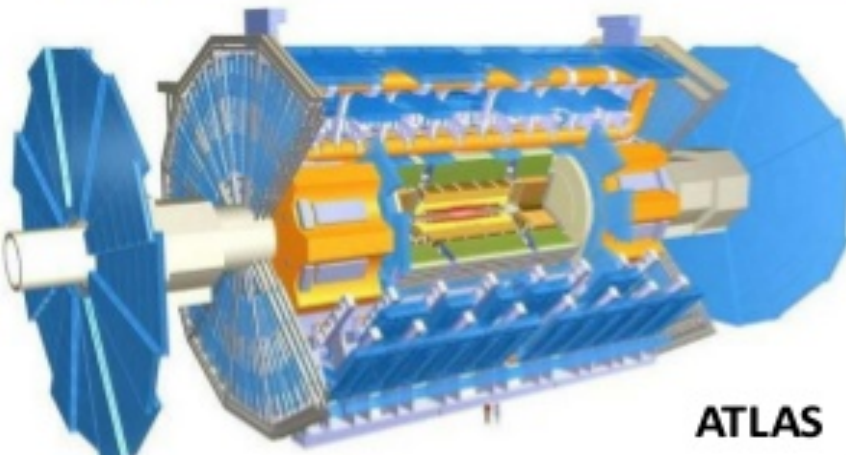
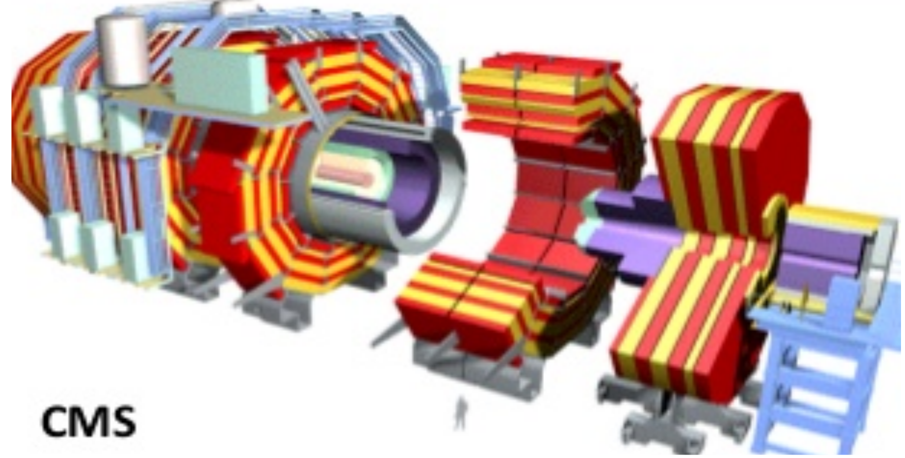
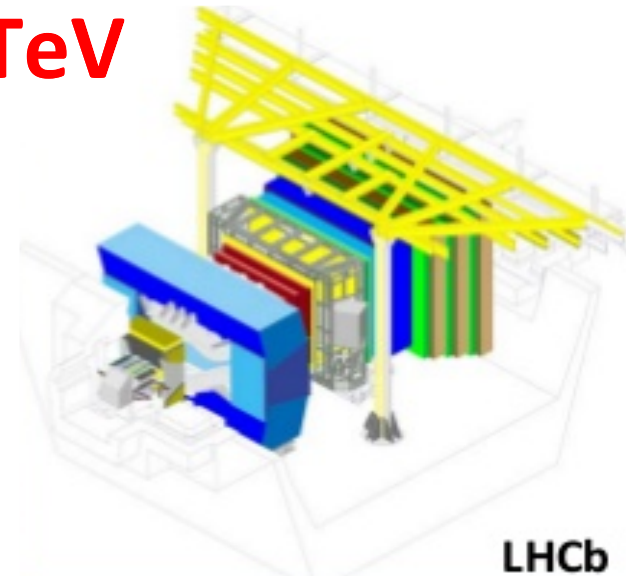




Heavy flavor production @13TeV

Sanjay Kumar Swain

NISER, India



Topics covered:

B-mesons,
Top quark

Introduction

- **Flavor production and study of its properties is one of the most interesting areas among the particle physics community.**
- **There are many unsolved questions in this sector (listing only few):**

  -> What are the principles for the observed pattern of fermion mass and mixing angles ?
  -> Are there any new sources of flavor symmetry breaking apart from SM Yukawa couplings at TeV scale ?
  -> Are there new sources of CP violation to explain the observed matter-antimatter asymmetry of universe ?

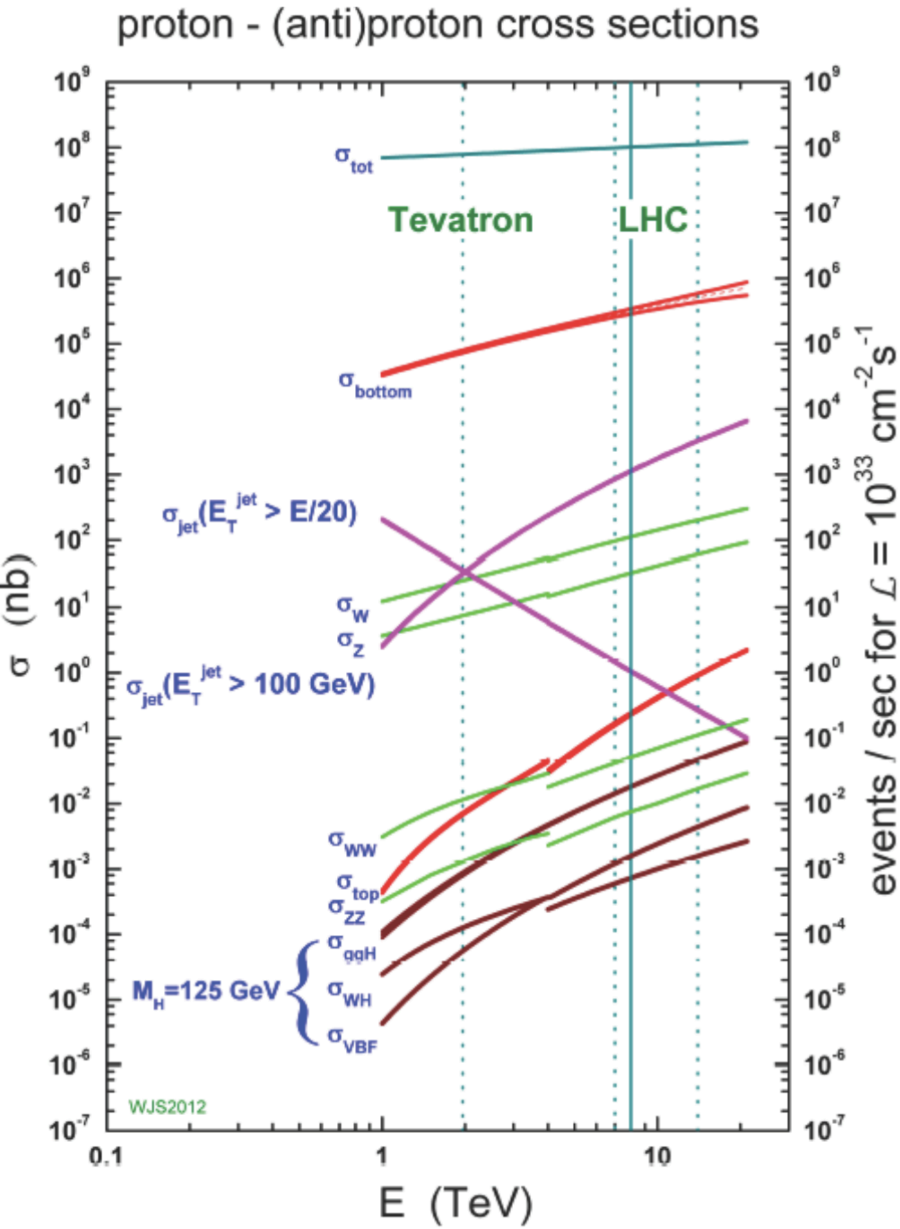
- **LHC era is very important pin down some of the flavor questions.**

It allows us to search for NP : (two ways for NP search)

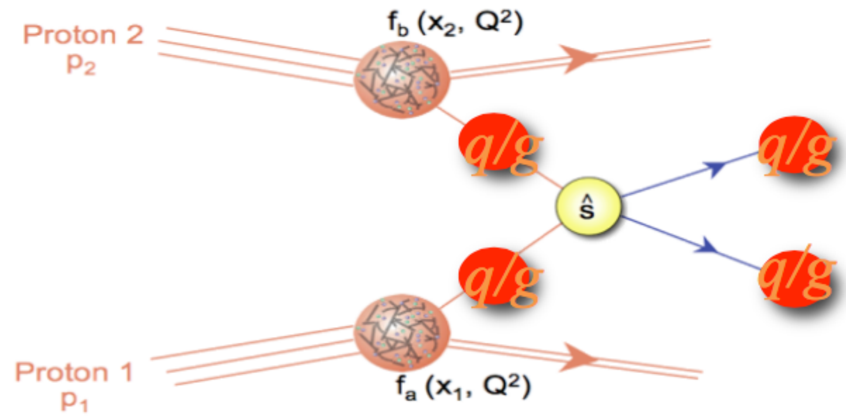
- **Produce heavy particles beyond SM. The production cross-section of those particles are usually small.**
- **Measure the observables/parameters of SM processes. Any significant deviation from SM prediction will be hint of NP.**

Studying both are important and complementary to each other

Why we can do better at higher energy ?



-> Because of large production rate



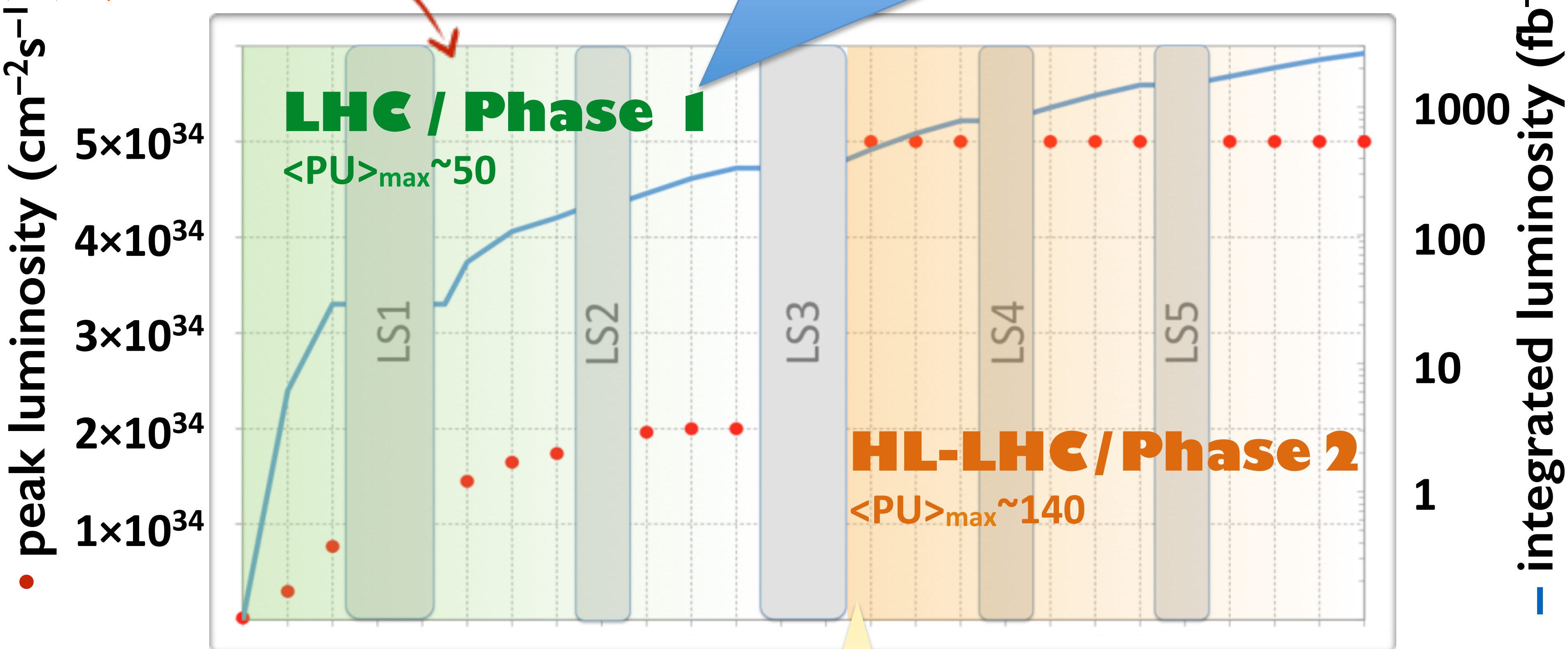
1. b-production cross-section goes up by factor of 2 [~o(100μb)]
2. ttbar-production cross-section increased by factor of 3 [~o(100pb)]
3. W/Z-production cross-section goes up by factor of almost 2 [~o(10 nb)]

But its not the production only, the type of final state decay that is also important to observe those events

From 8TeV -> 13TeV and beyond (LHC to HL-LHC)

Results from here for ATLAS & CMS

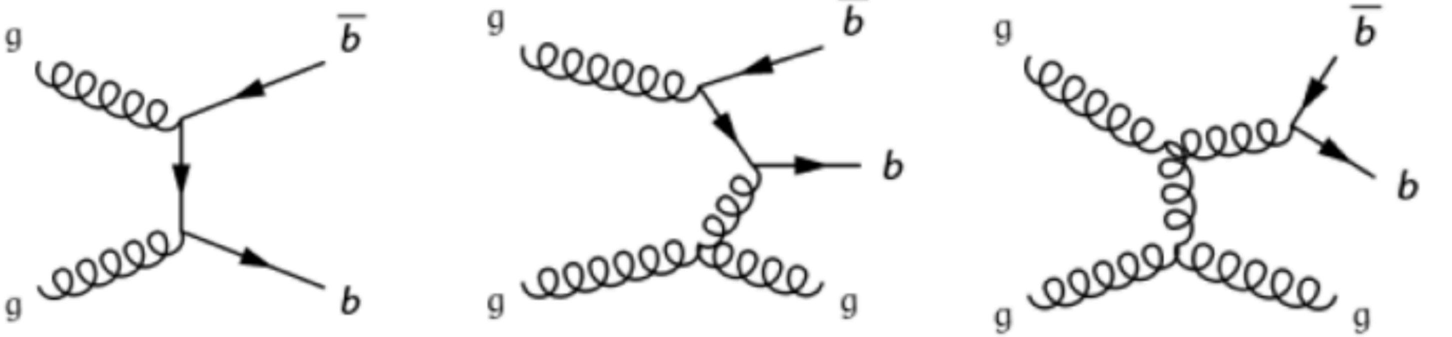
LHC operation up to LS3 (2023):
25 ns bunch spacing, instantaneous luminosities up to 2×10^{34} (2x design!). Accumulate ~300 fb^{-1} by 2022-2023



HL-LHC operation beyond LS3 (2025+)
New low-β beam configuration and crab-cavities to optimize the bunch overlap at the interaction region. Level the instantaneous luminosity at 5×10^{34} from a potential peak value of 2×10^{35}. Deliver ~250 fb^{-1} per year for 10 years of operation, accumulate up to 3000 fb^{-1}.

B-physics results from CMS, ATLAS and LHCb

Flavor Creation (FCR) Flavor Excitation (FEX) Gluon Splitting (GSP)

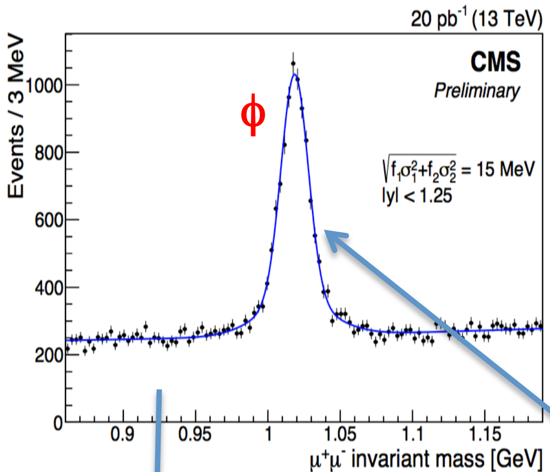


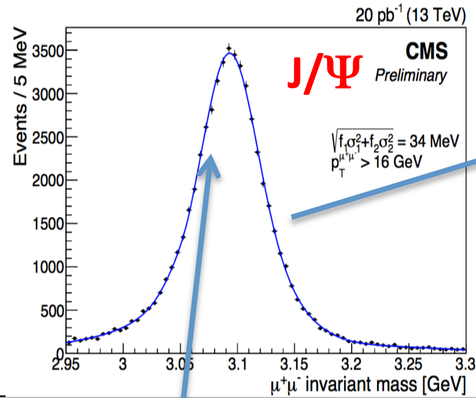
$$\sigma\left(b\bar{b}\right)^{14\ \mathrm{TeV}} = 2\times\sigma\left(b\bar{b}\right)^{7\ \mathrm{TeV}}$$

	LHC era		HL-LHC era		
	2010-2012	2015-2017	2019-2021	2024-2026	2028-2030+
ATLAS & CMS	25 fb^{-1}	100 fb^{-1}	300 fb^{-1}	→	3000 fb^{-1}
LHCb	3 fb^{-1}	8 fb^{-1}	23 fb^{-1}	46 fb^{-1}	100 fb^{-1}
Belle II	-	0.5 ab^{-1}	25 ab^{-1}	50 ab^{-1}	-

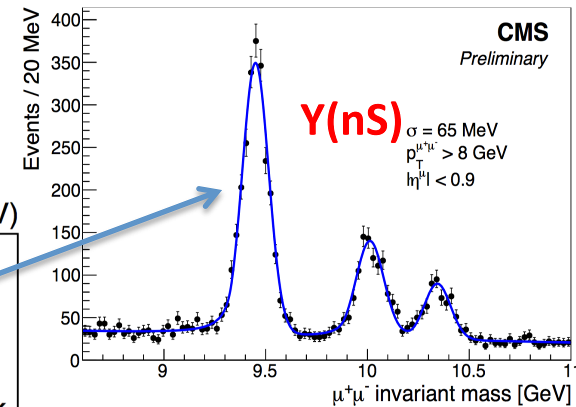
More on B-physics by: Valerie Gibson, Thomas Nikodem

Physics with di-muons from CMS @13TeV

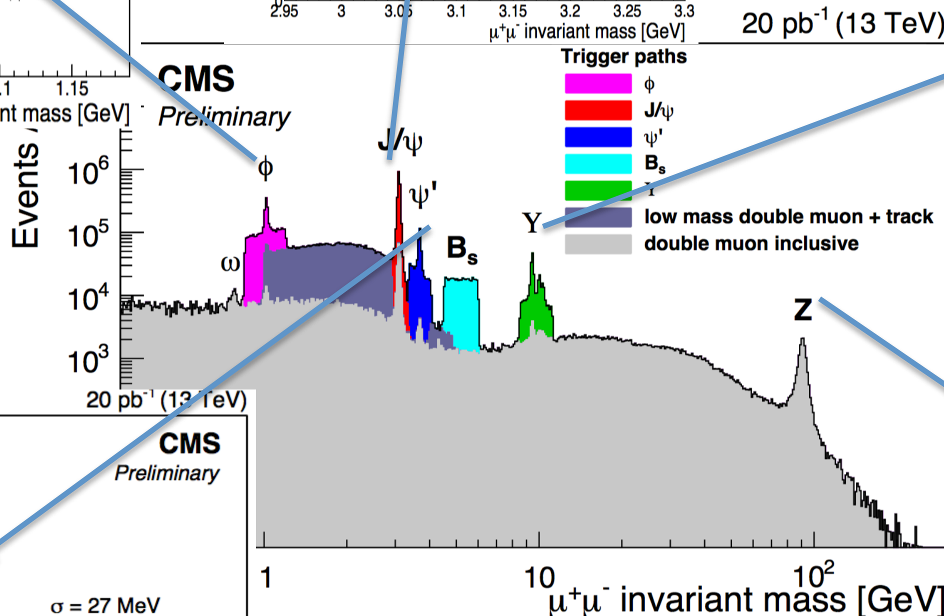


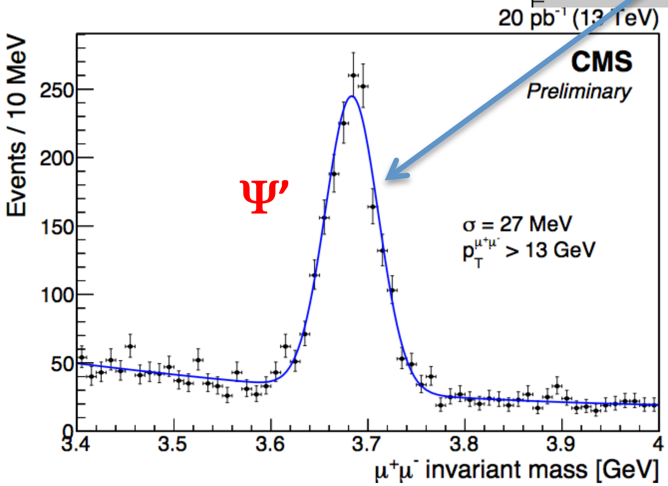


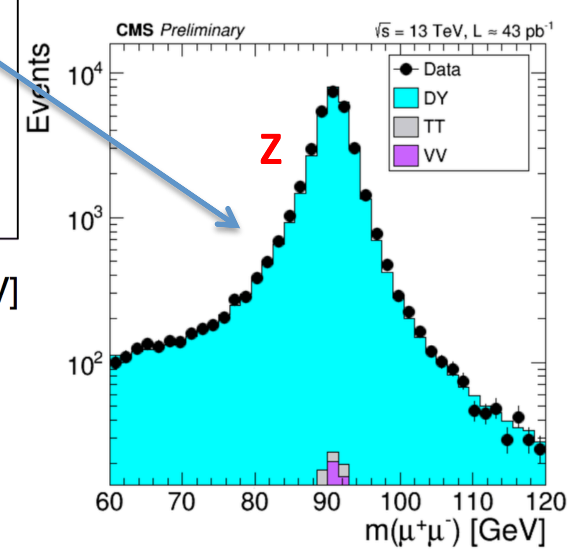
Double crystal ball with 2nd order Chebychev polynomial



Double Gaussian with common mean with 2nd order Chebychev Polynomial



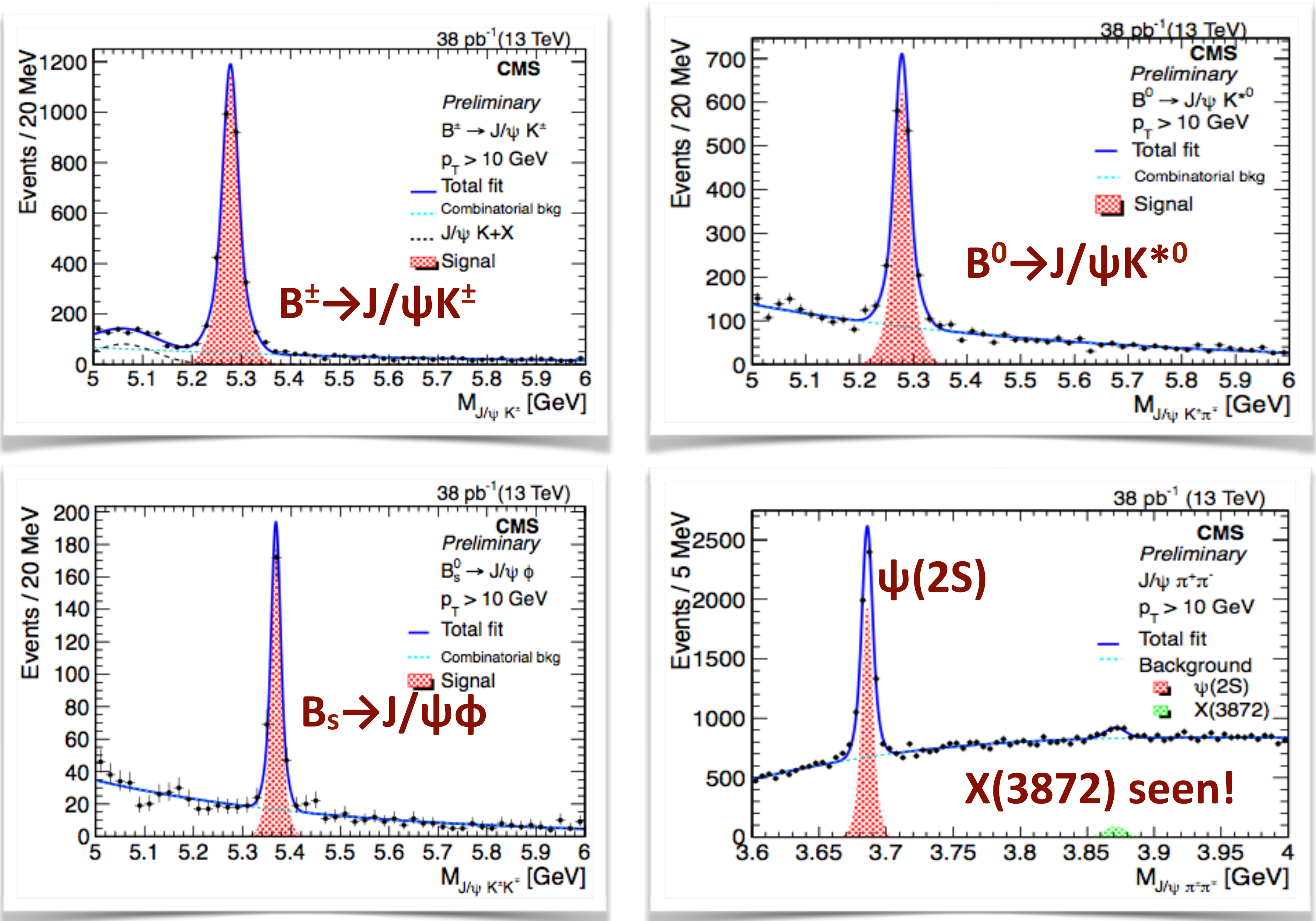




Confirms the spectrum from 7/8 TeV, physics results will be available soon !

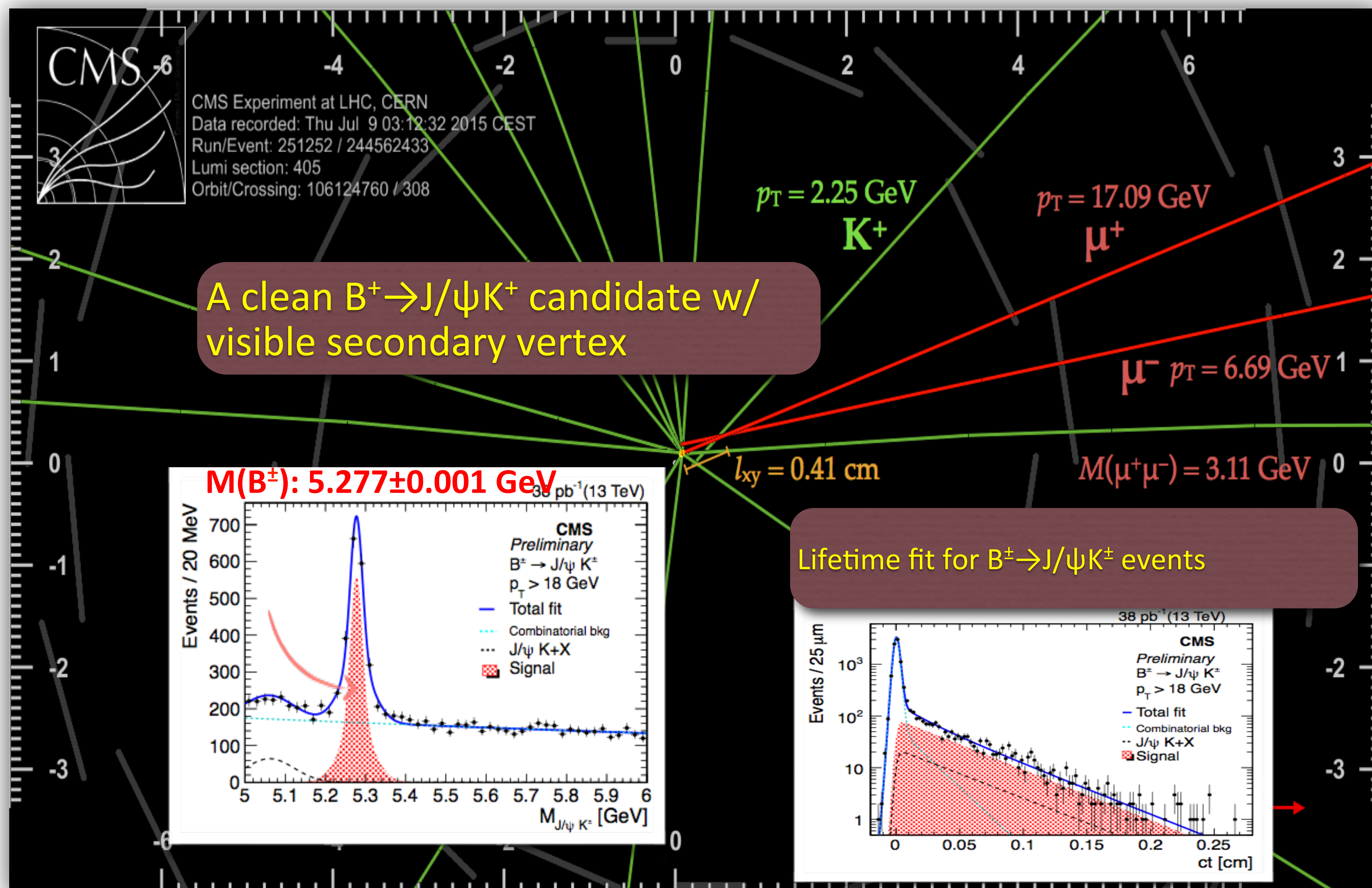
CMS DP-2015/018

B-physics @13TeV from CMS



CMS DP-2015/018

Event with di-muon from CMS @13TeV



CMS DP-2015/018

J/ψ production @13TeV from ATLAS

- Heavy quarkonium states are good testing ground for perturbative and non-pertubative regime of QCD
- First stage is short distance production of heavy quark pair (described perturbatively)
- Second stage is non-perturbative hadronisation of heavy quark pair into quarkonium state, such as J/Ψ

$$pp \xrightarrow[\text{Perturbative QCD}]{\text{Production}} Q\bar{Q} \xrightarrow[\text{Non-pertubative QCD}]{\text{Hadronisation}} J/\psi$$

- J/Ψ can be produced directly from hard collisions of partons in proton-proton machine (prompt J/Ψ) or via decay of b-flavor hadrons (non-prompt J/Ψ)

Here the fraction of non-prompt J/Ψ is obtained by:

$$f_b^{J/\psi} \equiv \frac{pp \to b + X \to J/\psi + X'}{pp \xrightarrow{\text{Inclusive}} J/\psi + X'} = \frac{N_{J/\psi}^{\text{NP}}}{N_{J/\psi}^{\text{NP}} + N_{J/\psi}^{\text{P}}}$$

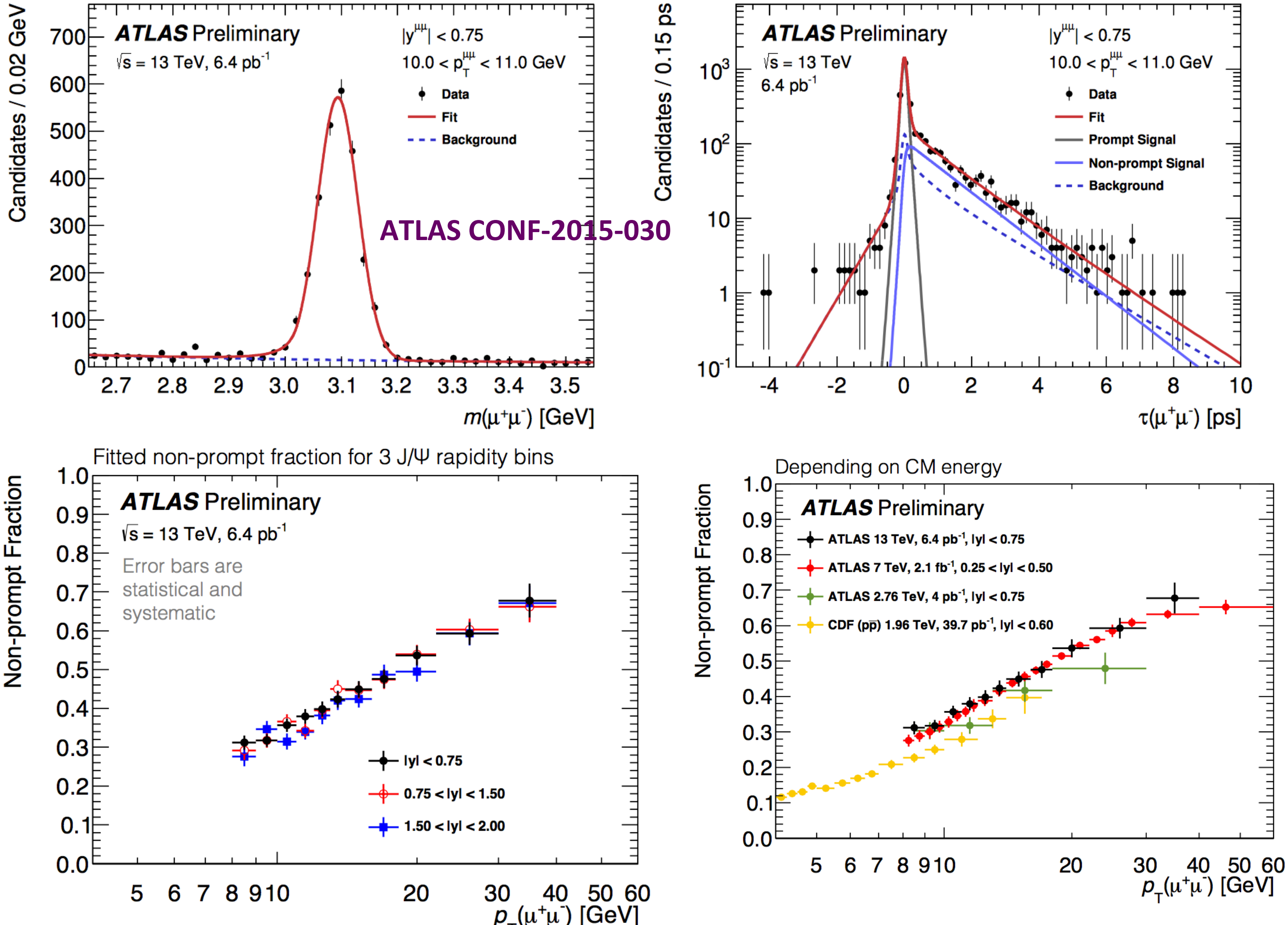
- The two can be differentiated by different decay times of reconstructed J/Ψ
- The yield is obtained by unbinned maximum liklihood fit to dimuon mass and decay time

Pseudo-lifetime: $\tau = L_{xy} m_{J/\psi}^{\text{PDG}} / p_{\text{T}} \qquad L_{xy} \equiv \vec{L} \cdot \vec{p}_{\text{T}} / p_{\text{T}}$

- J/ψ is particular interesting for detector calibration due to large BF

ATLAS CONF-2015-030

J/ψ production @13TeV from ATLAS (cont.)

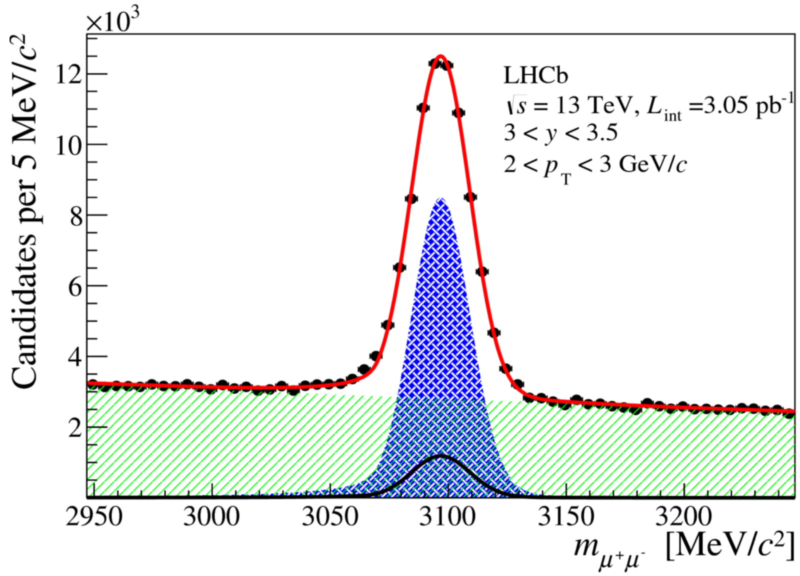


- **The non-prompt fraction increases from 0.25 at 8GeV J/Ψ P_T to 0.65 at 40 GeV**
- **Consistent with previous results**
- **No variation in different pseudo-rapidity regions.**

J/ψ production @13TeV from LHCb

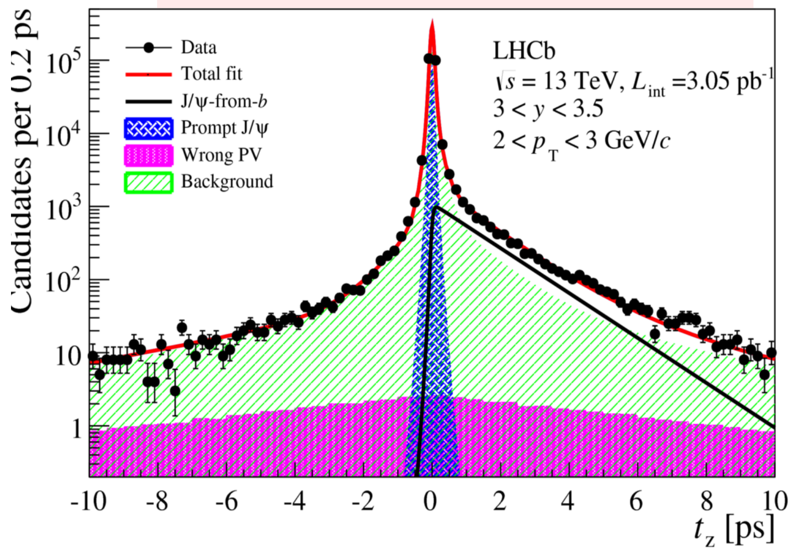
arXiv:1509.00771 (hep-ex)

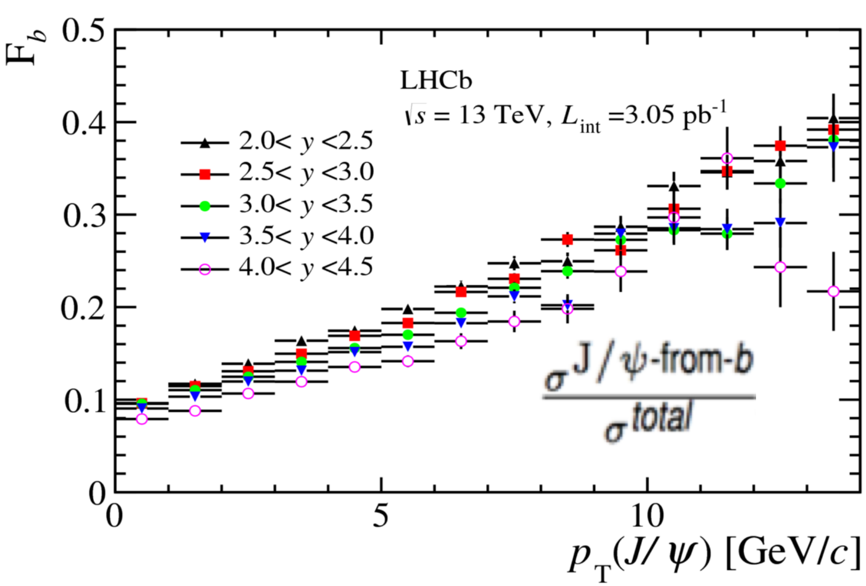
- Used about ~3 pb^{-1} data collected at 13 TeV
- The yield is obtained from two dimensional unbinned maximum likelihood fit to J/Ψ mass and lifetime
- Observables studied in bins of J/Ψ P_T and different
- pseudo-rapidity region.
- Results consistent with theory (FONLL) prediction



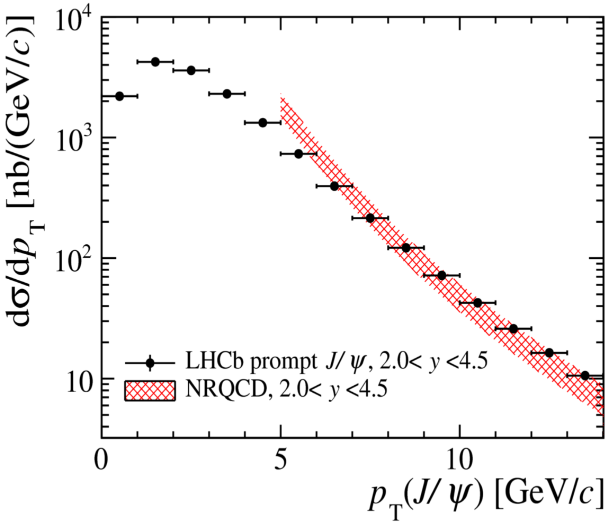
Distance along beam axis between J/Ψ decay vertex and the Primary vertex

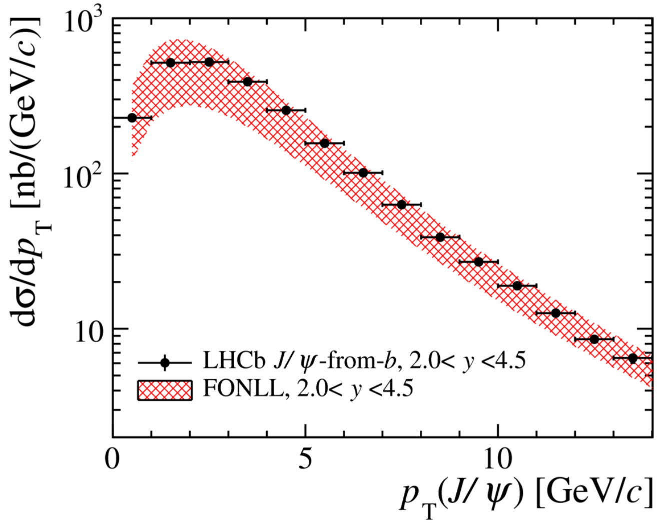
$$t_z = \frac{(z_{J/\psi} - z_{PV}) \times M_{J/\psi}}{p_z}$$

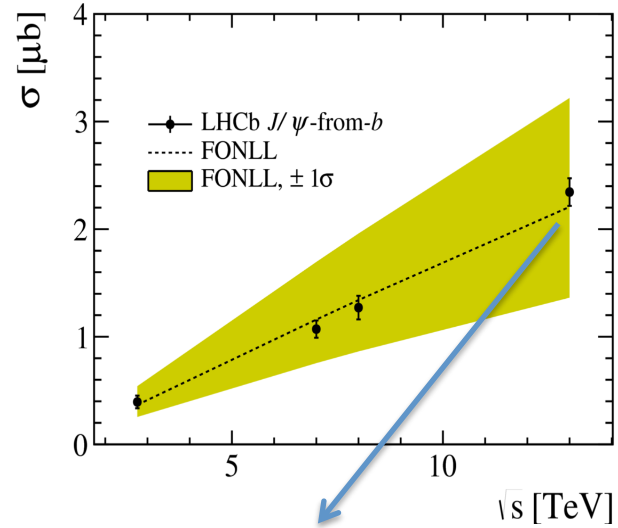


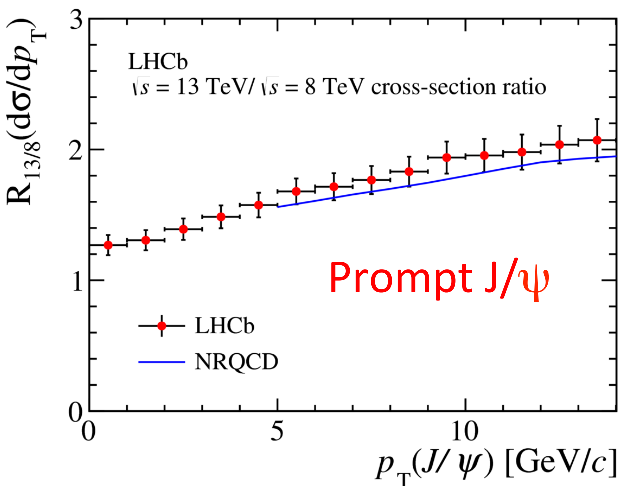


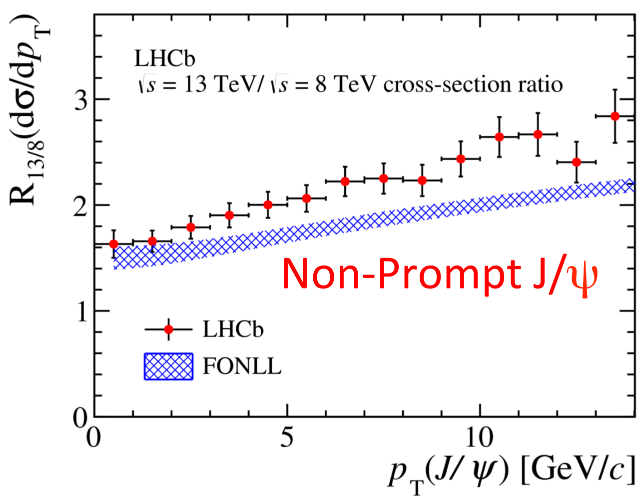
J/ψ production @13TeV from LHCb (cont.)











Source	Systematic uncertainty (%)
Luminosity	3.9
Hardware trigger	0.1 – 5.9
Software trigger	1.5
Muon ID	1.8
Tracking	1.1 – 3.4
Radiative tail	1.0
J/ψ vertex fit	0.4
Signal mass shape	1.0
$\mathcal{B}(J/\psi \to \mu^+\mu^-)$	0.6
p_{T}, y spectrum	0.1 – 5.0
Simulation statistics	0.3 – 5.0
t_z fit (J/ψ-from-b only)	0.1

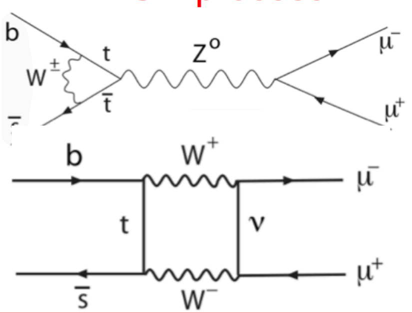
$\sigma_{\rm tot}$ (μb)	$\sqrt{s} = 2.76$ TeV	$\sqrt{s} = 7$ TeV	$\sqrt{s} = 8$ TeV	$\sqrt{s} = 13$ TeV
Prompt J/ψ	$5.2 \pm 0.3 \pm 0.3$	$9.4 \pm 0.5^{+0.7}_{-1.0}$	$10.9 \pm 0.5 \pm 0.6$	$15.3 \pm 0.6 \pm 0.6$
J/ψ -from-b	$0.39 \pm 0.04 \pm 0.04$	$1.07 \pm 0.05 \pm 0.06$	$1.27 \pm 0.06 \pm 0.09$	$2.34 \pm 0.09 \pm 0.09$

arXiv:1509.00771 (hep-ex)

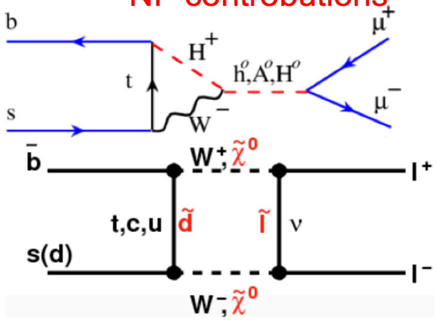
Results to watch out in 13/14TeV ($B_s \to \mu^+\mu^-$)

- **Golden decay for NP search**
- **Forbidden at tree level, can proceed via loop diagrams**
- **Helicity suppressed $(m_\mu/m_B)^2$ and Cabibbo suppressed $|V_{ts(td)}|^2$**

SM process



NP controbutions



Ref: Bobeth et al, PRL 112, 101801 (2014)

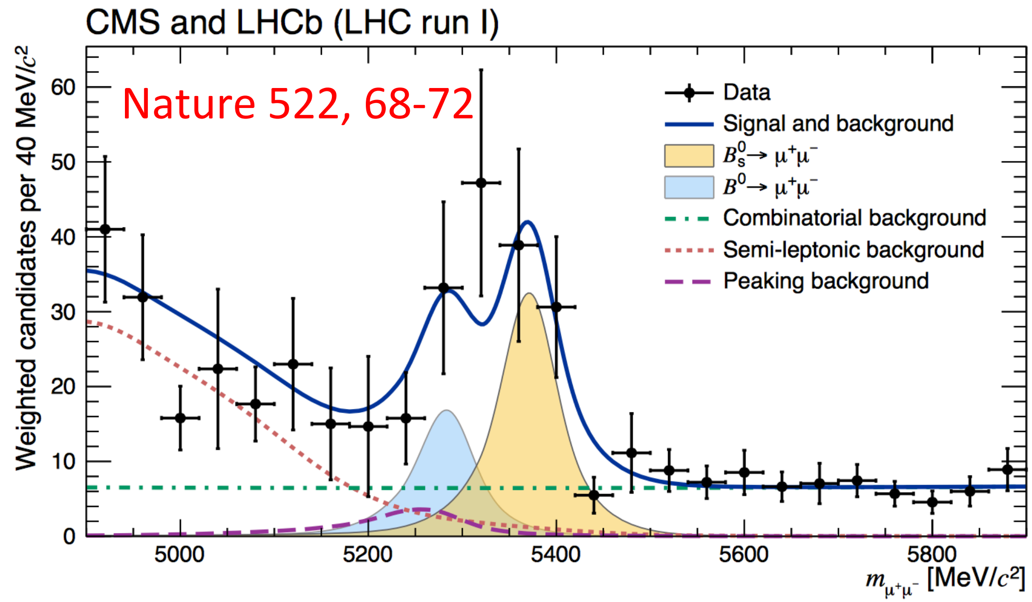
$\mathcal{B}(B_s \to \mu^+\mu^-) = (3.65 \pm 0.23) \times 10^{-9}$

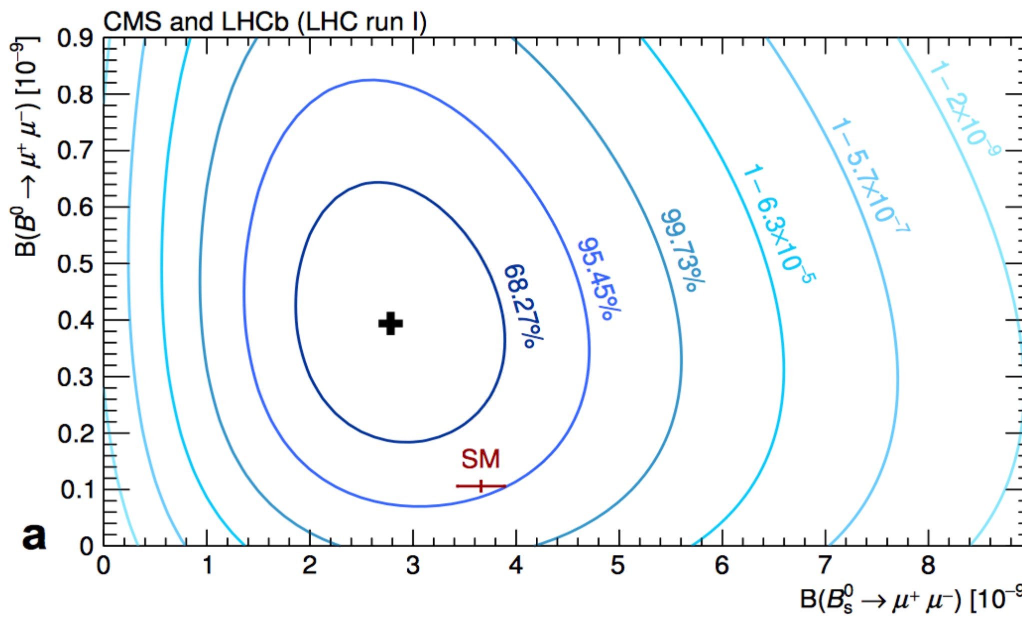
$\mathcal{B}(B_d \to \mu^+\mu^-) = (1.06 \pm 0.09) \times 10^{-10}$

CMS & LHCb combined result:

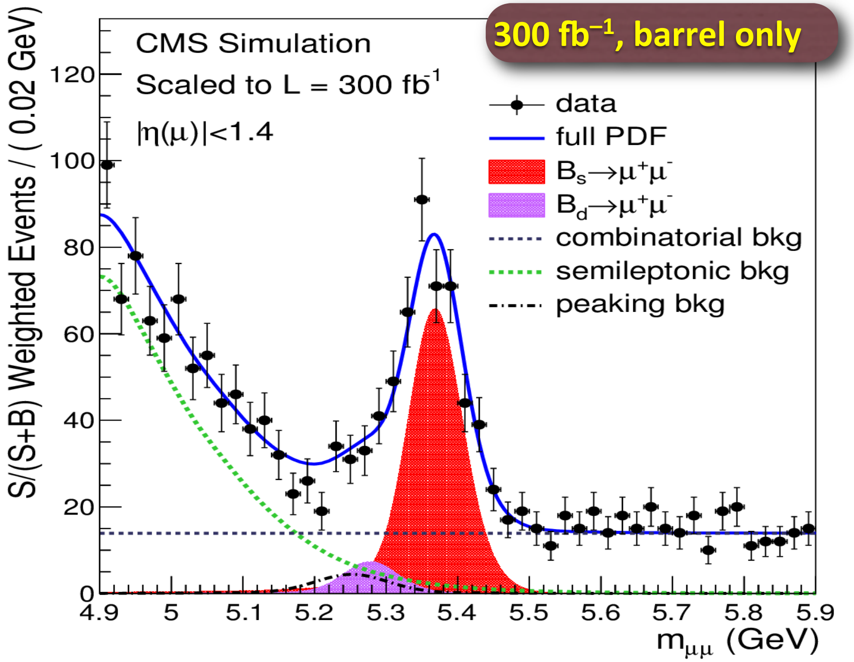
$BR(B^0_s) = (2.8^{+0.7}_{-0.60}) \times 10^{-9}$ (35% syst) 6.2σ observed

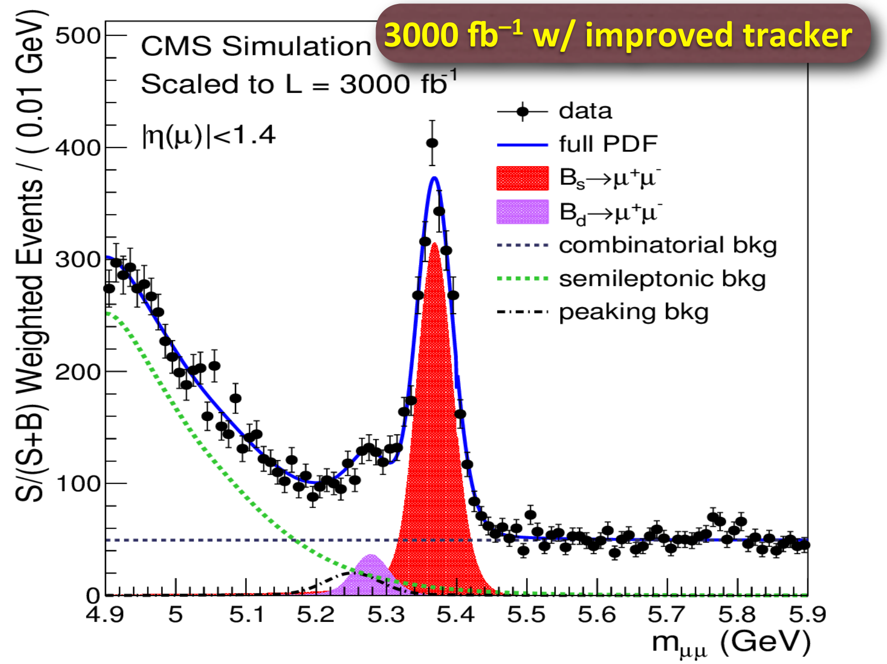
$BR(B^0) = (3.9^{+1.6}_{-1.4}) \times 10^{-10}$ (18% syst) 3.0σ observed





Prospect for $B_s \to \mu^+\mu^-$ at CMS



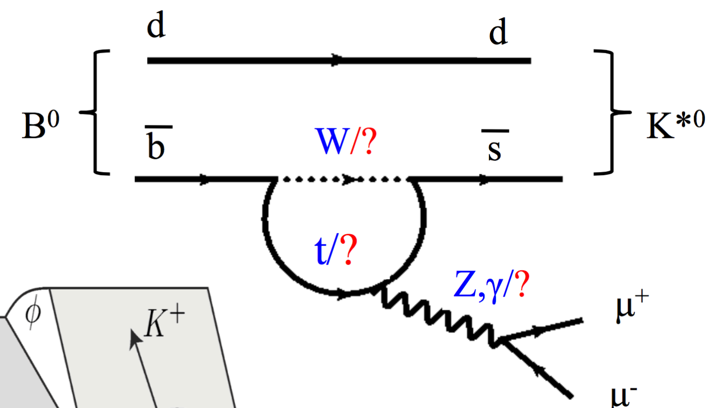


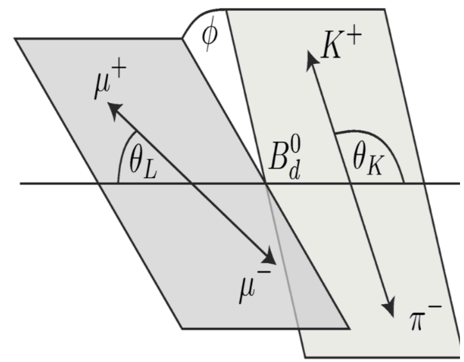
$\mathcal{L}(fb^{-1})$	$N(B_s)$	$N(B^0)$	$\delta\mathcal{B}(B_s \to \mu\mu)$	$\delta\mathcal{B}(B^0 \to \mu\mu)$	B^0 sign.	$\delta\frac{\mathcal{B}(B^0 \to \mu\mu)}{\mathcal{B}(B_s \to \mu\mu)}$
20	18.2	2.2	35%	>100%	0.0-1.5 σ	>100%
100	159	19	14%	63%	0.6-2.5 σ	66%
300	478	57	12%	41%	1.5-3.5 σ	43%
300 (barrel)	346	42	13%	48%	1.2-3.3 σ	50%
3000 (barrel)	2250	271	11%	18%	5.6-8.0 σ	21%

- Expectation assuming SM branching fraction and planned detector upgrade.
- Large pile up will affect detection efficiency, tightening selection criteria, reduce in background, better determination of peaking background.

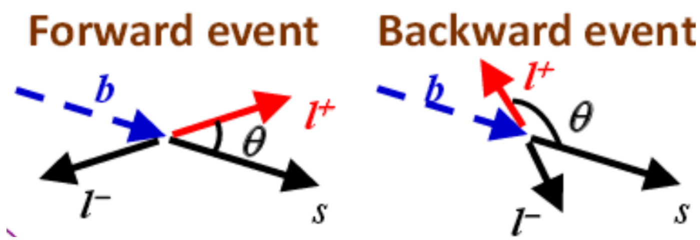
Prospect for B->$K^{*0}/\phi\ \mu^+\mu^-$ at CMS &LHCb

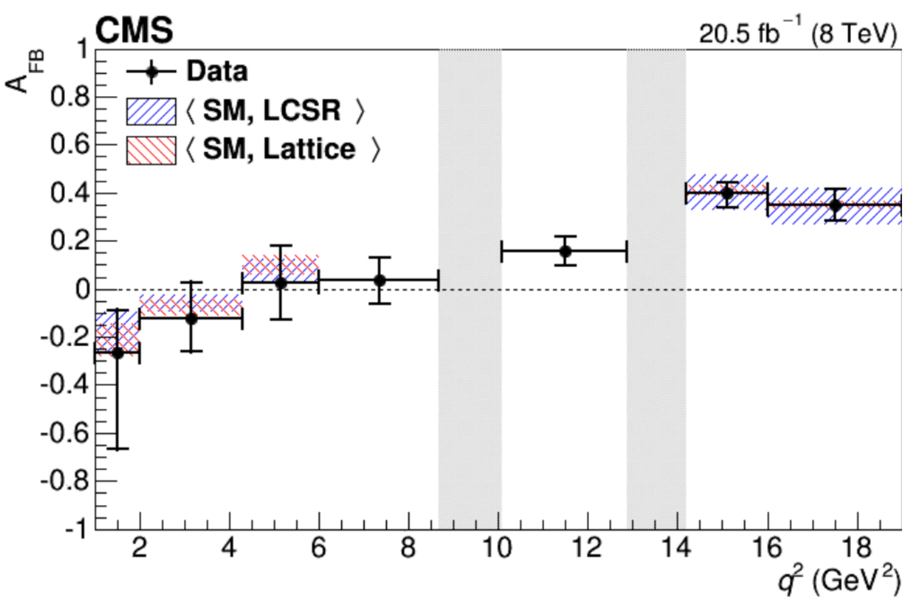
- Forbidden at tree level, but allowed via loop diagrams (as shown on right)
- Sensitive to NP through BSM particles in the loop
- Small branching fraction (10^{-6}) .
- Observables to compare with SM predictions: differential BF, A_{FB}, A_{CP}, P_5', Isospin asymmetry…

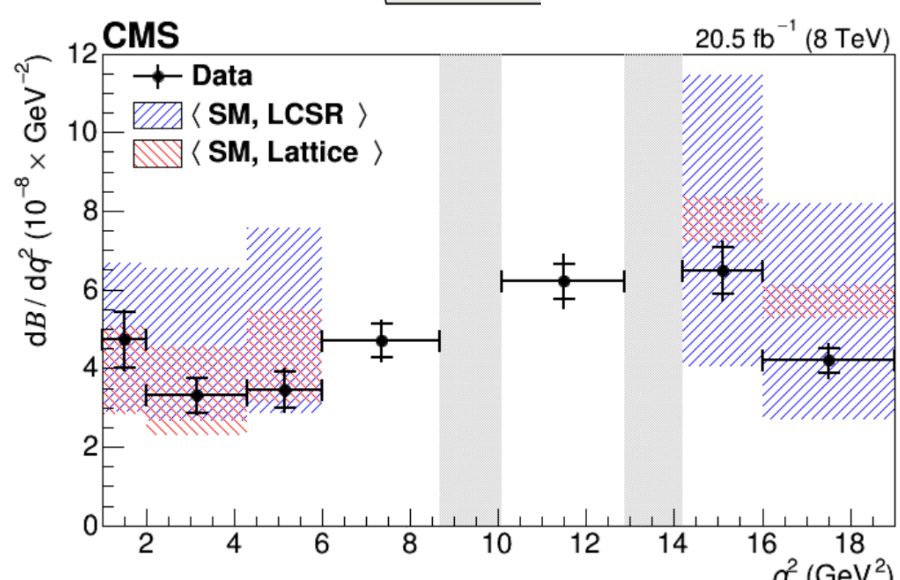




e.g A_{FB}



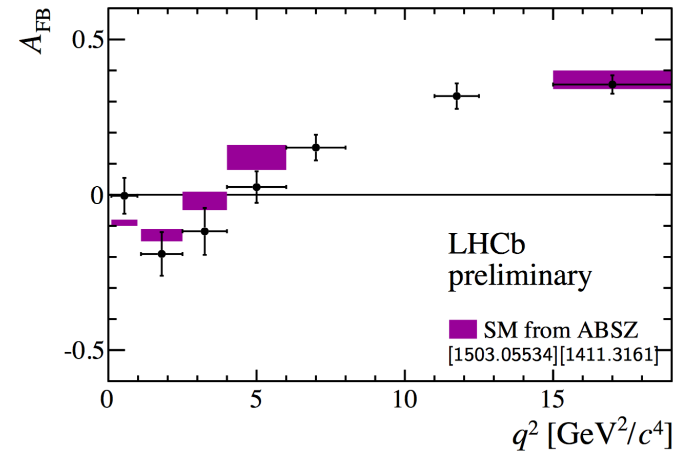




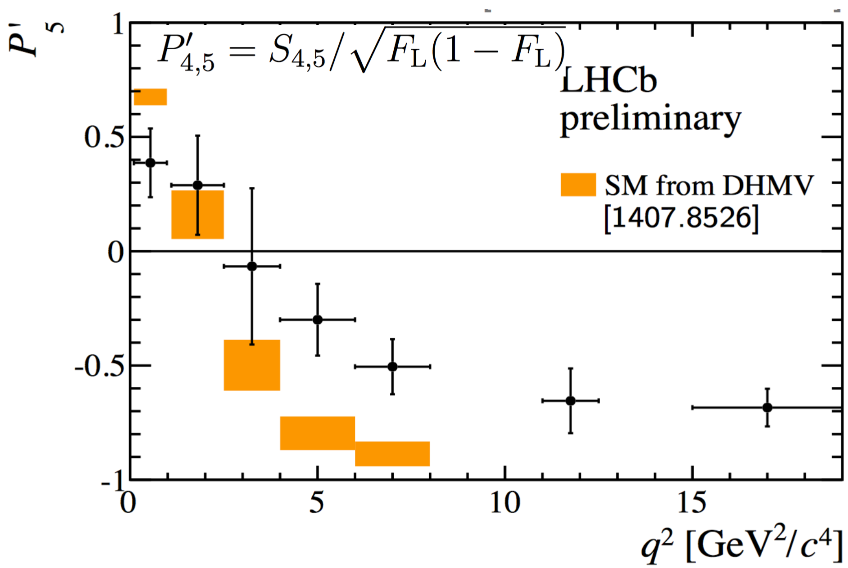
arXiv: 1507.08126 (hep-ex)

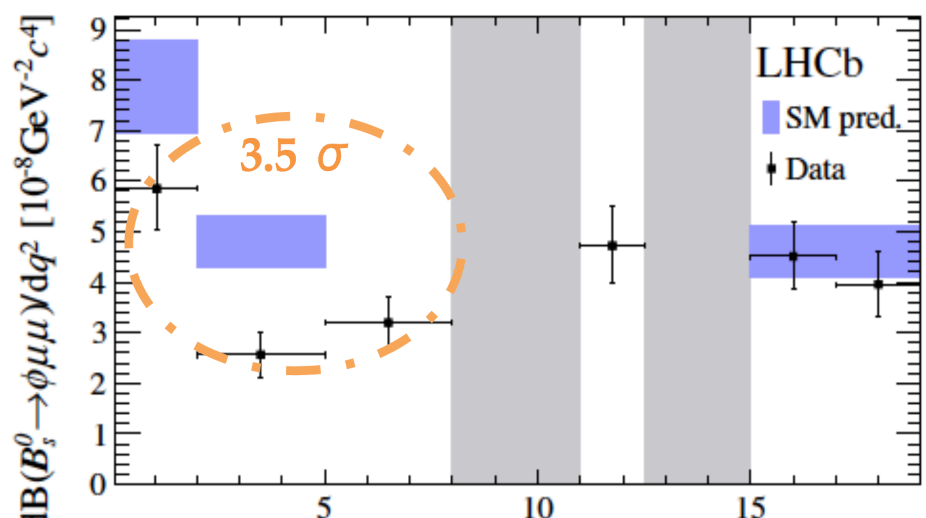
Prospect for B−>K*⁰/ϕ μ⁺μ⁻ from LHCb

- **LHCb showed the result using full available data from**
- **Run-I: 3fb^{-1}**
- **A_{FB} seems to be little lower than SM prediction**
- **However, the P_5' parameter has large deviation from**
- **SM expectation (seen also with 1 fb^{-1} data)**
- **Similar discrepancy in B->ϕμ$^+$μ$^-$ differential BF seen.**



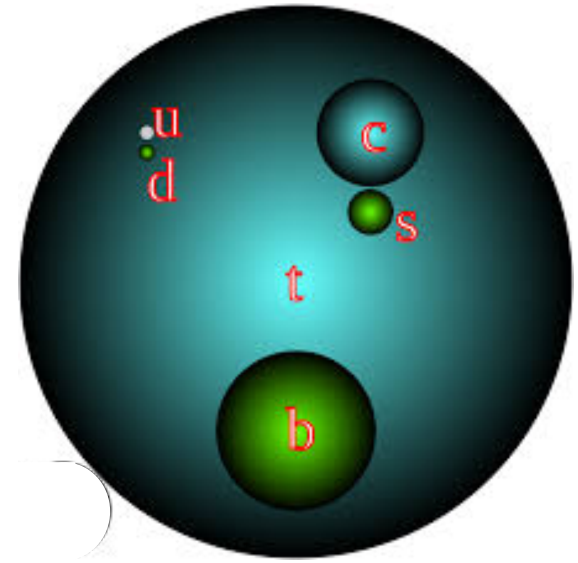
$$\frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2}\frac{\mathrm{d}^3(\Gamma+\bar{\Gamma})}{\mathrm{d}\vec{\Omega}} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell$$
$$+S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi + S_5\sin 2\theta_K\sin\theta_\ell\cos\phi + \frac{4}{3}A_{FB}\sin^2\theta_K\cos\theta_\ell$$
$$+S_7\sin 2\theta_K\sin\theta_\ell\sin\phi + S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big].$$





LHCb-CONF-2015-002

Top-quark results from CMS and ATLAS

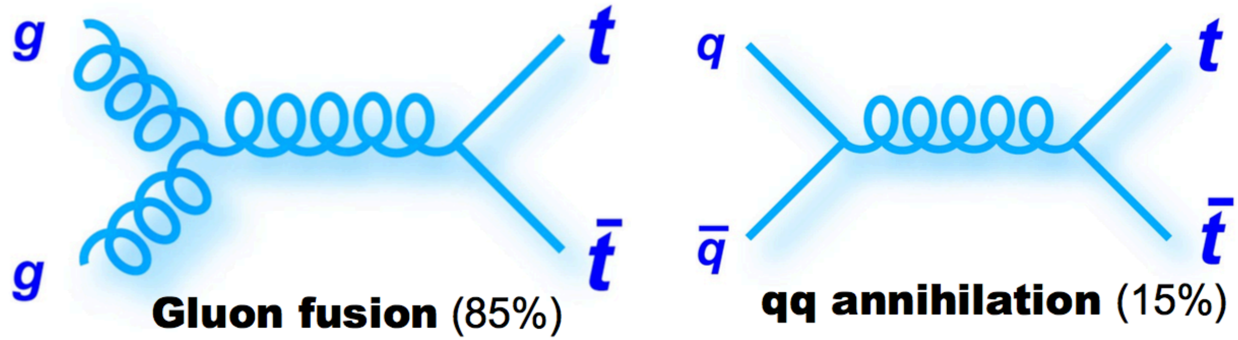


- Heaviest known elementary particle with very short life time.
- It's the SM particle with strongest coupling to Higgs boson.
- Top quark is the only "free quark" we have access to.
- Decays before hadronization -> gives access to its properties.
- Allows precision measurement of SM parameters: M_{top}, $V_{tb.}$
- One of the main background to many BSM searches.

More on top quark by: G. Mohanty, Veronique Boisvert

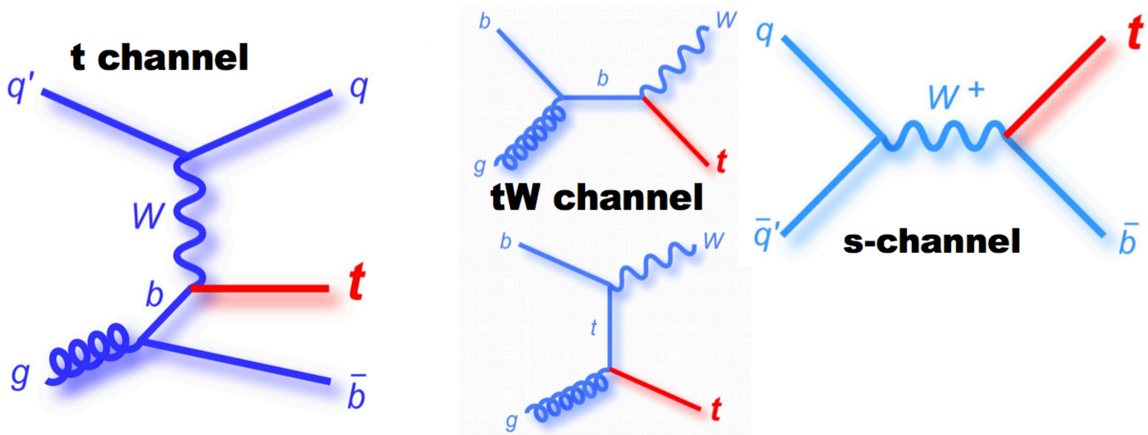
Top quark production at LHC

- Top quark pairs produced via QCD interaction:



CME	σ (pb)
7 TeV	177.3
8 TeV	252.9
13 TeV	831.7

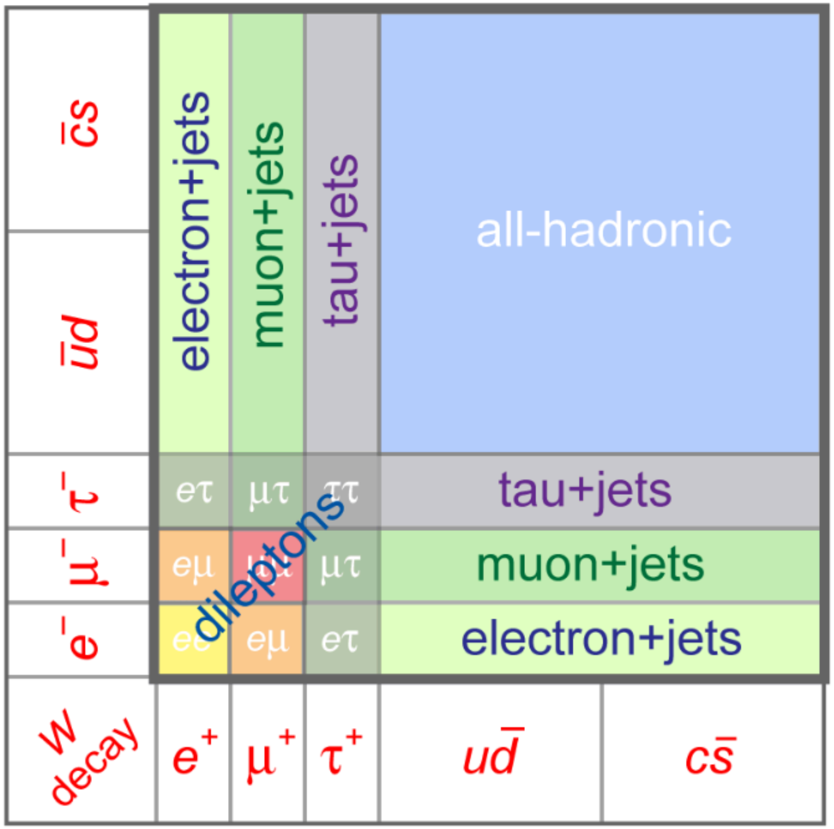
- Single top quark produced through EWK interaction:



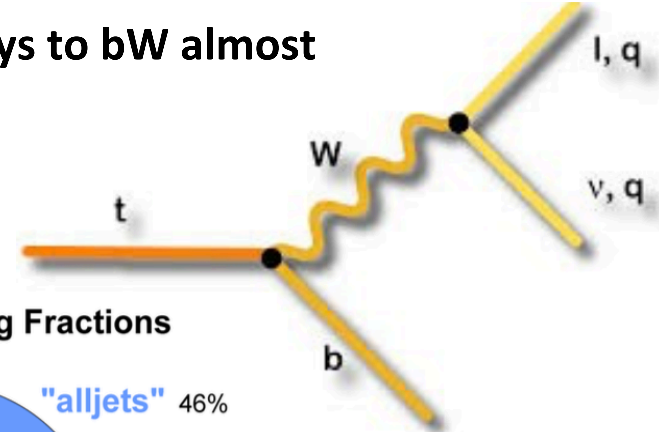
CME	σ (pb)		
	t-channel	tW	s-channel
7 TeV	63.9	15.7	4.3
8 TeV	84.7	22.2	5.6
13 TeV	217.0	71.2	11.4

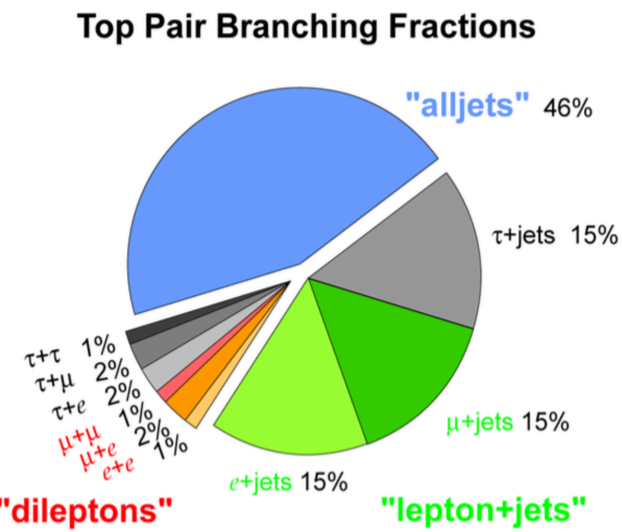
At high energy one can test the production mechanism dominated by gluon-gluon fusion, and check the validity of QCD

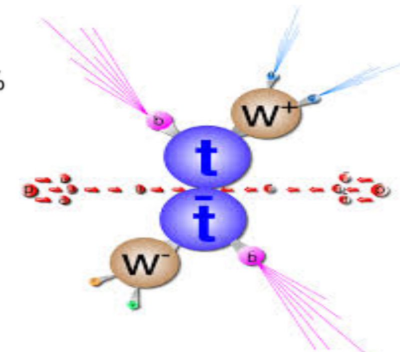
Top quark decay at LHC

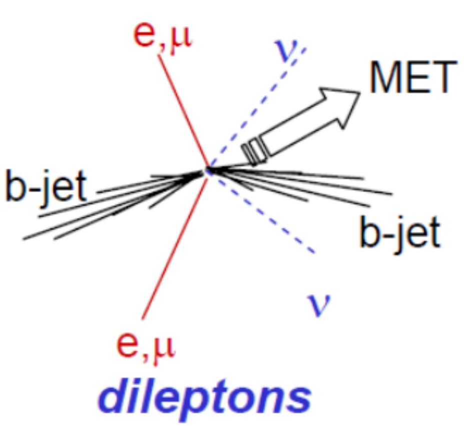


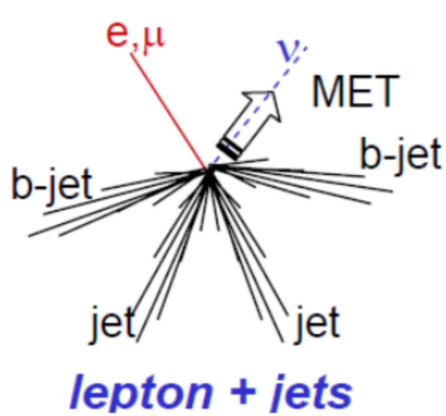
- top quark decays to bW almost 100% time.

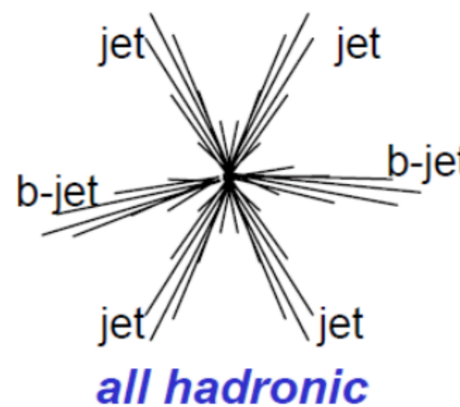




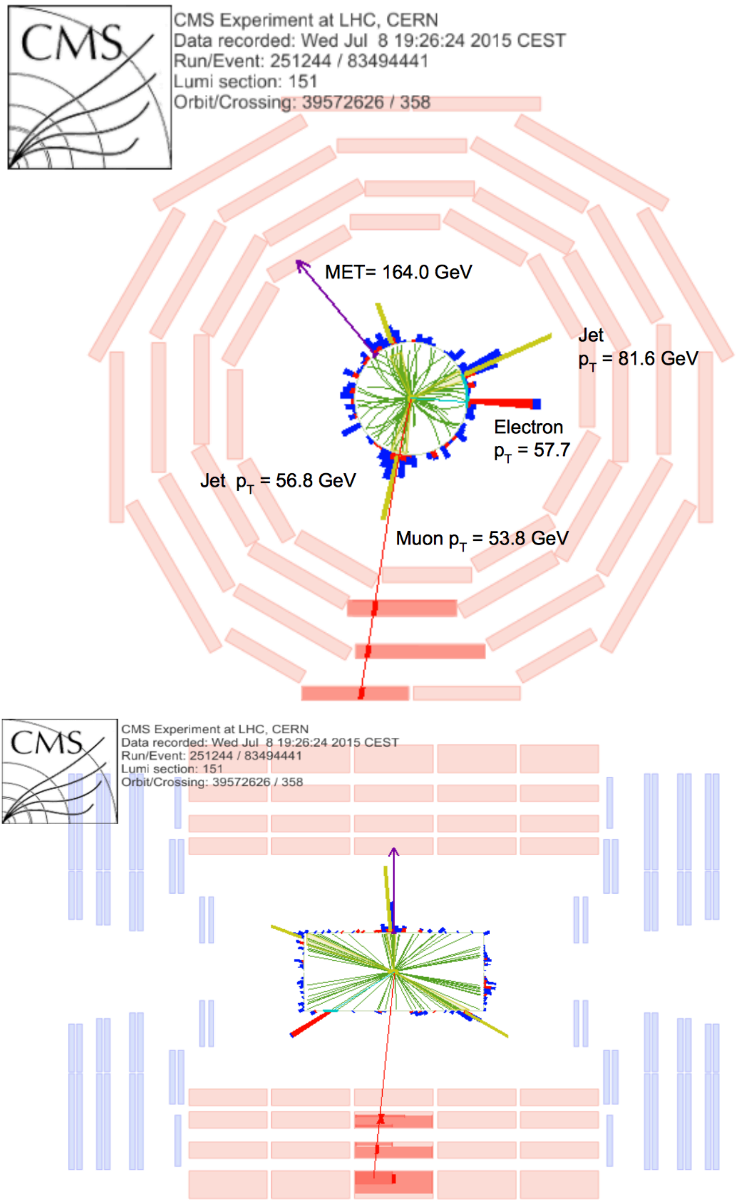


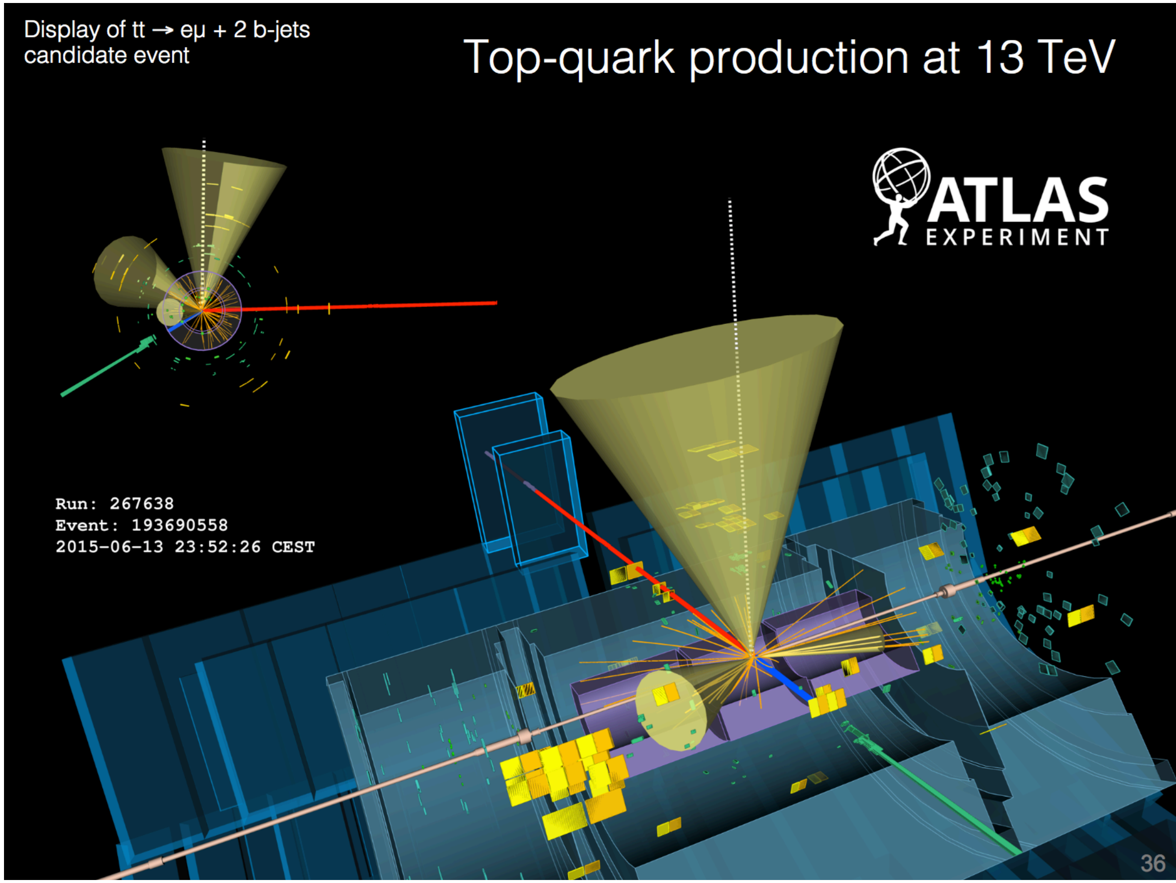






Event display of produced top pair



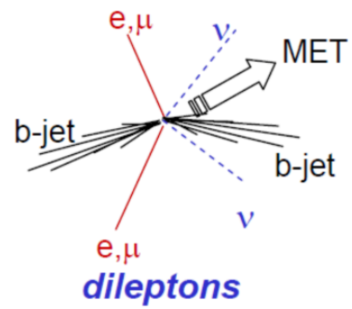


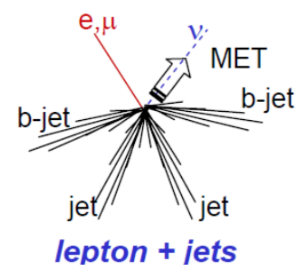
The event display taken with 13TeV data

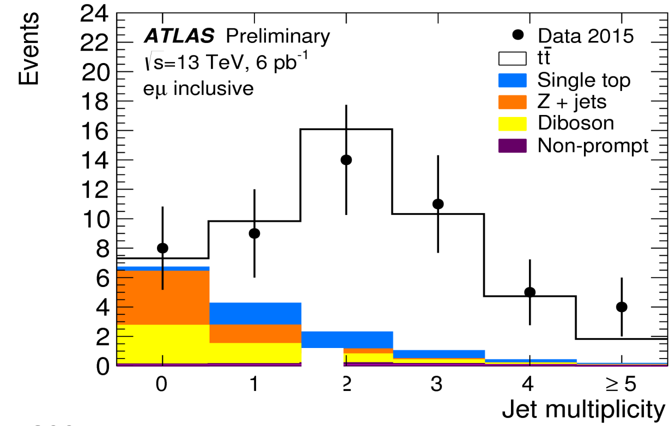
Kinematic distribution in "top" enriched sample

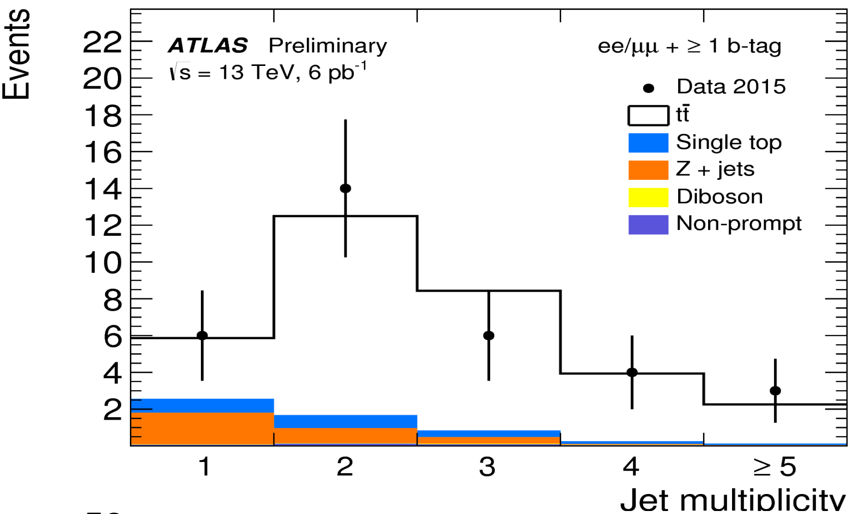
- **Uses 6pb^{-1} data at 13TeV** ATLAS-PHYS-PUB-2015-017
- **Selects tt events in di-lepton / single lepton decay mode**

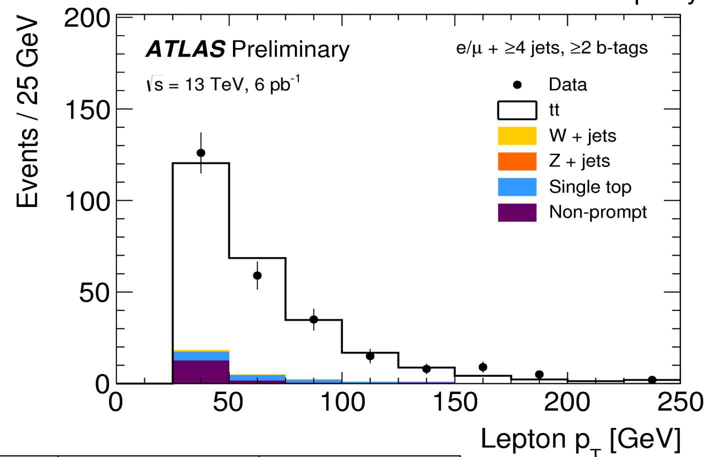
Selection: electrons P_T>25GeV, |η| <2.47
muons P_T>25GeV, |η| <2.5
jets P_T> 25 GEV, |η| < 2.5

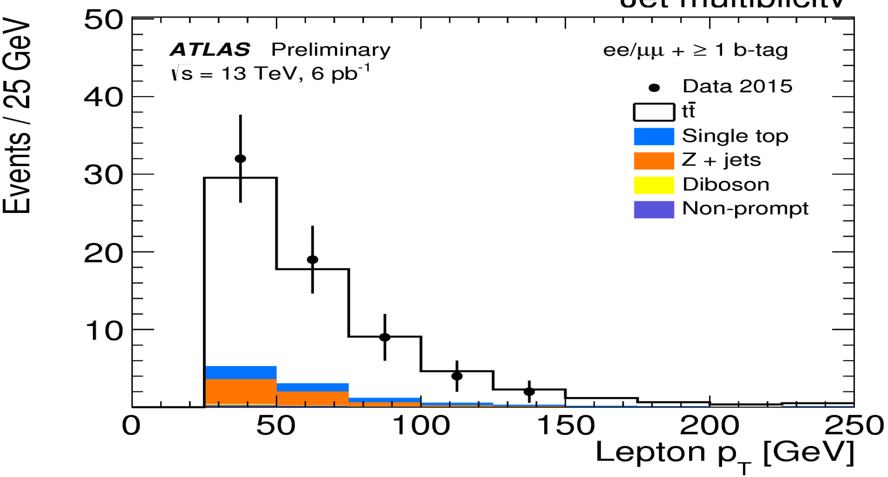


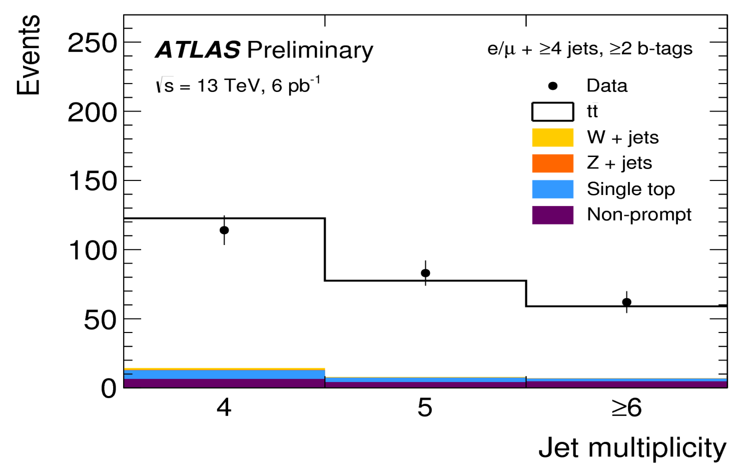








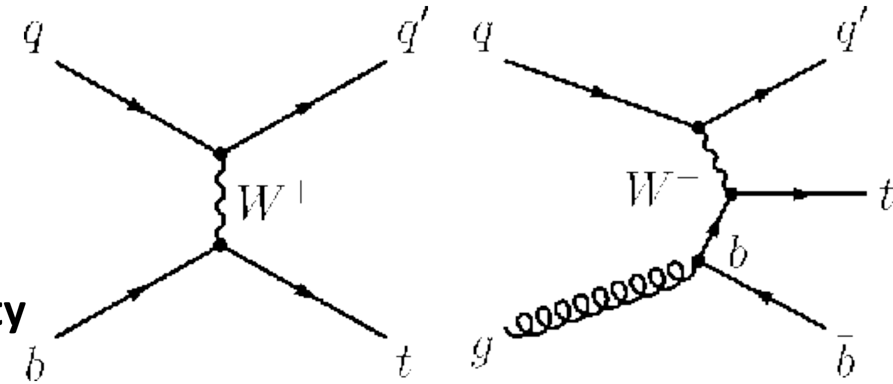




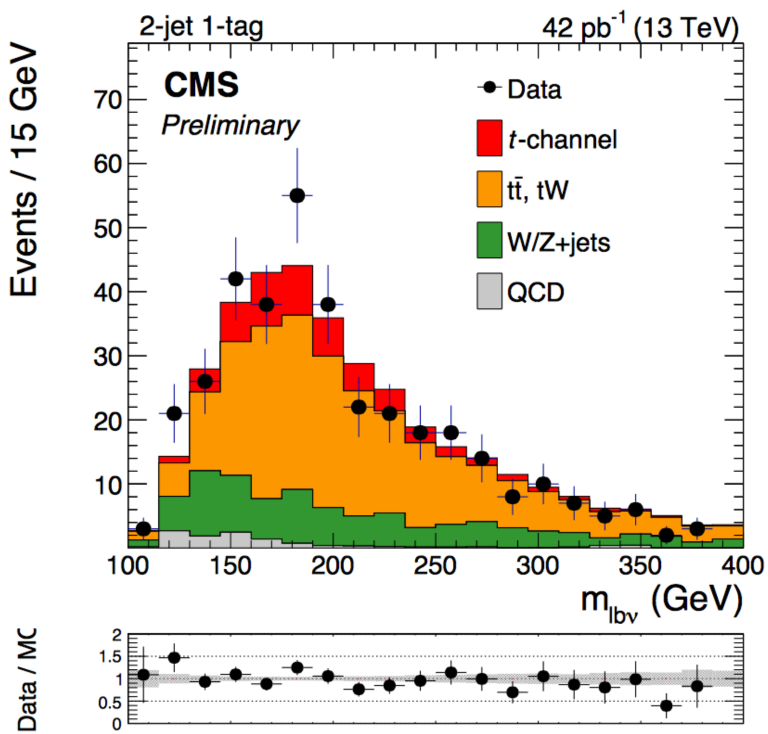
t-channel single top production

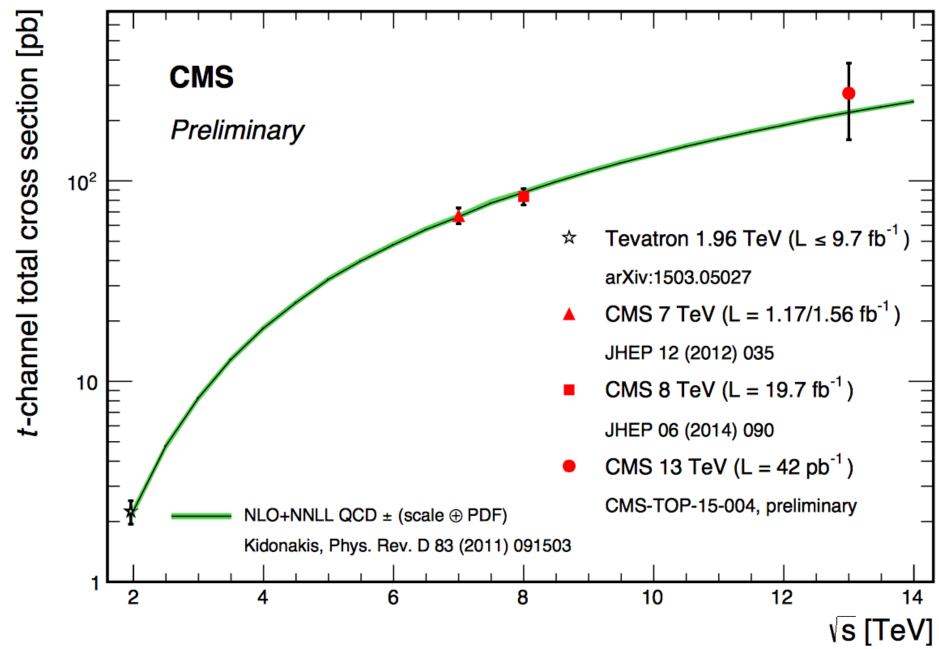
CMS-PAS TOP-15-004

- CMS uses 42pb^{-1} data at 13TeV
- Expects about 2.5 times increase in cross-section compared to 8TeV
- Requires one muon in the final state, one b-jet and a light jet
- Signal is extracted by fitting the pseudo-rapidity distribution of recoiling jet



Selection: muon P_T>22GeV, |η| <2.1
jets P_T> 40 GeV, |η| < 4.7





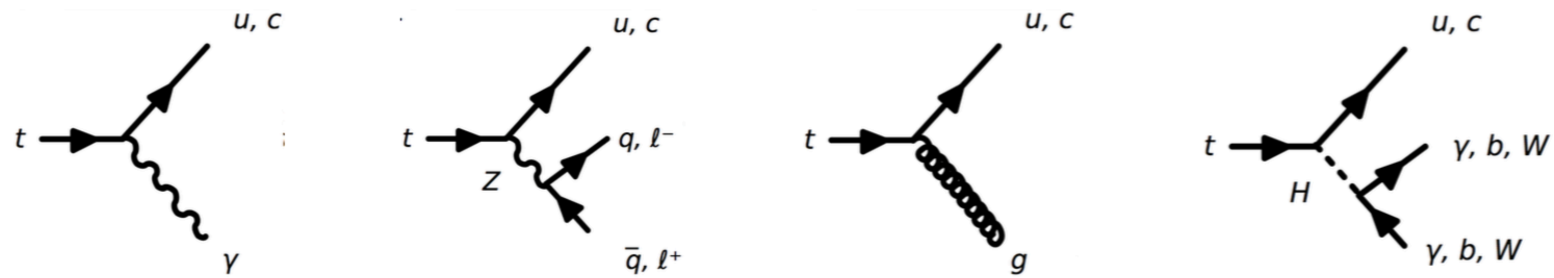
$$\sigma_{t\text{-ch.}} = 274 \pm 98\,(\text{stat.}) \pm 52\,(\text{syst.}) \pm 33\,(\text{lumi.})\ \text{pb}$$

$$|V_{tb}| = 1.12 \pm 0.24\,(\text{exp.}) \pm 0.02\,(\text{theo.})$$

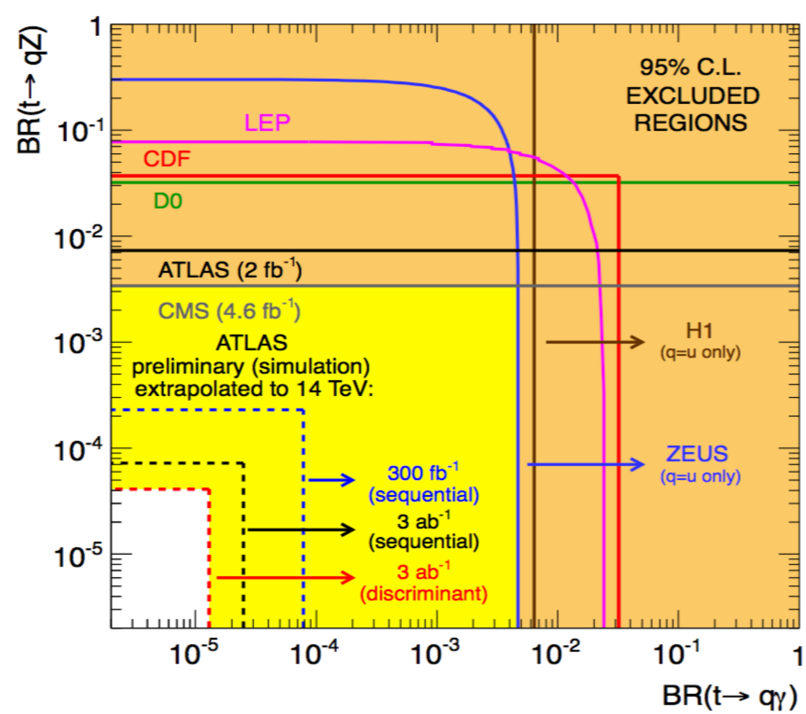
Looking for NP in top-sector at higher energy

- The SM FCNC processes are forbidden at tree level. However it can proceed via loop processes. However they are much smaller compared to dominant decay, t->bW, rate.
- Some models predict higher rates -> probe for NP

ACTA Phys Pol. B 35 (2004)



Decay Channel	95% CL Limit	Data Set and Exp.
$B(t \to qg)$	4.0×10^{-5} $(q = u)$	ATLAS-TOPQ-2014-13-002
	1.70×10^{-4} $(q = c)$	(8 TeV, 20.3 fb^{-1})
	3.55×10^{-4} $(q = u)$	CMS-PAS-TOP-14-007
	3.44×10^{-3} $(q = c)$	(7TeV,5.0 fb^{-1})
$B(t \to qZ)$	7×10^{-4} $(q = u, c)$	arXiv:1508.05796
		(8 TeV, 20.3 fb^{-1})
	5×10^{-4} $(q = u, c)$	PRL**112**,171802(2014)
		(7TeV,5.0 fb^{-1} $\oplus$8TeV,19.7 fb^{-1})
$B(t \to q\gamma)$	1.61×10^{-4} $(q = u)$	CMS-PAS-TOP-14-003
	1.82×10^{-3} $(q = c)$	(8 TeV, 19.1 fb^{-1})
$B(t \to qH)$	7.90×10^{-3} $(q = u, c)$	JHEP**1406**,008(2014)
		(7TeV,4.7 fb^{-1} $\oplus$8TeV,20.3 fb^{-1})
	4.20×10^{-3} $(q = u)$	CMS-PAS-TOP-14-019
	4.70×10^{-3} $(q = c)$	(8 TeV, 19.7 fb^{-1})

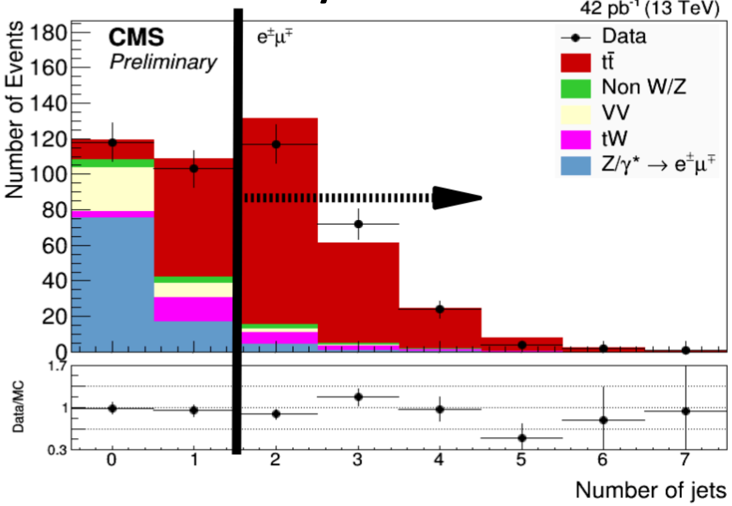


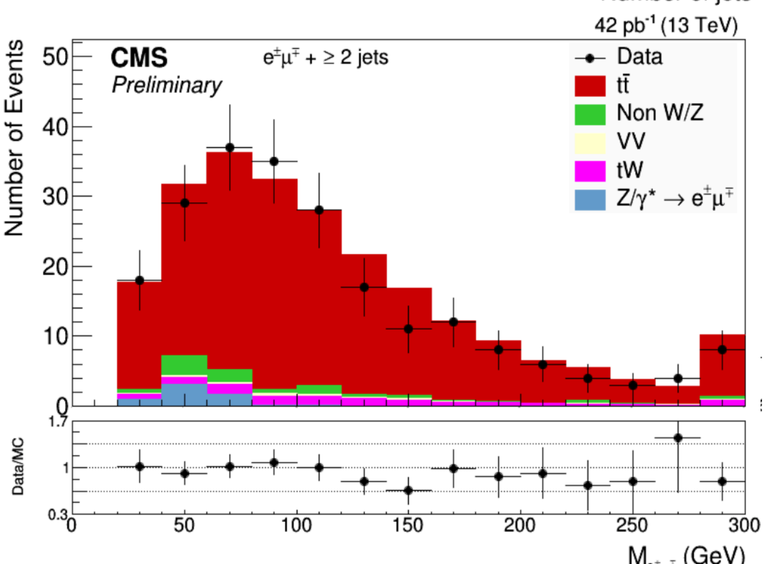
top anti-top production with CMS

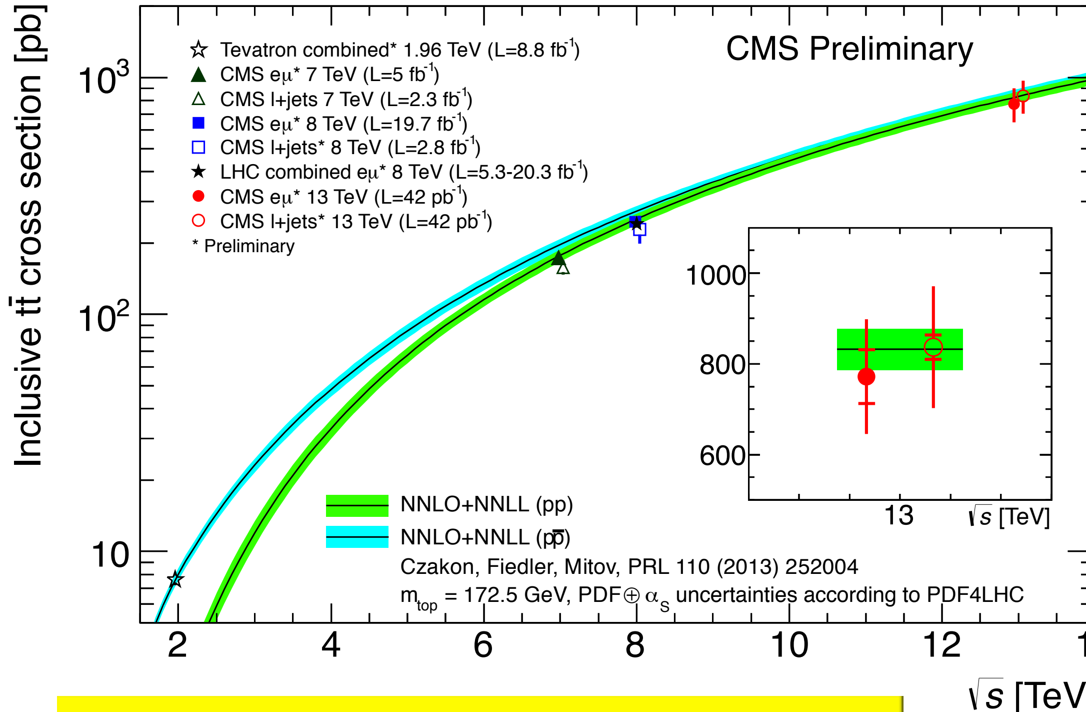
One of the cleanest channel: tt -> (e + ν + jet) + (μ + ν + jet) = eμ + 2 jets + E_T

Selection: electrons/muons P_T>20GeV, |η| <2.4; for jets P_T> 30 GEV, |η| < 2.4

Candidates with M ($e^+\mu^-$ / μ^+e^-) less than 20 GeV are removed to suppress background from heavy flavor resonances







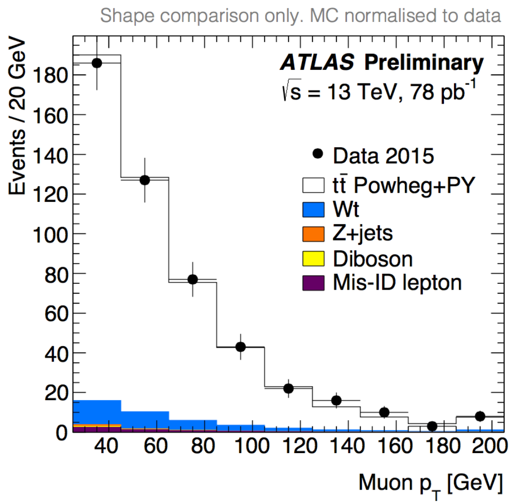
σ = 772 ± 60(stat) ± 62(syst) ± 93(lumi) pb

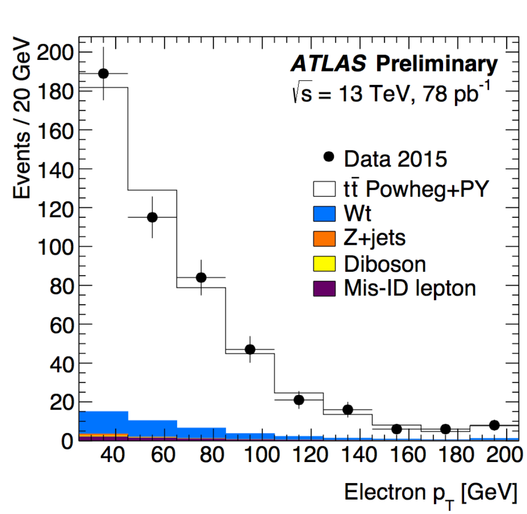
For data the dominant systematic uncertainty: luminosity, trigger/lepton efficiency, jet energy scale

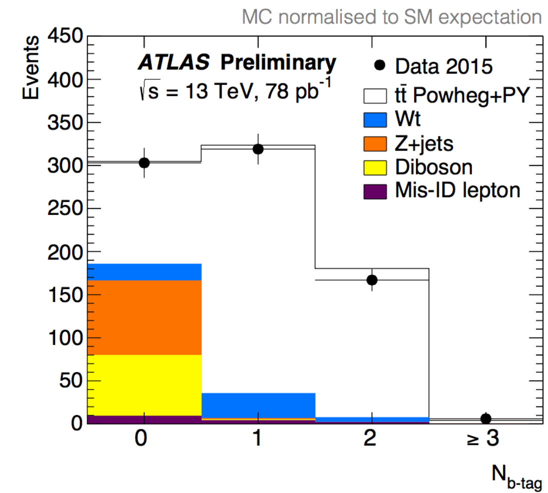
σ_{tt}[SM] (13 TeV) = 832^{+40}_{-46} pb (at NNLO + NNLL accuracy, m_t = 172.5 GeV, Top++ 2.0)

top anti-top production with ATLAS

ATLAS-CONF-2015-033

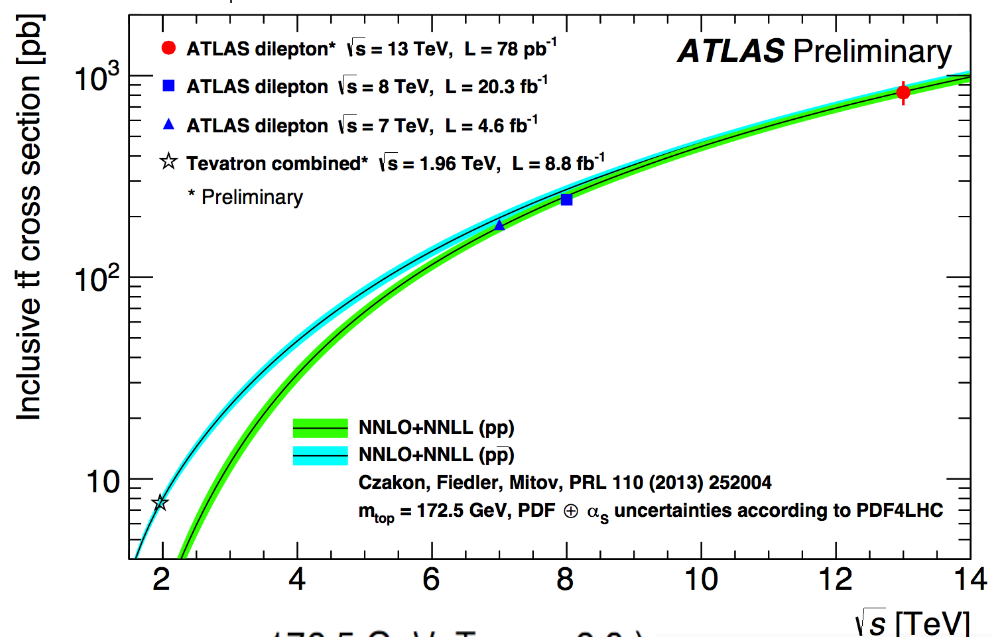






Selection:

OS electrons and muons with $P_T > 25$GeV, at least one b-tagged jets with $P_T > 25$GeV



At 13 TeV, pp -> tt + X cross-section:

σ_{tt} (13 TeV) = 825 ± 49 (stat) ± 60 (syst) ± 83 (lumi) pb

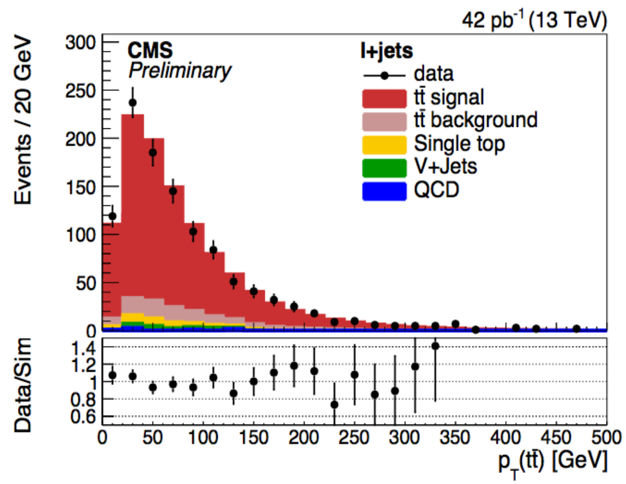
Syst: dominated by tt hadronization, luminosty, e-ID, mu-ID, mis-ID

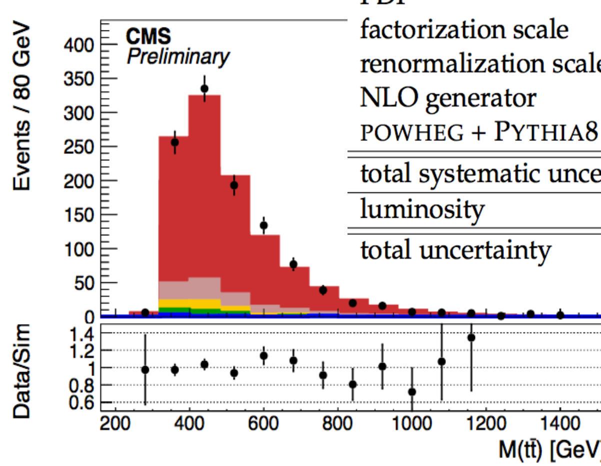
σ_{tt}[SM] (13 TeV) = 832^{+40}_{-46} pb (at NNLO + NNLL accuracy, m_t = 172.5 GeV, Top++ 2.0)

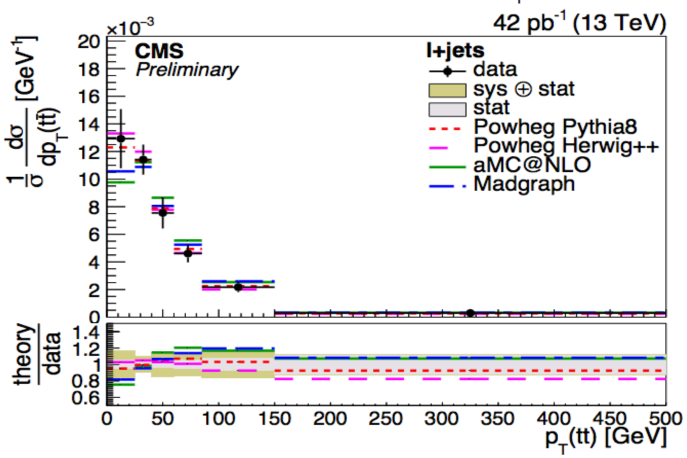
Inclusive & differential $t\bar{t}$ cross-section from CMS

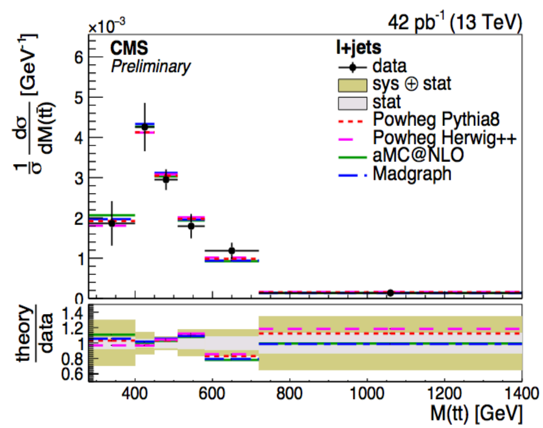
- **Inclusive and differential cross-section measurement in top pairs with lepton + jets mode, with an electron or muon in final state.**
- **Two b-jets + two jets from W + isolate e/μ**
- **Electron/muon P_T> 30 GeV, |η| < 2.1**
- **At least jets required, P_T> 25GeV, |η| < 2.4**

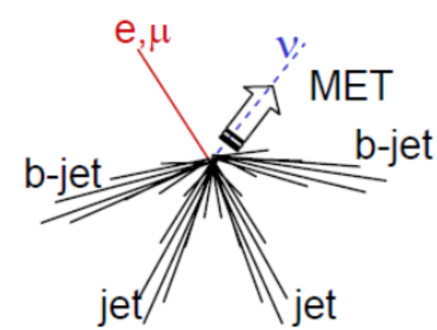
source	inclusive cross section [%]
statistical uncertainty	3.2
b tagging	5.1
jet energy scale	3.5
jet energy resolution	3.4
lepton selection	3.0
E_T^{miss} (non jet)	< 0.1
pileup	1.2
background	1.6
PDF	4.7
factorization scale	< 0.1
renormalization scale	< 0.1
NLO generator	2.0
POWHEG + PYTHIA8 vs. HERWIG++	3.4
total systematic uncertainty (no luminosity)	10.0
luminosity	12
total uncertainty	15.6











$$\sigma_{l+j} = 244 \pm 8\,(\text{stat}) \pm 24\,(\text{sys}) \pm 29\,(\text{lumi})\,\text{pb},$$
$$\sigma_{tot} = 836 \pm 27\,(\text{stat}) \pm 84\,(\text{sys}) \pm 100\,(\text{lumi})\,\text{pb}.$$

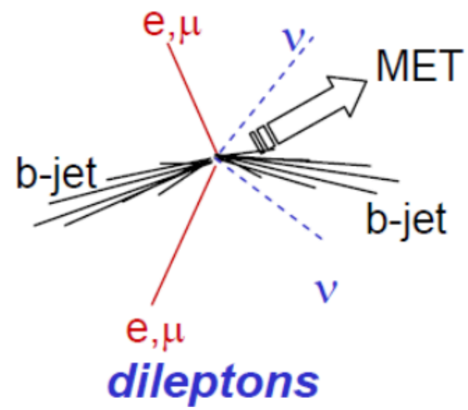
$$\sigma_{NNLO} = 832^{+20}_{-29}\,(\text{scale})^{+35}_{-35}\,(\text{PDF}/\alpha_s)\,\text{pb [20–25]}.$$

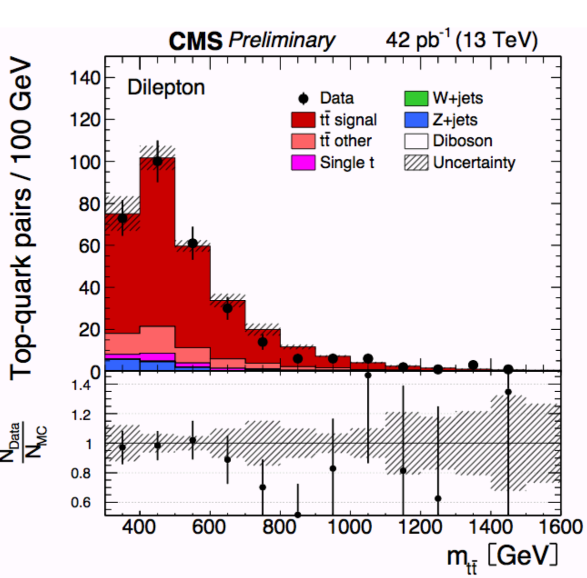
CMS PAS TOP-15-005

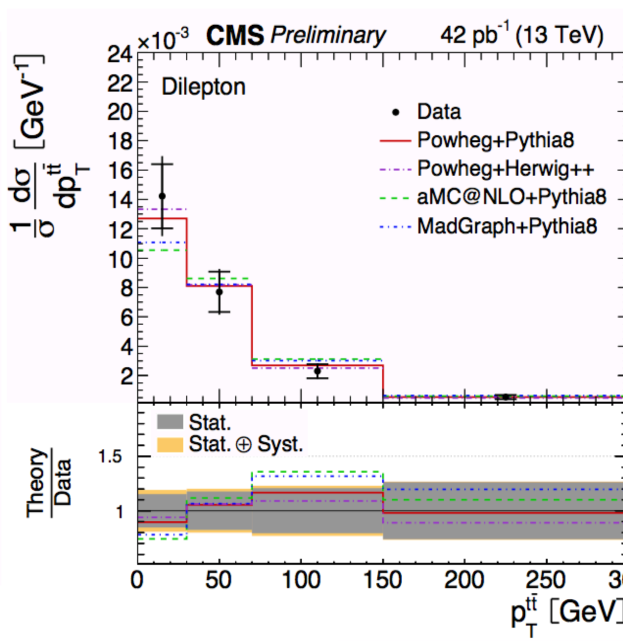
Top pair differential cross-section from CMS

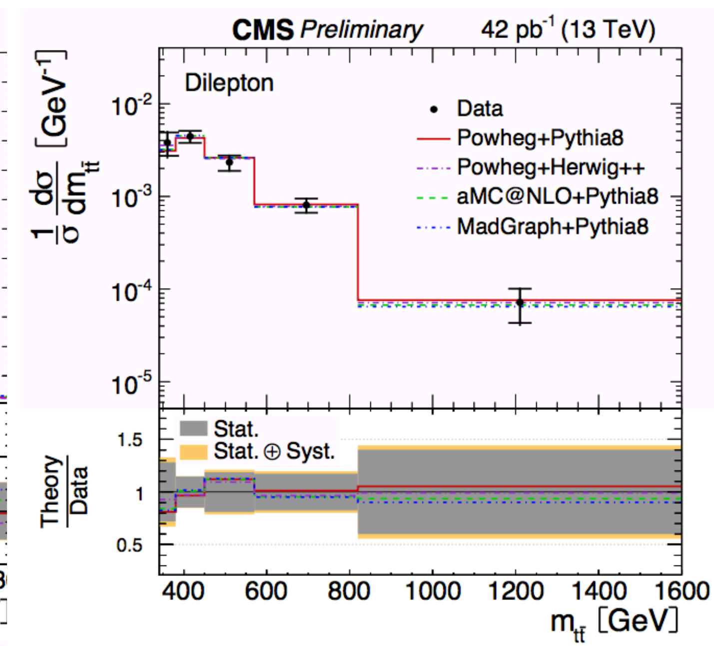
- Differential cross-section measured as function of top-quark and tt-pair system in di-lepton final state (and at least two jets)
- Uses 42 pb^{-1} at 13TeV

Selection: electrons/muons P_T>20GeV, $|\eta|$ <2.4
jets P_T> 30 GeV, $|\eta|$ < 2.4
Backgrounds from Z -> $\mu^+\mu^-$ / e^+e^- are suppressed by requiring the dilepton mass to be outside Z mass.









CMS PAS TOP-15-010

Conclusion

- It is exciting time for LHC as we are approaching the designed energy value
- Some of the 7/8TeV result have been reproduced and have been tested successfully.
- In the B-physics, it would interesting to see how the decay modes sensitive to NP would come out with 13/14TeV large dataset.
- The wealth of experimental results in the last few years are constraining NP contributions
- Rare decay of heavy mesons, in particular $b \to s l^+ l^-$ transitions.
- We didn't observe so far any unambiguous deviation from SM prediction.
- For top quark pair production, the 13TeV results are very consistent with theory prediction
- We are looking for more precise measurement of cross-section or differential cross-section
- Will top quark reveal its key for the world beyond TeV scale ?

Stay tuned, more data coming !

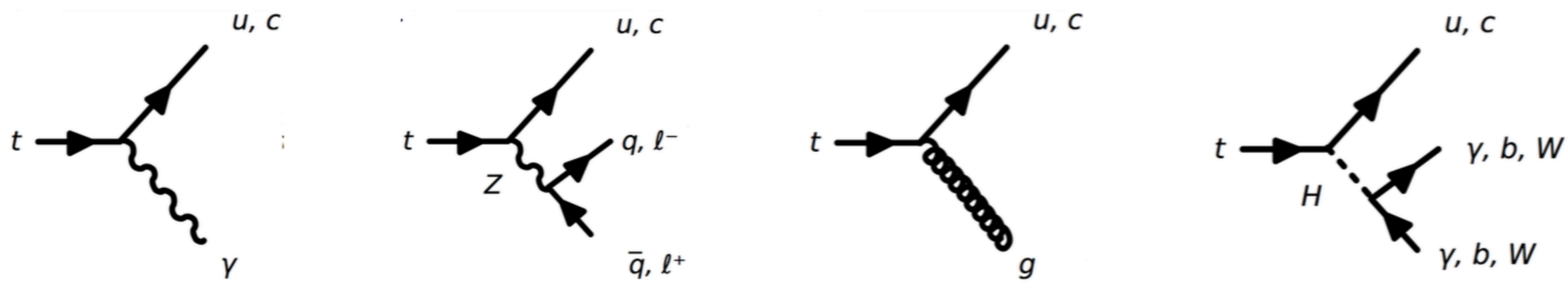
CMS & ATLAS comparison

		σ(pb)		Stat (%)	Syst (%)	Lumi (%)
		NNLO	Meas.			
7 TeV	CMS	177.3	174.5	1.2	2.5	2.2
	ATLAS[1]		182.9	1.7	2.3	2.0
8 TeV	CMS	252.9	245.6	0.5	2.4	2.6
	ATLAS[1]		242.4	0.7	2.3	3.1
13 TeV	CMS	831.7	772	7.7	8.0	12
	ATLAS		825	5.9	7.2	10

- Both the experiments are consistent with each other with each other (within error bars) and also with theory prediction. Although 13TeV results have large luminosity uncertainty.

Looking for NP in top-sector at higher energy

- The SM FCNC processes are forbidden at tree level. However it can proceed via loop processes. However they are much smaller compared to dominant decay, t->bW, rate.
- Some models predict higher rates -> probe for NP



Theoretical predictions for the BR of FCNC top quark decays

Process	SM	QS	2HDM	FC 2HDM	MSSM	$\not{R}$ SUSY	RS
$t \to uZ$	8×10^{-17}	1.1×10^{-4}	—	—	2×10^{-6}	3×10^{-5}	—
$t \to u\gamma$	3.7×10^{-16}	7.5×10^{-9}	—	—	2×10^{-6}	1×10^{-6}	—
$t \to ug$	3.7×10^{-14}	1.5×10^{-7}	—	—	8×10^{-5}	2×10^{-4}	—
$t \to uH$	2×10^{-17}	4.1×10^{-5}	5.5×10^{-6}	—	10^{-5}	$\sim 10^{-6}$	—
$t \to cZ$	1×10^{-14}	1.1×10^{-4}	$\sim 10^{-7}$	$\sim 10^{-10}$	2×10^{-6}	3×10^{-5}	$\leq 10^{-5}$
$t \to c\gamma$	4.6×10^{-14}	7.5×10^{-9}	$\sim 10^{-6}$	$\sim 10^{-9}$	2×10^{-6}	1×10^{-6}	$\leq 10^{-9}$
$t \to cg$	4.6×10^{-12}	1.5×10^{-7}	$\sim 10^{-4}$	$\sim 10^{-8}$	8×10^{-5}	2×10^{-4}	$\leq 10^{-10}$
$t \to cH$	3×10^{-15}	4.1×10^{-5}	1.5×10^{-3}	$\sim 10^{-5}$	10^{-5}	$\sim 10^{-6}$	$\leq 10^{-4}$

Acta Phys.Polon.**B35**,2695(2004), arXiv:1311.2028

Looking for NP in top-sector at higher energy

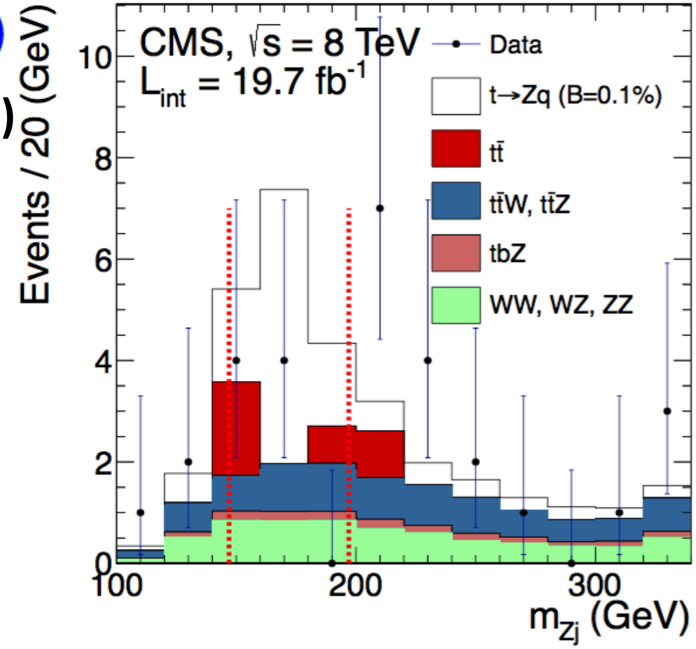
$t\bar{t} \rightarrow \ell\nu b + \ell\ell q$ (19.7 fb^{-1},8 TeV $\oplus$ 5.0 fb^{-1},7 TeV)

(PRL 112, 171802(2014))

3 iso. leptons (e,μ) with 2 $\ell^+\ell^-$
with 1 pair 78 GeV<$|m_{\ell^+\ell^-} - m_Z|$<102 GeV
E_T^{miss}>30 GeV
$\geq$ 2 jets, with p_T>30 GeV, only 1 b_{jet}

Results @ 7+8 TeV:

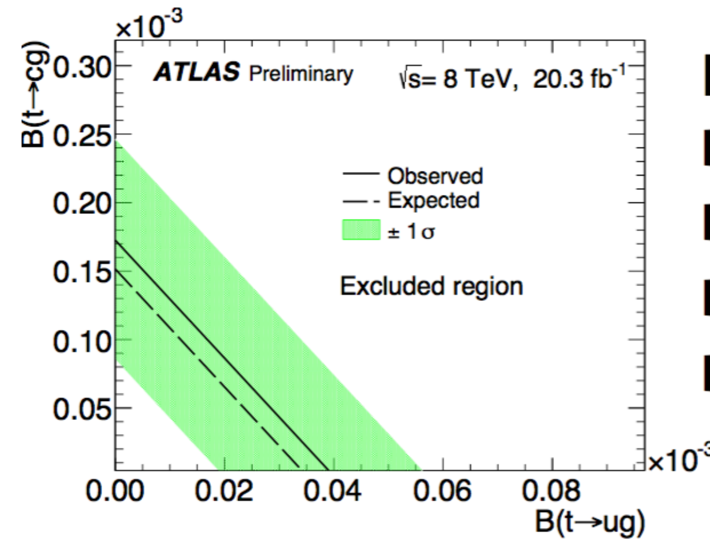
$Br(t \rightarrow qZ)$< **0.05% (obs.) 0.09% (exp.) @ 95% CL**



exactly 1 isolated e or μ
missing transverse energy
exactly 1 b_{jet}

Results:

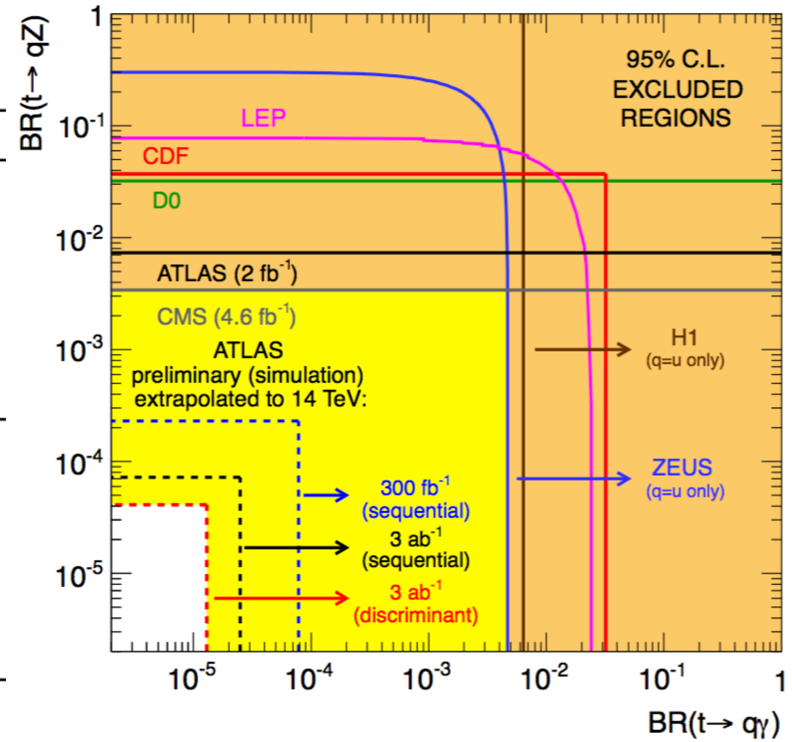
$Br(t \rightarrow ug) < 4.0 \times 10^{-5}$**(obs.)**
$Br(t \rightarrow cg) < 1.7 \times 10^{-4}$**(obs.)**



Looking for NP in top-sector at higher energy

FCNC Direct Bounds RUN I (short) Summary:

Decay Channel	95% CL Limit	Data Set and Exp.
$B(t \to qg)$	4.0×10^{-5} $(q = u)$	ATLAS-TOPQ-2014-13-002
	1.70×10^{-4} $(q = c)$	(8 TeV, 20.3 fb^{-1})
	3.55×10^{-4} $(q = u)$	CMS-PAS-TOP-14-007
	3.44×10^{-3} $(q = c)$	(7TeV,5.0 fb^{-1})
$B(t \to qZ)$	7×10^{-4} $(q = u, c)$	arXiv:1508.05796
		(8 TeV, 20.3 fb^{-1})
	5×10^{-4} $(q = u, c)$	PRL**112**,171802(2014)
		(7TeV,5.0 fb^{-1} $\oplus$ 8TeV,19.7 fb^{-1})
$B(t \to q\gamma)$	1.61×10^{-4} $(q = u)$	CMS-PAS-TOP-14-003
	1.82×10^{-3} $(q = c)$	(8 TeV, 19.1 fb^{-1})
$B(t \to qH)$	7.90×10^{-3} $(q = u, c)$	JHEP**1406**,008(2014)
		(7TeV,4.7 fb^{-1} $\oplus$ 8TeV,20.3 fb^{-1})
	4.20×10^{-3} $(q = u)$	CMS-PAS-TOP-14-019
	4.70×10^{-3} $(q = c)$	(8 TeV, 19.7 fb^{-1})



- **Run-I limits in the range of $10^{-3} - 10^{-4}$**
- **Expected to improve by order of magnitude in Run-2**