Prospects for Top Physics at the LHC

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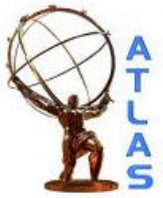

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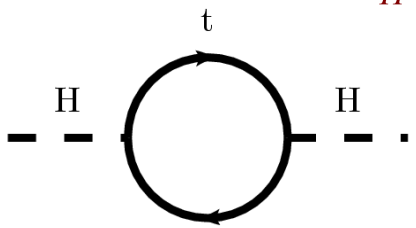
Prospects for top physics

- The unusually massive top quark:

  m_t = 172.4 ± 1.2 GeV (Tevatron:ICHEP08)

  * decays before hadronizing: $\lambda_t < 10^{-24}$ s
  * large coupling to Higgs: $y_t \approx 1$; dominant correction to m_H



- Top physics at LHC:

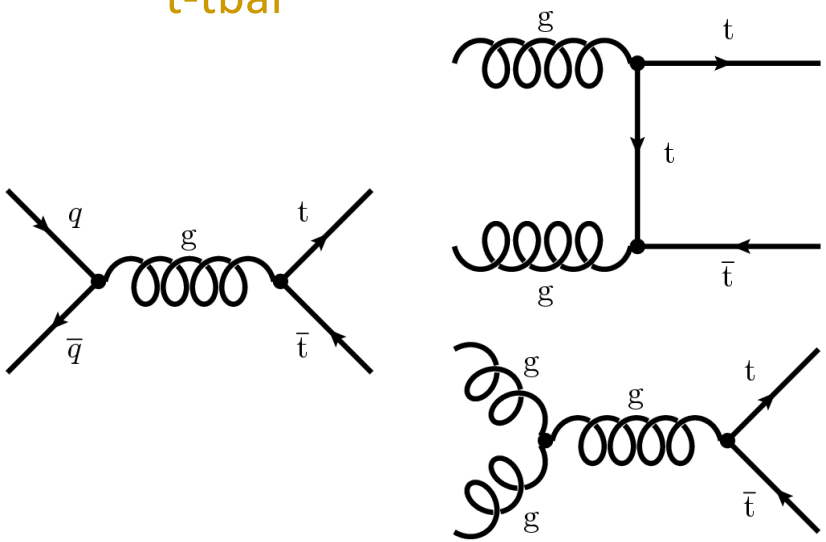
  * precision SM tests in quark sector
  * a probe, model, and background for new physics searches

Topics:

- ▶Making & reconstructing top at the LHC
- ▶Finding and using $t\bar{t}$ events
- ▶Standard model tests with LHC top data

Top production at the LHC

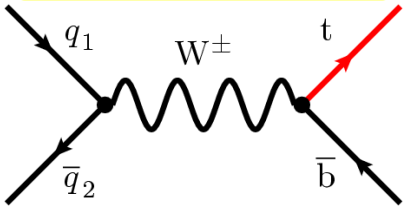
strong: ~900 pb
"t-tbar"



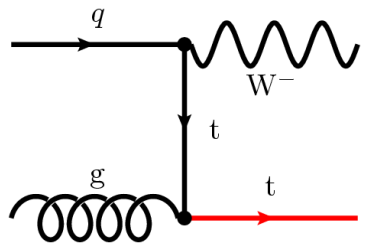
90% at LHC

electroweak ~320 pb
"single top"

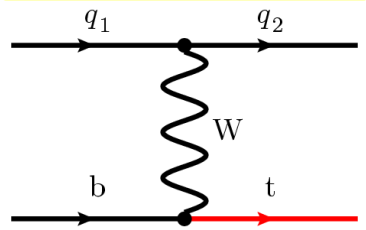
s-channel
10x Tevatron



W+top
70x Tevatron



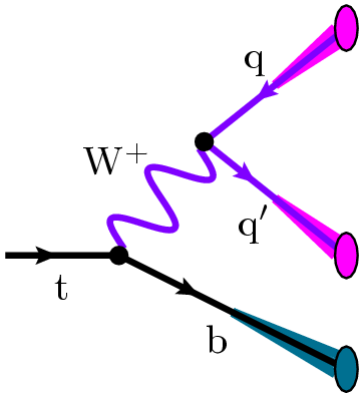
t-channel
100x Tevatron



- Abundant in 14 TeV collisions: ~ 1 pair/sec at 10^{33} cm^{-2} s^{-1}
  - ★ LHC in '09: **lower energy & luminosity:** $\mathcal{L} \approx 10^{31}$-$10^{32}$ cm^{-2} s^{-1} ? $\sqrt{s} \approx 10$ TeV?
    (σ_{tt} = 400 pb at 10 TeV)

(In this talk: $\sqrt{s}$ = 14 TeV results)

Top reconstruction at the LHC



Hadronic (BR≈⅔):

✓ can fully reconstruct W and top momenta

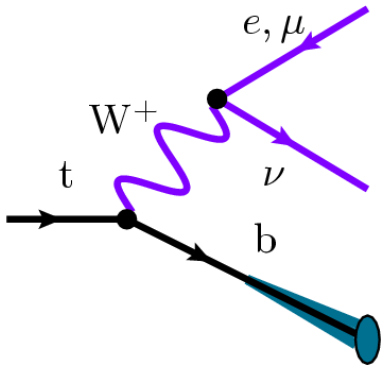
✗ Faked by QCD multijets (esp. heavy flavor)

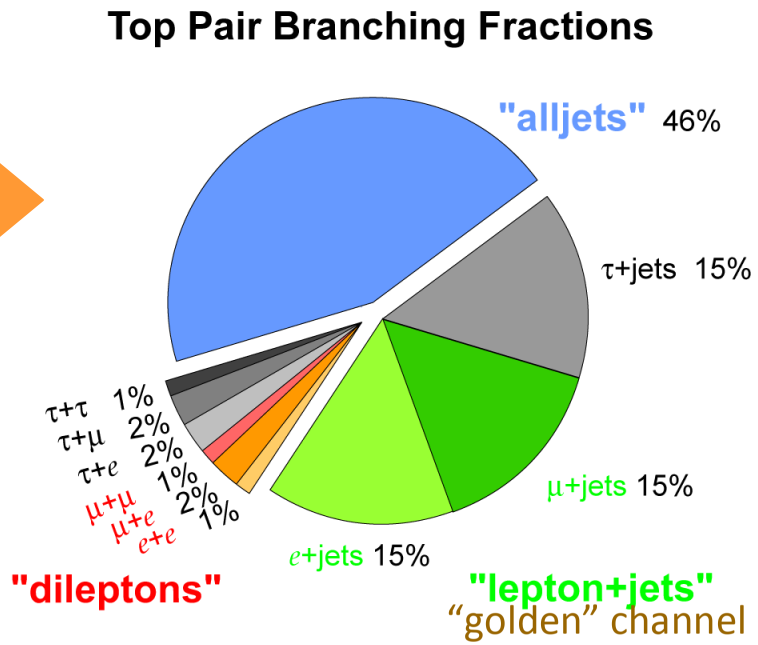
Leptonic (BR≈⅓):

✓ lepton indicates W's charge, helicity

✓ reject QCD via lepton and missing E_T

✗ kinematic info. lost (partly)

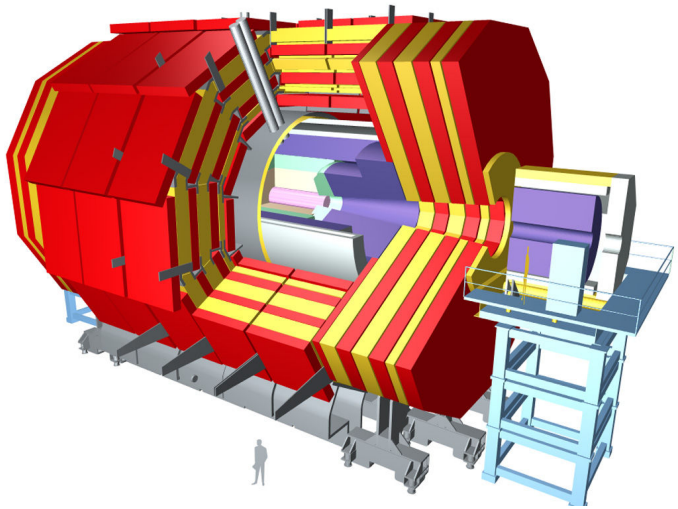


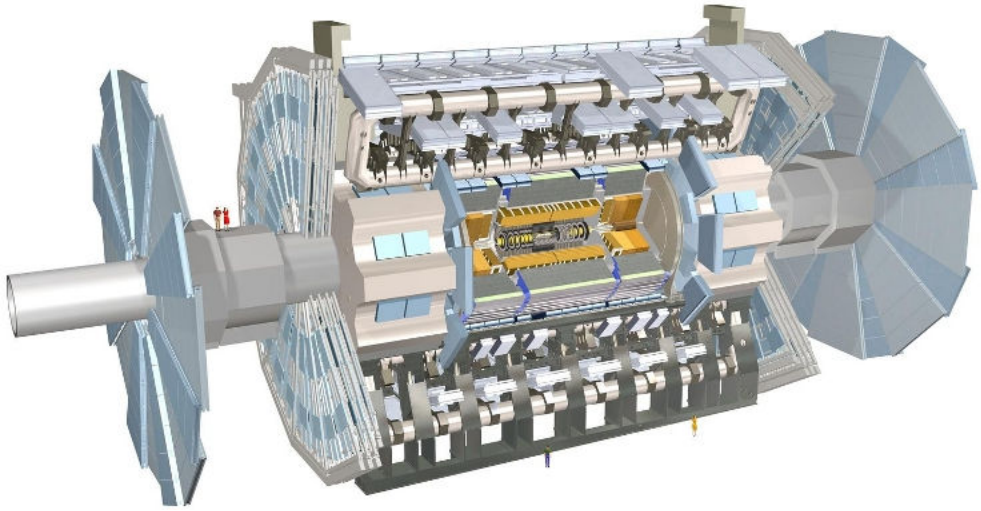


σ_{tt} measurements will validate:

- lepton identification
- jets/missing E_T
- b-tagging

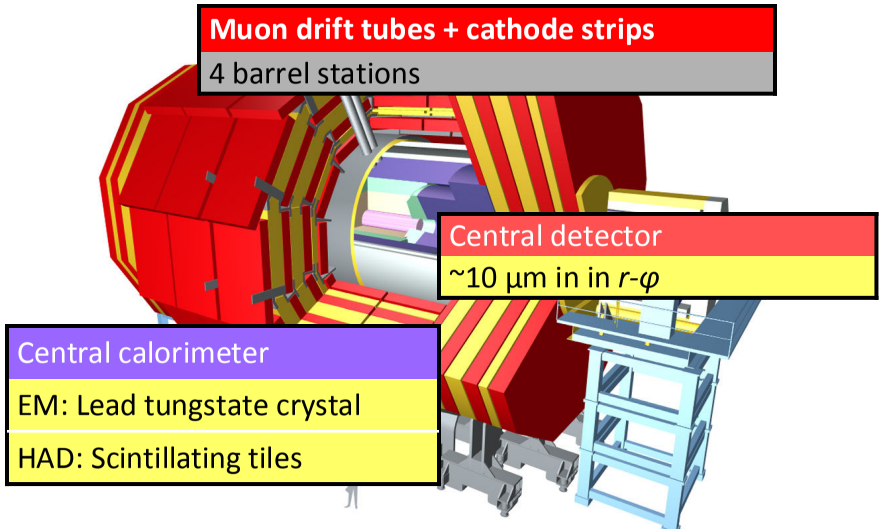
Top reconstruction at CMS and ATLAS

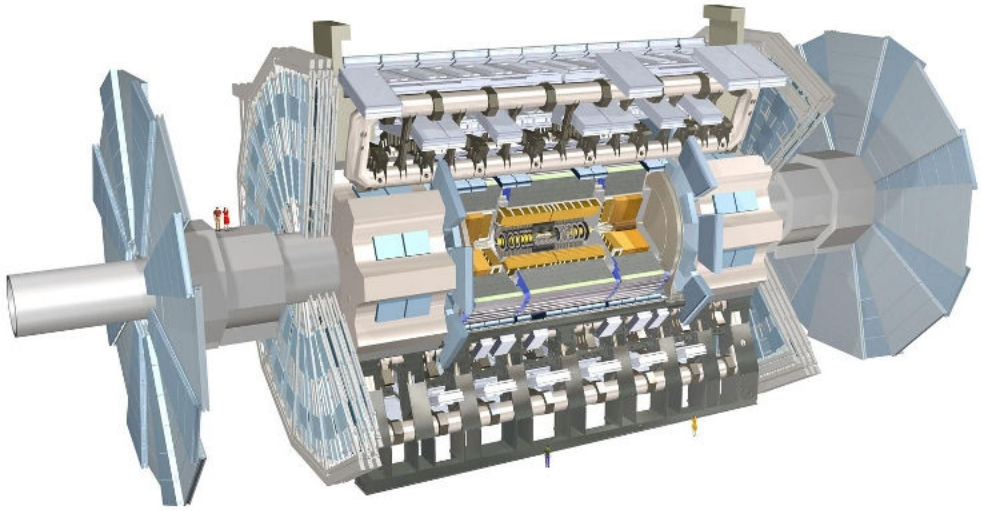




Jets	$\lvert\eta_{jet}\rvert < 5.0$ (typically: ≤ 2.5 for b-tag or mass resolution)
Electrons	$\lvert\eta_{electron}\rvert \leq 2.5$
Muon spectrometer	$\lvert\eta_{muon}\rvert \leq 2.5$
Tracks (precision)	$\lvert\eta_{charged}\rvert \leq 2.5$
Lepton triggers	$\lvert\eta_{lepton}\rvert \leq 2.5$; $p_T \sim 20$ GeV

Top reconstruction at CMS and ATLAS

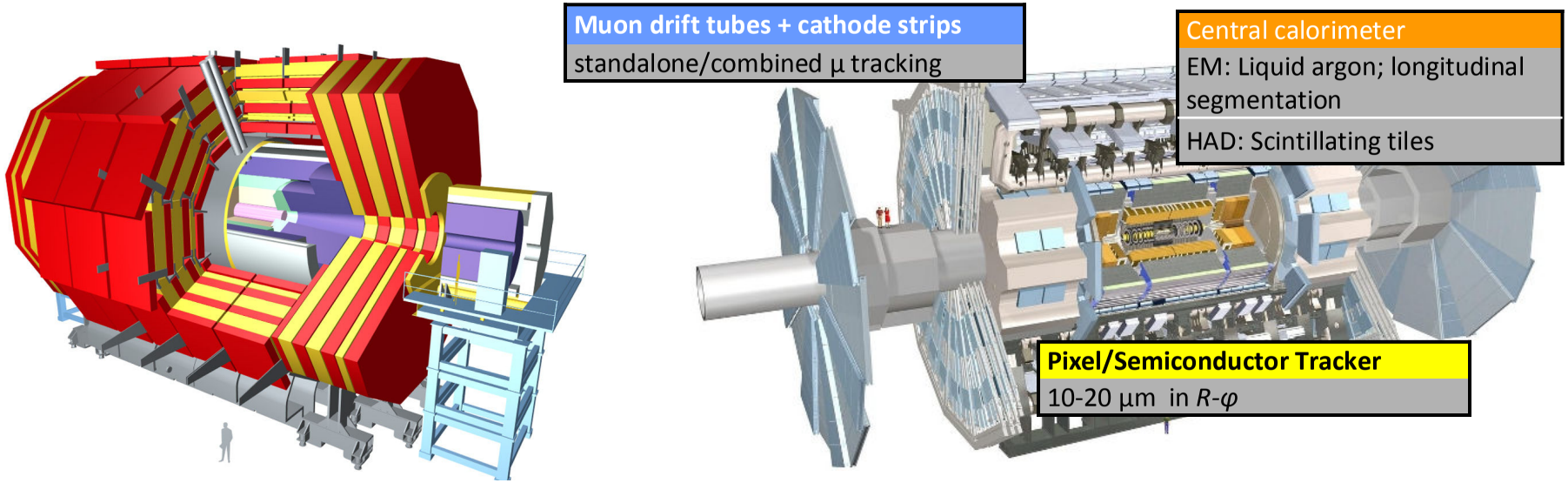




Jets	$\lvert\eta_{jet}\rvert < 5.0$ (typically: ≤ 2.5 for b-tag or mass resolution)	
Electrons	$\lvert\eta_{electron}\rvert \leq 2.5$	*for inner detector track match*
Muon spectrometer	$\lvert\eta_{muon}\rvert \leq 2.5$	
Tracks (precision)	$\lvert\eta_{charged}\rvert \leq 2.5$	
Lepton triggers	$\lvert\eta_{lepton}\rvert \leq 2.5$; $p_T > 17$ GeV (e), 16 GeV (µ)	

→ in early data: $\lvert\eta_{\mu}\rvert \leq 2.1$

Top reconstruction at CMS and ATLAS



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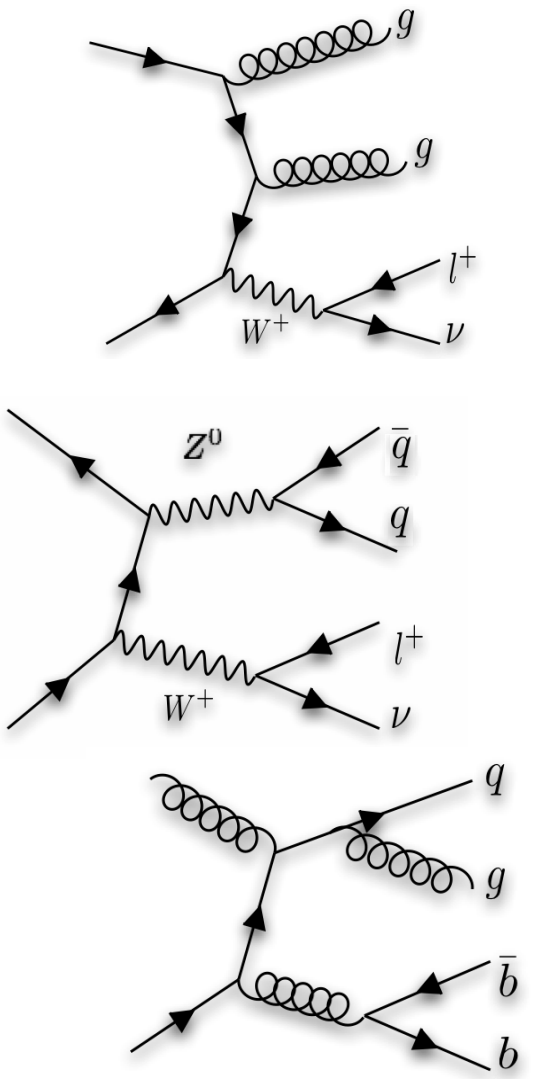
Tracks (precision)	$\lvert\eta_{charged}\rvert \leq 2.5$
Lepton triggers	$\lvert\eta_{lepton}\rvert \leq 2.5$; $p_T > 22$ GeV (e), 20 GeV (μ)

for inner detector track match

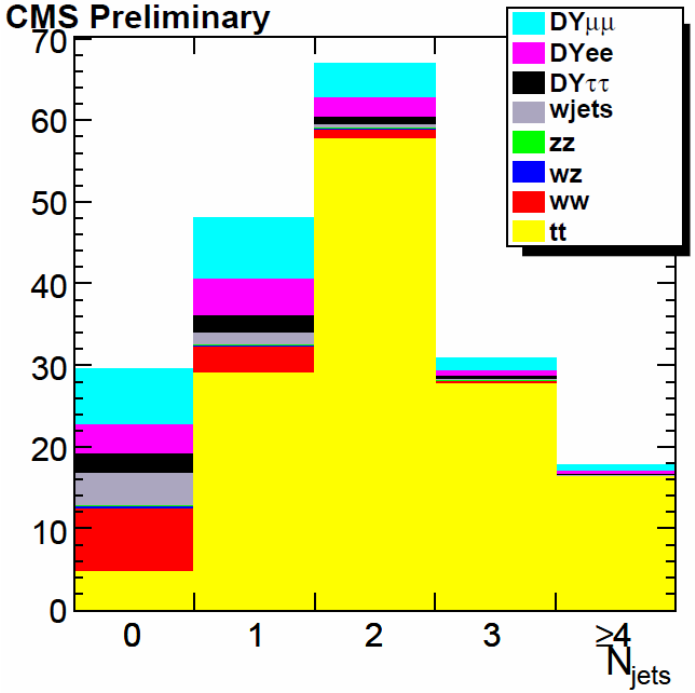
ATLAS: straw tracker ($|\eta|\leq 2$) can separate e/π

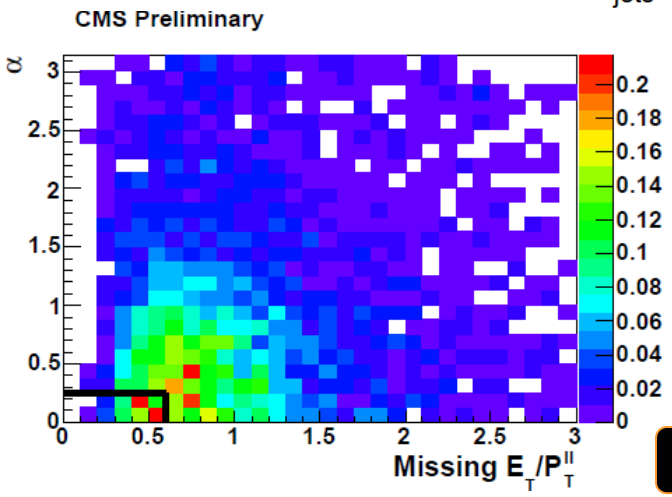
Measuring top pair production

- General strategy:
  - ✱ isolated, high p_T lepton: trigger
    - add missing E_T or W transverse mass
  - ✱ Purify sample:
    - second lepton *or*
    - tagged b-jets *or*
    - hadronic top decay (N_{jets}, m_{jj}, m_{jjj})
- Backgrounds:
  - ✱ W,Z + jets (W,Z + heavy flavor)
  - ✱ Single top
  - ✱ Dibosons
  - ✱ QCD multijets
  - ► most require tuning to data



First $t\bar{t}$ cross sections: 10 pb^{-1}

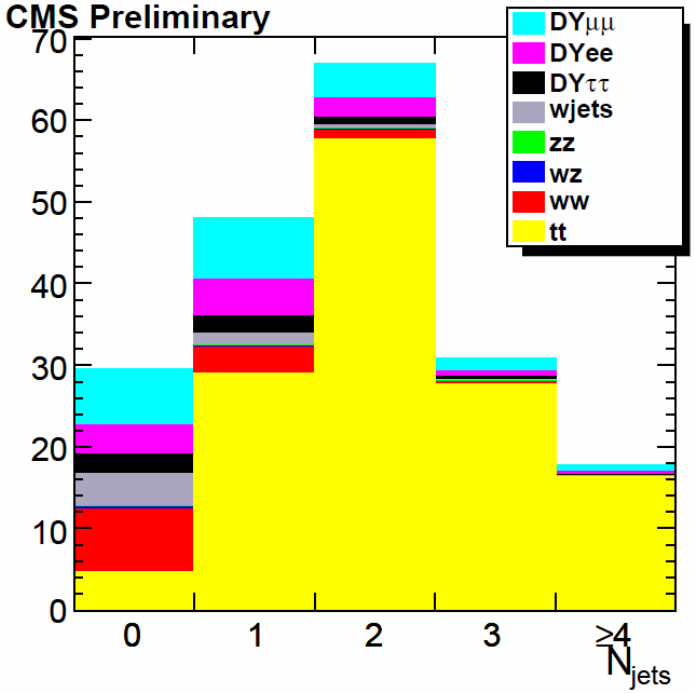




- **CMS** dilepton (ee/eμ/μμ)
  - use either single lepton trigger
  - 2 reco. leptons: p_T> 20 GeV
  - ≥2 central jets (E_T > 30 GeV)
  - missing E_T > 20 GeV;
    - tighter cuts in ee/μμ channels
- Δσ/σ = 9% (stat)

S/B ~ 7 in signal region without b-tag

First $t\bar{t}$ cross sections: 10 pb^{-1}



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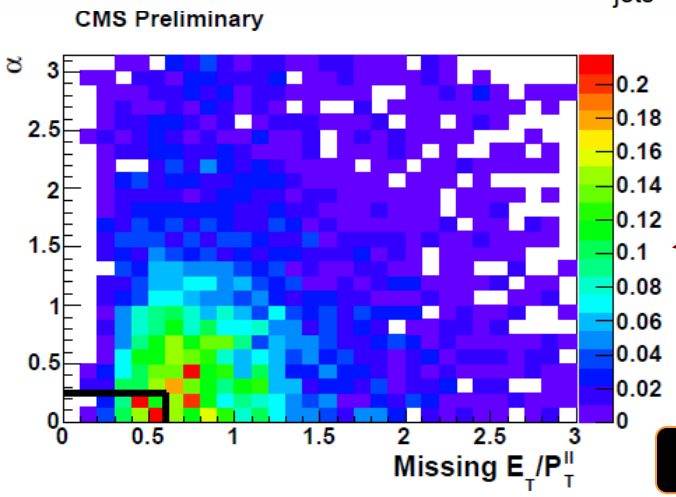
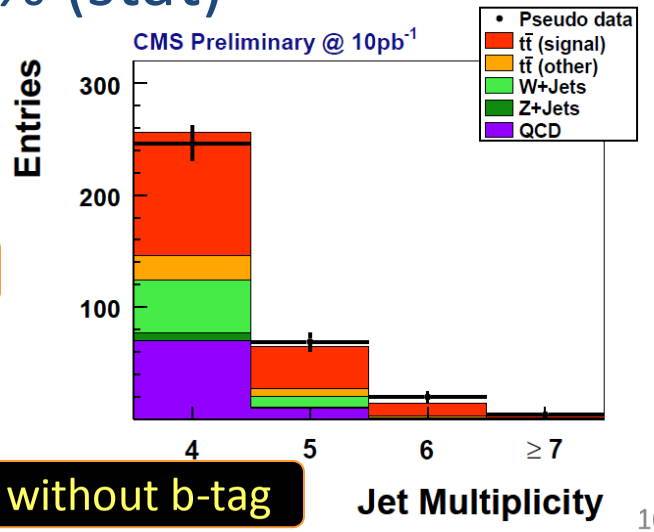
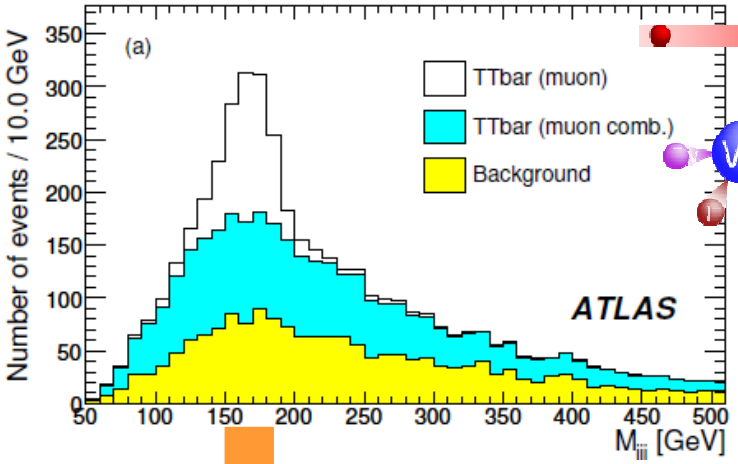


μ+jets →

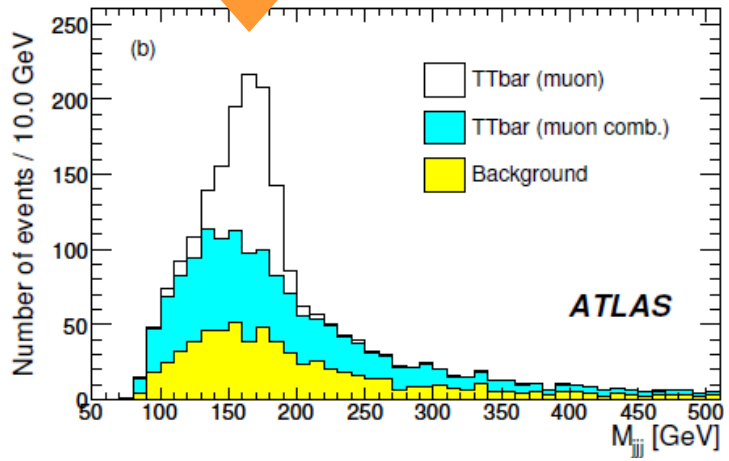


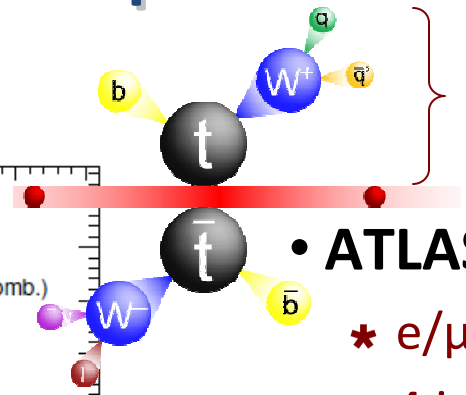
S/B ~ 7 in signal region without b-tag

Measuring $t\bar{t}$ production: 100 pb^{-1}



cut on W candidate mass





- **ATLAS** lepton + jets (e/μ)
  - e/μ p_T and E_T(miss): > 20 GeV
  - 4 jets > 20 GeV; 3 jets > 40 GeV
  - 2-jet m_W cut
- Likelihood: fit m_t to signal + bkg. model
  - $\Delta\sigma/\sigma = 7 \oplus 16\%$ (stat ⊕ syst)
- Counting method: just cut on m_t
  - $\Delta\sigma/\sigma = 3 \oplus 17\%$ (stat ⊕ syst)
  - More sensitive to BG normalization

mostly from BG shape in fit

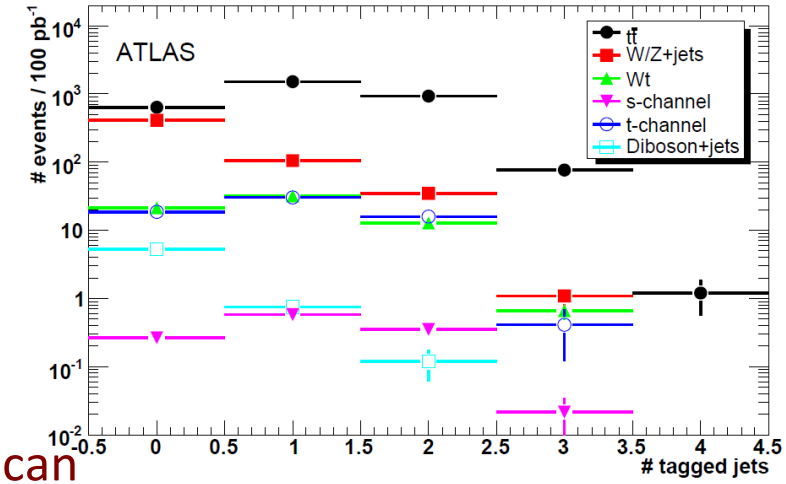
Using the first top events

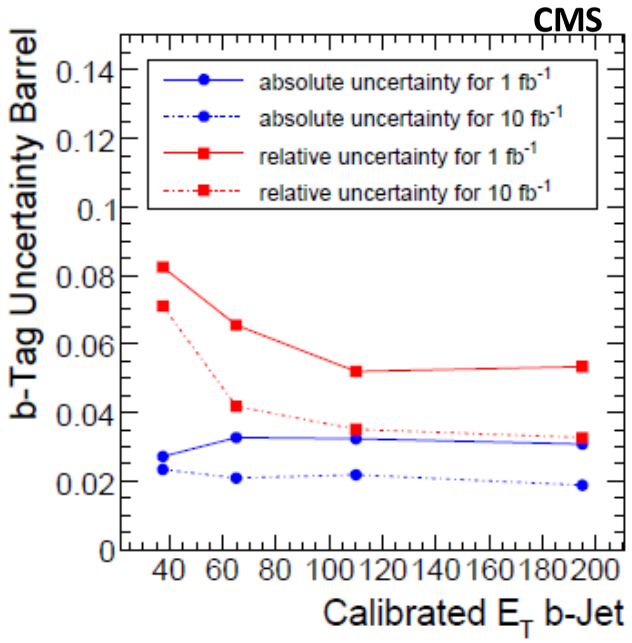
"golden" channel: 2 *b*-jets, 2 W daughters

- *b*-jets determine **b-tag efficiency** ε_b
  - ATLAS: **Global** ε_b from fit to N_{tag} distribution
    - also determines ε_c and $\sigma_{t\bar{t}}$
    - $\Delta\varepsilon_b/\varepsilon_b$ ~ 2.7 (stat) $\oplus$ 3.4 (syst)% with 100 pb^{-1}
  - event-by-event kinematic fit identifies *b*-jets: can check ε_b (p_T, η)
    - CMS with 1 fb^{-1} : $\Delta\varepsilon_b/\varepsilon_b$ ~ 6% in barrel
- *W* decay can set **jet energy scale**
  - in-situ calibration in top mass measurement

$$\chi^2 = \left(\frac{M_{jj}(\alpha_{E_{jet1}}, \alpha_{E_{jet2}}) - M_W^{PDG}}{\Gamma_W^{PDG}}\right)^2 + \left(\frac{E_{jet1}(1-\alpha_{E_{jet1}})}{\sigma_1}\right)^2 + \left(\frac{E_{jet2}(1-\alpha_{E_{jet2}})}{\sigma_2}\right)^2$$

  - CMS: P.D.G. (m_t, m_W) constrains *b* and light jets
    - 100 pb^{-1}: ΔJES /JES < 1% for *b* and light quark jets



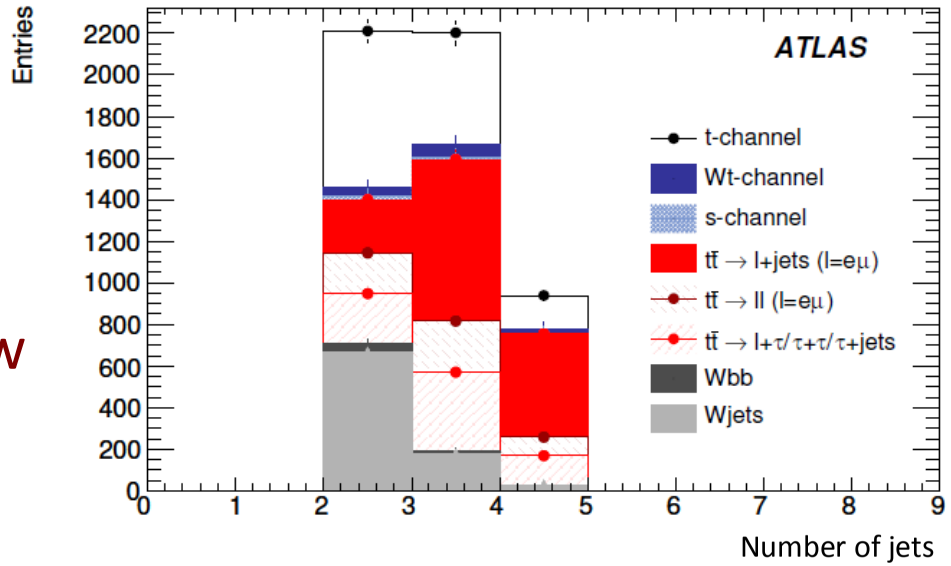


Standard Model tests with top

- production mechanisms:
  - ✱electroweak production cross sections: measure V_{tb}
  - ✱strong production: σ_{qq}/σ_{gg} ratio (spin correlation)
  - ✱*tt* production by new resonances
- properties:
  - ✱top mass: compare to precision electroweak fits
  - ✱charge: (2/3 *vs.* exotic -4/3 `top' quark?)
- decay properties:
  - ✱Electroweak (V-A) vertex : W helicity
  - ✱Rare top decays

Measuring single top production

- Interesting SM measurement & BSM constraint
  - ✱affected by couplings to new particles like W' or H^+
- Backgrounds (mostly $t\bar{t}$) bring large uncertainties



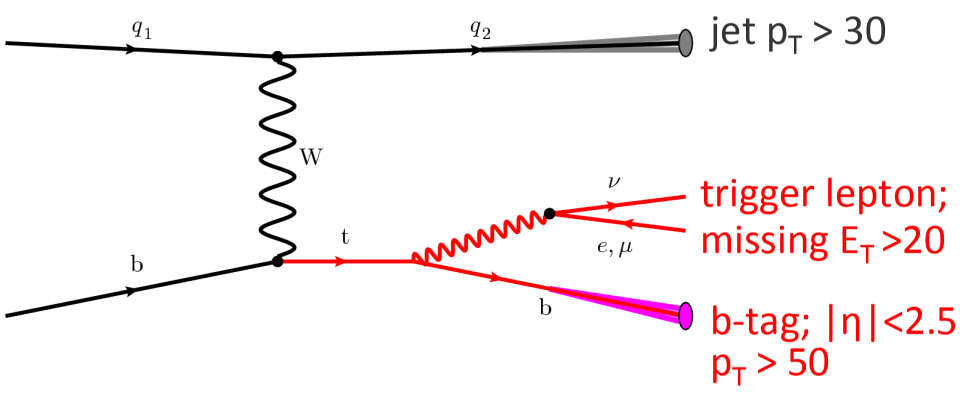
ATLAS projections (summary)	Δσ/σ (*1fb⁻¹*)		Δσ/σ (*10fb⁻¹*)	
	stat	***syst***	***stat***	***syst***
t-channel: 246 pb	6%	22%	2%	10%
W+top: 66 pb	21%	48%	7%	19%
s-channel: 11 pb	64%	94%	20%	48%

BDT

Likelihood

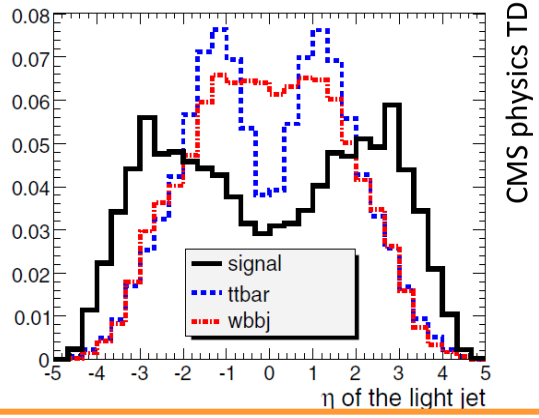
(CMS: similar 10 fb^{-1} results)

V_{tb} from single top (*t*-channel)



Cut-based selection (1 fb^{-1}):

- no additional leptons: p_T > 10 GeV
- ≤ 4 jets with p_T > 15 GeV
- leading light jet |η|> 2.5
  - ✱ efficiency reduced (÷3) to improve tt rejection (x10)
- Accepts 1.8% of signal; S/B=0.37

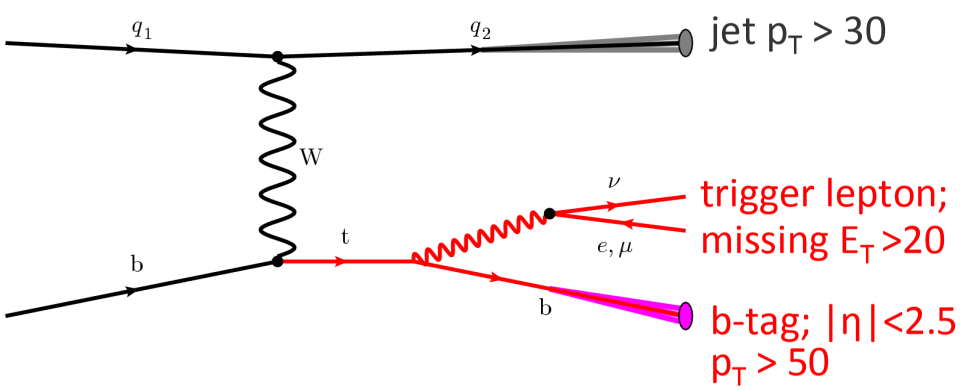


ATLAS: cut-based, 1 fb^{-1}

Statistics	*5.0%*
MC statistics	6.5%
Luminosity	18.3%
b-tagging	18.1%
Jet energy scale	21.6%
other experimental	2.3%
BG cross section	23%
PDF, ISR/FSR, signal model	16.3 %
Total	**45%**

CMS optimized (cut-based) for 10 fb^{-1}; μ+jets:
Δσ/σ = 2.7⊕10%

V_{tb} from single top (*t*-channel)



ATLAS: **Boosted Decision Trees**, 1 fb^{-1}

relax untagged jet η cut

add >15 variables chosen to be ~insensitive to JES

Statistics	*5.7%*
MC statistics	7.9%
Luminosity	8.8%
b-tagging	6.6%
Jet energy scale	9.9%
other experimental	1.8%
BG cross section	8.2%
PDF,ISR/FSR,signal model	9.8%
Total	**23%**

Cut-based selection (1 fb^{-1}):

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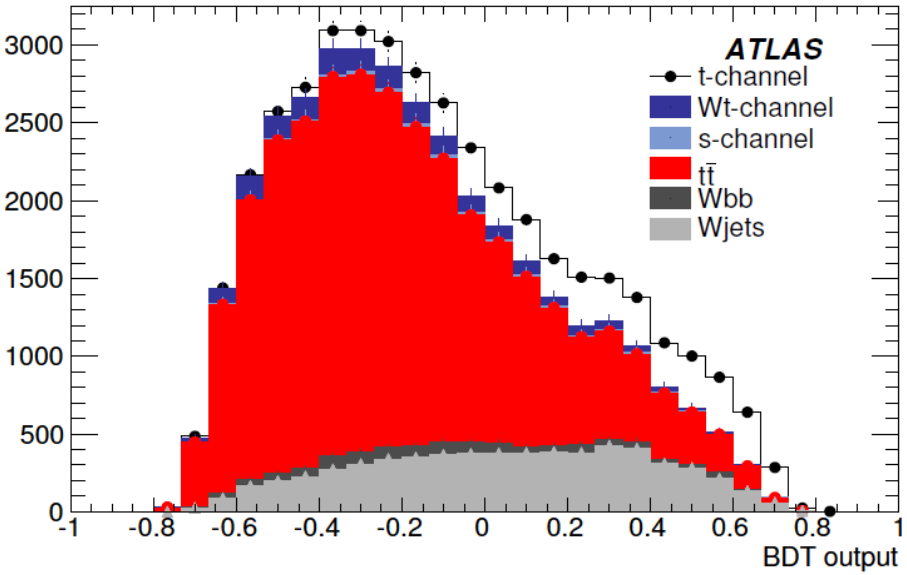
- ≤ 4 jets with p_T > 15 GeV



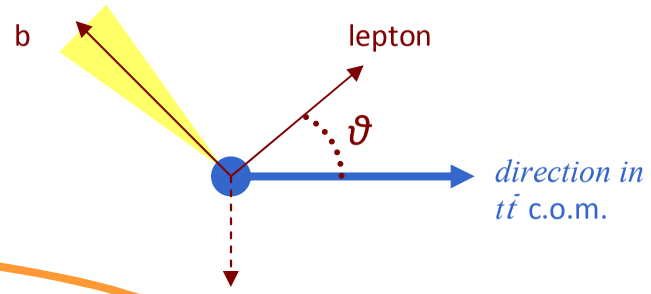
measure $|V_{tb}|$ to 12% with 1 fb^{-1}

Top spin correlations

- Top decays preserve spin:
  - ✱daughters' decay reflects *t* helicity

$$\frac{1}{\Gamma}\frac{d\Gamma}{d(\cos\theta)} = \tfrac{1}{2}(1+\kappa_f \cos\theta)$$

  - ✱lepton most informative: $\kappa_f = 1$



$$\frac{1}{N}\frac{d^2N}{d\cos\theta_l\, d\cos\theta_q} = \frac{1}{4}(1 - A\kappa_q\kappa_l \cos\theta_q \cos\theta_l)$$

- In standard model: top unpolarized (QCD), but $t\bar{t}$ spins correlated
- In new production models: modified correlations
  - ✱*e.g.:* graviton → $t\bar{t}$

quark diagrams : $A = -0.469 \pm 0.003$

gluon diagrams : $A = +0.431 \pm 0.002$

where $A = \dfrac{N_{same} - N_{opp}}{N_{same} + N_{opp}}$

Top spin correlations

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- In new production models: modified correlations
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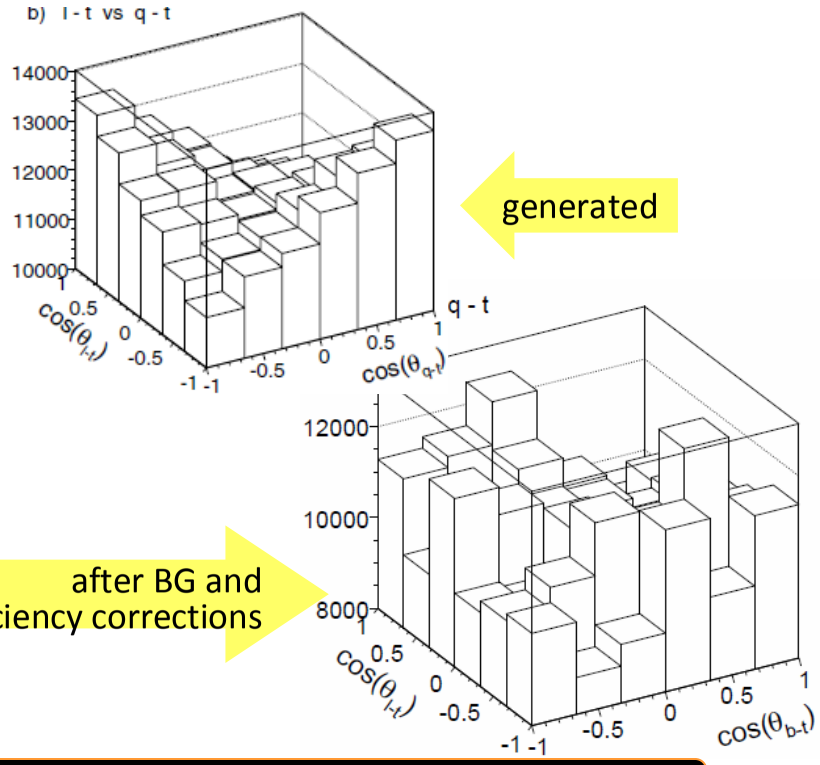
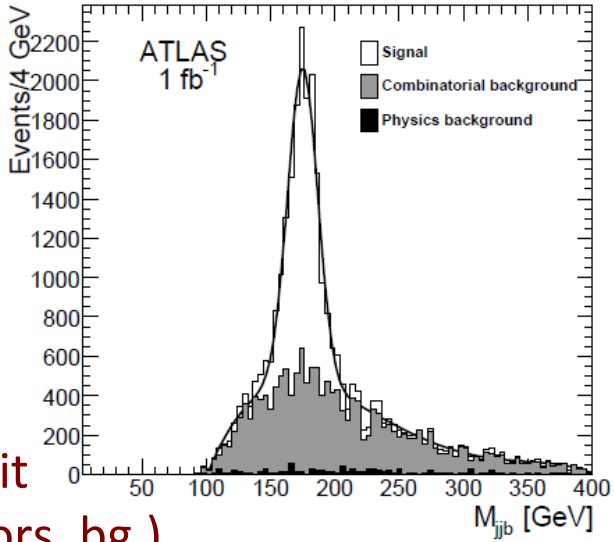
- **CMS** lepton+jets: (10 fb^{-1})
  - ✱ 2 tagged + 2 untagged jets
  - ✱ good kinematic χ^2
  - ✱ *t* and *t* separated in φ

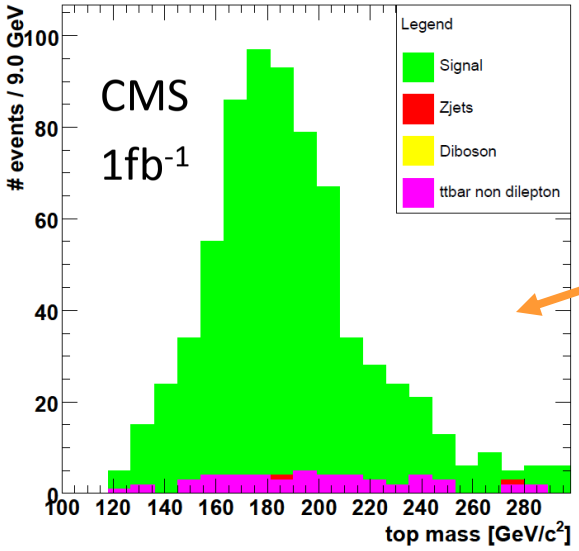


w/ lepton + light quark: 6% (stat) ⊕ 16% (syst)

Top mass with 1 fb^{-1}

- Tevatron precision: 0.7⊕1.0 (stat⊕syst) GeV
- LHC lepton+jets: can afford tight cuts
  - ✱ increase purity: require exactly 2 b-tags
  - ✱ reject other $t\bar{t}$ channels and combinatoric bg.
    - b usually close to W; jet charge (CMS)
  - ✱ estimators: hadronic m_t (gaussian fit) or likelihood fit (lineshape, reconstructed m_t(had), measurement errors, bg.)



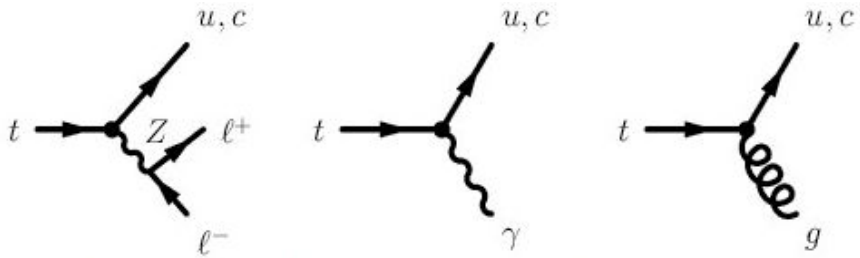


Channel	Uncertainty	
lepton+jets	≈1 GeV (syst): *b-jet energy scale, ISR/FSR*	
	ATLAS: 0.2 GeV (stat) (e+μ)	CMS: 0.7 GeV (stat), μ channel
dilepton (CMS)	0.5 ⊕ 4.2 GeV (stat ⊕ syst): *jet energy scale*	
	expect 1.1 GeV (syst) in 10 fb^{-1}	
all-hadronic (CMS)	0.6 ⊕ 4.2 GeV: *background, jet energy scale*	

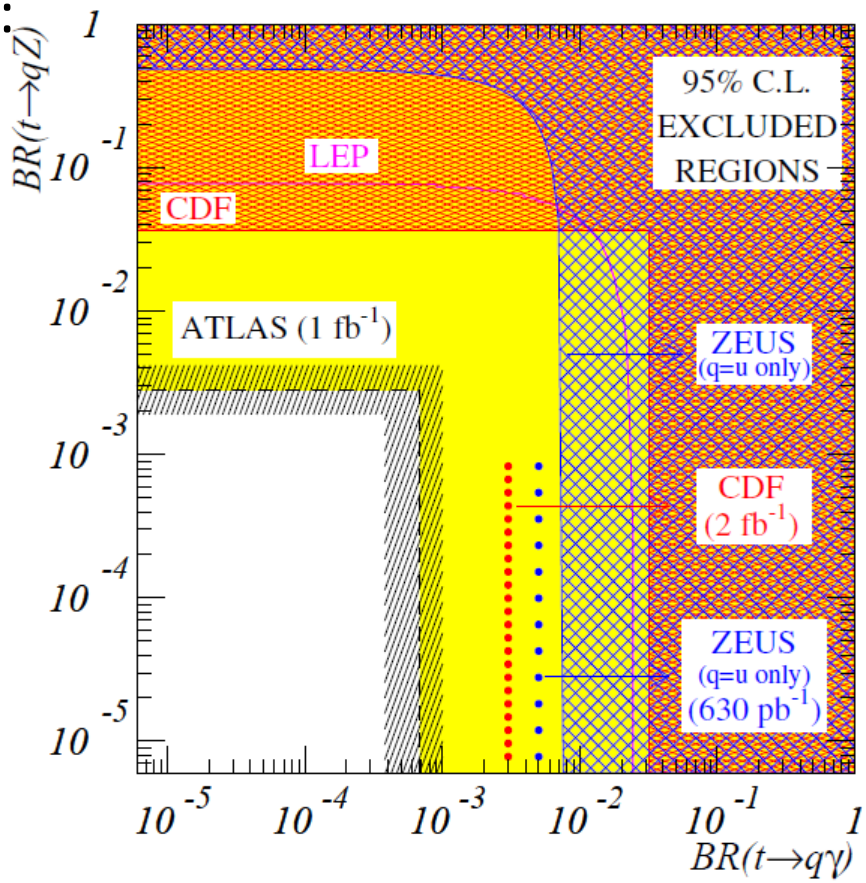
Complementary methods: B →J/Ψ decay length
Δm_t(JES) ~ **50 MeV** (CMS; 10 fb^{-1})

Rare top decays

- Flavor-changing neutral currents:
  - arise in many BSM models
  - usually, largest branching ratios around 10^{-4}



- ATLAS: look for top pairs with one rare decay
  - backgrounds are $t\bar{t}$, W/Z + jets
  - Select: ~ 130 events/fb^{-1} in cleanest (qZ) channel → refine using likelihood analysis



ATLAS : improve $q\gamma$ limit to 7 x 10^{-4} with 1 fb^{-1}

Summary/Outlook

- Top quarks play several essential roles in LHC physics program
  - unique laboratory for SM tests
  - cross-check that shows up in many reconstruction channels
  - valuable source of “known” jets for calibrations
- Even a short 2009 run may provide generous top samples:
  - ATLAS/CMS : ready to observe/measure top production with as little as 10 pb^{-1} (14 TeV studies – more data required at 10 TeV)
  - With 1-10 fb^{-1}, check an impressive array of properties
- Top reconstruction expertise will be rewarded:
  - associated production (*ttH*), resonant decays to *tt*…
  - Background rejection in searches for new physics