Sixth Workshop on Theory, Phenomenology and Experiments in Flavour Physics - FPCapri2016

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Recent Results on Flavor Physics by CMS

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on behalf of the CMS Collaboration

- Production cross sections:
  - B^+ & Quarkonium (13 TeV), $\Upsilon(1S)\Upsilon(1S)$ (8 TeV)
- FCNC Measurements & CPV:
  - $B \to K^* l^+ l^-$
  - Single t + γ, $t \to Zq$ & $t \to Hq$, CPV in tt events

Production Cross Sections

Preliminary Results @ 13 TeV:

- "Measurement of the B^+ hadronic production cross section in pp collisions at 13 TeV" [$L=50.8\ pb^{-1}$]
- "Quarkonium production cross section in pp collisions at 13 TeV" [$L=2.7\ fb^{-1}$]

Preliminary Results @ 8 TeV:

- "Observation of $\Upsilon(1S)$ pair production at CMS" [$L=20.7\ fb^{-1}$]

$\sigma(pp \to B^+X)$ @ 13 TeV

- Measurements of b-hadron production cross sections at the highest energy provide crucial test of QCD calculations

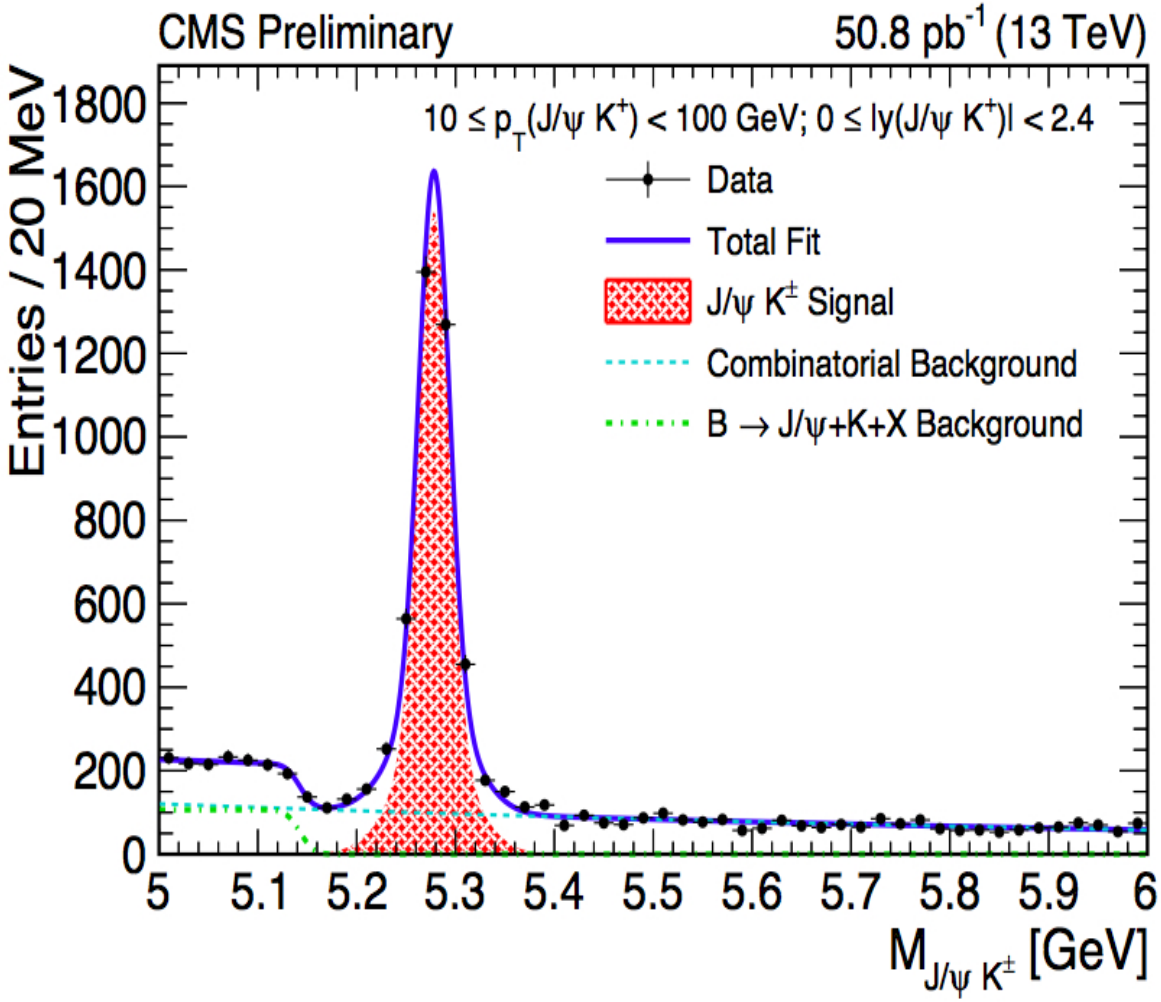
- Strategy:
  - Reconstruct $B^+ \to J/\psi\, K^+$, ($J/\psi \to \mu\mu$ & K^+ from the same vertex)
  - Measure differential cross sections as a function of P^B_T and y^B in the range $10\ \text{GeV} < P^B_T < 100\ \text{GeV}$; $|y^B| < 2.4$

$$\frac{d\sigma(pp \to B^+X)}{dp_T^B} = \frac{n_{sig}(p_T^B)}{2\,A \cdot \epsilon(p_T^B)\,\mathcal{B}\,\mathcal{L}\,\Delta p_T^B}, \qquad \frac{d\sigma(pp \to B^+X)}{dy^B} = \frac{n_{sig}(|y^B|)}{2\,A \cdot \epsilon(|y^B|)\,\mathcal{B}\,\mathcal{L}\,\Delta y^B}$$

- Acceptance x Efficiency jointly evaluated from simulated B^+ sample
- Trigger & Muon efficiencies from data inclusive $J/\psi \to \mu\mu$ decays

$\sigma(pp \to B^+X)$ @ 13 TeV

- Signal yields extracted in the different bins from a $m(J/\psi\, K^+)$ fit

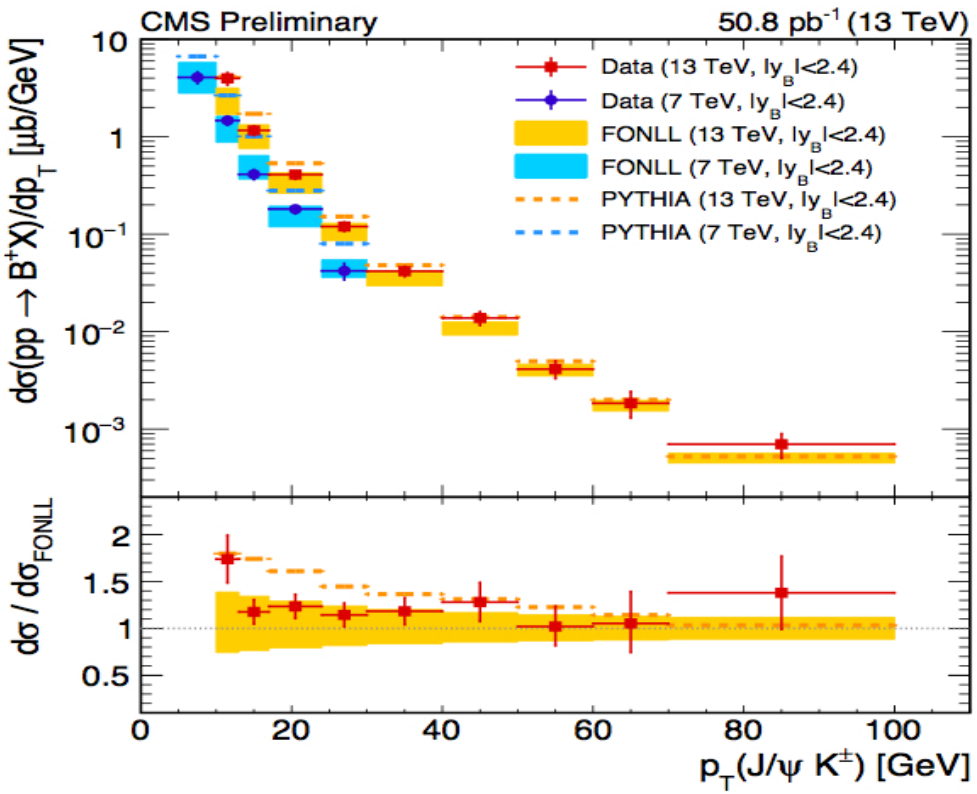


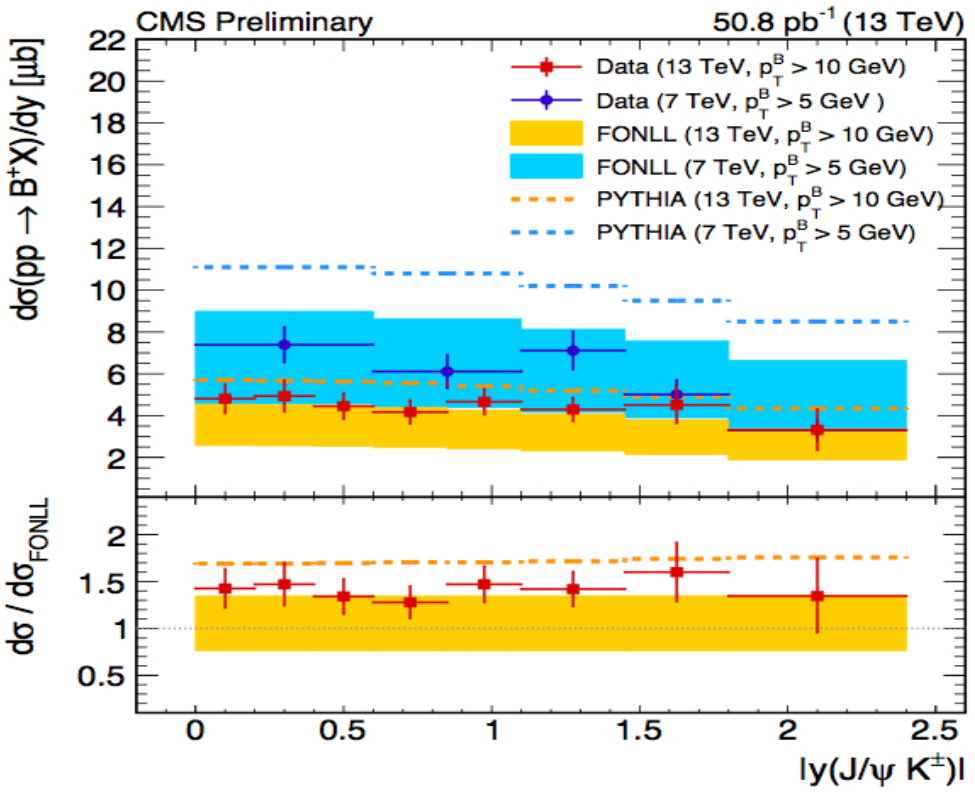
$m(J/\psi\, K^+)$ PDF:

- Signal: sum of two Gaussians (relative fraction from MC)
- Combinatorial: Exponential function (from inclusive J/ψ)
- Mis-reconstructed B → J/ψKX: Error function
- Negligible contribution from $B^+ \to J/\psi\, \pi^+$

$\sigma(pp \to B^+X)$ @ 13 TeV

- Differential cross sections:

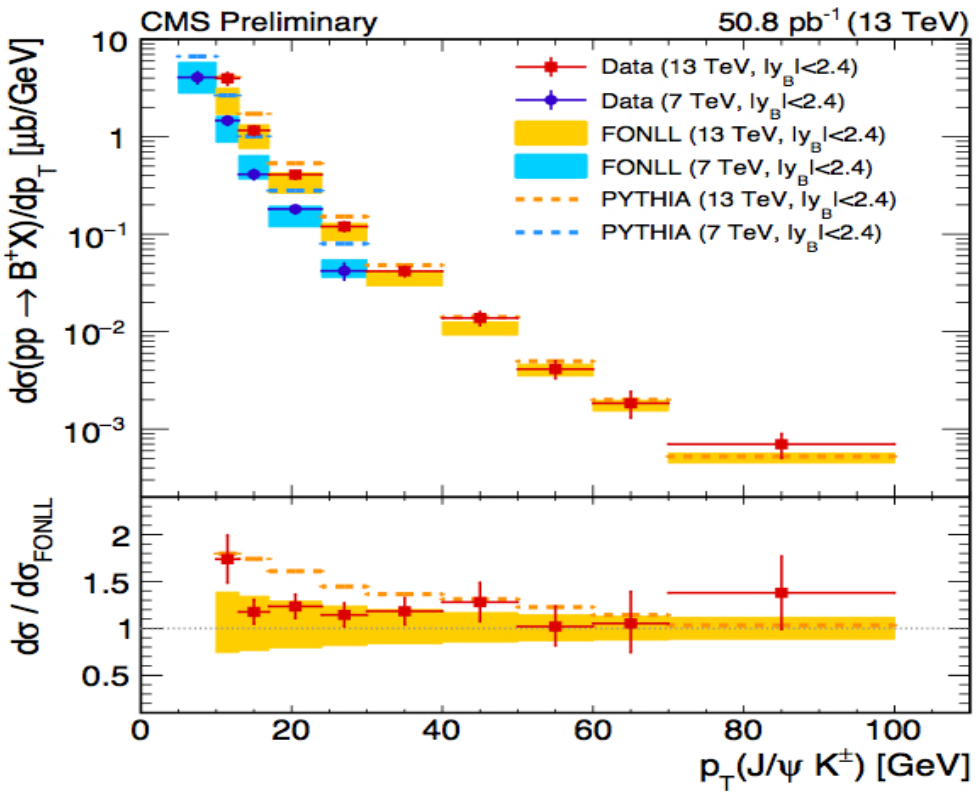


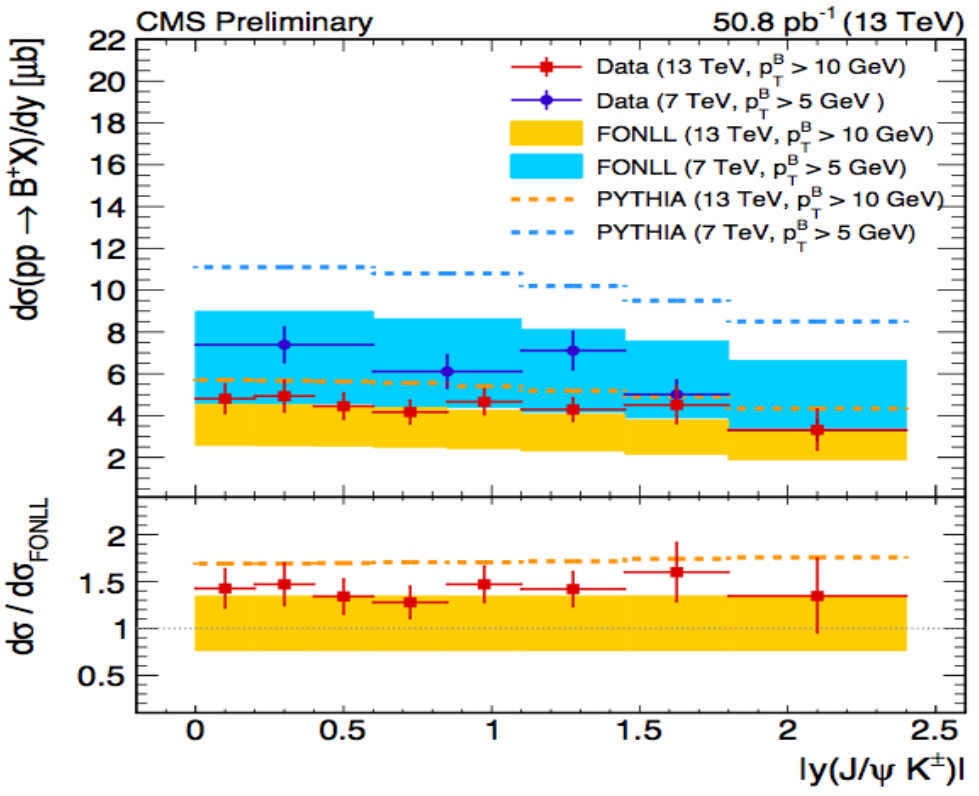


- Systematics from muon identification & reconstruction, signal & BKG PDFs, P^B_T & y^B resolution, track reconstruction, luminosity and $BR(B^+ \to J/\psi\, K^+ \to \mu\mu\, K^+)$

$\sigma(pp \to B^+X)$ @ 13 TeV

- Differential cross sections:





- Measured values show reasonable agreement with predicted shapes and normalizations by PYTHIA [Comput. Phys. Commun. 178, 852 (2008)] & FONLL [JHEP 0103, 006 (2001)]

σ(pp → Quarkonium) @ 13 TeV

- Quarkonium production described by Non-Relativistic QCD using factorization of perturbative & hadonization processes
  - Comparison of cross sections at 7 TeV and 13 TeV provides a test of the factorization hypotheses

- Measure pp → J/ψ, ψ(2S), Υ(nS) double differential cross sections as a function of transverse momentum and rapidity in the range

  $P_T > 20$ GeV; $|y| < 1.2$:

$$BR(q\bar{q} \to \mu^+\mu^-) \times \frac{d^2\sigma^{q\bar{q}}}{dp_T dy} = \frac{N^{q\bar{q}}(p_T, y)}{\mathcal{L}\Delta y \Delta p_T} \cdot \left\langle \frac{1}{\epsilon(p_T, y)\mathcal{A}(p_T, y)} \right\rangle$$

- Acceptance evaluated event-by-event using a simulated sample with flat rapidity and realistic P_T distribution assuming no polarization

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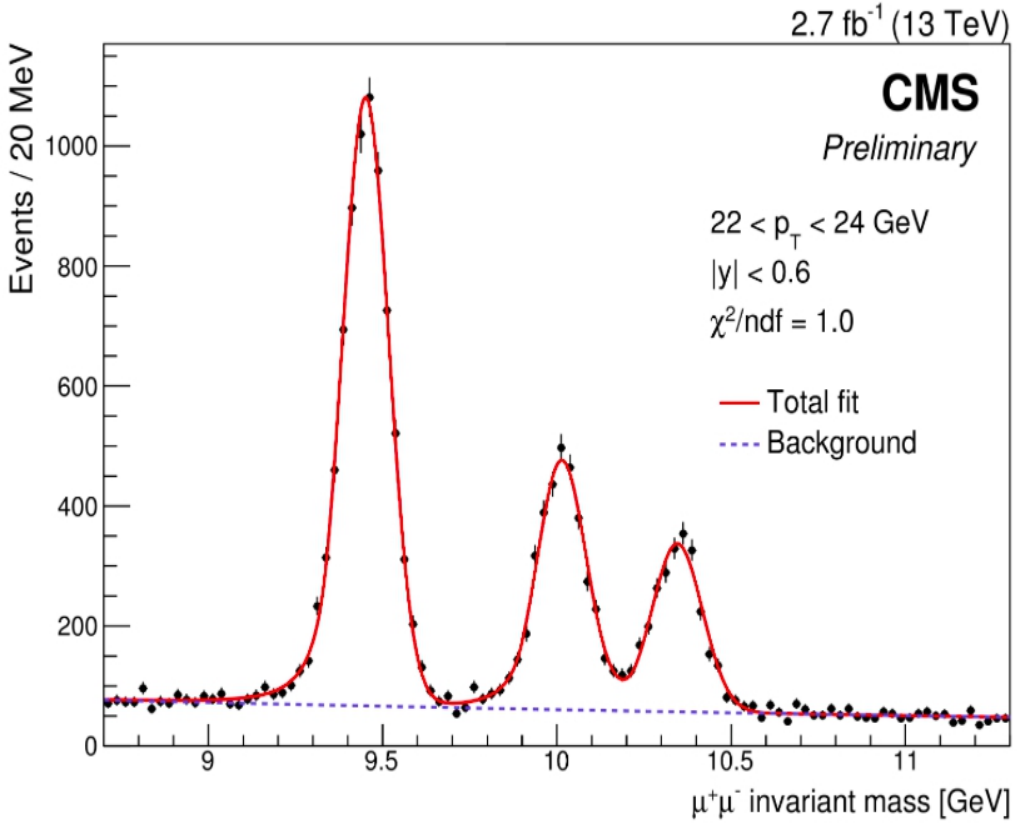
- Efficiency from data-driven studies using Tag & Probe technique on inclusive J/ψ → μμ decays

σ(pp → Quarkonium) @ 13 TeV

- Strategy:
  - Vertex of opposite charge muons fitted in high acceptance region

    $P_T(\mu) > 4.5$ GeV for $|\eta(\mu)| < 0.3$

    $P_T(\mu) > 4.0$ GeV for $0.3 < |\eta(\mu)| < 1.4$
- Signal yields extracted in the different bins from invariant mass fit



Mass PDFs:

Signal:

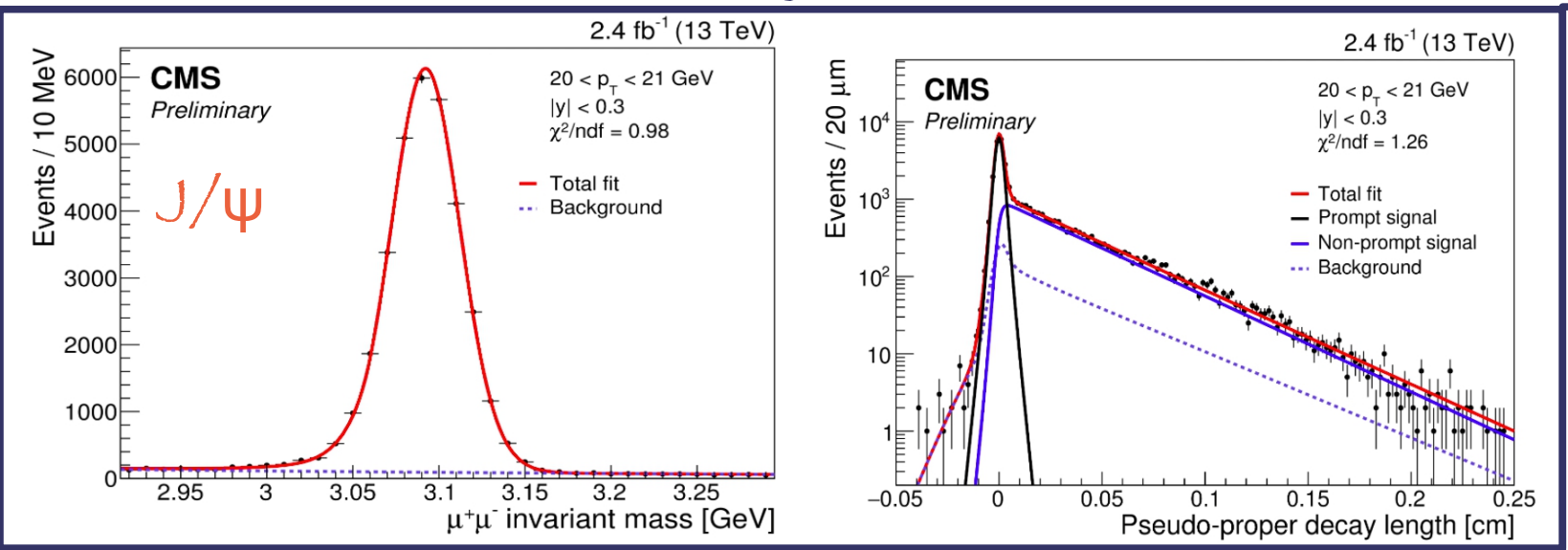
- ψ(2S), Υ: Crystal Ball
- J/ψ: Crystal Ball+Gaussian

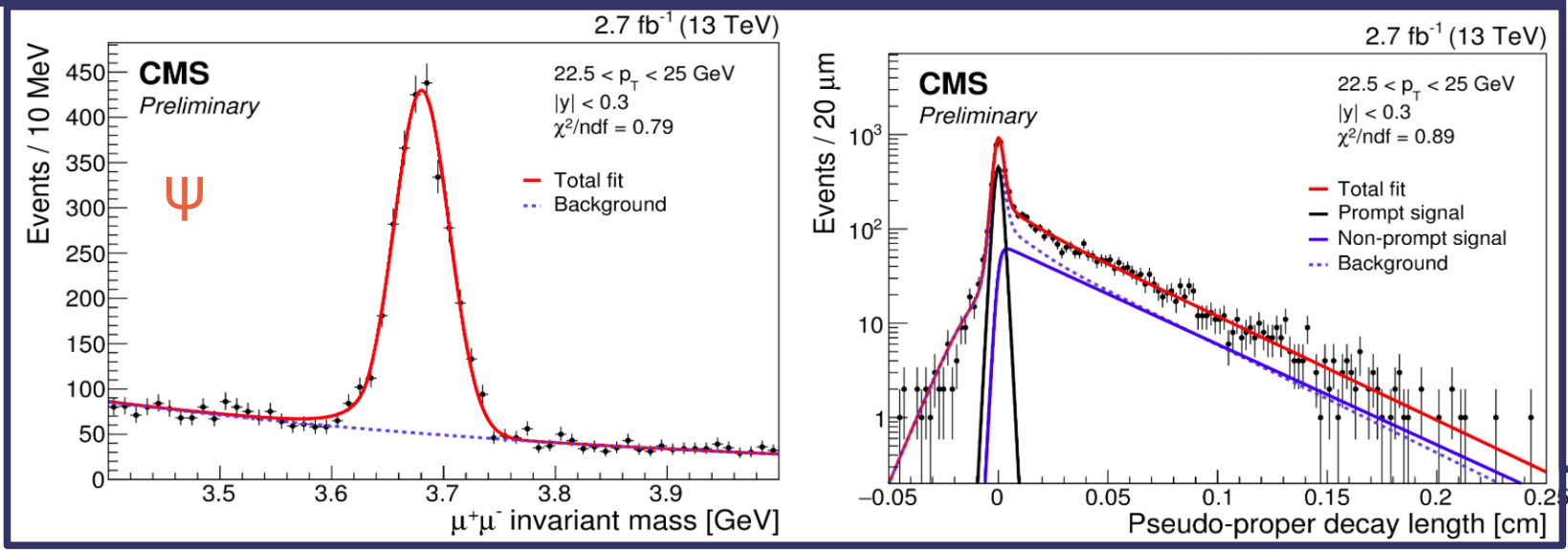
Combinatorial:

- Exponential function

σ(pp → Quarkonium) @ 13 TeV

- Non-prompt charmonium fraction from B decays extracted from a simultaneous 2D (m, decay length) fit:



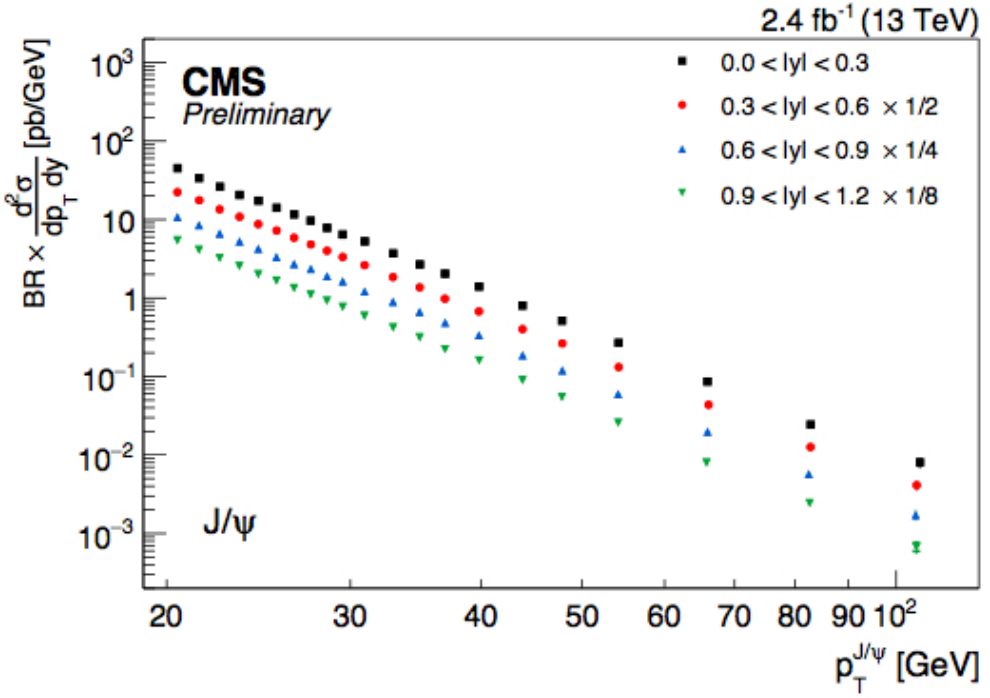


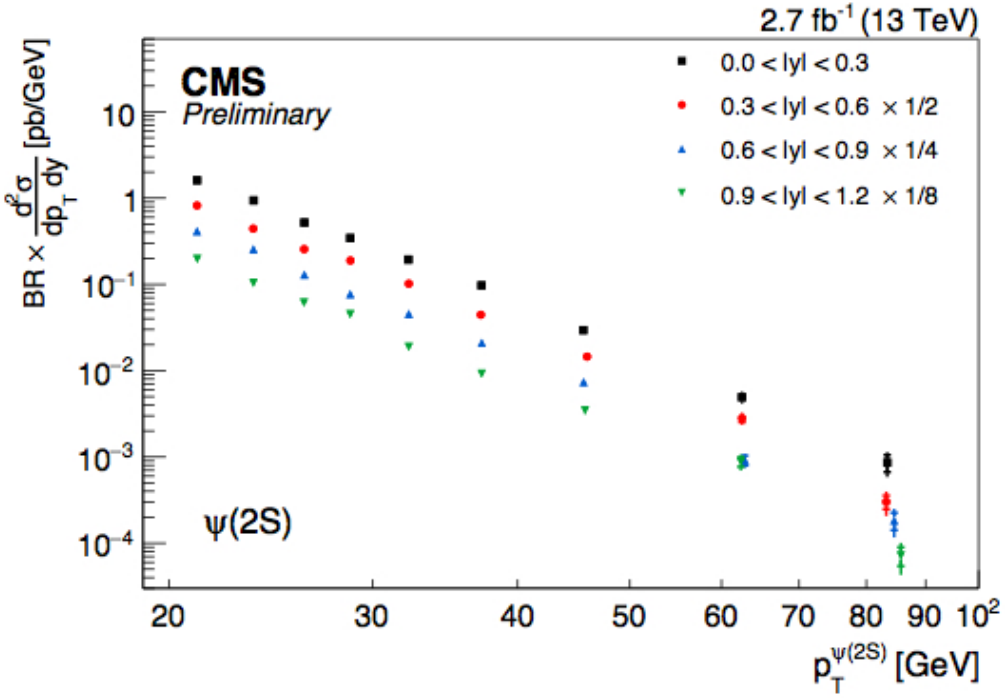
PDL PDFs

- Prompt: Resolution function
- Non-prompt: Exponential ⊗ resolution
- Combinatorial: 2 Gaussians centered at zero + Exponential

σ(pp → Quarkonium) @ 13 TeV

- Double differential charmonium cross sections:

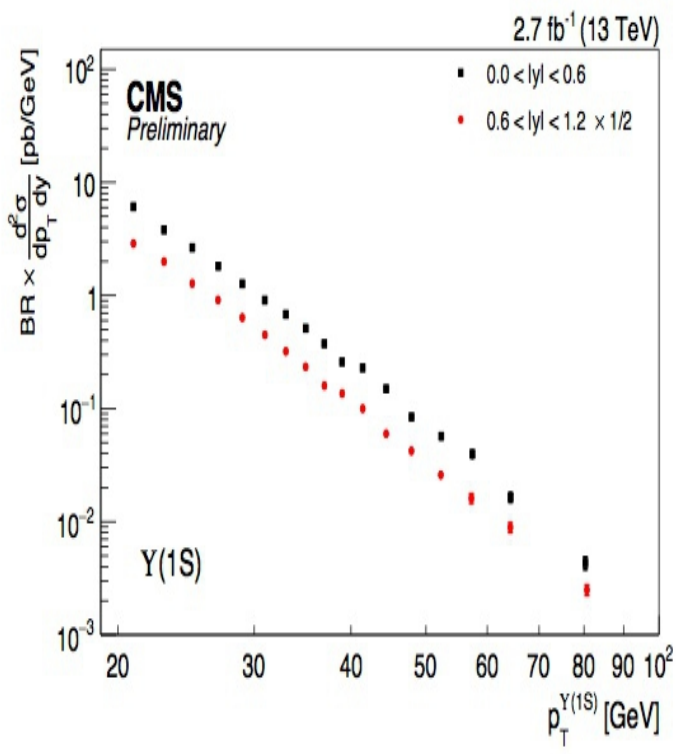


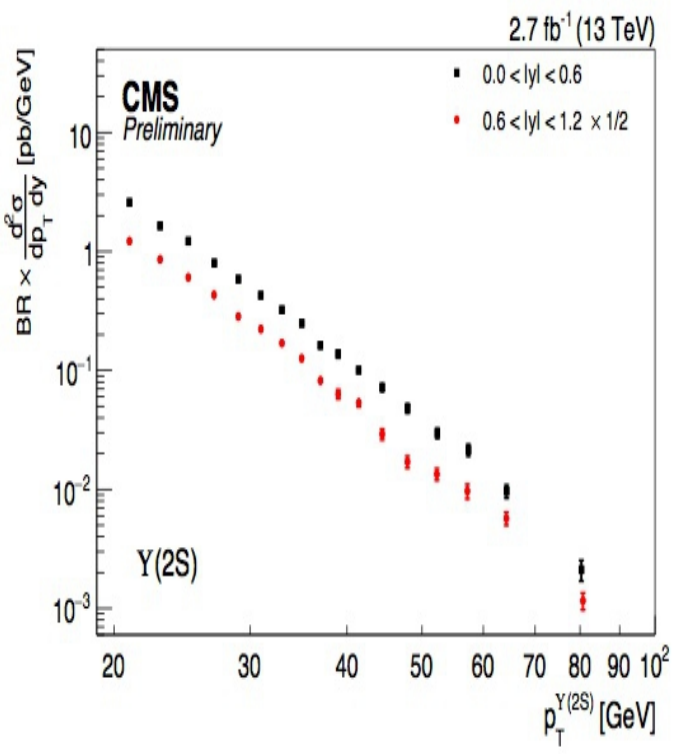


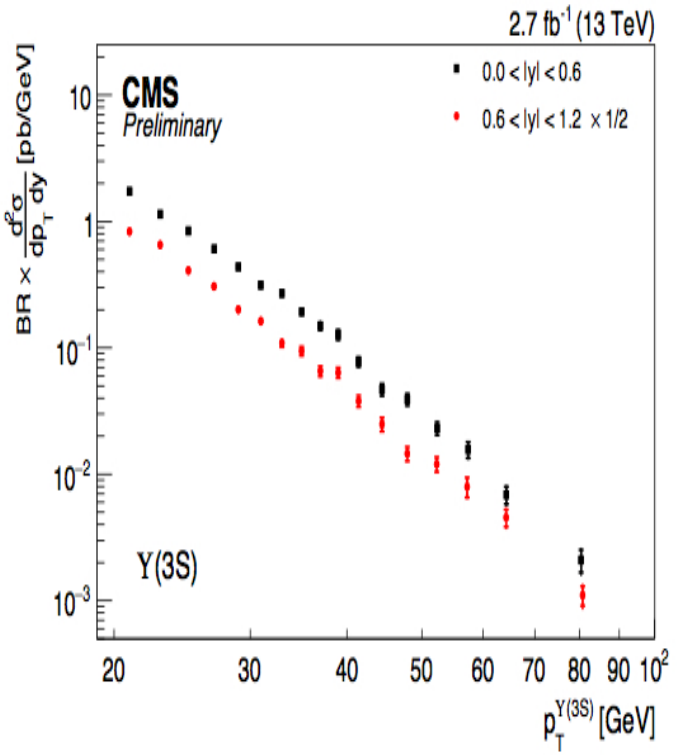
- Systematics include: Signal & BKG PDFs, resolution function, muon efficiency, limited MC statistics, non-prompt fraction (primary vertex choice, decay lenght PDFs)

σ(pp → Quarkonium) @ 13 TeV

- Double differential bottomonium cross sections:



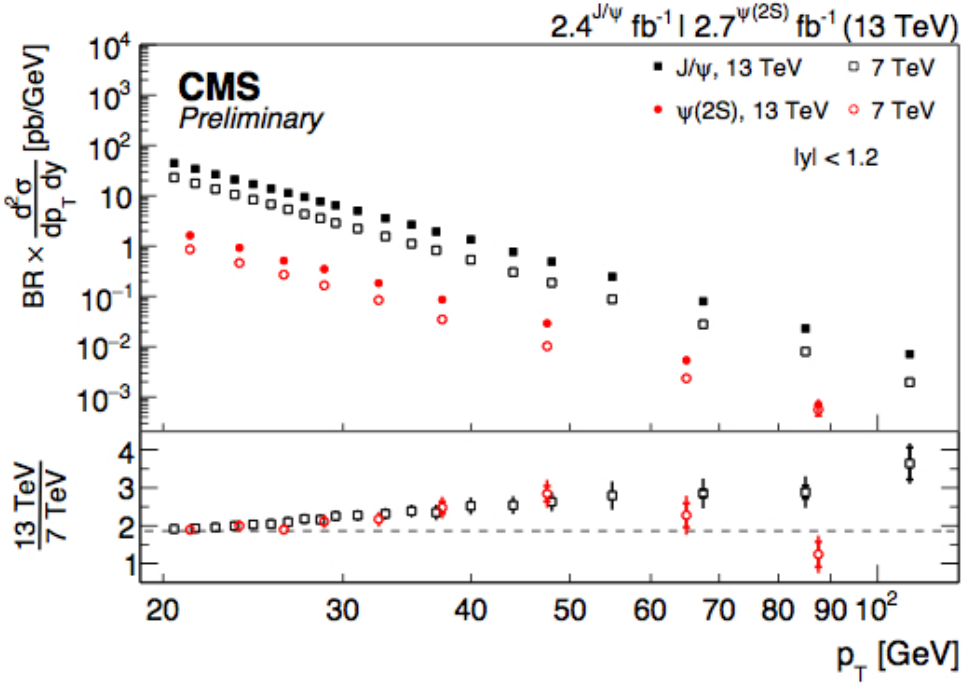


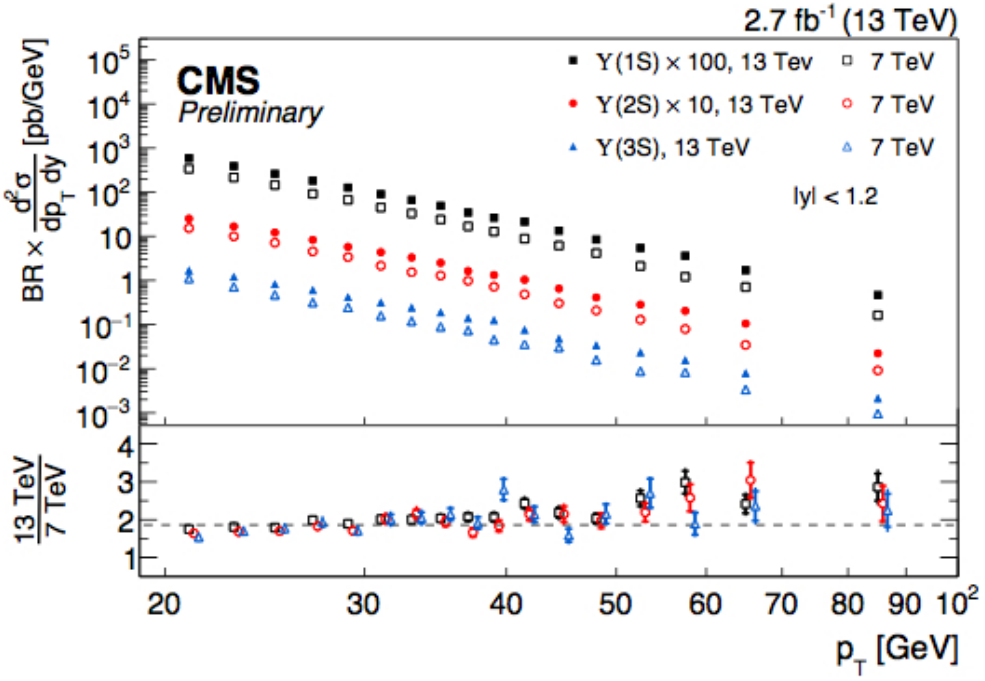


- Systematics include: Signal & BKG PDFs, resolution function, muon efficiency, limited MC statistics

σ(pp → Quarkonium) @ 13 TeV

- Comparison between different energies:





- Cross section ratios ~ 2-3 with slow P_T dependence (expected from evolution of parton distribution function)

Υ(1S) pair production

- Quarkonia pair production measurements provide important tests of single(double)-parton-scattering mechanisms and tetra-quark states decays
  - Measure pp → Υ(1S) Υ(1S) total cross section in the range

    P_T (Υ) < 50 GeV; |y (Υ)| < 2.0 :

$$\sigma(pp \to YY) = \frac{N^{YY}}{BR(Y \to \mu\mu)^2 \cdot \mathcal{L}} \cdot \left\langle \frac{1}{\epsilon \cdot \mathcal{A}} \right\rangle$$

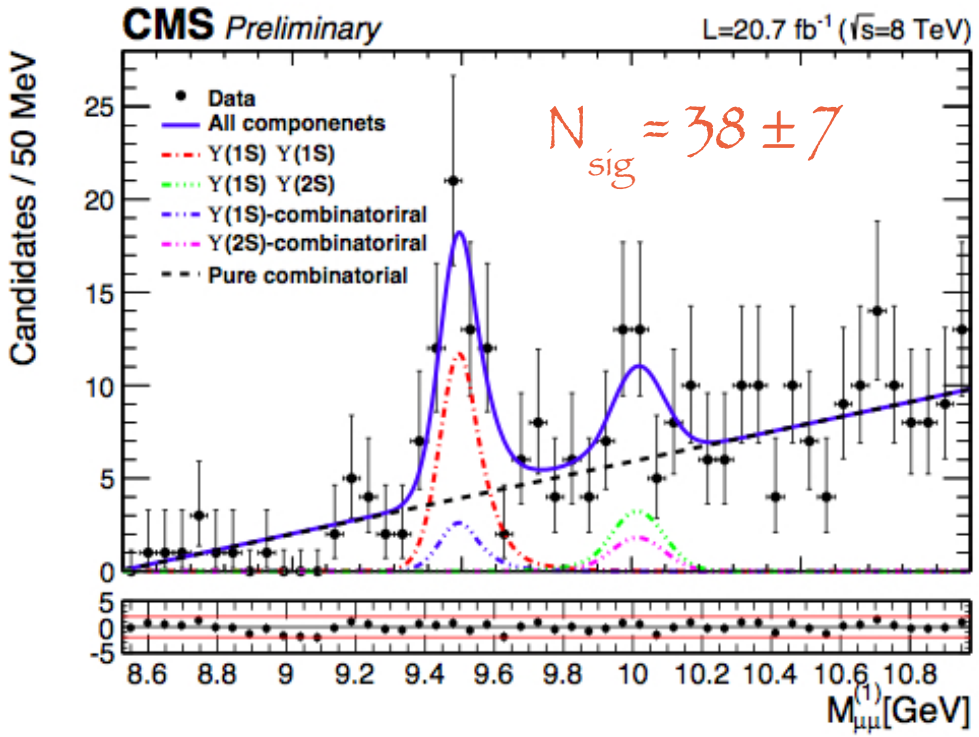
- Efficiency and Acceptance computed event-by-event on a MC sample using the measured Υ and muon momenta
- Υ pairs candidates reconstructed in events with four muons with total zero charge from the same vertex (P_T (μ) > 3.5 GeV; |y (μ)| < 2.4)

Υ(1S) pair production

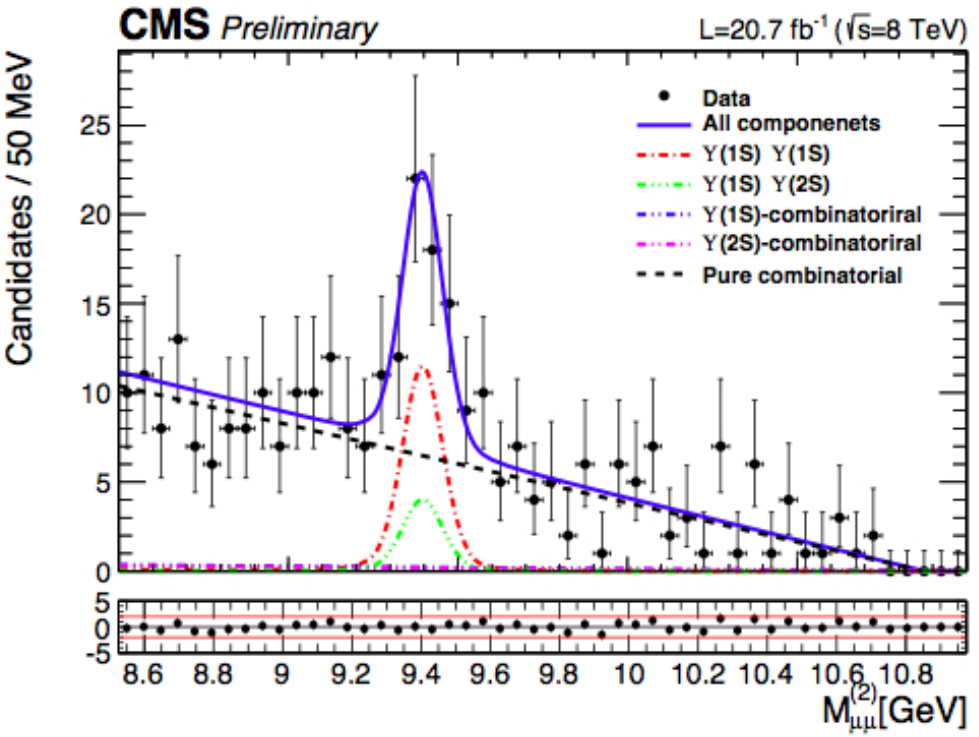
- Signal yields extracted from 2D ($m(\mu\mu)_{High}$, $m(\mu\mu)_{Low}$) invariant mass fit
- Five components considered:

  Υ(1S) Υ(1S), Υ(1S) Υ(2S), Υ(1S) BKG, Υ(2S) BKG, Pure BKG

Higher m(μμ)



Lower m(μμ)



Υ(1S) pair production

Result:

$$\sigma_{Tot} = 68.8 \pm 12.7 \pm 7.4 \pm 2.8\ (BR_{\Upsilon \to \mu\mu})\ pb$$

- Systematics from: signal & BKG PDF shapes, muon efficiency & acceptance, luminosity

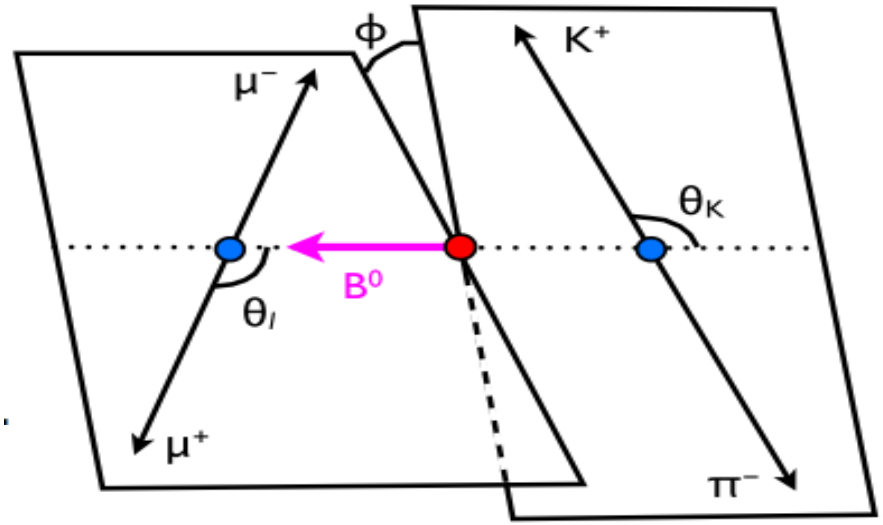
- Acceptance sensitivity on Υ decay angular distribution checked for extreme scenarios of 100% longitudinal (transverse) Υ polarization
  - Total cross section variation fom -38% to +36%

FCNC in B Decays

$B^0 \to K^*\mu\mu$:

- "Angular analysis of the decay $B^0 \to K^{*0}\mu\mu$ from pp collisions at $\sqrt{s} = 8$ TeV" [$L=20.5\ fb^{-1}$]
  Phys. Lett. B753, 424 (2016)

$B \to K^* \mu^+ \mu^-$



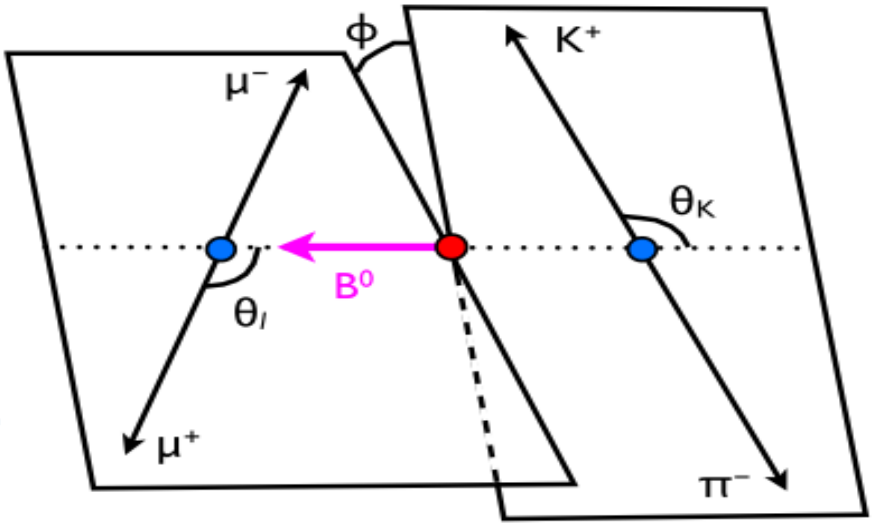
- Kinematics of the decay $B \to V \mu^+ \mu^-$ ($V=K^*, \varphi, \rho$) determined by three angles:
  - θ_l, θ_K, ϕ
- Event Yields reconstructed in bins of $q^2=m^2(\mu^+\mu^-)$
- ϕ integrated out in the current analysis

- Differential Amplitude:

$$\frac{1}{\Gamma}\frac{d^3\Gamma}{d\cos\theta_K\, d\cos\theta_l\, dq^2} = \frac{9}{16}\left\{\left[\frac{2}{3}F_S + \frac{4}{3}A_S\cos\theta_K\right](1-\cos^2\theta_l) + (1-F_S)\left[2F_L\cos^2\theta_K(1-\cos^2\theta_l) + \frac{1}{2}(1-F_L)(1-\cos^2\theta_K)(1+\cos^2\theta_l) + \frac{4}{3}A_{FB}(1-\cos^2\theta_K)\cos\theta_l\right]\right\}.$$

- Observables Include:
  - Differential Branching Ratio dB/dq^2
  - A_{FB} (forward-backward muon asymmetry)
  - F_L (fraction of longitudinally polarized K^*)

$B \to K^* \mu^+ \mu^-$



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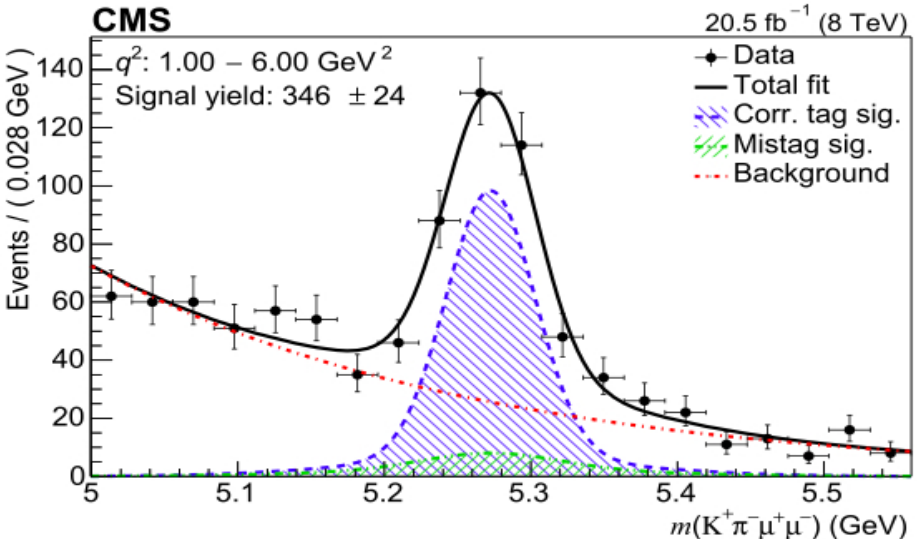
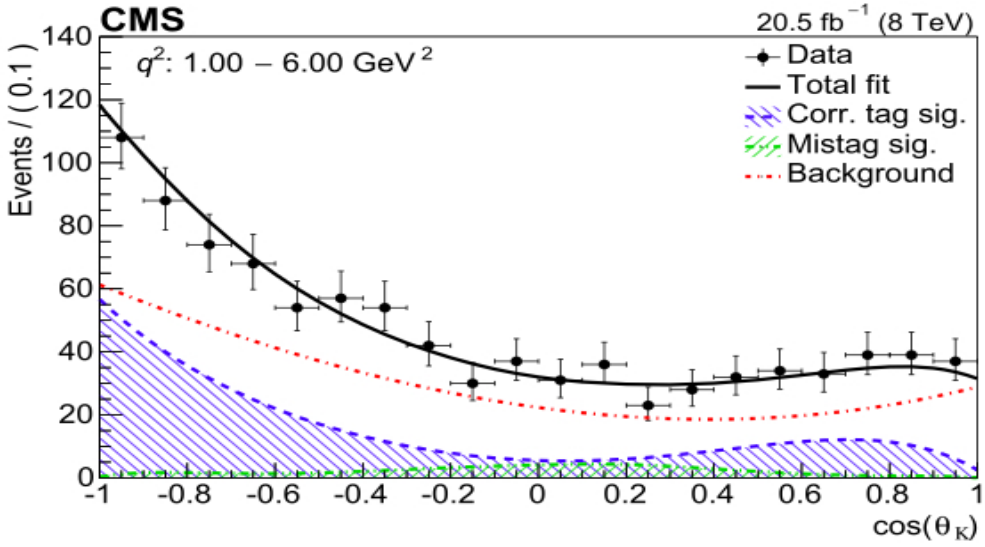
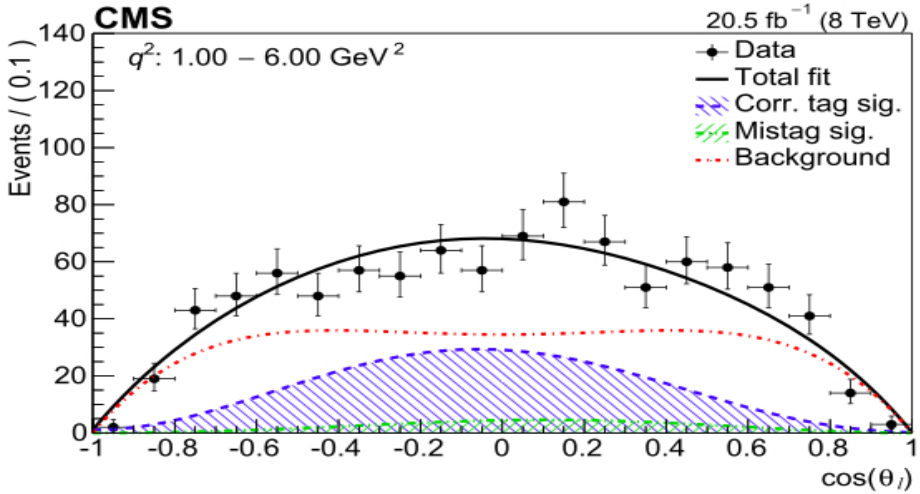
- F_S Fraction of spinless $K\pi$ (S-wave) combination
- A_S: Interference amplitude between S-wave and P-wave decays
- Small contributions (F_S <0.03, A_S ~-0.3/0.3 depending on the q^2 bin)

$B \to K^* \mu^+ \mu^-$

- Strategy:
  - Measure event yield A_{FB} and F_L from an unbinned simultaneous fit to $M(K\pi\mu\mu)$, $\cos(\theta_K)$ and $\cos(\theta_l)$ in bins of q^2





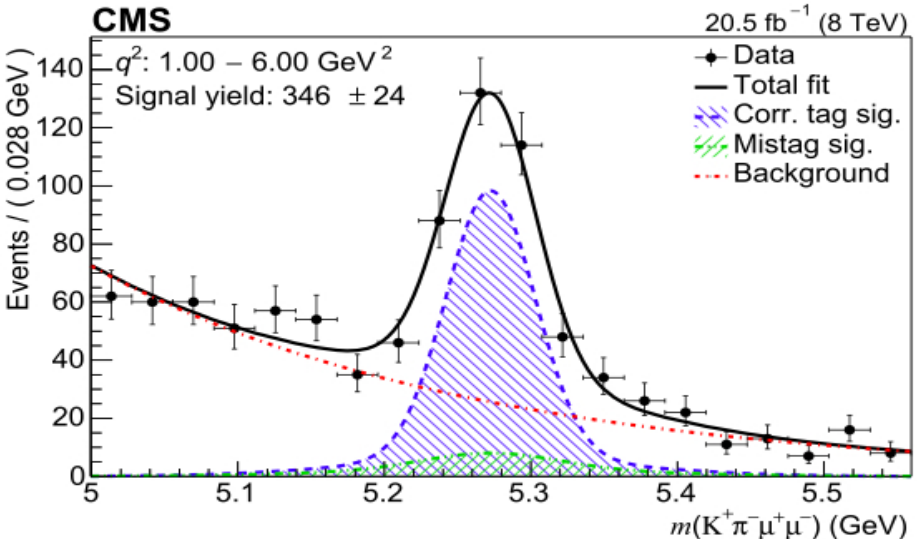


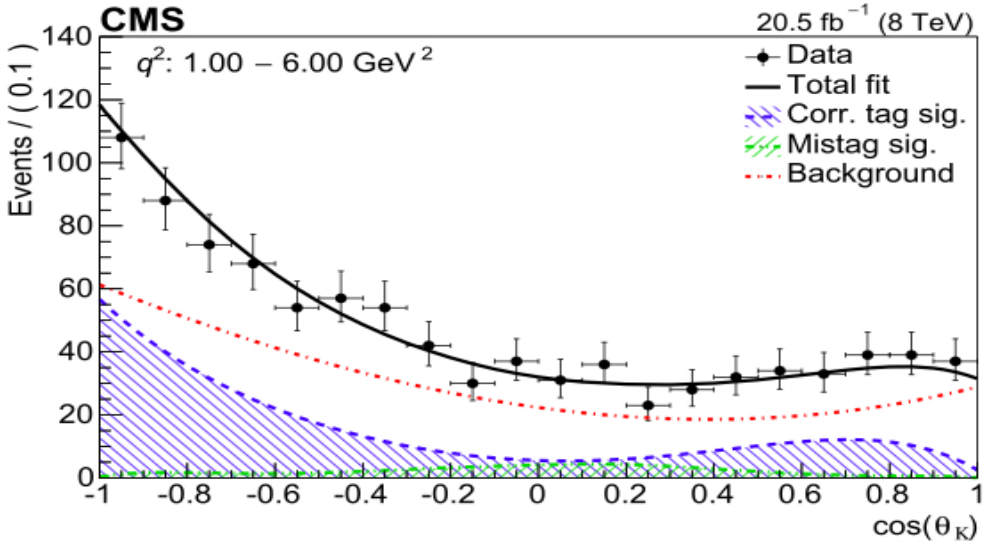
Example: $1 < q^2 < 6$ GeV^2

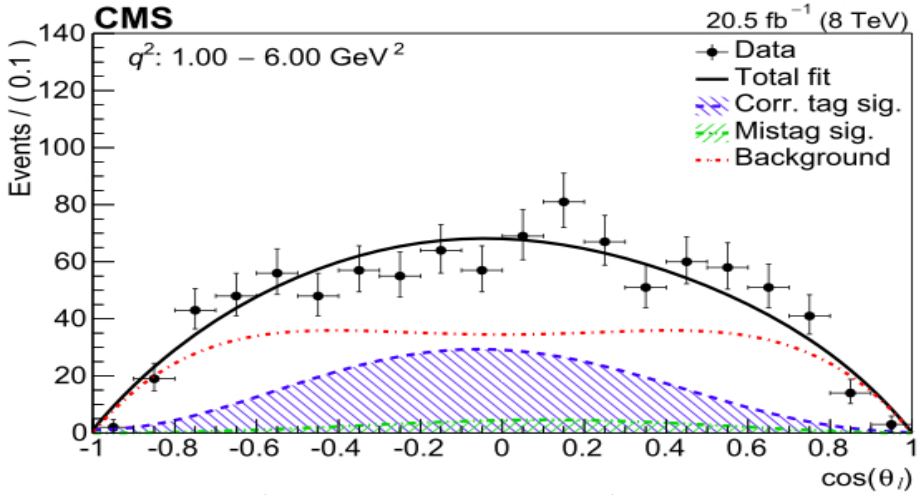
q^2 perturbative window with theory error under good control, away from $q^2 \to 0$ photon pole and $c\bar{c}$ resonances at higher q^2

$B \to K^{*}\mu^{+}\mu^{-}$

- Strategy:
  - Measure event yield A_{FB} and F_L from an unbinned simultaneous fit to $M(K\pi\mu\mu)$, $\cos(\theta_K)$ and $\cos(\theta_l)$ in bins of q^2

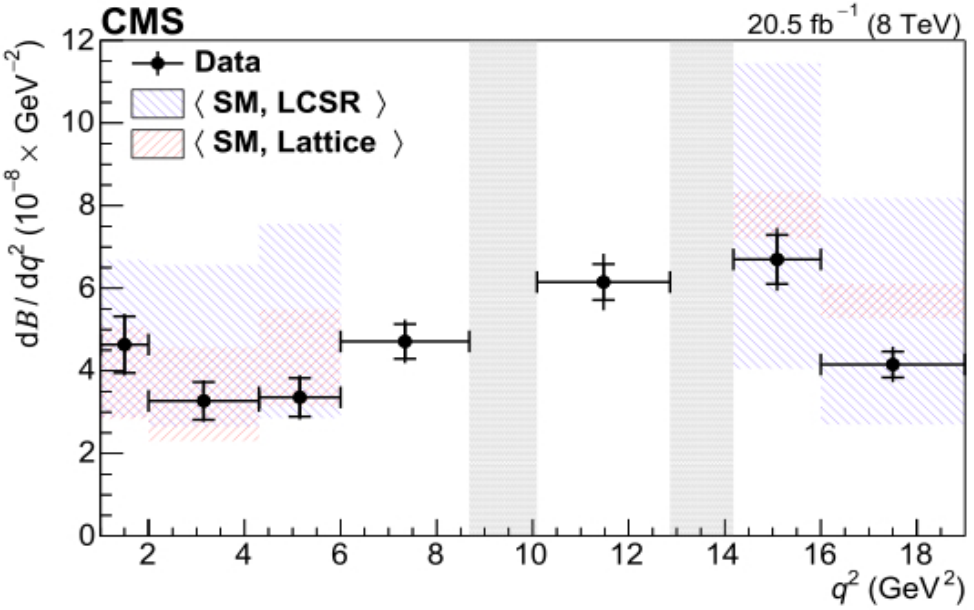


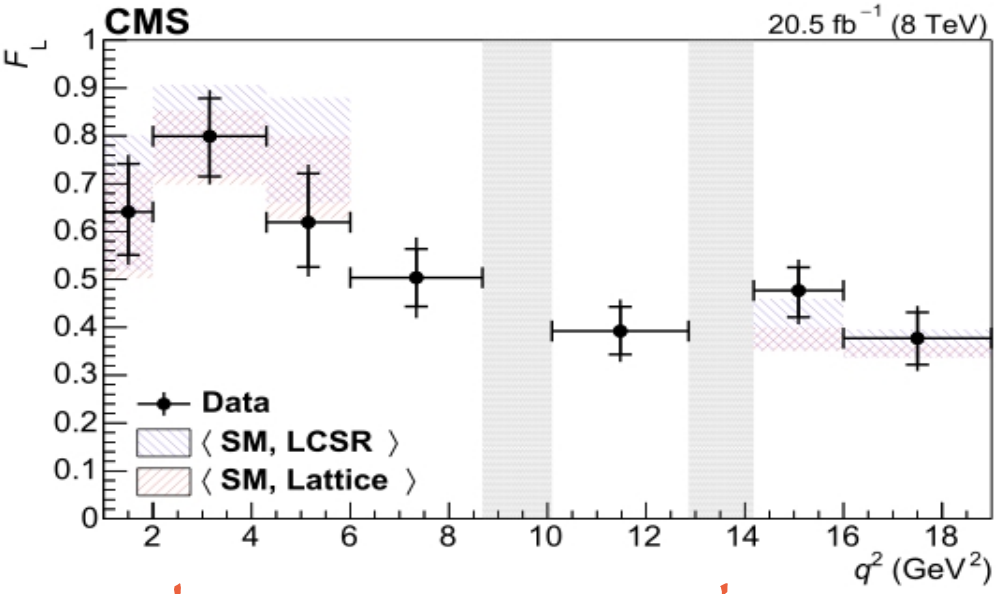


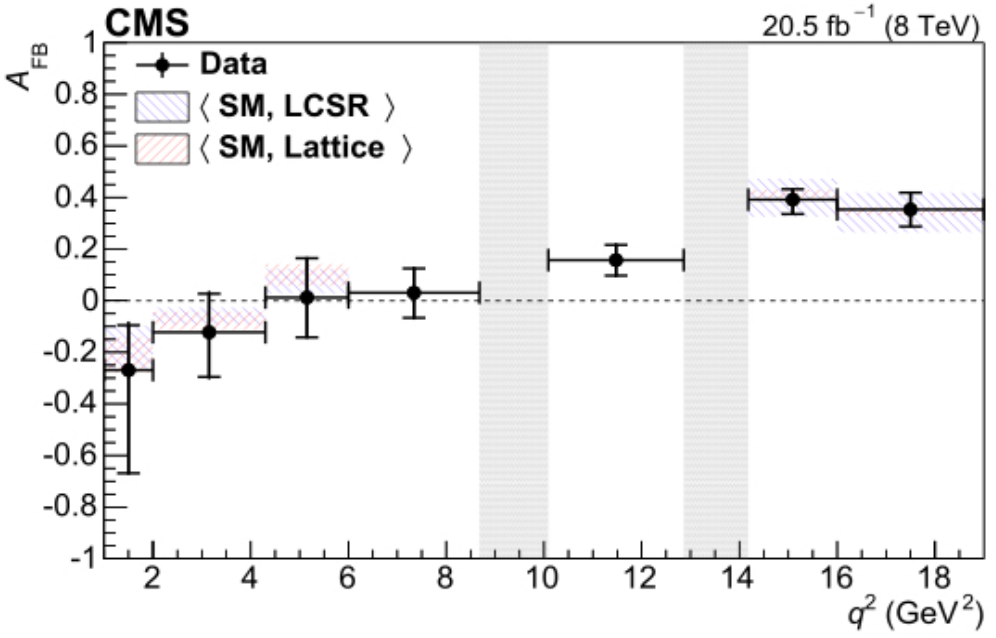


- Total of ~1400 signal evts reconstructed
- NO PID:
  - B flavor tagging from best m(Kπ)
  - Mistag fraction = 12-14% from MC
- BKG PDFs from Data Side Bands

$B \to K^* \mu^+ \mu^-$: Results



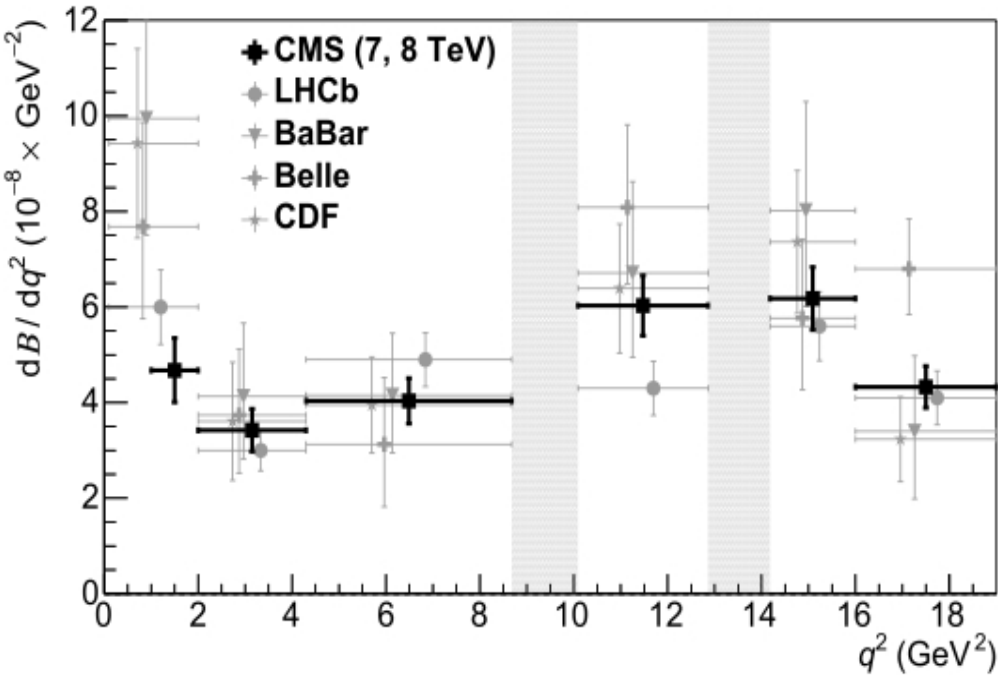


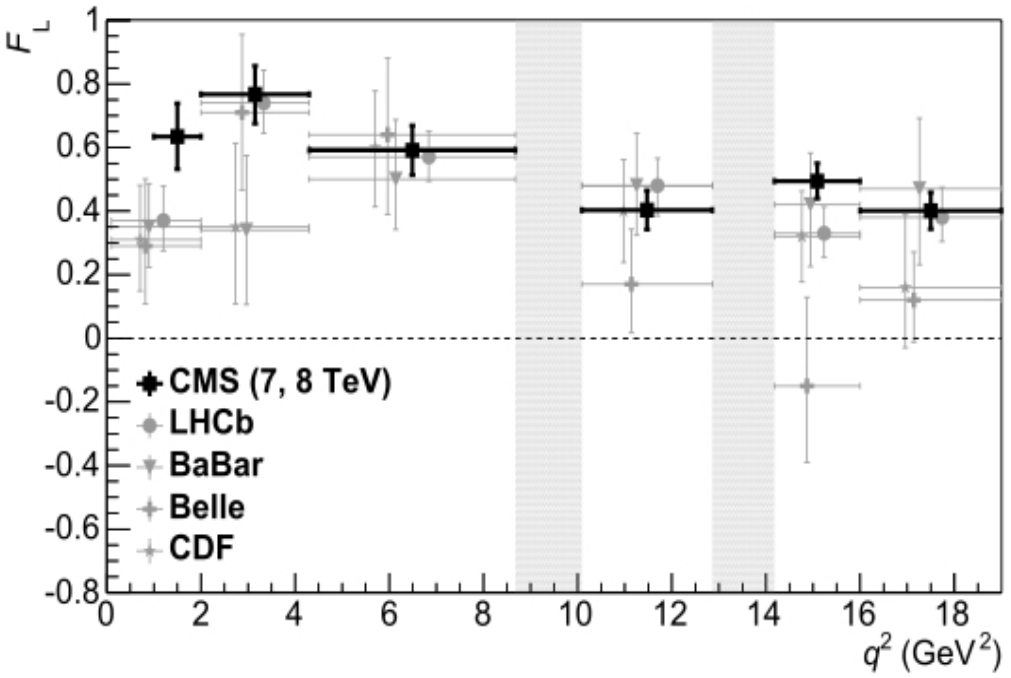


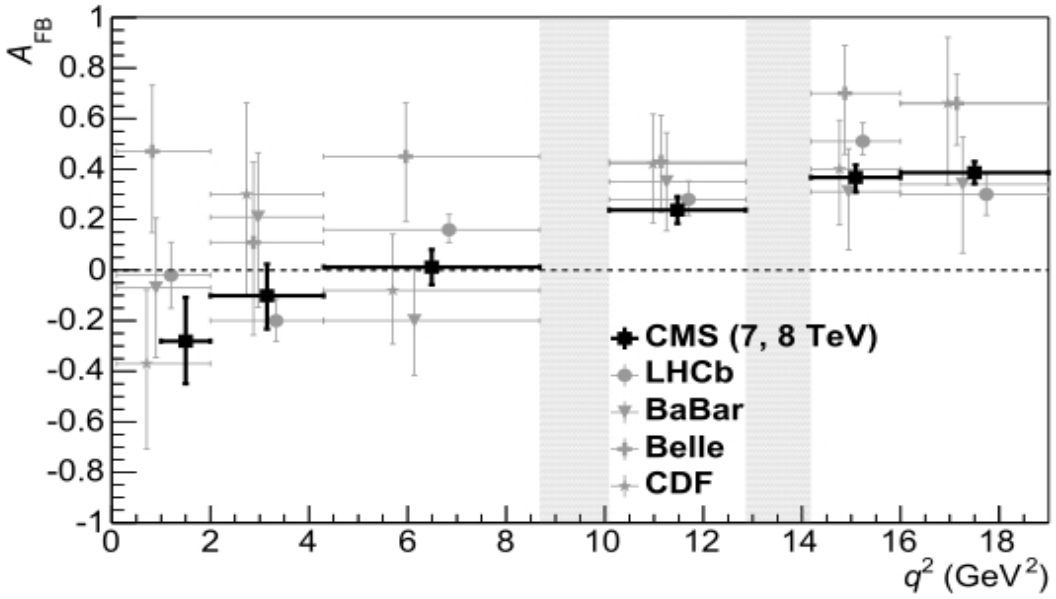
Results consistent with SM

- Systematics from BKG PDF shapes, efficiency, simulation mismodeling and fit bias.
- Theoretical predictions:
  - Light-cone sum rules at low q^2 and extrapolation at high q^2 [JHEP 09 089 (2010), JHEP 02 010 (2013)]
  - Lattice [Phys. Rev. D89 094501 (2014)]

Comparison with other experiments







Expected soon:

- Result using variable P5' with reduced Form-Factor dependence
- $B^+ \to K^+\mu\mu$, $K^{*+}\mu\mu$ angular analyses

From B to Top Physics: m_t measurement

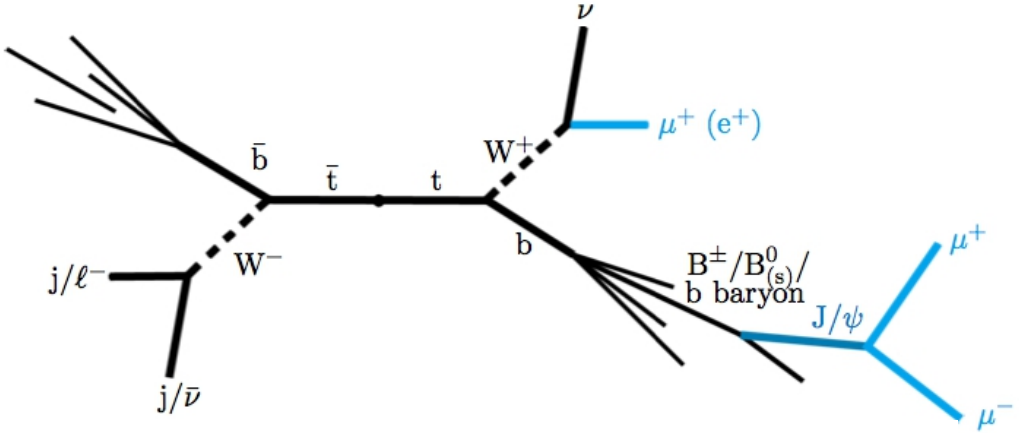
- "Measurement of the top quark mass in tt events with a J/ψ from pp collisions at 8 TeV" [L=19.7 fb^{-1}]
  Preliminary

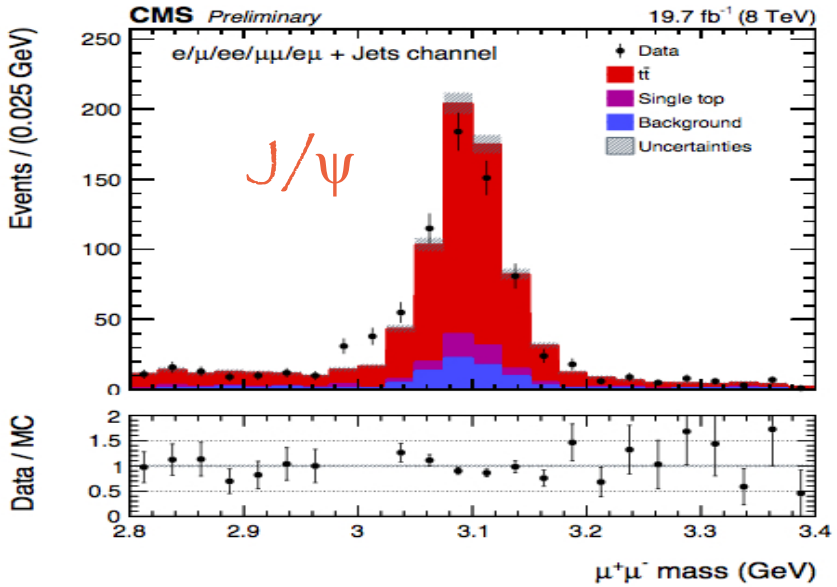
- "Measurement of the top quark mass using charged particles in pp collisions at $\sqrt{s}$ = 8 TeV" [L=19.7 fb^{-1}]
  Phys. Rev. D93, 092006 (2016)

From B to Top: m_t measurement

- m_t measurements using jets limited by hadronization modeling
  - Use cleaner observables sensitive to m_t: J/ψ-lepton invariant mass

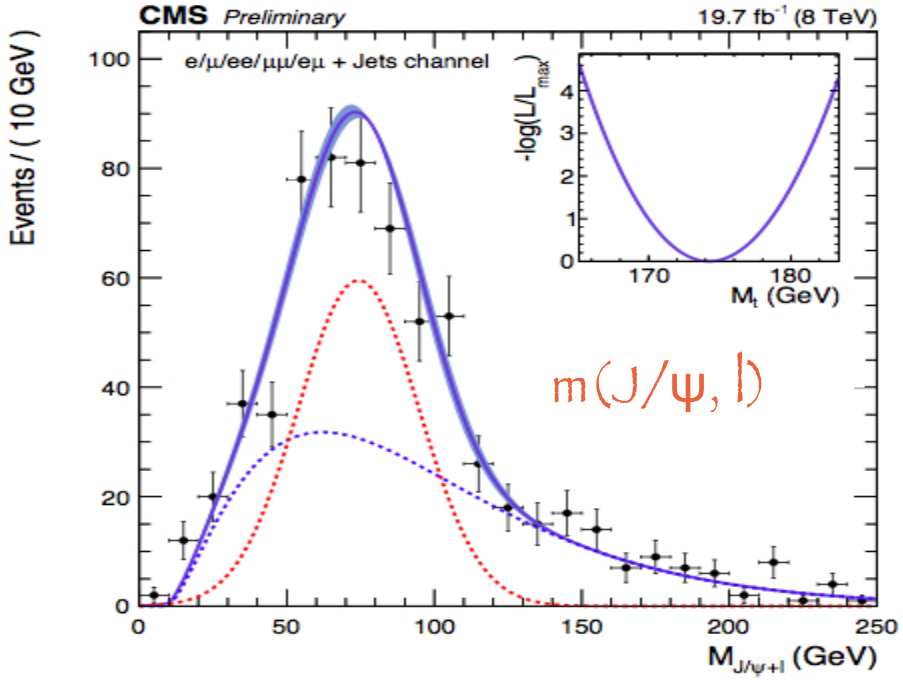
in $t \to blv$ decays: $(BR(tt \to Wb\ (W \to l\nu)\ (b \to J/\psi\ X)) \approx 3.2\ 10^{-4})$





Preliminary result:

$m_t = 173.5 \pm 3.0 \pm 0.9$ GeV



FCNC in Top Couplings

Single t + γ:

- "Search for anomalous single top quark production in association with a photon in pp collisions at $\sqrt{s}$ = 8 TeV" [L=19.8 fb^{-1}] JHEP 04, 035 (2016)

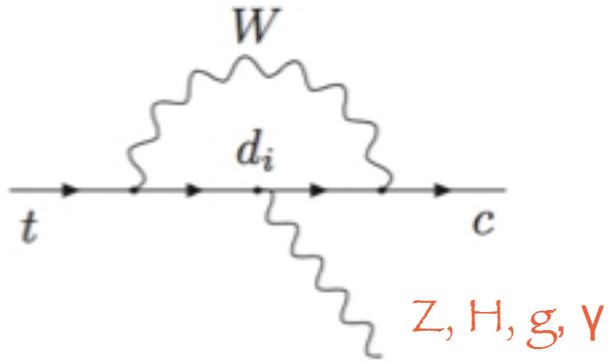
t → Zq:

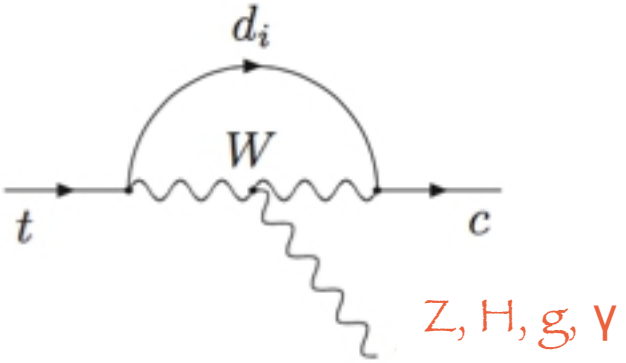
- "Search for Flavor-Changing Neutral Currents in Top-Quark Decays t → Zq in pp Collisions at $\sqrt{s}$ = 8 TeV" [L=19.7 fb^{-1}] Phys. Rev. L. 112, 171802 (2014)

t → Hq:

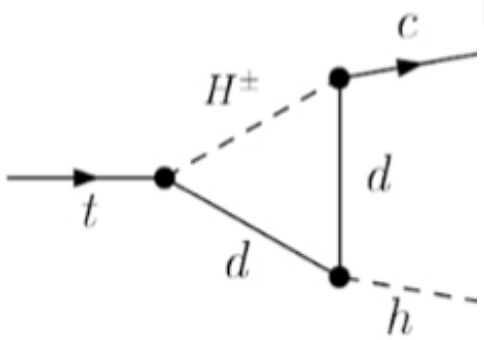
- "Search for top quark decays via Higgs-boson-mediated flavor changing neutral currents in pp collisions at $\sqrt{s}$ = 8 TeV" [L=19.7 fb^{-1}] Preliminary
- "Search for top quark decays t → qH with H → γγ in pp collisions at $\sqrt{s}$ = 8 TeV" [L=19.7 fb^{-1}] Preliminary
- "Search for the Flavor-Changing Neutral Current Decay t → qH where the Higgs decays to bb Pairs at $\sqrt{s}$ = 8 TeV" [L=19.8 fb^{-1}] Preliminary

FCNC in Top Couplings





FCNC process forbidden at tree level, BR~10^{-12}-10^{-17}: Probe the SM!



- Large sensitivity to New Physics due to large couplings with new heavy particles in the loops

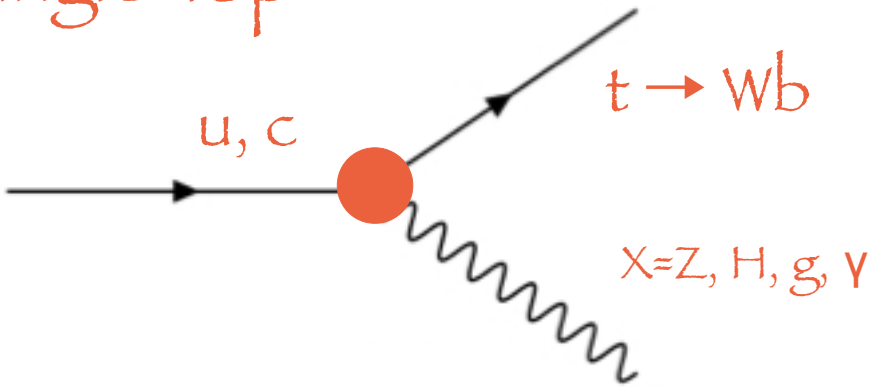
- BSM processes could enhance BRs up to 10^{-4} [arXiv : 1311.2028]:

Process	SM	2HDM(FV)	2HDM(FC)	MSSM	RPV	RS
$t \to Zu$	7×10^{-17}	–	–	$\leq 10^{-7}$	$\leq 10^{-6}$	–
$t \to Zc$	1×10^{-14}	$\leq 10^{-6}$	$\leq 10^{-10}$	$\leq 10^{-7}$	$\leq 10^{-6}$	$\leq 10^{-5}$
$t \to gu$	4×10^{-14}	–	–	$\leq 10^{-7}$	$\leq 10^{-6}$	–
$t \to gc$	5×10^{-12}	$\leq 10^{-4}$	$\leq 10^{-8}$	$\leq 10^{-7}$	$\leq 10^{-6}$	$\leq 10^{-10}$
$t \to \gamma u$	4×10^{-16}	–	–	$\leq 10^{-8}$	$\leq 10^{-9}$	–
$t \to \gamma c$	5×10^{-14}	$\leq 10^{-7}$	$\leq 10^{-9}$	$\leq 10^{-8}$	$\leq 10^{-9}$	$\leq 10^{-9}$
$t \to hu$	2×10^{-17}	6×10^{-6}	–	$\leq 10^{-5}$	$\leq 10^{-9}$	–
$t \to hc$	3×10^{-15}	2×10^{-3}	$\leq 10^{-5}$	$\leq 10^{-5}$	$\leq 10^{-9}$	$\leq 10^{-4}$

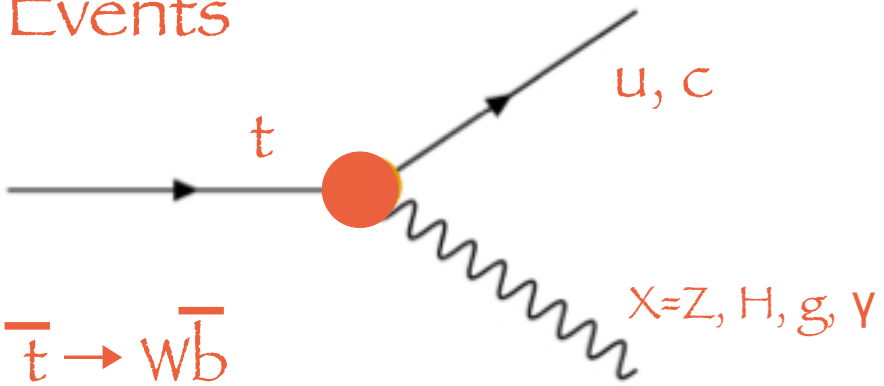
FCNC in Top Couplings

- FCNC searched at production level in Single top events and at the decay level in $t\bar{t}$ events: Similar final states.

Single Top

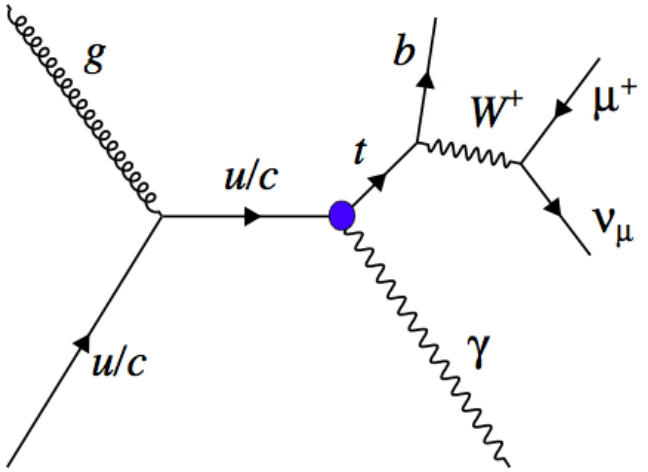


$t\bar{t}$ Events



- In the following:
  - FCNC in top production:
    - Single top + γ
  - FCNC in top decays:
    - $t \rightarrow Zq$ ($Z \rightarrow l^+l^-$)
    - $t \rightarrow Hq$ ($H \rightarrow \gamma\gamma$, WW, ZZ, $\tau\tau$, $b\bar{b}$)

Single t + γ



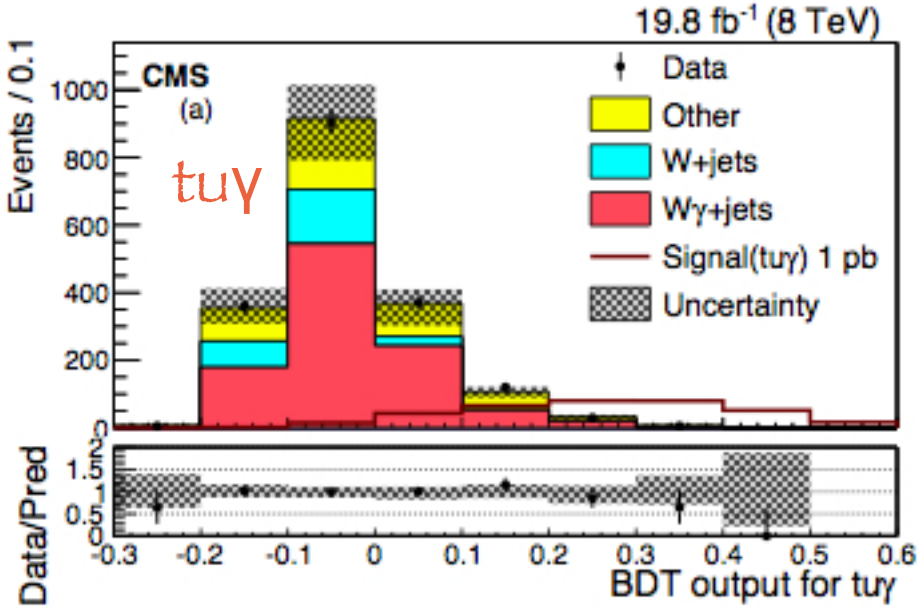
- $t \rightarrow bW\ (\rightarrow \mu\nu)$ decays selected in events with one high P_T isolated photon, one b-tagged jet ($\varepsilon = 70\%$) and significant missing P_T

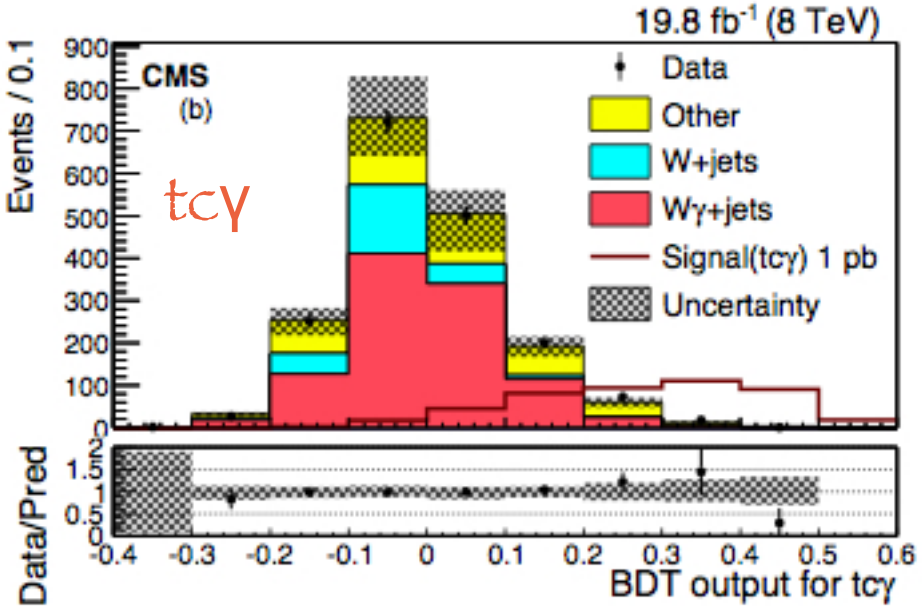
- Top decay kinematics from missing P_T, muon and b-jet four momenta

- Dominant BKG from $W\gamma$ + jets (57%) & W + jets (16%) estimated from data by means of Neural Network (NN) using photon & jets variables (e.g. P_T, $\theta(W, \gamma)$, hadronic/e.m. Energy in a cone around γ)

Single t + γ

- Signal extracted using two different Boosted Decision Trees (BDT) for tuγ & tcγ using several distributions from W(γ)+jets control samples





- No excess found: upper limits computed @ 95% CL:

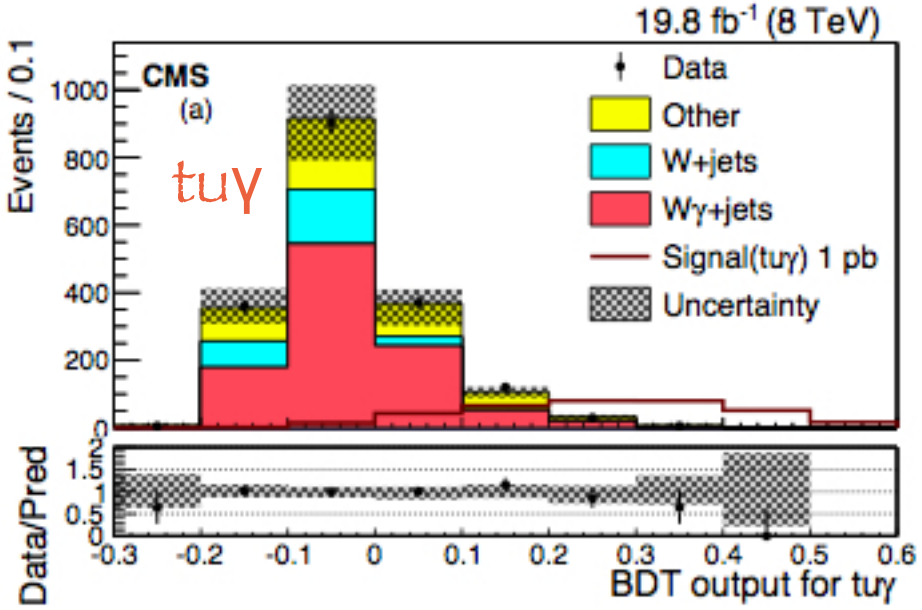
$\sigma_{tu\gamma}\, BR(t \to blv) < 26\ fb \to BR(t \to u\gamma) < 1.3\ 10^{-4}$

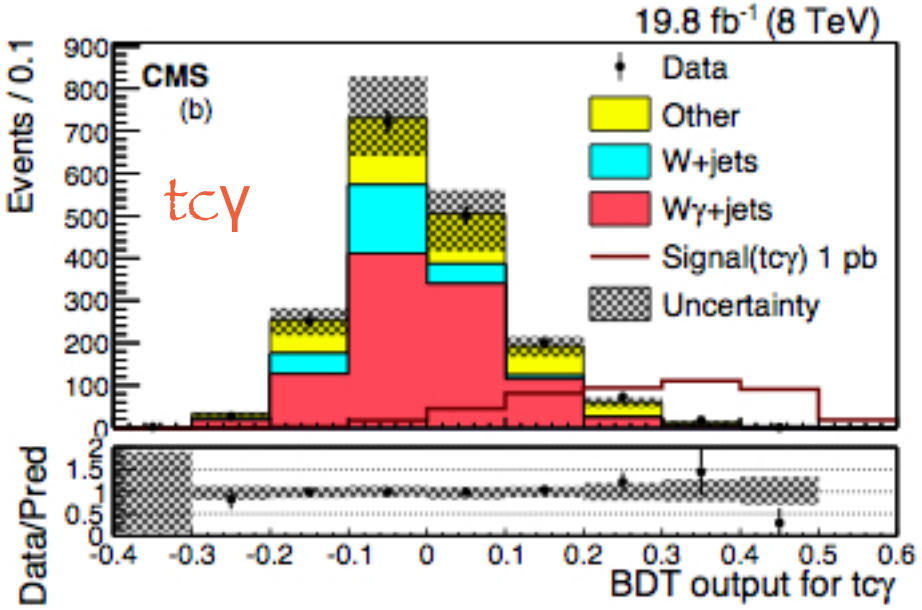
$\sigma_{tc\gamma}\, BR(t \to blv) < 37\ fb \to BR(t \to c\gamma) < 1.7\ 10^{-3}$

Using theoretical expectation from [Acta Phys. Polon. B 35, 2695 (2004)]

Single t + γ

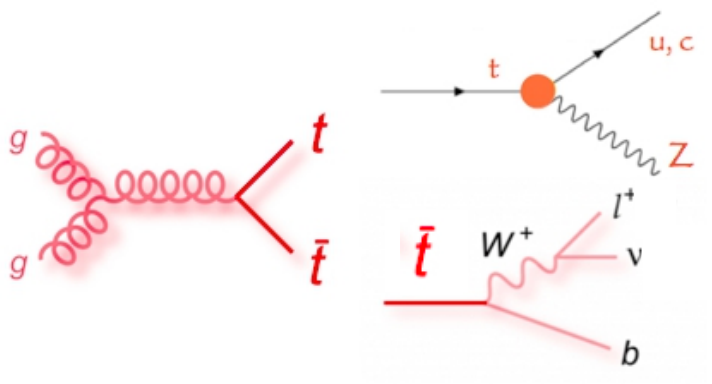
- Signal extracted using two different Boosted Decision Trees (BDT) for tuγ & tcγ using several distributions from W(γ)+jets control samples



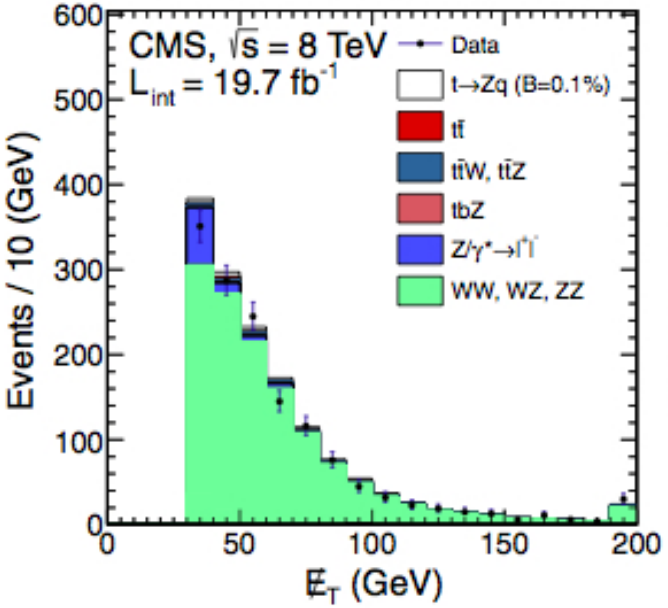


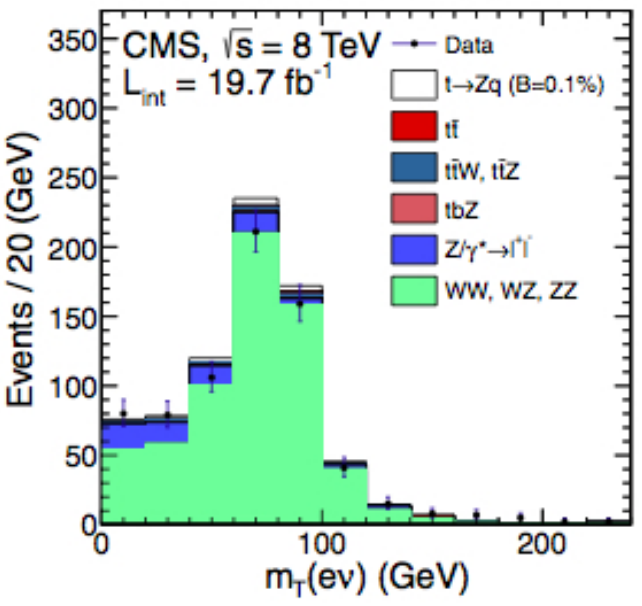
- Systematics from trigger, photon and lepton efficiencies (6.3%), BKG estimation (3.3%), photon energy scale (3.1%), signal efficiency (PDFs, factorization & renormalization scales, m_t) (2.8%), pileup (2.3%)

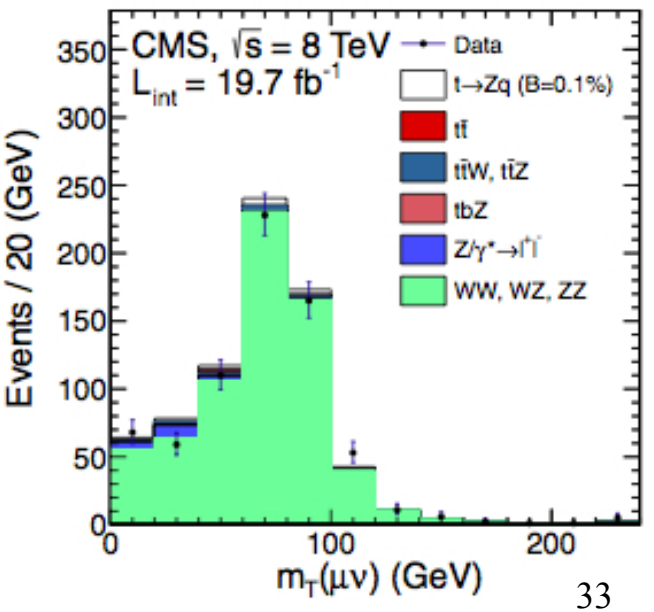
$t \to Zq$ in $t\bar{t}$ Decays



- Strategy:
  - $t\bar{t} \to qZ(\to l^+l^-)\, bW(\to l\nu)$ ($l \equiv e, \mu$) reconstructed requiring three high P_T isolated leptons & Missing E_T
- W transverse mass from P_T(lepton), $\not{E}_T$ and azimuthal angle between the two
- BKG dominated by diboson WW, WZ & ZZ:

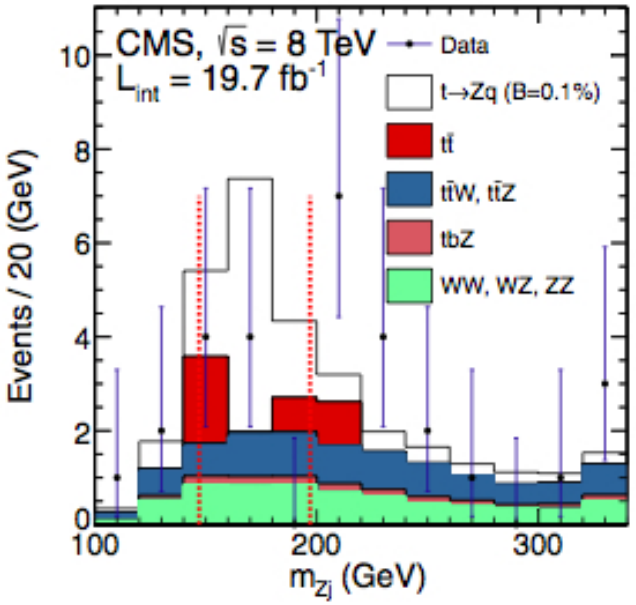


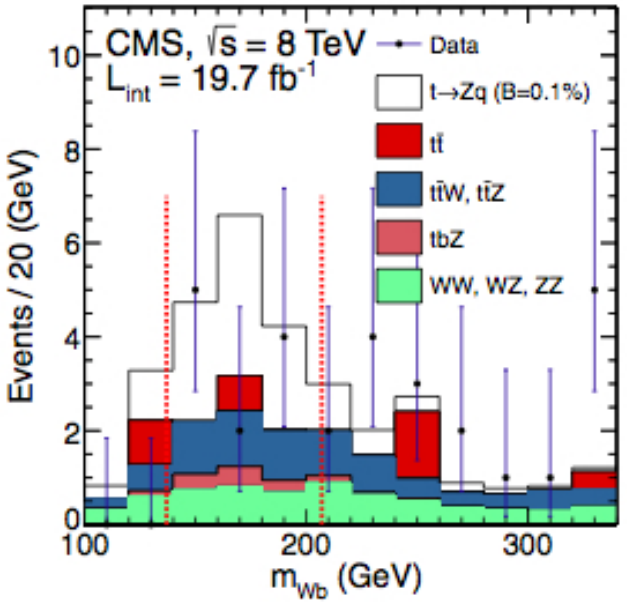


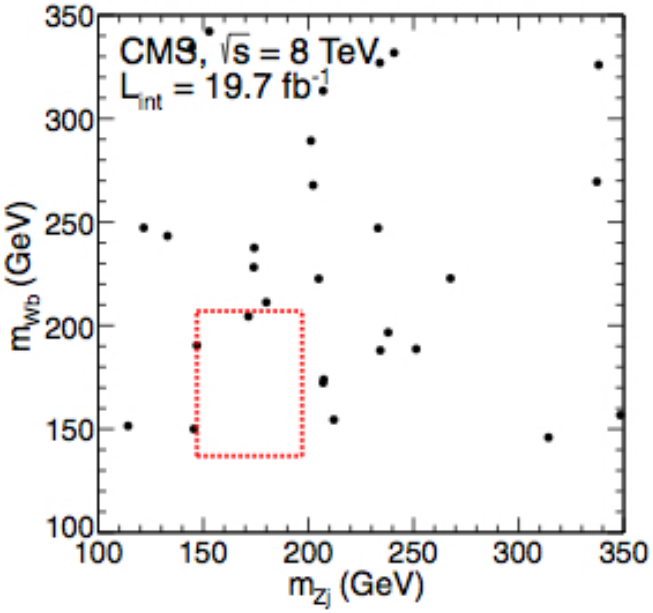


$t \to Zq$ in $t\bar{t}$ Decays

- BKG suppressed requiring ≥ 2 jets with one of them b-tagged
- Signal selected exploiting m(W, b-jet) & m(Z, non-b jet):
  - BKG yields from dibosons & ttX estimated from data





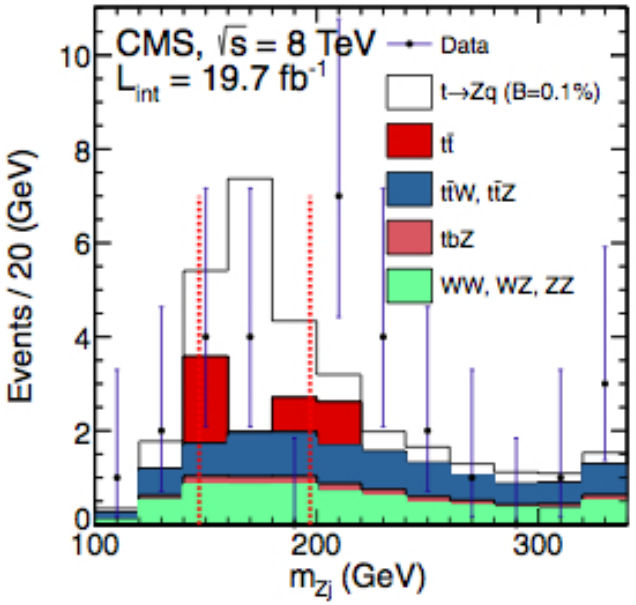


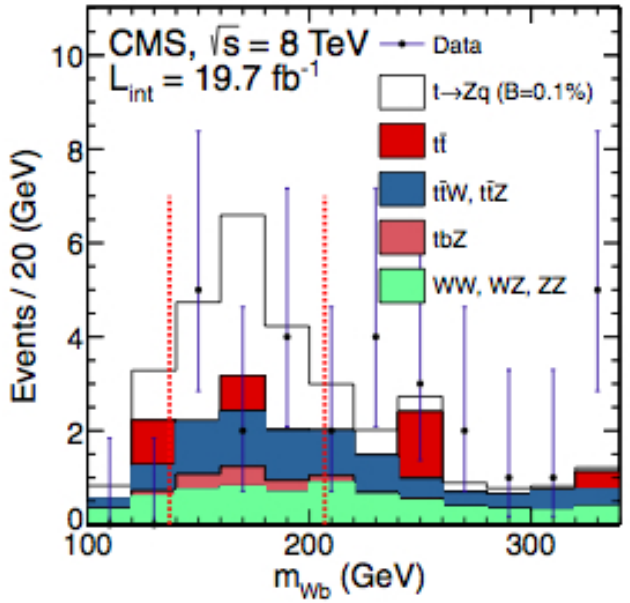
No excess found:

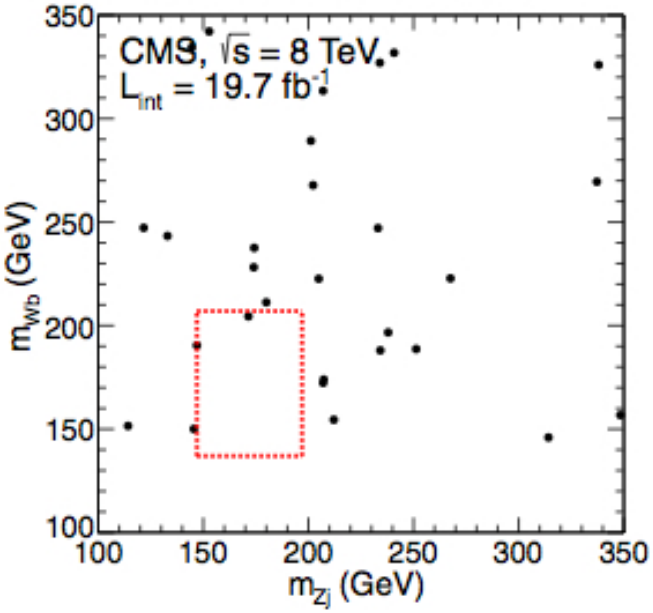
BR($t \to Zq$)<0.05% (exp. <0.09%) for 7+8 TeV @ 95% CL

t→Zq in tt Decays

- BKG suppressed requiring ≥ 2 jets with one of them b-tagged
- Signal selected exploiting m(W, b-jet) & m(Z, non-b jet):
  - BKG yields from dibosons & ttX estimated from data

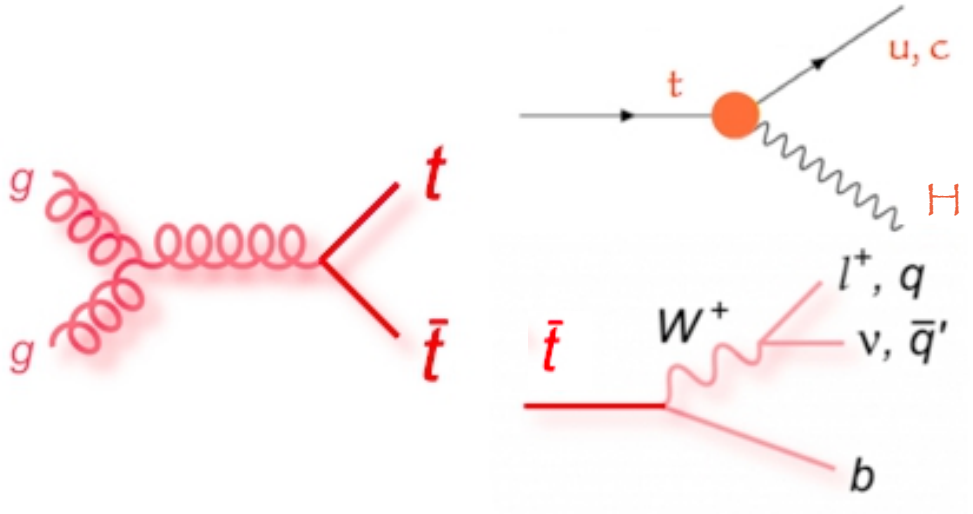






- Systematics:
  - Signal selection acceptance: PDFs & generator parameters (15.1%), trigger, lepton & b-tagging efficiencies (9.3%), tt cross section (7%)
  - BKG evaluation: b-tagging efficiency & m_t requirements (25%)

t → Hq in tt Decays

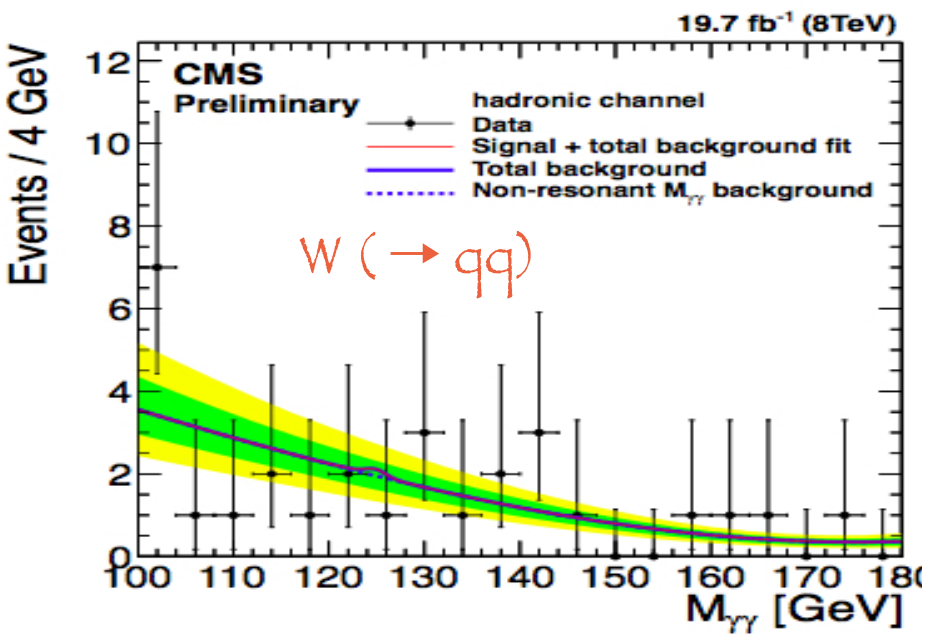


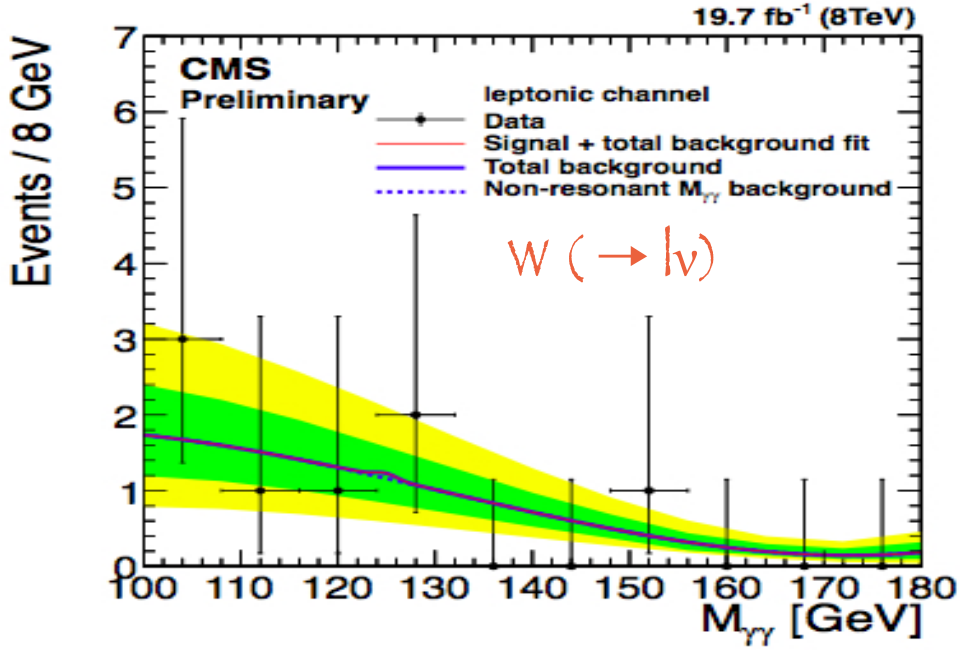
- tt → qH bW selected where
  - H → γγ, WW, ZZ, ττ, bb
  - W → qq, lν (l ≈ e, μ)

- Event Selection:
  - H → γγ: two high P_T photons and one b-tagged jet in events with ≥ 4 jets (W → qq) or one isolated lepton (W → lν)
  - H → WW, ZZ, ττ: trilepton (WW, ZZ, ττ → ll; W → lν) or same-sign dilepton events (W^+, Z^+, $\tau^+ \rightarrow l^+$; W^-, Z^-, $\tau^- \rightarrow$ hadrons; $W^+ \rightarrow l^+\nu$)
  - H → bb: one energetic lepton (W → lν) and ≥ 4 jets (≥ 3 b-tagged)

t → Hq in tt Decays

- H → γγ
- Dominant BKG from resonant H → γγ decays (estimated on MC) & non-resonant diphoton events (estimated on data)



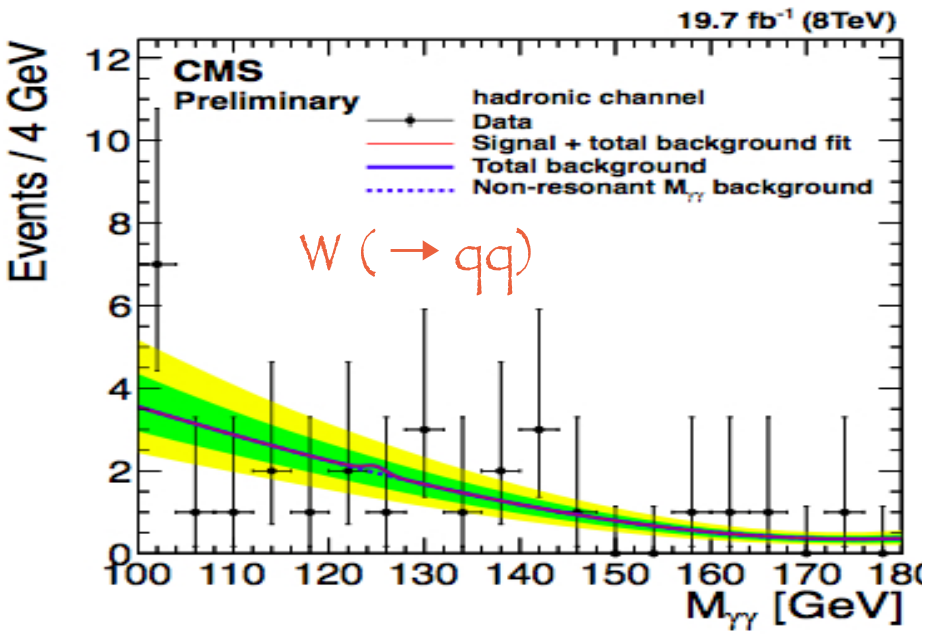


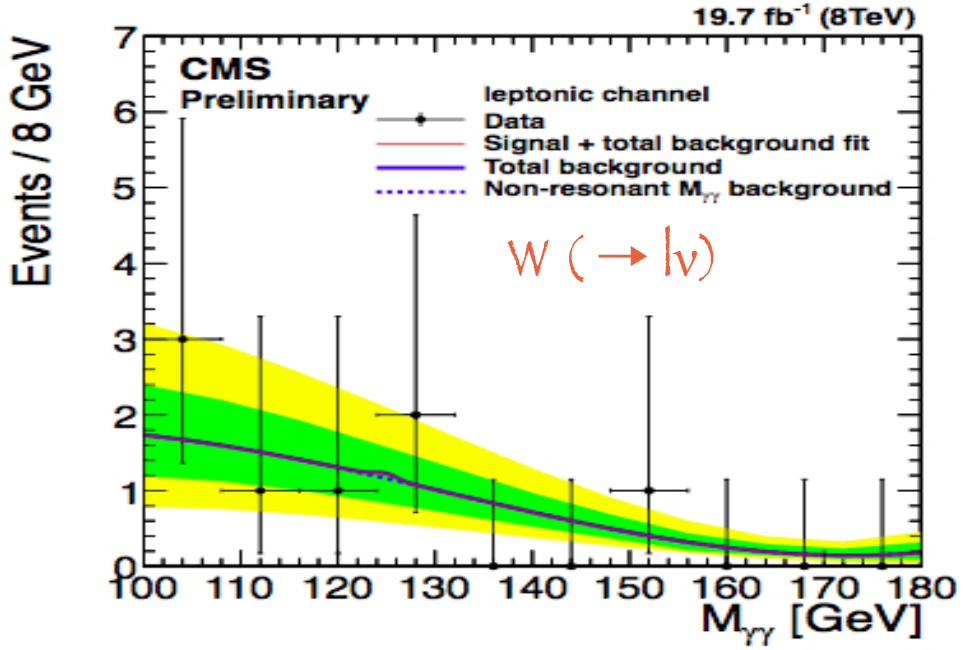
- No excess observed:

BR(t → Hc)<0.47%, BR(t → Hu)<0.57% @ 95% CL

$t \to Hq$ in $t\bar{t}$ Decays

- $H \to \gamma\gamma$
- Dominant BKG from resonant $H \to \gamma\gamma$ decays (estimated on MC) & non-resonant diphoton events (estimated on data)



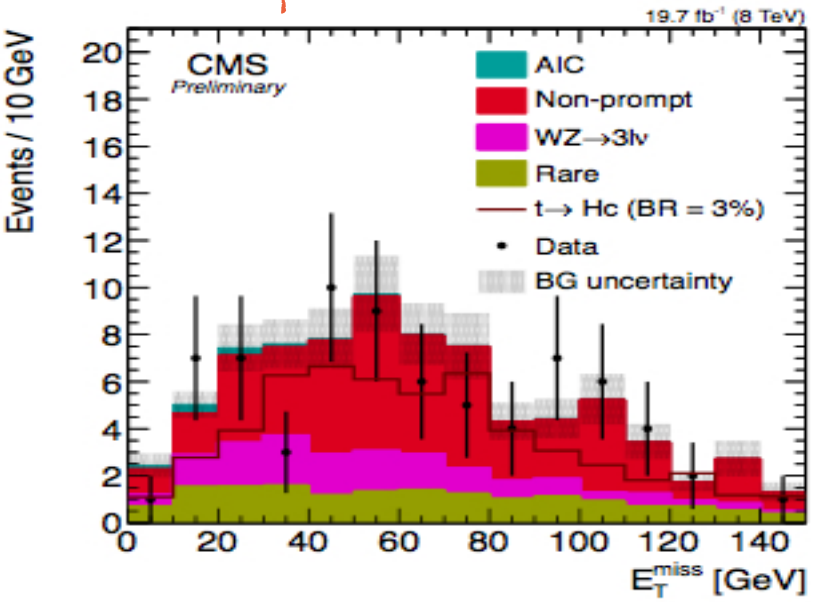


- Systematics:
  - Signal yield: PDFs (5.5%), b-tagging efficiency and jet energy resolution (4%)
  - BKG estimation: Higgs production cross section (12.3%)

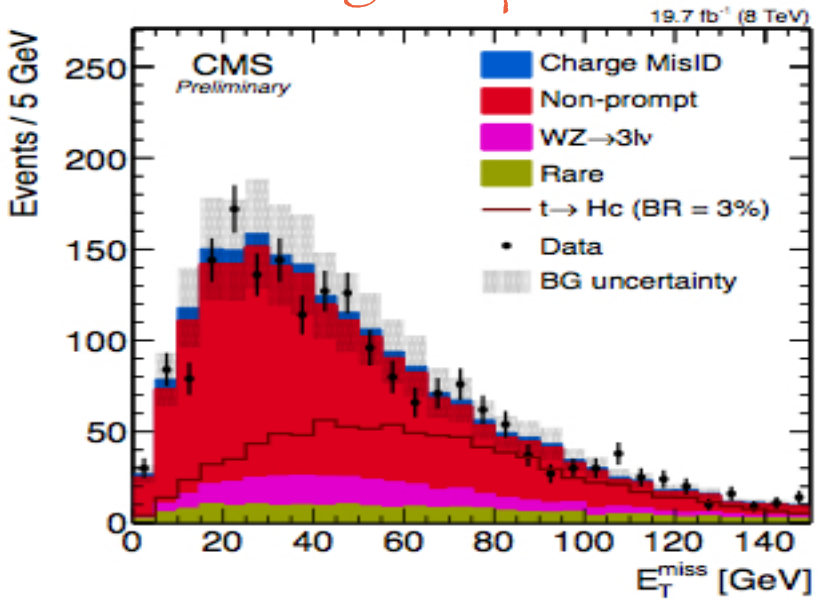
t → Hq in tt Decays

- H → WW, ZZ, ττ
- BKG from W, Z leptonic decays & non-prompt leptons from B decays or misidentified hadrons

Trileptons



Same-sign dileptons



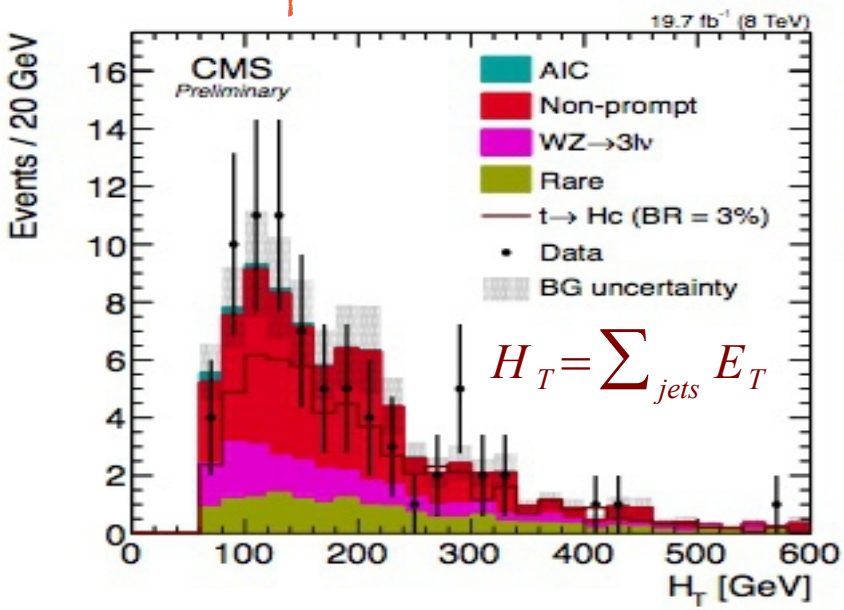
- No excess observed:

BR(t → Hc)<0.93% @ 95% CL

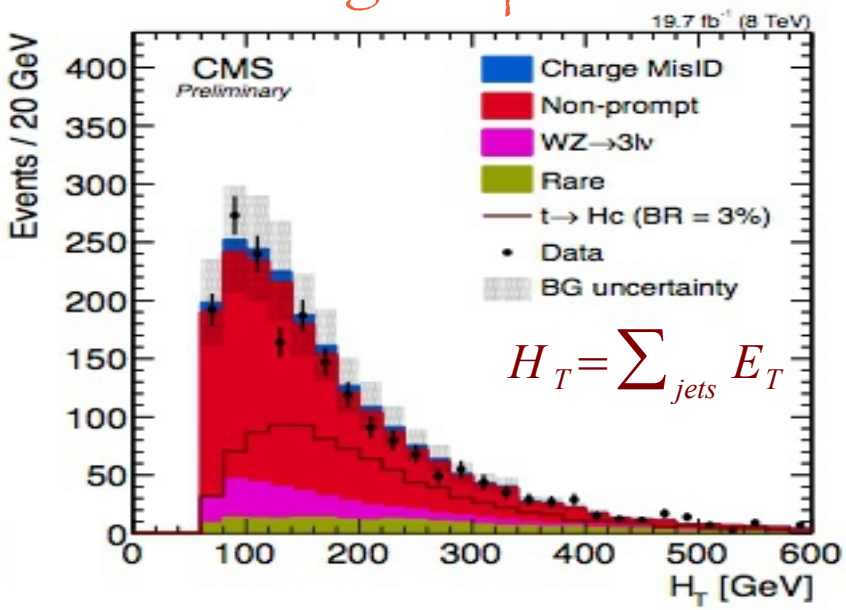
t → Hq in tt Decays

- H → WW, ZZ, ττ
- BKG from W, Z leptonic decays & non-prompt leptons from B decays or misidentified hadrons

Trileptons



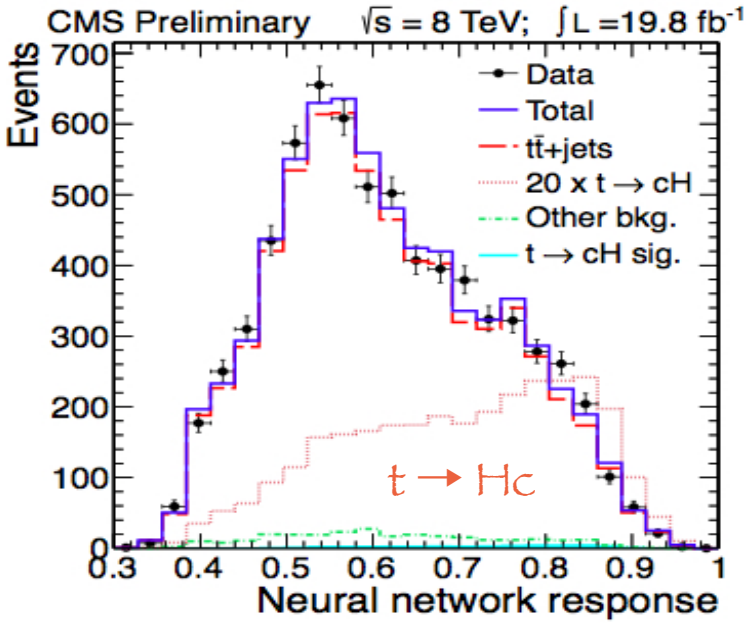
Same-sign dileptons

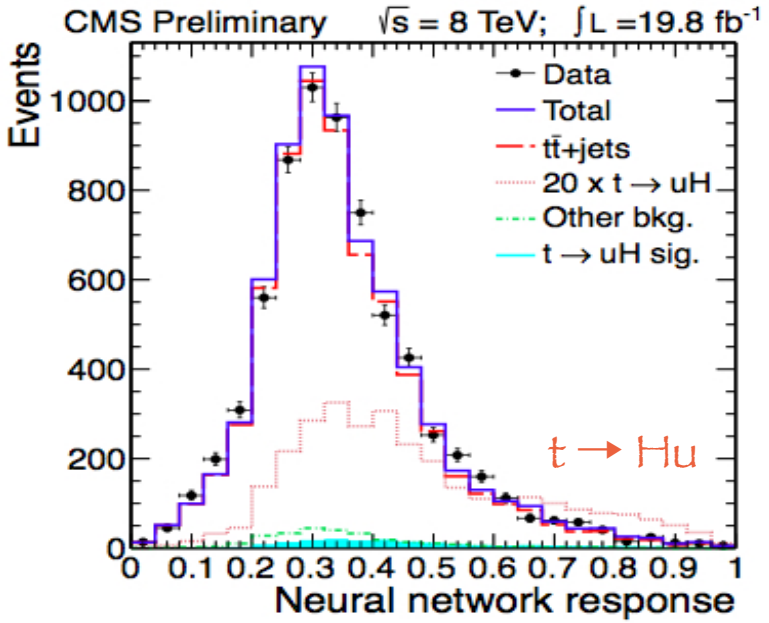


- Systematics:
  - Signal yield: trigger and lepton efficiencies (2.8%), luminosity (2.5%)
  - BKG estimation: cross sections (12%), Lepton misidentification (40% e, 30% μ)

t → Hq in tt Decays

- H → bb
- BKG dominated by tt → bbWW
- Signal extraction from a fit on the output of a NN using m_H & the jets b-tagging discriminants checked on BKG control samples



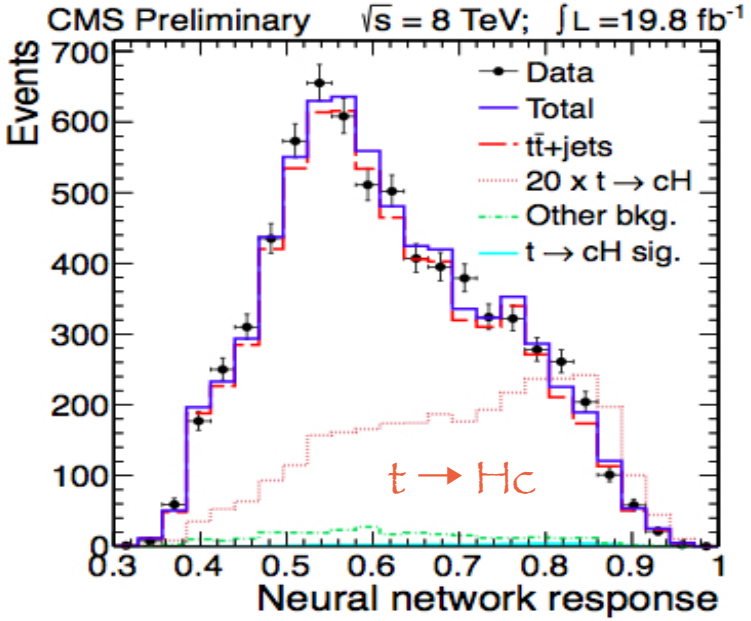


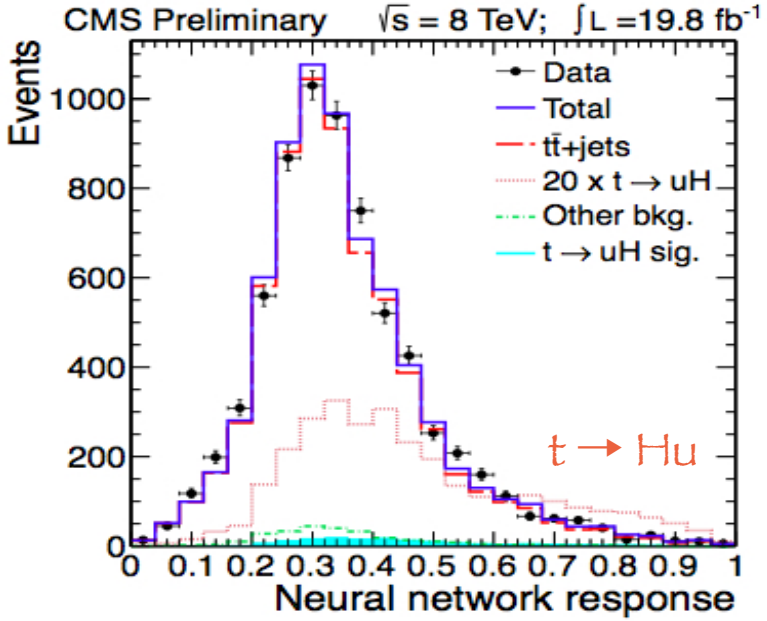
- No excess observed:

BR(t → Hc)<1.16%, BR(t → Hu)<1.92% @ 95% CL

t → Hq in tt Decays

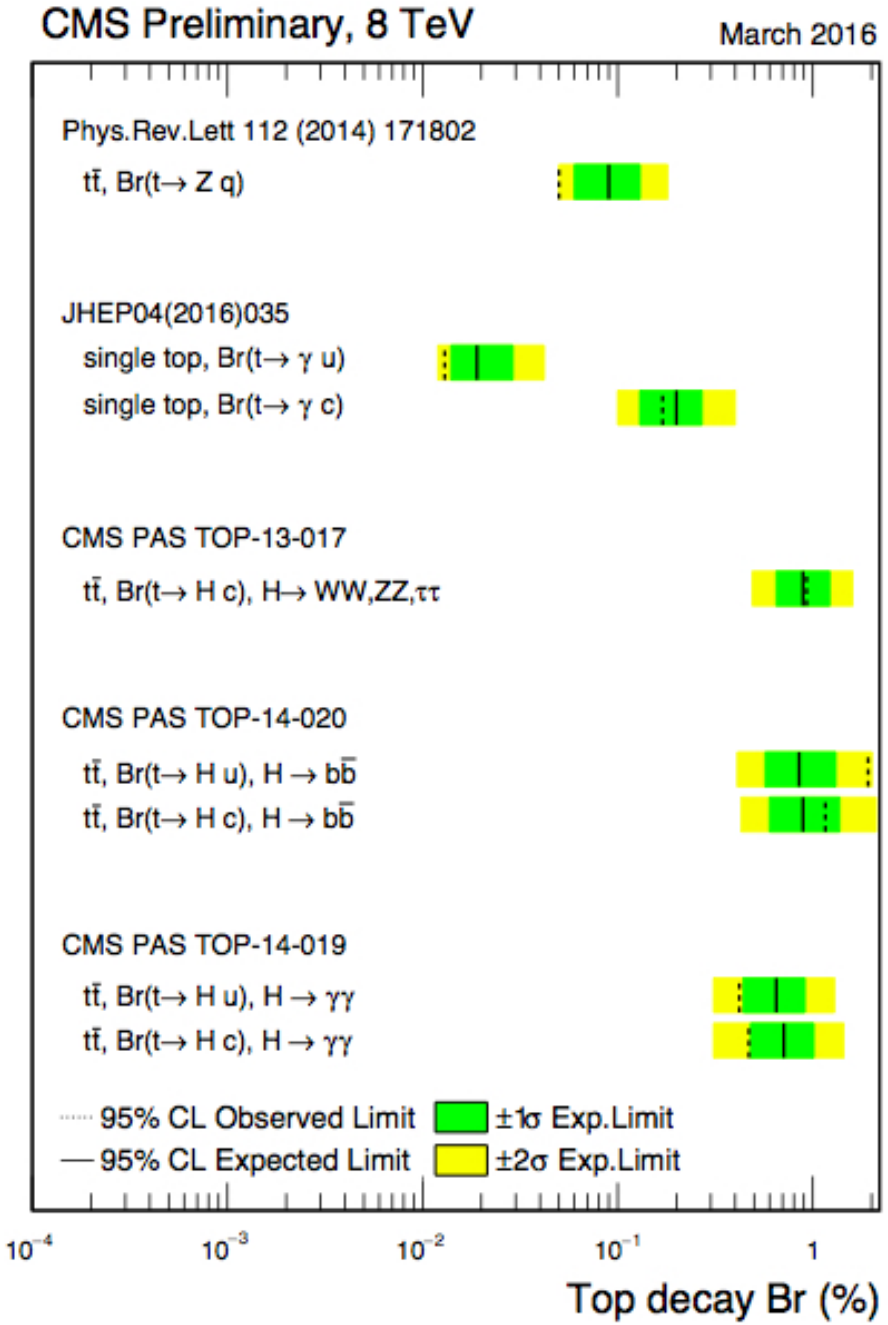
- H → bb
- BKG dominated by tt → bbWW
- Signal extraction from a fit on the output of a NN using m_H & the jets b-tagging discriminants checked on BKG control samples

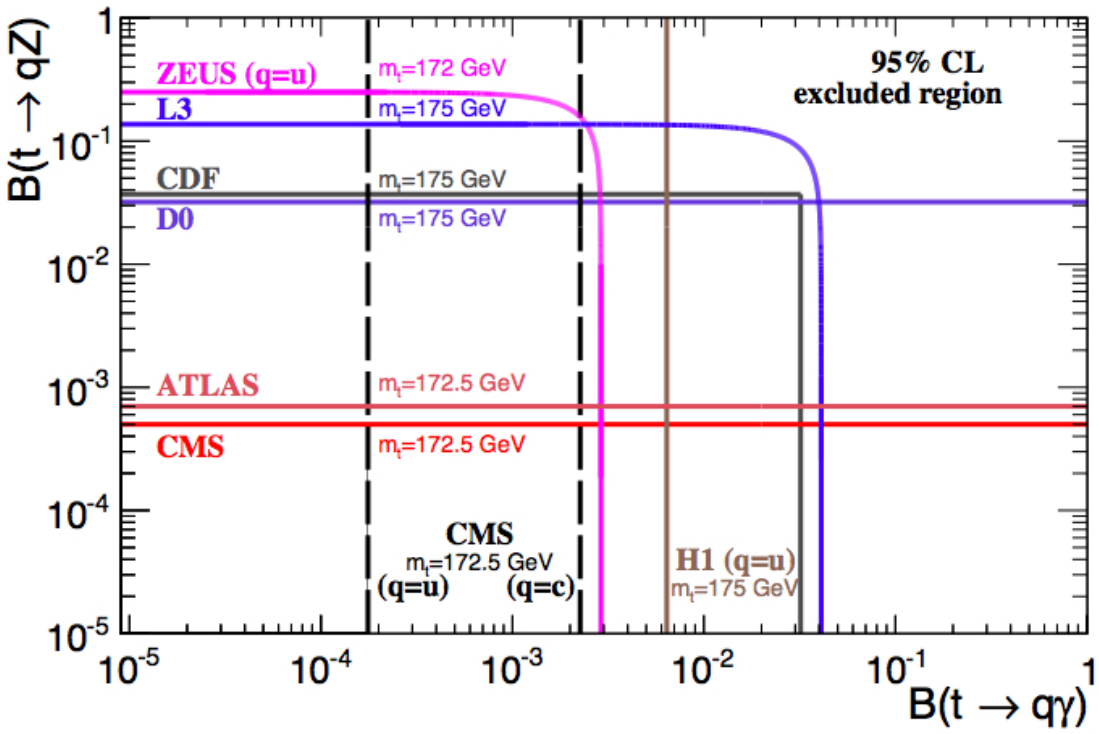




- Systematics on Signal Yield (BKG estimation):
  - b-jet tagging: 24% (1%), jet energy scale and resolution: 17% (11%), cross sections, generator parameters and PDFs: 12% (7%)

FCNC in Top Couplings: Summary





- BR limits still above SM prediction, but approaching BSM models

CP Violation in tt Events

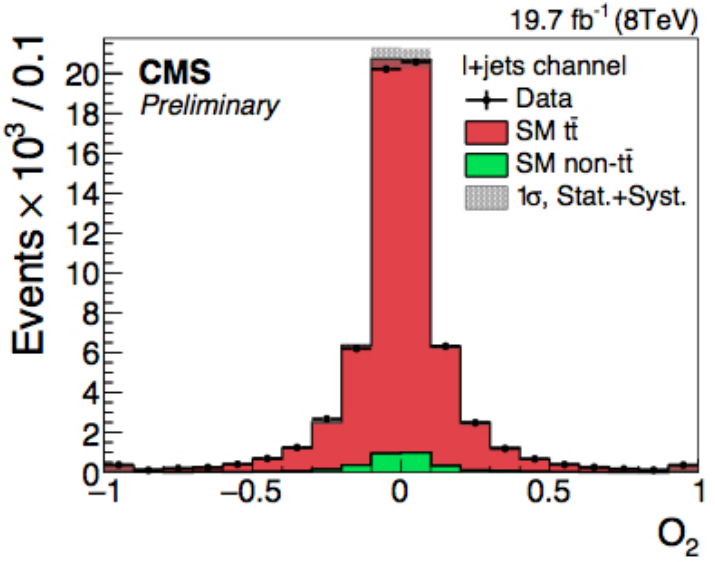
- "Search for CP violation in top quark pair production with the lepton + jets final state at $\sqrt{s}$ = 8 TeV" [L=19.7 fb^{-1}] Preliminary

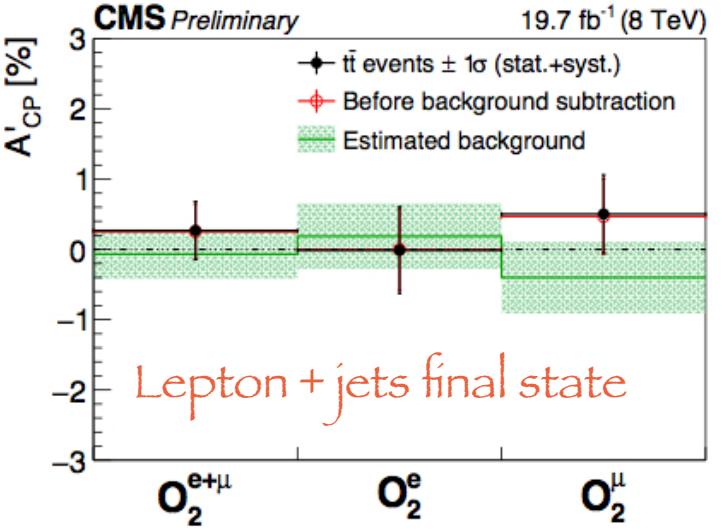
  First Measurement

CP Violation in tt Events

- CP Violation in top quarks production & decays predicted to be very small in the SM: Sizable effects could be hints of NP
- Four triple-product observables O_i, odd under CP transformation, defined in terms of final state objects momenta and charges
  - CPV measured from Asymmetries:

$$A_{CP}(O_i) = \frac{N_{events}(O_i > 0) - N_{events}(O_i < 0)}{N_{events}(O_i > 0) + N_{events}(O_i < 0)}$$





Results in agreement with SM

- Systematics dominated by theory

First Measurement

Conclusions

Conclusions

- Flavor Physics in the B and Top sector is an ideal means of investigating Standard Model and possible New Phenomena

- In the last few years several new measurements both on B mesons production and properties have been released by CMS

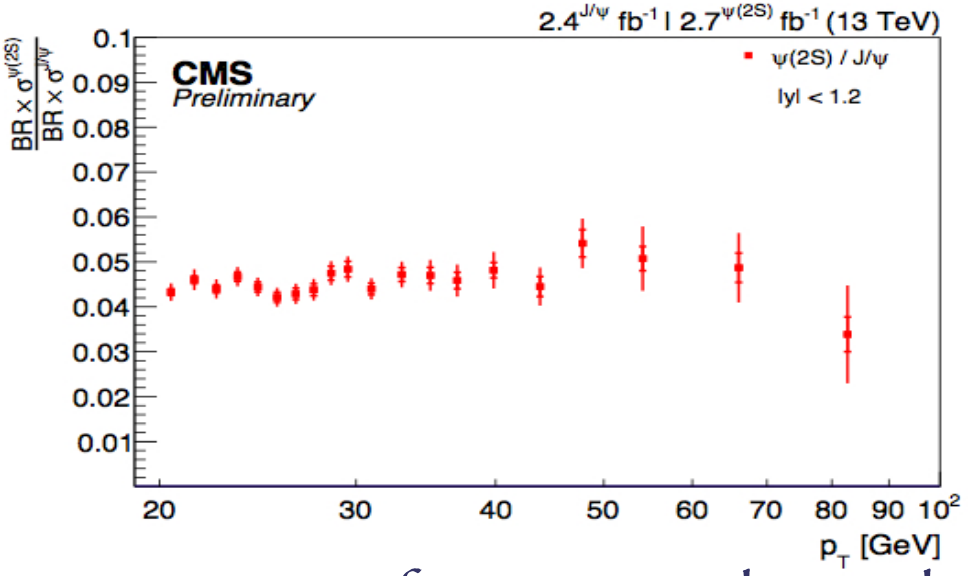
- Very precise measurements in the Top production and decays from LHC have significantly improved exclusion limits on FCNC couplings

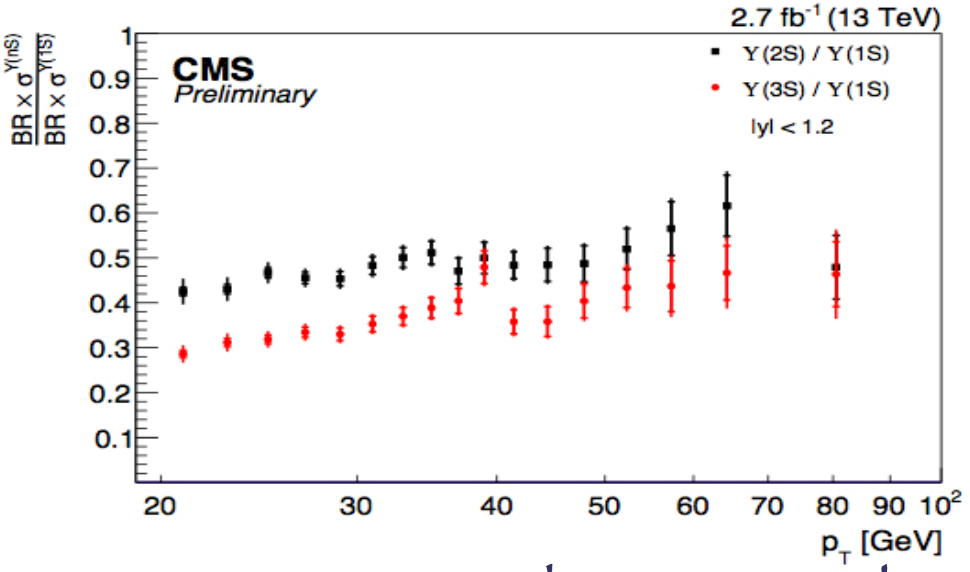
- LHC Run 2 analyses are ongoing: very important results will be available in the next years

Backup

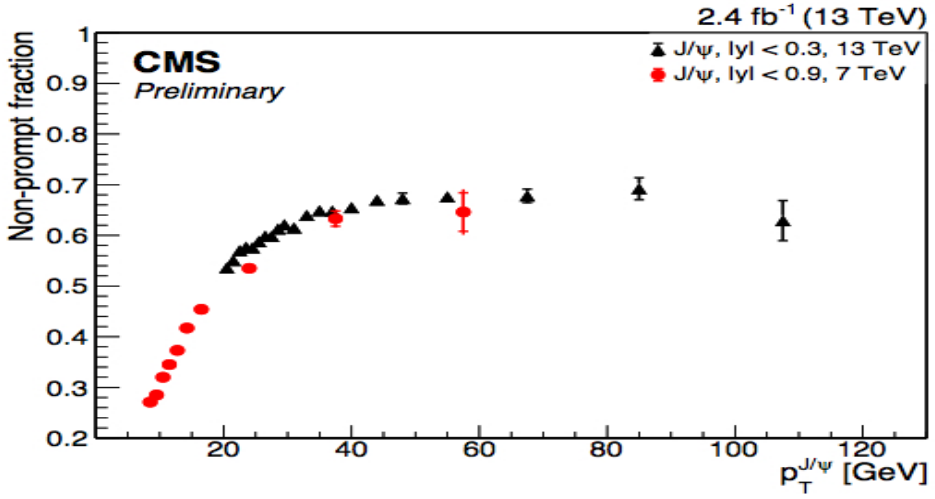
σ(pp → Quarkonium) @ 13 TeV

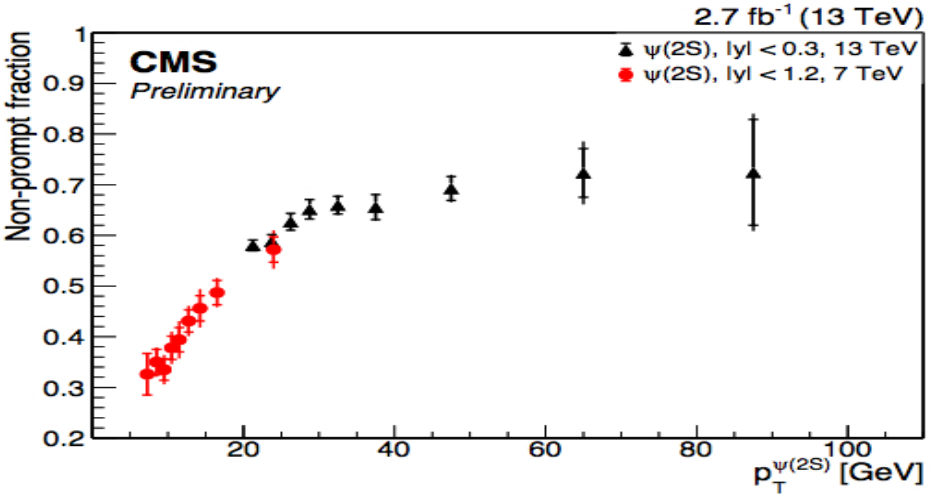
- Excited vs ground prompt fraction states :





- Non-prompt fraction P_T dependence in agreement with 7 TeV results





$B \to K^* \mu^+ \mu^-$

- Strategy:
  - Measure event yield Y_S, A_{FB} and F_L from an unbinned simultaneous fit to $M(K\pi\mu\mu)$, $\cos(\theta_K)$ and $\cos(\theta_l)$ in bins of q^2

$$PDF(m,\theta_K,\theta_l) = Y_S^C \left[S^C(m) S^a(\theta_K,\theta_l) \epsilon^C(\theta_K,\theta_l) \right] \quad \text{Correctly Tagged Signal}$$

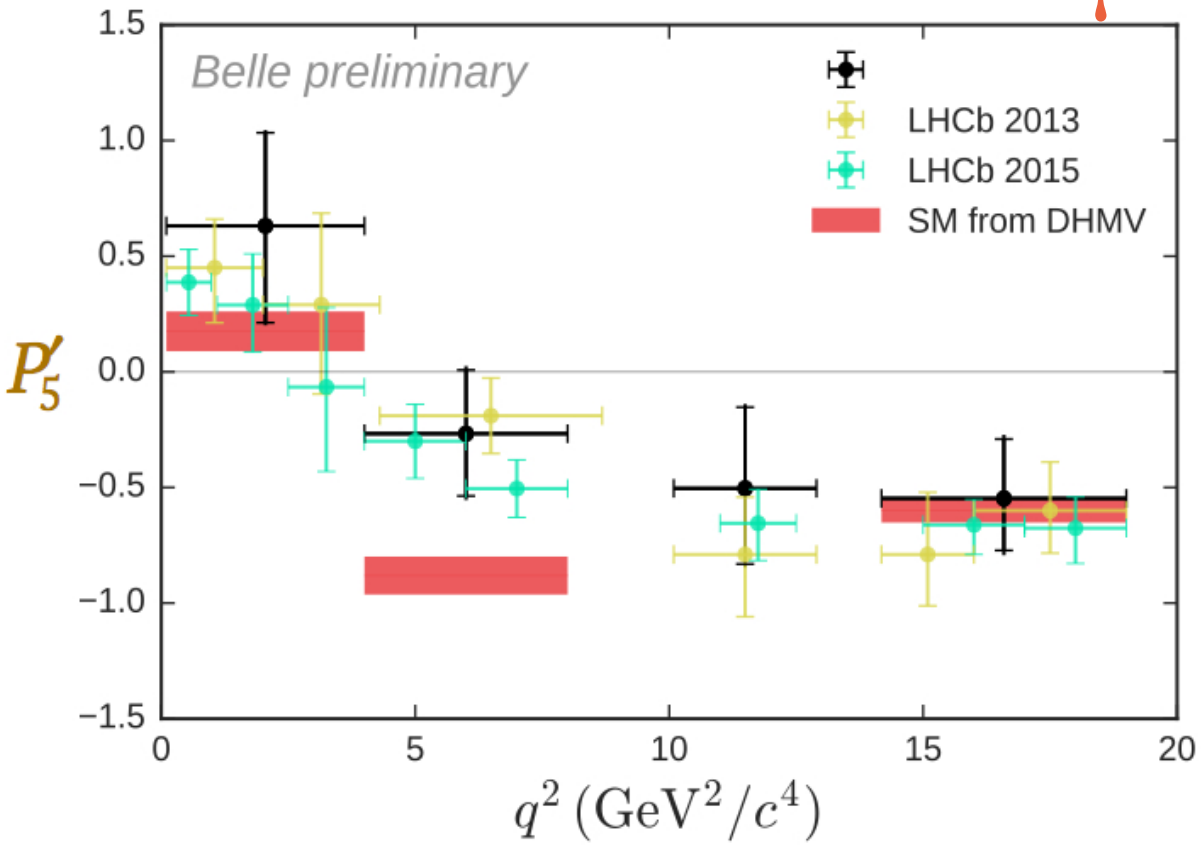
$$+ \frac{f^M}{1-f^M} S^M(m) S^a(-\theta_K,-\theta_l) \epsilon^M(\theta_K,\theta_l) \Big] \quad \text{Mistagged Signal}$$

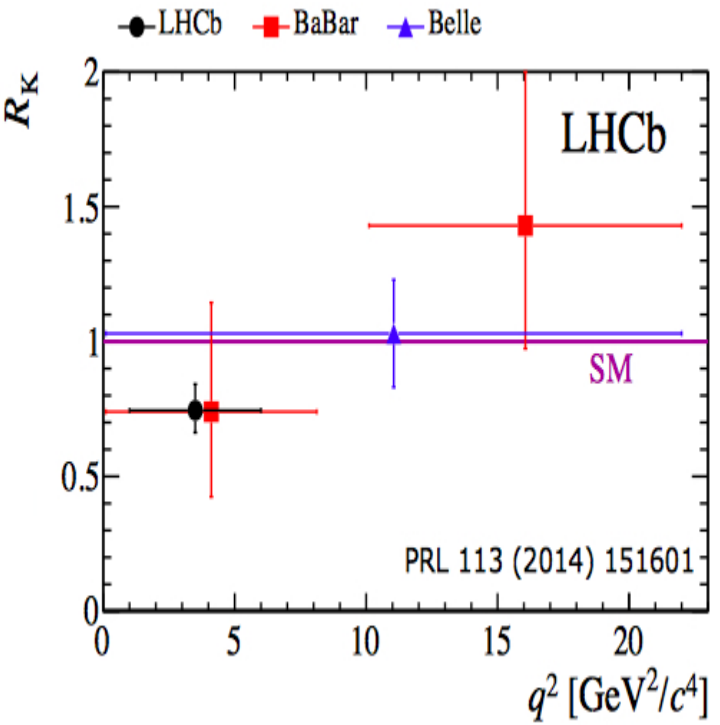
$$+ Y_B B^m(m) B^{\theta_K}(\theta_K) B^{\theta_l}(\theta_l) \quad \text{BKG}$$

Y_S^C, Y_B	Event Yields
f^M	Fraction of mistagged signal events
$S^a(\theta_K,\theta_l), \epsilon^C(\theta_K,\theta_l), \epsilon^M(\theta_K,\theta_l)$	Signal angular shape and efficiency
$S^C(m), S^M(m), B(m)$	Mass PDFs
$B(\theta_{K(l)})$	Angular BKG PDFs from Data Side Bands

  - dB/dq^2 obtained relative to the normalization channel $B^0 \to K^* J/\psi$

$B \to K^* \mu^+ \mu^-$

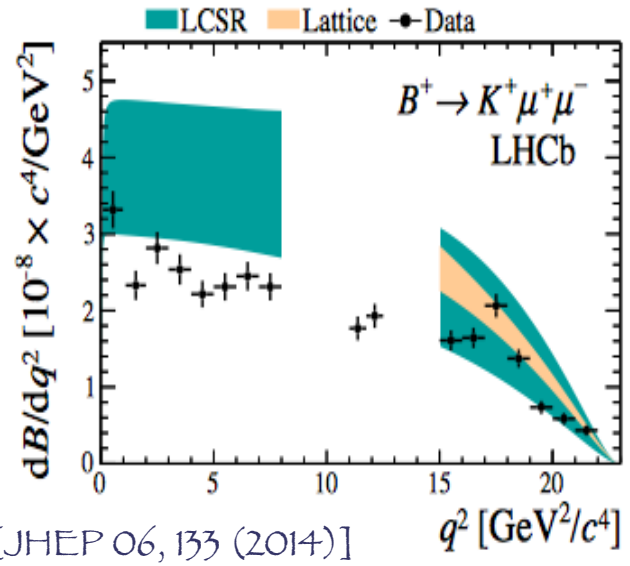


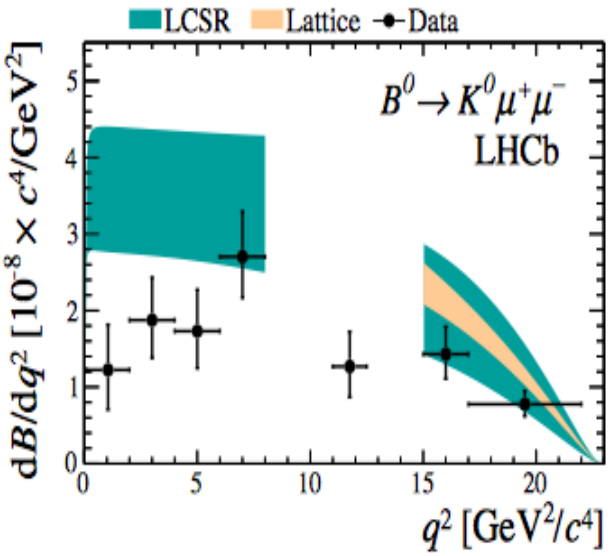


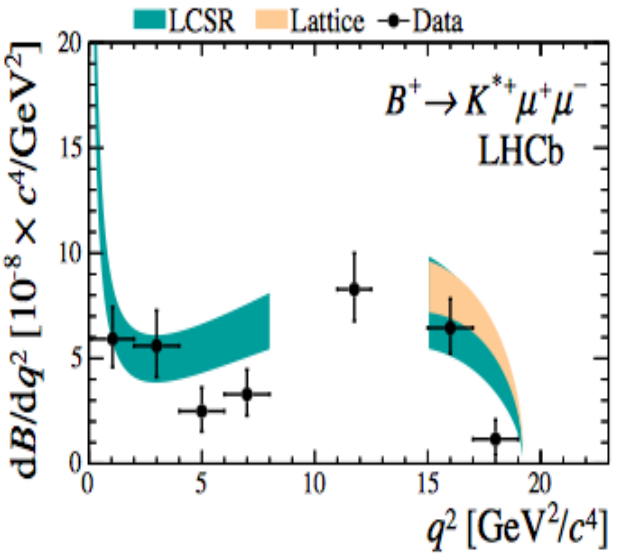
- LHCb full statistics result on P5': discrepancy at 3.4 σ level [JHEP 02, 104 (2016)]
- Belle confirms the tension at 2.1 σ level [arXiv:1604.04042]
- Need to control the charm penguin to disentangle SM from NP in C_7^{eff} and C_9^{eff}

B → K* ll Related quantities

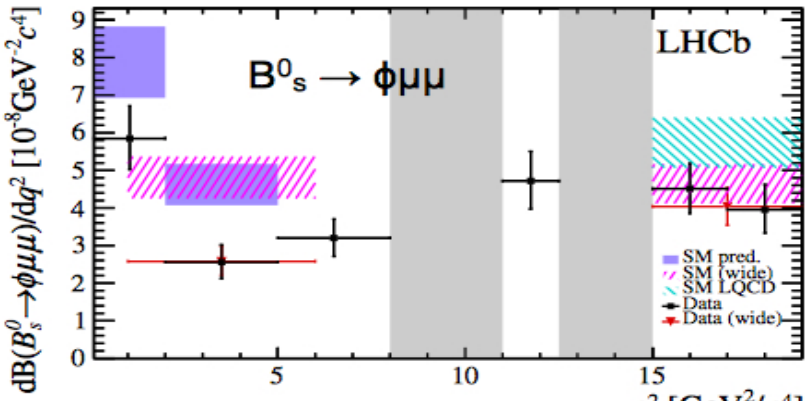
- K* μ⁺μ⁻ tension motivates studies of differential BRs



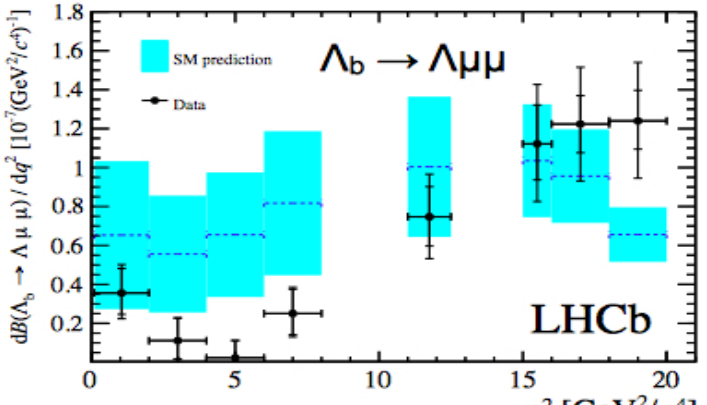




[JHEP 06, 133 (2014)]



[JHEP 09, 179 (2015)]

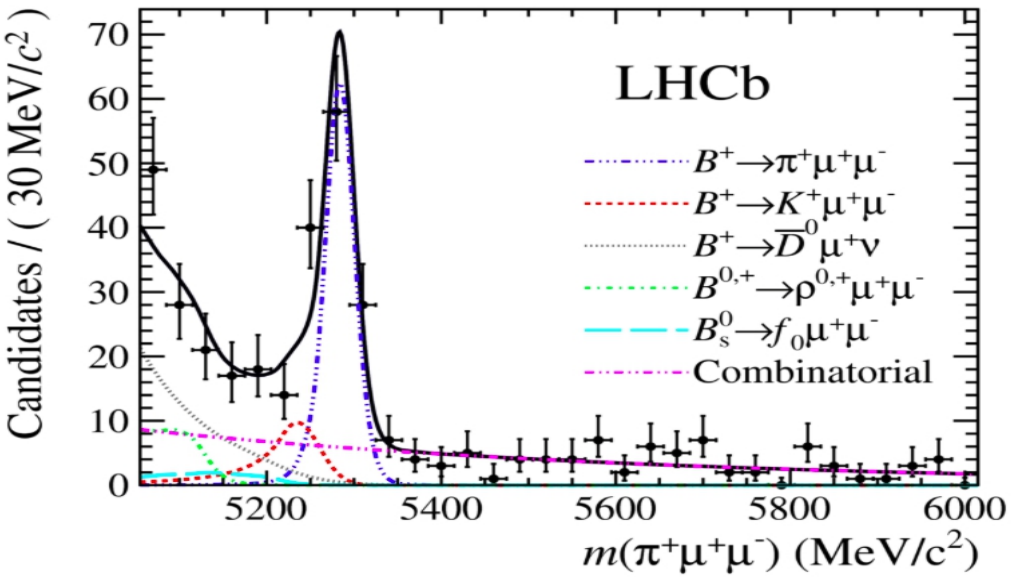


[JHEP 06, 115 (2015)]

- All the results are "consistent" with SM at <2.2 σ
- But all of them are lower than the predictions…

$B \to \pi\, l^+ l^-$

- Measurements of related b → dμμ channels very useful to reveal information on Minimal Flavor Violation nature of New Physics



LHCb [JHEP 10, 034 (2015)]:

$BR(B^+ \to \pi^+\mu^+\mu^-) = (1.83 \pm 0.24 \pm 0.05)\,10^{-8}$ in agreement with MFV

$BR(B^+ \to \pi^+\mu^+\mu^-)/BR(B^+ \to K^+\mu^+\mu^-) = 0.037 \pm 0.008 \pm 0.001$

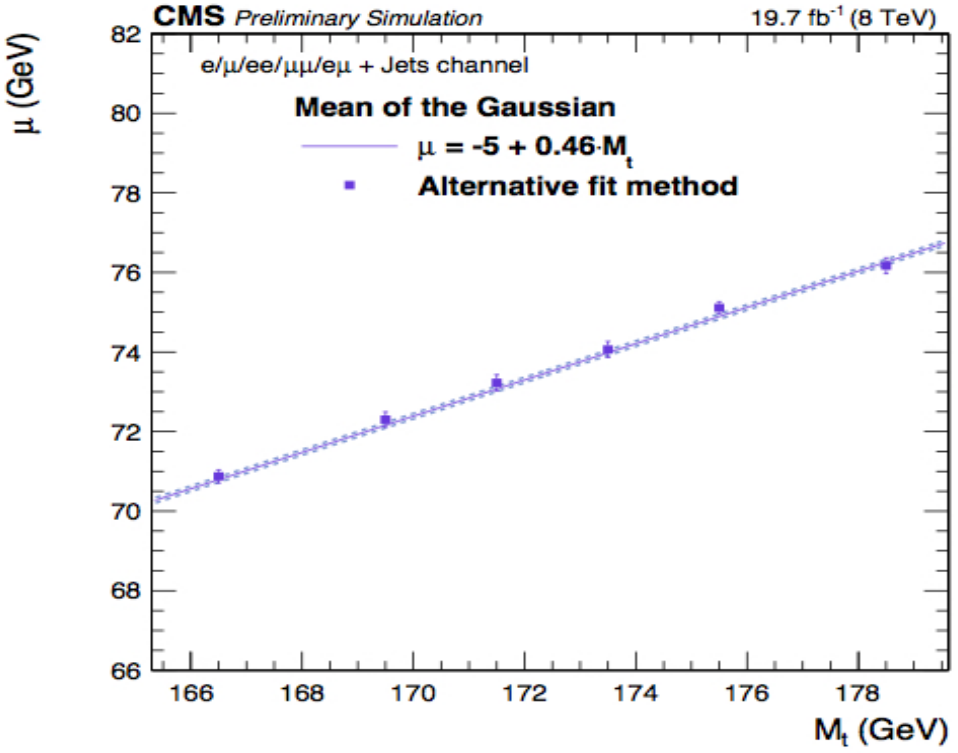
$|V_{td}|/|V_{ts}| = 0.24^{+0.05}_{-0.04}$ in agreement with box processes ($\Delta m_s/\Delta m_d$) results

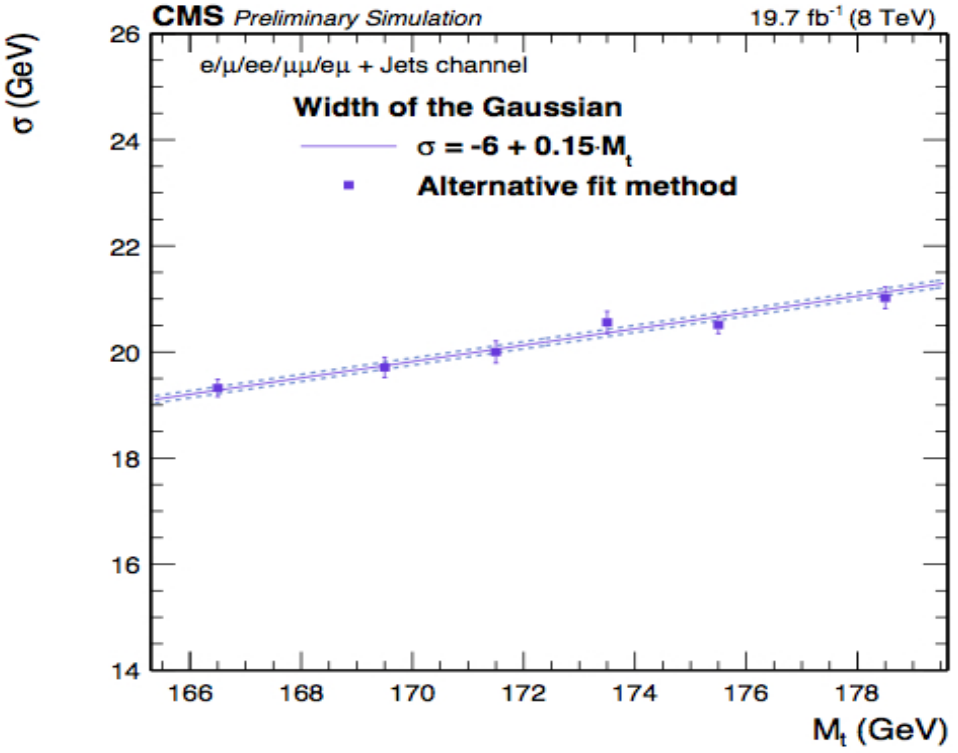
From B to Top: m_t measurement

- Fitting function:

$$P_{\text{sig+bg}}(M_{J/\psi+\ell}) = \alpha \frac{1}{\sigma_g\sqrt{2\pi}} \exp\left(-\frac{(M_{J/\psi+\ell}-\mu_g)^2}{2\sigma_g{}^2}\right) + (1-\alpha)\frac{\beta_\gamma{}^{-\gamma_\gamma}}{\Gamma(\gamma_\gamma)}(M_{J/\psi+\ell}-\mu_\gamma)^{\gamma_\gamma-1}\exp\left(-\frac{M_{J/\psi+\ell}-\mu_\gamma}{\beta_\gamma}\right)$$

- Parameters dependence on m_t:





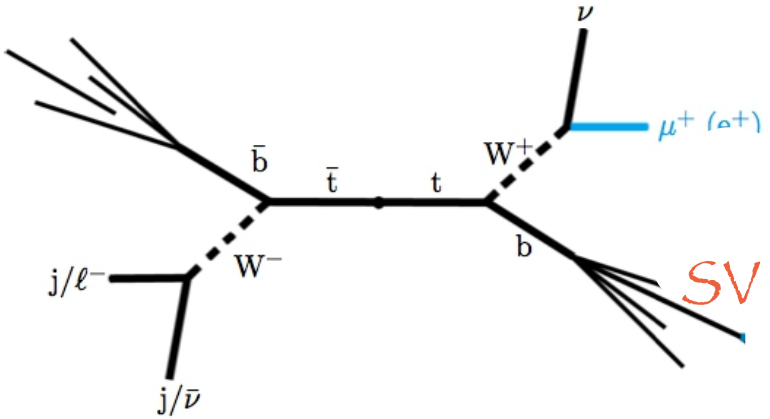
From B to Top: m_t measurement

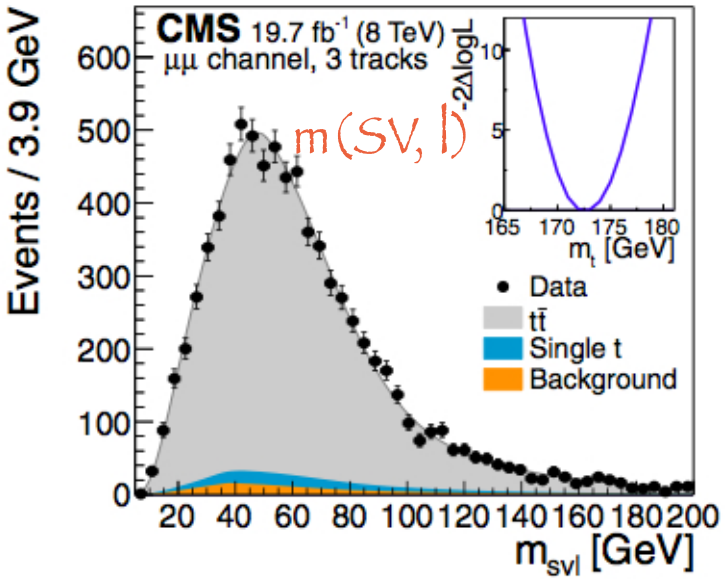
- Systematics:

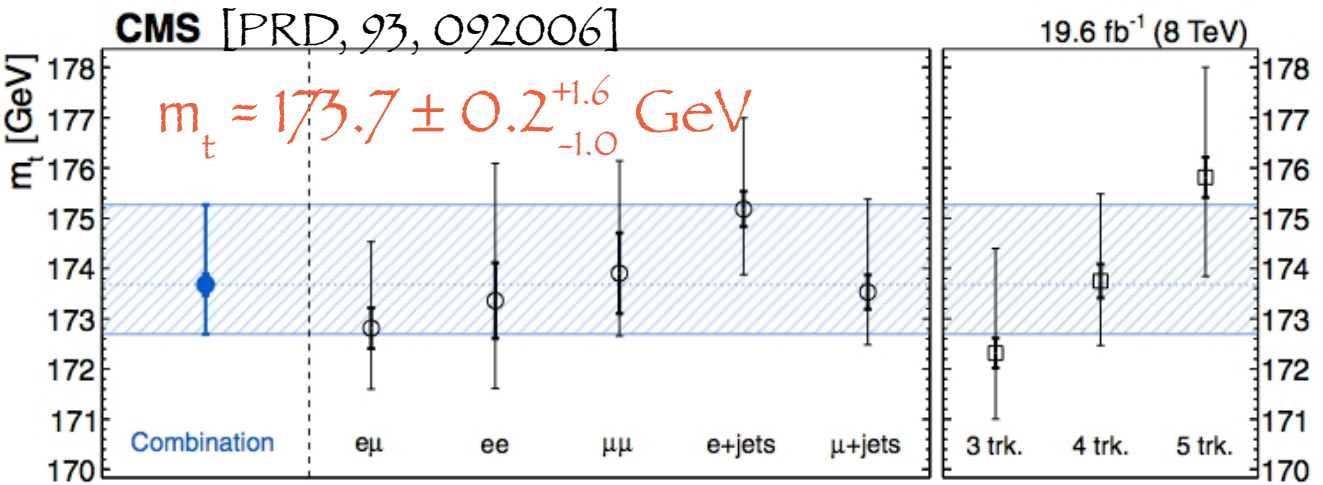
Source	Value (GeV)
Experimental uncertainties	
Monte Carlo statistics	± 0.22
Muon momentum scale	± 0.09
Electron momentum scale	± 0.11
Modeling of the J/ψ candidate mass distribution	$+0.09$
Jet energy scale	< 0.01
Jet energy resolution	< 0.01
Trigger efficiencies	± 0.02
Background normalization	± 0.01
Pileup	± 0.08
Theoretical uncertainties	
ME generator	-0.37
Renormalization scale	$^{+0.12}_{-0.46}$
ME-PS matching threshold	$^{+0.12}_{-0.58}$
top quark transverse momentum	$+0.64$
b fragmentation	± 0.30
Underlying event	± 0.13
Color reconnection modeling	$+0.12$
Parton density functions	$^{+0.39}_{-0.11}$
Total	$^{+0.89}_{-0.94}$

From B to Top: m_t measurements

- m_t measurements using jets limited by hadronization modeling:
  - Use cleaner observables sensitive to m_t: m(SV, l) in $t \to blv$ decays:

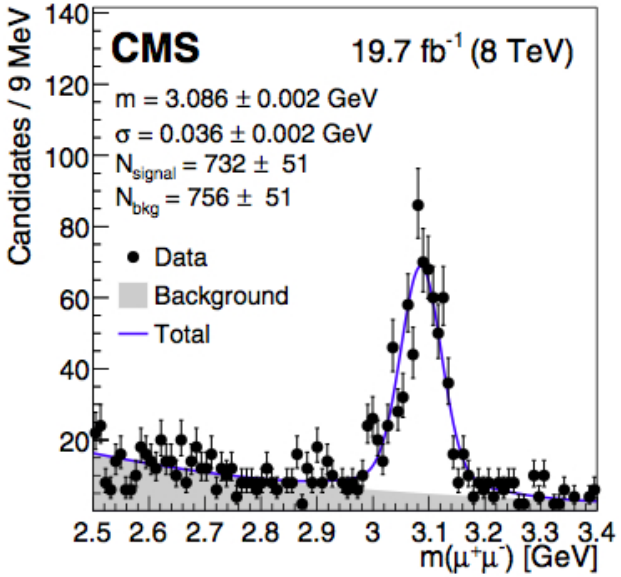


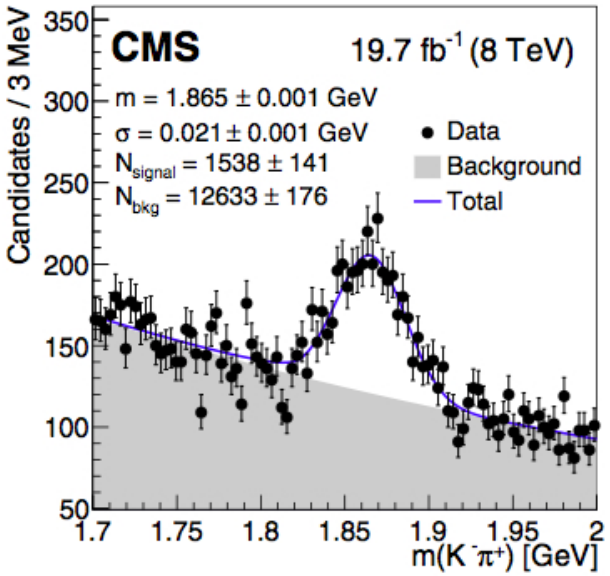


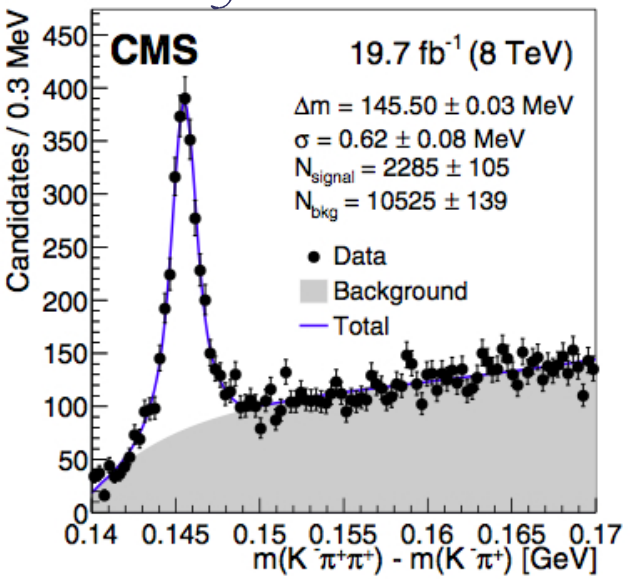


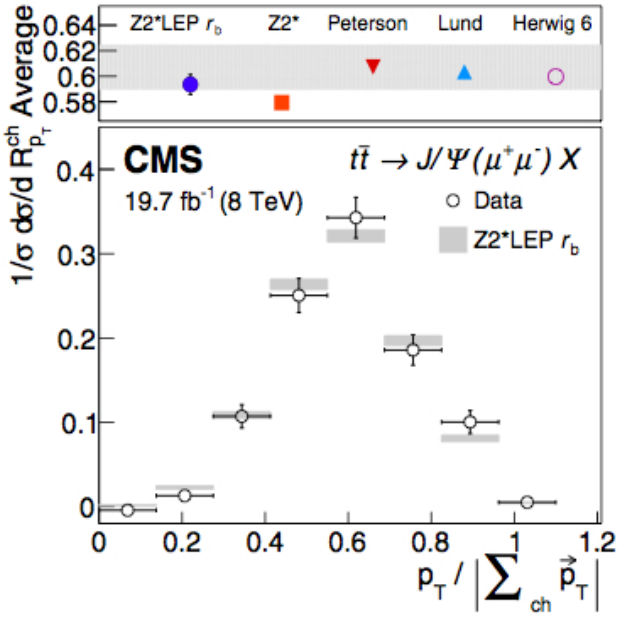
From B to Top: fragmentation tuning

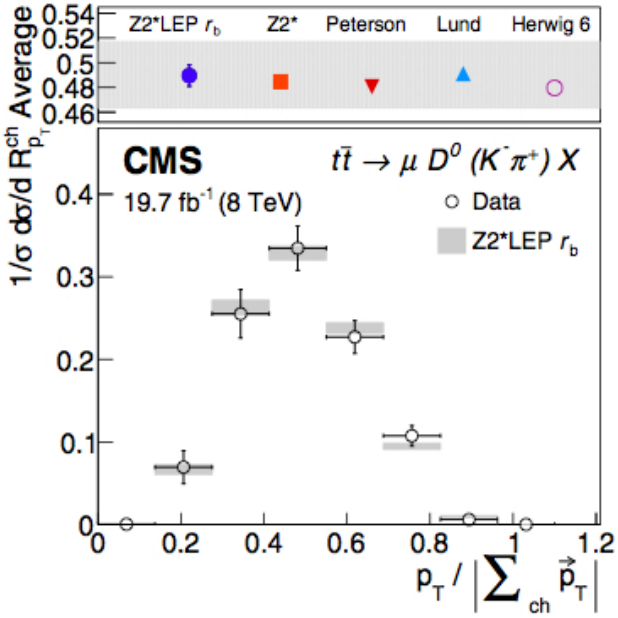
- Test of fragmentation using charmed mesons inside jets in tt events:

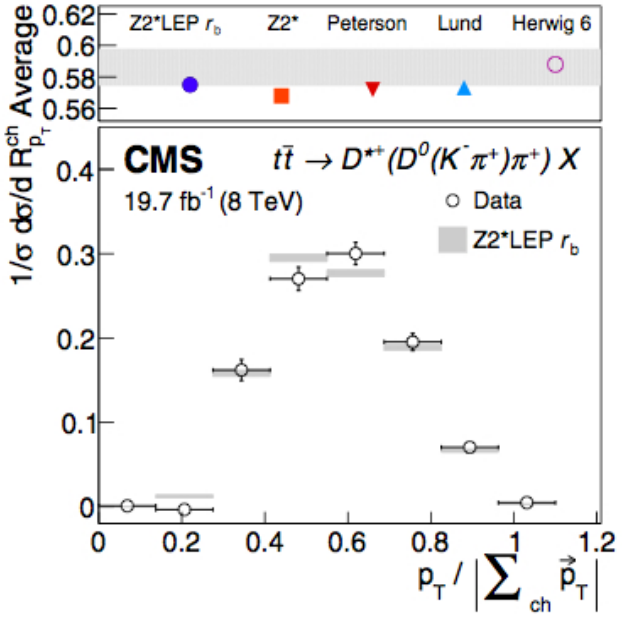




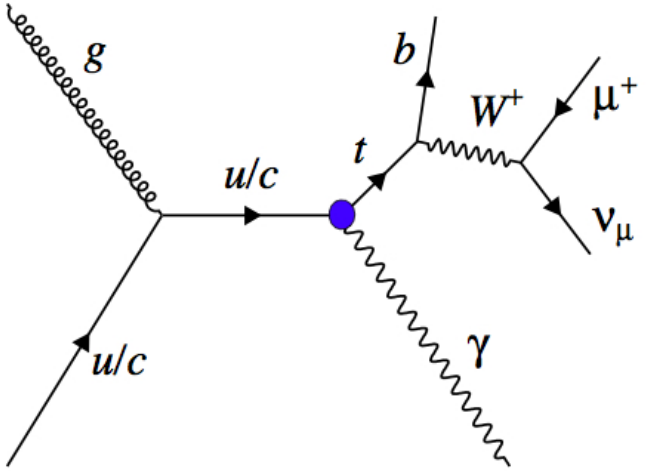








Single t + γ



- Process sensitive to the anomalous tqγ coupling
- Better sensitivity to tuγ than tcγ due to larger up quark parton density in the proton

- Asymmetry between tuγ and $\bar{t}u\gamma$ due to different quark & antiquark parton distribution functions.
- No asymmetry for tcγ
  - Possible to disentangle between tuγ & tcγ

$t \to gg$ in $t\bar{t}$ Decays

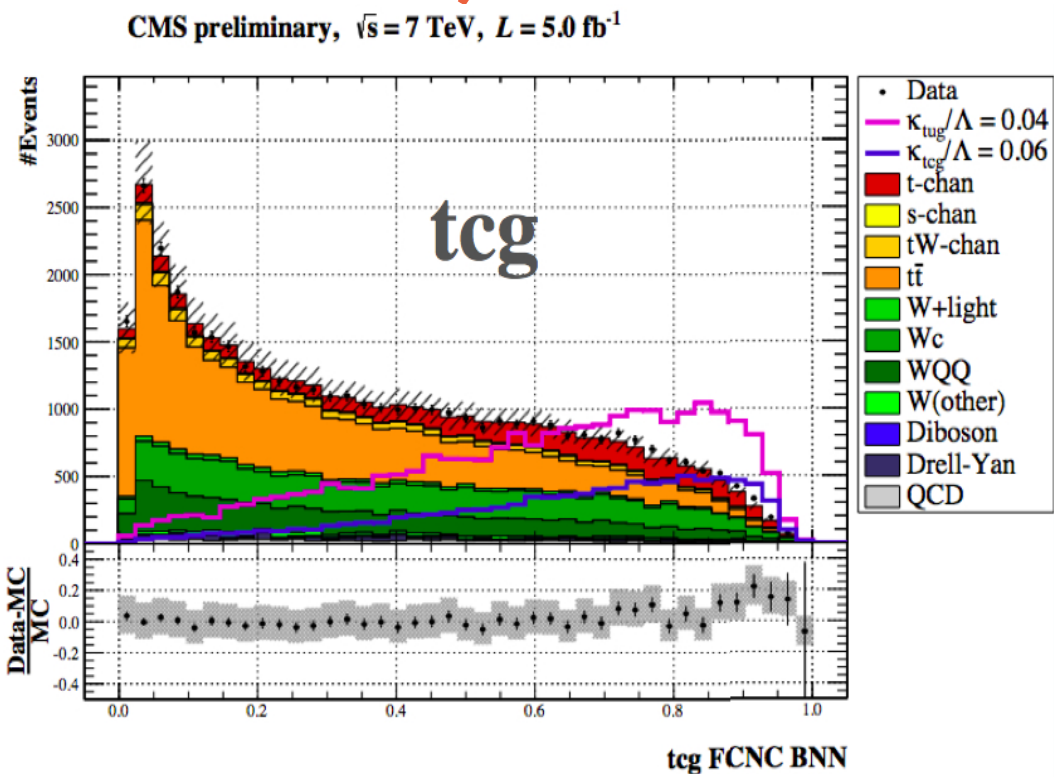
- Signature: one isolated muon, missing E_T, ≥ 1 b-jet and ≥ 1 non b-jet
- QCD BKG estimated on data using a BDT fit
- Signal extracted using a NN

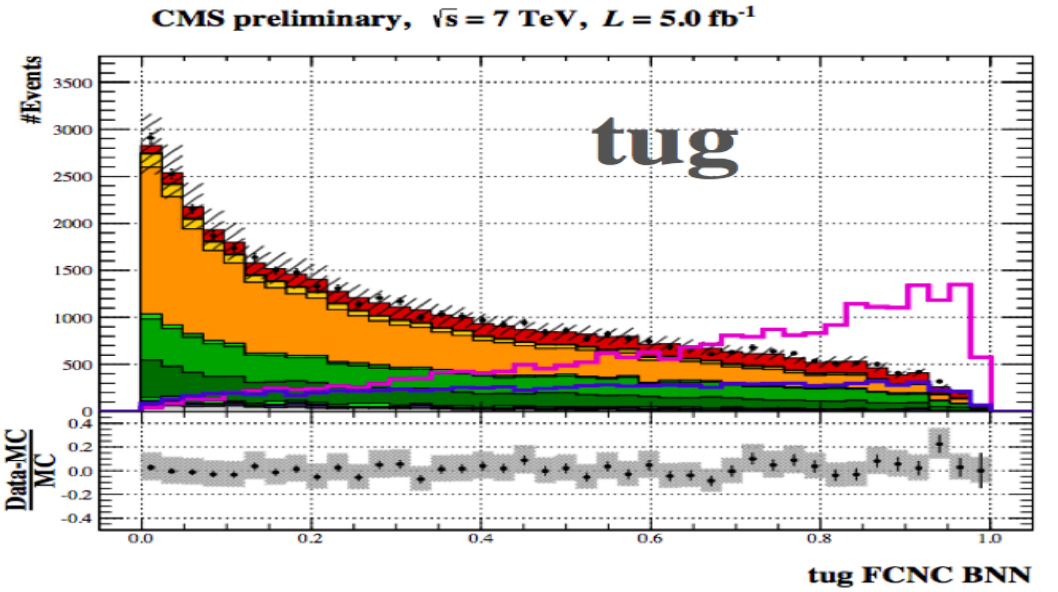
BR(t → gc)<0.34%

BR(t → gu)<0.036%

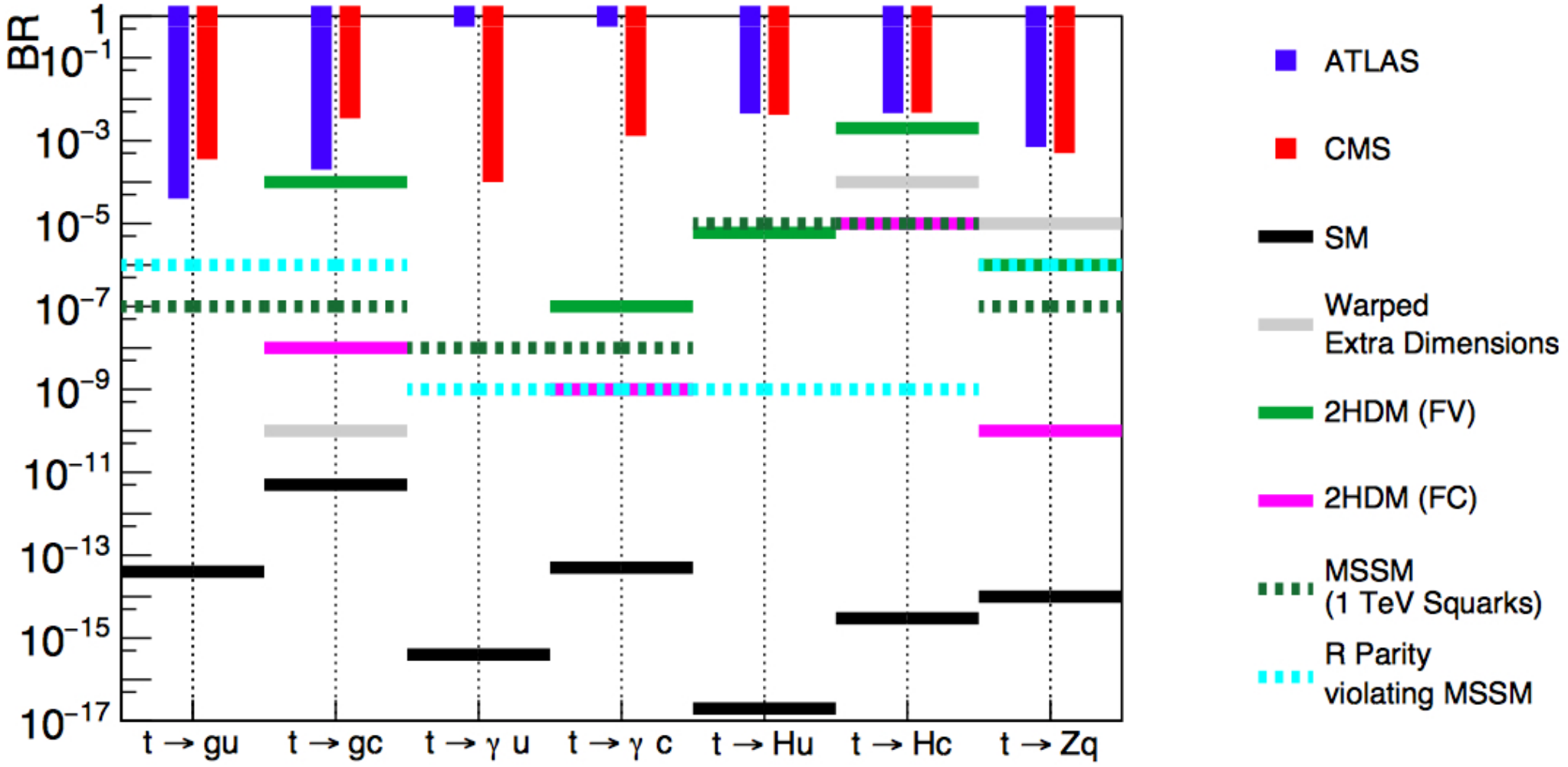
@ 95% CL

[CMS Preliminary, L=5 fb^{-1}, 7 TeV]





FCNC in Top Couplings: Summary



- Still above SM prediction, but approaching BSM models

Andreas Meyer

CP Violation in tt Events

$$A_{CP}(O_i) = \frac{N_{events}(O_i > 0) - N_{events}(O_i < 0)}{N_{events}(O_i > 0) + N_{events}(O_i < 0)}$$

$$O_2 = \epsilon(P, p_b + p_{\bar{b}}, p_\ell, p_{j1}) \xrightarrow{lab} \propto (\vec{p}_b + \vec{p}_{\bar{b}}) \cdot (\vec{p}_\ell \times \vec{p}_{j1})$$

$$O_3 = Q_\ell \epsilon(p_b, p_{\bar{b}}, p_\ell, p_{j1}) \xrightarrow{b\bar{b}\ CM} \propto Q_\ell \vec{p}_b \cdot (\vec{p}_\ell \times \vec{p}_{j1})$$

$$O_4 = Q_\ell \epsilon(P, p_b - p_{\bar{b}}, p_\ell, p_{j1}) \xrightarrow{lab} \propto Q_\ell (\vec{p}_b - \vec{p}_{\bar{b}}) \cdot (\vec{p}_\ell \times \vec{p}_{j1})$$

$$O_7 = q \cdot (p_b - p_{\bar{b}}) \epsilon(P, q, p_b, p_{\bar{b}}) \xrightarrow{lab} \propto (\vec{p}_b - \vec{p}_{\bar{b}})_z (\vec{p}_b \times \vec{p}_{\bar{b}})_z$$

Observable	O_2	O_3	O_4	O_7
Experimental uncertainties				
Pileup reweight	< 0.01	< 0.01	< 0.01	< 0.01
Jet energy corrections	< 0.01	±0.01	±0.01	< 0.01
Lepton ID and isolation	< 0.01	< 0.01	< 0.01	< 0.01
b-tagging scale factor	< 0.01	< 0.01	< 0.01	< 0.01
Theory uncertainties				
Top p_T	< 0.01	±0.01	±0.01	< 0.01
ME-PS	< 0.01	< 0.01	< 0.01	< 0.01
μ_R/μ_F	±0.01	±0.02	±0.02	±0.01
Top mass	< 0.01	±0.01	±0.01	< 0.01
Signal modelling	< 0.01	±0.01	±0.01	< 0.01
PDF	< 0.01	< 0.01	< 0.01	< 0.01
Total	±0.01	±0.03	±0.03	±0.01