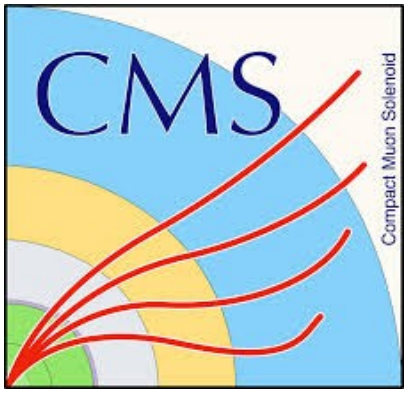
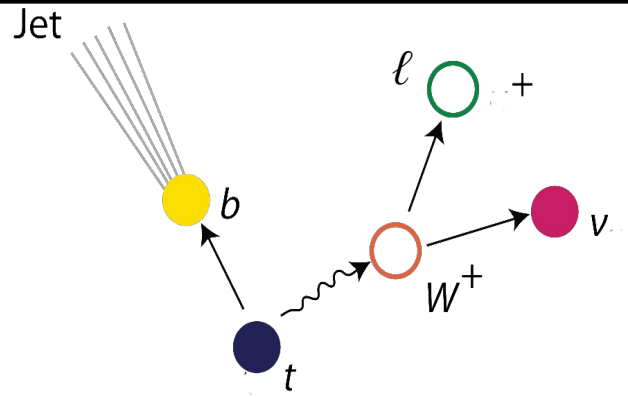


Top Quark Production Measurements with CMS

Abideh Jafari
UCLouvain, CP3, and FNRS
for the CMS collaboration

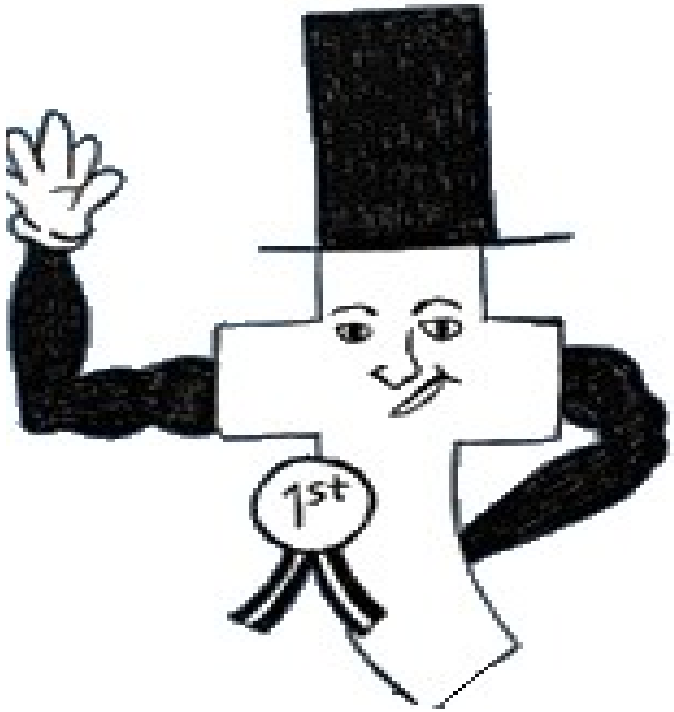
Les Rencontres de Physique de la Vallee d'Aoste
6th – 12th Mar. La Thuile, Italy

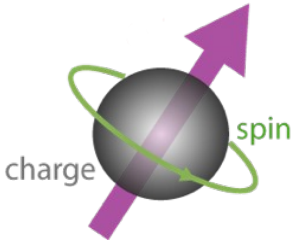
The Top Quark



A testing ground to validate SM or see hints for new physics

Diversity of particles in final state
→ a commissioning tool for early data

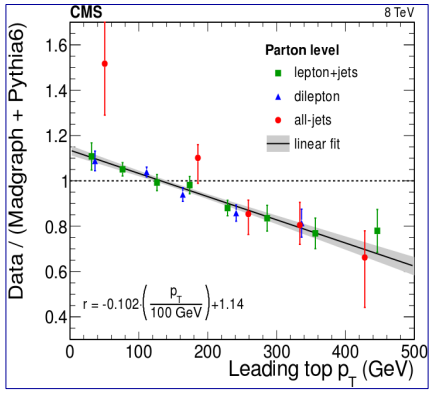


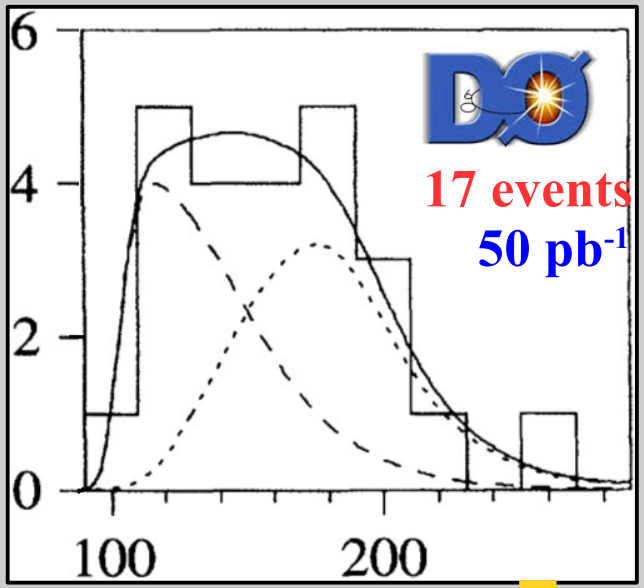


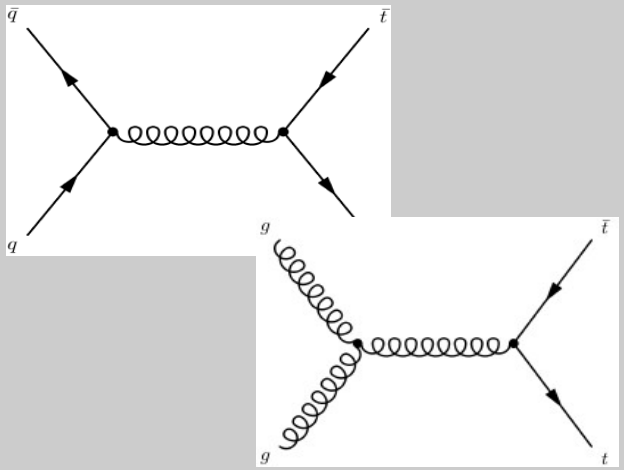
Large mass, short life time
→ bare quark properties

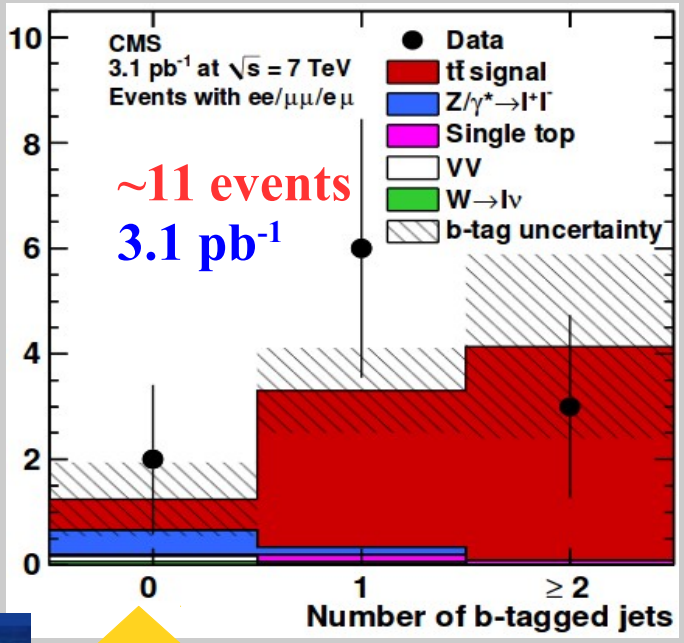
Background for searches …

Validate Monte-Carlo generators and theory calculations ...



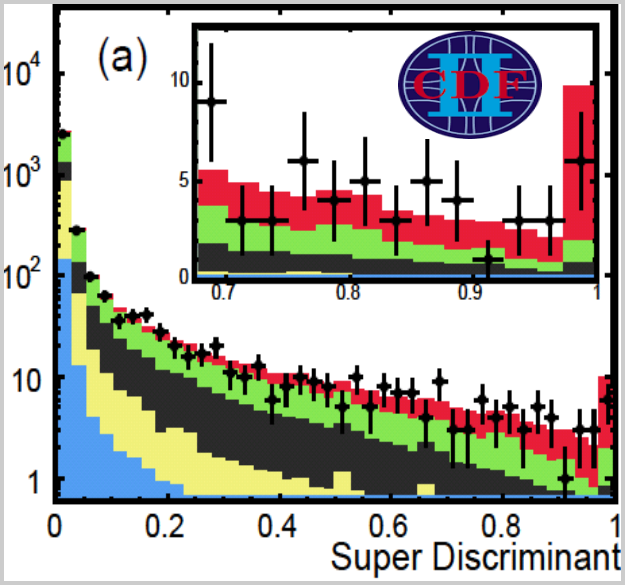


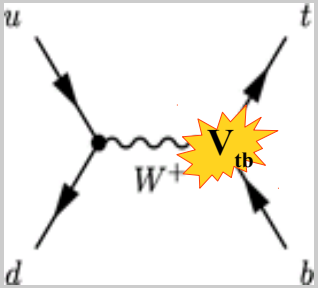


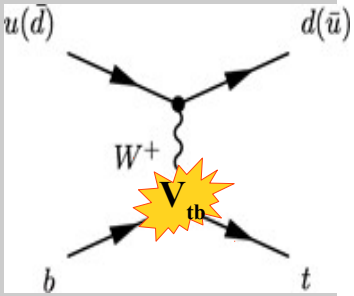


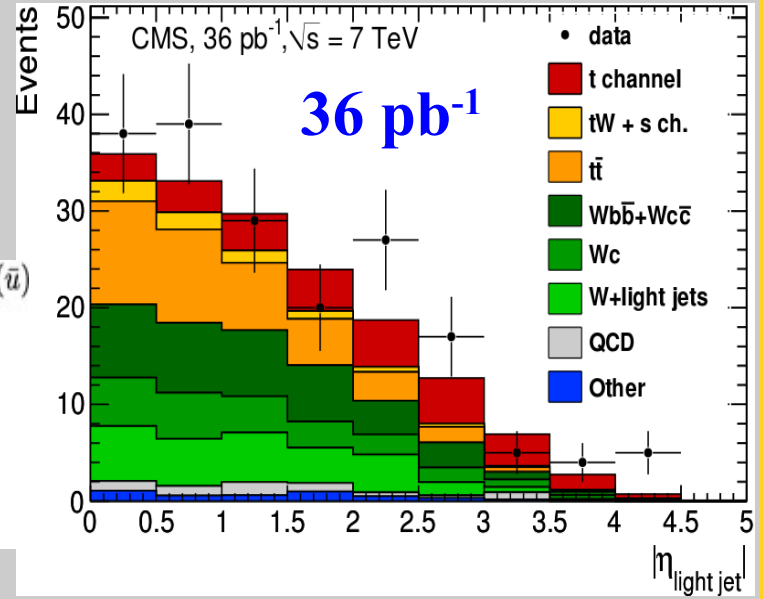
Eventually in run I

- Large statistics
- Limited by systematics

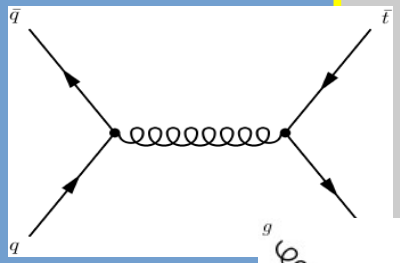


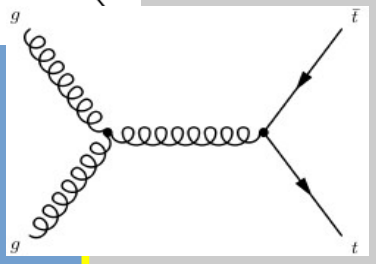


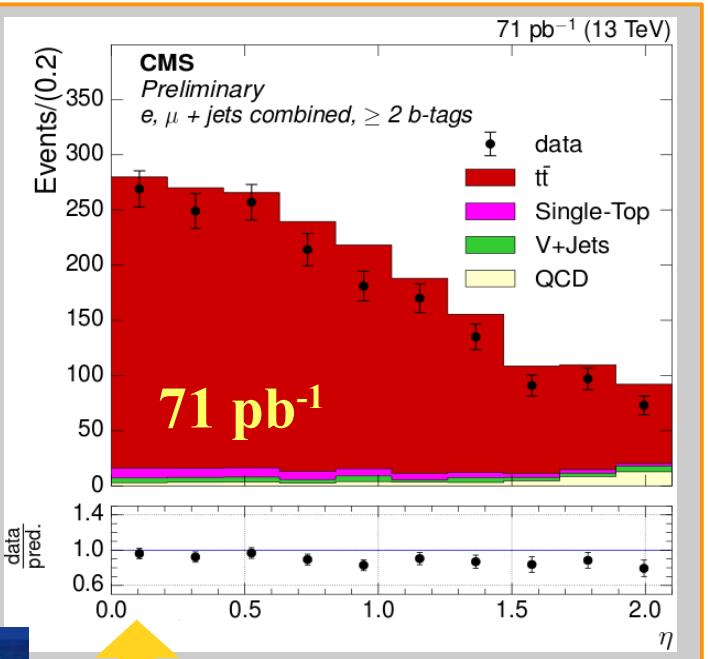


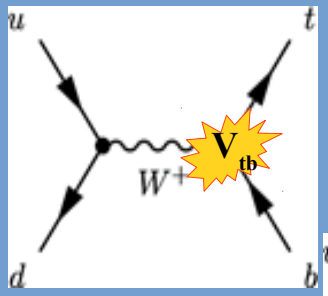


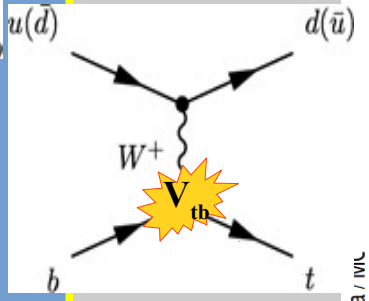
LHC 13 TeV collisions

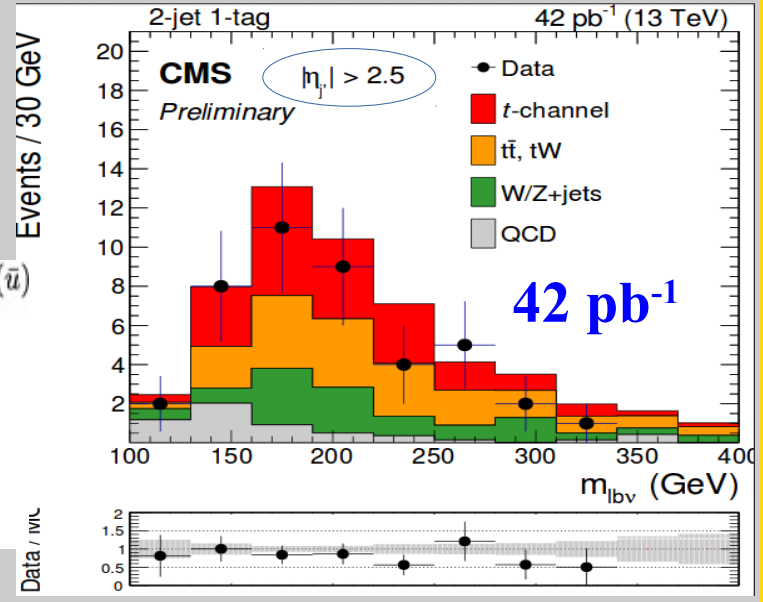


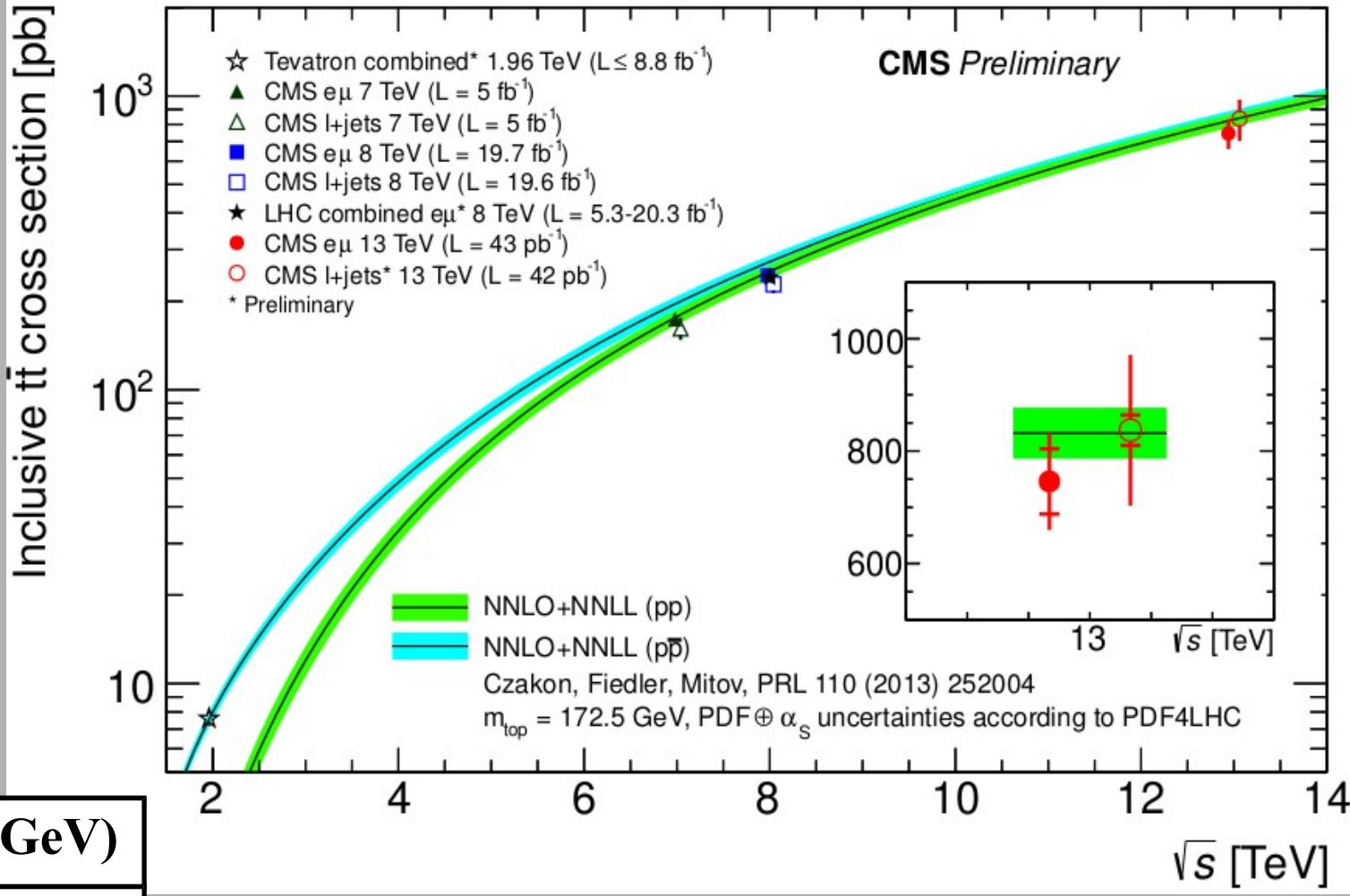












E_{COM}^{LHC}	σ_{tt} (m_t = 172.5 GeV)
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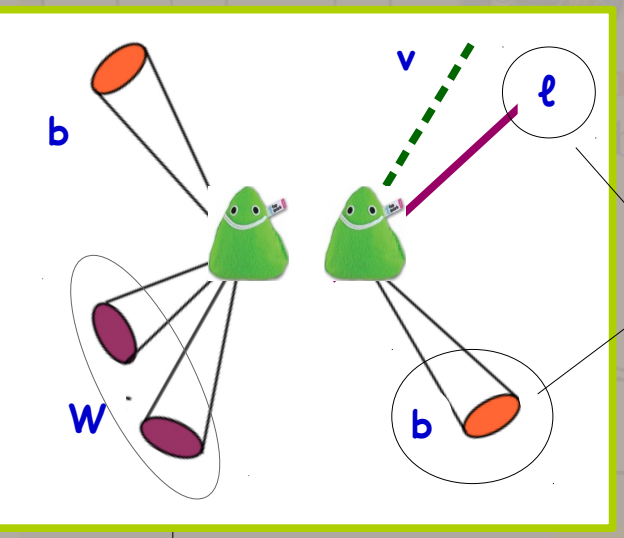
13 TeV	$831.76^{+40.2}_{-45.6}$

PAIR PRODUCTION

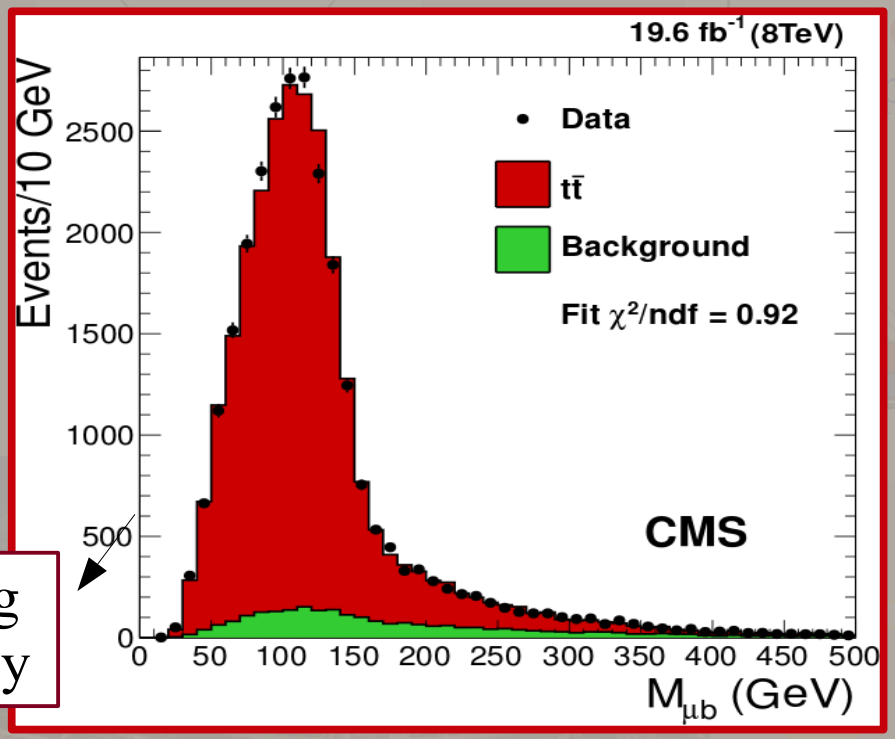
Inclusive cross section ℓ+jets "7+8" TeV

NEW



Jet energy recalibration

b-tagging efficiency

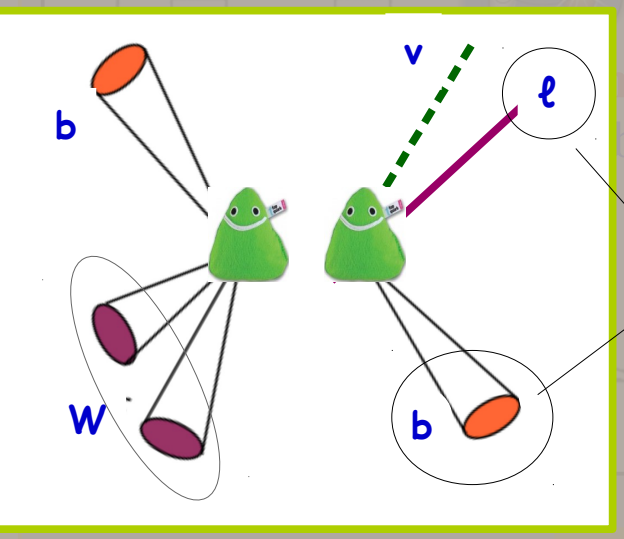


arXiv:1602.09024

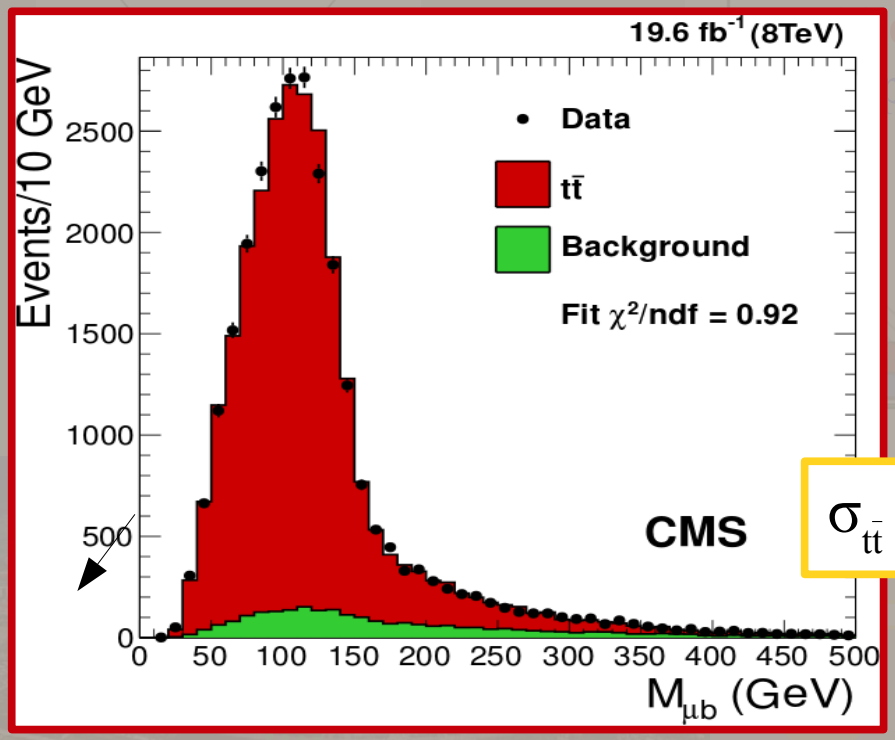
Reduced systematics

Inclusive cross section ℓ+jets "7+8" TeV

NEW



e/μ combined with BLUE



arXiv:1602.09024

$\sigma_{t\bar{t}}$ with template fit

Fiducial

$$\sigma_{t\bar{t}}^{fid}(8\,TeV) = 3.80 \pm 0.06(stat.) \pm 0.18(syst.) \pm 0.10(lumi.)\,pb$$

MadGraph

JES & modeling

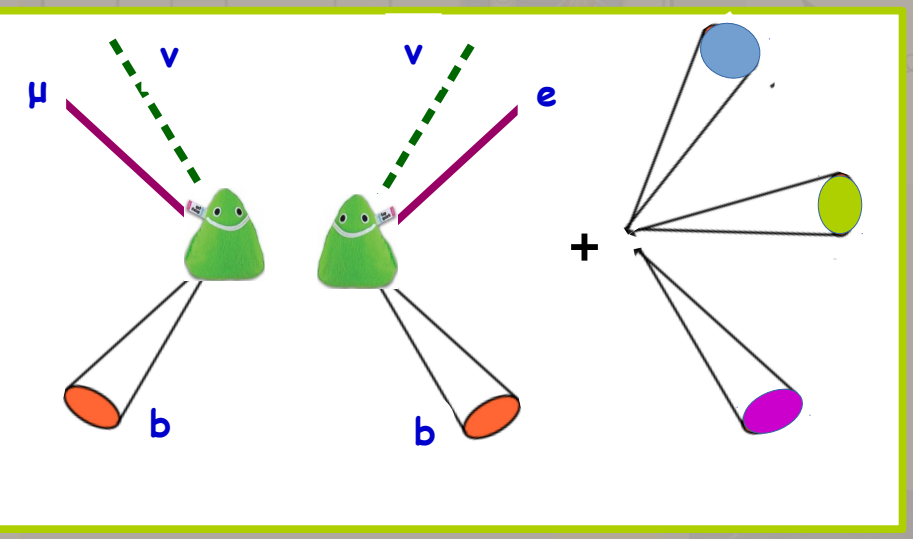
$$\sigma_{t\bar{t}}(8\,TeV) = 228.5 \pm 3.8(stat.) \pm 13.7(syst.) \pm 6.0(lumi.)\,pb$$

SM: 1.43 ± 0.01

A similar measurement at 7 TeV: $R_{t\bar{t}} = 1.43 \pm 0.09$

Inclusive cross section eμ “7+8” TeV

NEW



arXiv:1603.02303

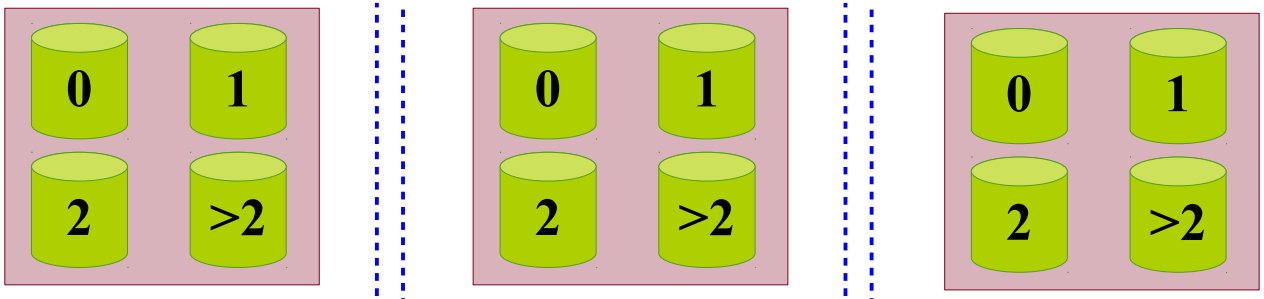
- Categories in b-tag multiplicity
- Categories in additional non-tagged jets
- Fit to p_T of softest jets:
  - Control extra radiations

CMS **1 b-jet**

CMS **2 b-jet**

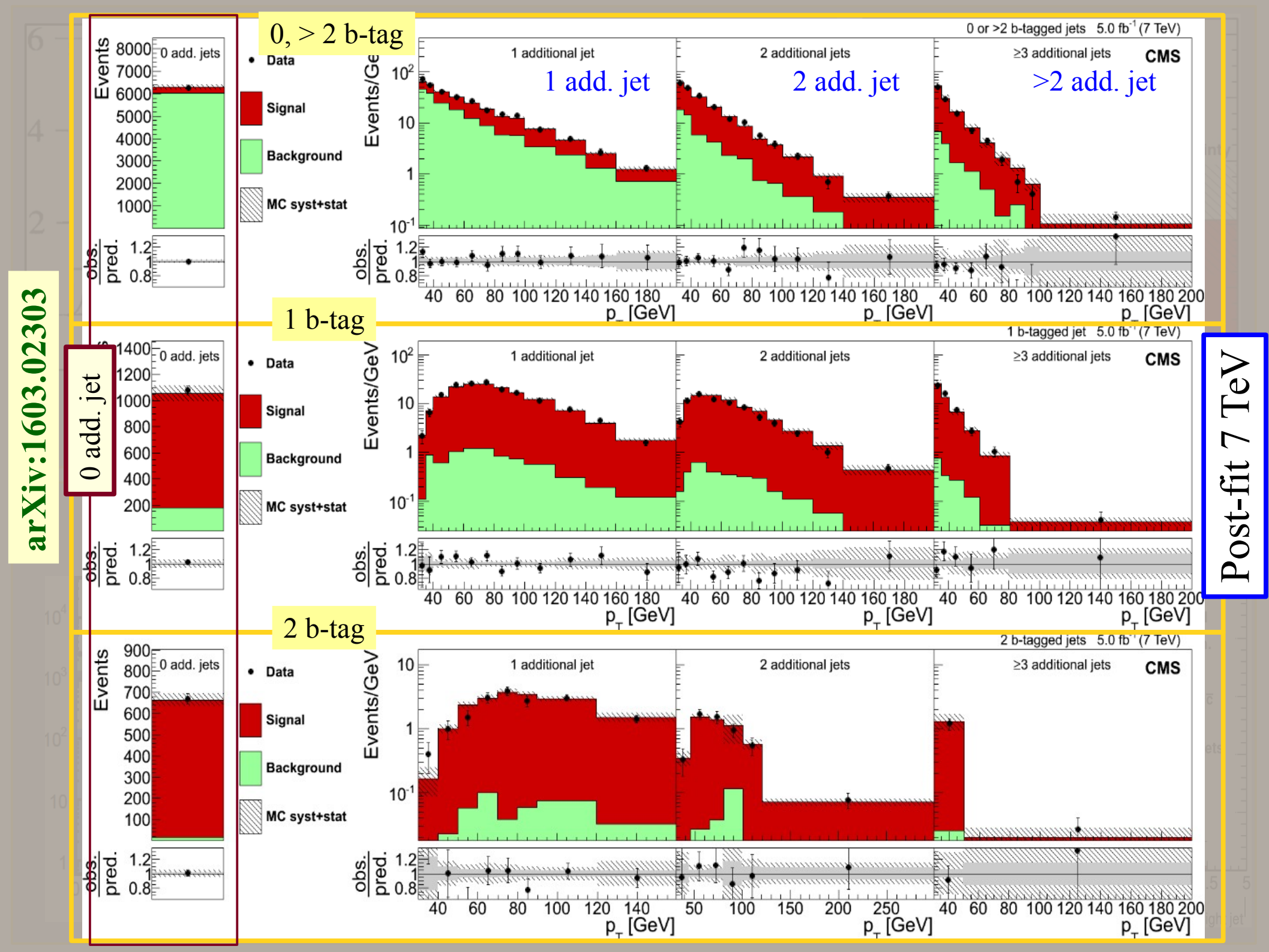
CMS **0, > 2 b-jet**

Additional non-tagged jets



Multi-differential

The p_T of the softest additional non-tagged jet


arXiv:1603.02303
0 add. jet
0, > 2 b-tag
1 b-tag
2 b-tag
Post-fit 7 TeV
0 add. jets
1 additional jet
2 additional jets
≥3 additional jets
1 add. jet
2 add. jet
>2 add. jet
Data
Signal
Background
MC syst+stat
Events
Events/GeV
obs./pred.
CMS
0 or >2 b-tagged jets 5.0 fb-1 (7 TeV)
1 b-tagged jet 5.0 fb-1 (7 TeV)
2 b-tagged jets 5.0 fb-1 (7 TeV)
p_T [GeV]

Inclusive cross section eμ "7+8" TeV

NEW

arXiv:1603.02303

Fiducial

$$\sigma_{t\bar{t}}^{fid}(7\,TeV) = 3.03 \pm 0.04\,(stat.)\,^{+0.08}_{-0.07}\,(syst.) \pm 0.07\,(lumi.)\,pb$$

$$\sigma_{t\bar{t}}^{fid}(8\,TeV) = 4.23 \pm 0.02\,(stat.)\,^{+0.11}_{-0.09}\,(syst.) \pm 0.11\,(lumi.)\,pb$$

Lepton, DY

MadGraph

Full phase space

$$\sigma_{t\bar{t}}(8\,TeV) = 244.9 \pm 1.4\,(stat.)\,^{+6.3}_{-5.5}\,(syst.) \pm 6.4\,(lumi.)\,pb$$

$$\sigma_{t\bar{t}}(7\,TeV) = 173.6 \pm 2.1\,(stat.)\,^{+4.5}_{-4.0}\,(syst.) \pm 3.8\,(lumi.)\,pb$$

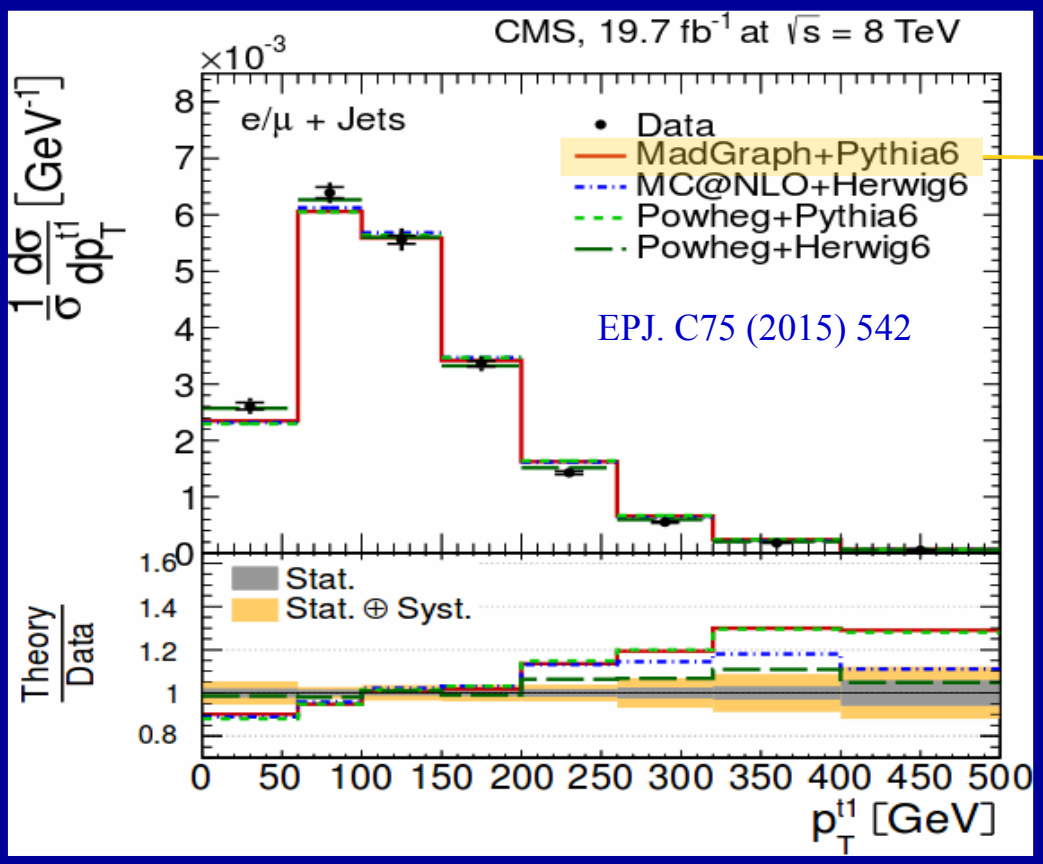
Lepton, DY

SM: 1.43 ± 0.01

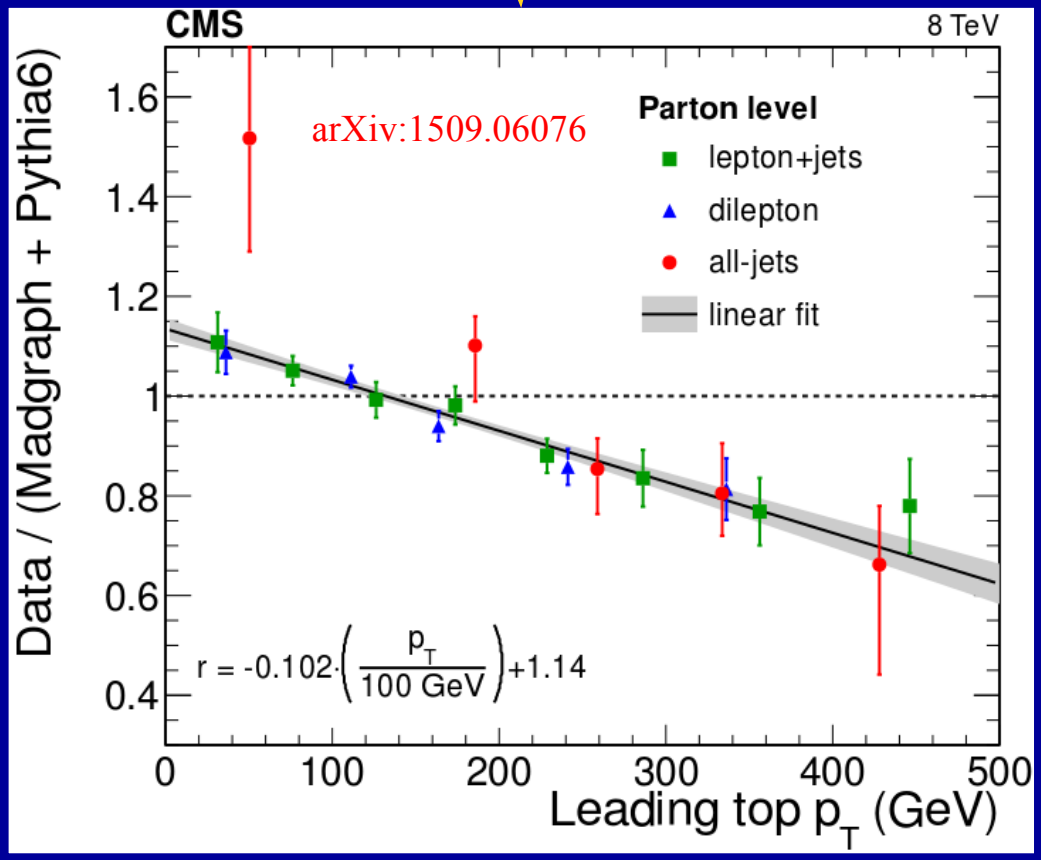
$R_{t\bar{t}} = 1.41 \pm 0.06$

E. Yazgan's talk for top quark pole mass!

Differential products of the Top Quark *Factory*



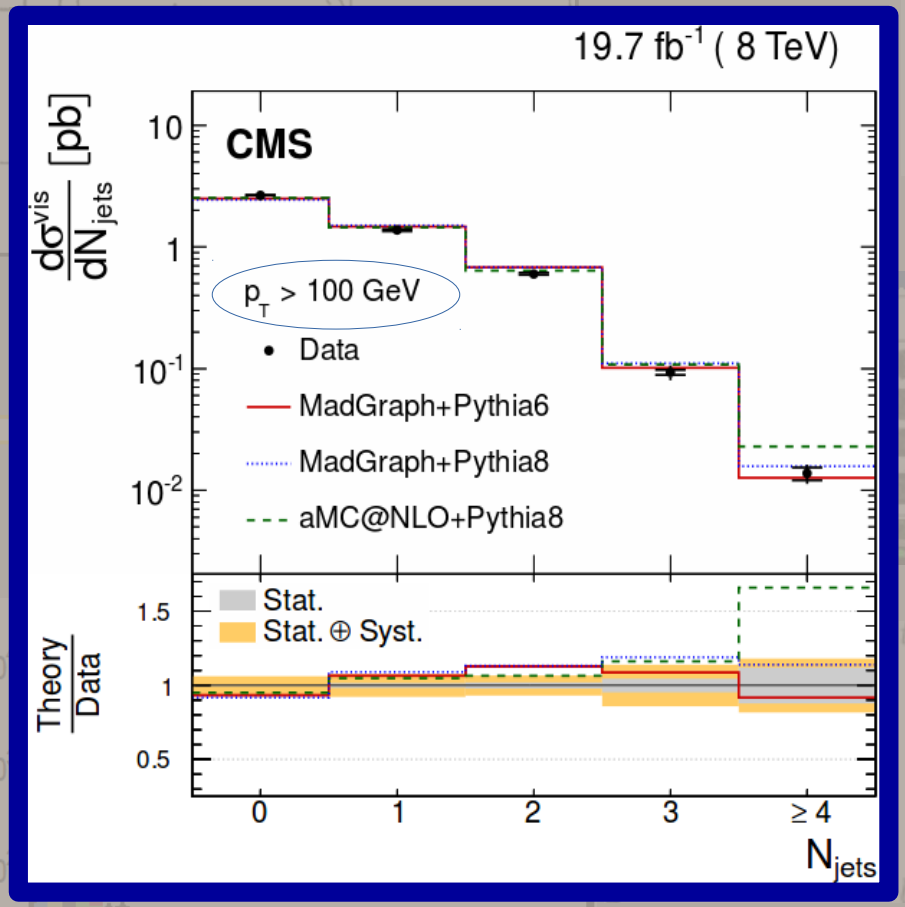
Differential in all final states!!

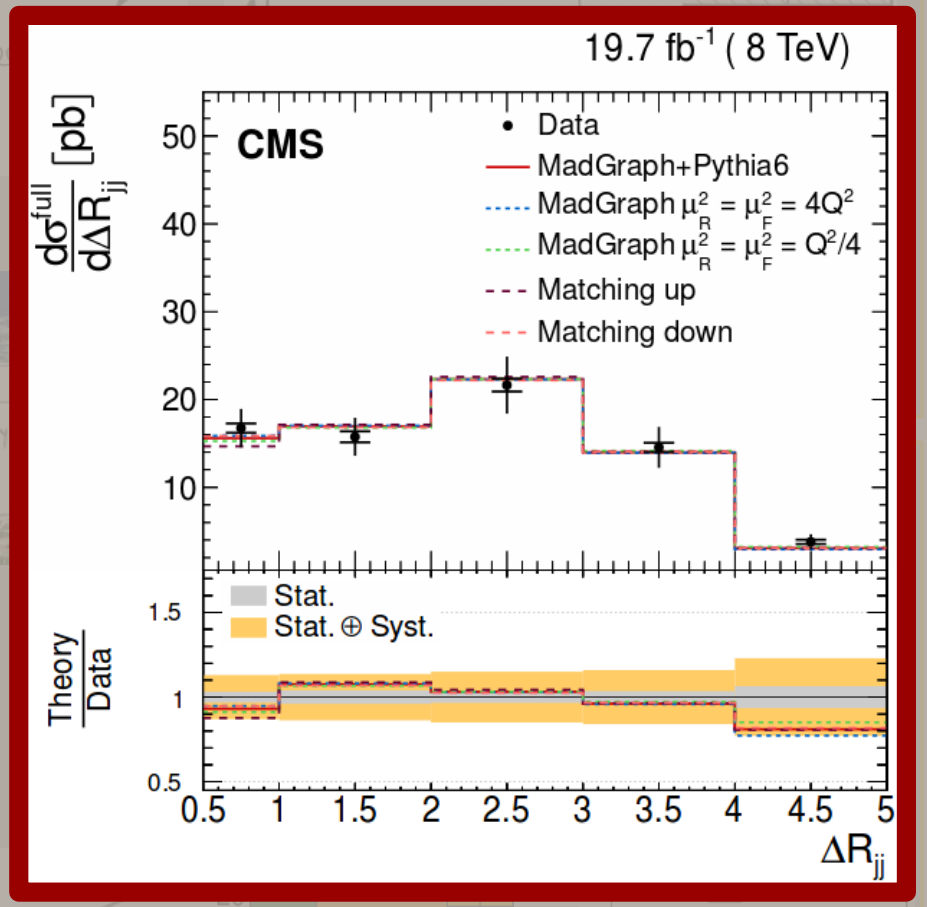


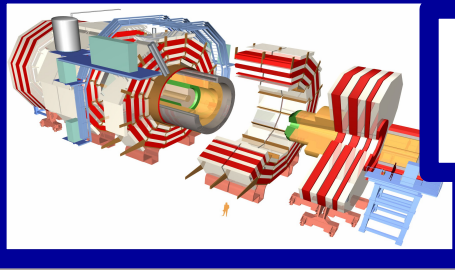
The Top Quark *and more* Production

Differential in $t\bar{t}$ + **jets**!

arXiv:1510.03072

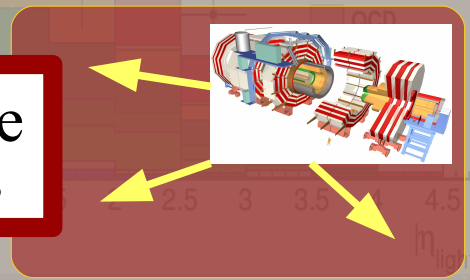




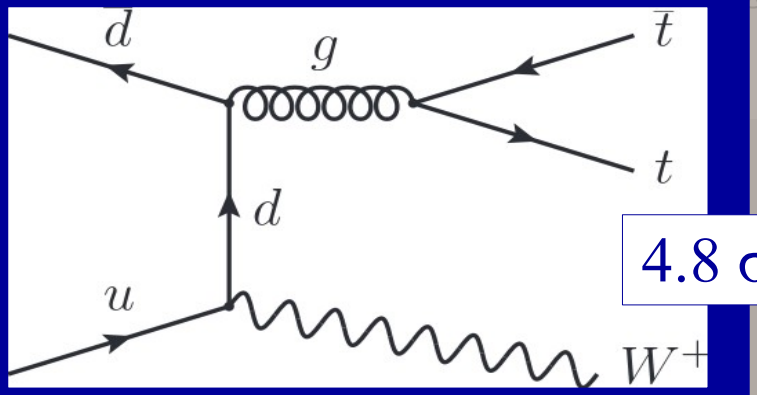


Fiducial
MC Modeling

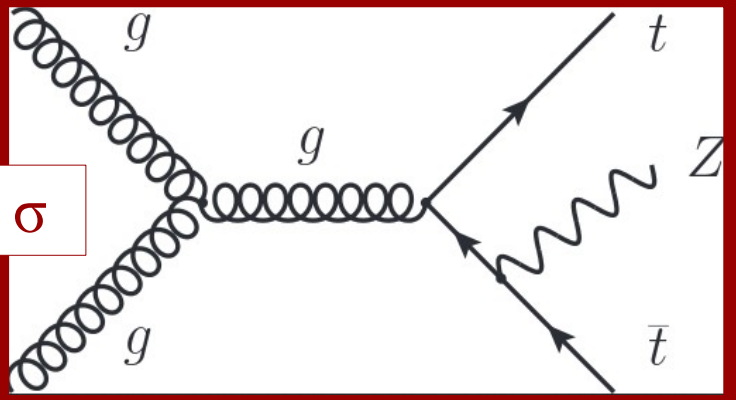
Full phase space
Theory calculations



The Top Quark *and more* Production

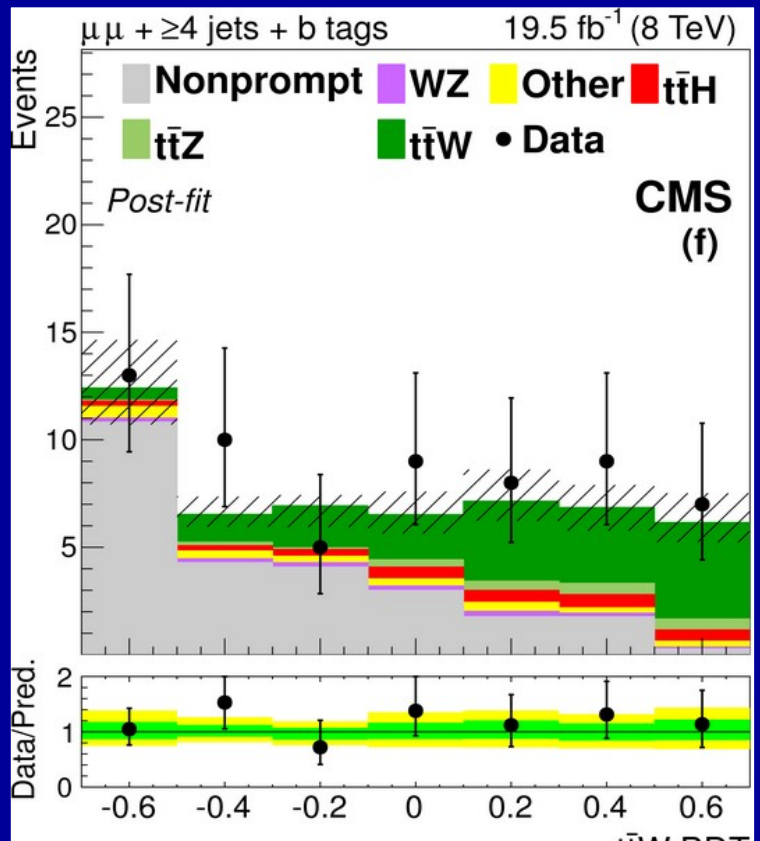


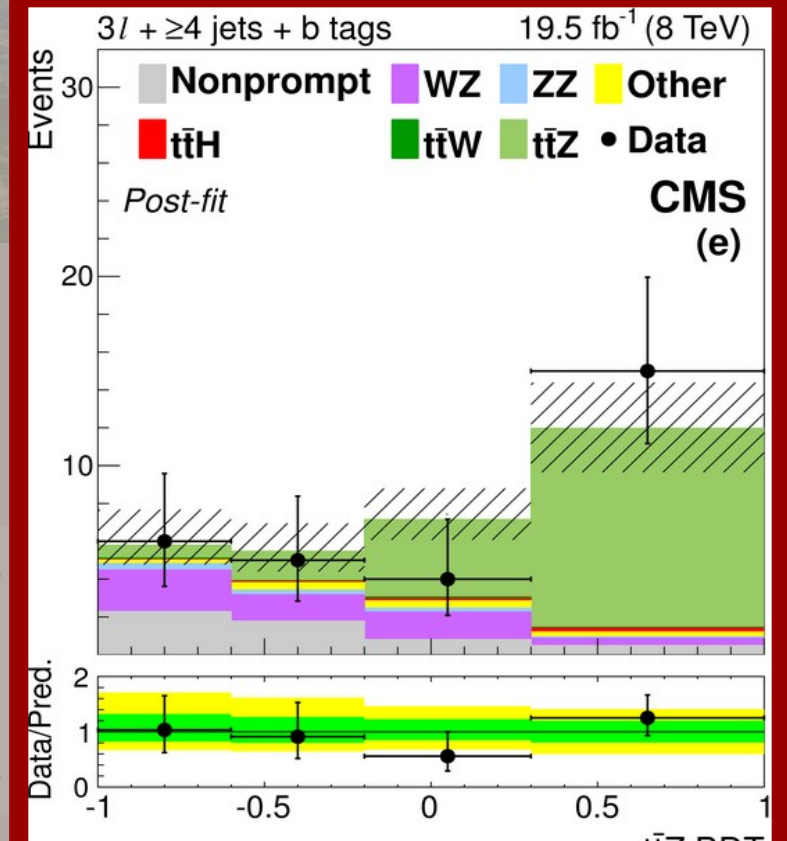
4.8 σ

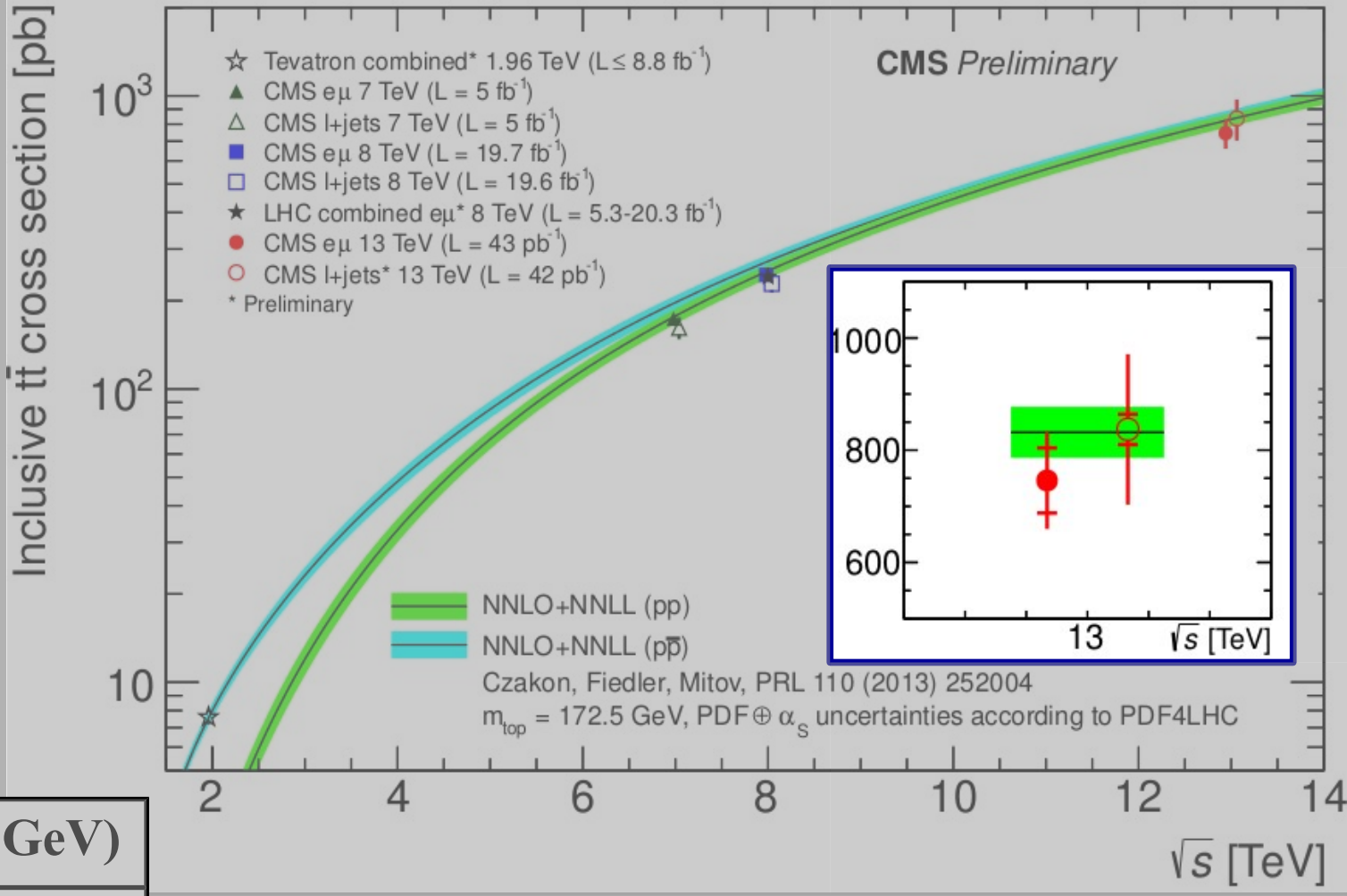


6.4 σ

JHEP 01 (2016) 096







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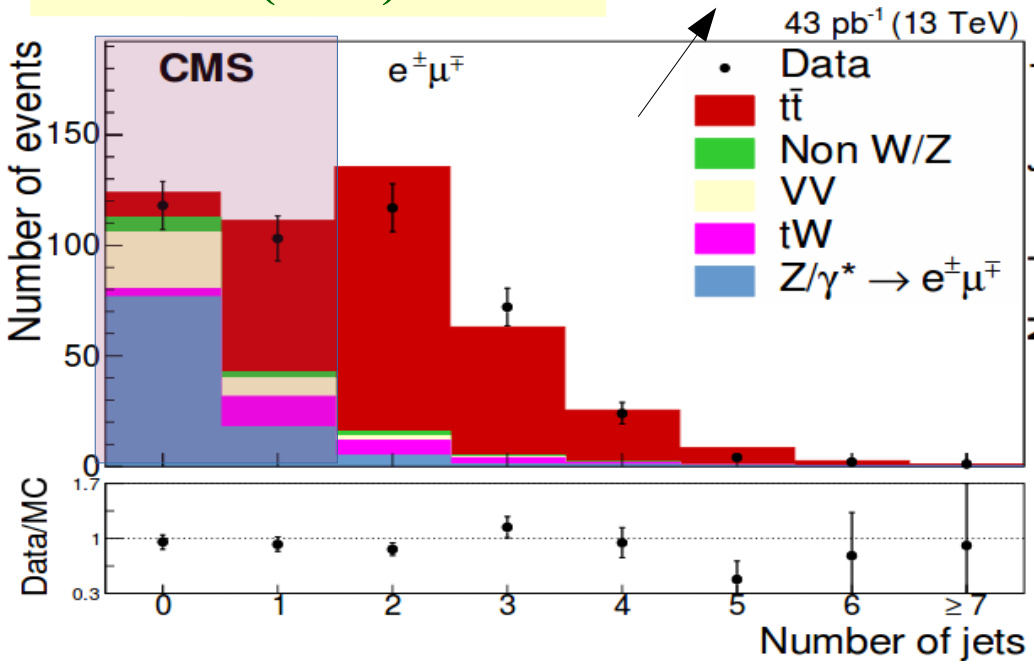
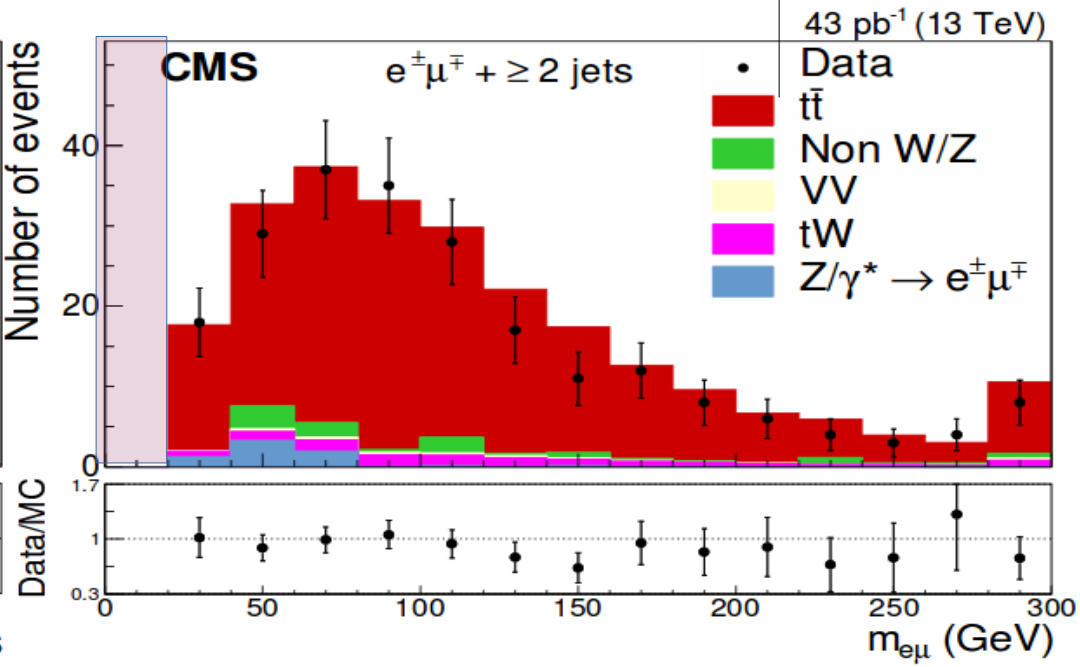
PAIR PRODUCTION

Inclusive cross section eμ 43 pb^{-1} 13 TeV

- An electron-muon trigger for online selection
- Reject heavy flavor resonances with $m_{e\mu} < 20$ GeV
- At least two jets and no b-tagging requirement

PRL 116 (2016) 052002





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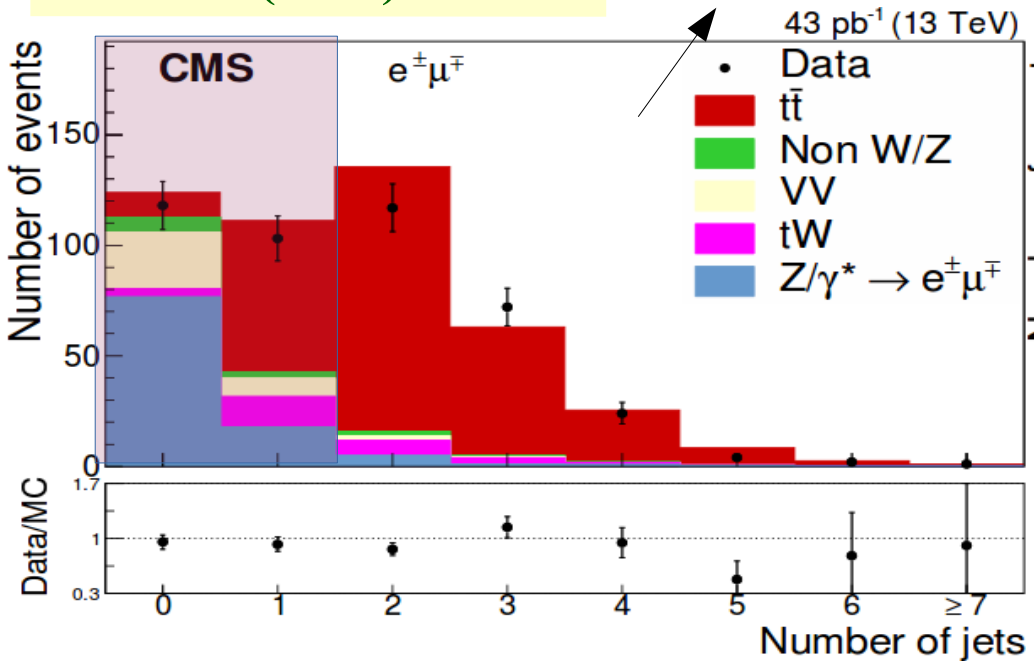
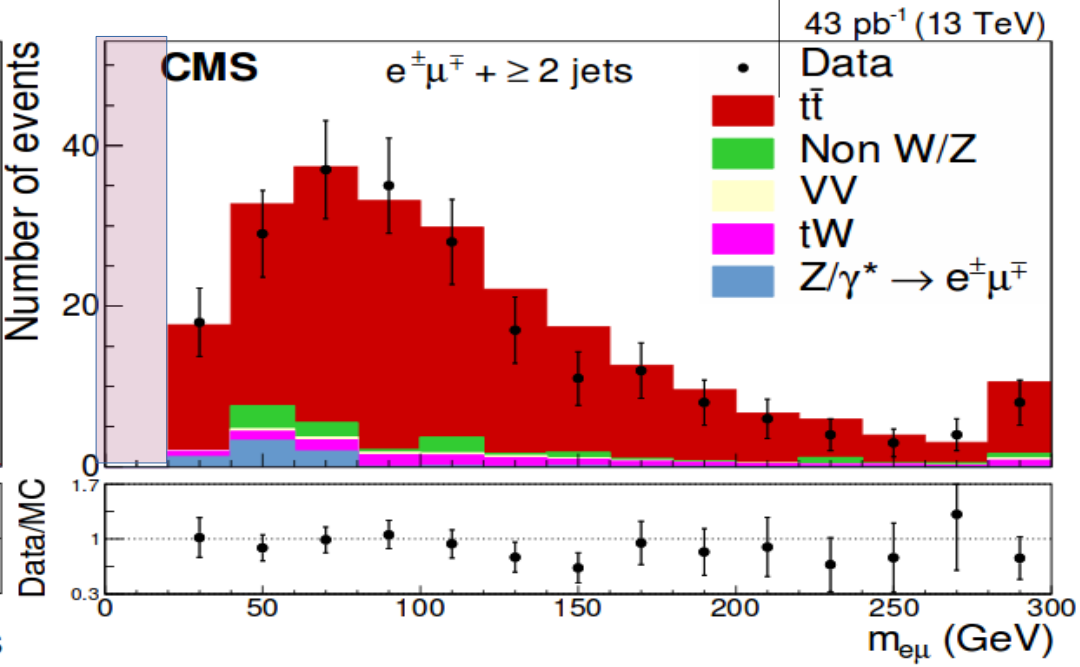
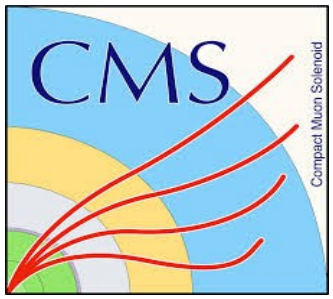




- **DY:** $R_{out/in}$ method in ee/μμ to correct the whole range using the Z-mass window. MC eμ is corrected with overall Data/MC SF of (1.04±0.16)
- **Non-prompt:** from same-sign data, scaled by MC scale of OS/SS

Inclusive cross section eμ 42 pb^{-1} 13 TeV



PRL 116 (2016) 052002

- A counting experiment in the selected sample

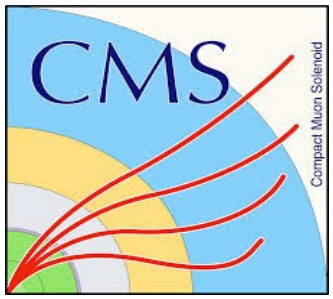
Source	Number of events $e^{\pm}\mu^{\mp}$
Drell–Yan	6.9 ± 1.2
Nonprompt leptons	8.6 ± 4.4
tW	10.6 ± 3.3
VV	2.7 ± 0.9
Total background	28.8 ± 5.7
Data	220

$m_t = 172.5$ GeV

$$A \times \epsilon_{sel.} \times Br(t \to e\mu) = (0.60 \pm 0.04)\%$$

$$\sigma_{t\bar{t}} = 746 \pm 58(stat.) \pm 53(syst.) \pm 36(lumi.)\ pb$$

Inclusive cross section eμ 42 pb^{-1} 13 TeV



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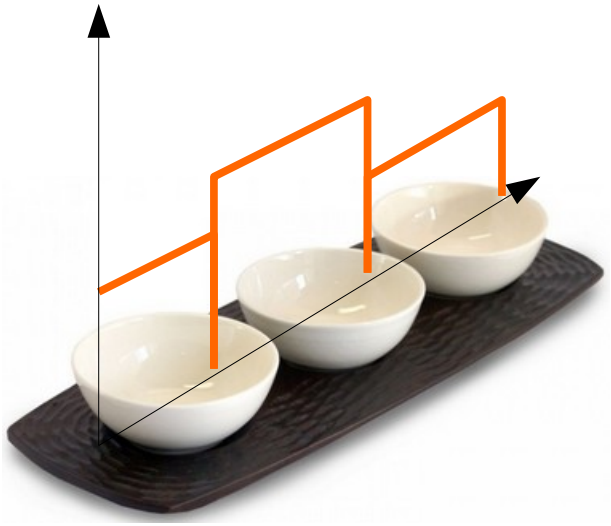
- **Dominant systematics** are lepton trigger and identification.
- Top mass dependence: small! 0.7% reduction on $m_t = 173.34$ GeV [1]
- Cross section in the **fiducial** volume:

$$\sigma_{t\bar{t}} = 12.4 \pm 1.0\,(stat.) \pm 1.0\,(syst.) \pm 0.6\,(lumi.)\ pb$$

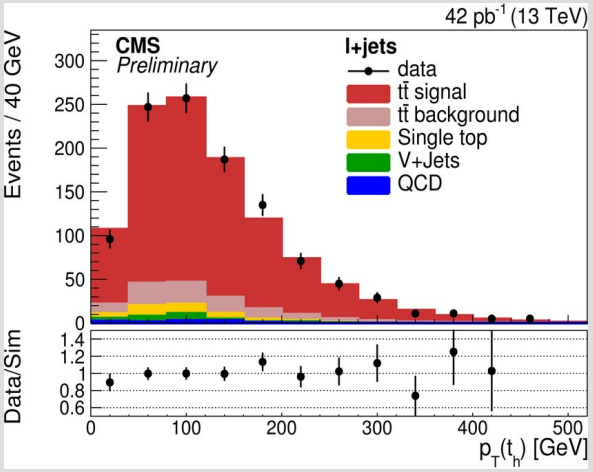
[1] arXiv:1403.4427



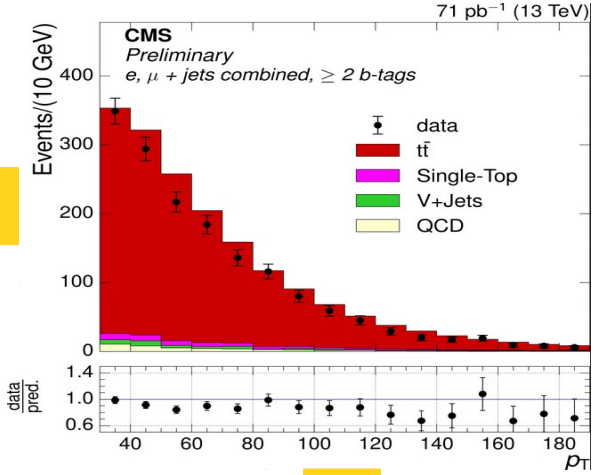
DIFFERENTIAL

Differential cross section

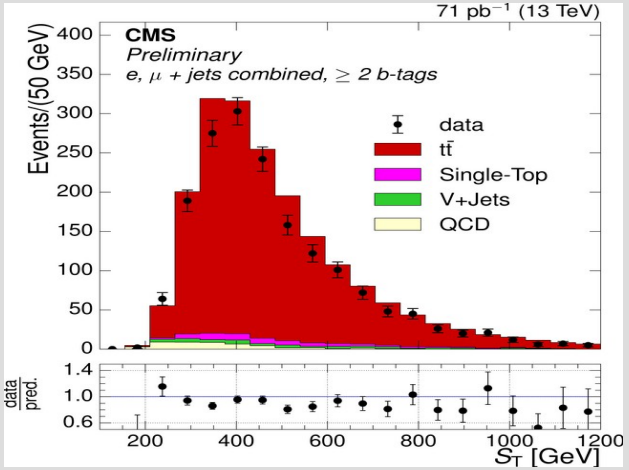
Top quark reconstruction



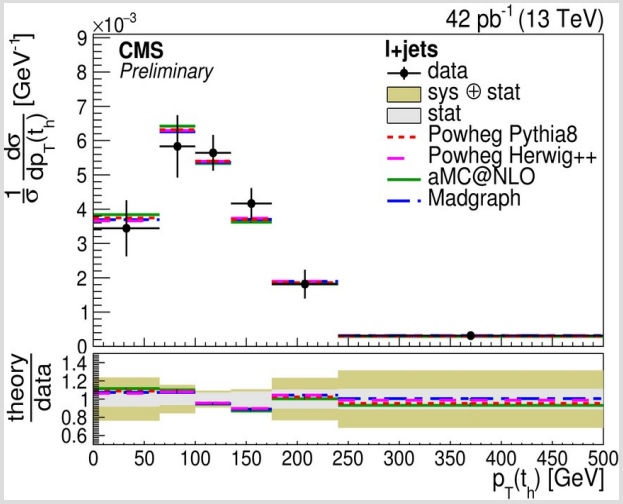
Object kinematics



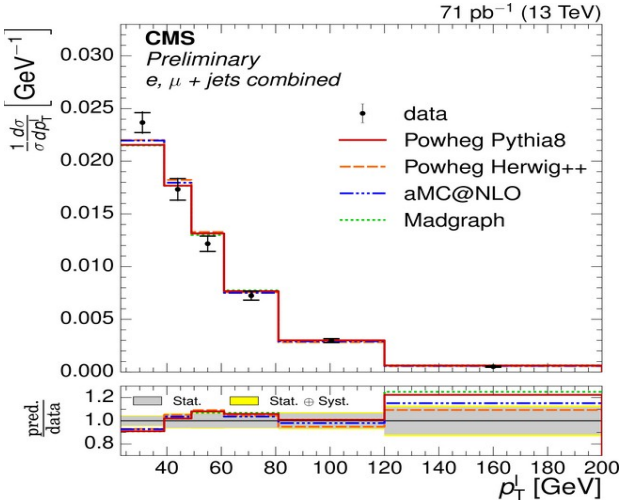
Event properties



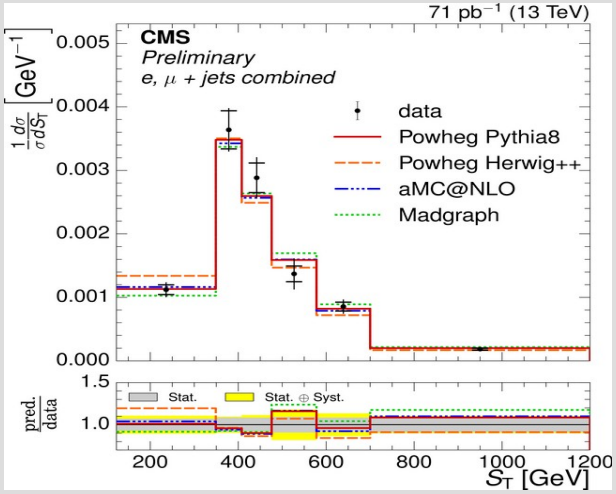
Compare to theory



Compare to theory



Compare to theory



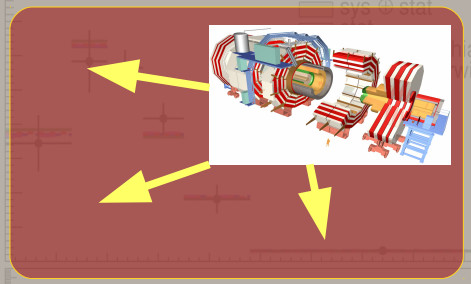
Differential cross section

Top quark reconstruction

Before decay after radiation

- Compare to ***Parton level***

Full phase space



- Compare to theory calculations

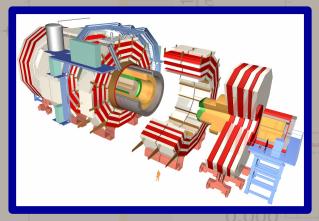
Object kinematics

Event properties

Stable particles after full ME + PS

- Compare to ***particle level***
- *Reconstructed* and *Selected* similarly to detector level objects

Fiducial

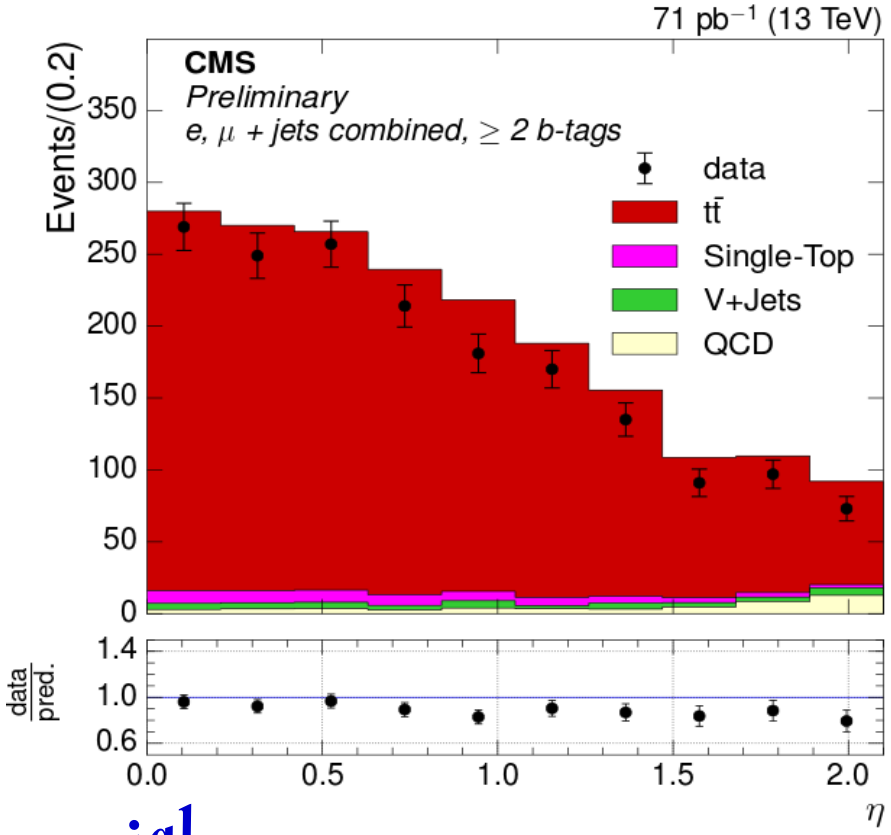


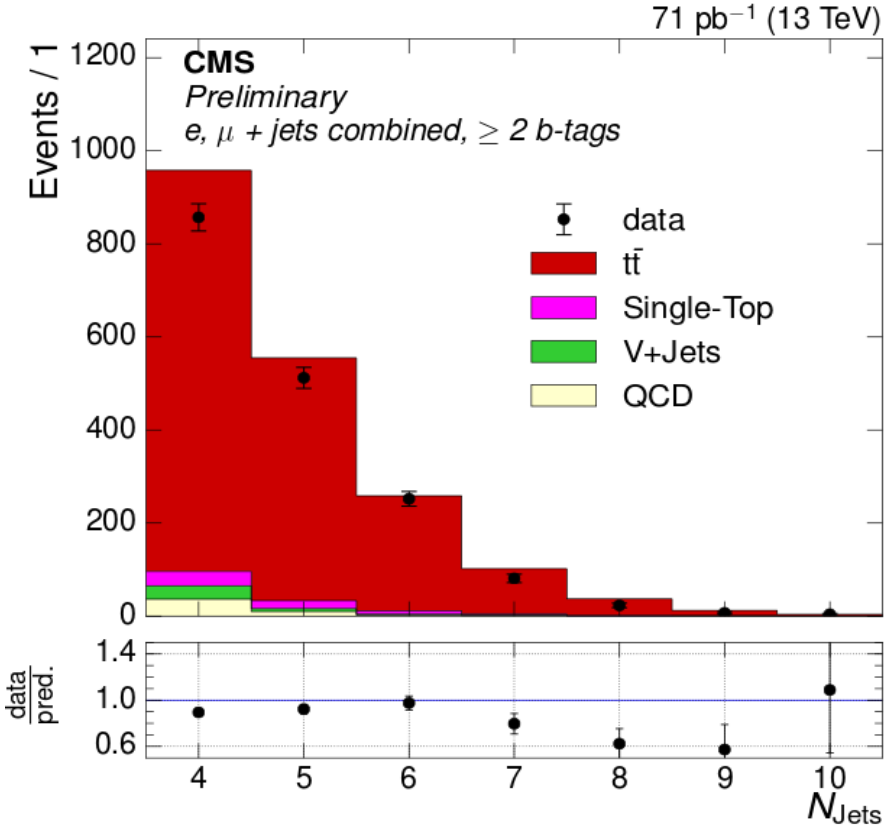
- Less dependence to extrapolation effects

Differential cross section ℓ+jets 71 pb^{-1} 13 TeV

- Events with one electron or one muon
- At least four high p_T jets, at least 2 b-tagged
- QCD background from data, rest from MC

TOP-15-013

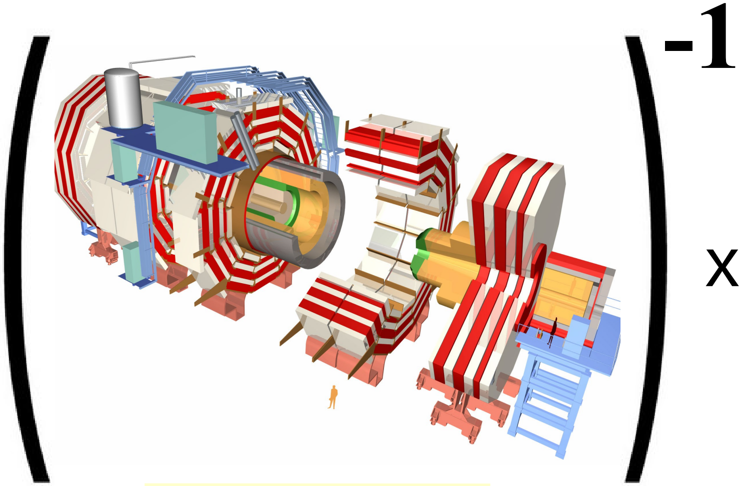




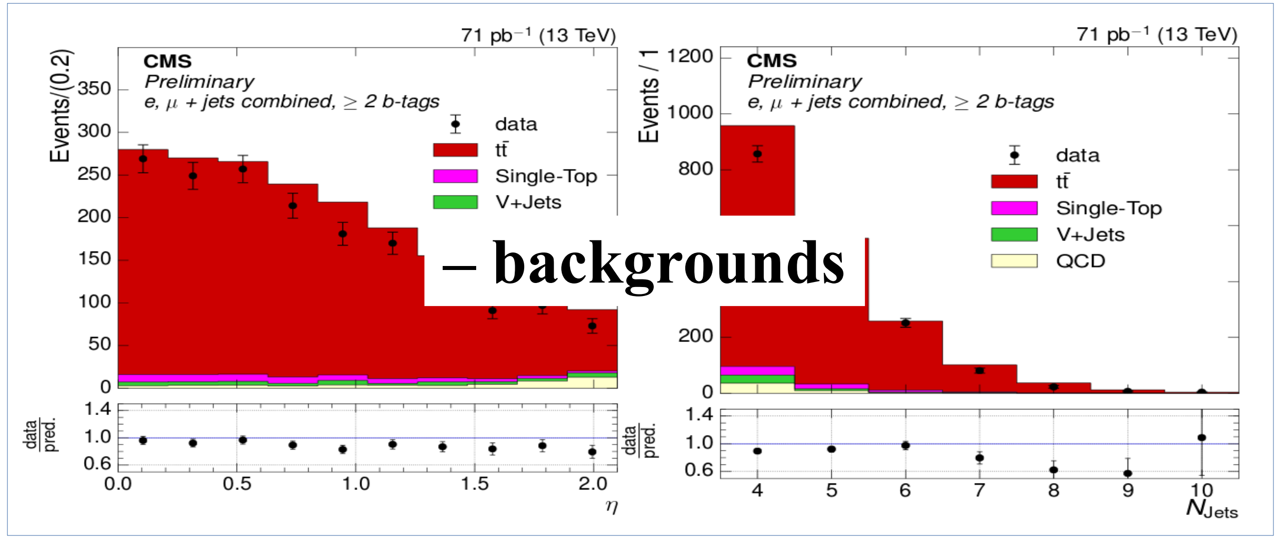
fiducial

Lepton kinematics and event properties are considered

Differential cross section ℓ+jets 71 pb^{-1} 13 TeV

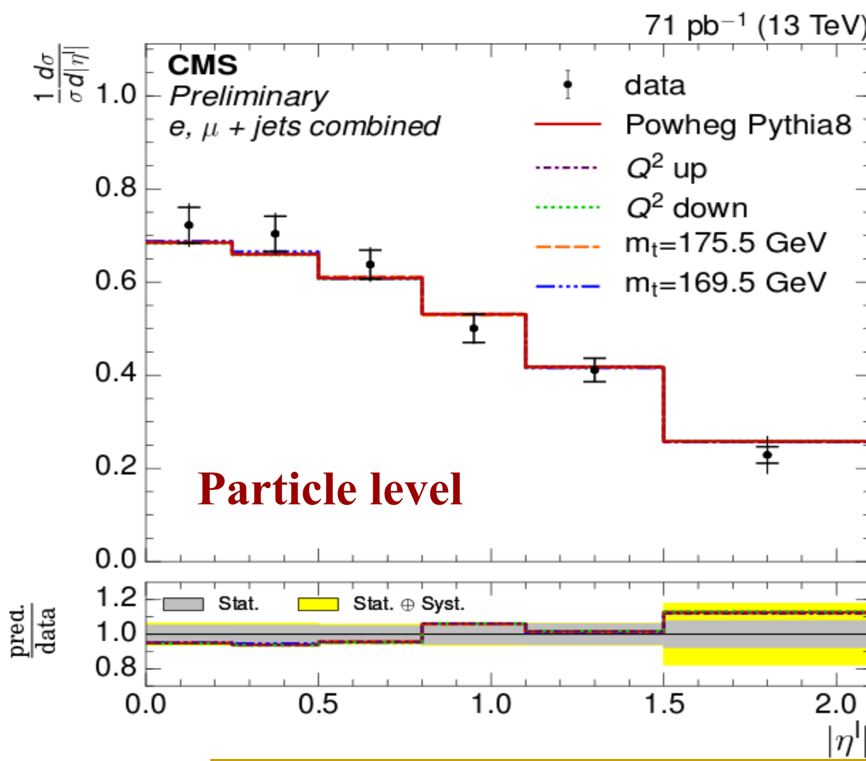


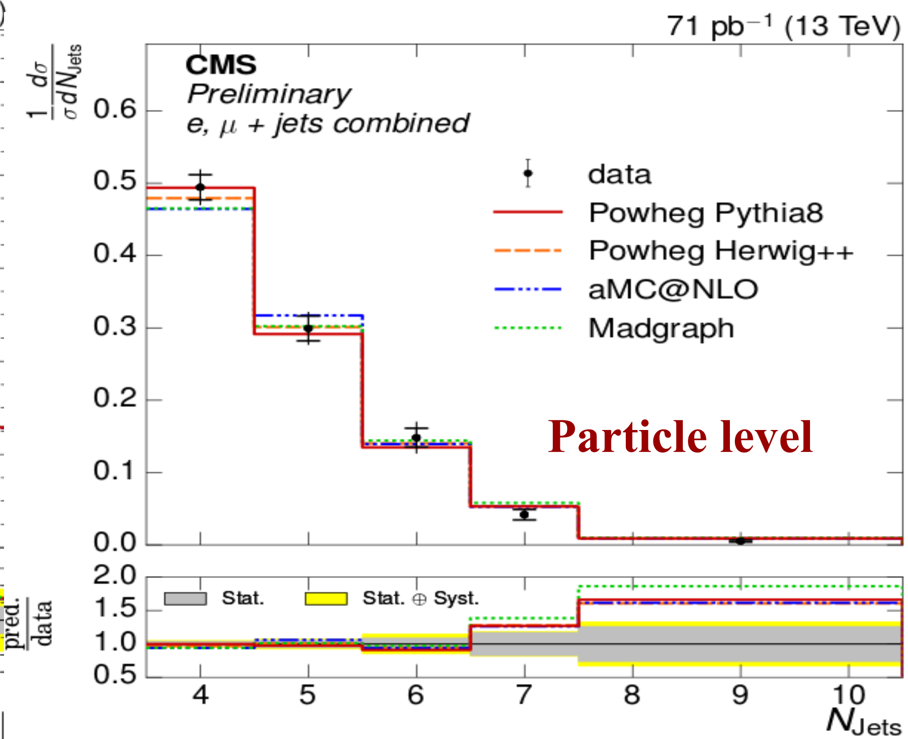
x



TOP-15-013

Regularized unfolding





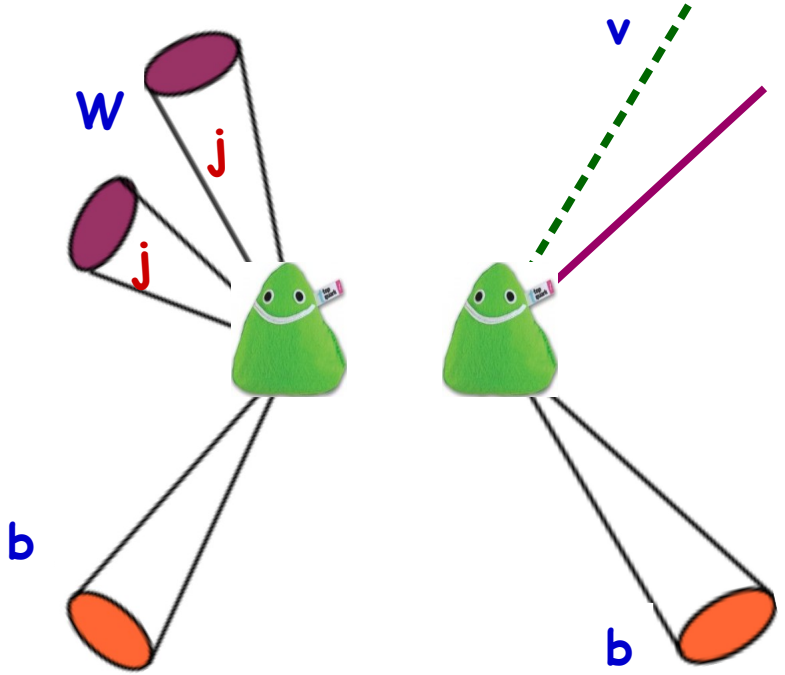
Fair agreement between data and simulation

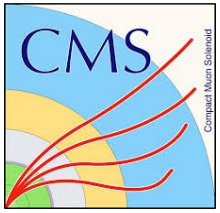
Differential cross section ℓ+jets 42 pb^{-1} 13 TeV

TOP-15-005

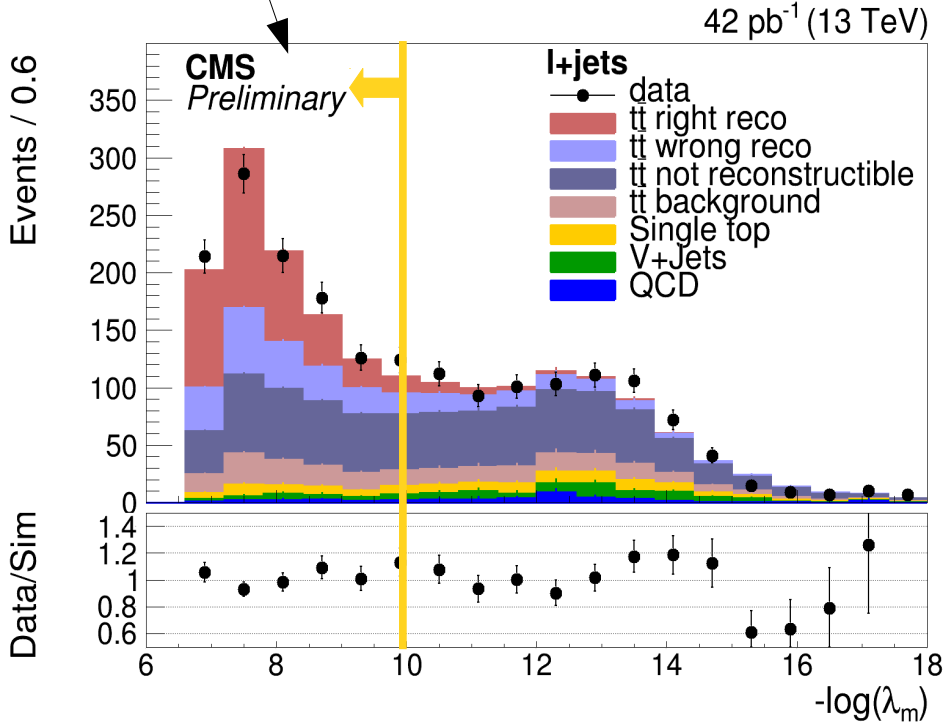
2D probability of mjj vs. mjjb

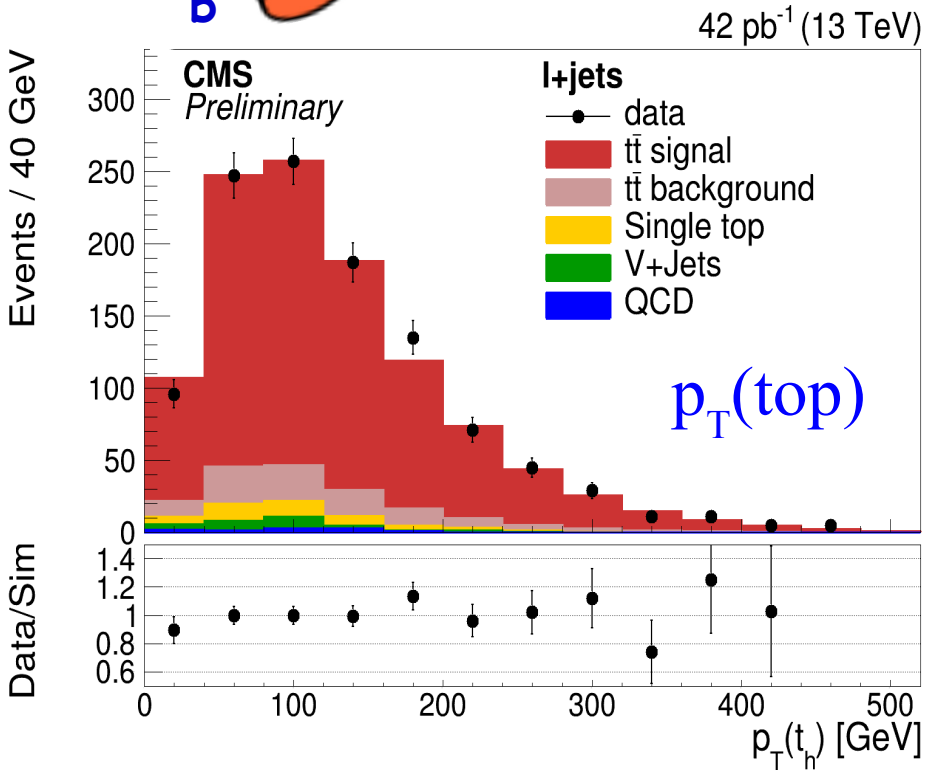
Select events with high probability





$$(p_\ell + p_\upsilon)^2 = m_W^2$$
$$(p_\ell + p_\upsilon + p_b)^2 = m_t^2$$





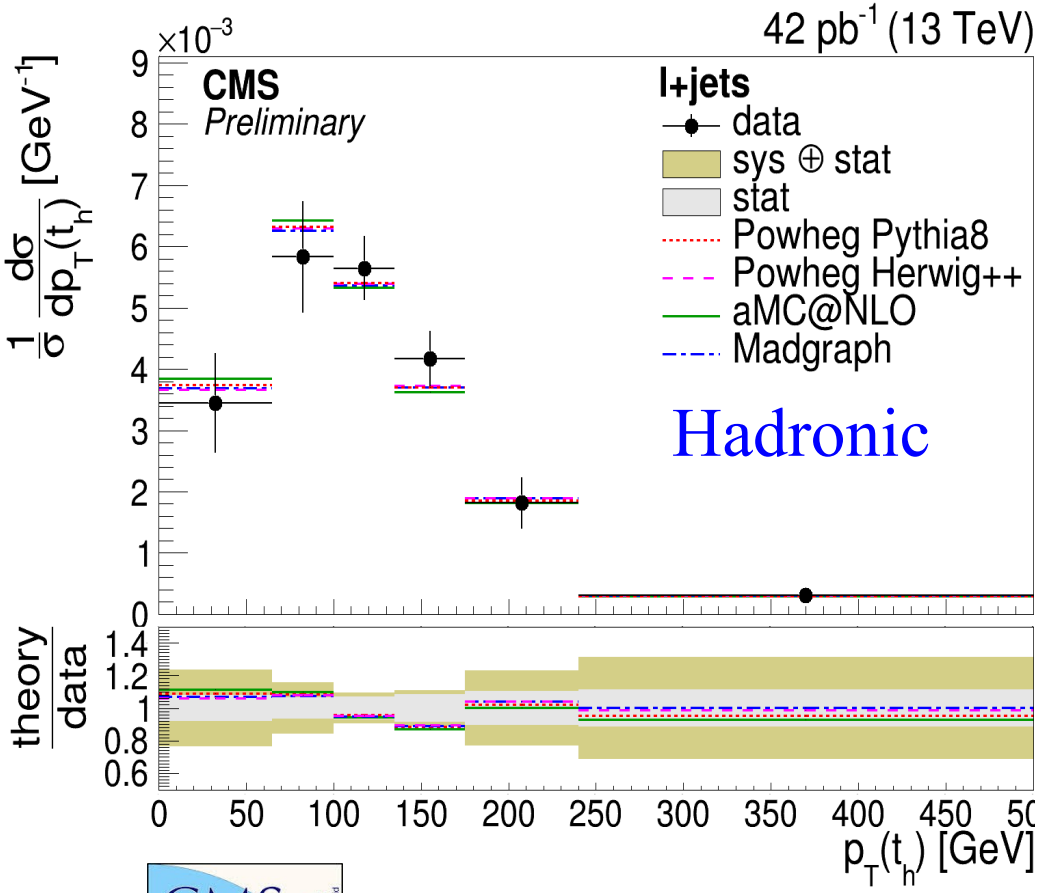
Differential cross section ℓ+jets 42 pb^{-1} 13 TeV

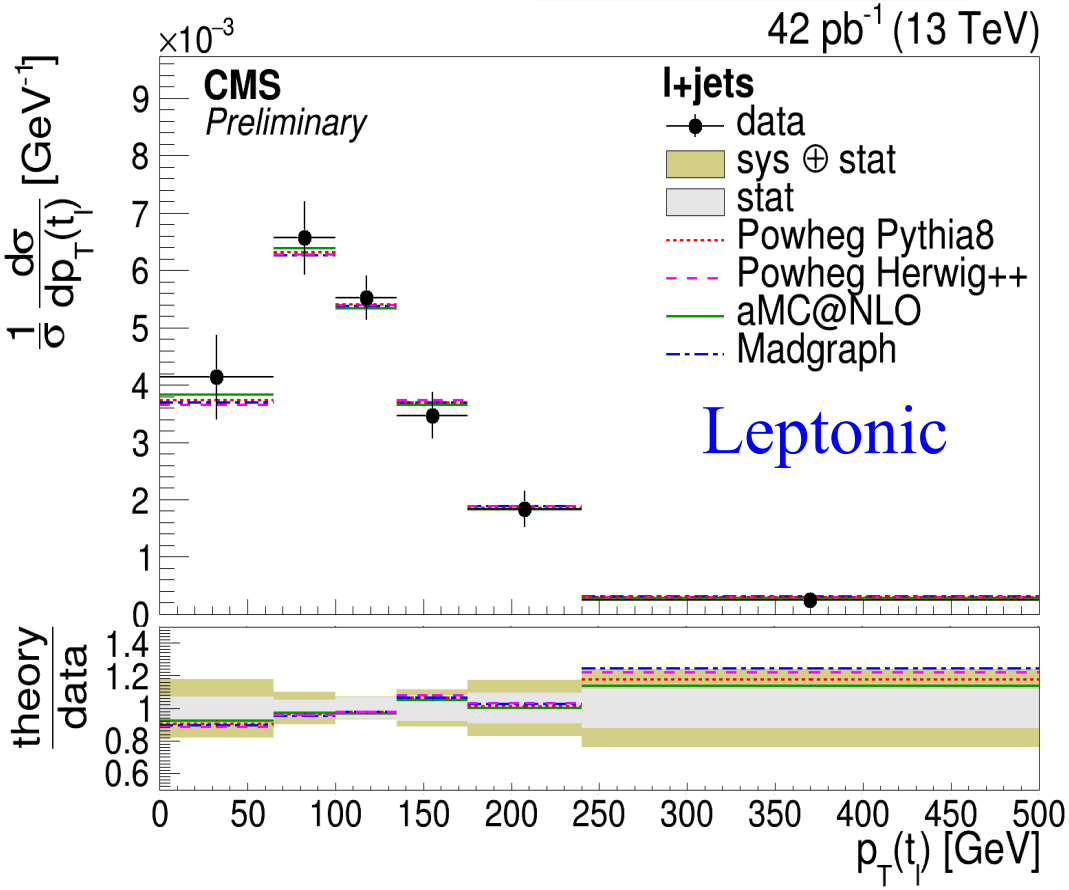
Backgrounds from simulation

$$\sigma_{t\bar{t}} = 836 \pm 27(stat.) \pm 84(syst.) \pm 100(lumi.)\, pb$$

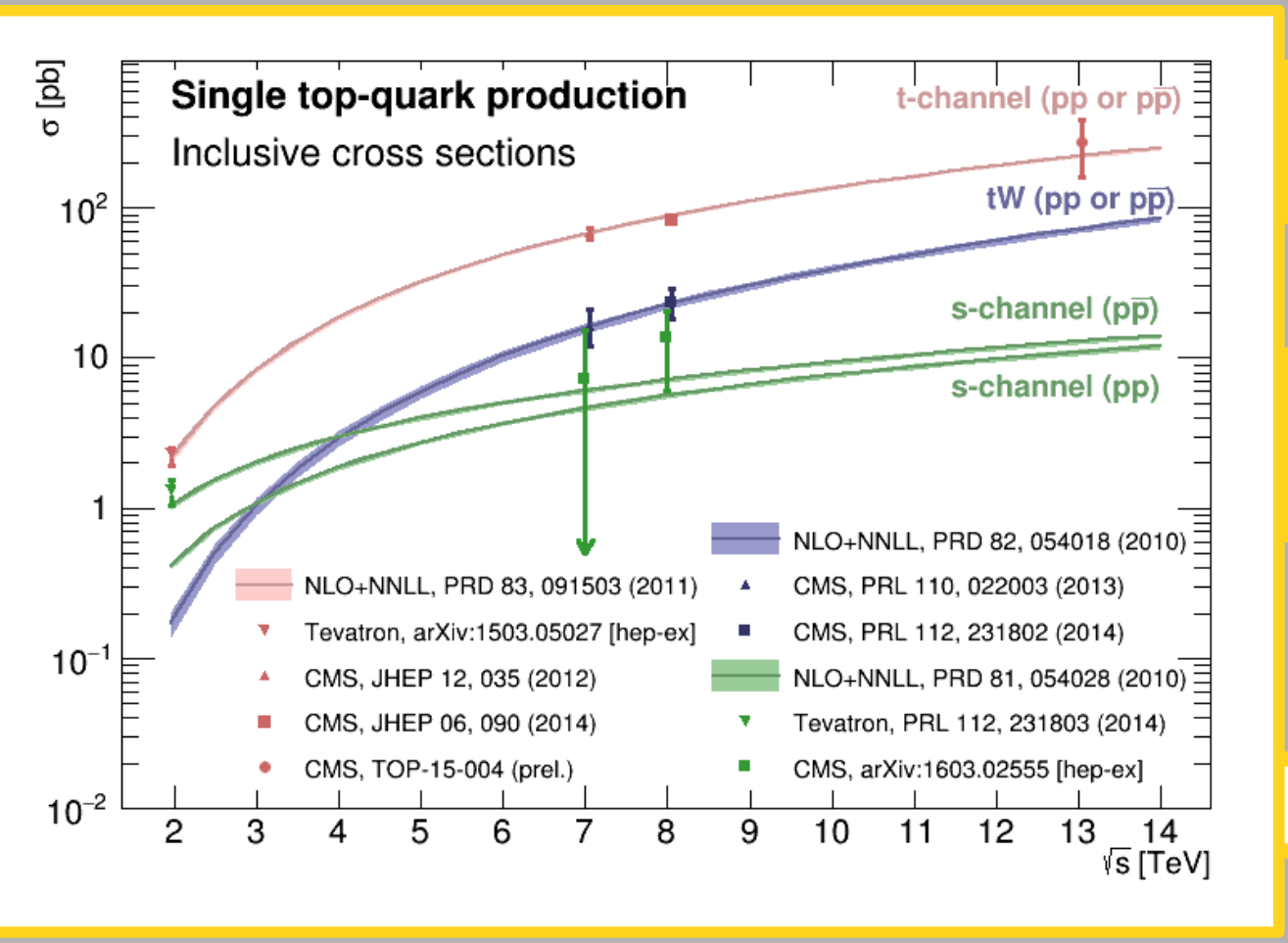
b-tagging ~ 5%

TOP-15-005



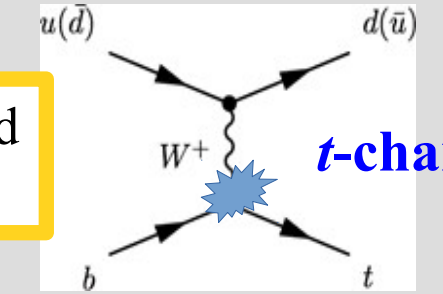


Generally good agreement between data and simulation

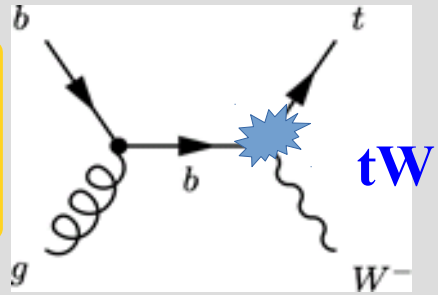


Detailed studies

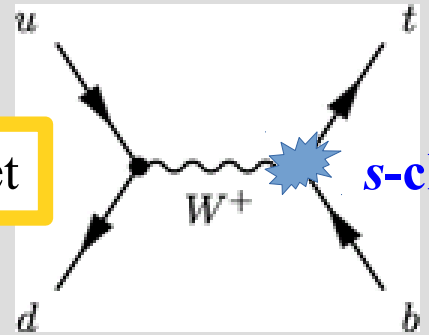
Limit set



***t*-channel**



tW



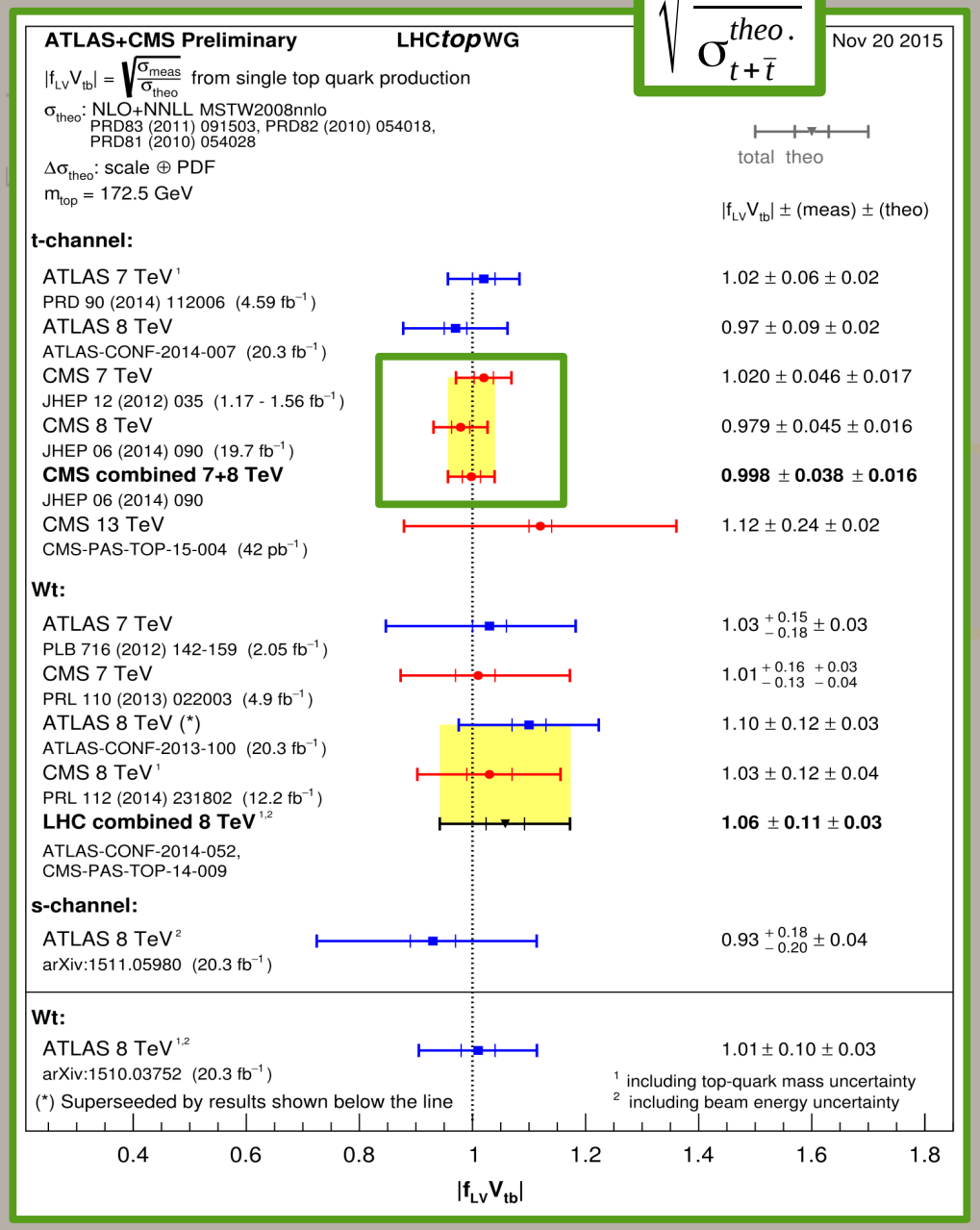
***s*-channel**

PRL 112 (2014) 231802

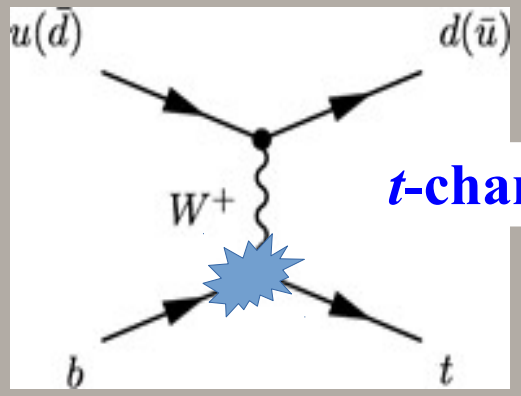
SINGLE PRODUCTION

The *single*-Top Quark *Factory*

$$\sqrt{\frac{\sigma^{exp.}_{t+\bar{t}}}{\sigma^{theo.}_{t+\bar{t}}}}$$



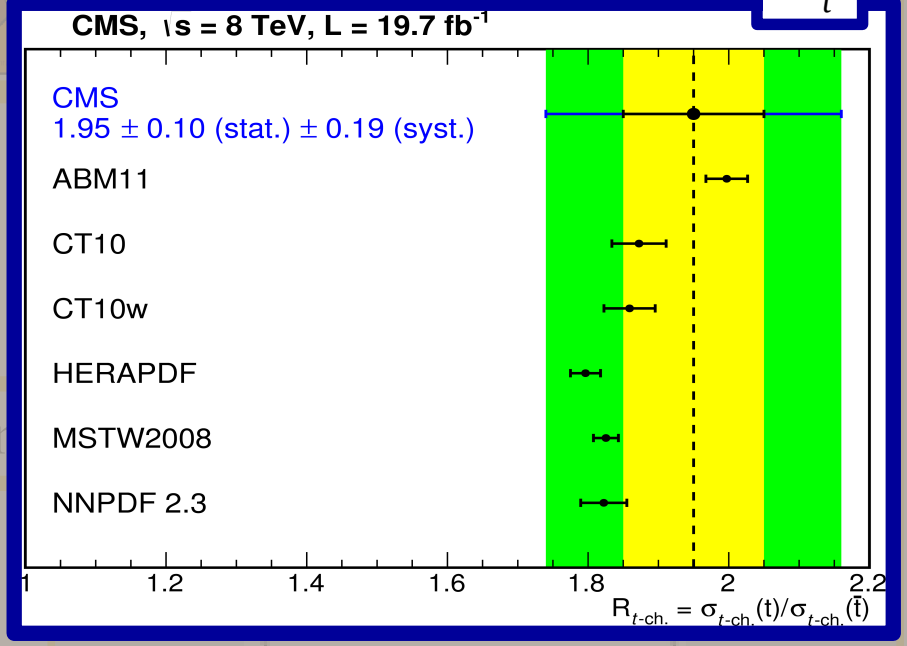
Detailed studies



t-channel

$$\frac{\sigma_t}{\sigma_{\bar{t}}}$$

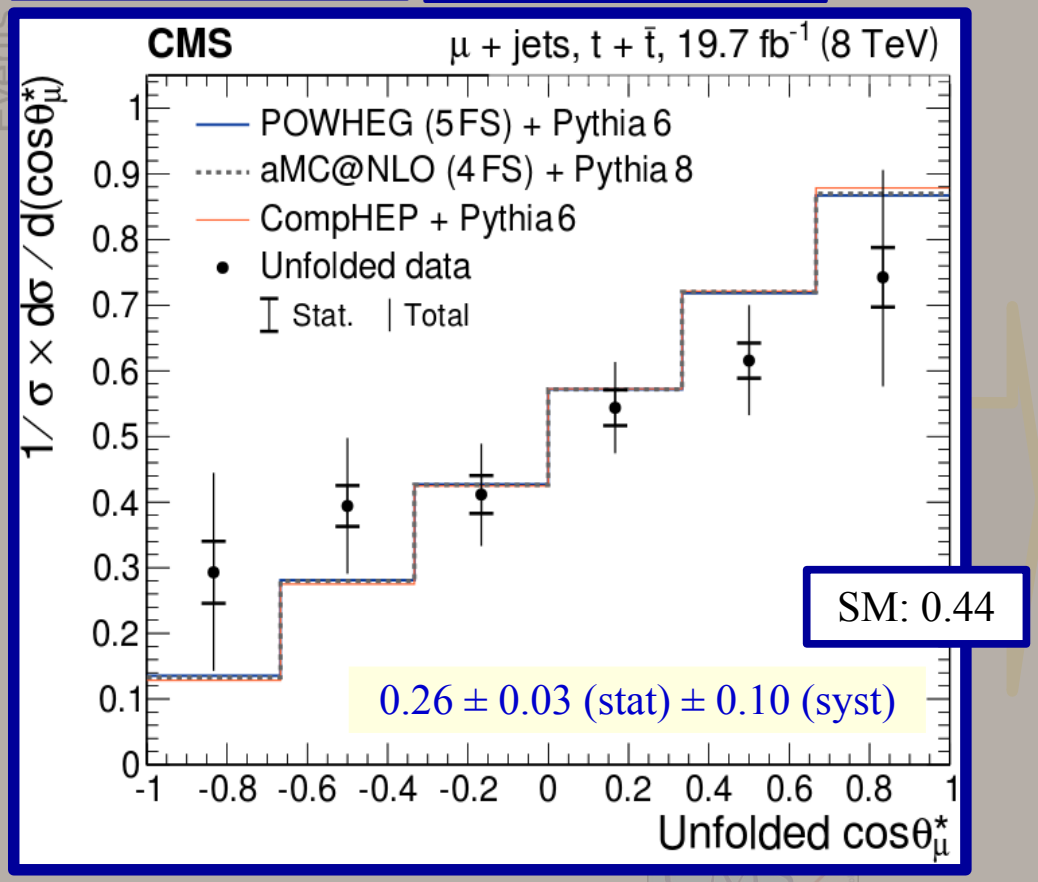
JHEP 06 (2014) 090



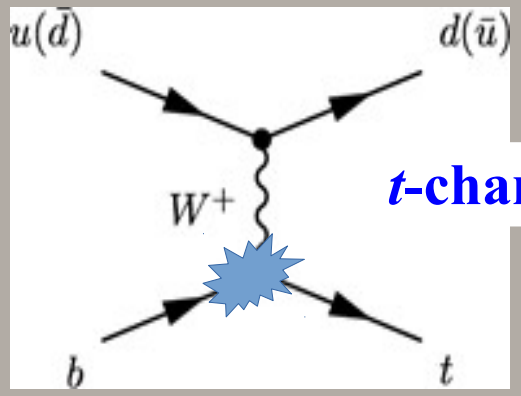
The *single*-Top Quark *Factory*

arXiv:1511.02138

Spin asymmetry



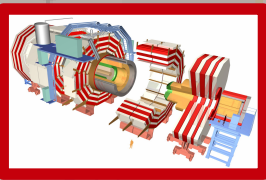
Detailed studies

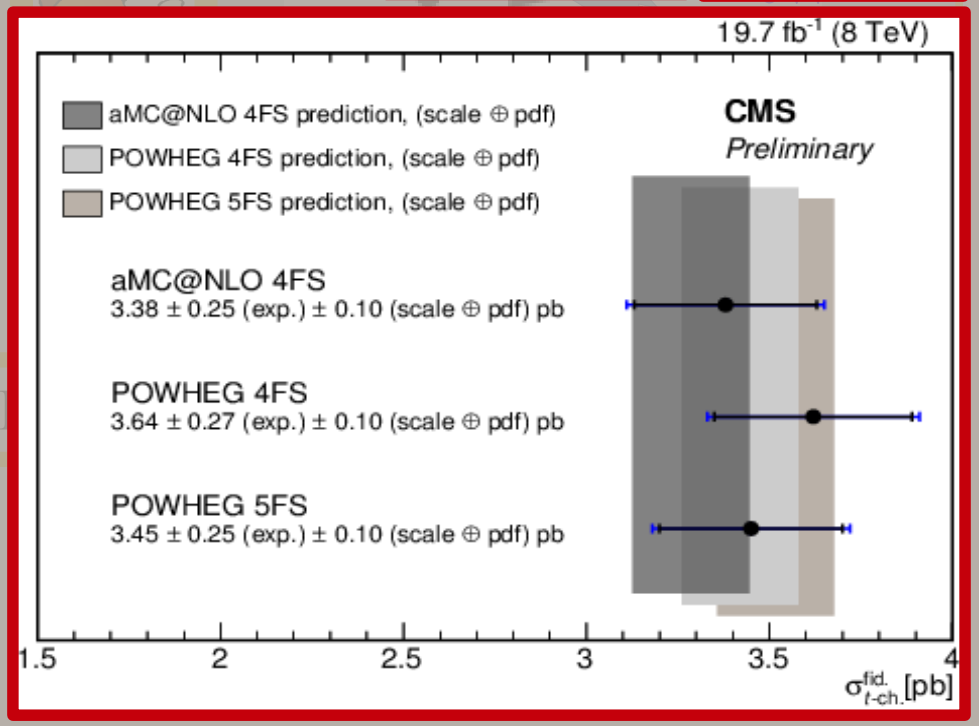


***t*-channel**

Fiducial

TOP-15-007

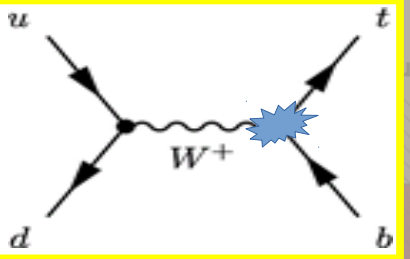




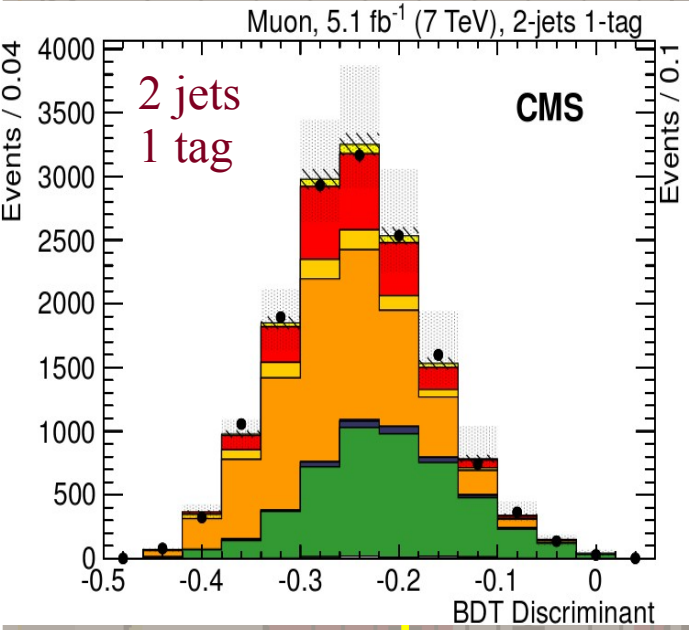
s-channel cross section 7+8 TeV

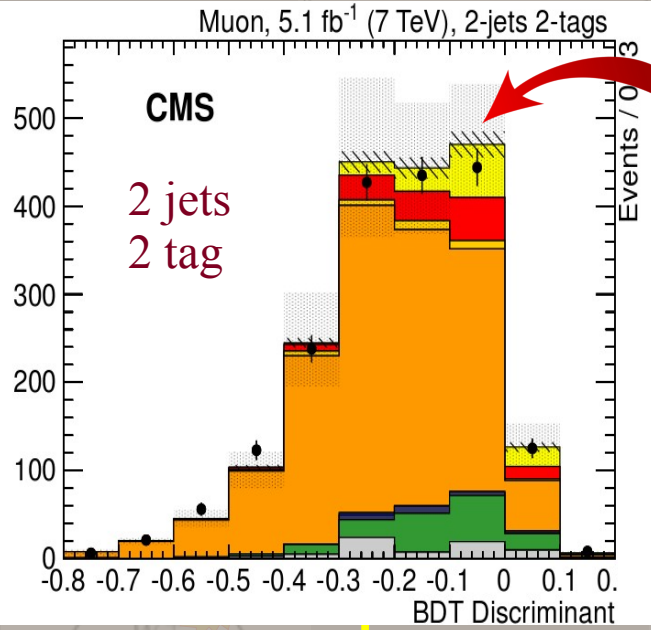
NEW

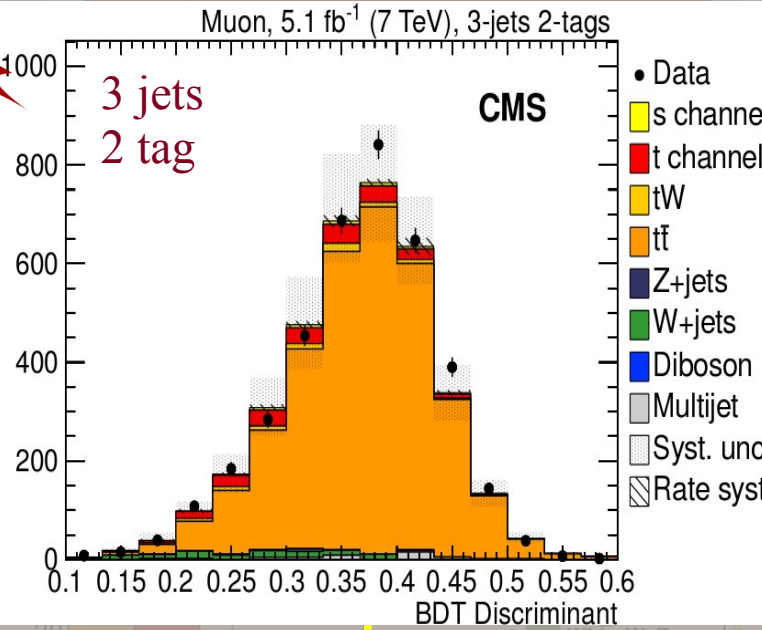
- Maximum likelihood fit to BDT discriminant
- QCD from data
- Other background rates as nuisance



arXiv:1603.02555







t-channel, W+ HF jets

s-channel

top-pair

Simultaneous fit to all regions & categories
And to 7 & 8 TeV

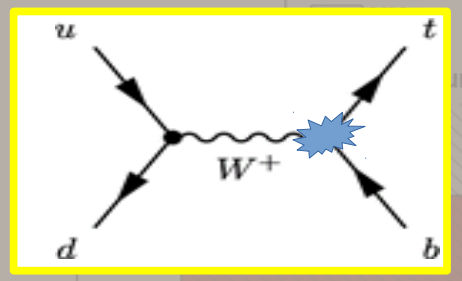
s-channel cross section 7+8 TeV

NEW

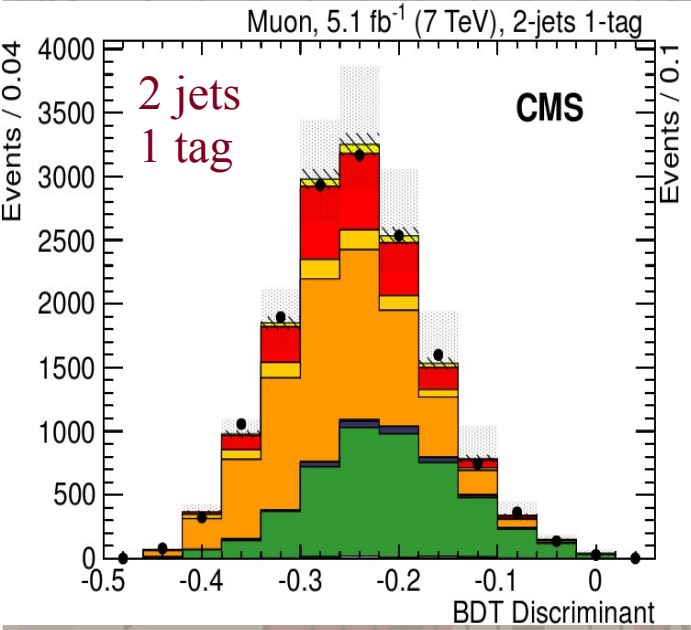
SM

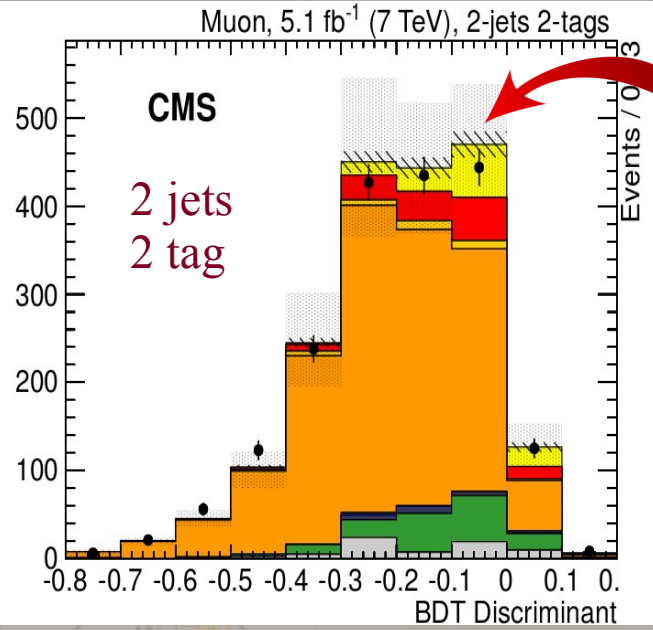
$\sigma_{s\text{-ch.}}$ (7 TeV) $= 4.56 \pm 0.18$ pb

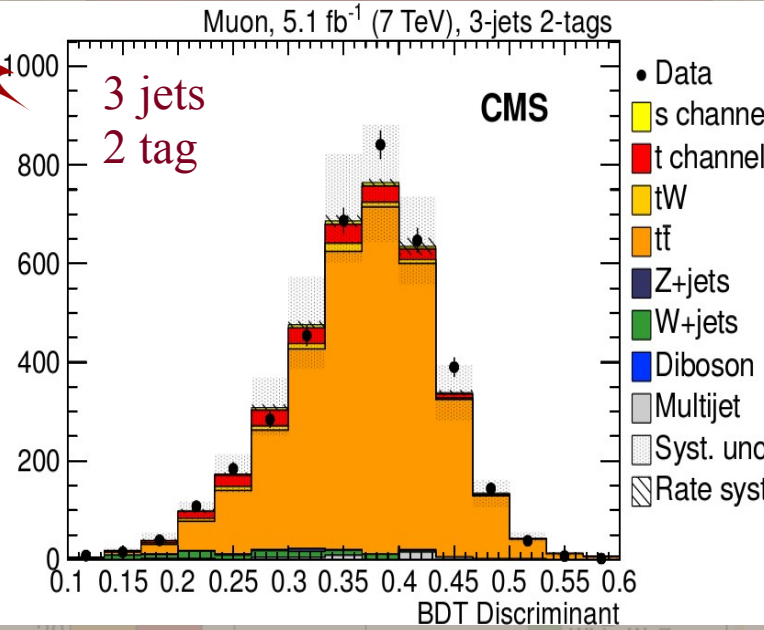
$\sigma_{s\text{-ch.}}$ (8 TeV) $= 5.55 \pm 0.22$ pb



arXiv:1603.02555







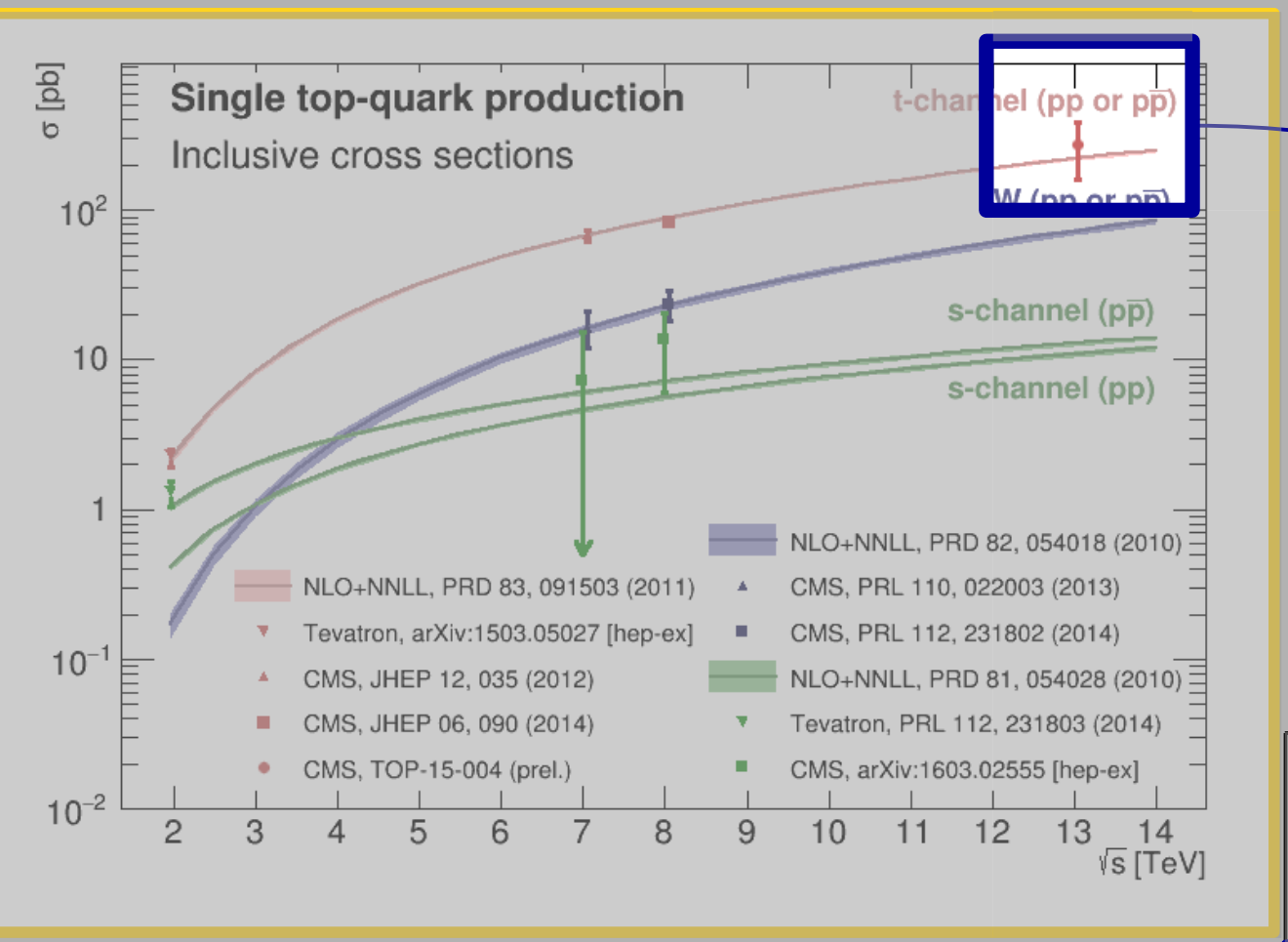
JES

$\sigma_{s\text{-ch.}}$ (7 TeV) $= 7.1 \pm 8.1$ pb $(\mu+jets)$

$\sigma_{s\text{-ch.}}$ (8 TeV) $= 13.4 \pm 7.3$ pb $(e/\mu+jets)$

Significance: 2.1 σ

$\frac{\sigma_{meas.}}{\sigma_{SM}} < 4.7 @ 95\%CL$



t-channel

7 TeV (pb)	63.9 ± 2.7
8 TeV (pb)	84.7 ± 3.5
13 TeV (pb)	217 ± 8.4

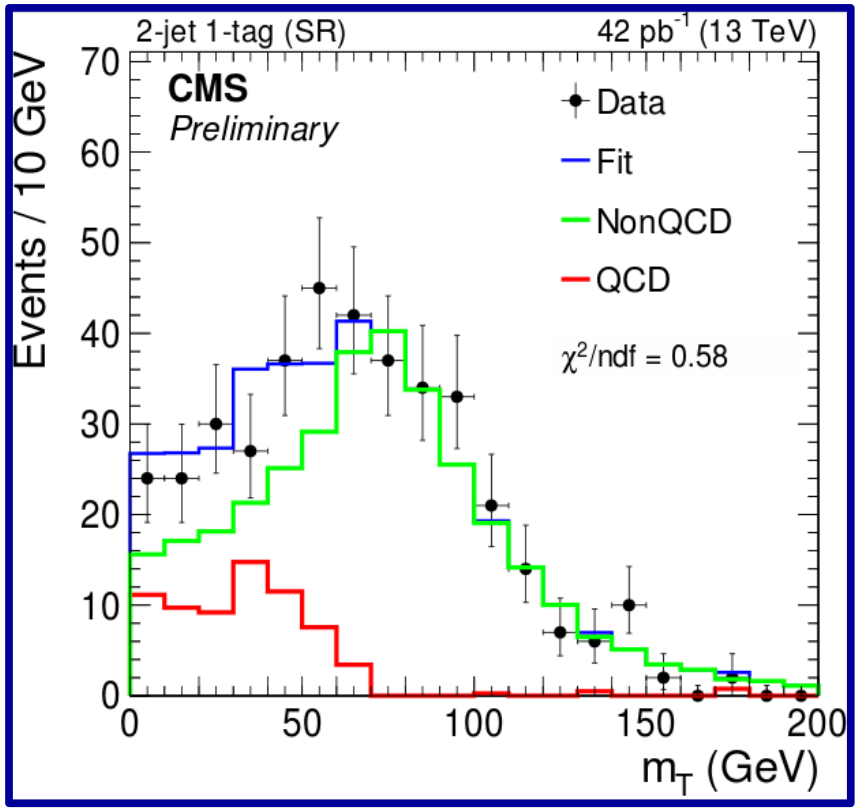
SINGLE PRODUCTION

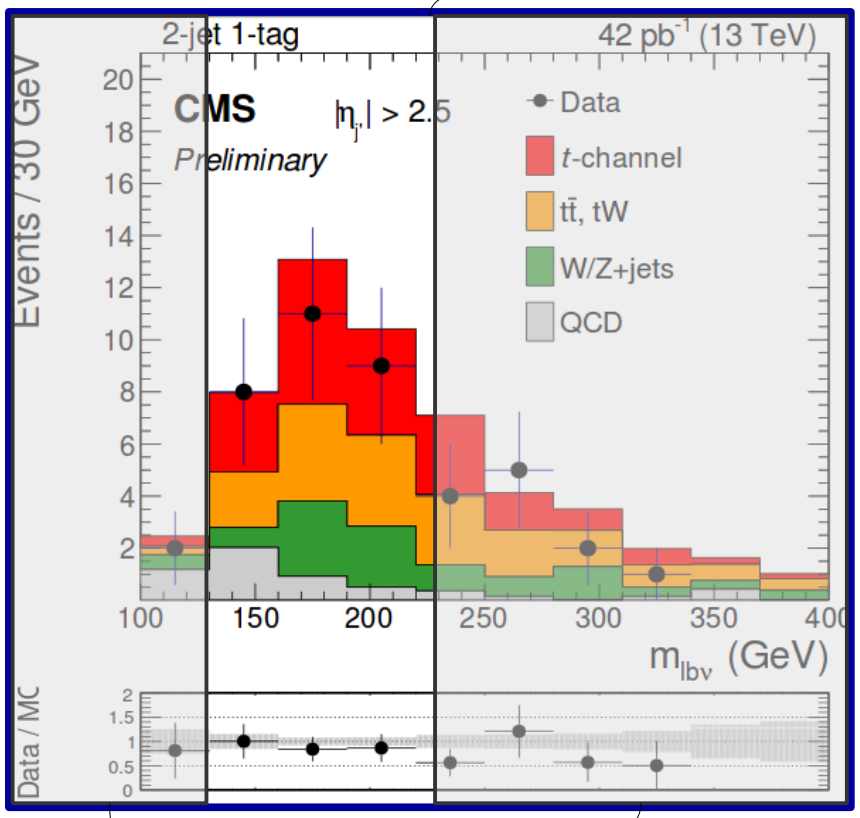
Single top cross section μ+jets 42 pb^{-1} 13 TeV

- Events with one muon
- Exactly 2 jets with 1 b-tagged jet
- Require $m_T > 45$ GeV

TOP-15-004

Signal region

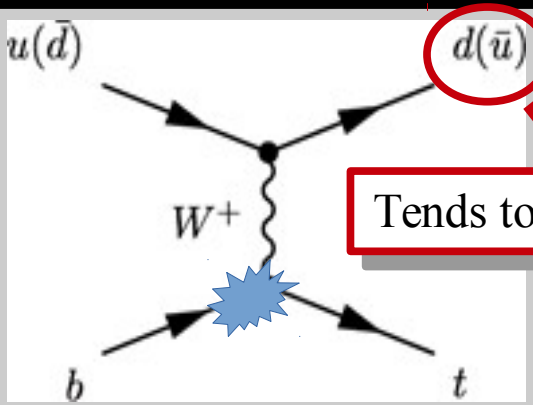




QCD:
- Shape from control region
- Yield from fit to data

W+jets validation

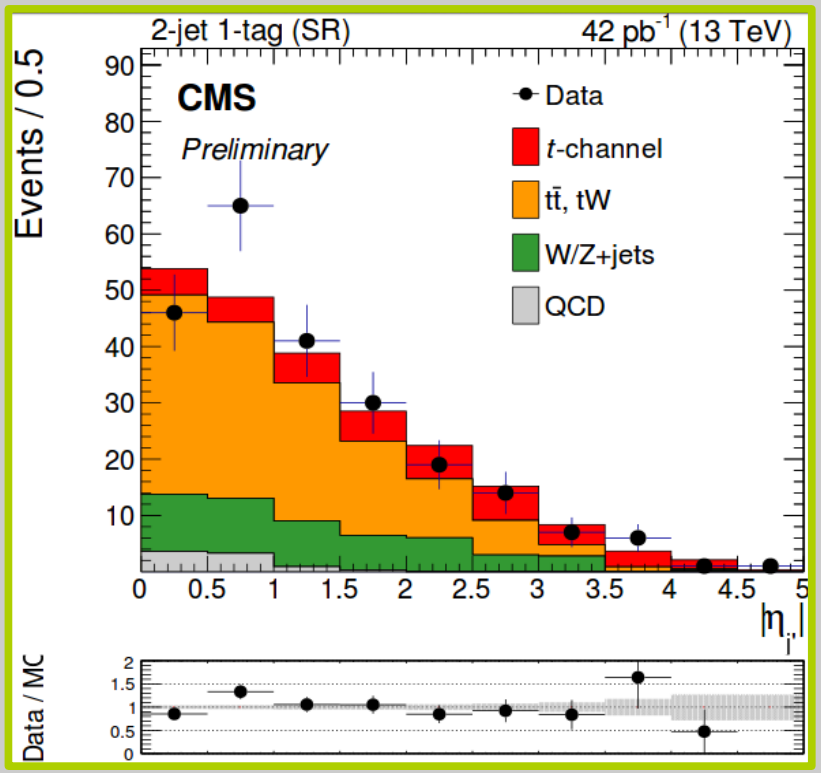
Single top cross section μ+jets 42 pb^{-1} 13 TeV

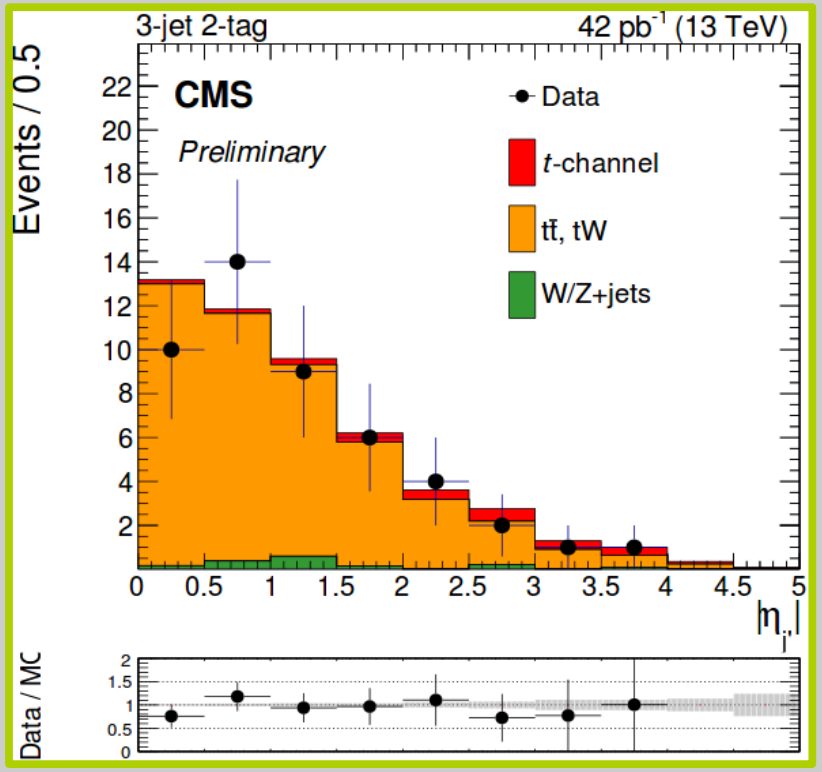


Tends to be forward!

Simultaneous fit to signal region and tt control region

TOP-15-004





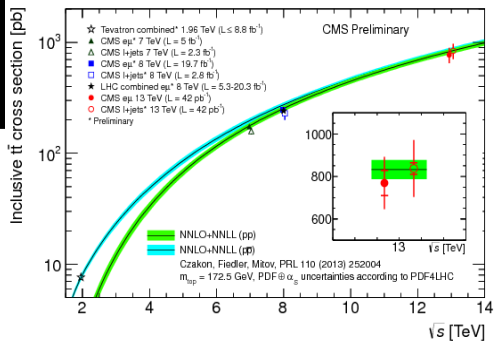
$$\sigma_{t-ch} = 274 \pm 98\,(stat.) \pm 52\,(syst.) \pm 33\,(lumi.)\ pb$$

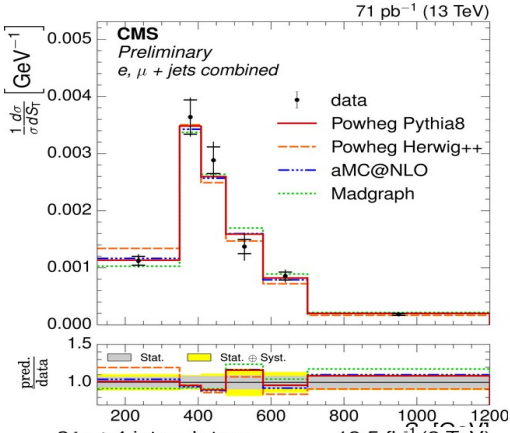
Summary

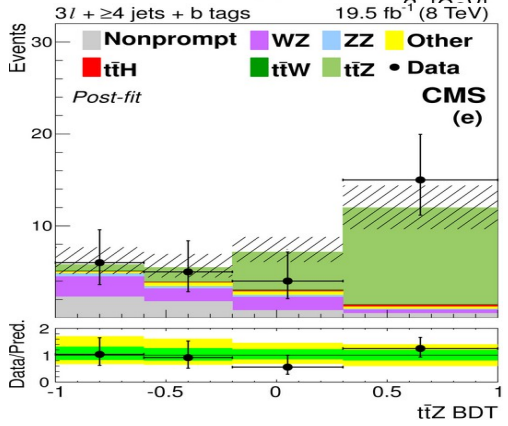
- The Run I has been full of achievements for CMS in top quark physics
  - Precise measurements and observations

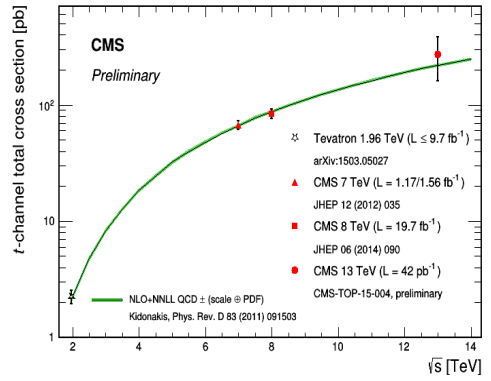
- The CMS experiment studied the very first top quarks from pp collisions at 13 TeV
- The production rate of $t\bar{t}$ is measured inclusively and in bins of top quark properties together with lepton and jets
- The first measurement of single-top production is performed

- It's only the beginning with the 13 TeV data
  - More fun and excitement are underway
  - Stay tuned ...



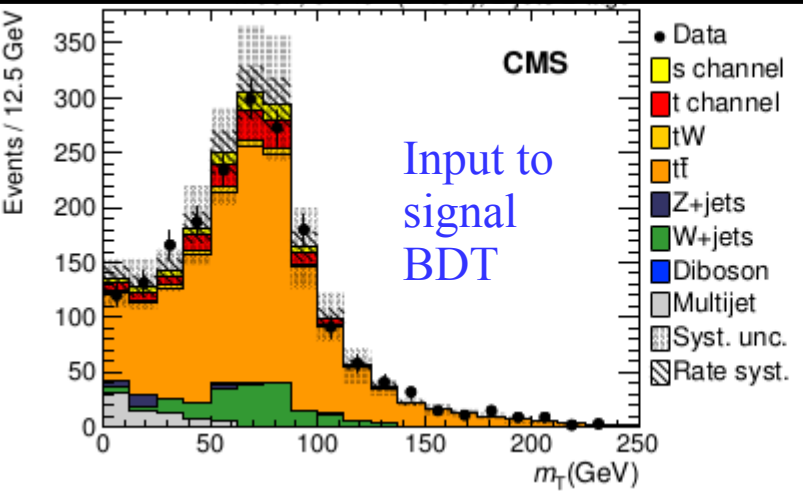


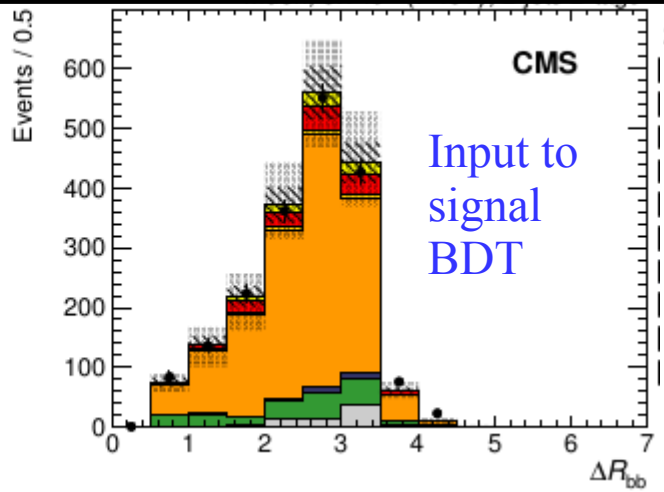


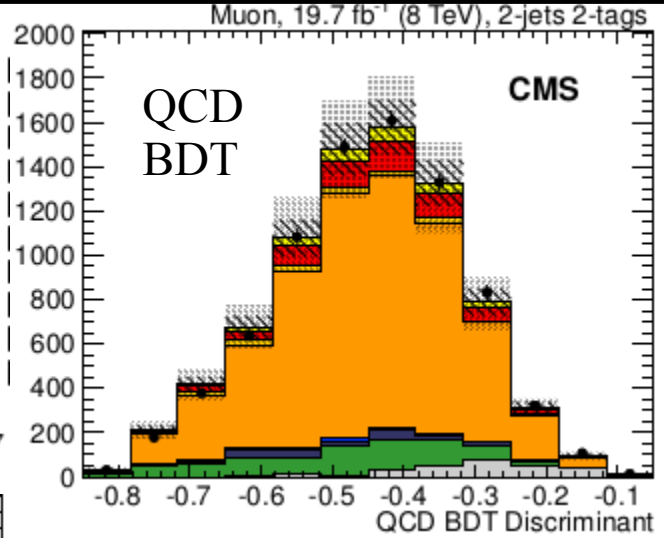


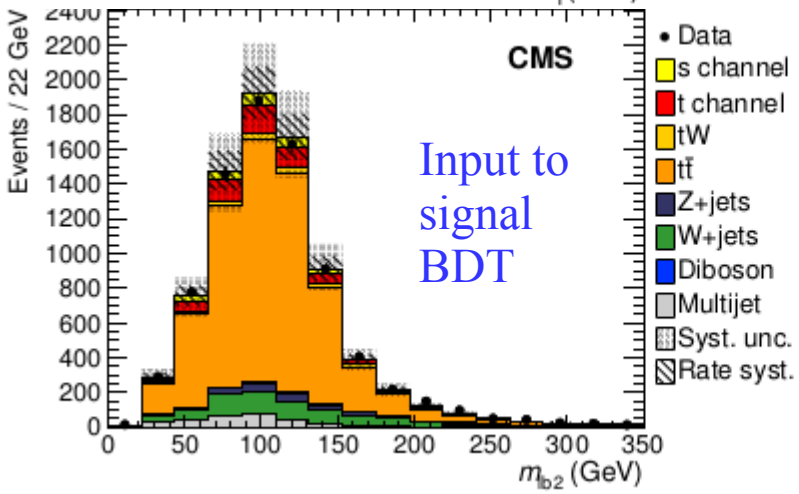
BACKUP

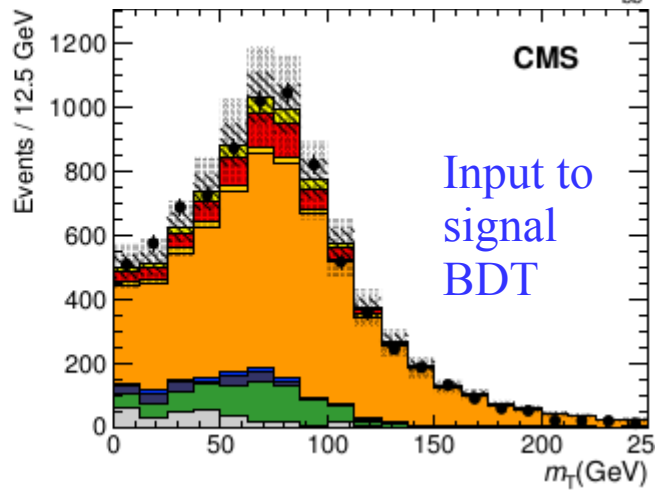
s-channel cross section 7+8 TeV











7+8 TeV

$\beta_{\text{signal}} = 2.0 \pm 0.9$

Channel	Observed UL	Expected UL—SM signal	Expected UL—no signal
μ, 7 TeV	31.4 pb	25.4 [19.0, 36.6] pb	20.2 pb
μ+e, 8 TeV	28.8 pb	20.5 [13.4, 26.7] pb	15.6 pb
7+8 TeV	4.7	3.1 [2.1, 4.0]	2.2