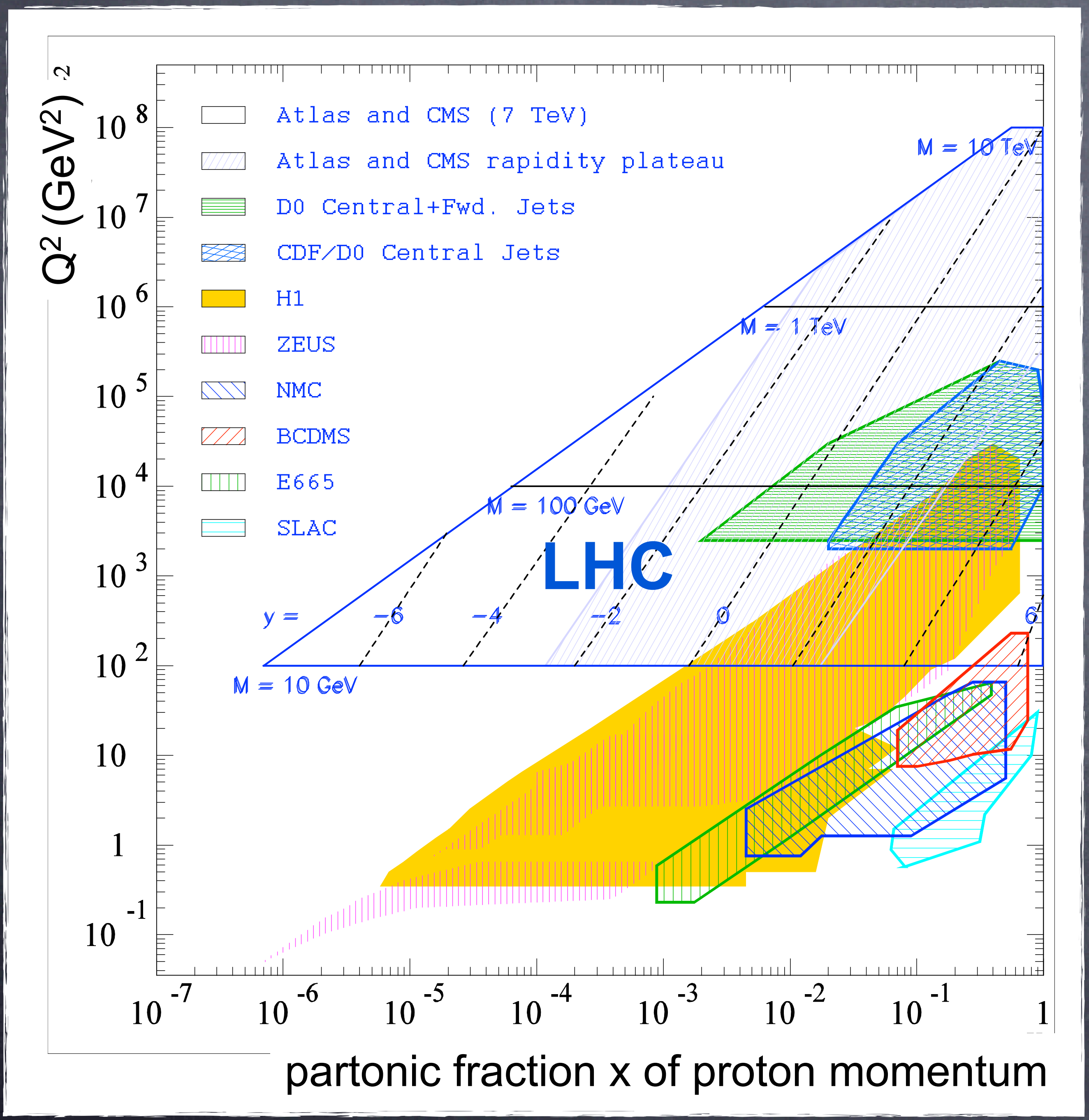
CMS Investigations on Parton Distribution Functions and QCD parameters

Katerina Lipka
on behalf of the CMS Experiment

LHC Monte Carlo Workshop, CERN 2-5 May 2017

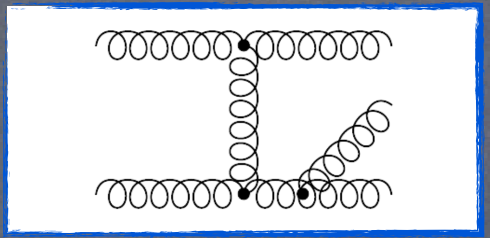
PDF CONSTRAINTS FROM LHC

impact of the LHC measurements:
improvements in quark flavor separation
gluon at low and at high x

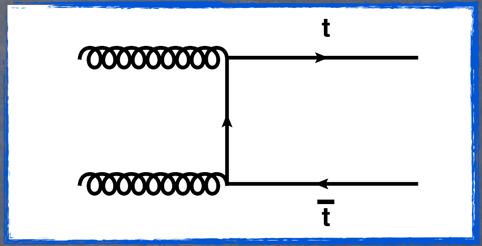


CMS delivers necessary data and
statistic/systematic correlations
many data sets tested in a QCD analysis

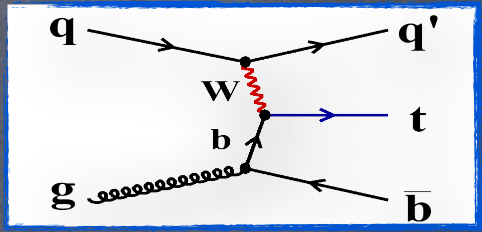
- jets: gluon, α_S
  medium-high x



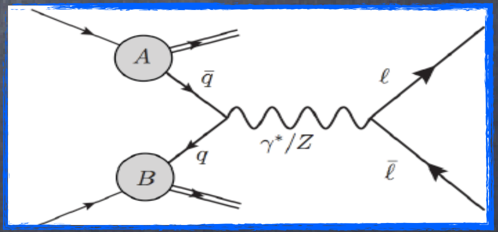
- top-pairs: gluon
  high x



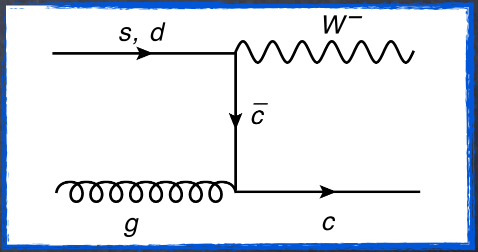
- single top: u, d, b



- DY+J: light quarks,
  flavor separation,
  gluon



- V+HQ: s-quark,
  intrinsic charm

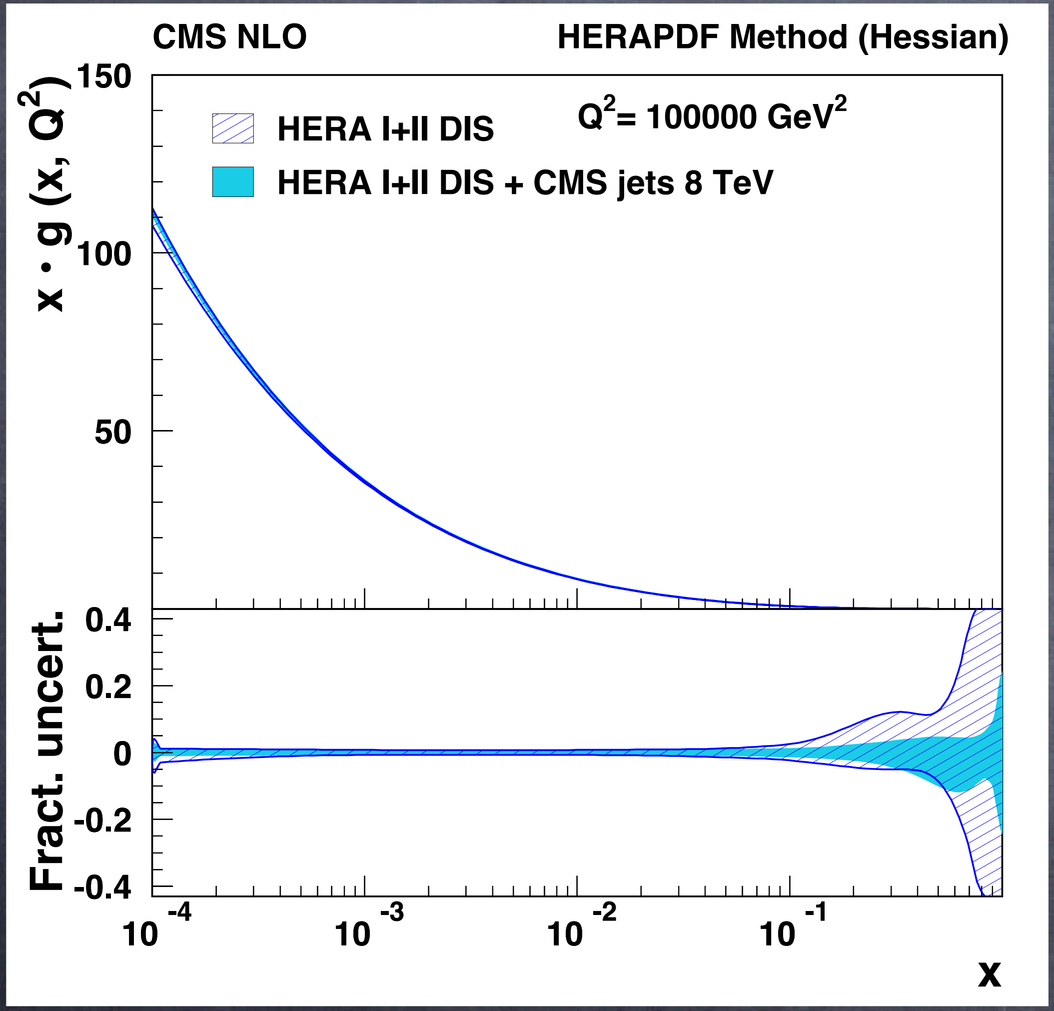


JETS @ CMS: GLUON AND STRONG COUPLING

CMS 8 TeV, $\mathcal{L}$ = 19.7 fb^{-1} inclusive jet production ***arXiv:1609.05331***, *accepted by JHEP*

2-differential cross sections vs of jet p_T and rapidity

Constraints on PDFs and α_S : QCD analysis at NLO using herafitter 1.1.1



simultaneous fit with PDFs:

$$\alpha_s(M_Z) = 0.1185^{+0.0019}_{-0.0026}(PDF)^{+0.0022}_{-0.0018}(scale)$$

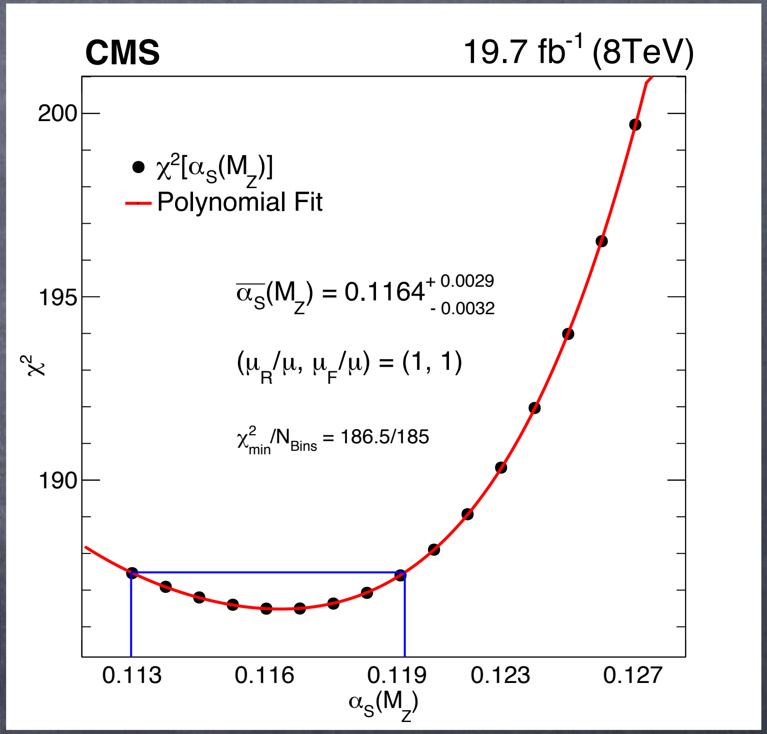
using fixed PDFs:

CT10NLO

$$\alpha_s(M_Z) = 0.1164^{+0.0060}_{-0.0043}$$

NNPDF3.0 NLO

$$\alpha_s(M_Z) = 0.1172^{+0.0083}_{-0.0075}$$



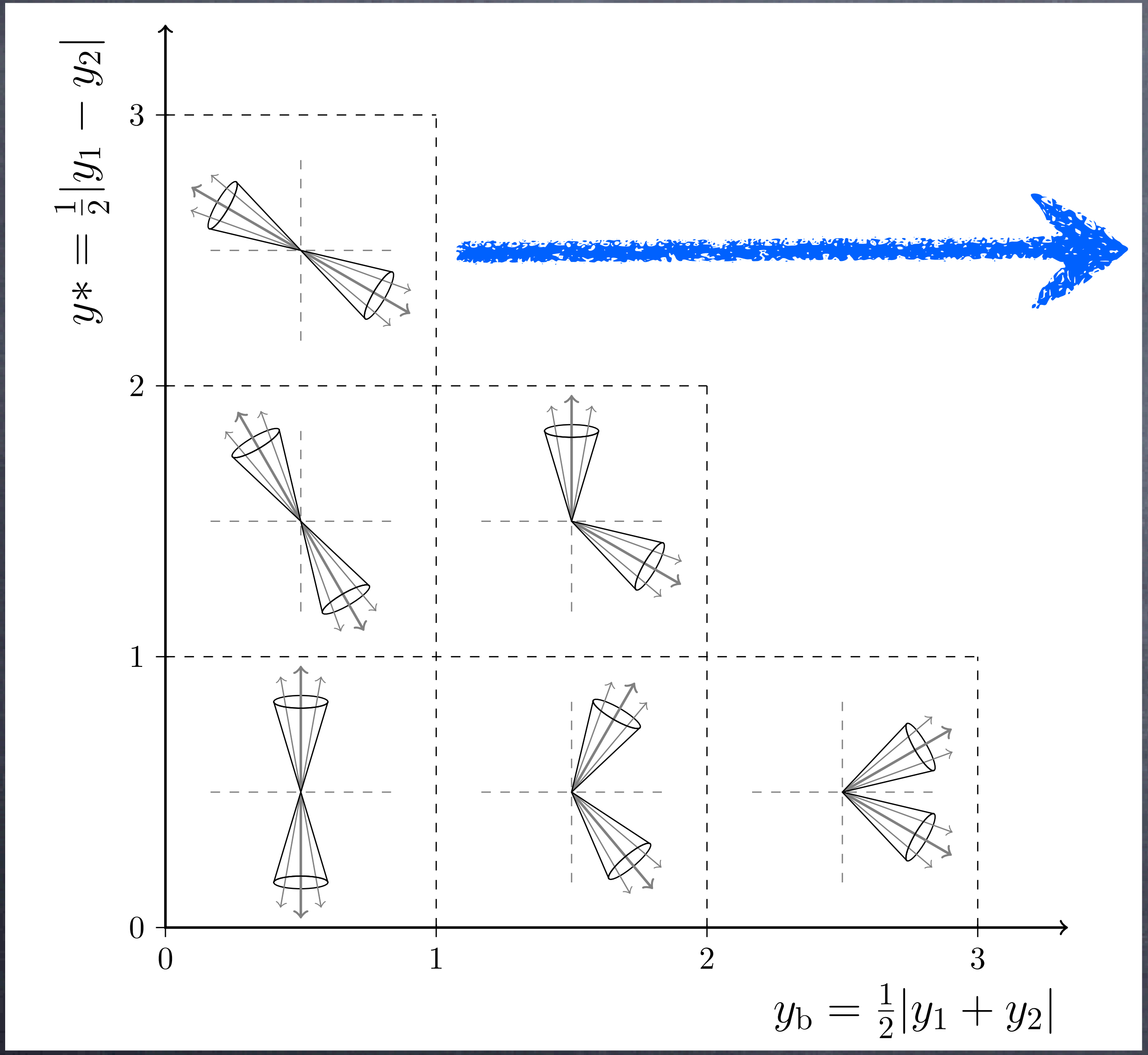
Significant impact on the gluon distribution, α_S consistent with world average, dominant uncertainty emerges from the variations of the scales

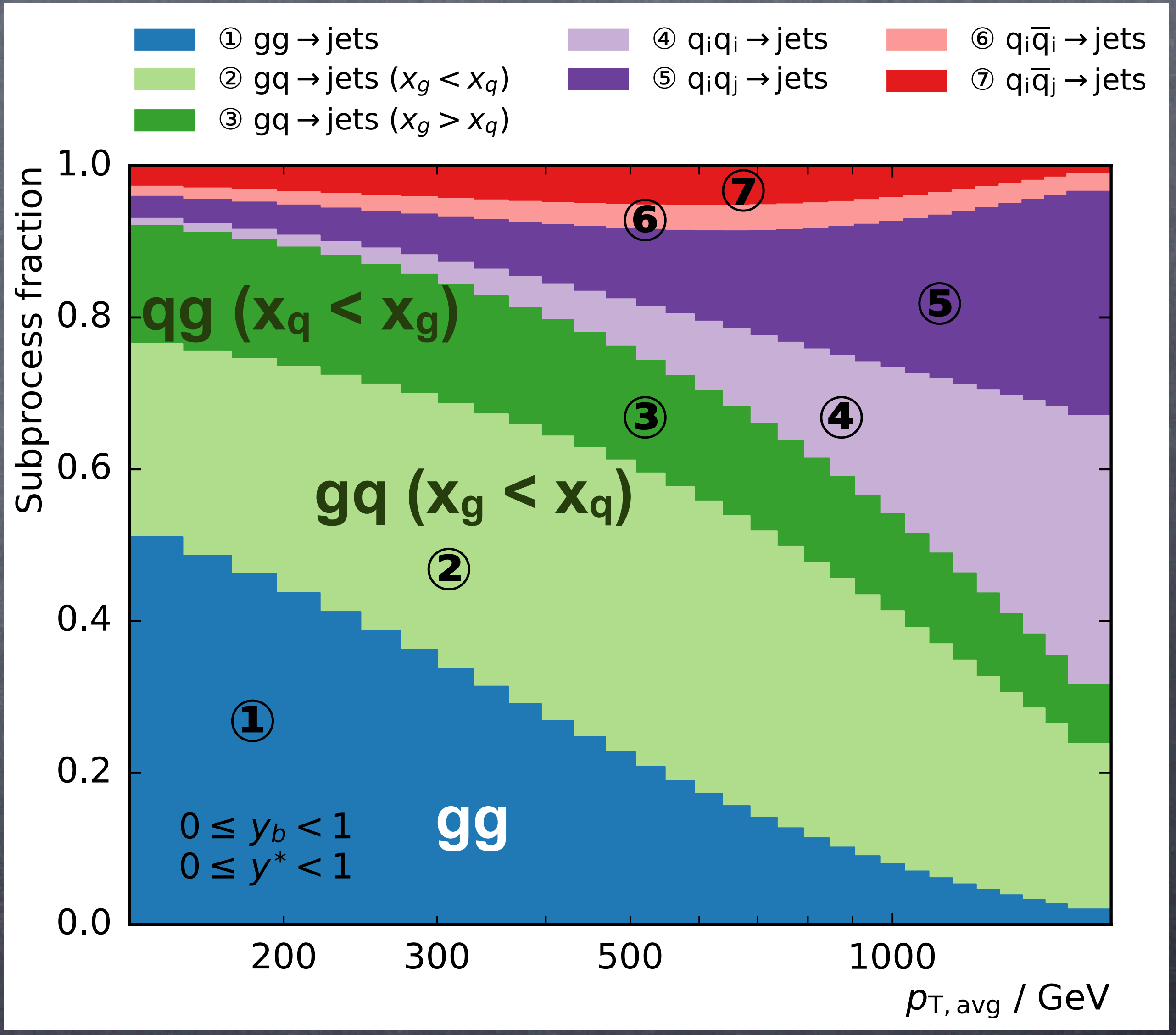
JETS @ CMS: GLUON AND STRONG COUPLING

CMS 8 TeV, $\mathcal{L}$ = 19.7 fb^{-1} dijet production: CMS-PAS-SMP-16-011

3-differential cross sections vs of jet average p_T, rapidity separation and boost

Probing x_1 and x_2 using different event topologies





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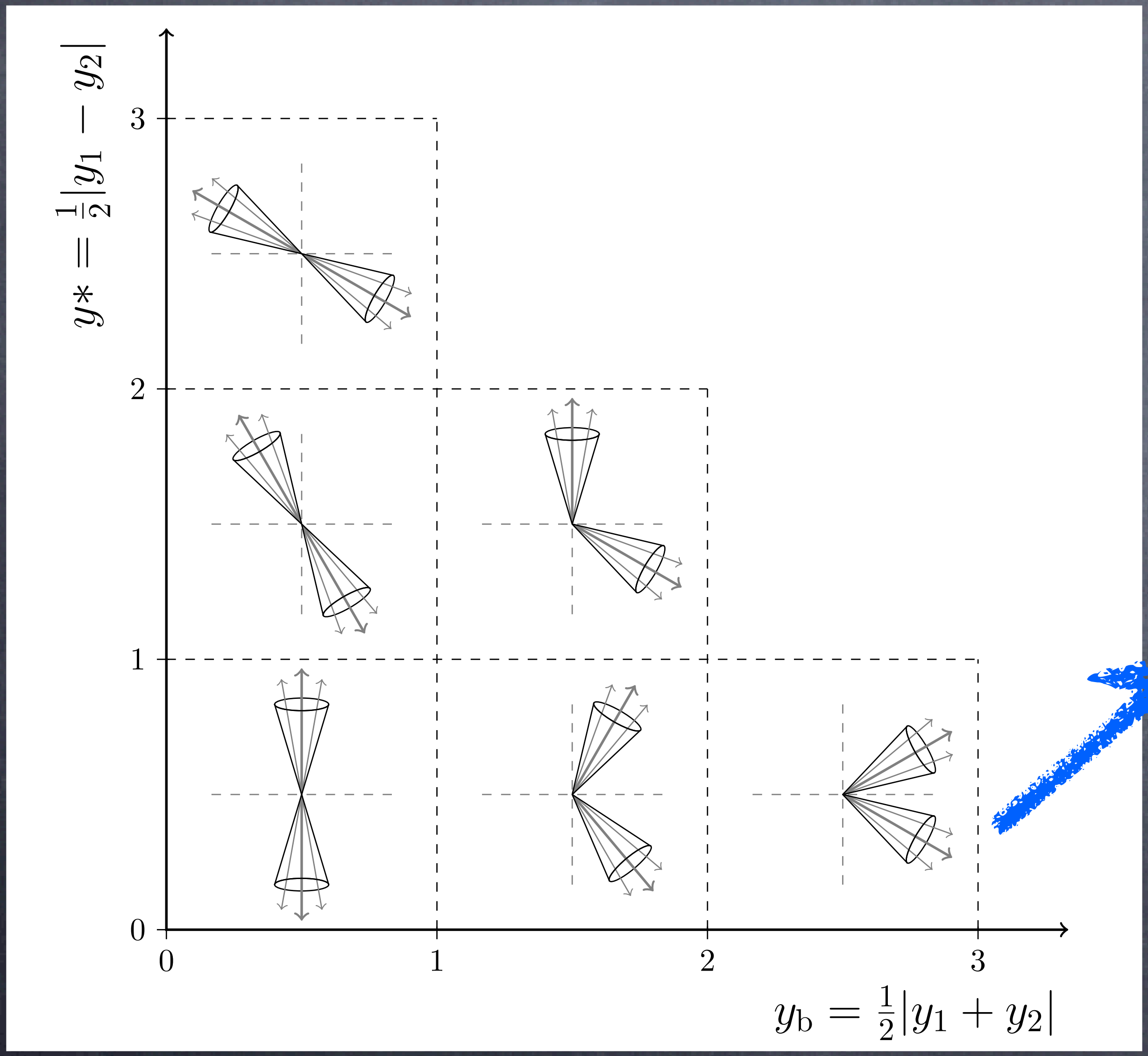

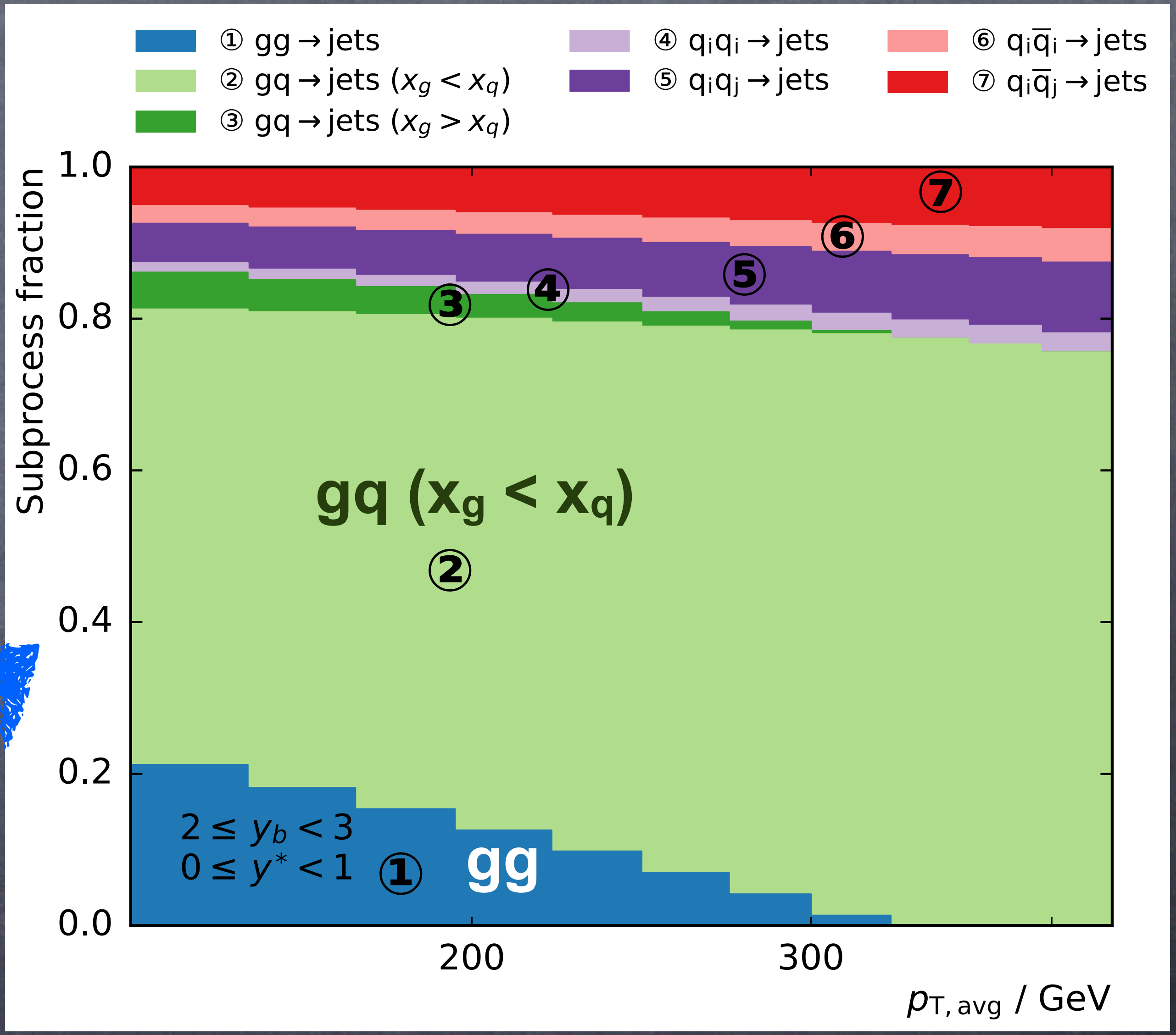

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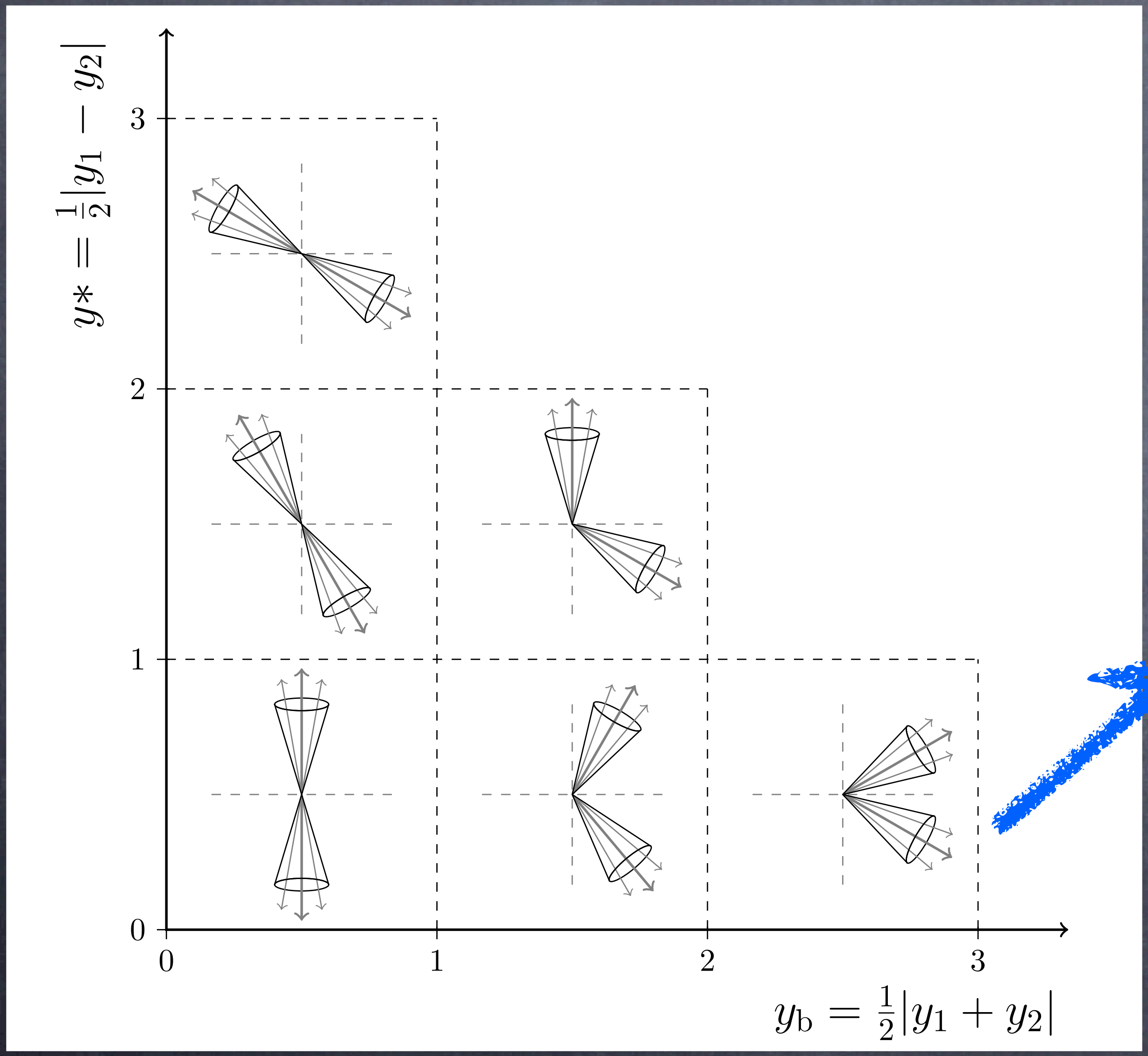
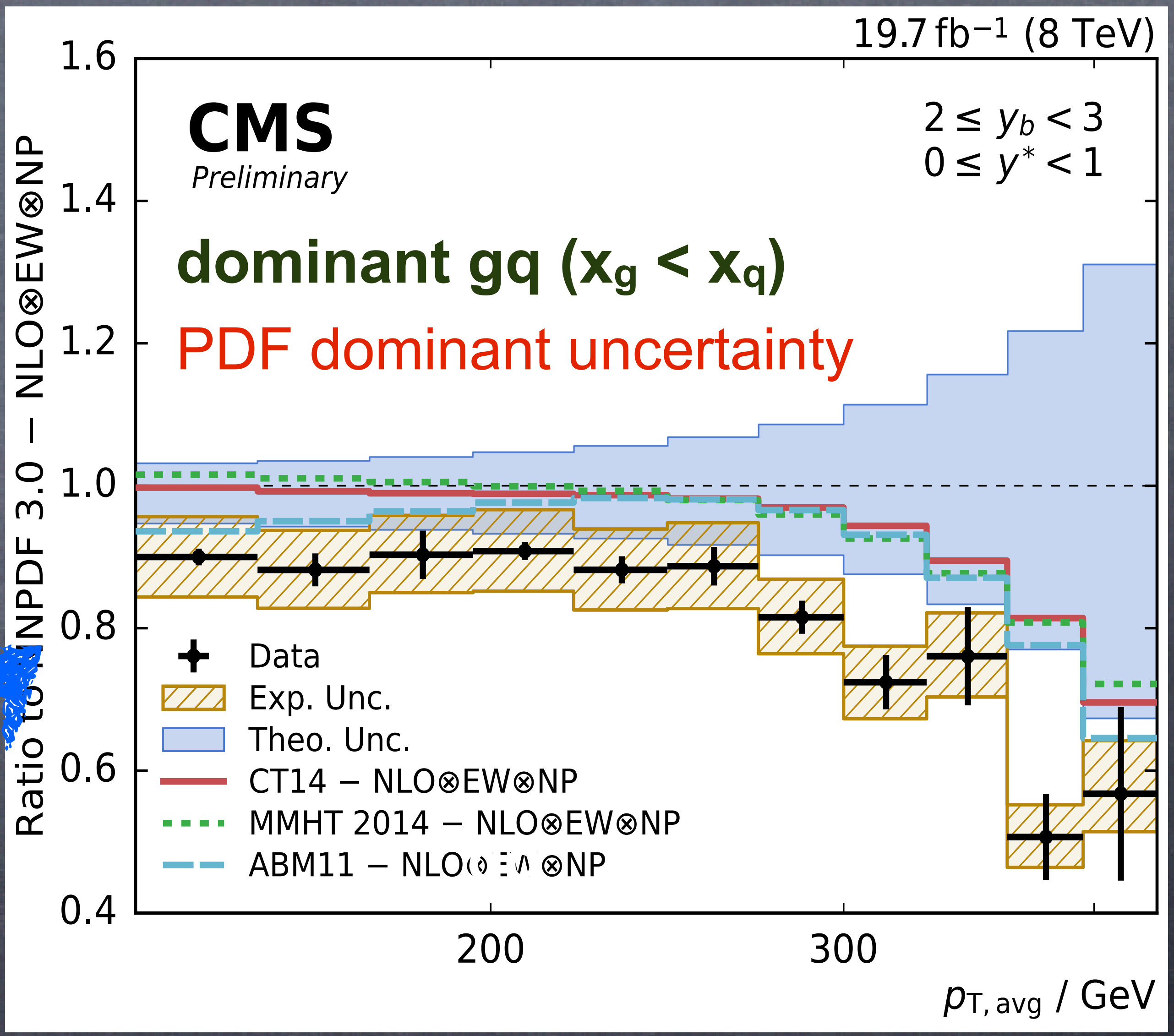
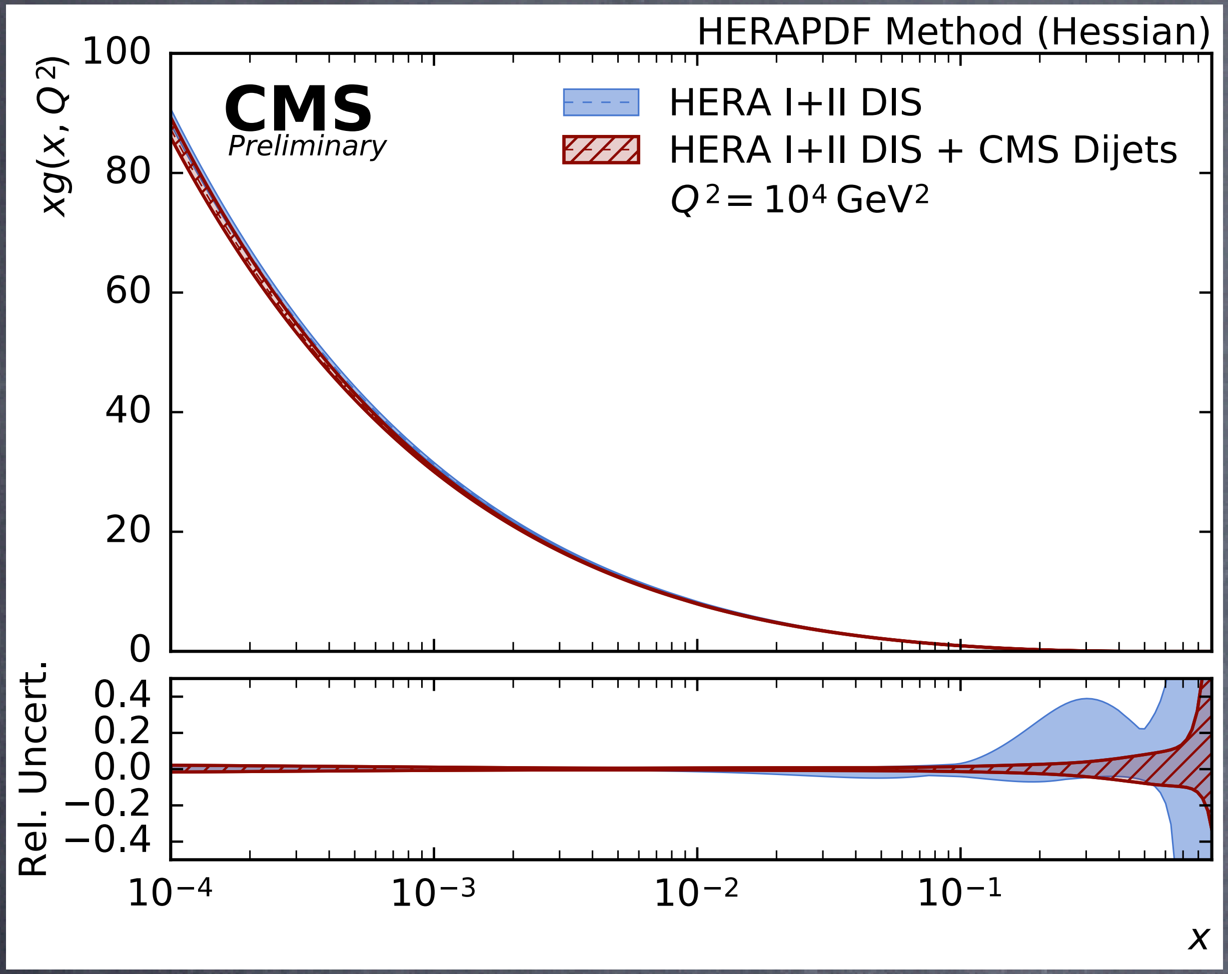
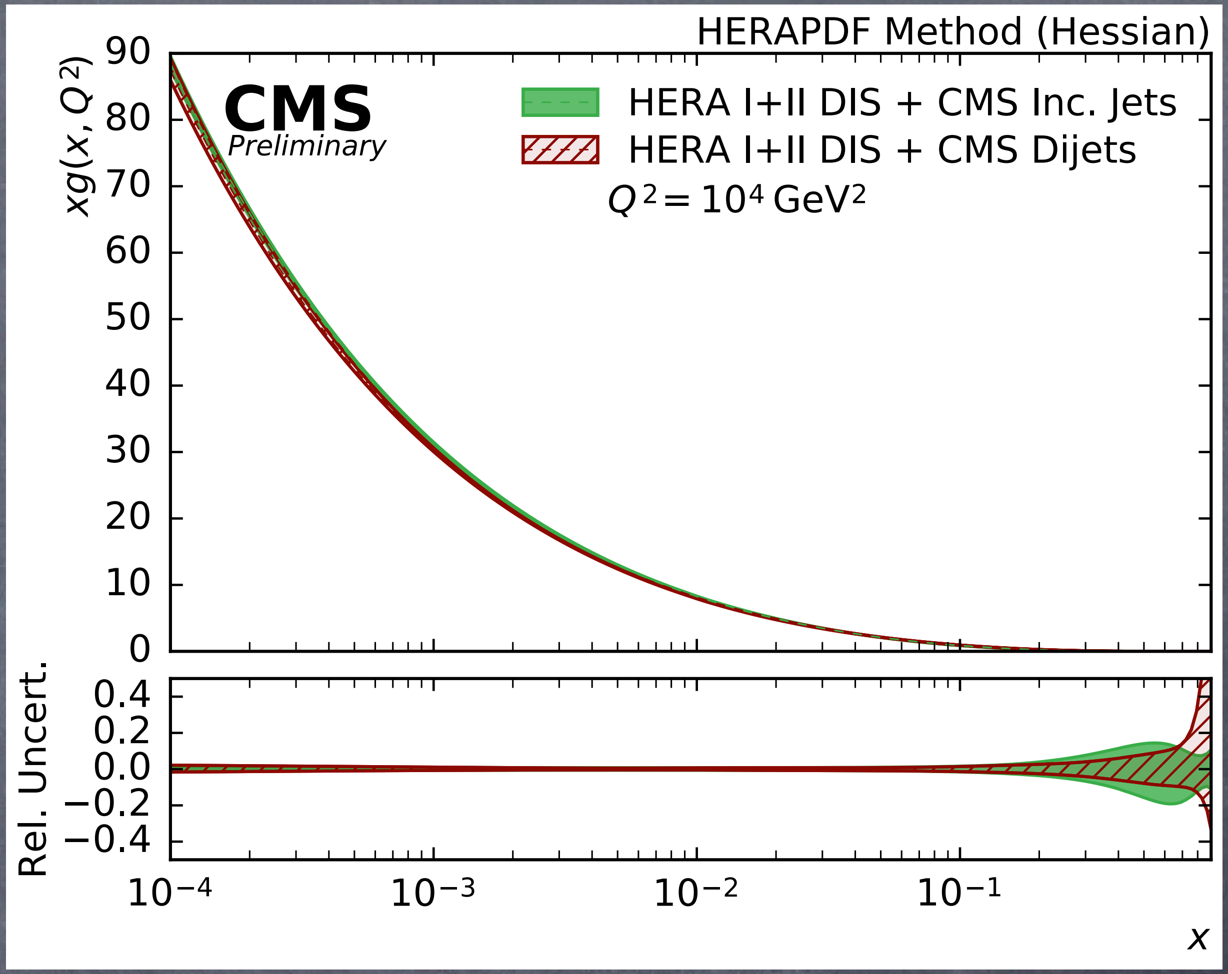




JETS @ CMS: GLUON AND STRONG COUPLING

By using dijet cross section in the QCD analysis in addition to HERA data...





- **change in the gluon shape** **similar as observed in the case of inclusive jet data**
- **significant reduction of the uncertainty in g(x) at high x**

similar to inclusive jet data (note different parametrisation)

- **strong coupling determined simultaneously with PDFs:**

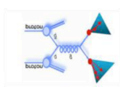
$$\alpha_s(M_Z) = 0.1199^{+0.0015}_{-0.0016}(PDF)^{+0.0026}_{-0.0016}(scale)$$

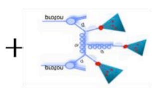
JETS @ CMS: GLUON AND STRONG COUPLING

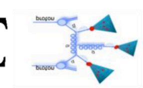
CMS 8 TeV, $\mathcal{L}$ = 19.7 fb^{-1} multi-jet production CMS-PAS-SMP-16-008

Ratio of 3/2 inclusive jet cross sections

$$R_{32} = \frac{\sigma_3}{\sigma_2} = \frac{\sigma_{pp\to n\ jets+X;\, n\geq 3}}{\sigma_{pp\to n\ jets+X;\, n\geq 2}} = \frac{\sum \text{[diagram]} + \text{[diagram]} + \cdots}{\sum \text{[diagram]} + \cdots} \sim \alpha_S$$

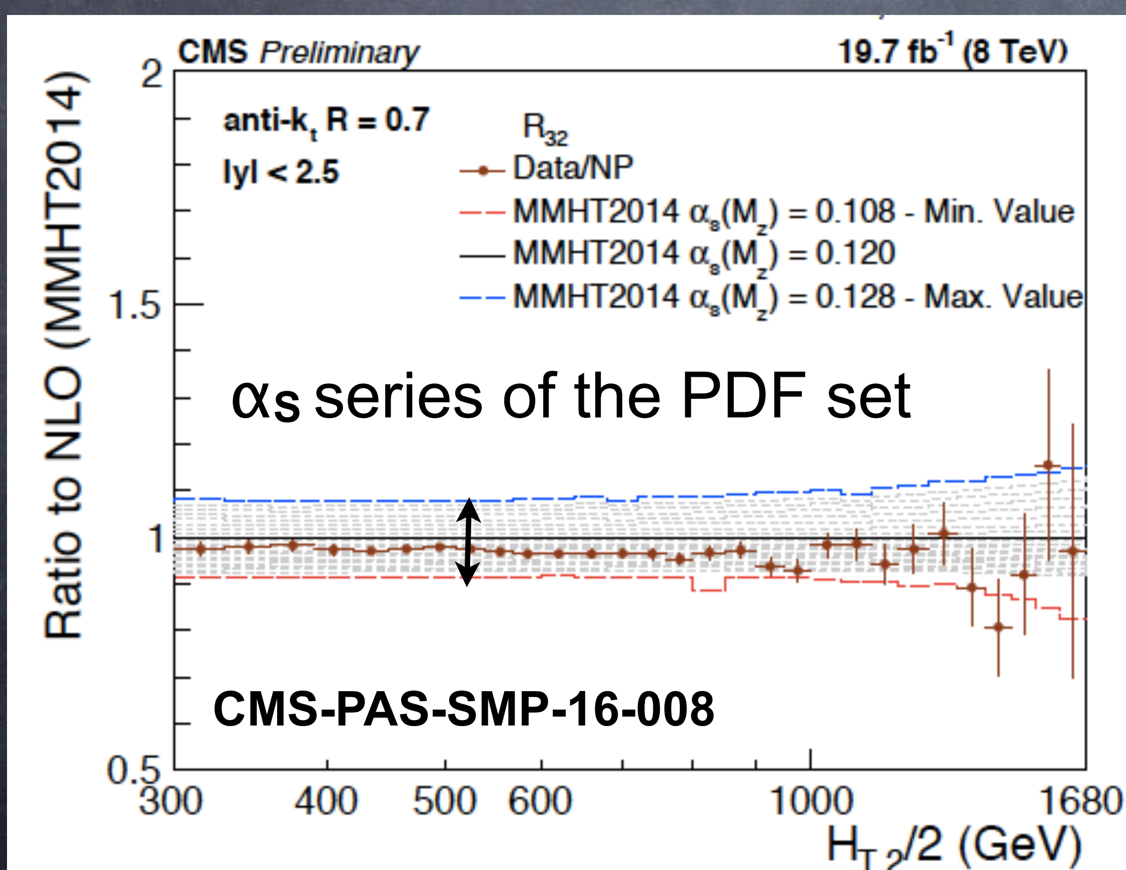






Theory: NLOJet++ via FastNLO, corrected for MPI, NP and EWK (2-jet);

scales $\mu_r=\mu_f=H_{T,2}/2=\frac{1}{2}(p_{T1} + p_{T2})$, varied independently by a factor of 2; different NLO PDF sets



MMHT14: χ^2/n_{dof} =24/28

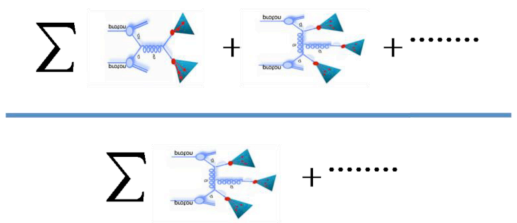
$$\alpha_S(M_Z) = 0.1142 \pm 0.0010(exp) \pm 0.0013(PDF)$$
$$\pm 0.0014(NP)^{+0.0049}_{-0.0006}(scale)$$

JETS @ CMS: GLUON AND STRONG COUPLING

CMS 8 TeV, $\mathcal{L}$ = 19.7 fb^{-1} multi-jet production CMS-PAS-SMP-16-008

Ratio of 3/2 inclusive jet cross sections

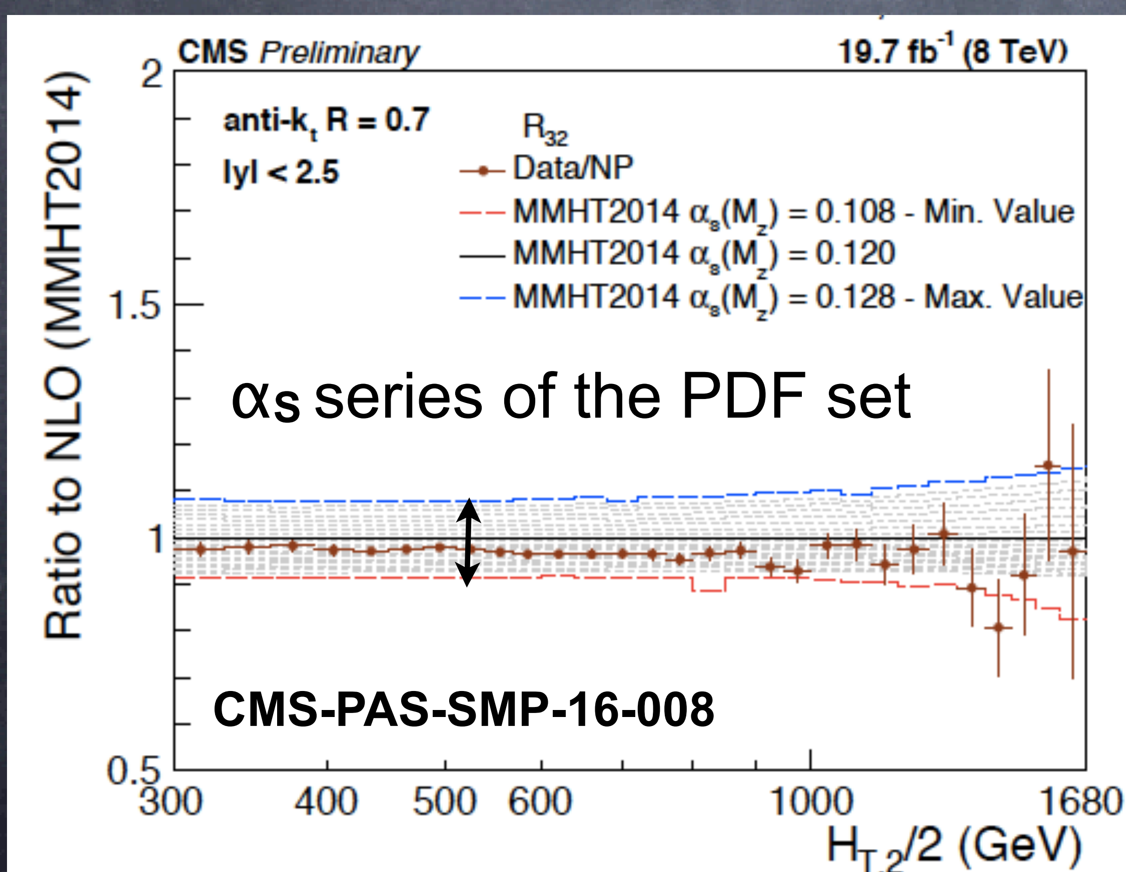
$$R_{32} = \frac{\sigma_3}{\sigma_2} = \frac{\sigma_{pp\to n\ jets+X;\, n\geq 3}}{\sigma_{pp\to n\ jets+X;\, n\geq 2}} = $$

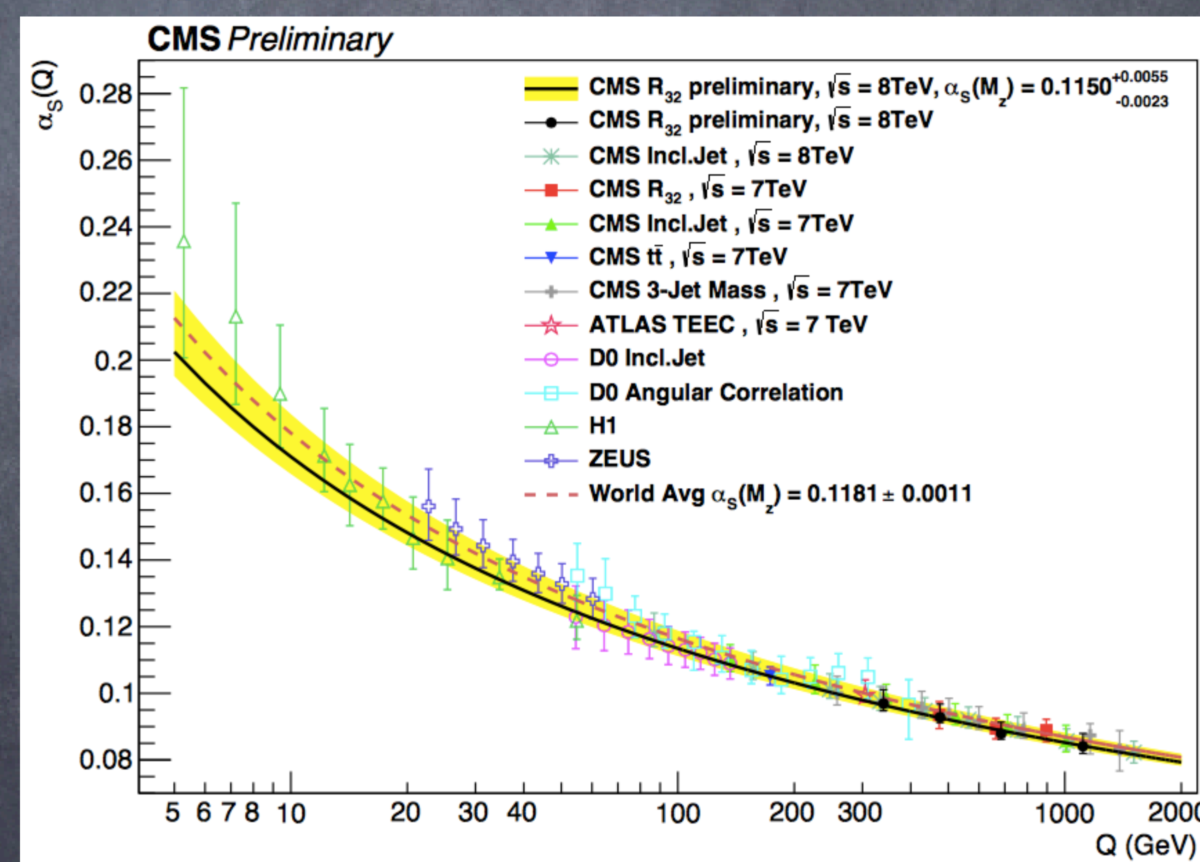


$\sim \alpha_S$

Advantage of R_{32} : partial or full cancellation or reduction of experimental uncertainties, theory uncertainties due to NP effects, PDFs, scale choice, EWK corrections

$\alpha_S(M_Z)$ value for each $H_{T,2}/2$ range $\rightarrow$ $\alpha_S(Q)$

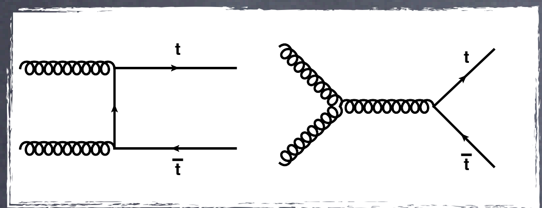




Evolution performed for N_f = 5 at 2-loops

$t\bar{t}$ @ CMS: GLUON DISTRIBUTION AT HIGH X

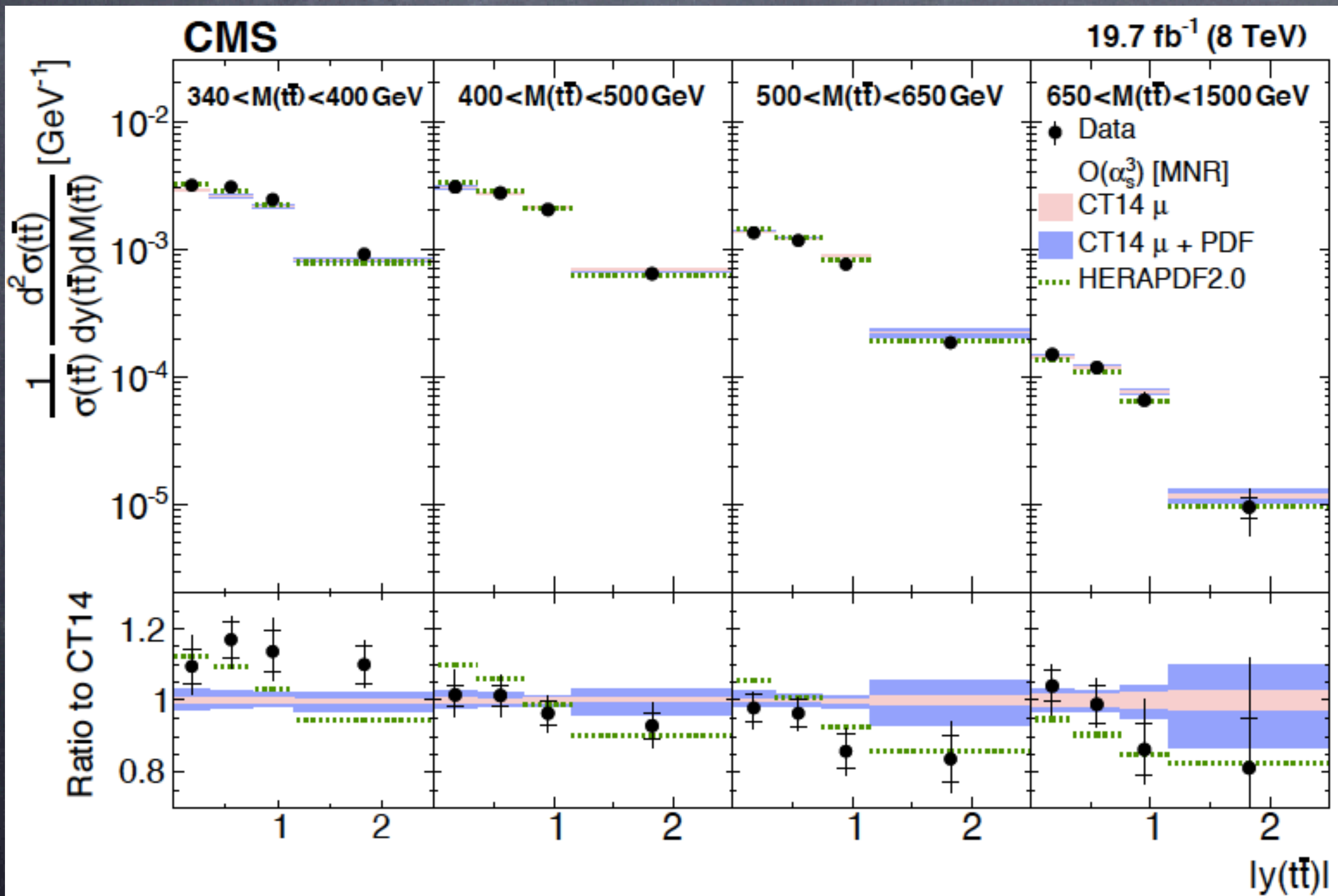
In pp collisions top-quark pairs are produced via gg fusion probing gluon at high x



CMS 8 TeV, $\mathcal{L}$ = 19.7 fb^{-1} :

For the first time 2d-differential $t\bar{t}$ cross sections used for g(x)

arXiv:1703.01630



M(tt) and y(tt)

most sensitive to PDFs

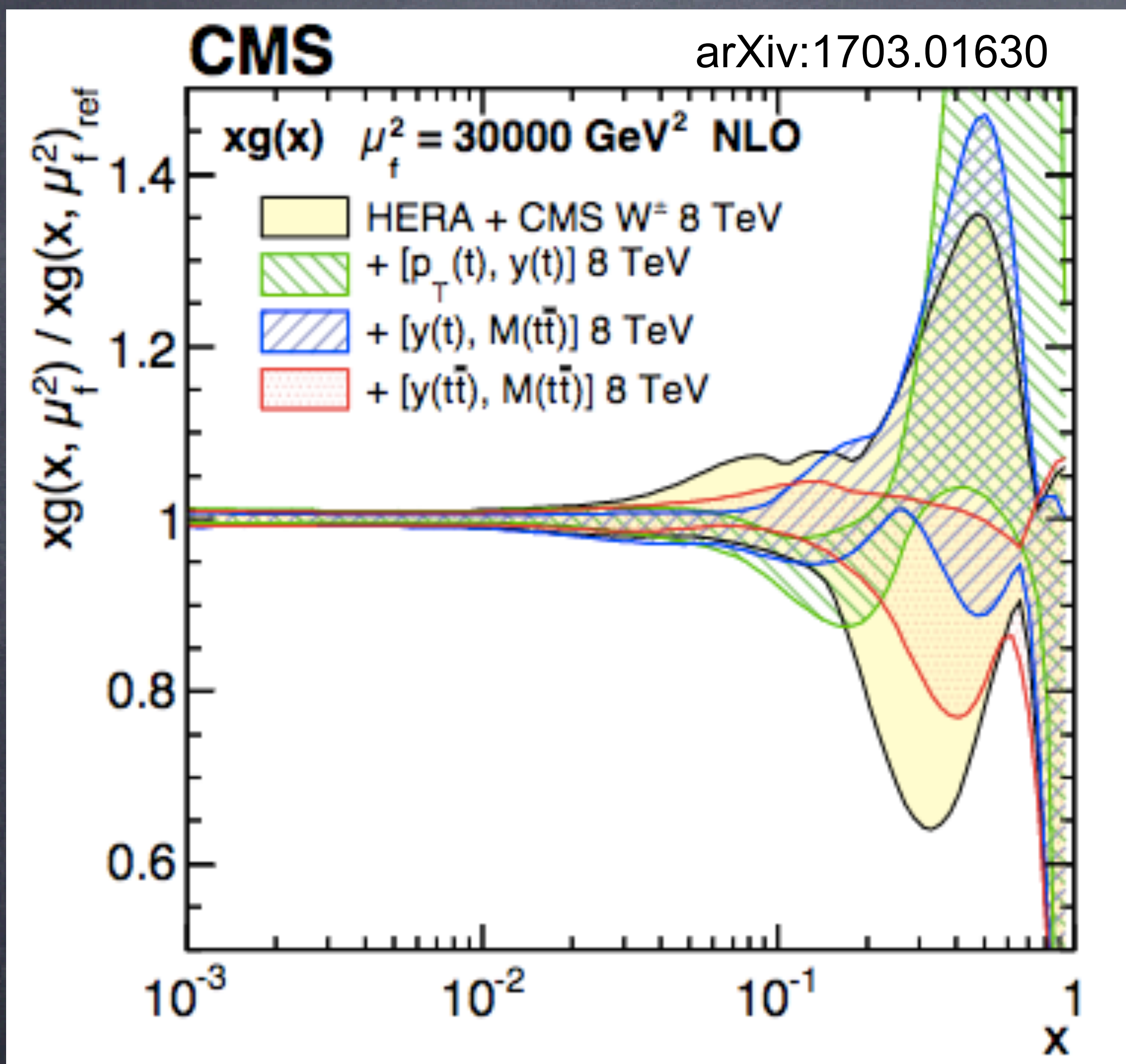
at LO:

$$x_{1,2} = \frac{M(t\bar{t})}{\sqrt{s}} e^{\pm y(t\bar{t})}$$

	HERA2	CT14
χ^2 (dof = 15)	29	16

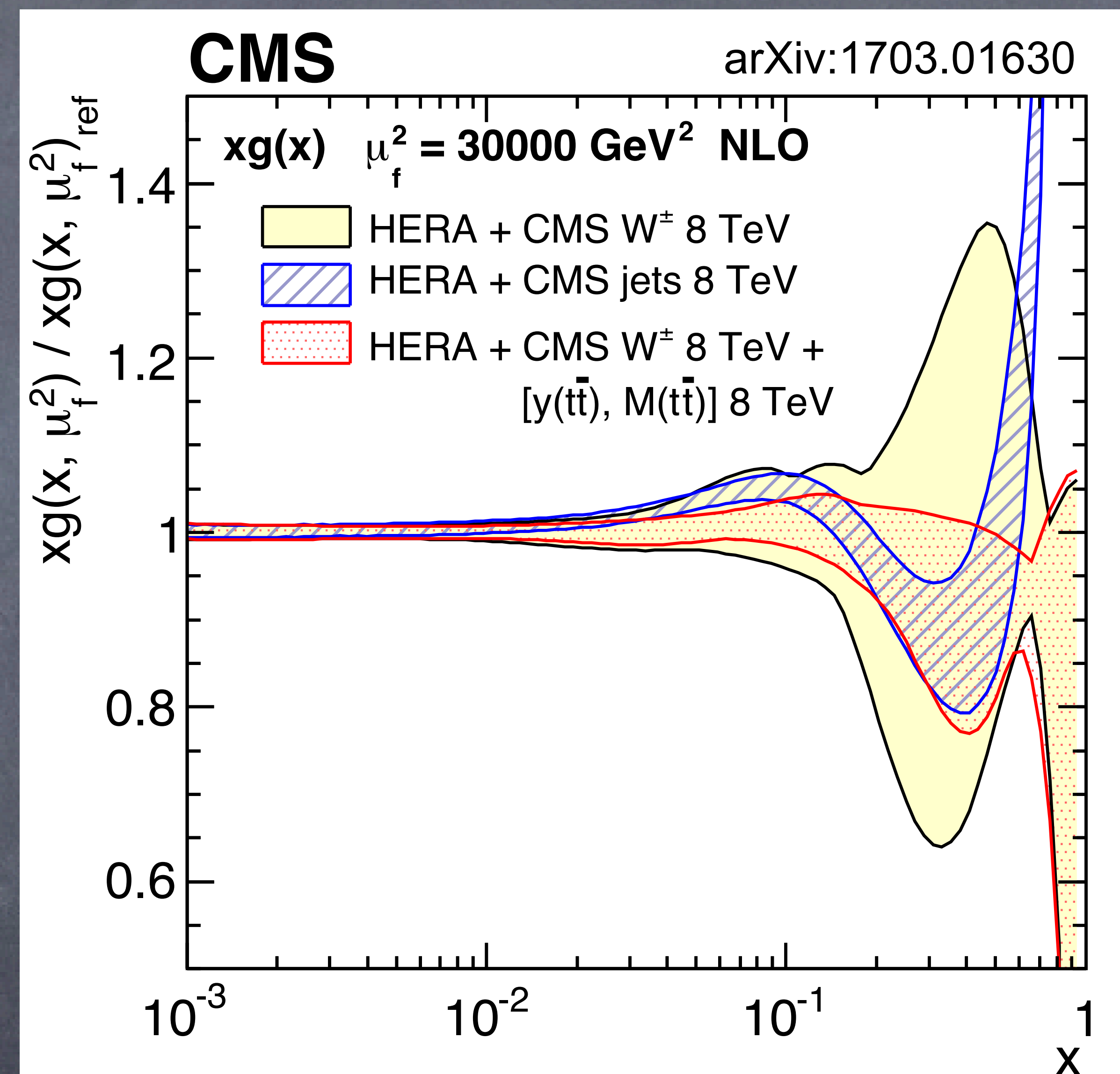
$t\bar{t}$ @ CMS: GLUON DISTRIBUTION AT HIGH X

1-d and 2-d differential cross sections for different observables studied



strongest constraints achieved by using 2d distributions in M_{tt} and y_{tt}

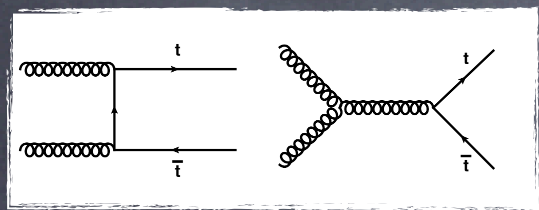
Results compared to those obtained by using inclusive jets @ 8 TeV



Recommend to use both data sets for further improvement of g(x) at high x

$t\bar{t}$ @ CMS: GLUON DISTRIBUTION AT HIGH X

In pp collisions top-quark pairs are produced via gg fusion probing gluon at high x



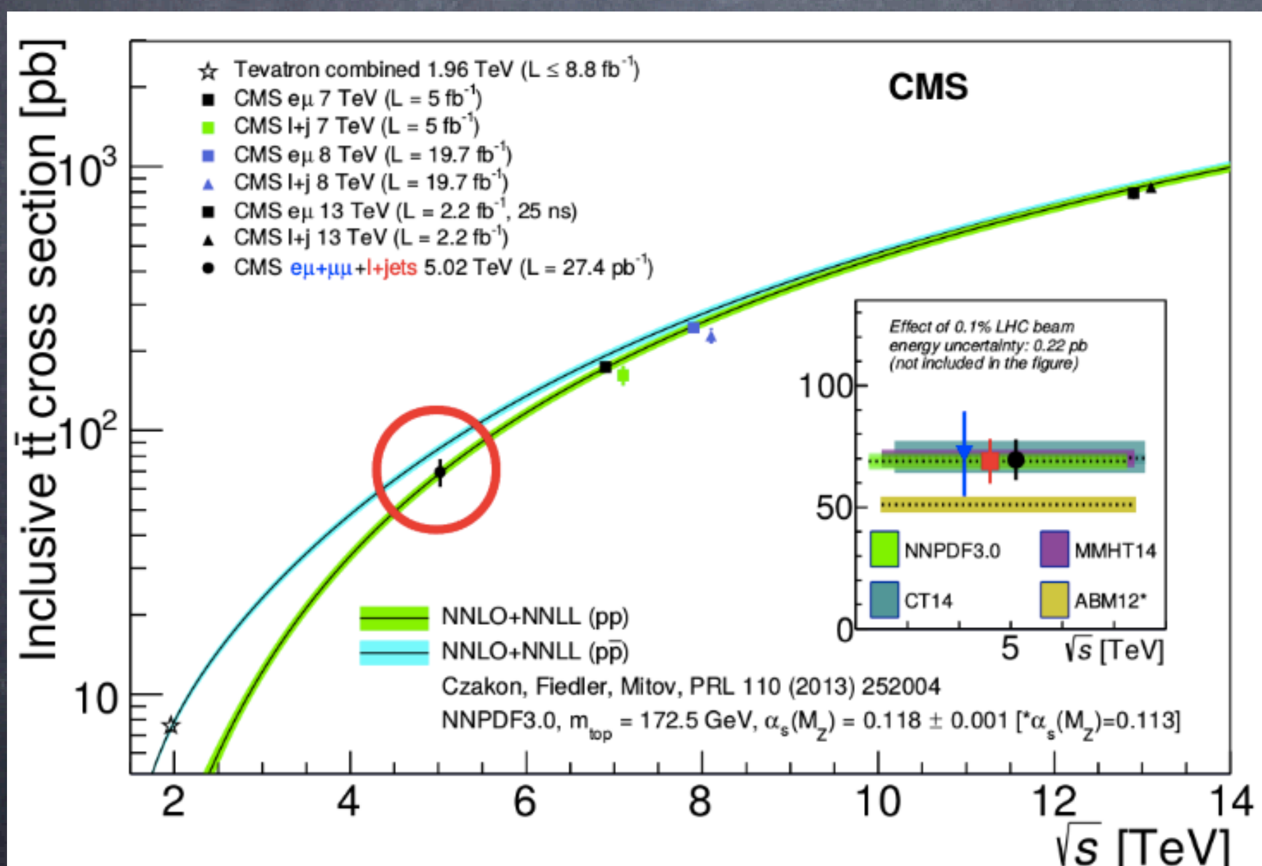
First measurement at 5.02 TeV, $\mathcal{L}$ = 27.4 pb^{-1}

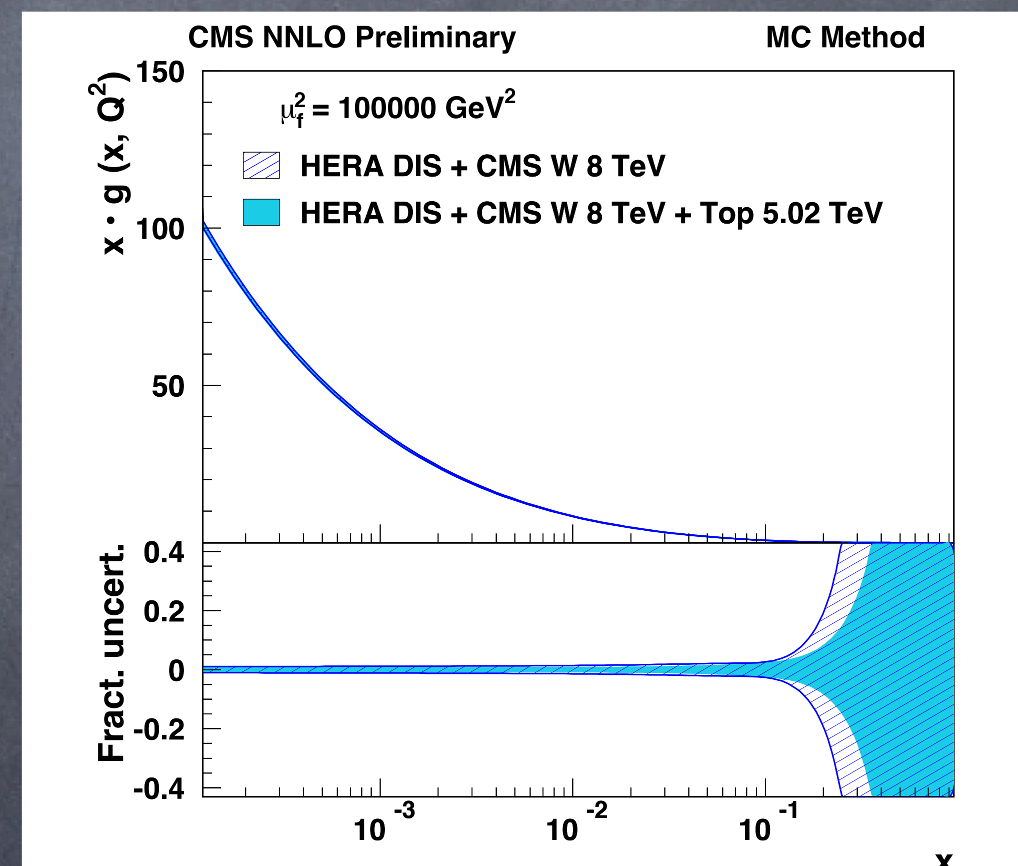
CMS-PAS-TOP-16-023

XFitter 2.0.0

new kinematic range probed

theory: HATHOR, m_t=172.5 GeV

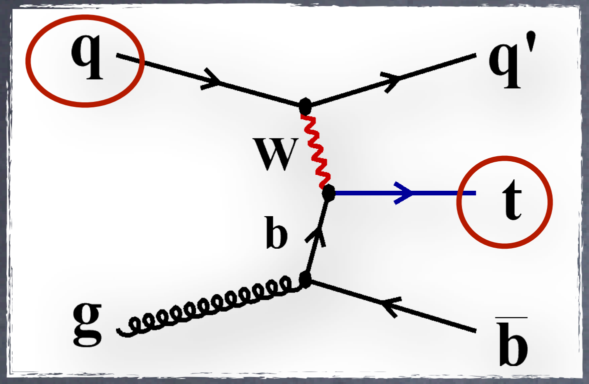




modest effect on g(x) at high x

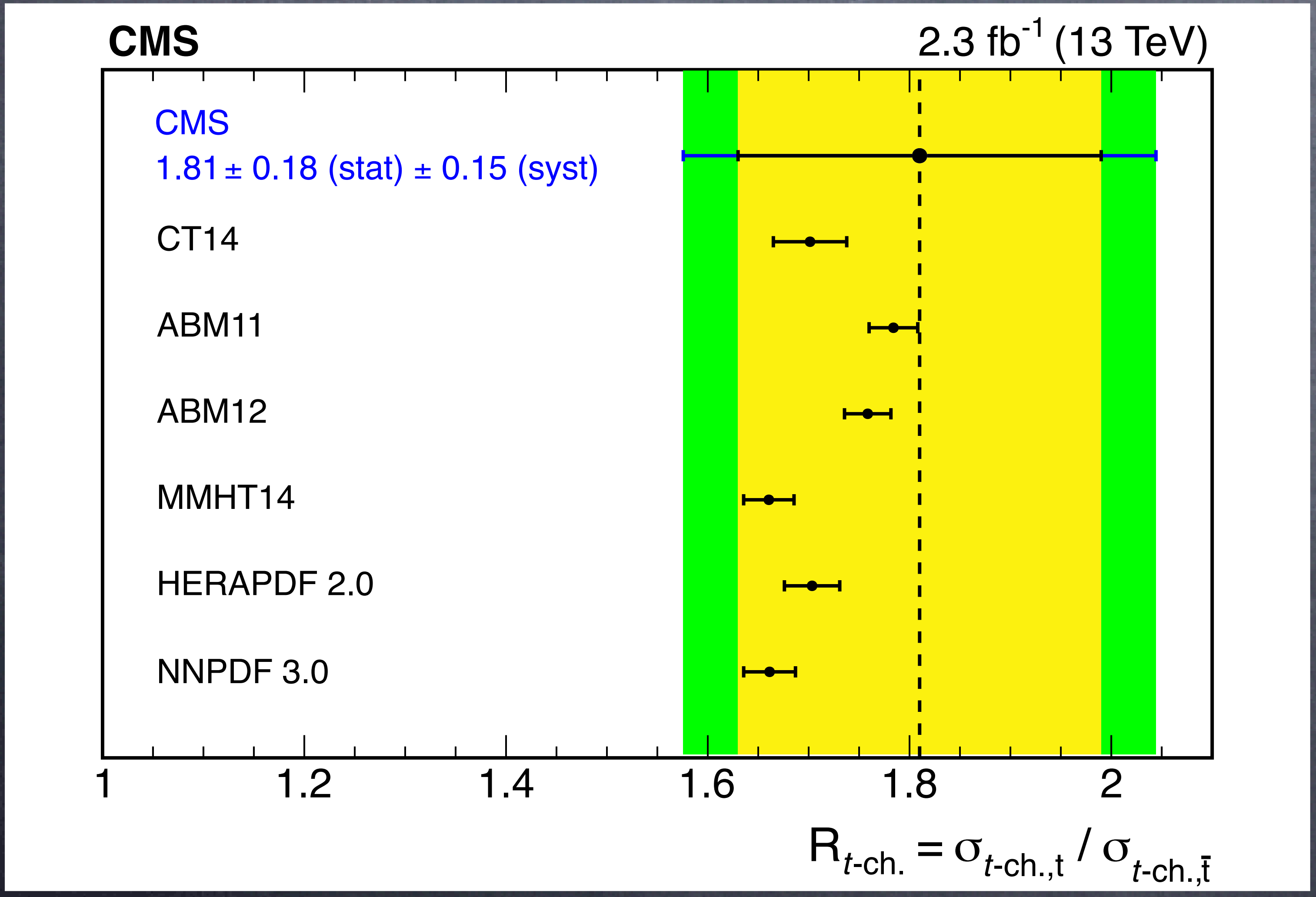
t and $\bar{t}$ @ CMS: PROBING THE LIGHT QUARKS

t-channel single top-quark production in pp collisions @ LHC



Probe the struck **light quark** through **charge** of top-quark measurement of $\sigma_t / \sigma_{\bar{t}}$ ratio R_t at **CMS 13 TeV (2.3 fb^{-1})**

arXiv:1610.00678, accepted by PLB



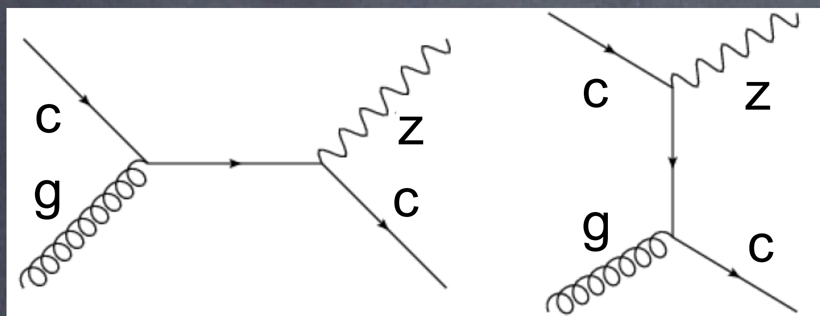
Dominant systematic uncertainty:
- Jet Energy Scale and Calibration
- Signal Modeling

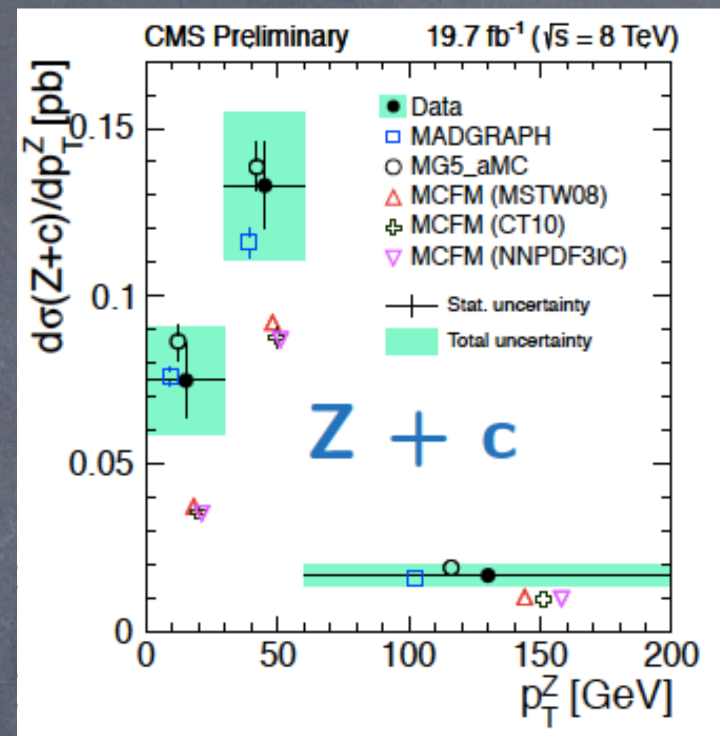
Theory via POWHEG 4FS
Uncertainties account for variation of the scales and m_t

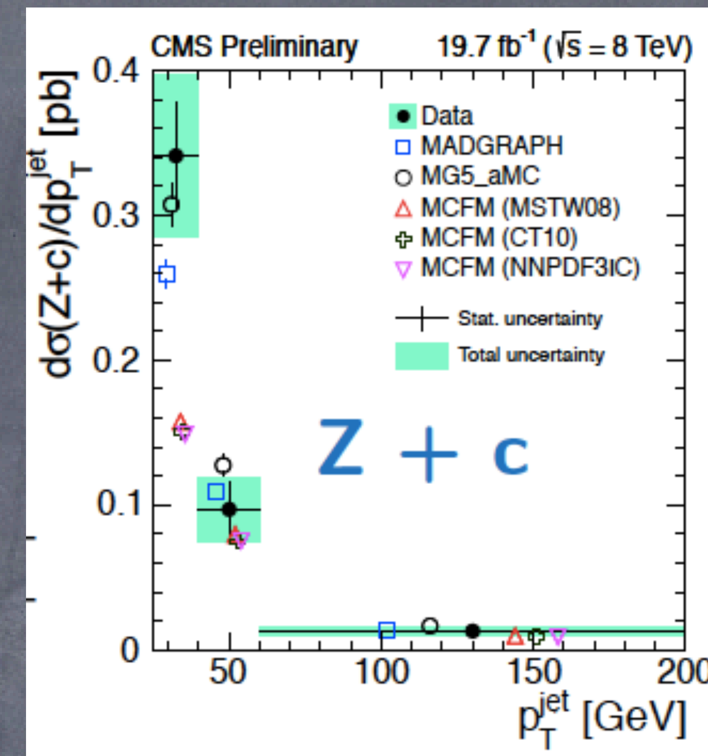
Associated production V + HQ

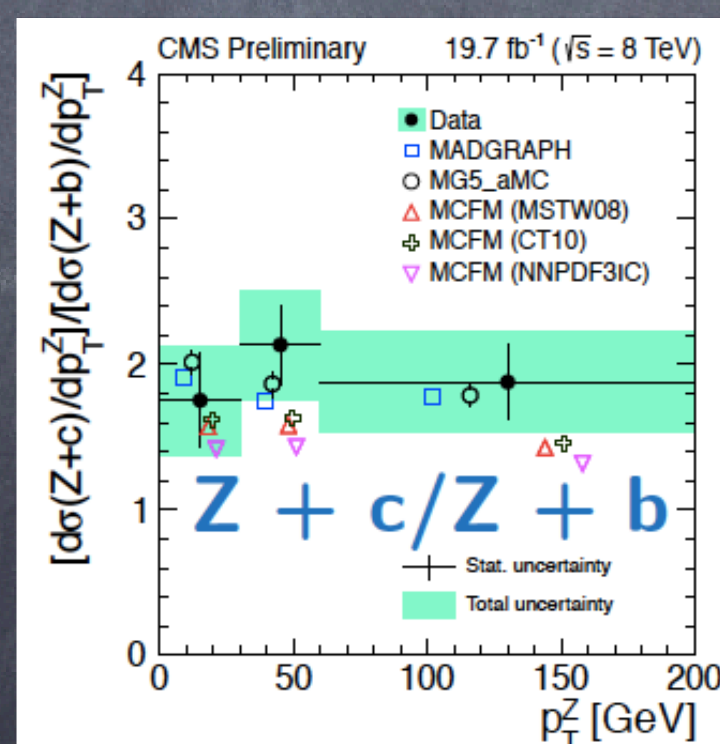
Z+c: direct probe of the charm content at the electroweak scale

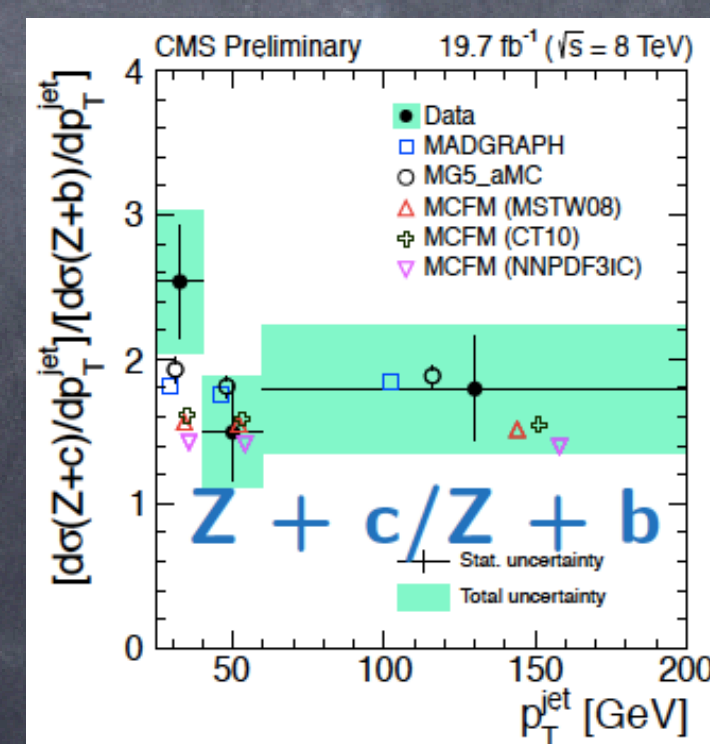
CMS-PAS-SMP-15-009











Fixed-order matrix elements matched to parton shower describe the data, at LO (MADGRAPH) and NLO (MADGRAPH5 AMC@NLO)

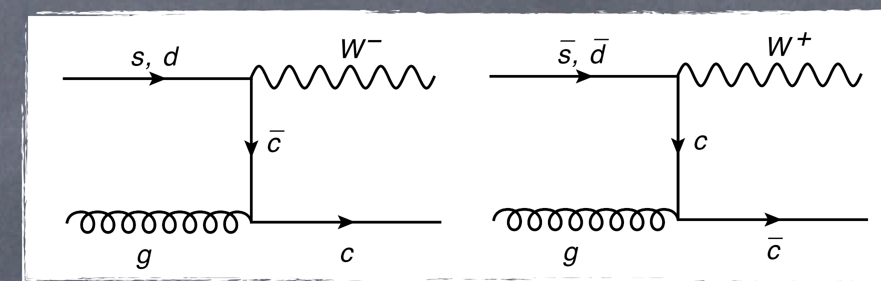
MCFM NLO predictions underestimate the cross sections, especially in the low pT region, better agreement for the ratios

No constraining power for PDFs at current level of precision

Associated production V + HQ

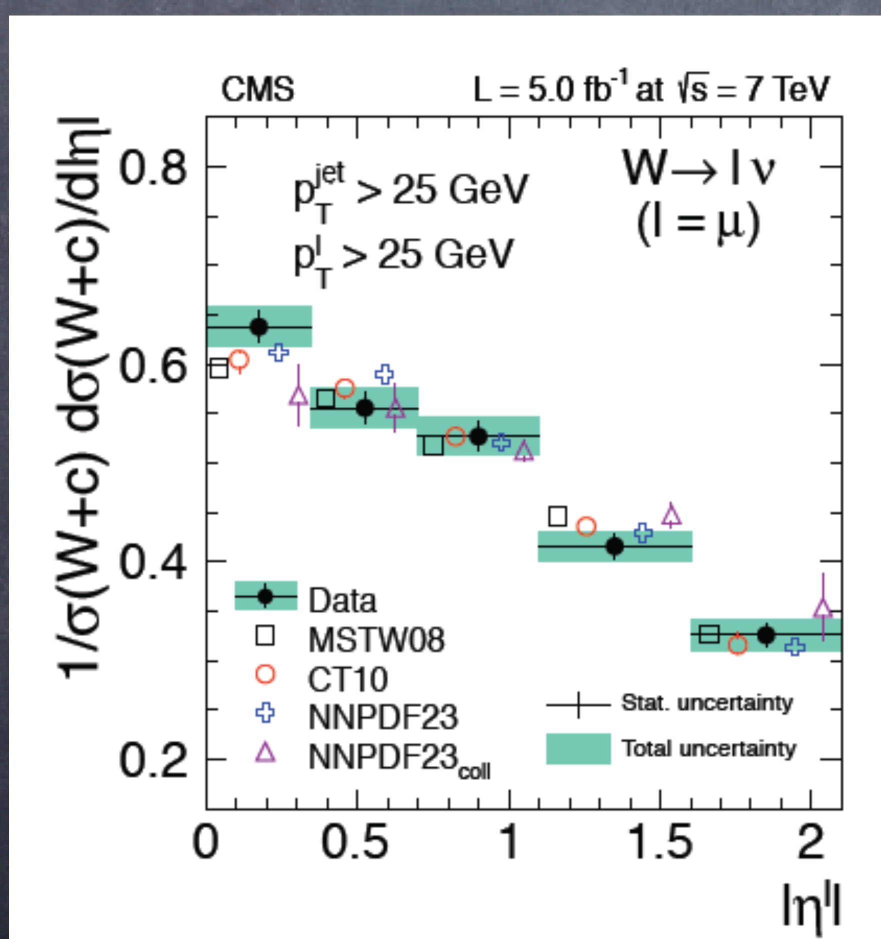
W+c: direct probe of the strange content at the electroweak scale

In pp collisions, production process of W+c probes strange quark directly at LO

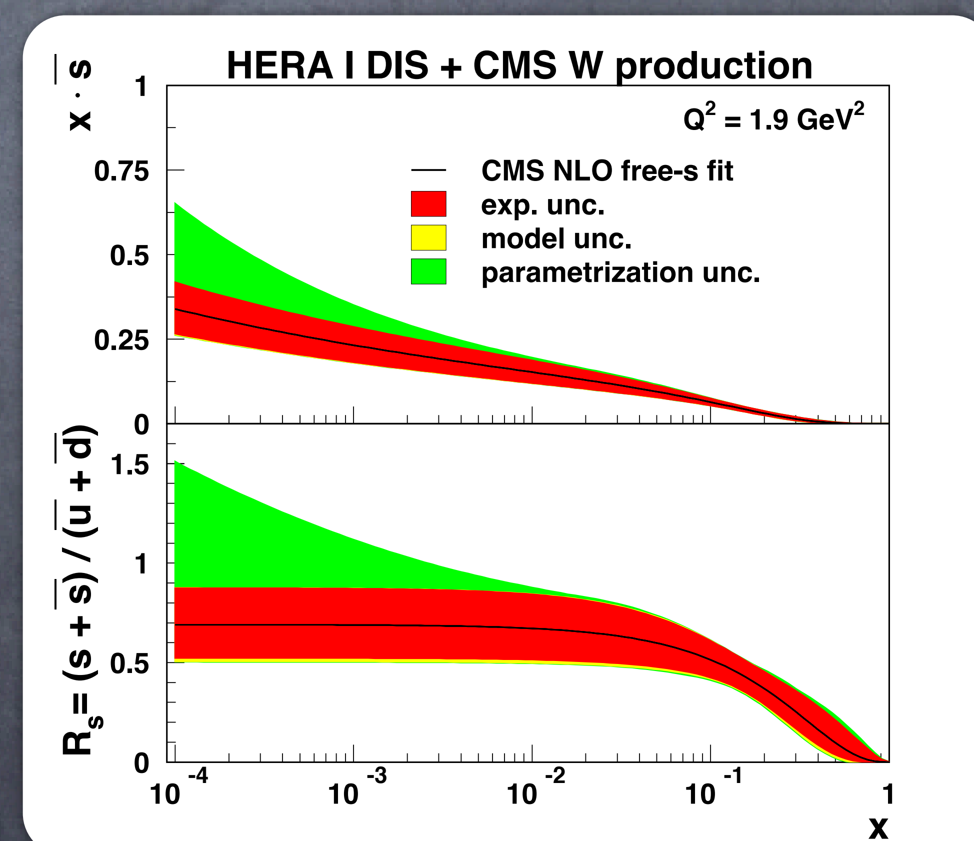


CMS JHEP 02 (2014) 013
CMS PRD 90 (2014) 032004

Measure W+c-hadron production



First direct determination of s-quark distribution at hadron collider



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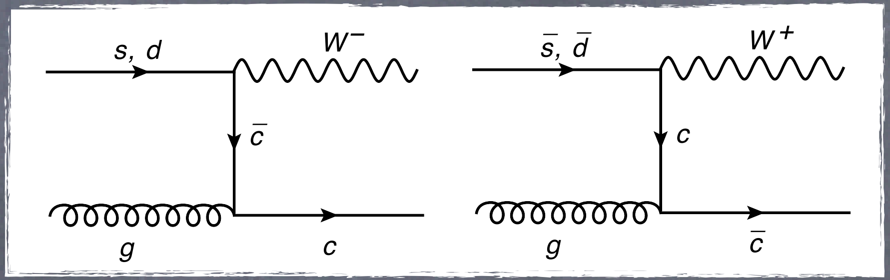

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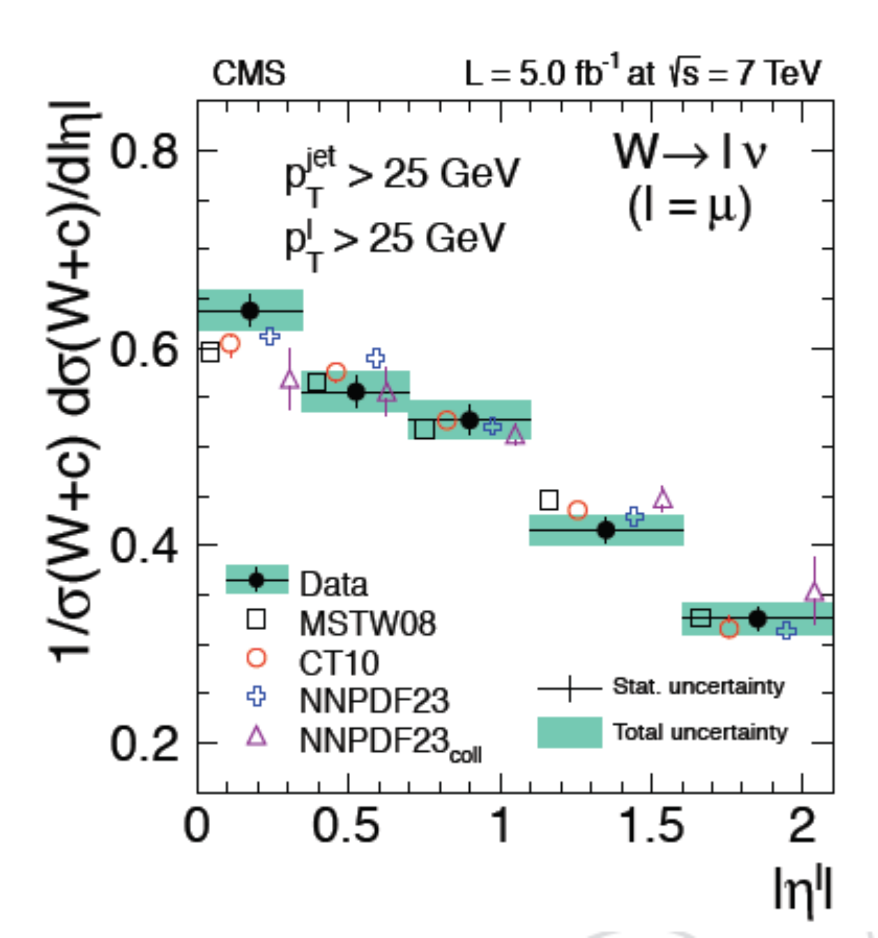
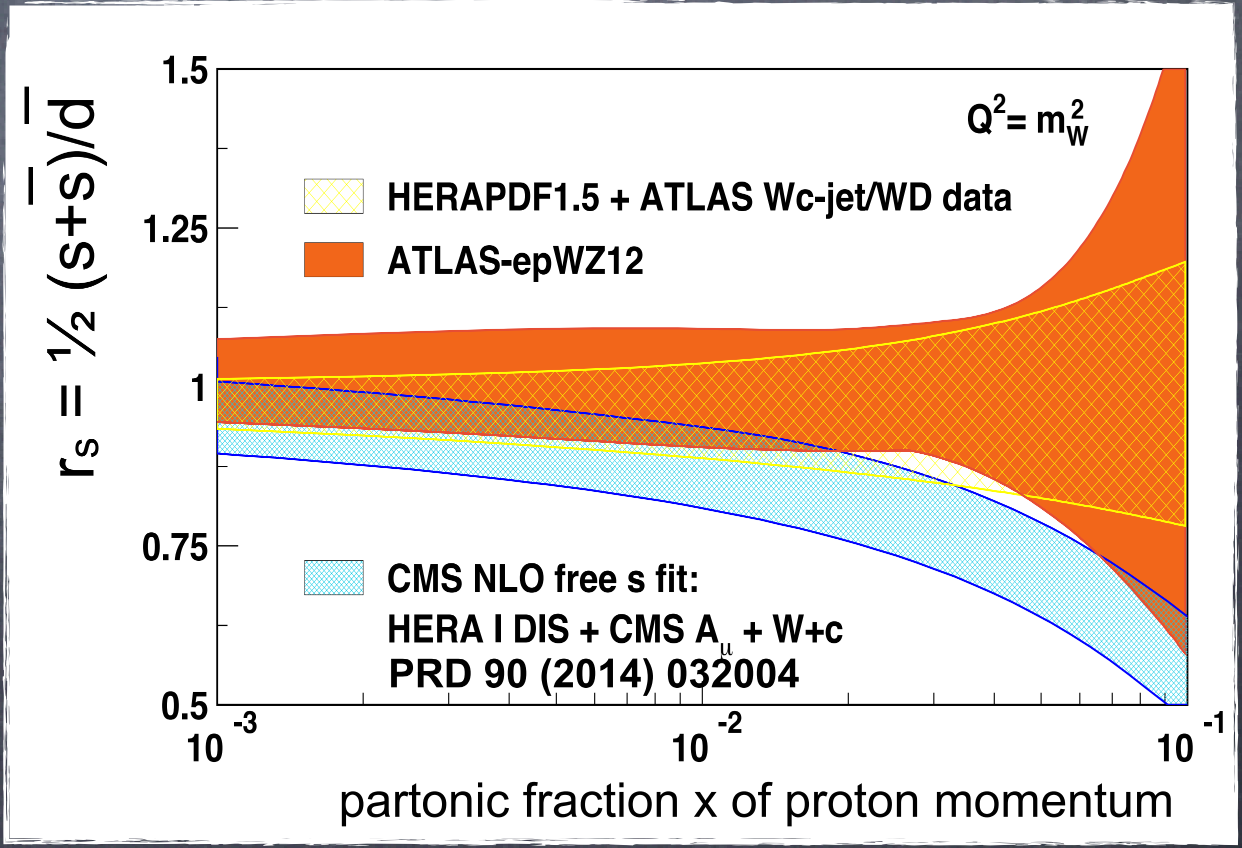


First direct determination of s-quark distribution at hadron collider

ATLAS and CMS results seem to differ

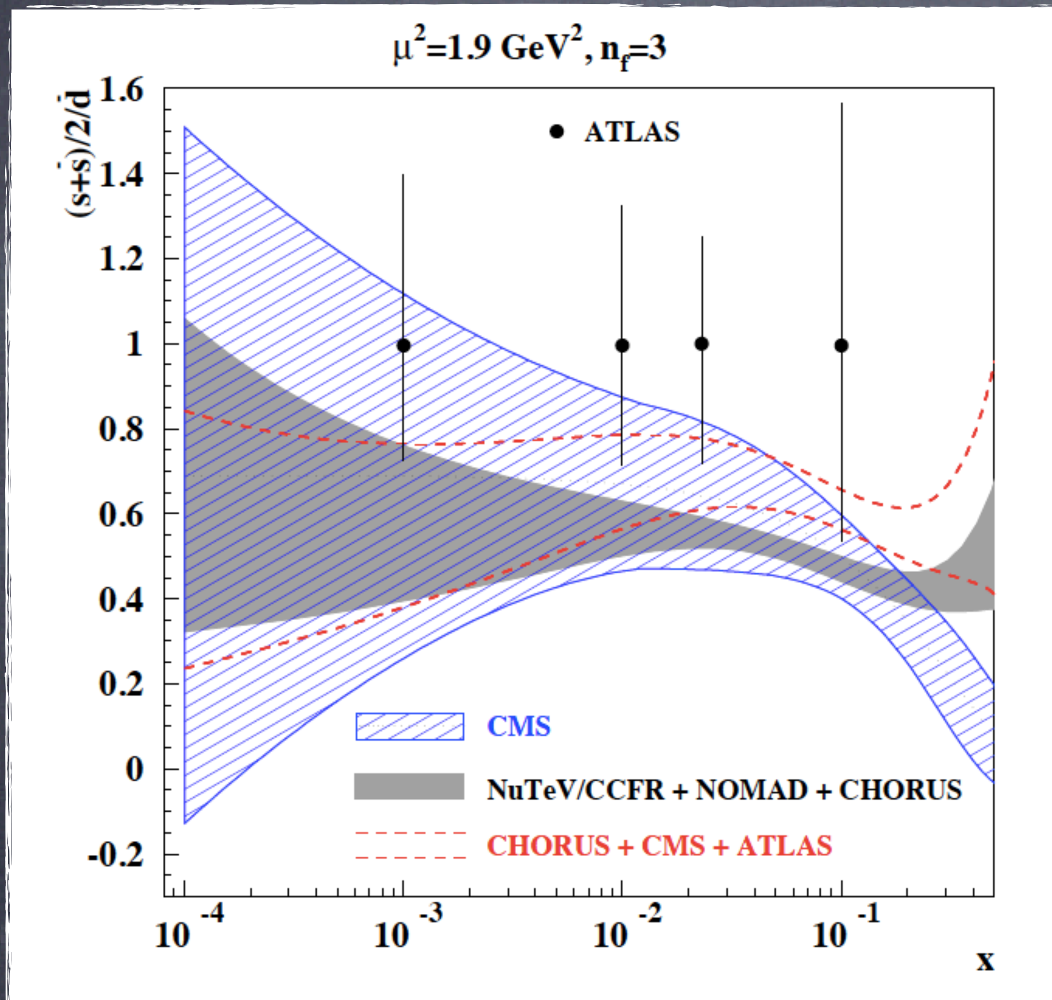


Check consistency of LHC measurements in a joined QCD analysis

Associated production V + HQ

Joined analysis of W+c from ATLAS and CMS data and neutrino scattering

[S. Alekhin et al.] arXiv:1404.6469

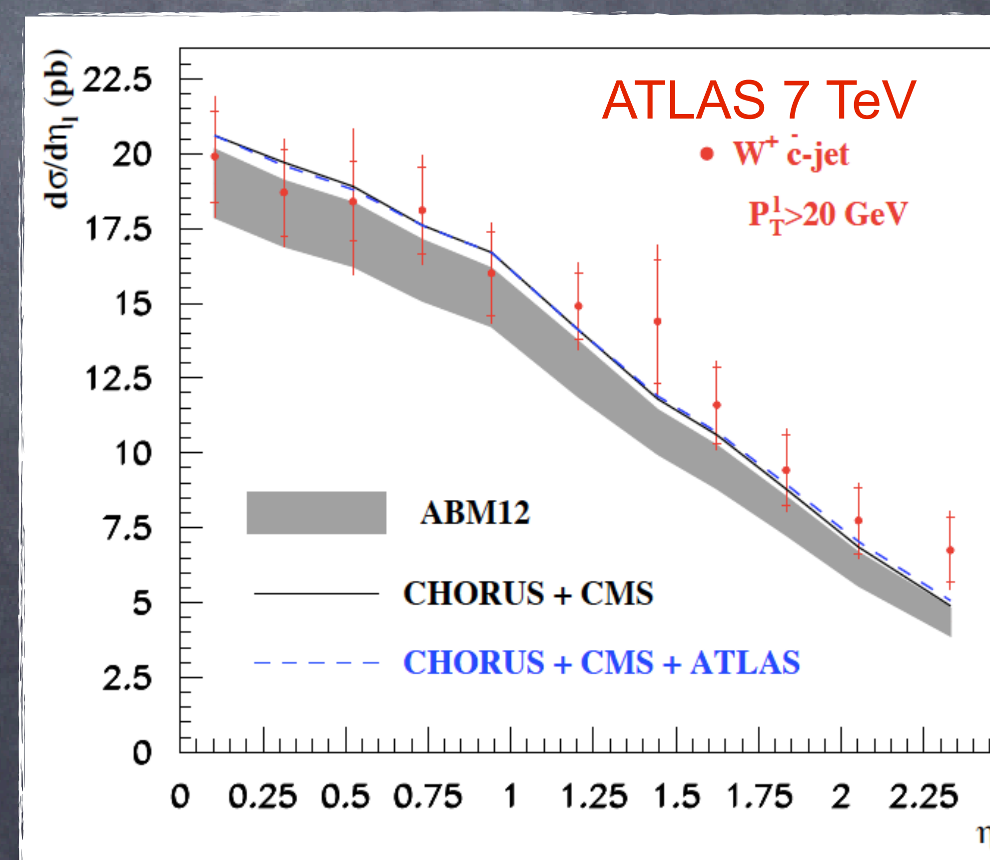


- Strangeness suppression factor determined

  $K_S(Q^2 = 20\ GeV^2) = 0.654 \pm 0.030$

- ABM PDF with updated results of ν−scattering experiments agrees well with CMS NLO fit

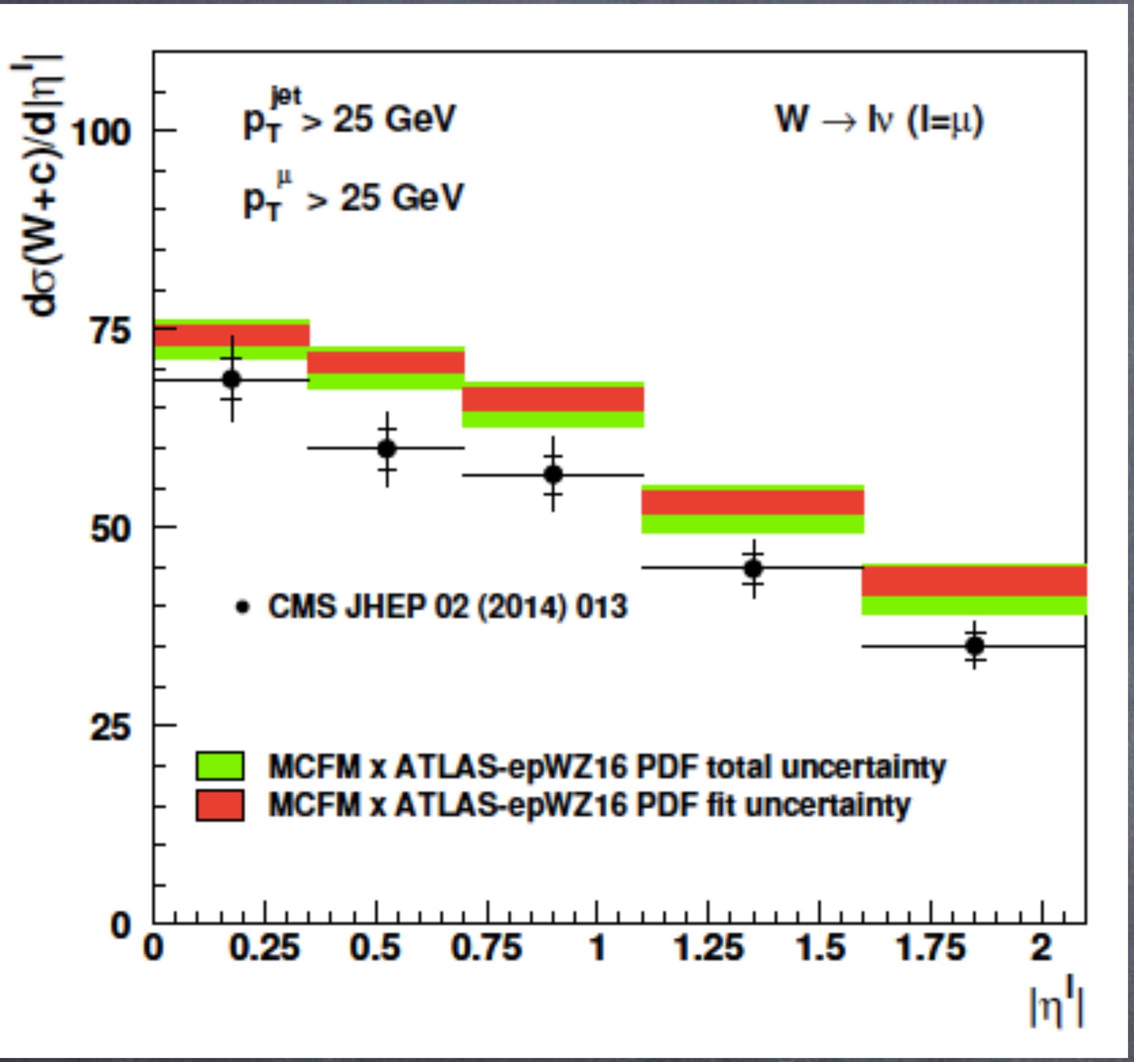
- ATLAS s-distribution is slightly enhanced,



In the combined analysis of CHORUS, CMS and ATLAS data
no inconsistency between
LHC measurements is observed.

Associated production V + HQ

Recent ATLAS analysis suggests enhanced strange-quark contribution in the proton



MCFM NLO with NLO ATLAS-epWZ16 pdfs
arXiv:1612.03016 [hep-ex]
NB: no scale variation performed here

ATLAS-epWZ16 pdfs imply larger strange contribution

13 TeV measurements of W+c are ongoing:

potential for improvement in ATLAS/CMS adjustments of binning, hadronisation parameters and MC settings.

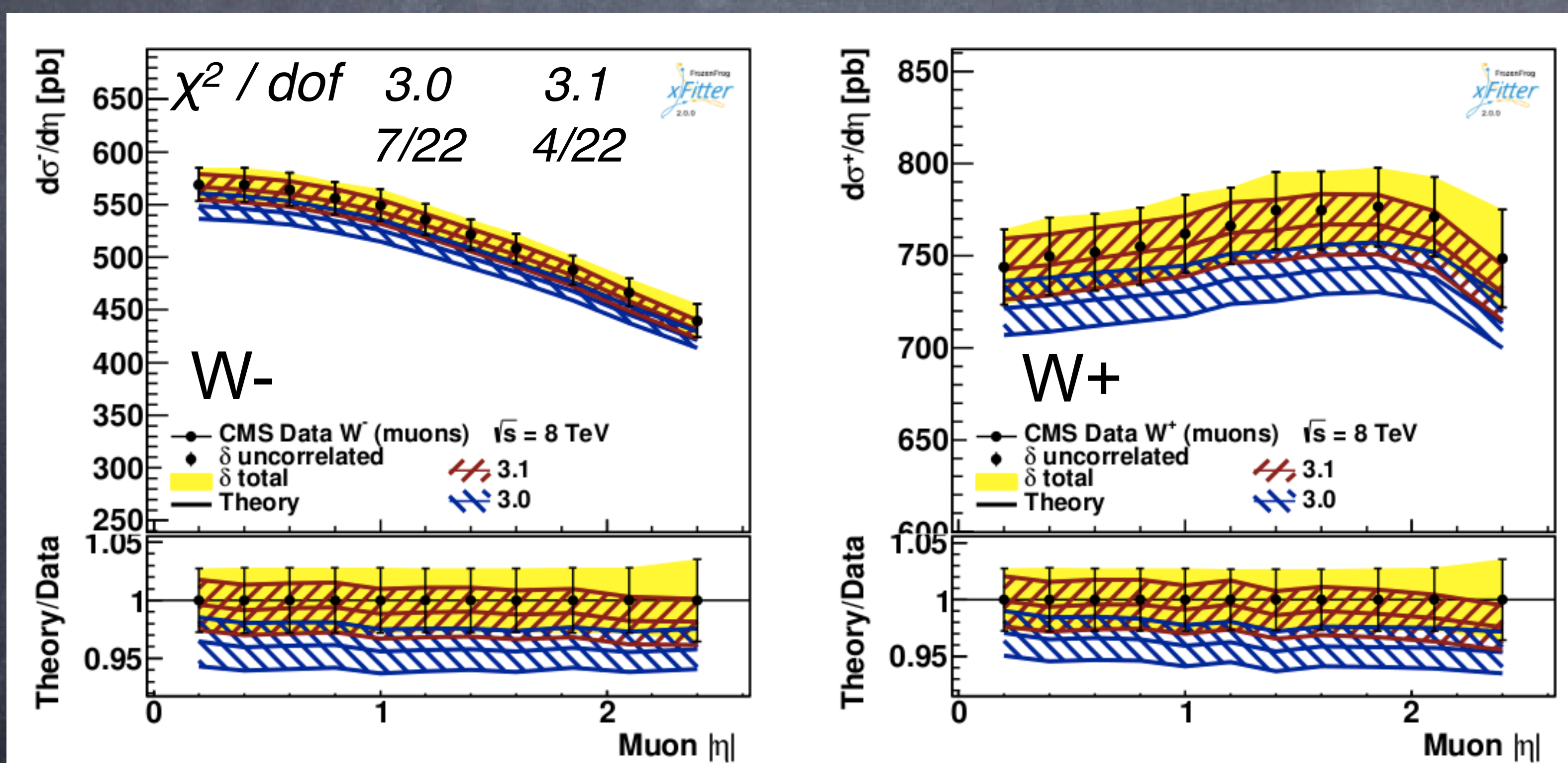
PDF as input in MC

Central PDF for the next MC production in CMS is NNPDF3.1 (hessian errors)

CT14, MMHT14, ABMP16, HERAPDF2.0, PDF4LHC15 to be added as additional weights

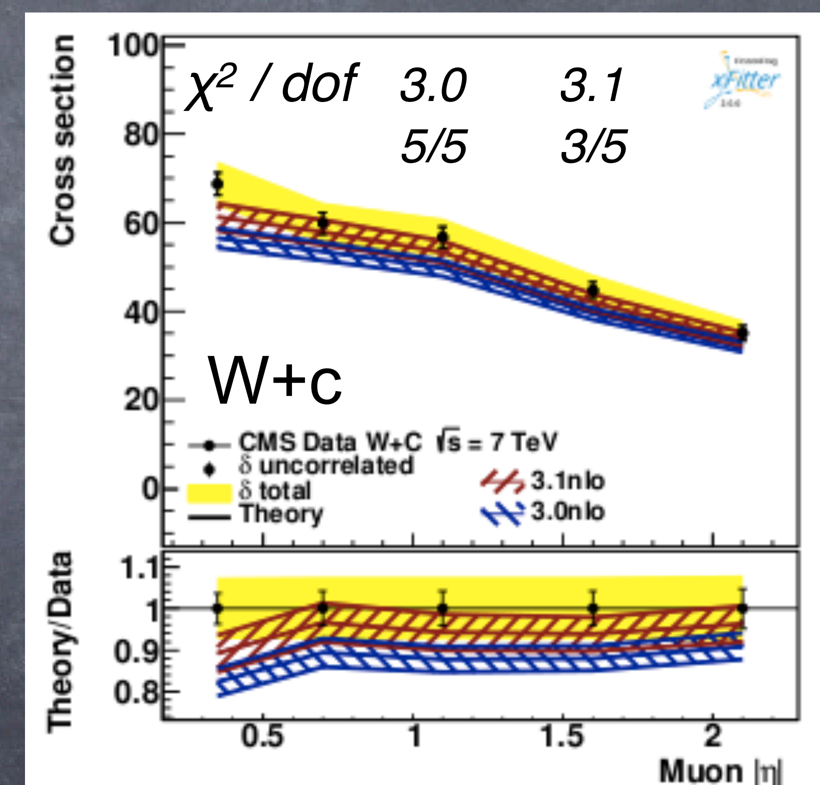
Validations and tunes in MC are ongoing. Here: Fixed order predictions CMS data

NNPDF3.1 vs 3.0 NNLO



Differences in u and d-valence distributions: better agreement with CMS W production

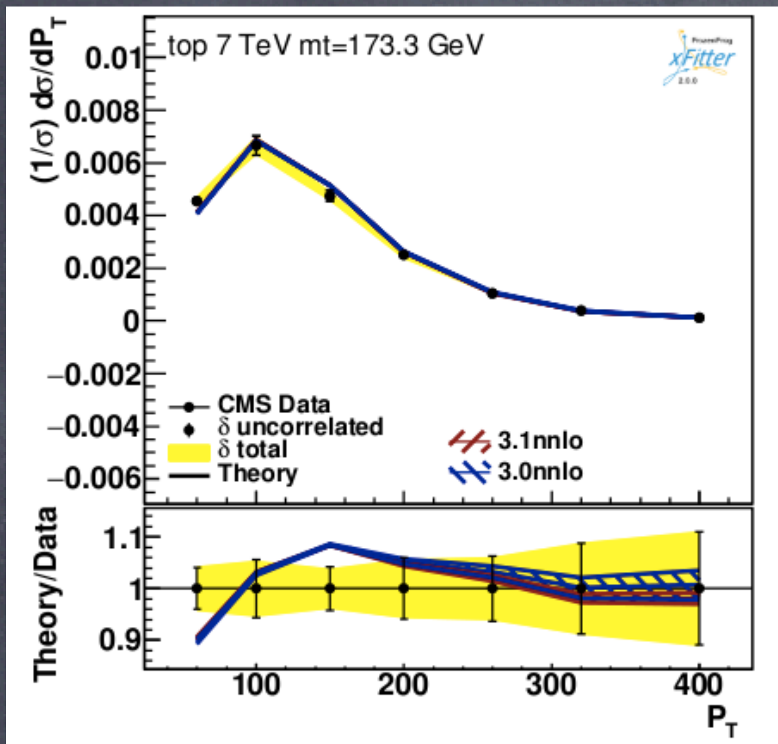
NNPDF3.1 vs 3.0 NLO

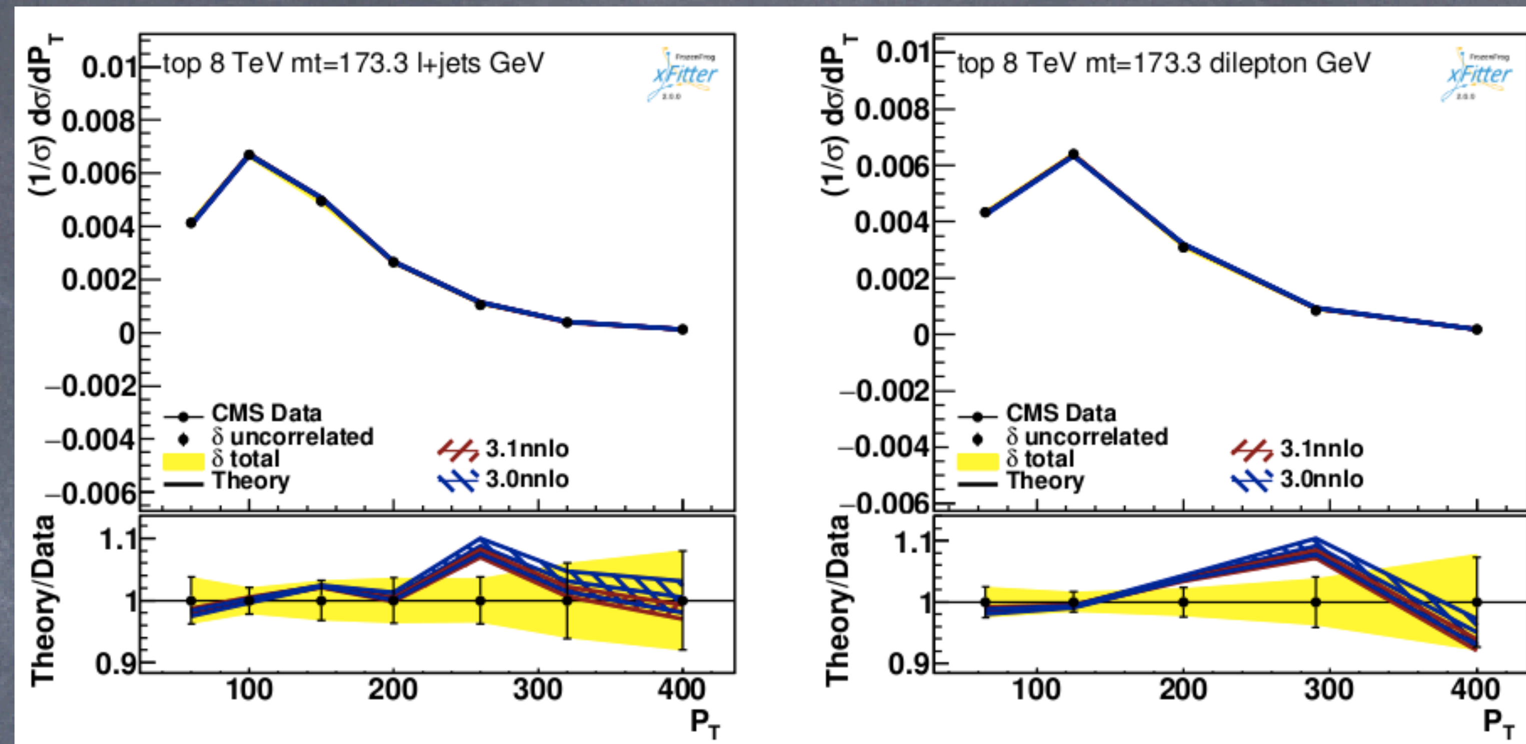


somewhat higher s(x) : better agreement with CMS W+c data

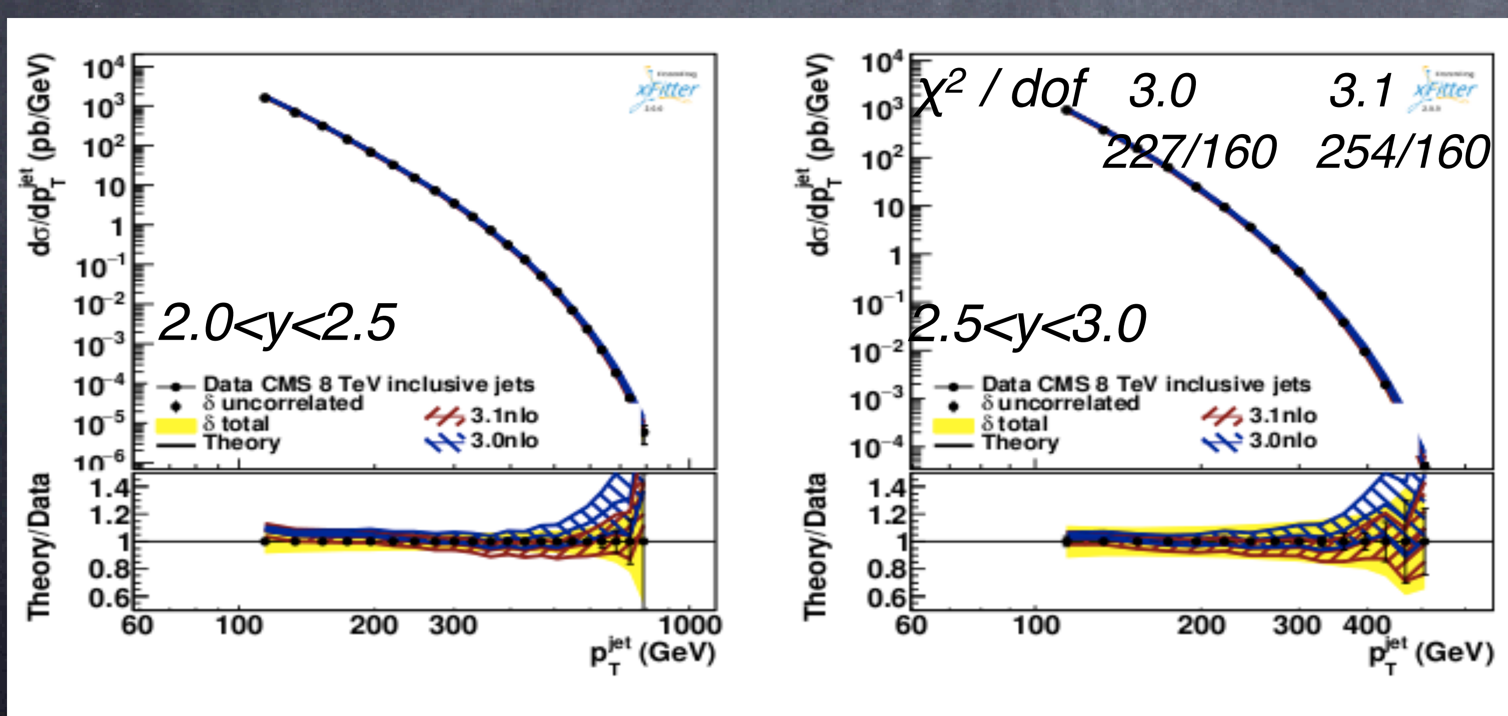
PDF as input in MC

Normalized top-quark pair cross section vs pt (T) 7&8 TeV : Difftop NNPDF3.0/3.1NNLO

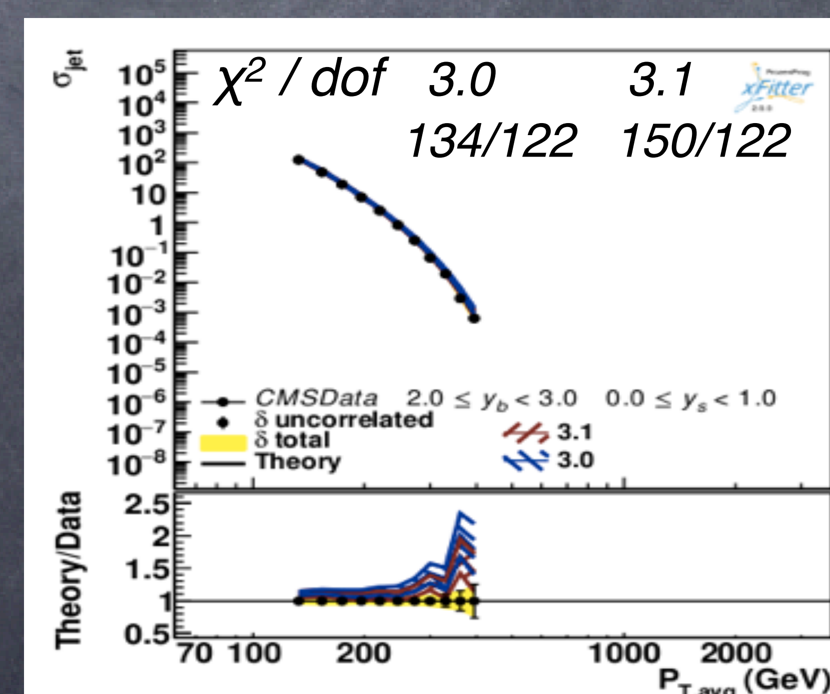




Inclusive jets 8 TeV : NLOJet++ NNPDF3.0/3.1NLO



Dijets:



SUMMARY

LHC Run I CMS data used for improvement of PDF accuracy

- jet data: gluon at medium & high x, strong coupling
  → getting even more interesting with available NNLO calculation
- Top-pair production has high potential to improve accuracy of g(x) at high x
  → remains important to constrain strong coupling & top quark mass

LHC Run II CMS data is forthcoming.

Need closer collaboration CMS/ATLAS for understanding details of measurements:

binning, MC settings and inputs, assumption on hadronisation etc.

for forthcoming combinations and inclusion in the global QCD analyses