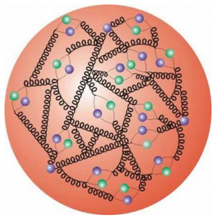
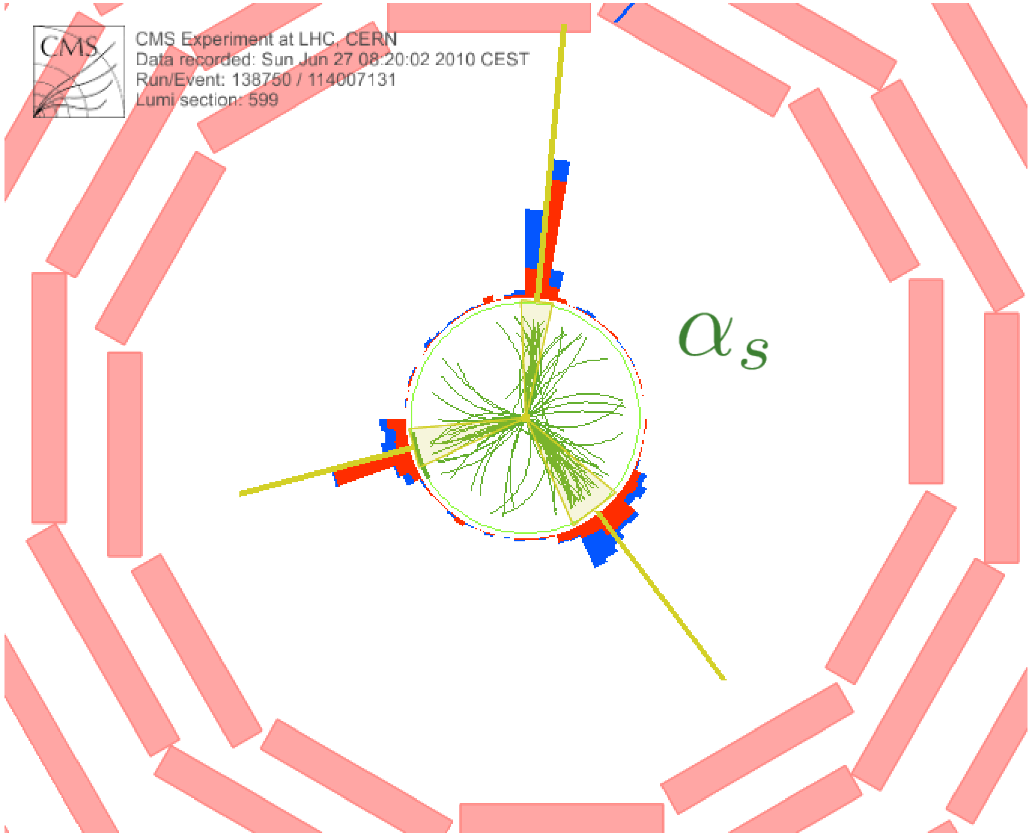
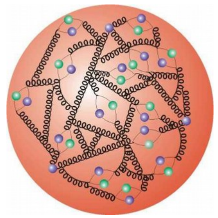
Jet measurements, alpha_s and PDF results from CMS



Proton Structure (PDF)





Proton Structure (PDF)

Klaus Rabbertz, KIT
(on behalf of CMS)

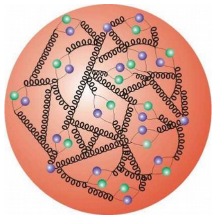
Karlsruhe Institute of Technology

Outline

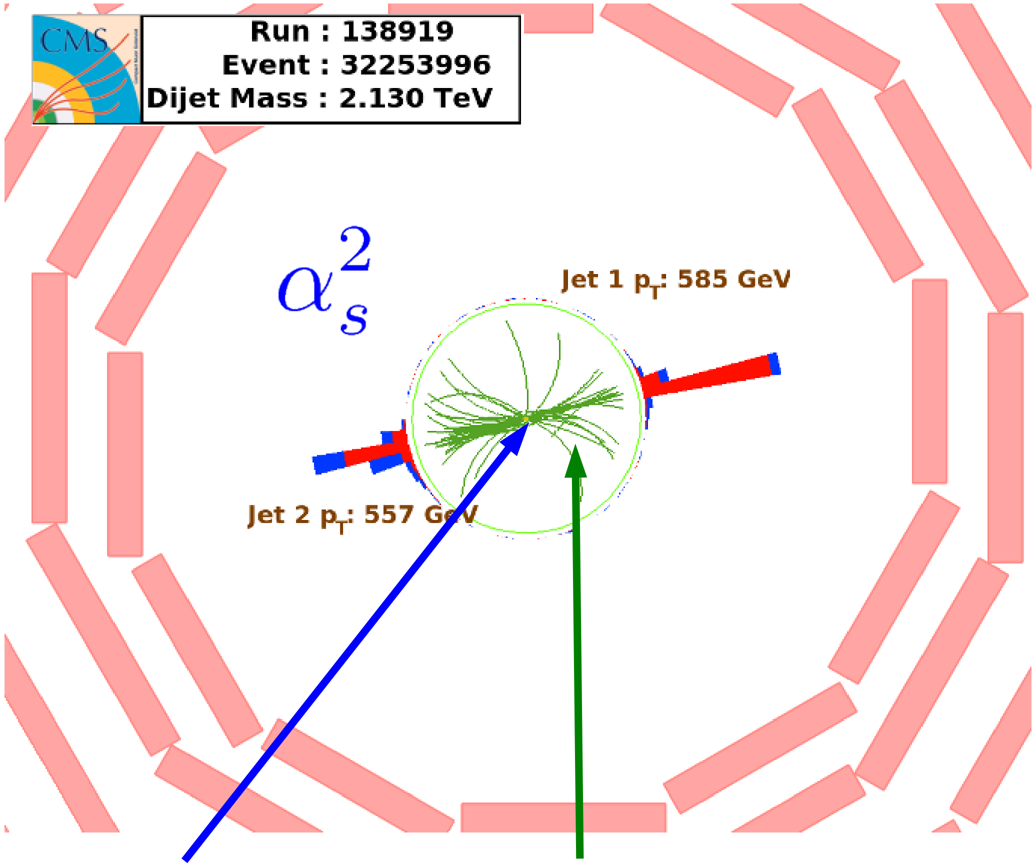
- Motivation
- Some News on Photons (on Request)
- Inclusive Jets
- Multi-Jet Production
- The strong Coupling Constant α_s
- α_s Summary
- Summary

Jets at the LHC

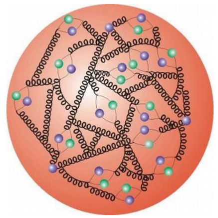
Abundant production of jets → hadron colliders are "jet laboratories"
Learn about hard QCD, the proton structure, non-perturbative effects ...



Proton Structure (PDF)



Matrix Element Hadrons

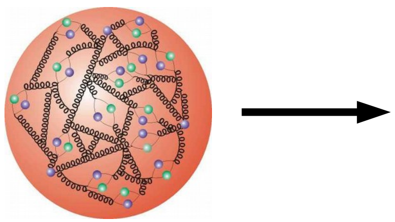


Proton Structure (PDF)

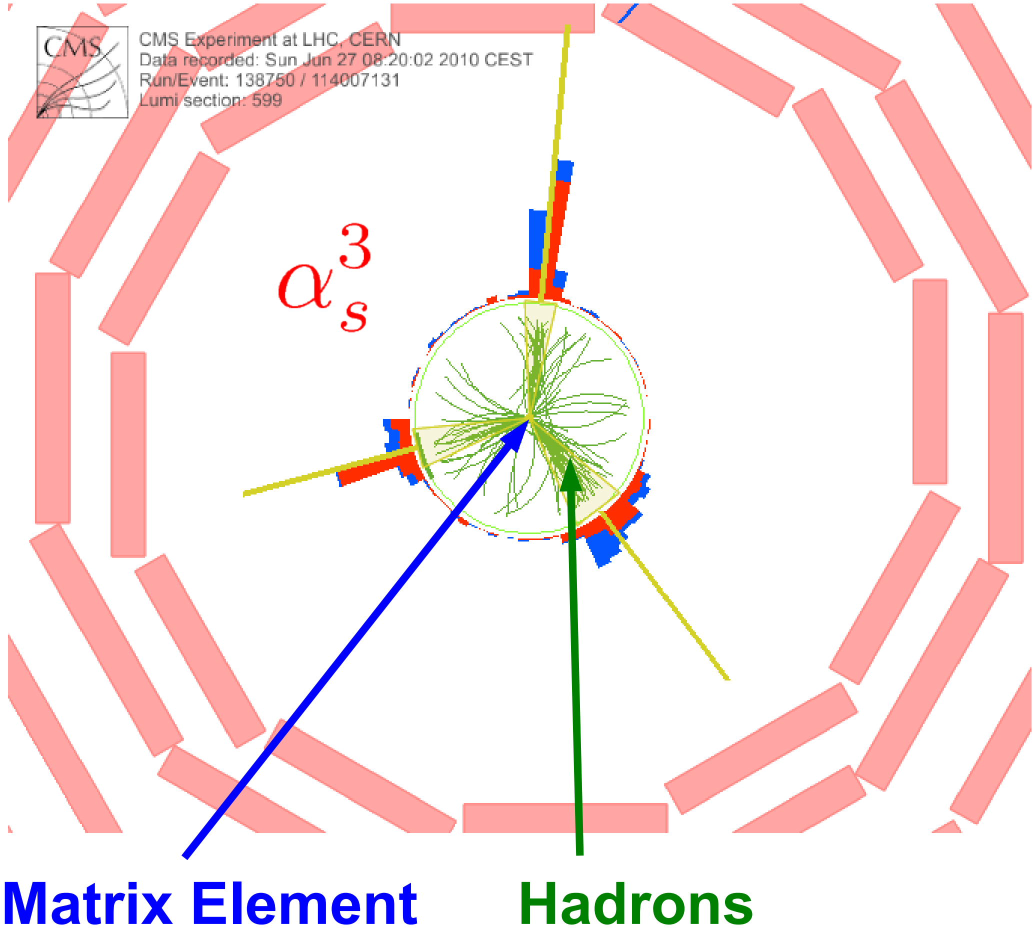
Jets at the LHC

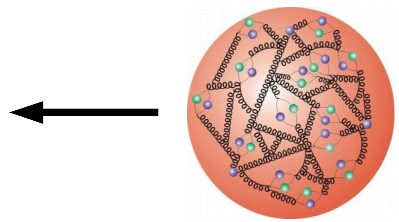
Abundant production of jets → hadron colliders are "jet laboratories"

… and the strong coupling α_s . Least known fundamental constant!



Proton Structure (PDF)



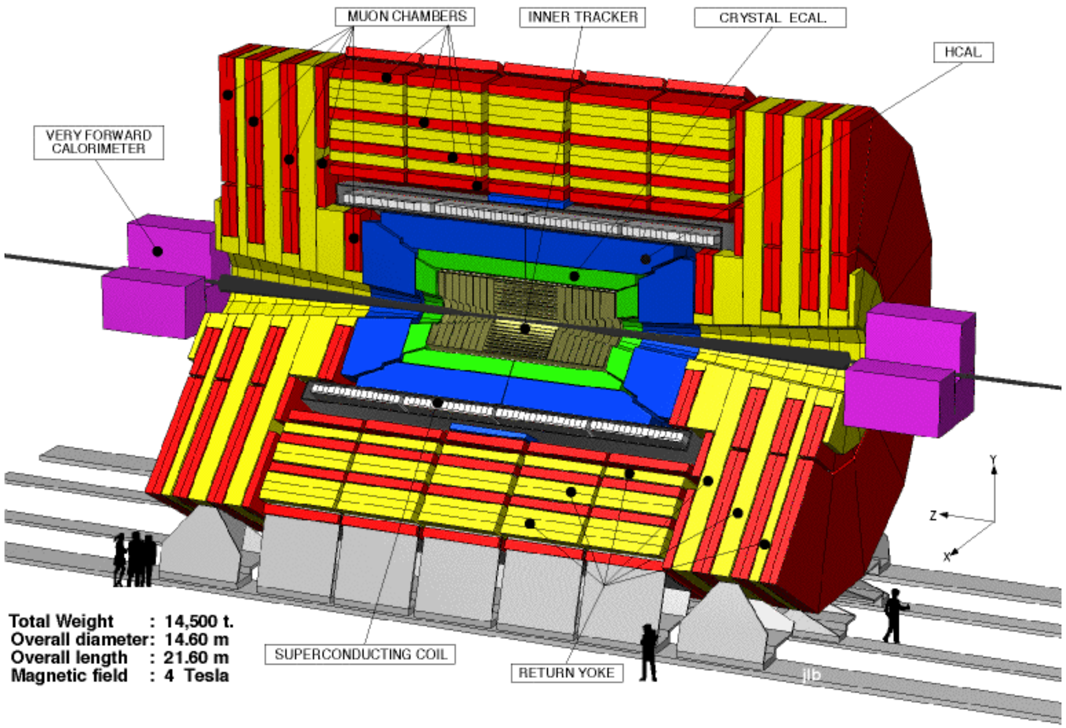


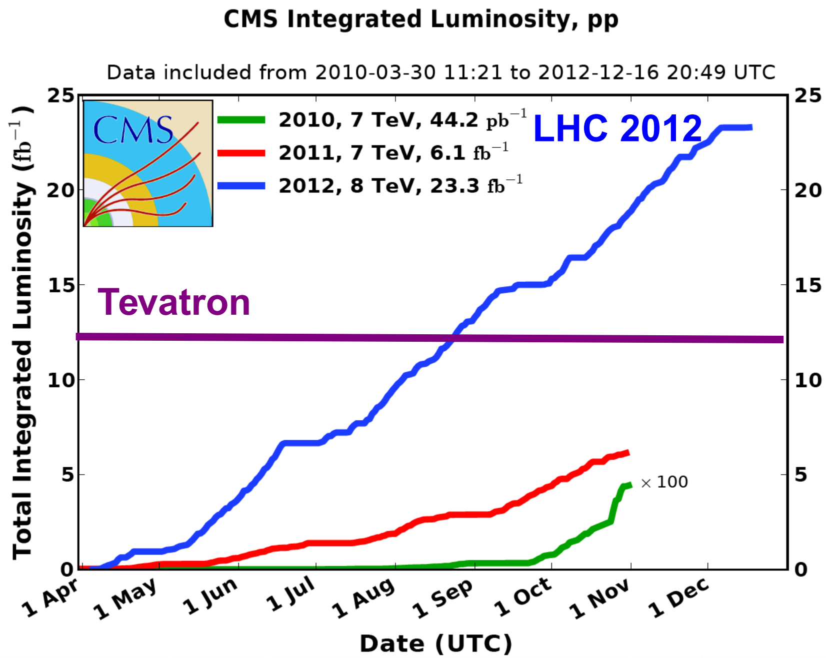
Proton Structure (PDF)

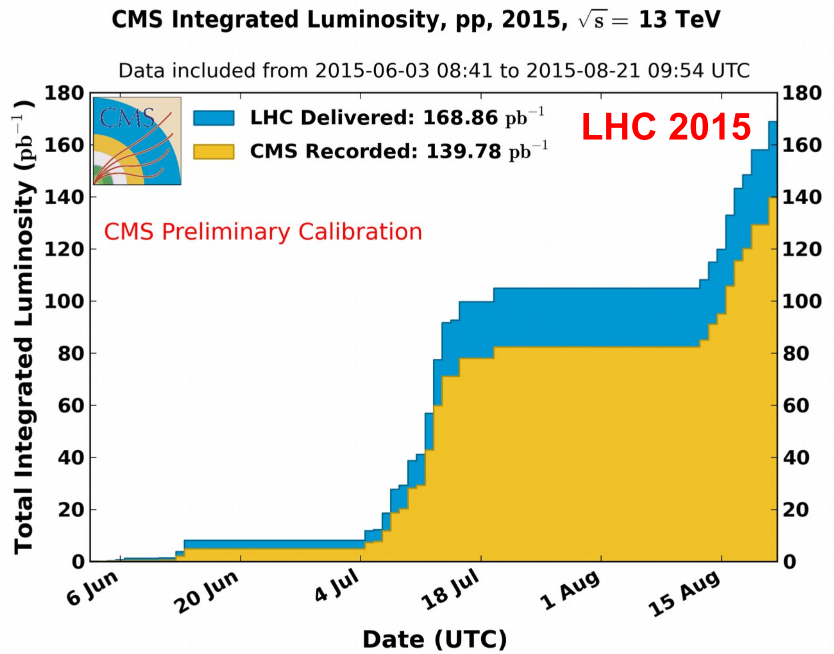
CMS & Luminosity

LHC: Collisions of Pb-Pb, p-Pb and p-p (23/fb)
E_{cms} = 0.9, 2.36, 2.76, 7, 8, and now 13 TeV
peak inst. lumi almost 8 x 10^{33} $cm^{-2}s^{-1}$

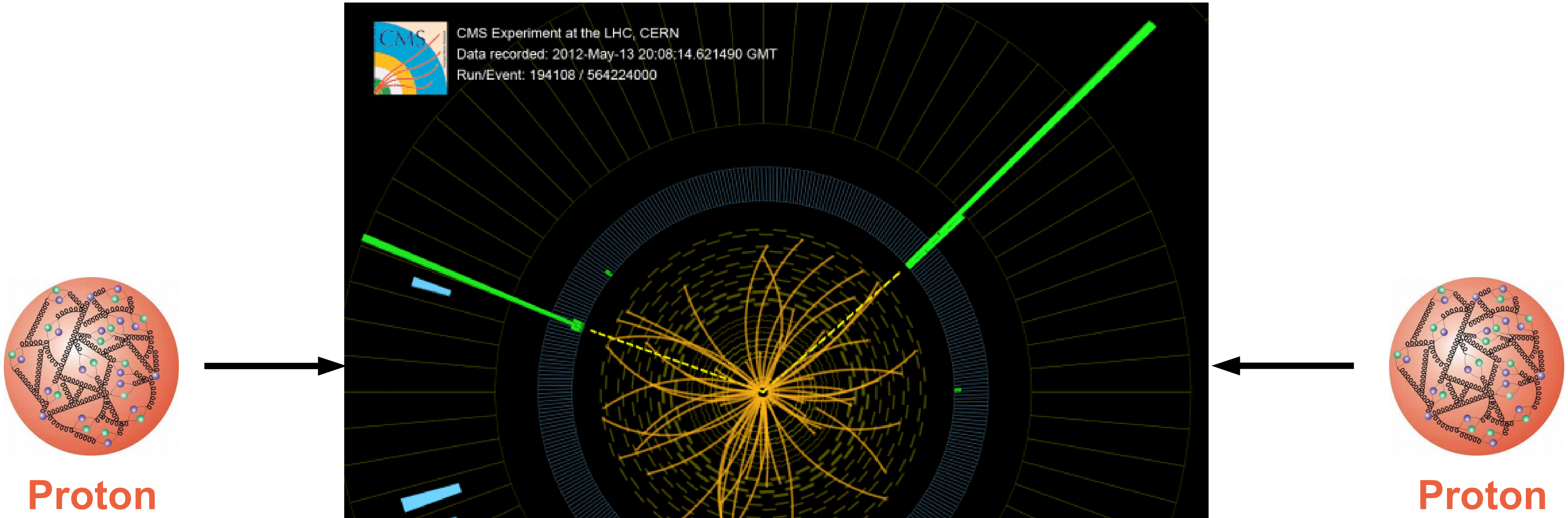
CMS global features:
- Silicon trackers: Up to |η| = 2.5
- Calorimetry: Up to |η| ~ 5.0
- Muon chambers: Up to |η| = 2.4-2.7
- Jet energy scale: 1 – 3 % prec. (Run 1)



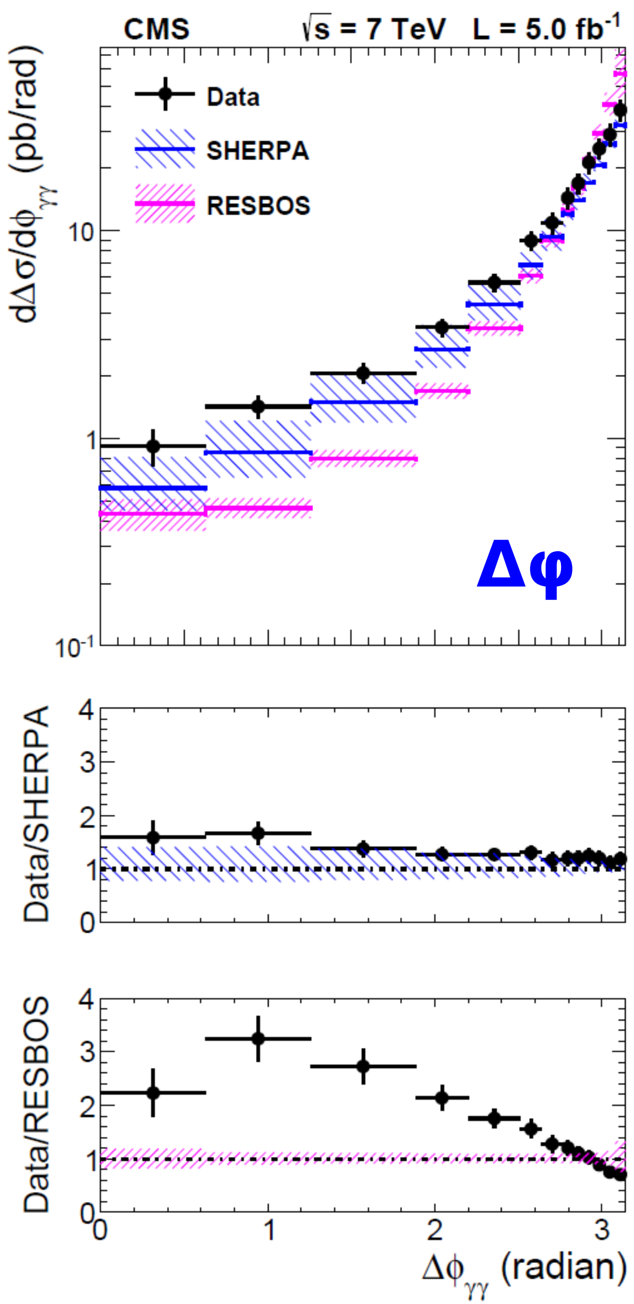




Higgs or no Higgs?



Di-Photons at 7 TeV



Significant improvement with NNLO (direct γ only!) at 7 TeV, some deviations visible in $\Delta\varphi_{\gamma\gamma}$ even to 2γNNLO

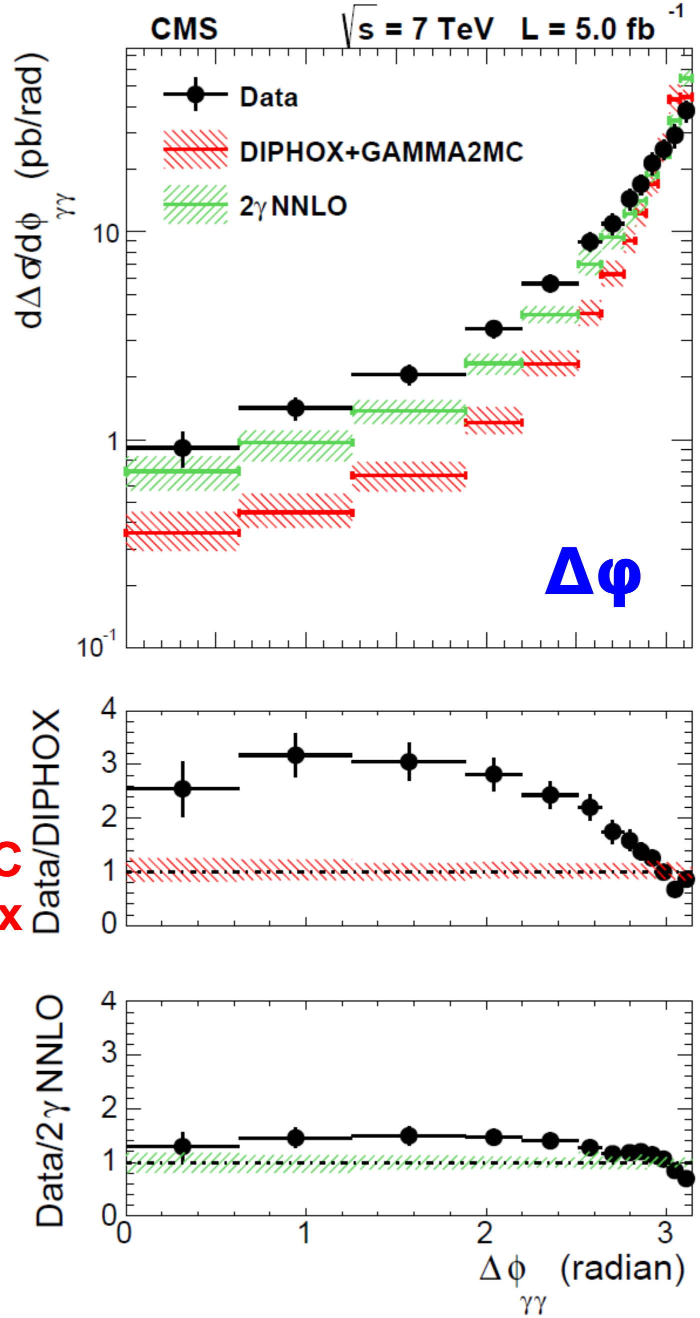
Parton → hadron level corrections for DIPHOX, RESBOS, 2γNNLO

SHERPA LO full MC

DIPHOX+Gamma2MC NLO incl. FF(2) & box

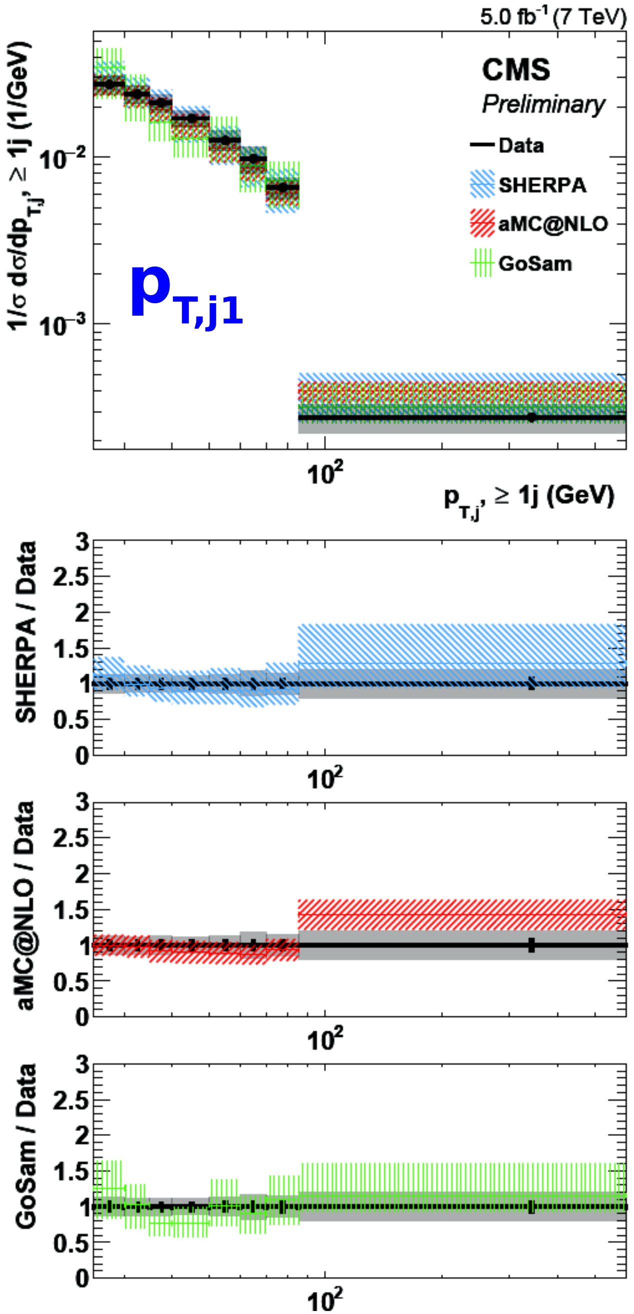
RESBOS NLO+NNLL incl. FF(1) & box

2γNNLO NNLO no FF



CMS, EPJC 74 (2014) 3129.

Di-Photons + Jets at 7 TeV

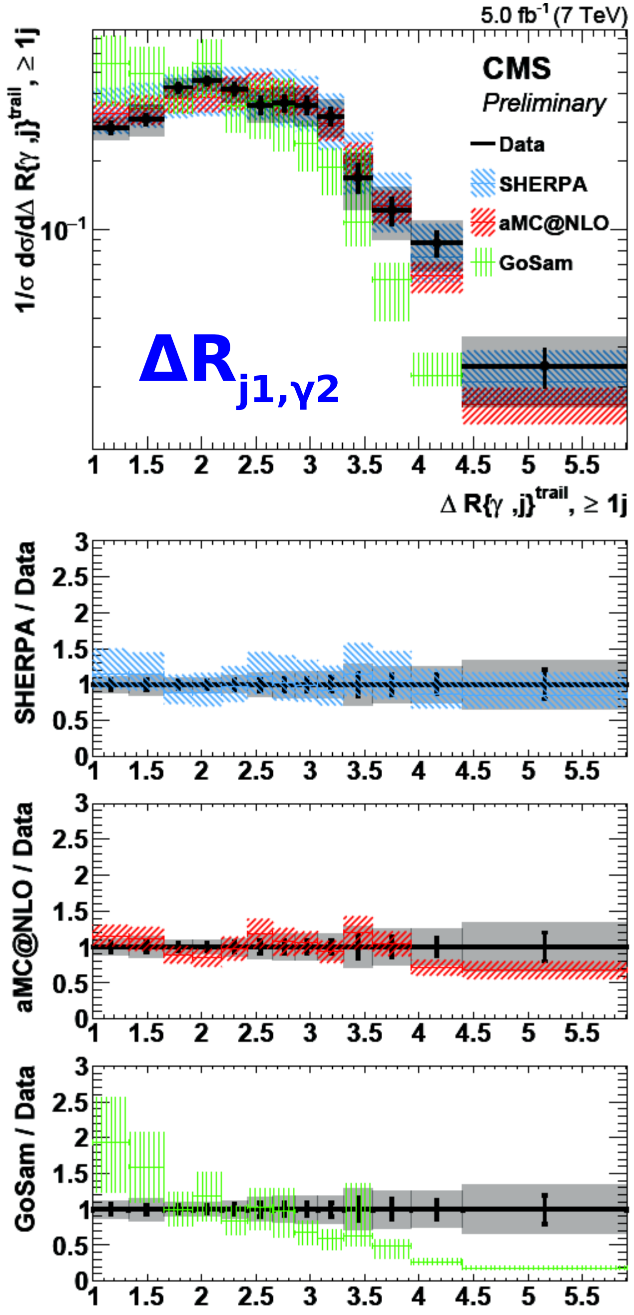


Good description of many diphoton and jet observables by investigated Theory predictions.

Some deviations visible for GoSam in angular correlations between photons+jets.

Example right:

ΔR between leading jet + subleading γ



SHERPA LO full MC

aMC@NLO NLO γγj(j) + box + hadr. Pythia8

GoSam NLO γγj or γγjj Part. → had. corr. Pythia8

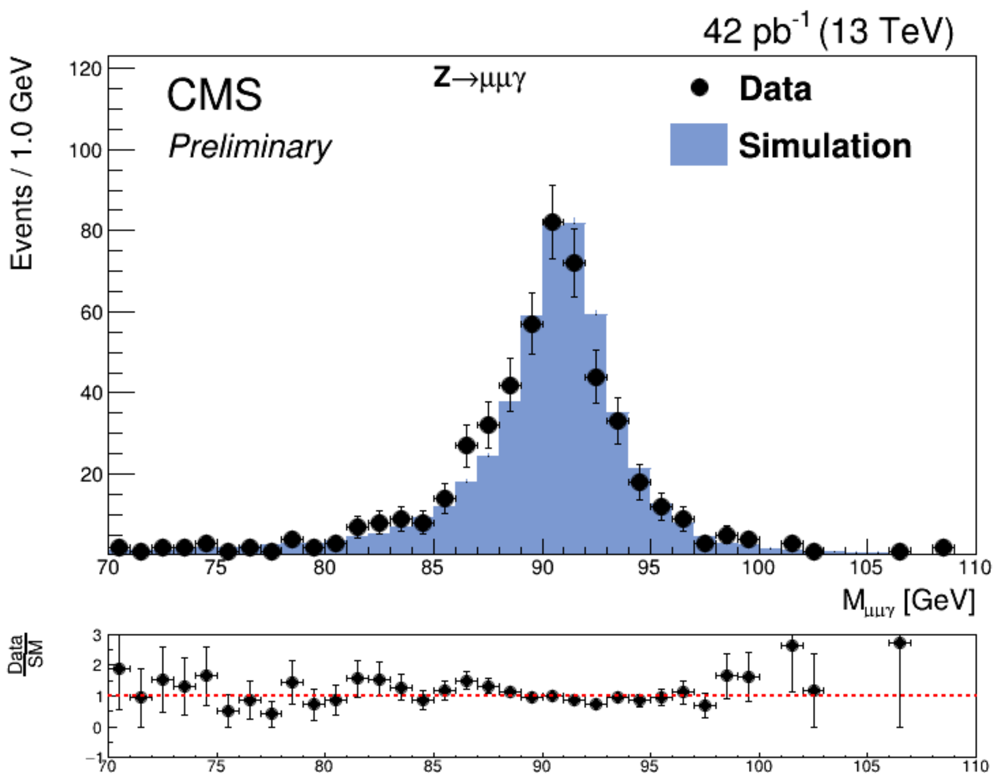
CMS-PAS-SMP-14-021.

Photons at 13 TeV

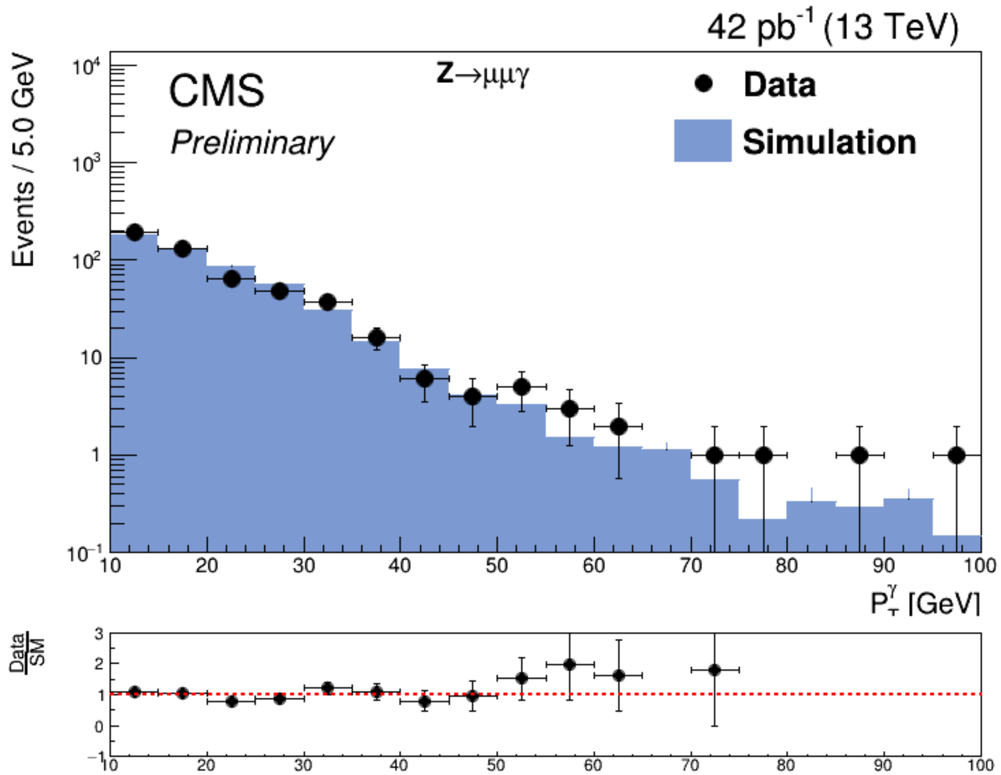
- No new results yet on photon+X or photon+jet+X from CMS :-(
- But first performance studies for Z → $\mu\mu\gamma$ at 13 TeV :-)

Event selection: $p_{T\mu1(2)}$ > 20 (10) GeV, $p_{T\gamma}$ > 10 GeV, 70 GeV < $M_{\mu\mu\gamma}$ < 110 GeV, $M_{\mu\mu\gamma} + M_{\mu\mu}$ < 180 GeV, photon id + isolation

$\mu\mu\gamma$ invariant mass



Photon pT



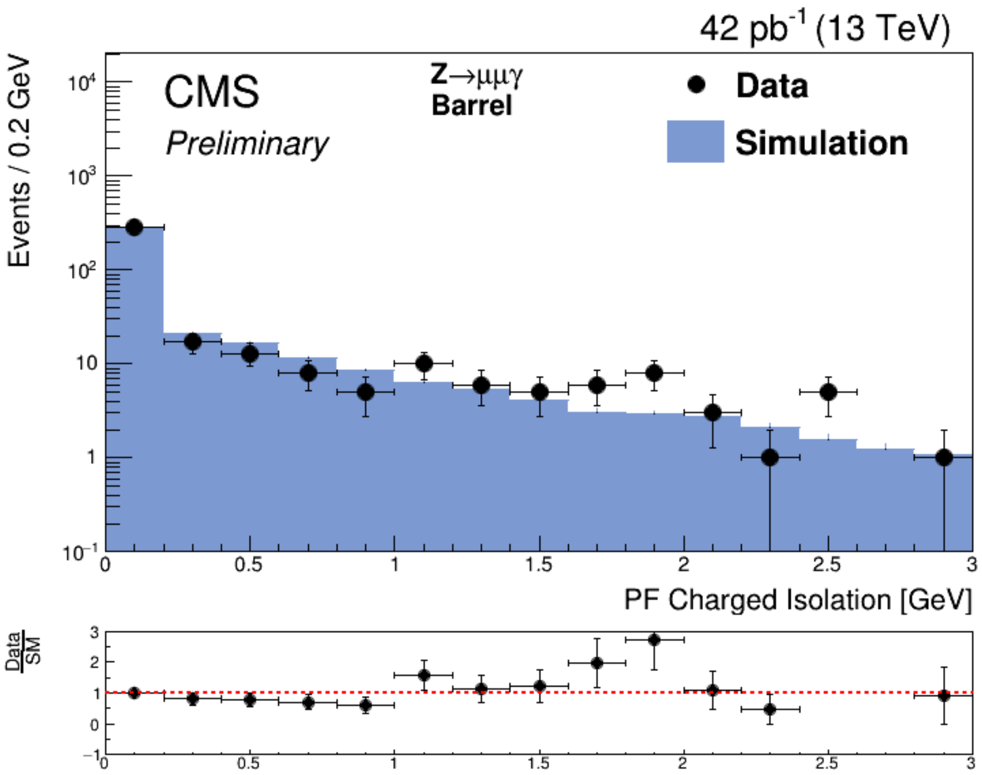
CMS DP-2015/013.

Photons at 13 TeV

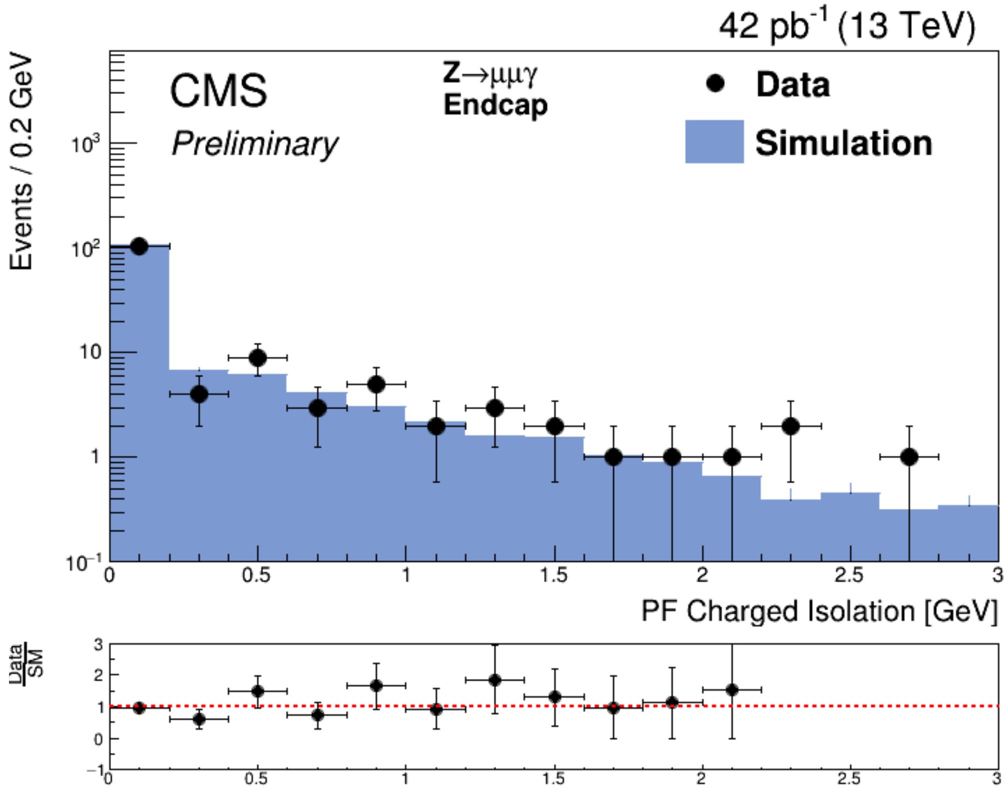
- No new results yet on photon+X or photon+jet+X from CMS :-(
- But first performance studies for Z → μμγ at 13 TeV :-)

Together with Z → ee essential for corrections to photon selection efficiency!

Isolation (charged) in barrel

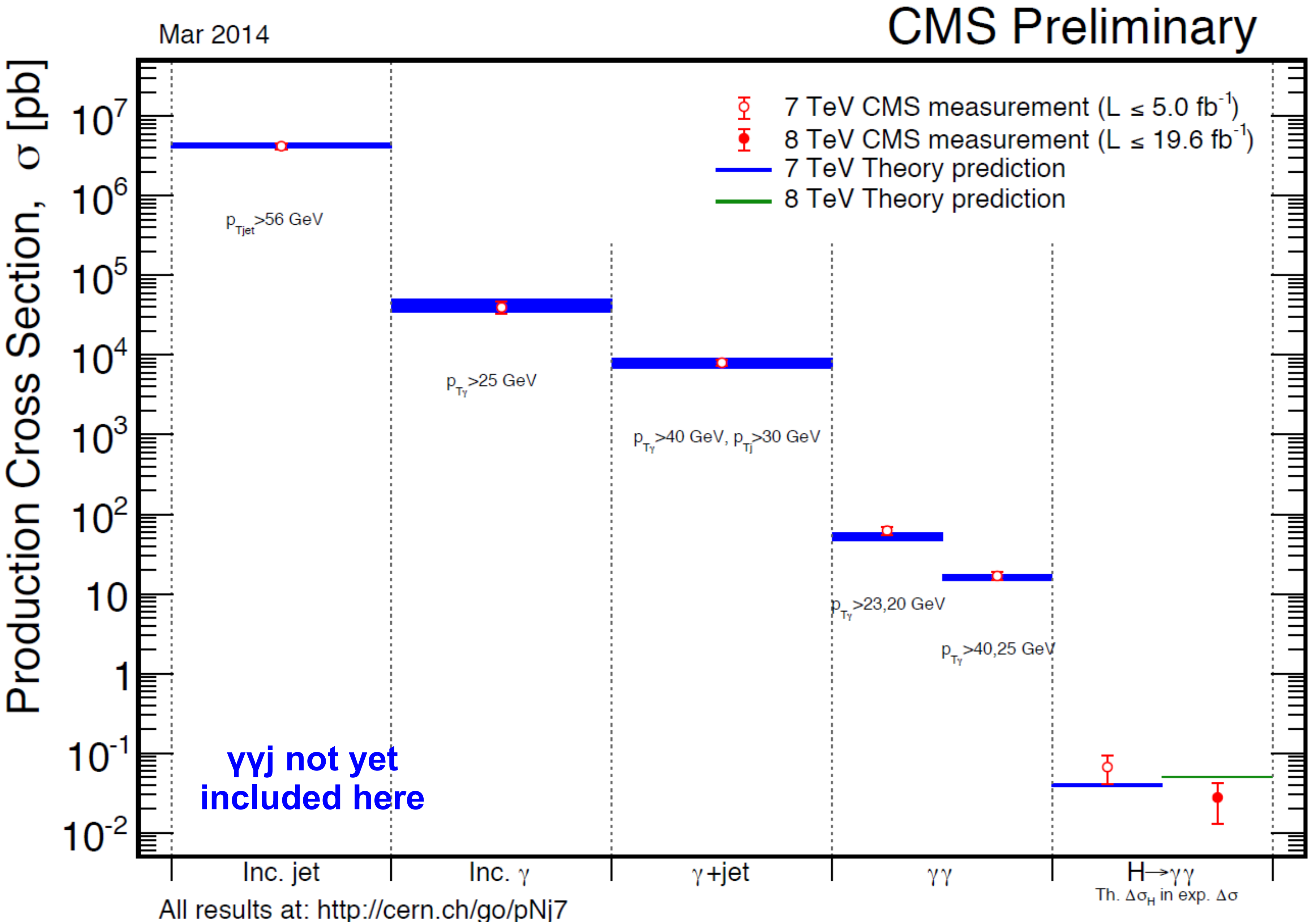


Isolation (charged) in end cap



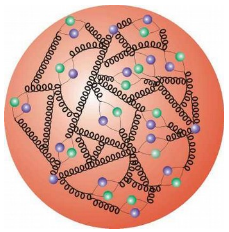
CMS DP-2015/013.

CMS Jet + Photon Summary

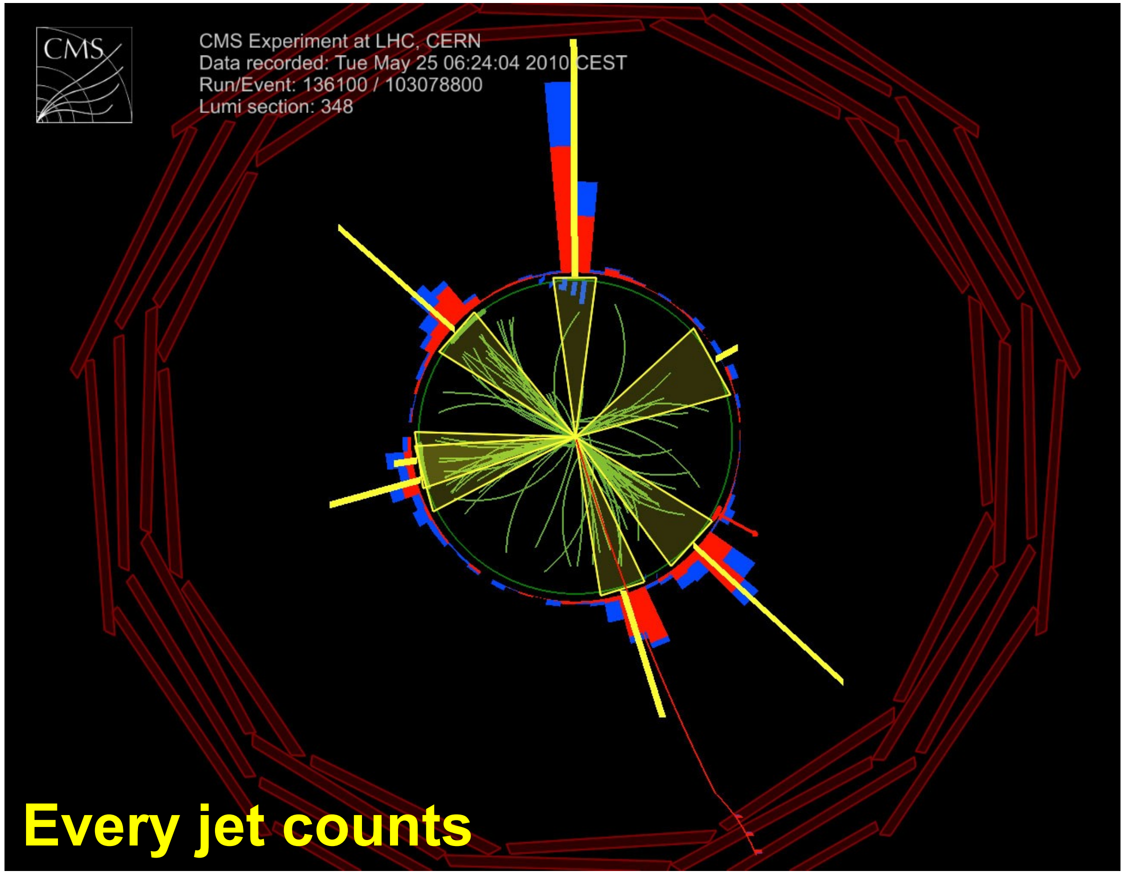


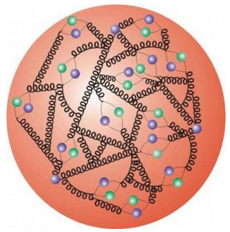
All Inclusive

High transverse Momenta



Proton





Proton

Inclusive Jets

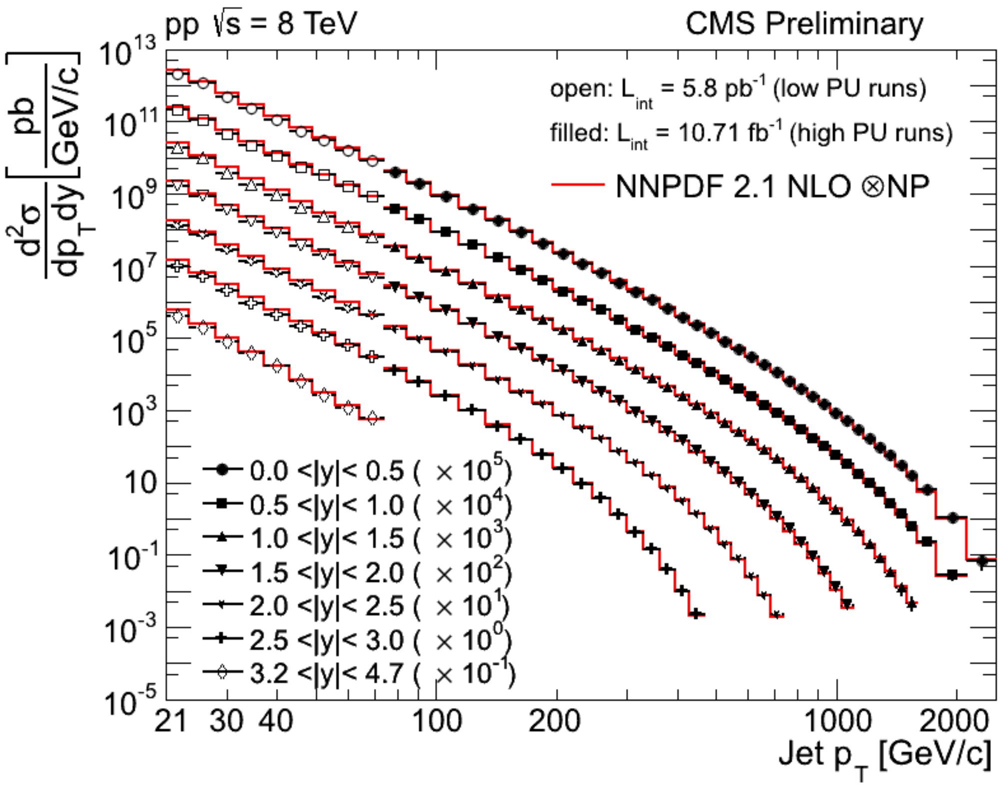
Agreement with predictions of QCD at NLO over many orders of magnitude in cross section and even beyond 2 TeV in jet p_T and for rapidities |y| up to ~ 5
Similar picture at 7 TeV, 8 TeV (left) or NEW 2.76 TeV (right)

$$\frac{d^2\sigma}{dp_T dy} \propto \alpha_s^2$$

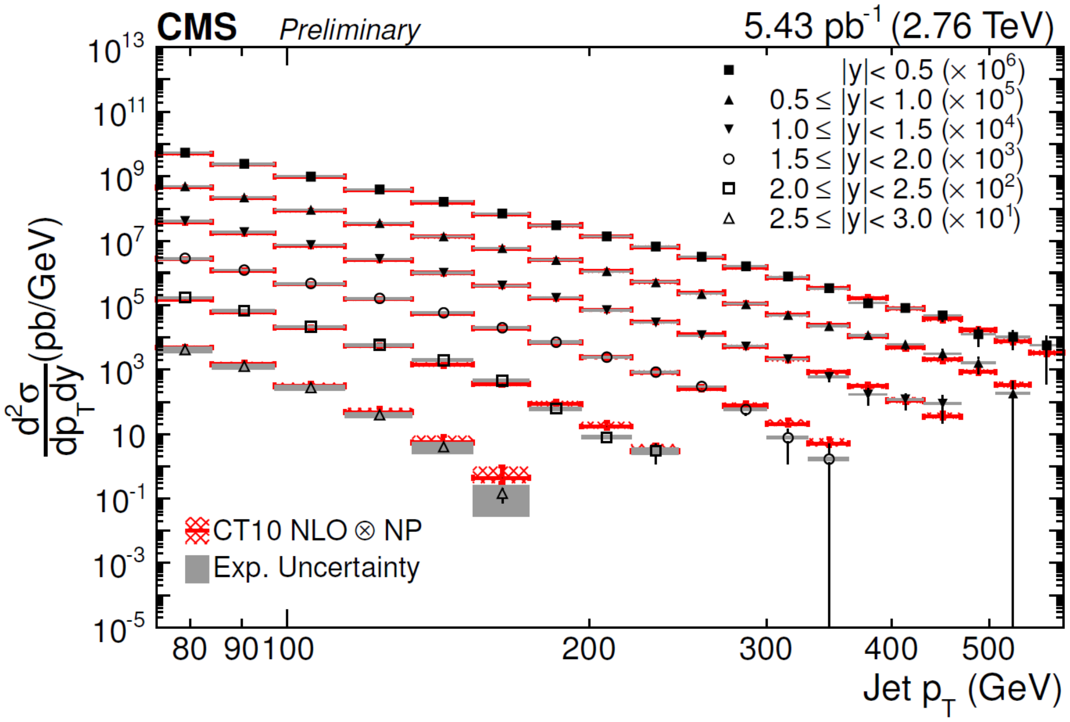
CMS-PAS-SMP-12-012 (2013), CMS-PAS-FSQ-12-031 (2013), CMS-PAS-SMP-14-017 (2015).

Data vs. NLO pQCD ⊗non-perturbative corrections

anti-kT, R=0.7, 8 TeV, 2012



anti-kT, R=0.6, 2.76 TeV, 2012



Inclusive Jets + PDFs

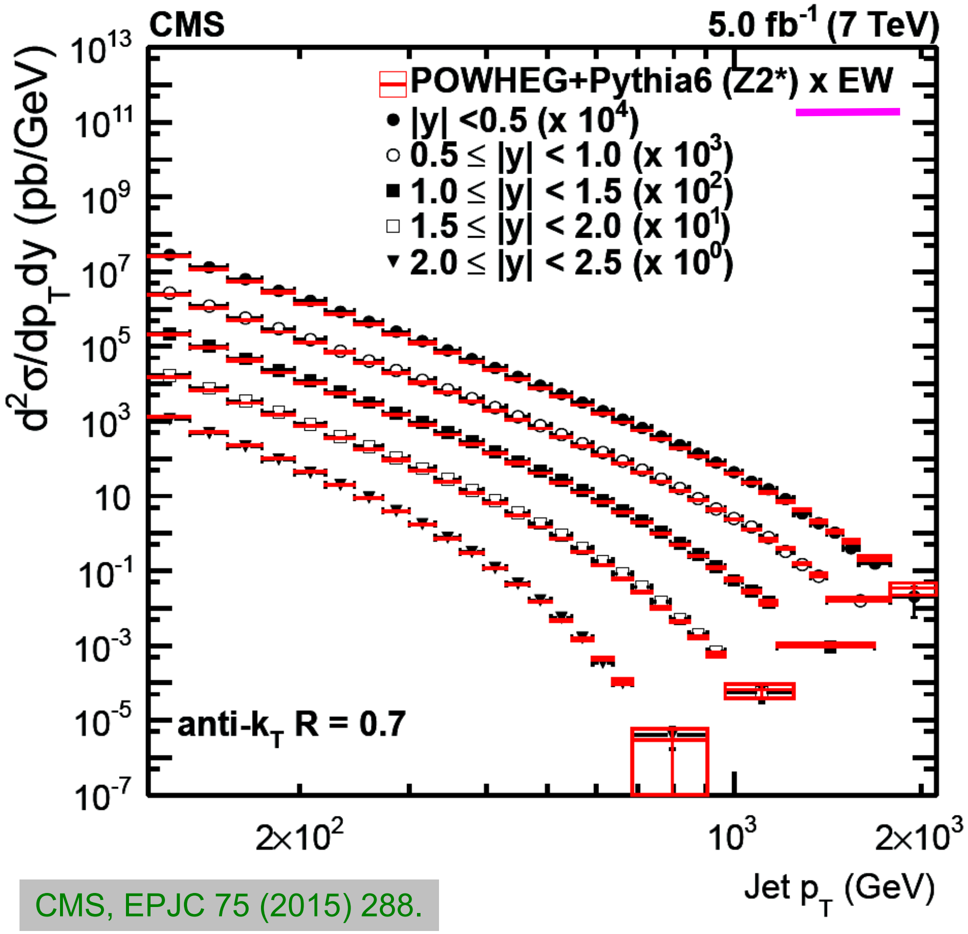
Agreement with predictions of QCD over many orders of magnitude in cross section and beyond 2 TeV in jet p_T

Constrains PDFs
"Harder" gluon at high x compared to DIS

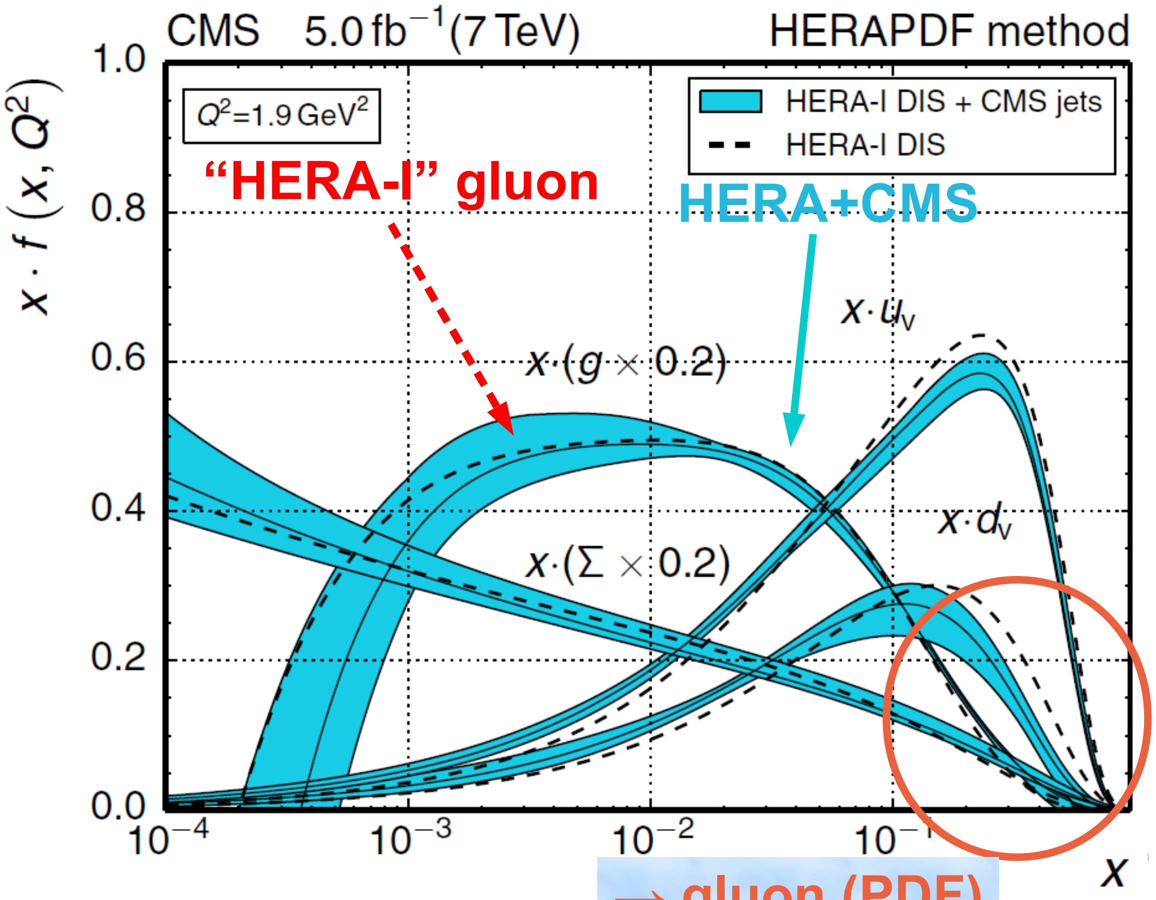
$$\frac{d^2\sigma}{dp_T dy} \propto \alpha_s^2$$

Data vs. NLO+PS ⊗ EW corrections
→ impact visible in dijet angular obs.

anti-kT, R=0.7, 7 TeV, 2011



CMS, EPJC 75 (2015) 288.

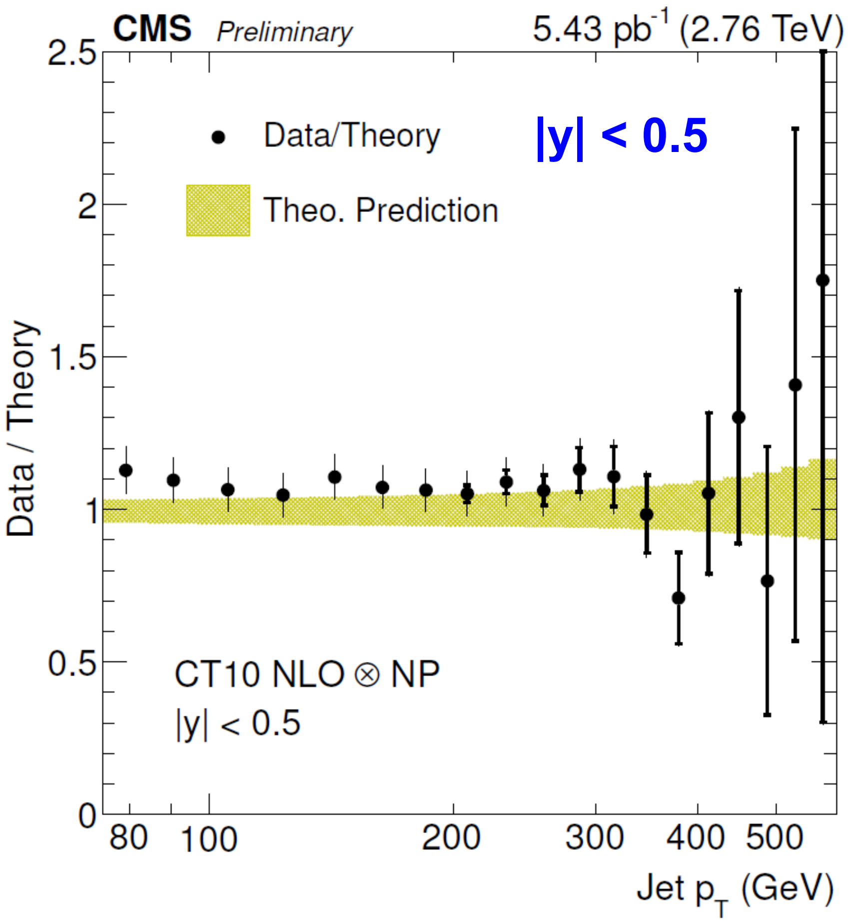


→ gluon (PDF)

Inclusive Jet Ratios: “2.76 / 8.0”

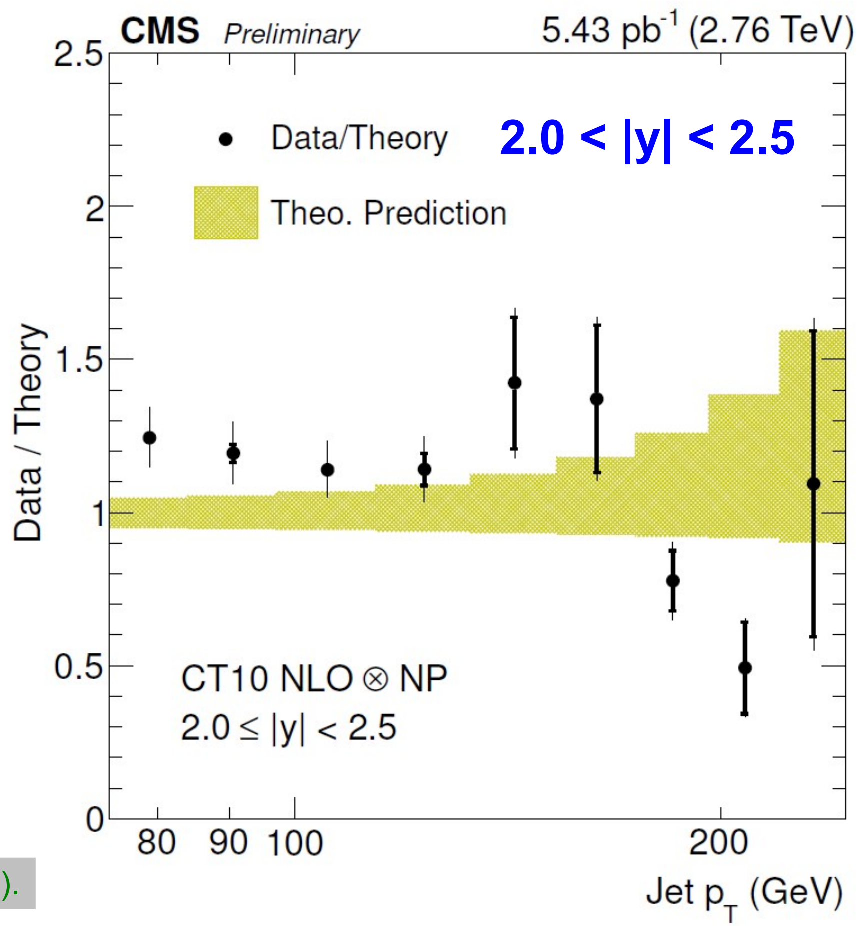
New from CMS:
- cross sections at 2.76 TeV
- ratios to 8 TeV
  Shown
- double ratio to theory

Ratio at E_{cms} = 2.76 and 8.0 TeV
→ at least partial cancellation of uncertainties
→ more precise comparisons

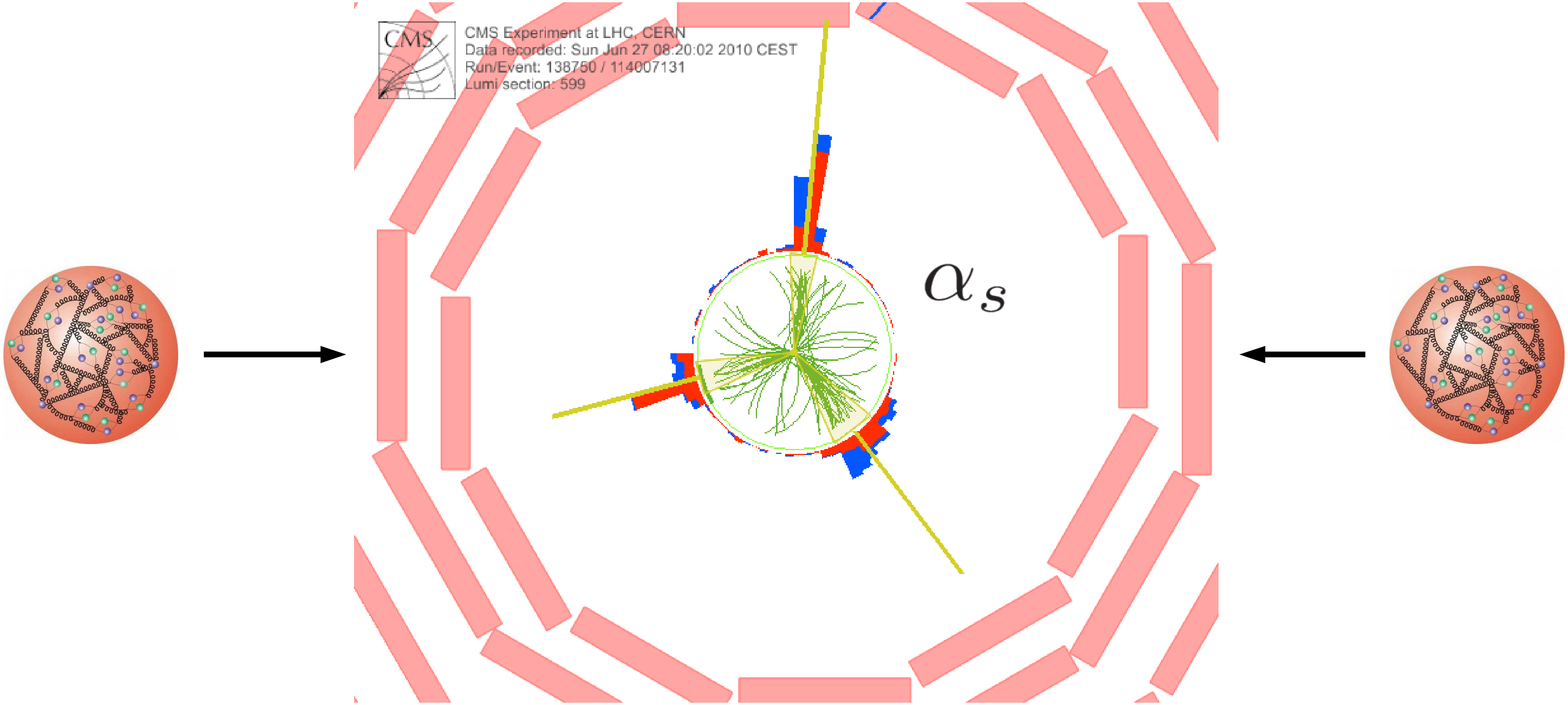


→ gluon (PDF)

CMS-PAS-SMP-14-017 (2015).

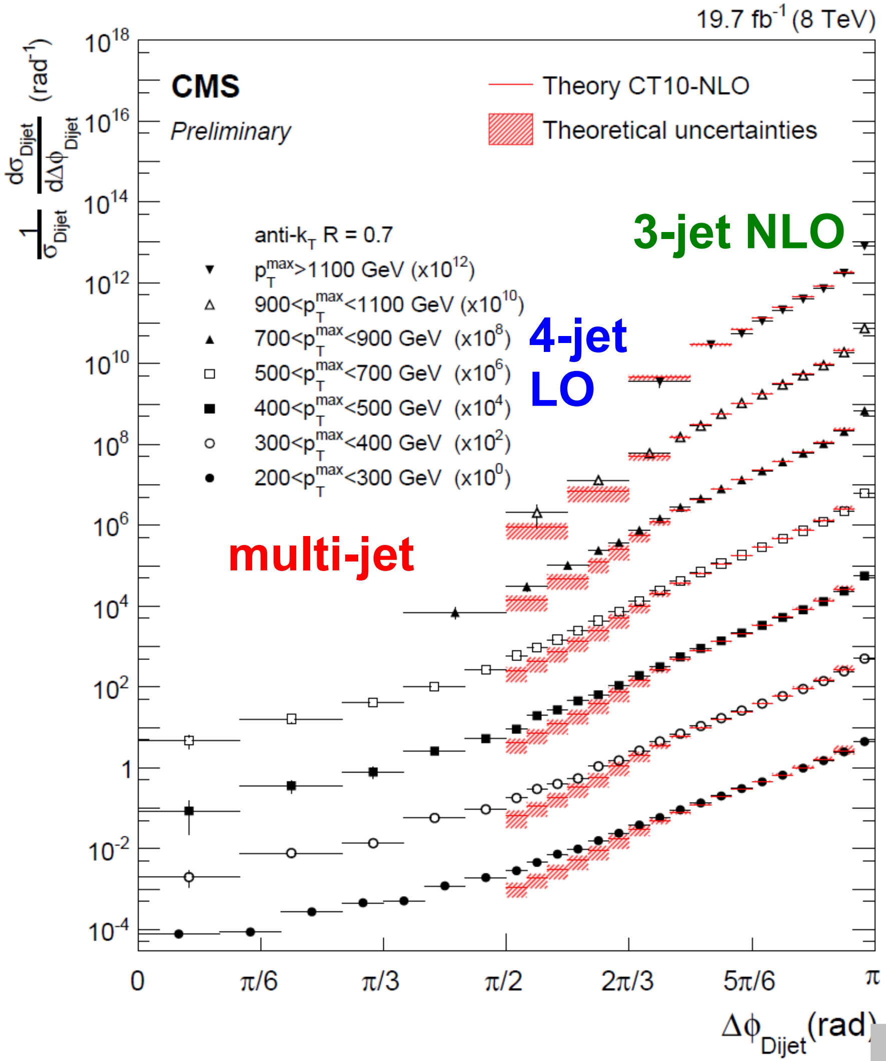


Multi-Jets and α_s



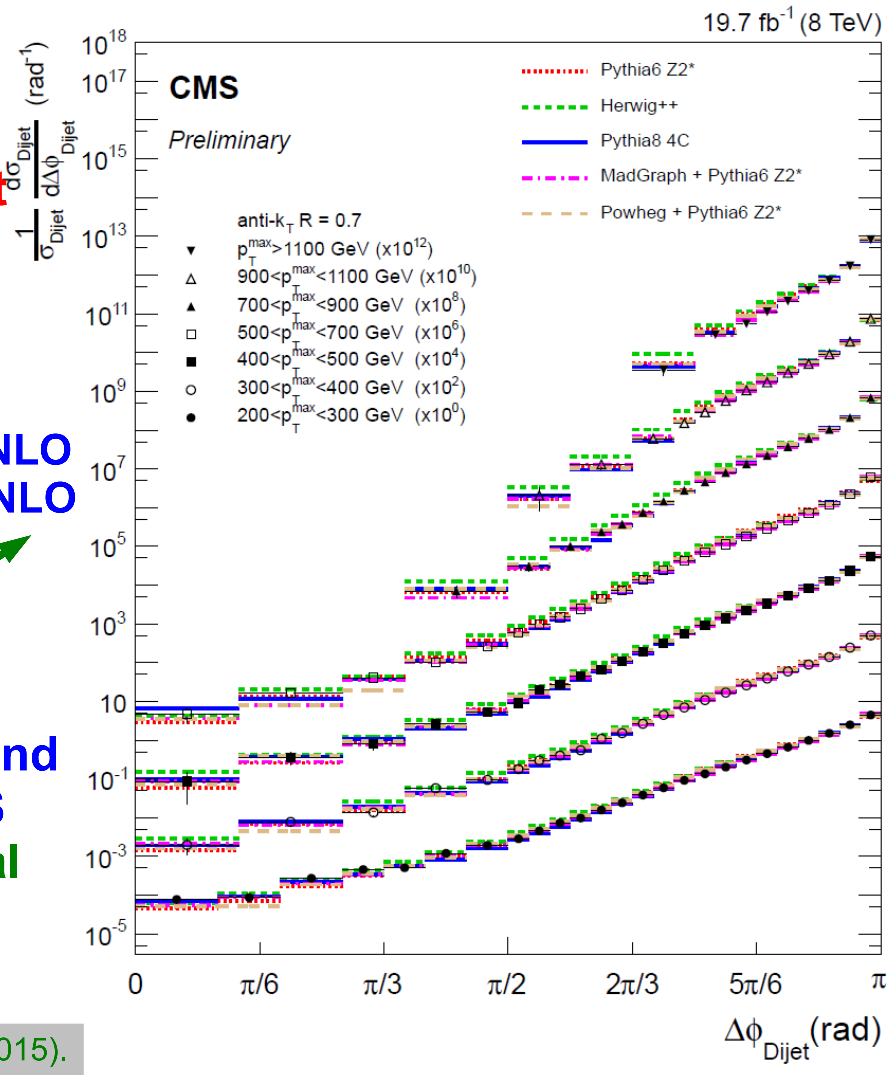
Azimuthal Decorrelations at 8 TeV

$\Delta\varphi_{jj}$ in bins of p_{T1} for p_T > 100 GeV, p_{T1} > 200 GeV, $|y_1|$, $|y_2|$ < 2.5
- dijet LO configuration is always $\Delta\varphi_{jj} = \pi$
- deviations through multijet production



Comparison to fixed-order PQCD
→ need multijet NLO

Sherpa + BlackHat → 4-jet NLO
Njet → 5-jet NLO
to be checked



Comparison to LO ME+PS and multijet ME+PS
→ good general description

CMS-PAS-SMP-14-015 (2015).

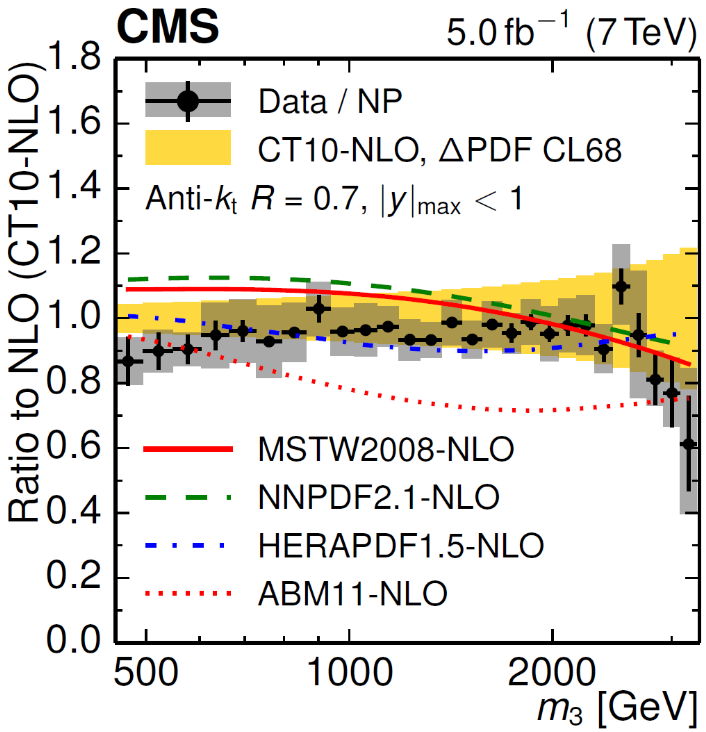
3-Jet Mass

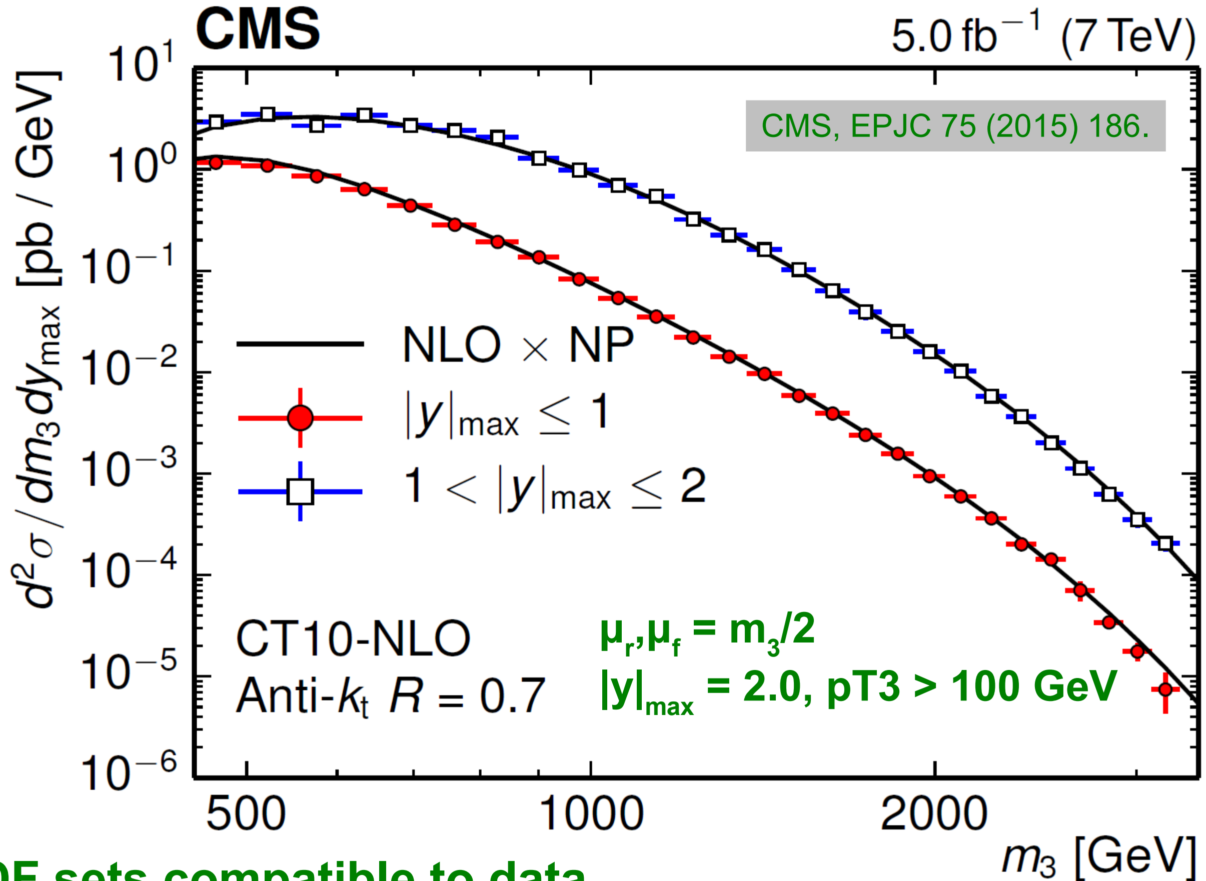
Sensitive to α_s beyond 2→2 process

NLO with 3-4 partons (NLOJet++)

Sensitive to PDFs **→ gluon (PDF)**

Involves additional "scale" $p_{T,3}$





Most PDF sets compatible to data

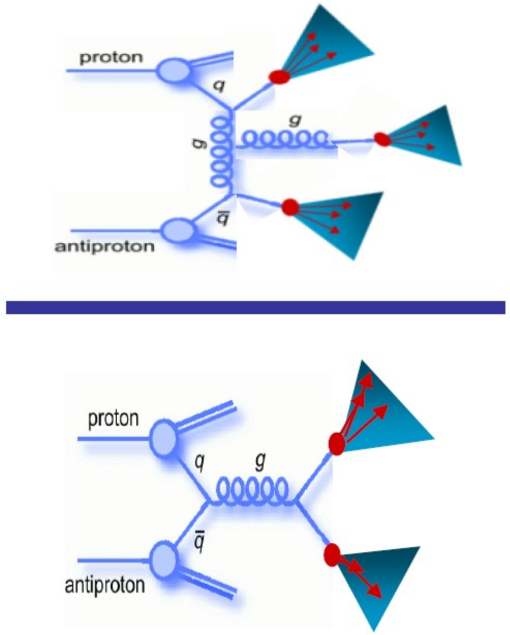
$$\frac{d\sigma_{3jet}}{dm_{3jet}} \propto \alpha_s^3$$

Extraction of $\alpha_s(M_Z)$ from scales up to 1.4 TeV

Dominated by theory uncertainty! NLO only

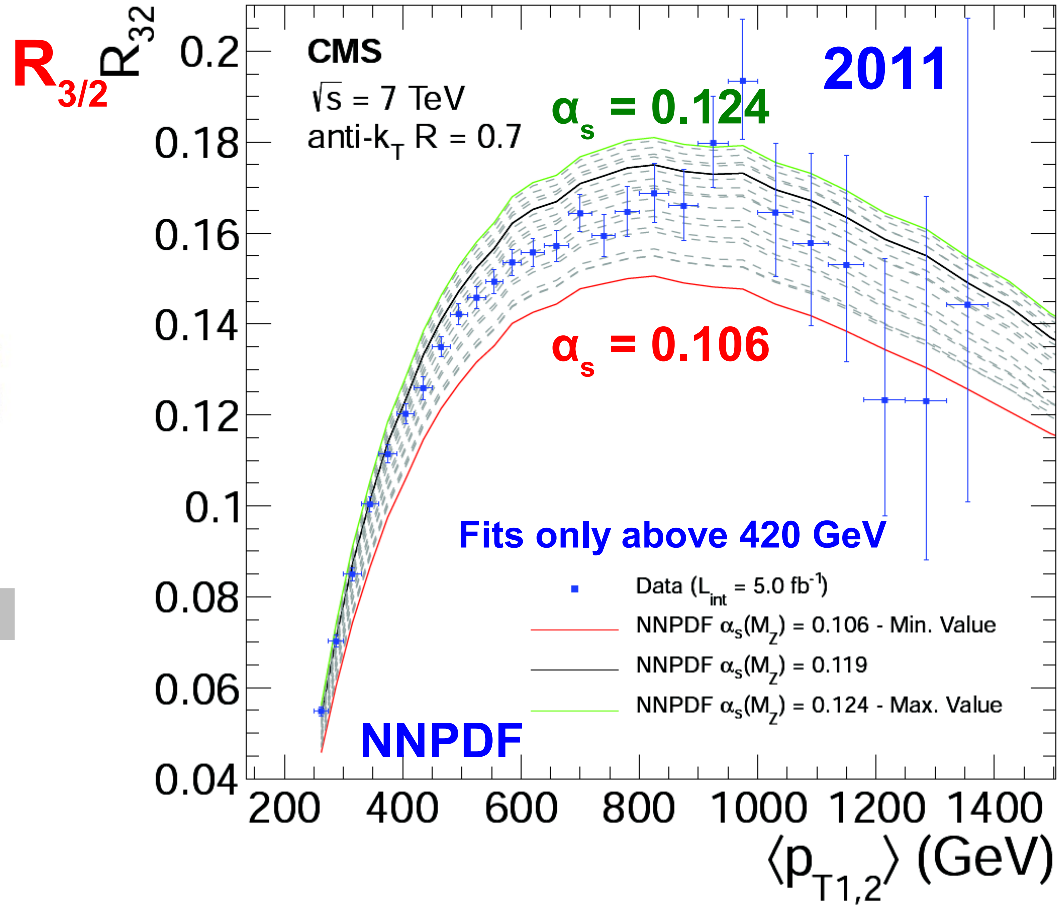
$$\alpha_S(M_Z) = 0.1171 \pm 0.0013(\mathrm{exp}) \pm 0.0024(\mathrm{PDF}) \pm 0.0008(\mathrm{NP})^{+0.0069}_{-0.0040}(\mathrm{scale})$$

3- to 2-Jet Ratios



M. Wobisch

$\Longleftrightarrow \alpha_s$



CMS: $R_{3/2}$
- **Ratio of inclusive 3- to inclusive 2-jet events**
- **anti-kT R=0.7**
- **Min. jet pT: 150 GeV**
- **Max. rap.: |y| < 2.5**
- **Scale: Average dijet pT**
- **Data 2011, 5/fb**

Similarly described by CT10 or MSTW2008
Deviations observed with ABM11

$$\alpha_s(M_Z) = 0.1148 \pm 0.0014\,(\text{exp}) \pm 0.0018\,(\text{PDF}) \pm 0.0050\,(\text{theory})$$

Dominated by theory uncertainty!

CMS, EPJC 73 (2013) 2604.

Fits with top-pair Production

Top-pair production is especially sensitive to:

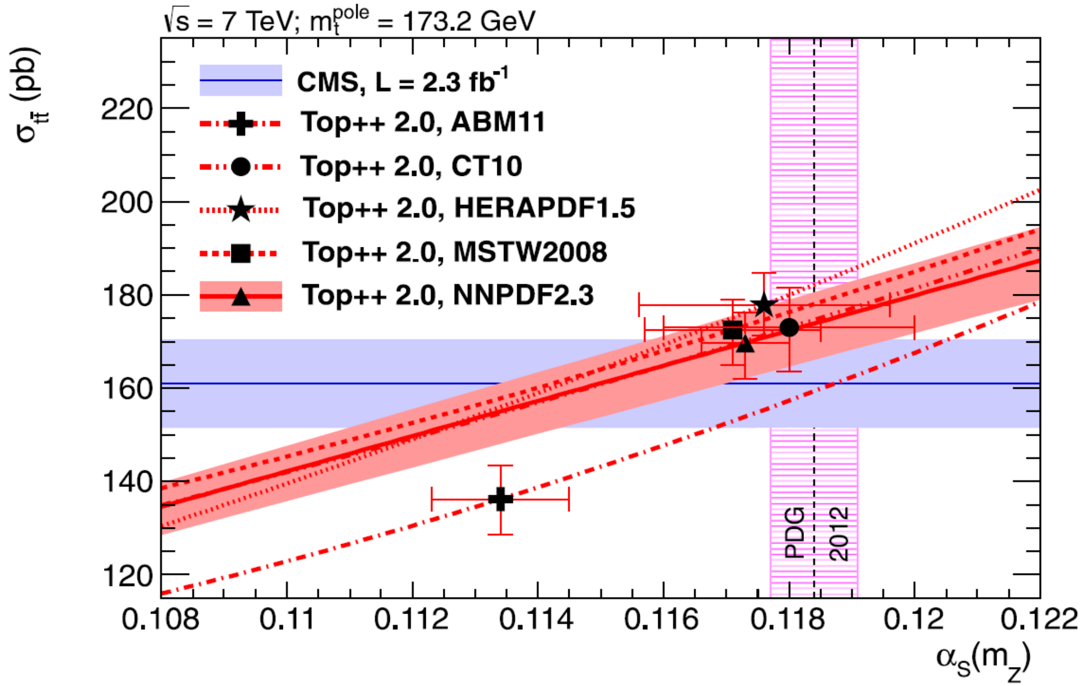
m_t^{pole} and α_s and $g(x,\mu_f^2)$ as the main production process at LHC is from gg

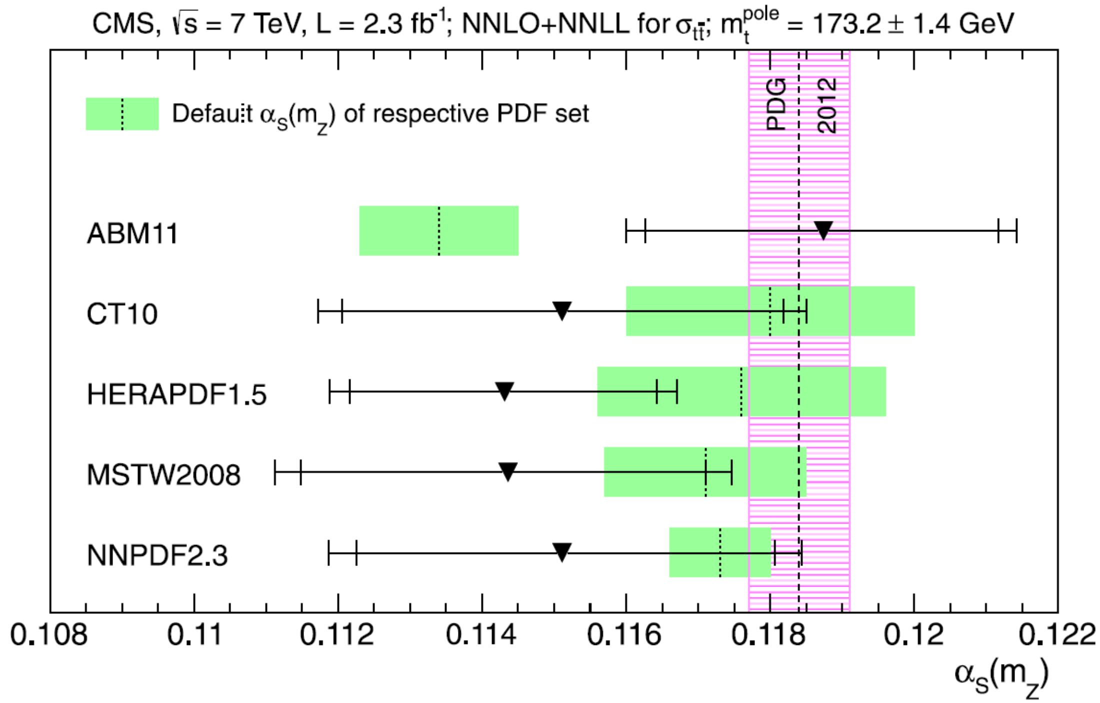
Using only the ttbar cross section measurement (dilepton channel) combined fits are not possible. Fixing the gluon to one of 5 PDF sets, however, it is possible to extract m_t^{pole} while fixing α_s or vice versa.

$$\alpha_s(M_Z) = 0.1151 \pm 0.0025(\mathrm{exp})^{+0.0013}_{-0.0011}(\mathrm{PDF})$$

NNLO + NNLL $\quad {}^{+0.0009}_{-0.0008}(\mathrm{scale}) \pm 0.0013(\mathrm{m_t^{pole}}) \pm 0.0008(\mathrm{E_{LHC}})$ **new top related**

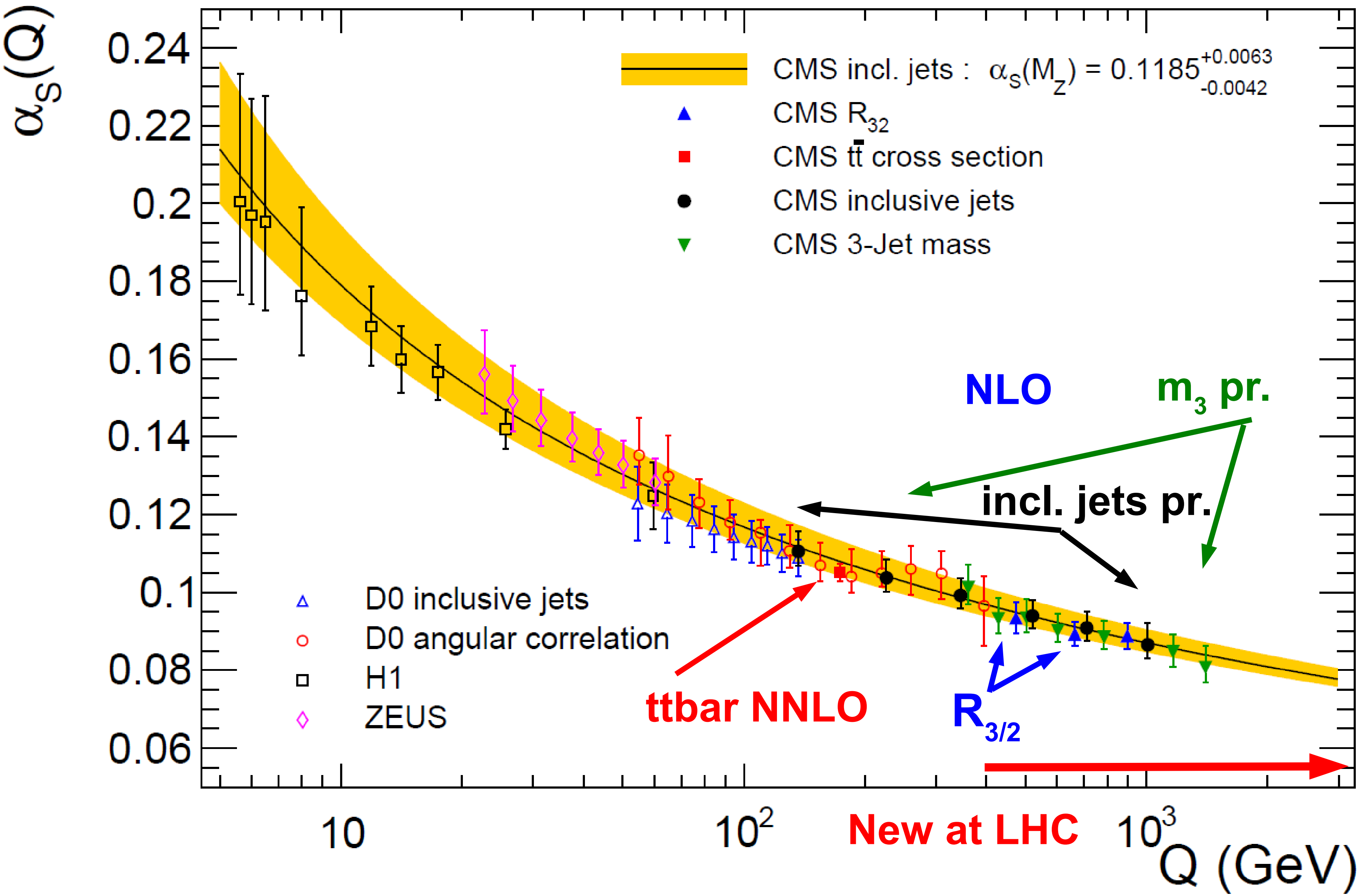
Fix $m_t^{pole} \rightarrow$ constrain α_s



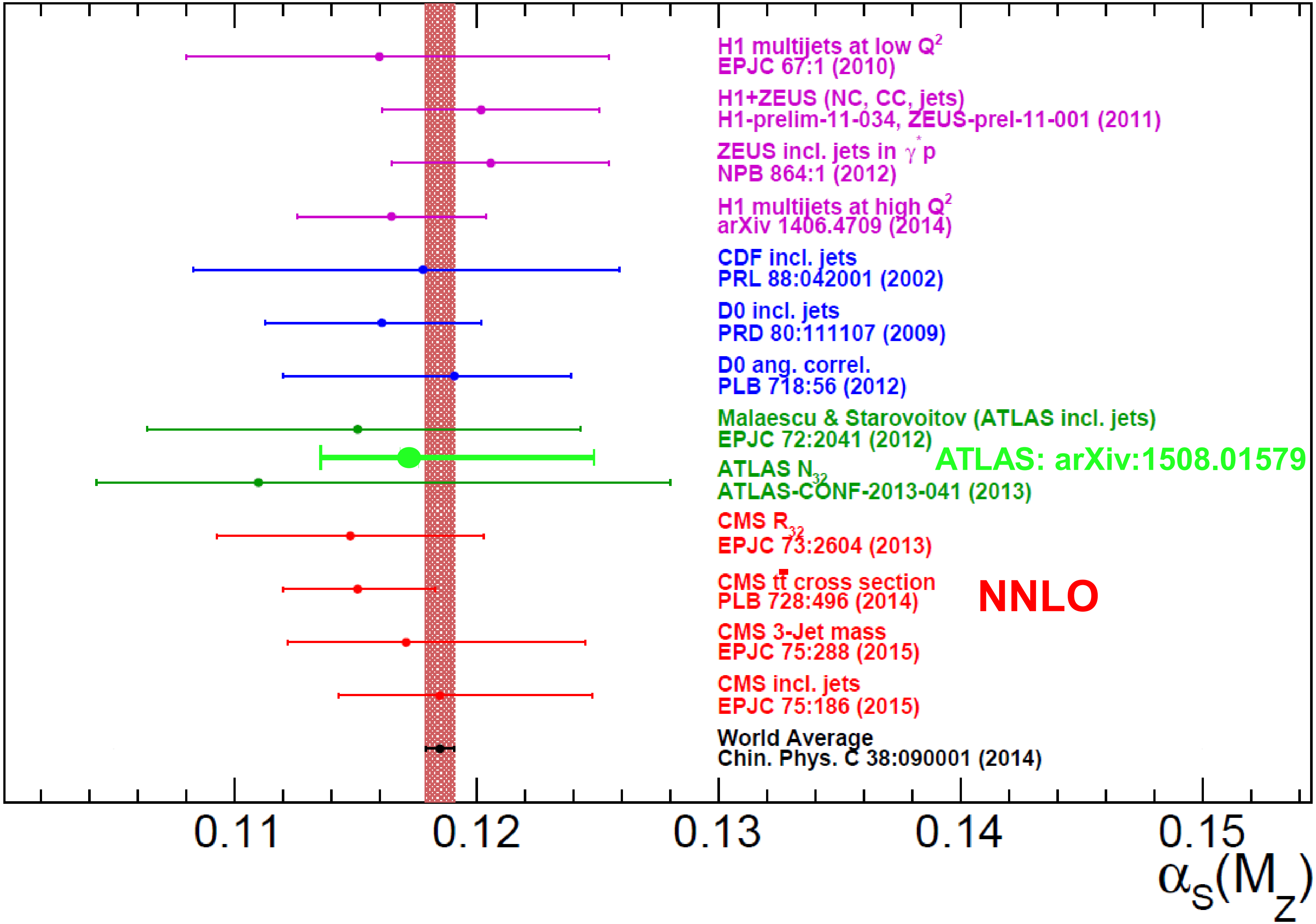


CMS, PLB 728, 496 (2013), JHEP 11, 067 (2012).

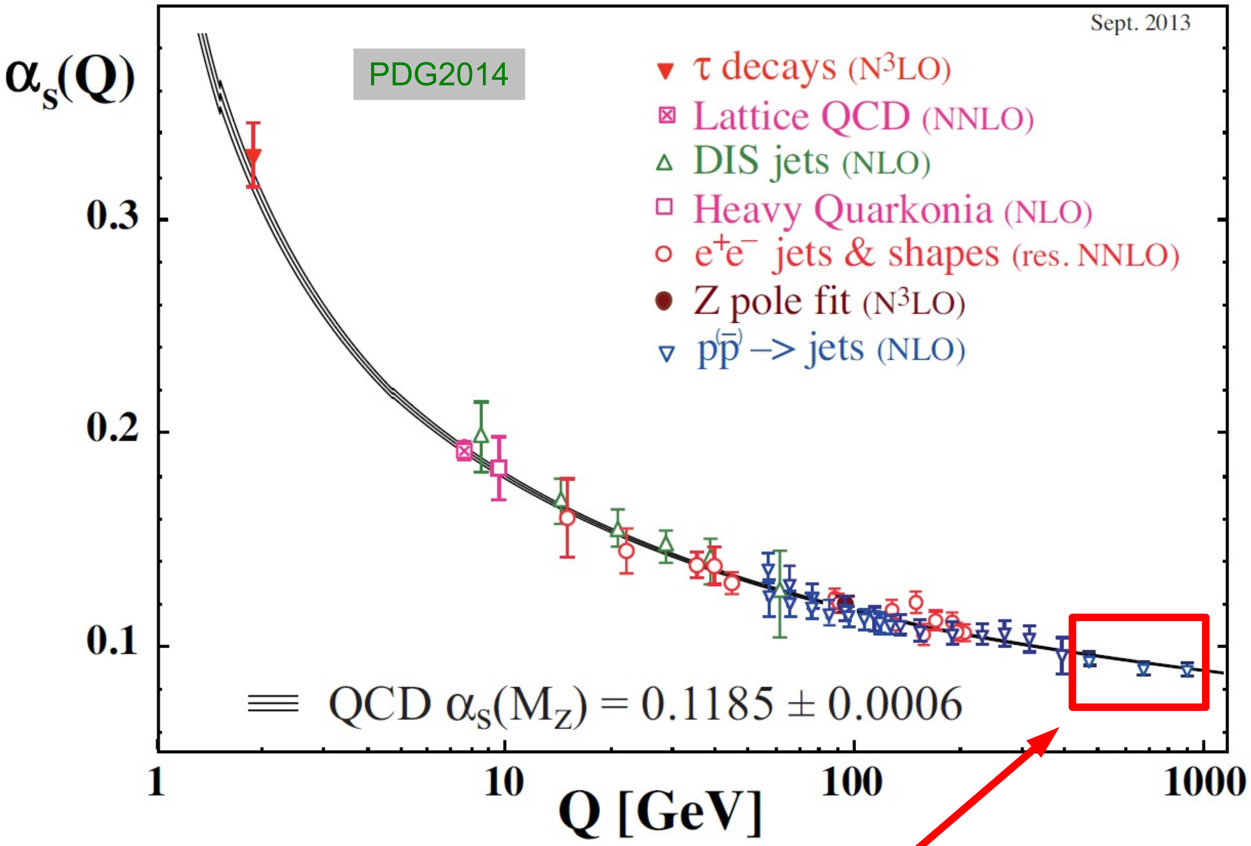
CMS α_s Summary

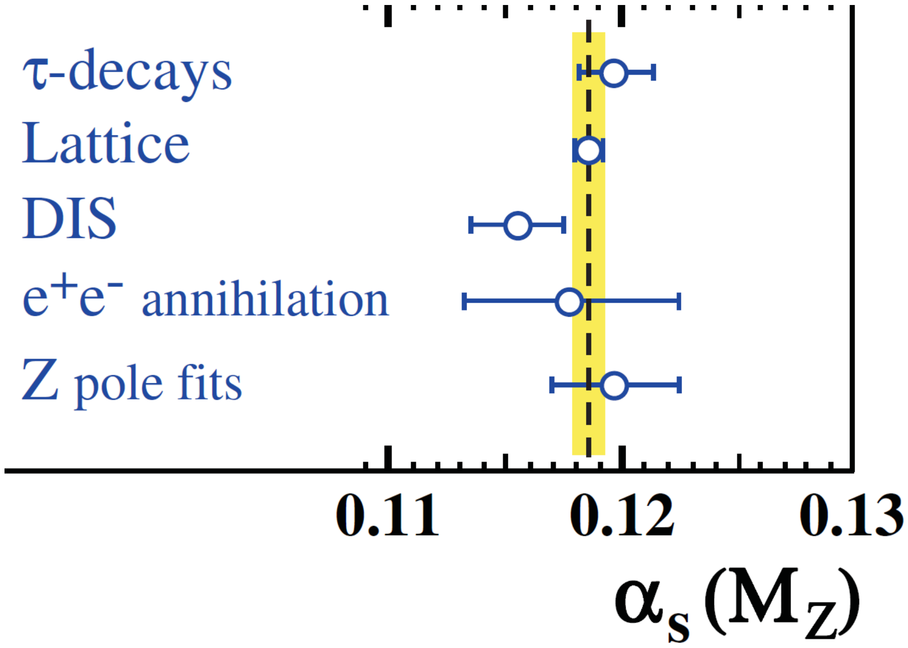


Jets (& ttbar) α_s Summary



PDG α_s Summary





Dominated by Lattice Gauge Theory

CMS data, but not in average since only NLO theory!

$$\alpha_s(M_Z) = 0.1185 \pm 0.0006$$

$$\frac{\Delta\alpha_S(M_Z)}{\alpha_S(M_Z)} = 0.5\%$$

PDG´92: 2.4%

PDG, Chin. Phys. C 38 (2014) 090001.

Summary

- Some LHC Results at 8 TeV still to be finalized … and 13 TeV ongoing
- Data quality makes jet measurements PRECISION PHYSICS
- Of course, we hope that our results are not only precise,
  but also "accurate" :-)
- Theory definitely entered regime of NLO as Standard
- But still theory uncertainty dominant, NNLO required at least …!
- … and photon data and PDFs.
- Many PDF/α_s relevant measurements from LHC ongoing or in near future
  → reduction of uncertainties possible

Summary

- Some LHC Results at 8 TeV still to be finalized … and 13 TeV ongoing
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- … and photon data and PDFs.
- Many PDF/α_s relevant measurements from LHC ongoing or in near future
  → reduction of uncertainties possible

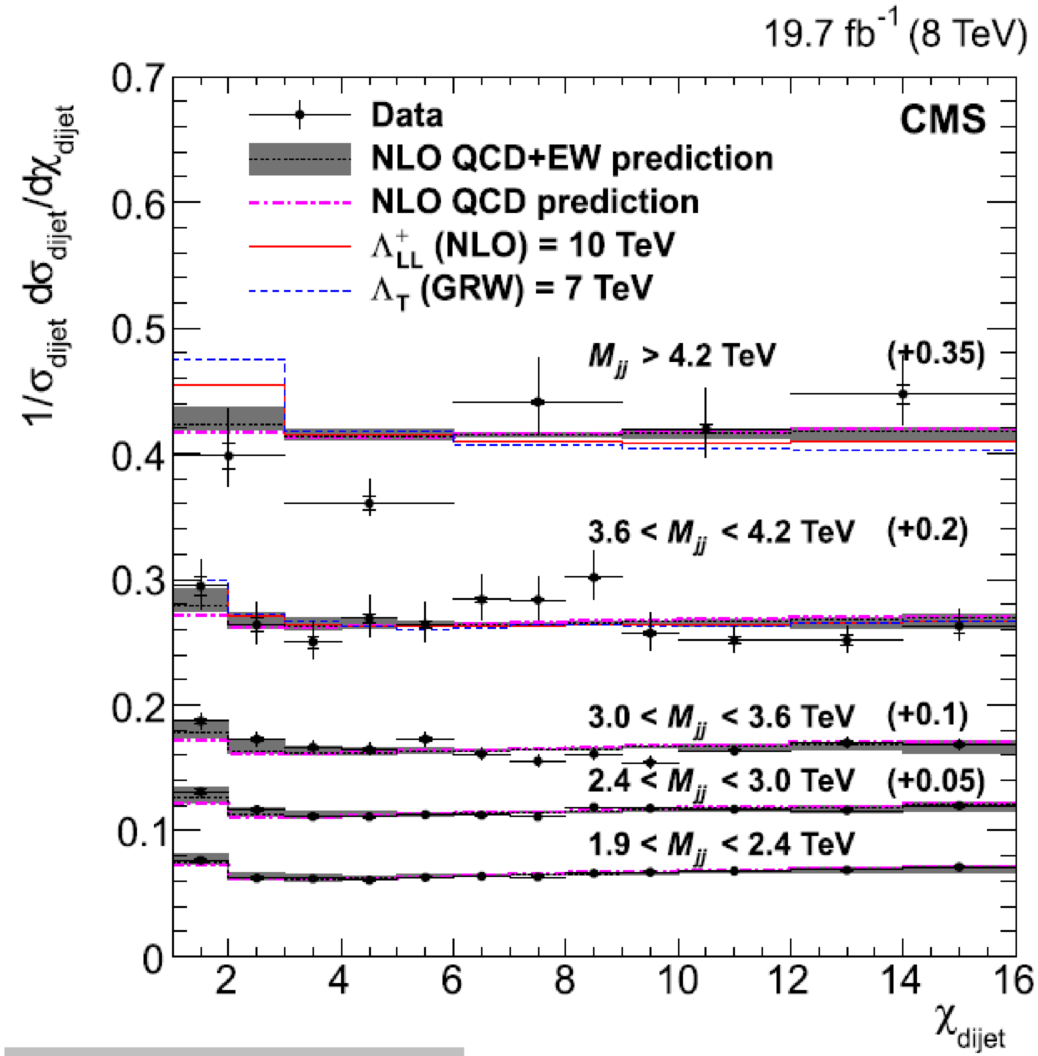
Thank you for your attention
and the invitation to speak here!

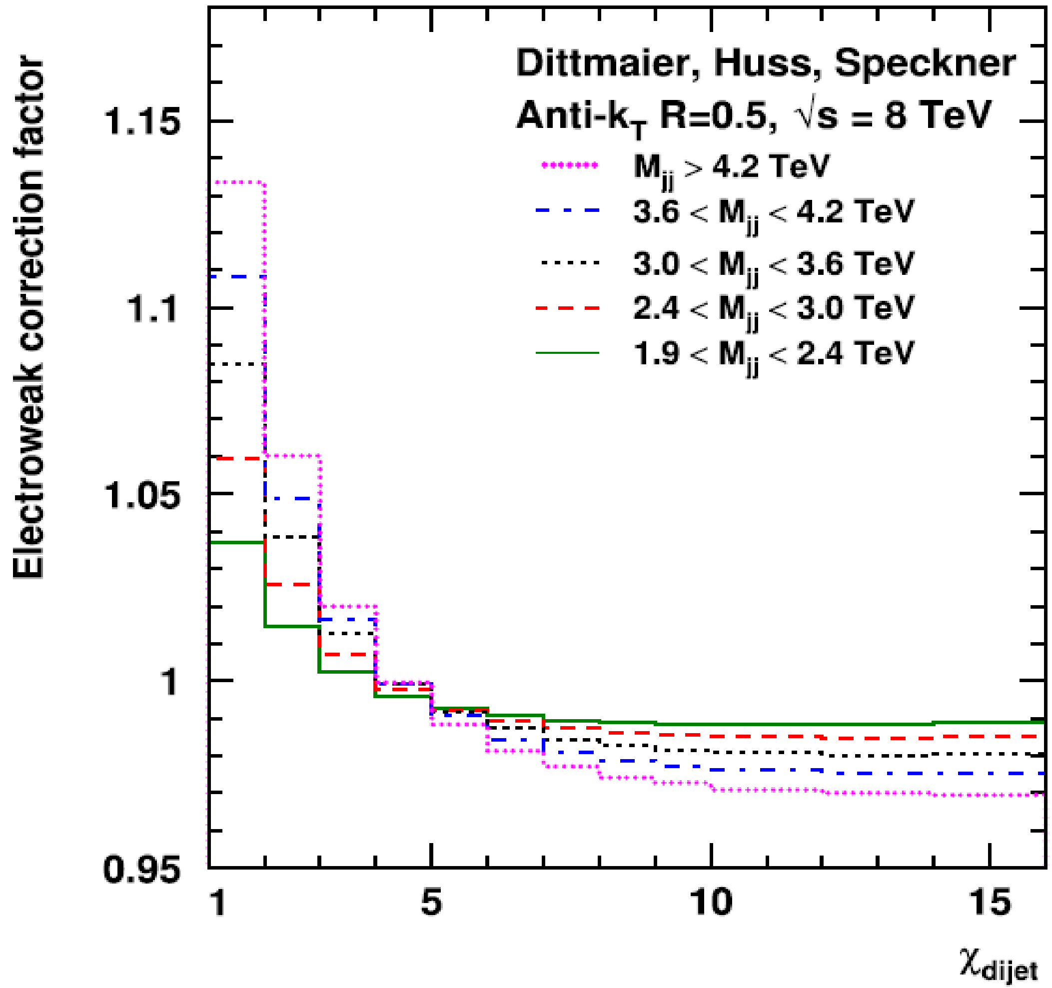
Backup Slides

Dijet Angular & EW Corrections

Better agreement theory vs. data WITH ew corrections
→ ~ 5% higher exclusion limits for searches

Dittmaier, Huss, Speckner, JHEP11 (2012) 095.

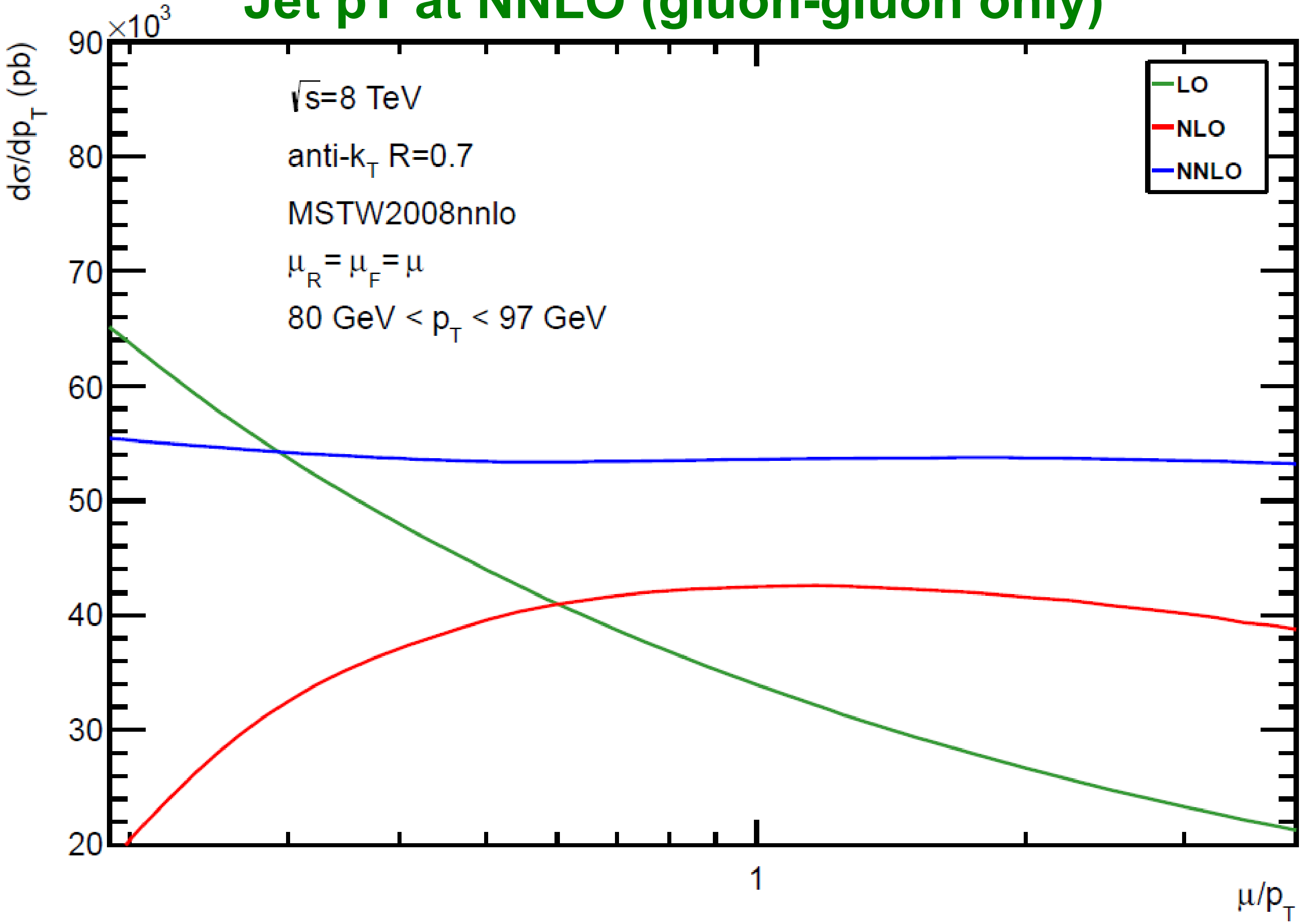




CMS, PLB 746 (2015) 79.

NNLO Scale Dependence

Jet pT at NNLO (gluon-gluon only)



Drastically reduced scale dependence!

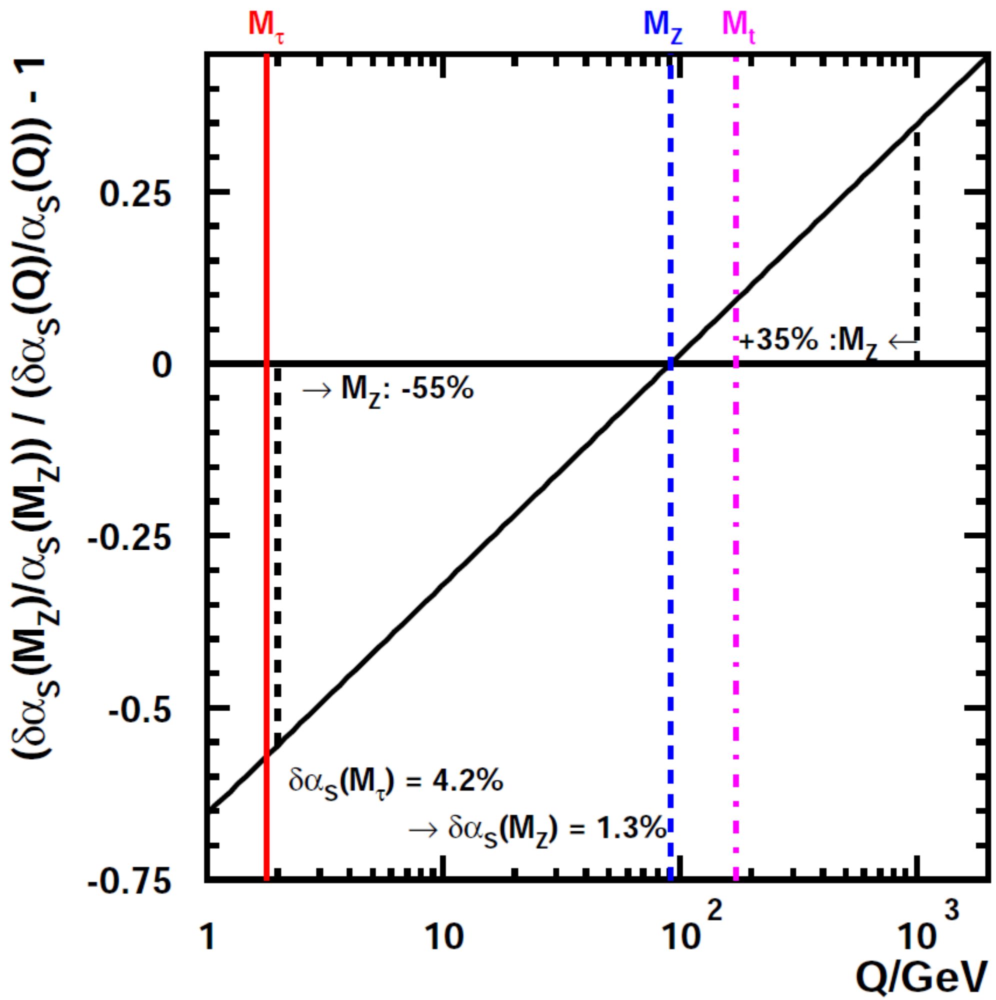
$|y| < 4.4$, 80 GeV $< p_T <$ 97 GeV

Gehrmann- de Ridder et al., PRL110 (2013), JHEP1302 (2013).

Evolving $\Delta\alpha_s$

Incredibly shrinking error →

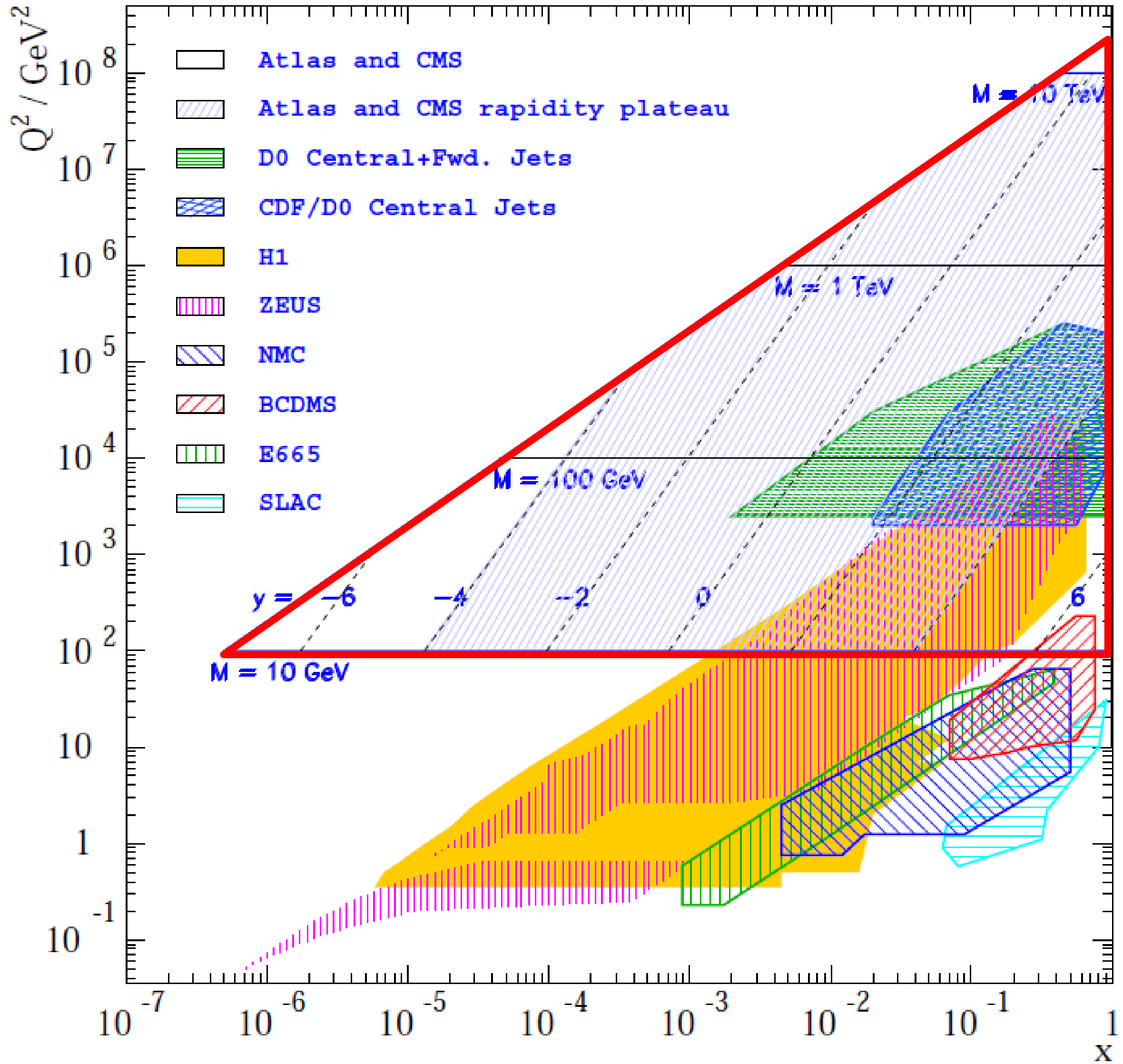
← Uncomfortably growing error



QCD at the LHC

- **Fascinating –**
  comprises a huge variety of phenomena
- **Unavoidable –**
  hadrons are “made of QCD”
- **Indispensable –**
  linking piece between many processes
- **Demanding –**
  enormous background to searches for new physics
- **Uncharted –**
  dominating uncertainty for Higgs cross sections

Huge accessible phase space

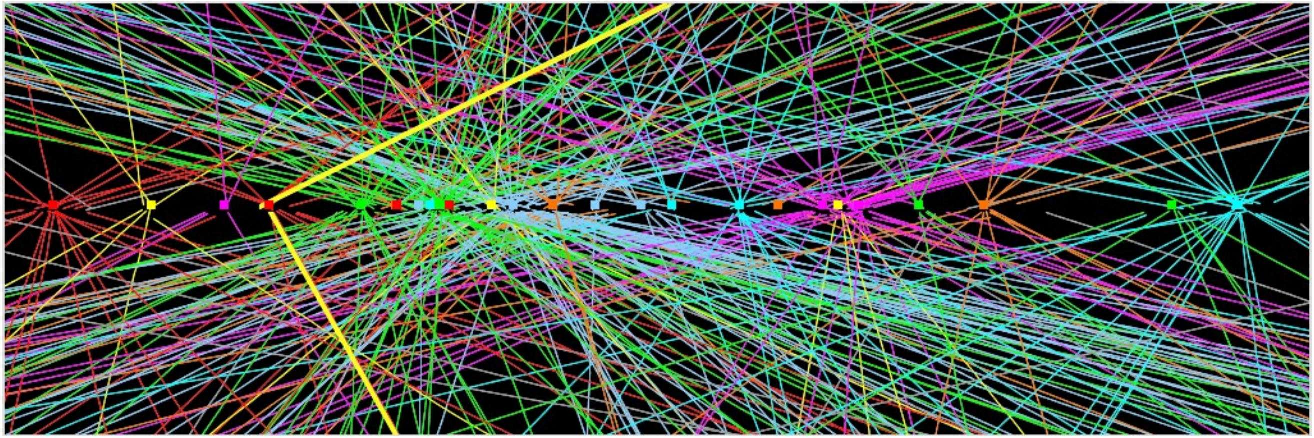


S. Glazov, Braz.J.Ph. 37 (2007) 793.

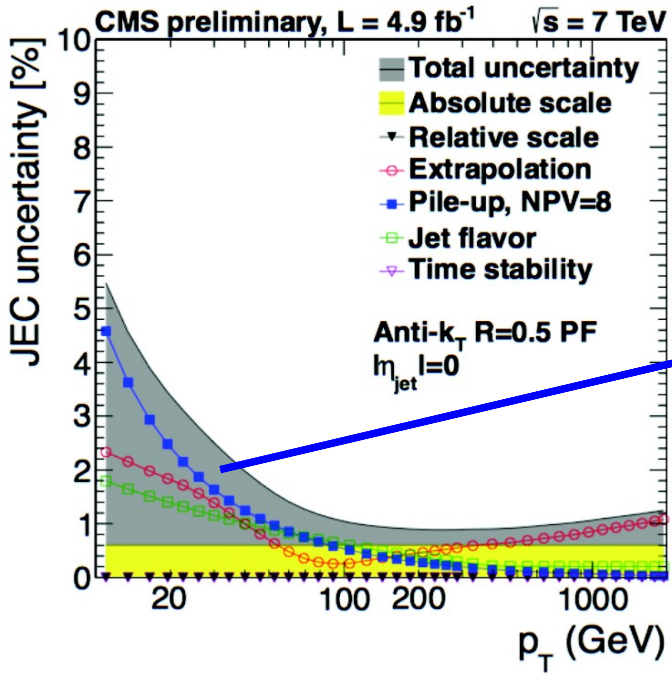
Jet Energy Scale and Pile Up

But:
New situation in 2012 at 8 TeV with many pile-up collisions!

ATLAS Z → μμ candidate with 25 reconstructed primary vertices:
(Record beyond 70!)

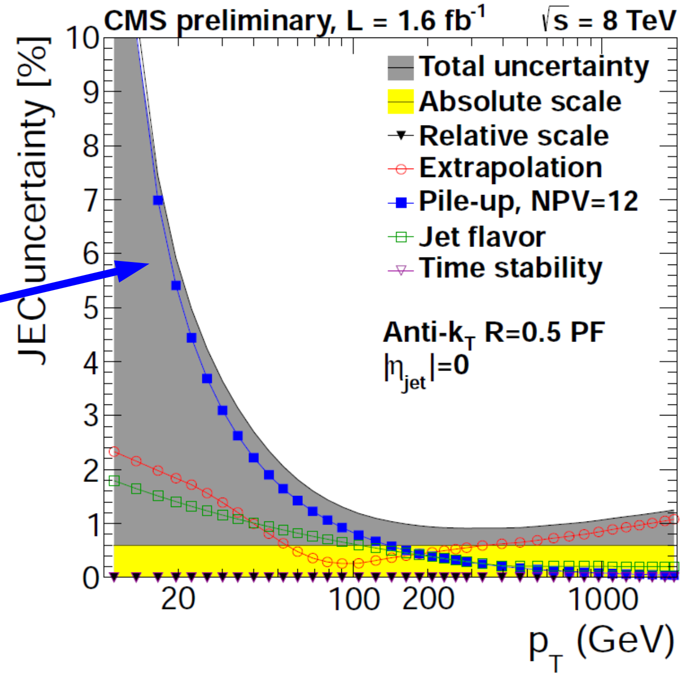


CMS from 5/fb (7 TeV, 2011)



Pile-up effect

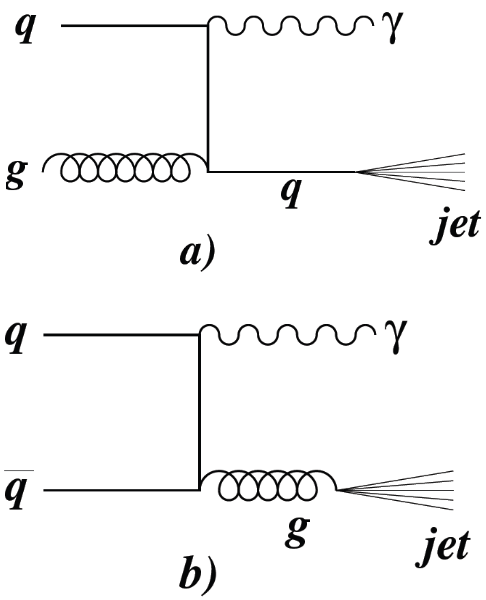
CMS from 1.6/fb (8 TeV, 2011)



CMS, DP2012-006
CMS, DP2012-012

Photon Production

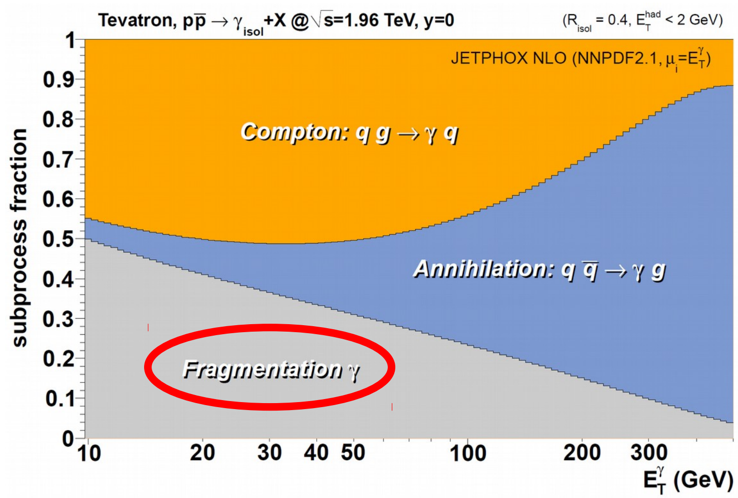
Formerly underexplored process:
– high fraction of fragmentation photons, cured by isolation
– theory available at NLO, sensitive to → gluon (PDF)

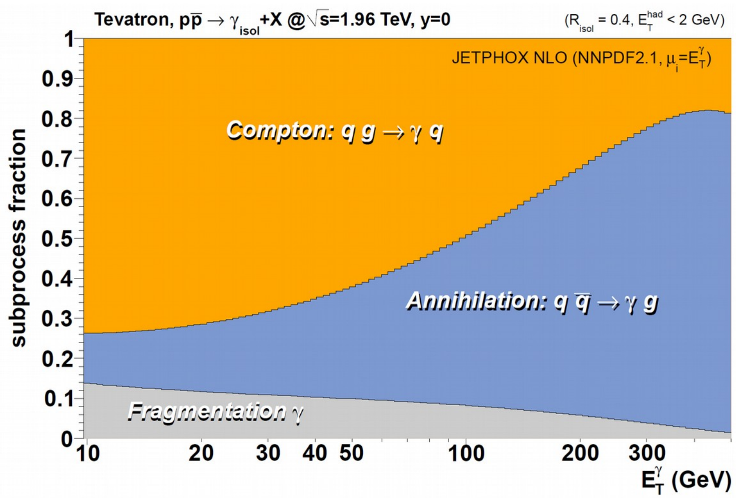


Inclusive

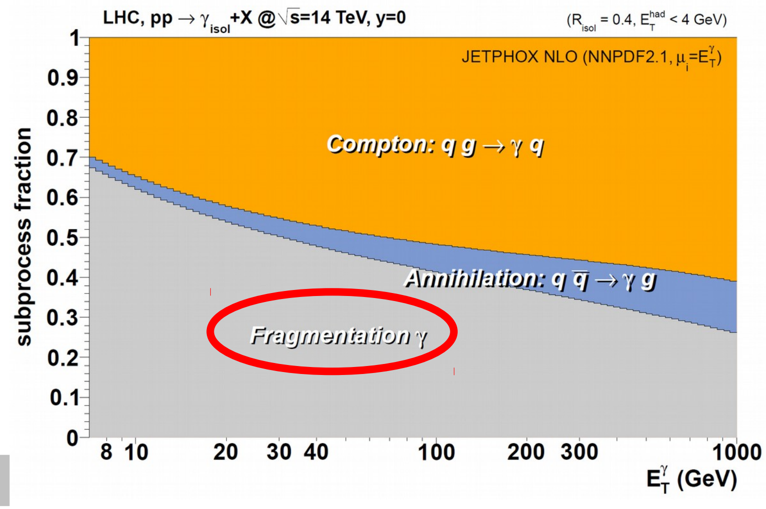
Isolated

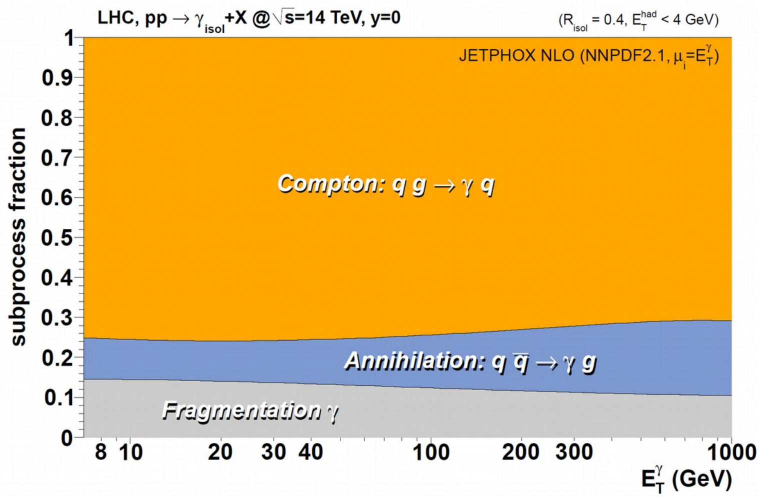
Tevatron





LHC 14 TeV





Background: Non-prompt Photons from Decays, e.g. π^0, η

d'Enterria, Rojo, NPB860 (1202) 311.