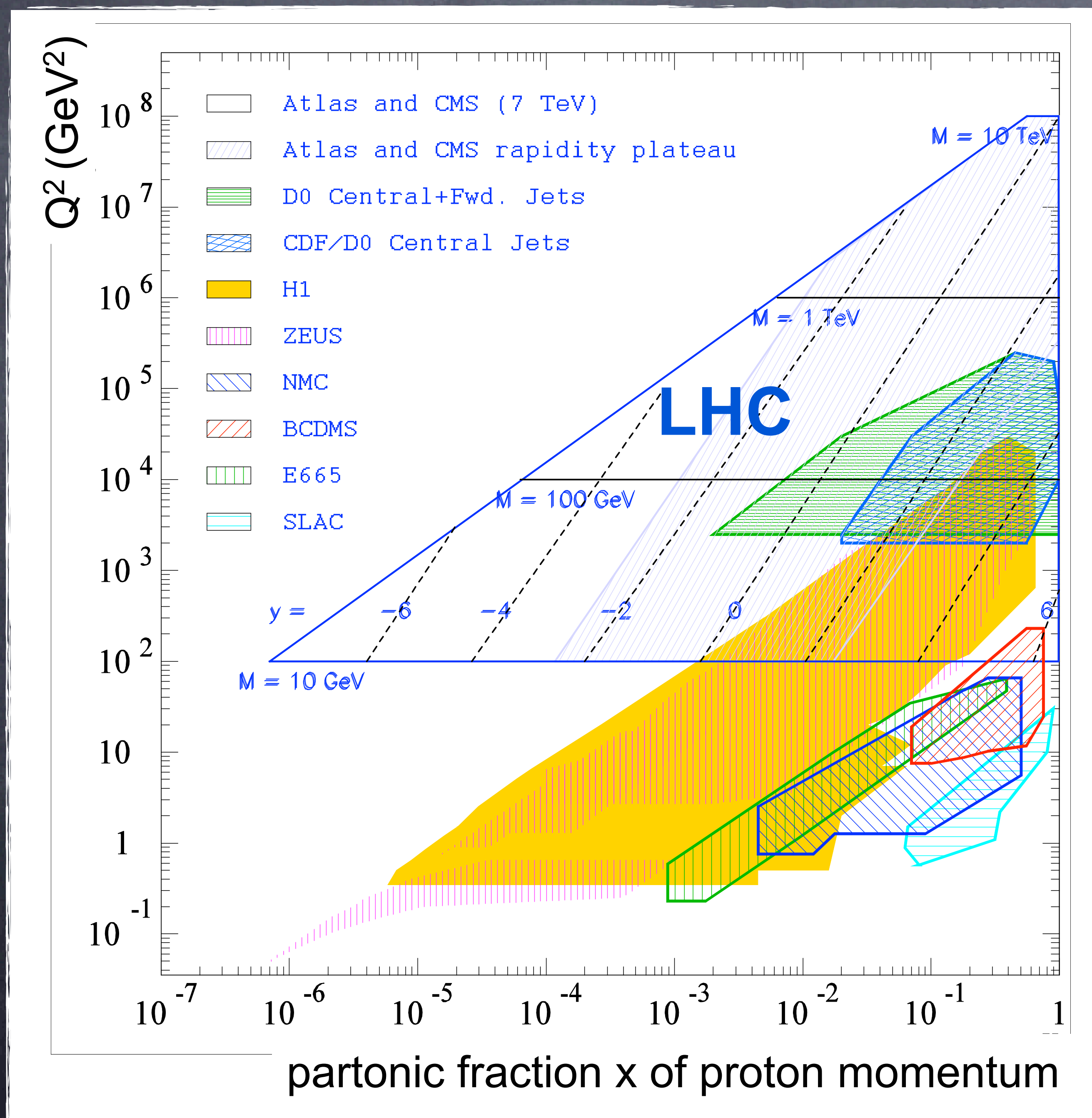
Impact of CMS Measurements on Parton Distribution Functions and QCD parameters

Katerina Lipka
on behalf of the CMS Experiment

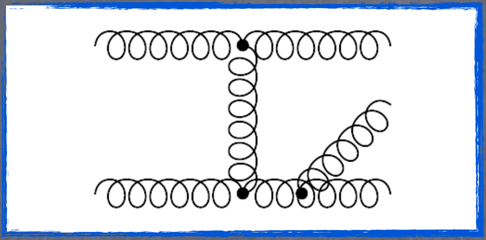
DIS Workshop, Birmingham 2017

PDF CONSTRAINTS FROM LHC

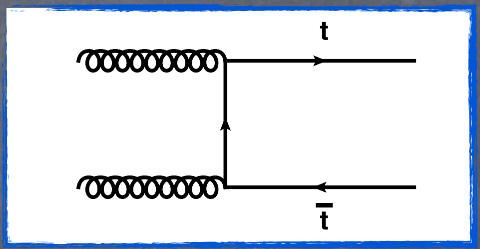
need improvements in
quark flavor separation at medium x,
gluon at low and at high x
➡ impact of the LHC measurements



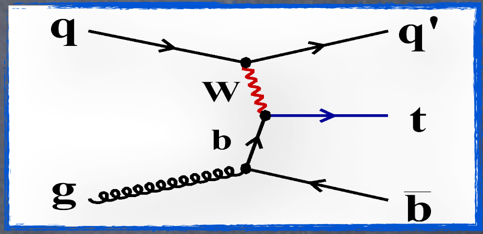
- jets: gluon, α_S
  medium-high x



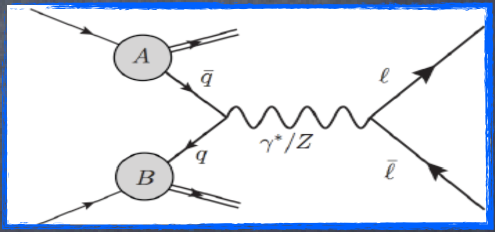
- top-pairs: gluon
  high x



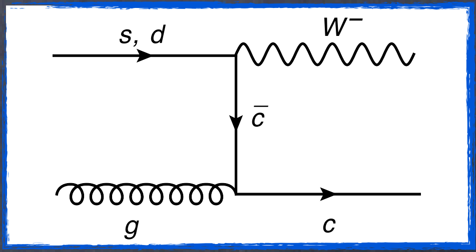
- single top: u, d, b



- DY: light quarks,
  flavor separation,
  gluon



- V+HQ: s-quark,
  intrinsic charm



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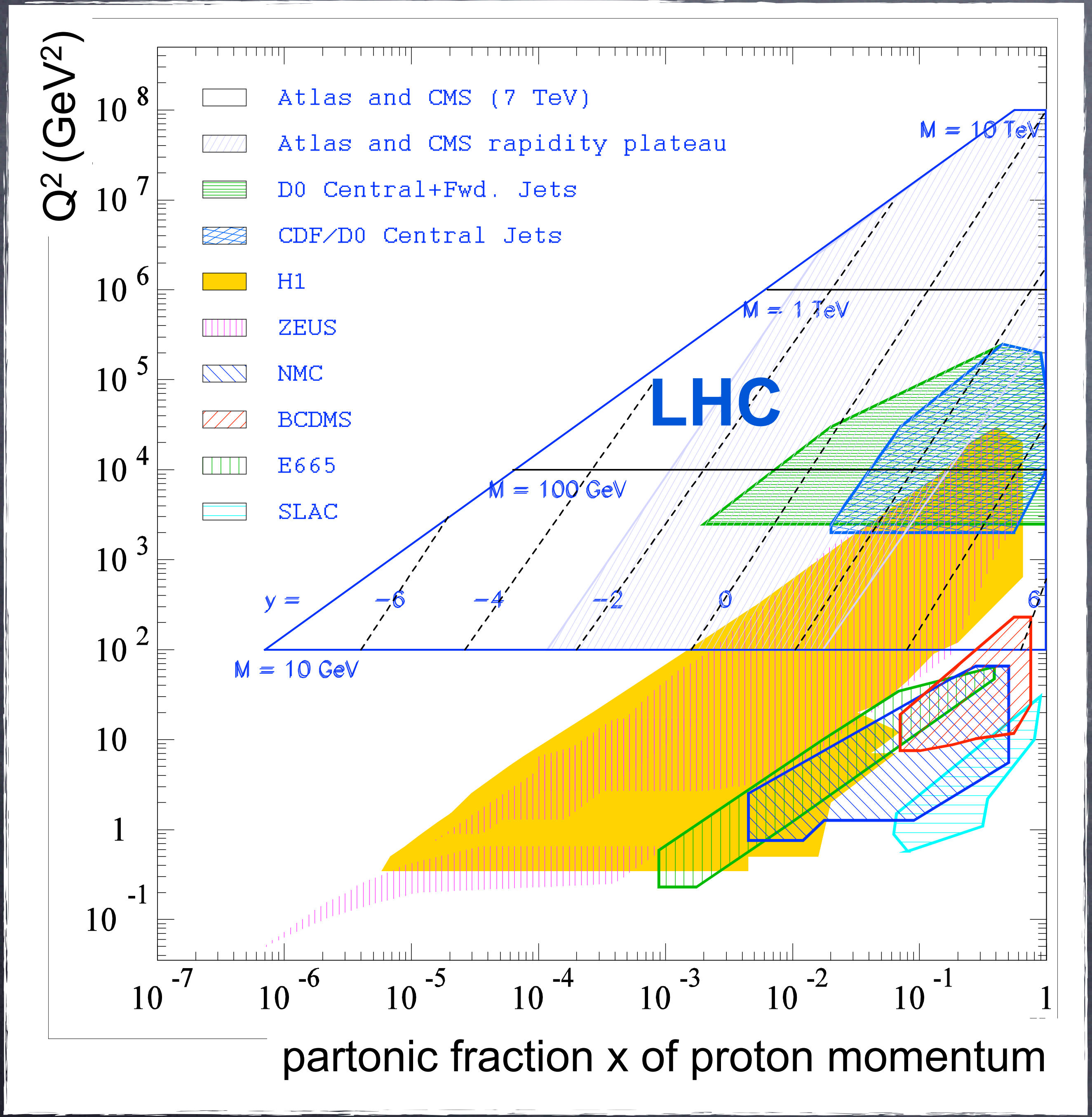
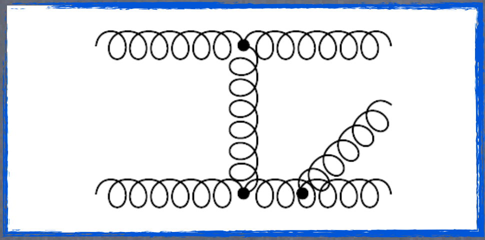


LHC Run I : mission accomplished
new since last DIS:

- jets: gluon, α_S
  medium-high x



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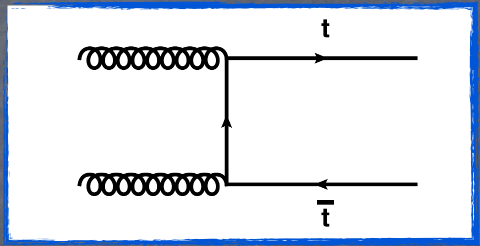

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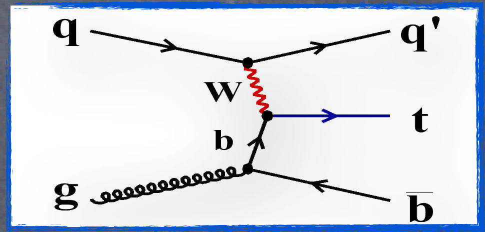

- DY+J: light quarks,
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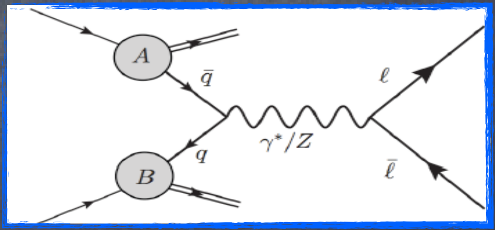

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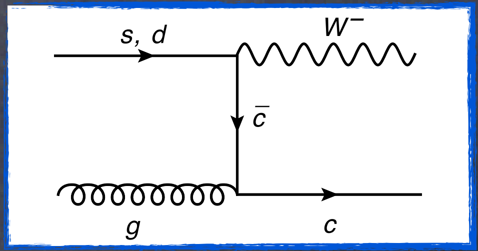
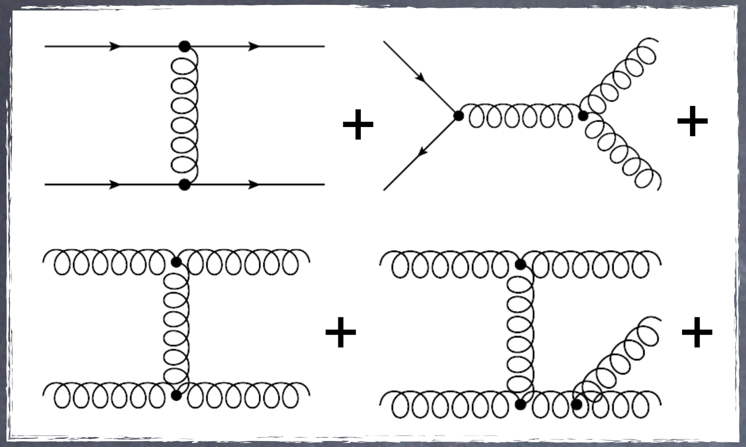


see talk B. Roland

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} :

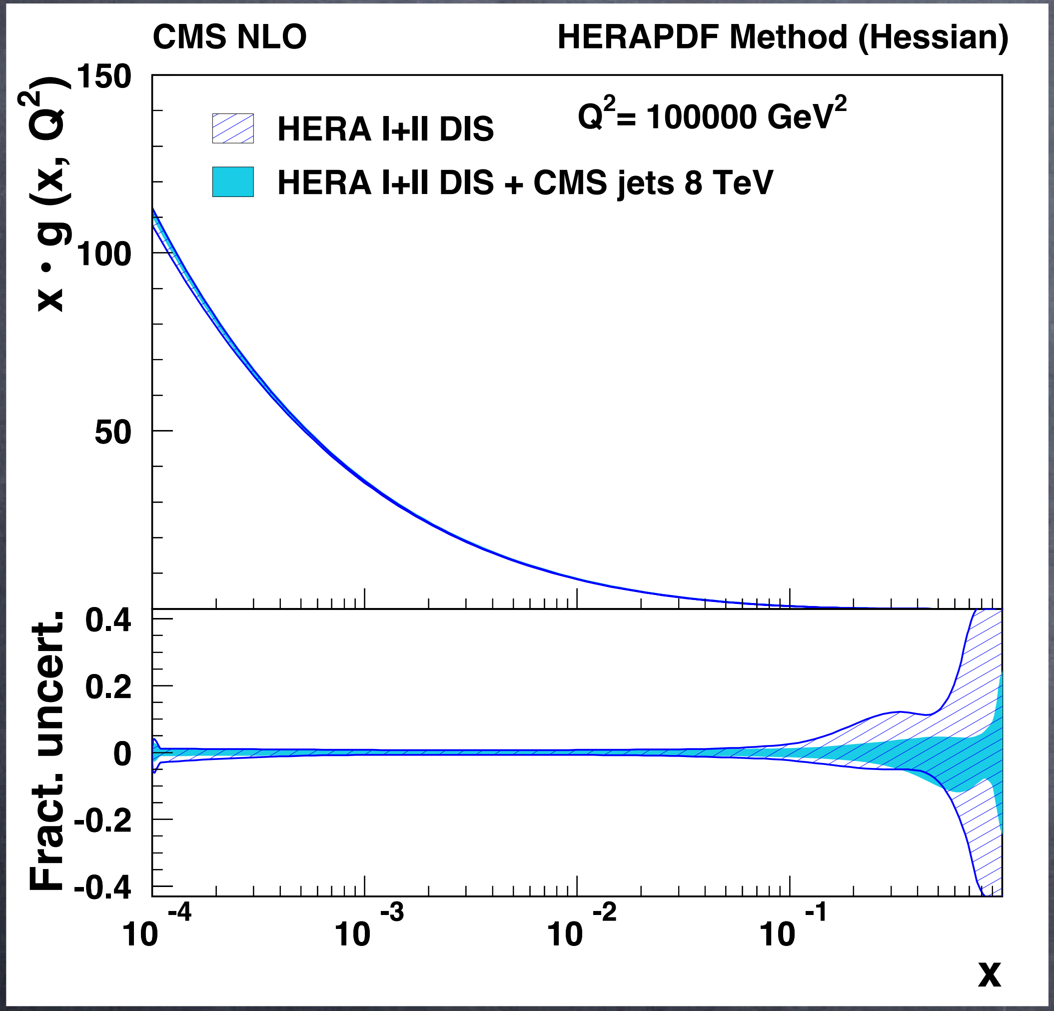
inclusive jet production *arXiv:1609.05331*
dijet production: CMS-PAS-SMP-16-011
multijet production: CMS-PAS-SMP-16-008

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:

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

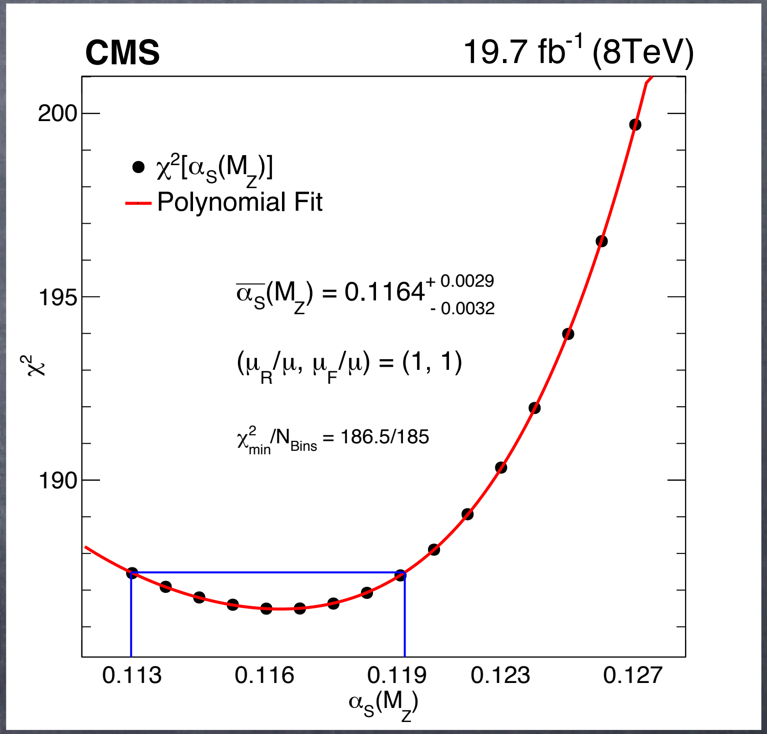
using fixed PDFs:

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

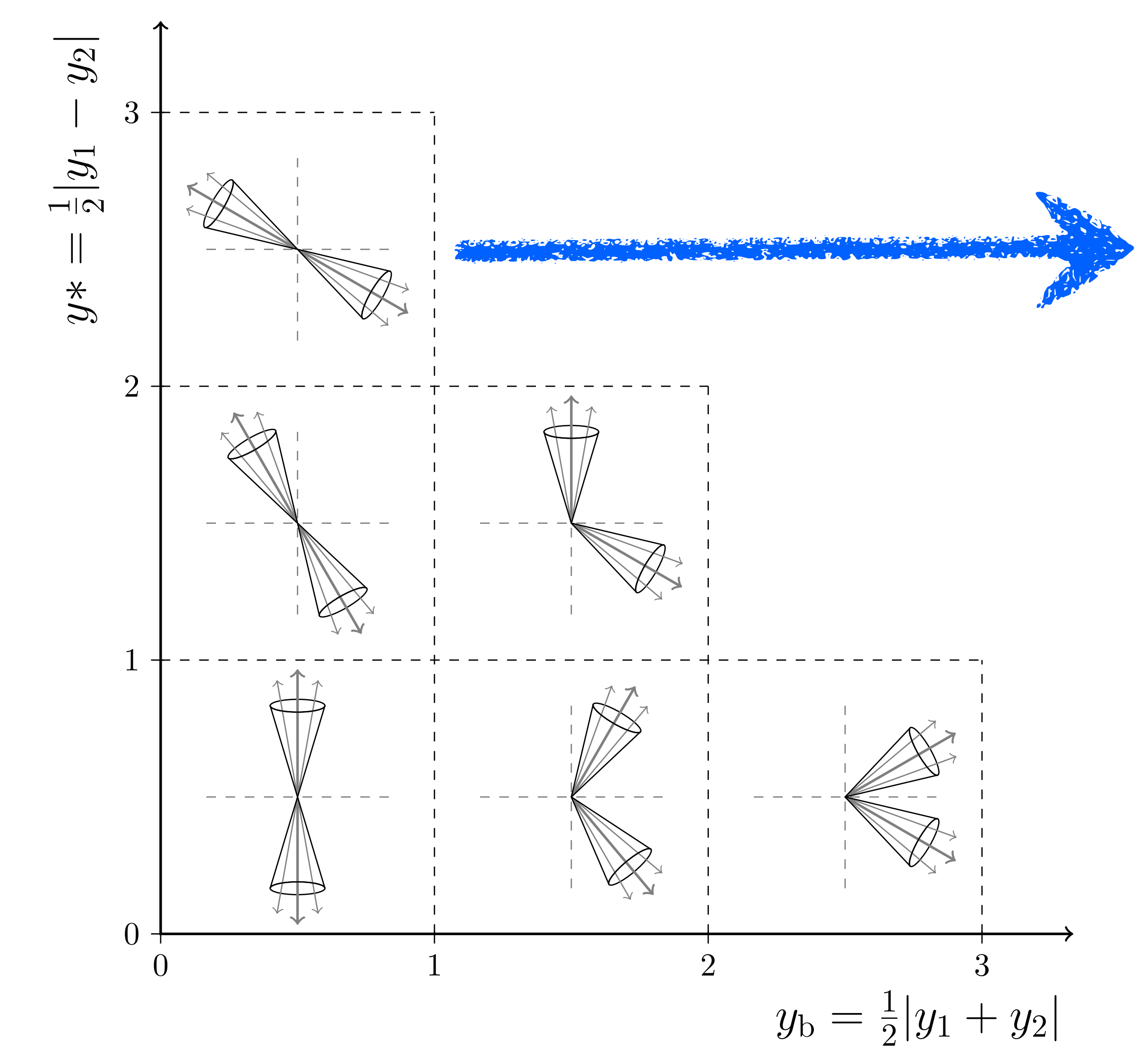
JETS @ CMS: GLUON AND STRONG COUPLING

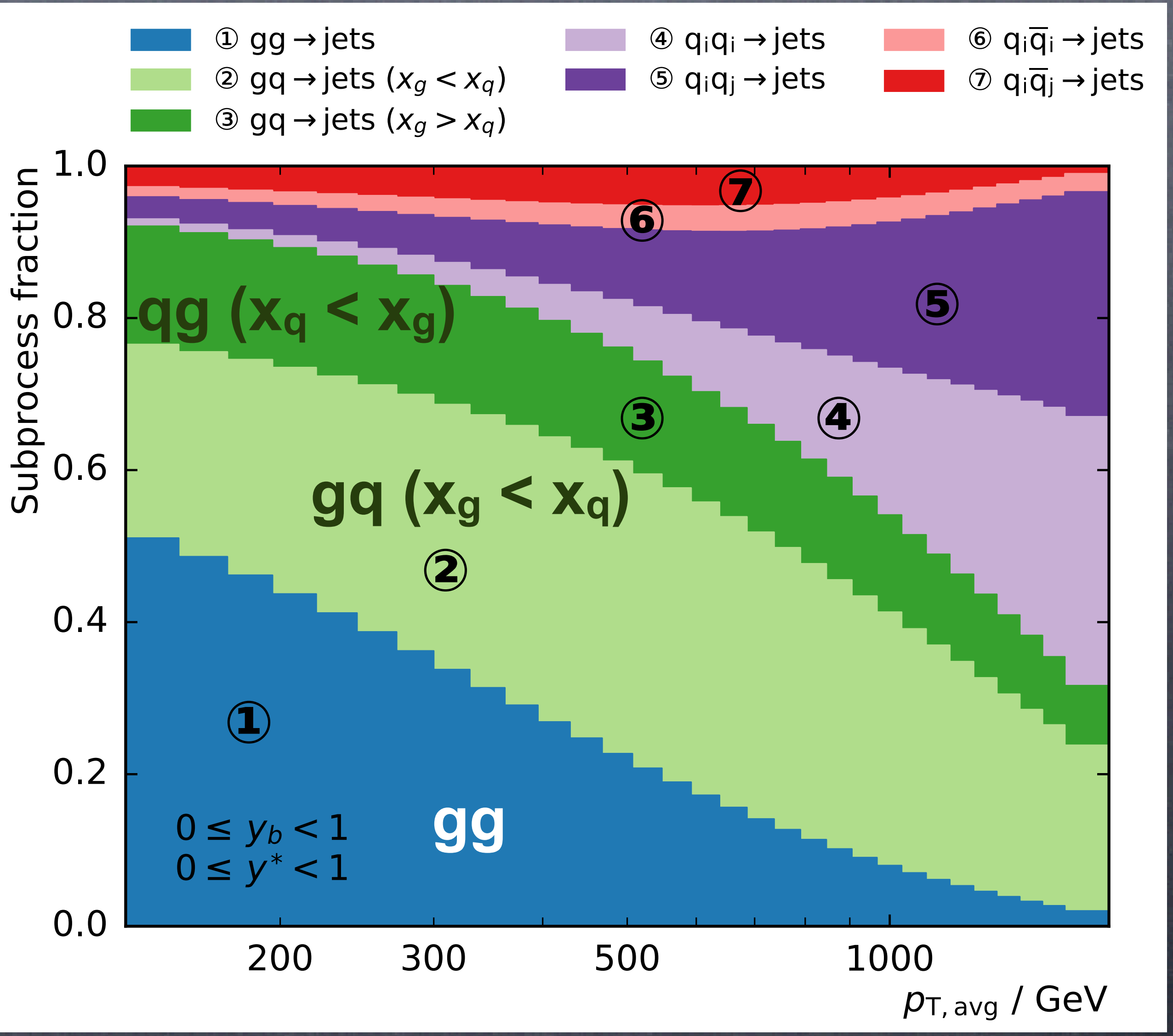
CMS 8 TeV, $\mathcal{L}$ = 19.7 fb^{-1} dijet production: CMS-PAS-SMP-16-011

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

for details see talk E. Eren

Probing x_1 and x_2 using different event topologies





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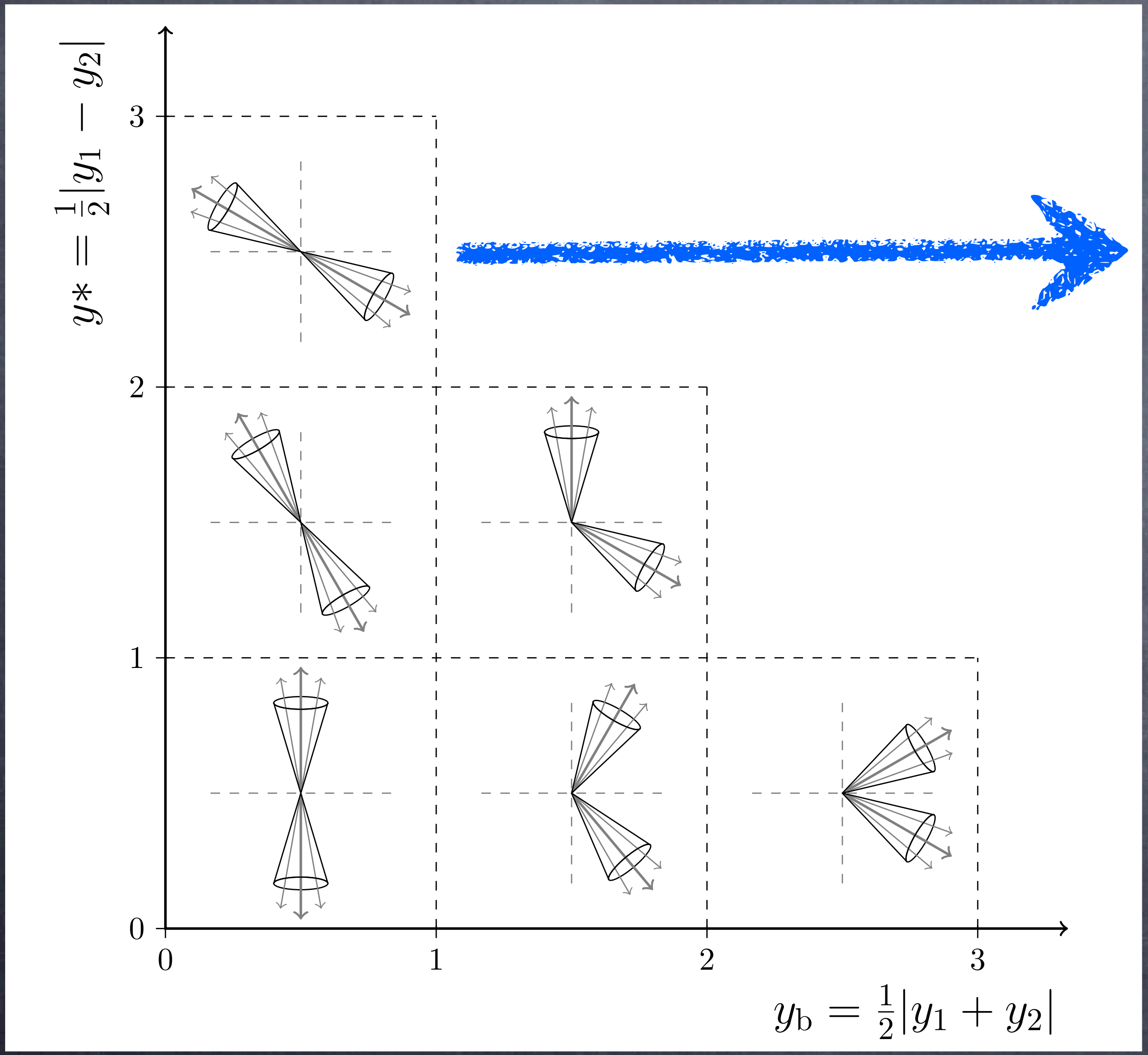

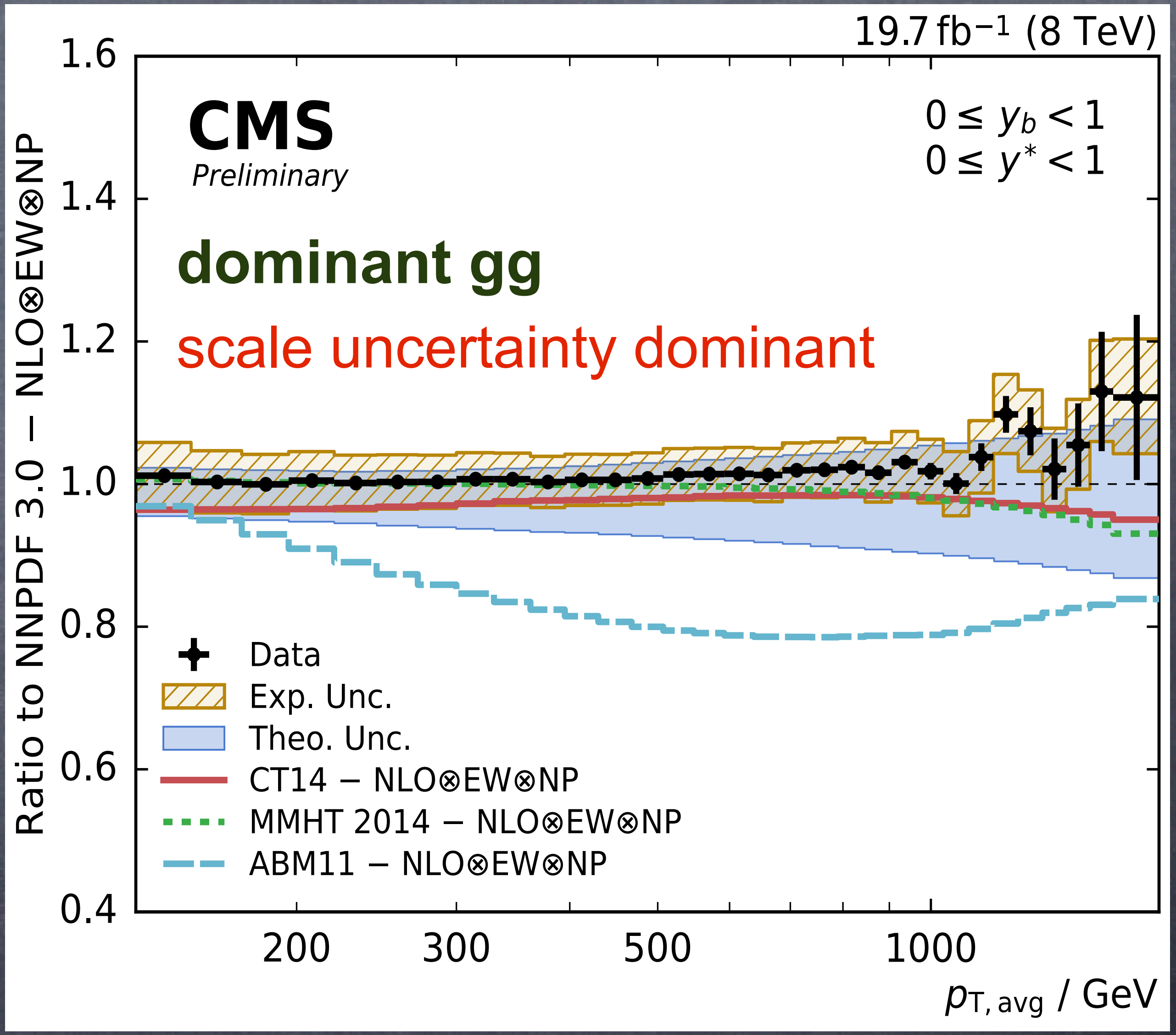

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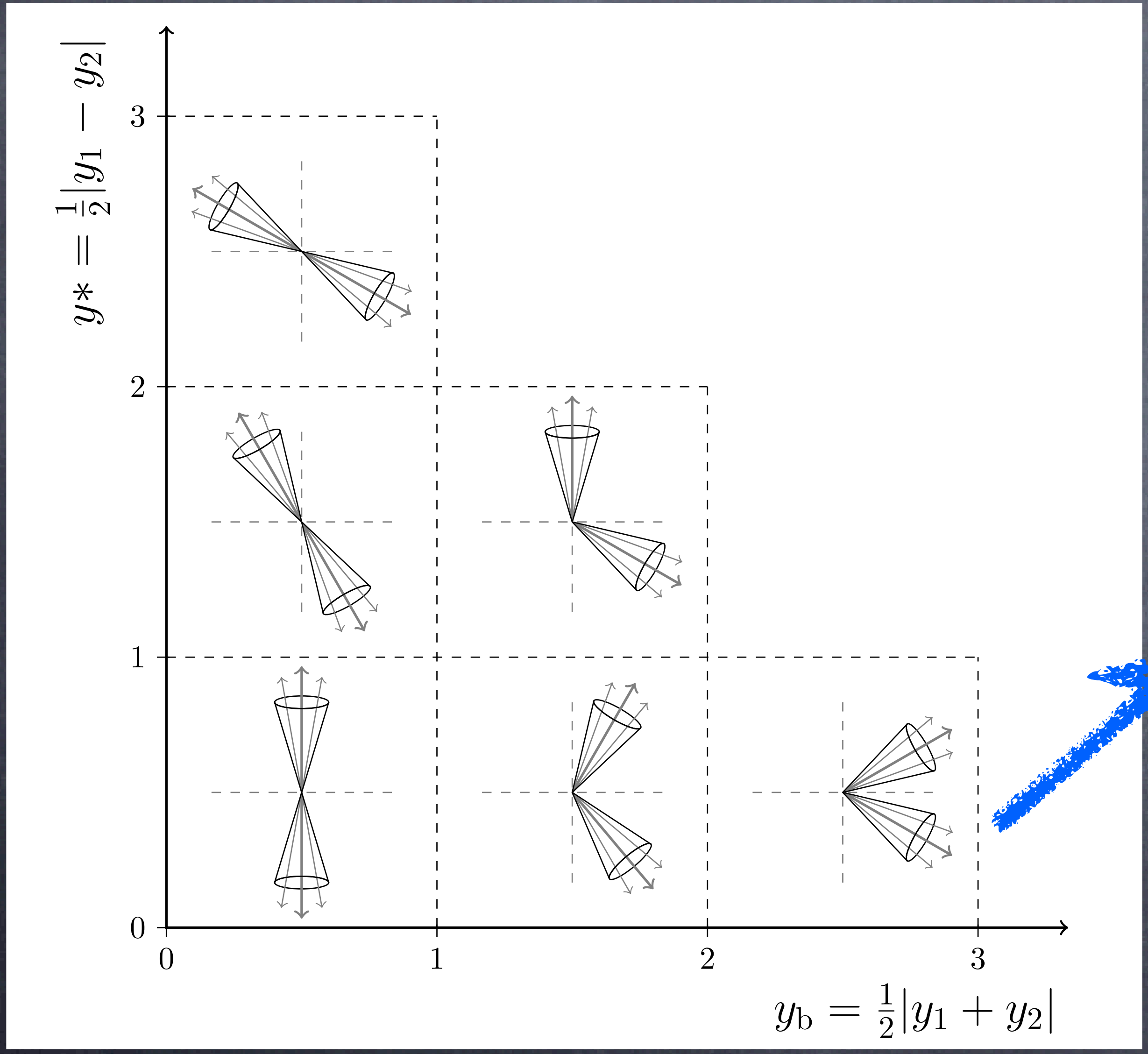

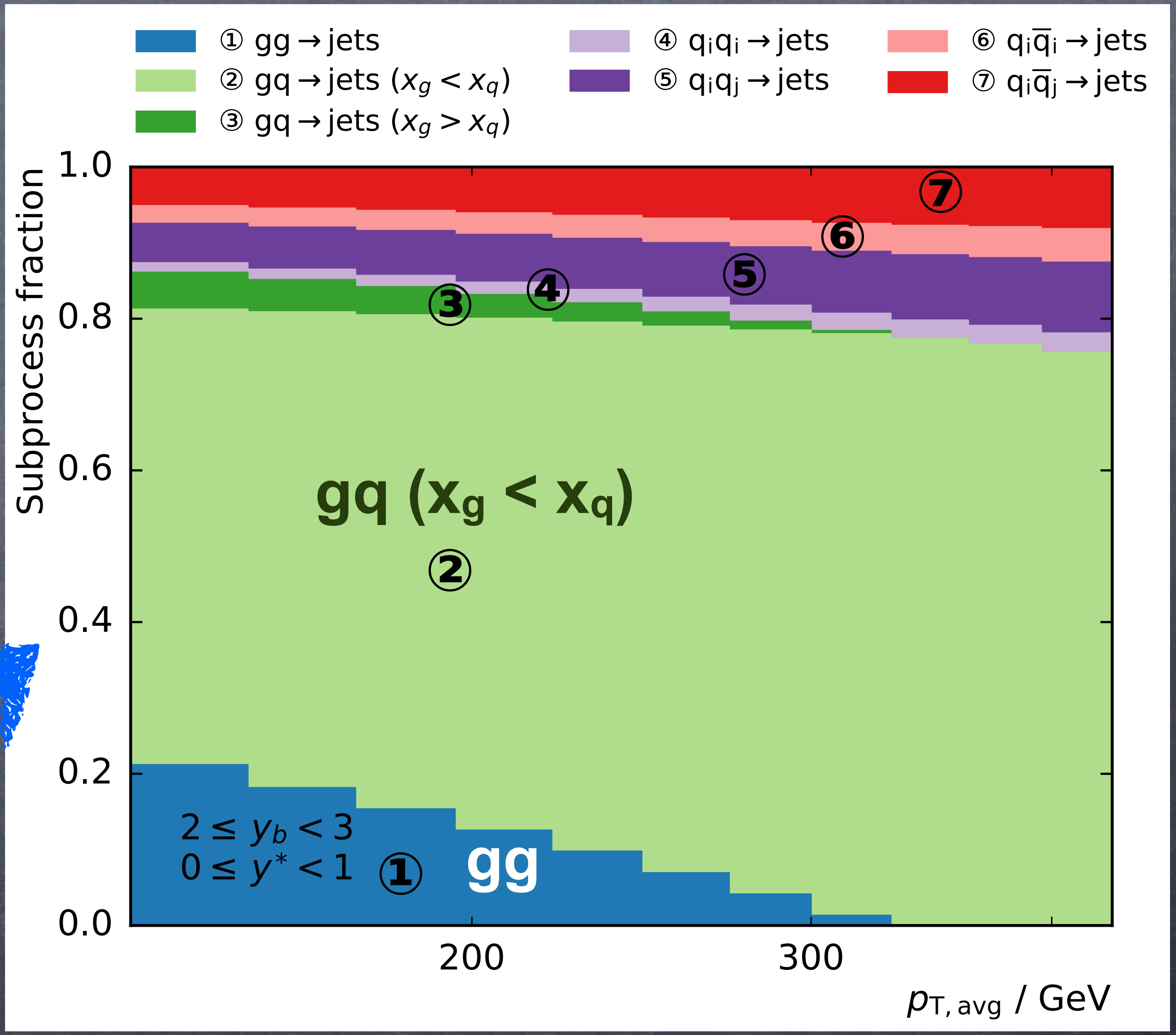

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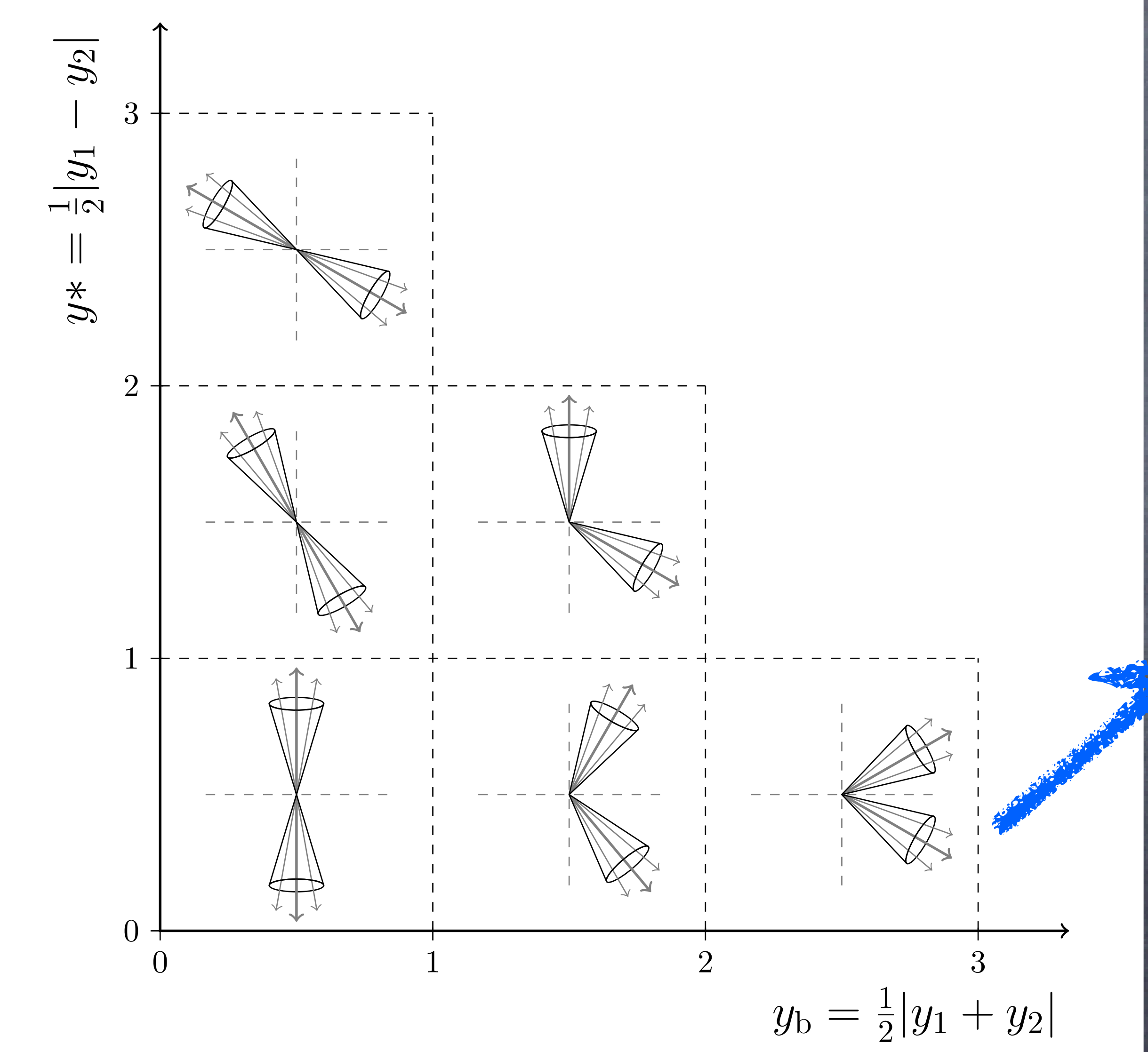
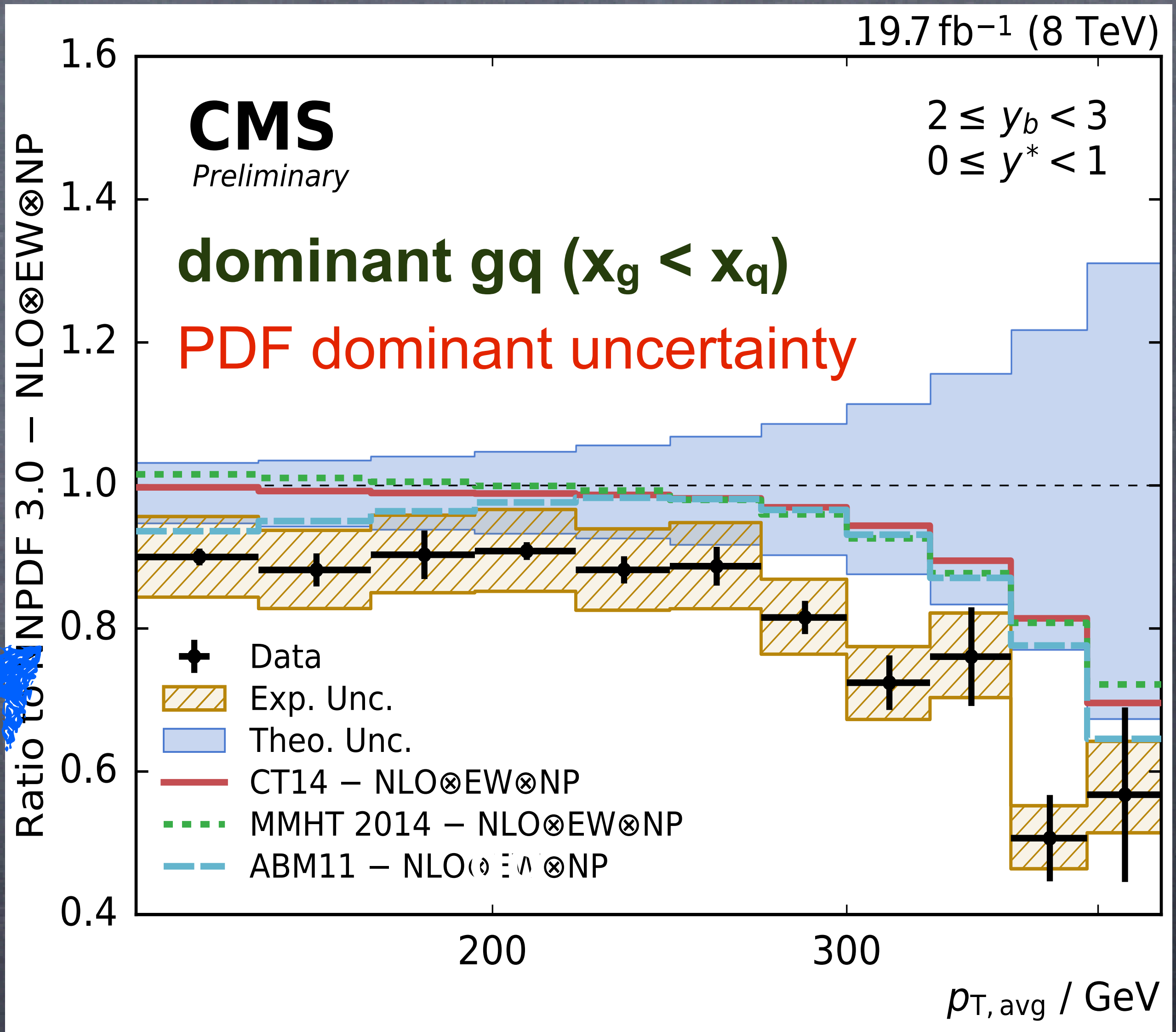




JETS @ CMS: GLUON AND STRONG COUPLING

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

$Bd_v \neq Bu_v$

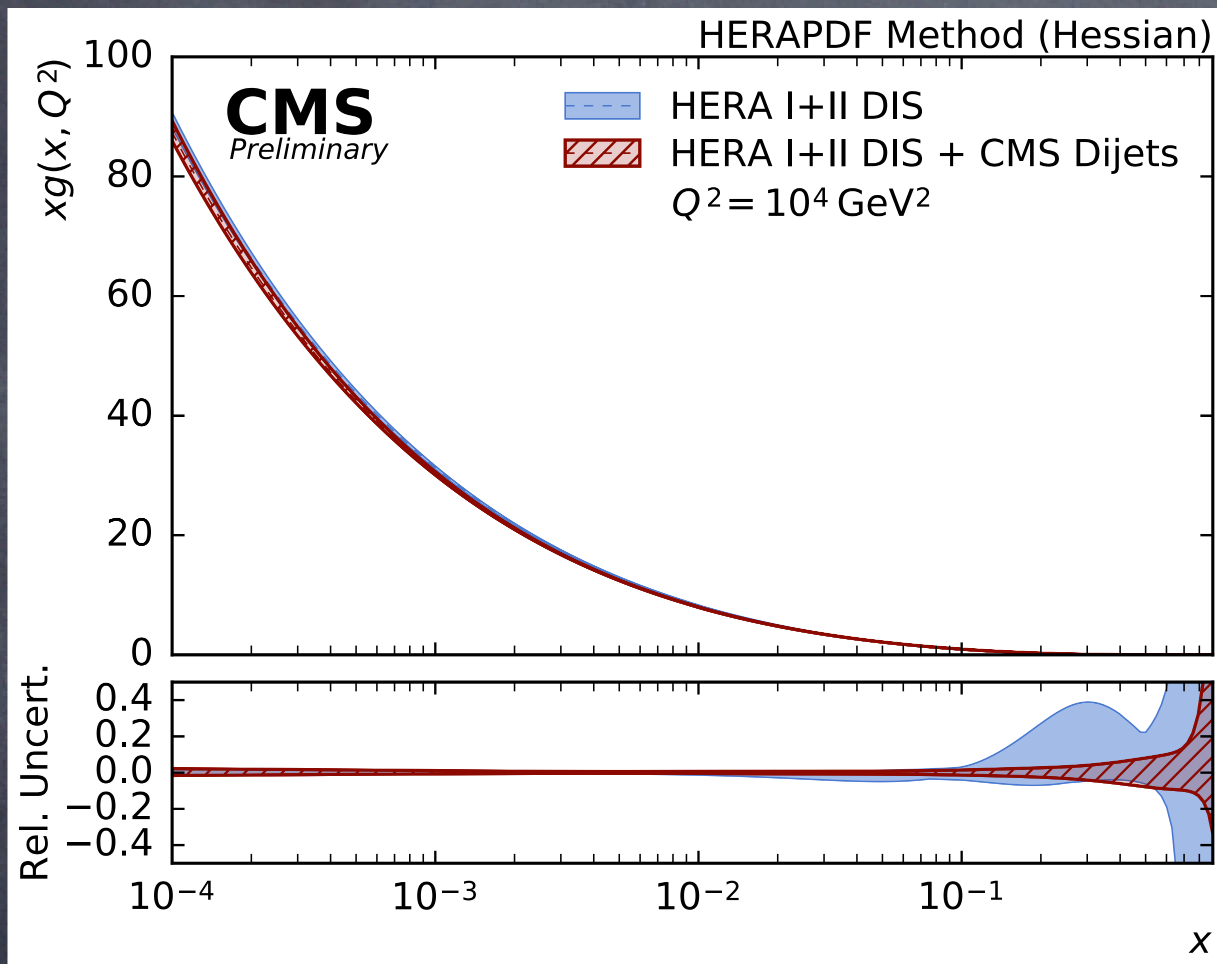
$\Rightarrow$ 16-parameter fit

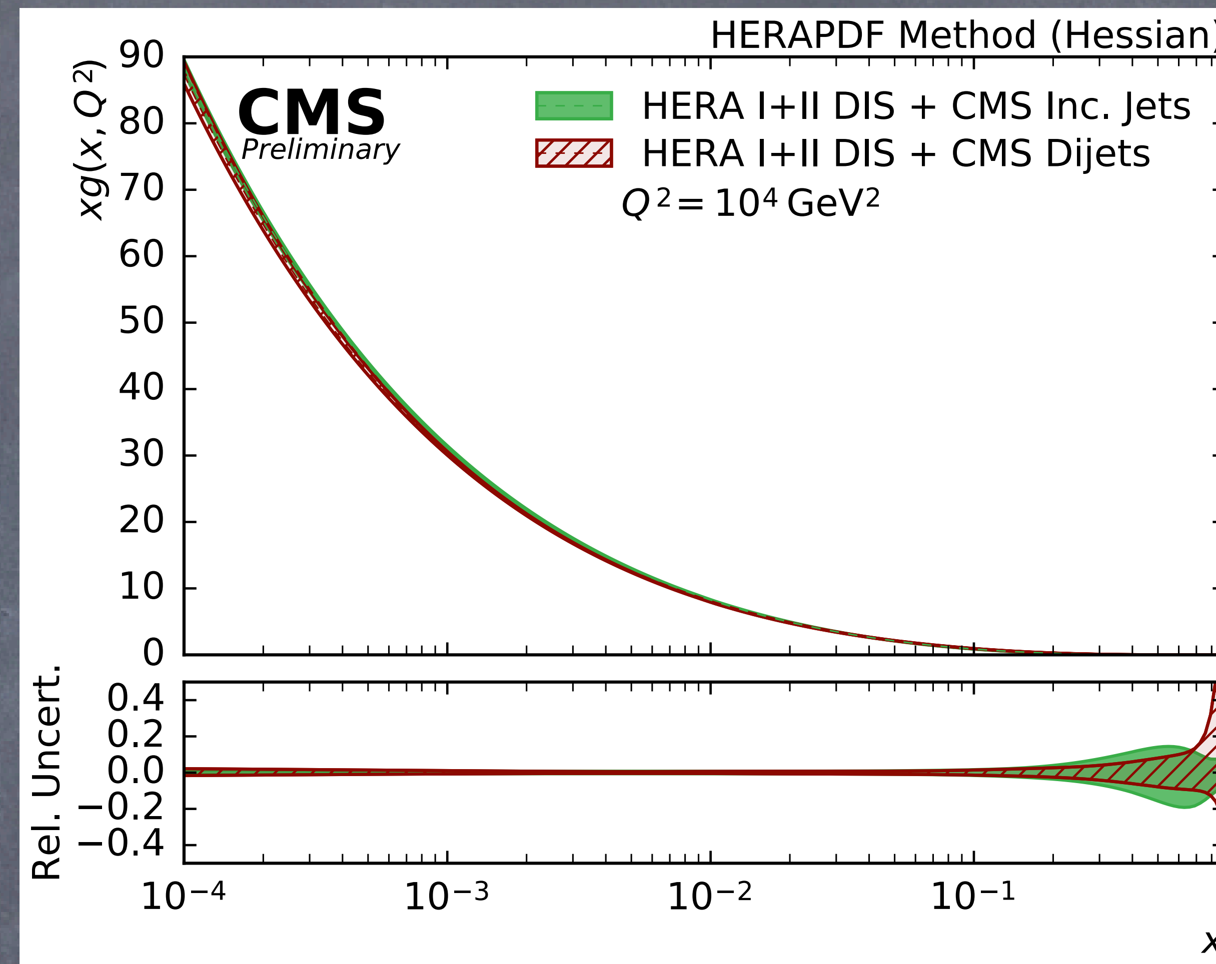
Data are consistent very good fit quality for the CMS jet data

		HERA data		HERA & CMS data	
data set	n_{data}	χ^2_p	χ^2_p/n_{data}	χ^2_p	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

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:**

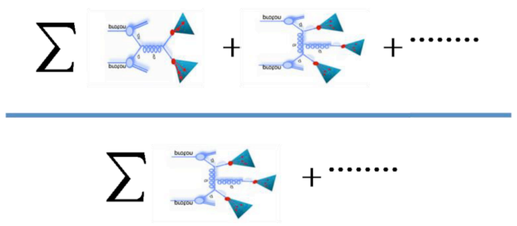
$$\alpha_s(M_Z) = 0.1199^{+0.0015}_{-0.0016}(PDF)^{+0.0026}_{-0.0016}(scale)$$

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

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

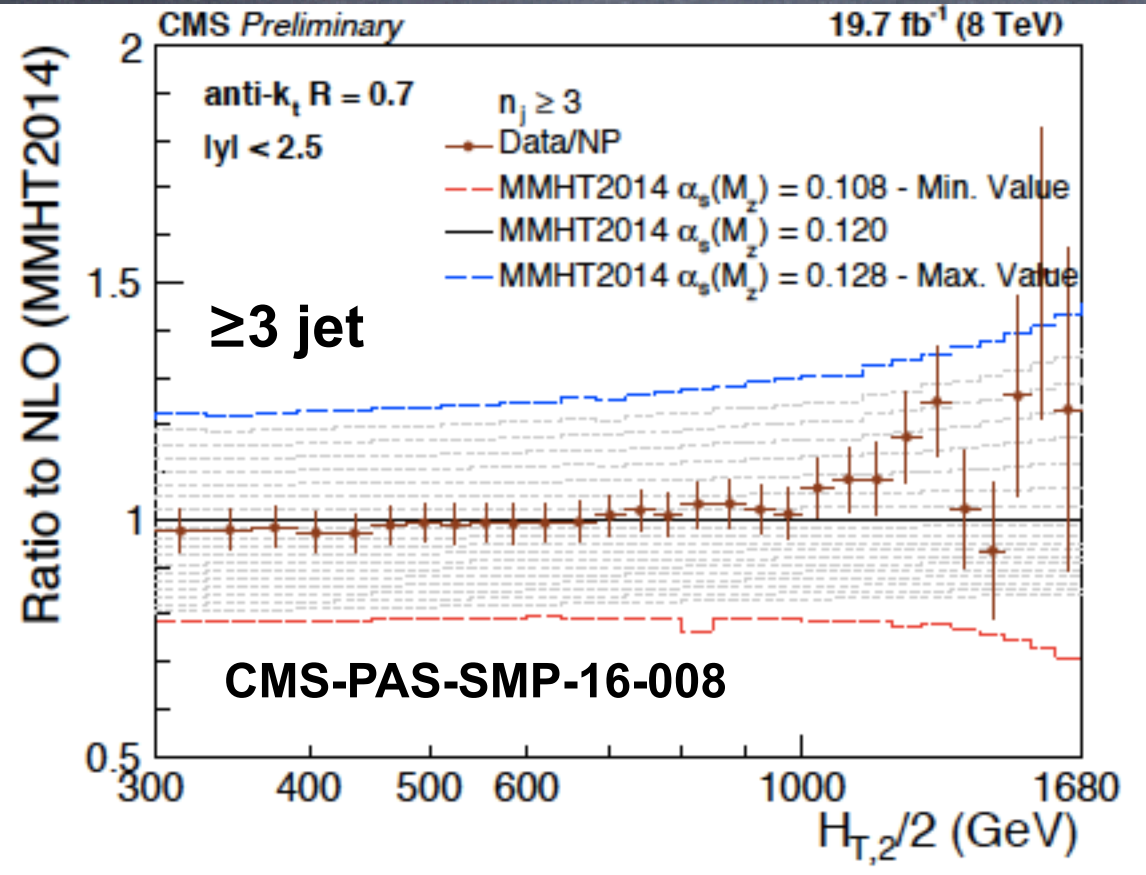


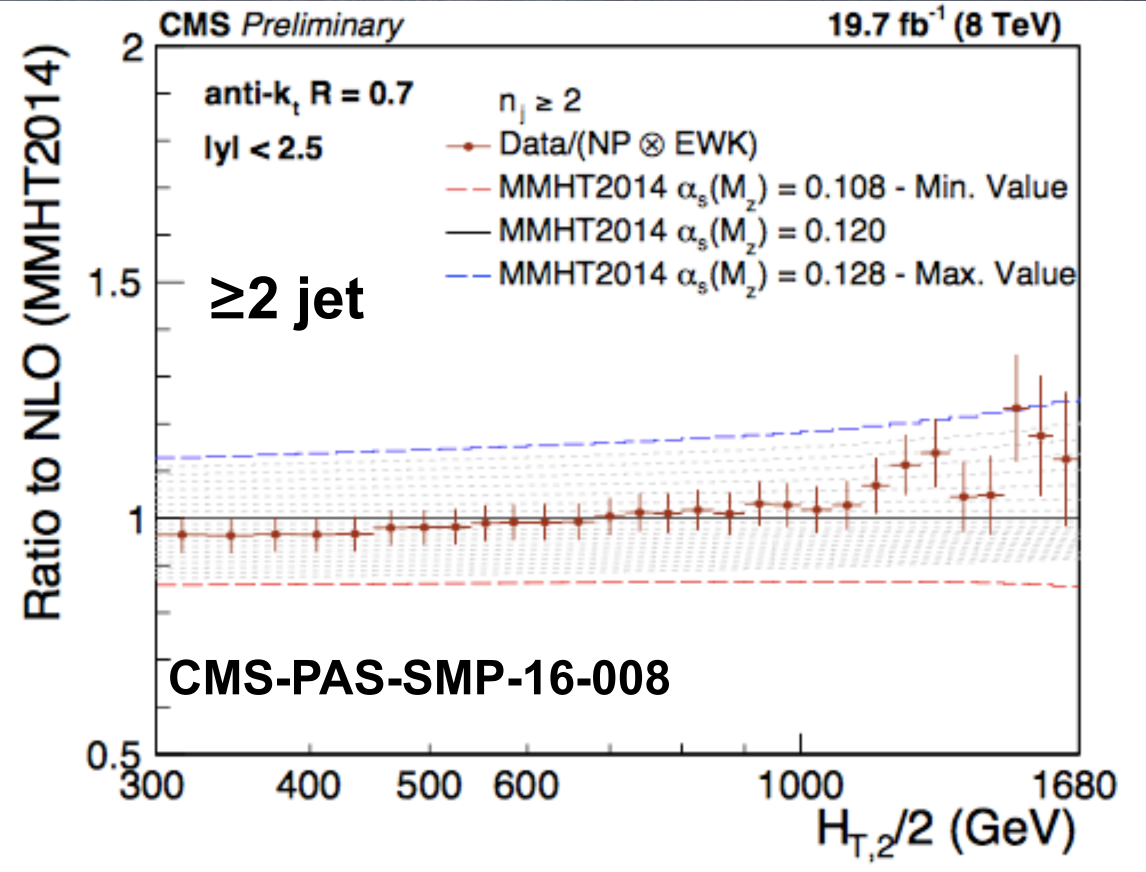
$\sim\alpha_S$

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

NLO PDF sets studied: MSTW08, CT10, ABM11(N_F=5), NNPDF2.3 and 3.0 MMHT14, CT14



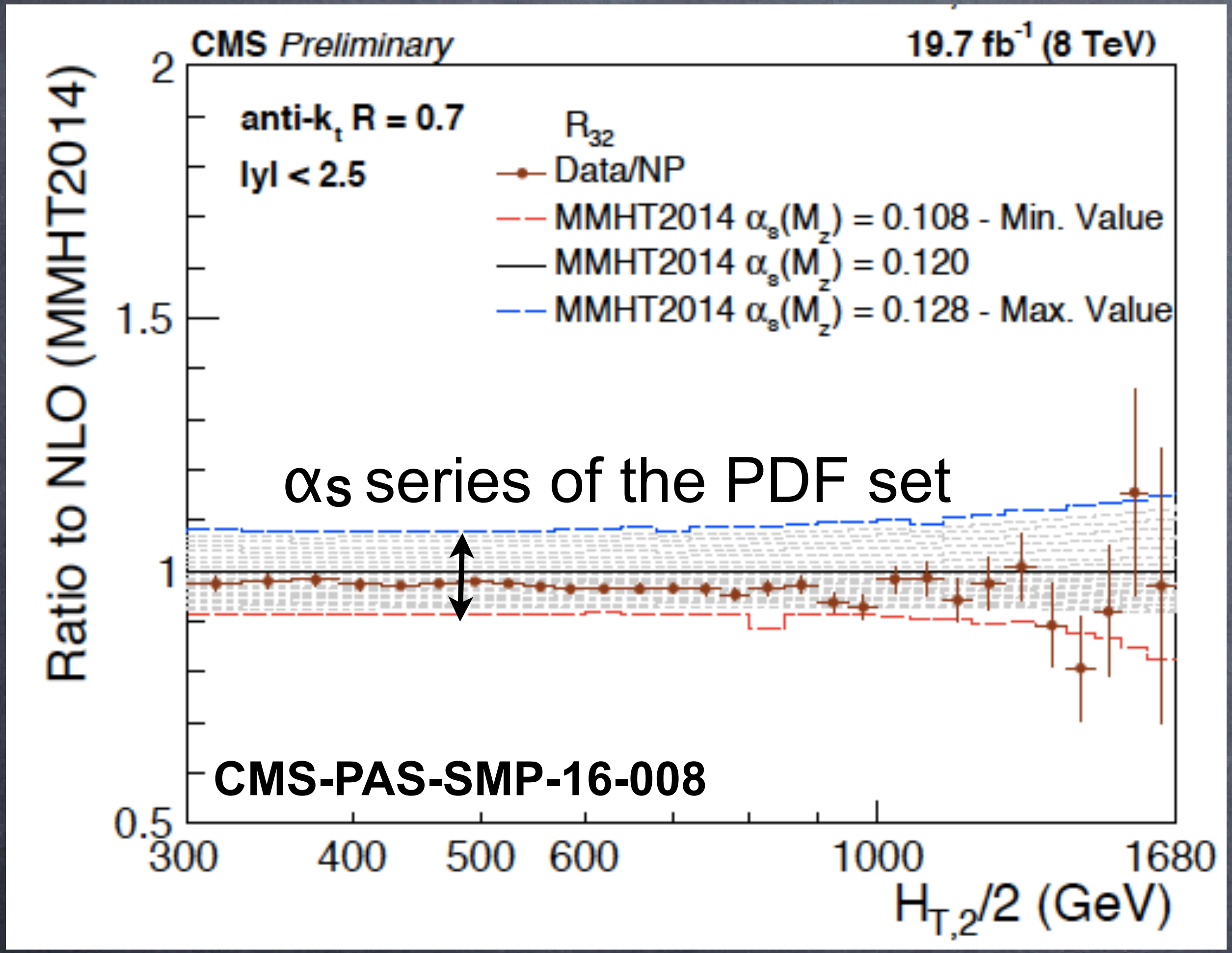


for details see talk E. Eren

JETS @ CMS: GLUON AND STRONG COUPLING

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: $\chi^2/\mathrm{n_{dof}}$ =24/28

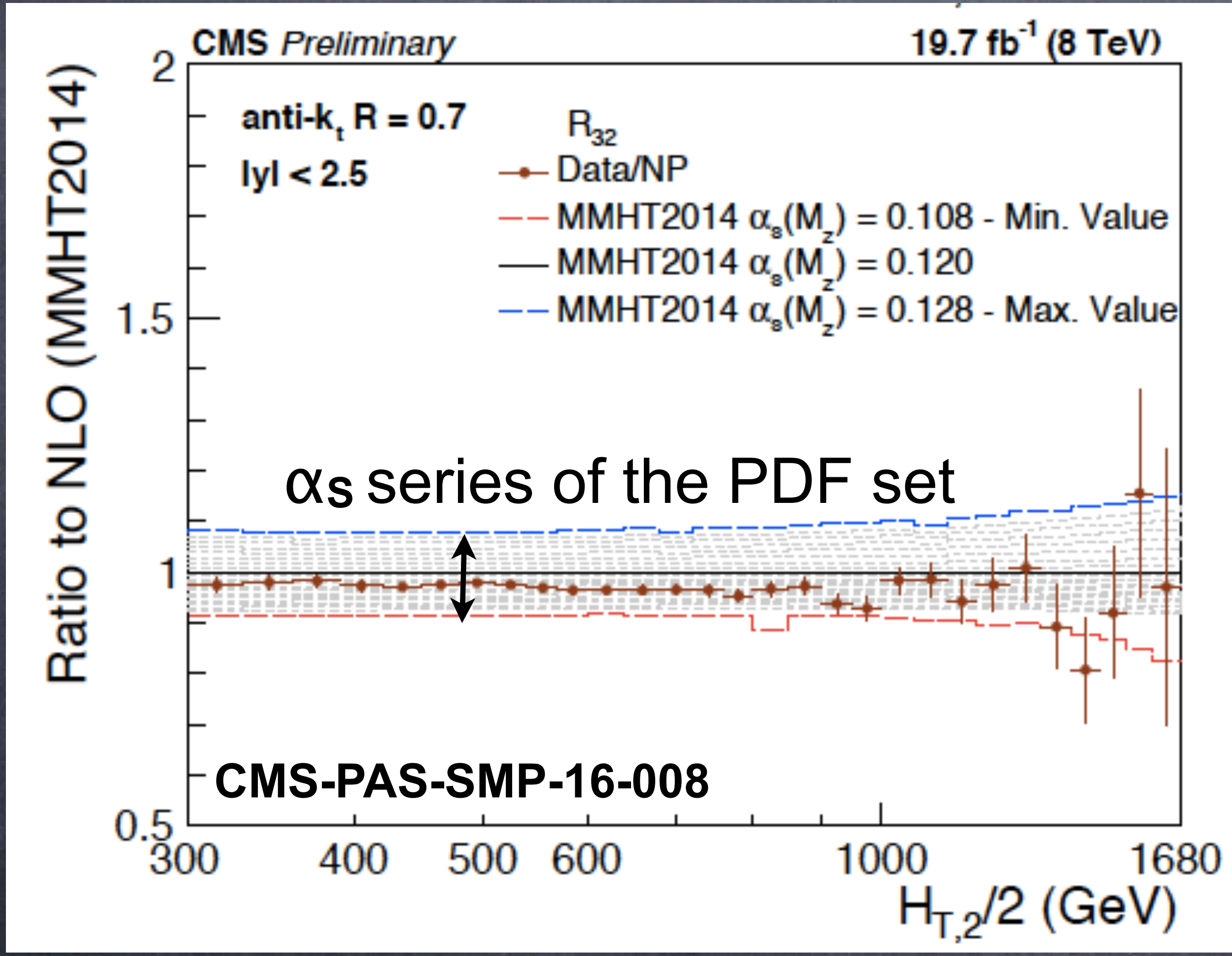
$$\alpha_S(M_Z) = 0.1142 \pm 0.0010(exp) \pm 0.0013(PDF)$$
$$\pm 0.0014(NP)^{+0.0049}_{-0.0006}(scale)$$

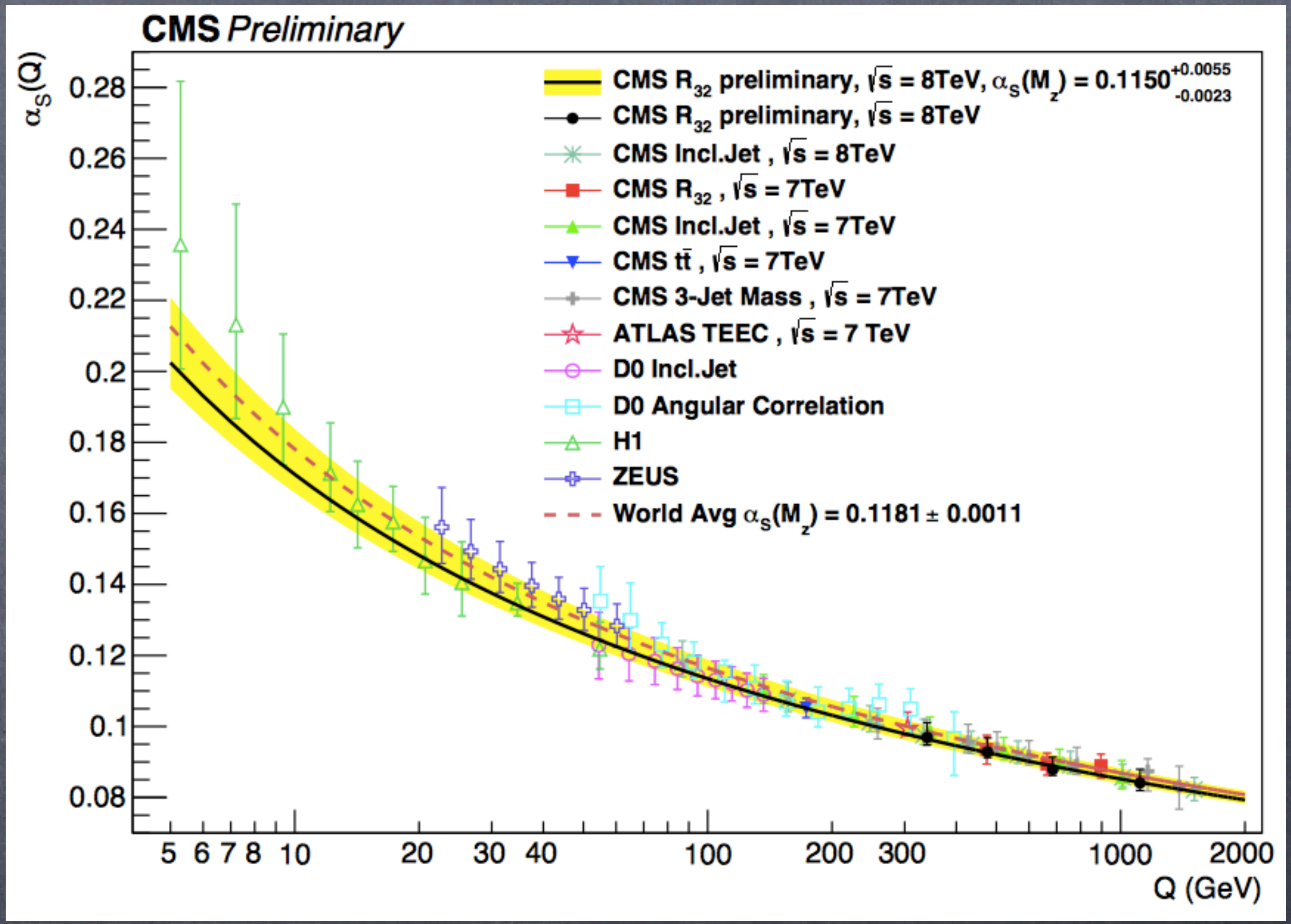
JETS @ CMS: GLUON AND STRONG COUPLING

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

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





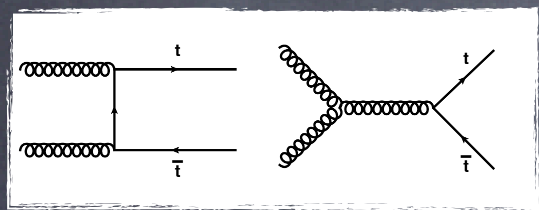
MMHT14: χ^2/n_{dof} =24/28

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

Evolution performed for $N_f = 5$ at 2-loops

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

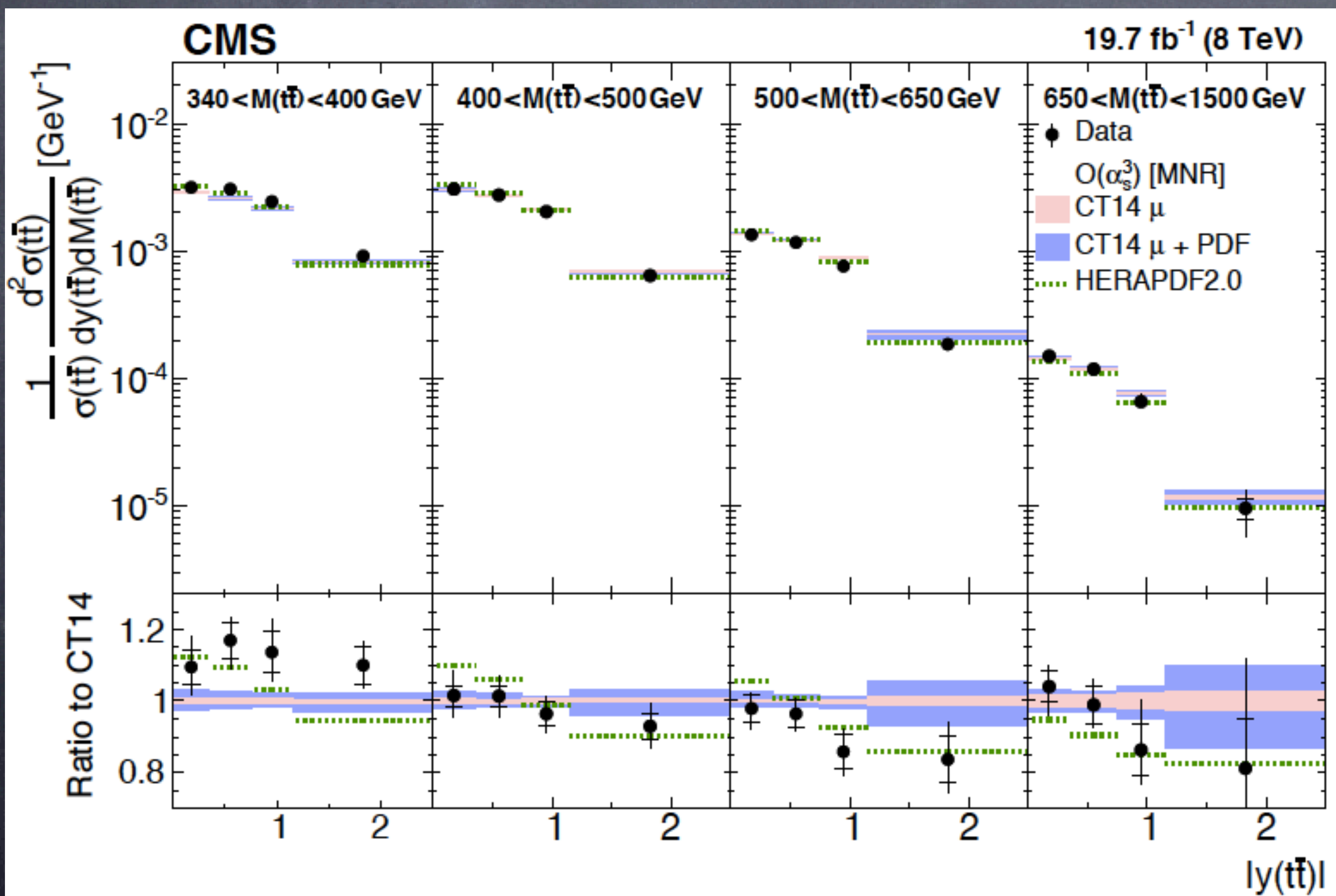
In pp collisions top-quark pairs are produced via gg fusion probing gluon at high x



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

2d-differential $t\bar{t}$ cross sections arXiv:1703.01630

for details see talk J.Gonzalez



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

QCD analysis: XFitter 1.2.2,

baseline data: HERA inclusive DIS [EPJ C75 (2015) 580], CMS W± [EPJ C76 (2016) 469]

Theory for $t\bar{t}$ MCFM via ApplGrid, scales $\mu_{r,f} = \sqrt{m_t^2 + [p_T(t)^2 + p_T(\bar{t})^2]/2}$

Q^2_0=1.9 GeV^2:

$$xg(x) = A_g x^{B_g} (1-x)^{C_g} (1 + E_g x^2 + F_g x^3) - A'_g x^{B'_g} (1-x)^{C'_g},$$

$$xu_v(x) = A_{u_v} x^{B_{u_v}} (1-x)^{C_{u_v}} (1 + D_{u_v} x + E_{u_v} x^2),$$

$$xd_v(x) = A_{d_v} x^{B_{d_v}} (1-x)^{C_{d_v}},$$

$$x\overline{U}(x) = A_{\overline{U}} x^{B_{\overline{U}}} (1-x)^{C_{\overline{U}}} (1 + D_{\overline{U}} x + F_{\overline{U}} x^3),$$

$$x\overline{D}(x) = A_{\overline{D}} x^{B_{\overline{D}}} (1-x)^{C_{\overline{D}}},$$

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

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

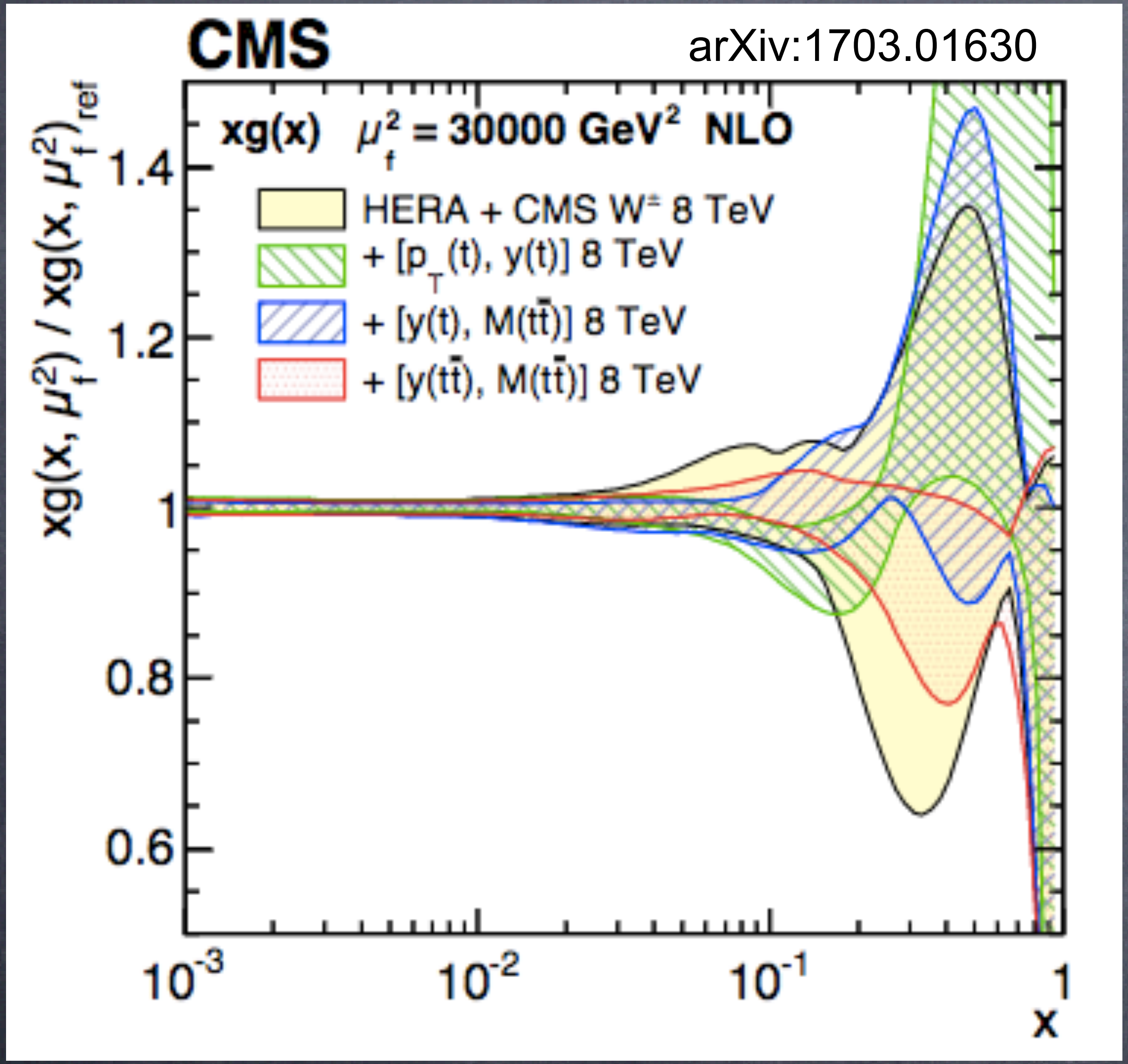
⇒ 18-parameter fit

Data are consistent very good fit quality for the CMS data

Data sets	χ^2/dof			
	Nominal fit	$+[p_T(t), y(t)]$	$+[y(t), M(t\bar{t})]$	$+[y(t\bar{t}), M(t\bar{t})]$
CMS double-differential $t\bar{t}$		10/15	7.4/15	7.6/15
HERA CC e^-p, E_p = 920 GeV	57/42	56/42	56/42	57/42
HERA CC e^+p, E_p = 920 GeV	44/39	44/39	44/39	43/39
HERA NC e^-p, E_p = 920 GeV	219/159	219/159	219/159	218/159
HERA NC e^+p, E_p = 920 GeV	440/377	437/377	439/377	441/377
HERA NC e^+p, E_p = 820 GeV	69/70	68/70	68/70	69/70
HERA NC e^+p, E_p = 575 GeV	221/254	220/254	221/254	221/254
HERA NC e^+p, E_p = 460 GeV	219/204	219/204	219/204	219/204
CMS $W^\pm$ asymmetry	4.7/11	4.6/11	4.8/11	4.9/11
Correlated χ^2	82	87	91	89
Log-penalty χ^2	−2.5	+2.6	−2.2	−3.3
Total χ^2/dof	1352/1138	1368/1153	1368/1153	1366/1153

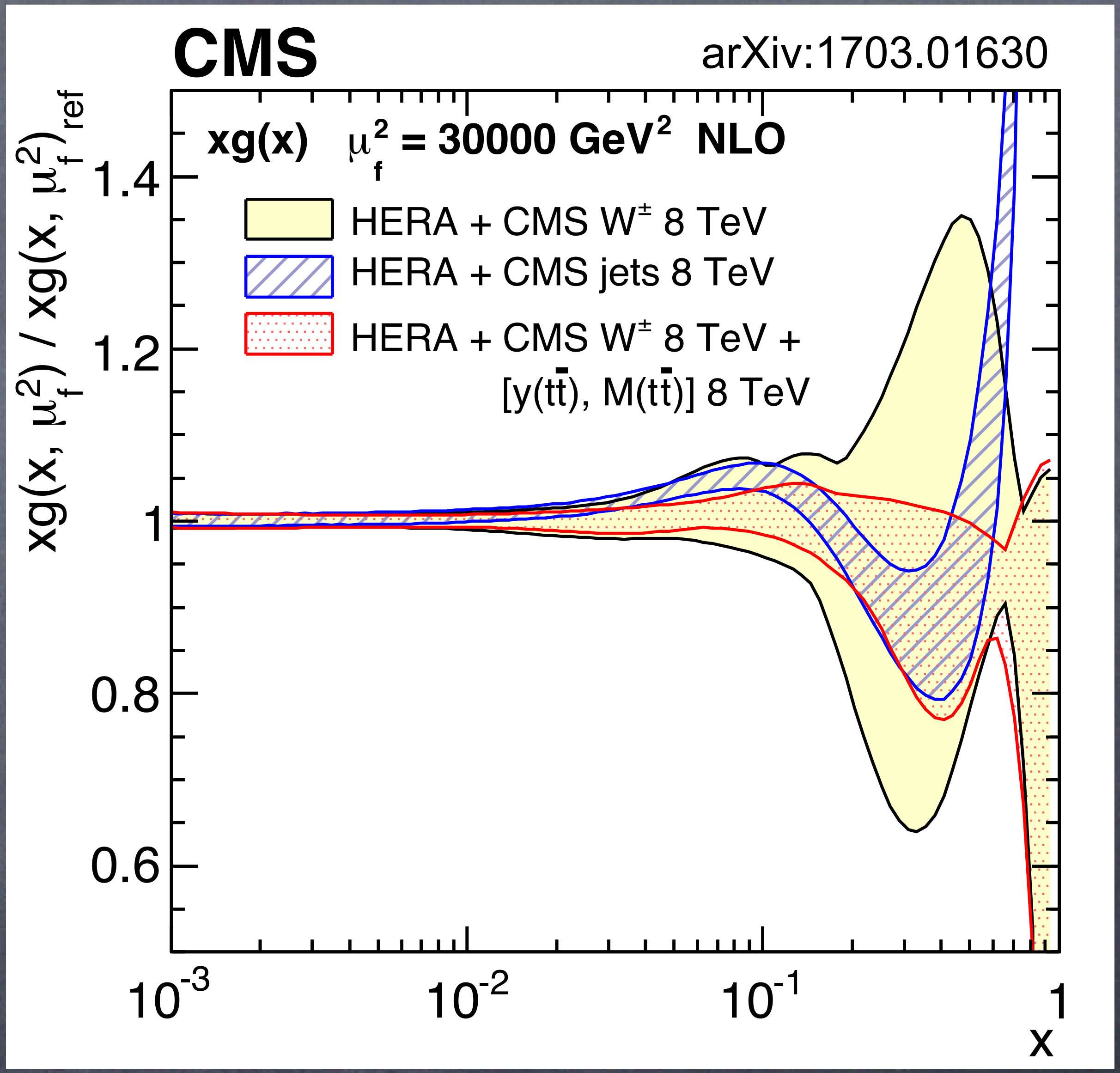
$t\bar{t}$ @ CMS: GLUON DISTRIBUTION AT HIGH X

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}

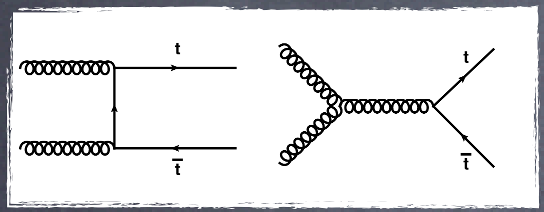
Results compared to those obtained by using inclusive jets @ 8 TeV



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



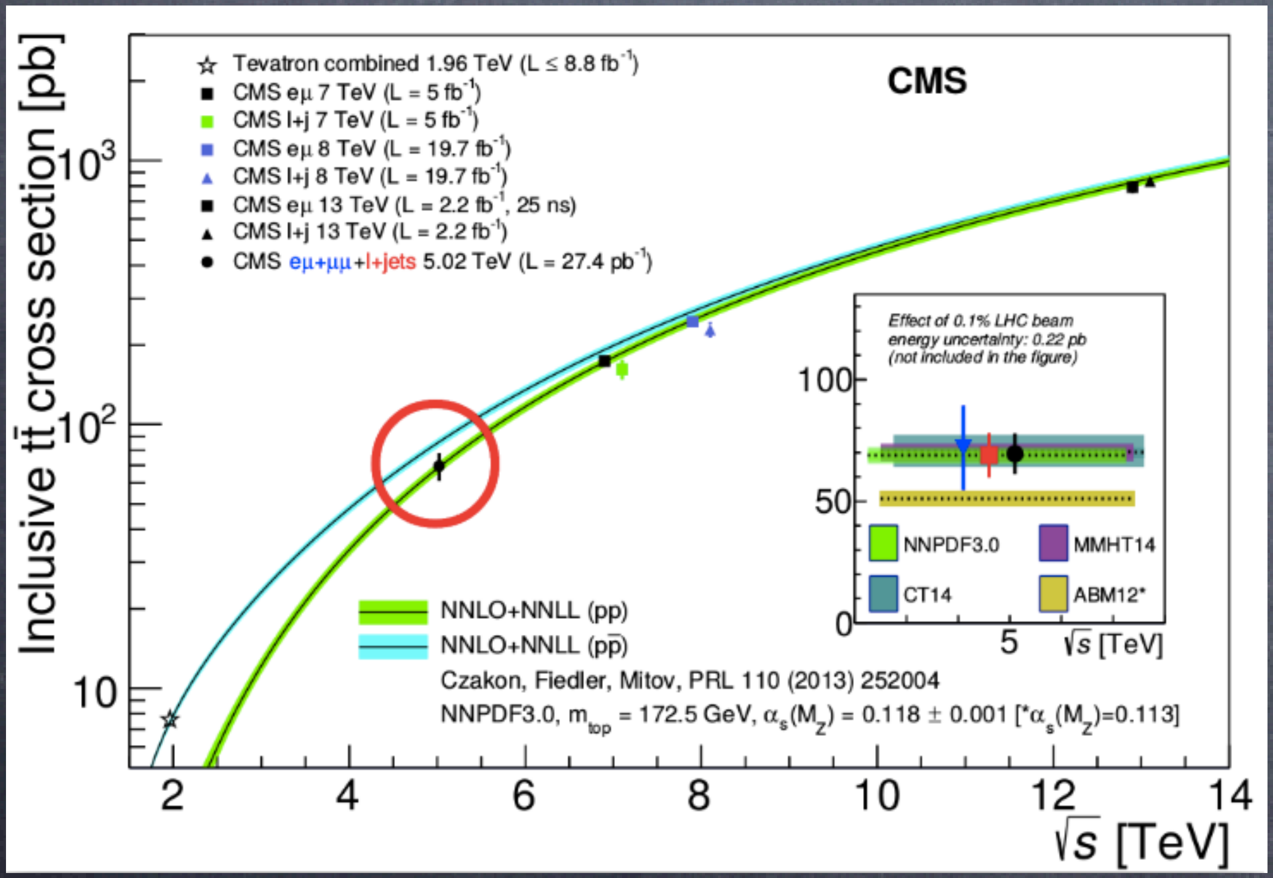
CMS 5.02 TeV, $\mathcal{L}$ = 27.4 pb^{-1} CMS-PAS-TOP-16-023

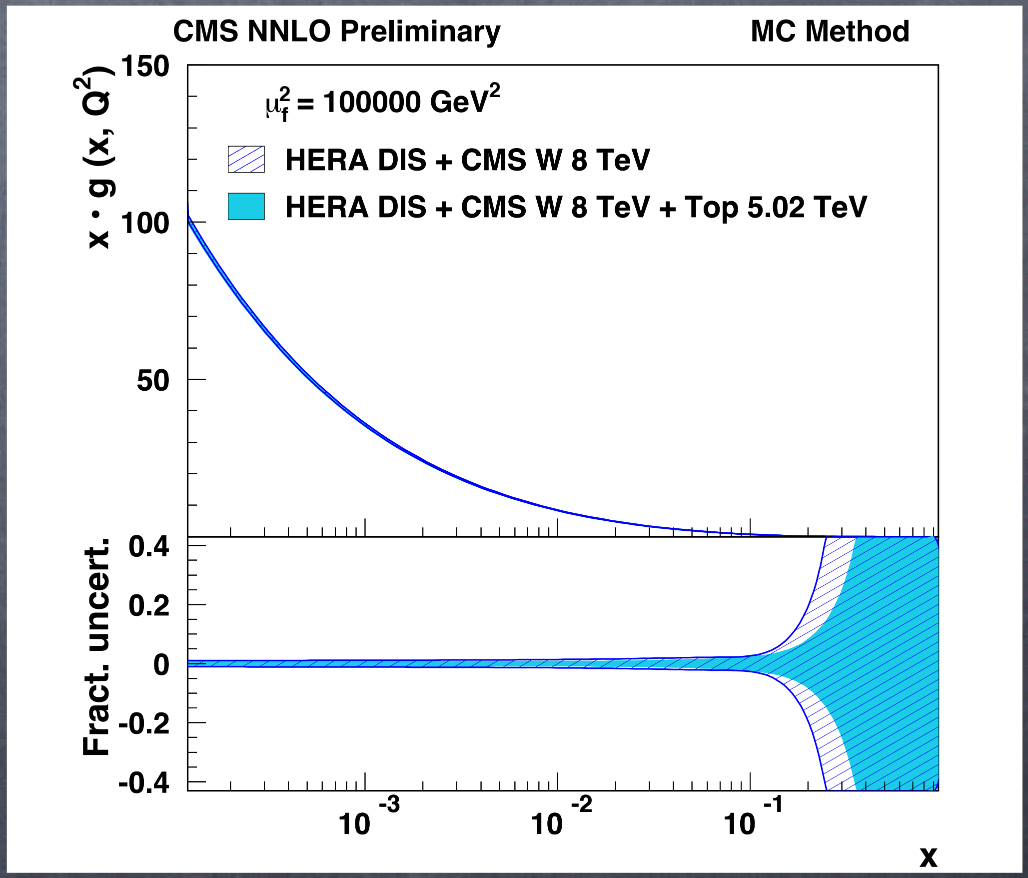
for details see talk J.Gonzalez

XFitter 2.0.0 *see talk F. Olness*

new kinematic range probed

theory: HATHOR, m_t=172.5 GeV

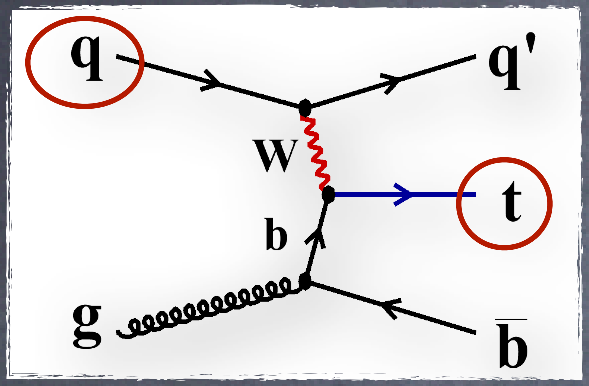




modest effect on g(x) at high x

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

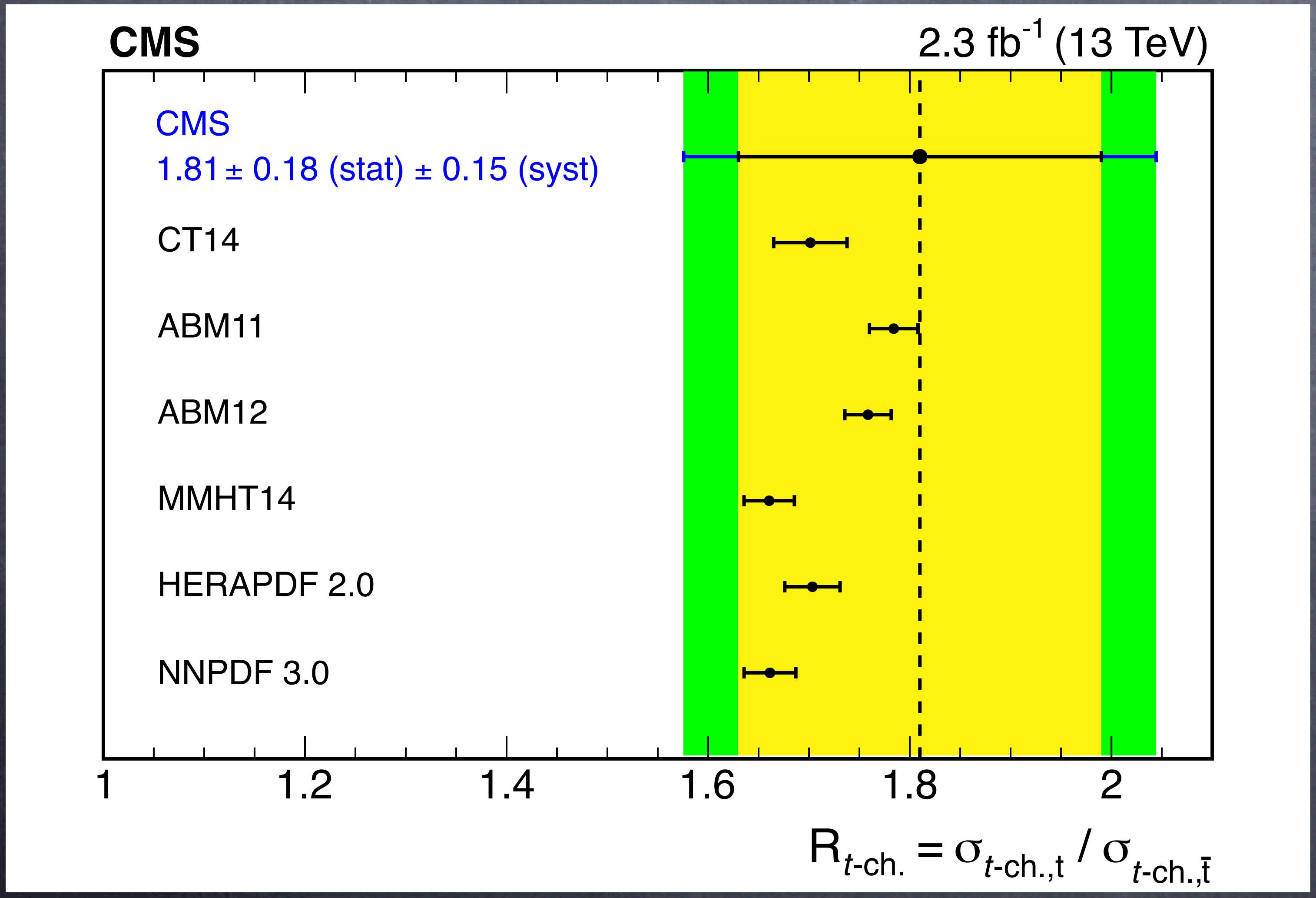
t-channel single top-quark production in pp collisions @ LHC



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

for details see talk A. Ahmad



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

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

SUMMARY

LHC Run I CMS data used for improvement of PDF accuracy

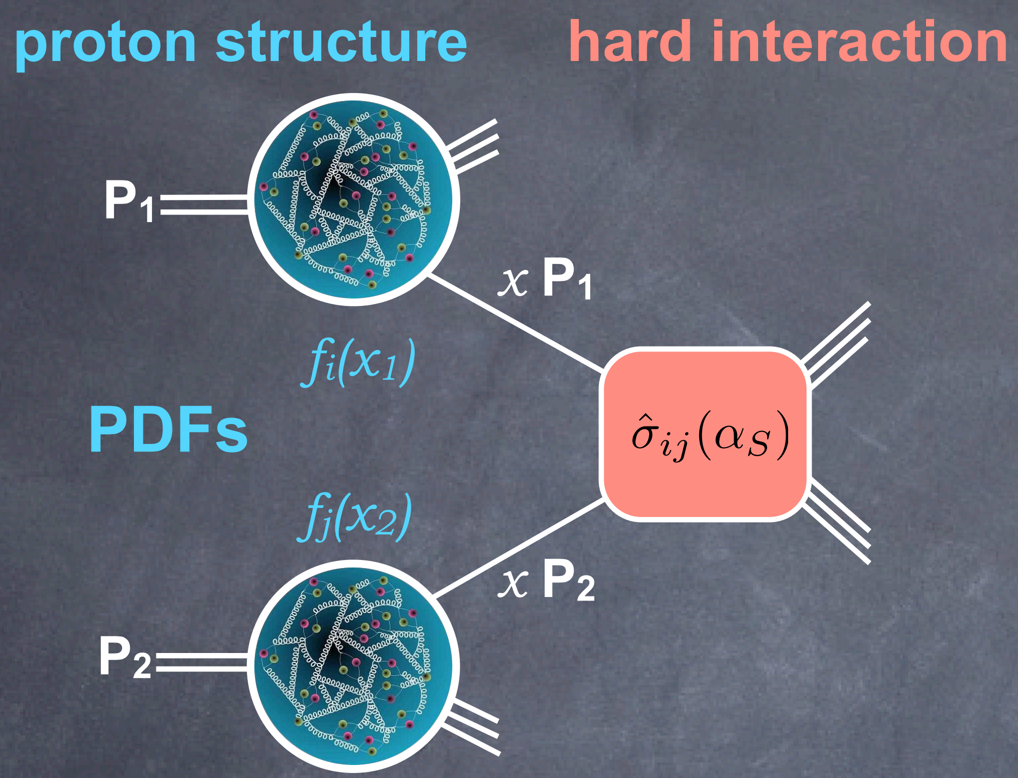
- jet data: gluon at medium & high x, strong coupling
  → getting even more interesting with available NNLO calculation
- Top-pair production has high potential to improve accuracy of g(x) at high x
  → remains important to constrain strong coupling & top quark mass

LHC Run II CMS data is forthcoming

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) ⊗ 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