HELMHOLTZ
GEMEINSCHAFT

Impact of CMS Measurements on Parton Distribution Functions and QCD parameters

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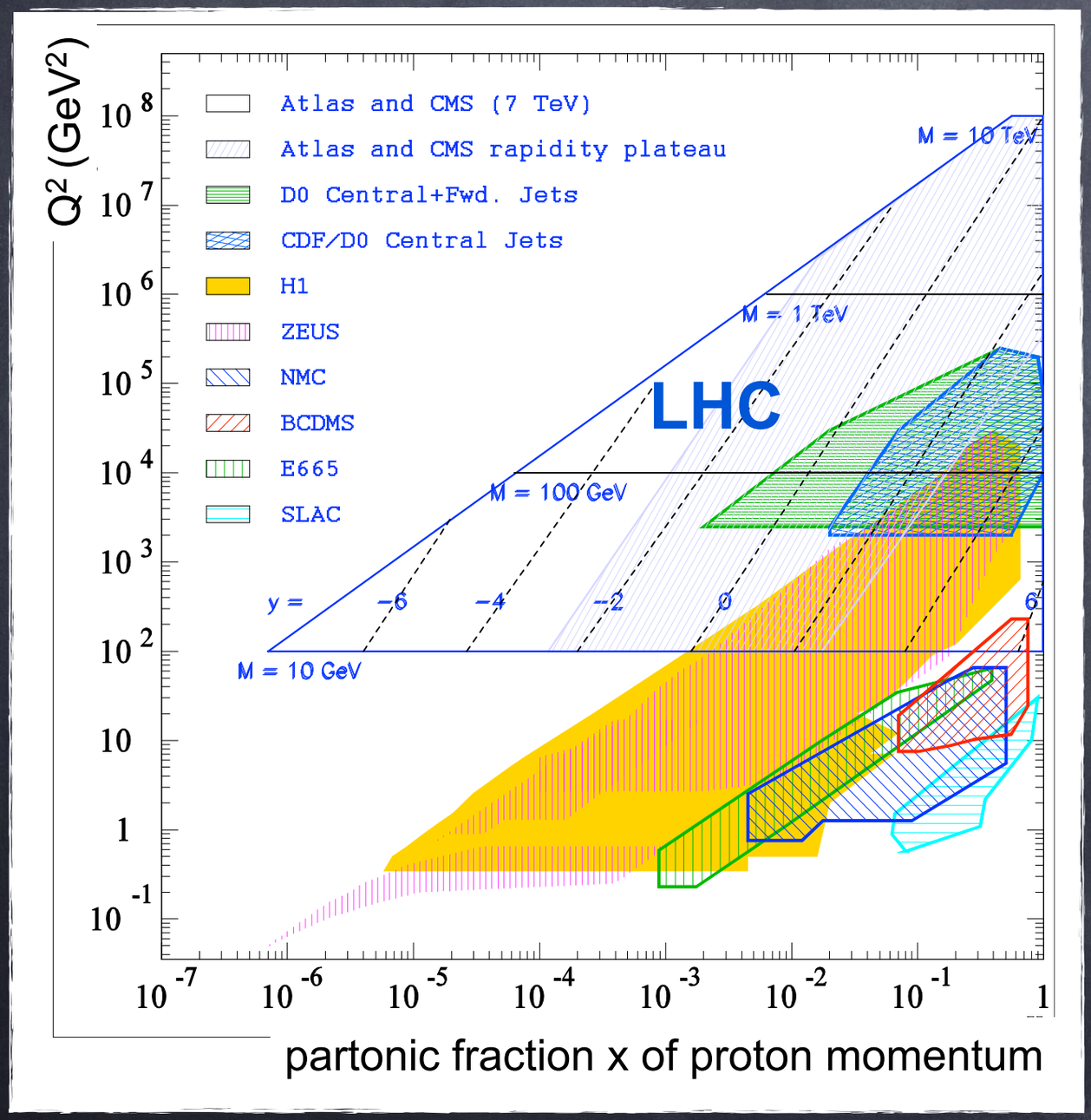
on behalf of the CMS Collaboration

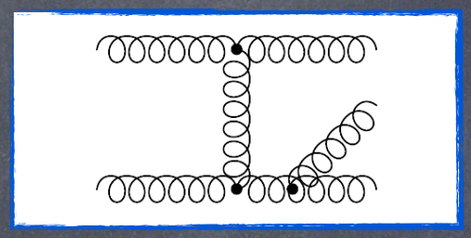
EPS Conference, Venice 2017

PDF CONSTRAINTS FROM LHC

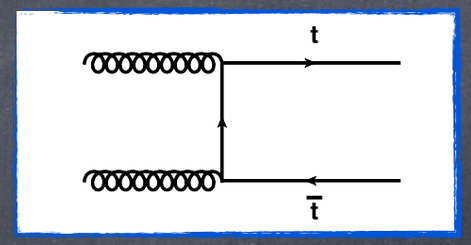
need improvements in
quark flavor separation at medium x,
gluon at low and at high x
➡ impact of the LHC measurements



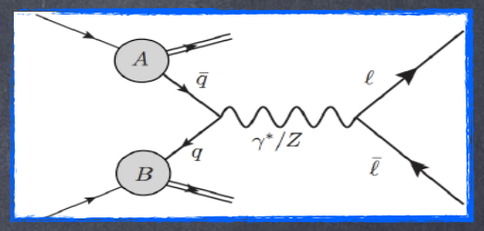
- jets: gluon, α_S (today)
  medium-high x



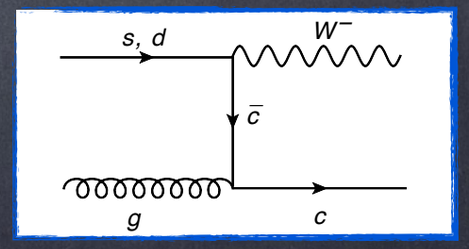
- top-pairs: gluon (today)
  high x



- DY: light quarks,
  flavor separation,
  gluon



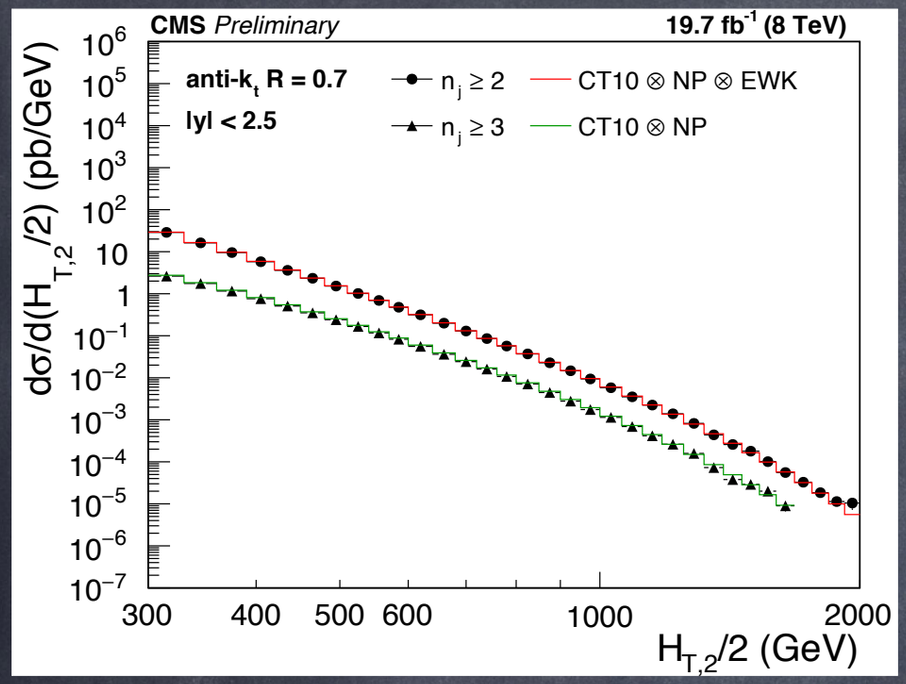
- V+HQ: s-quark,
  intrinsic charm



(S.Pflitsch's talk)

JETS @ CMS: GLUON AND STRONG COUPLING

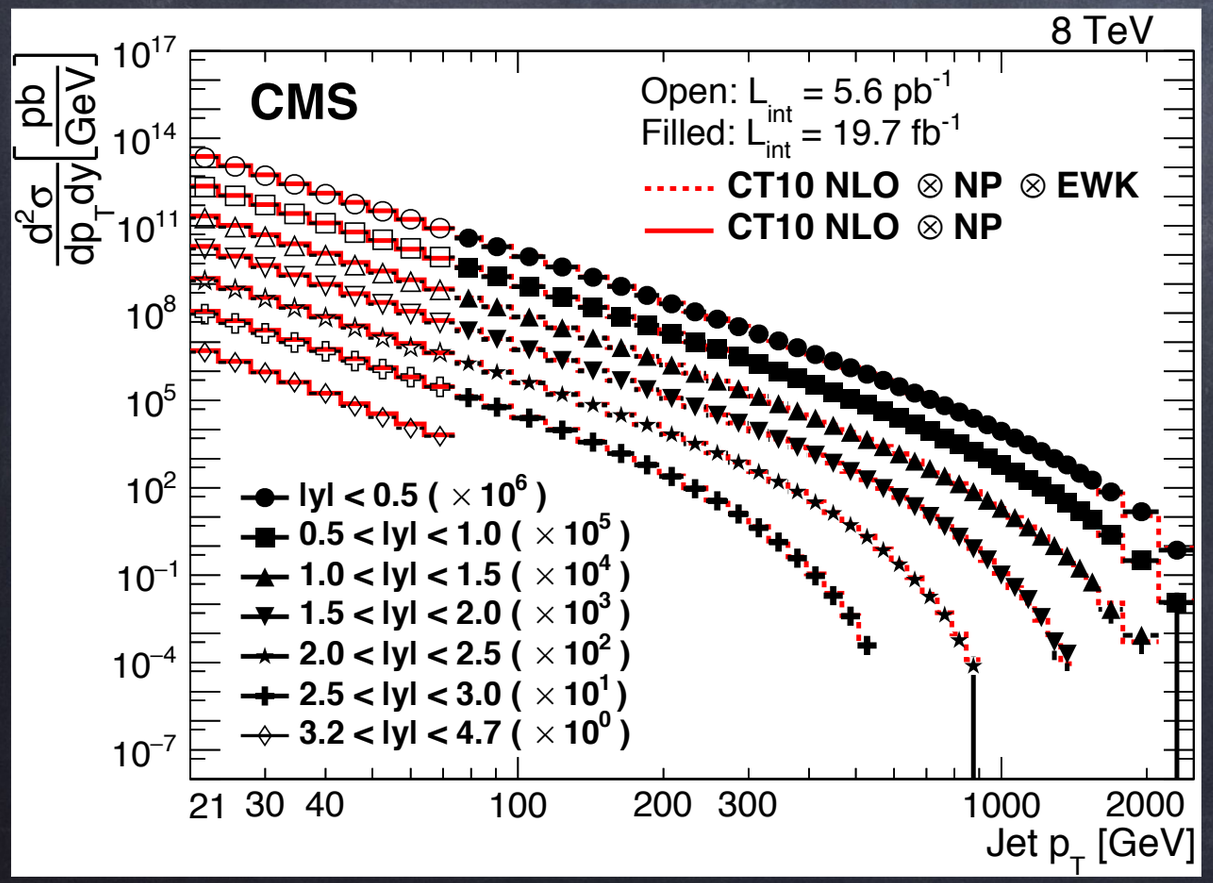
Jet production in pp collisions directly sensitive to PDFs and α_S

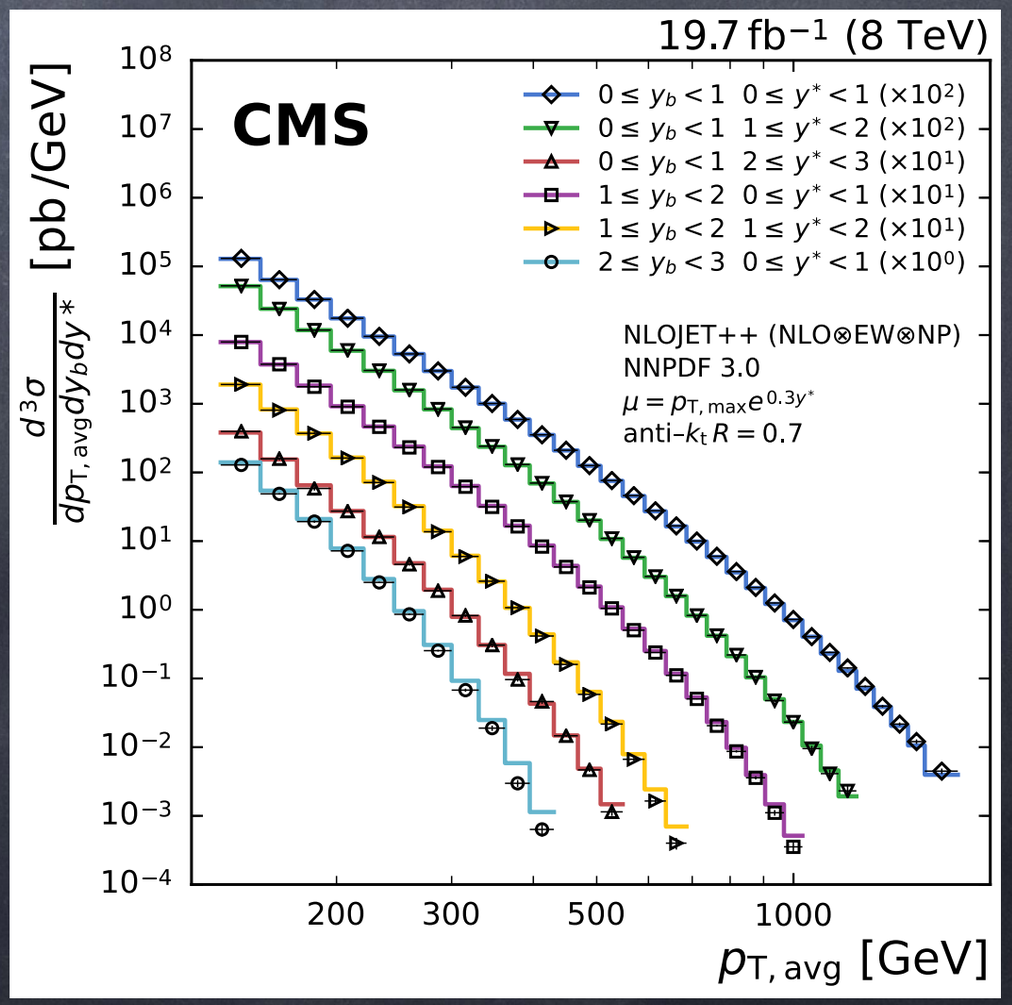


CMS 8 TeV, $\mathcal{L}$ = 19.7 fb^{-1} :

- **inclusive jet production : *JHEP 03 (2017) 156***
- ***3D* dijet production: *arXiv:1705.02628 (submitted to EPJC)***
- **multijet production: *CMS-PAS-SMP-16-008***

Details about measurements : P.Kokkas' talk.



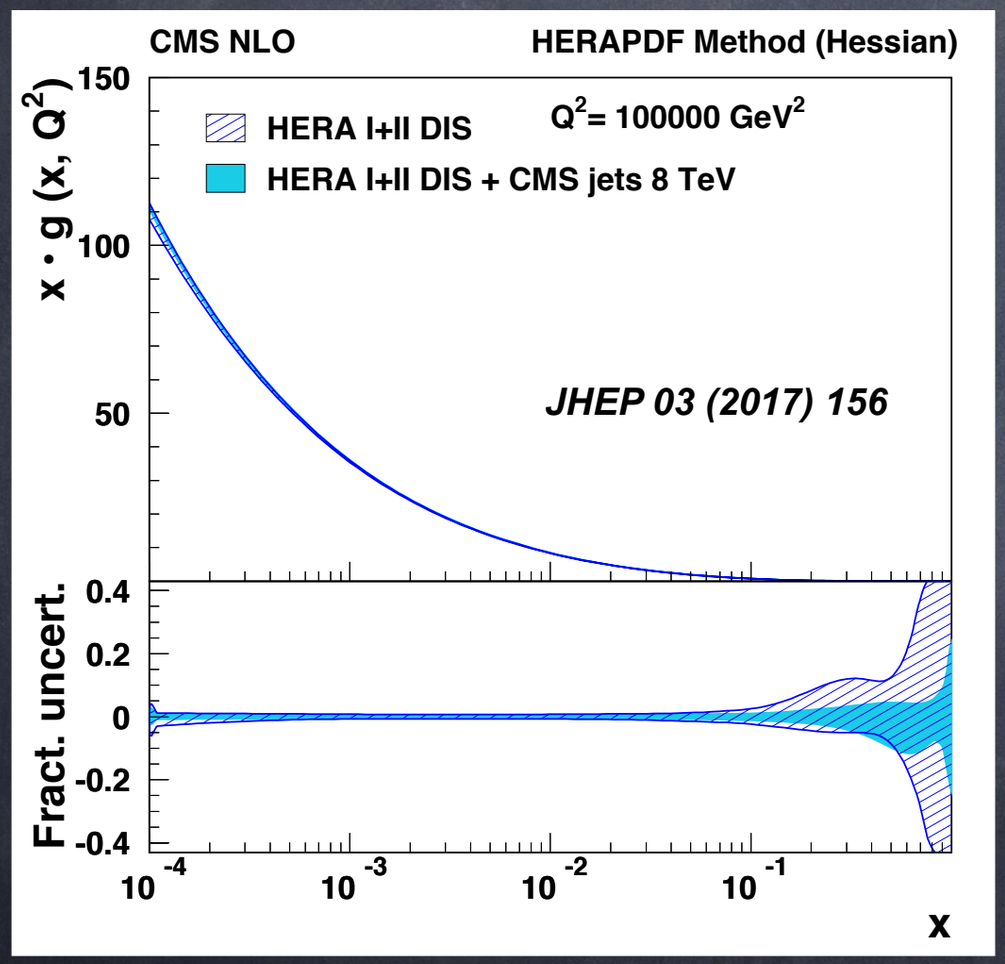


JETS @ CMS: GLUON AND STRONG COUPLING

CMS 8 TeV, $\mathcal{L}$ = 19.7 fb^{-1} inclusive jet production JHEP 03 (2017) 156

Double-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:

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

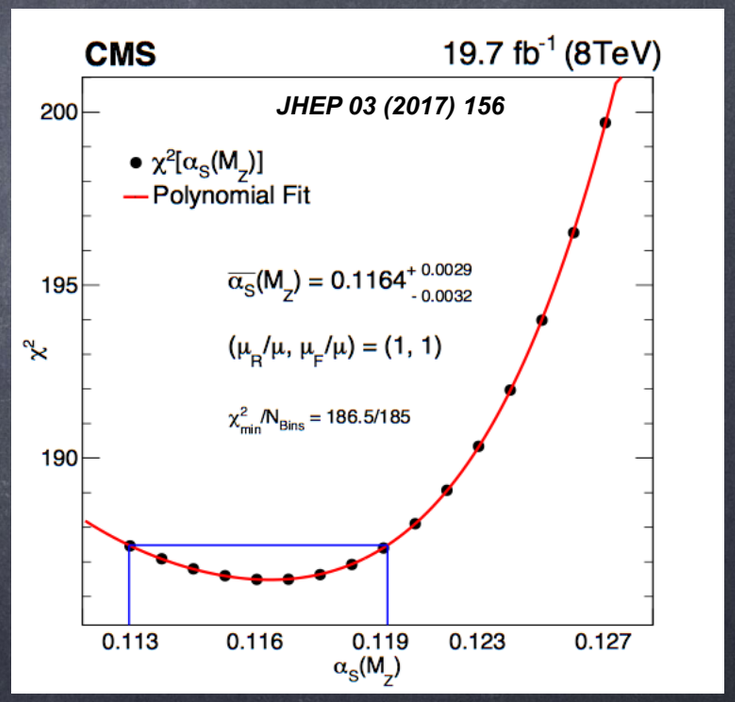
using fixed PDFs:

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

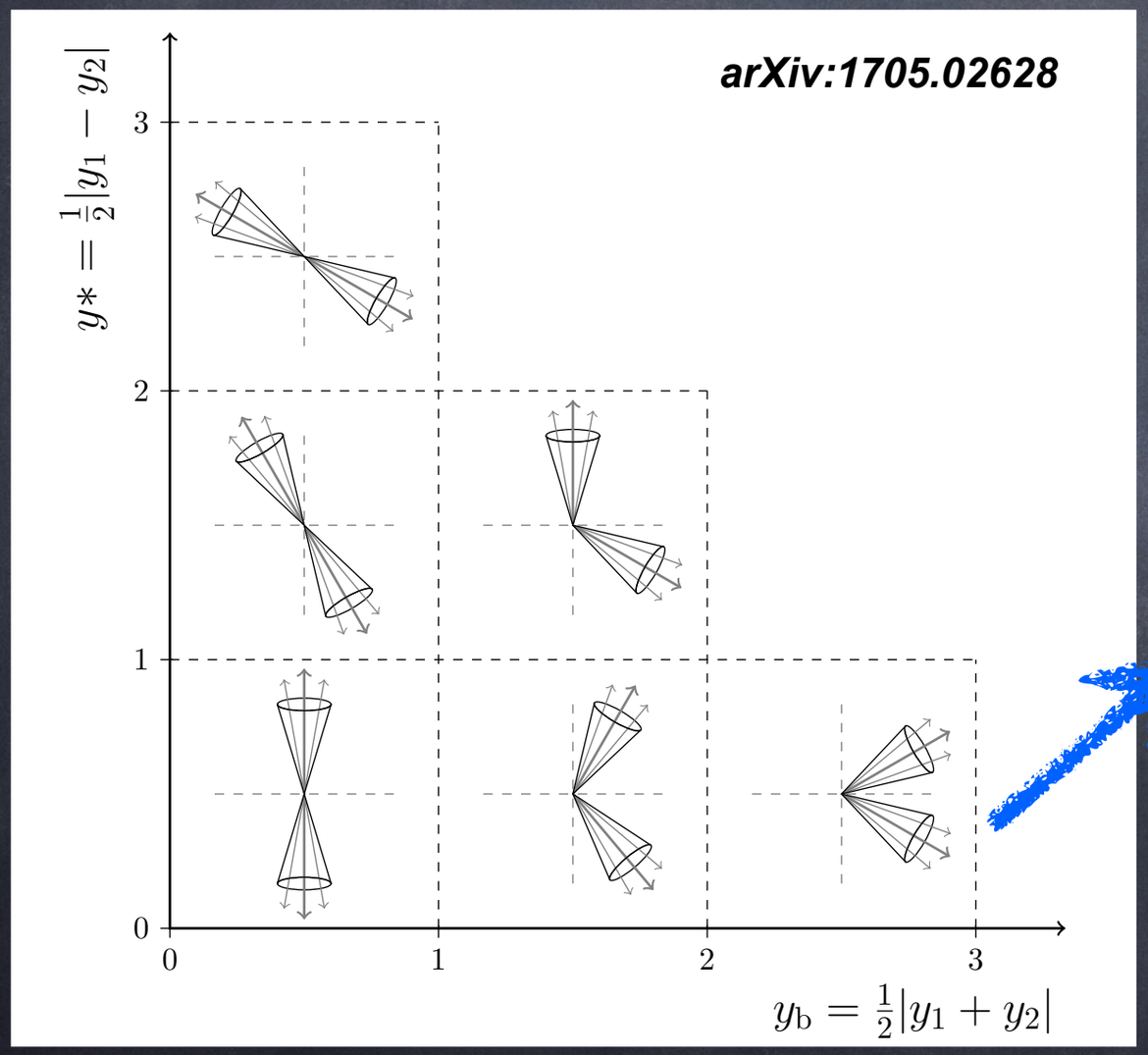
JETS @ CMS: GLUON AND STRONG COUPLING

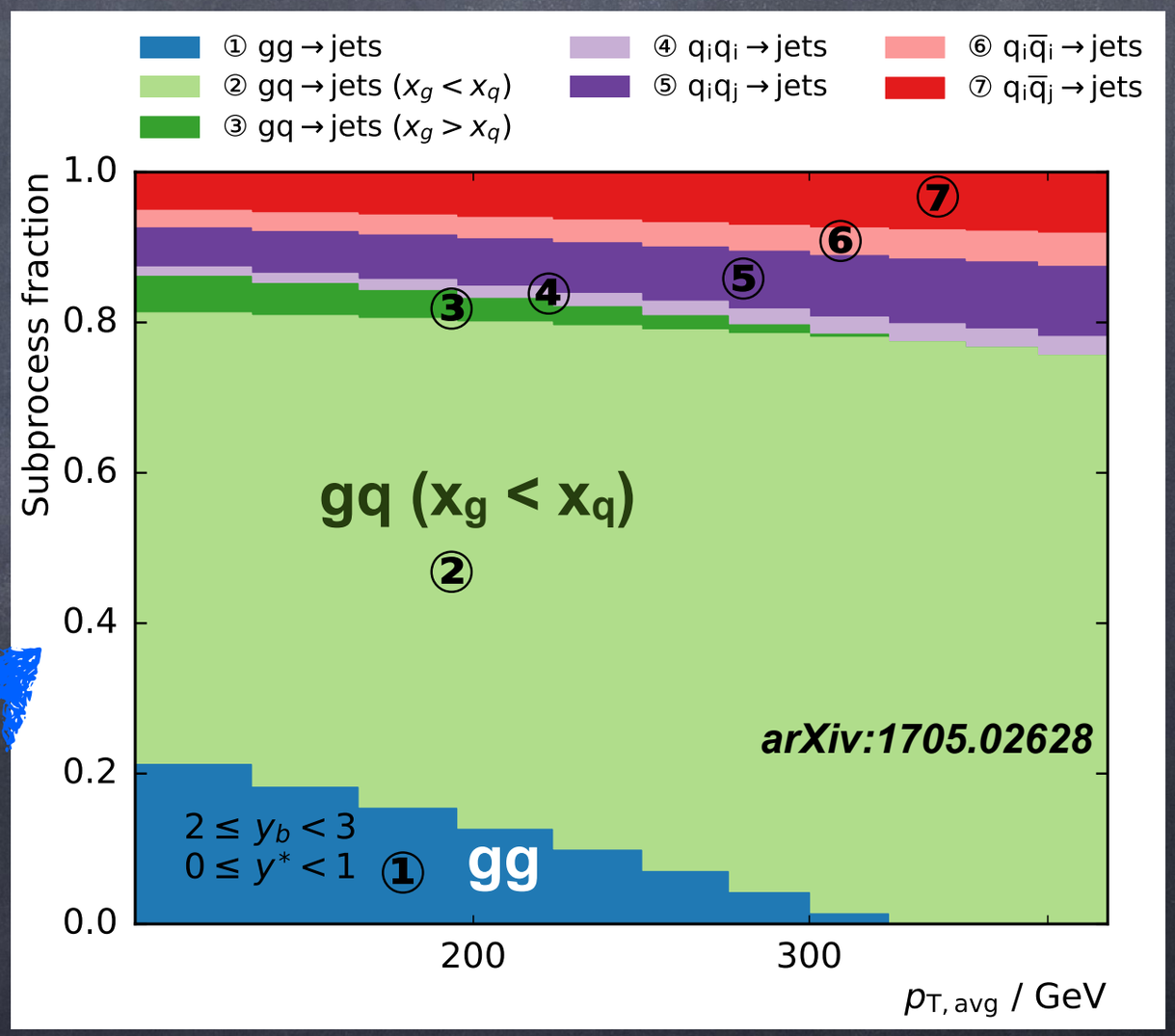
CMS 8 TeV, $\mathcal{L}$ = 19.7 fb^{-1} dijet production: *arXiv:1705.02628 (submitted to EPJC)*

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

for details see talk by P.Kokkas

Probing x_1 and x_2 using different event topologies





Novel technique to access highly boosted regime (x_1 << x_2)

JETS @ CMS: GLUON AND STRONG COUPLING

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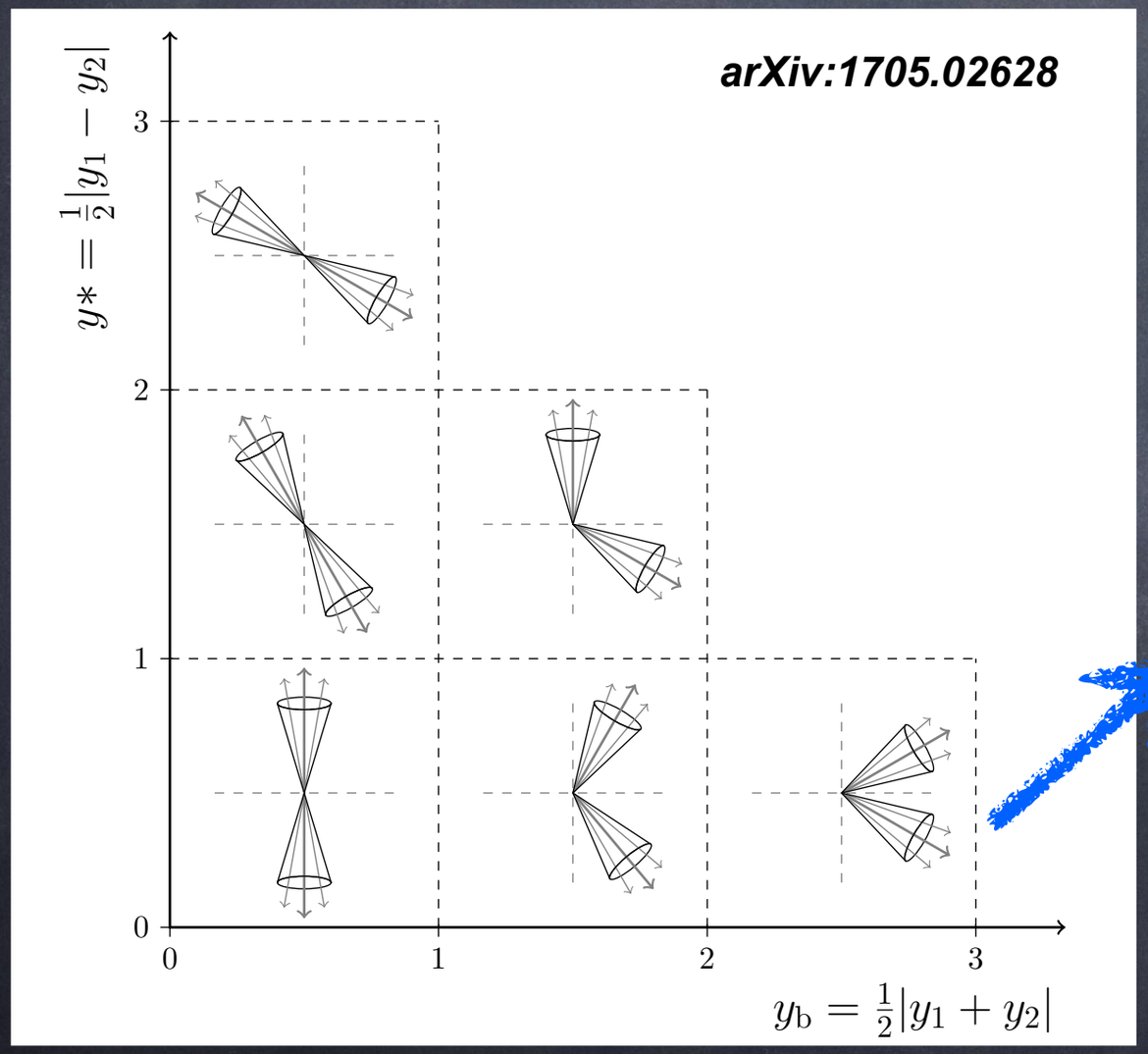
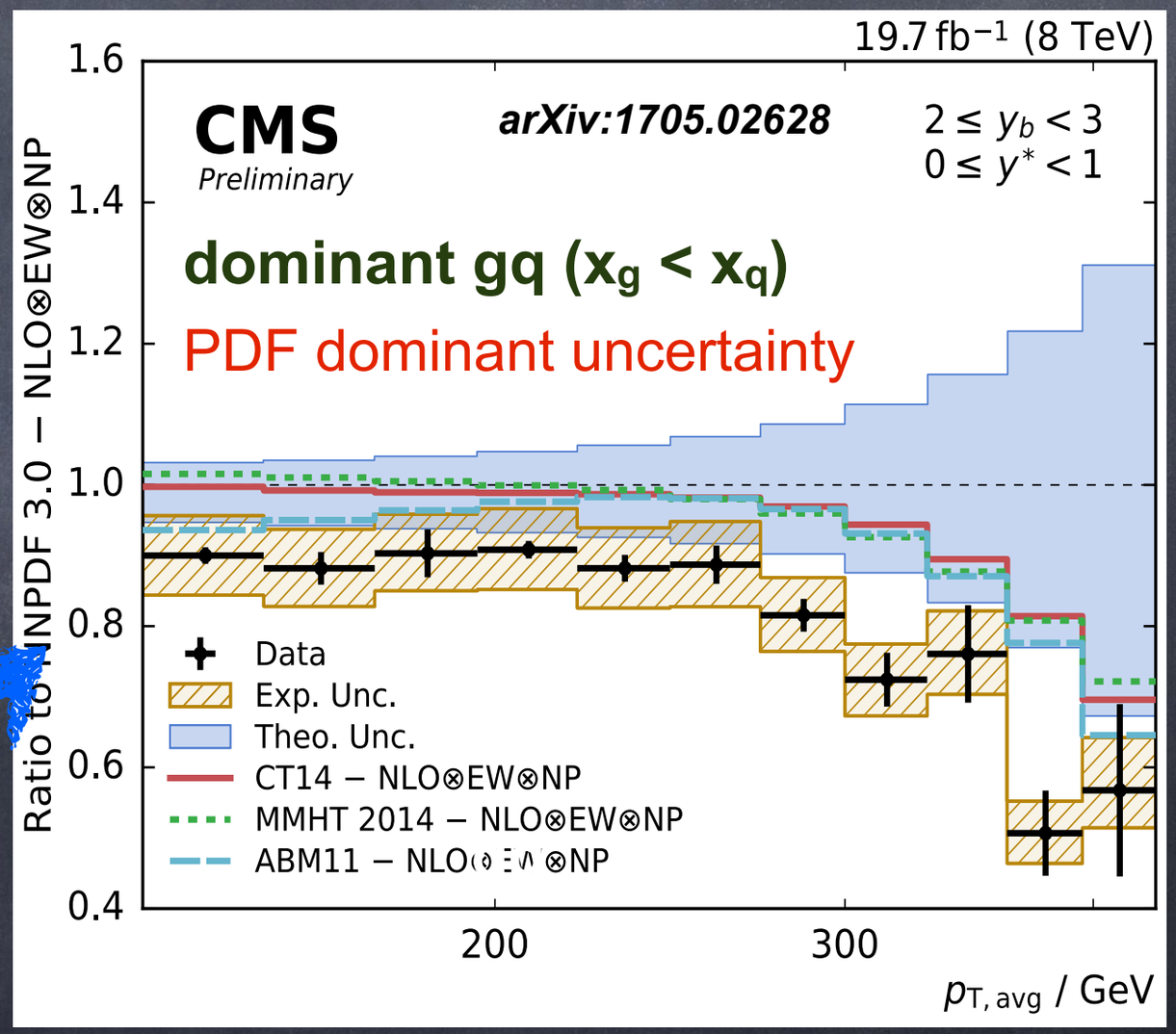
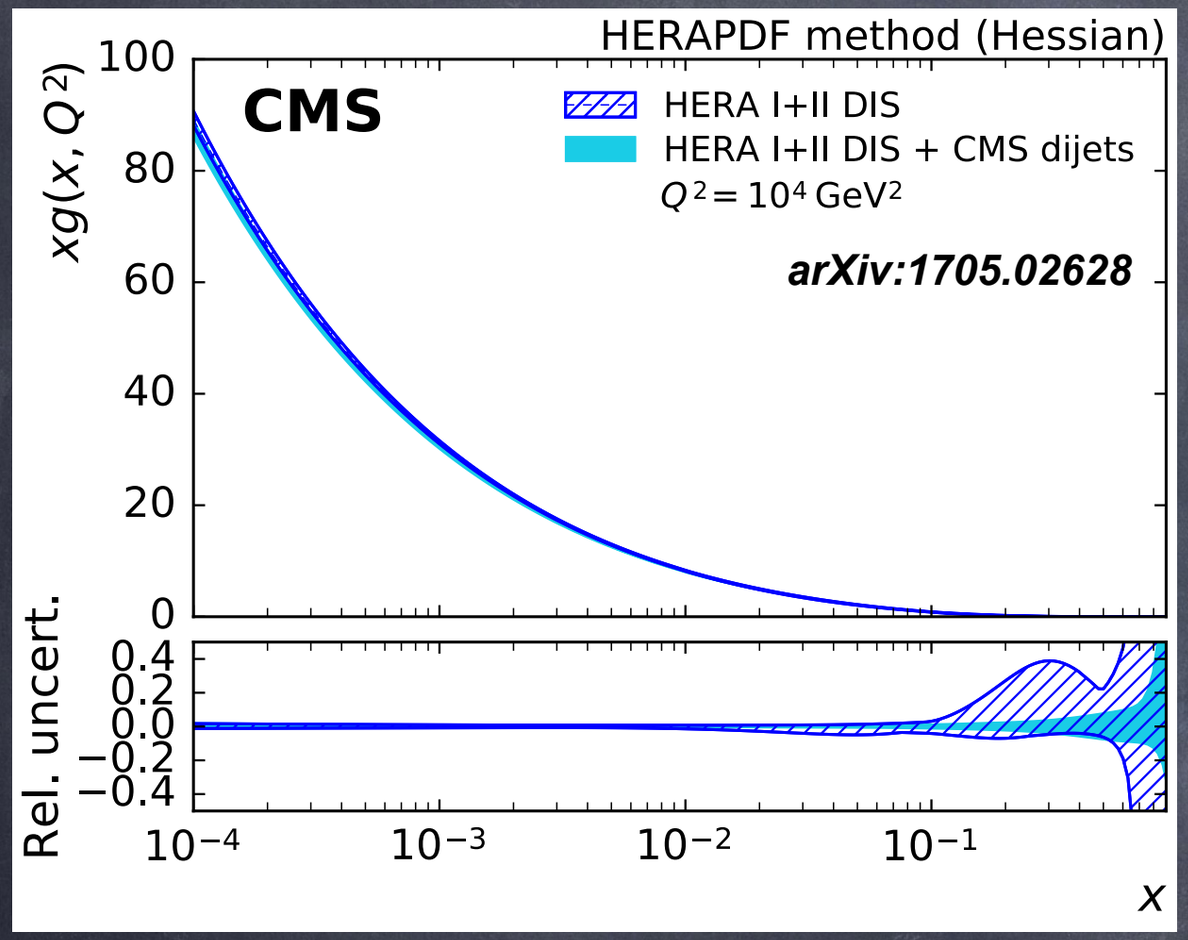
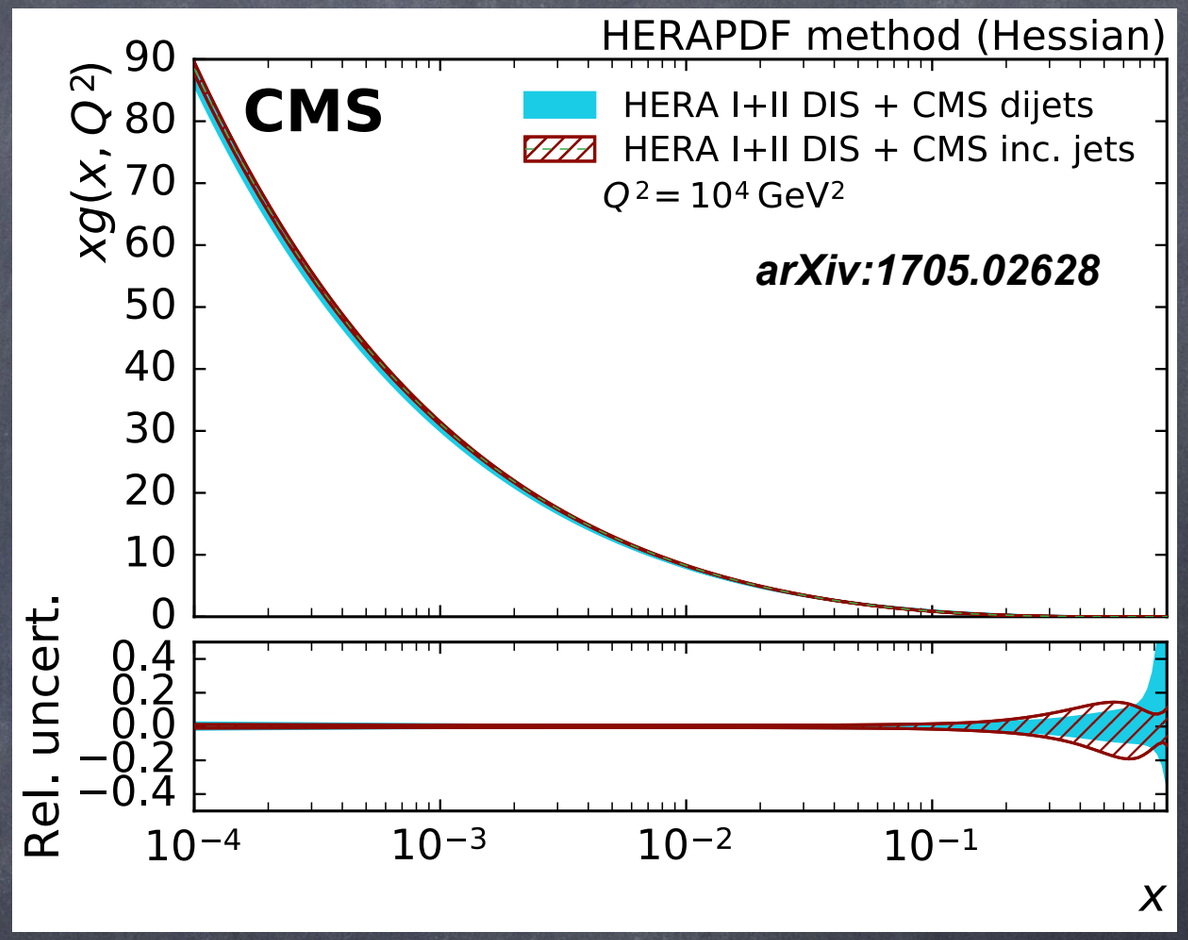




JETS @ CMS: GLUON AND STRONG COUPLING

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:**

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

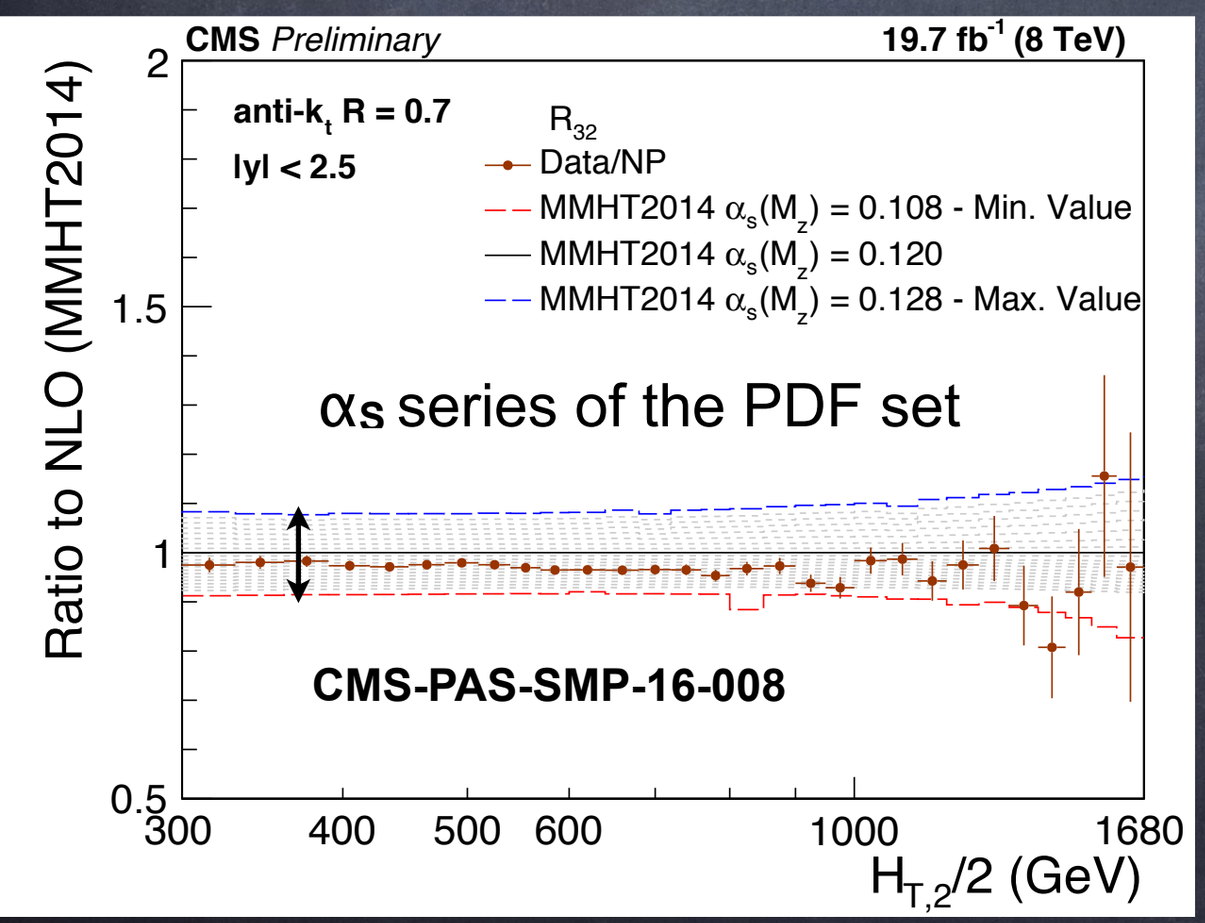
JETS @ CMS: GLUON AND STRONG COUPLING

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

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

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



α_s determined by minimizing χ^2 between the measurement and the theory

MMHT14: χ^2/n_{dof} =24/28

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

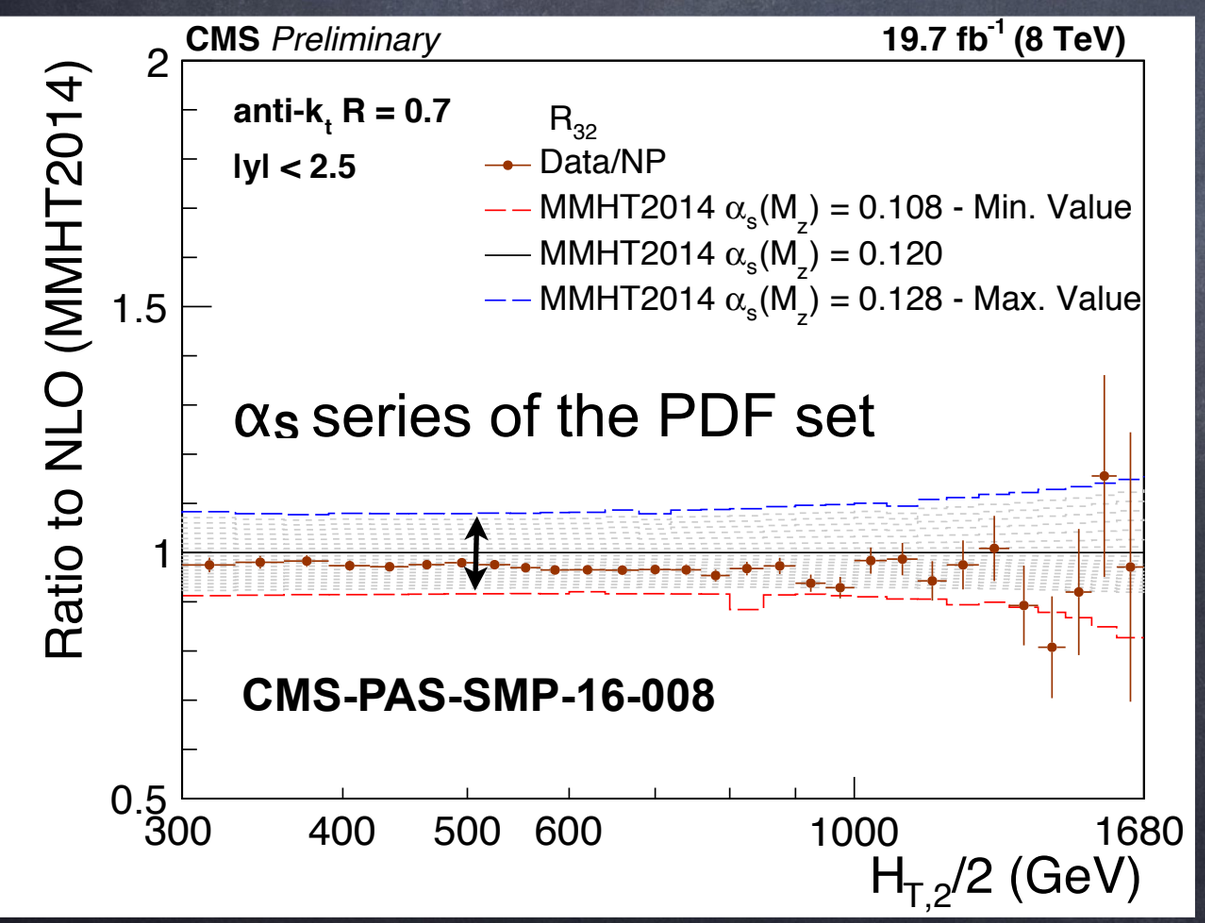
JETS @ CMS: GLUON AND STRONG COUPLING

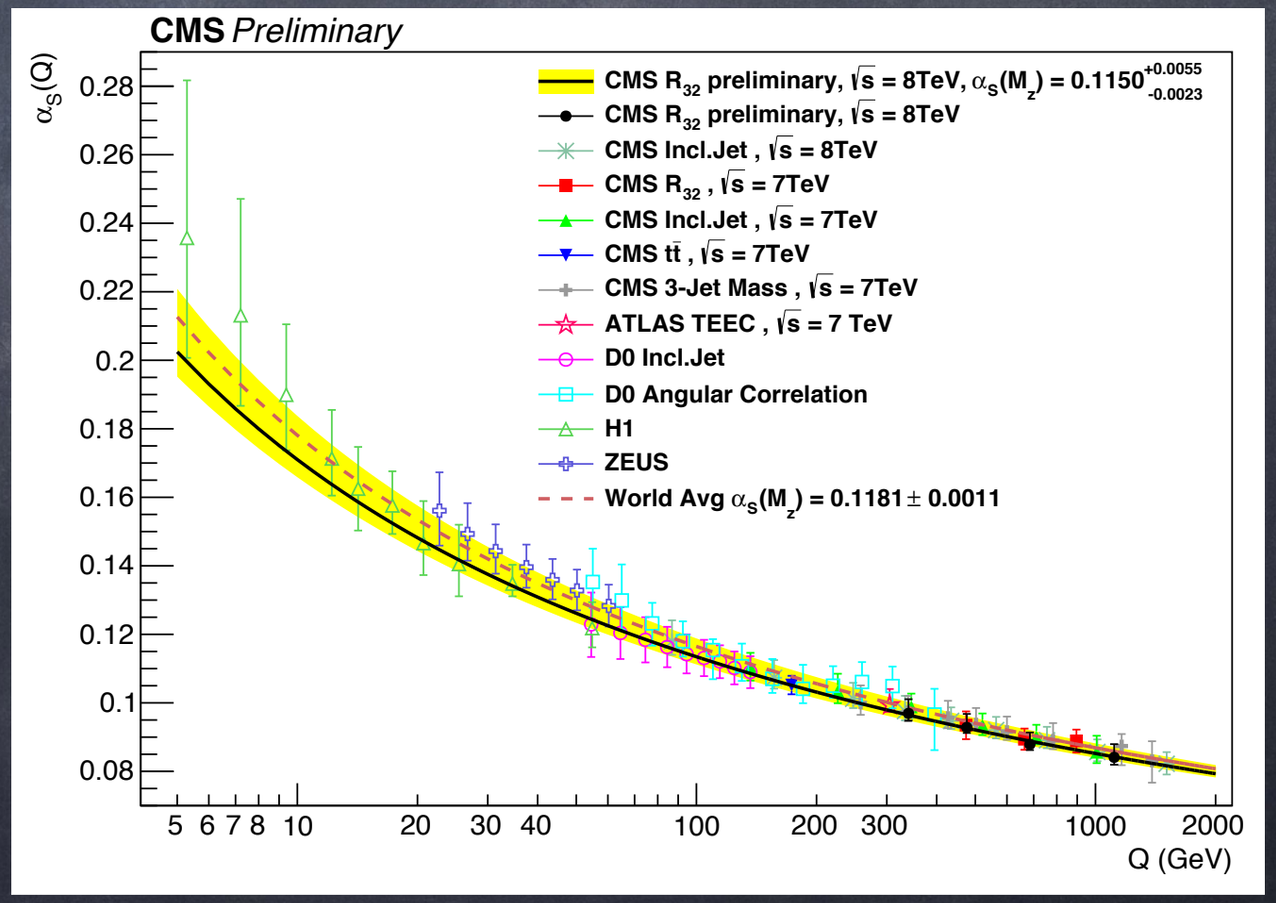
CMS 8 TeV, $\mathcal{L}$ = 19.7 fb^{-1} multi-jet production CMS-PAS-SMP-16-008

Ratio of 3/2 inclusive jet cross sections

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

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

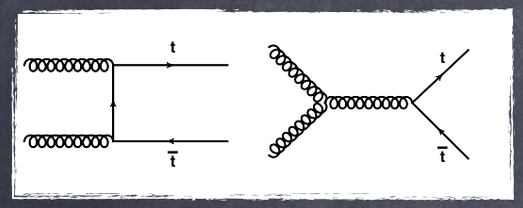




Evolution performed for N_f = 5 at 2-loops

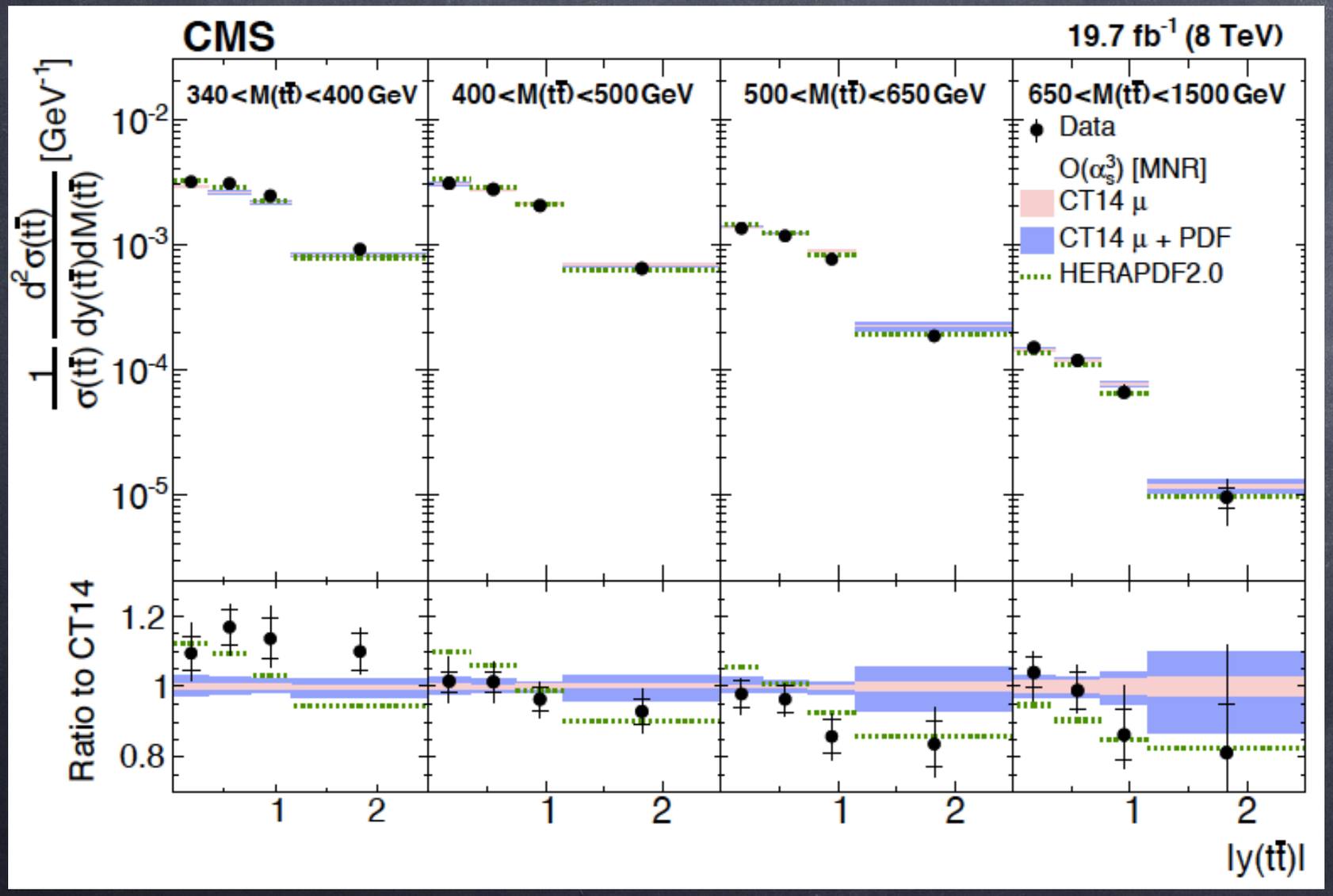
$t\bar{t}$ @ CMS: GLUON DISTRIBUTION AT HIGH X

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} :

2d-differential $t\bar{t}$ cross sections arXiv:1703.01630 (Submitted to EPJC)



M(tt) and y(tt)

most sensitive to PDFs

at LO:

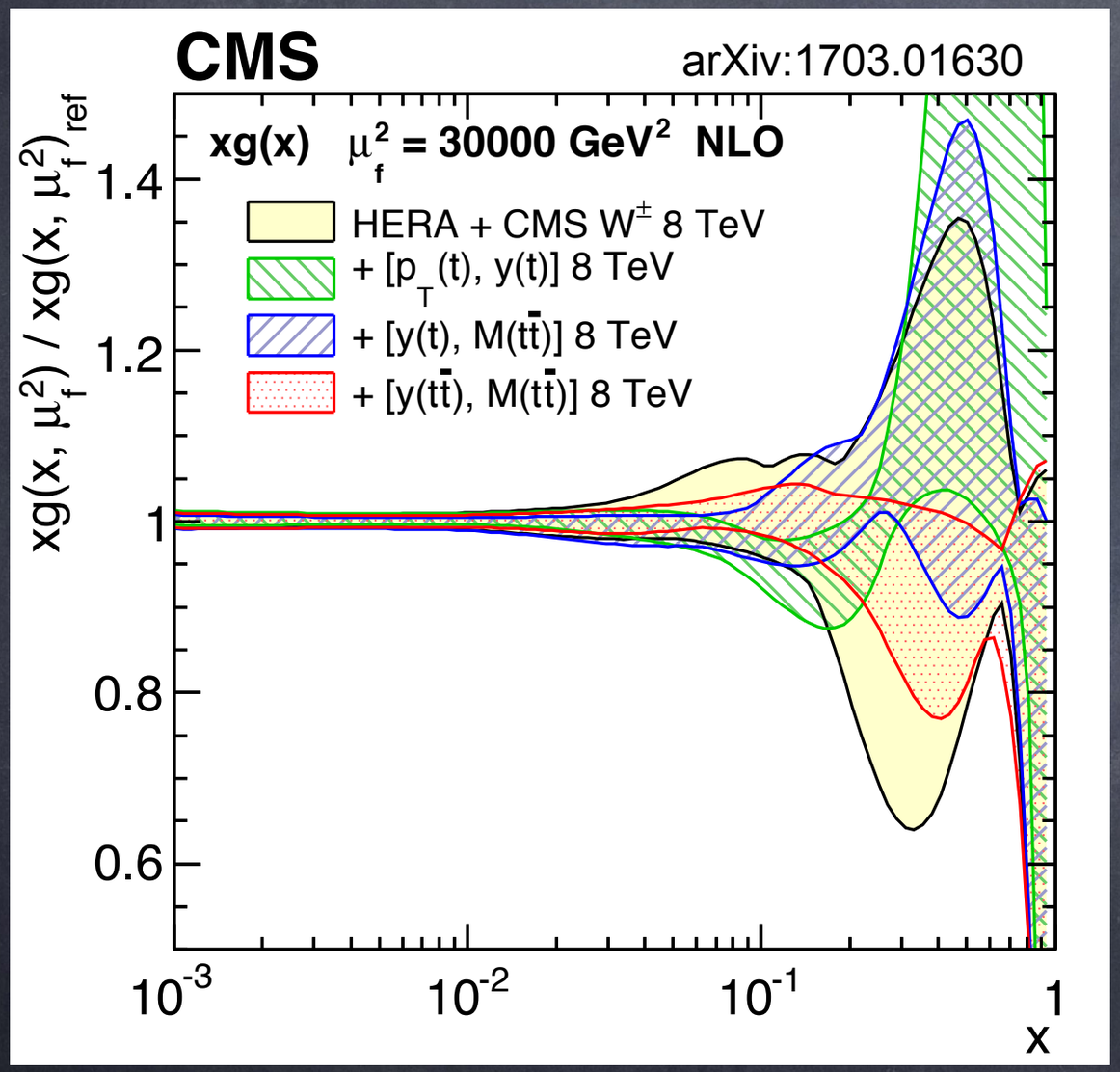
$$x_{1,2} = \frac{M(t\bar{t})}{\sqrt{s}} e^{\pm y(t\bar{t})}$$

	HERA2	CT14
χ^2 (dof = 15)	29	16

for details see talk T.Arndt

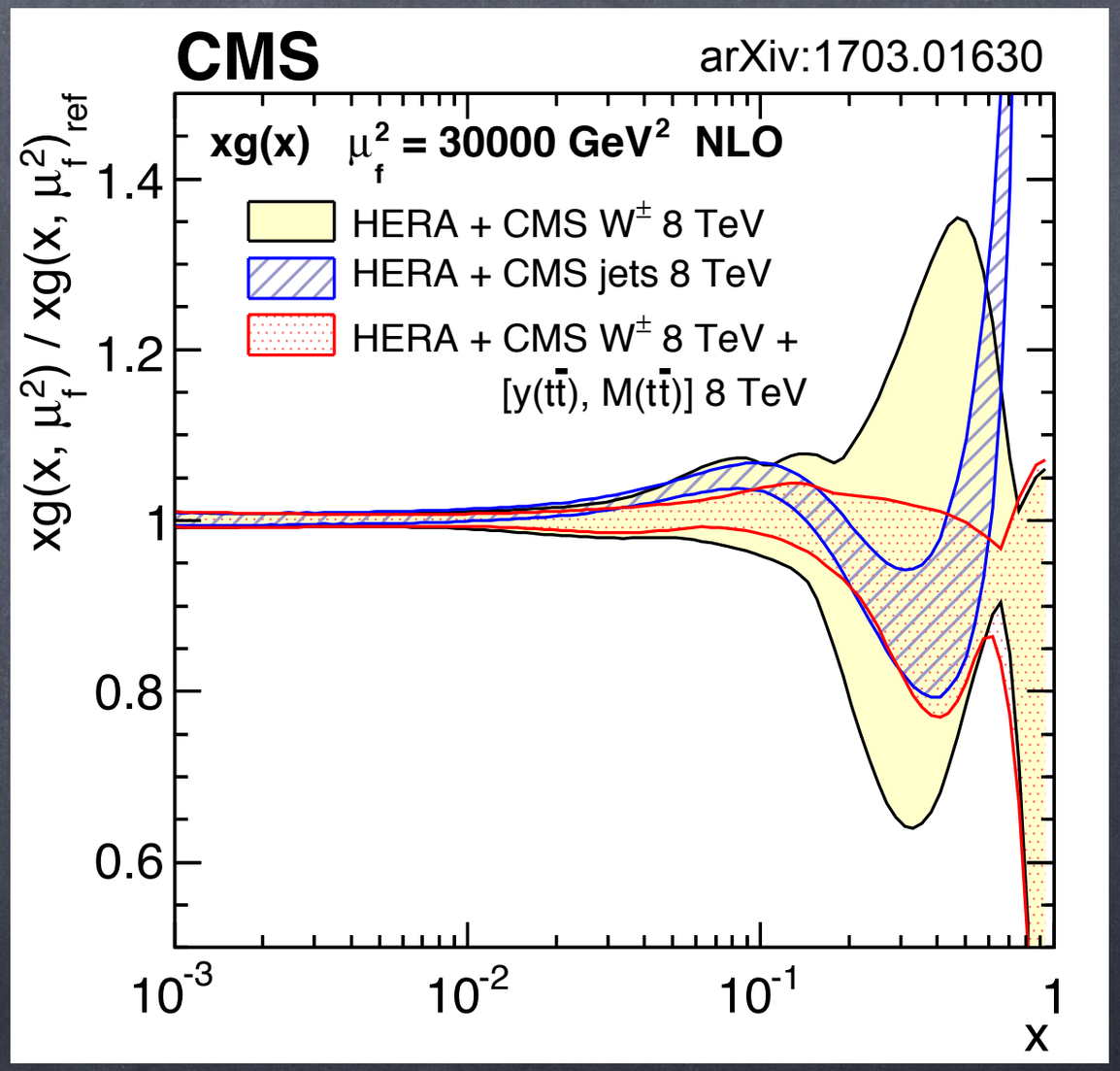
$t\bar{t}$ @ CMS: GLUON DISTRIBUTION AT HIGH X

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}

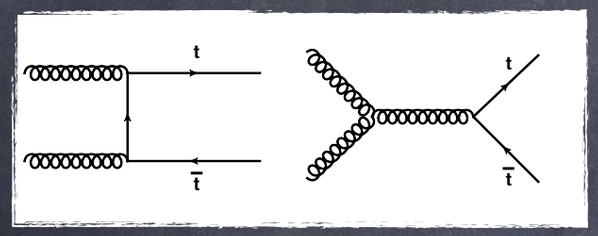
Results compared to those obtained by using inclusive jets @ 8 TeV



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



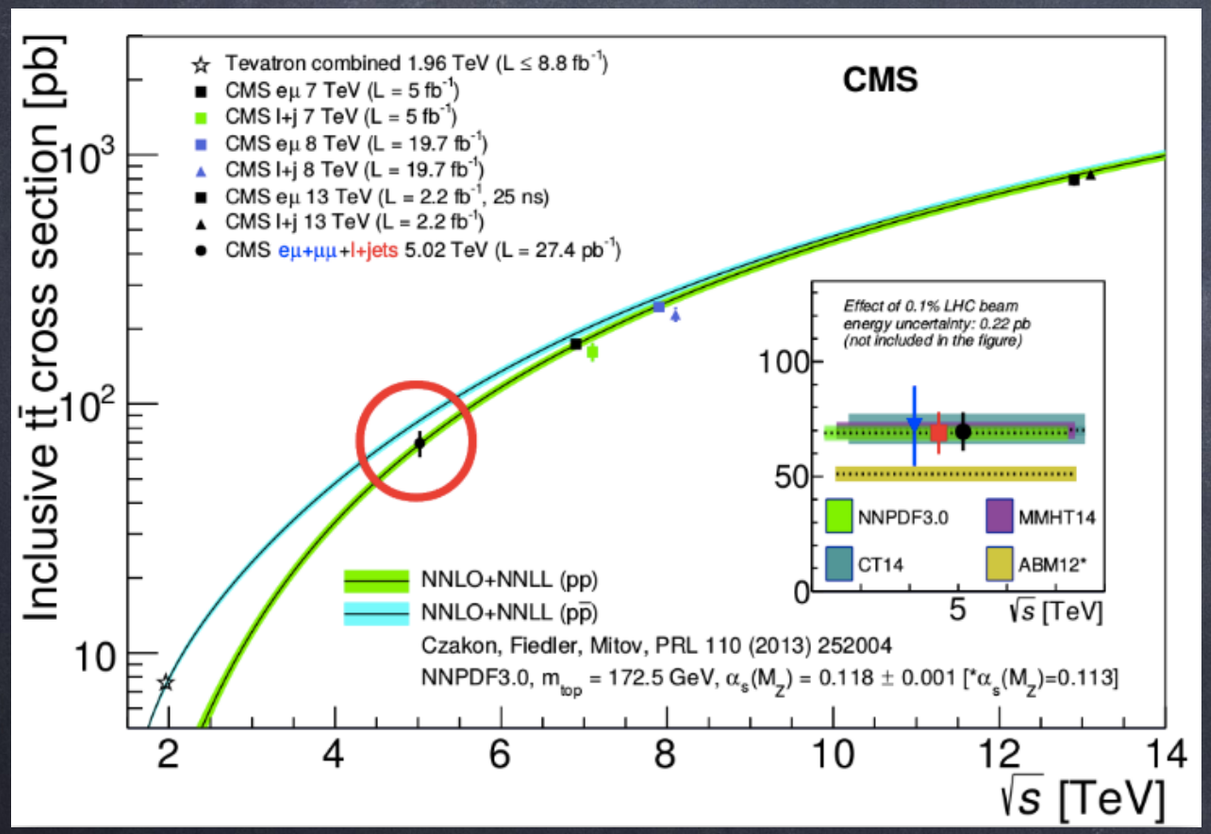
CMS 5.02 TeV, $\mathcal{L}$ = 27.4 pb^{-1} CMS-PAS-TOP-16-023

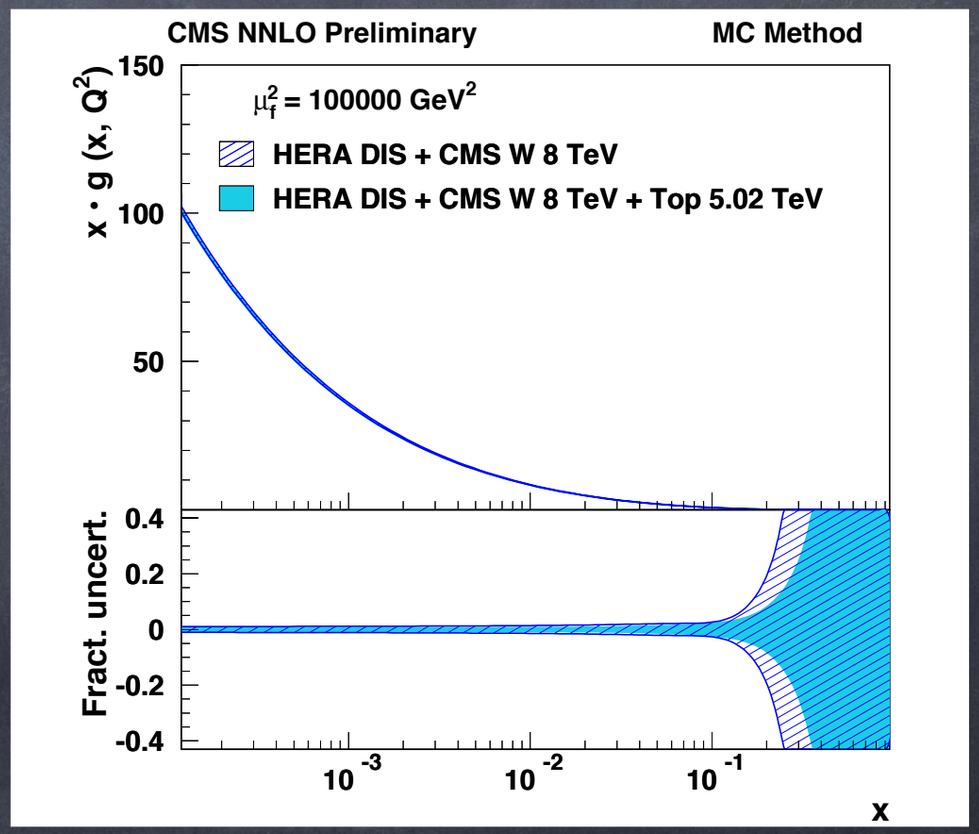
for details see talk T.Arndt

XFitter 2.0.0

theory: HATHOR, m_t=172.5 GeV

new kinematic range probed





modest effect on g(x) at high x

SUMMARY

LHC Run I CMS data used for improvement of PDF accuracy

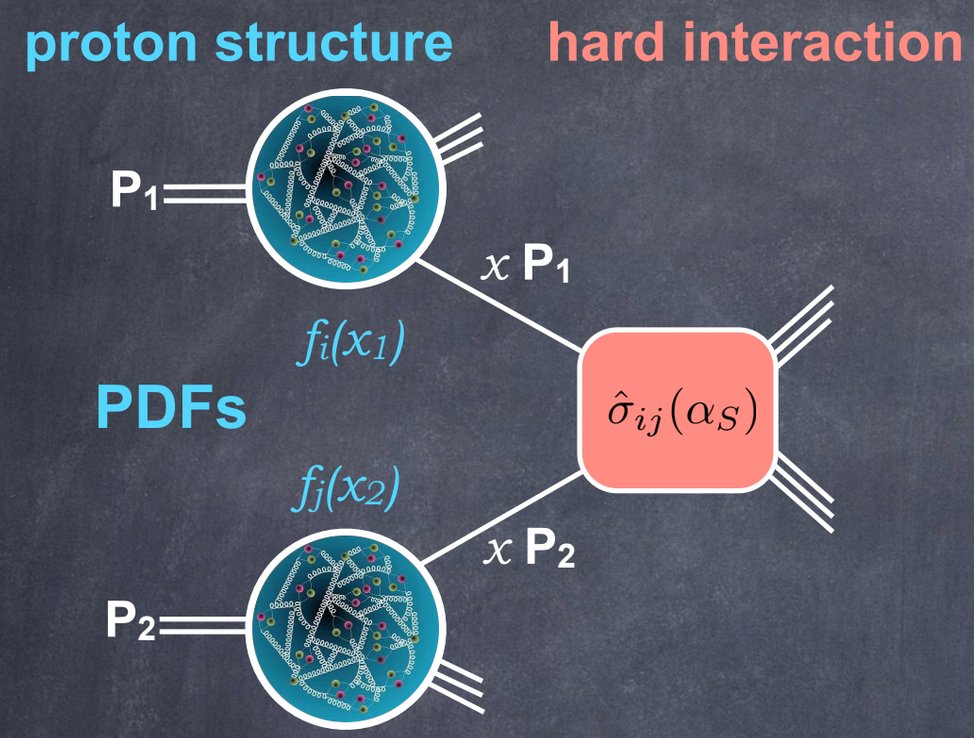
- jet data: gluon at medium & high x, strong coupling
  → getting even more interesting with available NNLO calculation
- top quark pairs : gluon at high x

LHC Run II CMS data is forthcoming

Run I has shown high potential of the LHC
to improve the understanding of the proton structure,
more data are still to come to be used in precision QCD analyses

BACK UP

NEED FOR EXPERIMENTAL INPUT



Partons: quarks & gluons

Q^2 : typical energy scale in the process

x : partonic fraction of the proton momentum

Rate = (structure of 2 protons) $\otimes$ σ_{ij}

Parton Distribution Functions

$f_i(Q^2, x)$

provided by theory

determined experimentally

at the very edge of theory and experiment, correlated with fundamental QCD parameters

Improvement of PDFs precision demands theory & experiment collaboration and implies a variety of measurements and theory calculations

JETS @ CMS: GLUON AND STRONG COUPLING

QCD analysis: XFitter 1.2. 2, baseline data HERA inclusive DIS [EPJ C 75 (2015) 580]

Theory via NLOJet++ via fastNLO, scale $\mu_r = \mu_f = p_{T,max} \cdot e^{0.3y^*}$

Q^2_0=1.9 GeV^2 :

$$xg(x) = A_g x^{B_g}(1-x)^{C_g} - A'_g x^{B'_g}(1-x)^{C'_g},$$
$$xu_v(x) = A_{u_v} x^{B_{u_v}}(1-x)^{C_{u_v}}(1+D_{u_v}x+E_{u_v}x^2),$$
$$xd_v(x) = A_{d_v} x^{B_{d_v}}(1-x)^{C_{d_v}}(1+D_{d_v}x),$$
$$x\overline{U}(x) = A_{\overline{U}} x^{B_{\overline{U}}}(1-x)^{C_{\overline{U}}}(1+D_{\overline{U}}x),$$
$$x\overline{D}(x) = A_{\overline{D}} x^{B_{\overline{D}}}(1-x)^{C_{\overline{D}}},$$

$x\overline{U}(x) = x\bar{u}(x)$, and $x\overline{D}(x) = x\bar{d}(x) + x\bar{s}(x)$

$B_{\overline{U}} = B_{\overline{D}}$ and $A_{\overline{U}} = A_{\overline{D}}(1-f_s)$

$Bd_v \neq Bu_v$

$\Rightarrow$ 16-parameter fit

Data are consistent
very good fit quality
for the CMS jet data

arXiv:1705.02628

data set	n_{data}	HERA data χ^2_p	HERA data χ^2_p/n_{data}	HERA & CMS data χ^2_p	HERA & CMS data χ^2_p/n_{data}
NC HERA-I+II e^+p $E_p = 920$ GeV	332	382.44	1.15	406.45	1.22
NC HERA-I+II e^+p $E_p = 820$ GeV	63	60.62	0.96	61.01	0.97
NC HERA-I+II e^+p $E_p = 575$ GeV	234	196.40	0.84	197.56	0.84
NC HERA-I+II e^+p $E_p = 460$ GeV	187	204.42	1.09	205.50	1.10
NC HERA-I+II e^-p	159	217.27	1.37	219.17	1.38
CC HERA-I+II e^+p	39	43.26	1.11	42.29	1.08
CC HERA-I+II e^-p	42	49.11	1.17	55.35	1.32
CMS Triple-Differential Dijets	122	—	—	111.13	0.91

data set(s)	n_{dof}	χ^2	χ^2/n_{dof}	χ^2	χ^2/n_{dof}
HERA data	1040	1211.00	1.16	—	—
HERA & CMS data	1162	—	—	1372.52	1.18

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