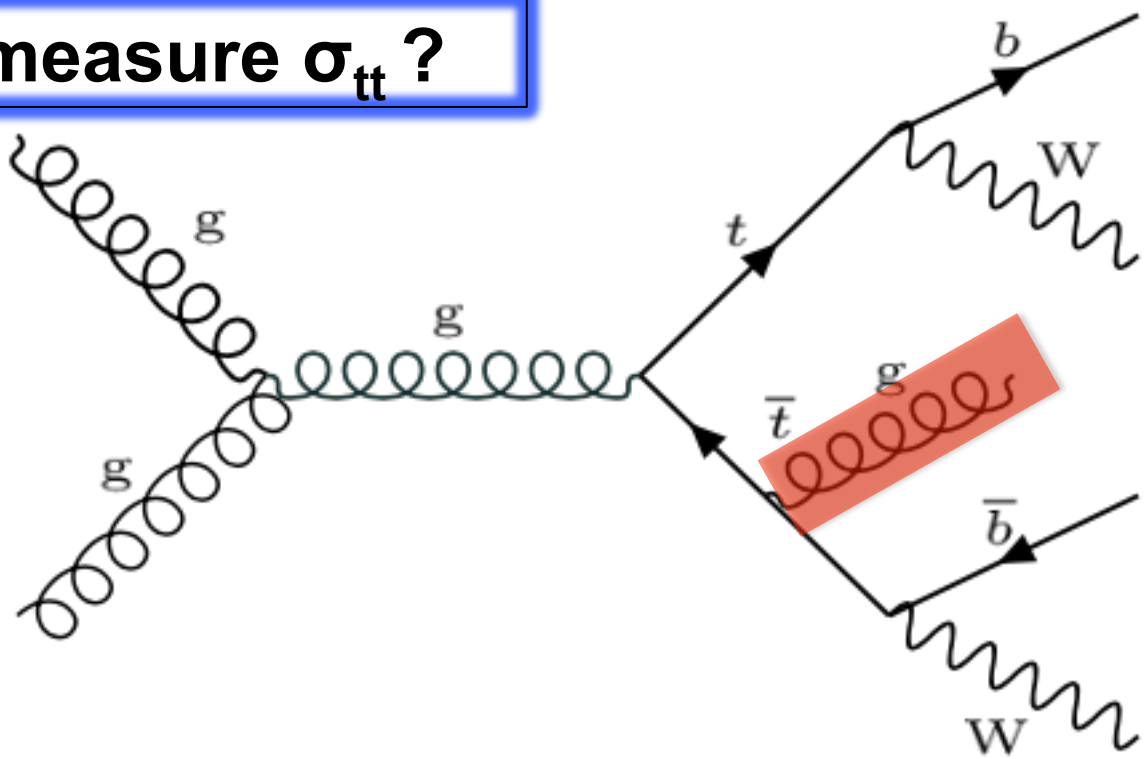
TOP PAIR CROSS SECTION MEASUREMENTS AND EVENT MODELLING WITH THE CMS DETECTOR

JAMES KEAVENEY, DESY

tt production at the lhc

Why measure σ_{tt} ?



QCD process with significant higher-order corrections
➔ probe pQCD

tt production at the lhc

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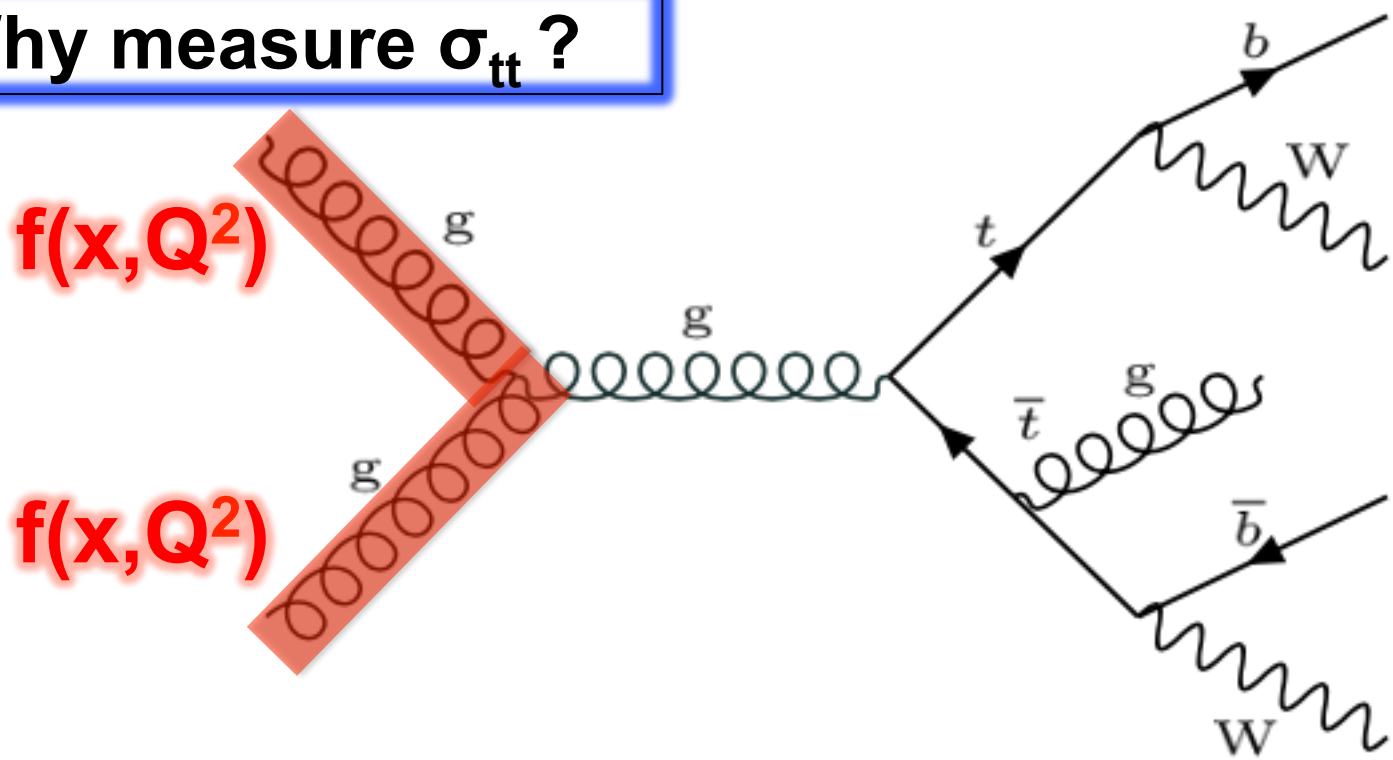

LHC tt produced mainly via by gluon fusion

➔ constrain gluon PDF

➔ extract α_s, M_{top}

tt production at the lhc

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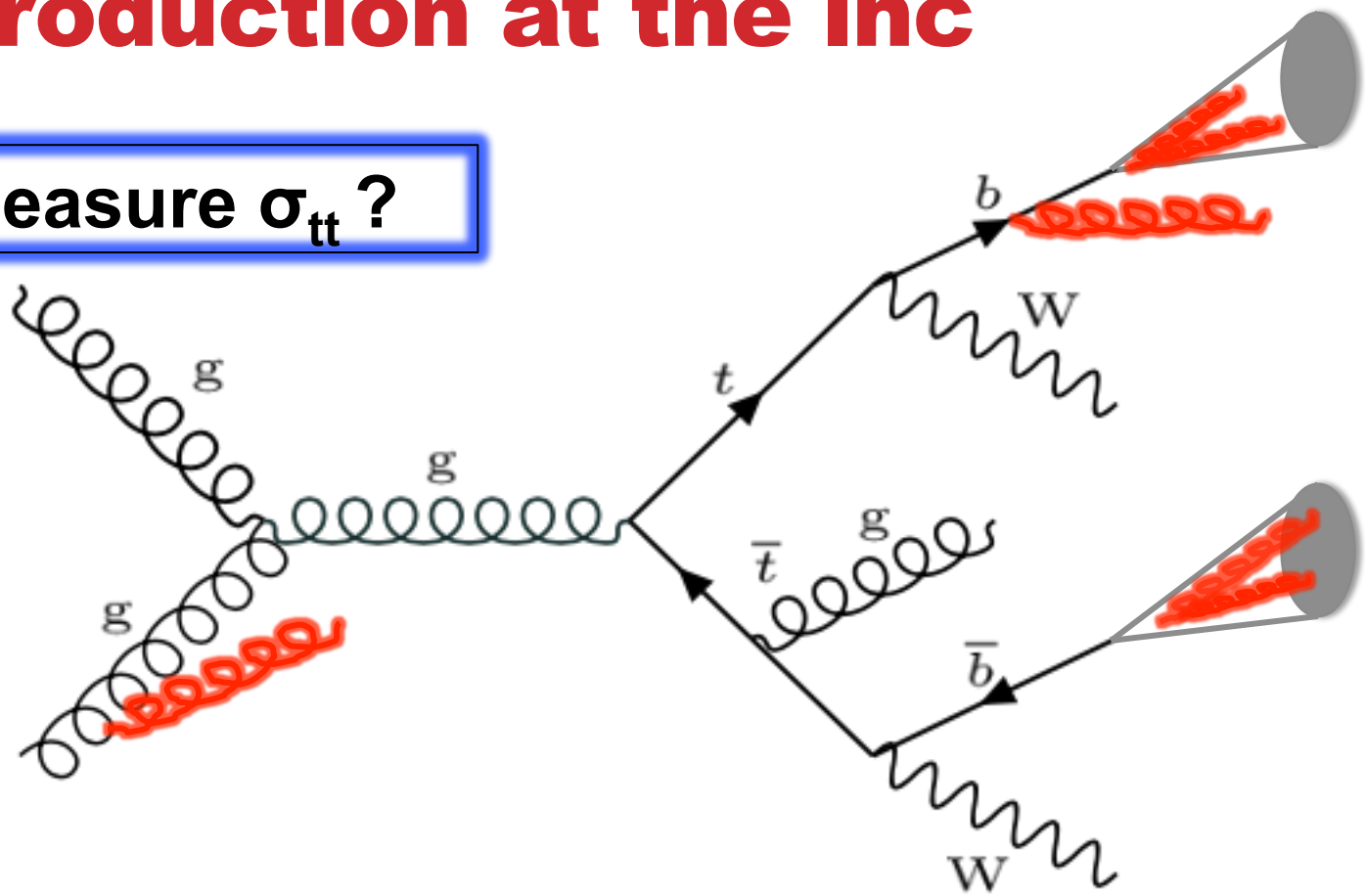

Soft radiation in production and decay

➔ **constrain modelling of parton shower and hadronisation**

tt production at the lhc

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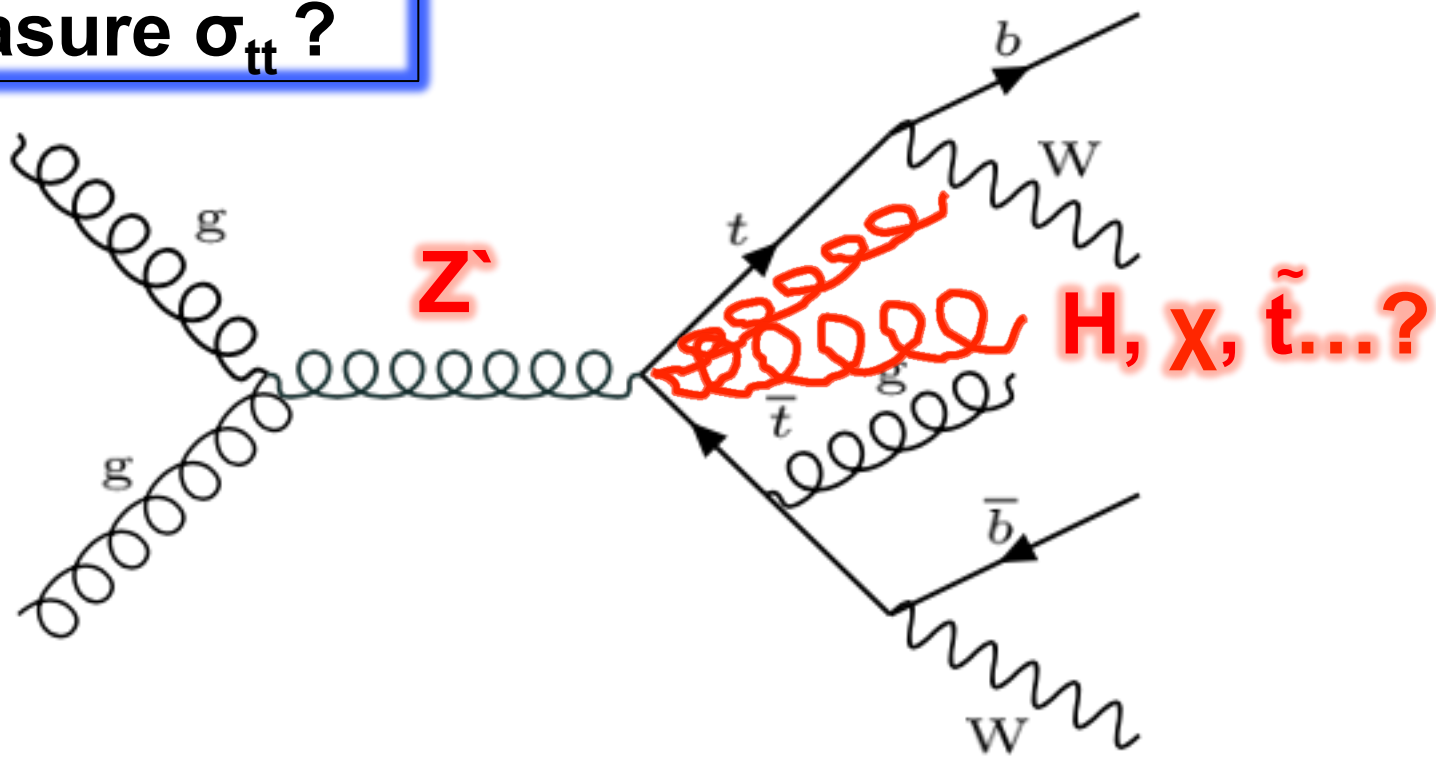
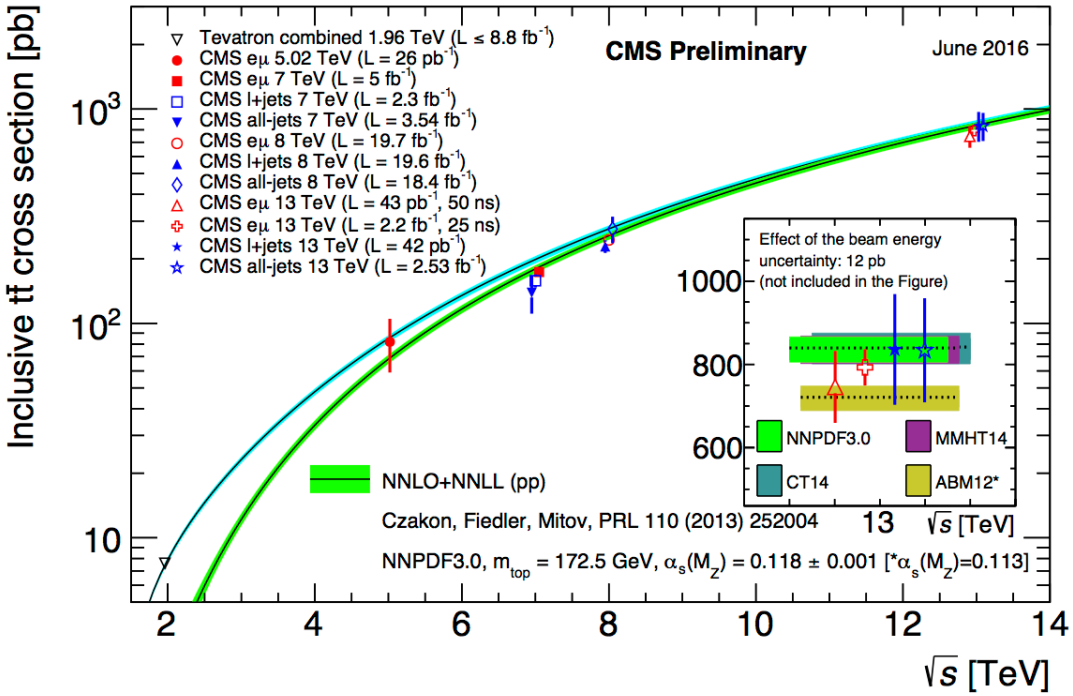


tt signature similar to many new physics signals
➔ constrain NP & backgrounds for searches

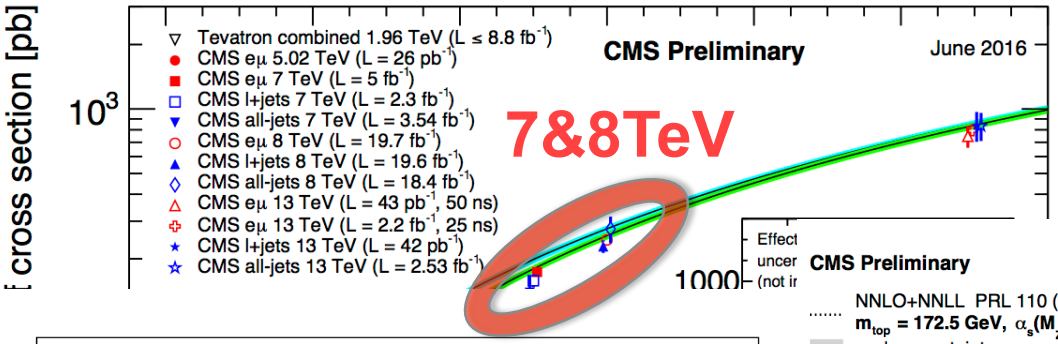
Incl. σ_{tt} measurements

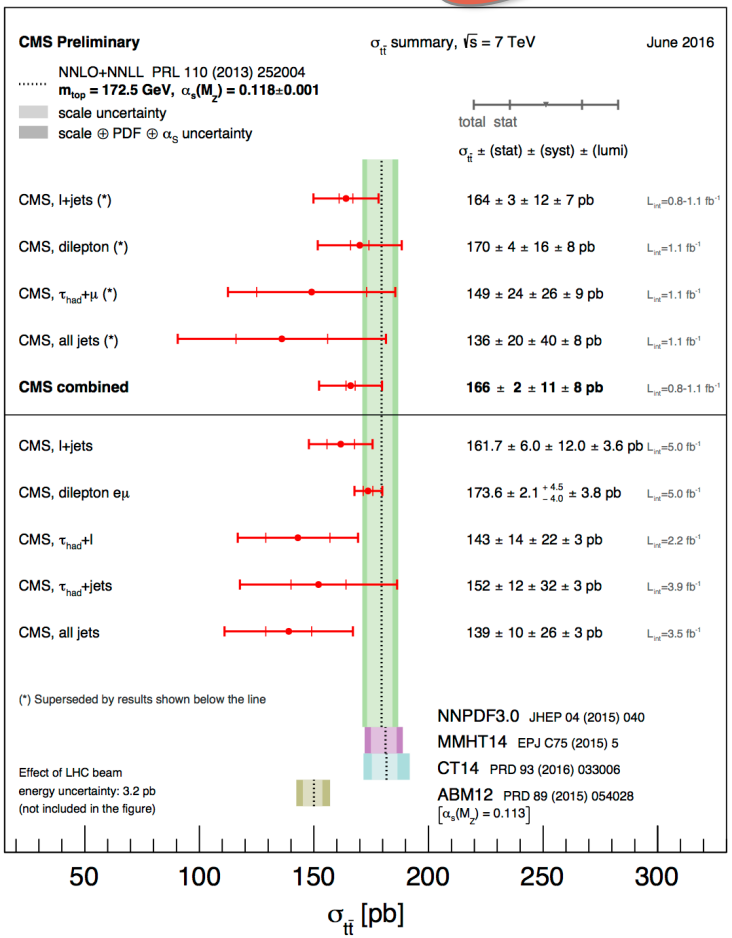


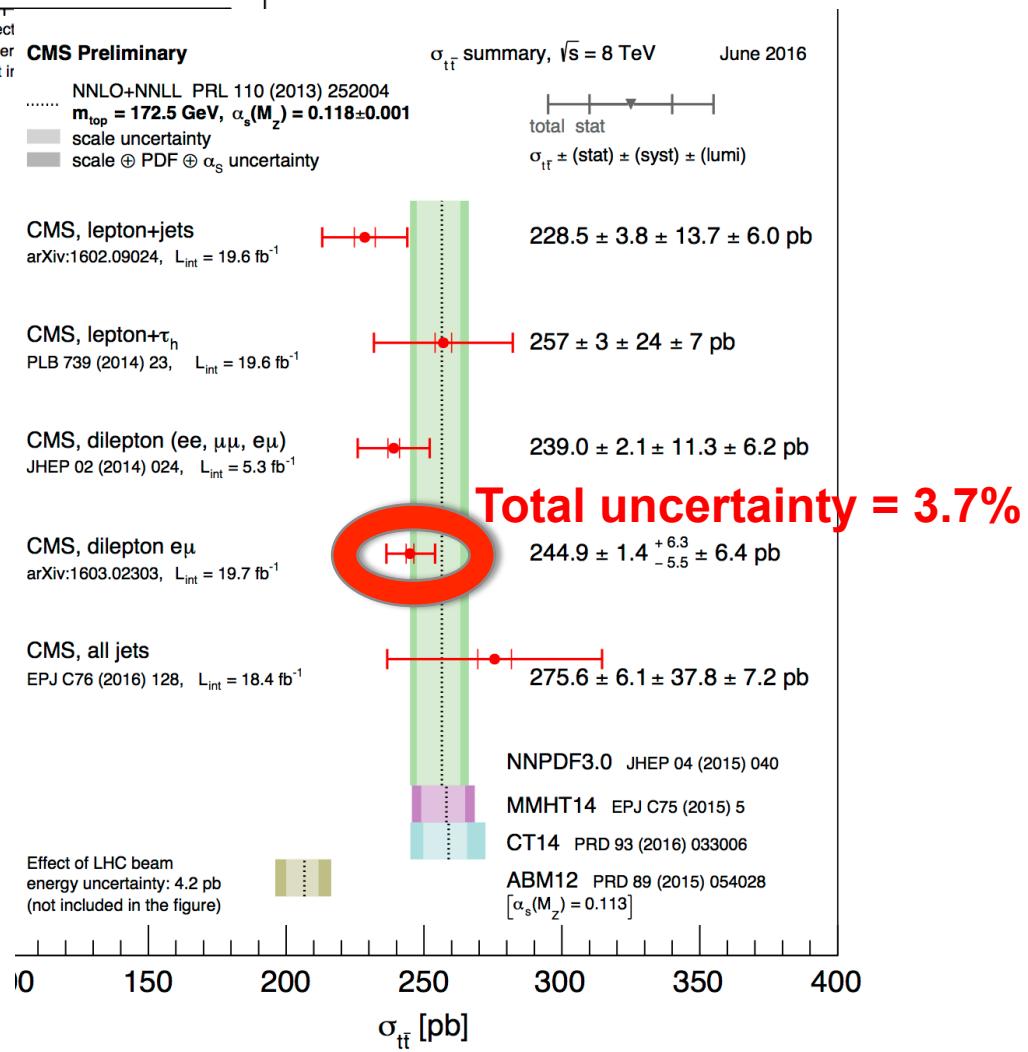
Link to CMS TOP Results Wiki

Today: focus on recent results

Incl. σ_{tt} measurements







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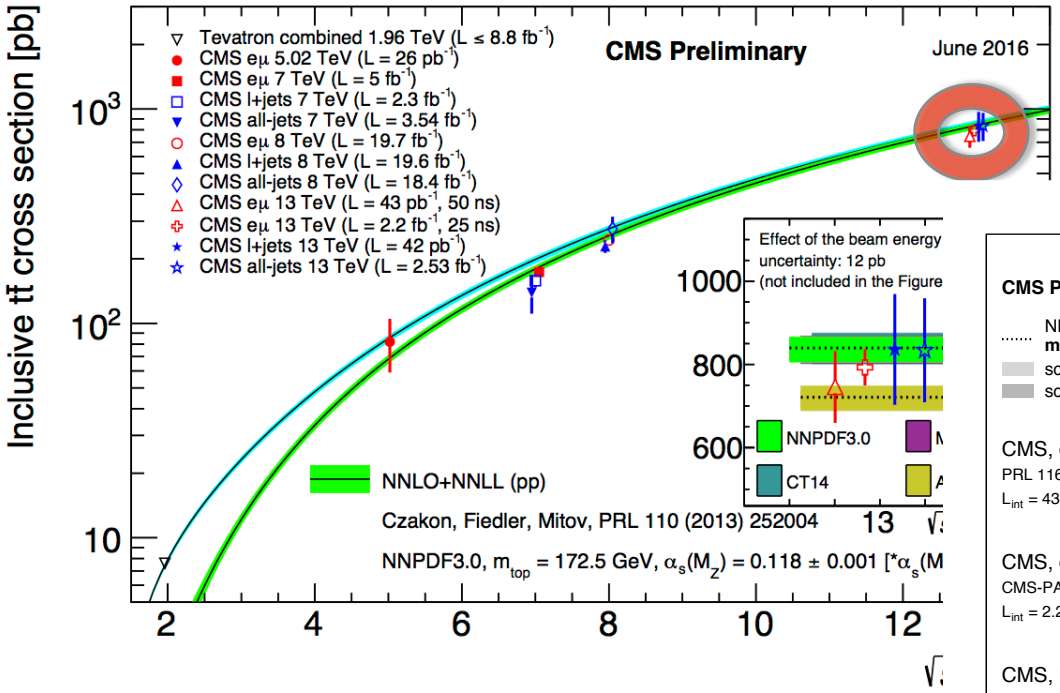
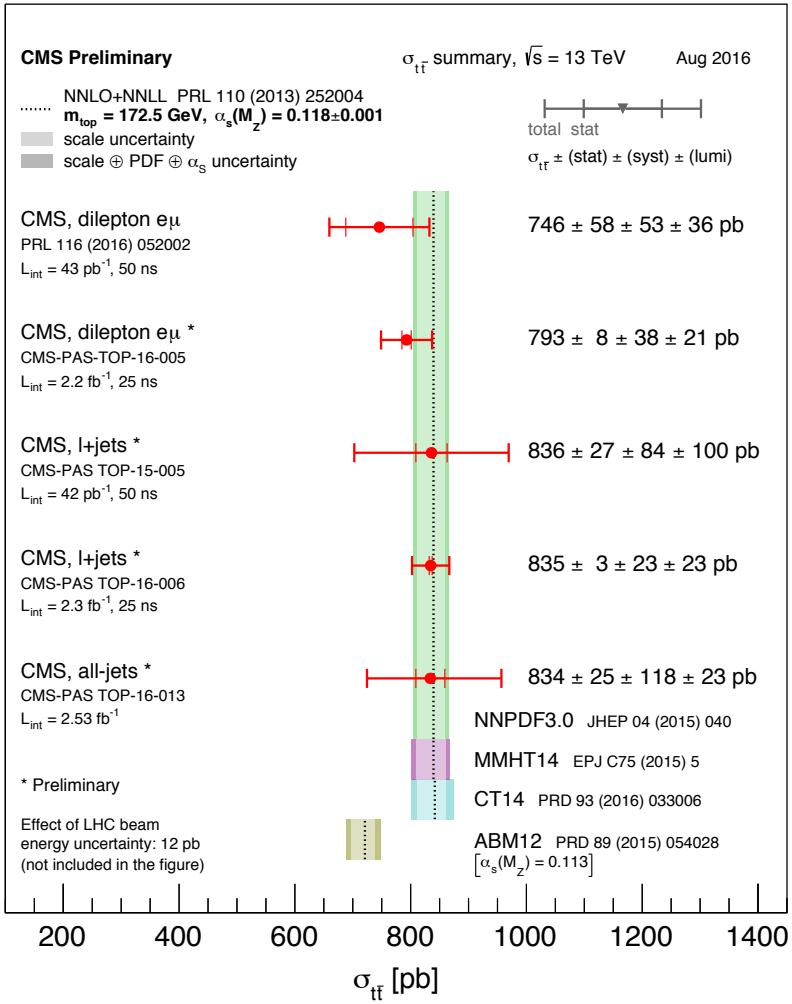


13 TeV



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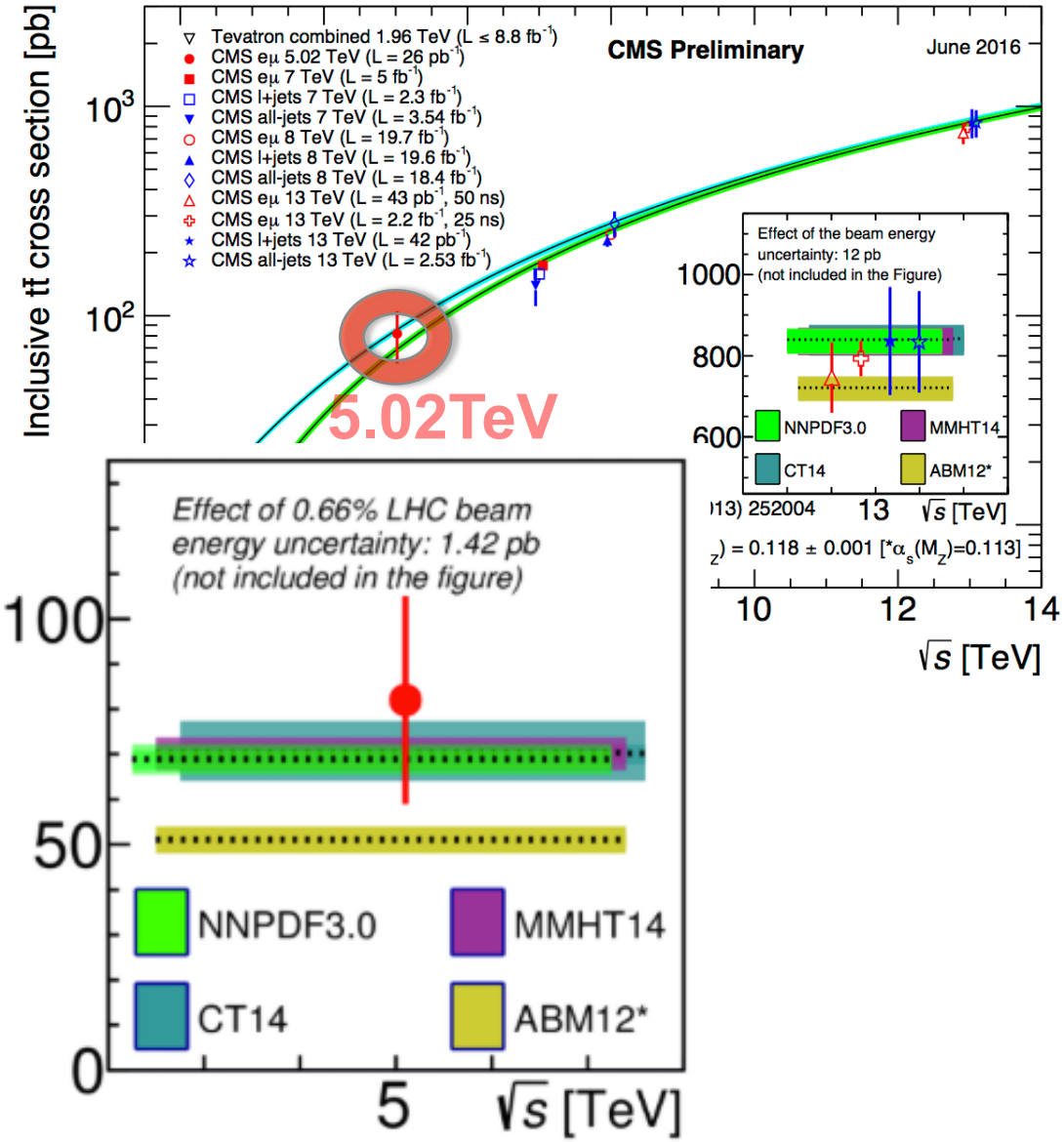

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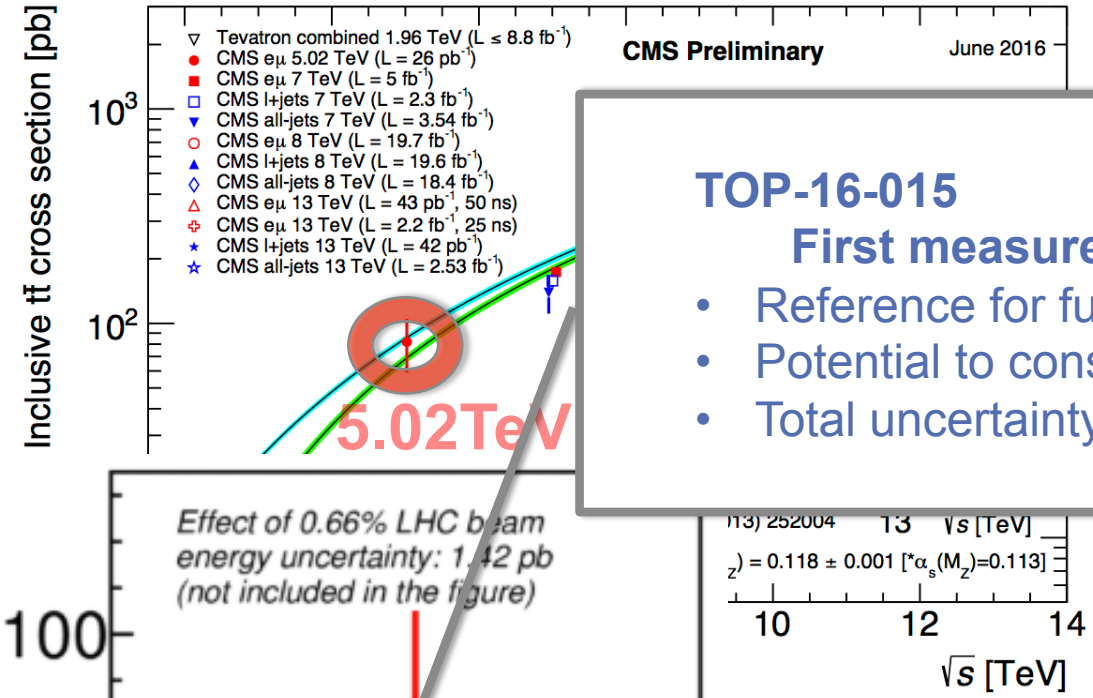
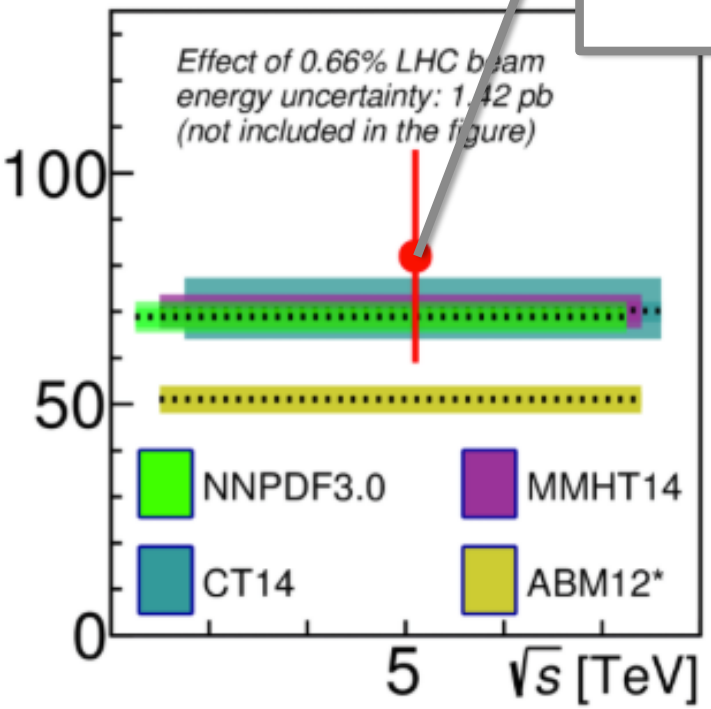


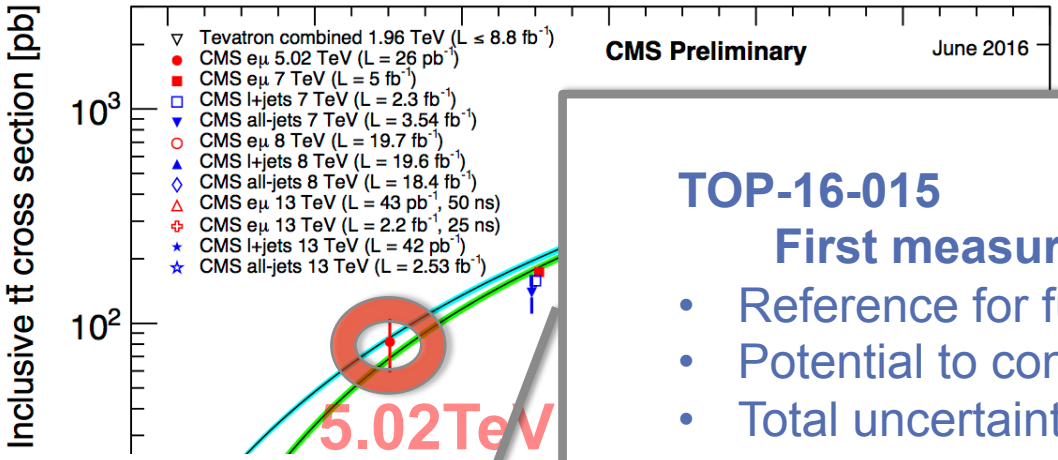


TOP-16-015

First measurement at this energy!

- Reference for future measurement with heavy ions.
- Potential to constrain high-x gluon PDF
- Total uncertainty ~25% (statistics dominate)

Incl. σ_{tt} measurements



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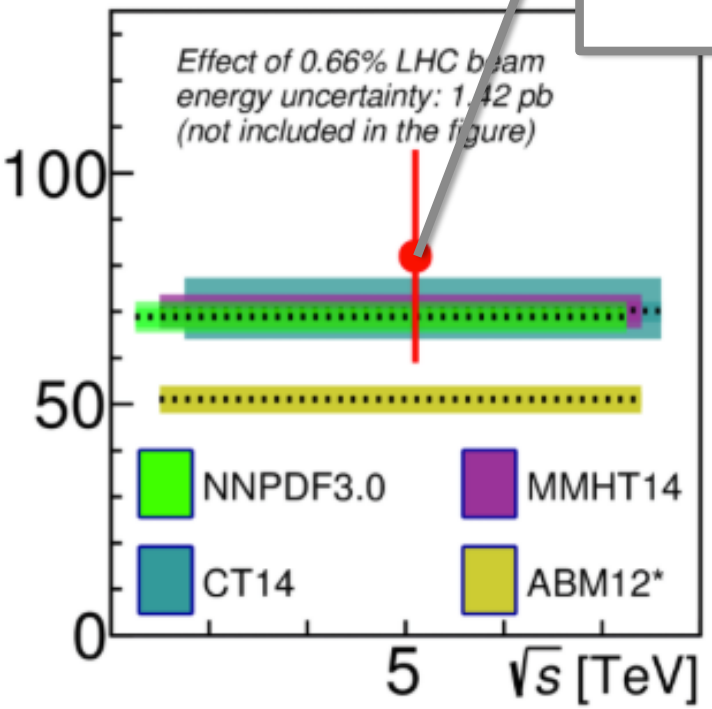
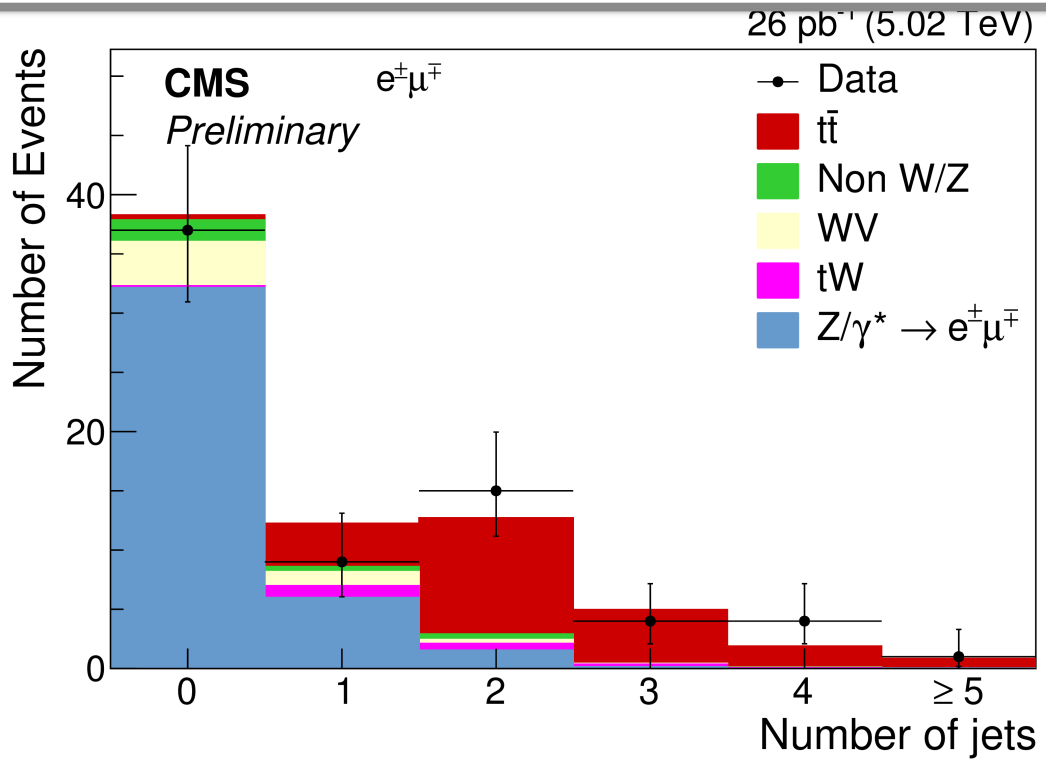


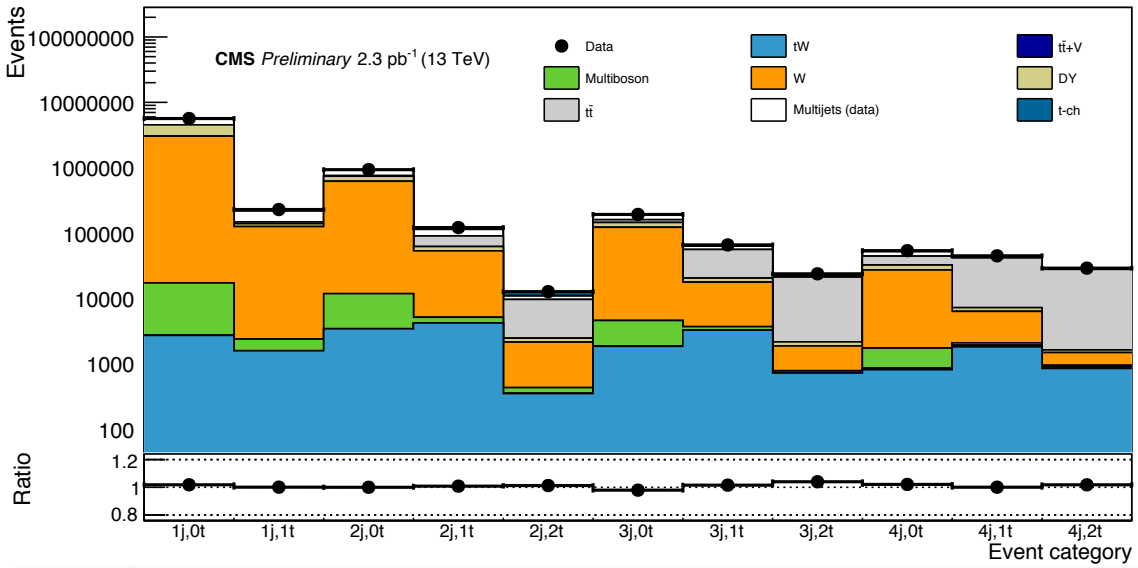


Incl. σ_{tt} measurements

NEW

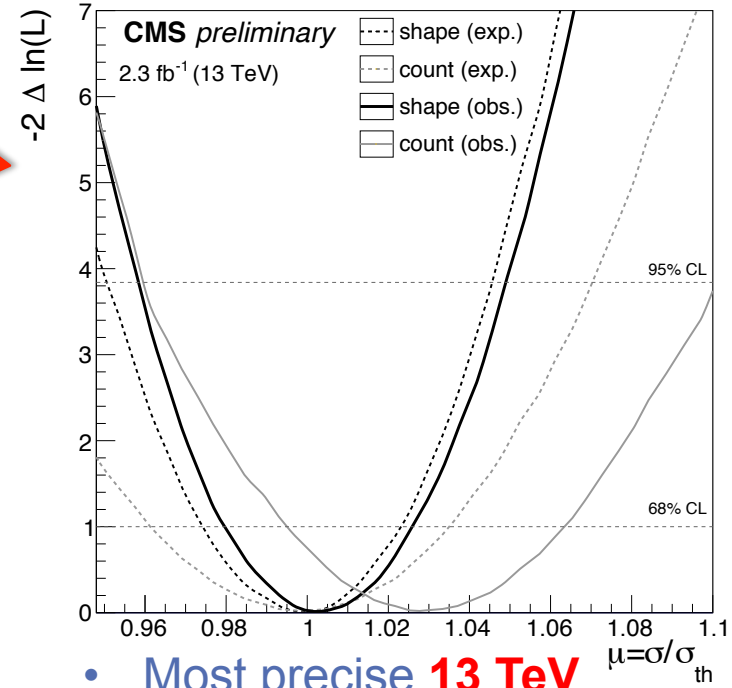
TOP-16-006 – e/μ +jets channel at 13 TeV

- Shape fit in 44 lepton charge (b) jet multiplicity categories.
- In-situ constraints on systematics
- Total uncertainty ~ **3.9%**



CMS, l+jets *
CMS-PAS TOP-16-006
L_{int} = 2.3 fb^{-1}, 25 ns

835 ± 3 ± 23 ± 23 pb



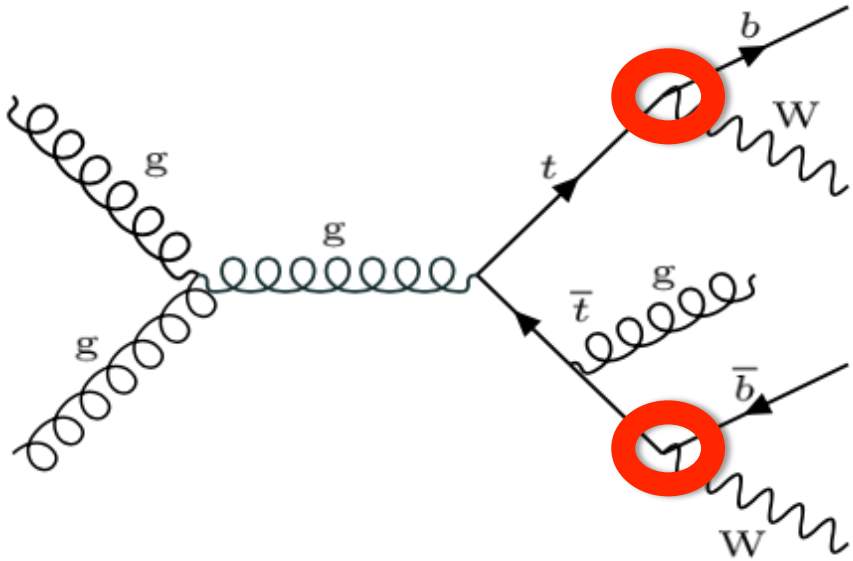
- Most precise **13 TeV** CMS measurement so far
- Largest uncertainties:
  - W+jets bkg. modelling
  - Luminosity
- Extraction of M_{top} (pole)

$$m_t = 172.3^{+2.7}_{-2.3}\,\text{GeV}$$

See talk from E. Bouvier on M_{top} extraction

measuring σ_{tt} differentially

Top quark definitions

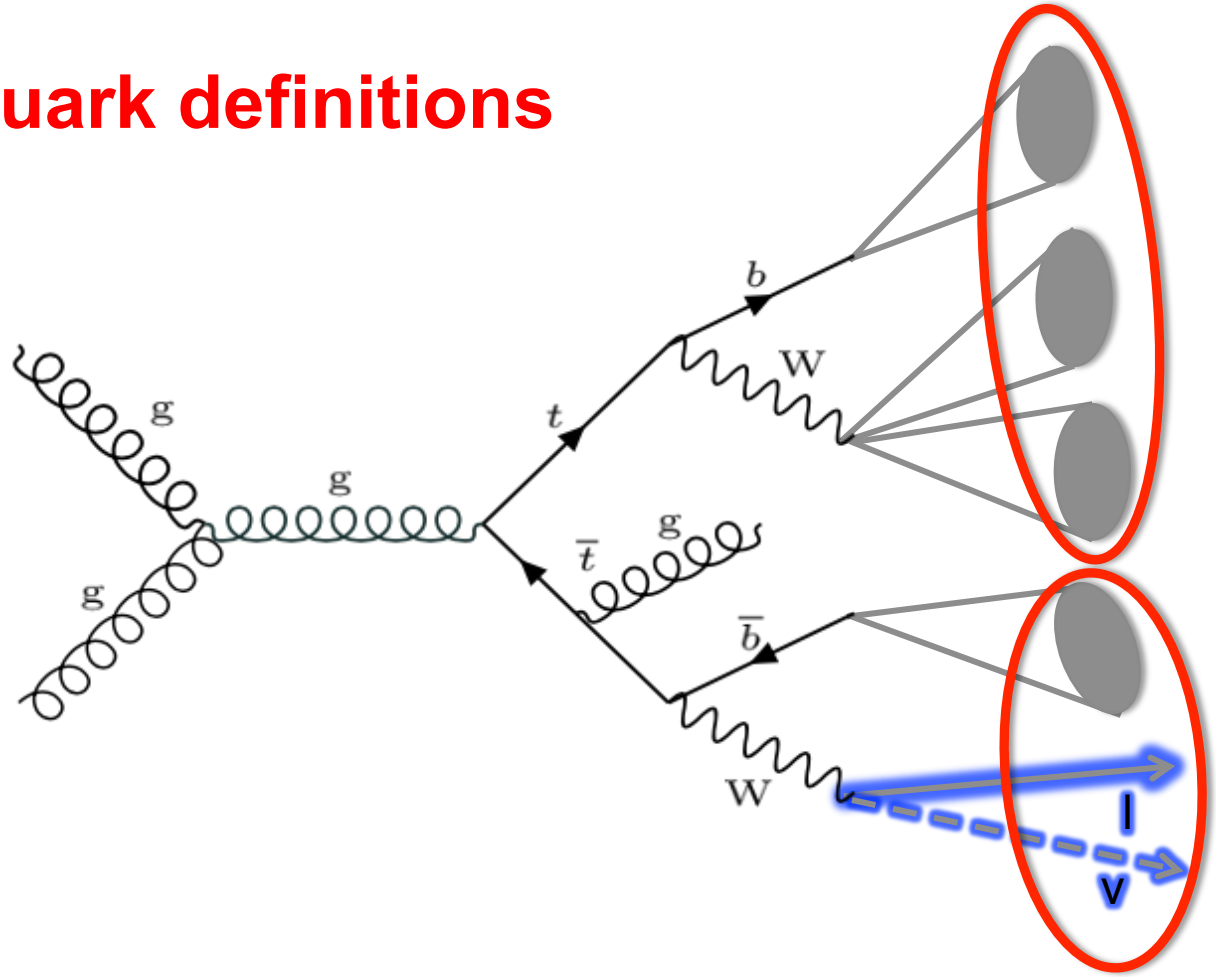


Parton-level:

top quark after radiation but before decay

measuring σ_{tt} differentially

Top quark definitions



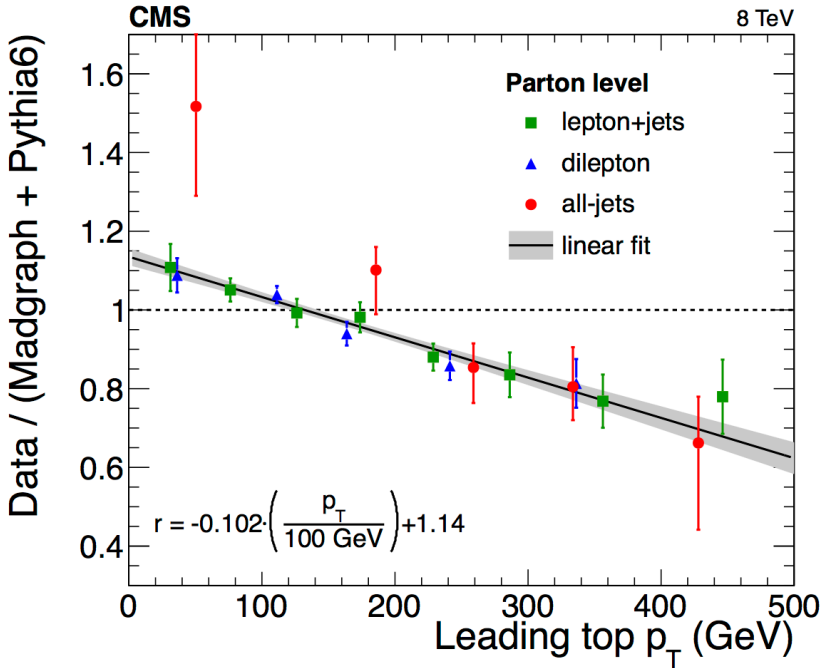
Particle-level:

top quark proxy reconstructed from decay products after hadronisation

differential σ_{tt}

TOP-14-018, TOP-12-028, TOP-15-011
(arXiv:1509.06076, arXiv:1505.04480)

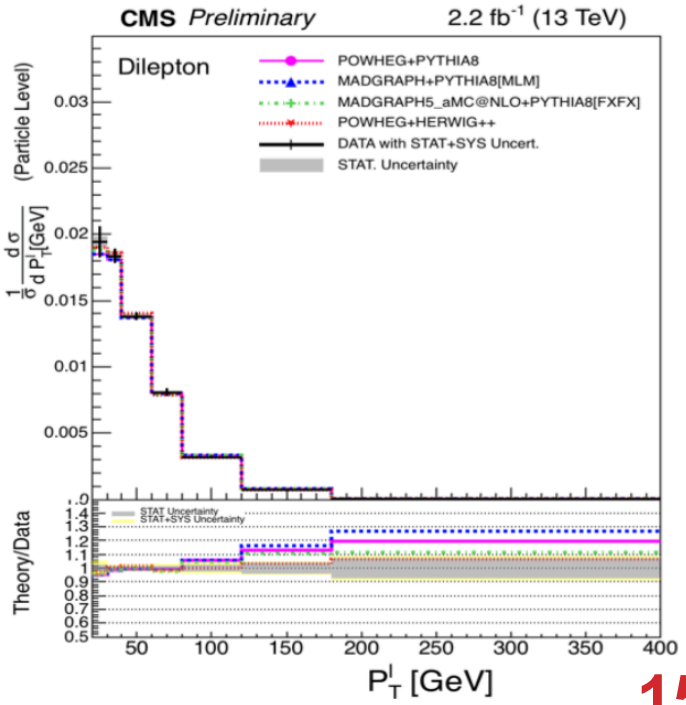
- Differential cross sections at **8 TeV**
  - Comparisons to NLO MC generators and $N^{N}LO$ QCD predictions
  - **Miss-modelling of top Pt spectrum observed in all decay channels.**



TOP-16-007

NEW

- Differential cross sections in the eμ channel at particle-level at **13 TeV**
  - Miss-modelling of top Pt spectrum re-confirmed at particle-level
  - Similar results at 13 TeV parton-level (TOP-16-008, TOP-16-011)



differential σ_{tt}

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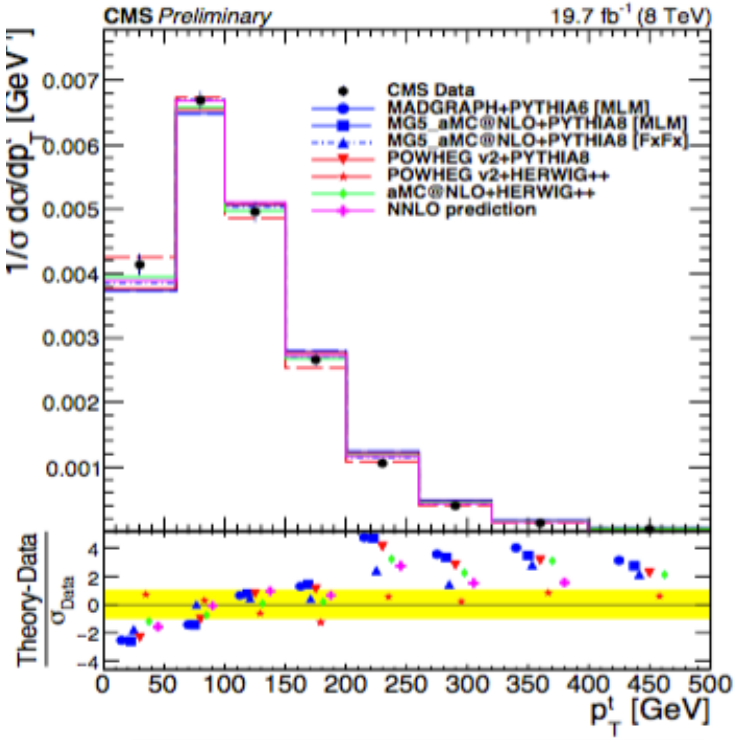

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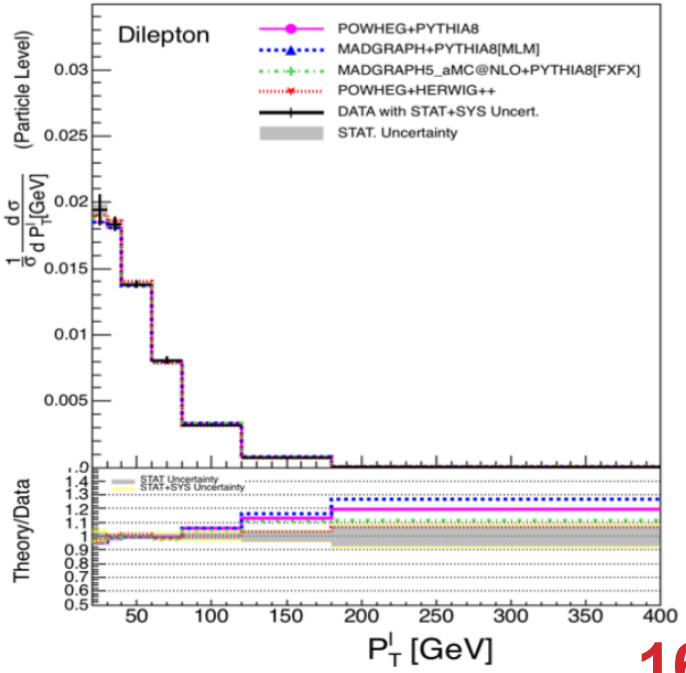
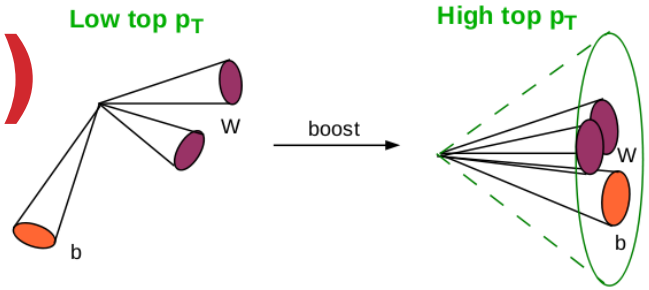


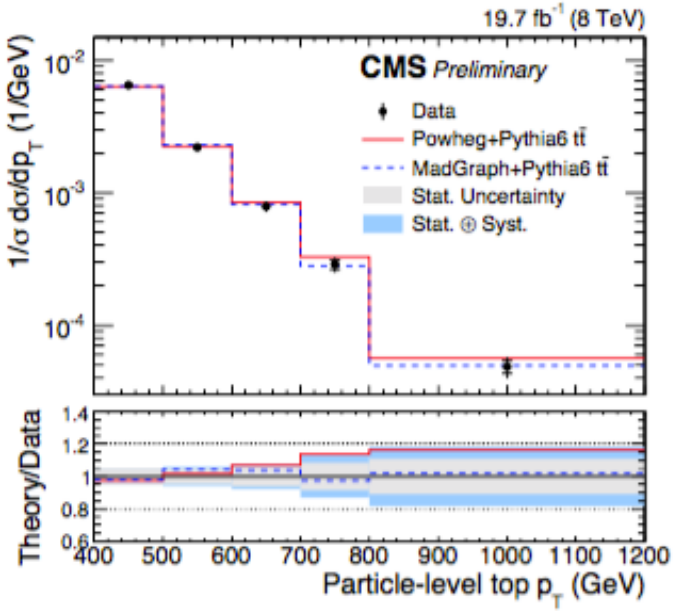
differential σ_{tt} (boosted)



***Boosted* reconstruction**

-> hadronic top decay reconstructed in one jet

-> jet substructure techniques used to ***tag*** tops



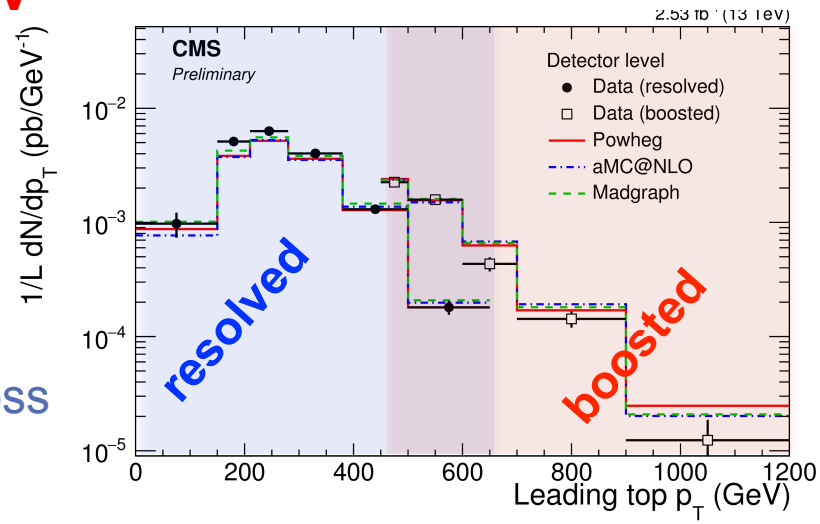
TOP-14-012 (arXiv:1605.00116)

- Parton and particle level at **8 TeV**
  - P_t >400 GeV
  - Pt mis-modelling observed again

TOP-16-013

Boosted **&** resolved reconstruction at **13 TeV**

- top P_t measured from **0 -> 1.2 TeV** at parton and detector levels
- compared to MC generator predictions
- P_t in data softer than MC prediction across spectrum



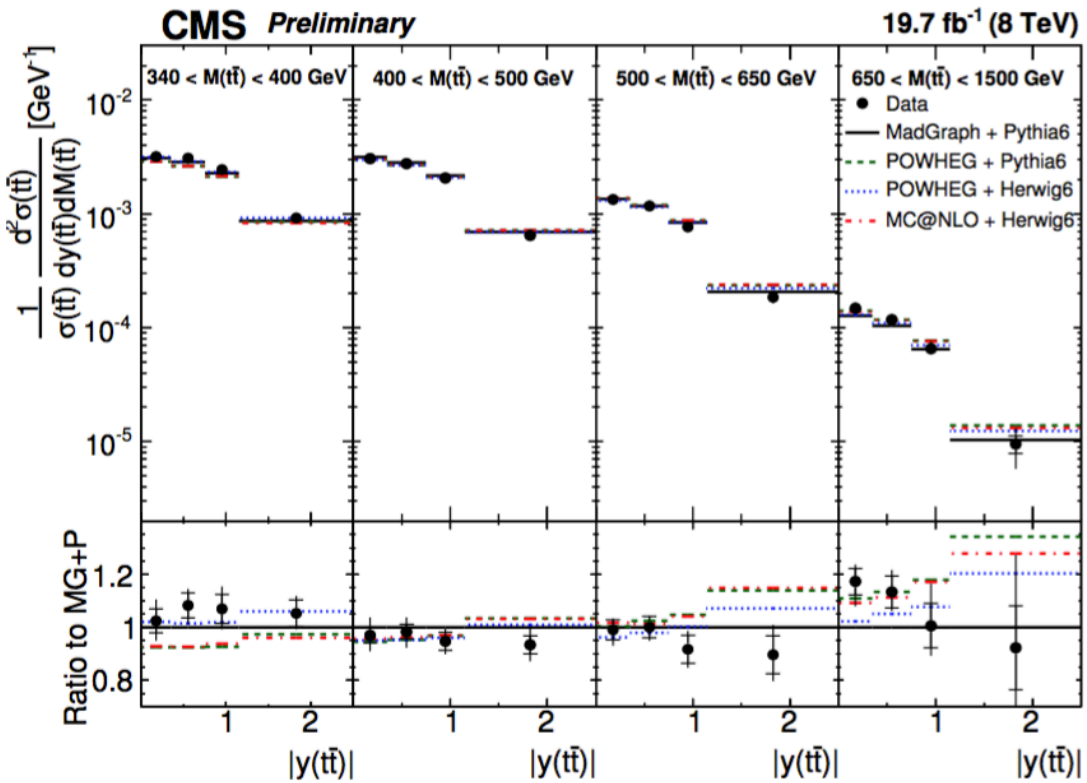
differential σ_{tt}

NEW

TOP-14-013

Double-differential tt cross sections at 8 TeV

- first measurement of this type at the LHC
- bin tt events in two variables e.g., $Pt_{top} - y_{top}$, $M_{tt} - y_{tt}$
- $M_{tt} - y_{tt}$ especially sensitive to PDFs
- 2D distributions provide stronger PDFs constraints than 1D



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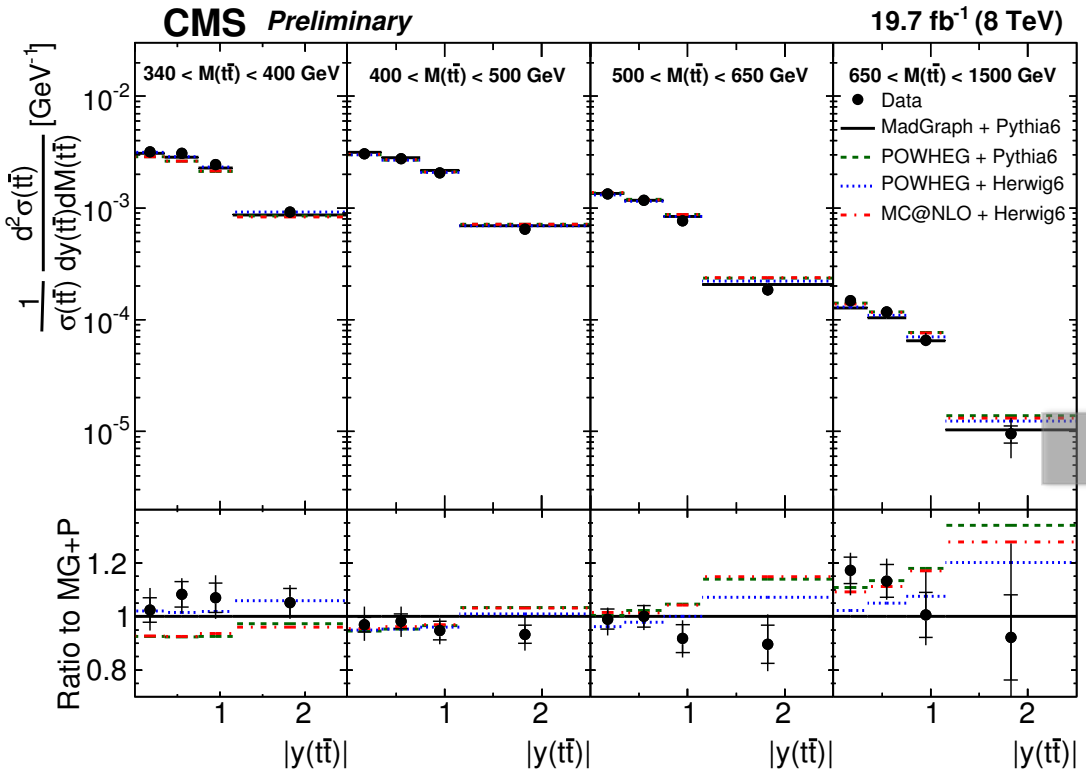
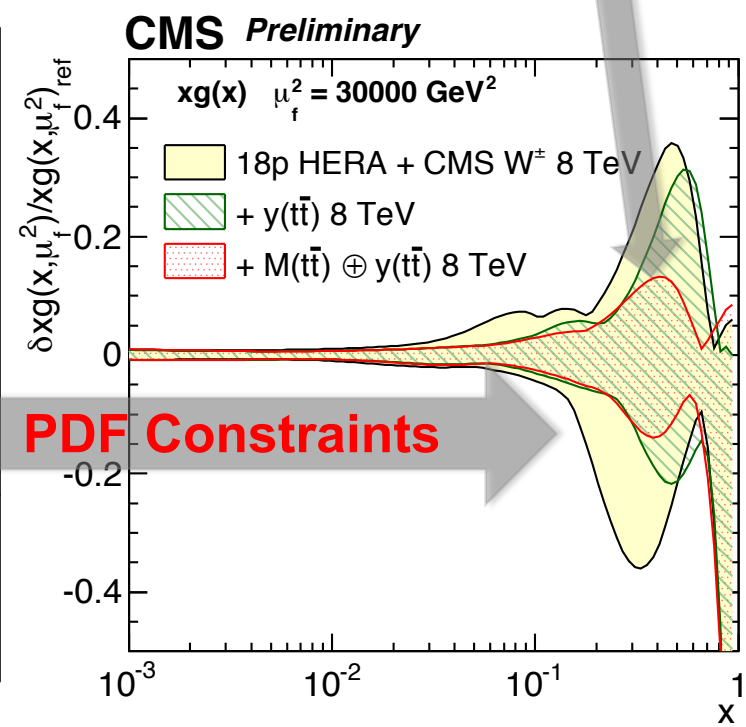
Significant reduction of uncertainty at high-x





PDF Constraints

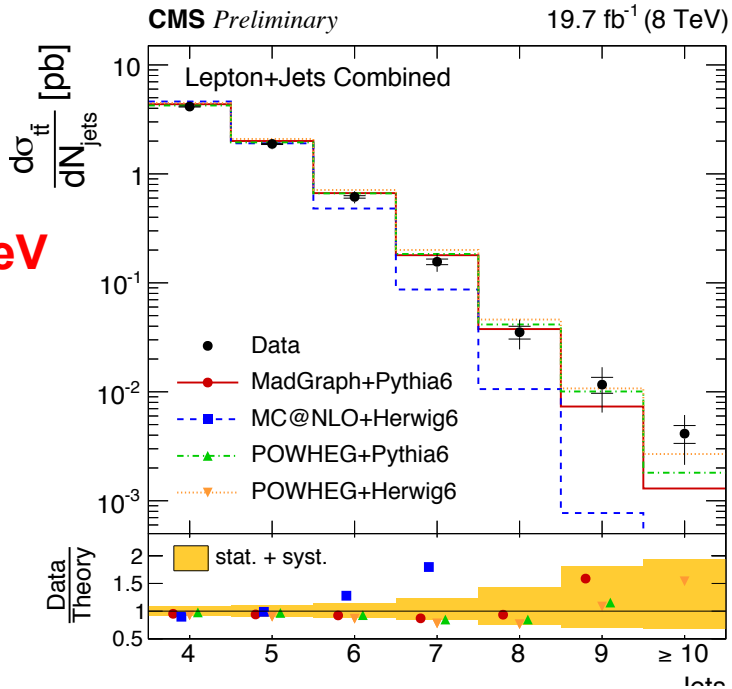
tt+jets, tt+bb

NEW

TOP-15-006, TOP-15-011

- Measurement of tt+jets, tt+jj cross sections at **8TeV**
- Jet multiplicity well modelled by most generators
- tt+jj cross section in agreement with prediction (***JHEP* 07 (2014) 135**)

Category	$d\sigma/dN_{jets}$ [pb]	Stat.	Exp.	Theor.	Total
$t\bar{t} \to \ell + 4$ jets	4.15	1.0%	6.2%	5.3%	8.6%
$t\bar{t} \to \ell + 5$ jets	1.88	1.3%	7.4%	7.0%	10.6%
$t\bar{t} \to \ell + 6$ jets	0.615	2.6%	8.7%	8.5%	12.7%
$t\bar{t} \to \ell + 7$ jets	0.156	5.9%	13.6%	11.7%	19.1%
$t\bar{t} \to \ell + 8$ jets	0.0352	13.4%	19.1%	19.3%	30.4%
$t\bar{t} \to \ell + 9$ jets	0.0116	16.7%	24.3%	33.3%	44.6%
$t\bar{t} \to \ell + \geq 10$ jets	0.00413	18.7%	27.9%	34.6%	48.3%

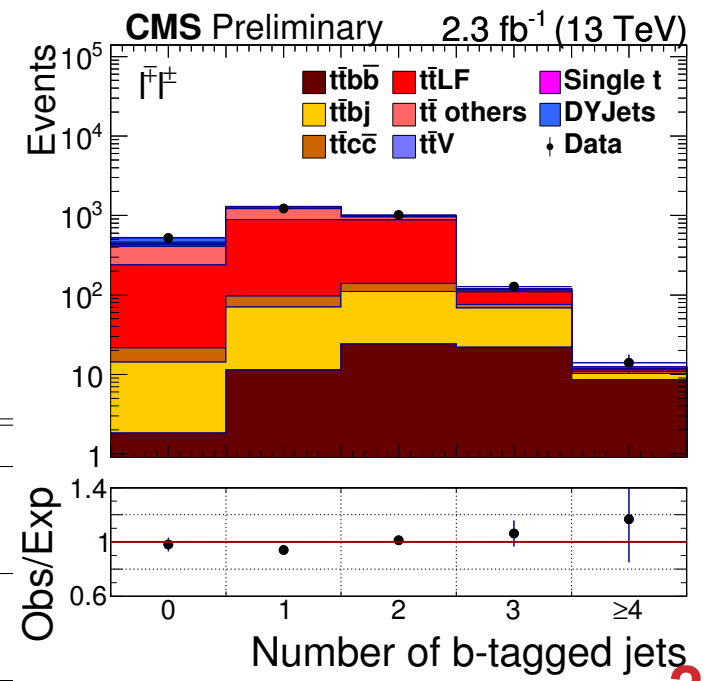


TOP-16-010

NEW

- tt+bb, tt+jj at particle level in visible region at **13TeV**
- Probes QCD, constrains bkd for tt +Higgs
- Results consistent with POWHEG MC prediction

Phase Space	$\sigma_{t\bar{t}b\bar{b}}$ [pb]	$\sigma_{t\bar{t}jj}$ [pb]	$\sigma_{t\bar{t}b\bar{b}}/\sigma_{t\bar{t}jj}$
Measurement			
Visible	$0.085 \pm 0.012 \pm 0.029$	$3.5 \pm 0.1 \pm 0.7$	$0.024 \pm 0.003 \pm 0.007$
Full	$3.9 \pm 0.6 \pm 1.3$	$176 \pm 5 \pm 33$	$0.022 \pm 0.003 \pm 0.006$
Simulation (POWHEG)			
Visible	0.070 ± 0.009	5.1 ± 0.5	0.014 ± 0.001
Full	3.2 ± 0.4	257 ± 26	0.012 ± 0.001



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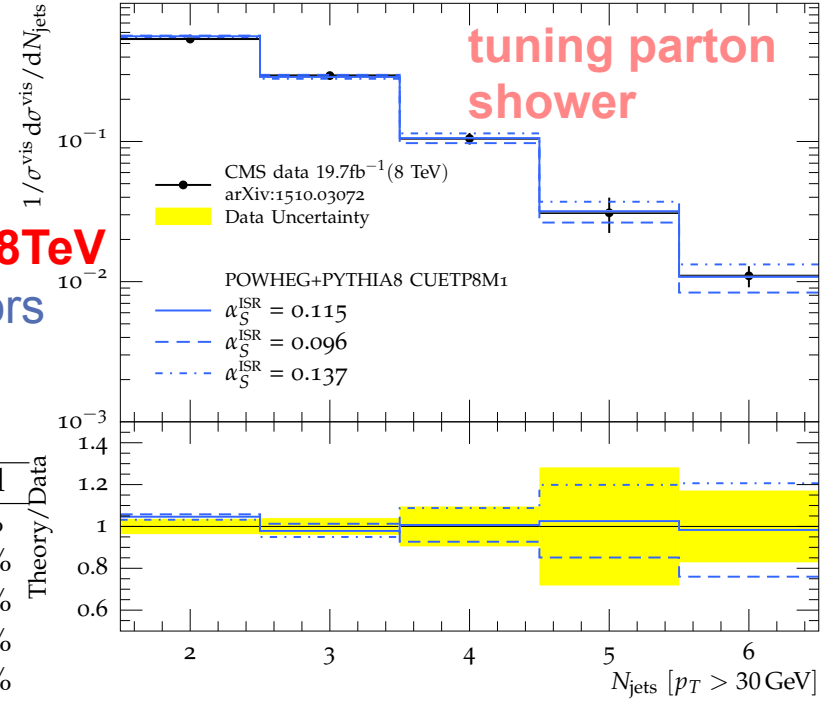

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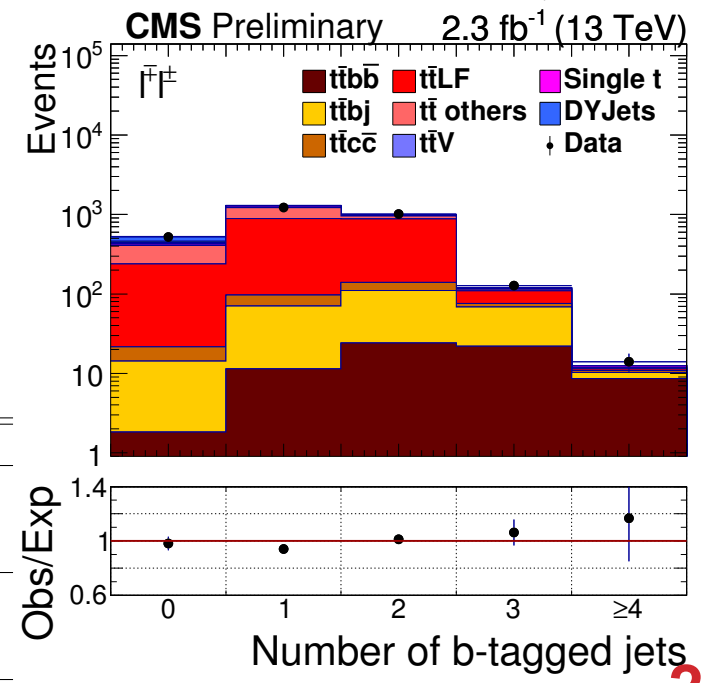


tttt

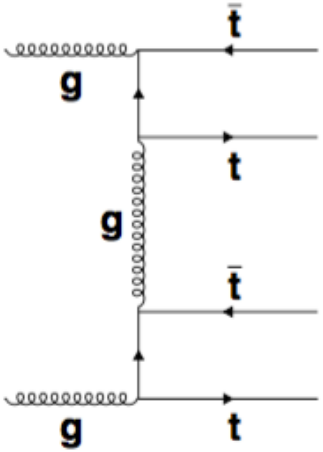
TOP-16-016 –

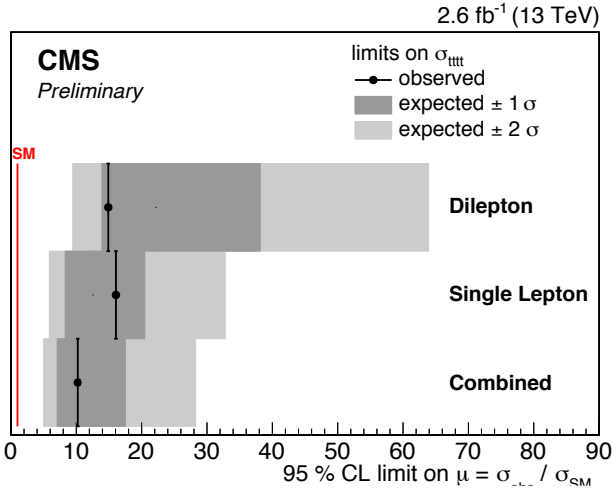
Search for SM four top production

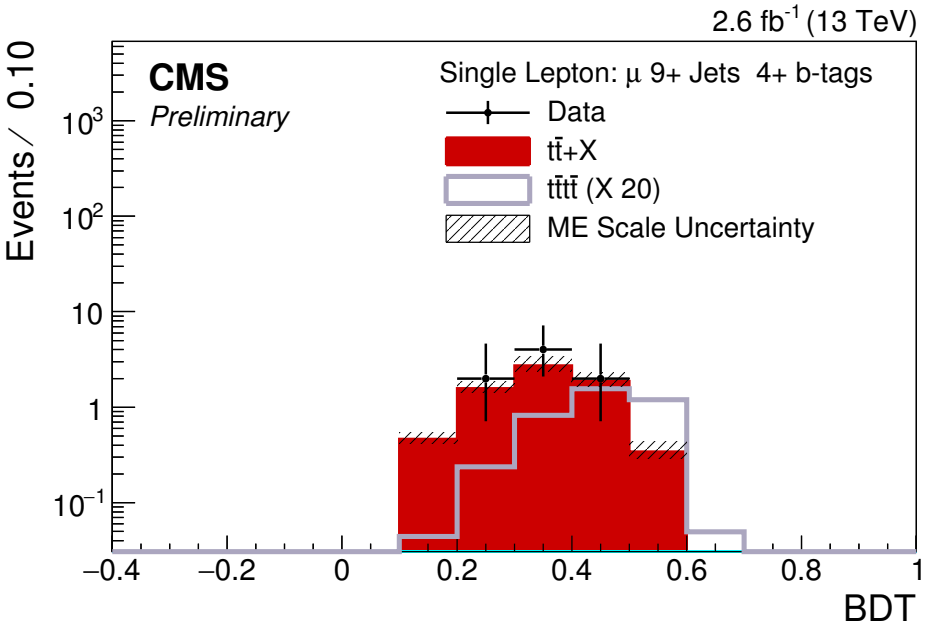
- Extremely rare SM process σ_{tttt} ~ 9 fb
- Sensitive to new physics
- Combining single- and dilepton channels
- Fit to multivariate discriminator in (b)jet categories

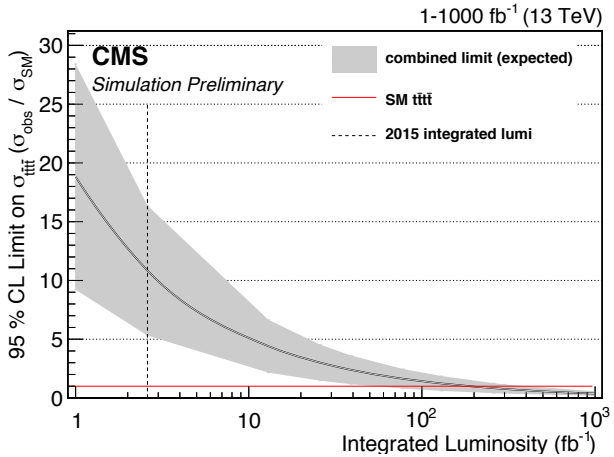
NEW

SM









- **Obs. (exp.) limits 10 (11) x SM σ_{tttt}**
  - **Sensitivity limited by statistics**
  - **Factor of 2 increase in sensitivity wrt 8 TeV results**

tttt

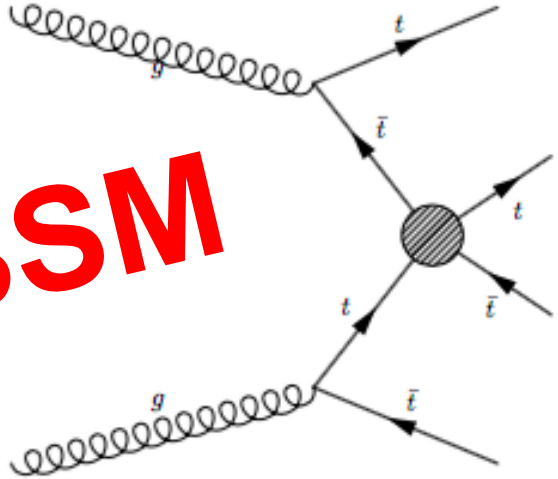
TOP-16-016 –

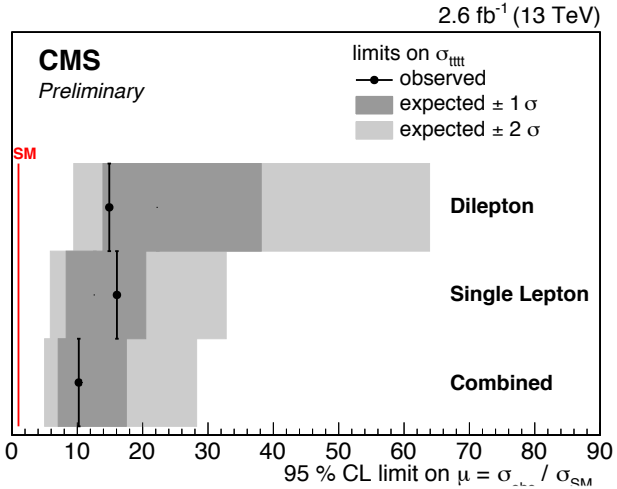
Search for SM four top production

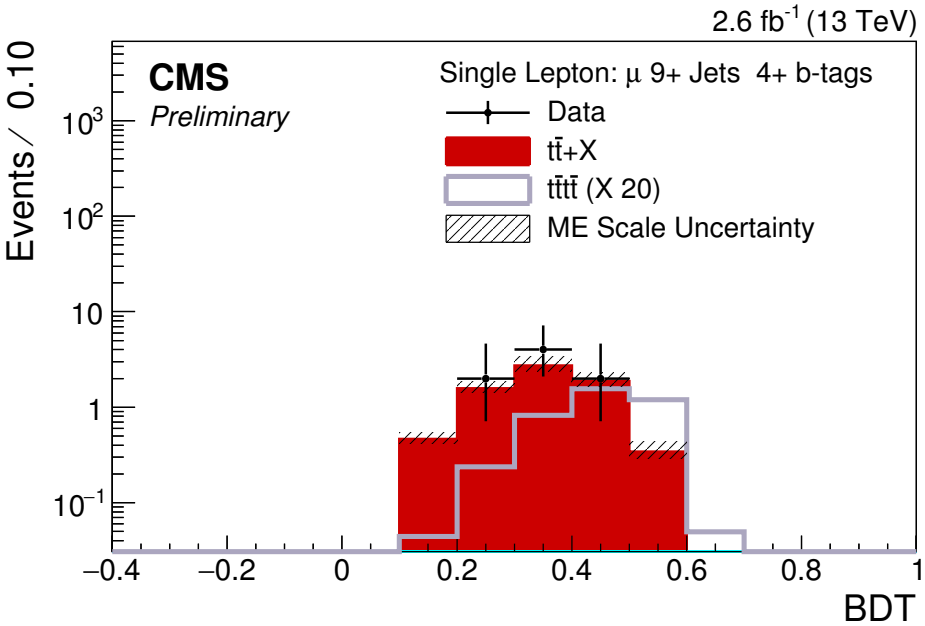
- Extremely rare SM process σ_{tttt} ~ 9 fb
- Sensitive to new physics
- Combining single- and dilepton channels
- Fit to multivariate discriminator in (b)jet categories

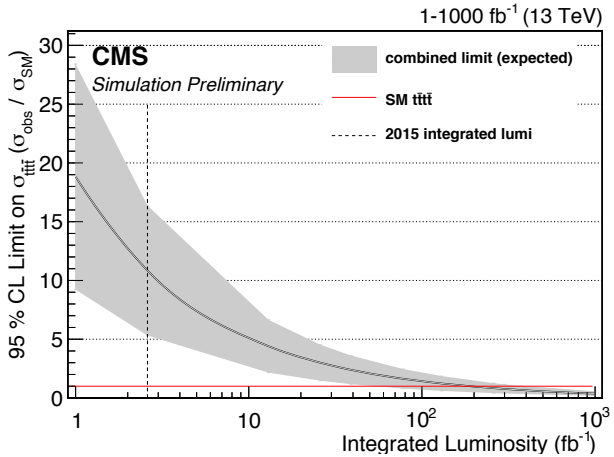
NEW

BSM









- **Obs. (exp.) limits 10 (11) x SM σ_{tttt}**
  - **Sensitivity limited by statistics**
  - **Factor of 2 increase in sensitivity wrt 8 TeV results**

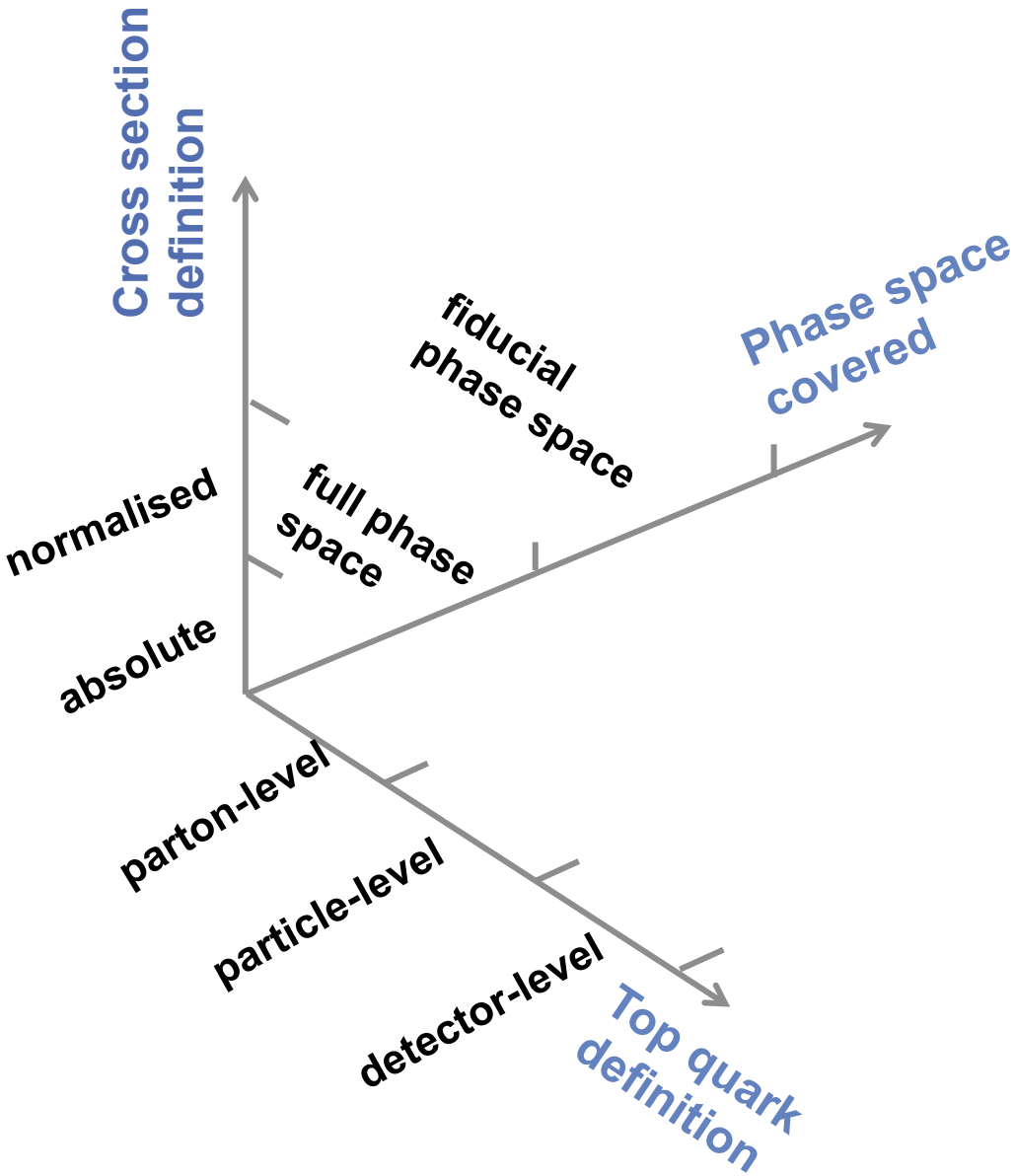
CONCLUSIONS AND OUTLOOK

Broad range of tt cross section measurements from CMS:

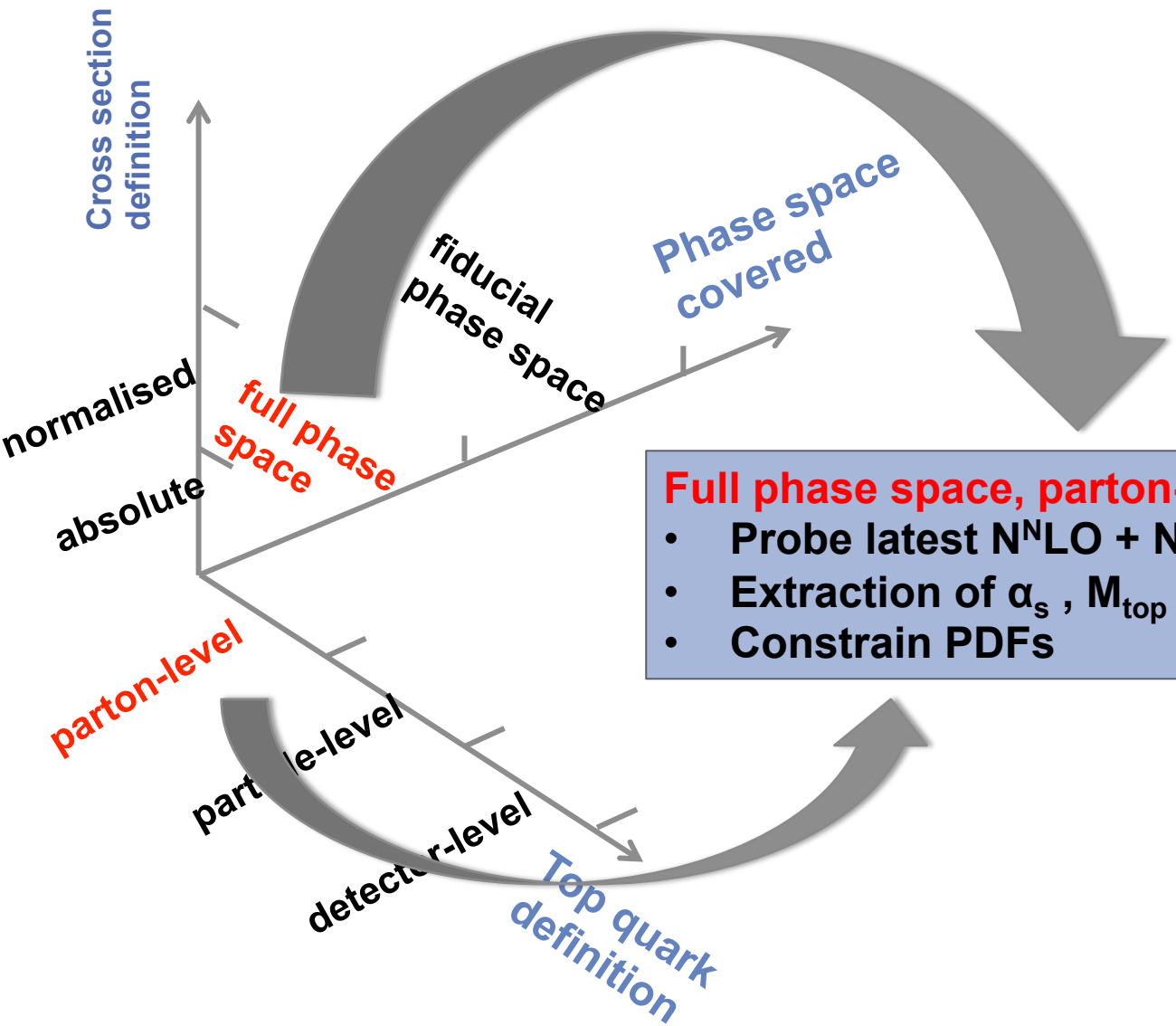
- **Incl. tt - results consistent with SM**
  - Constraints on light stops, PDFs and m_t
- **1D differential - top Pt spectrum mis-modelled**
  - NNLO predictions describe the data better
- **2D differential - deeper probe of modelling**
  - 2D measurements constrain PDFs at high-x
- **tt+jets,tt+bb - particle-level measurements**
  - tune MC prediction and constrain ttbb background for ttH
- **tttt - combined search in single and dilepton channels**
  - **world's tightest limit on SM tttt production**

BACKUP

DIFFERENTIAL MEASUREMENTS



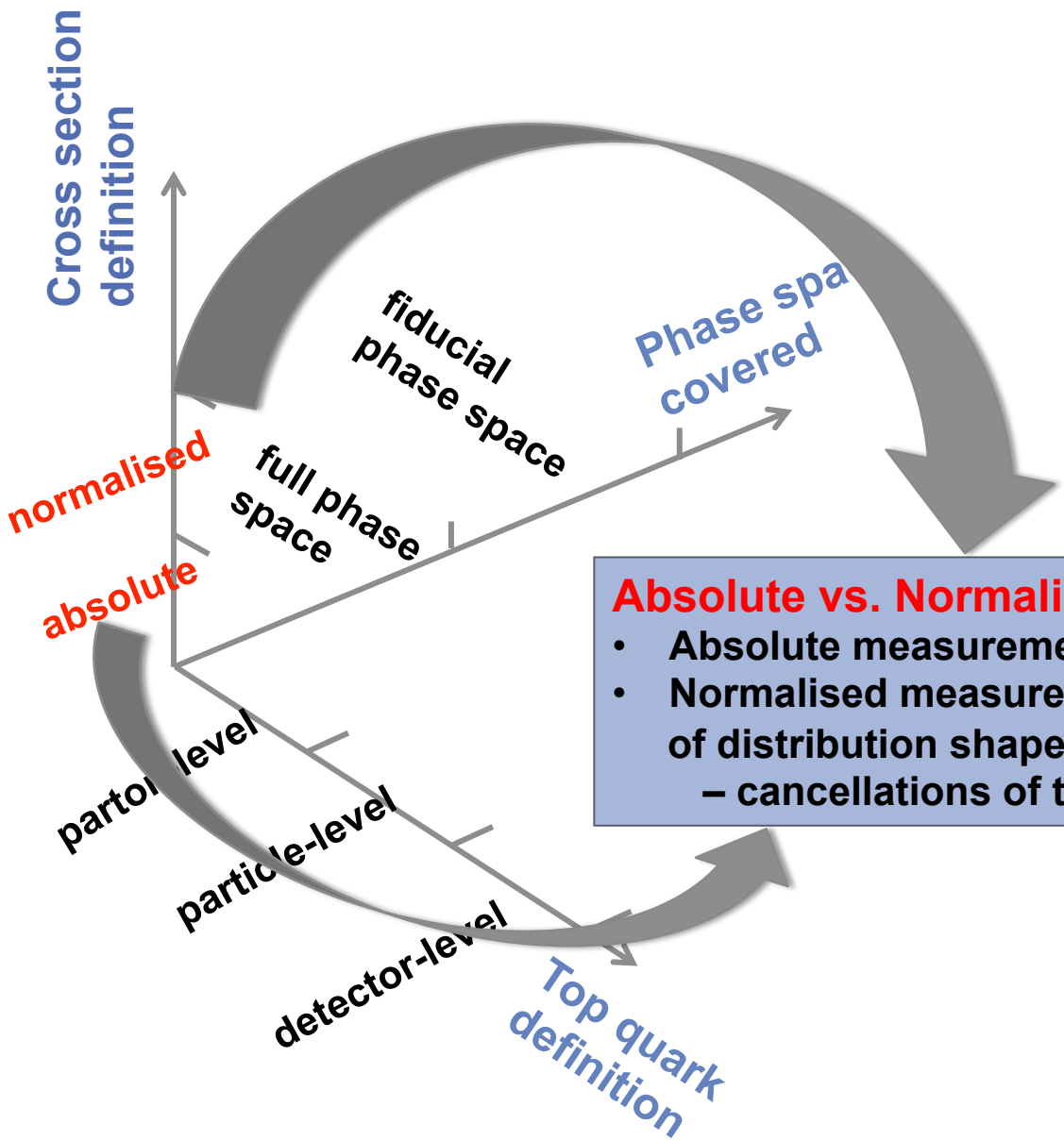
DIFFERENTIAL MEASUREMENTS



Full phase space, parton-level measurements

- Probe latest N^NLO + N^NLL pQCD
- Extraction of α_s , M_{top}
- Constrain PDFs

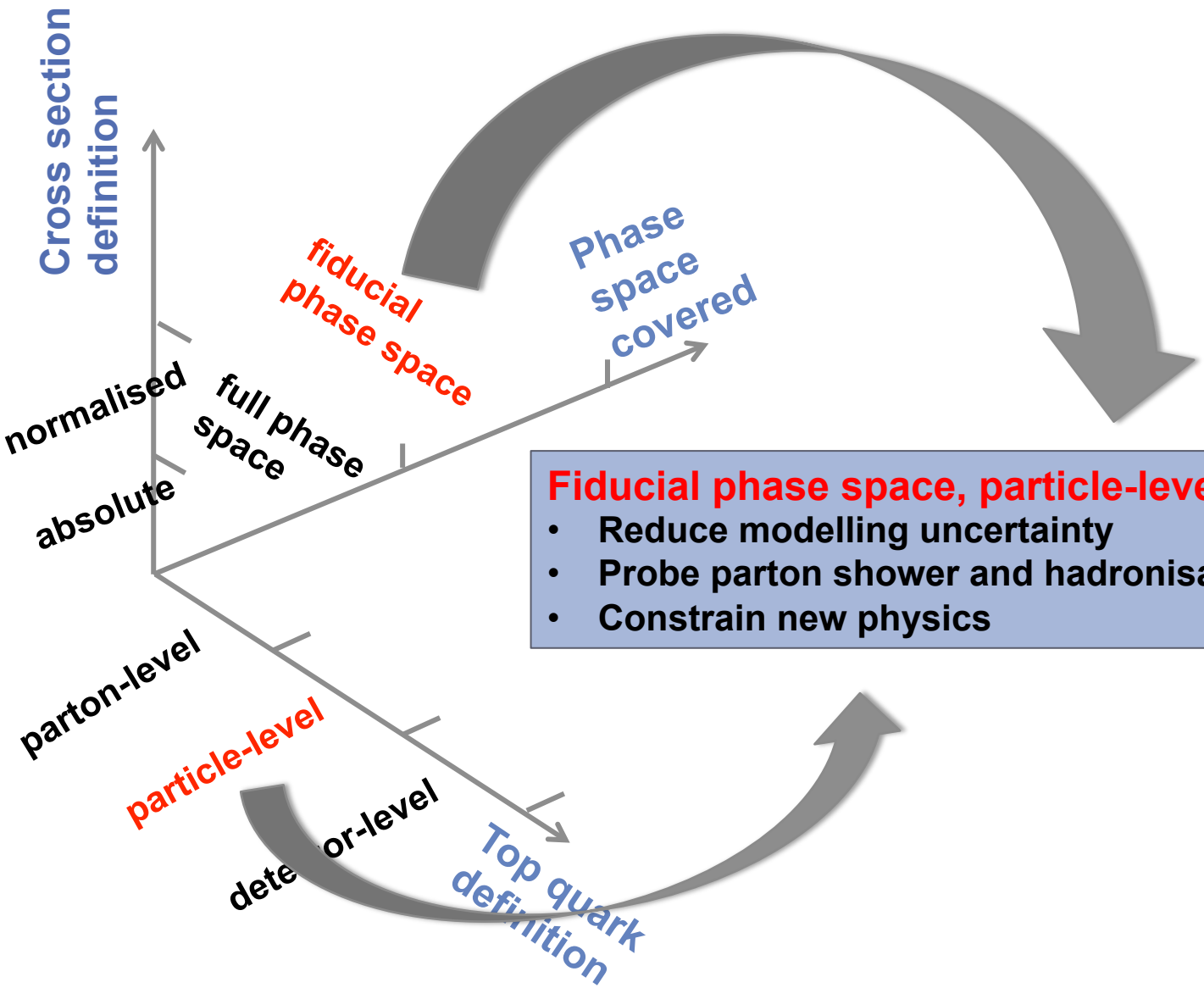
DIFFERENTIAL MEASUREMENTS



Absolute vs. Normalised measurements

- Absolute measurements reveal maximal information
- Normalised measurements allow more precise probes of distribution shapes
  - cancellations of th. and exp. uncertainties

DIFFERENTIAL MEASUREMENTS

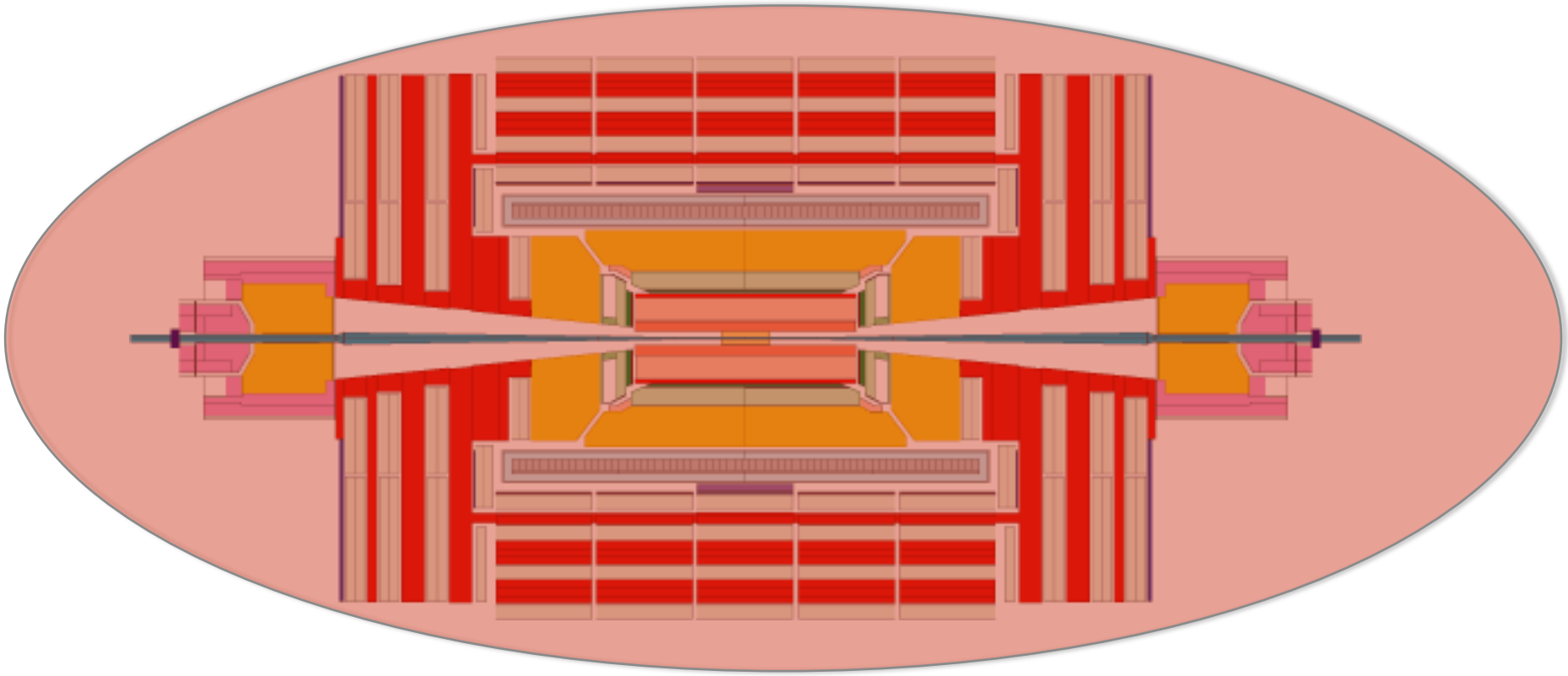


Fiducial phase space, particle-level measurements

- Reduce modelling uncertainty
- Probe parton shower and hadronisation models
- Constrain new physics

measuring tt differentially

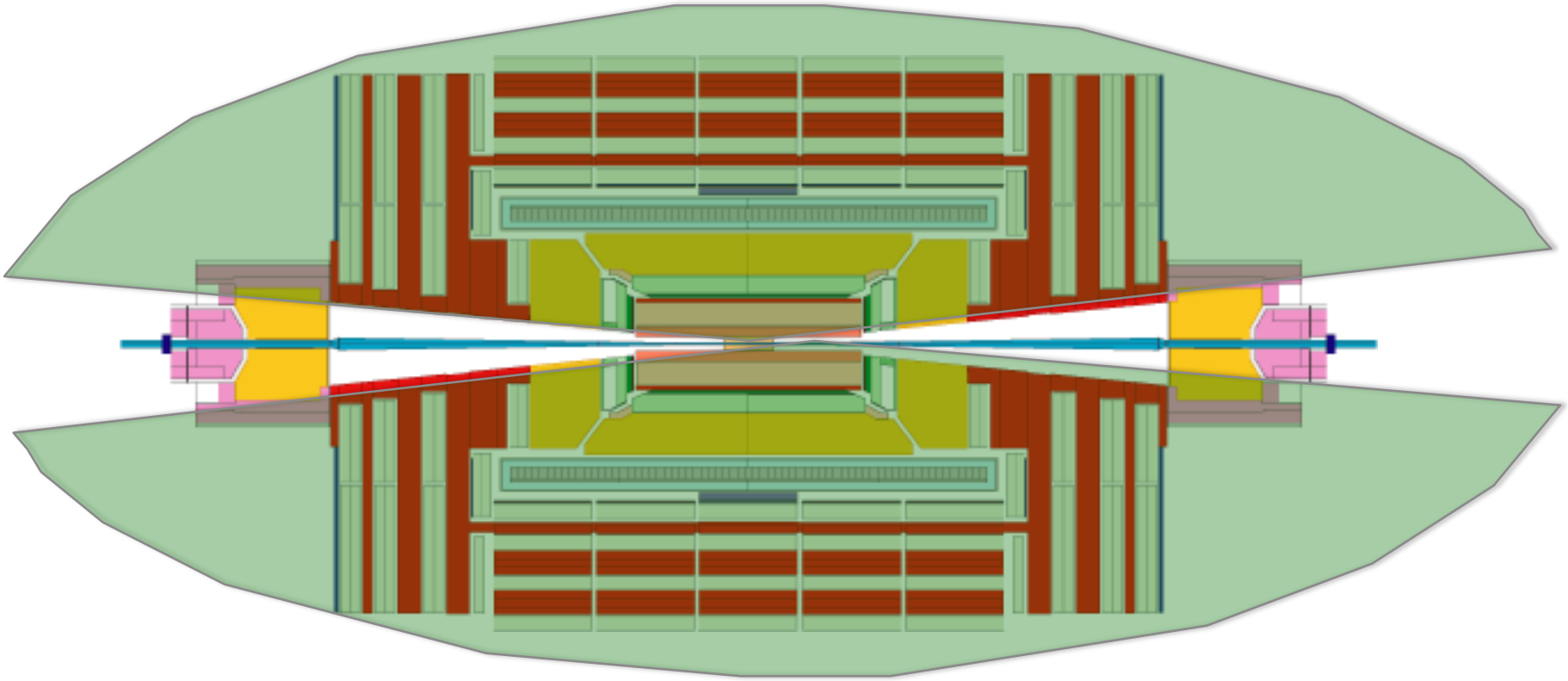
Top quark definitions



Full phase space:
Covers all possible tt kinematics.

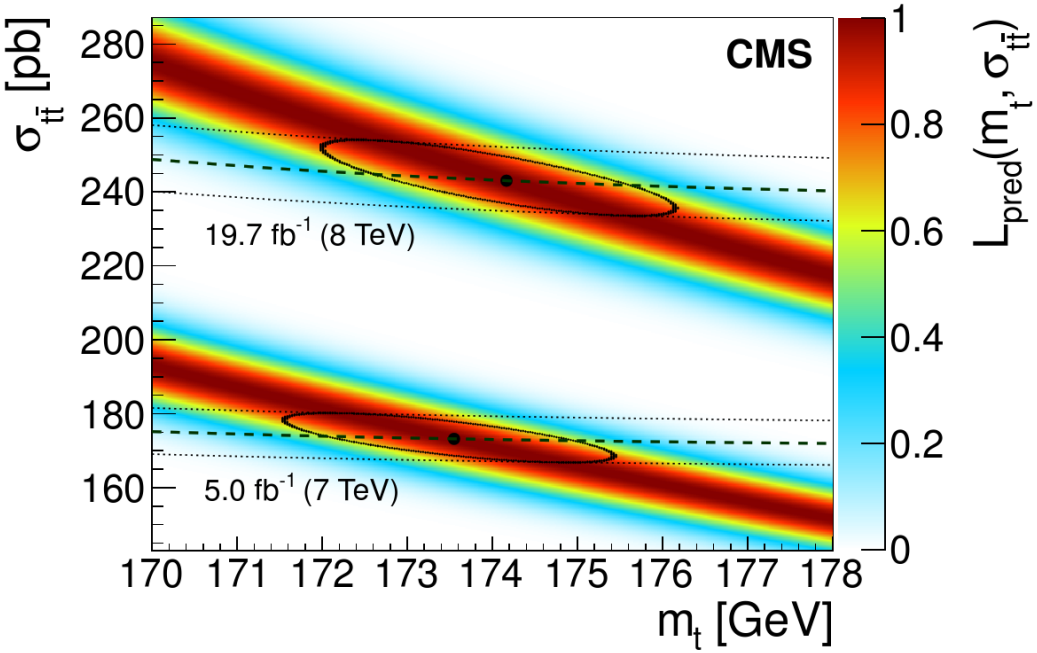
measuring tt differentially

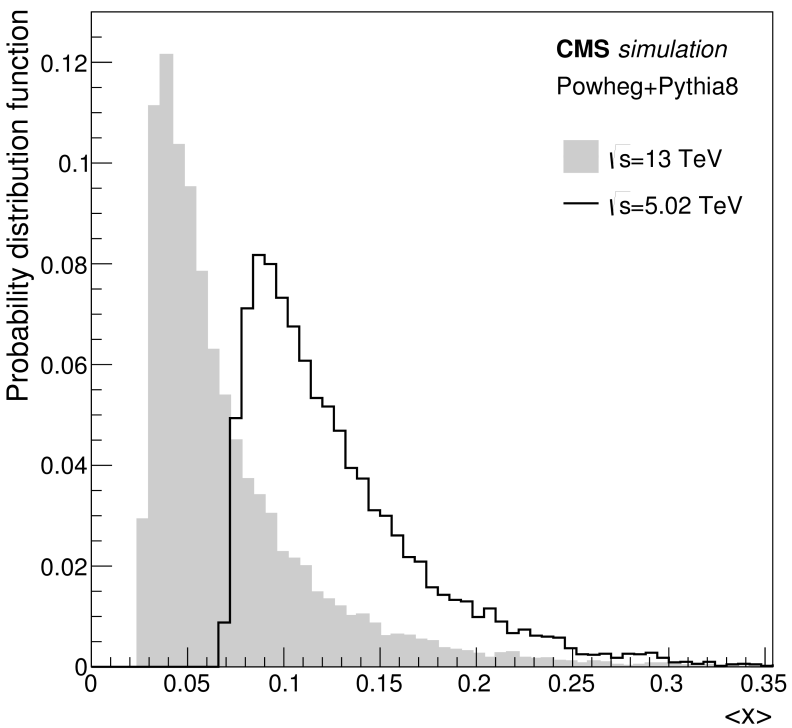
Top quark definitions



Visible phase space:
Kinematic region accessed by CMS detector

TOP-13-004

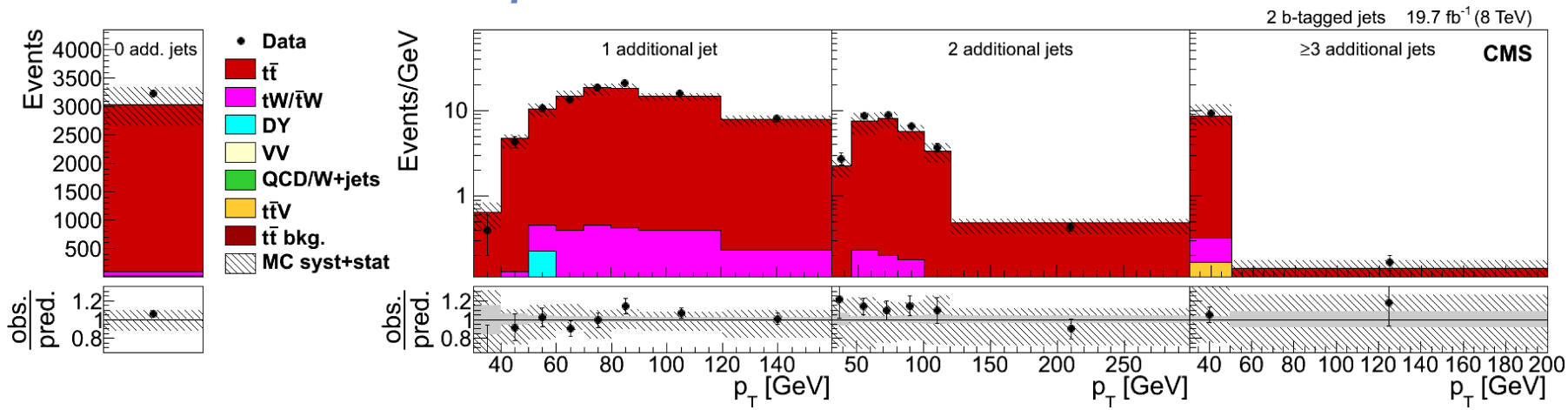


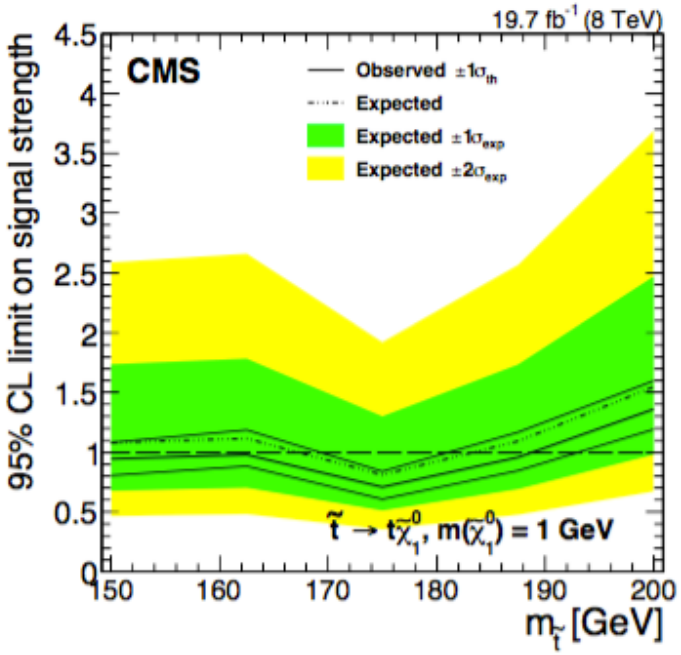


TOP-16-015

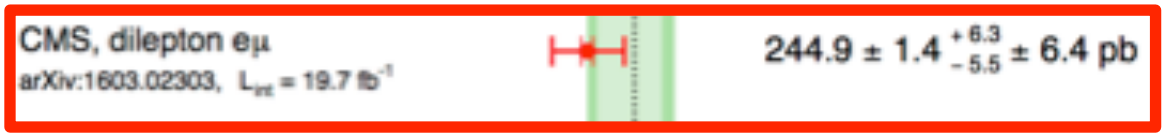
Incl. σ_{tt} measurements

TOP-13-004 –
tt cross sections in the eμ channel at 7 and 8 TeV





- Fit to Jet Pt in b and non-b jet categories



- **Total uncertainty ~ 3.7%**
- Extraction of M_{top} (pole) = **$173.8^{+1.7}_{-1.8}$ GeV**
- Limits on light stops