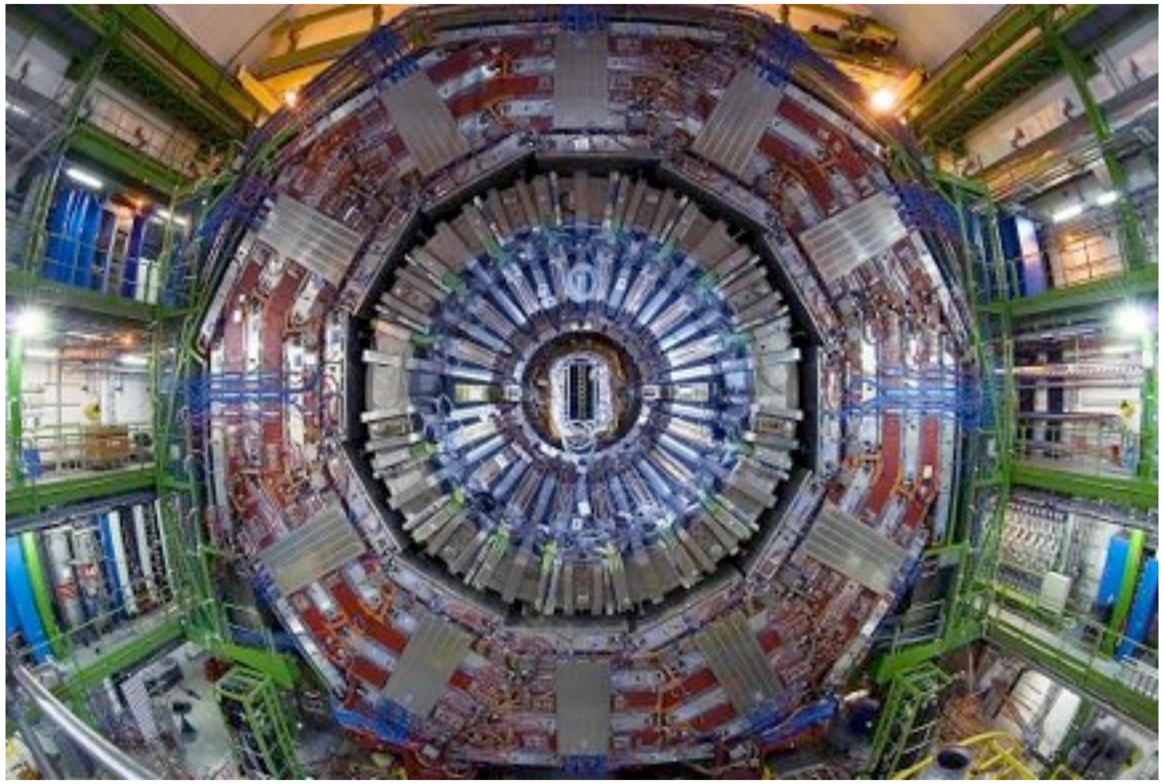
Top quark and Electroweak Physics Results from CMS experiment



USLUO 2012
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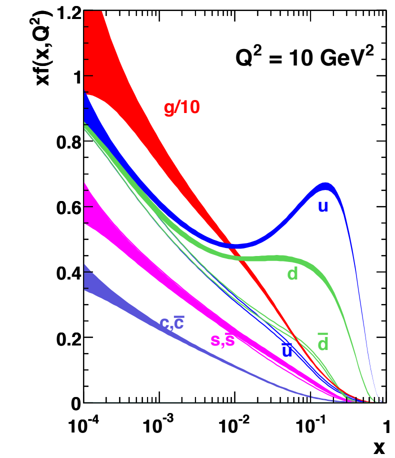
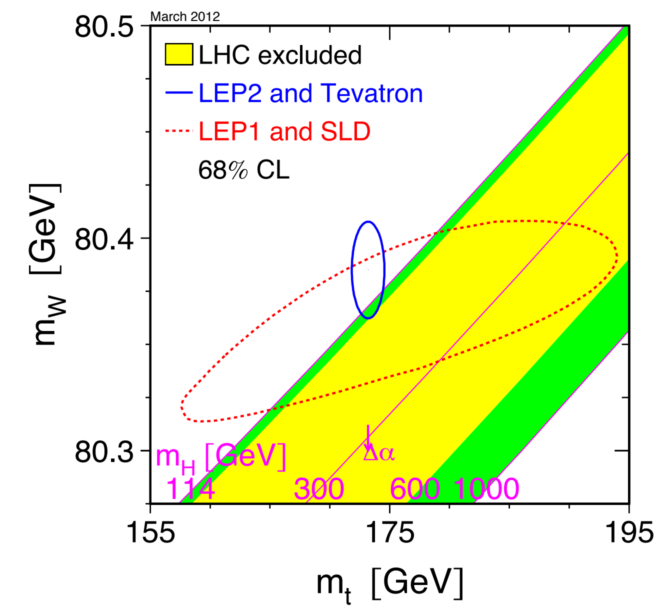
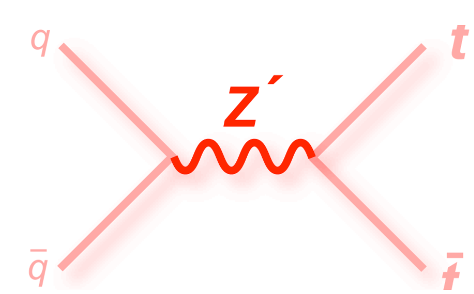
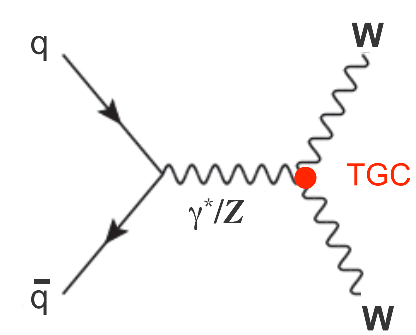
General Overview

- The top pair production, W/Z decays and V+jets production provides precession tests to QCD predictions: e.g; proton PDFs
- Top quark and EWK physics plays a significant role in understanding the EWSB
  - Role evident from M_W-M_t constraints on M_H
  - Can we improve the current precision on the masses?
    - Top quark is the only quark with natural mass, ($\lambda_t \sim 1$)?
    - Associated production: ttH, ttbb
- Single top production
  - Is $V_{tb}=1$? Anomalous couplings in W_{tb} vertex?
- A window to new physics
  - New physics might couple preferentially to top: $t \rightarrow H^{\pm}b$
  - New particles may decay to top: $Z' \rightarrow t$ tbar, $t' \rightarrow tW$
  - Couplings at the TGC vertex in diboson production can probe physics beyond the currently accessible mass range at the LHC
  - A lot more beyond: Technicolor, Z´, W´, RS graviton ...
- Great tool to calibrate detector and test physics object







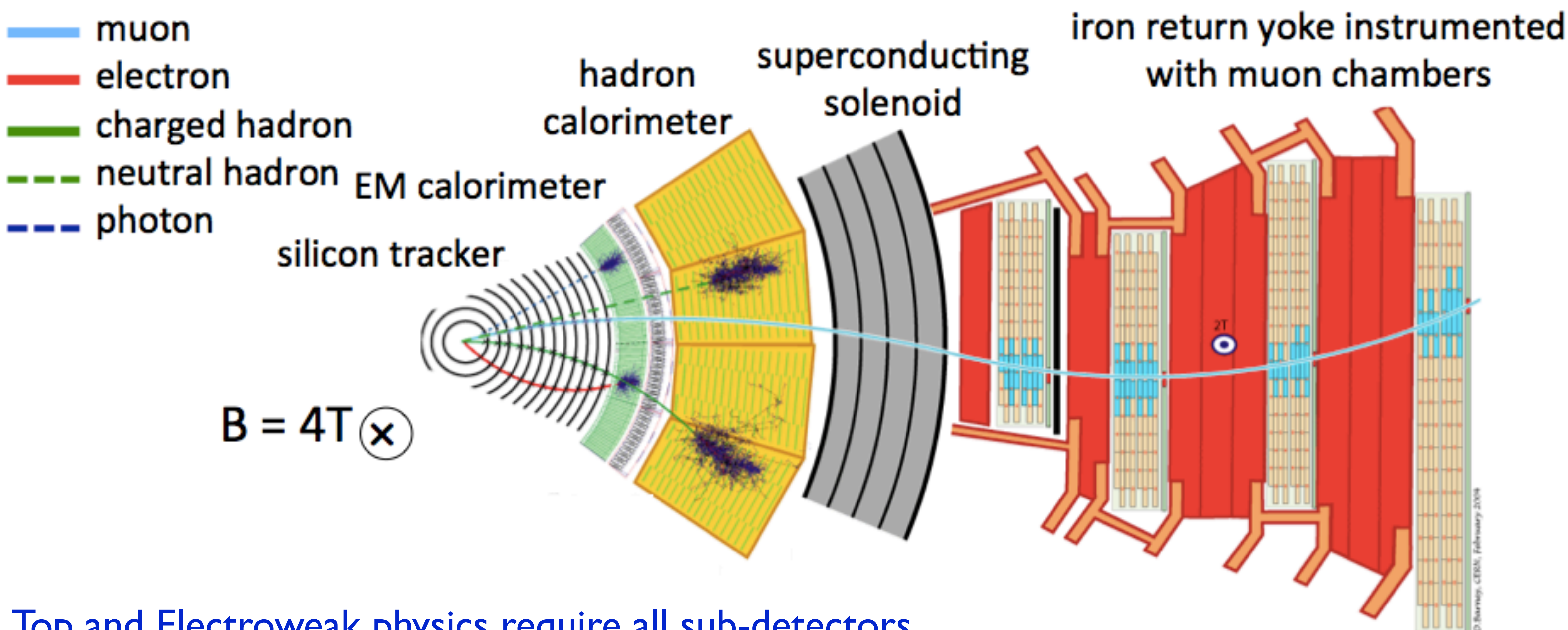


Outline

- Top quark physics results in this talk
  - cross-section measurement
  - α_S from cross-section
  - single top cross-section and V_{tb}
  - top quark mass
  - ttbar associated production with bbar pair
- Results not covered
  - search for Z´ resonant ttbar production
  - top spin correlations
  - top polarization in dilepton channel
  - W polarization in ttbar pair decays
  - constrains of top quark charge from ttbar pair
  - measurement of ttV
  - search for FCNC
  - charge asymmetry in top pairs
  - .....
- Electroweak physics results in this talk
  - W/Z inclusive x-section
  - W lepton charge asymmetry
  - V+jets production
  - Azimuthal correlation and event shape in Z+jets
  - Diboson production
  - aTGC limits
  - jet mass in dijet and V+jets using various jet algo
- Results not covered
  - DY differential cross sections
  - DY differential forward-backward asymmetry
  - DY weak mixing angle
  - Z rapidity and transverse momentum
  - W+2 jets, dijet mass spectrum
  - W,Z+jets differential cross sections
  - .....

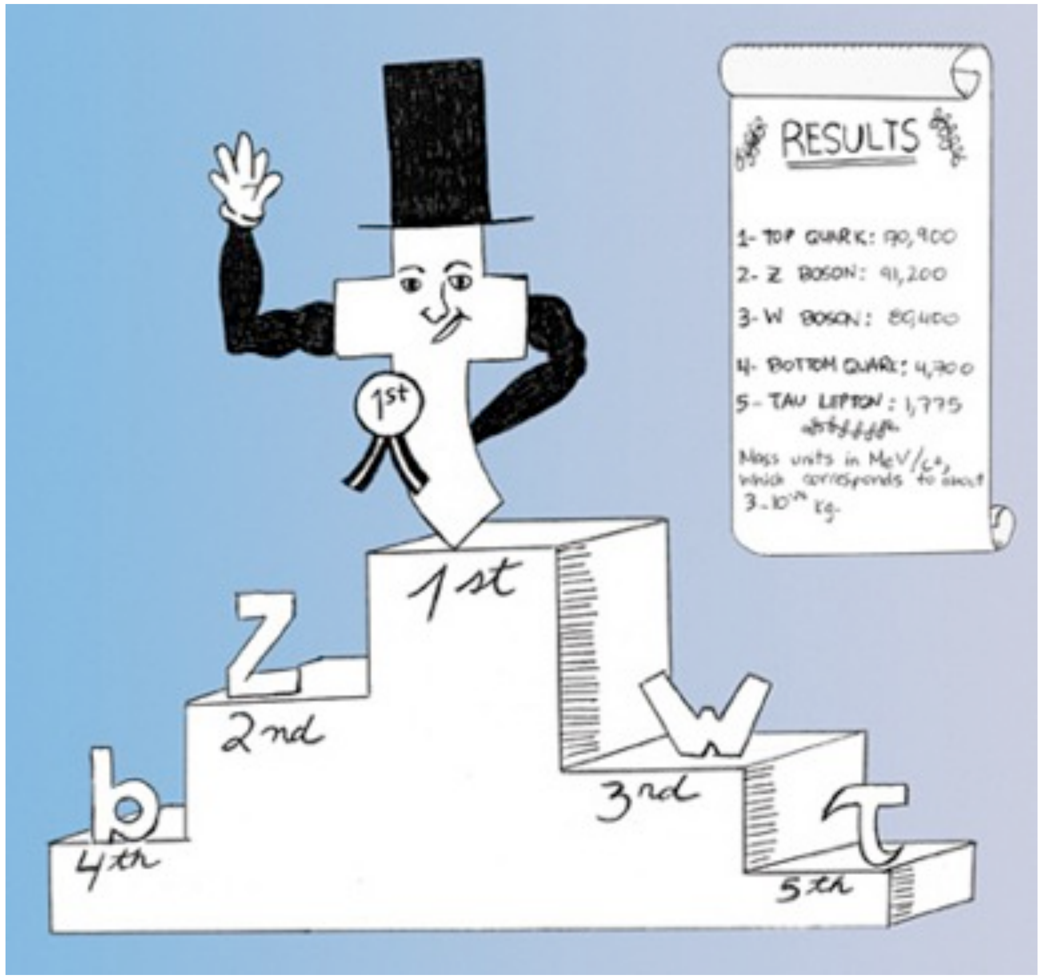
- **CMS Top public results:**
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP
- **CMS Standard Model public results:**
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP

CMS Detector

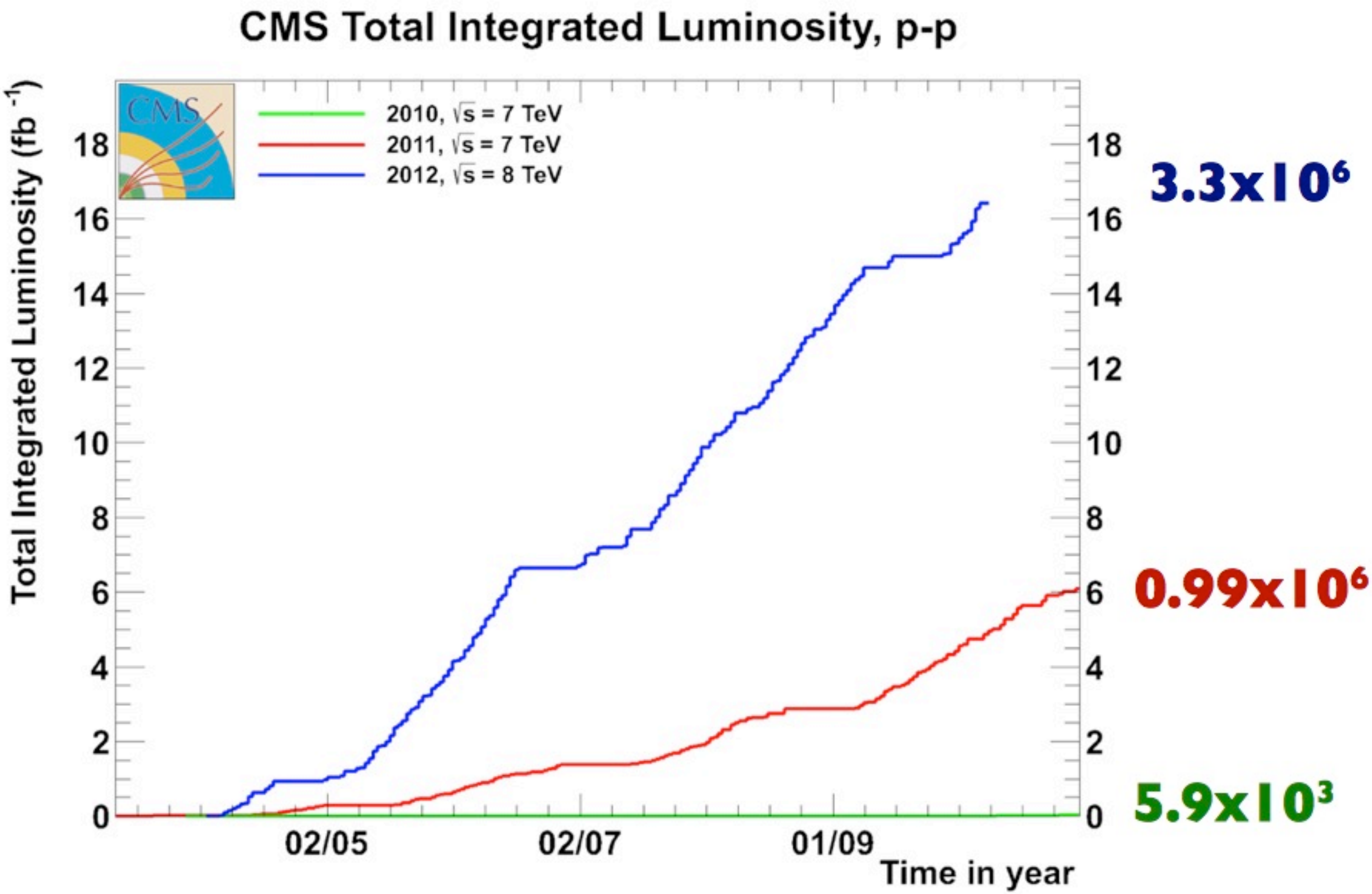


- Top and Electroweak physics require all sub-detectors
- Significant improvement due to Particle Flow Algorithm that uses information from all sub-detectors
  - muons, electrons, photons, charged and neutral hadrons
  - the list is used to reconstruct higher level objects like jets, MET
    - **electrons**: tracks matched to clusters in EM calorimeter
    - **muons**: minimum ionizing tracks, penetrate deep into muon system
    - **jets / H_T**: constructed with combined tracking + calo info
    - **MET**: constructed with combined tracking + calo info, hermetic detector

Top quark Physics Results



Top Quark Pairs @ CMS



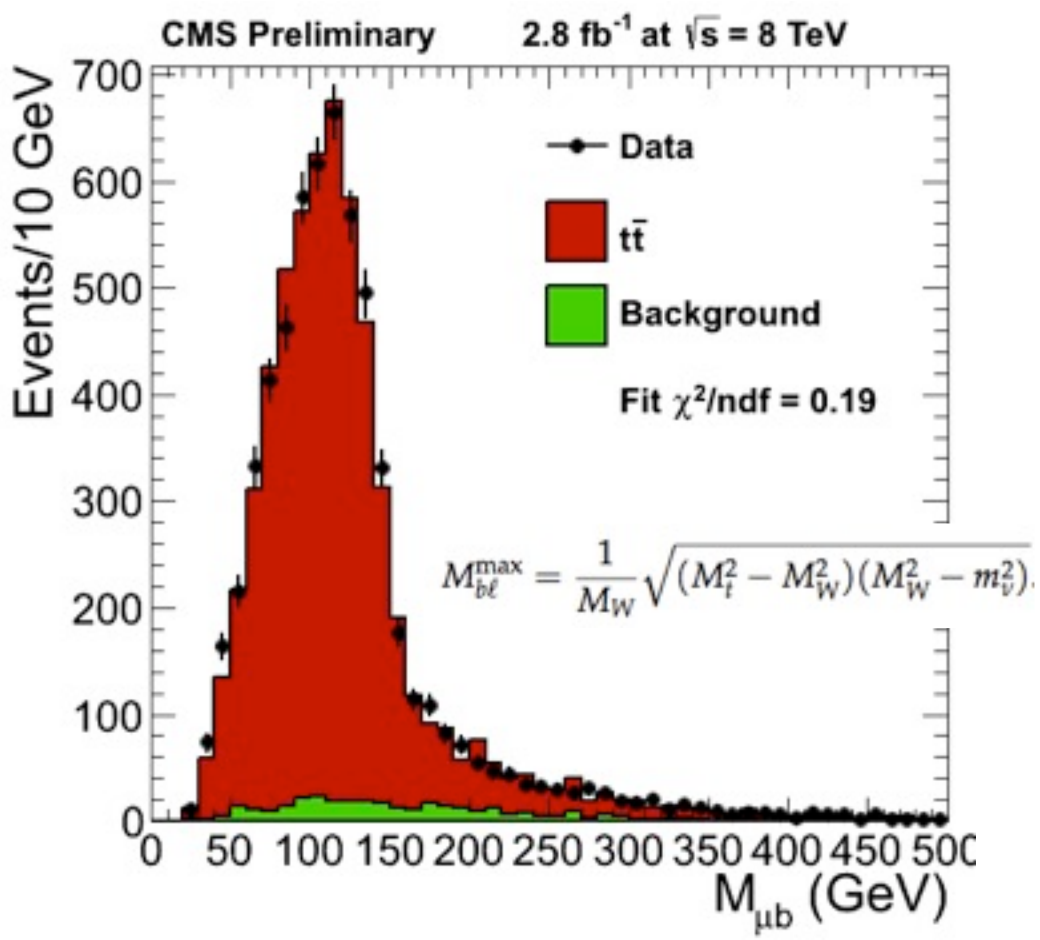
Top pair cross-section measurement @ 8TeV

NEW

l+jets (e/μ+jets)

CMS-PAS-TOP-12-006

- Event Selection
  - one isolated lepton, ≥ 4 jets (≥1-bagged)
- lepton+b-jet invariant mass



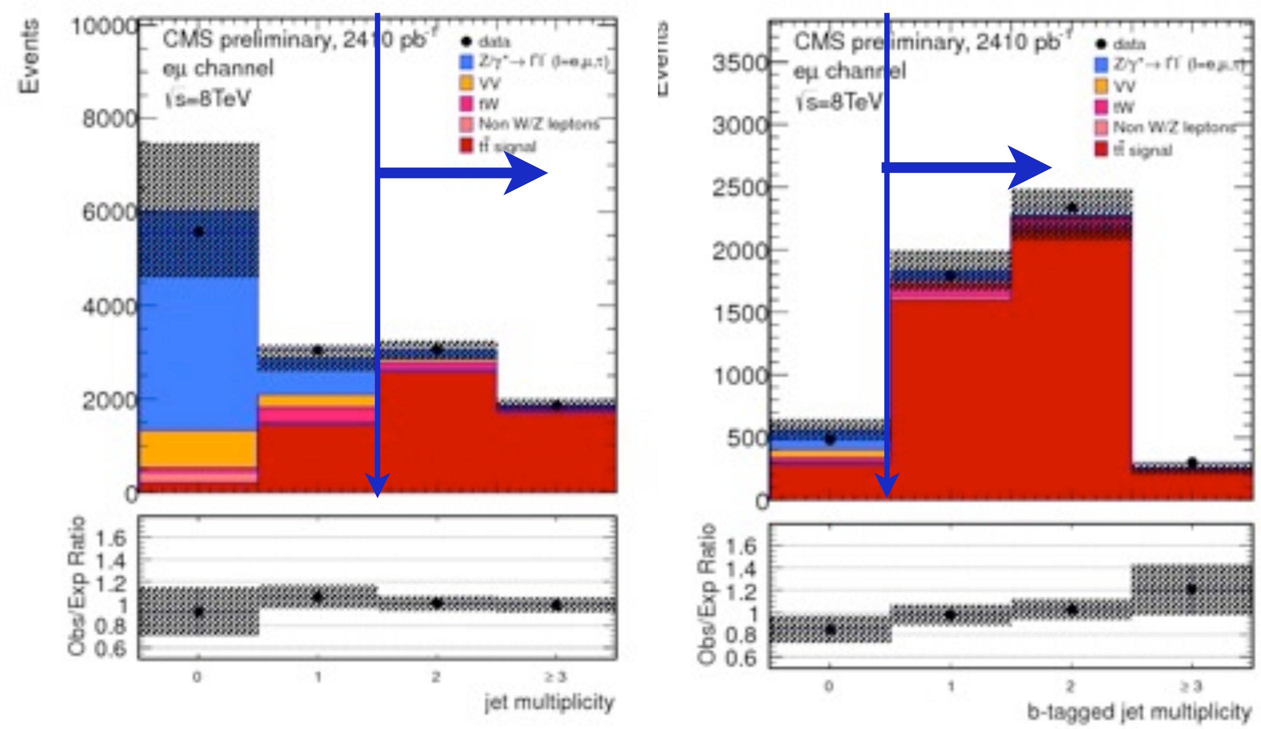
- Reconstruct kinematic from a X^2
  - Assign leptonic top decay
  - Binned fit M_{lb} distribution

$$228.4 \pm 9.0\,(\text{stat.})^{+29.0}_{-26.0}\,(\text{syst.}) \pm 10.0\,(\text{lum.})\,\text{pb},$$

dilepton(ee/eμ/μμ)

arXiv:1208.2671→JHEP

- Event Selection
  - ≥ 2 jets(≥1-btagged)
- Cleanest Signature, with main background from
  - Drell-Yan (Z-window is vetoed in ee/μμ and used to rescale DY contribution)
- Counting experiment



- Best Linear Unbiased Estimate (BLUE) method is used to combine all the channels

$$227 \pm 3_{\text{stat}} \pm 11_{\text{syst}} \pm 10_{\text{lumi}}\ \text{pb}$$

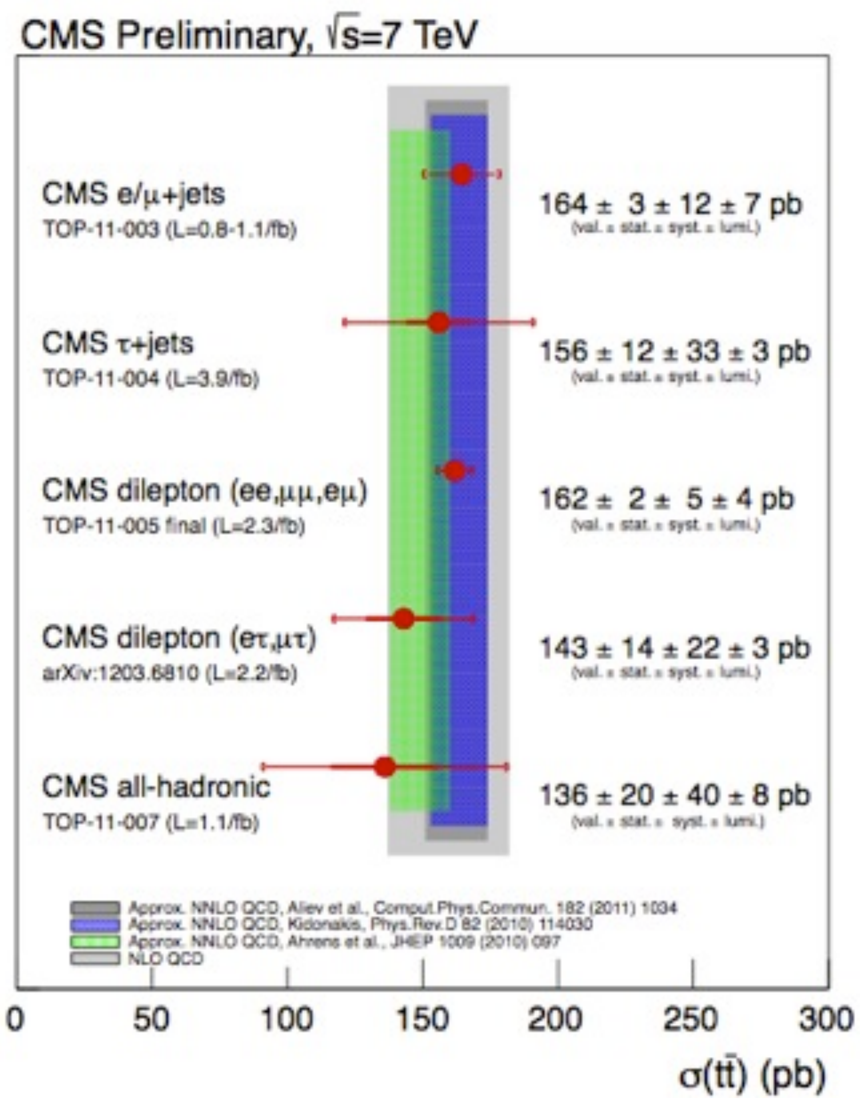
Combine measurement

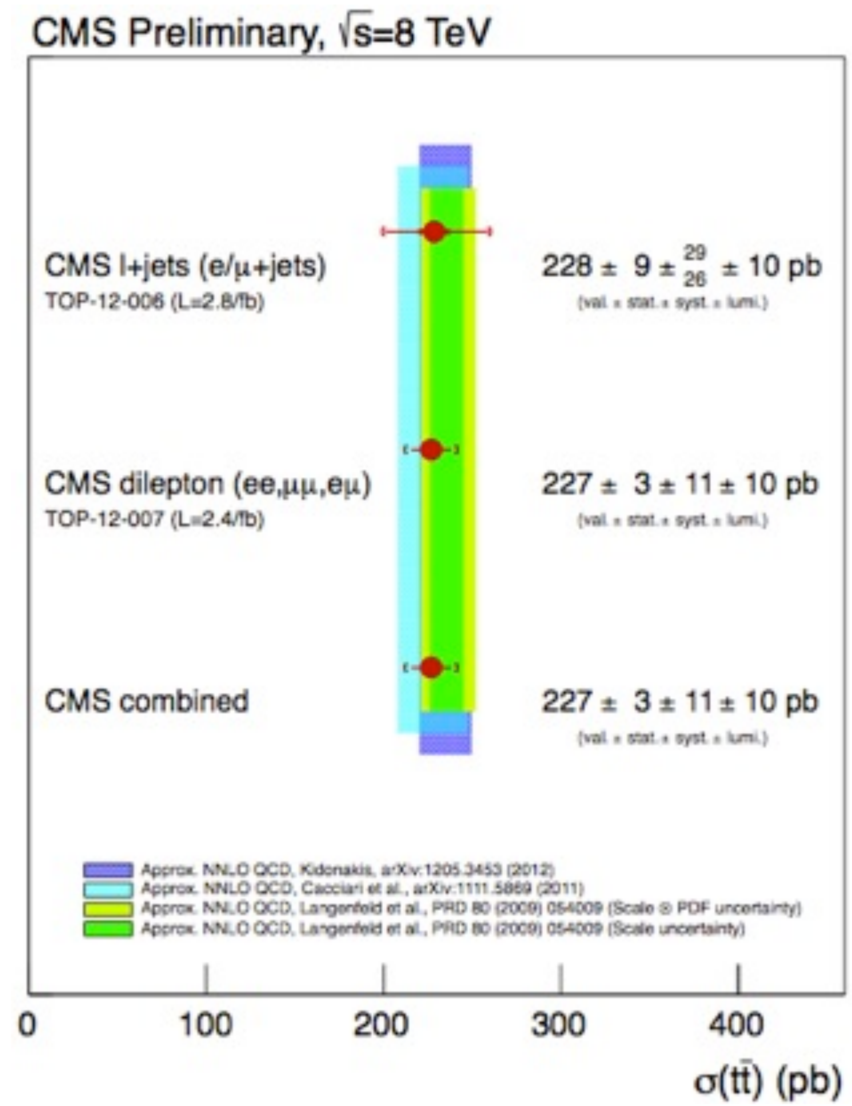
NEW

CMS-PAS-TOP-11-024

CMS-PAS-TOP-12-007

- Full combination is performed using a binned maximum likelihood fit
  - Add uncertainties as scale factors affecting rates (nuisance parameters)
  - Link common uncertainties to all channels with the same nuisance (100% correlation)
- Excellent agreement between different channels and theory





- Cross section ratio (assuming uncorrelated exp. unc.): $R_{8/7}$ = 1.41 ± 0.10

6-8% uncertainty on σ_{tt} starting to call for NNLO predictions.

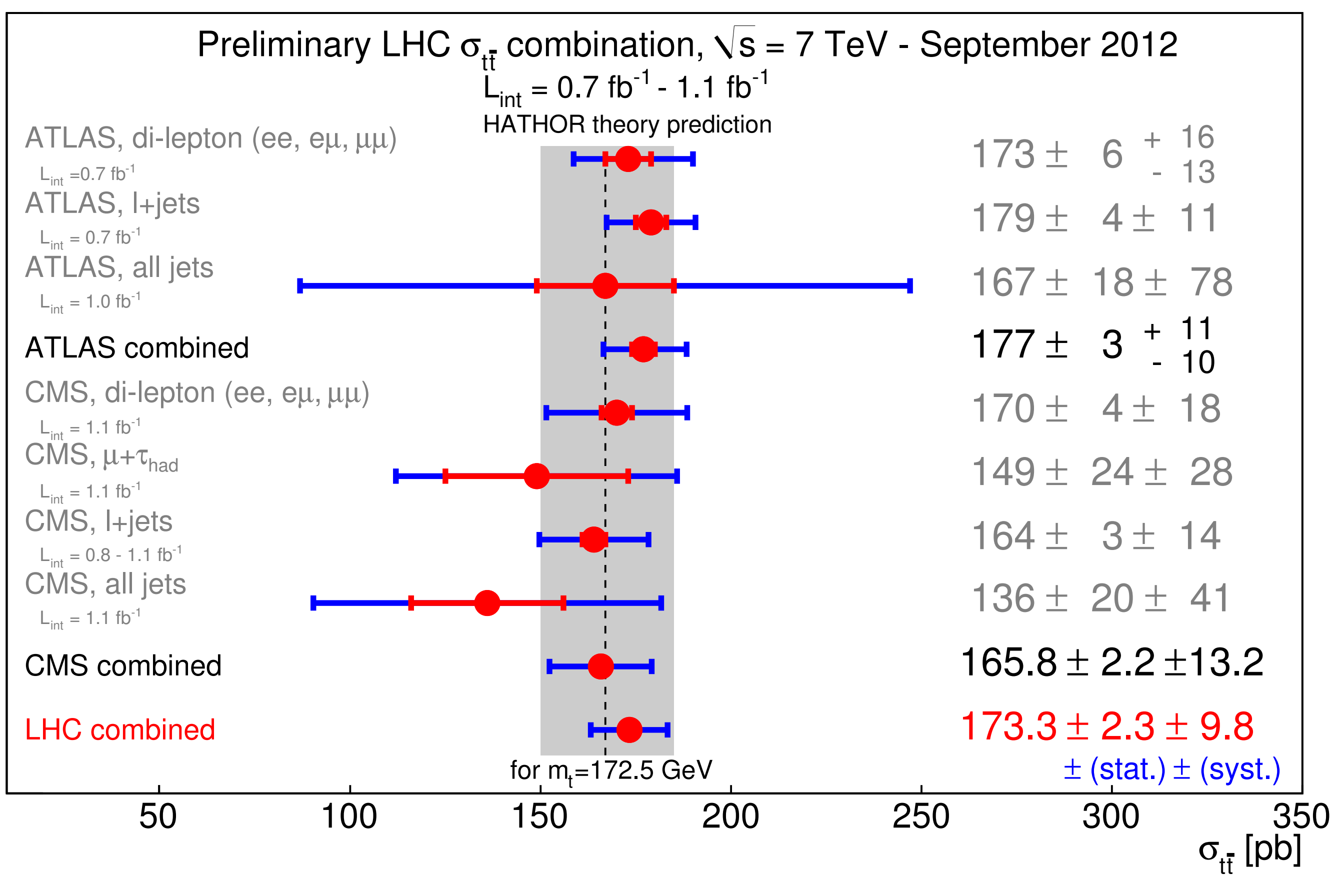
LHC combine measurement of top-pair cross-section (7 TeV)

NEW

CMS-PAS-TOP-12-003

- Use Best Linear Unbiased Estimate (BLUE) method:
  - Weighted sum of the input measurements that minimize the total uncertainty
- ATLAS: di-lepton, l+jets, all jets
- CMS: di-lepton, l+jets, all jets, μ+τ

LHC combination



Uncertainties

	ATLAS	CMS	Correlation	LHC combination
Cross-section	177.0	165.8		173.3
Uncertainty				
Statistical	3.2	2.2	0	2.3
Jet Enegy Scale	2.7	3.5	0	2.1
Detector model	5.3	8.8	0	4.6
Signal model				
Monte Carlo	4.2	1.1	1	3.1
Parton shower	1.3	2.2	1	1.6
Radiation	0.8	4.1	1	1.9
PDF	1.9	4.1	1	2.6
Background from data	1.5	3.4	0	1.6
Background from MC	1.6	1.6	1	1.6
Method	2.4	n/e	0	1.6
W leptonic branching ratio	1.0	1.0	1	1.0
Luminosity				
Bunch current	5.3	5.1	1	5.3
Luminosity measurement	4.3	5.9	0	3.4
Total systematic	10.8	14.2		9.8
Total	11.3	14.4		10.1

Extracting $\alpha_s(m_Z)$ from σ_{tt}

NEW

CMS-PAS-TOP-12-022

- m_{top} and α_s can't be determined simultaneously from σ_{tt} → constrain one when measuring the other
- maximize the joint likelihood

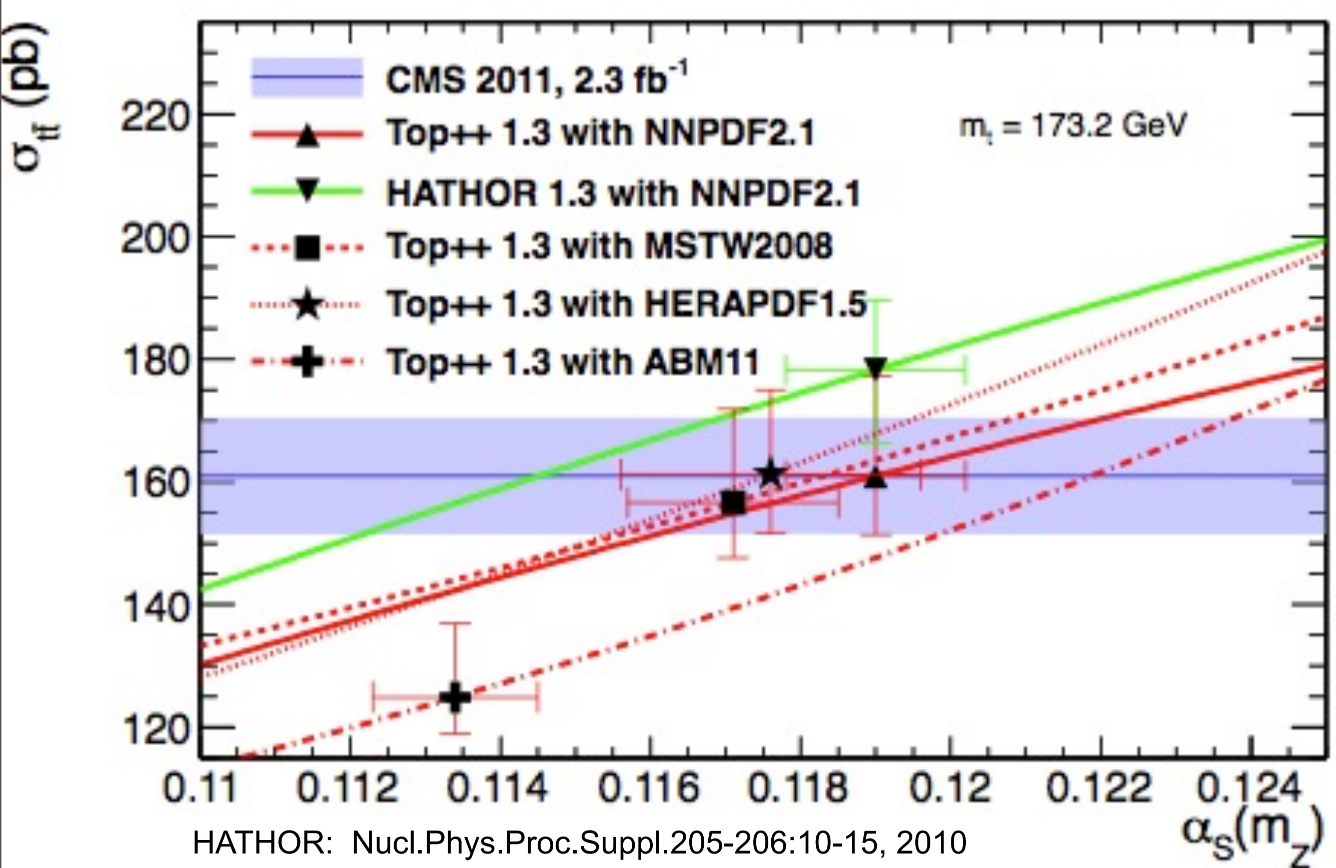
$$\mathcal{L}(x) = \int d\sigma\ \underbrace{f_{\rm exp}(\sigma_{t\bar{t}}|x)}\ \underbrace{f_{\rm th}(\sigma_{t\bar{t}}|x)} \qquad x = \alpha_S \text{ or } m_t$$

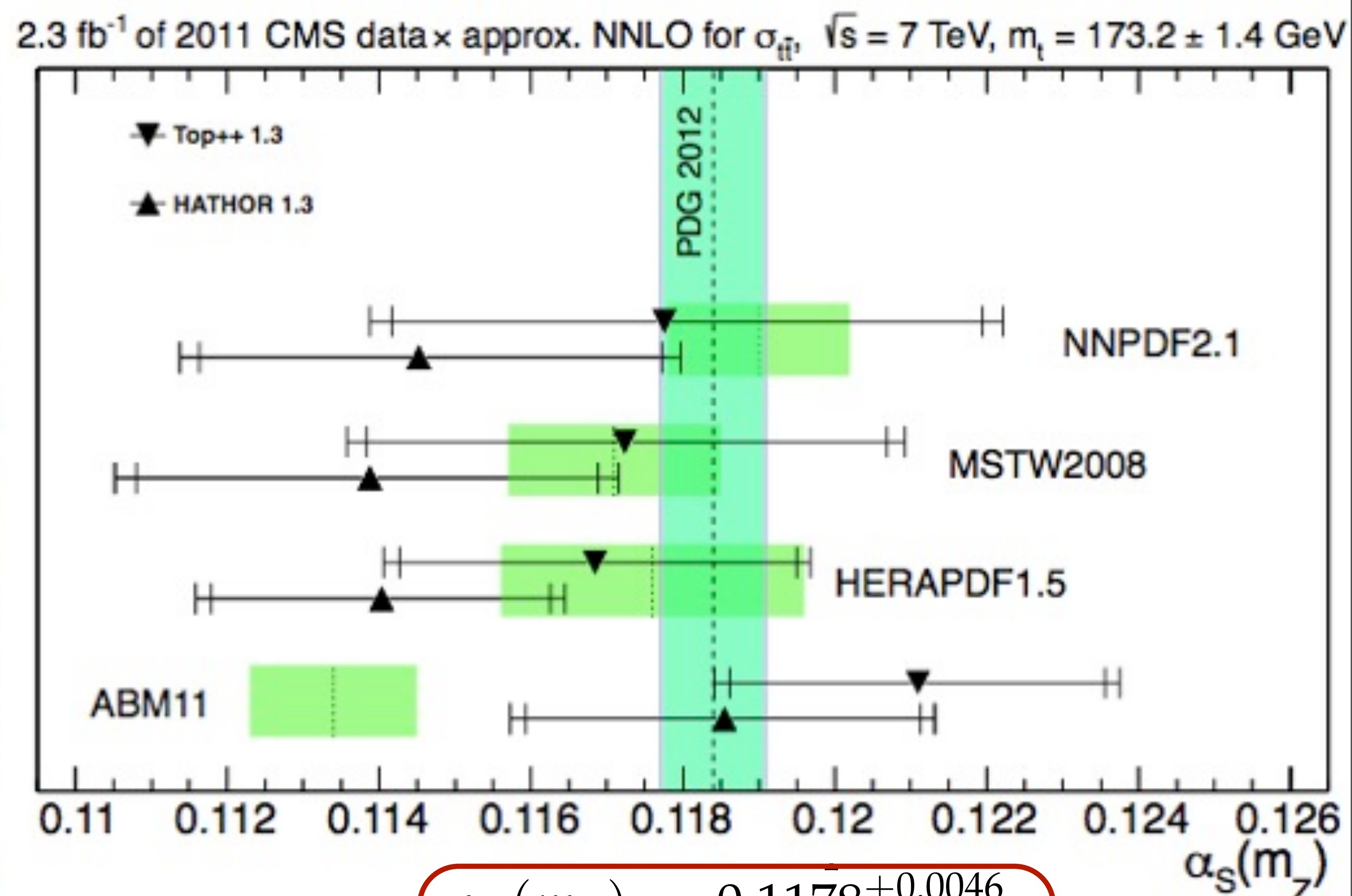
Experimental measurement (gaussian)

PDF uncertainty convolved with rectangular "prior" on Q^2 scale

$\sigma_{tt}(\alpha_S)$ is determined from **Top++** and **HATHOR** with different PDFs

Good agreement with world average





HATHOR: Nucl.Phys.Proc.Suppl.205-206:10-15, 2010

TOP++: http://arxiv.org/abs/1112.5675

$$\alpha_S(m_Z) = 0.1178^{+0.0046}_{-0.0040}$$

Top mass measurement @ 7 TeV

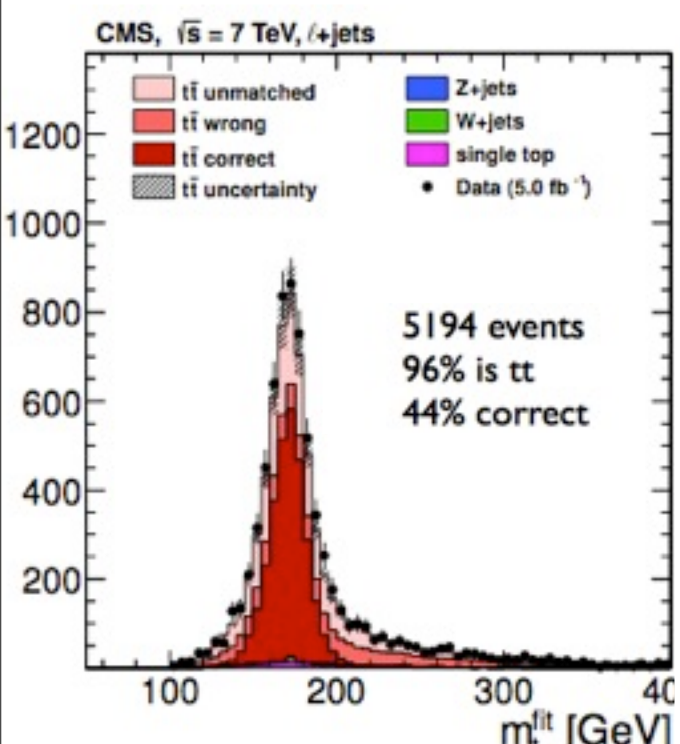
NEW

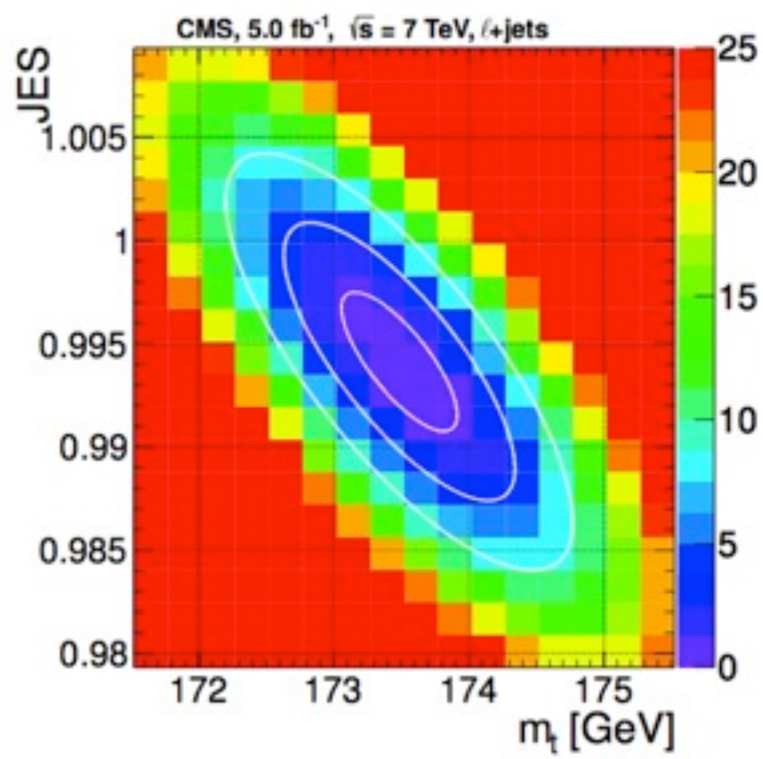
l+jets (e/μ+jets) arXiv:1209.2319→JHEP

- Event Selection:
  - One isolated lepton and ≥ 4 jets (≥2-bagged)
- Kinematic fitting to obtain the correct permutation, $P_{gof}(\chi^2)$>0.2
- Perform calibration of the light quark JES from hadronic side (W→qq´)

$$\mathcal{L}\left(m_{\mathrm{t}}, \mathrm{JES}|\mathrm{sample}\right) = \prod_{\mathrm{events}} \mathcal{L}\left(\mathrm{event}|m_{\mathrm{t}}, \mathrm{JES}\right)^{w_{\mathrm{event}}}$$

-





$$m_{\mathrm{top}} = 173.49 \pm 0.43_{\mathrm{stat+JES}} \pm 0.98_{\mathrm{syst}}$$

Results - world's best

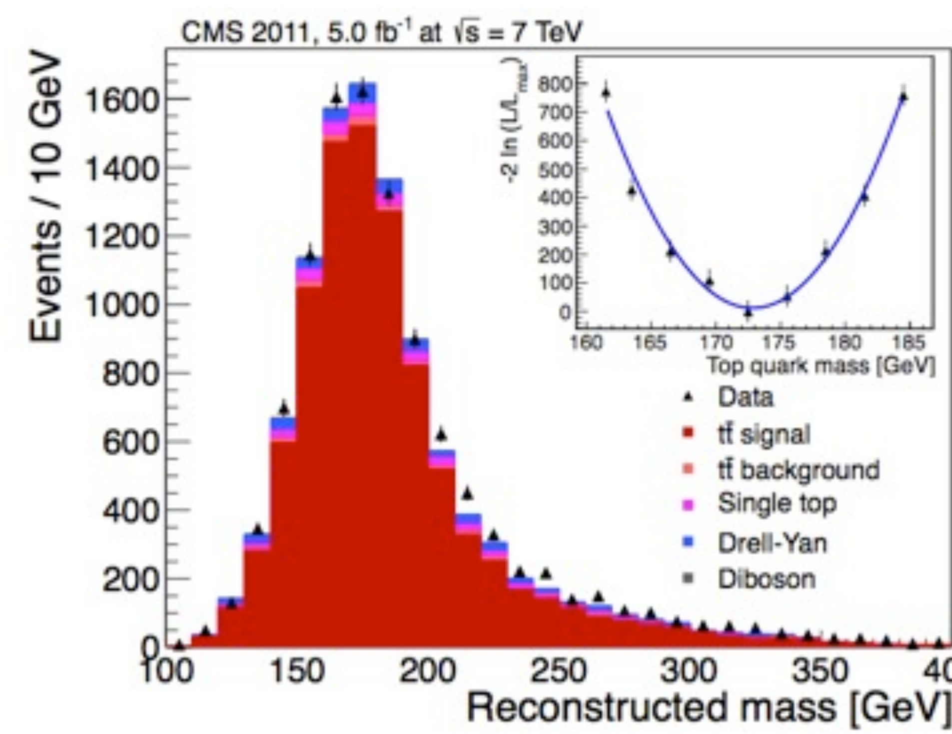
dilepton(ee/eμ/μμ) arXiv:1209.2393→EPJC

- Same reference selection as cross-section analysis
- 1 degree of freedom to reconstruct the m_{top}
  - 8 possible solutions per event
  - Use matrix weighting technique to weight solutions

$$w = \left\{\sum f(x_1) f(x_2)\right\} p(E^*_{\ell+}|m_t) p(E^*_{\ell-}|m_t)$$

PDF summed over all possible combinations

Probability to observed lepton in top rest frame

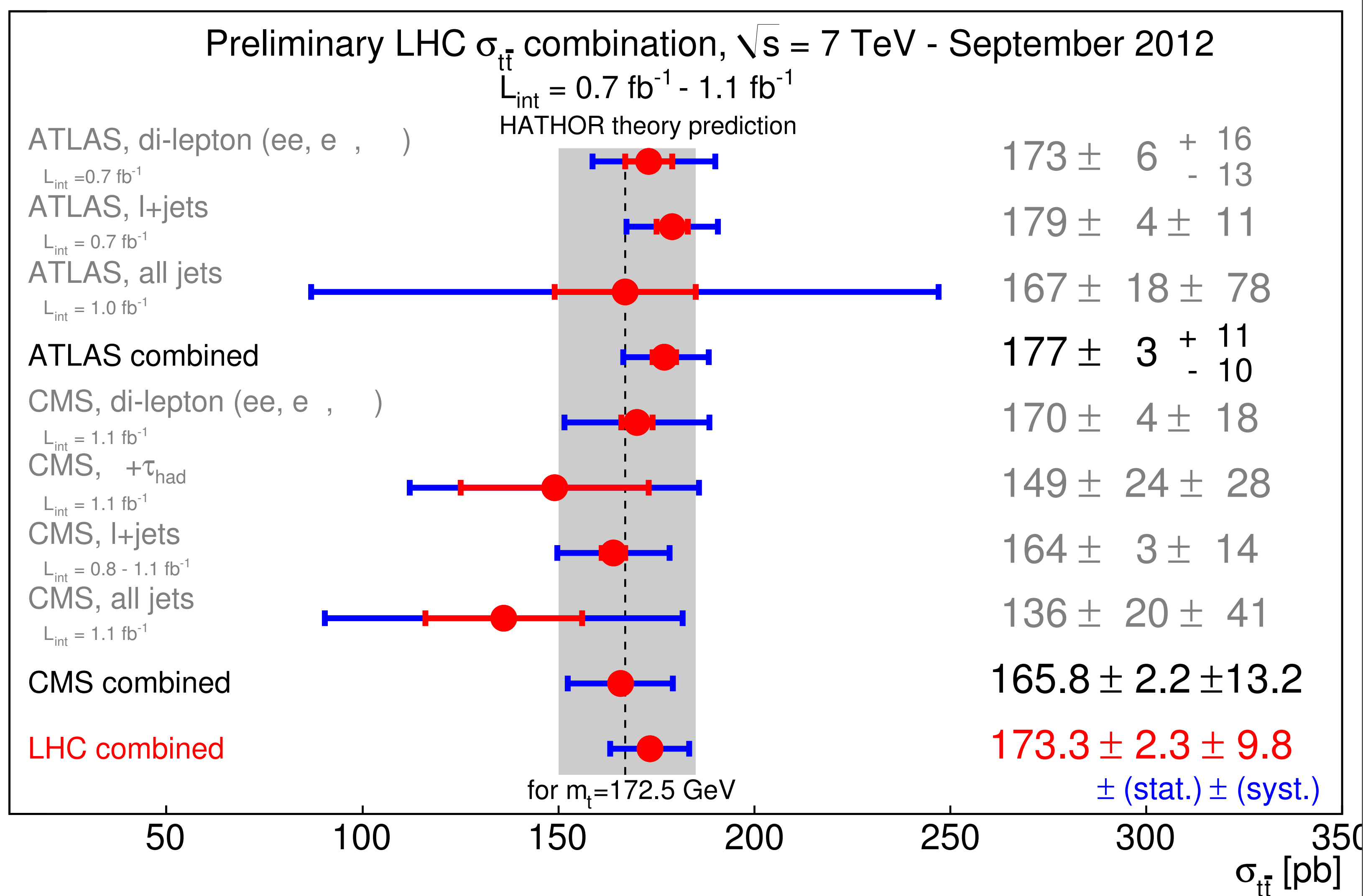


$$m_t = 172.5 \pm 0.4\,(\mathrm{stat.}) \pm 1.5\,(\mathrm{syst.})\,\mathrm{GeV}$$

Top mass combination @ 7 TeV

CMS-PAS-TOP-12-003

- Use Best Linear Unbiased Estimate (BLUE) method
- Channels assessed in different periods are statistically uncorrelated
- Systematics categories
  - Full correlation from common categories estimated with similar methods
- Final uncertainty = 0.57%
  - Mostly driven by l+jets result
  - 2D fit partially uncorrelates the JES uncertainty across channels



NEW

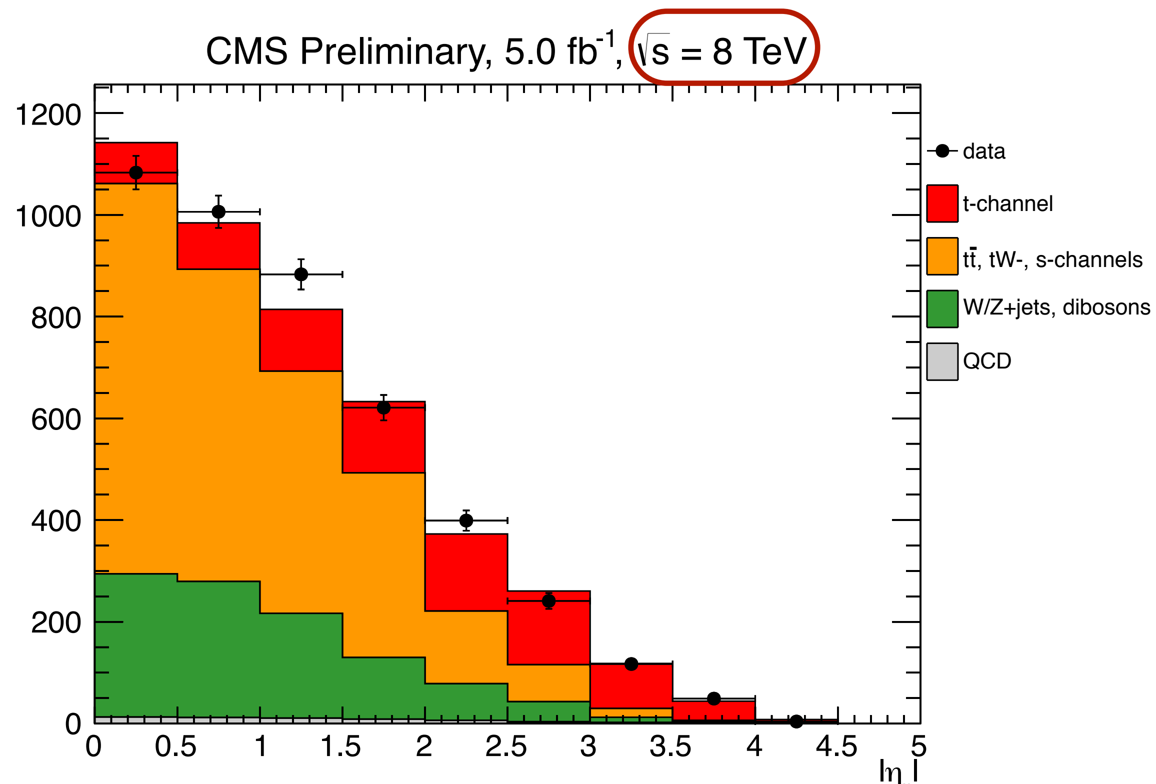
Cross-section measurement in single top

t-channel

CMS-PAS-TOP-12-001

arXiv:4533v1→JHEP

- Event Categorization
  - 1 central, isolated lepton + E_T^{miss} with main contribution from 1b-jet +1forward recoil jet
  - “2jets 1tag” category: events in a mass window of $130 < m_{l\nu b} < 220$ GeV
- Signal extraction
  - Perform maximum likelihood to **$|\eta_j|$** of the non b-tagged jets in the “2jets 1tag” category



$$67.2 \pm 3.7_{stat} \pm 3.0_{syst} \pm 3.5_{theor} \pm 1.5_{lum}\ \text{pb}$$ 7 TeV

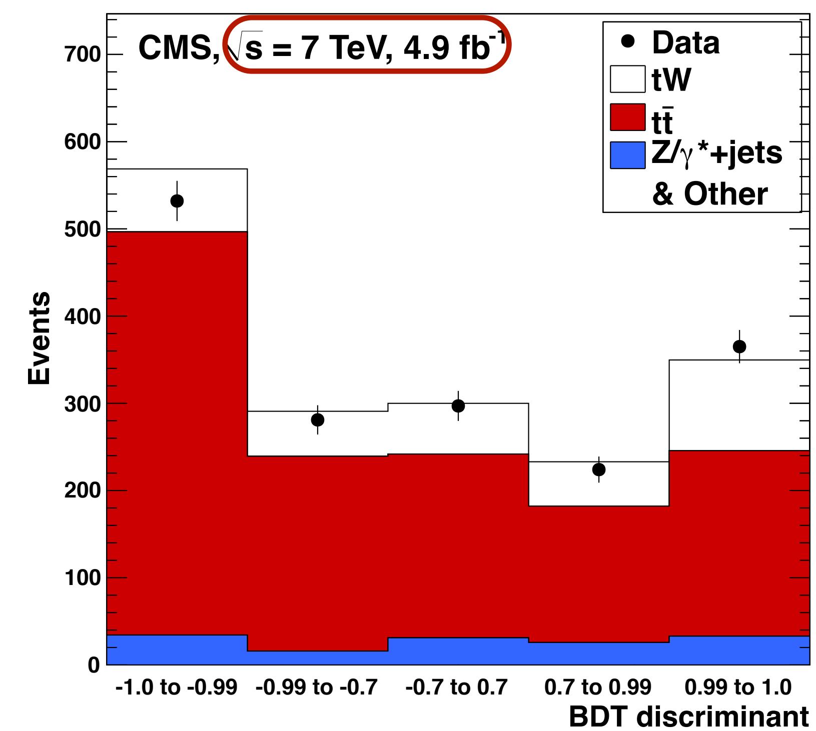
$$80.1 \pm 5.7_{stat} \pm 11.0_{syst} \pm 4.0_{lum}\ \text{pb}$$ 8 TeV

$$R_{8/7} = 1.14 \pm 0.12_{stat} \pm 0.14_{syst}^{*}$$

tW-channel

arXiv:1209.3489→PRL

- Final state: 2 leptons + 1 b-jet + E_T^{miss}
  - Signal region: 1jet,1tag
  - Control regions: 2jets,1tag; 2jet,2tags
- Balance (p_T of the system) $\sum_{\text{leptons}} \vec{p}_T + \vec{p}_T^{\,b-jet} + \vec{p}_T^{\,miss}$
- Multivariate discriminator
  - H_T, balance, leading jet p_T, $\min\Delta\varphi(l, E_T^{miss})$



BDT
4σ significance 16^{+5}_{-4} pb

Cross checked with cut and count for H_T>60 GeV

Cut and count
3.2σ significance 15 ± 5 pb

NEW

Extracting V_{tb} from single top

V_{tb} is (≈) the signal strength

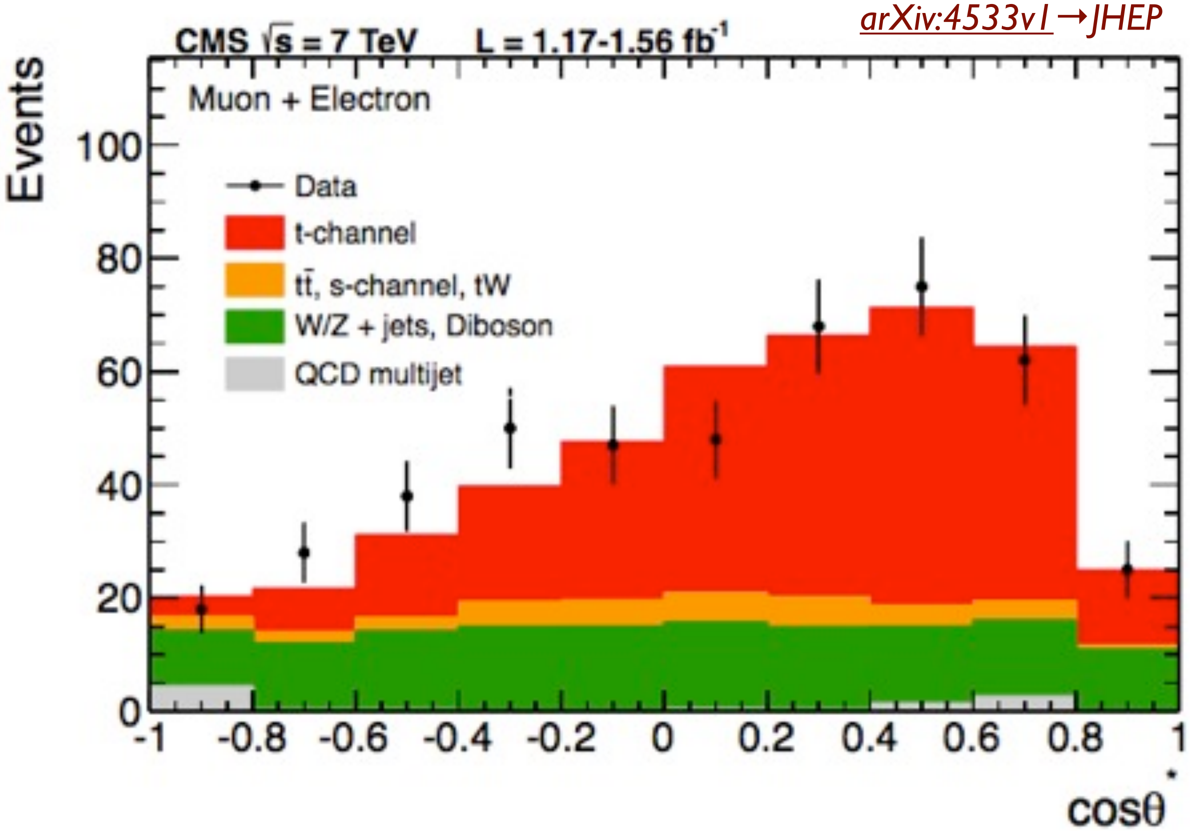
$$|f_{L_V} V_{\mathrm{tb}}| = \sqrt{\frac{\sigma_{t\text{-ch.}}}{\sigma^{\mathrm{th}}_{t\text{-ch.}}}} \quad \text{or} \quad |V_{\mathrm{tb}}| = \sqrt{\frac{\sigma_{\mathrm{tW}}}{\sigma^{\mathrm{th}}_{\mathrm{tW}}}}$$

Anomalous form factor=1 in SM   Is it really 1?

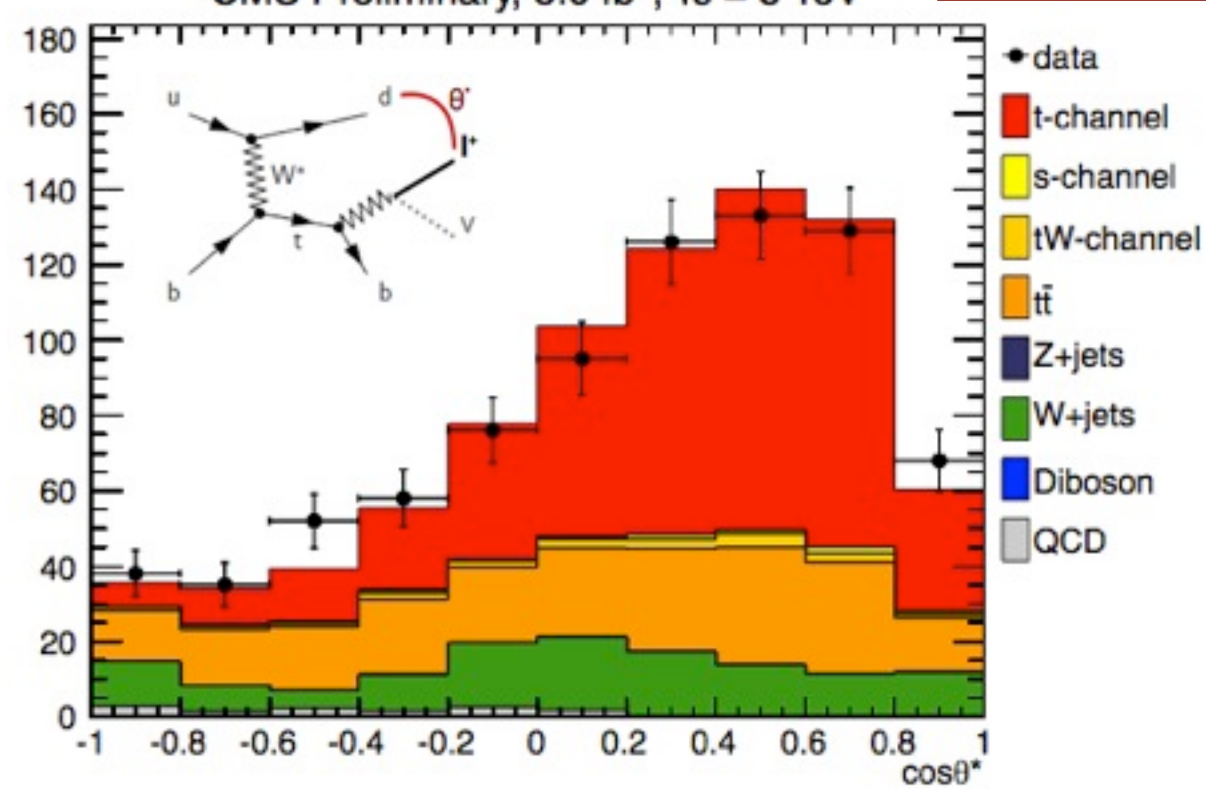
t-channel, 7 TeV	*t-channel, 8 TeV*	*tW-channel, 7TeV*
$1.020 \pm 0.046_{\mathrm{exp}} \pm 0.017_{th}$	$0.96 \pm 0.08_{\mathrm{exp}} \pm 0.02_{th}$	$1.01\ ^{+0.16}_{-0.13}\ \mathrm{exp}\ ^{+0.03}_{-0.04}\ \mathrm{th}$
$\lvert V_{\mathrm{tb}}\rvert > 0.92$ @ 95%CL	$\lvert V_{\mathrm{tb}}\rvert > 0.81$ @ 95%CL	$\lvert V_{\mathrm{tb}}\rvert > 0.79$ @ 90%CL

- What other properties can be studied?
  - polarization, mass, differential distributions ...

arXiv:4533v1→JHEP



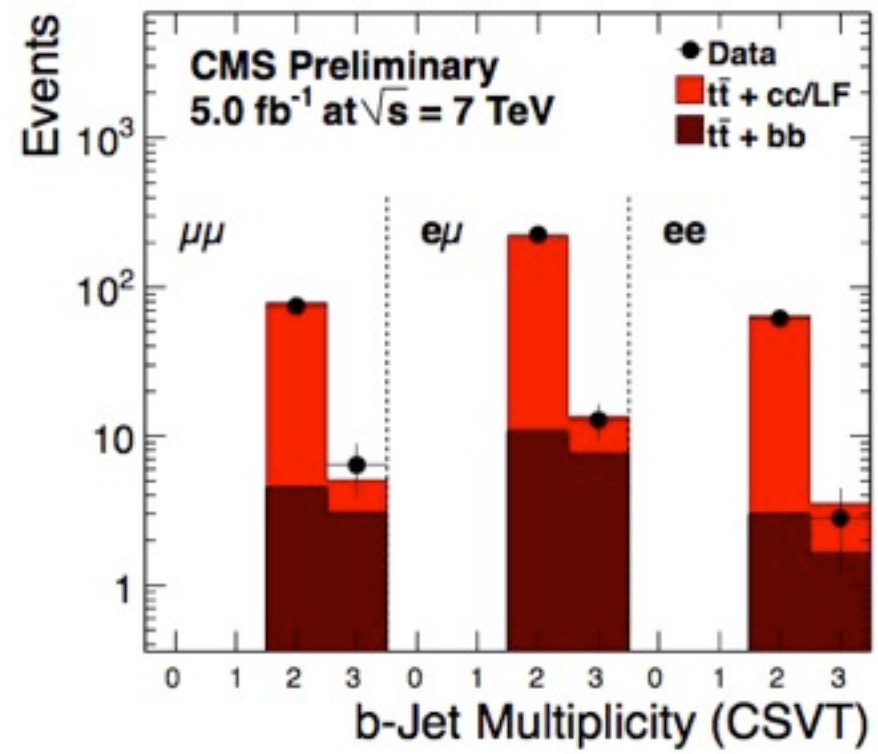
CMS-PAS-TOP-11-021



Associated Production with two b´s: ttbb @ 7 TeV NEW

CMS-PAS-TOP-12-024

- The ttbb process is the main background for ttH
  - precisely understanding help us to test the Higgs boson at 125 GeV
- Analysis strategy
  - The ratio of tt+2 jets to tt+2 b-jets is measured
    - allows for cancellation of many uncertainties
    - cleaner environment to study heavy flavor content of top pair sample
- Main challenges:
  - Experiment: b-tagging efficiency and rate for b´s from gluon splitting? mistag rate for light flavor
  - Theory: importance of npQCD? Signal is define at generated particle level with generated jets of p_T>20 GeV matched to b-hadrons
- Mistag rate for light flavors known to ~10% dominate final uncertainty

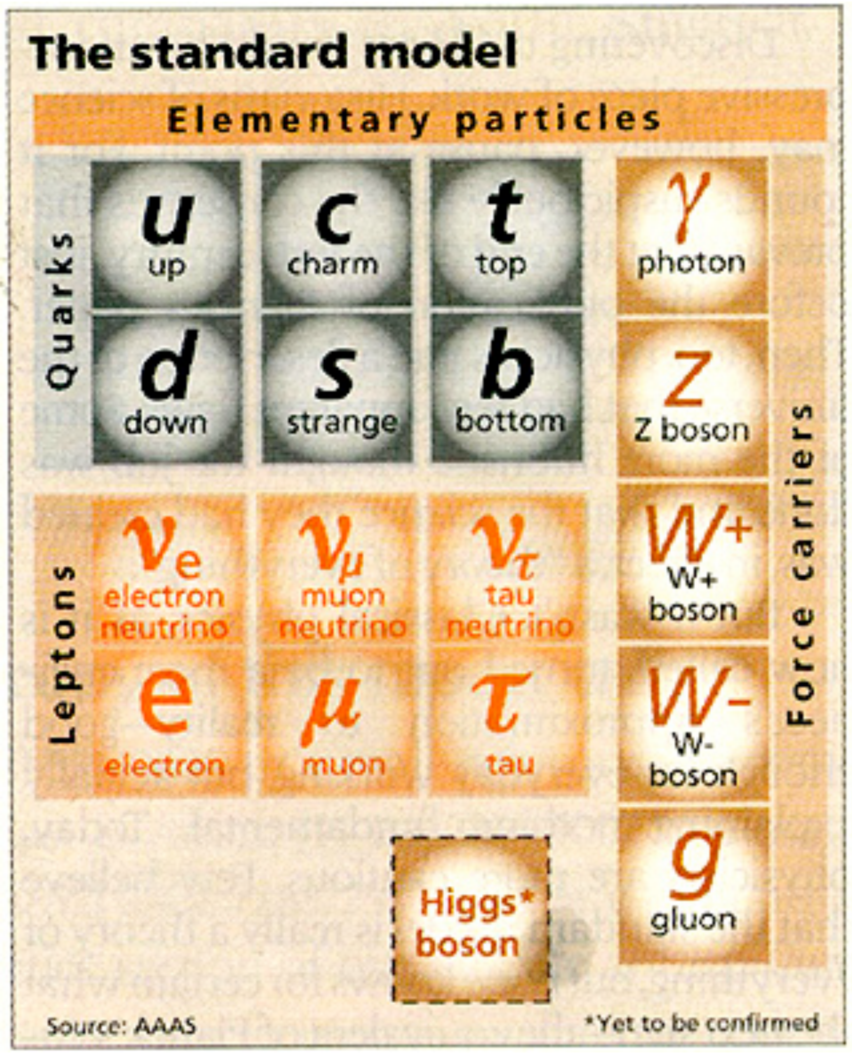


Uncertainties

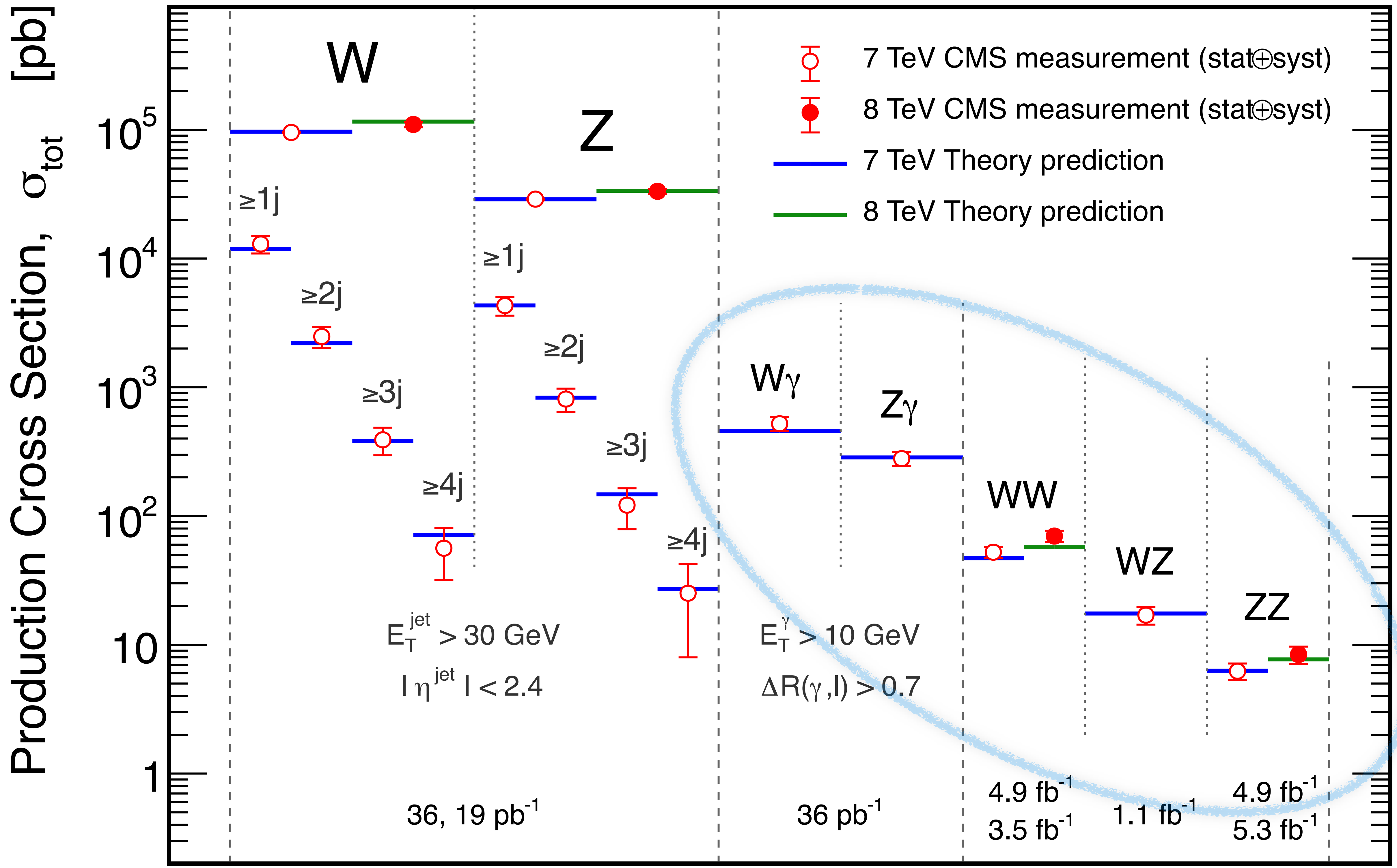
Source	$\sigma_{t\bar{t}b\bar{b}}/\sigma_{t\bar{t}jj}$ (%) Medium b-tagging	Tight b-tagging
Pileup	0.5	0.5
Jet energy scale	3.0	2.0
b-tag efficiency	6.0	4.0
mistag efficiency	+23 -19	+18 -15
MC generator	3.0	3.0
Q^2	6.0	6.0
Total	**+25 -21**	**+20 -17**

$$\frac{\sigma_{t\bar{t}b\bar{b}}}{\sigma_{t\bar{t}jj}}(\text{exp}) = 3.6 \pm 1.1_{\text{stat}} \pm 0.9_{\text{syst}}\%$$

Electroweak Physics Results



Production cross section in CMS



JHEP10(2011)132
JHEP01(2012)010
CMS-PAS-SMP-12-011 (W/Z 8 TeV)

PLB701(2011)535

CMS-PAS-EWK-11-010 (WZ)
CMS-PAS-SMP-12-005,
007, 013, 014 (WW ZZ)

W/Z Production Cross Sections

NEW

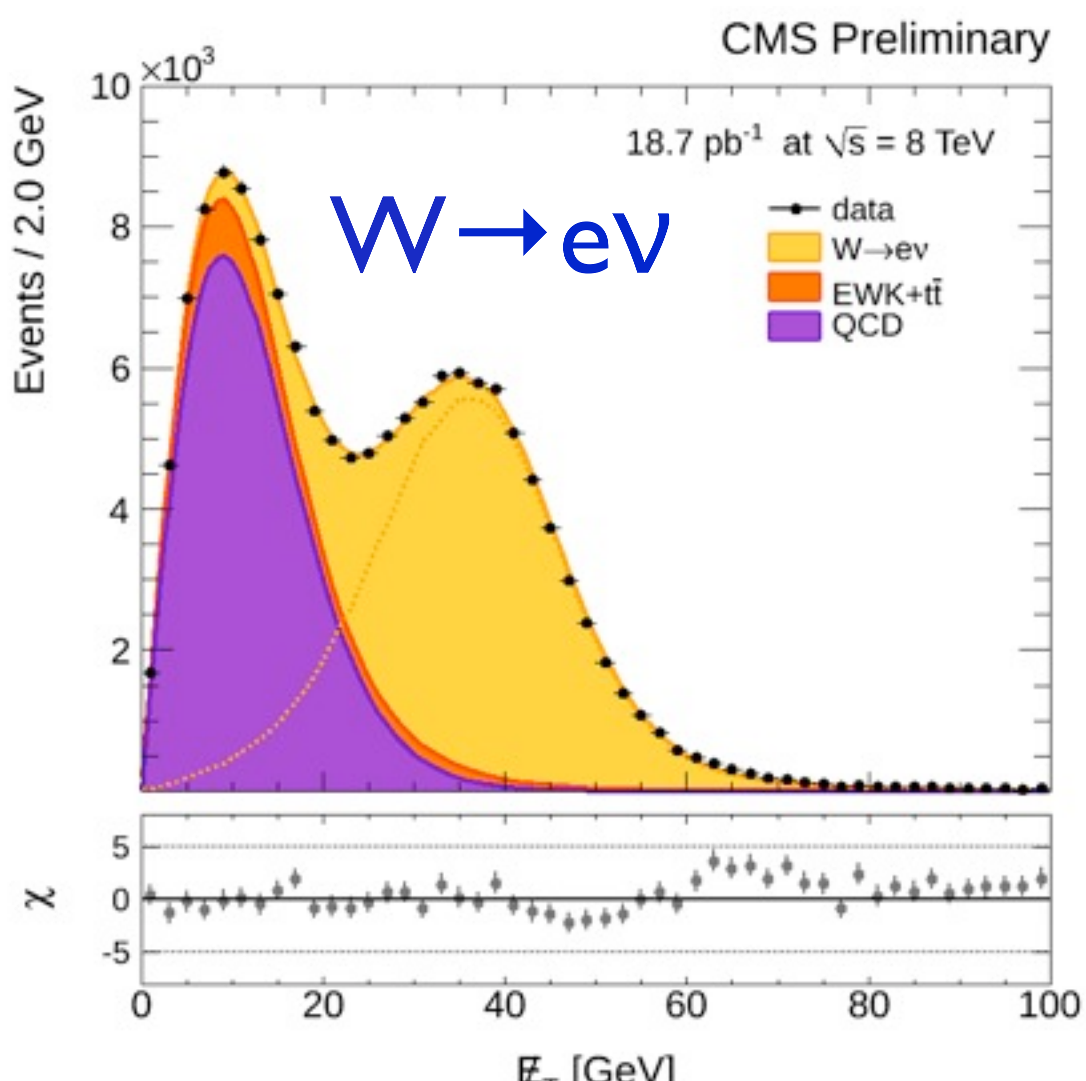
- Inclusive production cross section and leptonic decays, W→lν and Z→ll reached experimental accuracy of few % in l= e/μ channels with early 2010 data

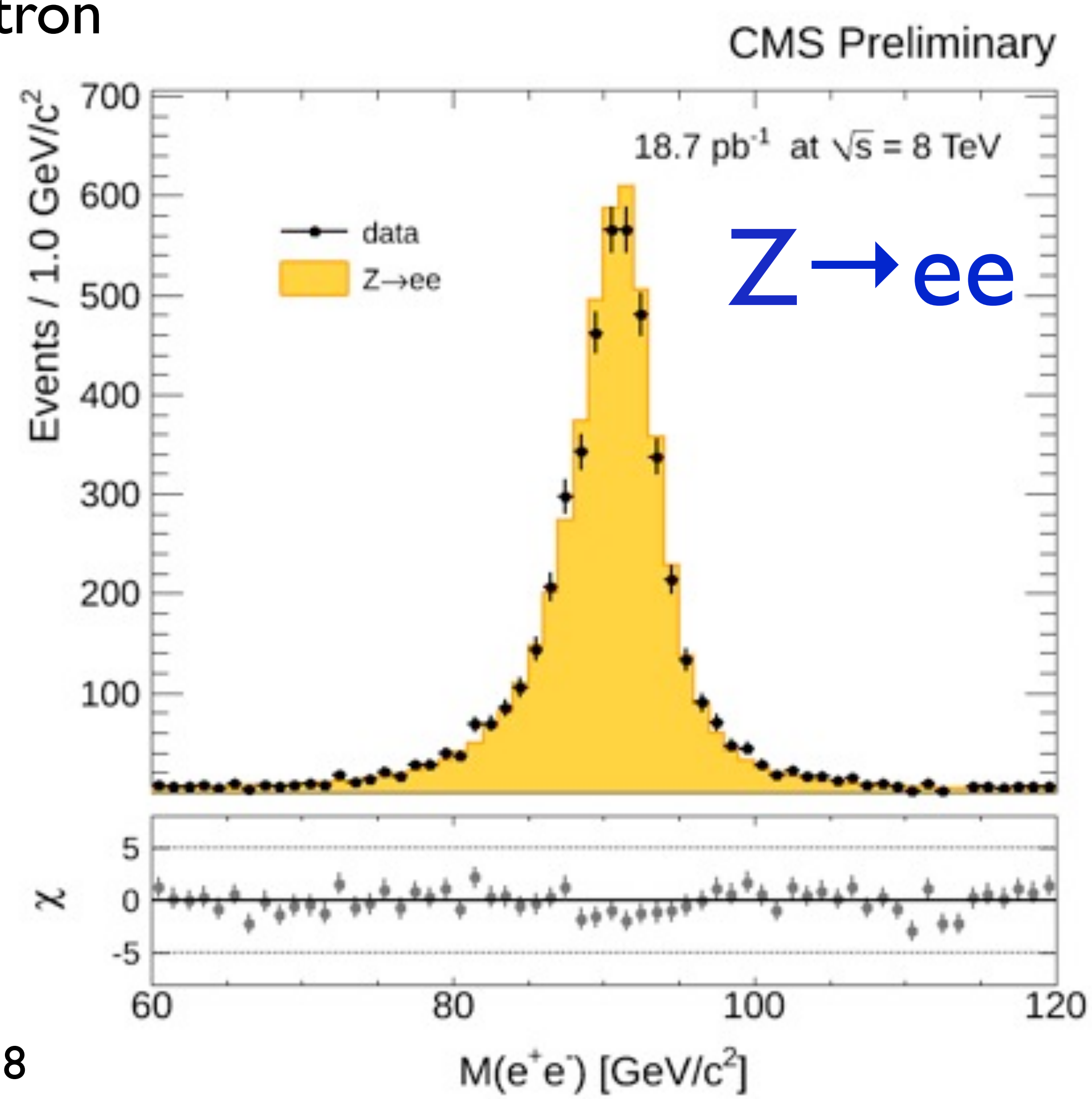
CMS-PAS-SMP-12-011

- 2010 @ 7 TeV
  - 0.2 pb^{-1}(ICHEP 10)
  - 2.9 pb^{-1}(first CMS publication)
  - 36 pb^{-1} (detailed studies)
- 2012 @ 8 TeV
  - 18.7 pb^{-1}

- Essentials to understand and calibrate our detector response (trigger, object ID, resolution, efficiencies)

Electron

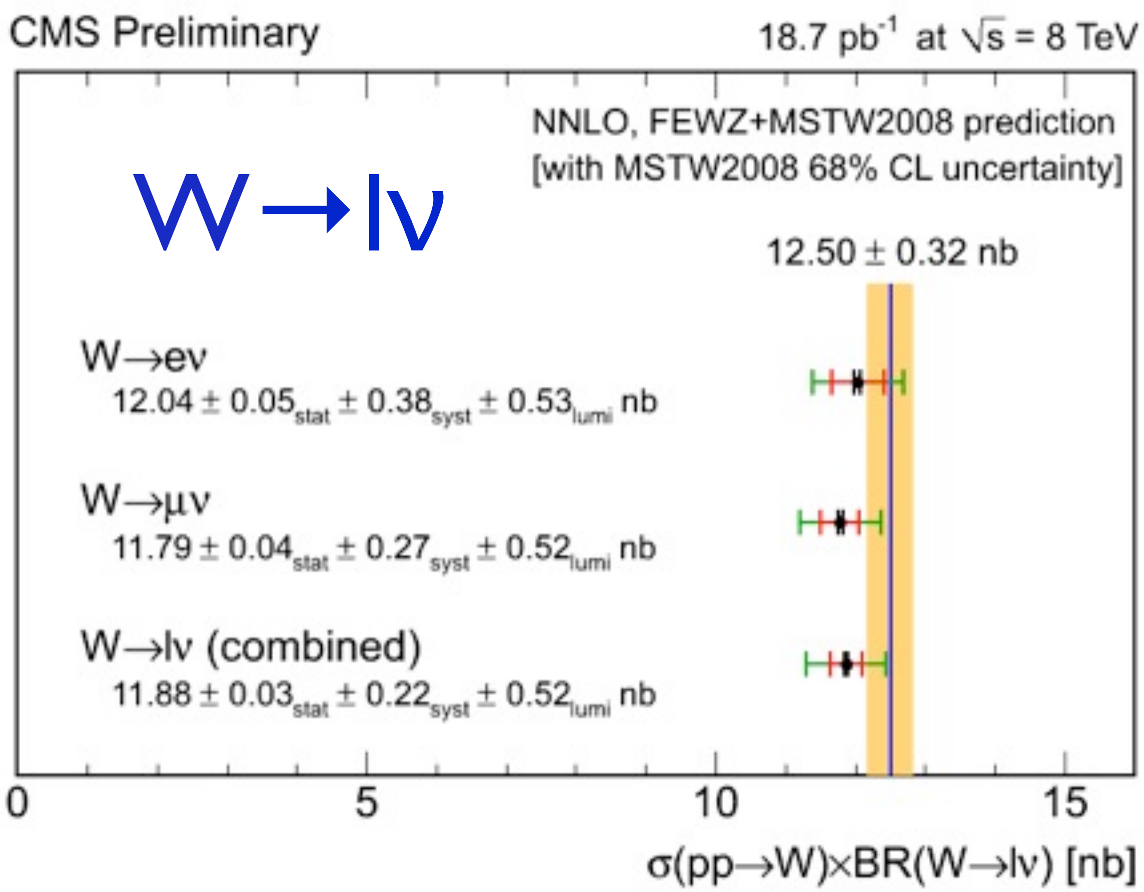


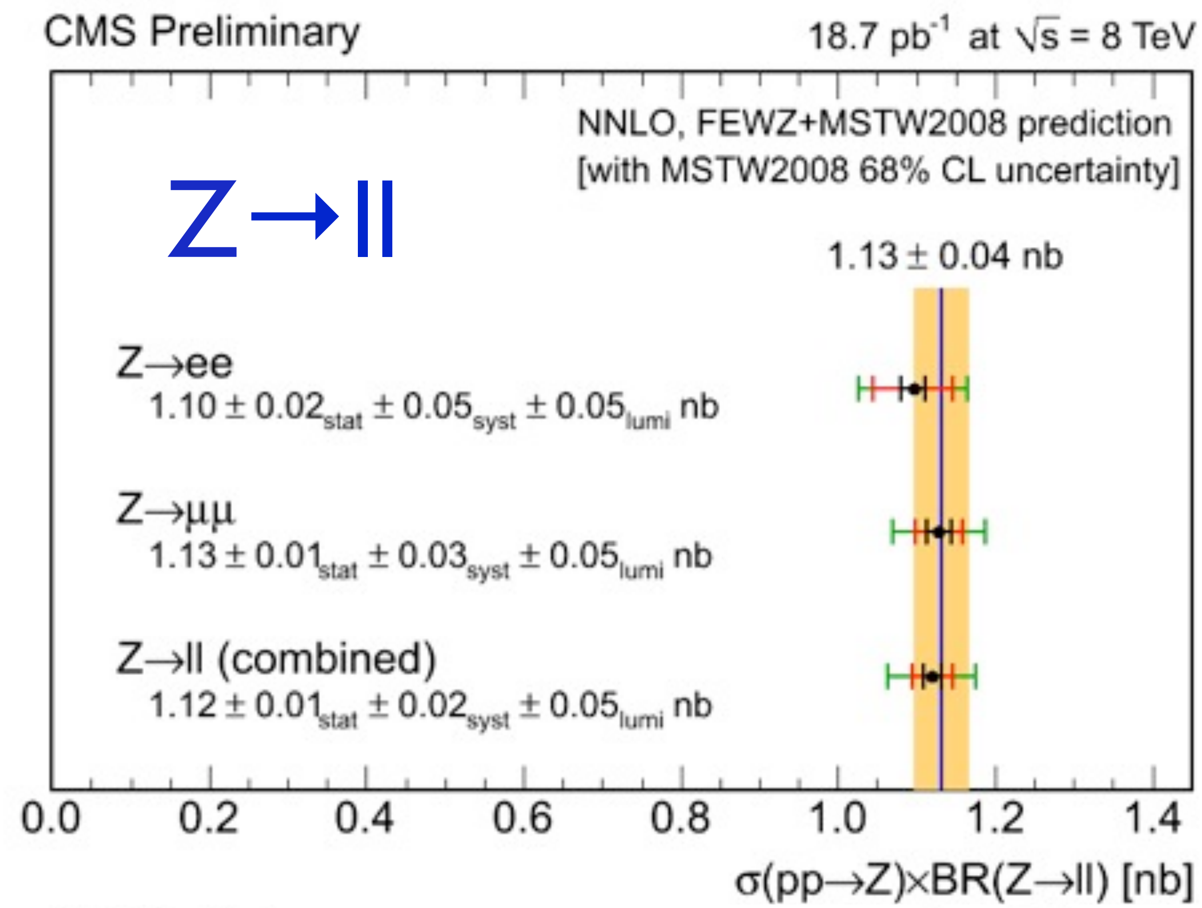


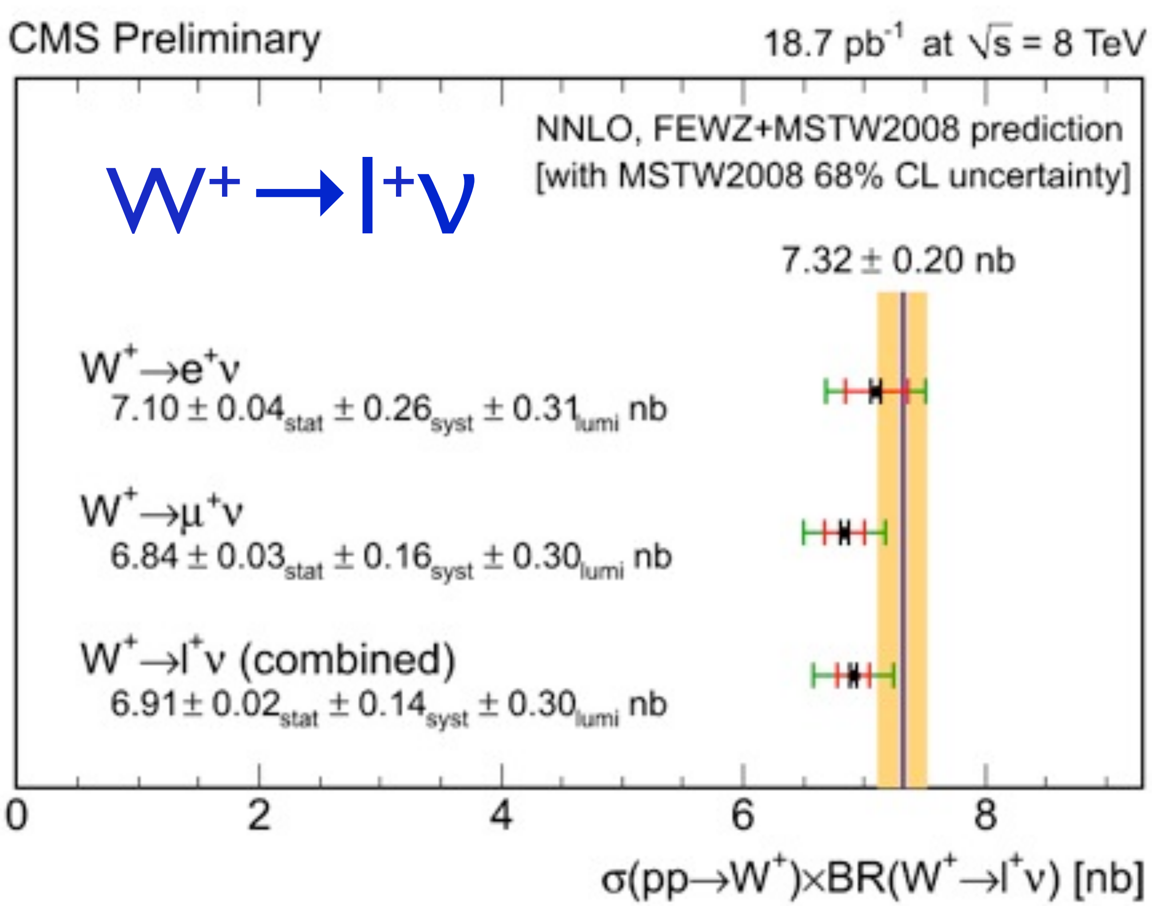
W/Z Production Cross Sections

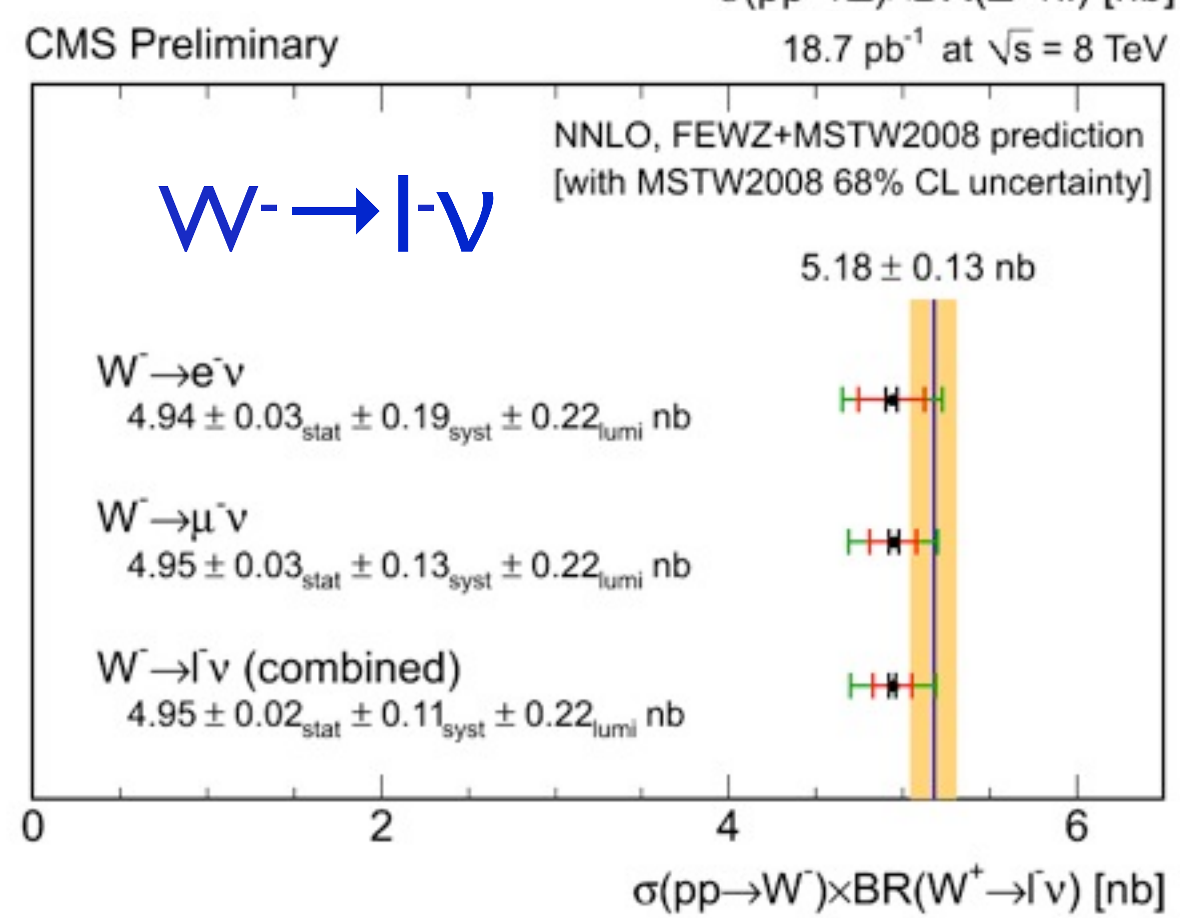
NEW

CMS-PAS-SMP-12-011









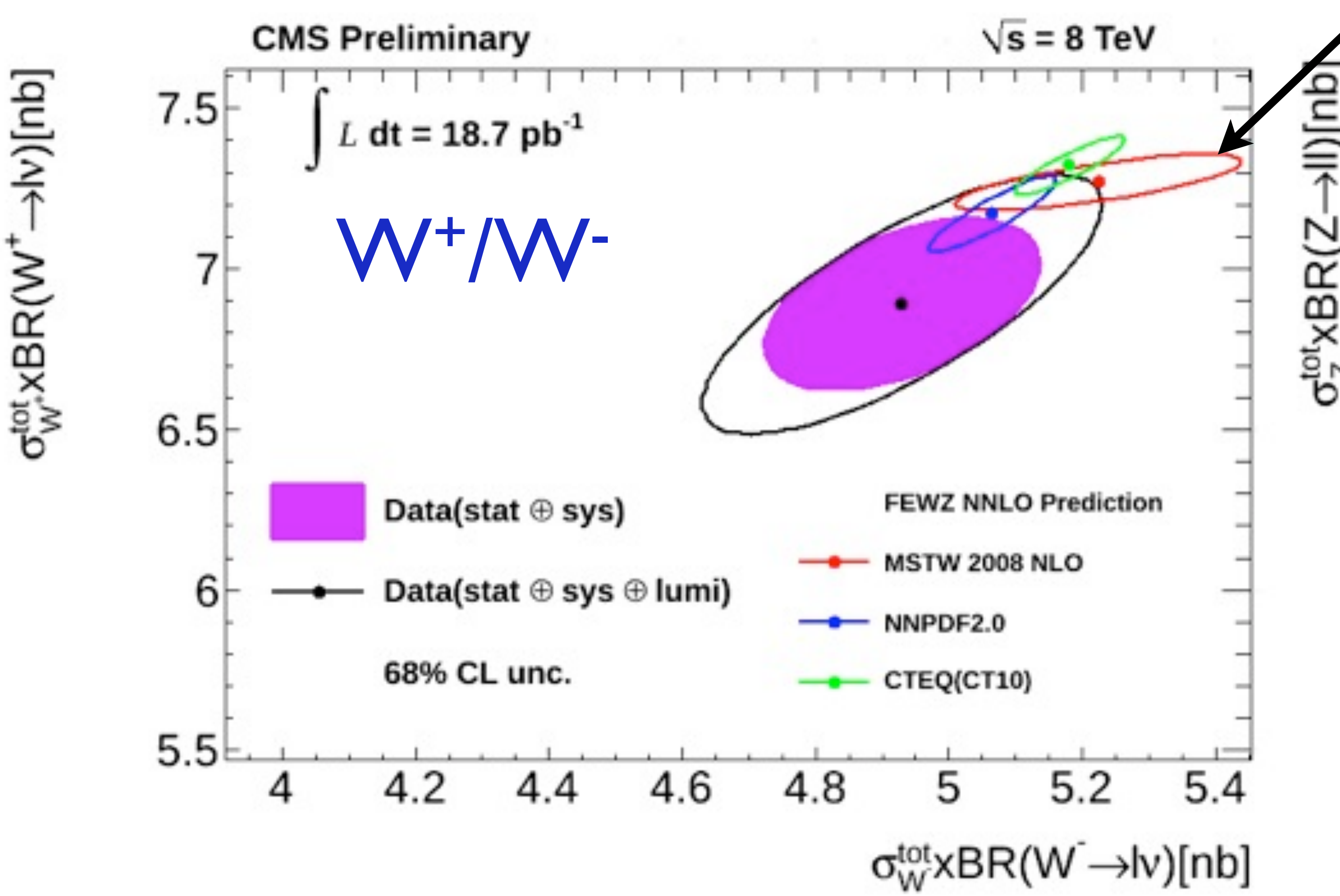
W^+/W^- and W/Z Cross Sections Ratio

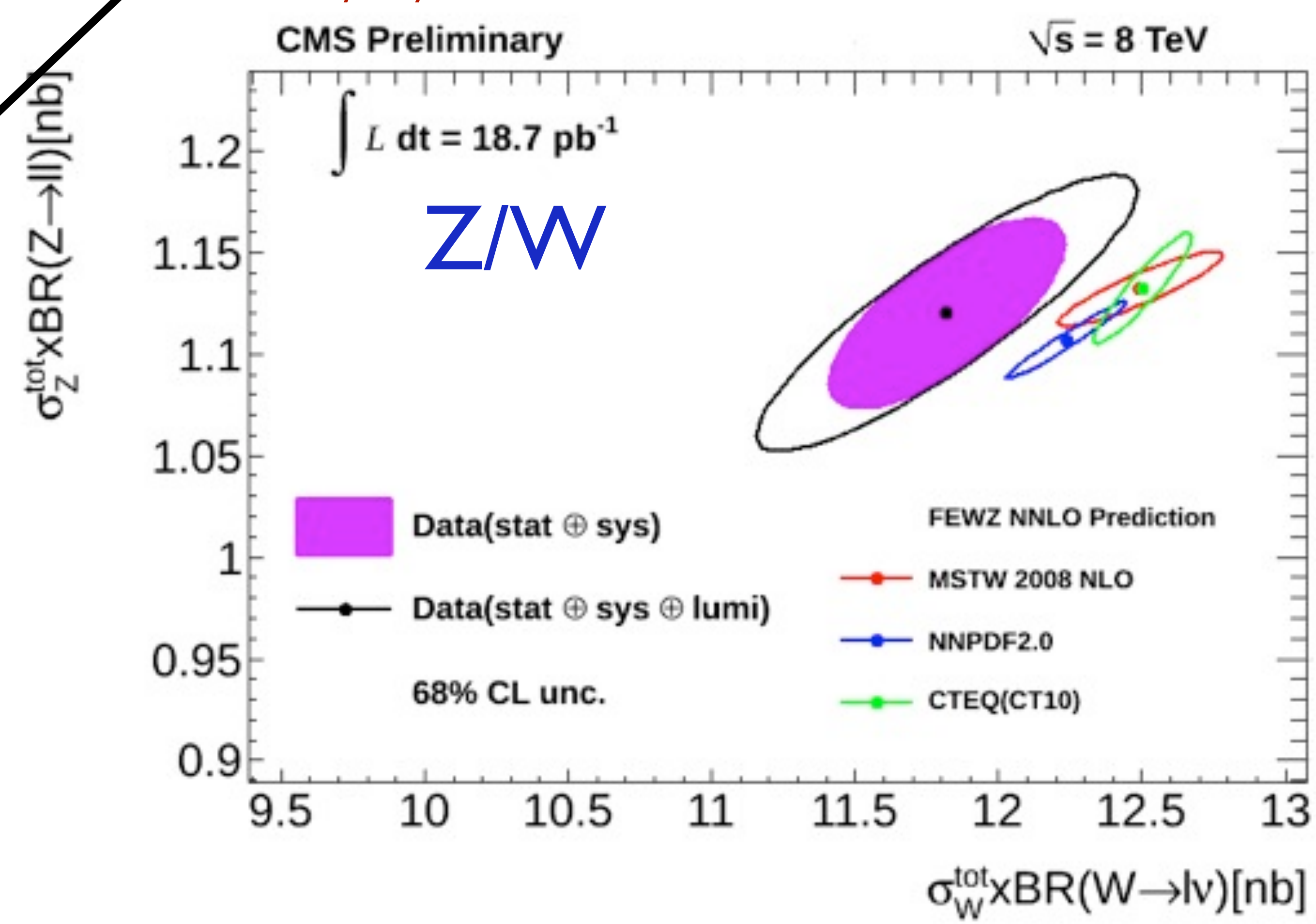
- Maximize sensitivity using ratios and correlations
- Precession tests from proton PDFs and SM

NEW

CMS-PAS-SMP-12-011

The uncertainty for theory prediction corresponds to PDF uncertainty only





- The largest systematic uncertainty in these measurements is from PDFs (2%)
- The feed back from these precise measurements to PDF calculation can help to constrain them better

W lepton charge asymmetry

NEW

CMS-PAS-EWK-11-005

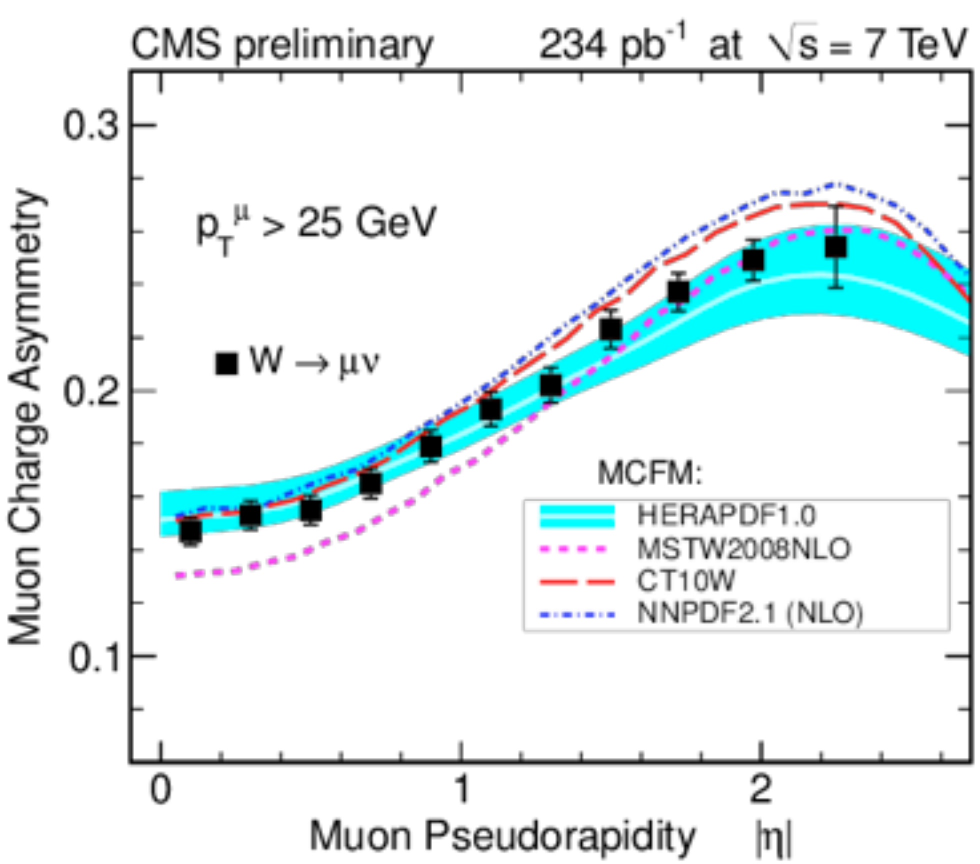
arXiv:1206.2598(PRL)

- A first natural extension of W inclusive x-section is to study the W^+/W^- ratio, R_W as a function of kinematic variable: pseudorapidity, |η|
- Charge Asymmetry

$$\mathcal{A}(\eta) = \frac{d\sigma/d\eta(W^+ \to \ell^+\nu) - d\sigma/d\eta(W^- \to \ell^-\bar{\nu})}{d\sigma/d\eta(W^+ \to \ell^+\nu) + d\sigma/d\eta(W^- \to \ell^-\bar{\nu})},$$

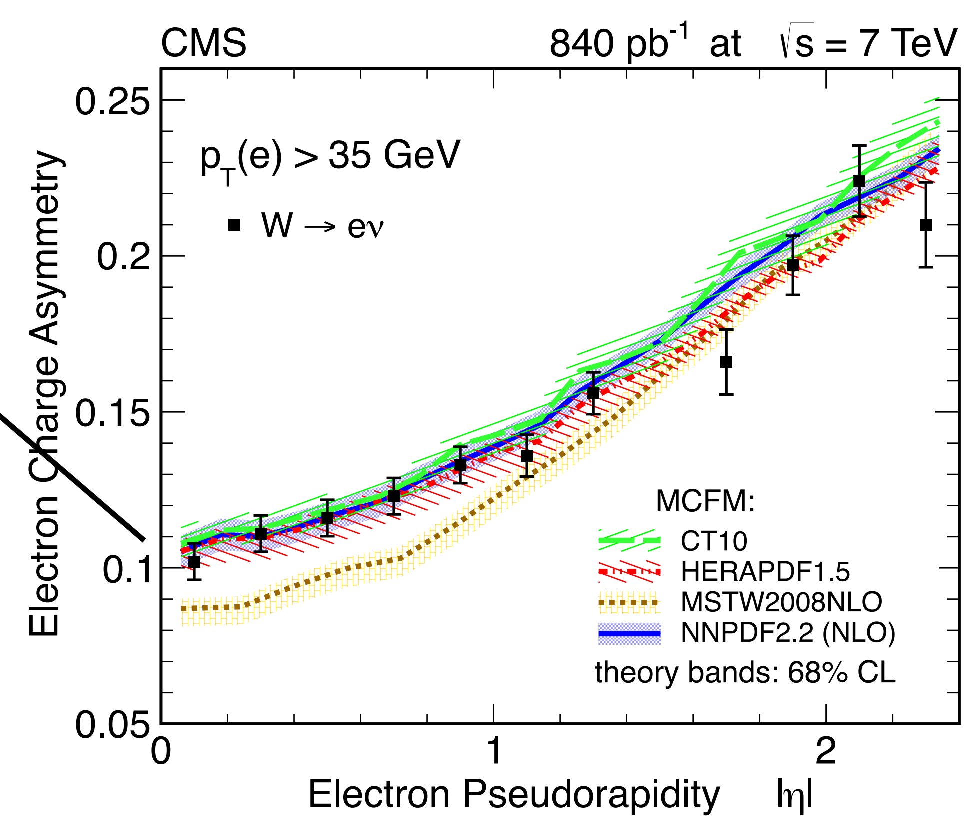
- The differential cross section is found in each |η| bin by fitting $\mathbf{E_T^{miss}}$ **for electrons** and **detector isolation variable ξ for muons**
- Provides stringent constraints for PDFs, since boson rapidity y is directly linked to parton momentum fractions

Muon



PDF uncertainty band corresponds to 68% CL

Electron

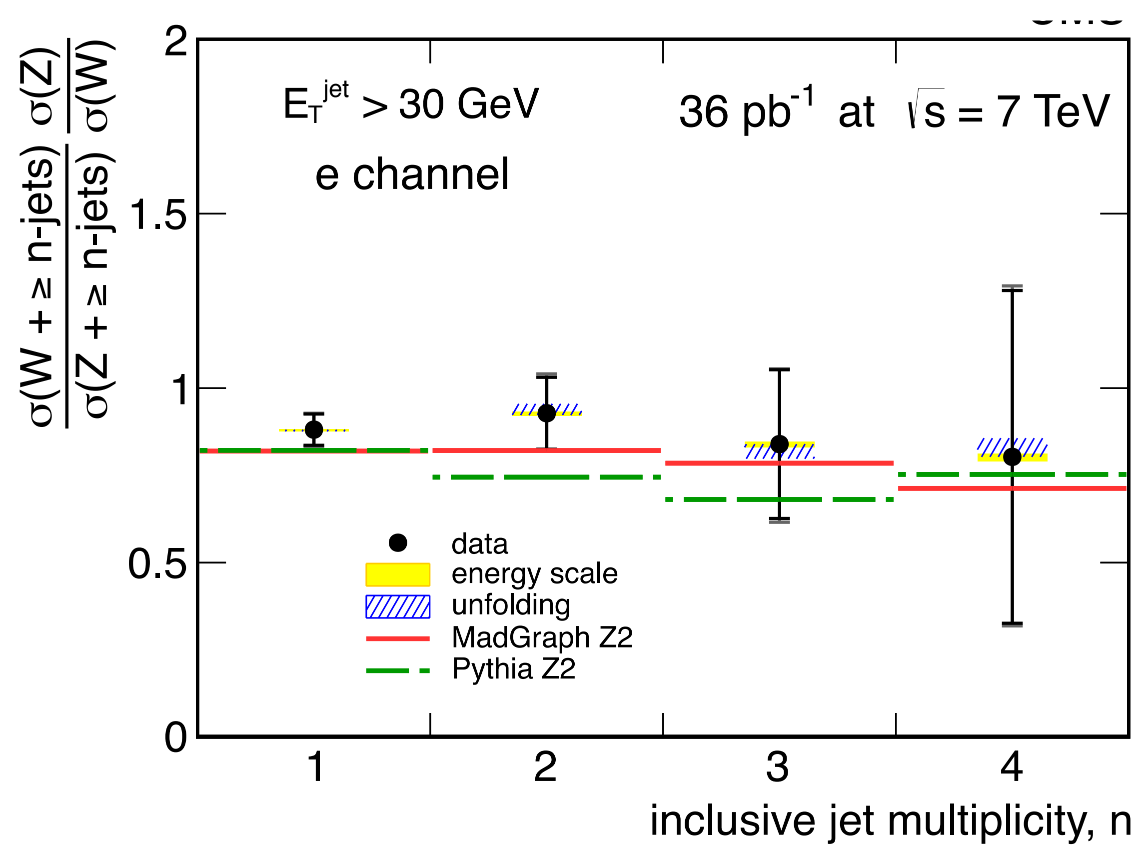


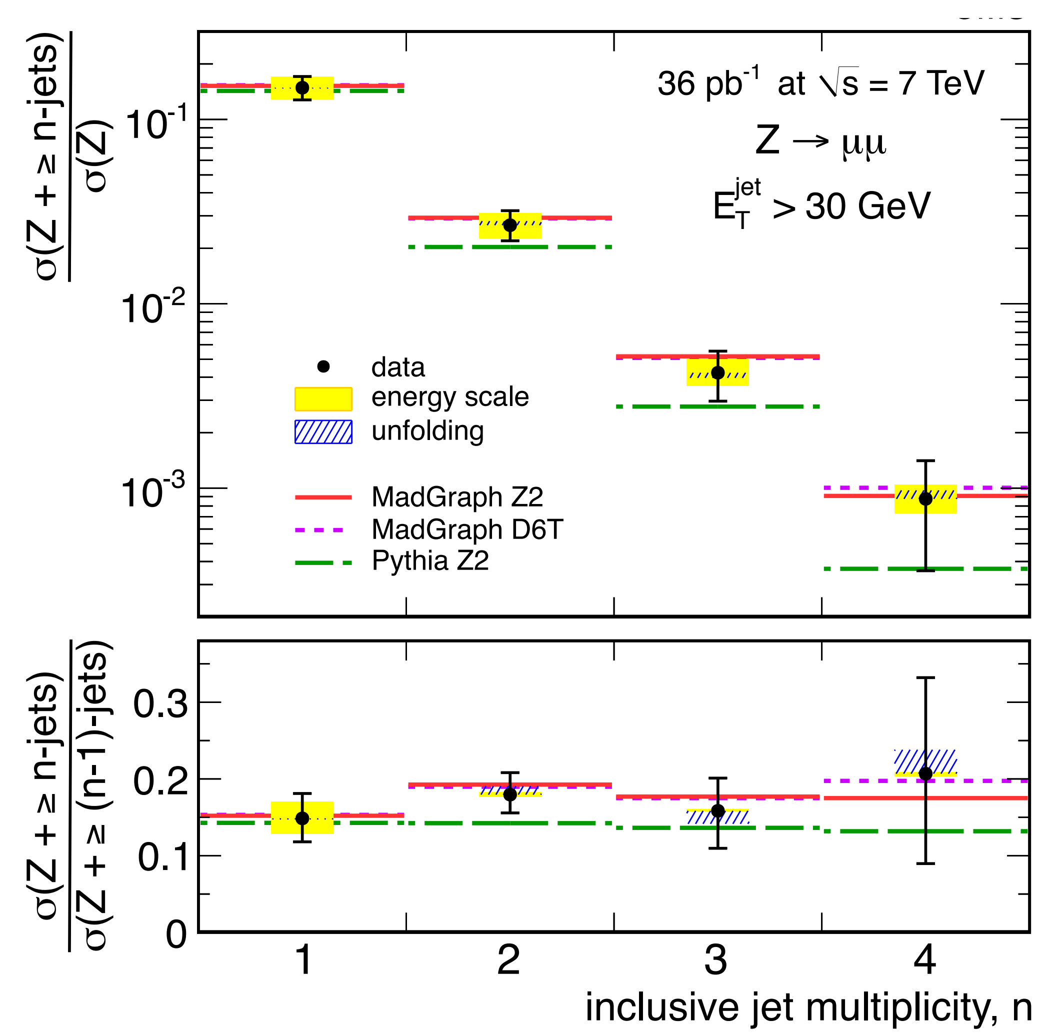
A(η): 0.1 → 0.2 with relative precision: ~ 7%

V+jets production

JHEP 01 (2012) 010

- CMS has published a rich menu of cross sections and ratios of V+jets
- An important test of pQCD
  - Flavor specific final states allow probing different PDFs
  - Test of tree-level matrix element generators V+n jets with n≃0,..,4 (Madgraph, Sherpa,..)
- Important SM candles for detector commissioning



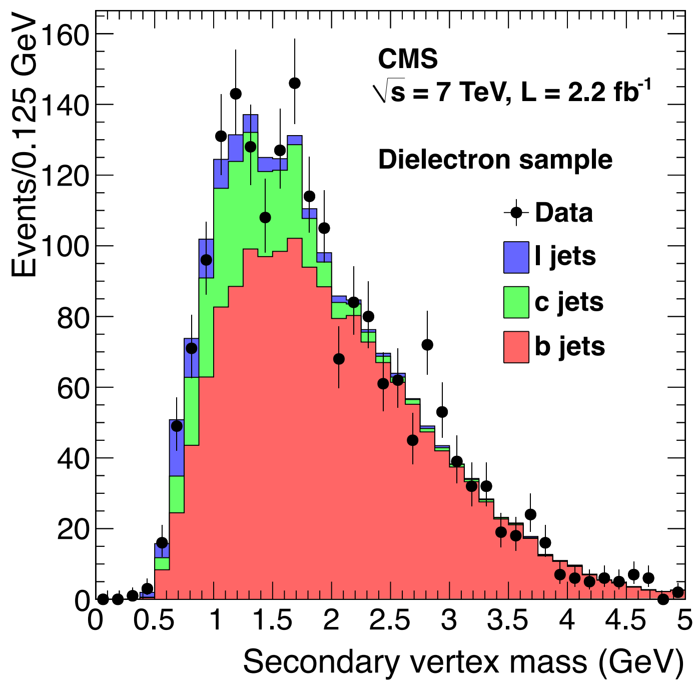


V+HF production

- CMS has studied a vast variety of V+HF production, Z+b, Z+bb, W+c, ..

Measurement of the Z/γ* + b-jet cross section

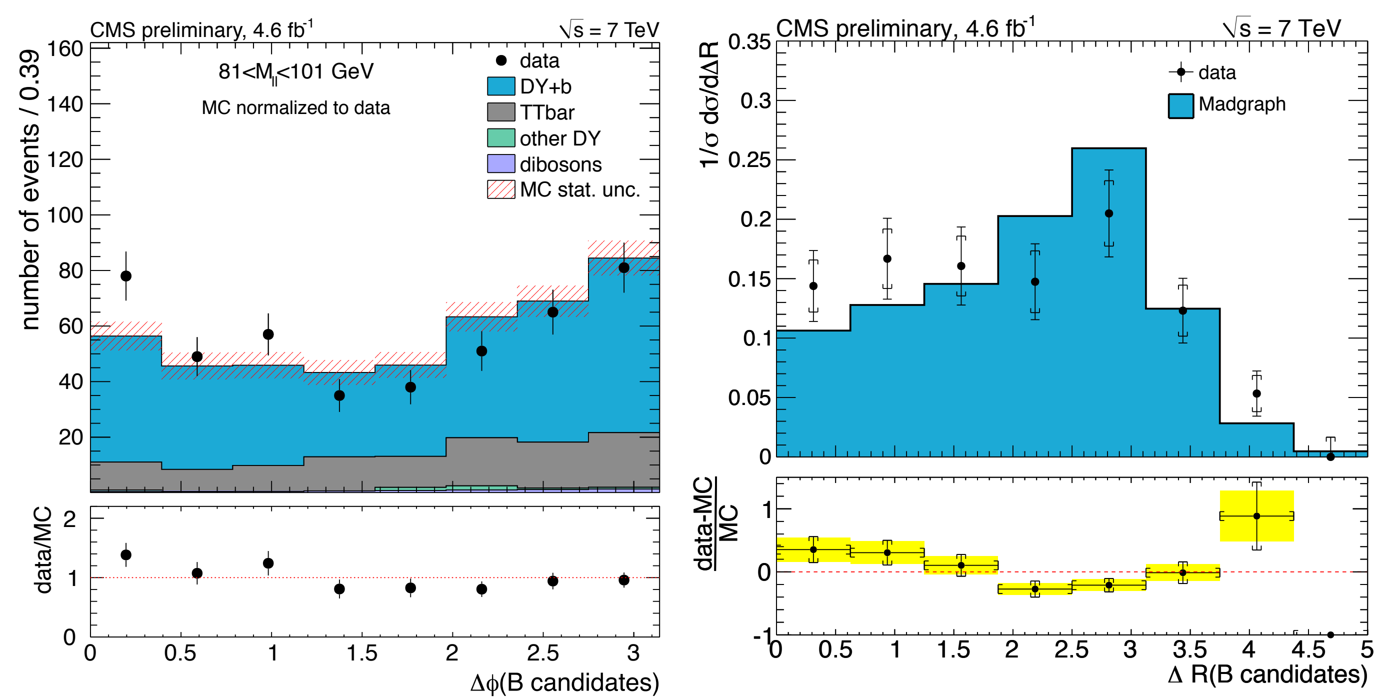
arXiv:1204.1643→JHEP



$$5.84 \pm 0.08\,(\text{stat.}) \pm 0.72\,(\text{syst.})^{+0.25}_{-0.55}\,(\text{theory})\ \text{pb}$$

Angular correlation between B hadrons produced in association with a Z

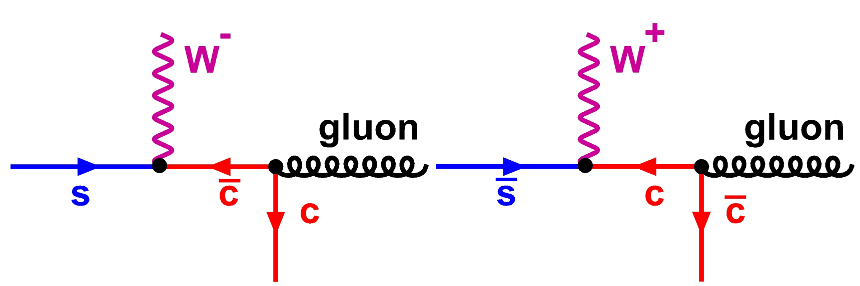
CMS-PAS-EWK-11-015



- Identify displaced secondary vertices with no use of jets
- Obtain normalized production cross section as function of the angular separation
- Compare with QCD predictions at tree-level and NLO accuracy.

Cross section ratios

CMS-PAS-EWK-11-013



a) $\sigma(W^+\bar{c}+X)/\sigma(W^-c+X) = 0.92 \pm 0.19\,(stat.) \pm 0.04\,(syst.)$

b) $\sigma(W+c+X)/\sigma(W+jet+X) = 0.143 \pm 0.015\,(stat.) \pm 0.024\,(syst.)$

Azimuthal Correlations and Event Shape Distributions in Z+jets

- Events: Z+≥ 1,2 3 jets with jet p_T >50 GeV and Z p_T > 0 GeV (all region) and >150 GeV (boosted regime)
  - The boosted regime provides an important phase space for BSM searches with large E_T^{miss}
- Variables are differential cross sections as a function of
  - $\Delta\Phi(Z,J_i)$
  - $\Delta\Phi(J_1,J_k)$, i,k = 1,2,3
  - log of transverse thrust: $\ln(\tau_T) \rightarrow \ln(1-2/\pi) \simeq -1$

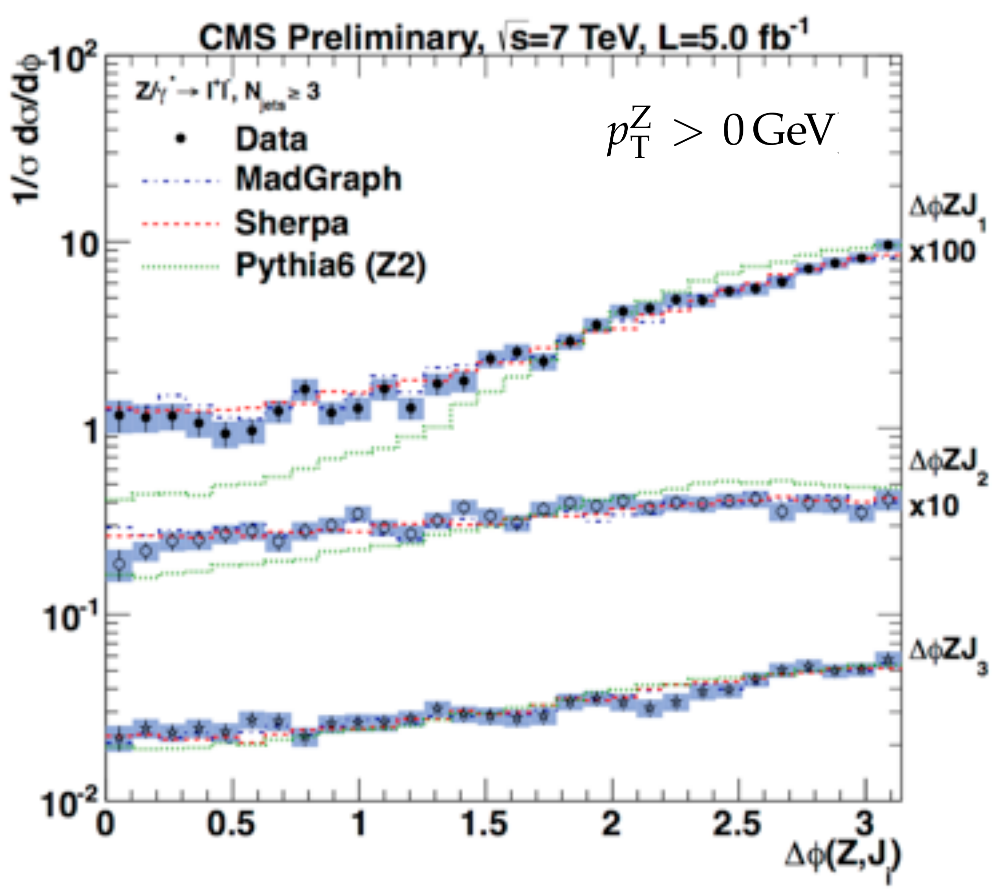
measures radiation along n_T

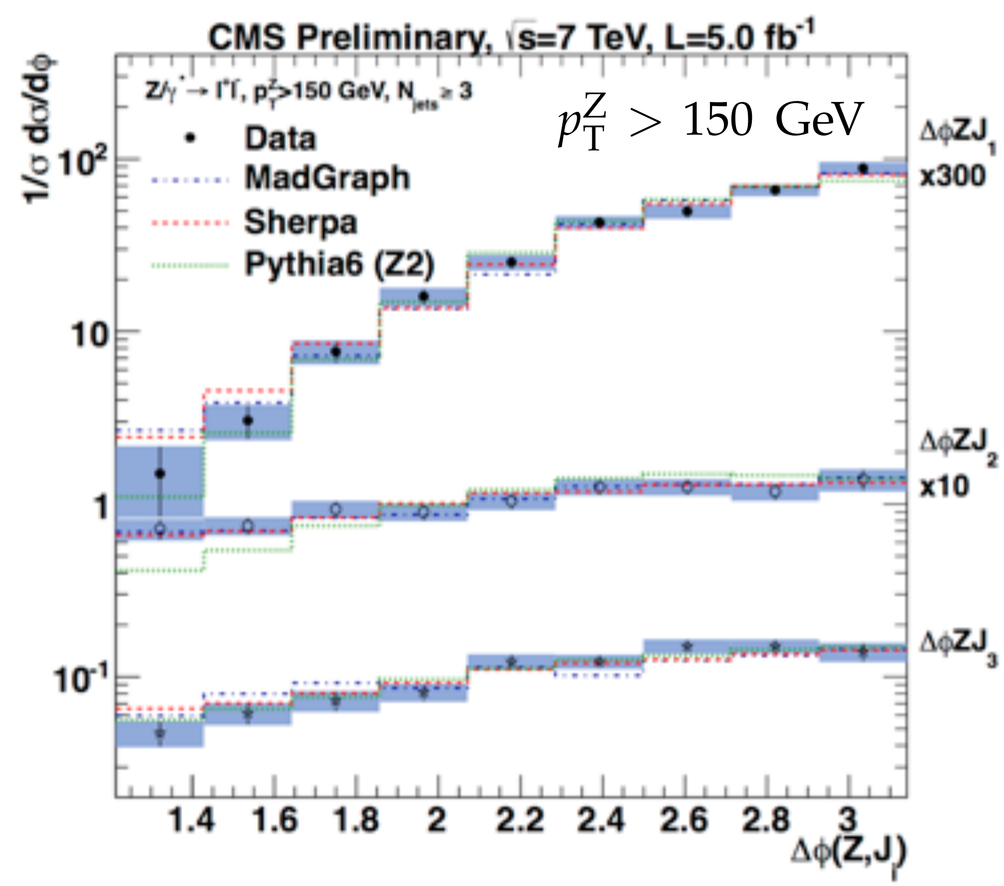
axis that maximize the sum p_T

$$\tau_{\perp,\mathcal{C}} \equiv 1 - \max_{\hat{n}_T} \frac{\sum_i |\vec{p}_{\perp,i} \cdot \hat{n}_T|}{\sum_i p_{\perp,i}}$$

CMS-PAS-EWK-11-021

NEW





- Pythia gauges the additional corrections from LO ME formulation interfaced with parton showers
- Pythia alone provides adequate description of event topology with increase phase space for parton emission (boosted regime)

WW→2l2ν measurements

NEW

CMS-PAS-SMP-12-013

Signal and background yields

Sample	yield ± stat. ± syst.
gg→WW	43.3 ± 1.0 ± 13.4
qq→WW	640.3 ± 4.9 ± 47.4
Total Background	292.7 ± 22.3 ± 31.8
Signal + Background	976.3 ± 22.9 ± 63.9
Data	1111

8 TeV

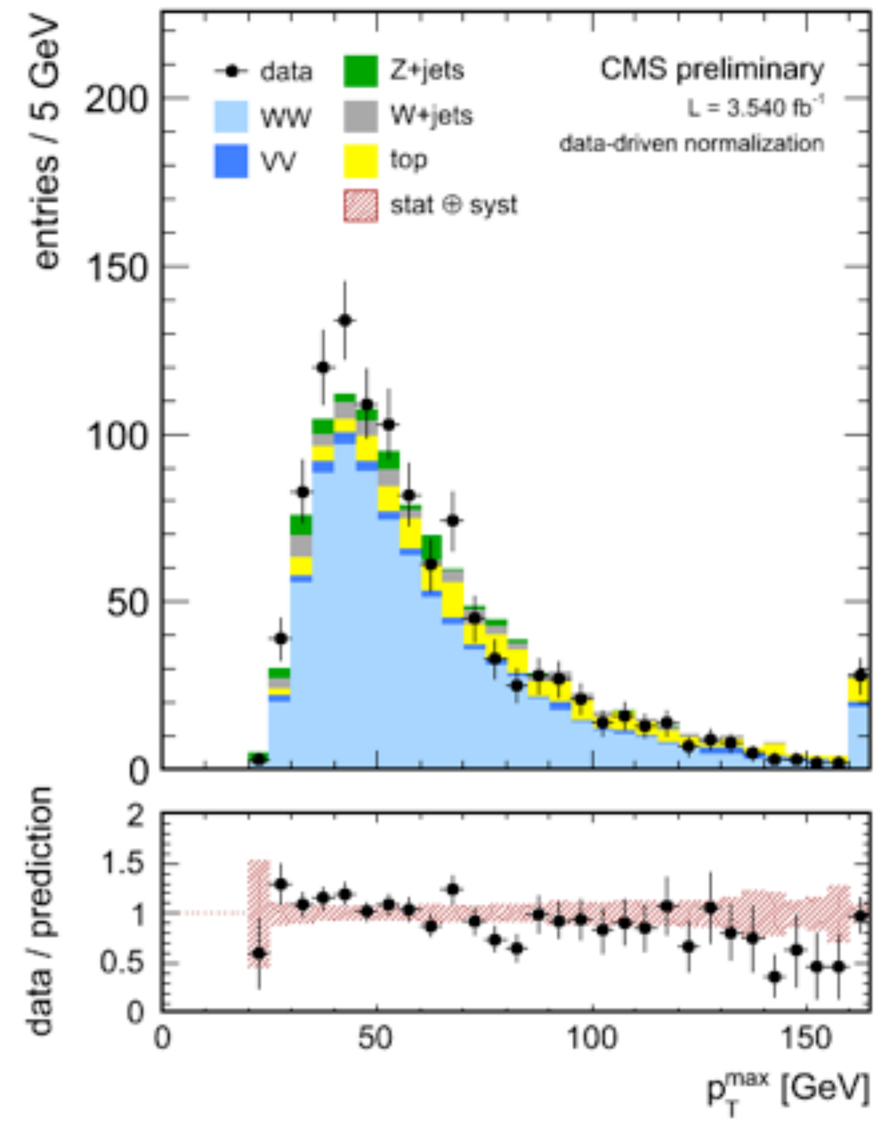
σ = 69.9 ± 2.8 (stat) ± 5.6 (sys) ± 3.1 (lum) pb
NLO prediction (MCFM): 57.3 ± 2.0 pb

- 4% stat precision. Main systematics:
  - Theory (PDF and jet veto)5%, Luminosity 4.4%

7 TeV

σ = 52.4 ± 2.0 (stat) ± 4.5 (sys) ± 1.2 (lum) pb
NLO prediction (MCFM): 47.0 ± 2.0 pb

- Consistent with NLO



1.8σ above NLO prediction

Could be a conspiracy of syst bias & upward fluctuation, but has generated some buzz ...

Charginos Hiding In Plain Sight

David Curtin,[1] Prerit Jaiswal,[1,2] and Patrick Meade[1]

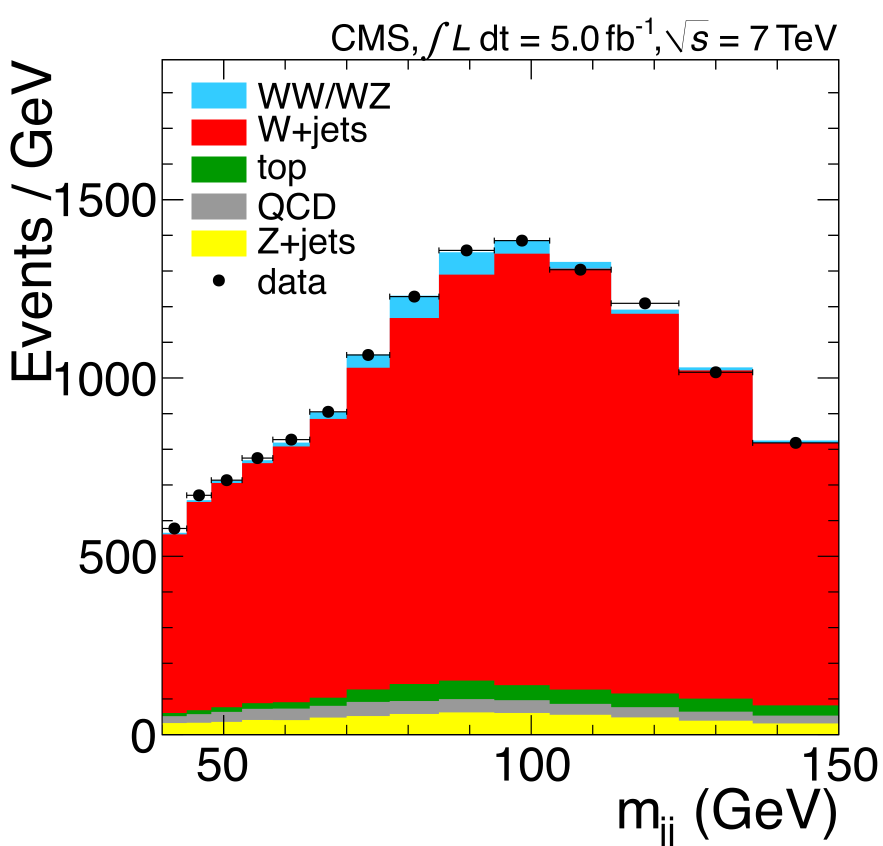
arXiv:1206.6888v2

WW/WZ→lνqq measurements @ 7 TeV

NEW

CMS-PAS-SMP-12-015

- Jet resolution doesn't allow to cleanly separate WW from WZ
- Fit the dijet mass spectrum
  - W+2j background is constrained in a data-driven manner by floating a linear combination of shapes with LO scales
  - QCD constrained using data. Other backgrounds constrained using (N)NLO predictions



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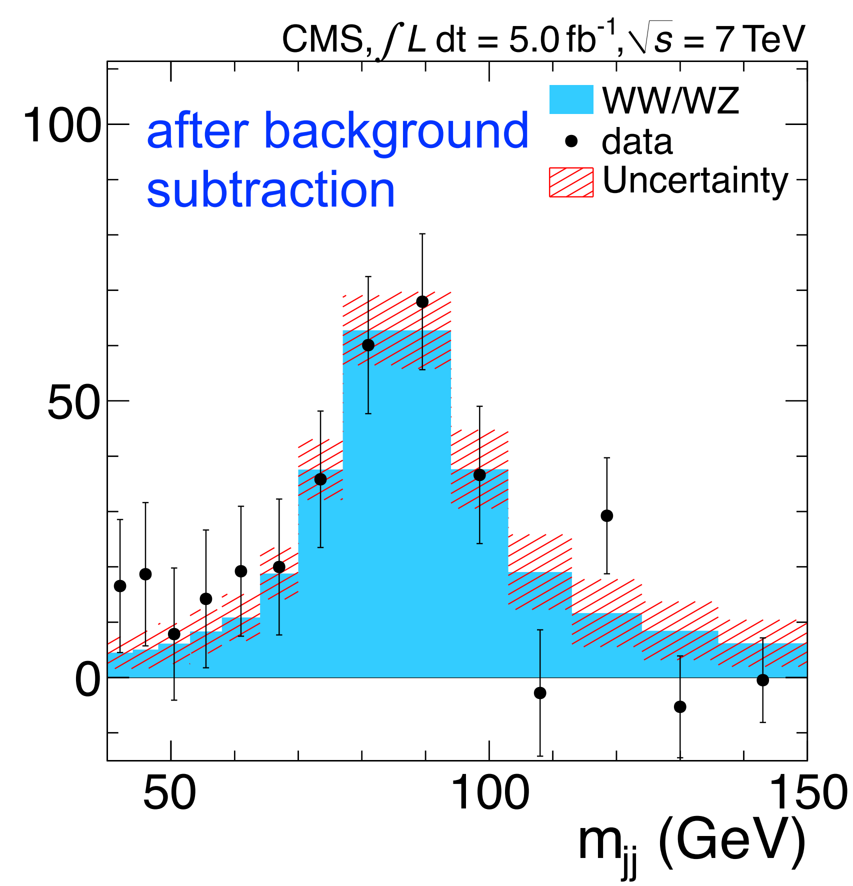


7 TeV

σ = 68.9 ± 8.7 (stat) ± 9.7 (sys) ± 1.5 (lum) pb
NLO prediction (MCFM): 65.6 ± 2.2 pb

- Consistent with NLO

•The first observation of diboson in semi-leptonic channel at LHC.

#diboson = 2682 ± 339(stat) ± 357(syst)
NLO prediction = 2564

ZZ→4l measurements

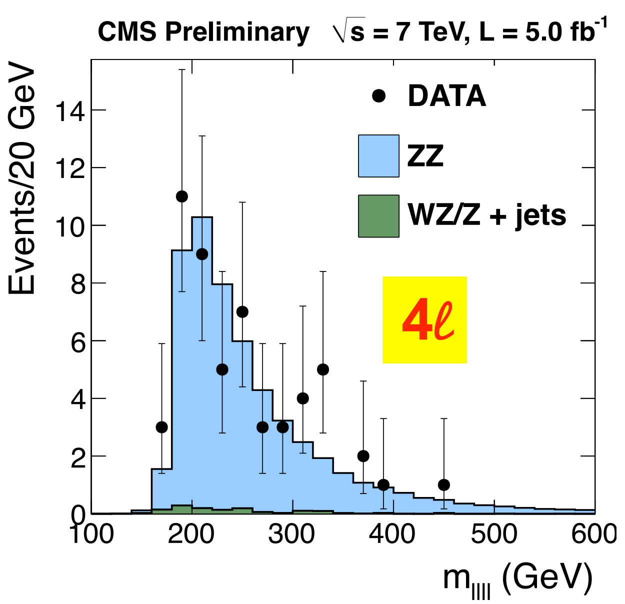
NEW

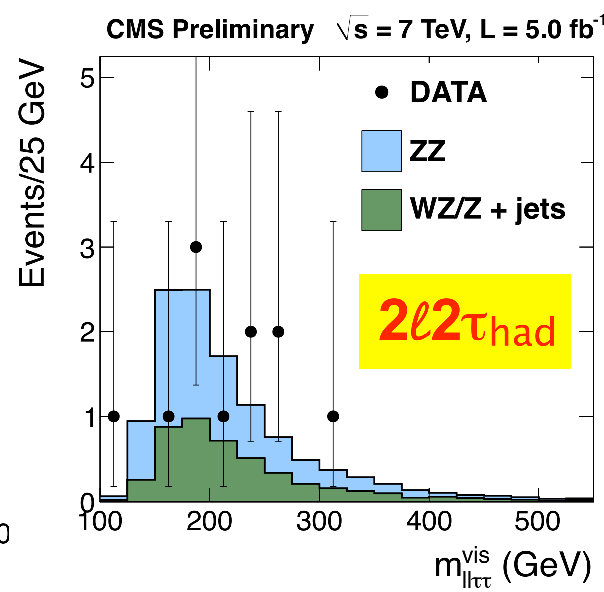
- Event Selection
  - Lepton P_T: e >7 GeV, μ >5 GeV, τ_{had} >10 GeV
  - 60 < m_Z < 120 GeV (30 < m^{vis} < 80 for l+τ_{had})

7 TeV CMS-PAS-SMP-12-007

8 TeV CMS-PAS-SMP-12-014

7 TeV





Channel	ZZ expected	Backgr-d	Observed
4e	10.5	0.5	9
4mu	15.9	0.2	14
2e2mu	26.7	0.6	31
Total		54.4	54
2l2tau	7.0	4.4	11
4l+2l2tau		65.8	65

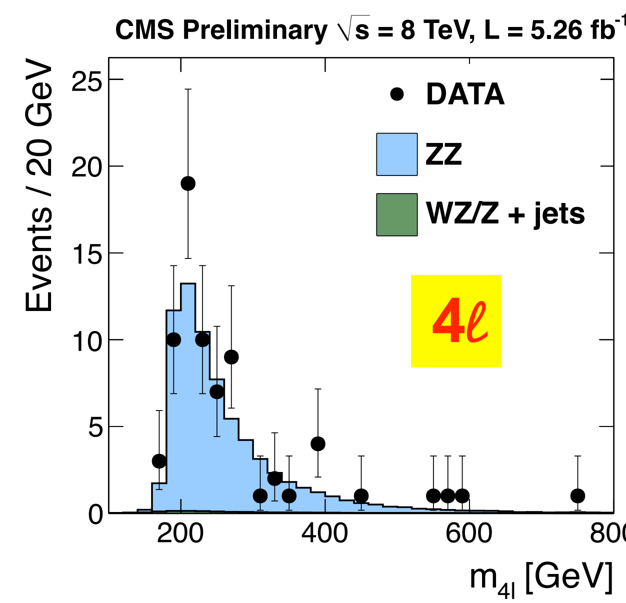
7 TeV

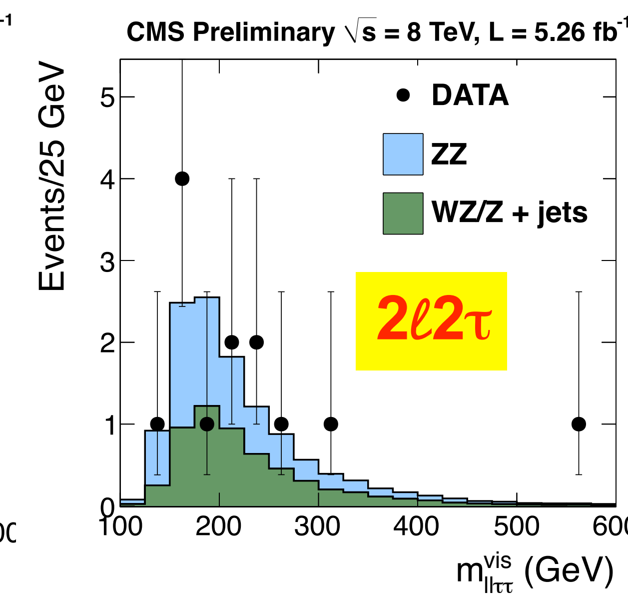
σ = 6.2 ± 0.9 (stat) ± 0.4 (sys) ± 0.1 (lum) pb

NLO prediction (MCFM): 6.3 ± 0.4 pb

- Consistent with NLO

8 TeV





Channel	ZZ expected	Backgr-d	Observed
4e	11.6	0.4	14
4mu	20.3	0.4	19
2e2mu	32.4	0.5	38
Total		65.6	71
2l2tau	6.5	5.6	13
4l+2l2tau		77.7	84

8 TeV

σ = 8.4 ± 1.0 (stat) ± 0.7 (sys) ± 0.4 (lum) pb

NLO prediction (MCFM 6.0): 7.7 ± 0.4 pb

- Consistent with NLO

Anomalous triple gauge boson couplings

NEW

CMS-PAS-SMP-12-015 **WW/WZ** **7 TeV** CMS-PAS-SMP-12-007 **ZZ**

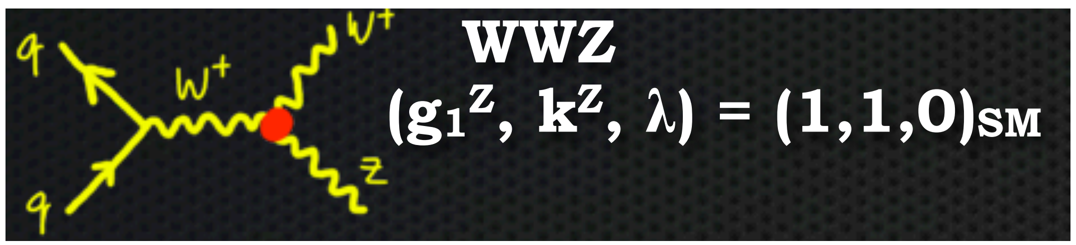
Scale dependent form-factor with cutoff scale Λ

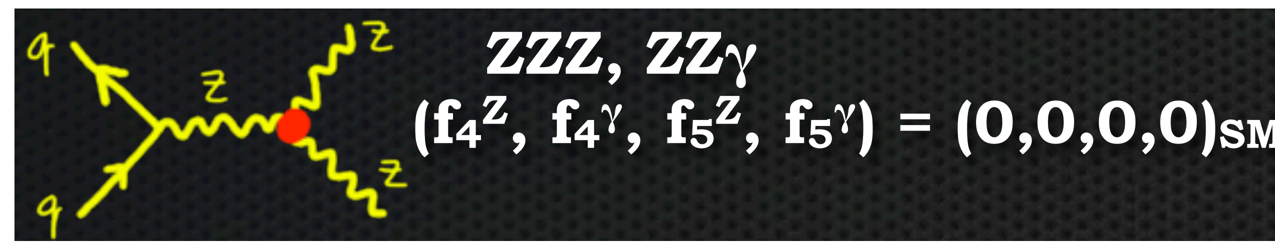
$$\alpha(\hat{s}) = \frac{\alpha_0}{(1+\hat{s}/\Lambda^2)^2}$$

- Possible vertices using an effective Lagrangian

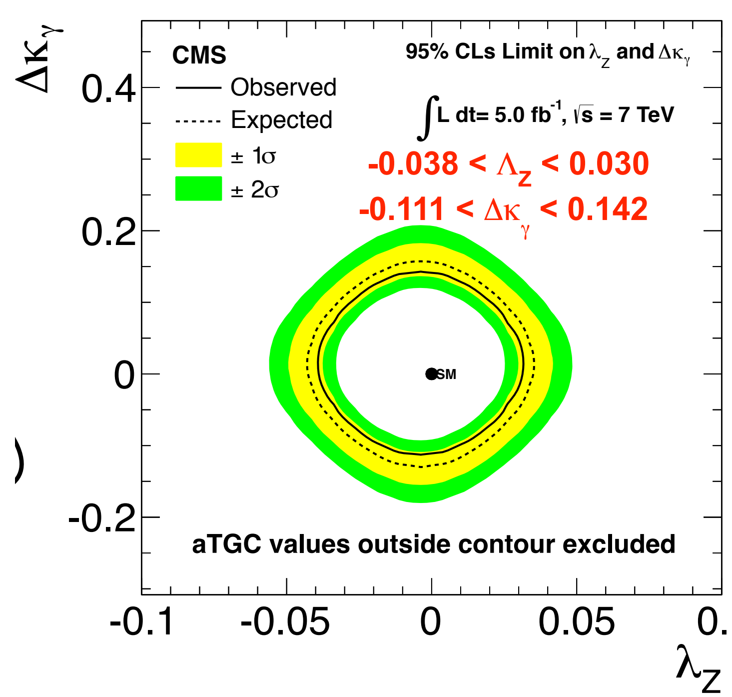
$$\frac{\mathcal{L}_{WWV}}{g_{WWV}} = i\left[g_1^V(W^\dagger_{\mu\nu}W^\mu V^\nu - W_{\mu\nu}W^{\dagger\mu}V^\nu) + \kappa^V W^\dagger_\mu W_\nu V^{\mu\nu} + \frac{\lambda^V}{m_W^2}W^\dagger_{\rho\mu}W^\mu_\nu V^{\nu\rho}\right]$$

$$\mathcal{L}_{VZZ} = -\frac{e}{M_Z^2}\left[f_4^V(\partial_\mu V^{\mu\beta})Z_\alpha(\partial^\alpha Z_\beta) + f_5^V(\partial^\sigma V_{\sigma\mu})\tilde{Z}^{\mu\beta}Z_\beta\right]$$

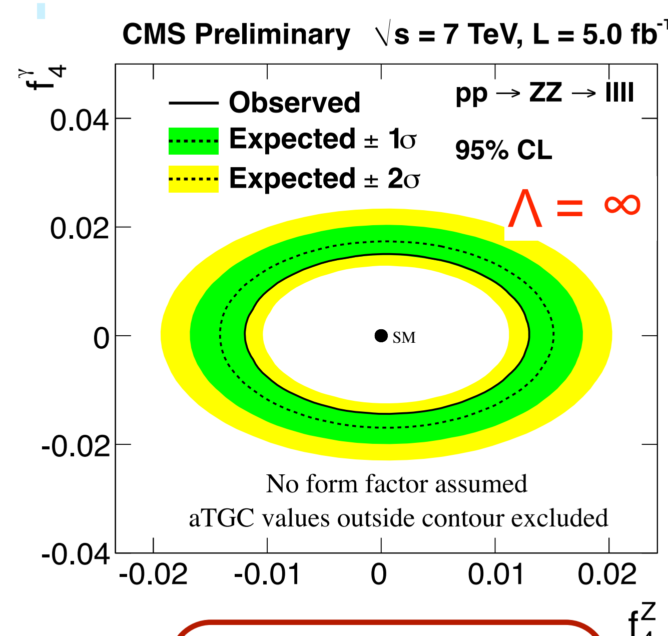


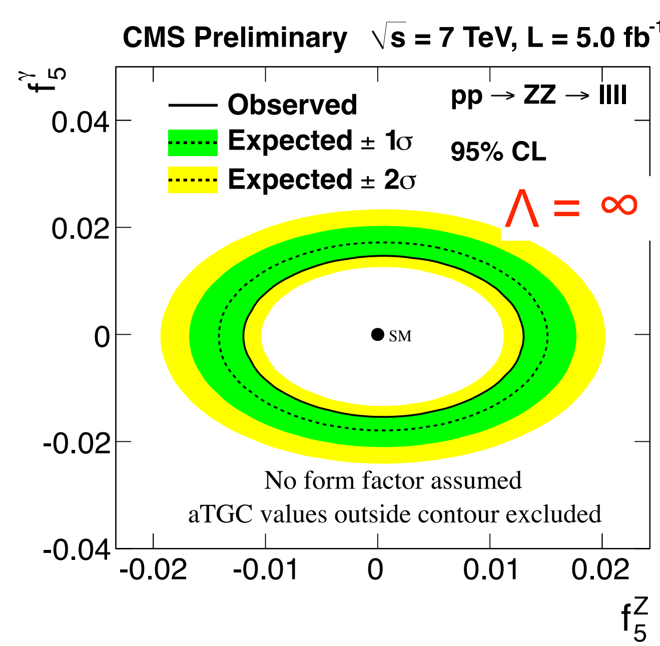


Use dijet (hadronic W) p_T as the observable



Use m_{4l} as the observable





$-0.012 < f_4^Z < 0.013$

$-0.012 < f_5^Z < 0.013$

$-0.014 < f_4^\gamma < 0.014$

$-0.015 < f_5^\gamma < 0.015$

Competitive to world average(LEP combination). Will surpass with 8 TeV data

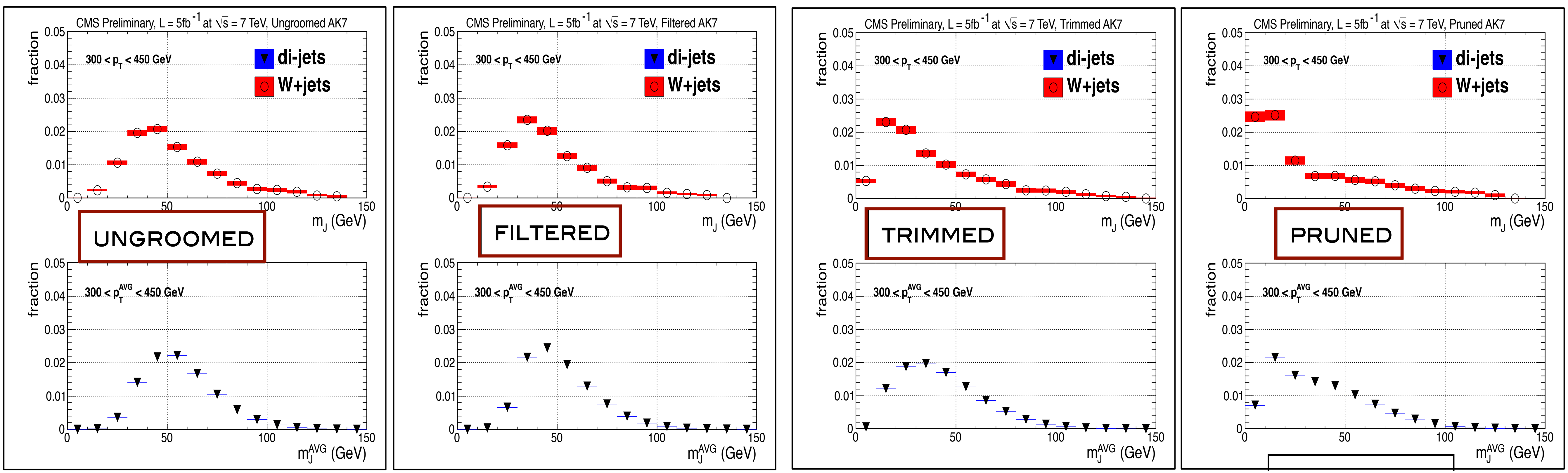
CMS limits are an order of magnitude more constraining than LEP

NEW

Jet mass in dijet and V+jets events

CMS-PAS-SMP-12-019

- It is necessary to understand the high p_T **“boosted” boson** production in the future, SM or Higgs-like or exotic scenarios
- This is a study of the behaviors of those algorithm in ordinary jet production, which is the main background to such an application
- Unfold the jet mass distributions in dijet and V+jet channels for a variety of recently proposed jet algorithms: **ungroomed, filtered, trimmed, and pruned jets**



- Difference in jet mass for di-jet and V+jet processes where the former (latter) radiates more (less) due to lager composition of gluon (quark)-initial jets

Conclusion

- CMS has realized full-fledged top and electroweak physics research programs in 2.5 years of operation at 7 TeV and 8 TeV

Double and single top production
Top Mass
Top properties
Precision W and Z studies
Multiboson x-sections
Diboson production: aTGC
W,Z + jets studies

- It has produced several worlds best results
- It's a fully operational machine for discoveries of all varieties

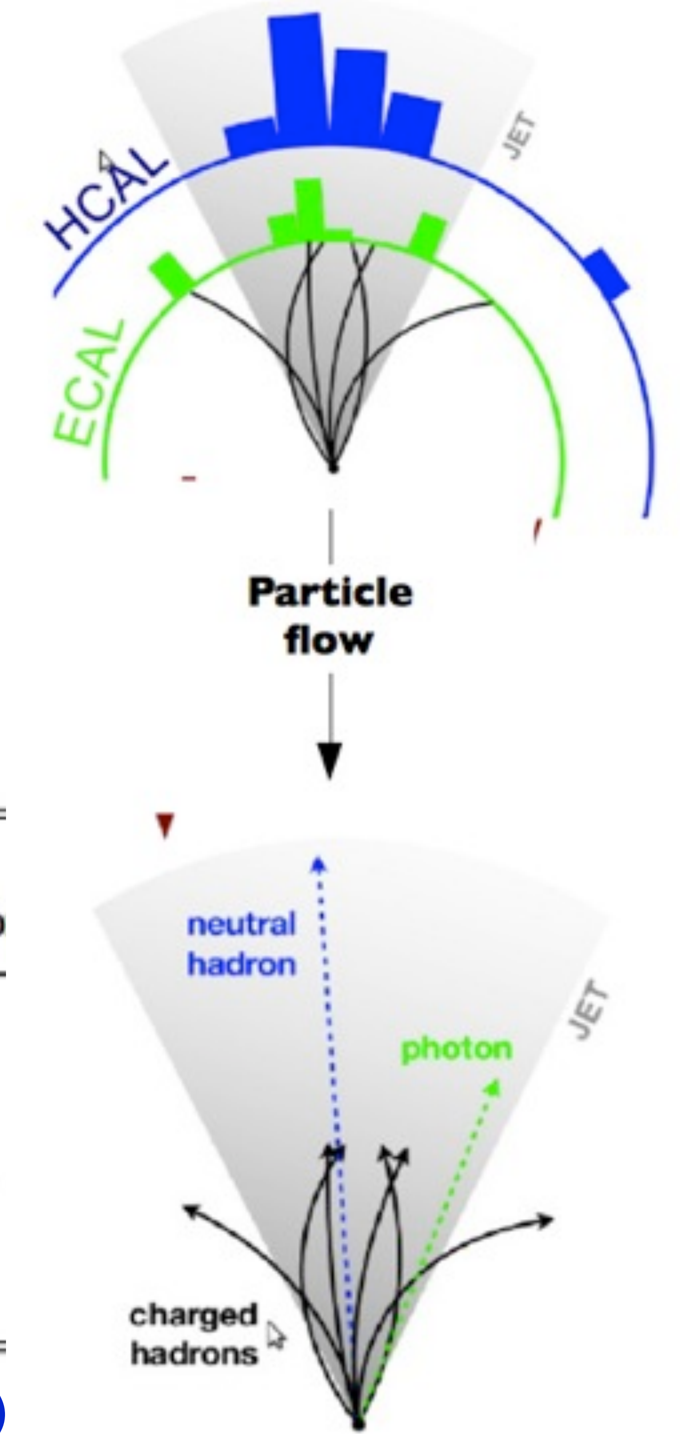
Thank you!


CERN
CMS
The Compact Muon Solenoid
Letter of Intent
Happy 20th Birthday,
CMS!
October 1992 — October 2012

Extra material

Global Event Description

- Charged-based separation of components making best use of
  - field integral $B \times R = 4.9\ \mathrm{T \cdot m}$
  - calorimeter granularity $\Delta\eta \times \Delta\phi|_{\mathrm{ECAL}} \sim 0.017^2$
    $\Delta\eta \times \Delta\phi|_{\mathrm{HCAL}} \sim (5 \cdot \Delta\eta) \times (5 \cdot \Delta\phi)|_{\mathrm{ECAL}}$
  - iterative tracking(progressively relaxing constrains/removing hits)
  - linking algorithm yields blocks sub-detector elements called **particle candidates**
- Particle flow provides a global description of each event
- A reconstructed jet is "again" a cluster of particles



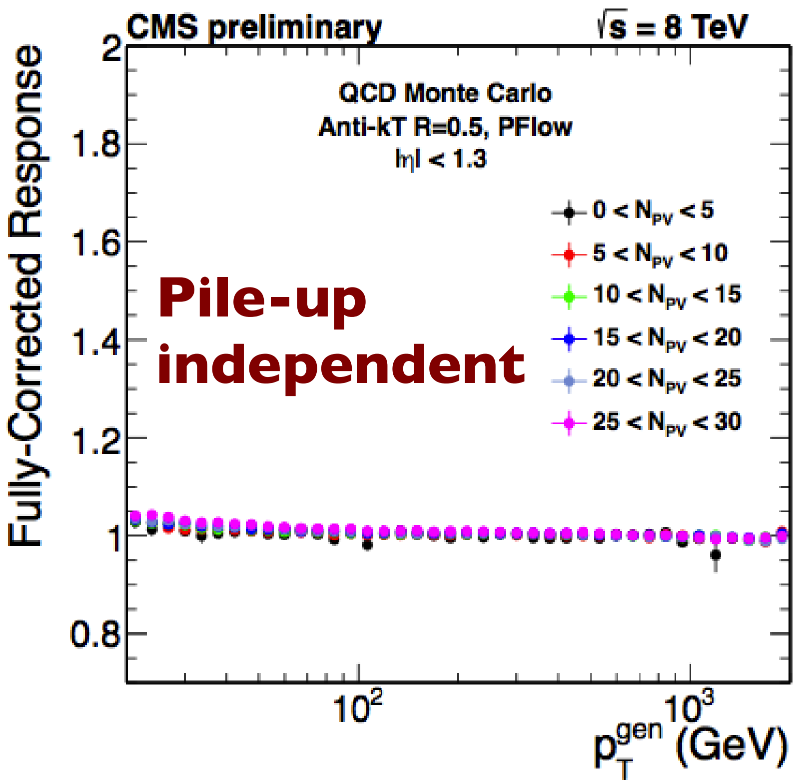
Algorithm	Calorimeter-based	Particle Flow		
Composition	Towers	Charged Hadrons	Photons	Neutral hadro
Energy fraction	100%	65%	25%	10%
Energy	$E_{HCAL} + E_{ECAL}$		$\sum_{k=h^\pm,h^0,\gamma,\ell} E_k$	
Resolution (σ)	$120\% \sqrt{E}$	$1\%\ p_T$	$1\% \sqrt{E}$	$120\% \sqrt{E}$
Direction	biased by $\vec{B}$	vertex-based	good resolution	-

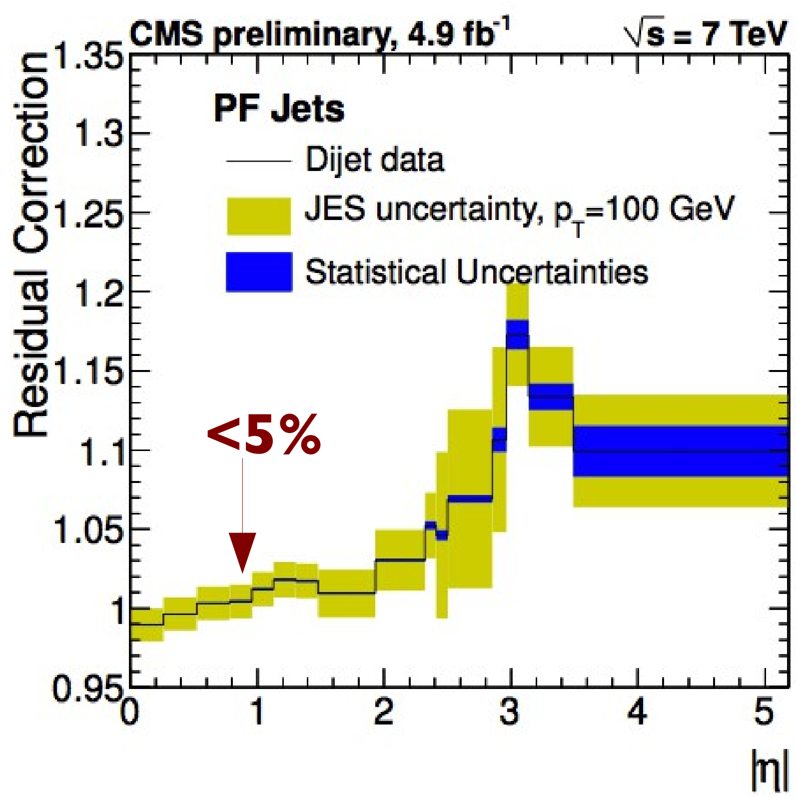
- crucial for b-jets (e.g. reduce material budget uncertainty on energy scale)
- crucial for missing transverse energy $\vec{p}_{\mathrm{T}}^{\,\mathrm{miss}} = -\sum_{k=h^\pm,h^0,\gamma,\ell} \vec{p}_{\mathrm{T},k}$

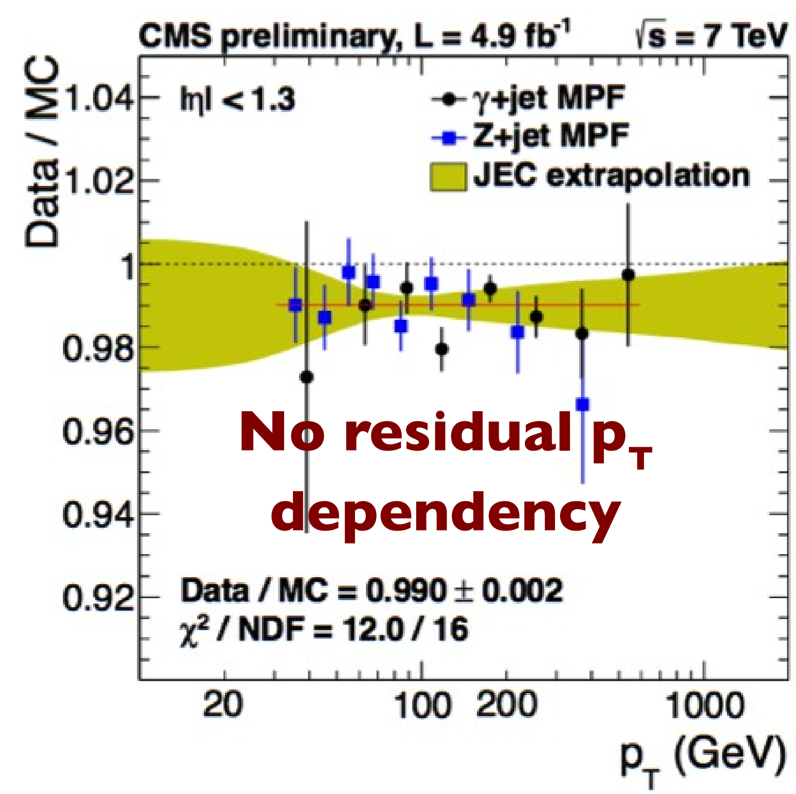
Jet calibration at CMS-I

P. Silva
CERN PH-LHC Seminar

- Jets are reconstructed with the **anti-kT algorithm (R=0.5)**
- Factorized approach for jet calibration in CMS
  - **Offset** corrections for pile-up and electronic noise
  - Corrections for **detector calibration and reconstruction efficiencies** (MC-based)
  - relative residual η **dependency corrections** (data-based) **absolute and residual p_T** corrections (data-based)

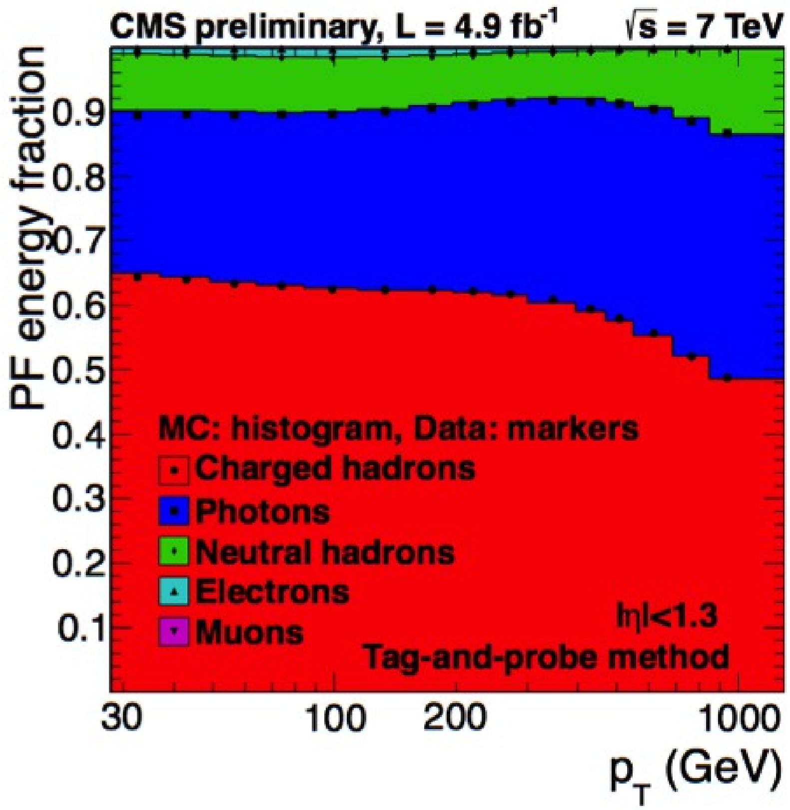


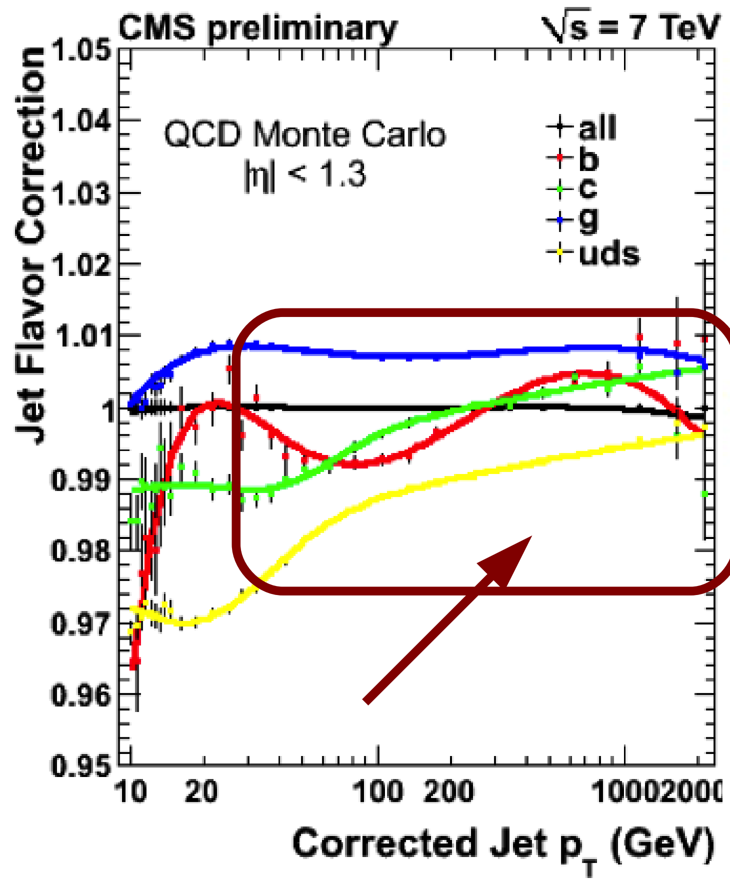


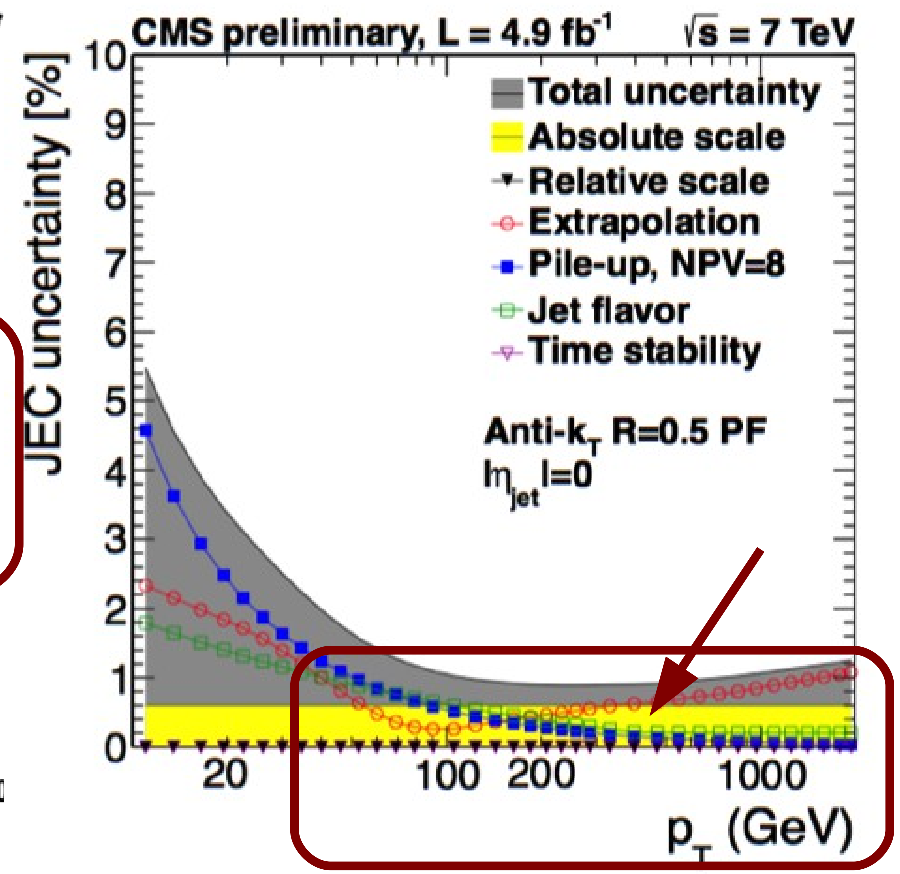


Achieve <2% uncertainty on energy scale and ~10% on energy resolution

b-jet Identification at CMS-I



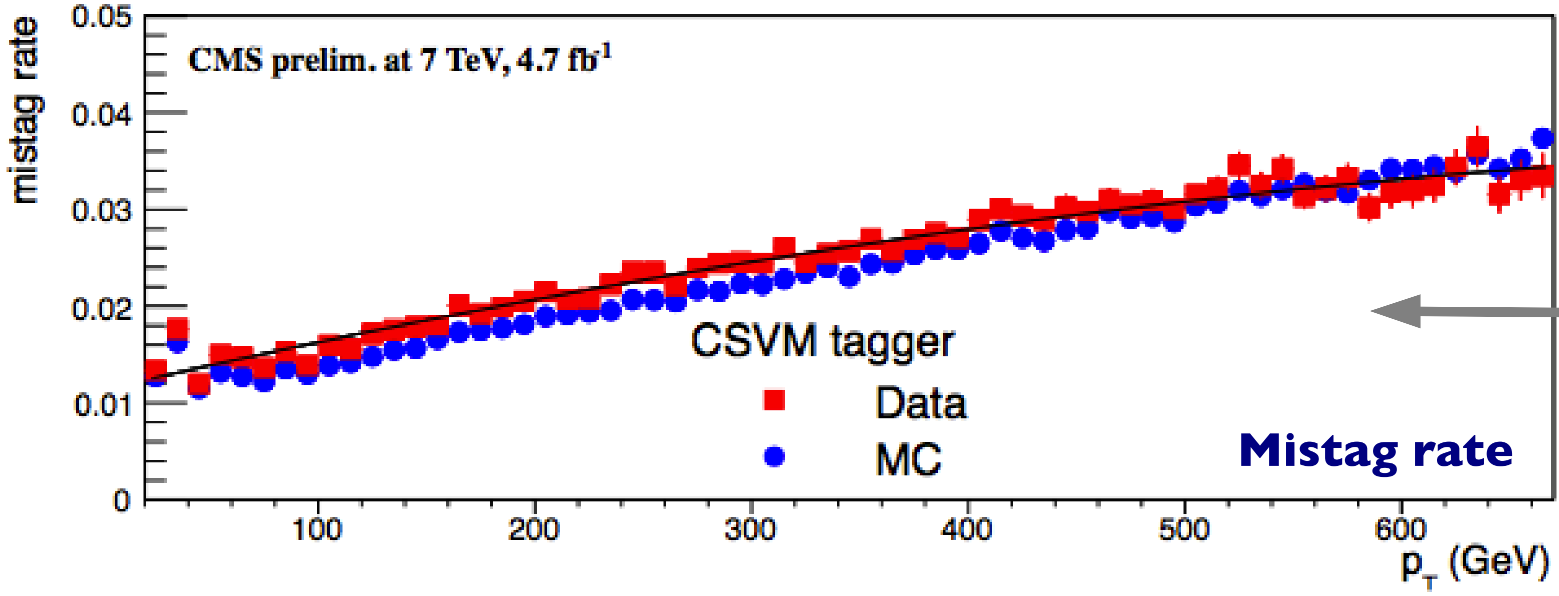


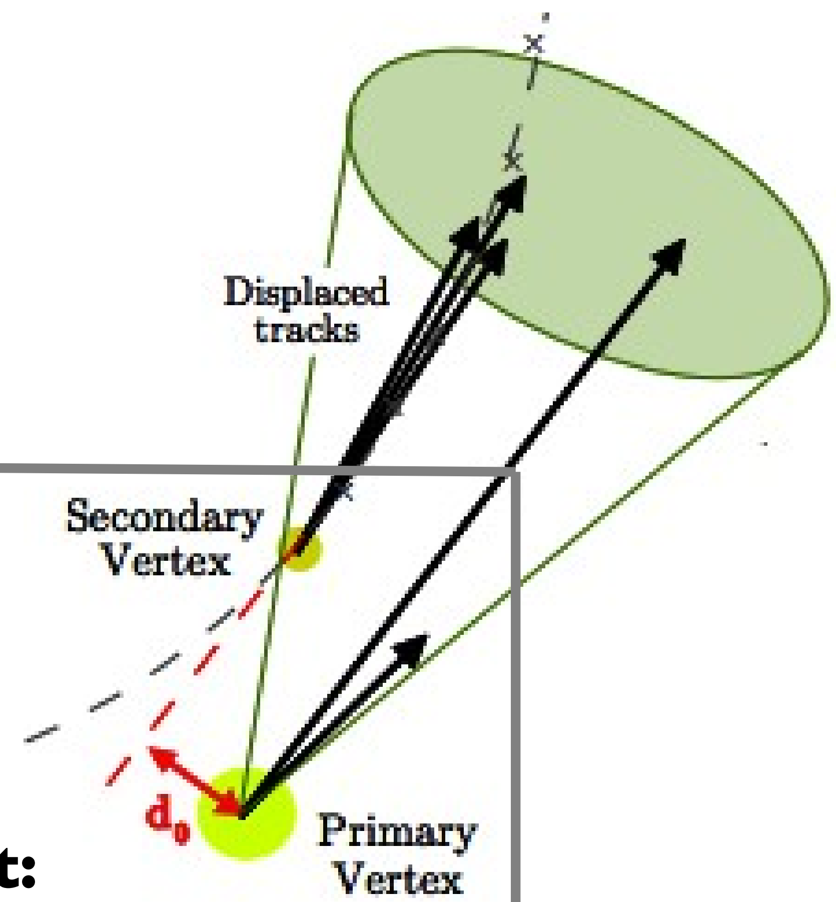


Contribution of particle flow jet components to jet energy scale is understood to within <1%

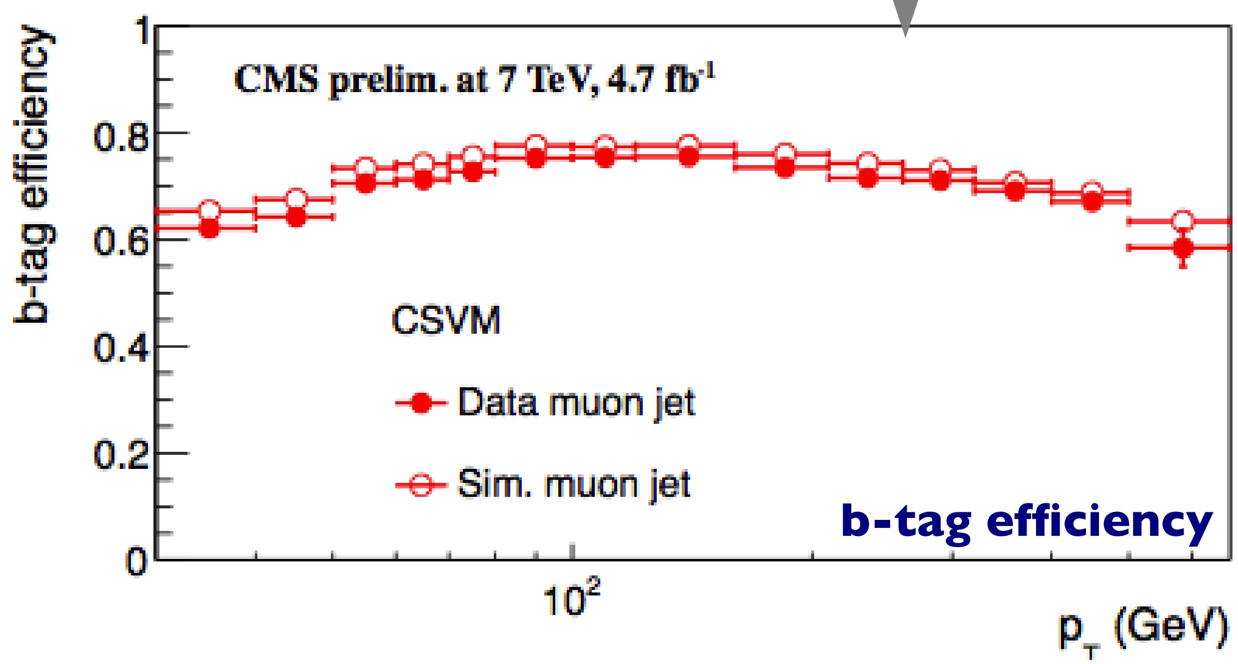
- **Flavor specific corrections within 1-3%** of the absolute correction
  - b-jet response is within 1% for pT>15 GeV
  - pure flavor modeling within 1.5% comparing Pythia6 vs Herwig++
- We factorize **16 independent sources** of jet energy scale uncertainty correlations
  - key feature: sources may cross 0 and produce anti-correlations
  - e.g. extrapolation includes fragmentation (*correlated*) and π response (*anti-correlated*) components

b-jet identification at CMS-I



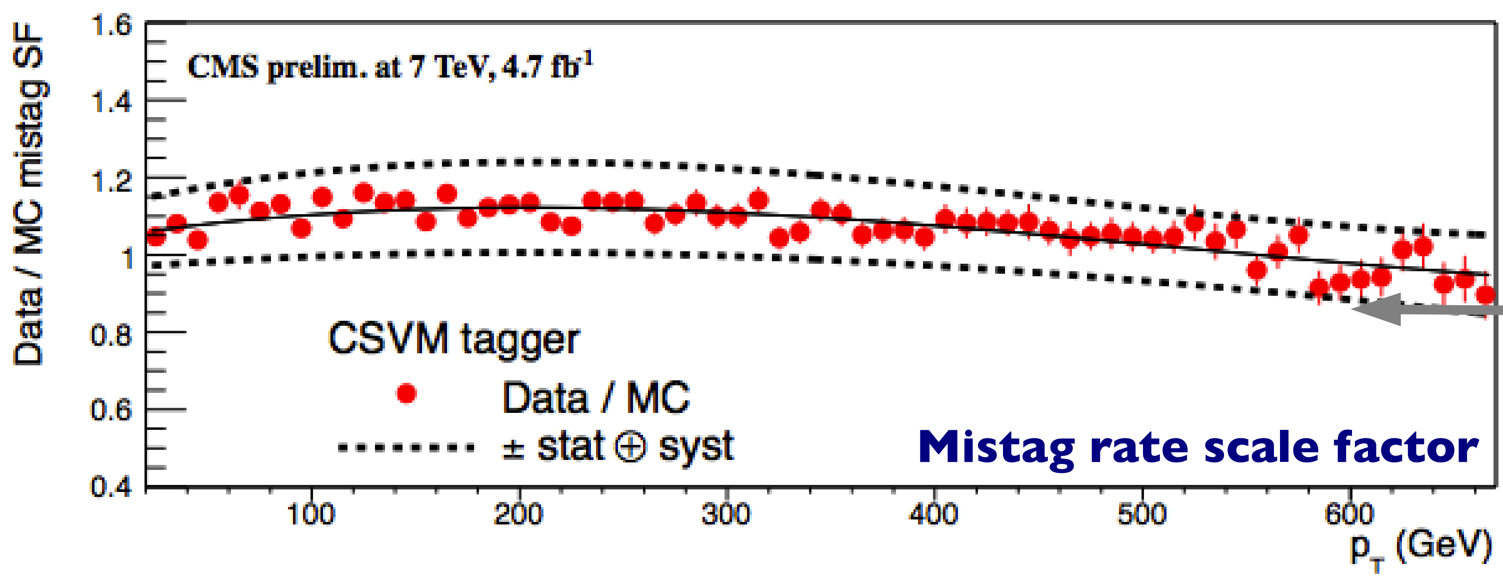


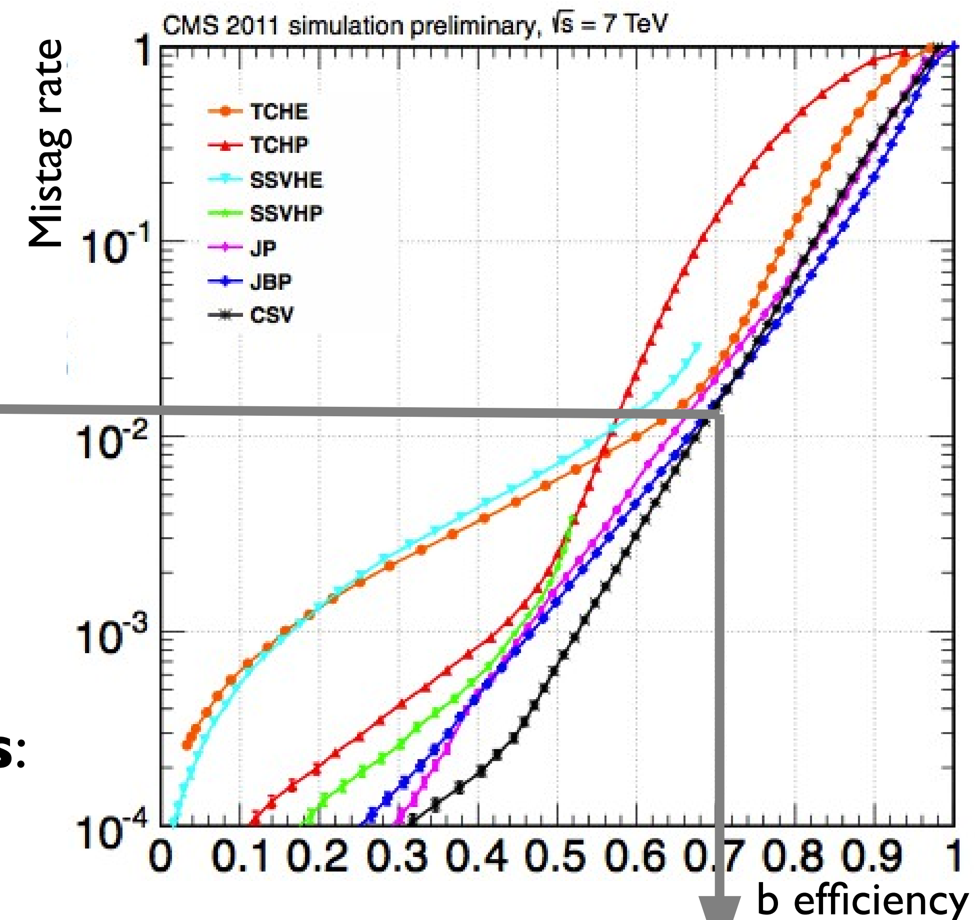
- **Jets stemming from the hadronization of b's are distinct:**
  - Large lifetime of B-hadrons τ ~ 1.5 ps
  - yields displaced decays cτ ~ 492 μm
  - massive secondary vertices M_{secVtx}~ 3 GeV (M_B~5 GeV)
  - may contain soft leptons $BR(B \rightarrow l\nu_l+X)$ ~ 20%



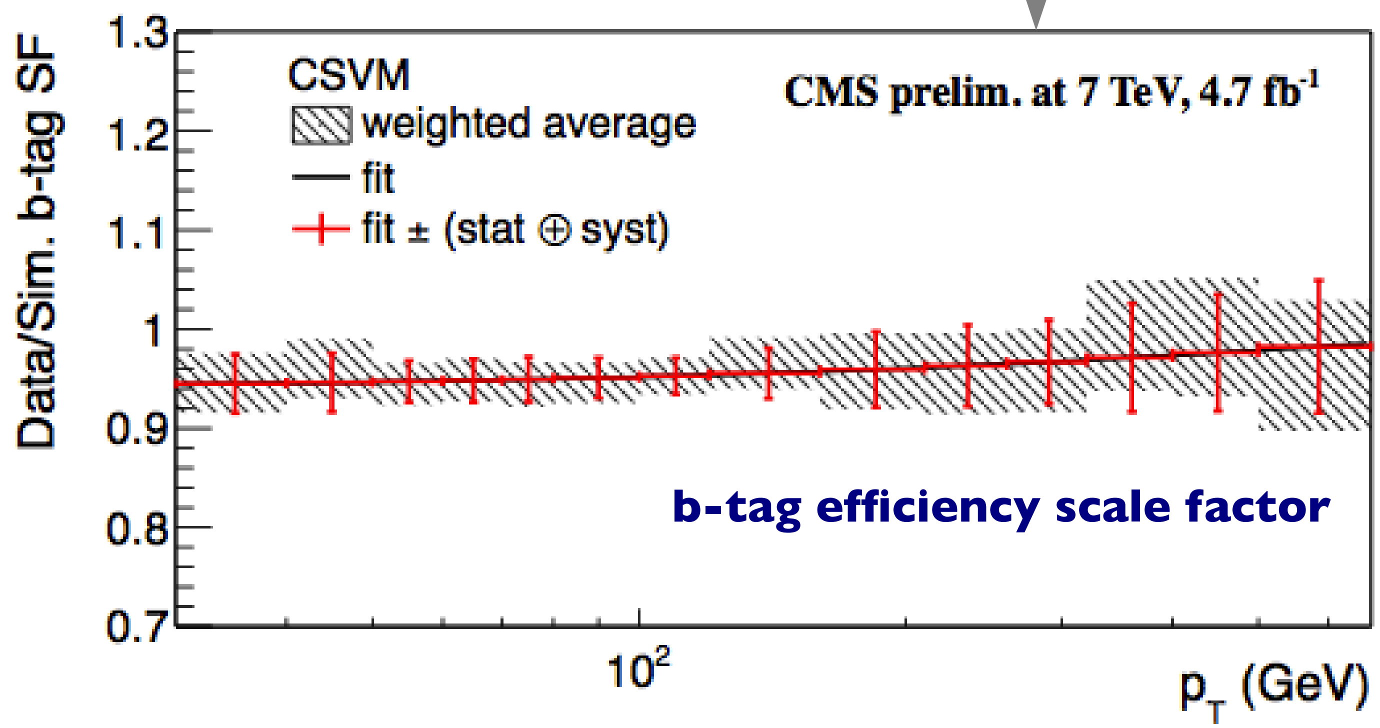
- **Identification algorithms** characterized by **efficiency** and **mistag rate** (probability to mis-identify c- or light flavoured-jets)

b-jet identification at CMS-2





- Efficiency measurement affected by different **uncertainties**:
  - Gluon splitting and flavour composition
  - Jet trigger and offline selection
  - Template shapes, pileup, etc.
- **Combine different measurements**
  - Different sensitivity to different systematics
  - **2-4%** uncertainty on **b-tagging efficiency**
  - **9-11%** uncertainty on **mistag rate**

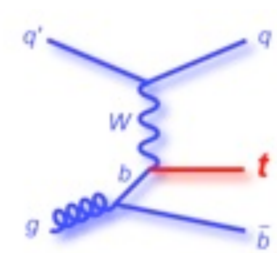


Friday, October 19, 2012

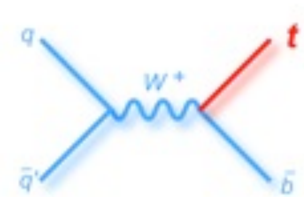
Production

- Pair production
  - $\sigma = 164_{-10}^{+13}$ pb @7TeV (✷ HATHOR)
  - σ =225 pb @ 8TeV (✳ MCFM)

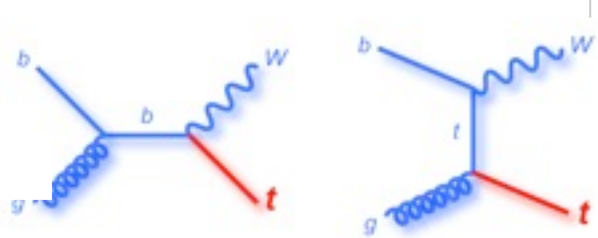
- Single Top quark production
  - t channel
    $64.57^{+2.09}_{-0.71}\,{}^{+1.51}_{-1.74}$ pb @ 7 TeV
    Kidonakis,N. PRD83:091503,2011



  - s channel
    $4.63 \pm 0.07^{+0.19}_{-0.17}$ pb @ 7 TeV
    Kidonakis,N. PRD81:054028,2010

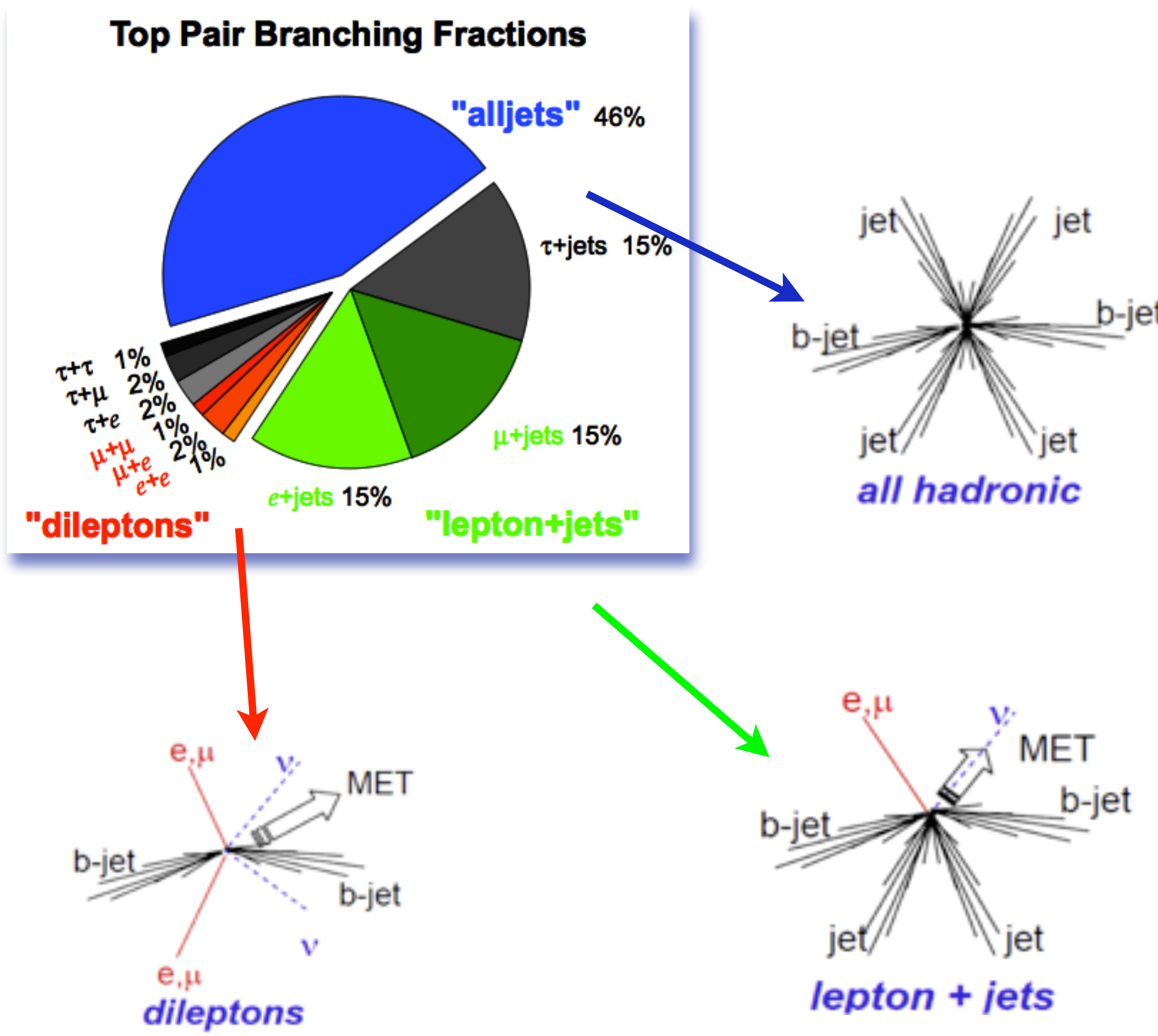


  - tW channel
    $15.74 \pm 0.40^{+1.10}_{-1.14}$ pb @ 7 TeV
    Kidonakis,N. PRD82:054018,2010



Decay

- Final state categorized by the decay of the W boson
  - Golden channels: lepton + jets and dilepton
  - Challenging channels: full hadronic, tau + mu



✳ Nucl.Phys.Proc.Suppl.205-206:10-15, 2010

✷ Comp.Phys.Commun. 182(2011)1034

Top mass measurement @ 7 TeV

NEW

arXiv:1209.2319→JHEP

arXiv:1209.2393→EPJC

l+jets (e/μ+jets)

$$\mathcal{L}\left(m_t, \mathrm{JES}|\mathrm{sample}\right) = \prod_{\mathrm{events}} \mathcal{L}\left(\mathrm{event}|m_t, \mathrm{JES}\right)^{w_{\mathrm{event}}}$$

$$= \prod_{\mathrm{events}} \left(\sum_{i=1}^{n} c\, P_{\mathrm{gof}}(i)\, P\left(m_{t,i}^{\mathrm{fit}}, m_{W,i}^{\mathrm{reco}} | m_t, \mathrm{JES}\right) \right)^{w_{\mathrm{event}}},$$

Calibration of the ideogram method

a) Scan for the biases

b) Look the the pull distributions

$$\text{mass bias} = \left\langle m_{t,\mathrm{extr}} - m_{t,\mathrm{gen}} \right\rangle,$$

$$\text{JES bias} = \left\langle \mathrm{JES}_{\mathrm{extr}} - \mathrm{JES} \right\rangle.$$

$$\text{pull} = \frac{m_{t,\mathrm{cal}} - m_{t,\mathrm{gen}}}{\sigma\left(m_{t,\mathrm{cal}}\right)},$$

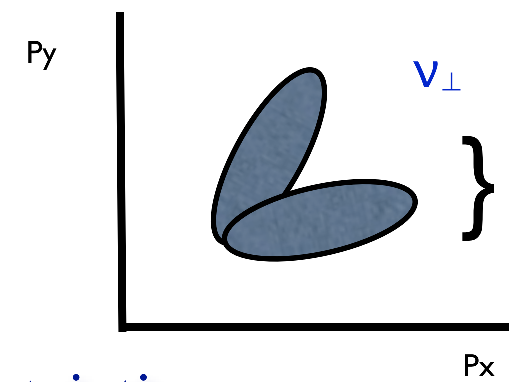
Uncertainties

	μ+jets		e+jets		ℓ+jets	
	$\delta^{\mu}_{m_t}$ (GeV)	$\delta^{\mu}_{\mathrm{JES}}$	$\delta^{e}_{m_t}$ (GeV)	$\delta^{e}_{\mathrm{JES}}$	$\delta^{\ell}_{m_t}$ (GeV)	$\delta^{\ell}_{\mathrm{JES}}$
Fit calibration	0.08	0.001	0.09	0.001	0.06	0.001
b-JES	0.60	0.000	0.62	0.000	0.61	0.000
p_T- and η-dependent JES	0.30	0.001	0.28	0.001	0.28	0.001
Lepton energy scale	0.03	0.000	0.04	0.000	0.02	0.000
Missing transverse momentum	0.05	0.000	0.07	0.000	0.06	0.000
Jet energy resolution	0.22	0.004	0.24	0.004	0.23	0.004
b tagging	0.11	0.001	0.15	0.001	0.12	0.001
Pileup	0.07	0.002	0.08	0.001	0.07	0.001
Non-$t\bar{t}$ background	0.10	0.001	0.16	0.000	0.13	0.001
Parton distribution functions	0.07	0.001	0.07	0.001	0.07	0.001
Renormalization and factorization scales	0.23	0.004	0.41	0.005	0.24	0.004
ME-PS matching threshold	0.17	0.000	0.15	0.001	0.18	0.001
Underlying event	0.26	0.002	0.24	0.001	0.15	0.002
Color reconnection effects	0.66	0.004	0.39	0.003	0.54	0.004
Total	1.06	0.008	1.00	0.007	0.98	0.008

dilepton(ee/eμ/μμ)

- 24 parameters (P4 of 2l + 2ν + 2j), known = 14 (P3 of 2j+2l) +2$\nu_\perp$, constrained = 9 (2 m_W + 1m_t + 6 m_p)
- ⇒1 degree of freedom to reconstruct the m_{top}
  - 8 possible solutions per event

AMWT,



8 solutions due to 2 possible combination of l+j

Uncertainties

Source	Δm_t (GeV)
Jet energy scale	$^{+0.90}_{-0.97}$
b-jet energy scale	$^{+0.76}_{-0.66}$
Jet energy resolution	±0.14
Lepton energy scale	±0.14
Unclustered E_T^{miss}	±0.12
b-tagging efficiency	±0.05
Mistag rate	±0.08
Fit calibration	±0.40
Background normalization	±0.05
Matching scale	±0.19
Renormalisation and factorisation scale	±0.55
Pileup	±0.11
PDFs	±0.09
Underlying event	±0.26
Colour reconnection	±0.13
Monte Carlo generator	±0.04
Total	±1.48

Top pair cross-section measurement @ 8TeV

NEW

Uncertainties

l+jets (e/μ+jets) CMS-PAS-TOP-12-006

Systematic	Combined fit $\delta\sigma_{t\bar{t}}$ (%)	
Jet Energy Scale	+4.3	-5.0
Jet Energy Resolution	+0.5	-1.1
Pileup	+0.7	-0.7
Background Composition	+0.1	-0.1
W + Jets template shape from unweighted 7 TeV	+0.9	-0.9
Normalisation of data-driven multijet shape	+0.9	-0.9
b tagging efficiency measurement	+8.0	-8.0
Trigger Efficiency	+3.2	-2.8
Lepton selection	+2.8	-2.4
Factorization scale (*)	+6.2	-2.1
ME-PS Matching threshold (*)	+4.6	-3.1
PDF uncertainties (*)	+1.6	-2.0
Top Quark Mass (*)	+0.3	-1.4
Total	+12.7	-11.4
Luminosity	+4.4	-4.4

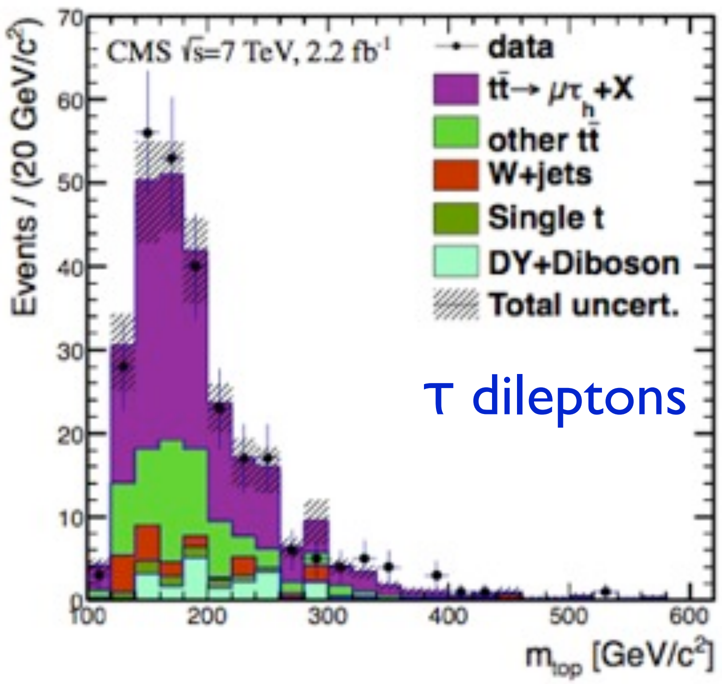
Scaled from 7 TeV

dilepton(ee/eμ/μμ) arXiv:1208.2671→JHEP

Source	Uncertainty on $\sigma_{t\bar{t}}$(pb)
Diboson	0.4
Single top	2.3
Drell-Yan	1.0
Non-W/Z leptons	0.6
Lepton efficiencies	1.7
Lepton energy scale	0.5
Jet energy scale	2.8
Jet energy resolution	0.5
$\not{E}_T$ efficiency	1.9
b-tagging	1.1
Pileup	0.7
Scale of QCD (μ)	1.0
Matching partons to showers	1.0
W branching fraction	2.7
Total systematic	5.6
Integrated luminosity	3.6
Statistical	2.6

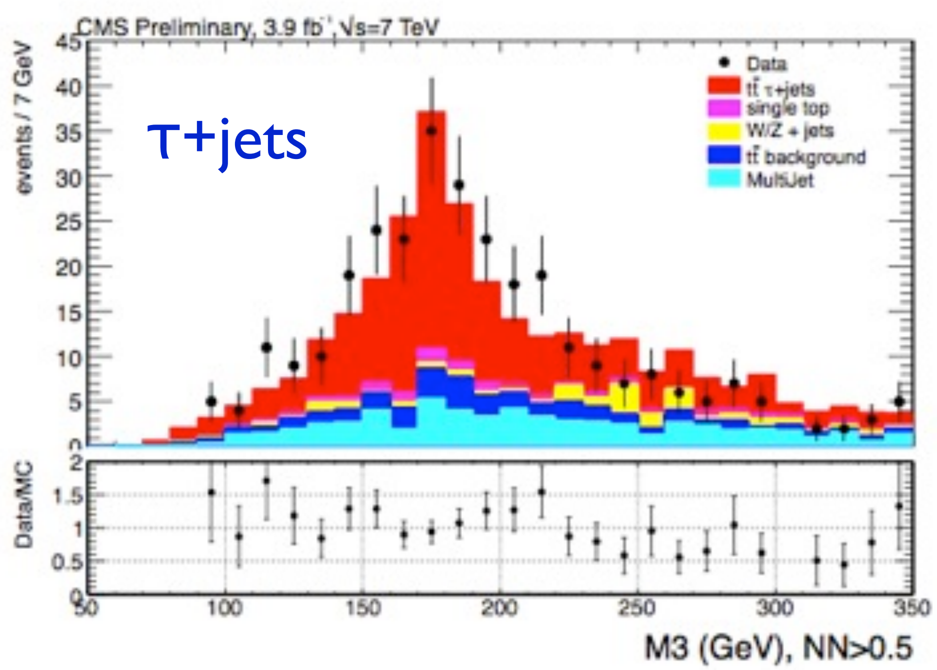
Top pair cross-section: Challenging channels @ 7 TeV

3rd generation only



- Main uncertainty due to τ fake rate is estimated from W+jets sample

- Multivariate analysis (fakes modeled from 0 b-tags sideband) → main uncertainty is JES

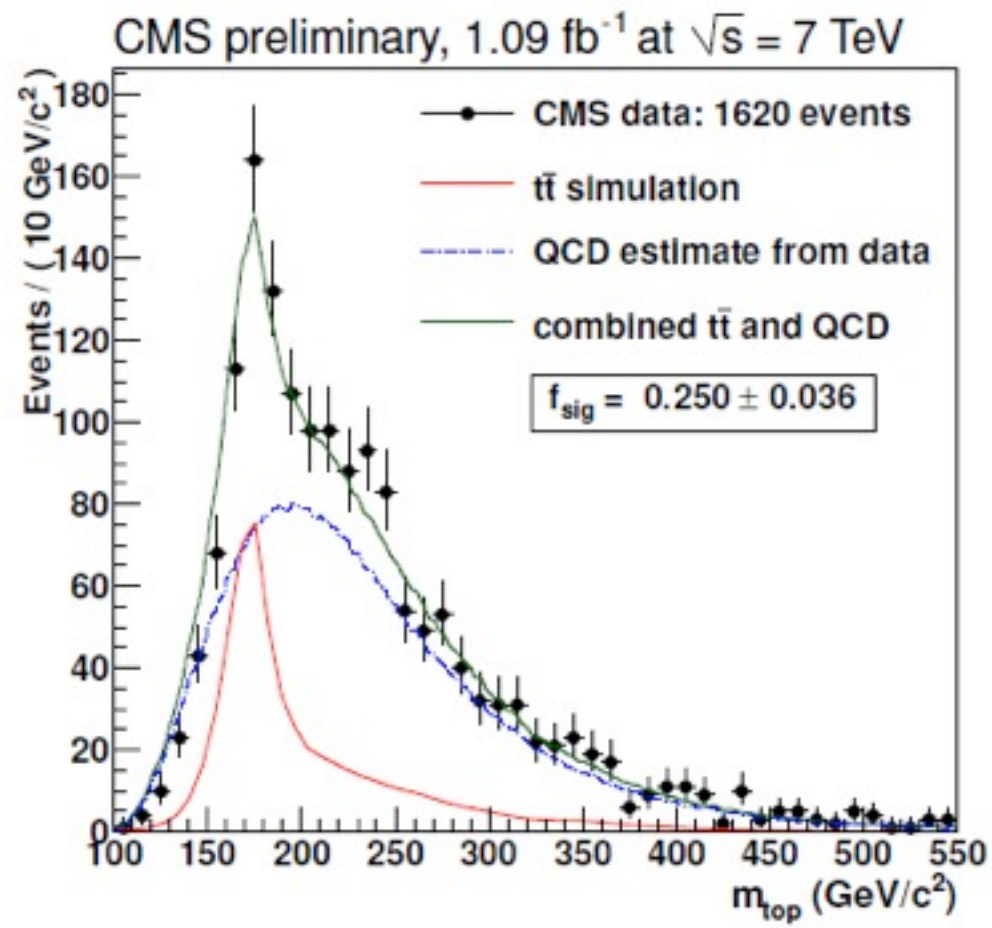


τ dileptons: $143 \pm 14(\text{stat.}) \pm 22(\text{syst.}) \pm 3(\text{lumi.})$ pb
τ+jets: $156 \pm 12\,(\text{stat.}) \pm 33\,(\text{sys.}) \pm 3\,(\text{lumi})$ pb

Fully hadronic

NEW

- Kinematic fit sorts combination to reconstruct m_{top}
- Re-weight multijets from 0 b-tags control region

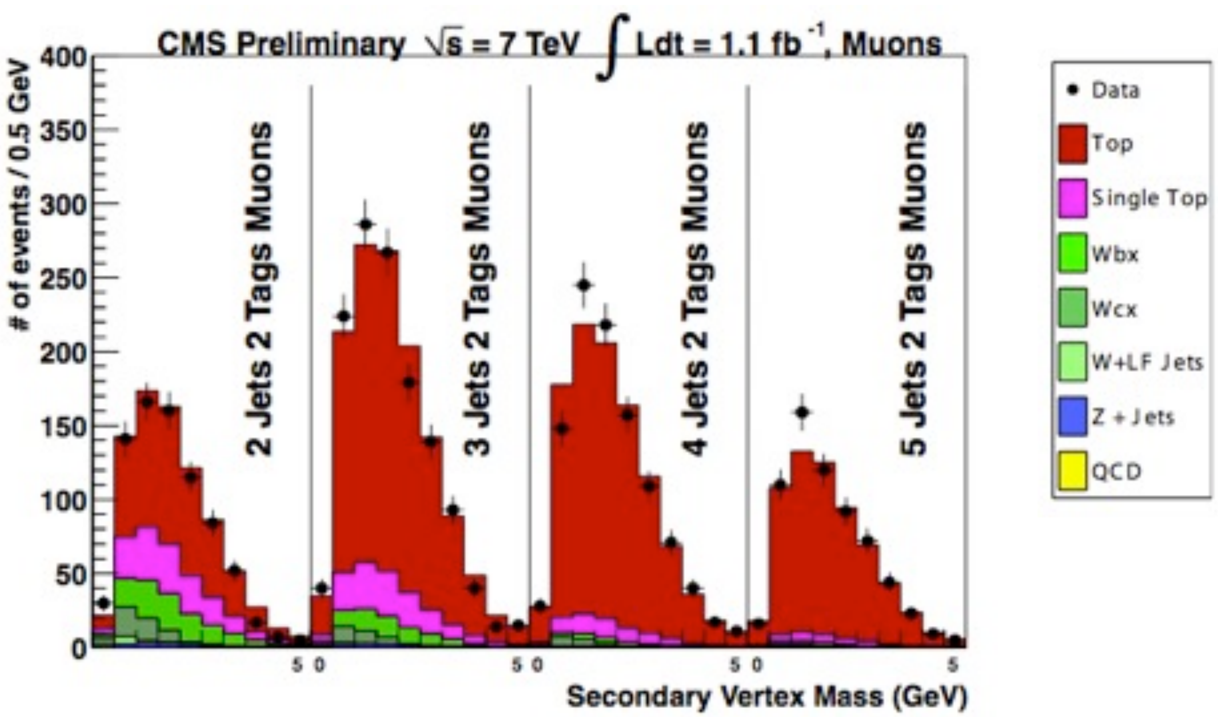


$136 \pm 20\ (\text{stat.}) \pm 40\ (\text{sys.}) \pm 8\ (\text{lumi.})$ pb

Top pair cross-section measurement (l+jets)

7 TeV

- Event Selection
  - ≥ 1 isolated lepton with p_T>35 GeV
  - ≥ 1 jets (≥ 1-bagged) with p_T > 30 GeV
- Mass of secondary vertex



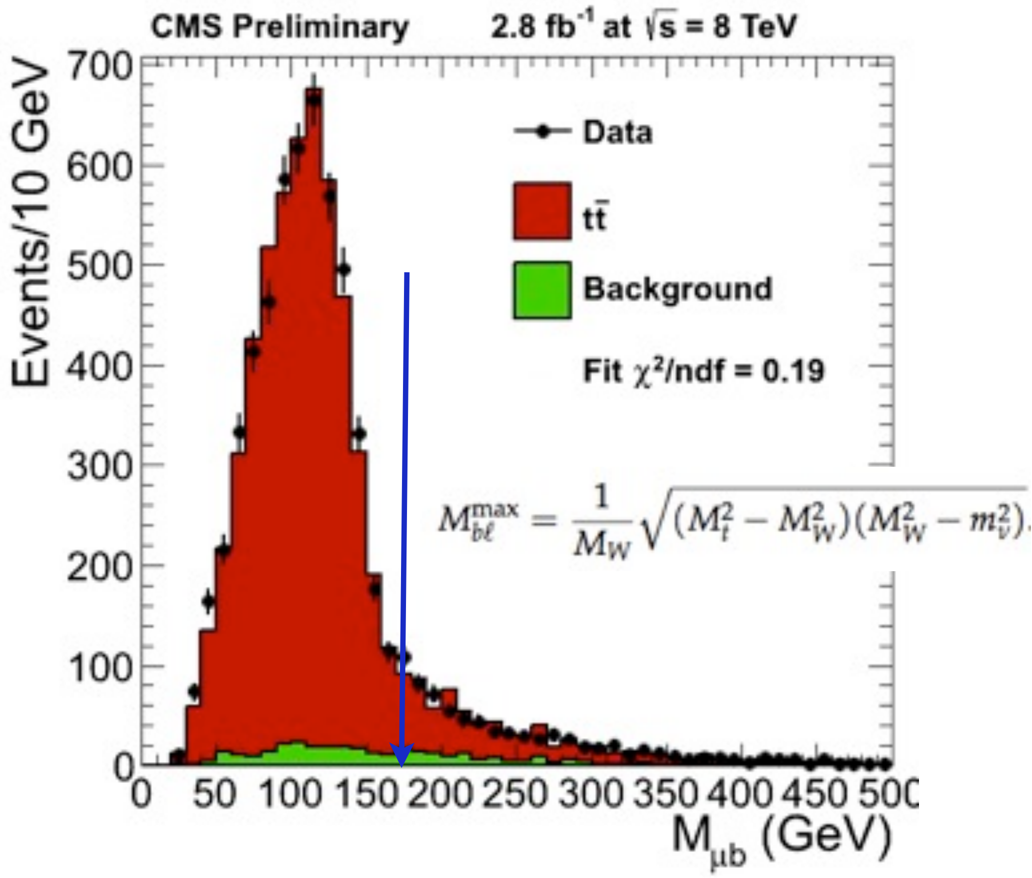
- Categorize events and fit σ_{tt}
  - W+HF (in particular Heavy Flavor, controlled by jet and tag multiplicity)
  - Systematic treated as nuisance parameter (W+Jets Q^2, b-tag SF, JES)

$$164.4 \pm 2.8\,(\text{stat.}) \pm 11.9\,(\text{syst.}) \pm 7.4\,(\text{lum.})\ \text{pb}$$

8 TeV

NEW

- Event Selection
  - ≥ 1 isolated lepton with p_T>26 GeV
  - ≥ 4 jets (≥ 1-bagged) with p_T > 35 GeV
- lepton-b invariant mass



- Reconstruct kinematic from a X^2
  - Assign leptonic top decay
  - Binned fit M_{lb} distribution

$$228.4 \pm 9.0\,(\text{stat.})^{+29.0}_{-26.0}\,(\text{syst.}) \pm 10.0\,(\text{lum.})\ \text{pb},$$

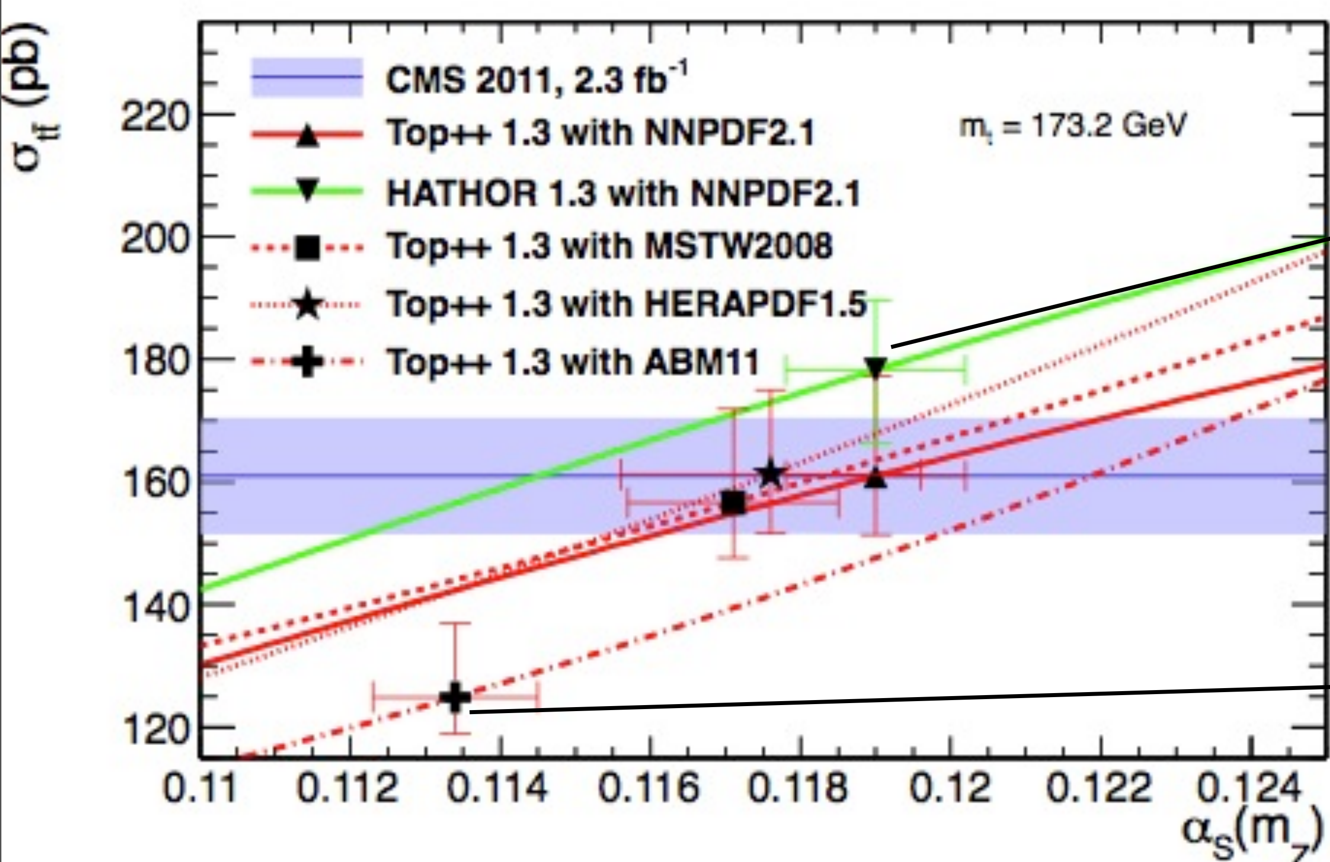
Extracting $\alpha_s(m_Z)$ from σ_{tt}

NEW

CMS-PAS-TOP-12-022

Table 1: Default $\alpha_S(m_Z)$ values and provided $\alpha_S(m_Z)$ scan ranges of the four NNLO PDF sets used in the present analysis. The uncertainties on the default values will be employed for illustration purposes only. The step size for the $\alpha_S(m_Z)$ scans is 0.0010 in all four cases.

			Provided $\alpha_S(m_Z)$ scan		
	Default $\alpha_S(m_Z)$	Uncertainty	Range	Center	# of points
NNPDF2.1	0.1190	$\pm$ 0.0012	0.1140-0.1240	0.1190	11
MSTW2008	0.1171	$\pm$ 0.0014	0.1070-0.1270	0.1170	21
HERAPDF1.5	0.1176	$\pm$ 0.0020	0.1140-0.1220	0.1180	9
ABM11	0.1134	$\pm$ 0.0011	0.1040-0.1200	0.1120	17



The predictions obtained with HATHOR 1.3 are 3% higher compared to those from Top++ mostly due to the new high-energy approximation

1% uncertainty included due to change in σ_{tt} when α_s is varied in one step from its default value = 0.1180

The σ_{tt} predictions obtained with ABM11 are lower due to a smaller gluon density in the relevant kinematic range

Extracting $\alpha_s(m_Z)$ from σ_{tt}

NEW

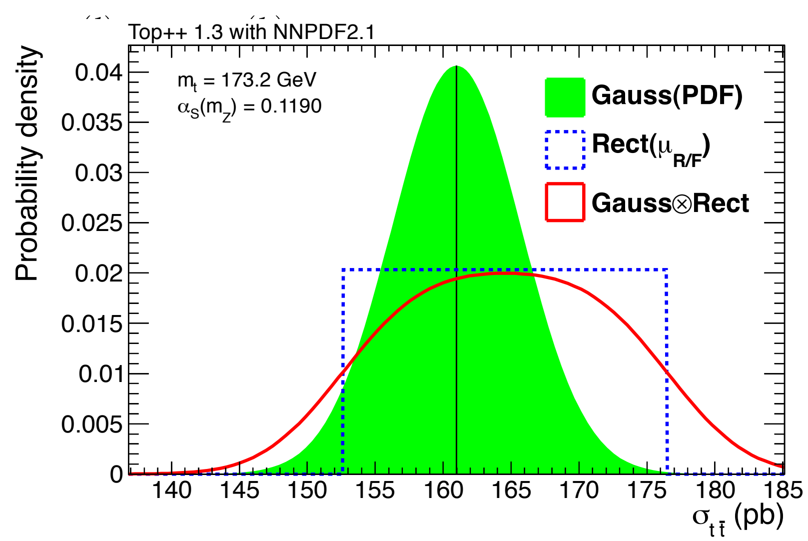
CMS-PAS-TOP-12-022

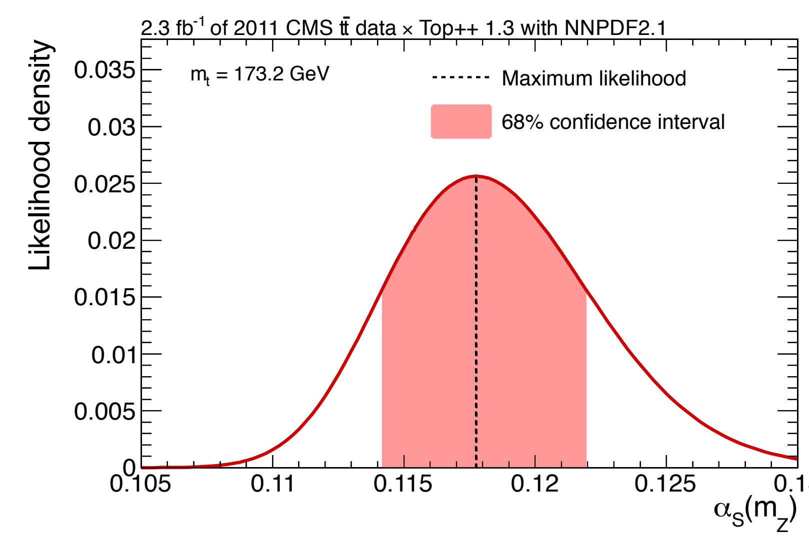
$$\mathcal{L}(x) = \int d\sigma\ \underbrace{f_{\rm exp}(\sigma_{t\bar{t}}|x)}_{}\ \underbrace{f_{\rm th}(\sigma_{t\bar{t}}|x)}_{} \qquad x = \alpha_S \text{ or } m_t$$

Experimental measurement (gaussian)

PDF uncertainty convolved with rectangular "prior" on Q^2 scale

$$f_{\rm th}(\sigma_{t\bar{t}}) = \mathcal{G}(\delta_{\rm PDF}) \otimes {\rm rect}(\sigma_{t\bar{t}}|\sigma_{t\bar{t}}^{(l)}, \sigma_{t\bar{t}}^{(h)}) = \frac{1}{2\left(\sigma_{t\bar{t}}^{(h)} - \sigma_{t\bar{t}}^{(l)}\right)} \left({\rm erf}\left[\frac{\sigma_{t\bar{t}}^{(h)} - \sigma_{t\bar{t}}}{\sqrt{2}\,\delta_{\rm PDF}}\right] - {\rm erf}\left[\frac{\sigma_{t\bar{t}}^{(l)} - \sigma_{t\bar{t}}}{\sqrt{2}\,\delta_{\rm PDF}}\right] \right)$$





		Most likely value	Uncertainty Total	From δm_t
Top++ 1.3	with NNPDF2.1	0.1178	$^{+0.0045}_{-0.0039}$	$^{+0.0015}_{-0.0015}$
HATHOR 1.3	with NNPDF2.1	0.1145	$^{+0.0034}_{-0.0031}$	$^{+0.0013}_{-0.0013}$
Top++ 1.3	with MSTW2008	0.1172	$^{+0.0037}_{-0.0037}$	$^{+0.0013}_{-0.0014}$
HATHOR 1.3	with MSTW2008	0.1139	$^{+0.0033}_{-0.0034}$	$^{+0.0013}_{-0.0013}$
Top++ 1.3	with HERAPDF1.5	0.1168	$^{+0.0028}_{-0.0028}$	$^{+0.0010}_{-0.0011}$
HATHOR 1.3	with HERAPDF1.5	0.1140	$^{+0.0024}_{-0.0024}$	$^{+0.0010}_{-0.0010}$
Top++ 1.3	with ABM11	0.1211	$^{+0.0027}_{-0.0027}$	$^{+0.0010}_{-0.0010}$
HATHOR 1.3	with ABM11	0.1185	$^{+0.0028}_{-0.0028}$	$^{+0.0010}_{-0.0010}$

ttH Search @ 7 TeV

NEW

- Search is carried in two different channels
  - **Lepton+jets:** one isolated lepton, ≥ 1 jets (2-btagged)
  - **Dilepton:** $l^{\pm}l^{\mp}$, ≥ 1 jets(2-btagged)
- Events are categorized into N jets, M tags

Lepton+jets

Expected event yields in each Lepton plus jets category in 5 fb^{-1}

Category	signal (M=120) H→anything	background	S/√B
≥ 6 jets, 2 tags	6.3	2255.8	0.13
4 jets, 3 tags	3.5	1041.6	0.11
5 jets, 3 tags	4.7	666.7	0.18
≥ 6 jets, 3 tags	4.4	404.9	0.22
4 jets, ≥ 4 tags	0.5	20.0	0.11
5 jets, ≥ 4 tags	1.2	31.8	0.21
≥ 6 jets, ≥ 4 tags	1.7	39.3	0.27

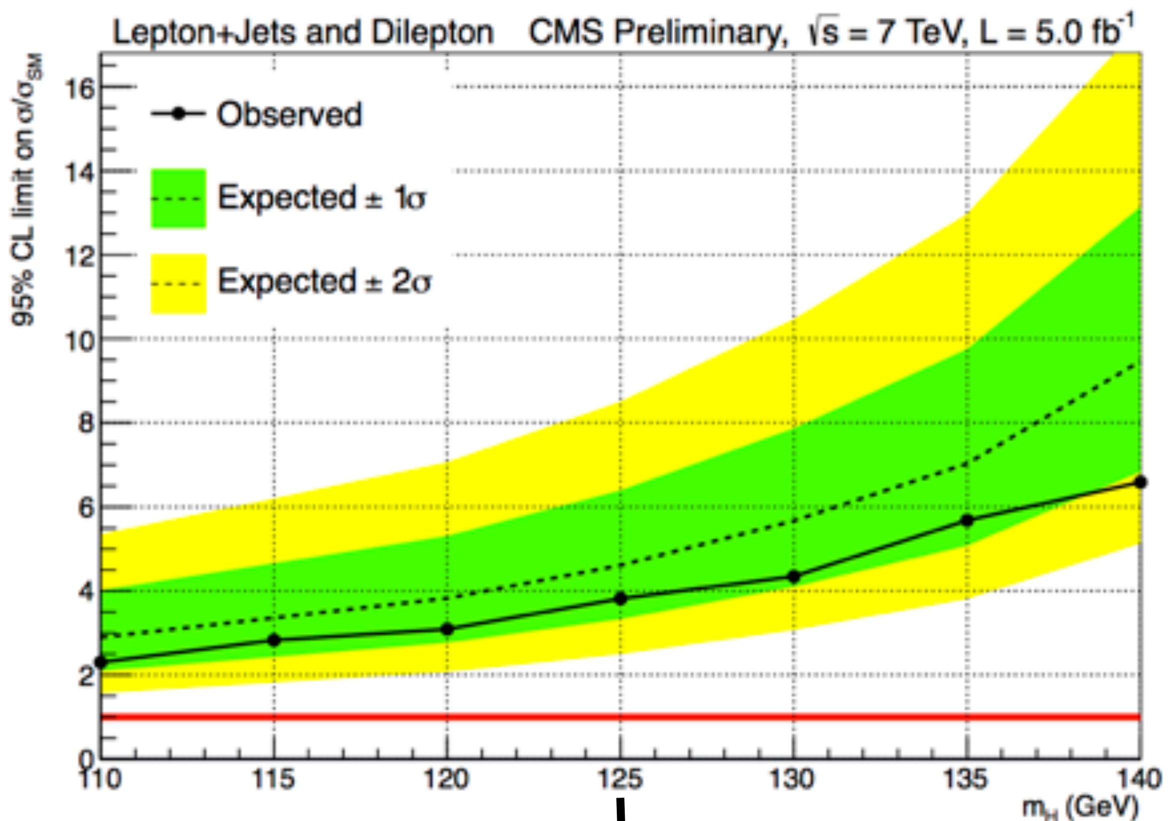
Dilepton

Expected event yields in each Dilepton category in 5 fb^{-1}

Category	signal (M=120) H→anything	background	S/√B
2 jets, 2 tags	0.7	4306.0	0.01
≥ 3 jets, ≥ 3 tags	2.9	167.6	0.22

- Train ANN: 10 variables depending on category
  - av. b-tag disc. value for tag jets
  - lowest CSV (tags)
  - sum of devs from av. CSV (tags)
  - second highest CSV (tags)
  - av. ΔR for all tagged jet pairs
  - h3
  - sphericity
  - av. mjj for all untagged jet pairs
  - h2
  - mass (lepton, jet, MET)

e.g 6j3t



expected limit: 4.6 σ_{SM}
observed limit: 3.8 σ_{SM}

Jet Grooming Techniques

- **Jet pruning** -- this technique attempts to remove soft and large-angle components of a jet. The clustering process is repeated, but at each recombination step, the softer constituent is discarded if it has a large separation from the second constituent, or if it has a low fraction of the total p_T of the two constituents proposed for combination.
- **Jet filtering** -- this technique re-clusters the original jet into subjets, with a smaller distance parameter R_{filt}. After this is done, only the hardest N subjets are kept and recombined to form a new jet.
- **Jet trimming** -- similar to jet filtering, but instead of restricting to a fixed number of subjets, the subjets are selected based on a cut on the fraction of the subjet p_T relative to the original jet p_T