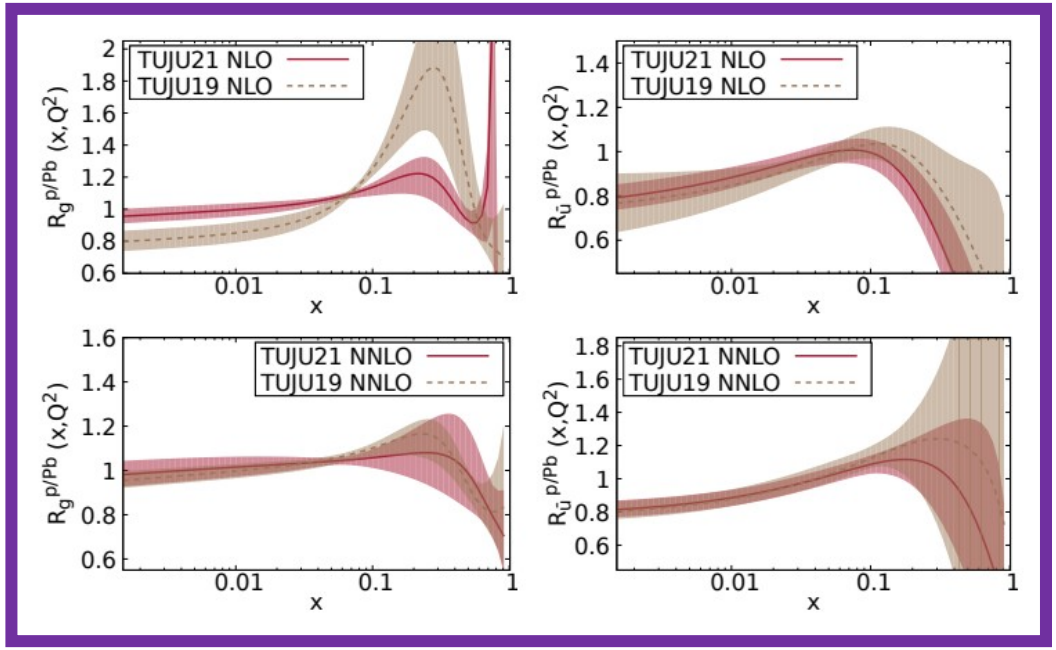
New constraints on nPDFs!

nNNPDF3.0 Fit



- Coverage on small-x and high Q2 regions from D-meson and di-jets data
- Plan for simultaneous fit of proton and nuclear PDFs

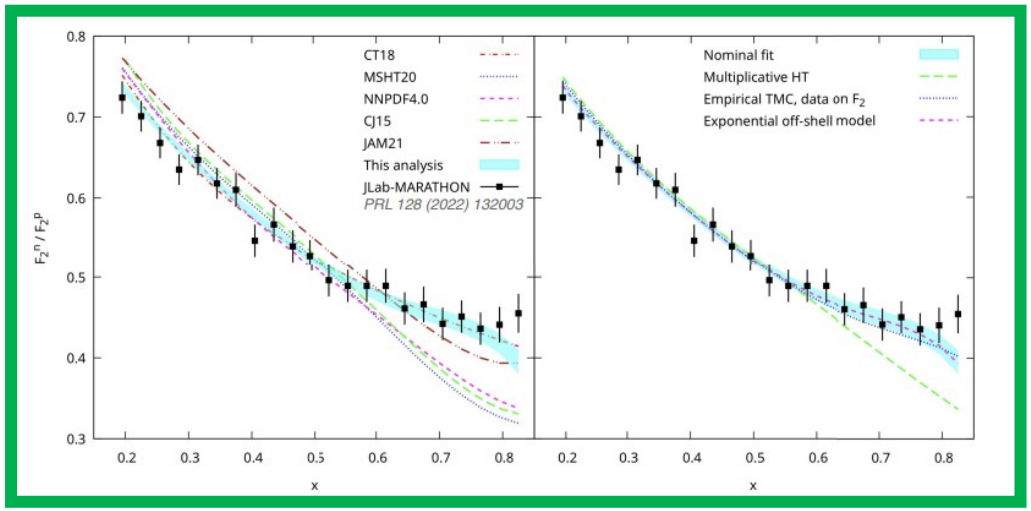
TUJU21



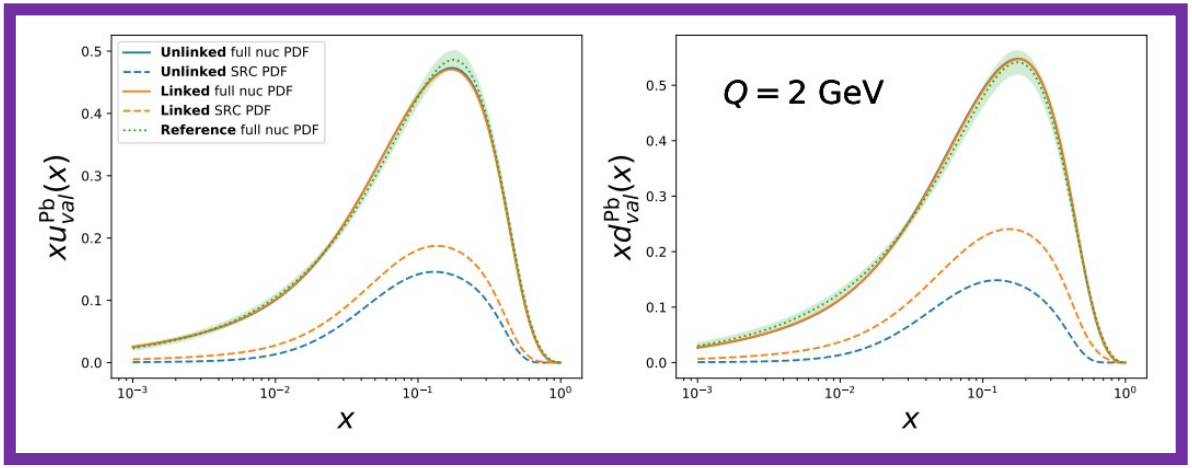
- Fits at NLO and NNLO
- NNLO corrections improve description of the LHC EW-boson data

High-x and new SRC model!

KP model comparison to MARATHON data



Short Range Correlations (SRC)-Based Model



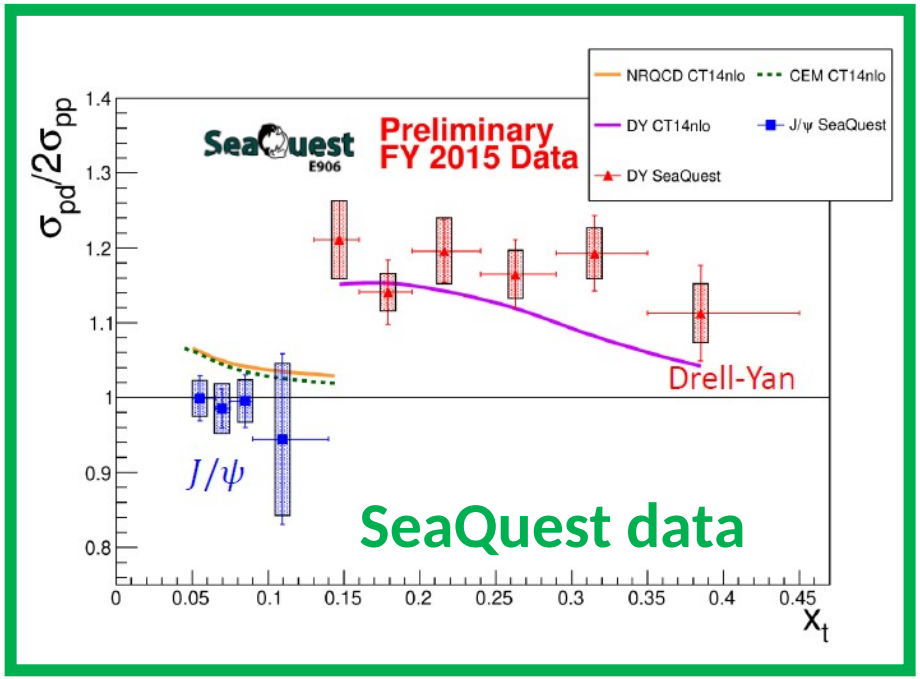
- Focus on modification at high-x (>0.1)
- Model agrees well with recent MARATHON structure function ratio data. Data is sensitive to HT effects for x>0.6

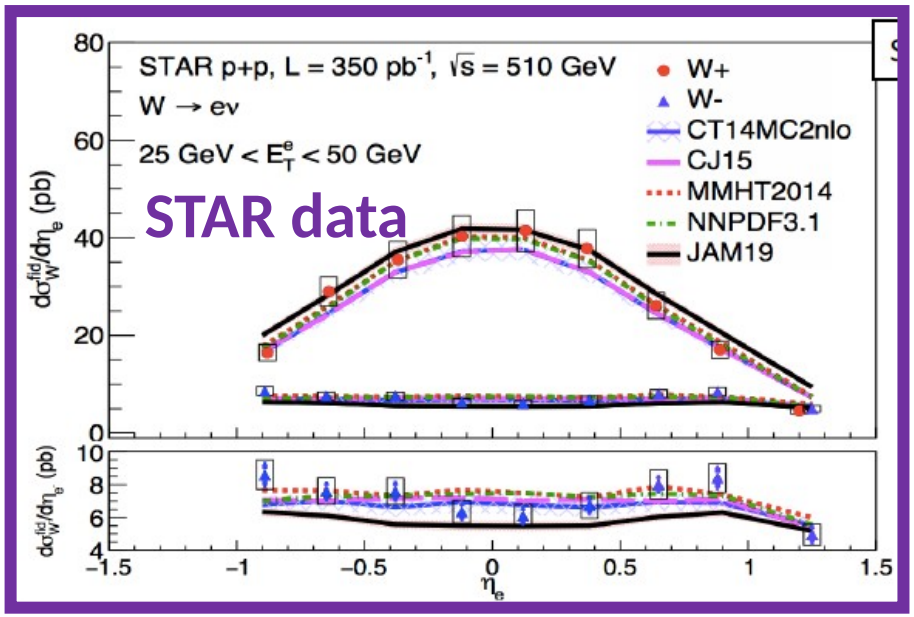
- Simple SRC-based picture of nPDFs leads to comparable or better data description than the traditional nPDF parameterization

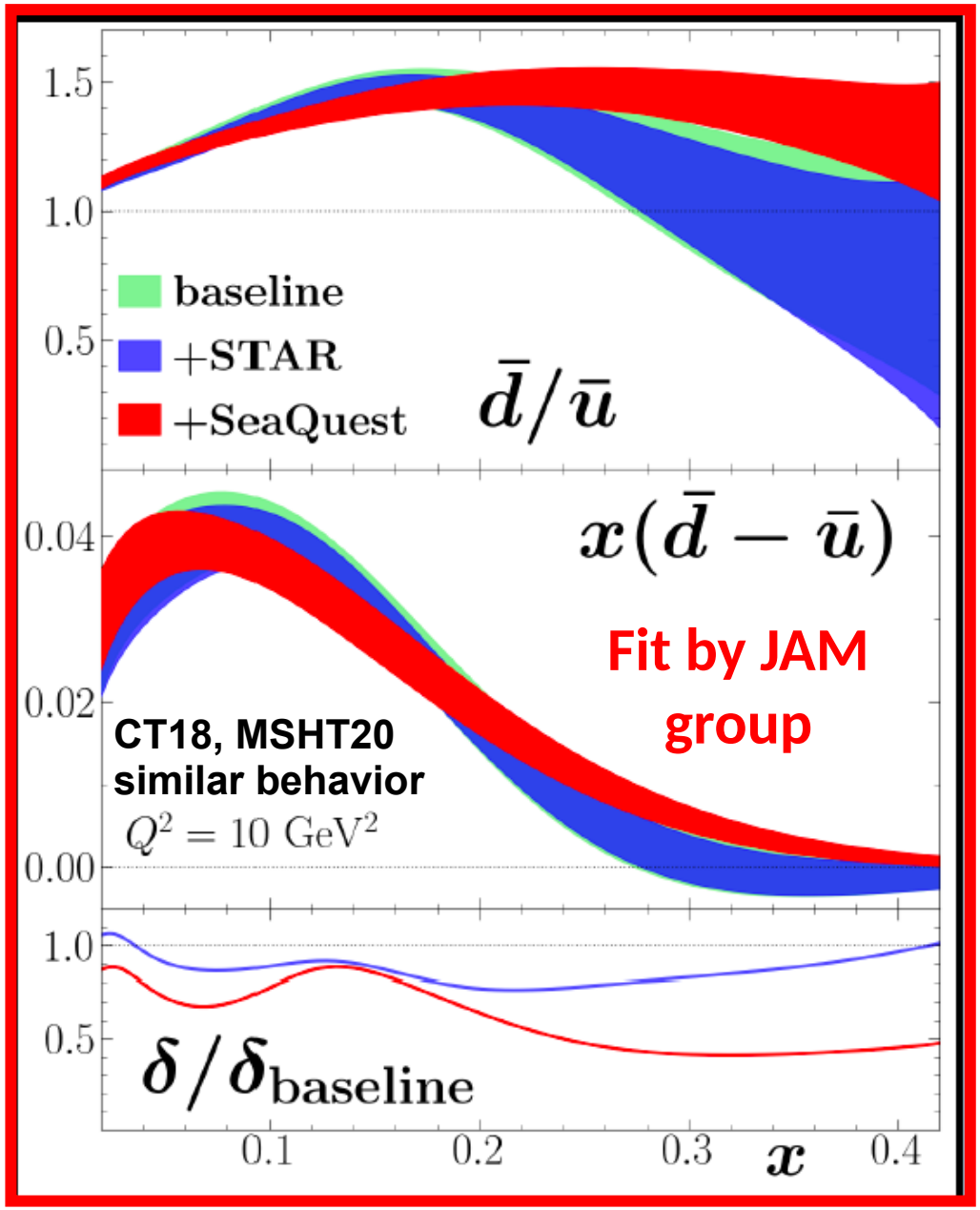
JLAB, SeaQuest, STAR & ZEUS

- JLab neutron-tagged DIS– **Efrain Segarra**
  - New results from the CLAS12+BAND detectors
- Fermilab SeaQuest– **Ching Him Leung**
  - New measurement of charmonium production
- STAR – **Jae D. Nam**
  - W^+/W^- cross-section ratios in pp collisions
- JAM – **Chris Cocuzza**
  - Extraction of Sea asymmetry with SeaQuest and STAR data
- New method for ZEUS data – **Allen Caldwell**
  - New technique to use high-x ZEUS data in PDF fits

Cross-section ratios – data and fits!

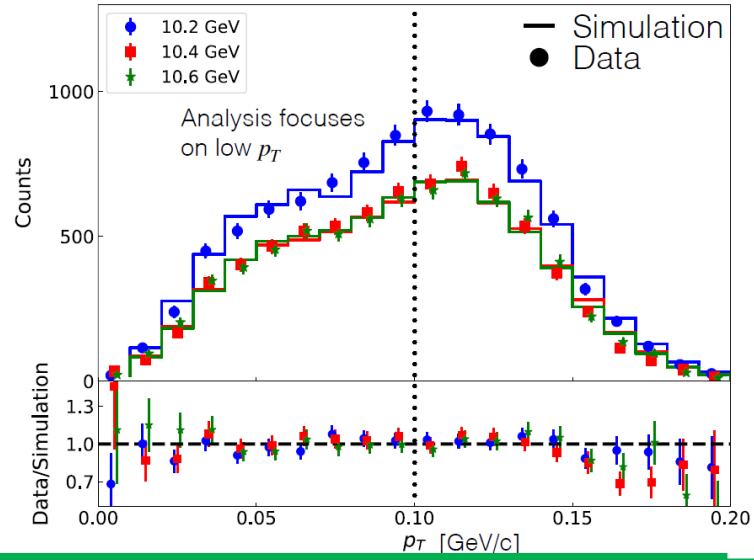


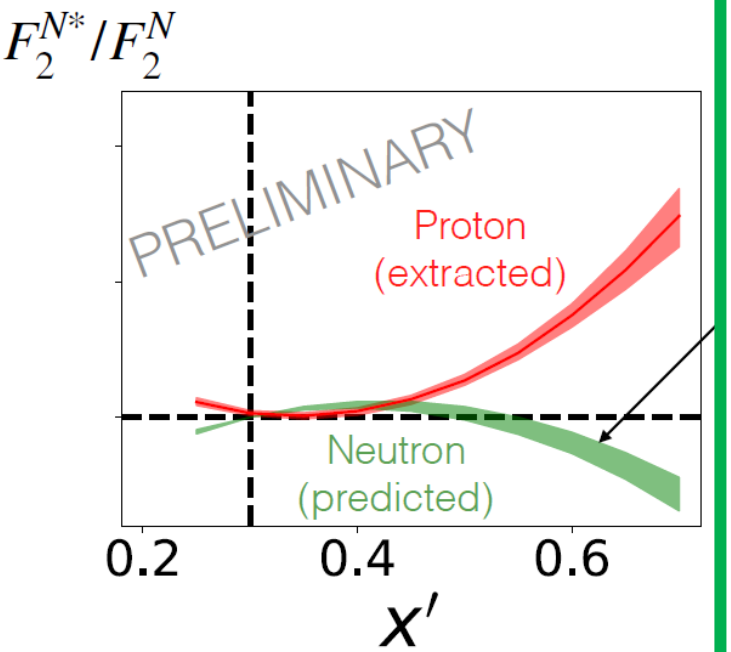




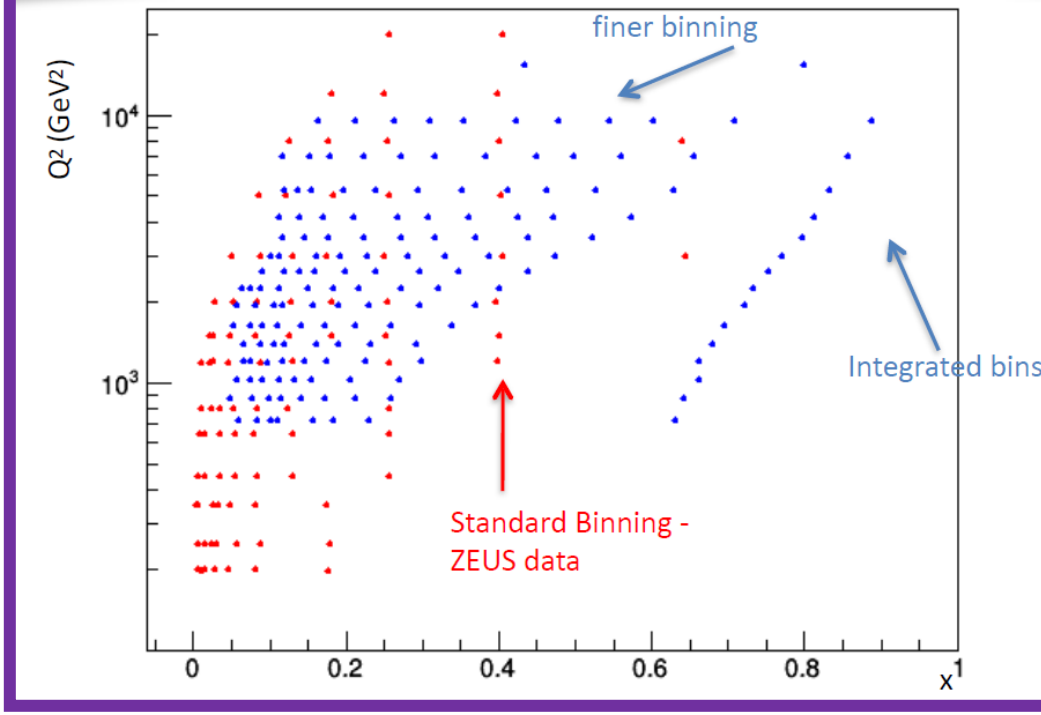
High-x electron DIS!

Spectator tagging d(e, e′n)X with BAND





New method – forward modeling for PDF extraction



expected counts at generator level

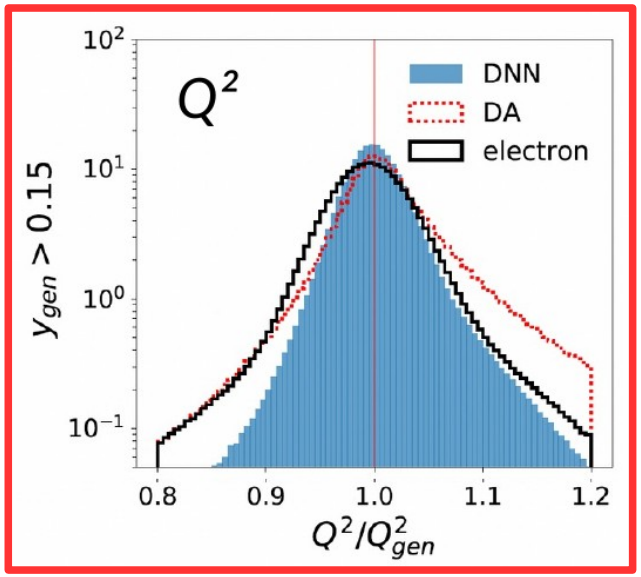
$$\nu_j = (1 + 0.018 \cdot \beta_0^{+-}) \left[\sum_i \nu_i \cdot (a_{ij} + \sum_k \beta_k \delta_{ij}^k) \right]$$

normalization uncertainty — transfer matrix — systematic variations

$\beta's$ are Unit Normal distributed nuisance parameters

New (and old) tools

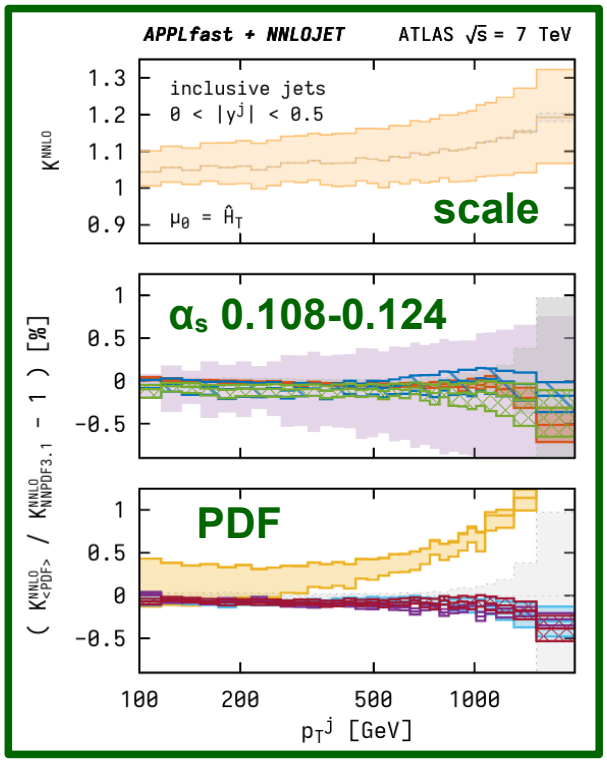
DeepNeuralNetworks for DIS kinematics



Better resolutions in Q^2 (and y, x) than standard electron or DA

D.Britzger

APPLfast pp jet grids at NNLO coming in



NNLO K factor dependence on: $\mu_{R/F}$, α_s, PDFs

K. Rabbertz

QCD fit framework: Brand new release!

More modular
Better user interface

F. Giuli

Tools for DGLAP and DIS coefficients

F. Hekhorn

EKO Evolution Kernel Operators

Yadism — Yet Another DIS Module

Part of new theory prediction pipeline

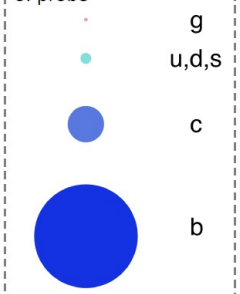
Future Experiments

- sPHENIX – **John Lajoie**
  - Overview of the upcoming sPHENIX experiment
- Top quarks at HL-LHC – **Giancarlo Panizzo**
  - Prospect for four-top-quark cross section with ATLAS
- Neutrinos and the EIC – **Joint WG1+6 session**
  - See WG6 summary talk

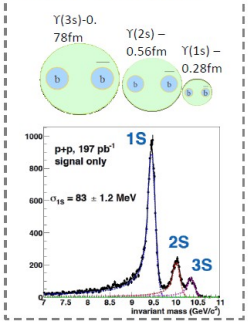
Future Experiments

sPHENIX

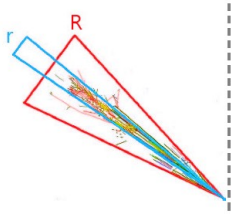
Parton energy loss
Vary mass/momentum of probe



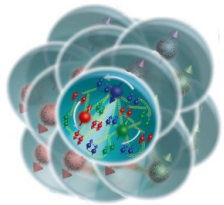
Upsilon spectroscopy
Vary size of the probe

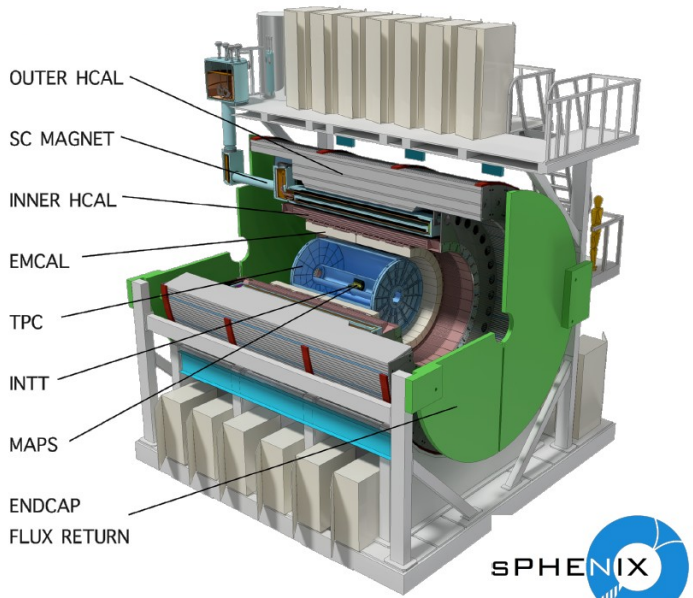


Jet cor. & substructure
Vary momentum/angular size of probe

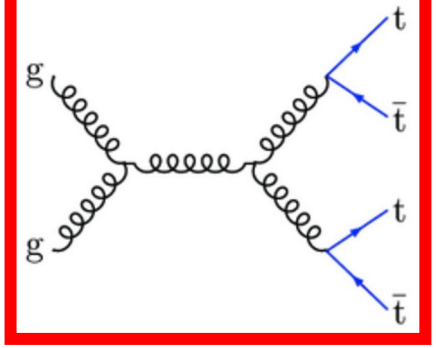


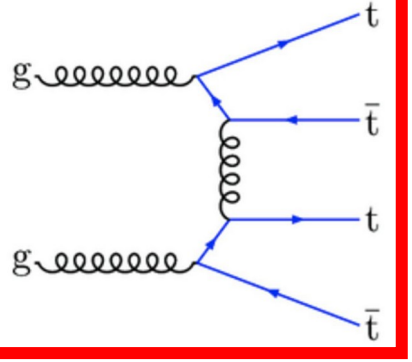
Cold QCD
Spin-orbit correlations in the nucleon
CNM effects and hadronization

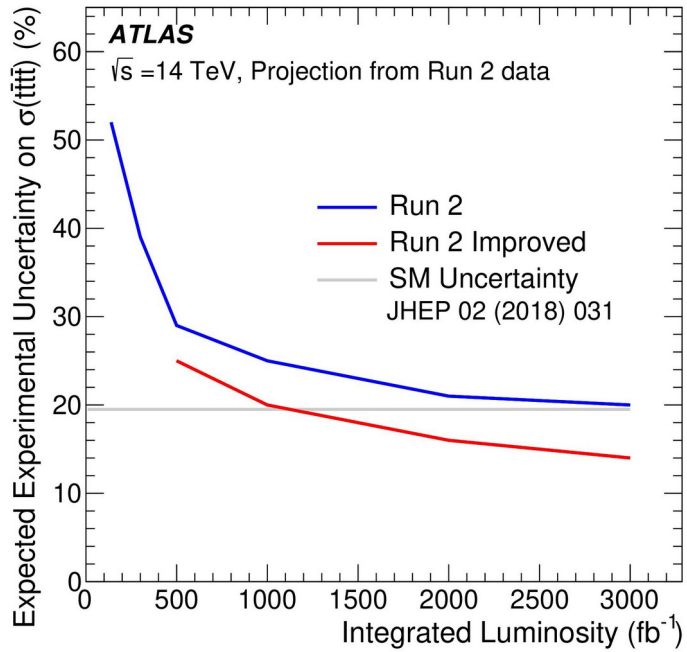




Top quarks at HL-LHC







WG1 Summary

Big thanks to organisers, speakers and all those involved!