Searches for new physics in top quark final states

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ATLAS EXPERIMENT http://atlas.ch

Outline

- **Why top quark ?**

- **Top Quark at the LHC: tools of the trade**

- New physics searches in **top quark production**
  - Resonances
  - tt+E_T^{miss}
  - charge asymmetry
  - same sign tops
  - single top summary

- New physics searches in **top quark decay**
  - FCNC in top decay
  - status of top polarization

- Conclusions

Mostly ATLAS results

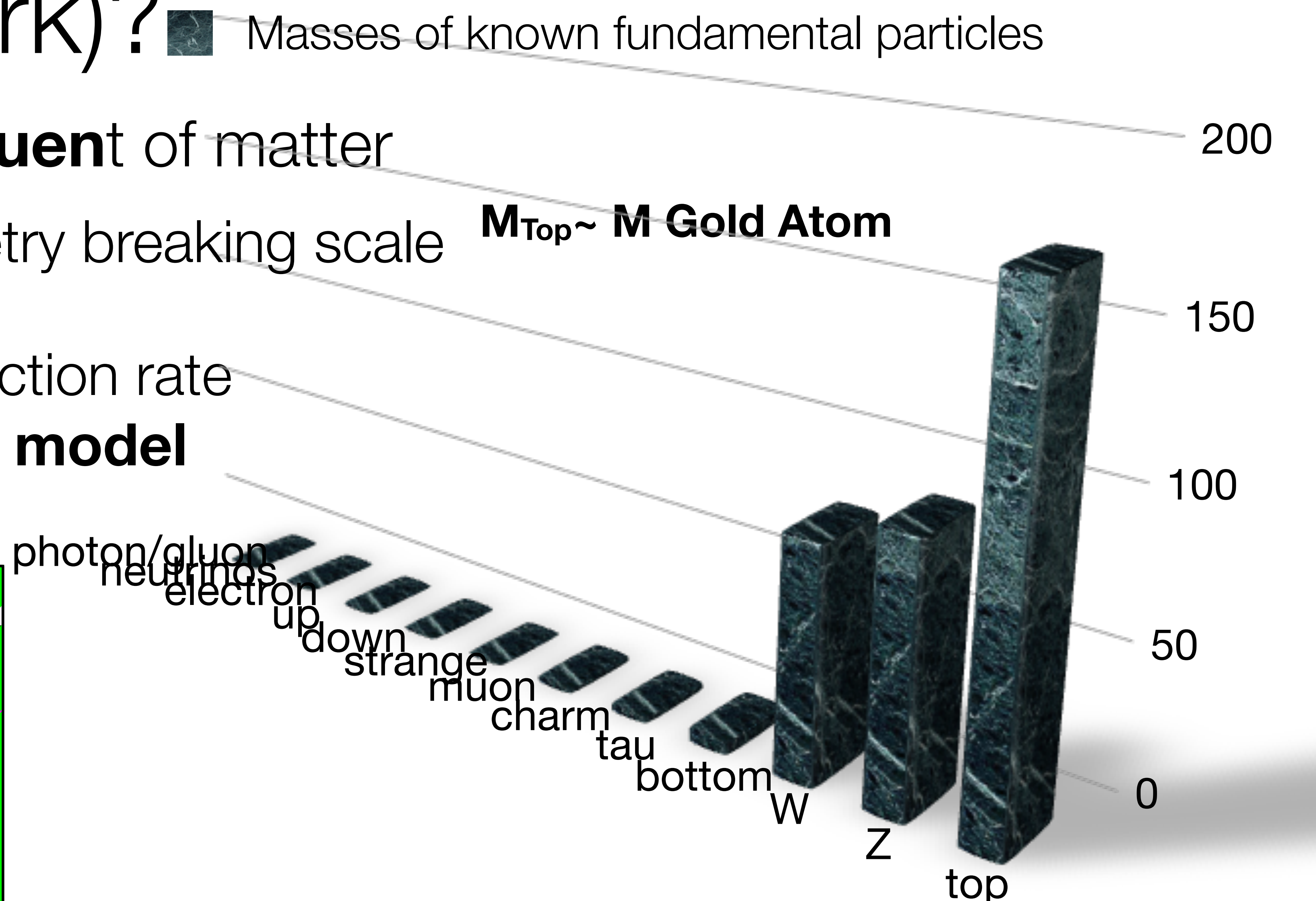
some CMS results

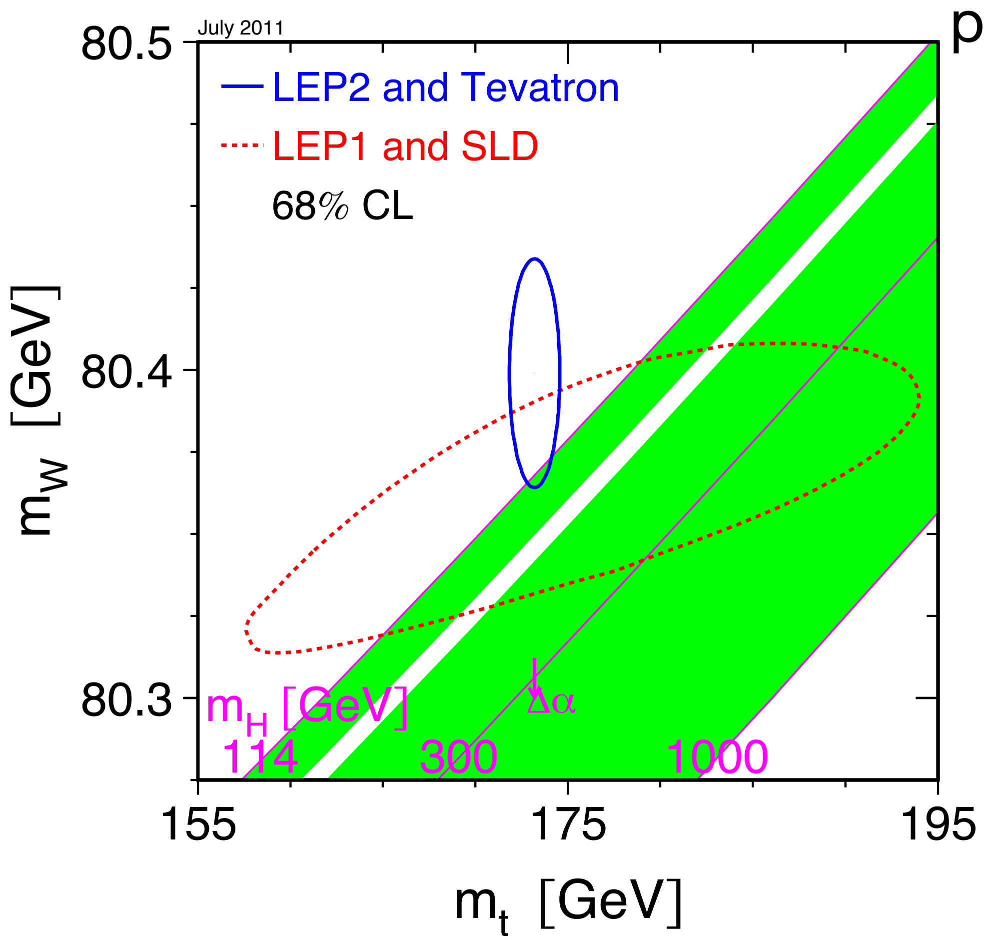
Why Top (quark)?

Most massive constituent of matter

M_{top}~ electroweak symmetry breaking scale

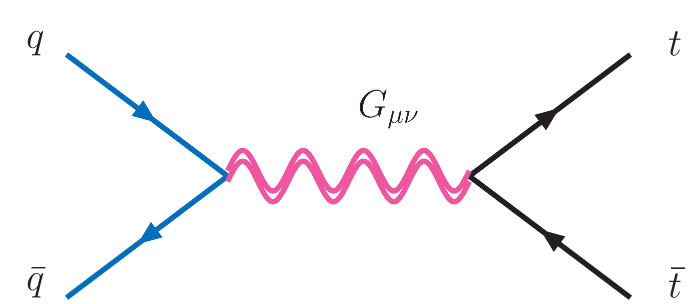
Decay and strong production rate are **tests of standard model**

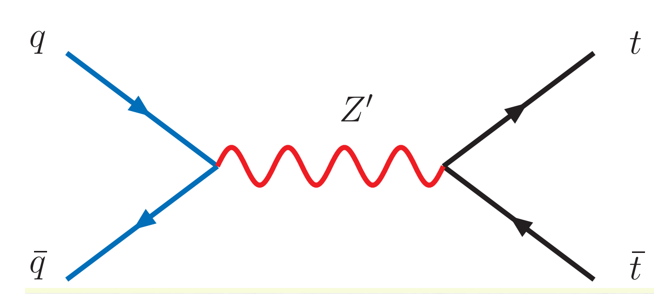




Background to possible **new physics** (Higgs, SUSY)

Various scenarios with **direct/indirect coupling to new physics:**
from extra dimensions to new strong forces



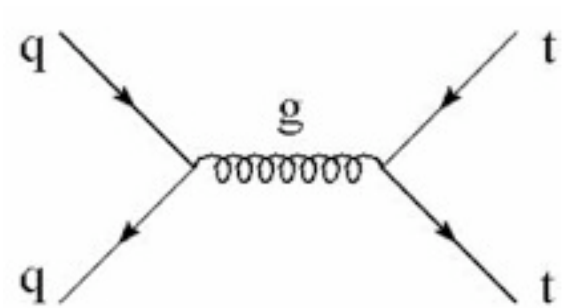


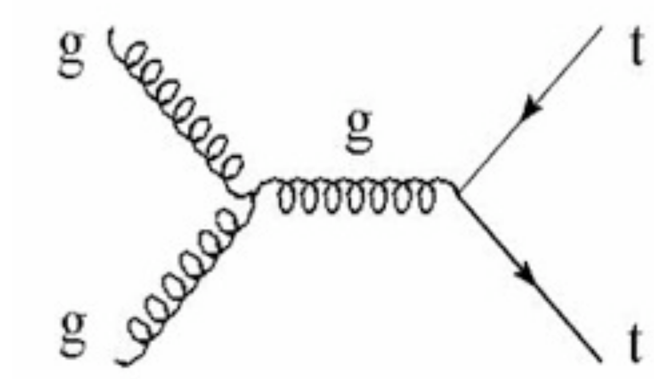
Top quark @ LHC: production

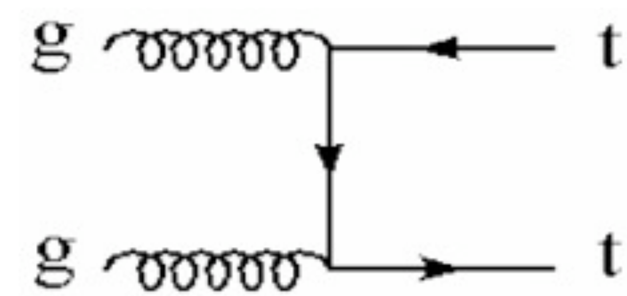
probe low x in pdfs →gluon fusion dominated

	Tevat	LHC(7)	LHC(14)
gg	~10%	~85%	~90%
qq	~90%	~15%	~10%

top pairs: strong





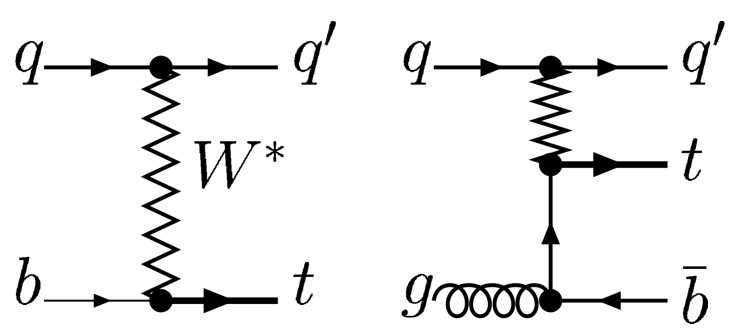


Aliev et al 2011
Beneke et al 2010
Langefeld Moch Uwer 2009
Moch,Uwer 2008

σ = 165$^{+11}_{-11}$ pb

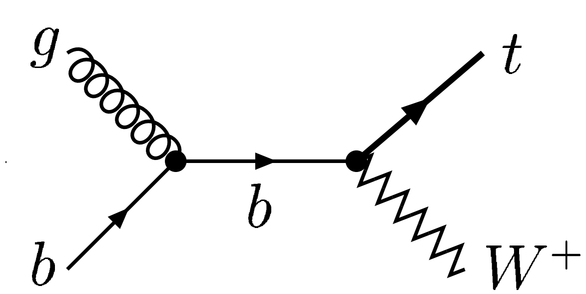
single top: electroweak

t chan



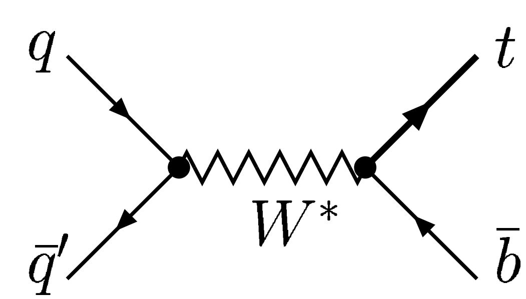
σ = 64$^{+3}_{-3}$ pb

Wt chan



σ = 15.7$^{+1.3}_{-1.4}$ pb

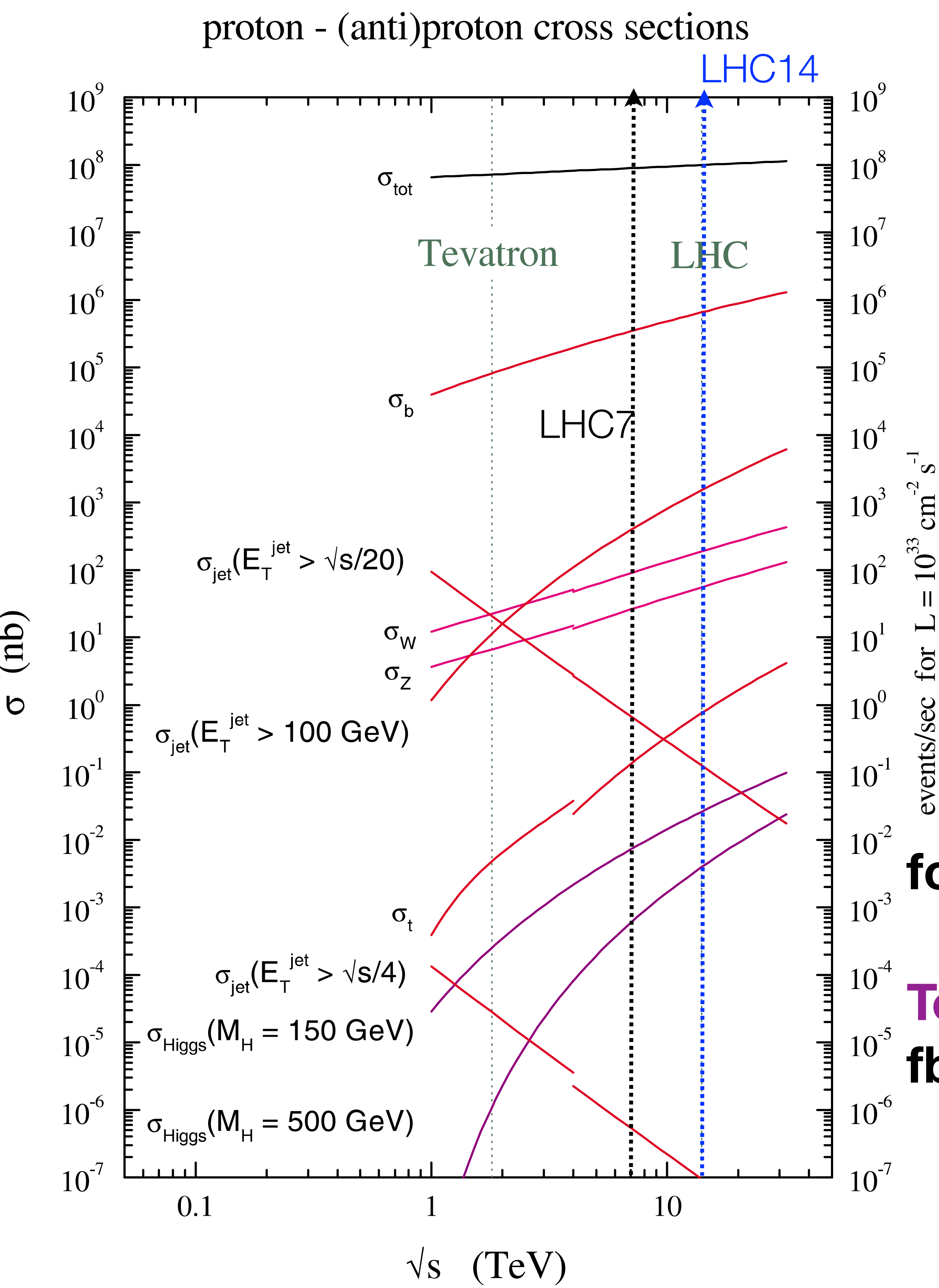
s chan



σ = 4.6±0.3 pb

Kidonakis 2010

Top @ LHC: in the context



$t\bar{t}$ cross section

$\sqrt{s}$(TeV)	xsec (pb)
1.96 ($p\bar{p}$) 7 (pp) 14 (pp)	~7 ~165 ~900

Rate at L= 10^{33}cm^{-2} s^{-1}

0.2Hz

0.9Hz

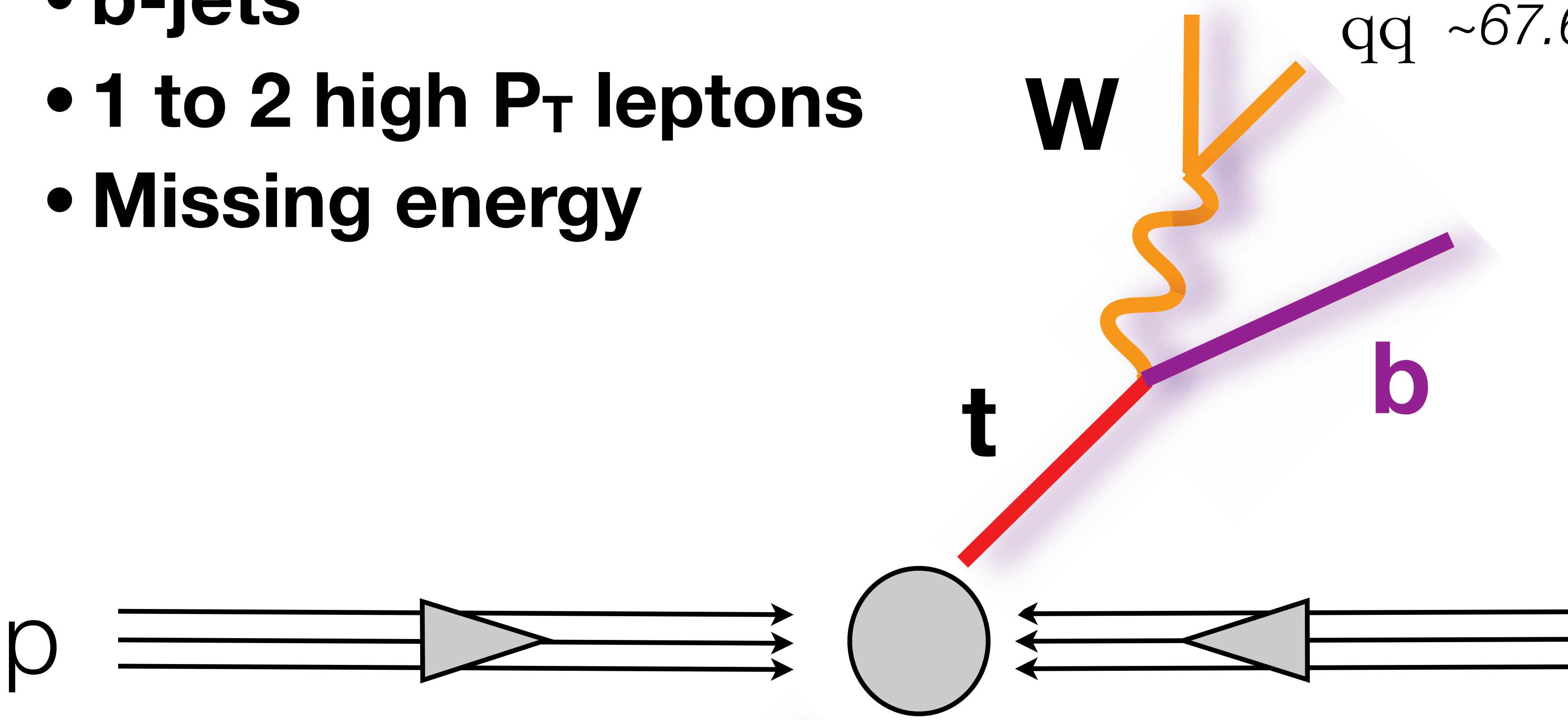
for $\int Ldt$ =5 fb^{-1} @ 7TeV, expect $8 \cdot 10^5$ events

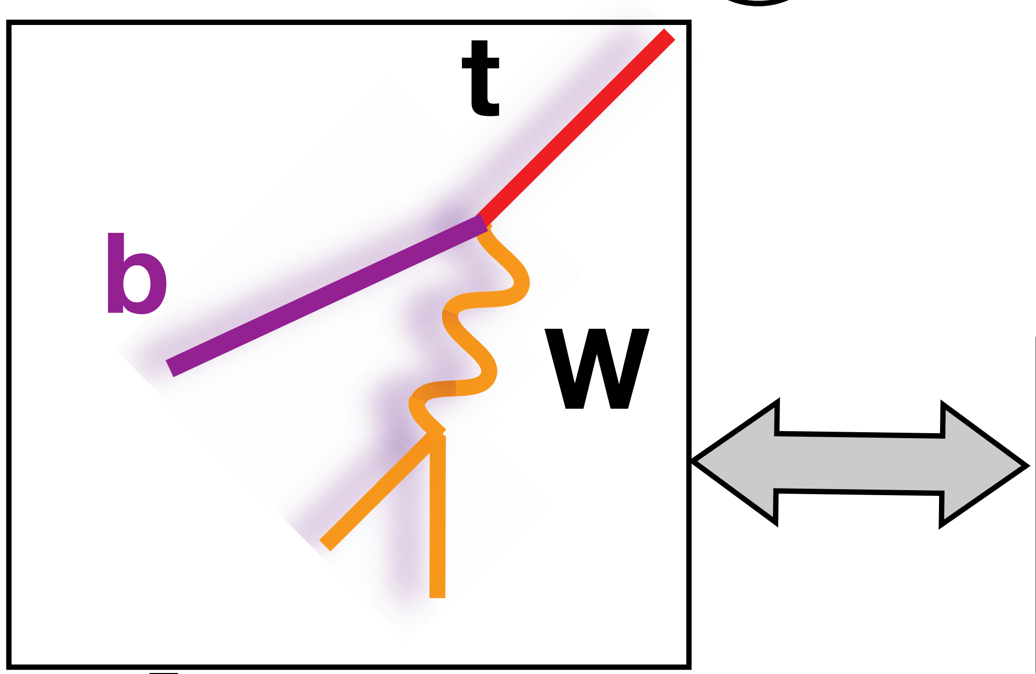
Tevatron (lower energy collider): $\int Ldt$ =9.4 fb^{-1} on tape, expect ~ $6.6 \cdot 10^4$ events

Top signatures

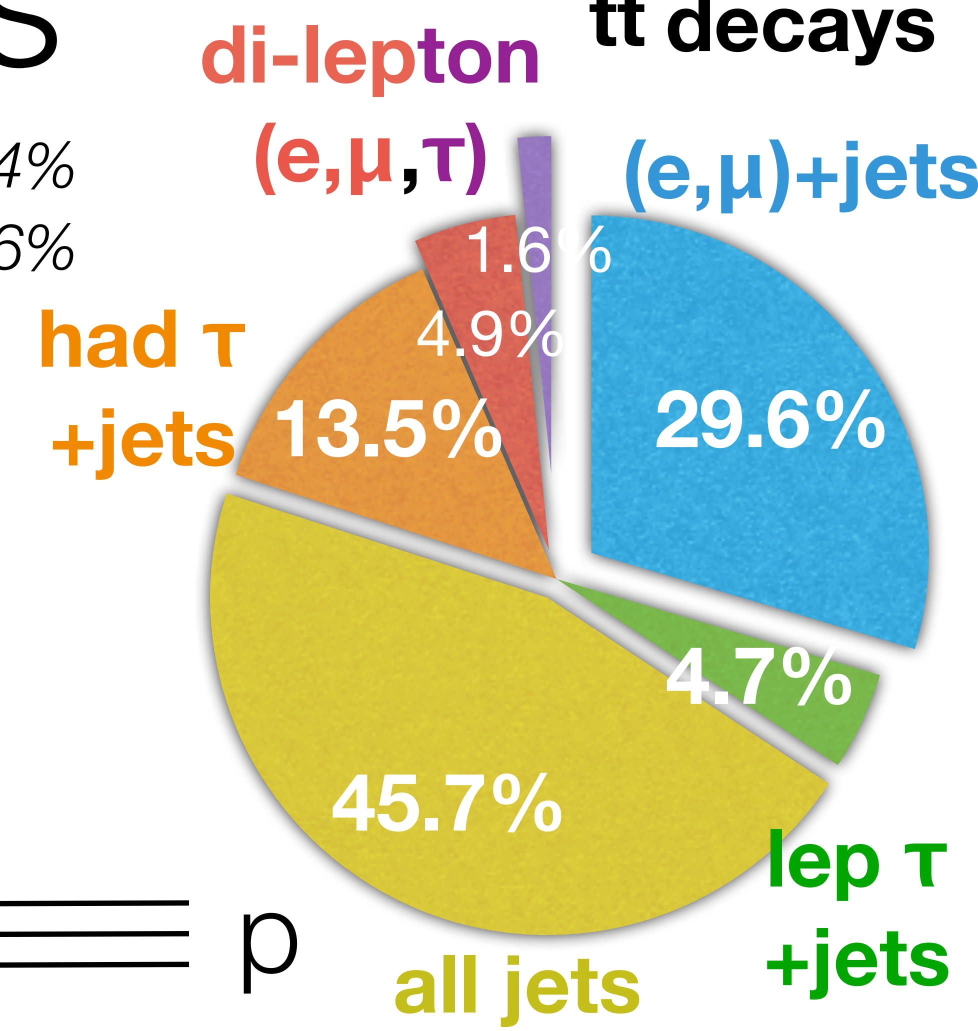
- **High P_T jets**
- **b-jets**
- **1 to 2 high P_T leptons**
- **Missing energy**

$\ell\nu$ *~32.4%*
qq *~67.6%*

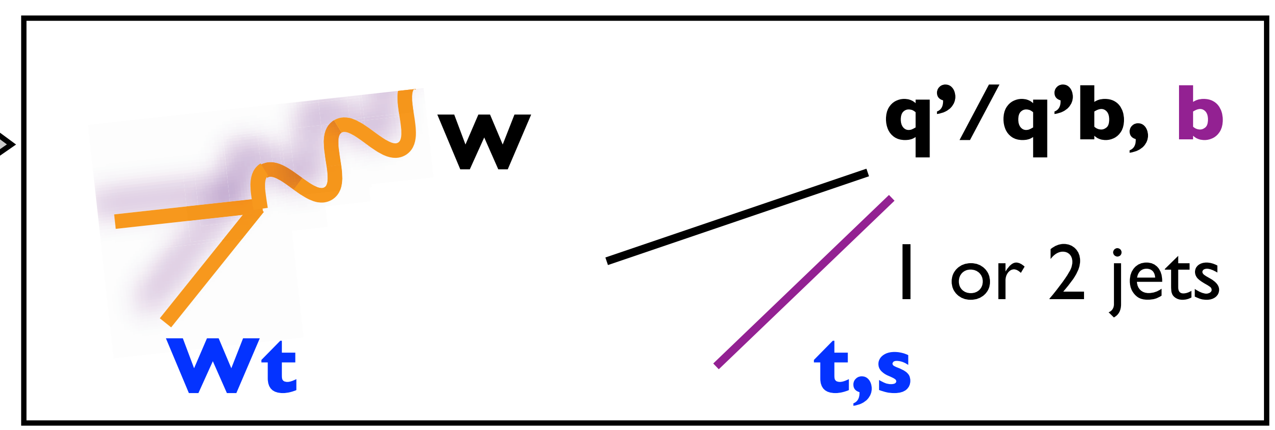




$t\bar{t}$ decays



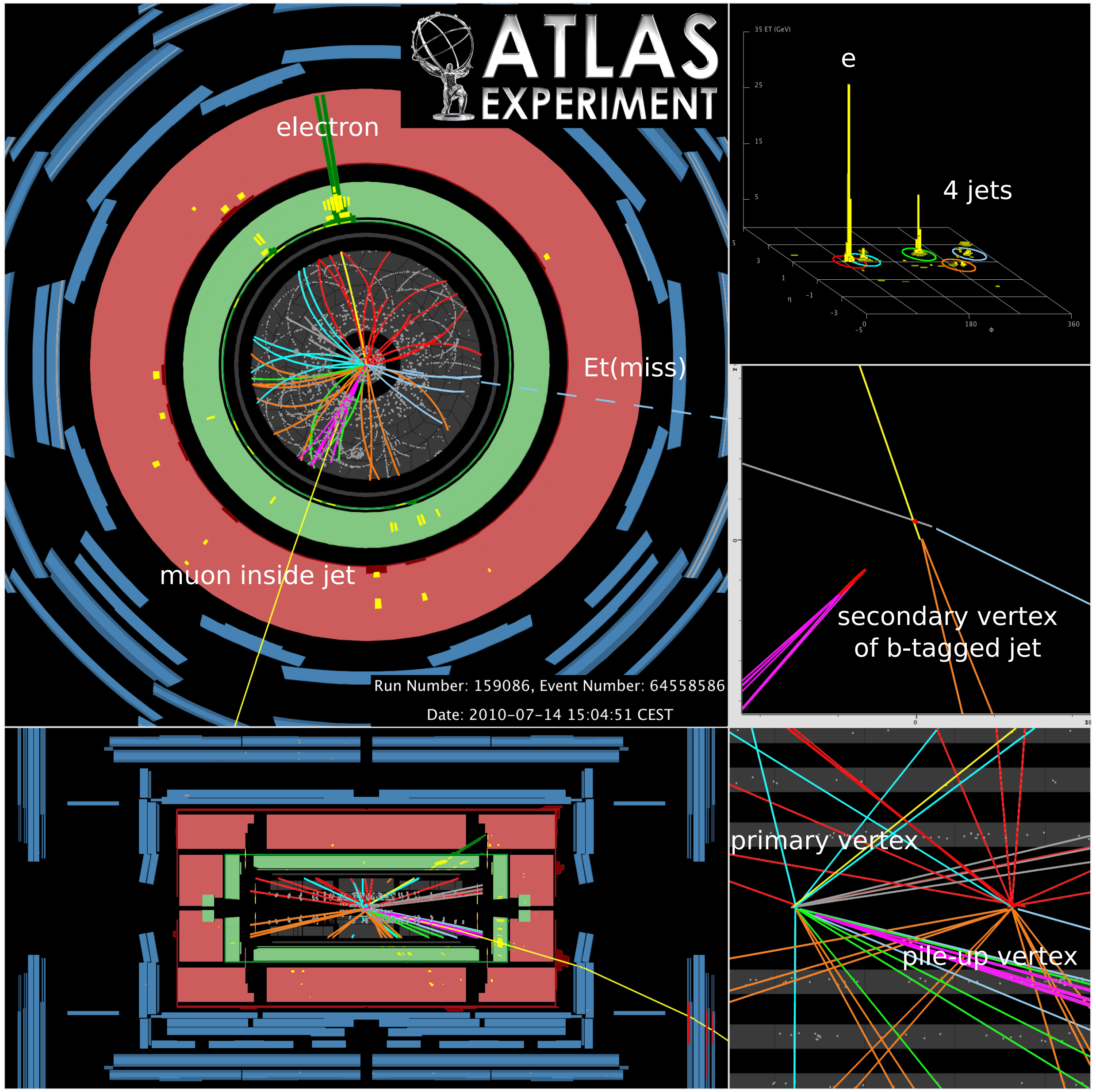
single top



bkgs_tt: W/Z(+jets), single top, QCD, Di-bosons

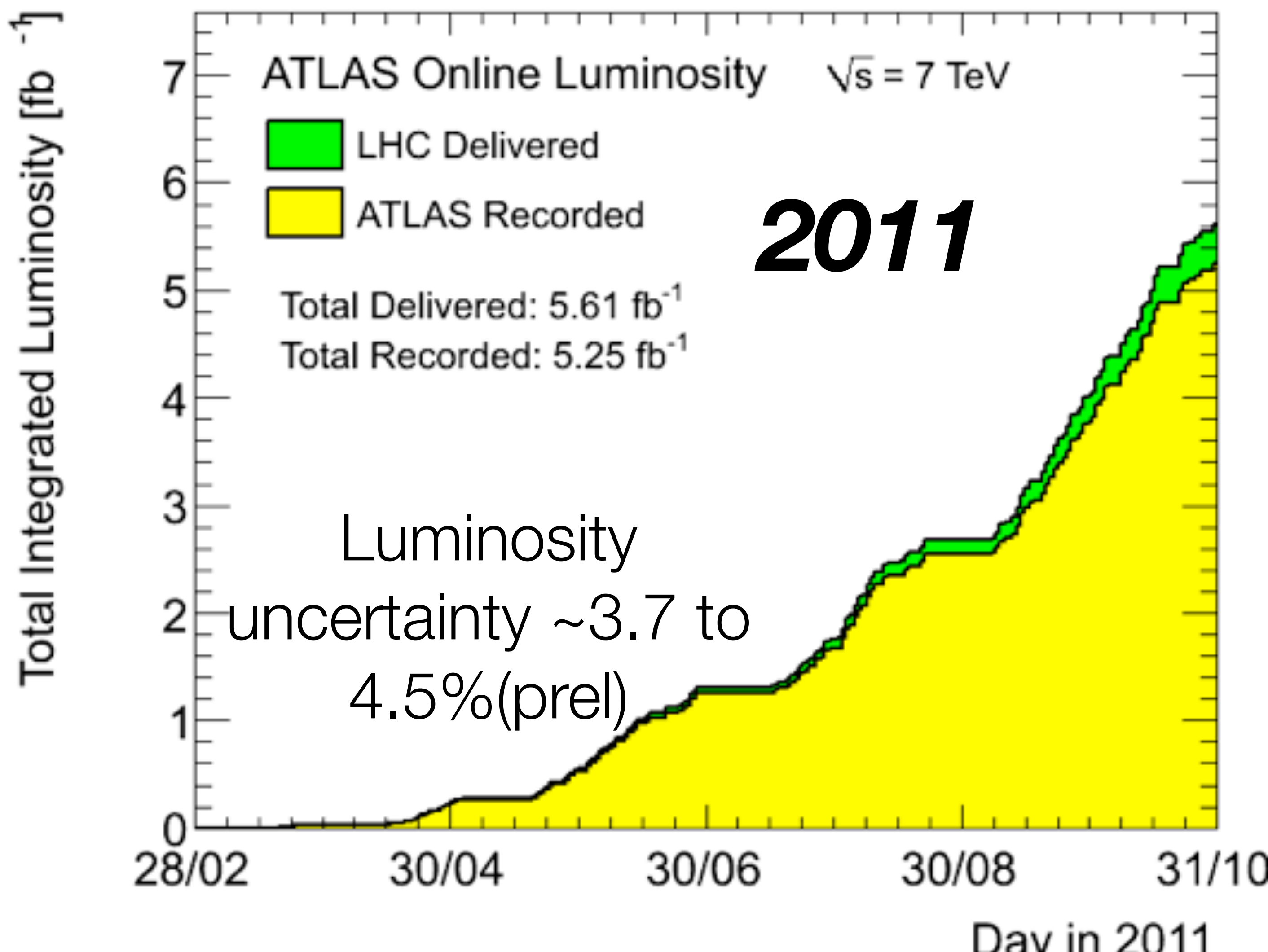
bkgs_single_t: tt +some bkgs_tt

Sizeable data set *(example form ATLAS)*



e+jets candidate

Top events are real commissioning tool: full detector at play!!



2010

Total Recorded (Delivered) Lumi: 45.0 (48.1) pb^{-1}

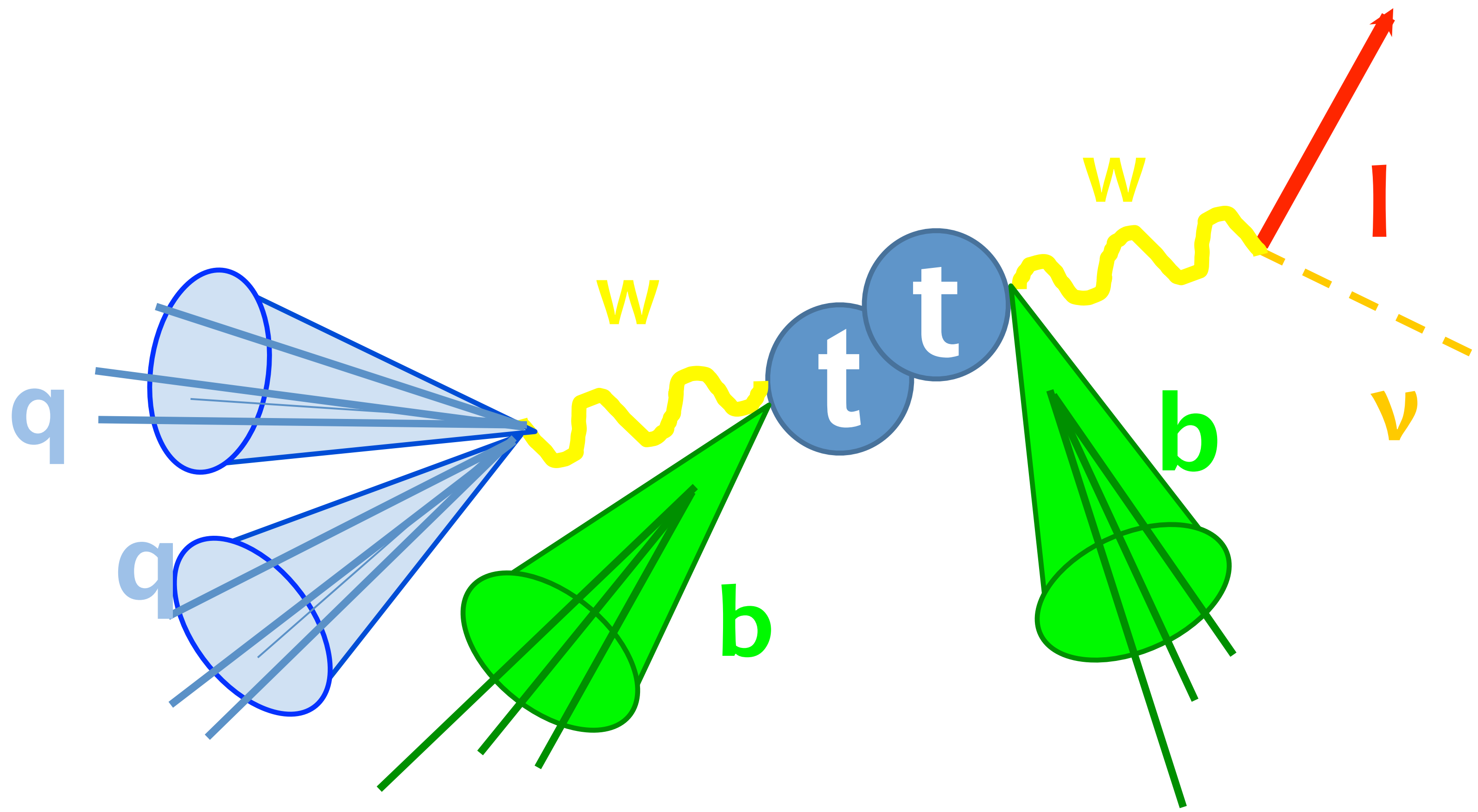
Lumi uncertainty~3.4%

Data sample for first top paper~3 pb^{-1}

Analyses use 36 pb^{-1}(2010) and 0.2 to 1.6 fb^{-1} (2011)

Selection/Ingredients of top quark pairs/single-top

(*ATLAS*)



Selection/Ingredients of top quark pairs/single-top

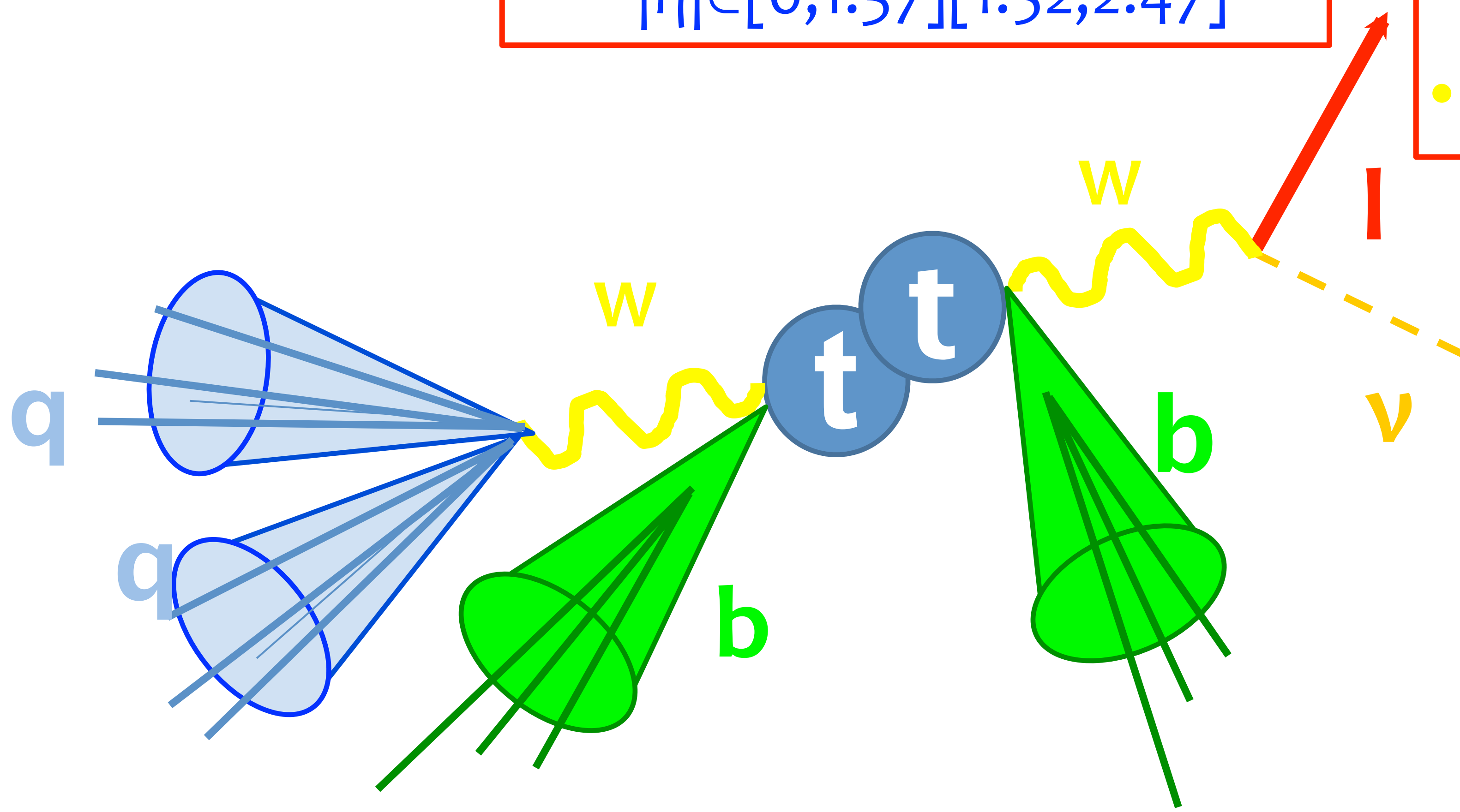
(*ATLAS*)

Electron

- Good isolated calo object
- Matched to track
- E_T>25 GeV
- $|\eta| \in [0;1.37][1.52;2.47]$

Muon

- Segments in tracker and muon detector
- Calo and track isolation
- p_T > 20 GeV $|\eta|$ < 2.5



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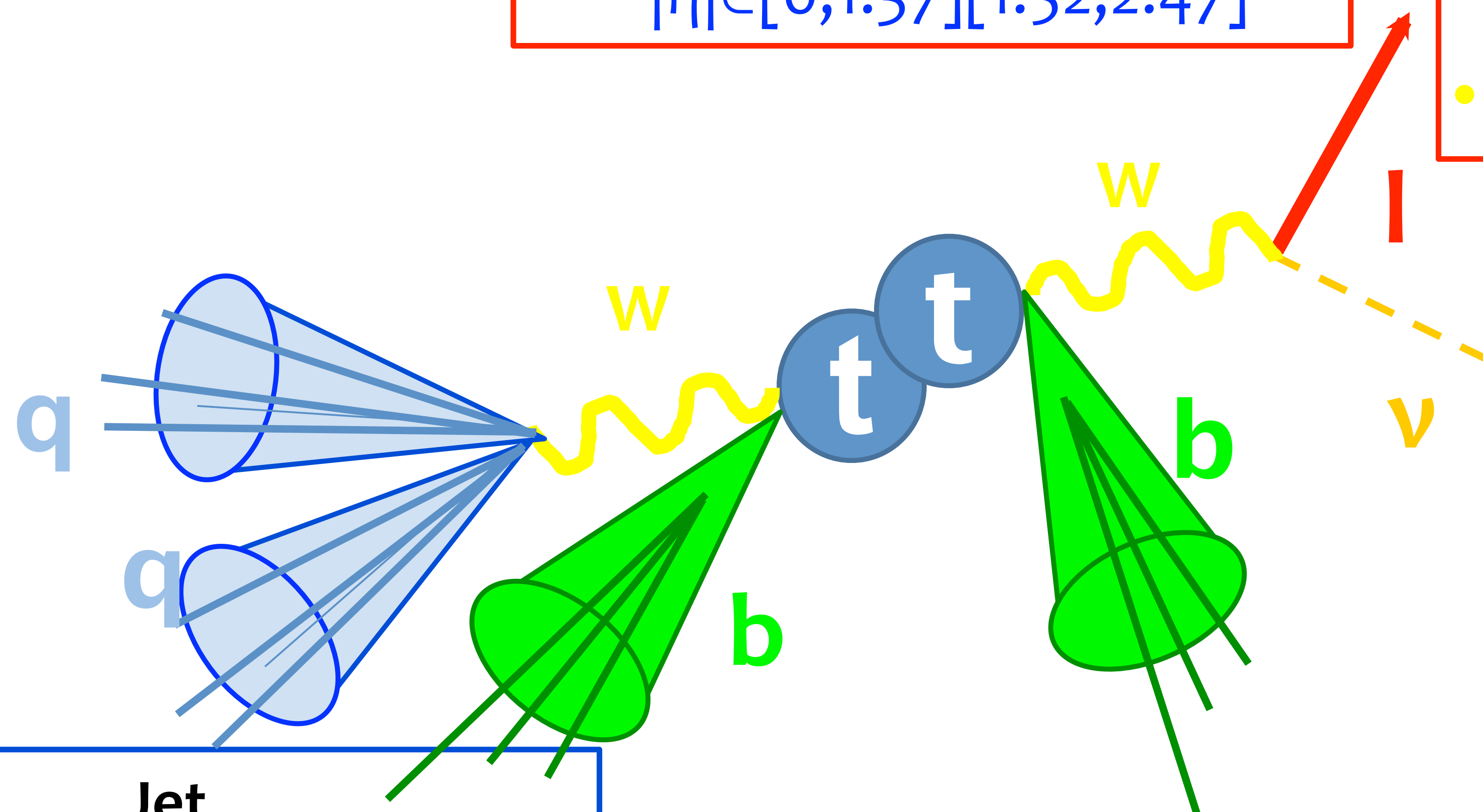

Jet

- Topological clusters
- Anti-k_T (R=0.4)
- Calibration checked w/data
- p_T > 25 (20) GeV
- $|\eta|$ < 2.5

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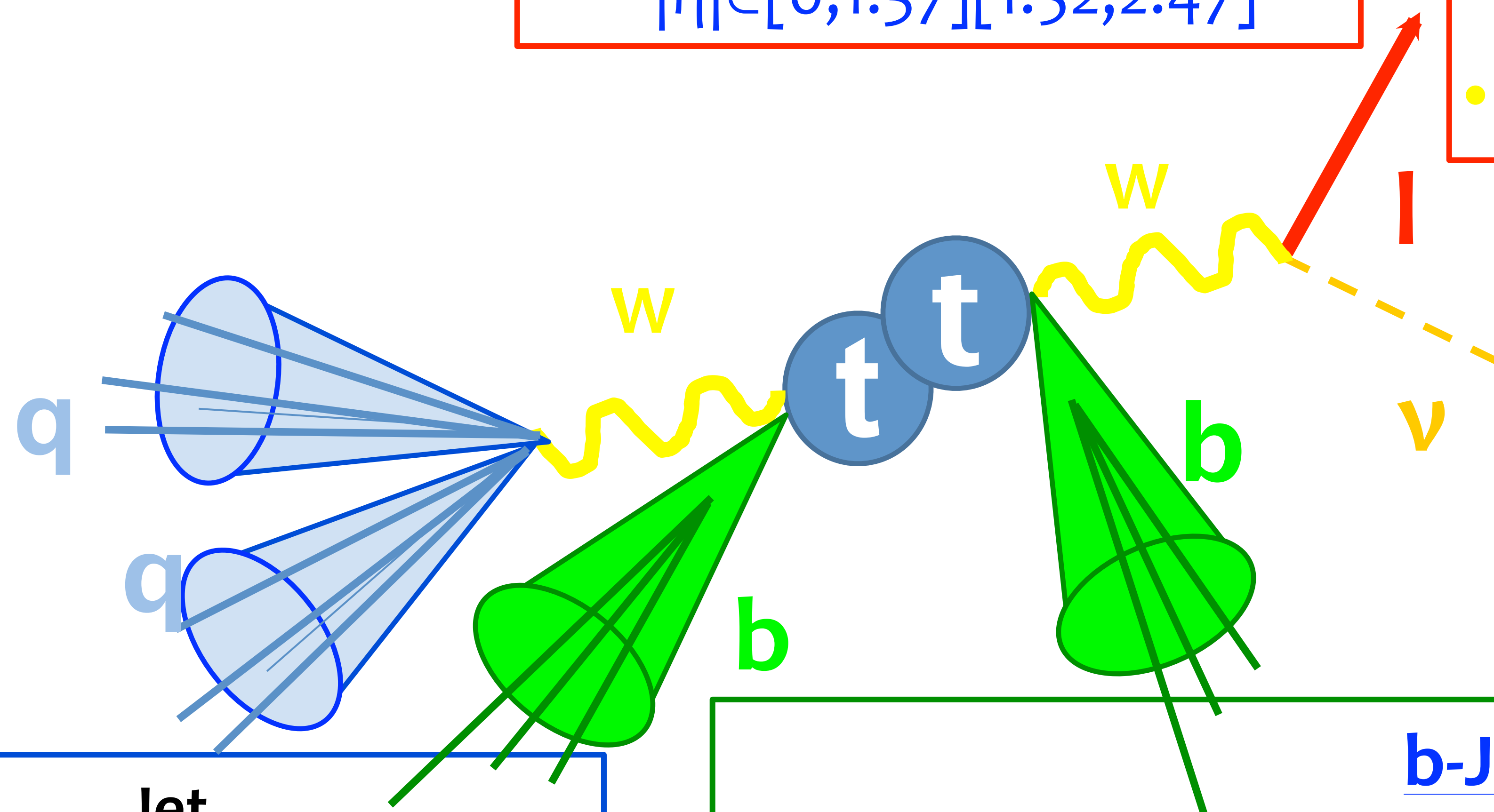

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b-Jet

- Displaced tracks or secondary lepton
- SV0: reconstruct sec.vertex
- JetProb: track/jet compatibility with primary vertex
- IP3D+SV1 and JetFitter: advanced taggers

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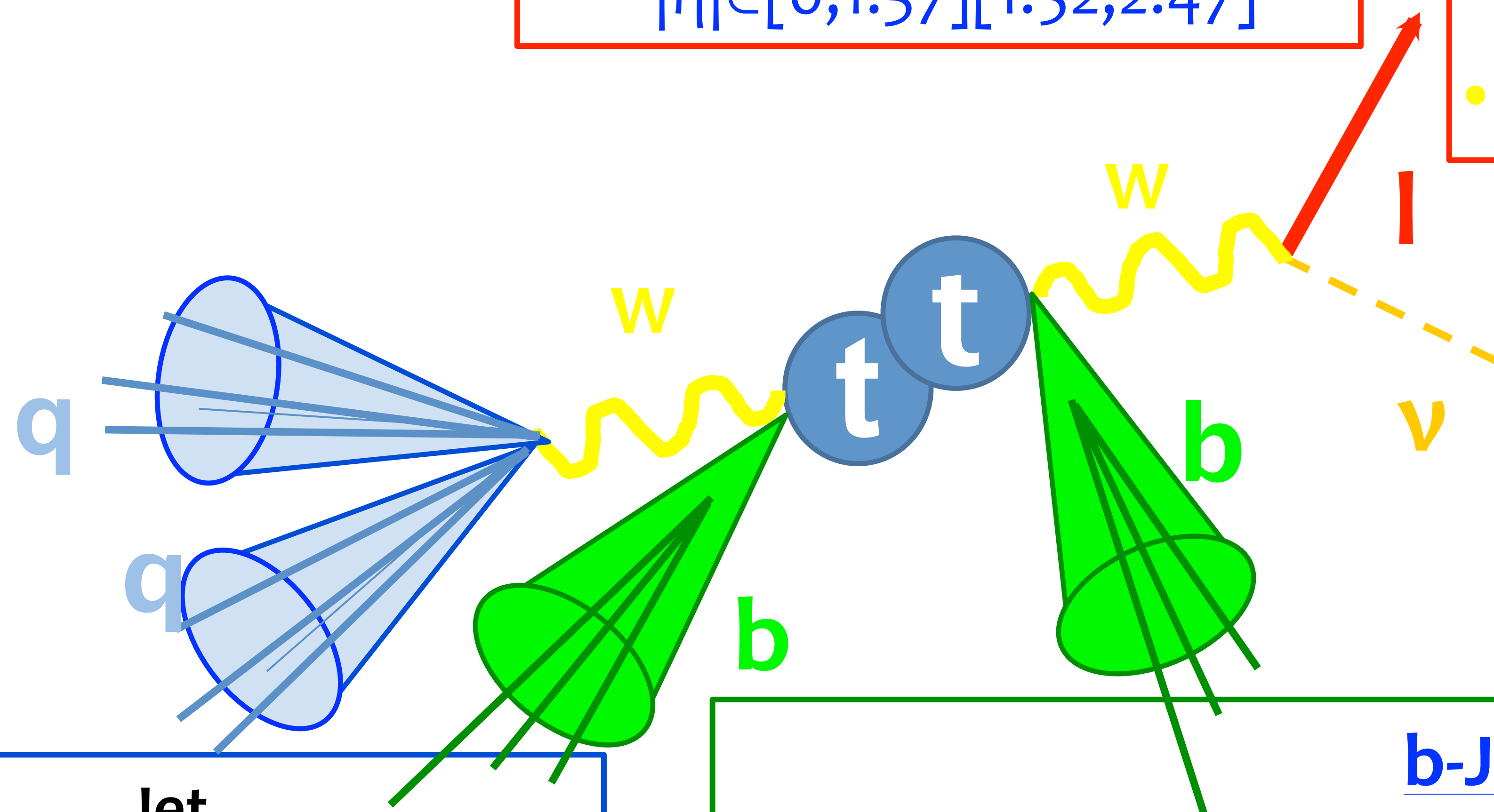

E_T^{miss}

- Vector sum of calo energy deposits
- Corrected for identified objects

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Selection/Ingredients of top quark pairs/single-top

(*ATLAS*)

Event cleaning

- Good run conditions
- PV at least 5 tracks
- Bad jet veto
- Cosmic veto ($\mu\mu$)

Electron

- Good isolated calo object
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- E_T>25 GeV
- $|\eta|\in[0;1.37][1.52;2.47]$

Muon

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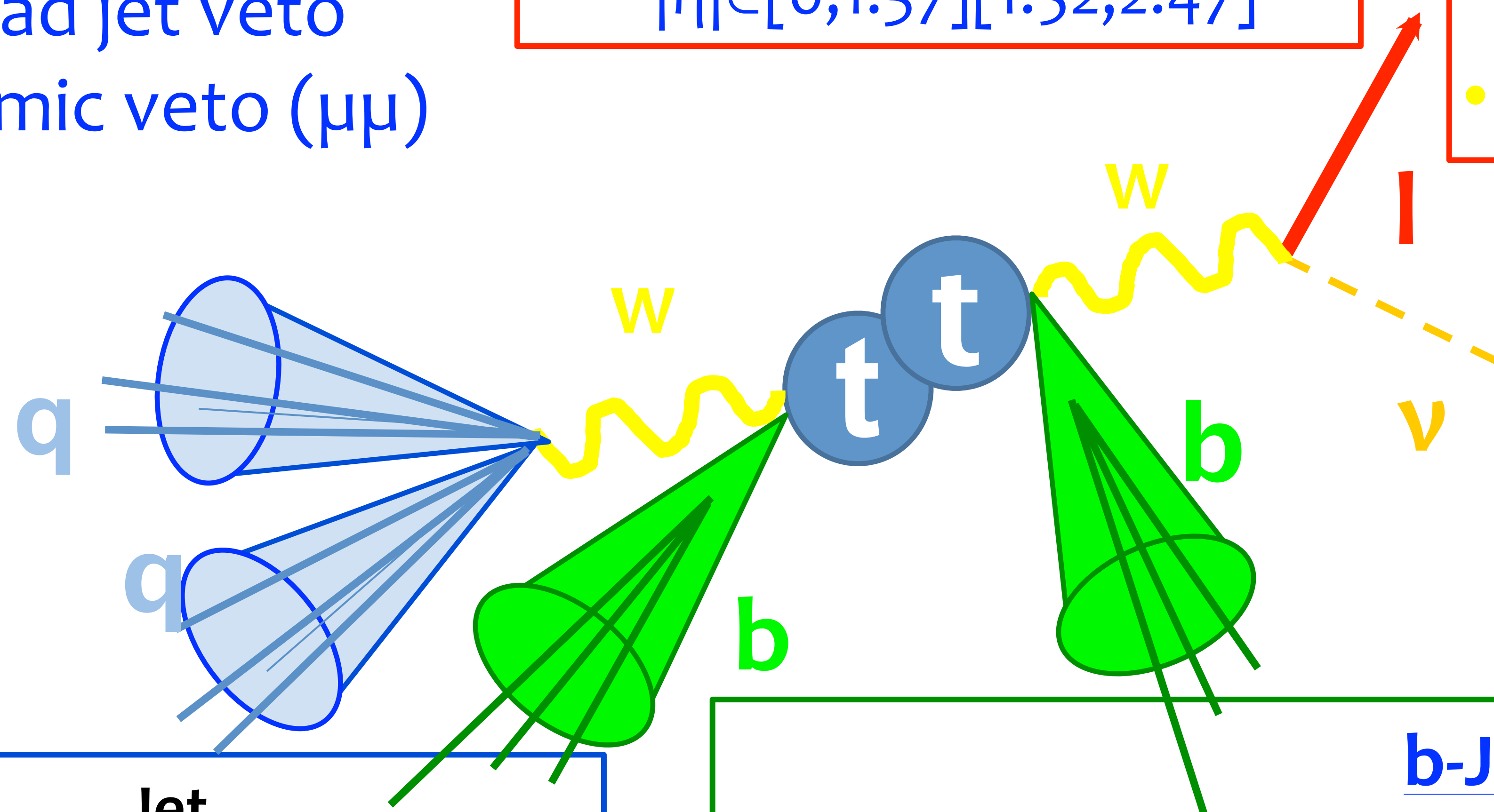

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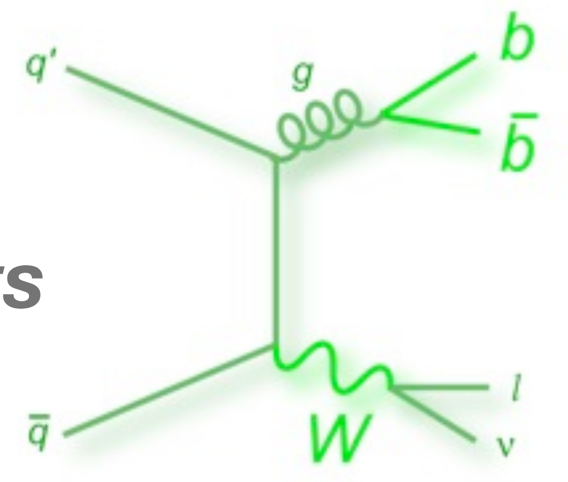
Backgrounds estimates (single lepton)

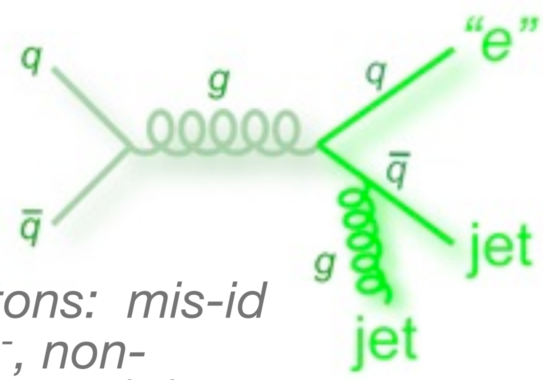
- **W+jets**



- *simulated shape*
- ***normalization scaling from charge asymmetry of W prod** before b-tag **or** from jet multiplicity in W+jets enriched sample*

$$N_{W^+} + N_{W^-} = \left(\frac{r_{MC}+1}{r_{MC}-1}\right)(D^+ - D^-)$$

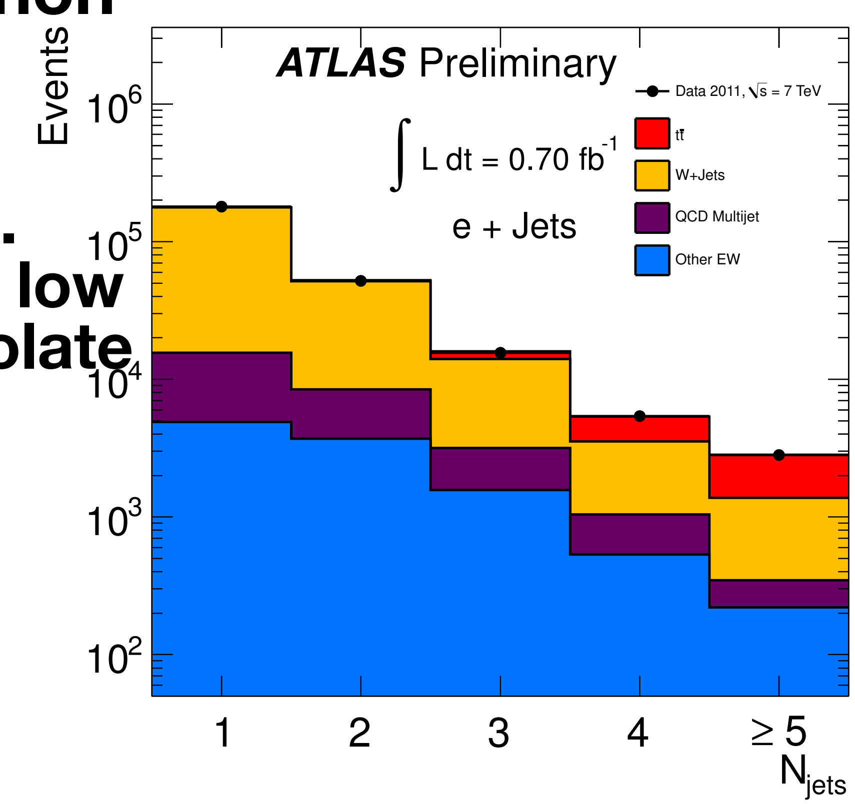
- **QCD**



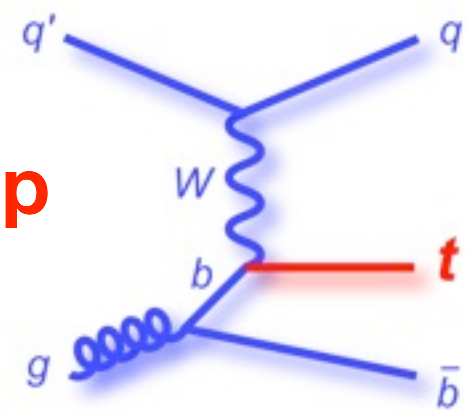
- *"Fake" leptons: mis-id jets, $\gamma \rightarrow e^+e^-$, non-prompt leptons (b/c-decays)*

- *Matrix method*: Combine **isol. prob for real and fake** lep in control region **with N(isol. lep) and N(non-iso lep)→isolated fake lep**
- *Jet template*:**shape from jet triggered events with 1 high em. content jet. Normalize by fitting low E_T^{miss} shape to data and extrapolate**

ATLAS-CONF-2011-121

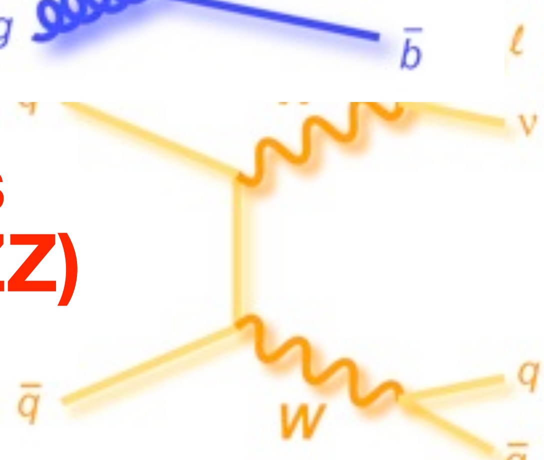


- **Single top**



Simulated shape+ rate set to SM

- **Di-bosons (WW,WZ,ZZ)**

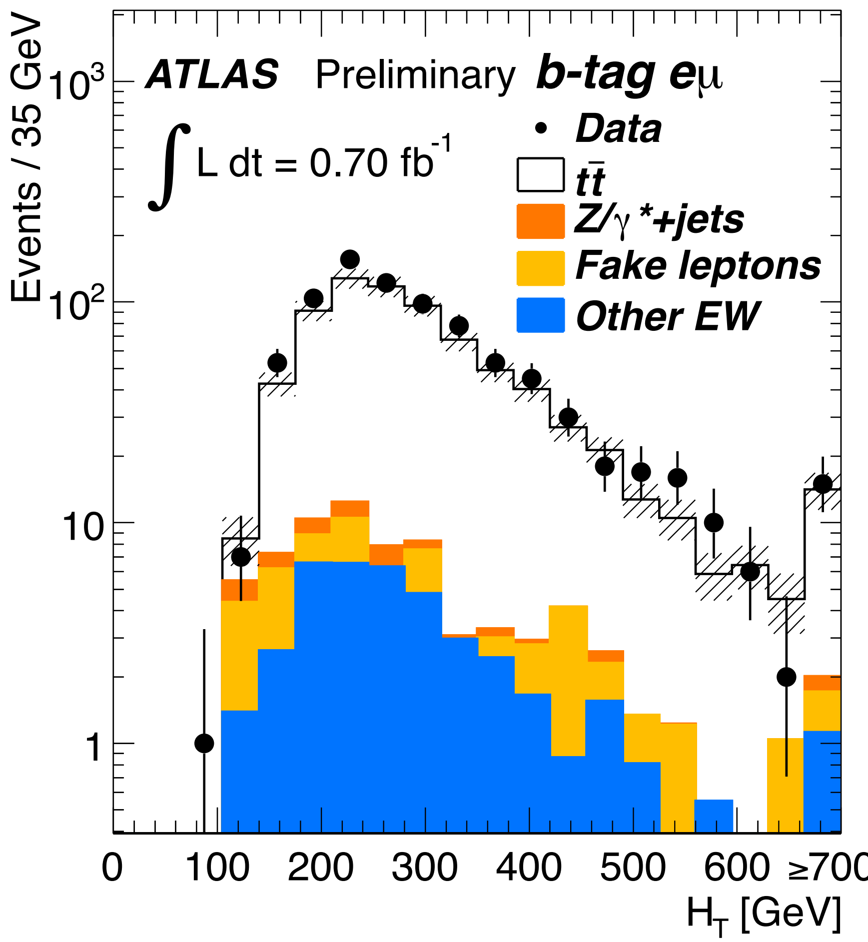


simulated shape+ rate from simul.

Backgrounds (di-lepton)

- "Fake" leptons from data
  - Get **probability** for **loose** "fake" and real leptons ***to be in signal region (A)*** ← **control samples** enriched with real (in Z window) or "fake" (low E_T^{miss}) leptons
  - **Combine** with **N(di-lep)** for **all loose/tight** pairs→**fake tight** (i.e. signal) **lep**

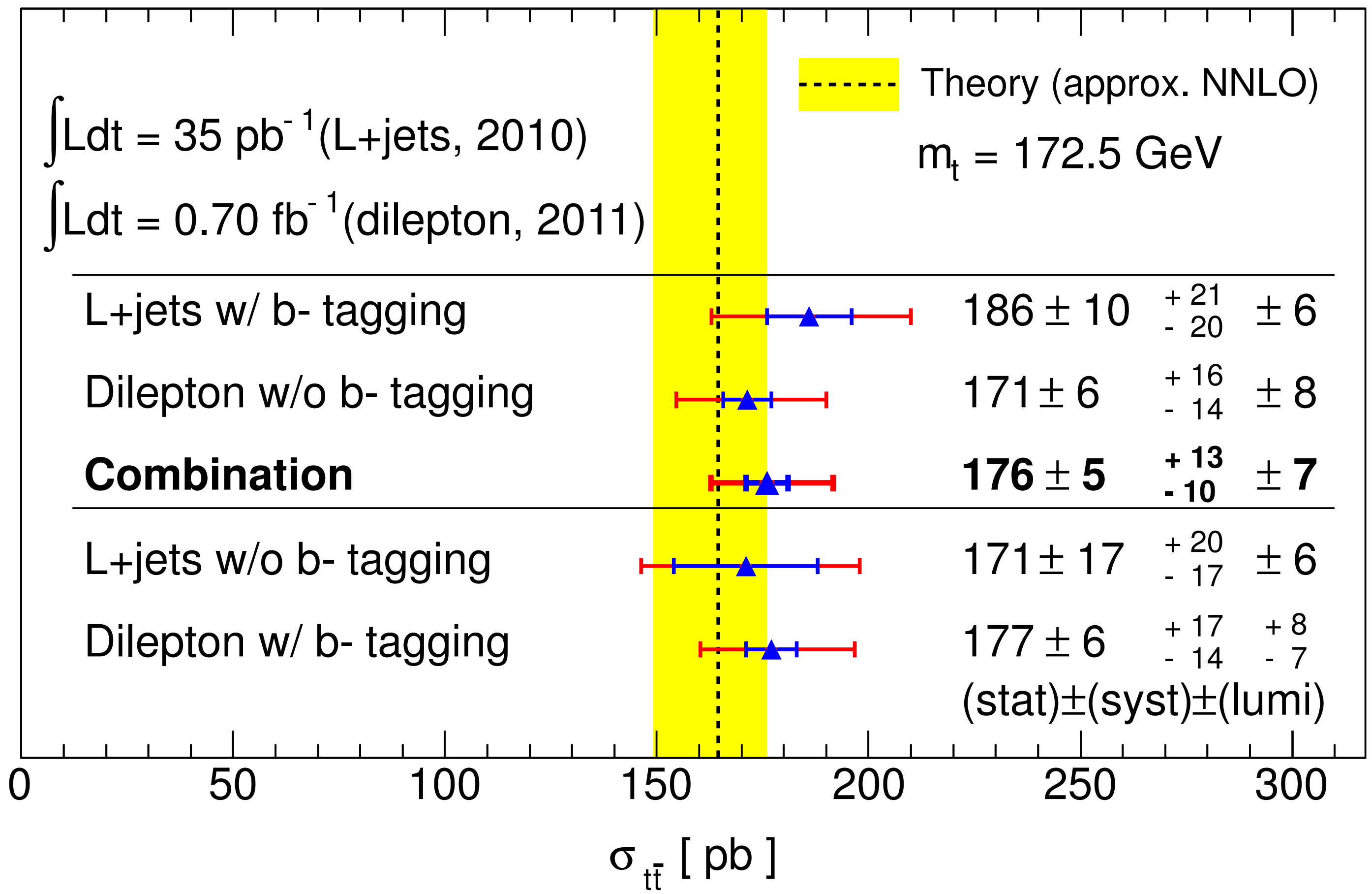
ATLAS-CONF-2011-100



- Z/γ* bkg (ee, μμ) : **scale** non-Z/γ*-bkg-subtracted **data in** Z-mass window **control region with ratio** of N(Z/γ*) in signal region to control region **from simul.**

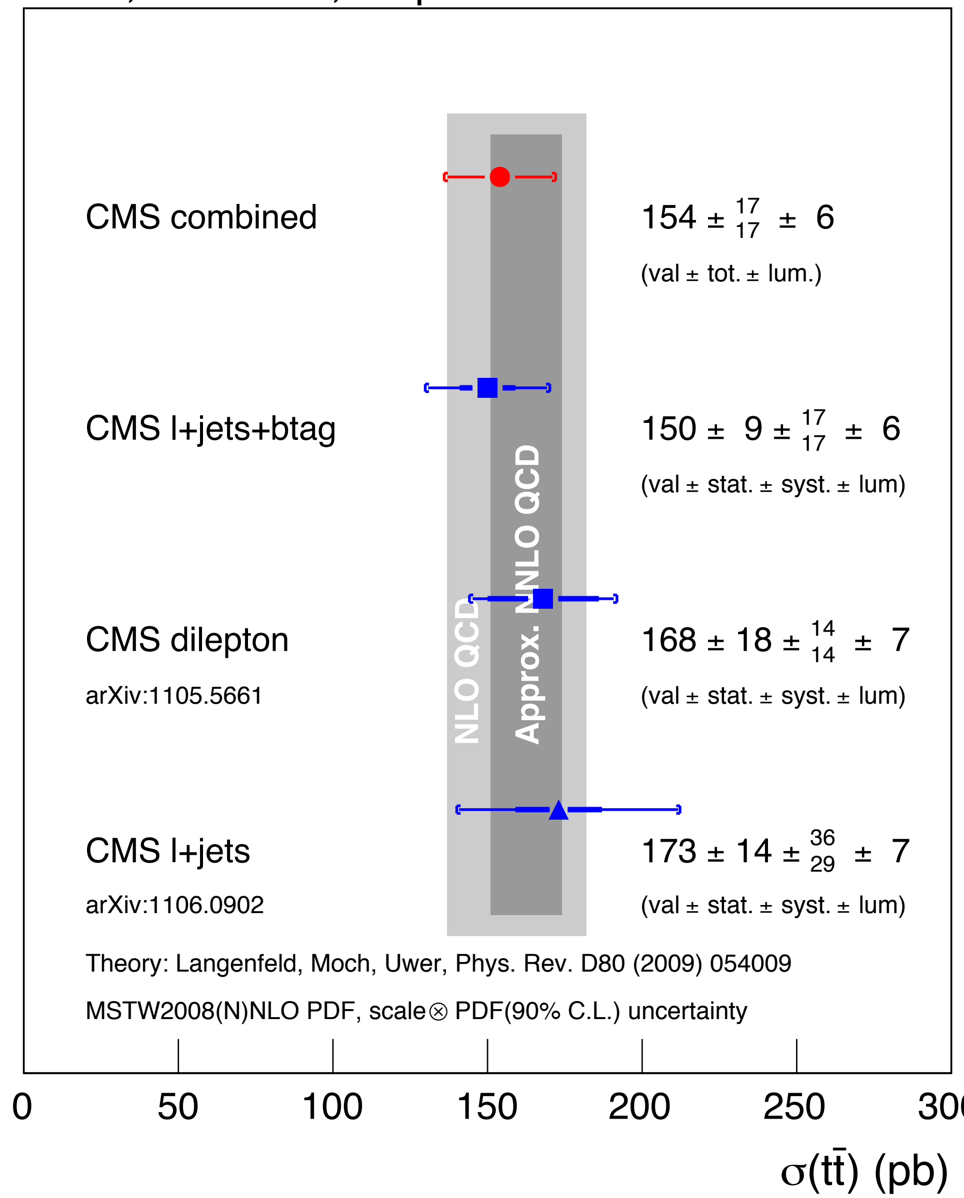
Combined top pair cross section results

ATLAS Preliminary, = 7 TeV ATL-CONF-2011-108



arxiv.1108.3773

CMS, $\sqrt{s}$=7 TeV, 36 pb^{-1}



L+jets w/o b-tagging (∫Ldt = 0.7fb^{-1} 2011) **σ=179 ±3.9 ± 9.0 ±6.6 pb**

NEW! (∫Ldt = 35pb^{-1} 2010)

arxiv.1201.1889

L+jets w b-tagging **σ=179 ±17 ± $^{18}_{16}$ ±6 pb**

L+jets w/o b-tagging **σ=187 ±11 ± $^{18}_{17}$ ±6 pb**

dilepton (∫Ldt = 1.14fb^{-1} 2011) **σ=169.9 ±3.9 ± 16.3 ±7.6 pb**

- Combined uncertainty is ~**10% dominated by systematics. Comparable to theory**
  - **ATLAS:** 176±5$^{+13}_{-10}$+7 pb
  - **CMS** : 154±10$^{+17}_{-17}$+6 pb

do not include ***NEW + out of table*** *results*

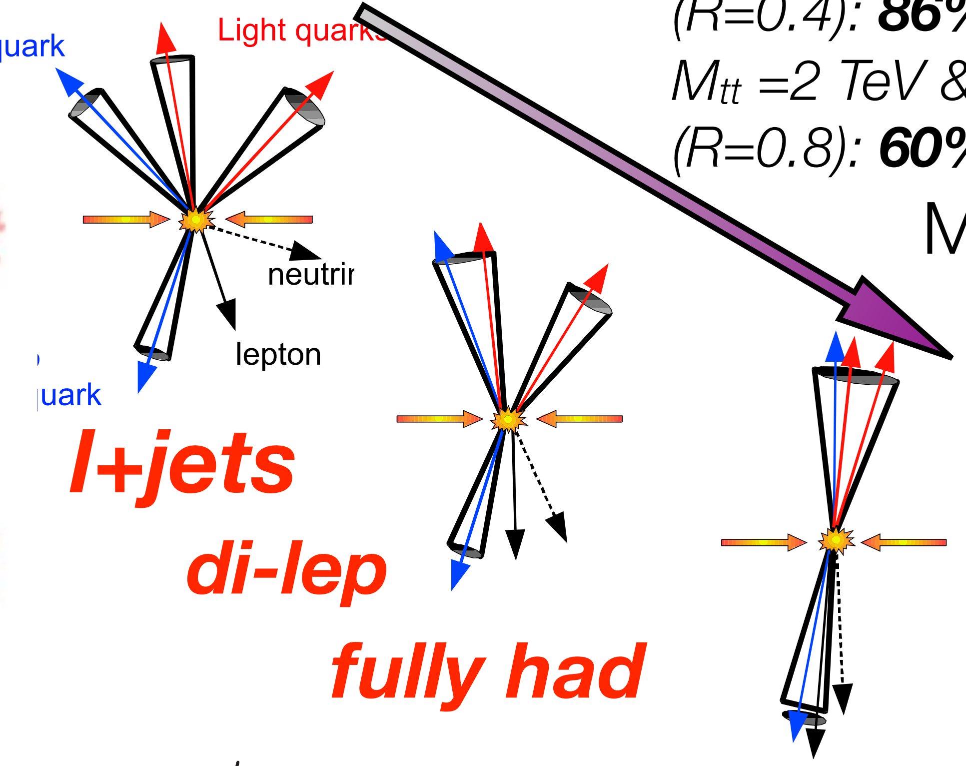
top mass (GeV) (stat+sys)	ATLAS-CONF-2011-120	CMS-PAS-TOP-10-009
	175.9±0.9±2.7	**173.4±1.9±2.7**

Top production as a window on new physics

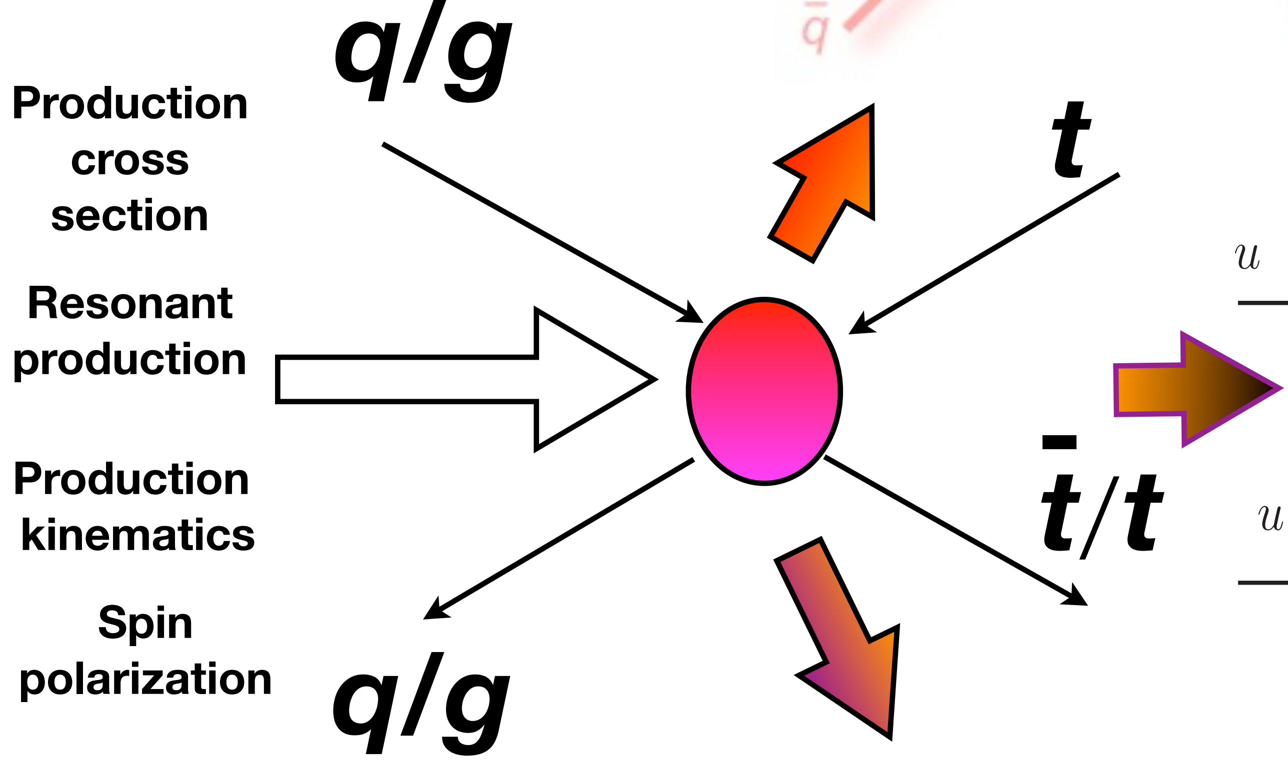
P_T^{Top}

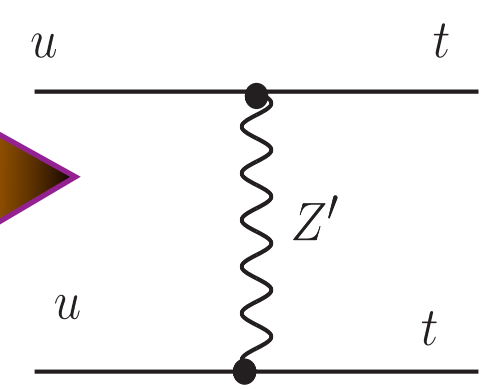
M_{tt} =1 TeV & anti-k_T (R=0.4): ***86% resolved***

M_{tt} =2 TeV & antikt (R=0.8): ***60% boosted***



For ΔR=0.8, M_{tt} ~1.7 TeV, P_T ~600 GeV



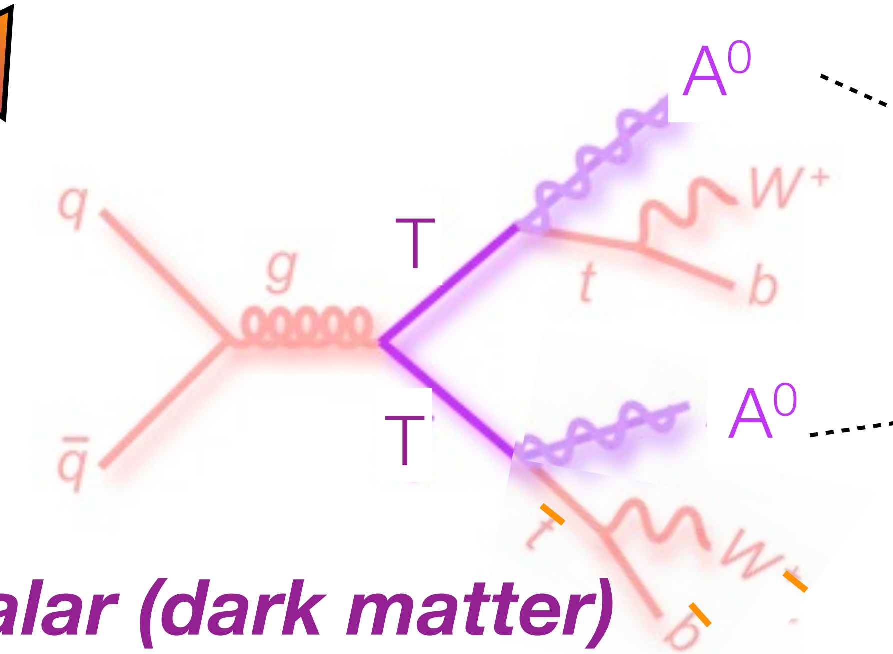


t/t̄ charge asymmetry

color octect vector, color singlet Z', color triplet scalars

Same sign top pair

4th gen, FCNC, left-right symetric, higgs triplets, SUSY, UED, little higgs



$tt+E_T^{miss}$

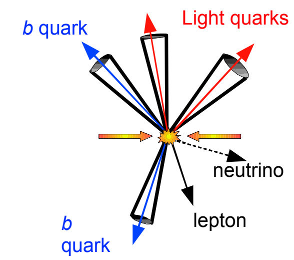
exotic 4th gen, leptoquarks, stop →top +neutralino, UED, little higgs,

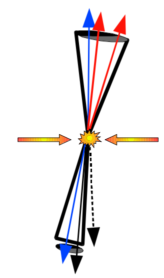
top partner + stable scalar (dark matter)

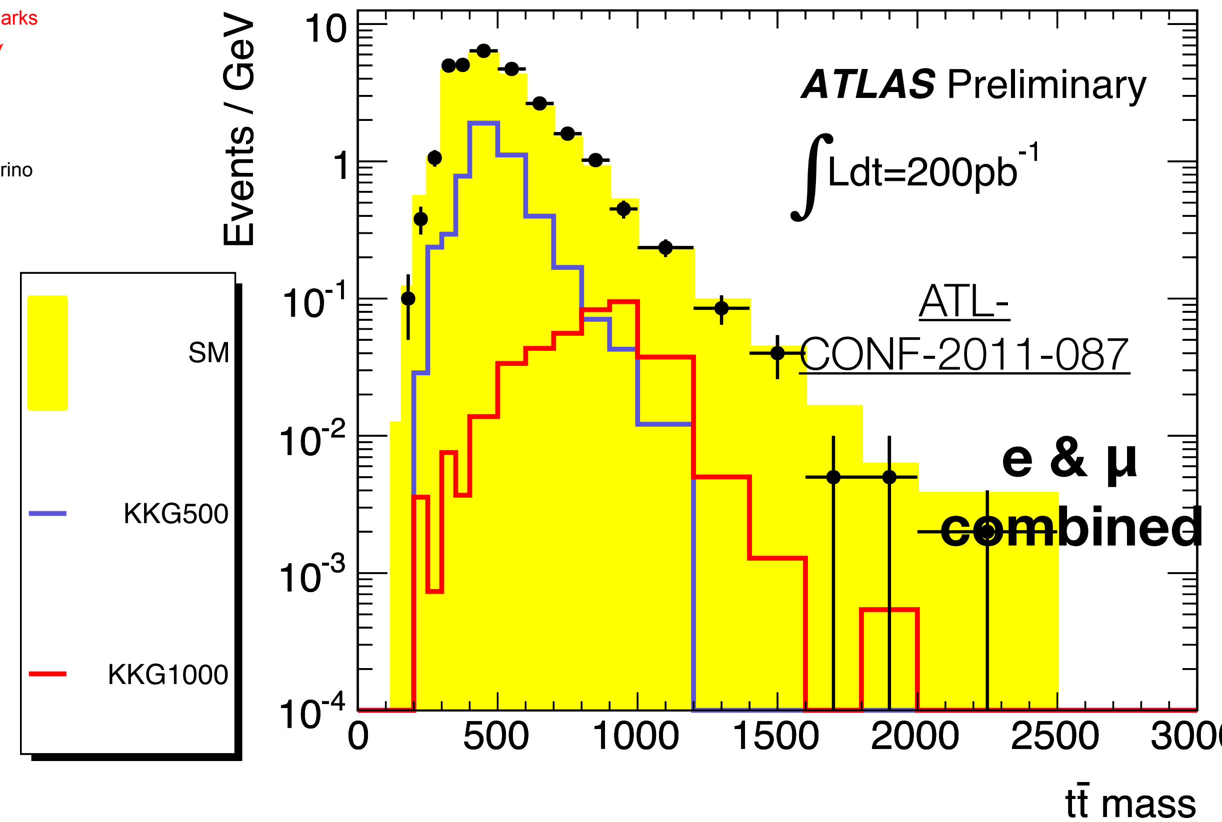
Search for excess in $t\bar{t}$ production vs $M_{t\bar{t}}$ - single-lepton

A=ATLAS, C=CMS

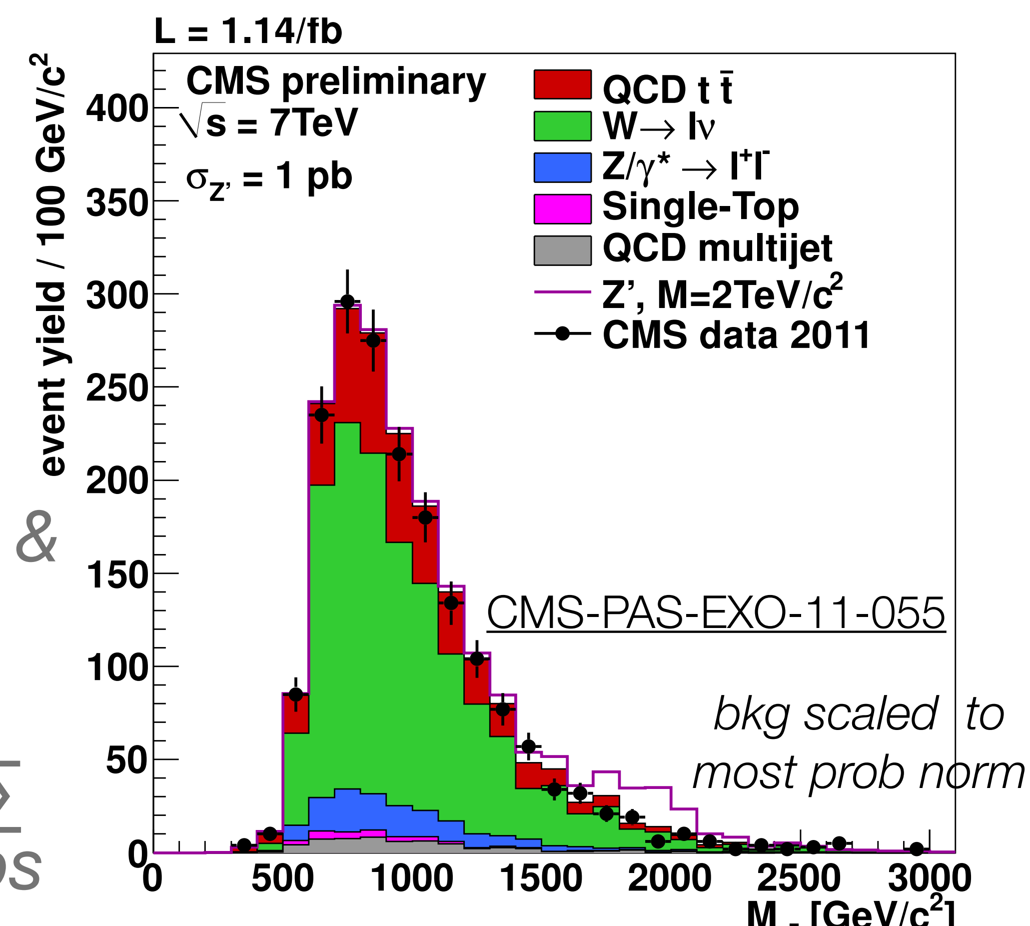
(2011) $\int L dt$ = **0.2 fb^{-1}** (***A***) **1.14 fb^{-1}** (***C***)







- **A**: **standard single lep** (e μ)
  sel: ≥4 jets, ≥1 b-tag
- **C**: **single μ, *boosted top sel.***
  - **≥ 2 jets with** p_T>50 GeV, **lead jet p_T>250 GeV**
  - **one non-iso μ** with ΔR>0.5 from closest jet OR p_T rel. to jet >15 GeV
  - **high $p_{T,lep}$+E_T^{miss}** >150 GeV
- Data-driven **QCD** (*jet template method normalize to low E_T^{miss} (A),shape from ev. failing mu 2D cut (C)),* **W+jets normalization (A)** *(extrapol. from N_{jet} in W+jets-enriched sample)*



- **Reconstruct leptonic W** *from E_T^{miss}, lepton & W mass*, **then $M_{t\bar{t}}$**
  - ***sum leptonic W to** (A) **4** leading p_T **jets** or (C) **jets giving back-to-back top-jets** ←minimal ∑ ΔR (lep/b-jet, leptonic top) & max ΔR betw. tops*

Search for excess in $t\bar{t}$ production vs $M_{t\bar{t}}$ -single lepton

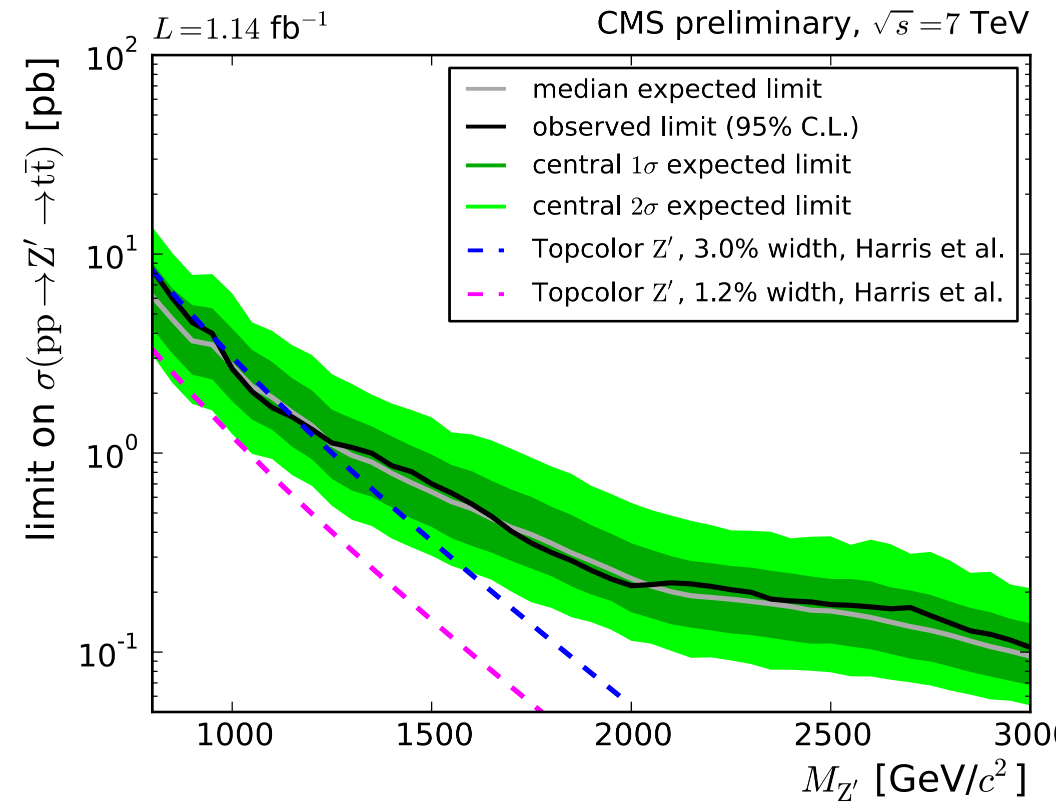
A=ATLAS, C=CMS

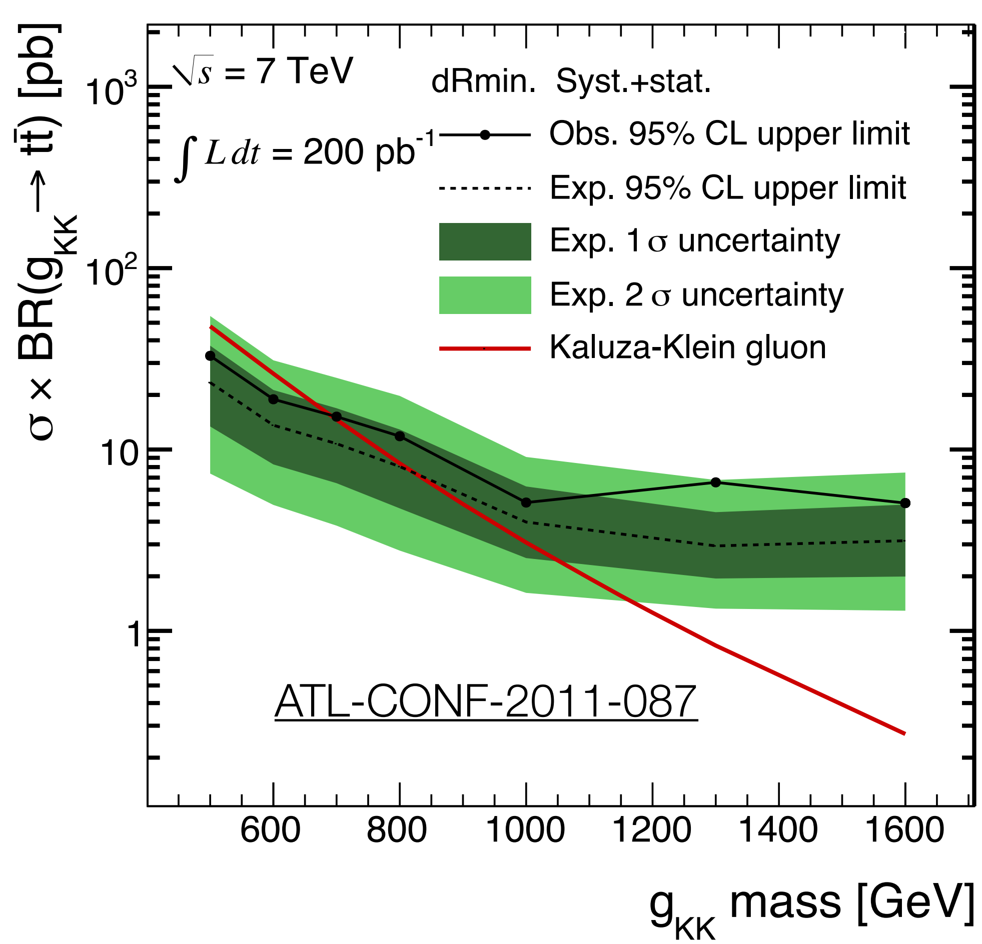
- No excess found → **95% Bayesian credible interval for Z' & RS KKGluon σ**BR*, including systematics** *as integrated (CMS), averaged(A) nuisance pars.*

- Upper observed (expected) limit at **95% prob on Z' σ**BR* (with $\Gamma_{Z'}/m_Z \sim 1\%$)**
  - C:**sub-pb for** $m_{Z'}$>1.3 TeV, <0.2 pb for $m_{Z'}$> 2.3 TeV
  - A: **38 (40) pb** *for $m_{Z'}$=500 GeV* **to 3.2 (5) pb** *for $m_{Z'}$=1.3 TeV*

- C: For **Z' with 3% width exclude 805 GeV** <$m_{Z'}$< **935 GeV** and **960 GeV** <$m_{Z'}$< **1060 GeV** at 95% CL

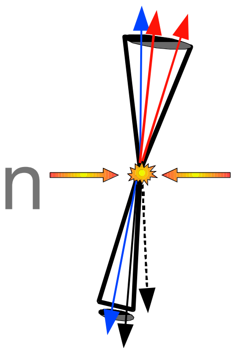
- A: KK Gluons with masses < **650 GeV are excluded with 95%prob**





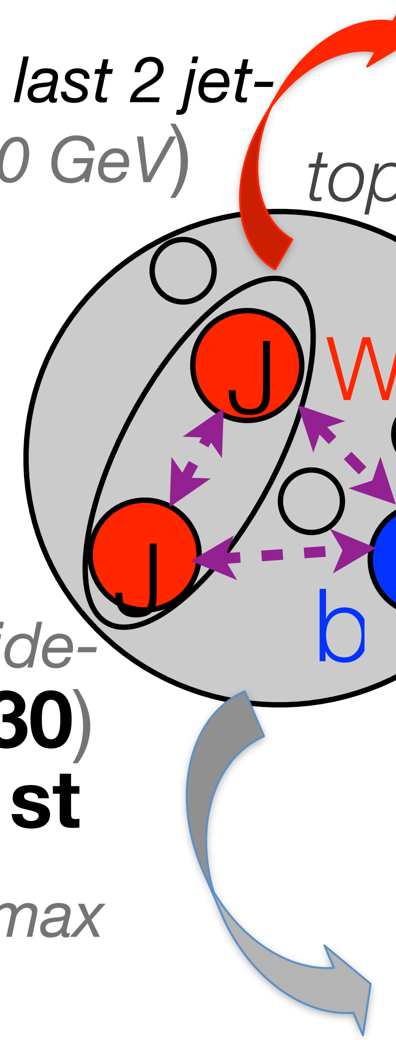
Search for excess in $t\bar{t}$ production vs $M_{t\bar{t}}$ - fully hadronic

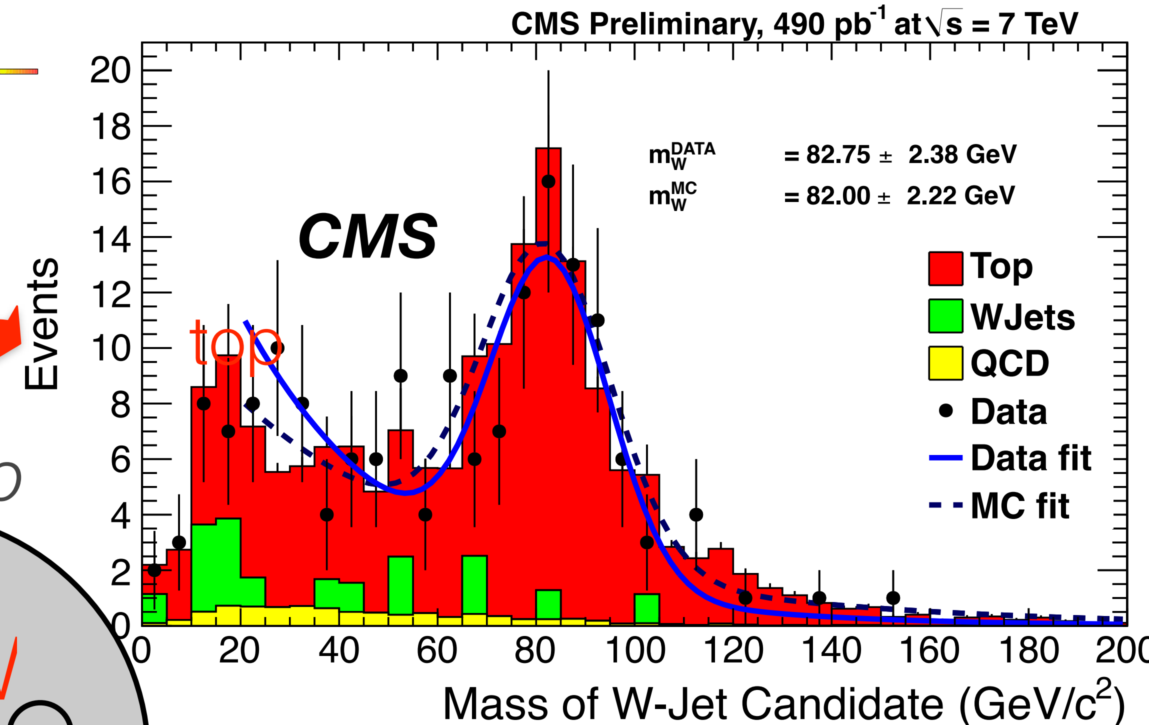
- *Trigger on ≥ 1 jet with p_T>200 GeV*



$\int Ldt$ = **0.89 fb^{-1}** *(2011)*

- ***"1+1"***: **≥ 2** R=**0.8** Cambridge-Aachen **(CA) jets**
  - **p_T>350 GeV & large Δφ** *>2.1*
  - **top-tagged** *(m_{jet} ~m_{top} ,$N_{sub\text{-}jets}$ in last 2 jet-making steps ≥ 3, min($m_{2\ sub\text{-}jets}$) > 50 GeV)*

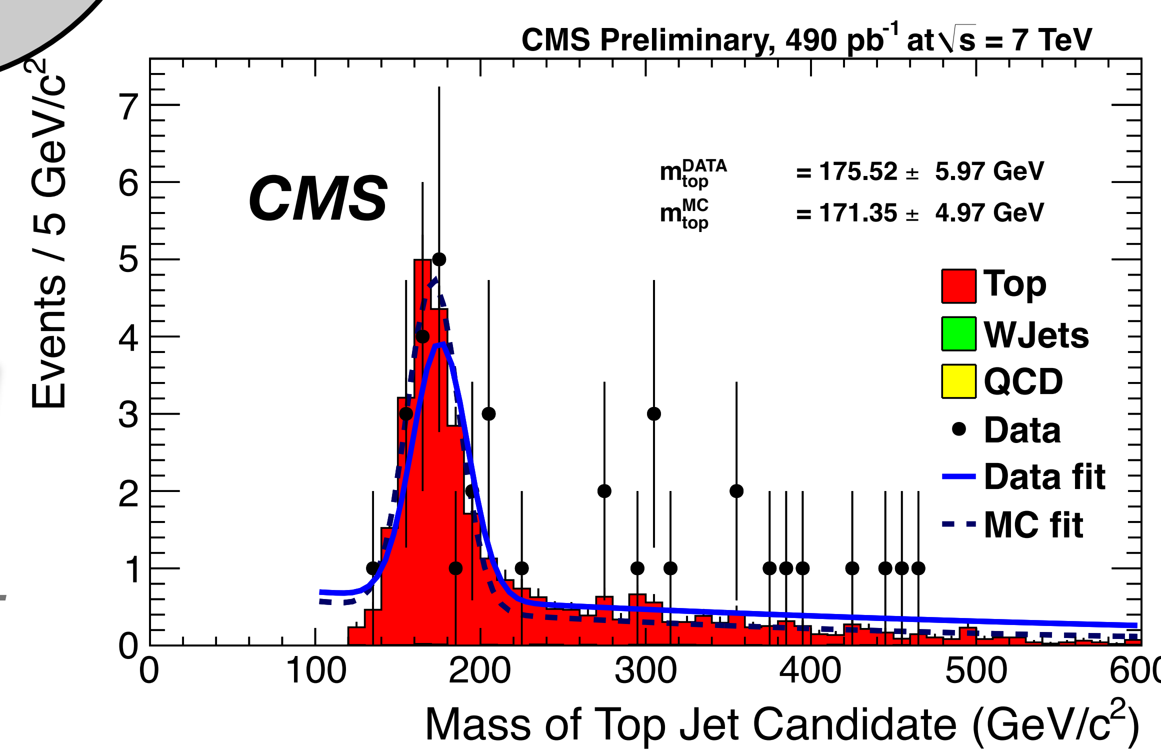




validation in boosted-W semi-lep events

CMS-PAS-EXO-11-006

- ***"1+2"*: ≥3 R=0.8 CA jets**
  - **leading top-tagged jet** with **p_T>350 GeV**
  - **2nd**(3rd) **pruned** *(discard soft, wide-angle clusters)* **jet** with **p_T>200 (30)** GeV, **large Δφ** *>2.1(1.7)* **from 1st**
  - **j2 is W-tag** *(m_{jet} ~m_W ,2 sub-jets,max ($m_{sub\text{-}jet}$)/m_{jet} <0.4)*, **m(j2,j3)~m_{top}**



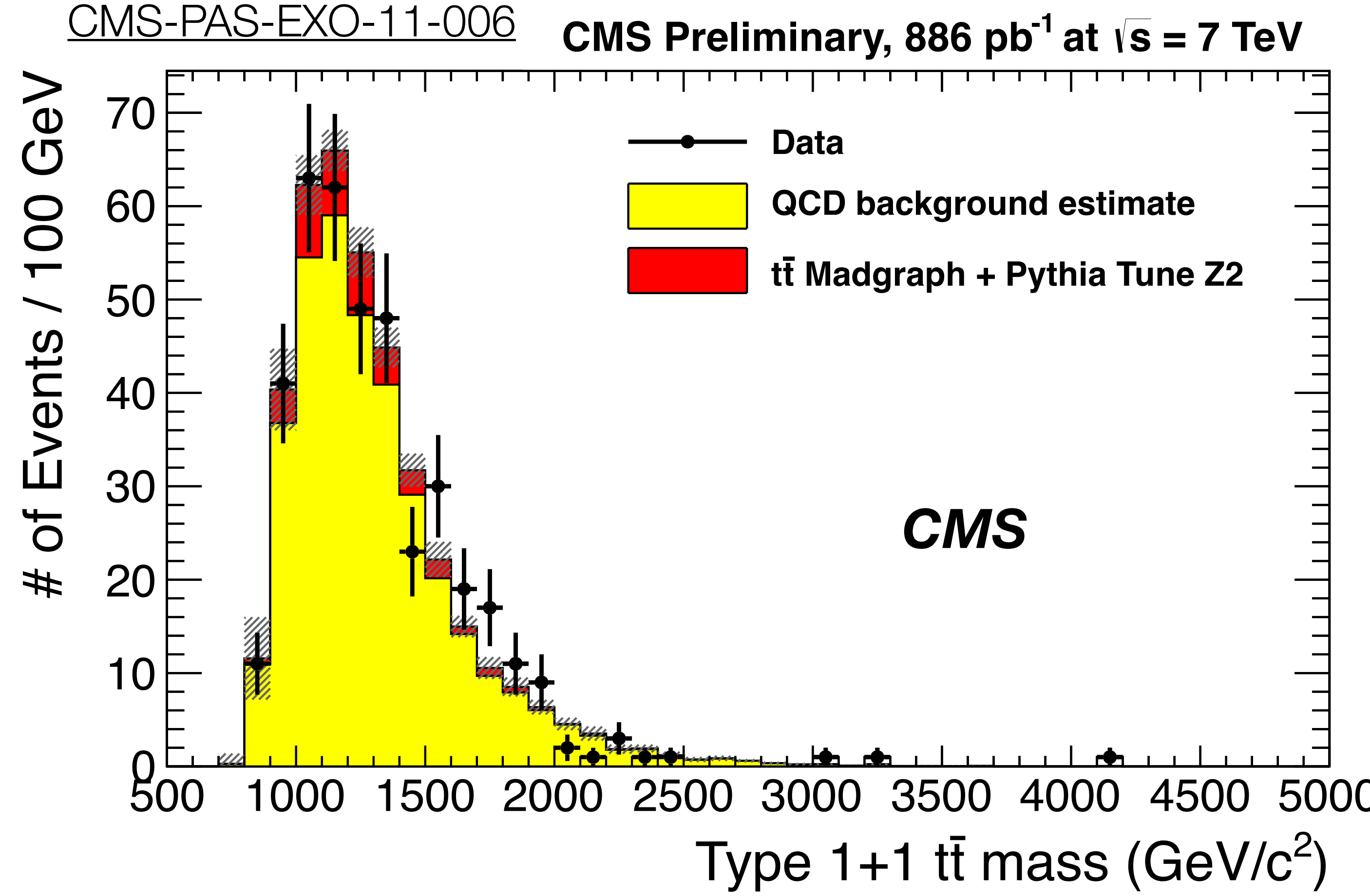
- Data-driven **QCD: weight 1-**top or W-**tag control sample *with mis-tag prob*** ← *anti-tag (fail top tag cuts) & probe in semi-lep evs*

Search for excess in $t\bar{t}$ production vs $M_{t\bar{t}}$ - fully hadronic

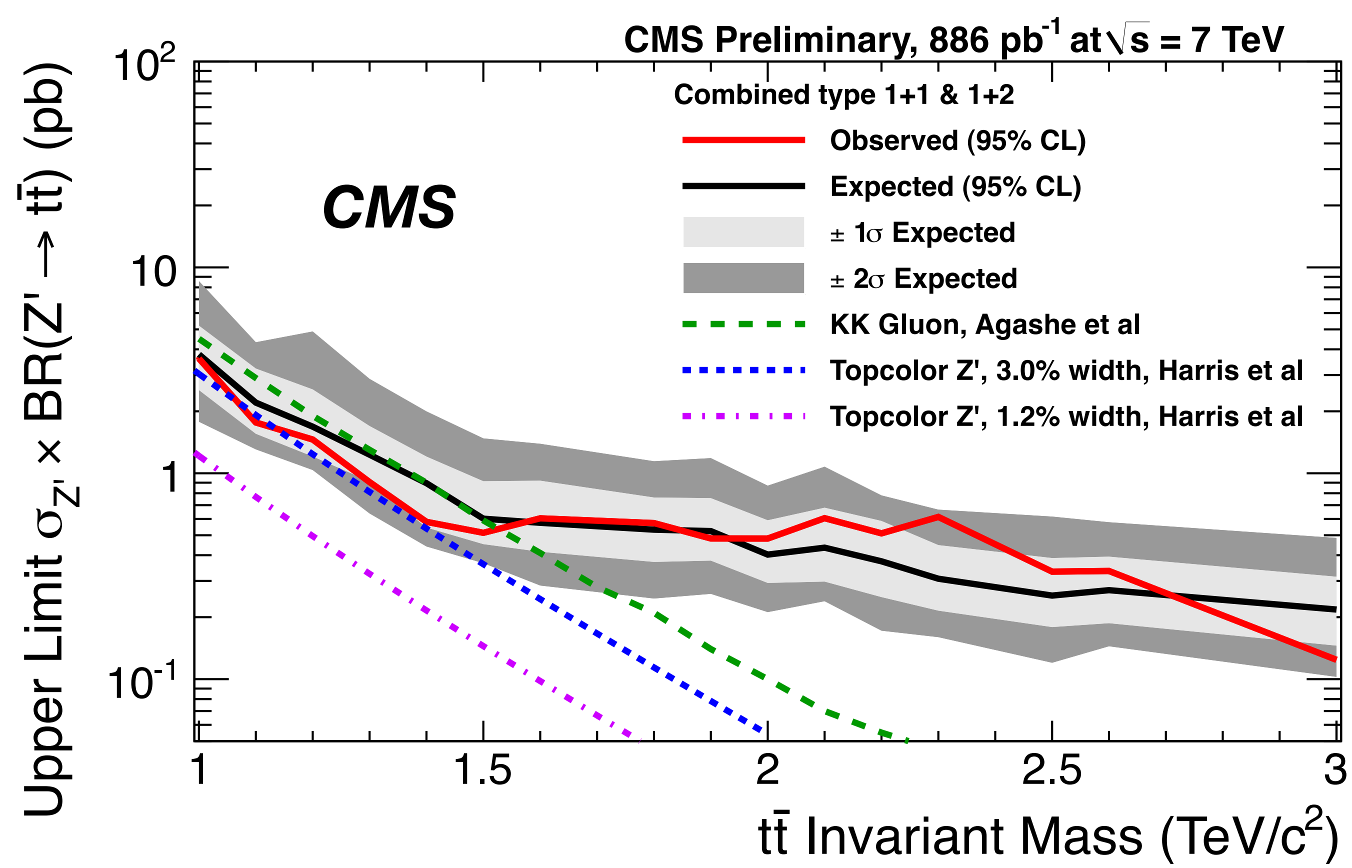
$\int L dt$ = ~**0.89 fb^{-1}** *(2011)*

- **M_{tt}: sum top jets** in "1+1", **sum top jet, Wjet and closest jet** in "1+2"
  - QCD: **sum tag(s) & probe jet,** random m_{probe} around m_{top}

CMS-PAS-EXO-11-006



- No excess found→**95% Bayesian credible interval for Z'/RS KKGluon σ****BR*** **including systematics** *as integrated nuisance pars.*
- **Sub-pb limit on Z' σ*BR**
- **exclude 1 TeV<$m_{KKGluon}$<1.5 TeV @ 95%CL**



Search for excess in $t\bar{t}$ production - di-lepton

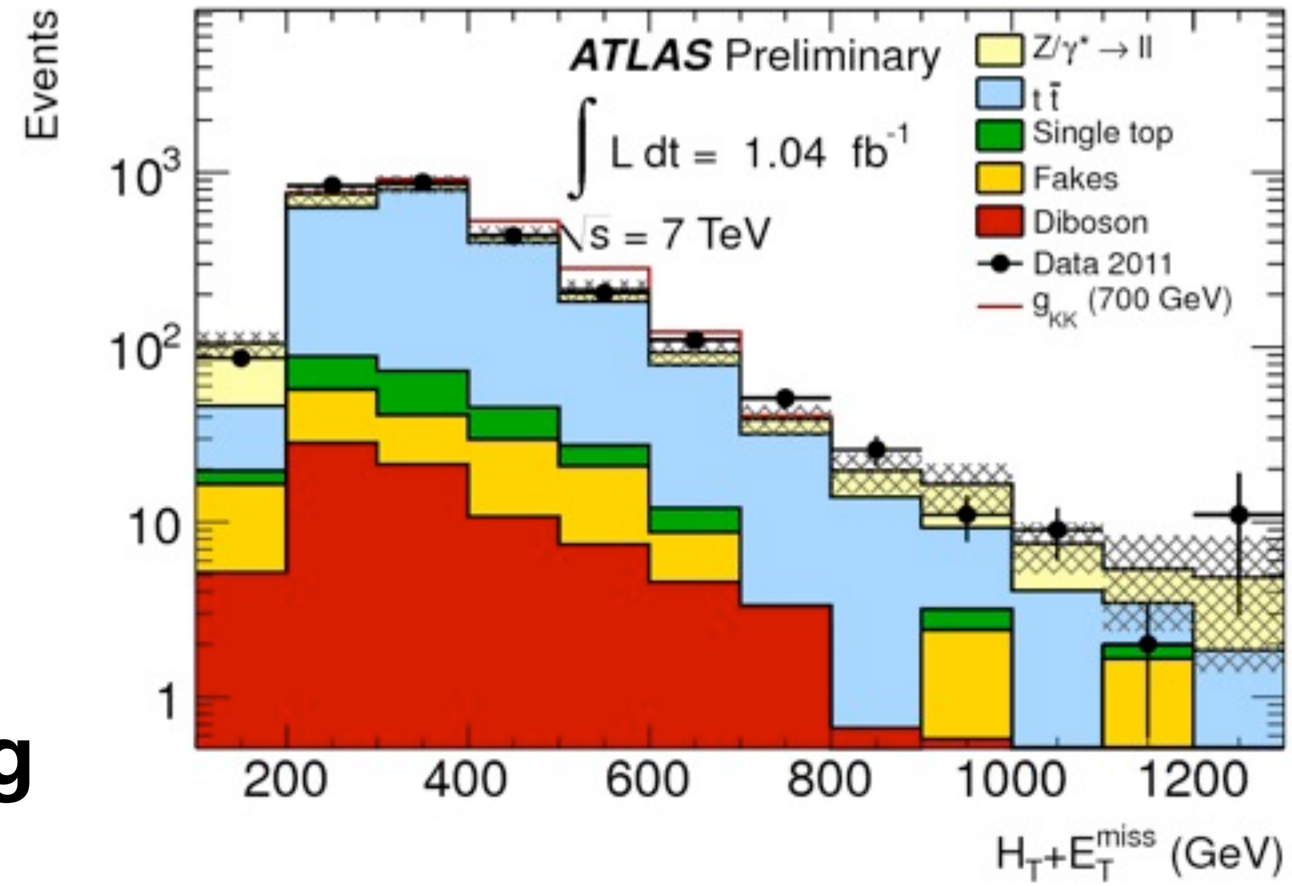
$\int L dt$ = **1.04 fb^{-1}** *(2011)*

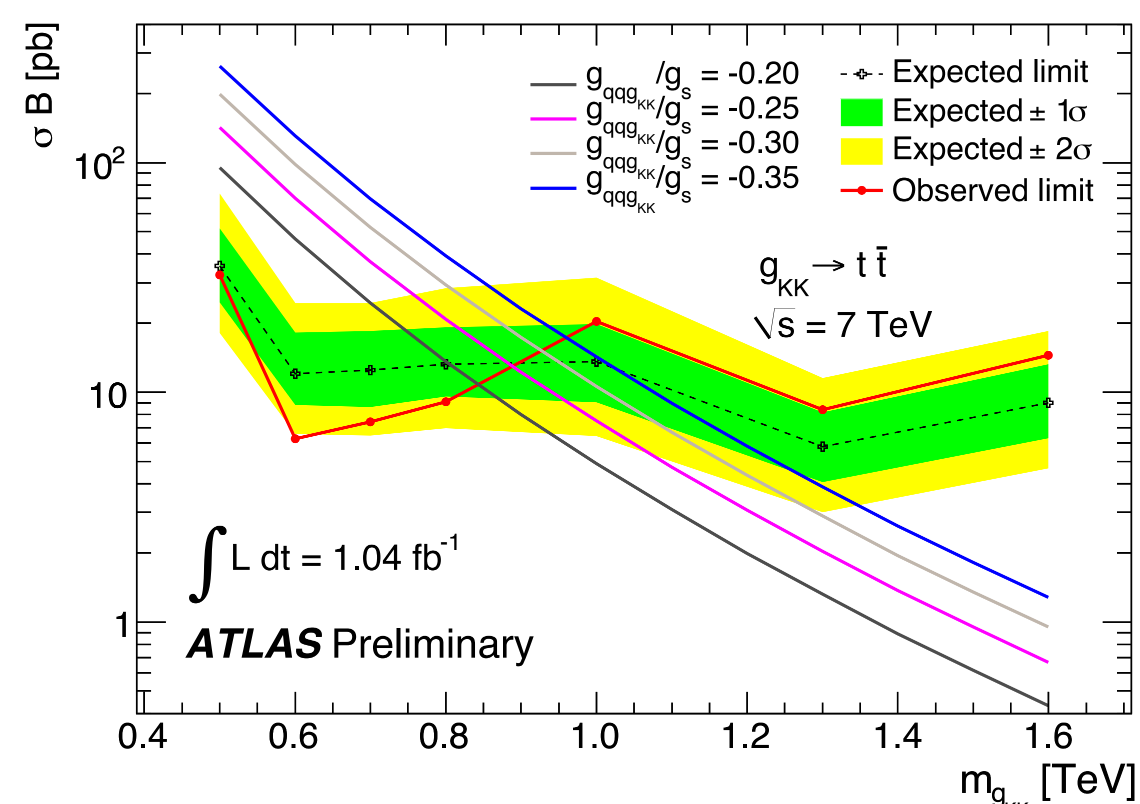
ATLAS-CONF-2011-123

- **Standard: di-lepton selection** (e,μ) + **data-driven Z/γ*+jets** (*E_T^{miss}-dep Z-window*) and **QCD** bkg estimates

- No excess found in $H_T+E_T^{miss}$ → **95% Bayesian credible interval for RS KKGluon σ*BR including systematics** *as integrated nuisance pars.*

- **Exclude RS KKGluon with M_{KK} below 0.84 TeV** at 95% CL



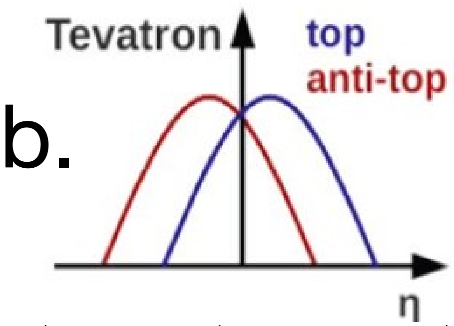


default →

	Mass Limit (TeV)	
$g_{qqg_{KK}}/g_s$	Expected	Observed
-0.20	0.80	0.84
-0.25	0.88	0.88
-0.30	0.95	0.92
-0.35	1.02	0.96

Top Charge Asymmetry measurement

- In pp/p$\bar{p}$→tt **t/anti-t** have **different** differential distributions from pQCD. NLO effect in q$\bar{q}$ /qg→tt/ttq: interference of amplitudes that are ***relatively odd*** under t ⇔ anti-t exchange.



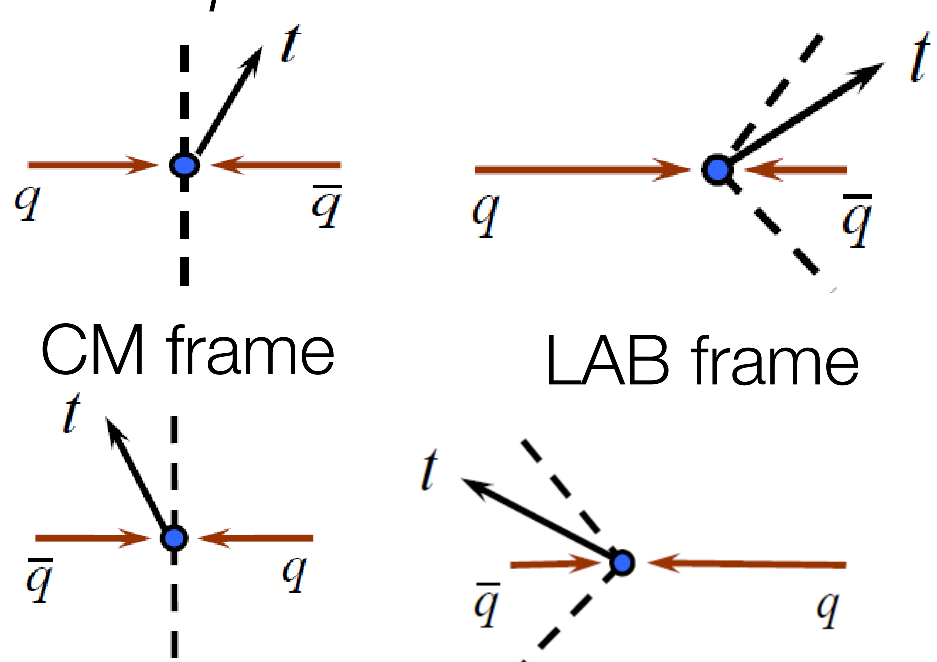
- At Tevatron (qq~85%) manifests as FB asymmetry in lab.

- Observe discrepancies with SM (i.e. A_{FB} (CDF)~3.4σ SM for m_{tt}> 450 GeV)
Interference of SM gluon with new phys?

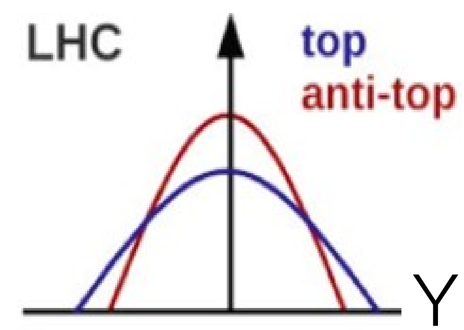
$$A_{FB} = \frac{N(\Delta Y > 0) - N(\Delta Y < 0)}{N(\Delta Y > 0) + N(\Delta Y < 0)}$$

where $\Delta Y = Y_t - Y_{\bar{t}}$

- At LHC A_{FB} = 0. Charge asymmetry ⇔ ***t*** emitted along ***q*** direction.
- As generally z(**q**) > z(**anti-q**), **t is more forward than anti-t in LAB frame** *z = proton momentum fraction*



t/anti-t figures by K.Suruliz



$$A_C = \frac{N(\Delta|Y| > 0) - N(\Delta|Y| < 0)}{N(\Delta|Y| > 0) + N(\Delta|Y| < 0)}$$

where $\Delta|Y| = |Y_t| - |Y_{\bar{t}}|$

SM MC@NLO prediction is 0.006

Top Charge Asymmetry measurement

$\int Ldt$ = **0.7 fb^{-1}** *(2011)*

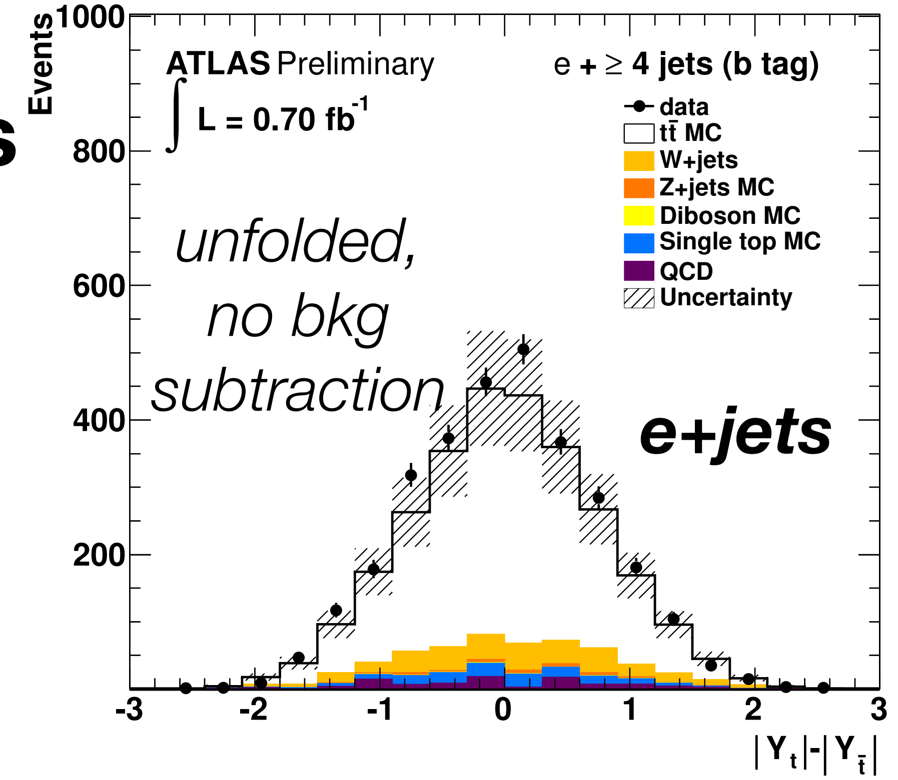
ATLAS

ATLAS-CONF-2011-106

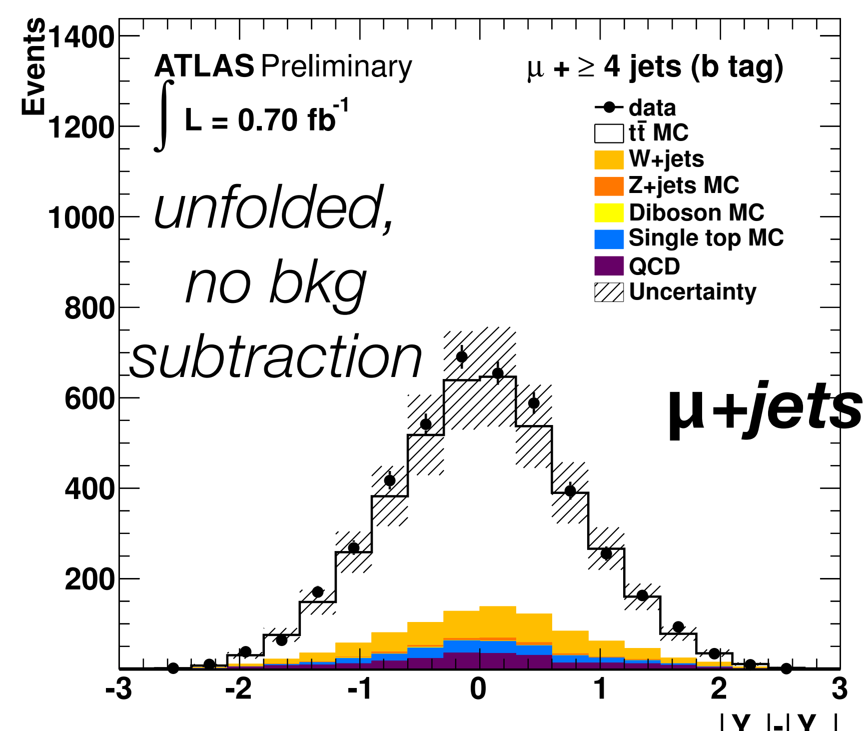
- **Trigger on** high p_T **single lepton (e,μ)**
- **1** high p_T **single lepton (e,μ), ≥4** high p_T **jets**
- **high E_T^{miss} and large transverse leptonic W mass** (M_T^W) * **to** reduce QCD bkg
  - *E_T^{miss} > 35 (25) GeV for e (μ) chan*
  - *M_T^W > 25 GeV (60GeV - E_T^{miss}) for e (μ) chan*
- Data-driven **QCD** (*matrix method*), **W+jets normalization** (*from W asymmetry meas.)*
- **Reconstruct $t\bar{t}$ with kinematic lkl fit** *(m_{top},m_W constraint)* → Δ|Y| distribution
- **Subtract bkg and unfold** dN/dΔ|Y| for det effects *(iterative bayesian)* → **derive A_C**
- **Combine e and μ chan** with weighted average *including syst and correlations*

$$A_C = -0.024 \pm 0.016\,(\text{stat}) \pm 0.023\,(\text{syst})$$

consistent with SM, *main accep syst: generator, pshower*

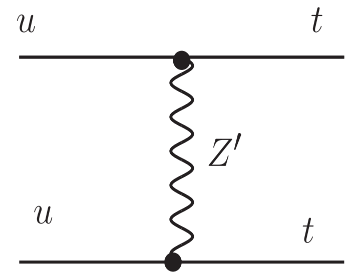


$$A_C = -0.009 \pm 0.023\,(\text{stat.}) \pm 0.032\,(\text{syst.})$$



$$A_C = -0.028 \pm 0.019\,(\text{stat.}) \pm 0.022\,(\text{syst.})$$

Search for same-sign $t\bar{t}$ production with $\mu^+ \mu^+$ pairs



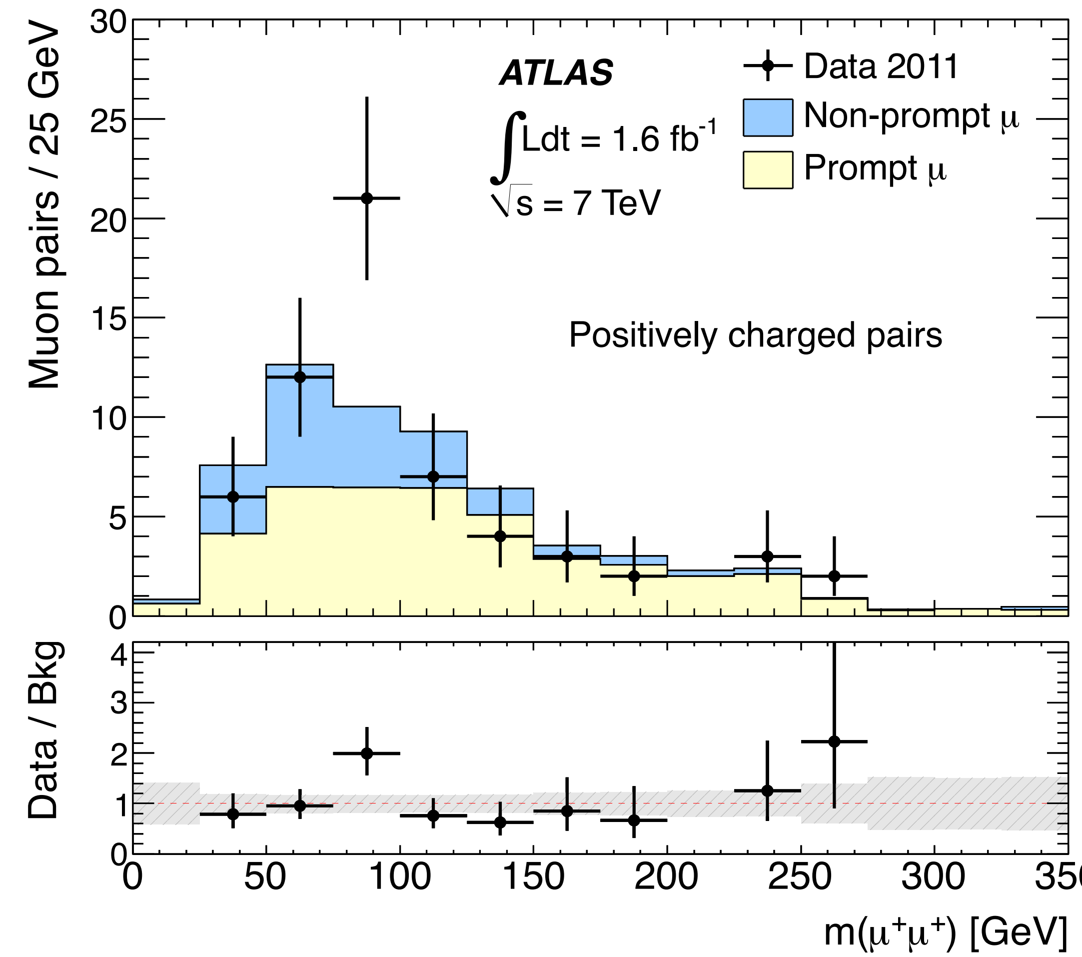
$\int L dt$ = **1.6 fb^{-1}** *(2011)*

NEW!

arxiv:1201.1091

- **Single μ trigger, ≥2** central isolated **μ^+** $q_{spectr}=q_{ID}$**,** ≥1 ($\mu^+\mu^+$) pair with M($\mu^+\mu^+$) > 15 GeV

- **Bkg: simulated di-boson prompt μs** *(WZ/γ,Z/γZ/γ, W±W±,ttW).* **Data-driven non prompt μs** (heavy/light favour decay) *(matrix method with iso prob for prompt/non-prompt μ from 1 μ, high d/σ(d) region).* ***Negligible charge mis-id*** *from Z→μμ.*



- **No excess found→ Bayesian 95%CL on N($\mu^+\mu^+$)** *including syst and correlations →* ***fiducial limits →upper limit on σ($t_R t_R$)***

$$\sigma_{95}^{fid}(\mu\mu) = \frac{N_{95}(\mu\mu)}{\varepsilon_{fid} \int \mathcal{L}\mathrm{d}t}; \qquad \sigma_{95} = \frac{\sigma_{95}^{fid}(\mu\mu)}{A_{fid}}$$

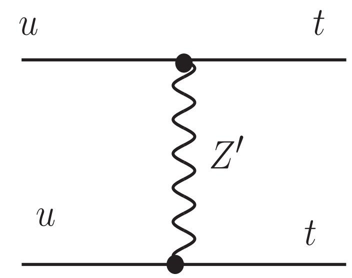
same cuts as sel

$m(Z')$	$\sigma_{95}(t_R t_R)$ [pb] expected	observed
100 GeV	$4.2^{+2.3}_{-0.9}$	3.7
150 GeV	$3.3^{+1.9}_{-0.7}$	3.0
200 GeV	$2.9^{+1.6}_{-0.6}$	2.6
$\gg$ 1 TeV	$2.5^{+1.4}_{-0.5}$	2.2

Search for FCNC-induced same sign top pair production

∫Ldt = **35 pb^{-1}** *(2010)*

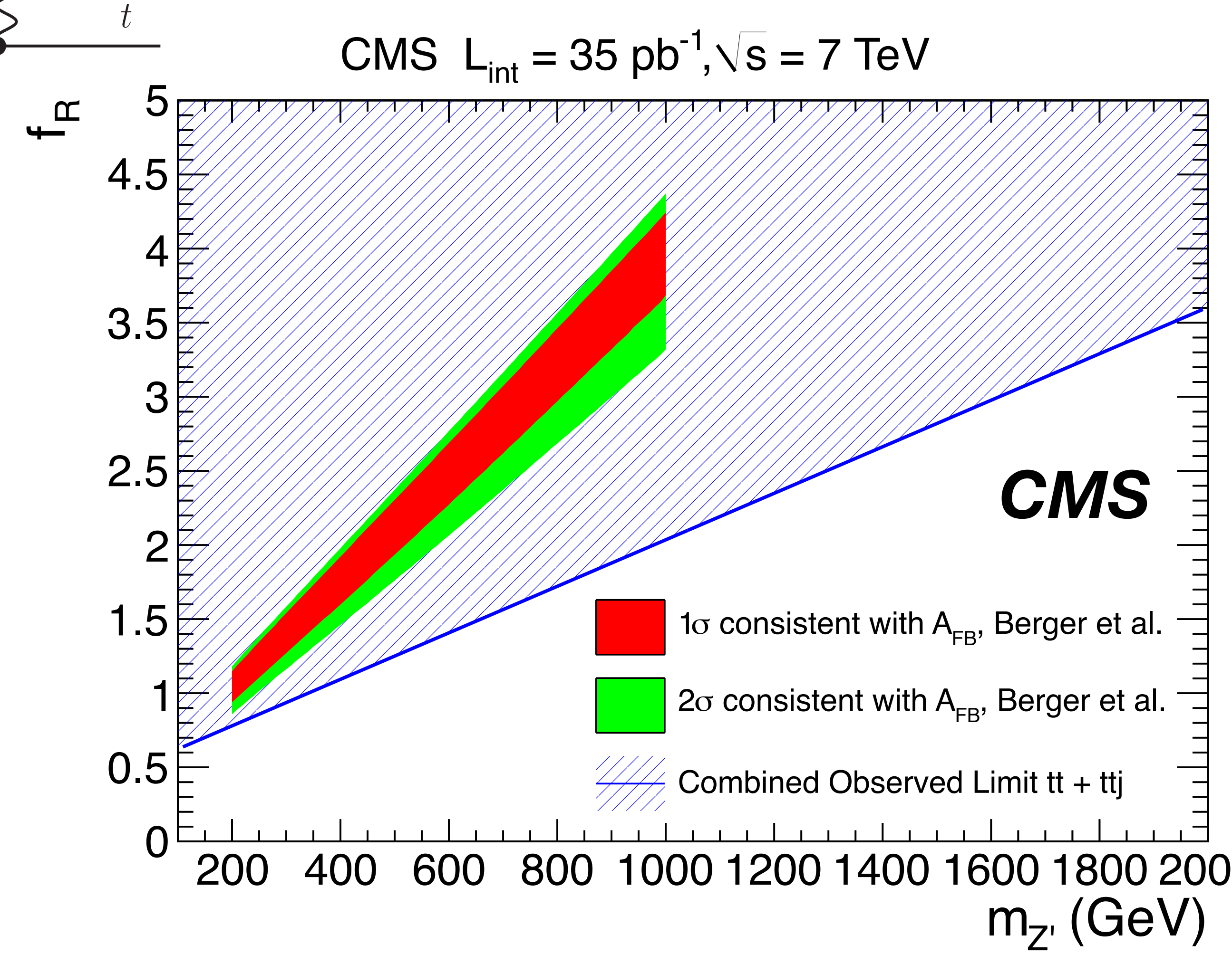
arxiv:1106.21421



- **2 positive** isolated **leptons**, ≥2 jets with p_T >20 GeV, large E_T^{miss} *>20 (30) GeV. Also check with negative lepton pair.*

- **Data driven dominant single lepton ttbar bkg with one fake lep** *from control sample with loose lepton isolation & ID*

- **No excess over bkg → 95%CL Bayesian limits** *systematics as log-normal nuisance pars, cross check with CLs,* **on σ(tt+ttj) as function of r.h. coupling f_R and $M_{Z'}$ →Disfavour preferred region from Tevatron AFB measurement**



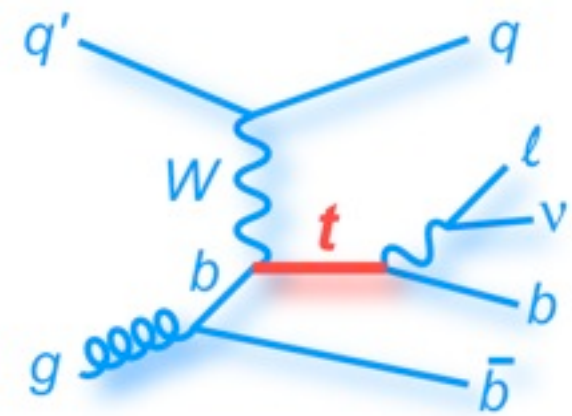
For $M_{Z'}$ = 2 TeV get limit on contact interactions

$$\frac{C_{RR}}{\Lambda^2} < 2.7\ \mathrm{TeV}^{-2}$$

Single top status

$\int L dt$ = **0.7 fb^{-1}** *(2011)*

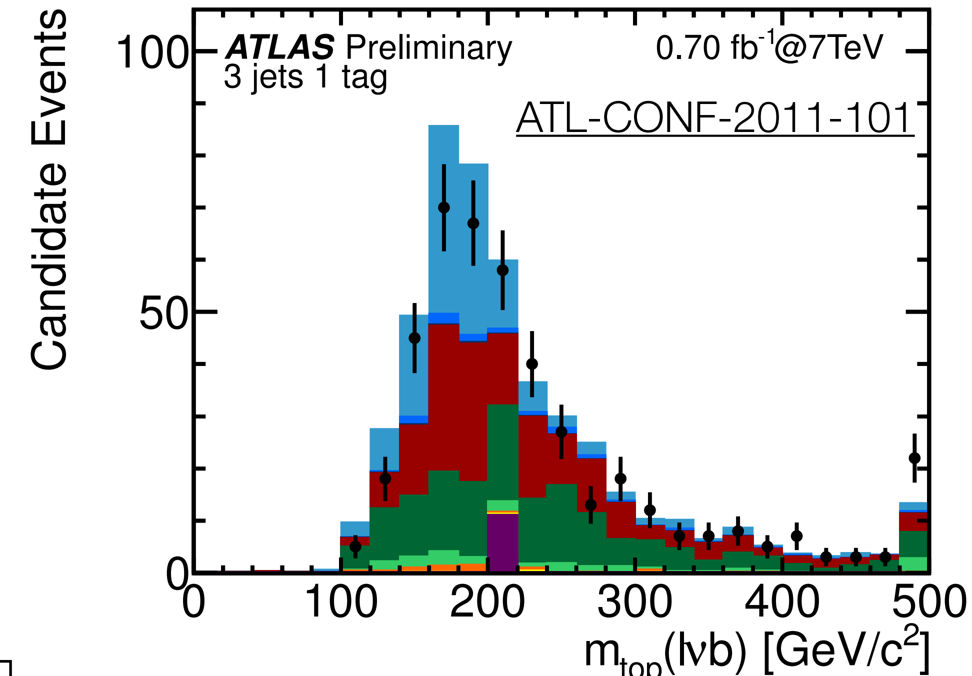
t-chan: qℓνb(b)



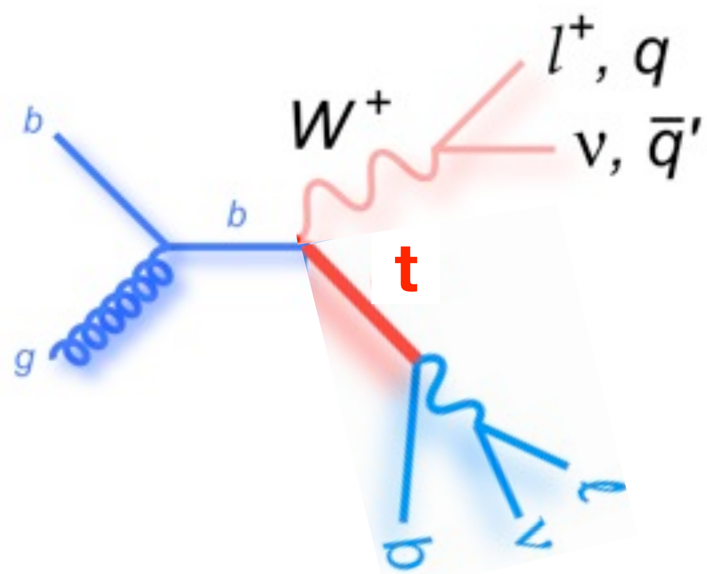
- Observed in t-chan with 7.6 sigma

$$\sigma_t = 90^{+9}_{-9}(\text{stat})\,^{+31}_{-20}(\text{syst})$$

δσ/σ~36%

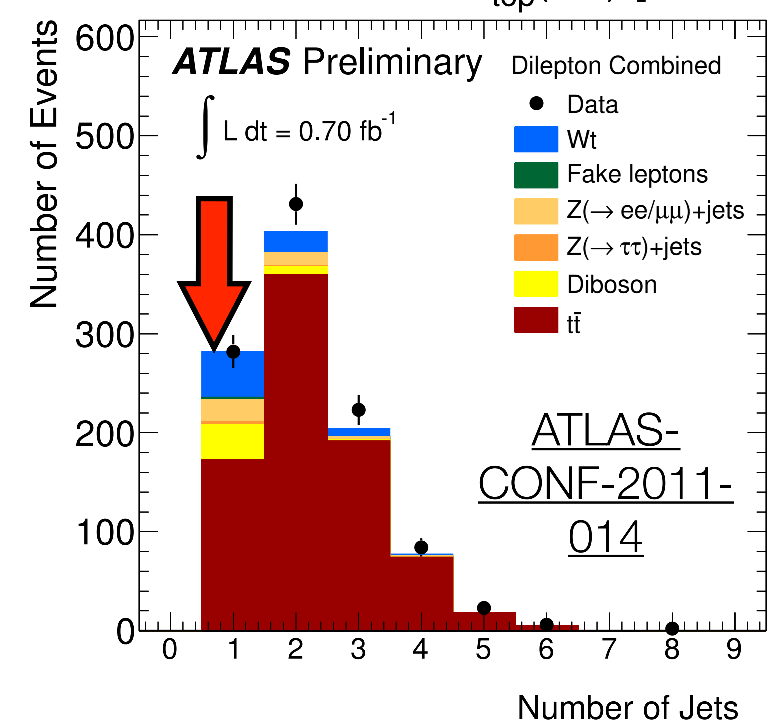


Wt-chan: qqℓνb,ℓνℓνb

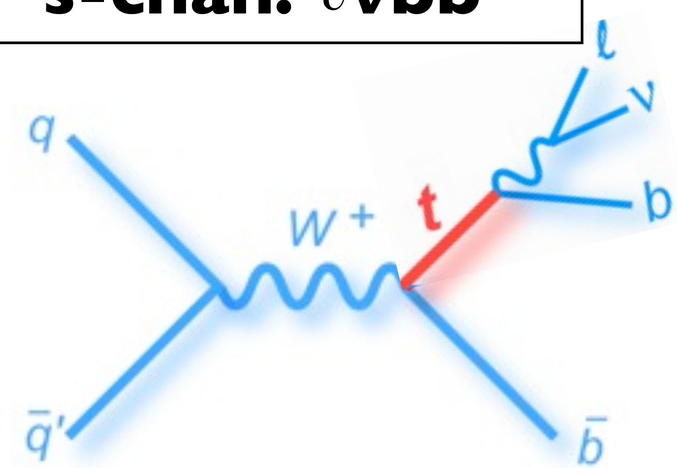


- Have 95% CL obs (exp) upper limit

$$\sigma(pp \to Wt + X) < 39\ (41)\ \text{pb}$$

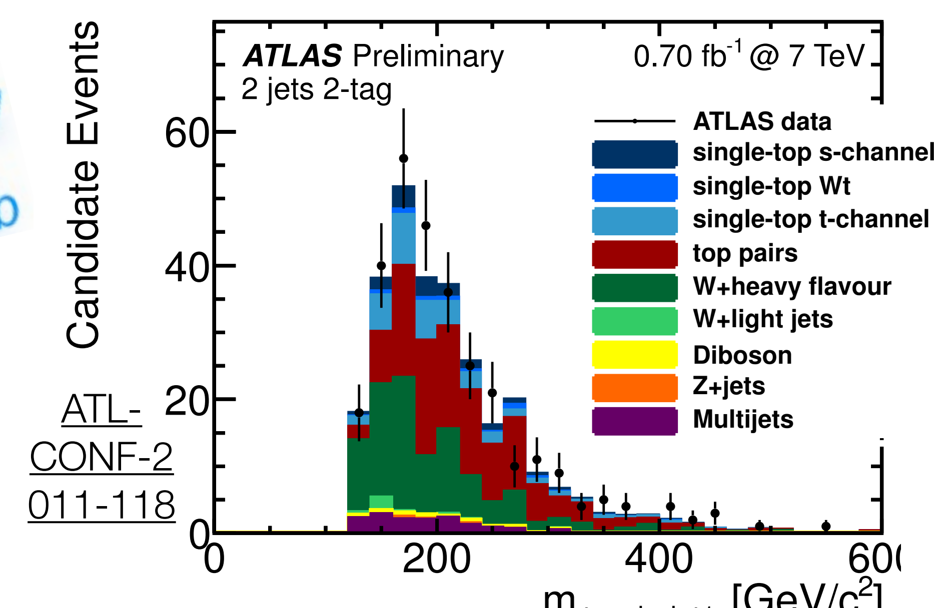


s-chan: ℓνbb



- Have 95% CL obs (exp) upper limit

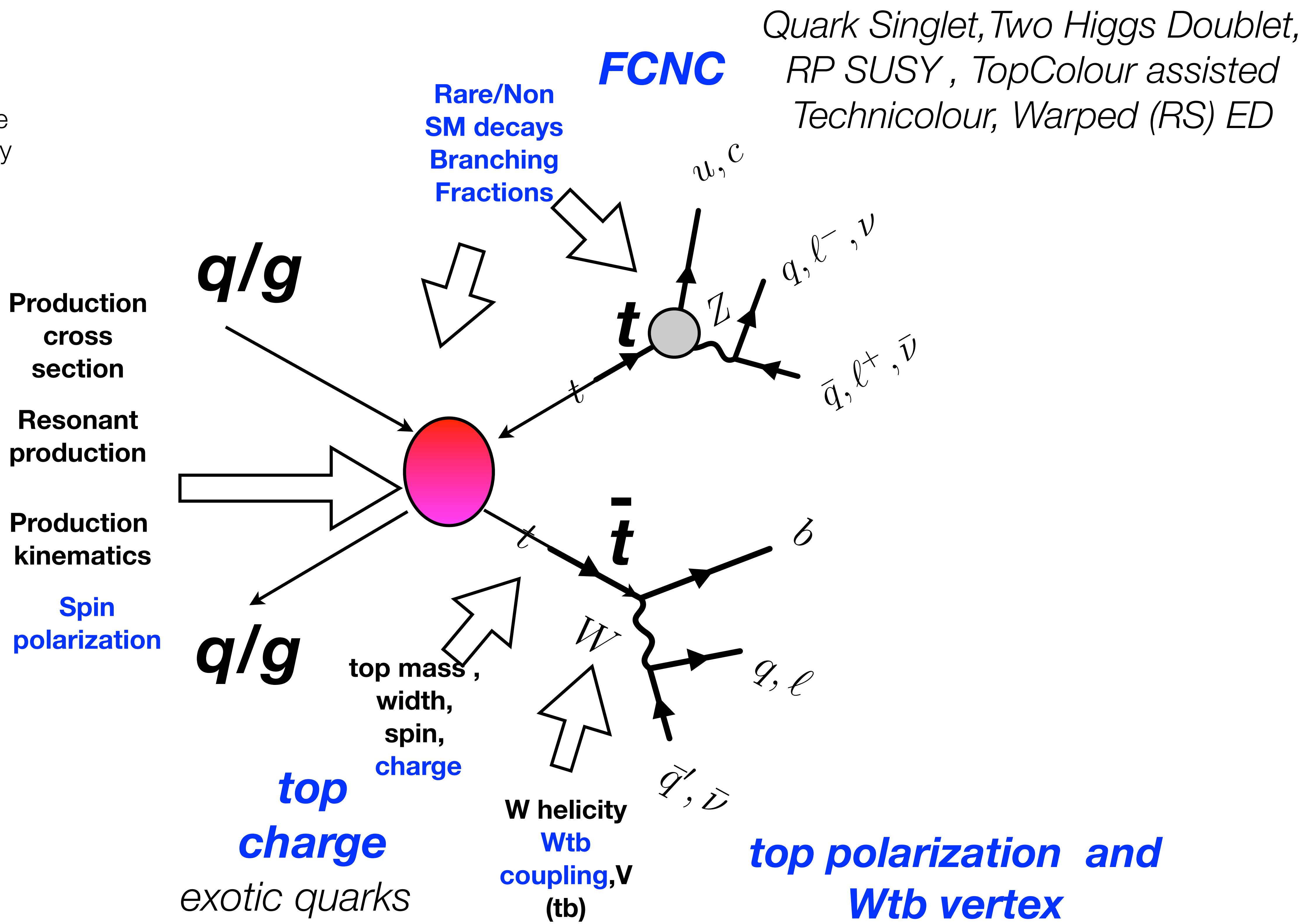
$$\sigma_t\ (s\text{-channel}) < 26.5\ (20.5)\ \text{pb}$$



No deviation from SM observed

Top decay as a window on new physics

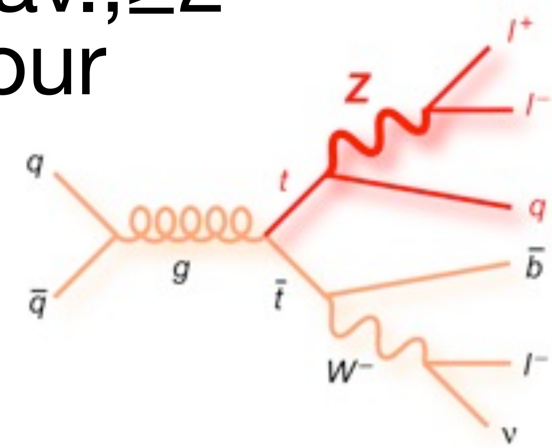
inspired by figure
by D Chakraborty

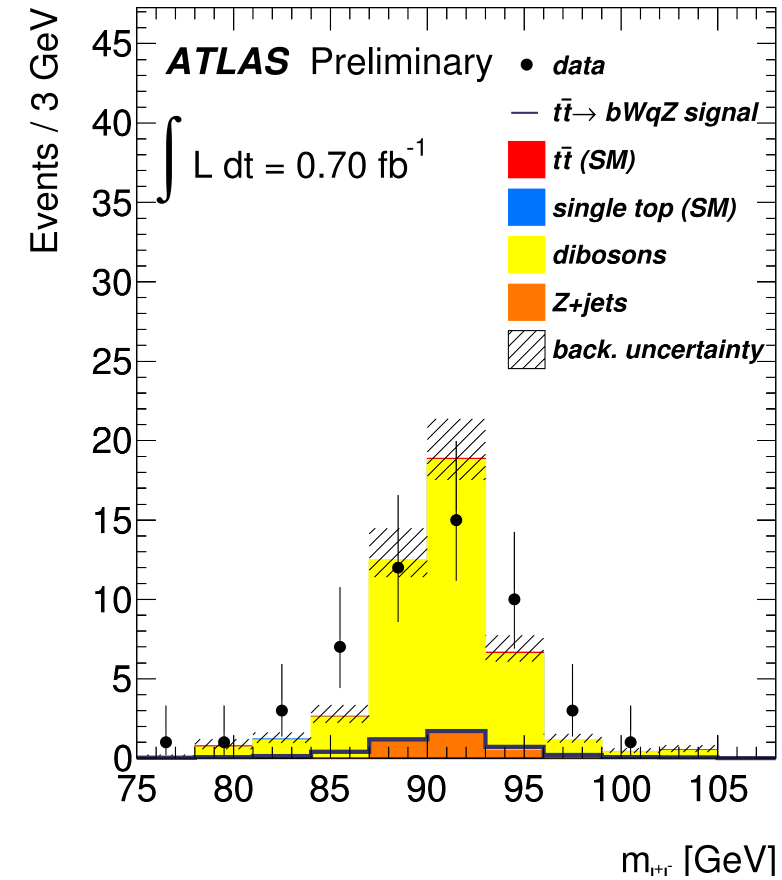


Search for Flavour Changing Neutral Currents in $t\bar{t}$

$\int L dt =$ **0.7 fb^{-1}** *(2011)* ATLAS-CONF-2011-154

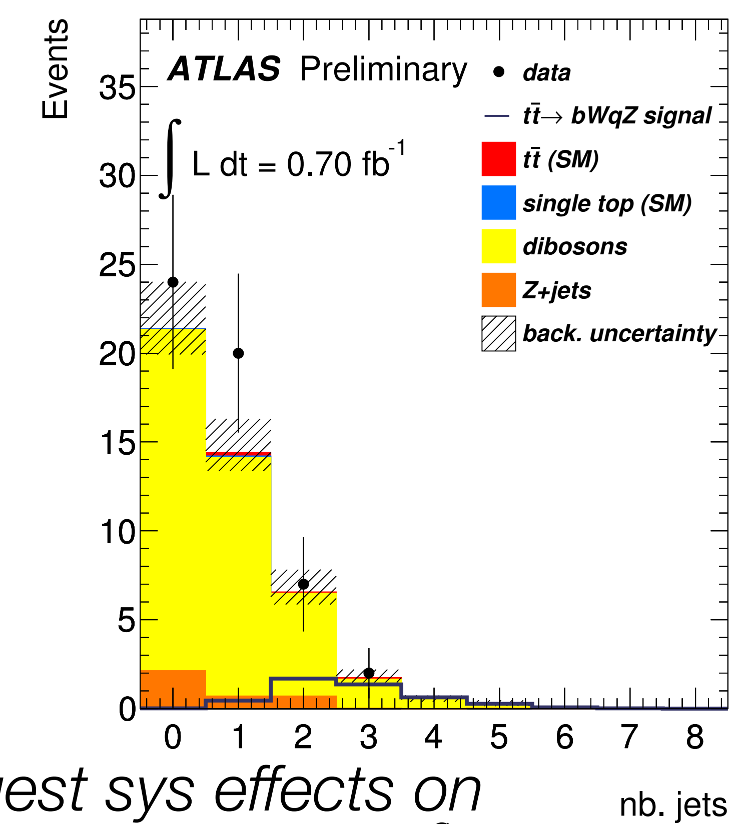
- **single lepton trigger, 3** isolated high p_T **leptons (e,μ)** *from same prim. vertex,* leading lep flav.= trigger flav.,≥2 opposite charge and same flavour
- $|M(\ell^+,\ell^-) - M_Z| < 15$ GeV
- ≥2 jets: *(sub) leading with p_T >20 (30) GeV*, large E_T^{miss} *>20 GeV.*





- **Bkg: dominant di-boson from simul.***(WZ,ZZ).* **Data-driven fake lepton (jets) bkgs: 1** *(WW & di-lepton tt from sim., Z+jets from Z-control region)*, **2** *(W +jets and single top)* **and 3** *(QCD and tt) extrapol. from 3 same-sign lep sample*. *Negligible 1fake+$\ell^+\ell^-$*

- **Reconstruct tt→ WbZb with min Least Square** *(m_{top},m_W,m_Z constraint) → $|m_W^{rec}-m_W|$ <30 GeV & $|m_{top}^{rec} - m_{top}|$<40 GeV* → **No excess found→ frequentist 95%CL on BR(t qZ) =1.1% (exp 1.3%)** *including syst*

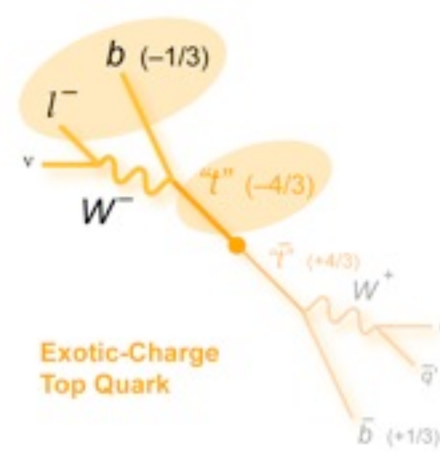


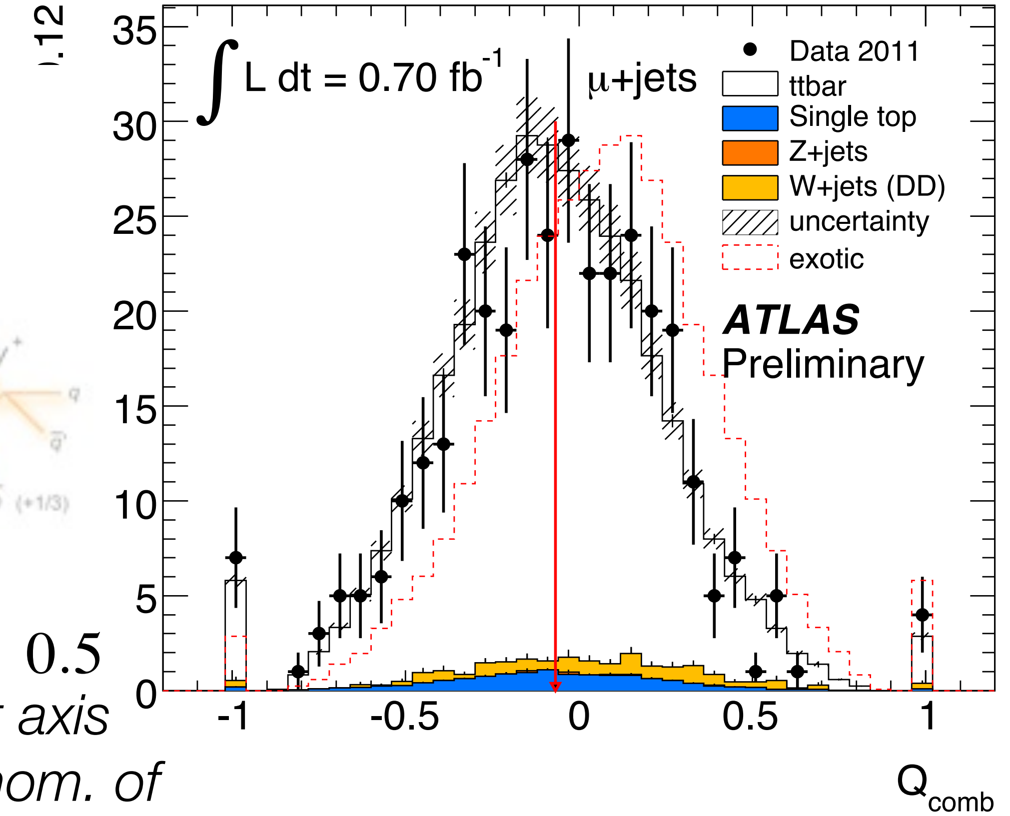
largest sys effects on yield:JES,mu trigger, el id

Top quark charge measurement

ATLAS-CONF-2011-141

- **Same charge asymmetry sel +** *2 b-tags or 1 soft μ with p_T rel to jet axis >0.8 GeV & DR (μ,b)<0.4*
- Data-driven **QCD** (*matrix method*), **W+jets normalization** (*from W asymmetry meas.)*





- **Two top charge determinations**
  - **In 2 b-tag** : weighted sum of (at most) 10 b-track charges in a 0.25 cone

$$Q_{b\,jet} = \frac{\sum_i q_i |\vec{j}\cdot\vec{p}_i|^\kappa}{\sum_i |\vec{j}\cdot\vec{p}_i|^\kappa}$$

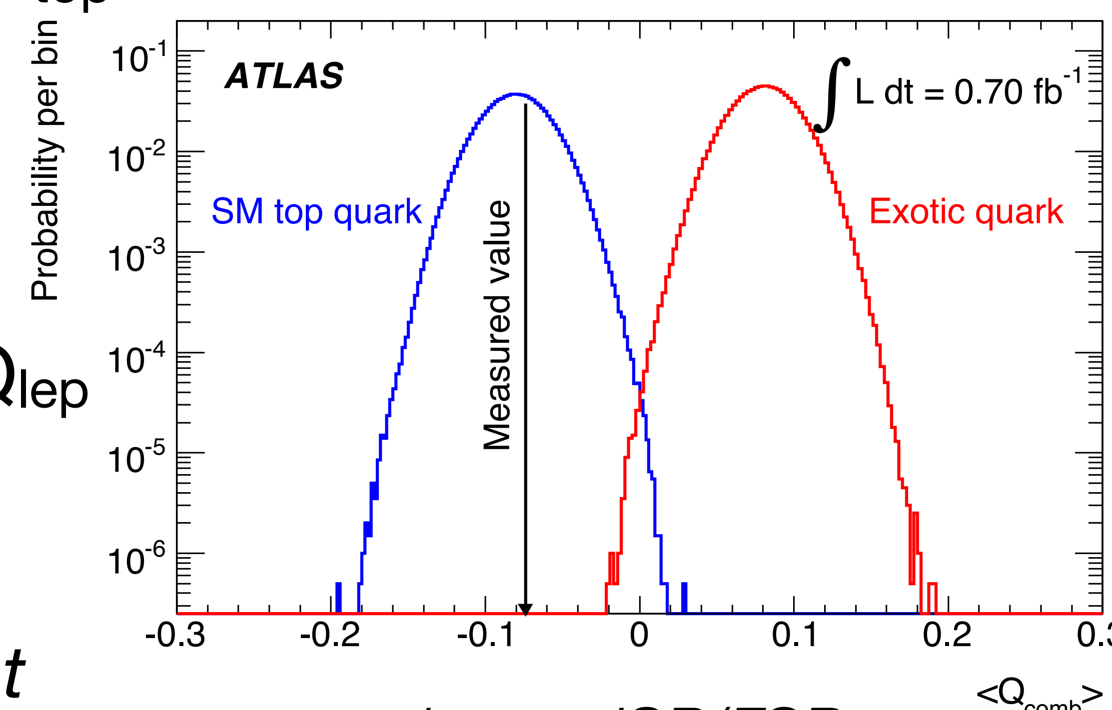
$\kappa = 0.5$

j = jet axis

p_i = mom. of i^{th} track

  - **top charge** is $Q_{comb} = Q_{b\,jet} \cdot Q_\ell$

    Q_ℓ charge of b-matched lepton ← m(ℓ,b) < m_{top}
  - Keep only events with 1 matched b-tag
  - **In soft mu** : Reconstruct events with Kinematic Fitter → pair jet with soft μ from W decay: **top charge is** $Q_{conb}^{soft} = Q_{soft\mu} * Q_{lep}$



main syst:ISR/FSR

- **Compare measured <Q> with expected distribution** for SM and exotic quark (Q = -4/3e) from pseudo exp *(Gaussian fluct for syst and stat)* →***exclude exotic q at C.L. > 5 sigma***

Measuring Top Polarization

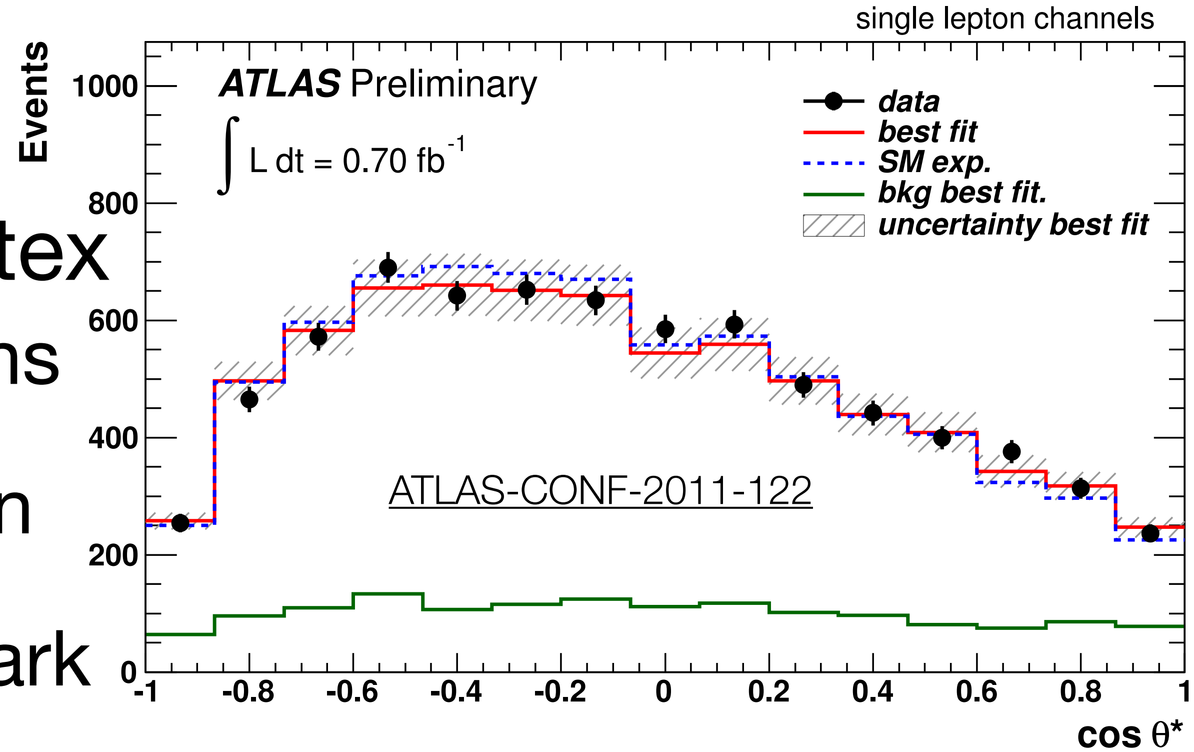
$\int L dt$ = **0.7 fb^{-1}** *(2011)*

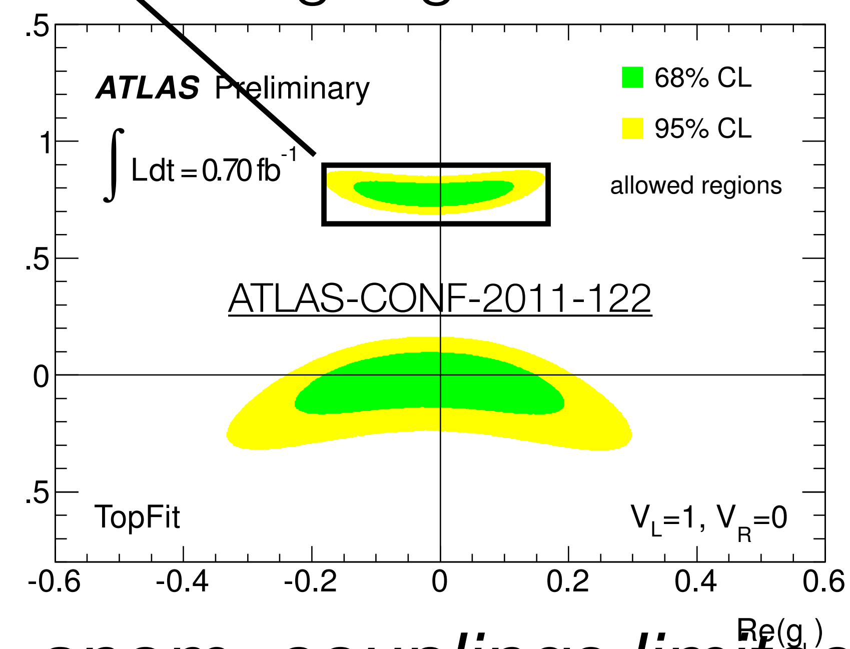
- Top quark decays before hadronization: $1/\Gamma_{top} < 1$ fm → top polarization preserved in angular distrib of decay products

incompatible with single top

SM: $g_R = g_L = 0$ at LO

- t → Wb V-A vertex
  - helicity fractions from angle between lepton from W and reversed b-quark direction in W rest frame

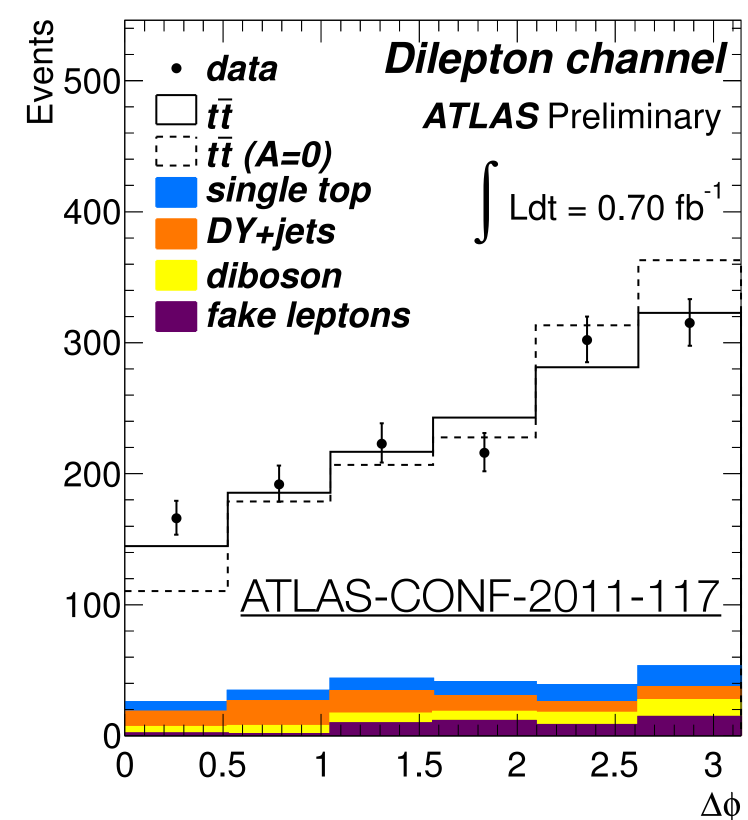




anom. couplings limited by asymmetries

- tt spin correlations: expect correlation in decay products

In di-lepton events ($l^+\nu l^-\nu b$), $|\phi_{l+} - \phi_{l-}|$ separates SM from no-corr



No deviations from SM

Some words on prospects *(personal view)*

- **Expect higher statistic searches to extend limits in the TeV/ sub pb region**
  - **boosted top regime** will use new tagging/reconstruction techniques, associated syst uncertainties
  - consider jet triggers for boosted regime
  - pile-up understanding for standard and "fat jets"

- **Go for precision realm in tt cross section + observe single top** beyond t channel. Measurements are mostly **systematics dominated (that's where the work is).**

- Go for differential xsec measurements ($d\sigma/dm_{tt}$, $d\sigma/dp_{T,tt}$, $d\sigma/dp_{T,top}$, $d\sigma/dy_{tt}$) test SM and complement direct searches

Conclusions

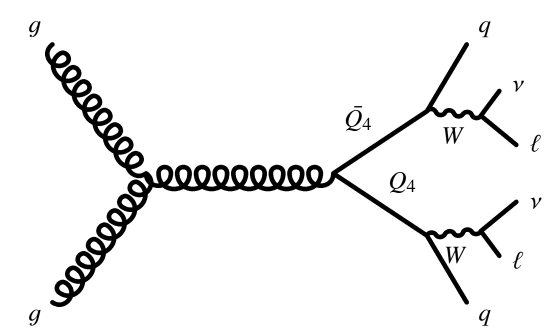
- **Top analysis is in full swing** thanks to the combined performance of LHC & detectors: **a very rich program is already underway.**
- The rapidly **increasing data-set and detector understanding** is quickly opening **unprecedented phase space for new physics searches linked to both top production and decay** *ranging from resonances to dark matter candidates*
- Present measurements do not show deviations form the standard model.
- Analysis of full 2011 dataset is in process. Expect new results in coming months. Eagerly await more luminosity in 2012.

BACK-UP

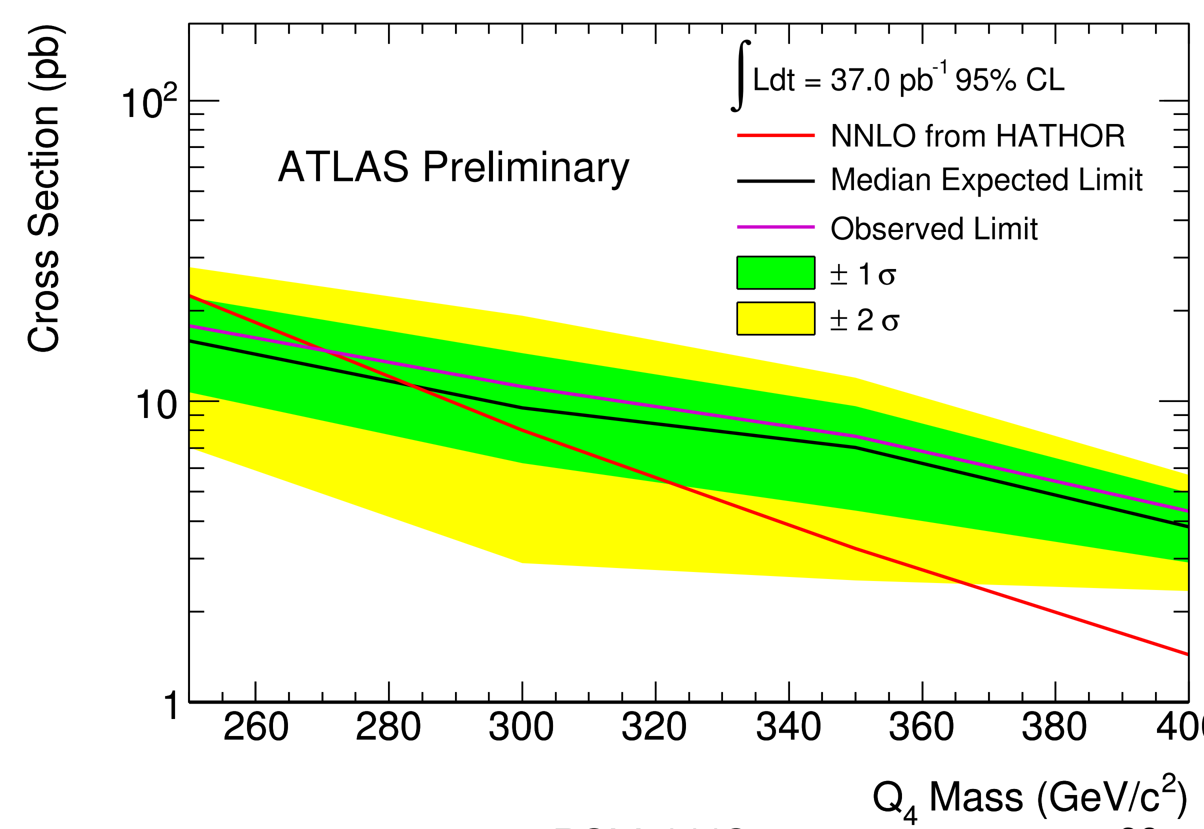
Search for 4th generation quarks

$\int L dt$ = **35 pb^{-1}** *(2010)*

- **Approximate mass reco in collinear assumption**



- **Binned max lkl Fit of data ->sigma and shape**
- **No excess over bkg → 95%CL limit** *set with Neyman construction a la Feldman-Cousins:* **m_{Q4} >270 GeV**



LHC : a *Top* producer

counter-rotating high intensity proton bunches colliding at center of mass energy (E_{cm}) = 7 TeV in 27 Km tunnel

E_{cm}*(Tevatron)= 1.96 TeV*

$$\mathcal{L} \propto \frac{N_1 N_2 n_b}{\sigma^2}$$

parameters:

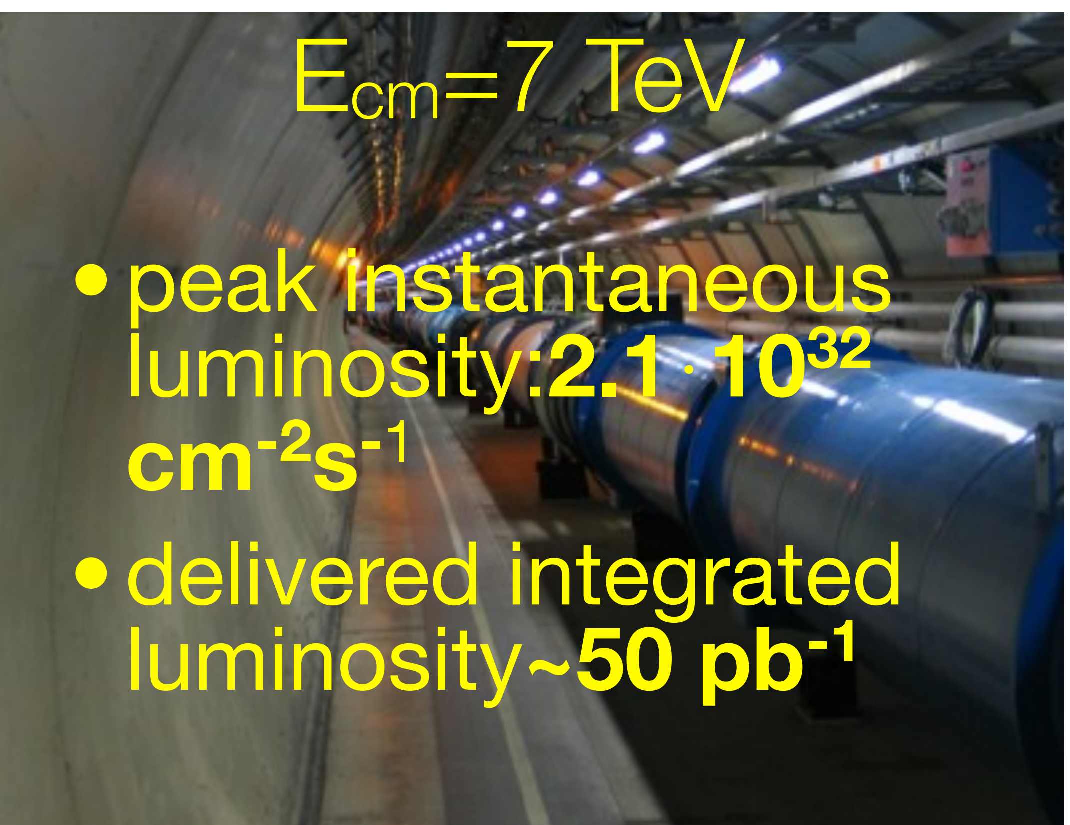
N_i = bunch intensity

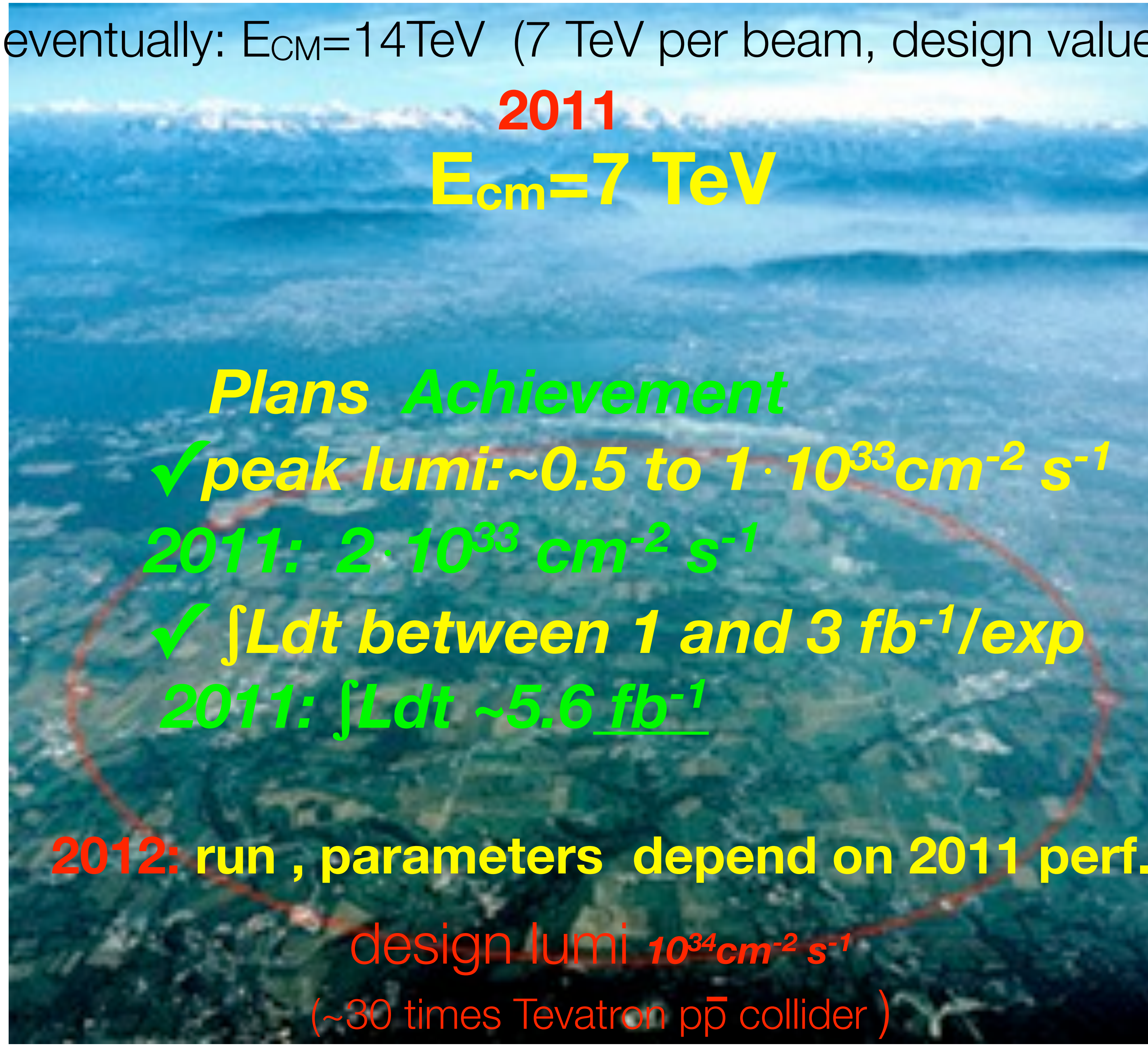
n_b = number of bunches

σ = colliding beam size

Ad maiora..

2010





$N_{events}(\Delta t)$= ***∫Ldt*** * cross section

Simulation SM Monte Carlo used in top analyses

Generation

A=ATLAS**, **C=CMS

- **Top quark : MC@NLO (A), MADGRAPH(C)**
  - xsec is normalized to NNLO from HATHOR
  - variations with ACER (A), POWHEG(A,C)
  - tau decays with TAUOLA
- **Single top : MC@NLO(A), MADGRAPH (C)**
  - t, Wt and s channels
  - normalized to NNLO, <u>remove Wt overlaps</u> with tt final state

Simulation for pile-up mostly included (from zero to 8 events on av (A))

- **Z/gamma+jets** : **PYTHIA (A)** for Z_tautau, **ALPGEN (A)** for Z to ee and Z to mumu NLO factor of 1.25, MADGRAPH(C) $Q_4 \to Wq$
  - Z+cc,Z+bb
- **Di-boson** : *WW, WZ,ZZ:* ALPGEN normalized to MC@NLO, HERWIG normalized to NLO from MCFM (A); $W^{\pm}W^{\pm}$,*ttW* with MADGRAPH (A),
- **W+jets**: **ALPGEN** (A), **MADGRAPH**(C)
  - W+n light partons (exclusive MLM for n,4, inclusive for n=5) W+bb, W+cc, W+c

Hadronization

- **HERWIG + JIMMY for underlying event for xsec(A), PYTHIA for di-boson, PYTHIA(C)**

Detector

- **GEANT4**

Simulation BSM Monte Carlo used in top analyses (II)

Generation

A=ATLAS, C=CMS

- **FCNC production (u→tZ'): PROTOS**
  - xsec is normalized to NNLO
- **FCNC decay (t→uZ) decay: TopReX**
  - t, Wt and s channels
  - normalized to MC@NLO, remove Wt overlaps with tt final state
- **Z/gamma+jets** : **PYTHIA (A)** for Z_tautau, **ALPGEN (A)** for Z to ee and Z to mumu NLO factor of 1.25, MADGRAPH(C)
- **Di-boson** : *WW, ZZ:* HERWIG (A) normalized to NLO from MCFM; $W^{\pm}W^{\pm}$*,ttW* with MADGRAPH (A), PTHIA(C)
- **W+jets**: **ALPGEN** (A), **MADGRAPH**(C)
  - W+n light partons, W+bb, W+cc, W+c

Simulation for pile-up mostly included (from zero to 8 events on av (A))

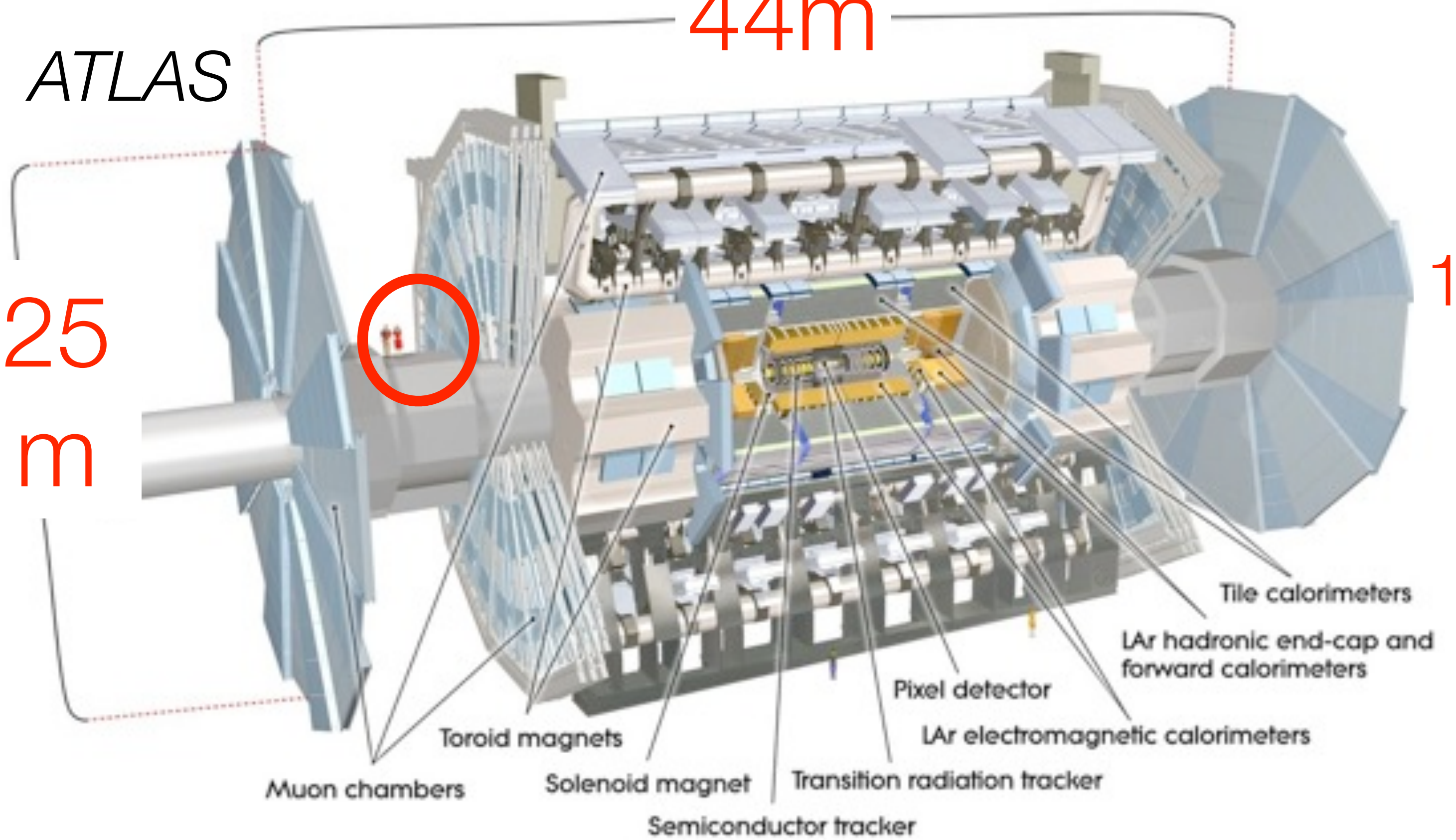
Hadronization

- **PYTHIA**

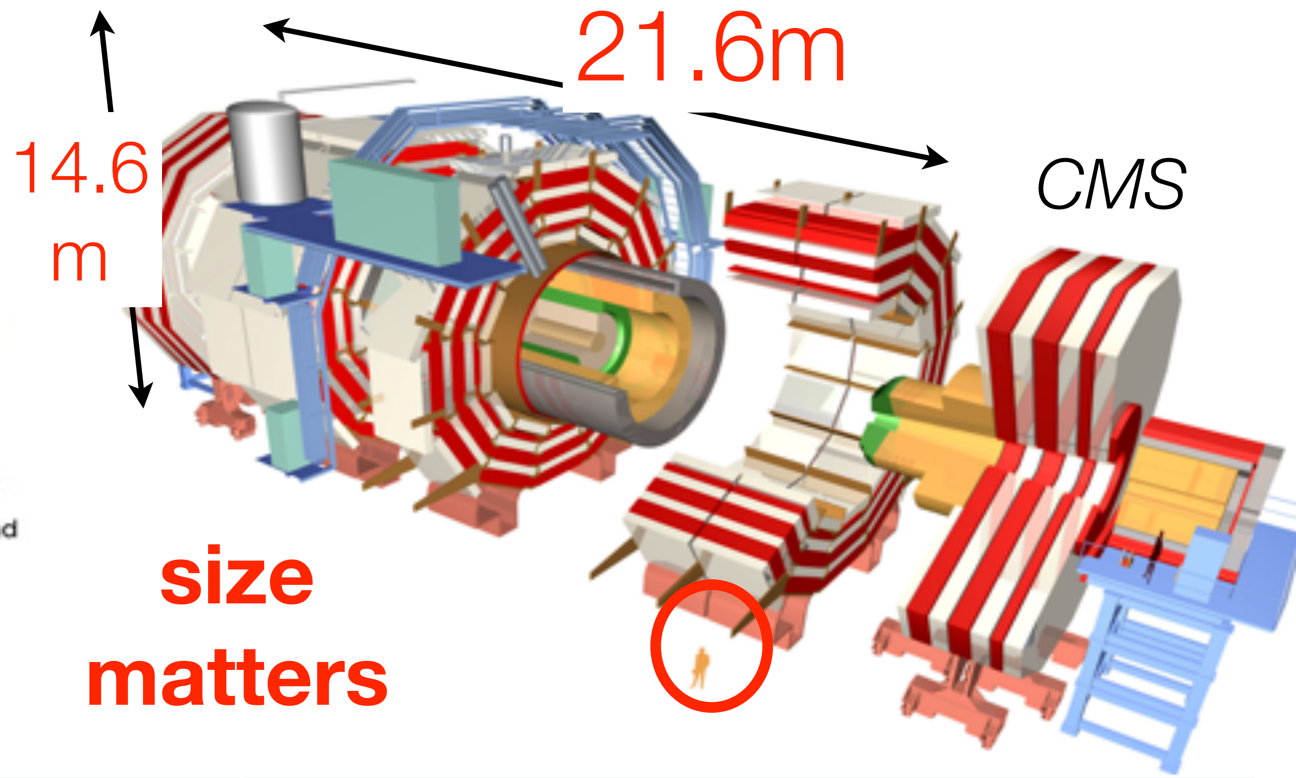
Detector

- **GEANT4**

ATLAS & CMS: *Top* observers



3 (ATLAS) or 2(CMS) trigger levels for event selection



size matters

	ATLAS	CMS
Magnetic field	2 T solenoid + toroid (0.5 T barrel 1 T endcap)	4 T solenoid + return yoke
Tracker	Si pixels, strips + TRT $\sigma/p_T \approx 5x10^{-4} p_T + 0.01$	Si pixels, strips $\sigma/p_T \approx 1.5x10^{-4} p_T + 0.005$
EM calorimeter	Pb+LAr σ/E ≈ 10%/√E + 0.007	PbWO4 crystals σ/E ≈ 2-5%/√E + 0.005
Hadronic calorimeter	Fe+scint. / Cu+LAr/W+LAr (10λ) σ/E ≈ 50%/√E + 0.03 GeV (central)	Cu+scintillator (5.8λ + catcher)/Fe+quartz fibres σ/E ≈ 100%/√E + 0.05 GeV
Muon	$\sigma/p_T \approx$ 2% @ 50GeV to 10% @ 1TeV (ID+MS)	$\sigma/p_T \approx$ 1% @ 50GeV to 5% @ 1TeV (ID+MS)
Trigger	L1 + RoI-based HLT (L2+EF)	L1+HLT (L2 + L3)

Ingredients I : leptons

A=ATLAS,C=CMS

* A=$|\eta_{cluster}| \notin$ [1.37,1,52]

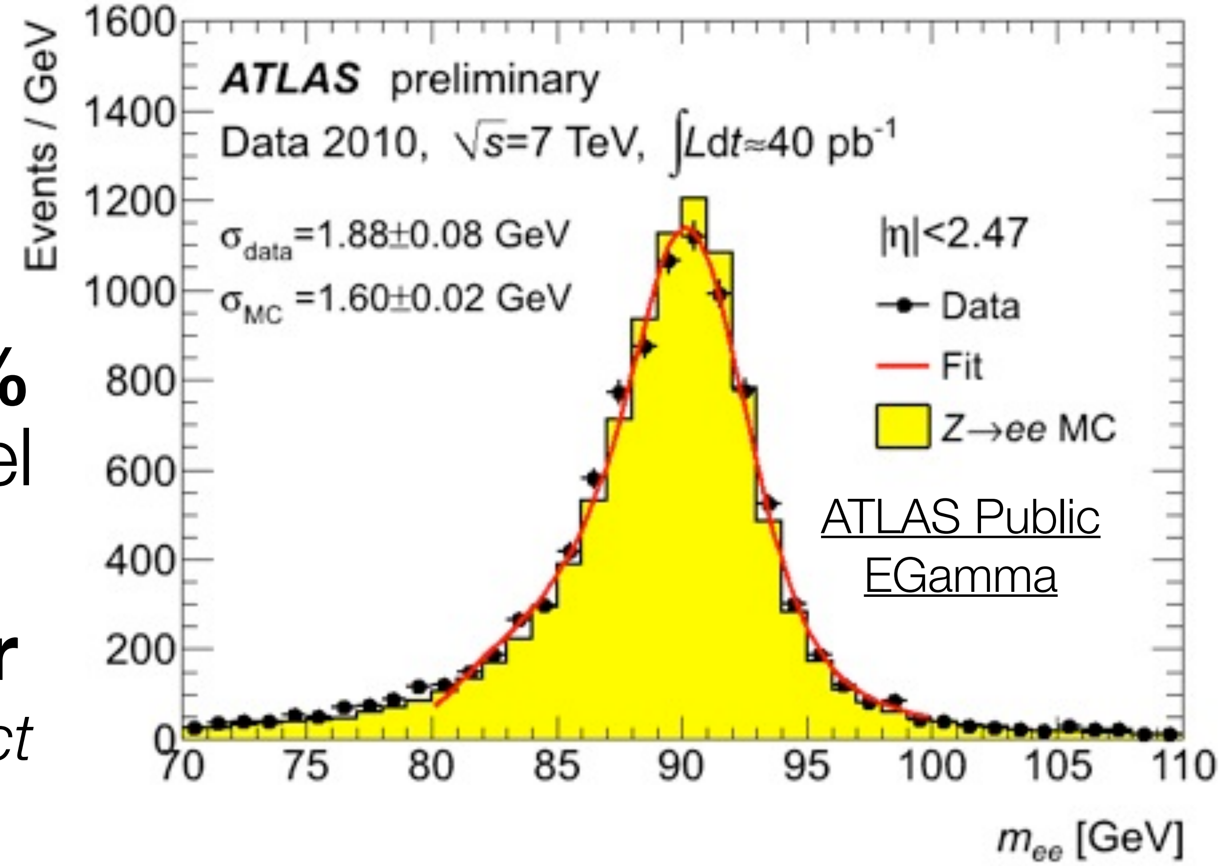
* C=$|\eta_{cluster}| \notin$ [1.44,1,57]

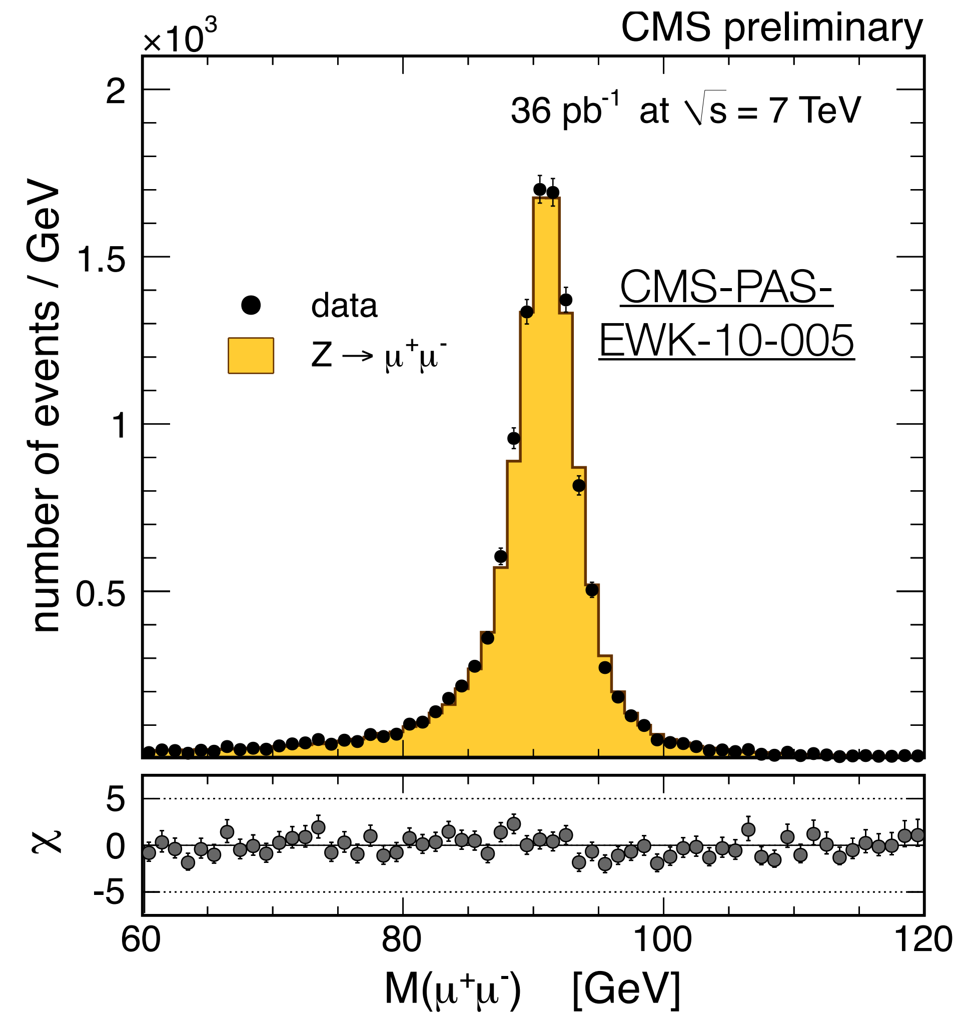
Electrons

- (A) E **scale** *from data known* ***at*** **0.3 to 1.6%** up to 1 TeV (C) ECAL **scale** known **at** level of **0.6% to 1.5%**
- isolated **central*combination of shower shape , track/calo-cluster match** *(correct for Bremsstrahlung, veto conversions)*
  - $|\eta_{cluster}|$<2.4 (A) or 2.5(C), p_T>25(A) or 30(C) GeV
  - **remove duplicate** *close-by (ΔR< 0.2)* **jets** (A) ***or*** *reco* **objects** *(with Particle Flow(PF))*

- **Muons**
  - **p_T scale known at ≈<1%**
  - **isolated central combined fitted track from primary vertex**
    - ❖$|\eta_{track}|$<2.5 (*A*) <2.1(*C*), p_T>20 GeV
    - ❖**suppress heavy flavour decays**: no μ with ΔR< 0.4 (A) or 0.3 (C) from a jet

scale factors to correct small data/MC mismatch

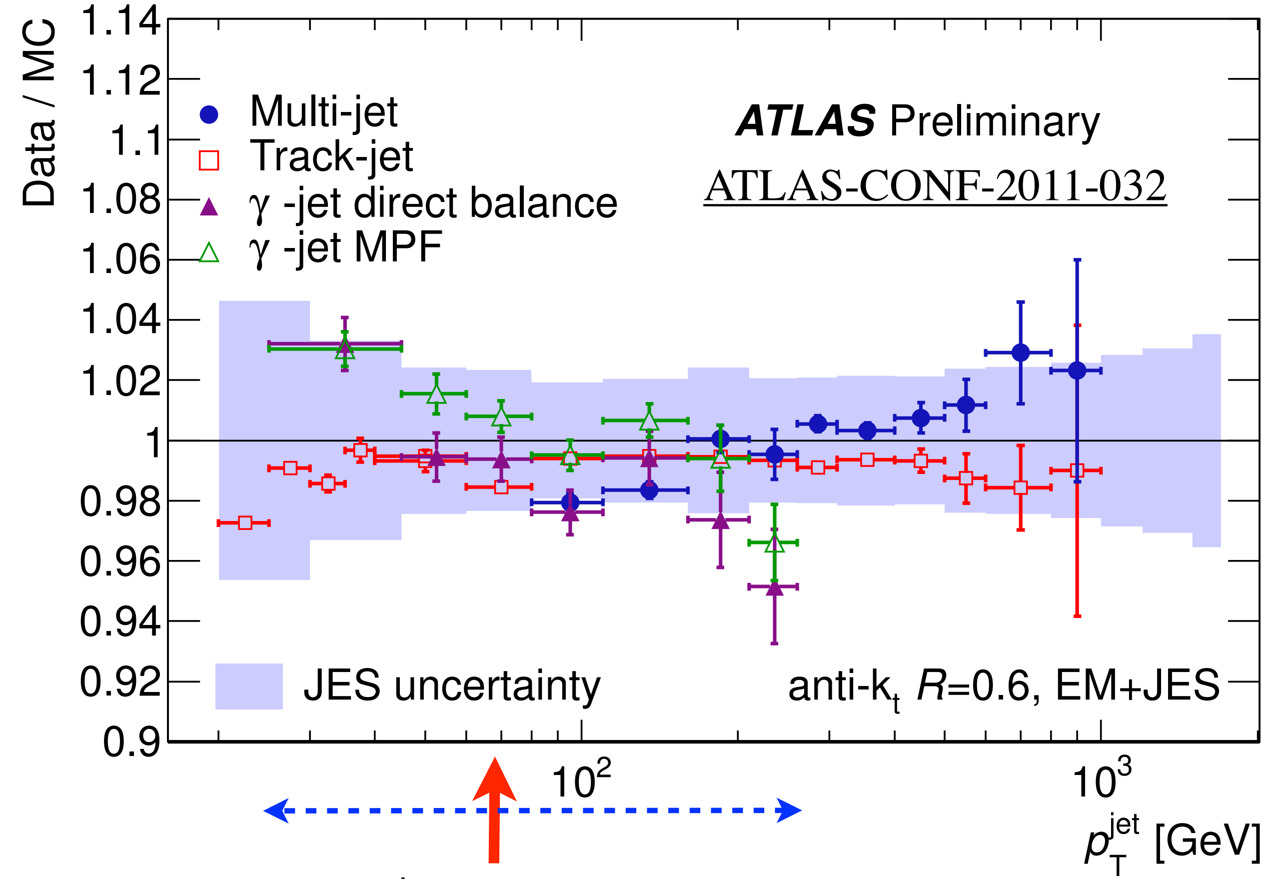




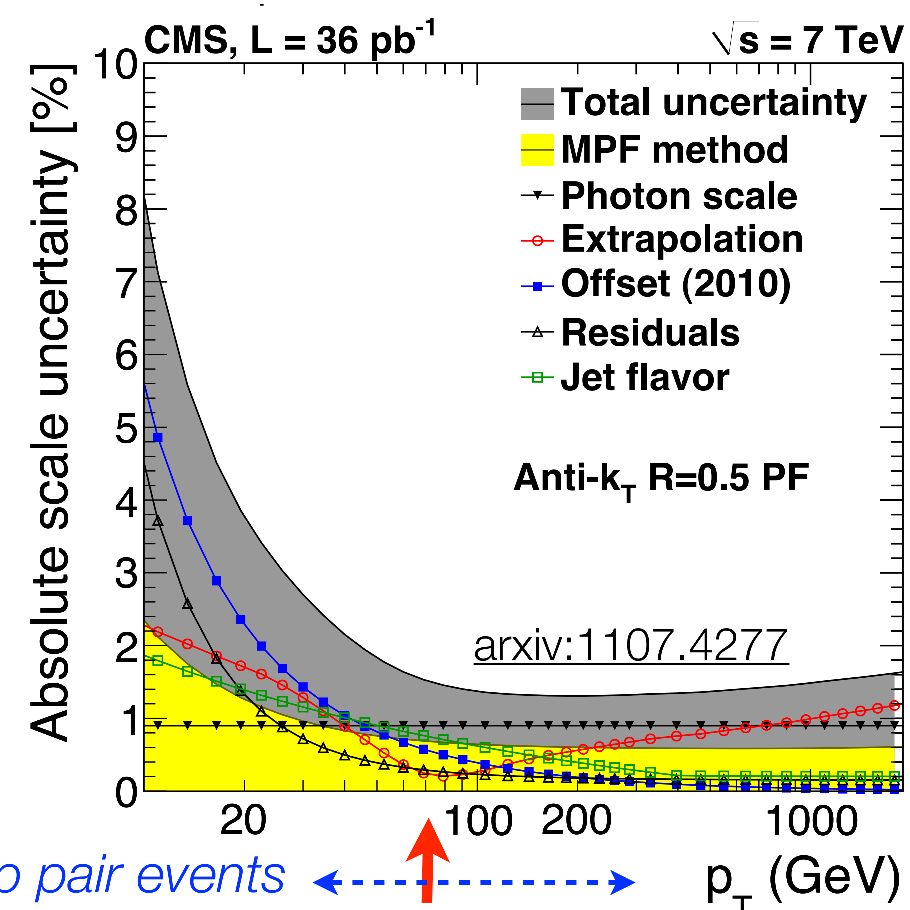
Ingredients II : jets

A=ATLAS,C=CMS

- **Reco**: particle flow objects (C) or 3d calo clusters(A)→ **anti-k_T algorithm** (R=0.4(A),0.5(C))
- p_T > 25(*A*) or 30(*C*) GeV
- $|\eta_{jet}|$ <2.4(*A*) or 2.5 (*C*)



- **Calibrate jet energy scale** with (η,p_T) dependent weight ***from simulated "true" jet kinematics***+ *pile-up offset correction*



- **Scale uncertainty:** *between 2% to 8% in* $\boldsymbol{p_T}$ *and* η
  - Contributions from physics modelling, calo response, det simulation
  - in-situ validation

jet p_T range in single lept top pair events

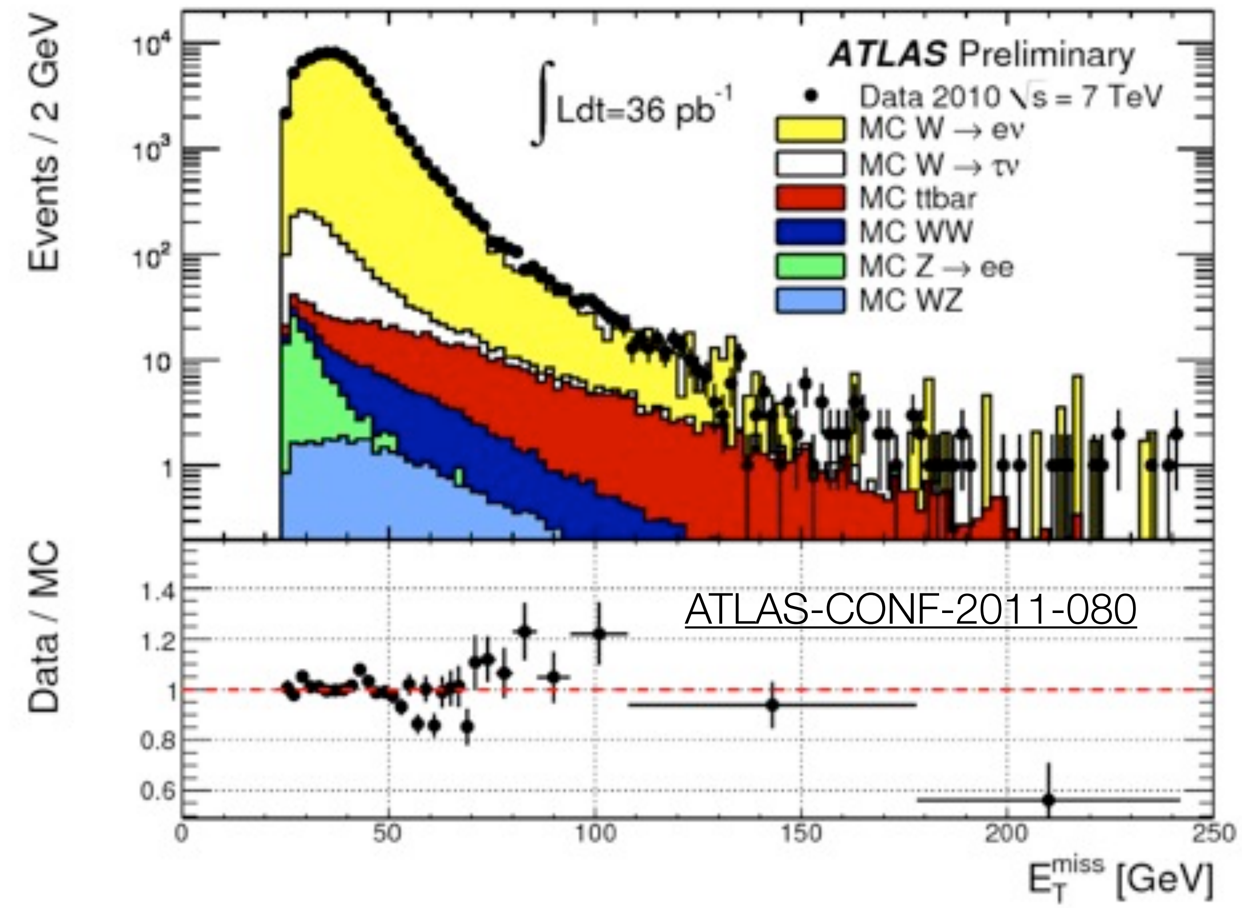
~average jet p_T in single lept top pair events

Ingredients III: missing transverse energy (E_T^{miss})

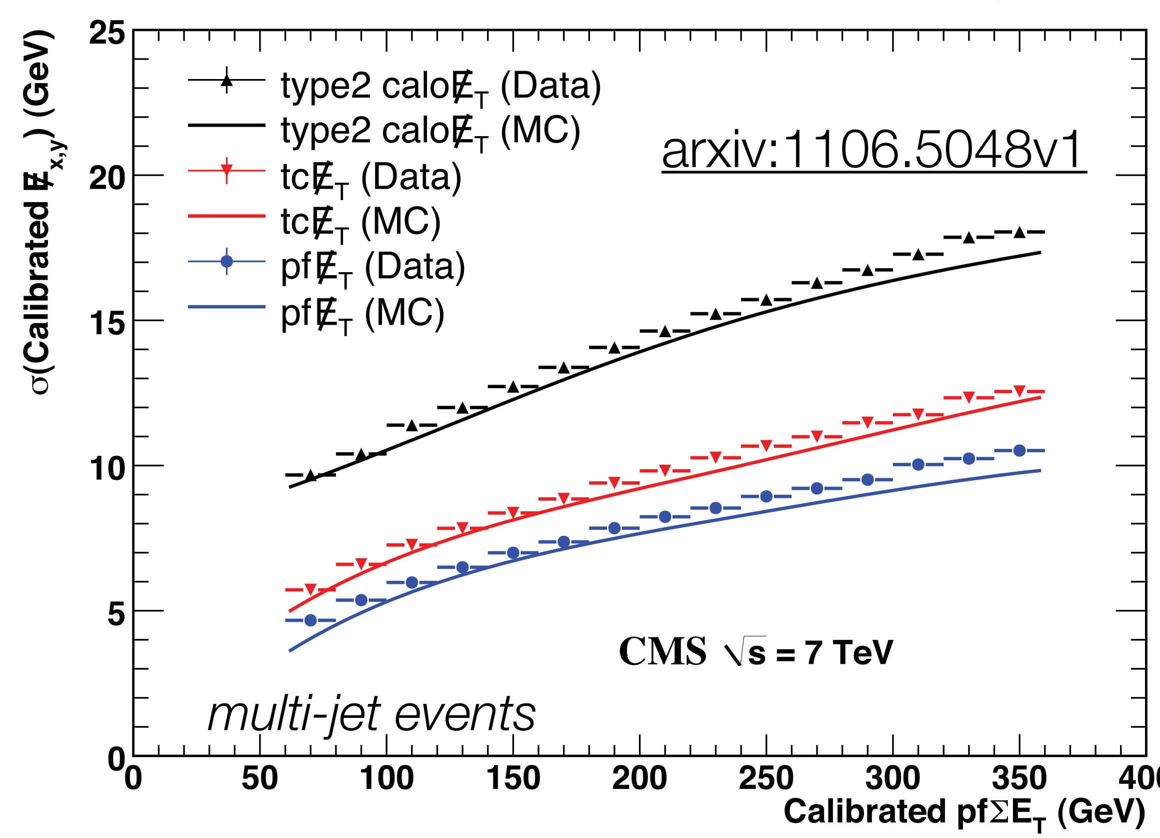
A=ATLAS,C=CMS

- **Negative vector sum** of
  - A: **energy in calorimeter cells,** projected in transverse plane **associated with high p_T object + μ** mom. + dead material loss
  - C: energy/momentum from 1) PF **particle flow objects** or 2) **Calo** towers + μ or 3) **TC**: **Track +Calo**, no double counting

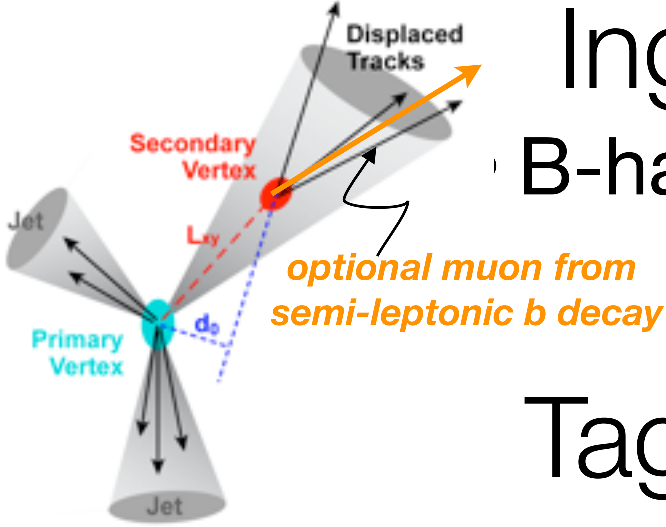
  projected in transverse plane



- Cells/towers/tracks are **calibrated according to association** to high p_T object (electron, photon,tau, jet, muon)



- *Calo cells with overlapping association are counted once*



Ingredients IV : enter b-jets

A=ATLAS, C=CMS

B-hadrons~ long lifetime ~observable flight (few mm)

Tagging

d_0/σ_{d_0}

$L_{3D}/\sigma_{L_{3D}}$

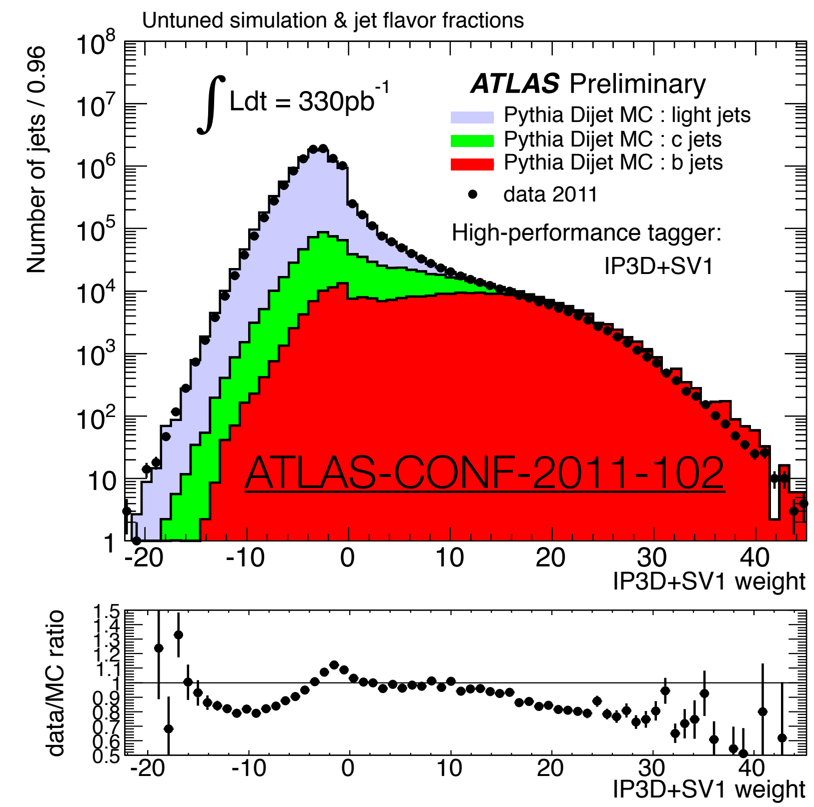
- **A**: (1) jet prob from **track impact parameter** (IP) (2) **3D decay length** significance of sec. vertex (SV) (3) **Neural net** *with 1), 2) + mass of SV tracks + N_{2track} vertices+ E_{SV}(tracks)/E_{PV}(tracks)*
- **C**:(1) 3D **SV decay length significance** *(& N_{tracks} >3)* (2) **track IP** signif. & ≥2 or 3 high **IP** signif. tracks

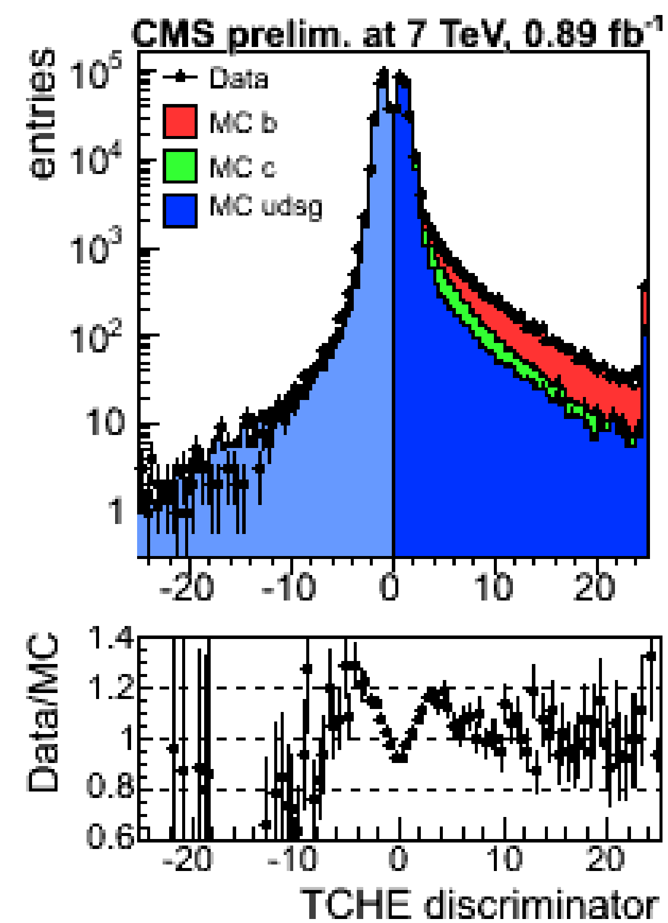
Performance

- **Efficiency: fit fraction** of b-jets in sample with muons in jets, *count # b-tagged*
- **Mis-tag rate**: **from SV properties** (*invariant mass of tracks (A), rate of negative decay length / impact par significance (A,C))*

Efficiency/mis-tag : from **80%/10%** (track/NN based) to **40%/0.1%** (SV based)

p_T dependent scale factors to correct MC





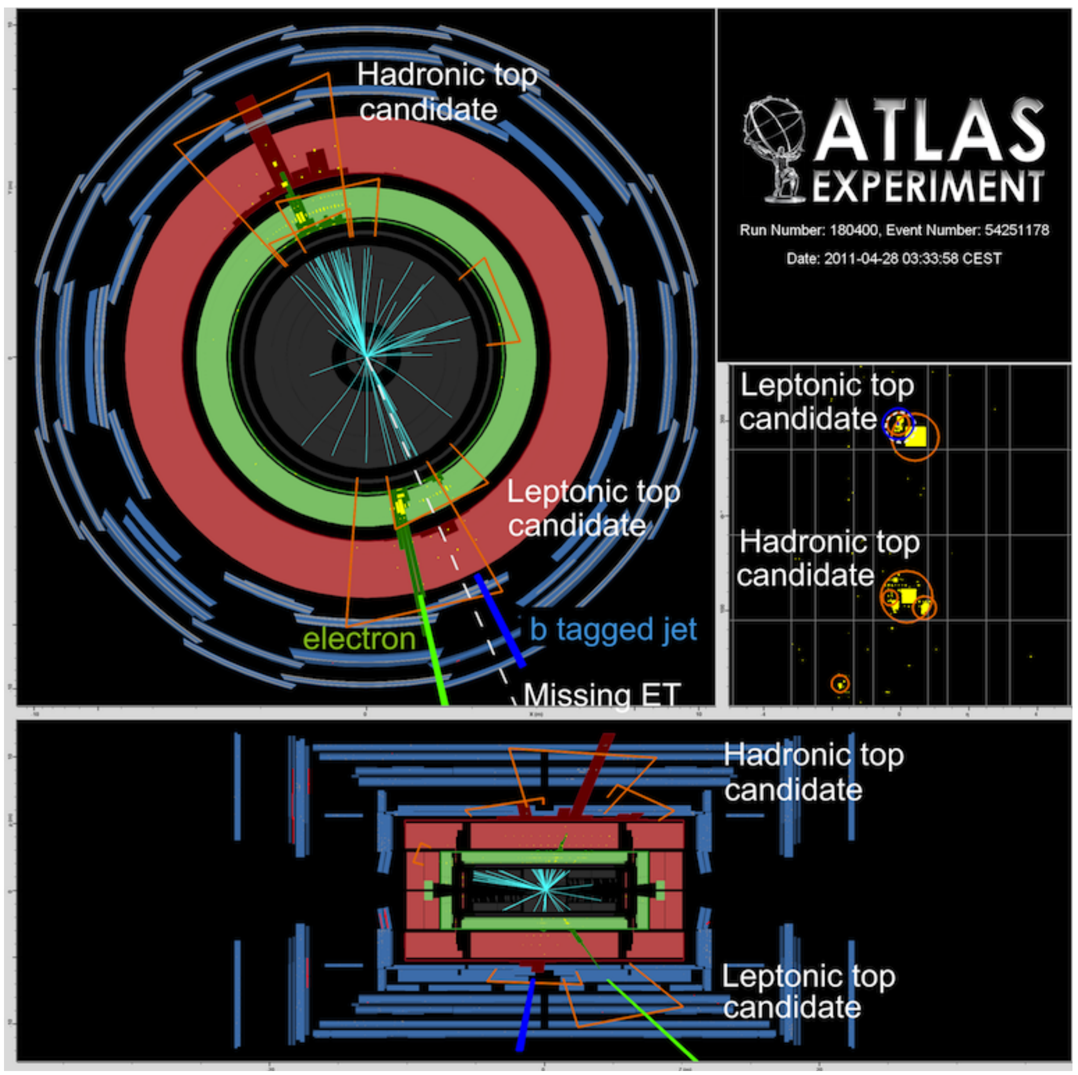
CMS-PAS-BTV-11-001

shape comparison

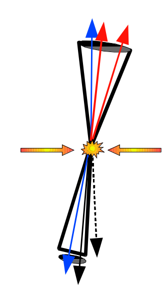
Boosted top ingredients in ATLAS

Search for excess in top pair production vs $M_{t\bar{t}}$: towards boosted config

ATL-CONF-2011-087



semi-leptonic di-top-jet candidate



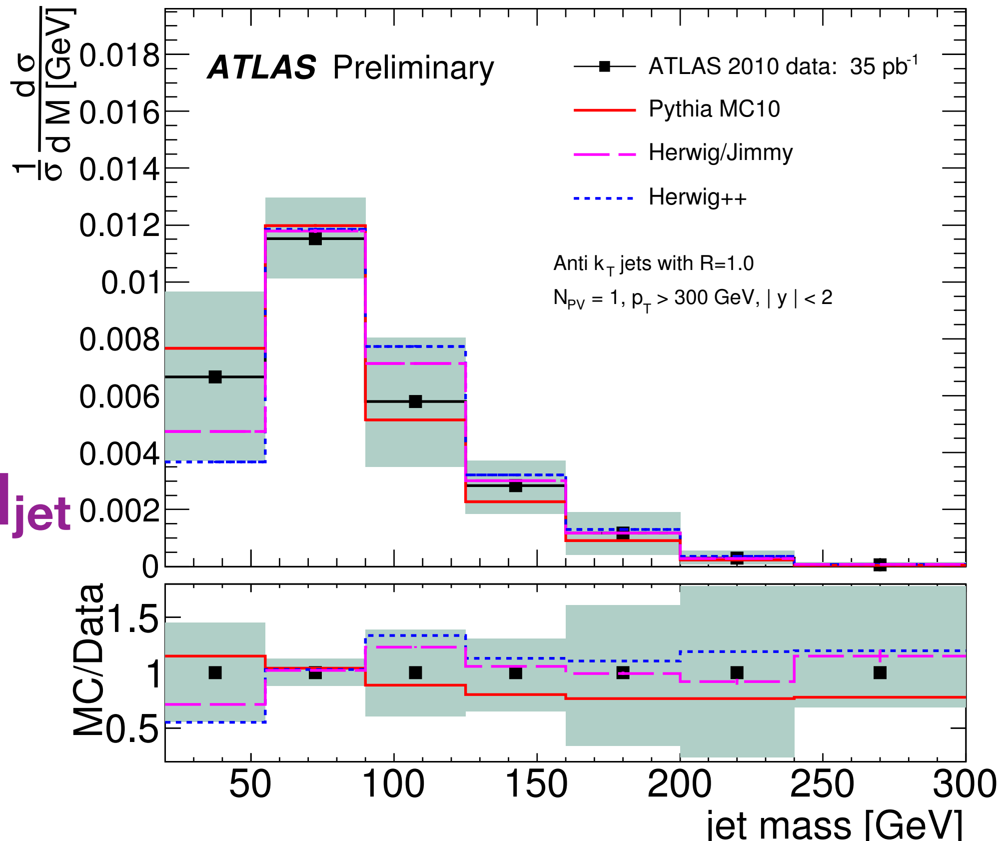
Towards boosted tops: understand "fat" jet substructure

The hadronic leg

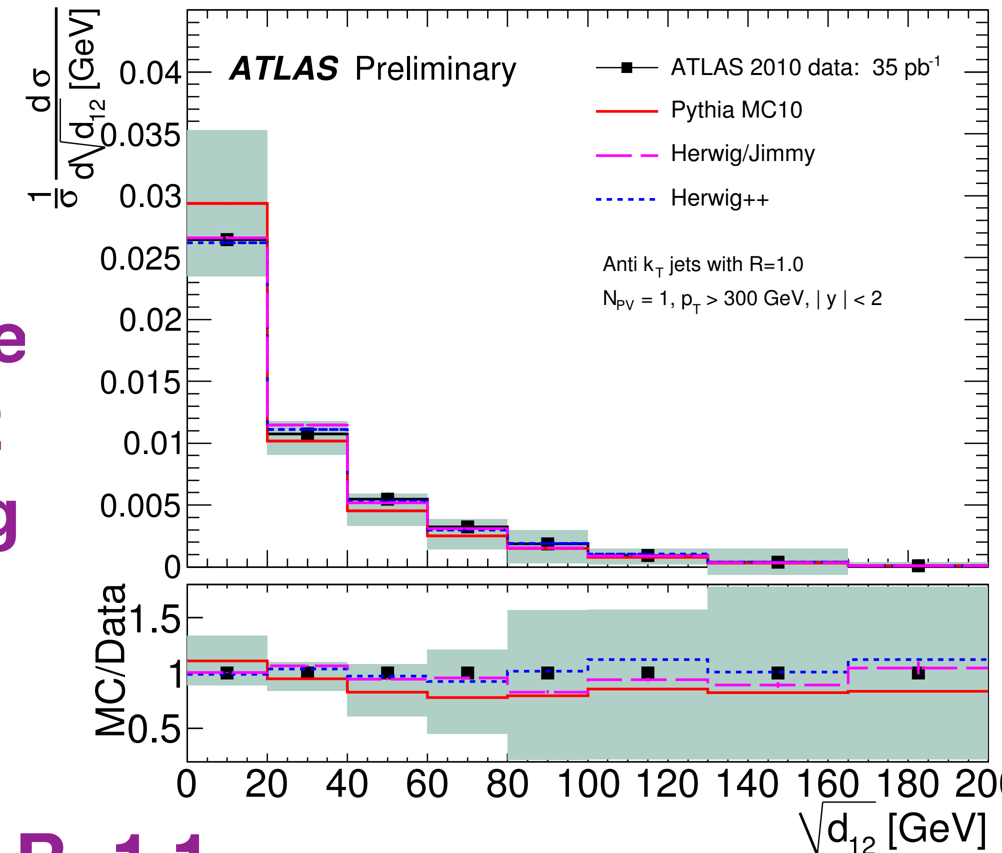
ATL-CONF-2011-073

Anti-k_T R=1.0

M_{jet}

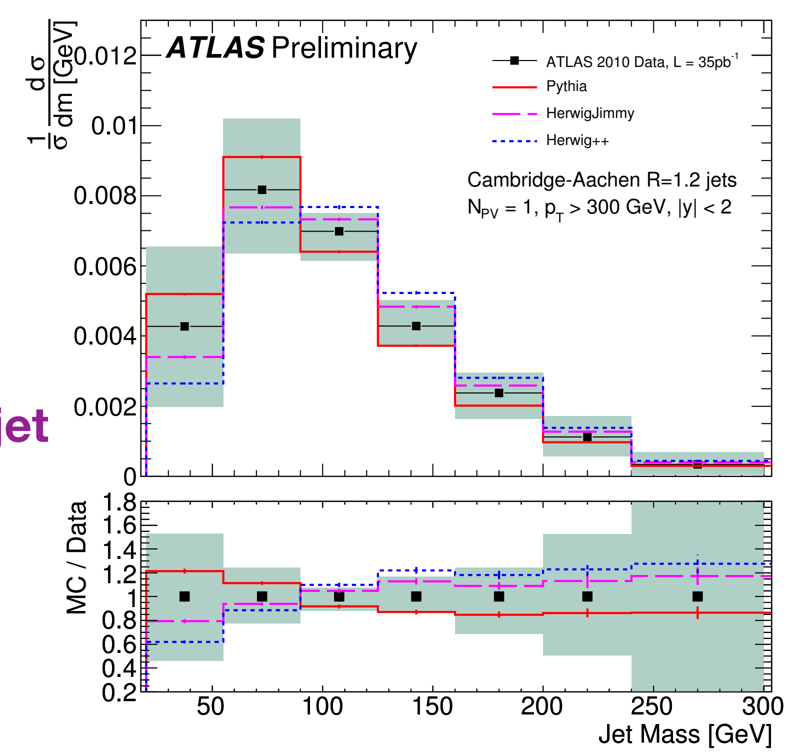


k_T distance of 1→2 splitting

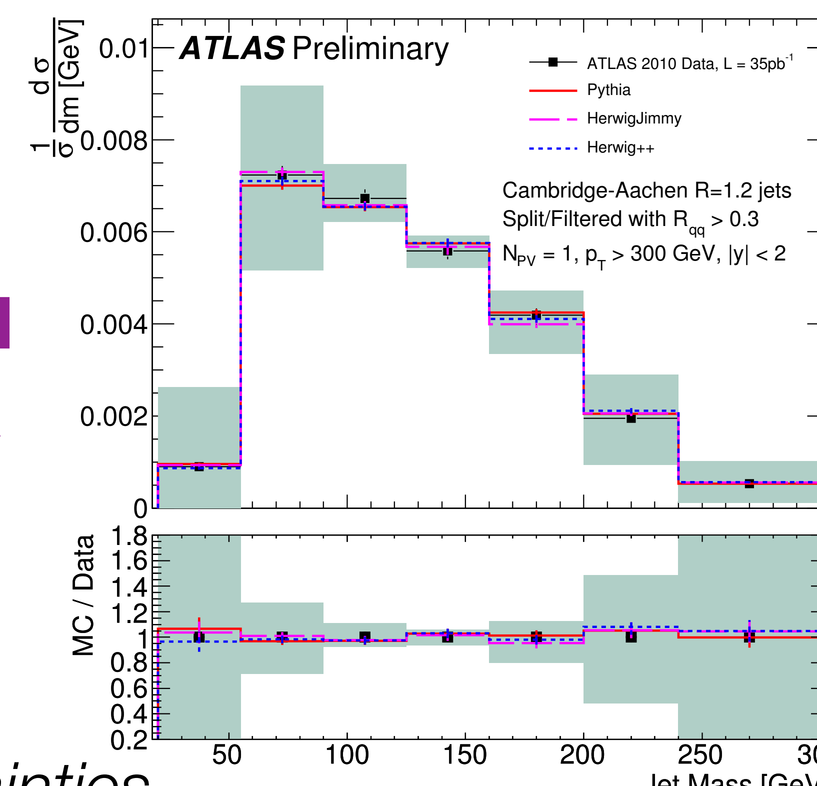


Cambridge-Aachen jets R=1.1

M_{jet}



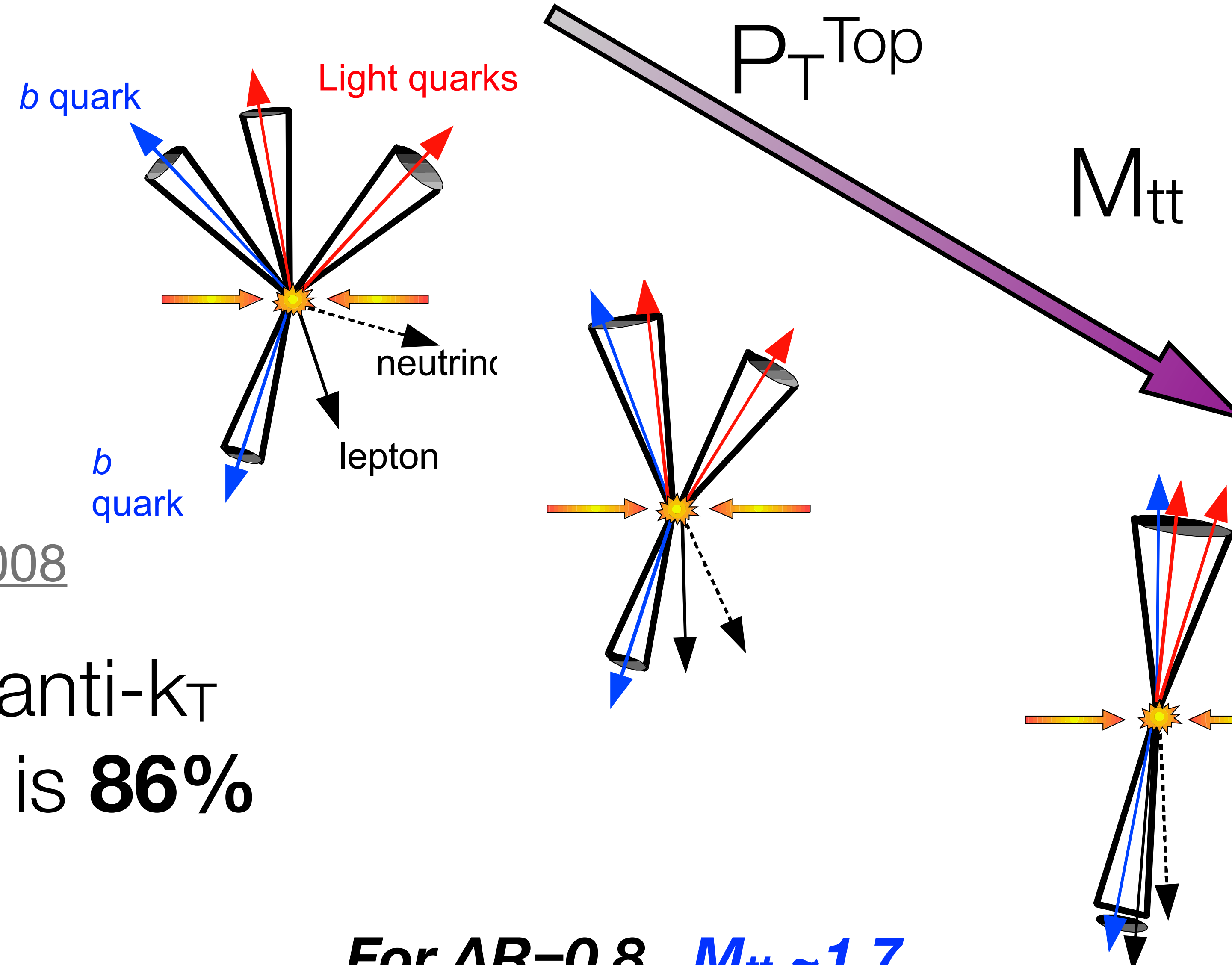
M_{jet} after splitting and filtering a la BDRS



shaded areas include syst+stat uncertainties

Where to from here? Towards new territory...

Resolved



ATLAS-PHYS-PUB-2010-008

M_{tt} =1 TeV mass and anti-k_T (R=0.4): **resolved** case is **86%** of events

M_{tt} =with 2 TeV mass and antikt (R=0.8): **60%** events are **boosted**

For ΔR=0.8, M_{tt} ~1.7 TeV, P_T ~600 GeV

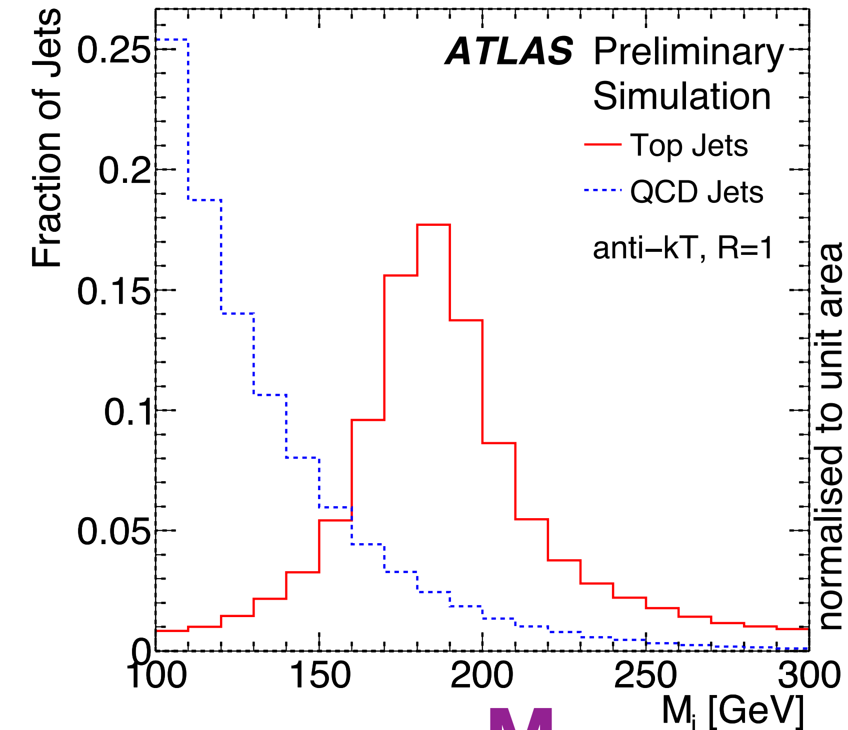
Boosted

Prospects:reconstructing **had** boosted top jets

At higher p_T^{top} (M_{tt})→"top jet" uses large cone

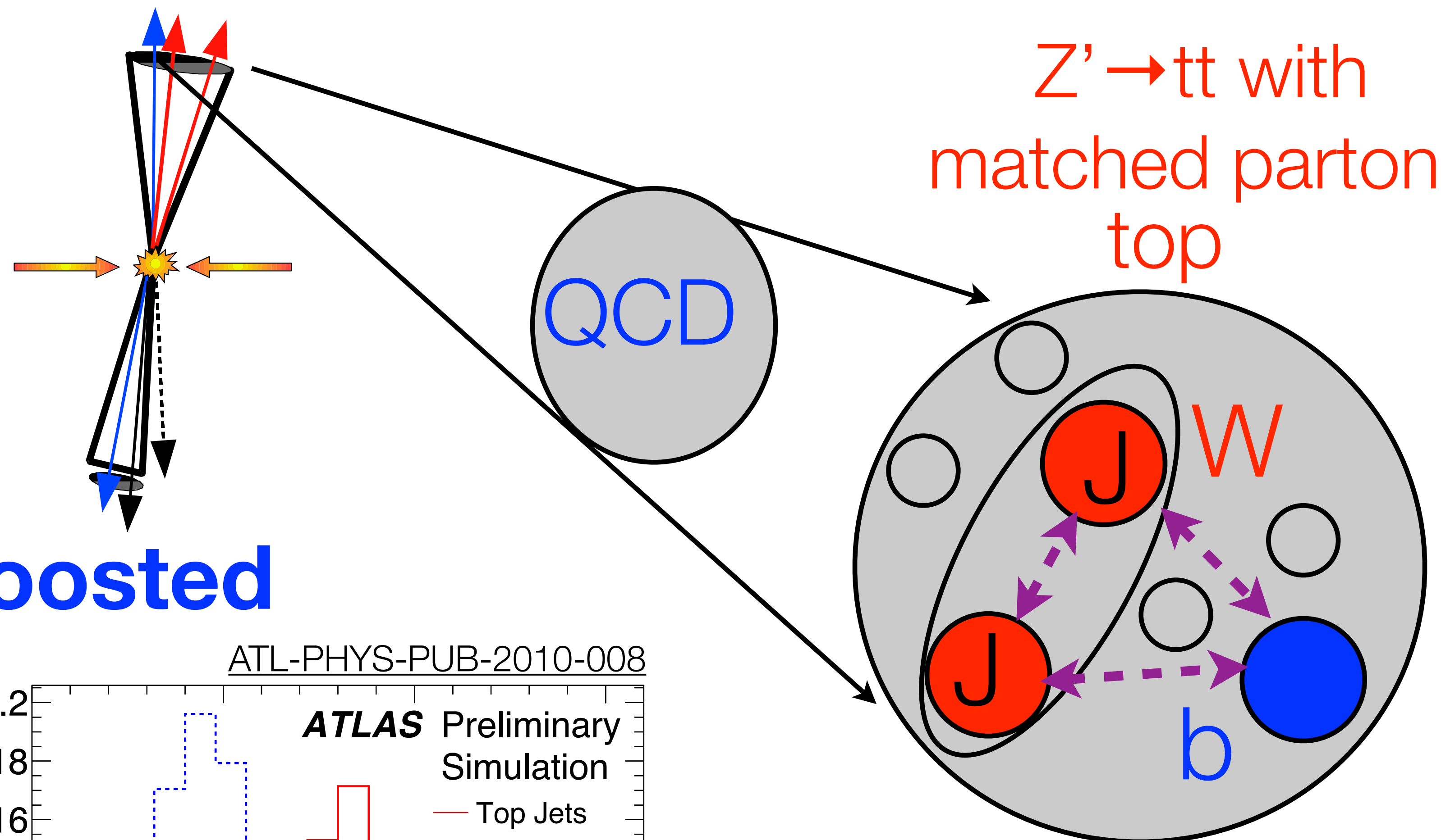
anti-k_T R=1.0, *$p_{T,jet}$ >200 GeV, M_{jet} >100 GeV*

ATL-PHYS-PUB-2010-008



M_{jet}

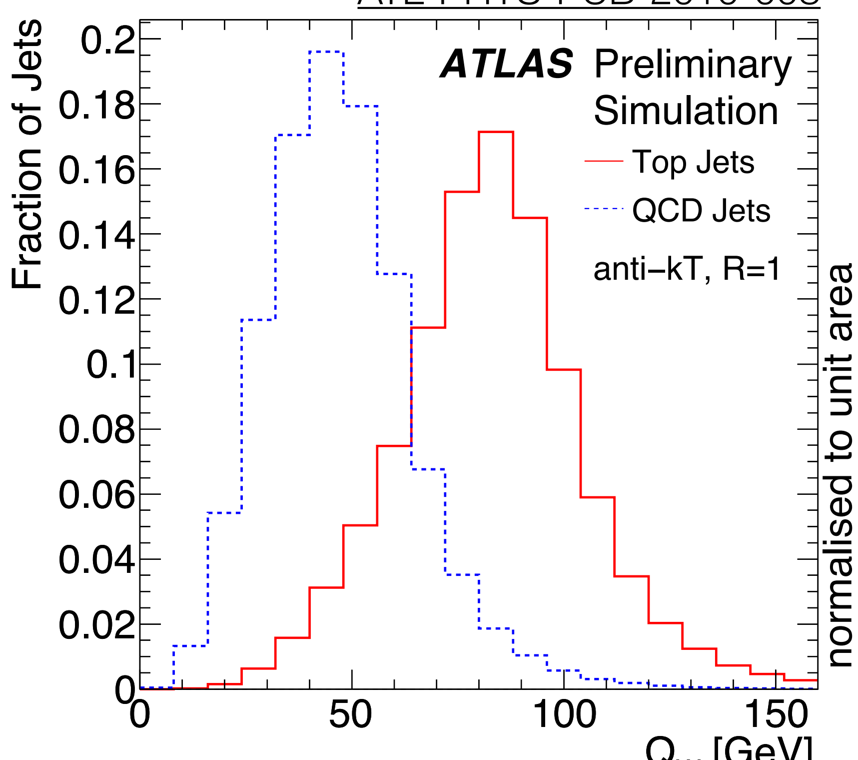
Z'→tt with matched partons top



Boosted

hadronic leg

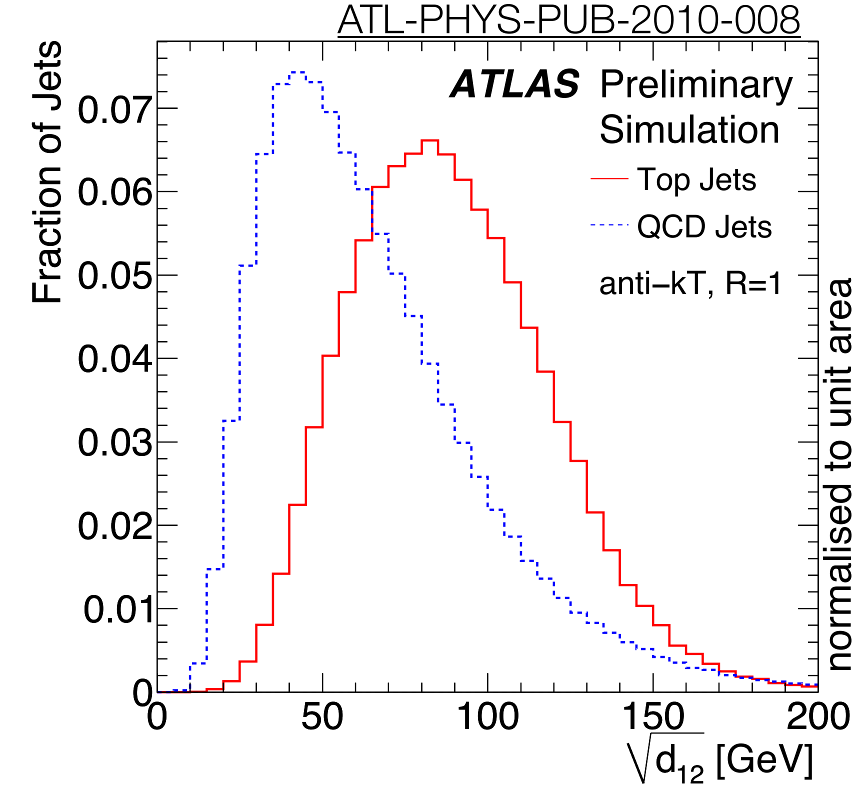
ATL-PHYS-PUB-2010-008



mass of sub-jet pair with lowest mass

force 1→3 split

ATL-PHYS-PUB-2010-008



k_T distance of 1→2 splitting

Split and filter procedure for Cambridge -Aachen jets

- 1) Undo last clusterig step : get two subjets j_1 and j_2

- 2) If the splitting is such that
  - most massive sub-jet has small mass compared to parent jet :m<mu large mass drop
    - indication of hard interaction
  - symmetry in distance variable
    - opposite to QCD behaviour: peaked to low z i.e. y due to gluon splitting
- go to step 4)
- 3) Redefine jet as the starting jet for un-clustering
  - because one considers that j2 is just a soft jet from QCD
- 4) Re-cluster constituents of parent jet j with CA with R=min (0.3, dRj1,j2/2)
- 5) Re-define the jet as the sum of at least 3 of the new sub-jets

$$j = \sum_{i=1}^{\min(n,3)} s_i .$$

$$y_2 = \frac{\min(p_{tj1}^2, p_{tj2}^2)}{m_j^2} \delta R_{j1,j2}^2 \qquad \delta R_{j1,j2} = \sqrt{\delta y_{j1,j2}^2 + \delta\phi_{j1,j2}^2}.$$

Searches for new phenomena with top: Results

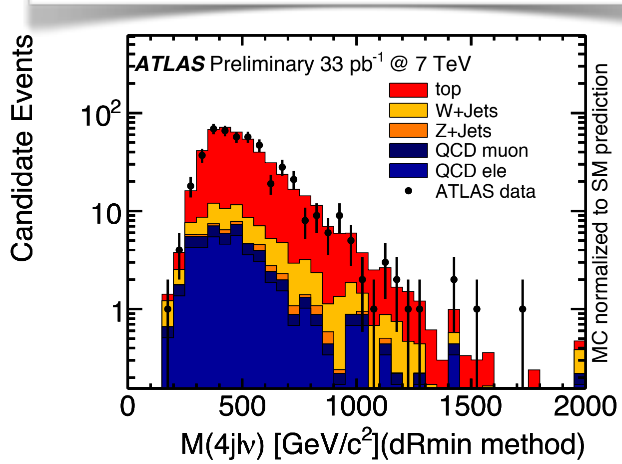
- Compare data to Standard Model prediction. **No excess found.**

Set limit

one spectrum

$$P(\sigma,\mathcal{L},\epsilon,b|k,I) \propto \frac{e^{-(b+\mathcal{L}\epsilon\sigma)}(b+\mathcal{L}\epsilon\sigma)^k}{k!}P(\sigma|I)P(\mathcal{L},\epsilon,b|I)\ ,$$

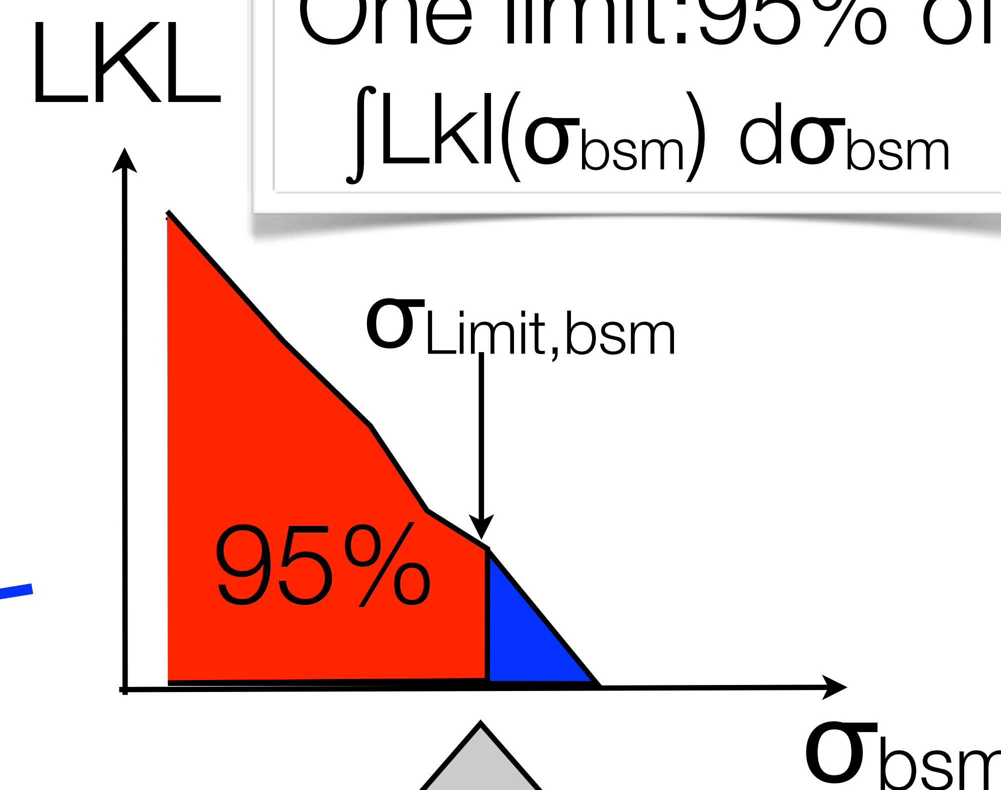
one likelihood value (LKL)



$\sigma=\sigma_{BSM}$

FLAT PRIOR

One limit:95% of $\int Lkl(\sigma_{bsm})\, d\sigma_{bsm}$



BSM=Z' or QBH

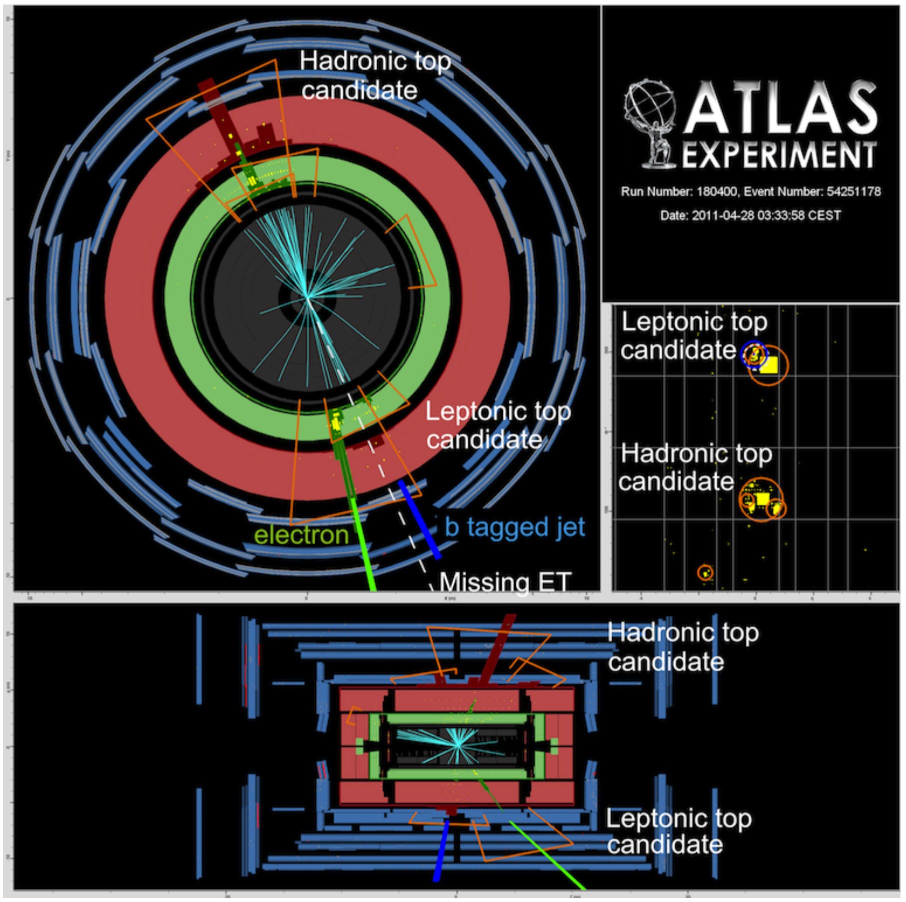
Data: do it once

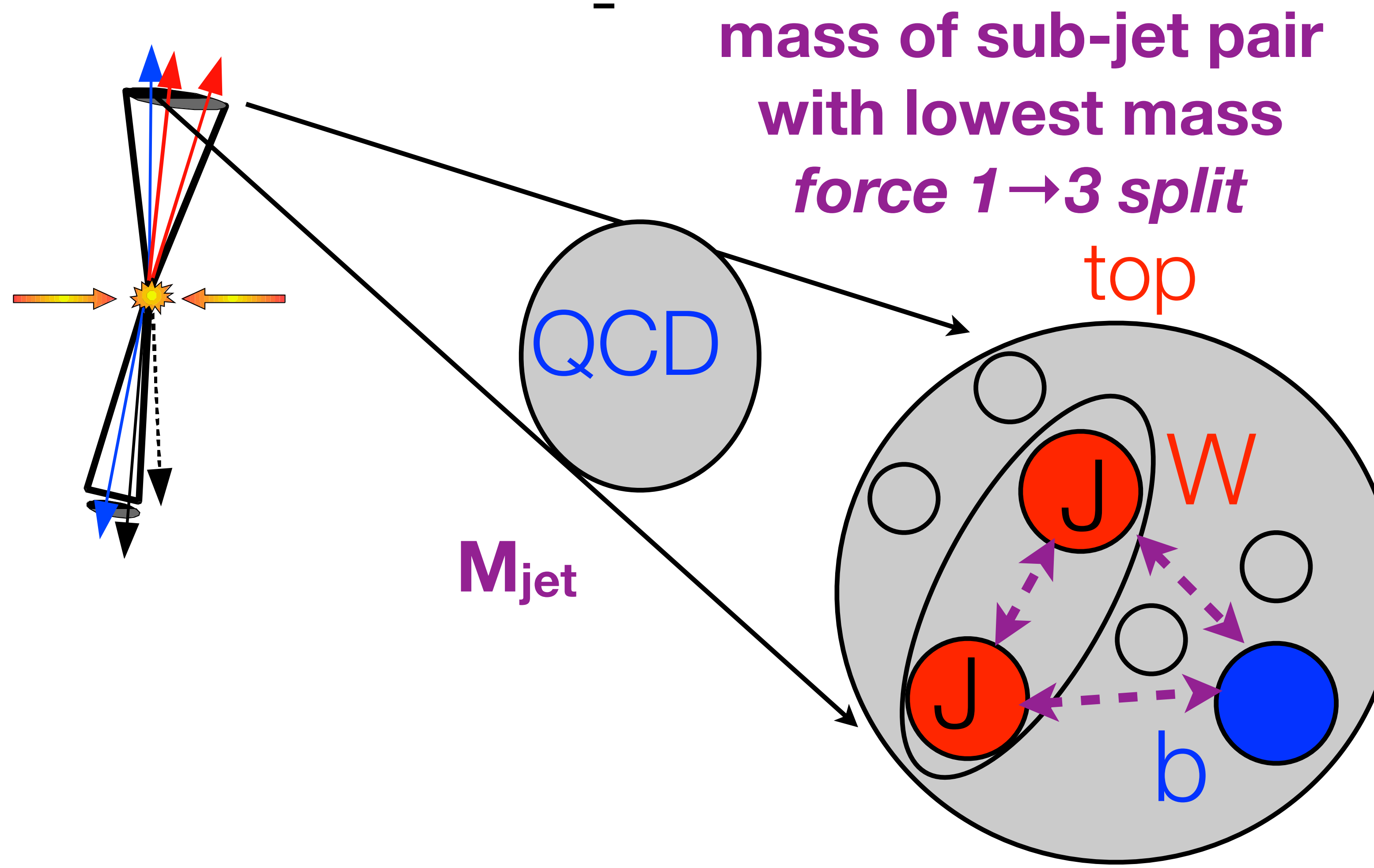
Monte Carlo: take SM only, fluctuate bins content for 5000 exp i.e. 5000 limits

Expected limit = Median of limits,
Error bands = Spread of limits

Include syst: fluctuating SM shape with Gaussian/Log-Normal for each syst then average to get one LKL

Search for excess in $t\bar{t}$ production vs $M_{t\bar{t}}$:towards boosted tops





ATL-CONF-2011-087

semi-leptonic di-top-jet candidate

k_T distance of 1→2 splitting

MC expectation

Tag top jets Understand substructure of large cone (fat) jets

Top cross sections in ATLAS/CMS

Selecting top pairs - single lepton

- **Trigger on** high p_T **single lepton (e,μ)**
- Good collision and no jet from noise/ out-of-time activity
- **≥ 1** high p_T central **lepton, reject di-leptons**
  - ***A: exactly one lepton***
  - ***C: ≥ 1 electron, reject if |m(ee) -M_Z| <15 GeV for any ee pair,*** *no lower p_T μ* ***OR only one μ,*** *no lower E_T e*
- **≥ 3** central high p_T **jets**

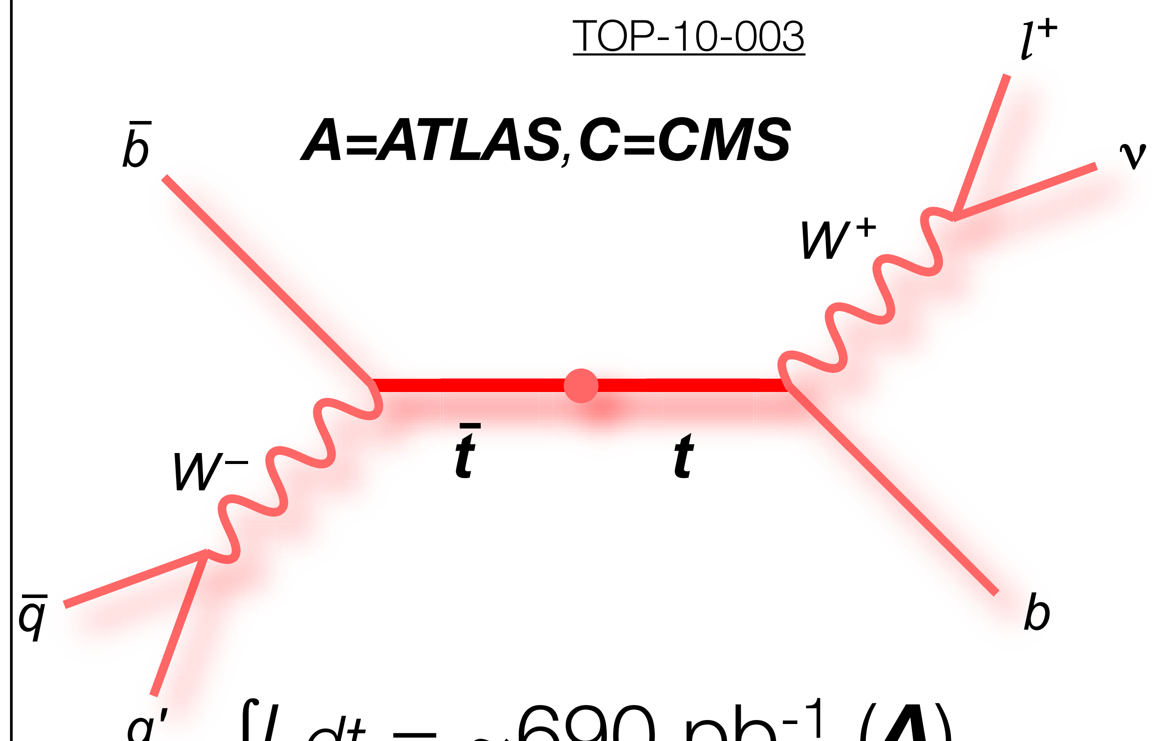
- ***A*: high E_T^{miss} and large transverse leptonic W mass** (M_T^W) * **to** reduce QCD bkg
  - *E_T^{miss} > 35 (25) GeV for e (μ) chan*
  - *M_T^W > 25 GeV (60GeV - E_T^{miss}) for e (μ) chan*

NEW! ATLAS-CONF-2011-121

arxiv:1106.0902

TOP-10-003

A=ATLAS, C=CMS



$\int L dt$ = ~690 pb^{-1} (***A***) (2011), 36 pb^{-1} (***C***) *(2010)*

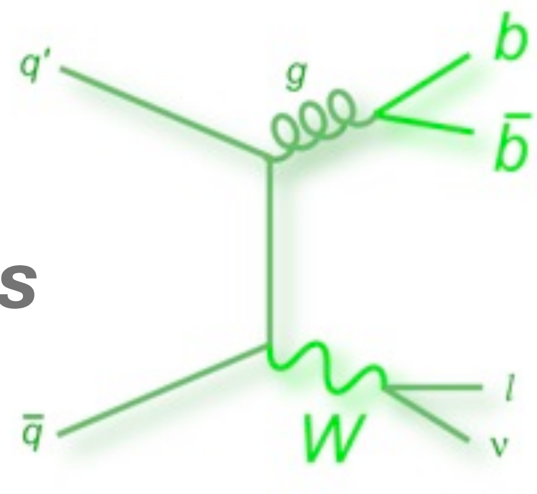
	A		C	
	e	**μ**	**e**	**μ**
tt bkg	5232 18920	7478 33482	325 948	408 757
TotEx	**24152**	**40960**	**1273**	**1165**
Data	**23824**	**41137**	**1611**	**1487**

$$* = \sqrt{2 p_T^\ell p_T^\nu (1 - \cos(\phi^\ell - \phi^\nu))}$$

Backgrounds estimates - single lepton

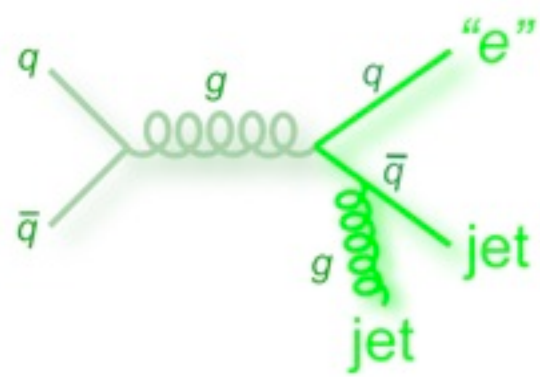
A=ATLAS,C=CMS

- **W+jets**



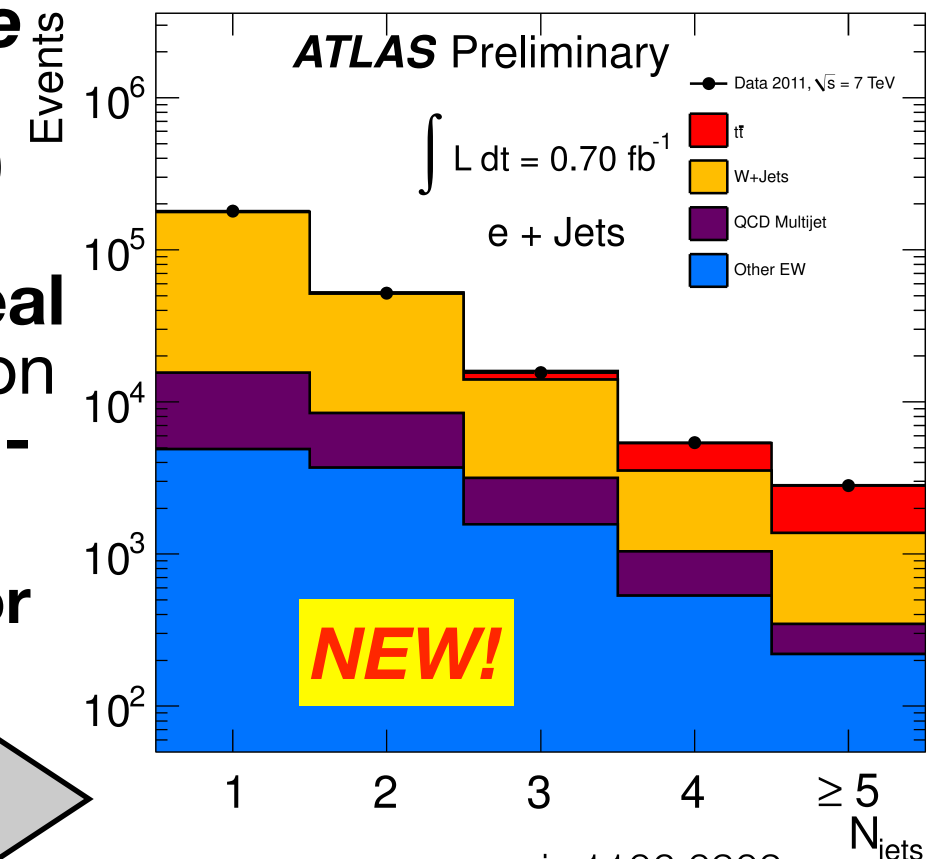
- *simulated shape*
- ***normalization from charge asymmetry of W prod*** *before b-tag (**A**),floating(**C**)*

- **QCD**



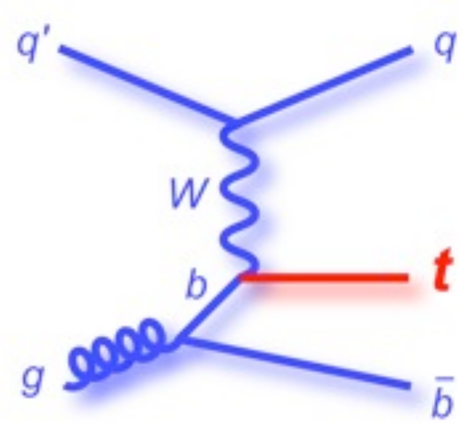
- A:Combine **isol. prob for real and fake** lep in control region **with N(isol. lep) and N(non-iso lep)→isolated fake lep**
- C:**shape from non-isolated or failing el-ID/quality, floating norm.**

ATLAS-CONF-2011-121

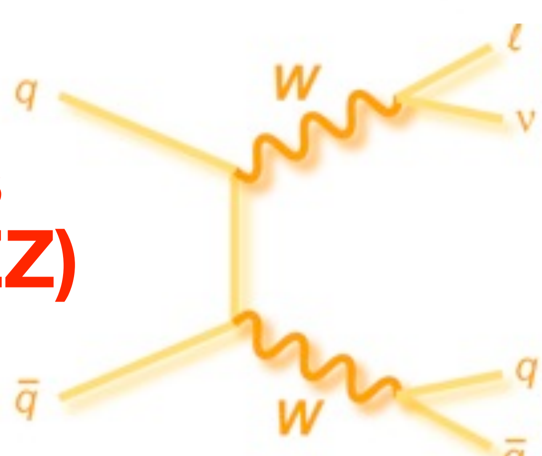


arxiv:1106.0902

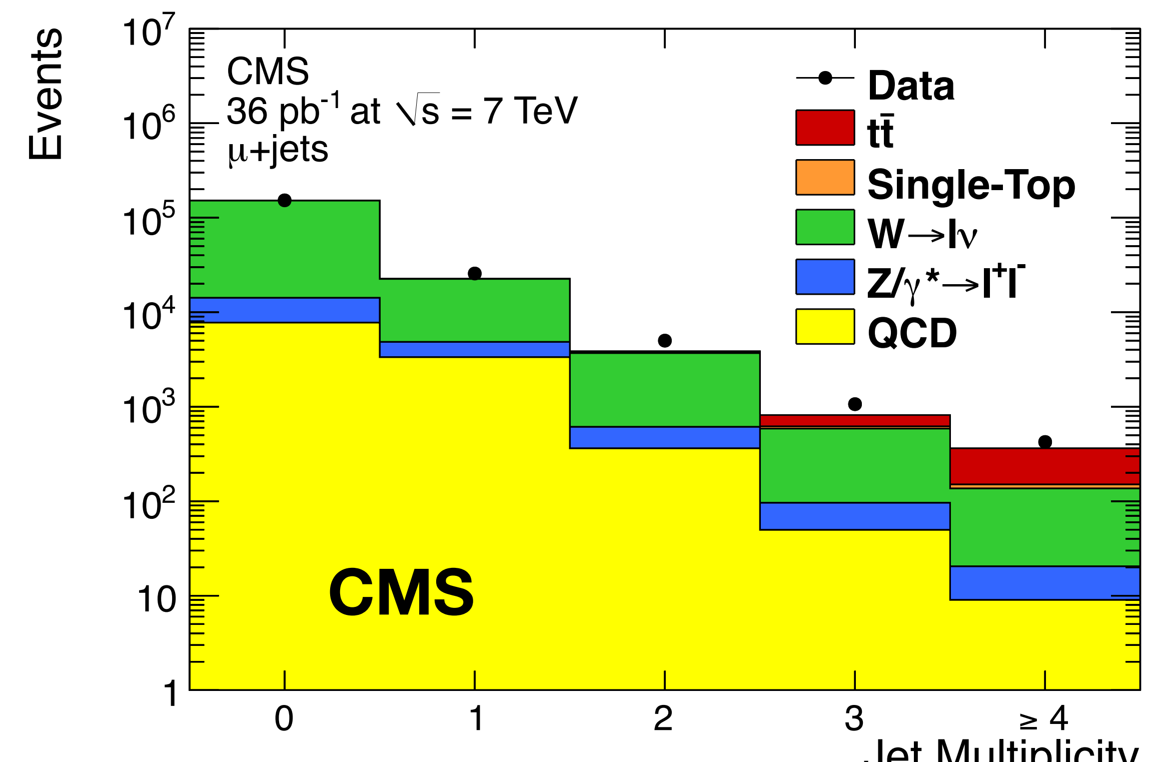
- **Single top**



- **Di-bosons (WW,WZ,ZZ)**



Simulated shape+ rate set to SM (A), floating (C)

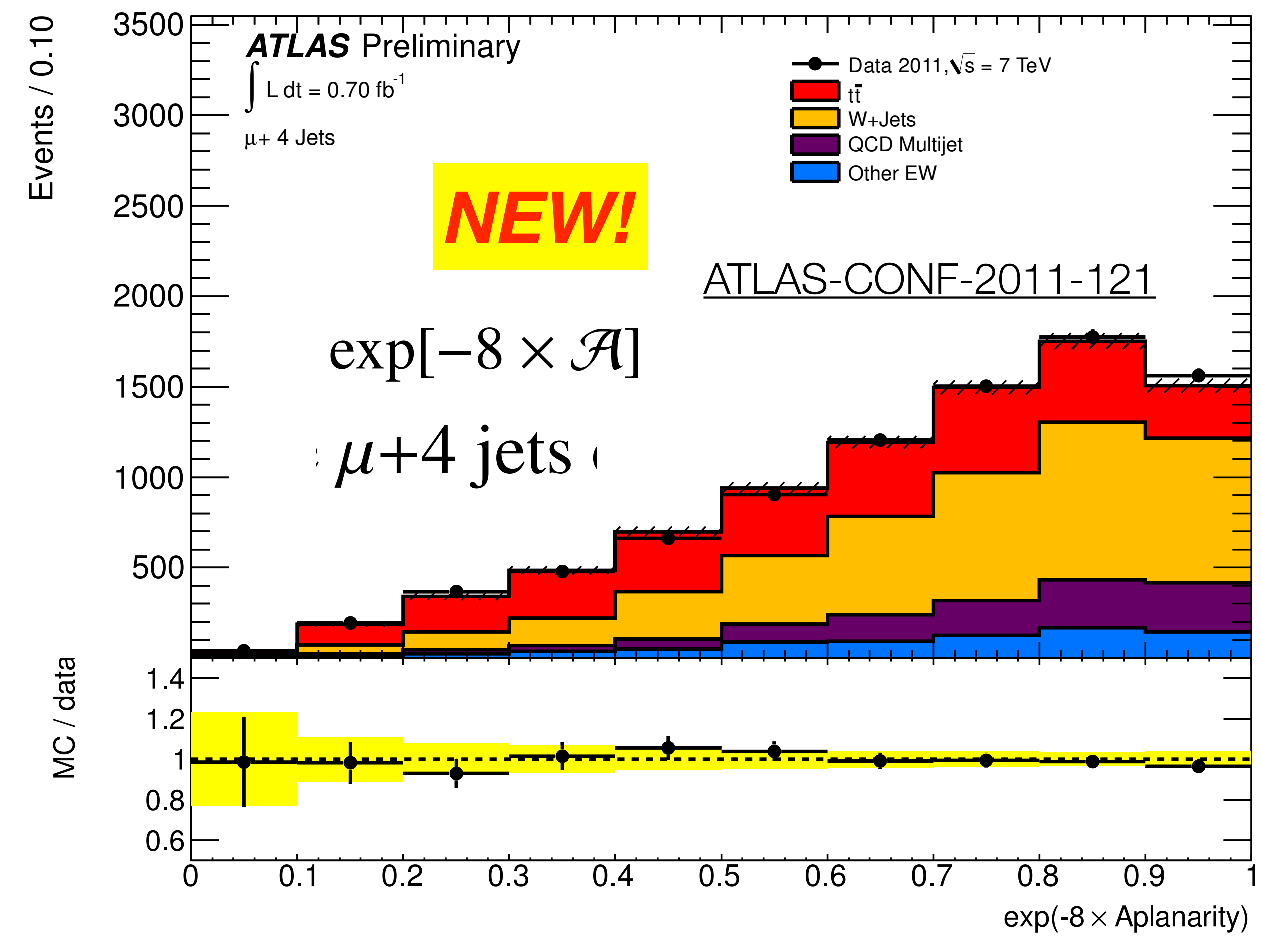


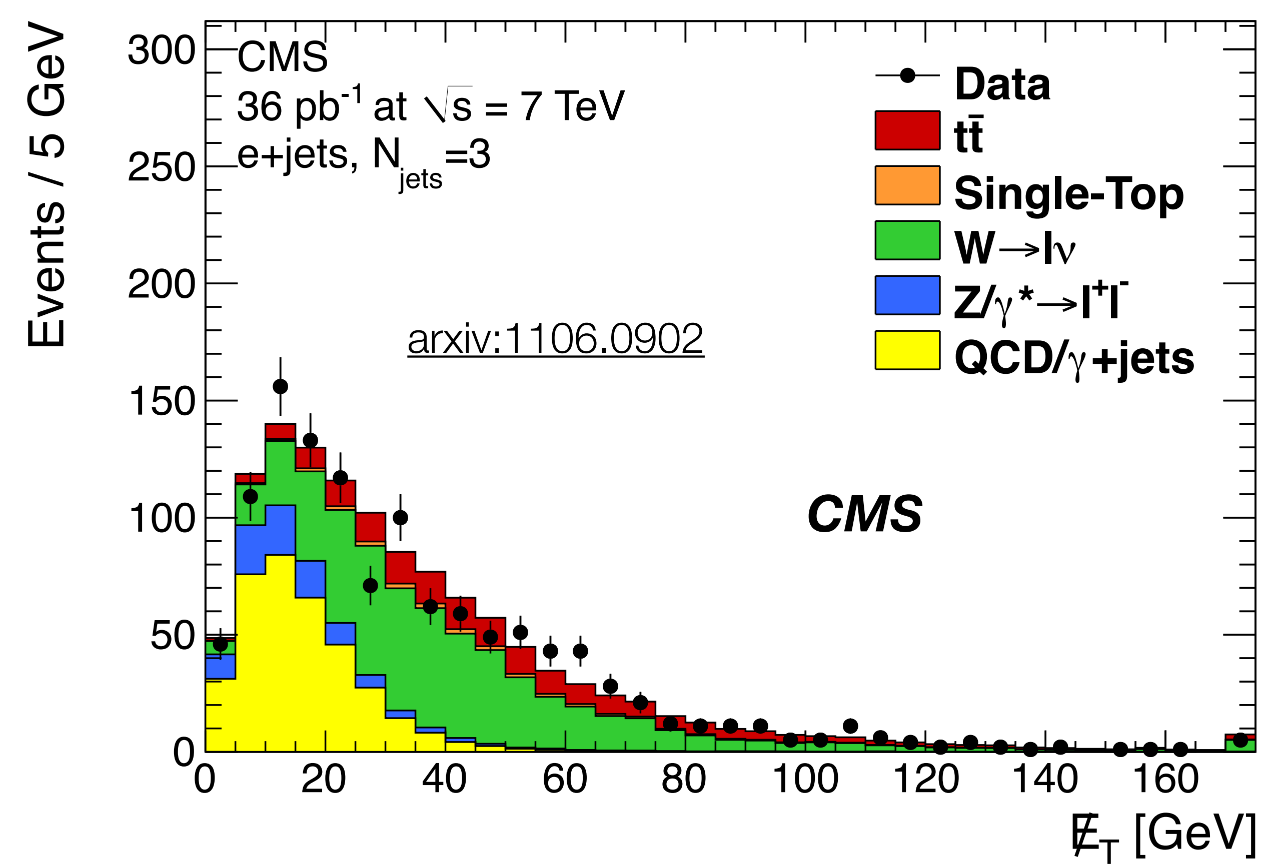
Cross section - single lepton

A=ATLAS, C=CMS

- **Build discriminant from** signal+ bkg **templates of**
  - ***A*: lepton η, p_T of highest p_T jet aplanarity** (←*top is more spherical*), **$H_{T,3p}$**, ratio of transverse to longitudinal activity (←*top is more transverse)*
  - ***C*: E_T^{miss} for 3-jet bin** (*vs QCD*), **M3 for ≥ 4-jet bin,** mass of 3-jet system with highest vectorially combined p_T

- **Extract σ_{tt}, σ_{bkg} by binned likelihood fit of discriminant** to data in ***A*:** 3, 4 and **≥ 5**-jet bins, ***C***: 3 and **≥4-jet bins**



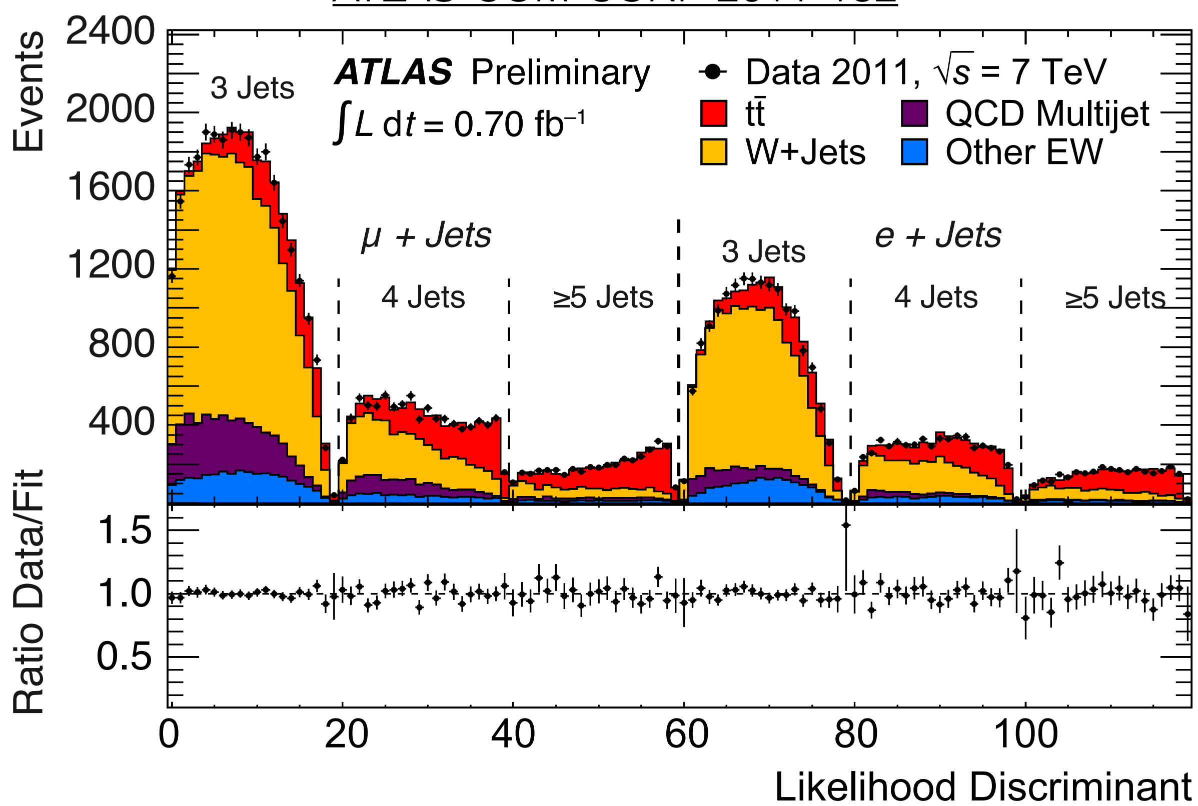


Cross section and syst. uncertainties - single lepton

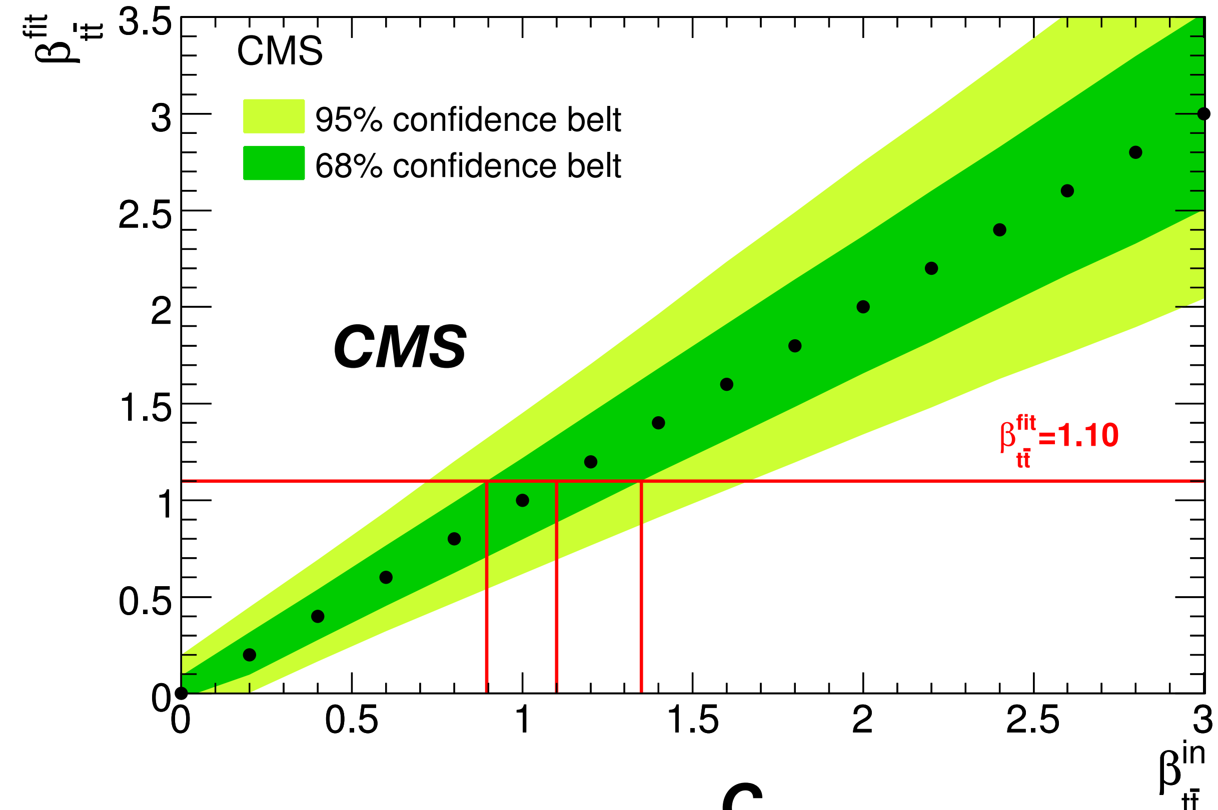
(e, μ combined)

A=ATLAS, C=CMS

ATLAS-COM-CONF-2011-132



arxiv:1106.0902



A

$\boxed{\sigma_{t\bar{t}} = 179.0 \pm 3.9\,(\text{stat}) \pm 9.0\,(\text{syst}) \pm 6.6\,(\text{lumi})\ \text{pb}}$ ***NEW!***

C

$\sigma_{t\bar{t}} = \boxed{\mathbf{173 \pm 14(stat)\ ^{+36}_{-29}\,(syst) \pm 7(lumi)}}\ \text{pb}$

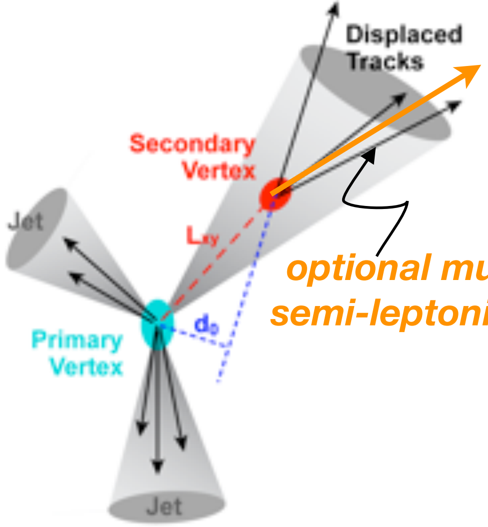
- **most syst uncertainties part of lkl fit** as Gaussian nuisance parameters→reduction in JES,ISR/FSR (20% to 70% of initial value)
- still syst-dominated: generator ~3% lepton scale~2%
- δσ/σ=6.6% (stat~0.5%, sys~5%)

- syst included in pseudo exp to derive **Neyman CL belt for max lkl fit**
- syst-dominated (JES~18%, factorization scales~7%)
- δσ/σ~23% (stat~8%, sys~21%)

Ingredients IV : enter b-jets

A=ATLAS, C=CMS

B-hadrons~ long lifetime ~observable flight (few mm)



Tagging

d_0/σ_{d_0}

$L_{3D}/\sigma_{L_{3D}}$

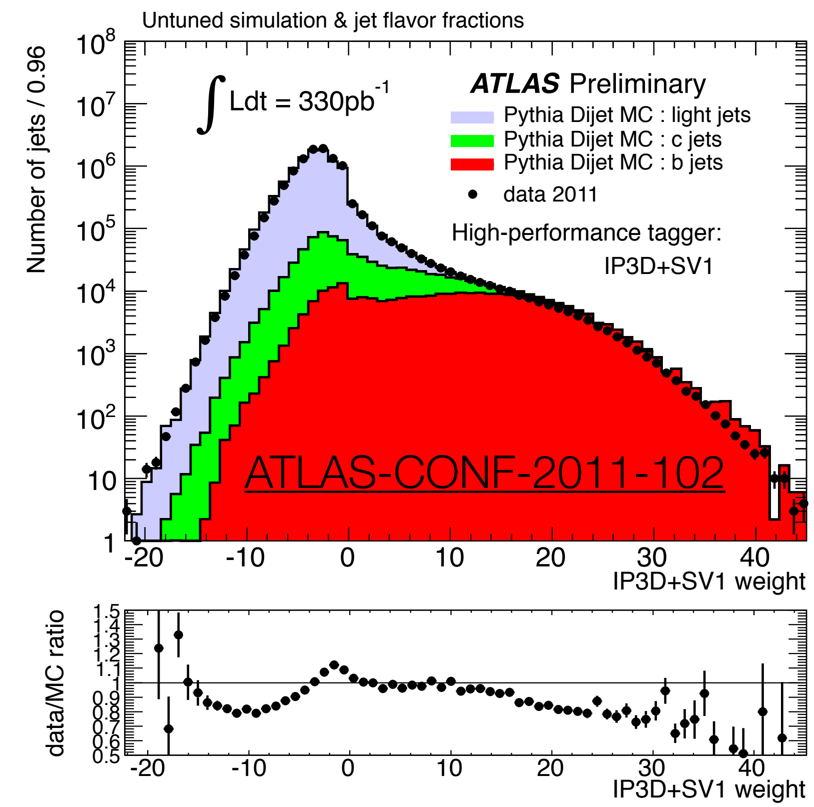
- **A**: (1) jet prob from **track impact parameter** (IP) (2) **3D decay length** significance of sec. vertex (SV) (3) **Neural net** *with 1), 2) + mass of SV tracks +* N_{2track} *vertices+* E_{SV}*(tracks)/*E_{PV}*(tracks)*
- **C**:(1) 3D **SV decay length significance** *(&* $N_{tracks}>3$*)* (2) **track IP** signif. & ≥2 or 3 high **IP** signif. tracks

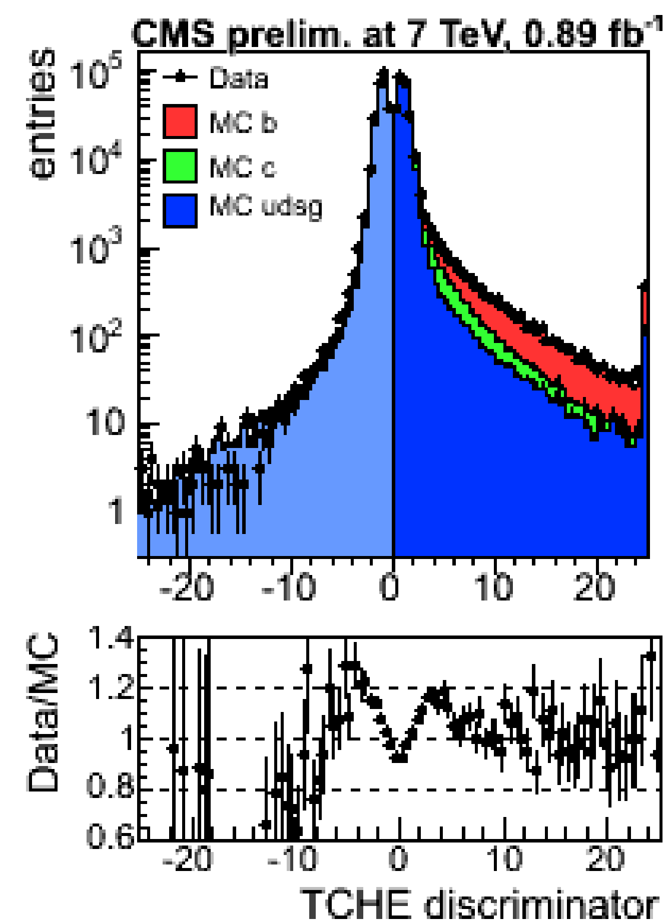
Performance

- **Efficiency: fit fraction** of b-jets in sample with muons in jets, *count # b-tagged*
- **Mis-tag rate**: **from SV properties** (*invariant mass of tracks (A), rate of negative decay length / impact par significance (A,C))*

Efficiency/mis-tag : from **80%/10%** (track/NN based) to **40%/0.1%** (SV based)

p_T dependent scale factors to correct MC





CMS-PAS-BTV-11-001

shape comparison

Cross section - single lepton *with b-tag*

A=ATLAS,C=CMS

$\int L dt$ = **36 pb^{-1}**
(***A***,***C***), (2010)

- Standard single lepton selection + large $\mathbf{E_T^{miss}}$ and M_T^W
- Bkg shapes/normalization as no-btag

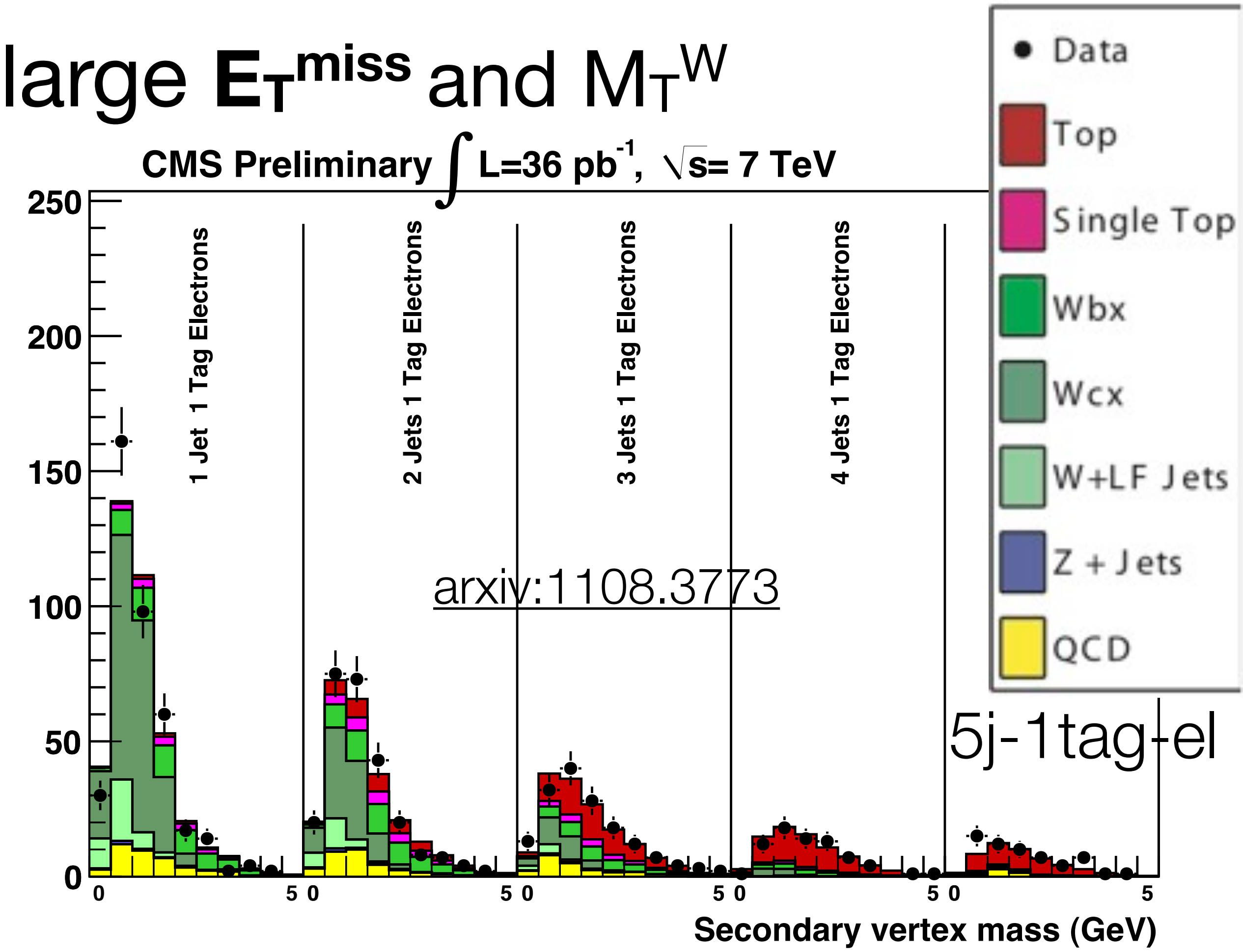
C

- **≥ 1 b-tagged** central high p_T **jet**

Max lkl fit to secondary vertex mass in 2d plane of (N_{jet} ,$N_{b\text{-}jet}$)

$$\sigma_{t\bar{t}} = 150 \pm 9\,(\text{stat.}) \pm 17\,(\text{syst.}) \pm 6\,(\text{lum.})\ \text{pb.}$$

$\delta\sigma/\sigma \sim 13\%$

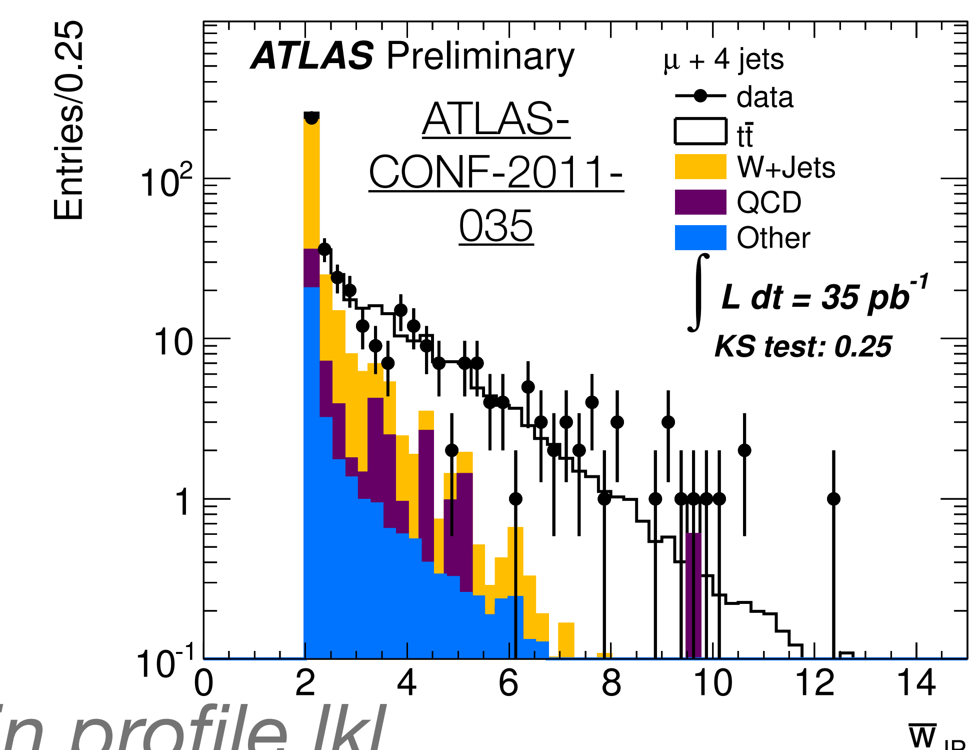


A

- Max lkl fit of 4-variable discriminant
- replace leading jet p_T with **average** of two largest **jet b-tagging** probability (←*top has more b-jets)*

$$\sigma_{t\bar{t}} = \mathbf{186 \pm 10\,(stat) \pm {}^{21}_{-20}\,(syst) \pm 6\,(lumi)\ pb}$$

$\delta\sigma/\sigma \sim 13\%$



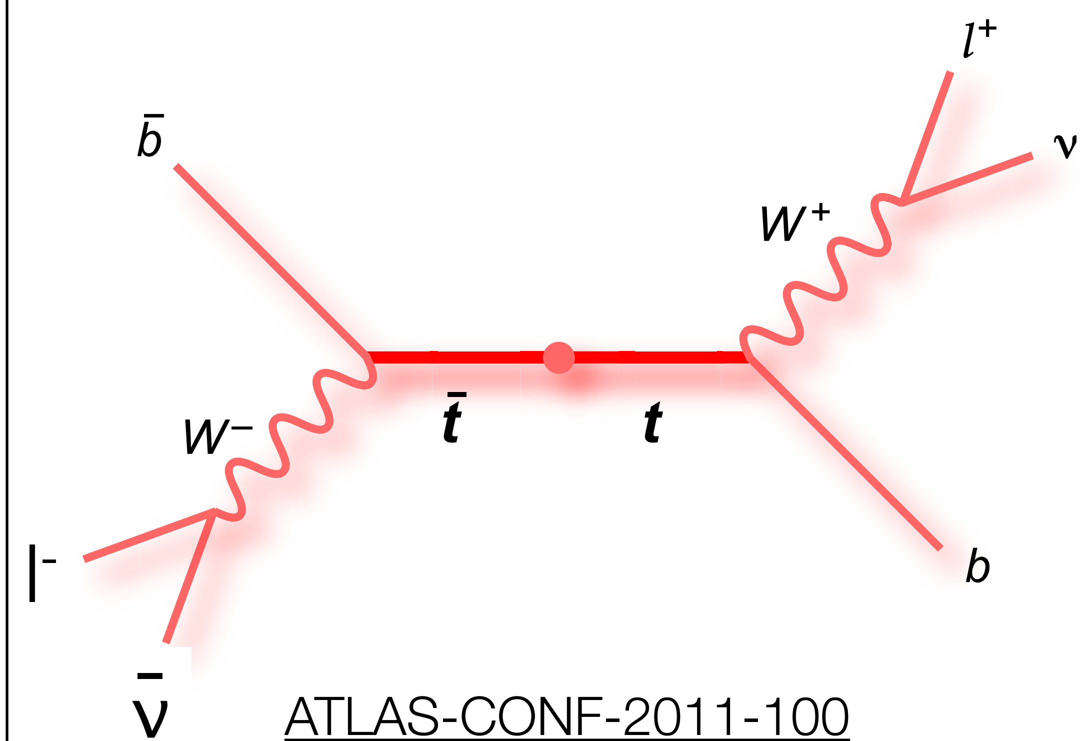
Syst uncertainties fitted *as nuisance pars in profile lkl*

Selecting top pairs : di-lepton

A=ATLAS, C=CMS

- Vertex and quality cuts
- After single (A,C) lepton and di-el (C) trigger (A), **exactly (A) or at least (C) two opposite sign** high p_T central **leptons (ee, eμ, μμ)**
- **≥ 2 central** high p_T **jet**
- High $\mathbf{E_T^{miss}}$ **for (ee, μμ)** *(at least >30 GeV)* **or transverse activity (eμ)**
  - $H_T = \sum_{jets,lepts} |p_T|$ *(A) or* $\sum_{lept}$ *transv. mass(C)*
- **for (ee, μμ) veto low di-lep mass** *(<15(A),12(C) GeV)* & **Z-like***(mass window)* **events**
- *if* **≥ 1 b-tag,** *relax* E_T^{miss}

(2011) $\int L dt$ = **0.7 pb^{-1}** (***A***), **1.14 fb^{-1}** (***C***)



ATLAS-CONF-2011-100

CMS-TOP-11-005 ***NEW!***

Backgrounds

Z/γ*+jets
QCD, Di-bosons
single lepton

Di-lepton - main backgrounds

A=ATLAS,C=CMS *(2011)* $\int L dt$ = **0.7 pb^{-1}** (***A***), **1.14 fb^{-1}** (***C***)

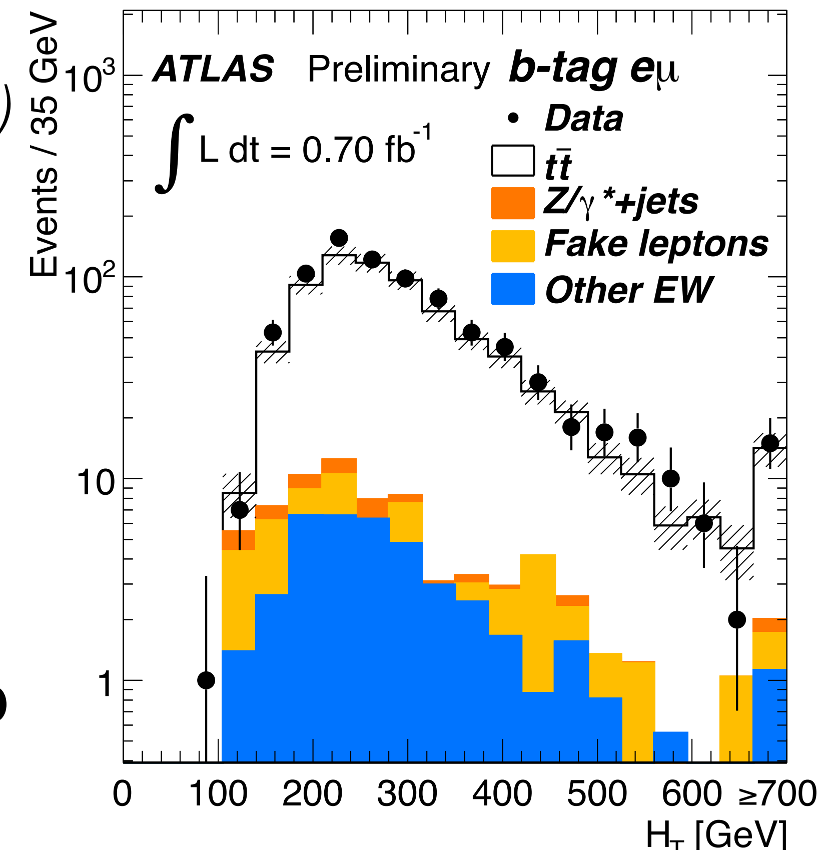
- "Fake" leptons from data
  - Get **probability** for **loose** "fake" (A, C) and real (A) leptons ***to be in signal region (A)*** ← **control samples** enriched with real (in Z window) or "fake" (low E_T^{miss}) leptons **(A)**, multi-jet single loose lepton sample **(C)**
  - **Combine** with **N(di-lep)** for **all loose/tight** pairs (A) **or only loose pair** *(fail tight)* **(C)→fake tight** (i.e. signal) **lep**

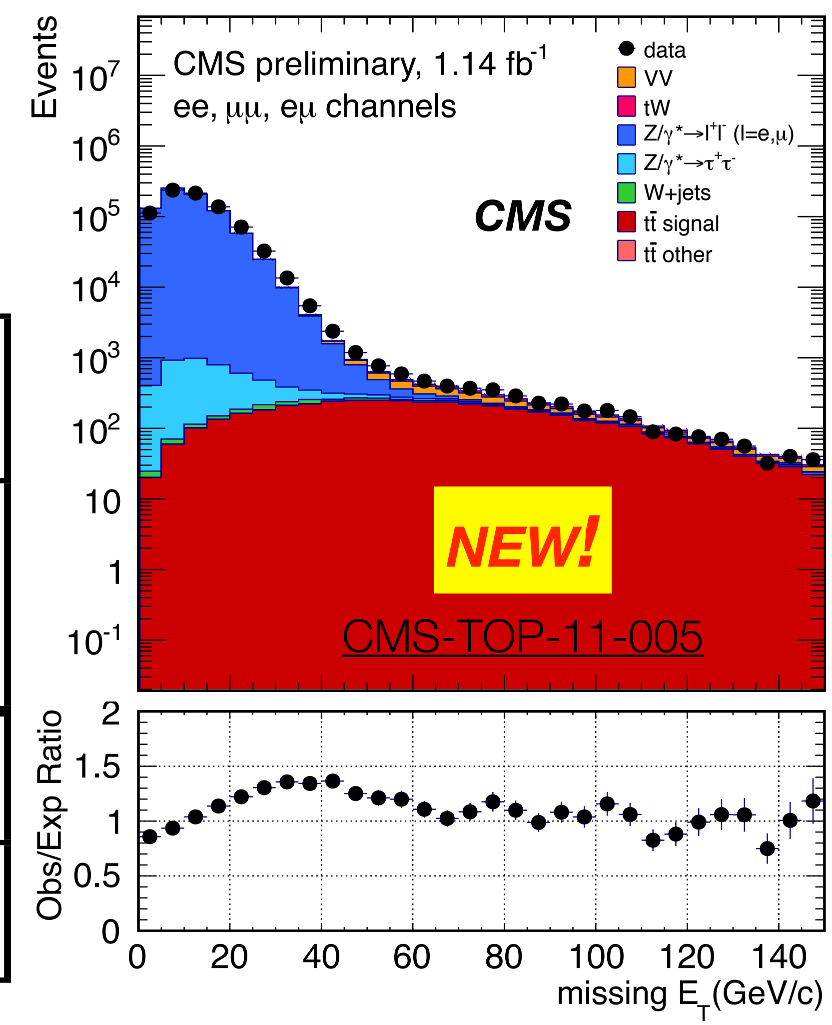
- Z/γ* bkg (ee, μμ) : **scale** non-Z/γ*-bkg-subtracted **data in** Z-mass window **control region with ratio** of N(Z/γ*) in signal region to control region **from simul.**

≥1-btag

	ee (A)	ee(C)	μμ(A)	μμ(C)	eμ(A)	eμ(C)
tt Bkg	167 25	427 78	314 45	559 100	666 68	1487 141
Tot Exp	**192**	**505**	**359**	**659**	**734**	**1628**
Data	**202**	**589**	**349**	**688**	**823**	**1742**

ATLAS-CONF-2011-100





Di-lepton results

A=ATLAS,C=CMS

- **Include** estimated **background**
- **Cross section from likelihood fit** combining channels and including systematics as nuisance parameters

A

no b-tag $\sigma_{t\bar{t}} = 171 \pm 6(\text{stat.})^{+16}_{-14}(\text{syst.}) \pm 8(\text{lum.})$ pb.

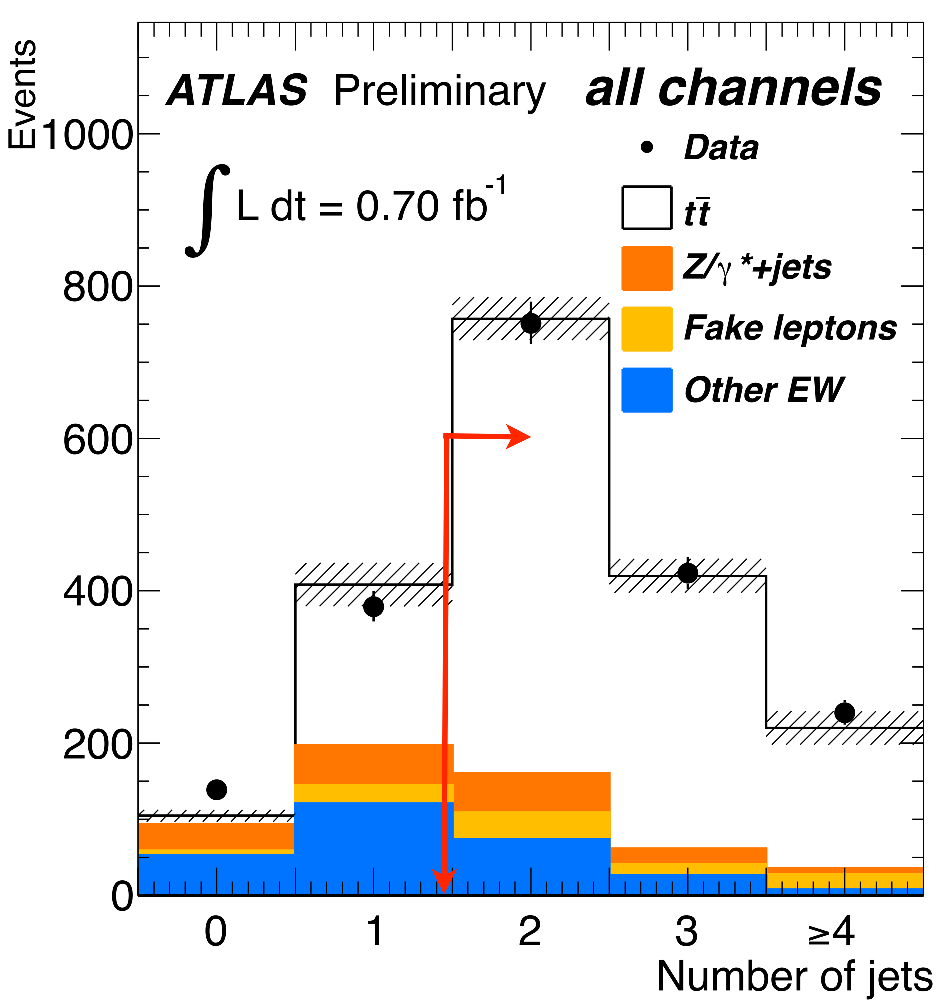
b-tag $\sigma_{t\bar{t}} = 177 \pm 6(\text{stat.})^{+17}_{-14}(\text{syst.})^{+8}_{-7}(\text{lum.})$ pb.

$\delta\sigma/\sigma$~11% (no-tag) and b-tag)

C

$\delta\sigma/\sigma$~11% ***NEW!***

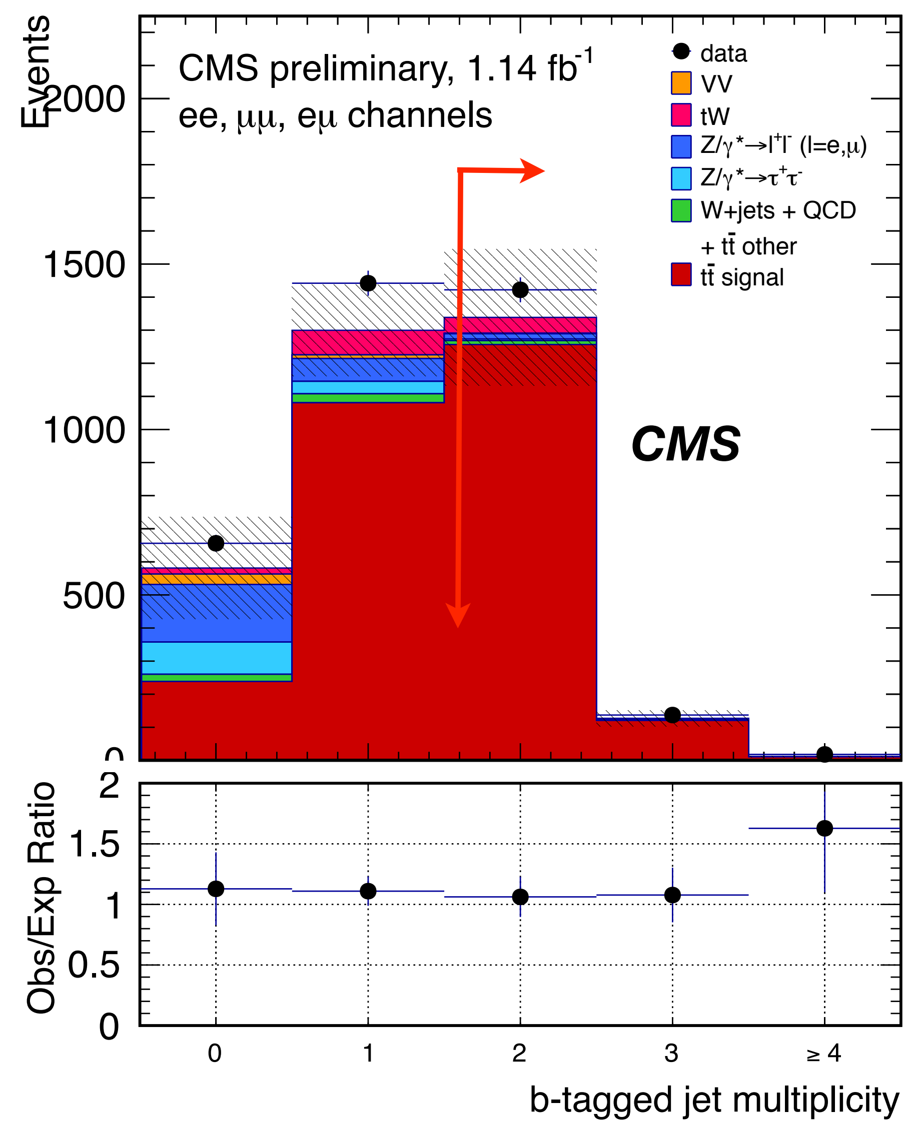
169.9 ± 3.9(stat.) ± 16.3(syst.) ± 7.6(lumi.) pb



distributions after all cuts, except N_{jets}

syst dominated!

JES~5% (A),
b-tag~4-5% (A-tag,C)
C: pile-up~5%,lep sel~4%
A:ISR~2.6%



Di-lepton: $\mu+\tau$ ($\tau\rightarrow$ *had*) channel **NEW!**

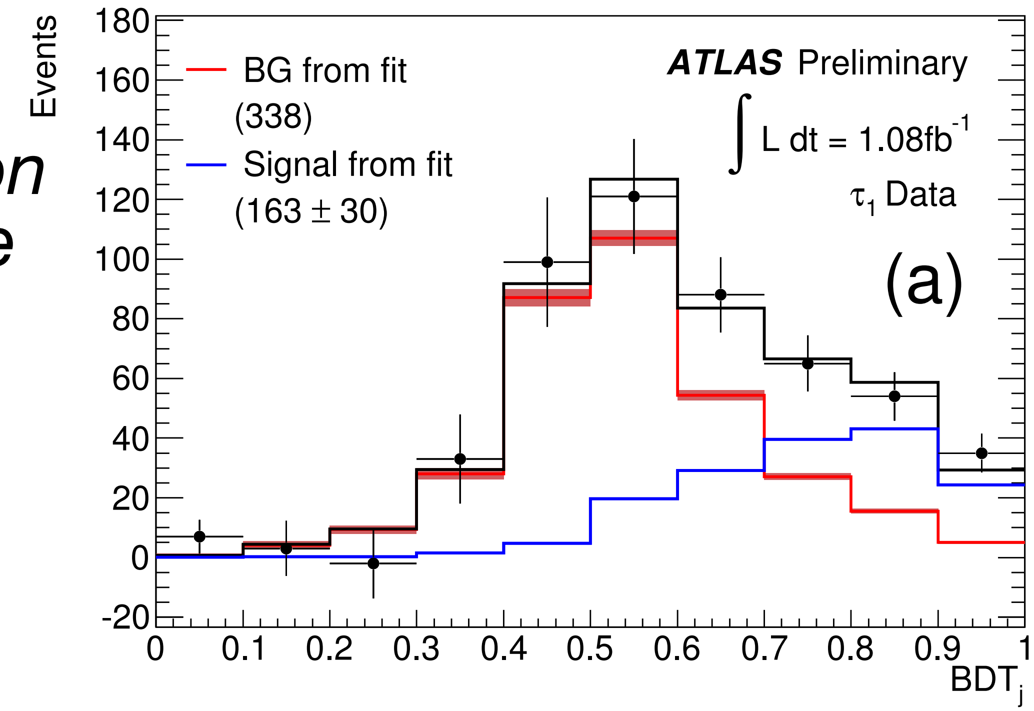
A=ATLAS, C=CMS

Check universality + sensitivity to $t\rightarrow H^{\pm}+b\rightarrow\tau\nu b$

$\int Ldt$ = ~**1.08 fb^{-1}** (***A***,***C***) (2011)

ATL-CONF-2011-119

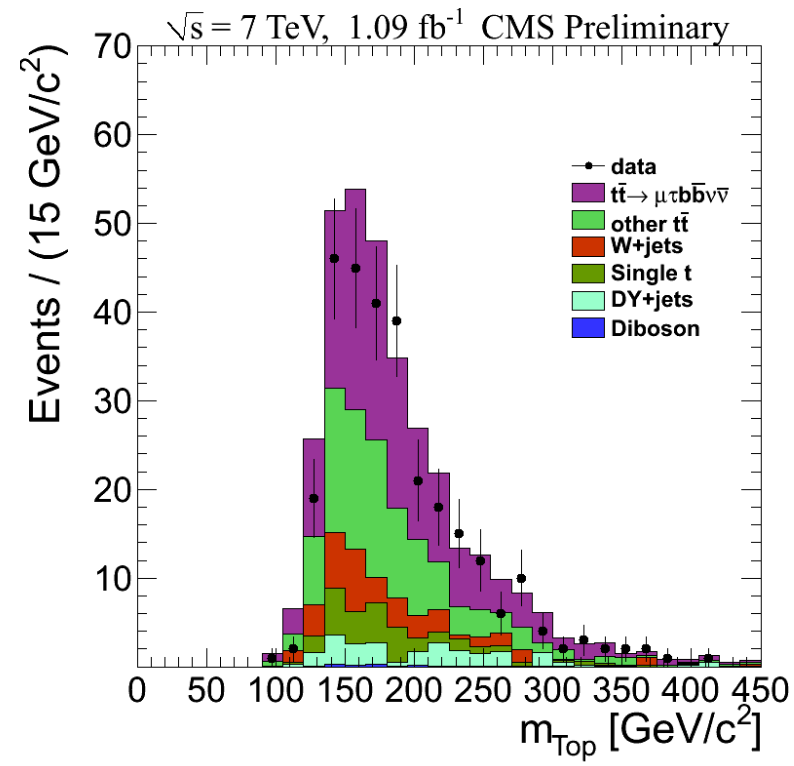
- **One** *central* high p_T **μ, no** low p_T (C) **el**
- **≥1** *jet-seeded* **τ candidate** *(←cut-based algo on particle flow objects (C) or Boosted Decision Tree (BDT) (A))* **with opposite charge to μ (OS)**
- ≥2 jets & ≥1 b-tag
- **large E_T^{miss}** *>40 (C) or 30 (A) GeV* **& H_T**>*200 GeV (A)*



A $\sigma_{t\bar{t}} = 142 \pm 21\ \text{(stat.)} \pm^{20}_{16}\ \text{(syst.)} \pm 5\ \text{(lumi.)}$ pb

$\delta\sigma/\sigma$~21%

- **Data-driven** *dominant* **tt & W+jets** *(enriched low N_{jet} region (A), weight W+≥3jet with jet fake prob. from average of W+≥1jet & QCD enriched (C),***QCD** *(non-iso mu sample normalized to low E_T^{miss})*



- σ_{tt} =$N_{\mu+\tau}$ /A*Lumi. **$N_{\mu+\tau}$ from**
  - C: **bkg-subtracted data**
  - A: **template lkl fit** of difference of **BDT** in OS & SS samples *(cancel most gluon & b-jet fakes)*

C $\sigma_{t\bar{t}} = 148.7 \pm 23.6(\text{stat.}) \pm 26.0(\text{syst.}) \pm 8.9(\text{lumi.})$ pb

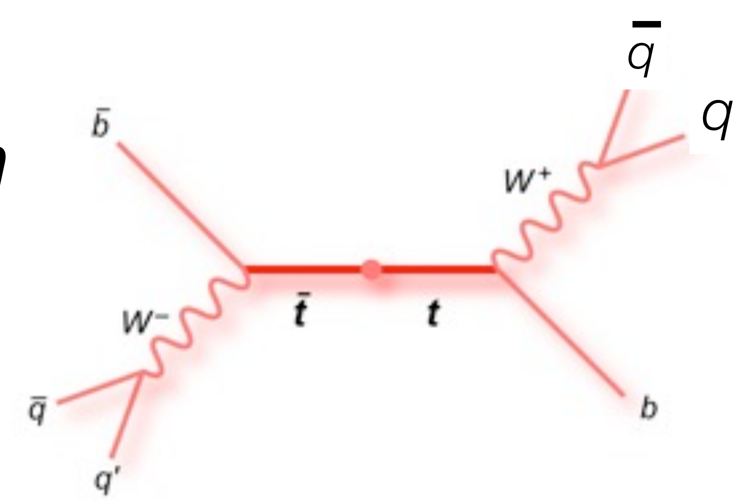
$\delta\sigma/\sigma$~24%

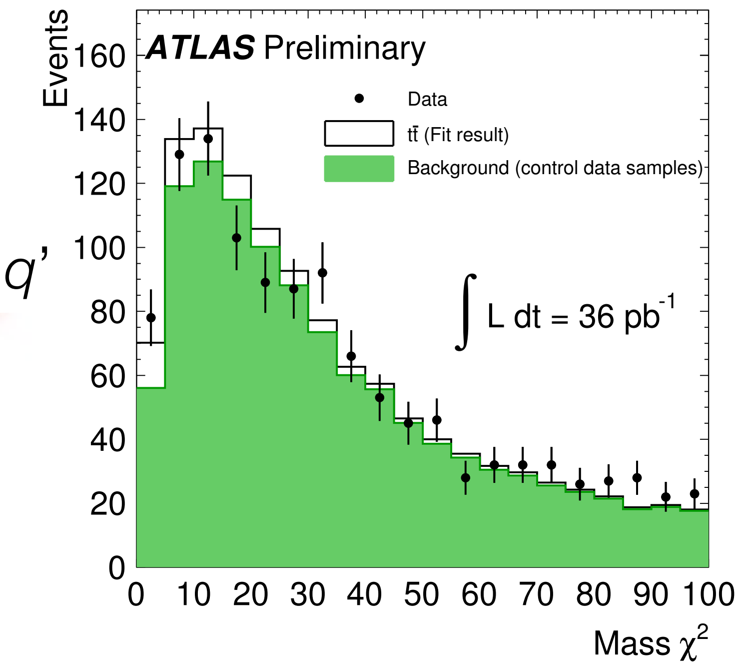
Fully hadronic channel

$\int Ldt$ = **35 pb^{-1}** (***A***) (2010), **~1.0 fb^{-1}** (***C***) (2011)

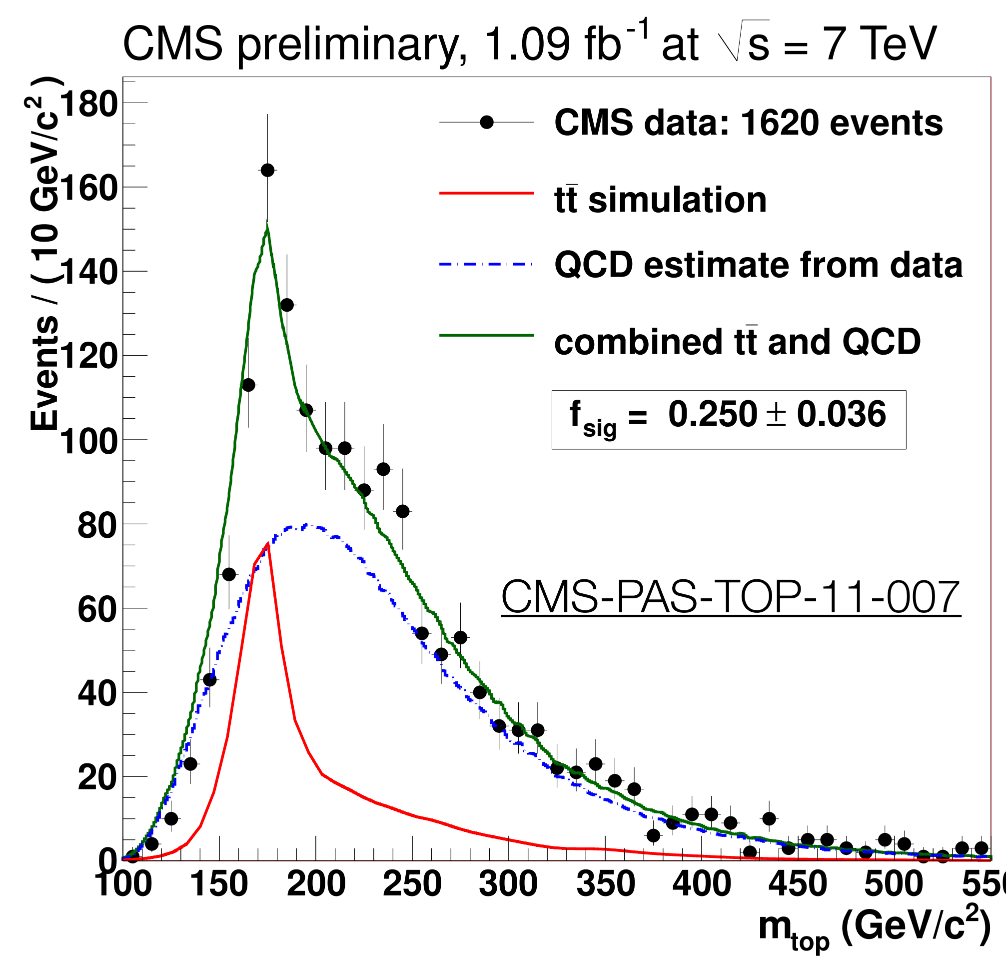
- **≥ 4 jet trigger**, *good jets*
- **≥ 6 high p_T jets, ≥ 2 b-tags**
  - *4 jets with p_T ≥ 60 GeV (A,C), 5th (6th) jet p_T ≥ 50 (40) GeV (C)*
- ***A***: no e or μ, small $E_T^{miss}/\sqrt{E_T^{calo}}$ & large H_T > *300 GeV*
- **Reconstruct with χ^2 kine fit**

A=ATLAS, C=CMS





95% CL upper limit $\sigma_{t\bar{t}} < 261$ pb.



- Data-driven **QCD bkg: weight control samples** *>=6 jets no b-tag (C) or 6,5 jets(A)* **with** *data driven* **b-tag prob**
- **N_{tt} from lkl fit to top mass (C)** *checked by neural network discr.* **or χ^2(A)**→σ=N_{tt}/A*Lumi

Systematics from pseudo exp. *(dominated by b-tag, jet scale, bkg norm)*

δσ/σ~33%

syst dominated!

$$\sigma_{t\bar{t}} = 136 \pm 20\,(\text{stat.}) \pm 40\,(\text{sys.}) \pm 8\,(\text{lumi.})\ \text{pb}.$$

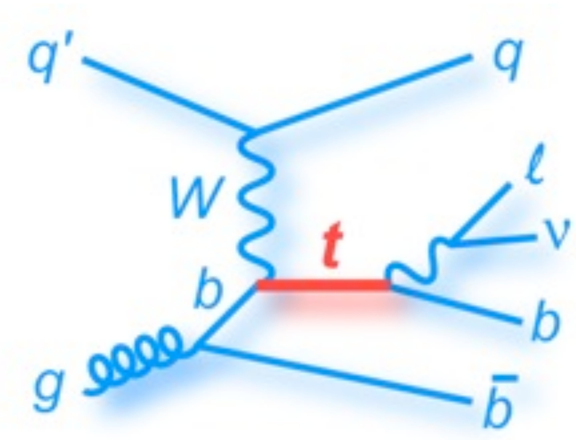
Single top - t channel

$\int L dt$ = **0.7 fb^{-1}** (***A***) *(2011)*, ~**36 pb^{-1}** (***C***) *(2010)*

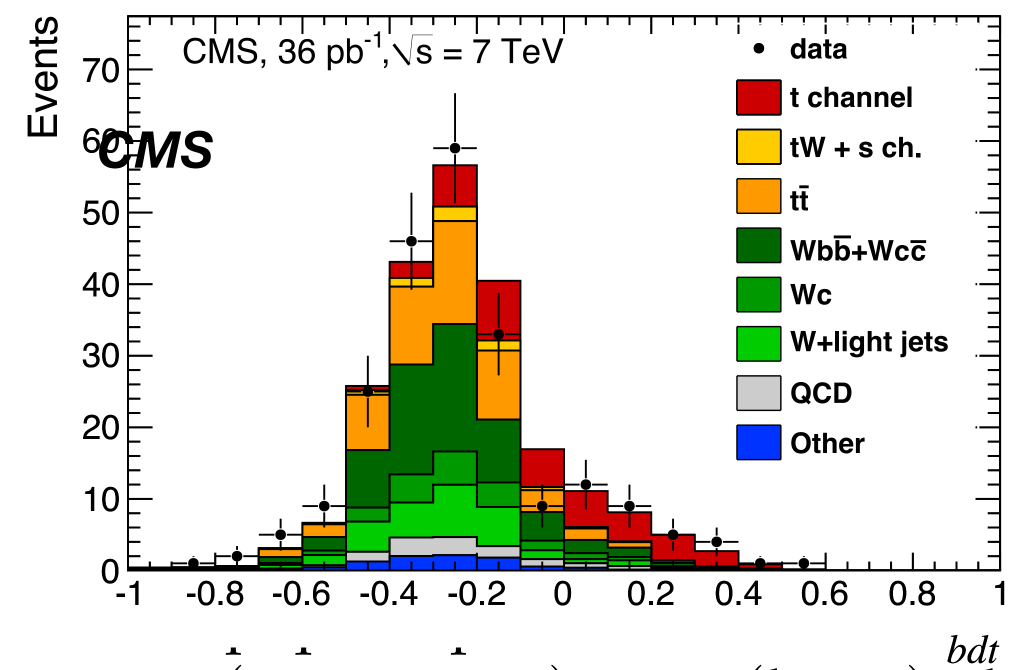
t-chan: $q\ell$**vb(b)**

A=ATLAS, C=CMS

- Exactly **1 high p$_T$ central lepton** (e,μ), **high E$_T^{miss}$** (A) and M$_T^W$(A,C), require **exactly 2** (A,C) or **3 jets** (A) **in |η|<4.5**(A) or **5**(C)
  - *2 samples: pre-tag,1 b-tag (A,C),>=1b-tag (C)*
  - ***QCD and W+jets norm from data***



arxiv:1106.3052



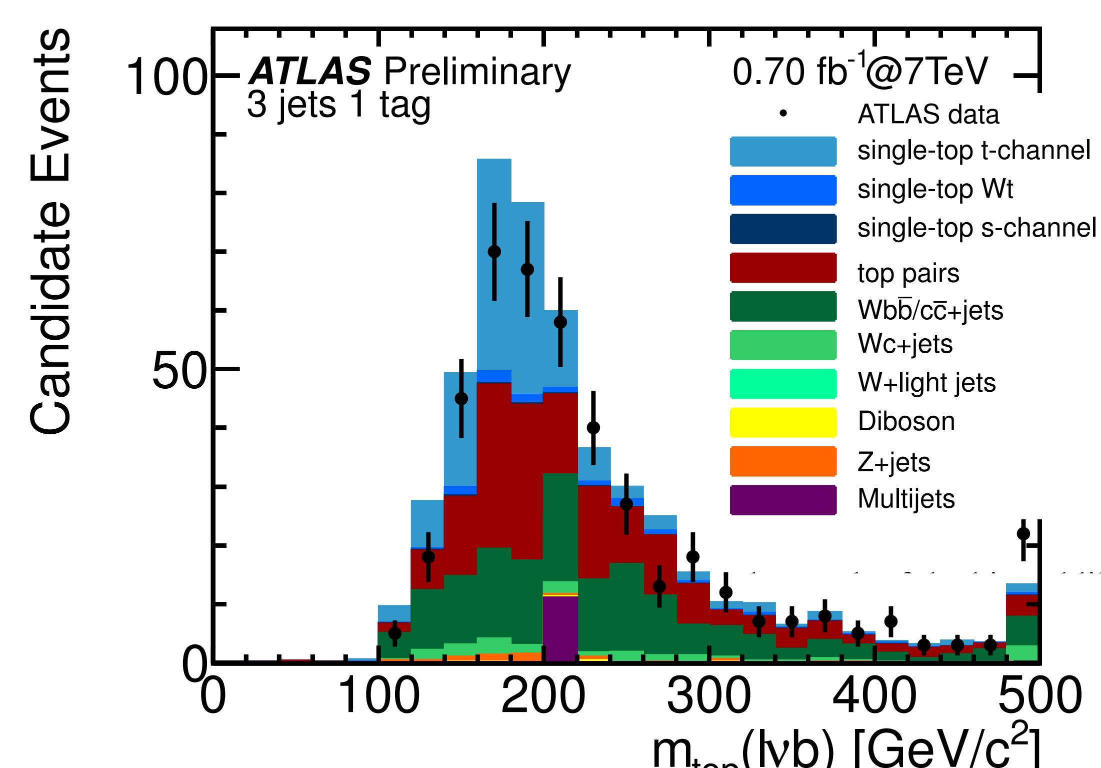
$83.6 \pm 29.8\ (\text{stat.} + \text{syst.}) \pm 3.3\ (\text{lumi.})\ \text{pb},$

δσ/σ~36%

- **C**: **combine 2 results**: **2D-max lkl fit** to *lepton-untagged jet angle & η of untagged jet* + **Bayesian estimate** from BDT
- **A**: **cut/count on angular jet var.,top mass and H$_T$**, *confirmed by max Lkl fit to neural network discriminant (13 var.)*

syst dominated!

ATL-CONF-2011-101



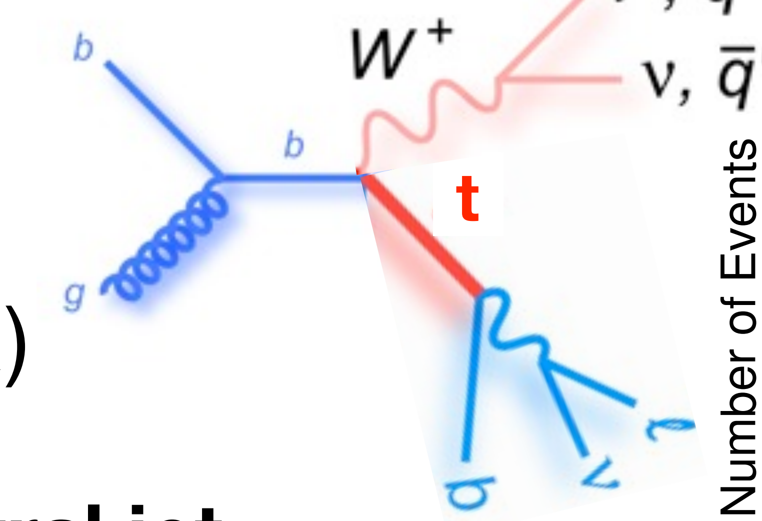
$\sigma_t = 90^{+9}_{-9}(\text{stat})\,^{+31}_{-20}(\text{syst})$ δσ/σ~36%

Single top - Wt channel

$\int L dt$ = **0.7 fb^{-1}** (***A***)

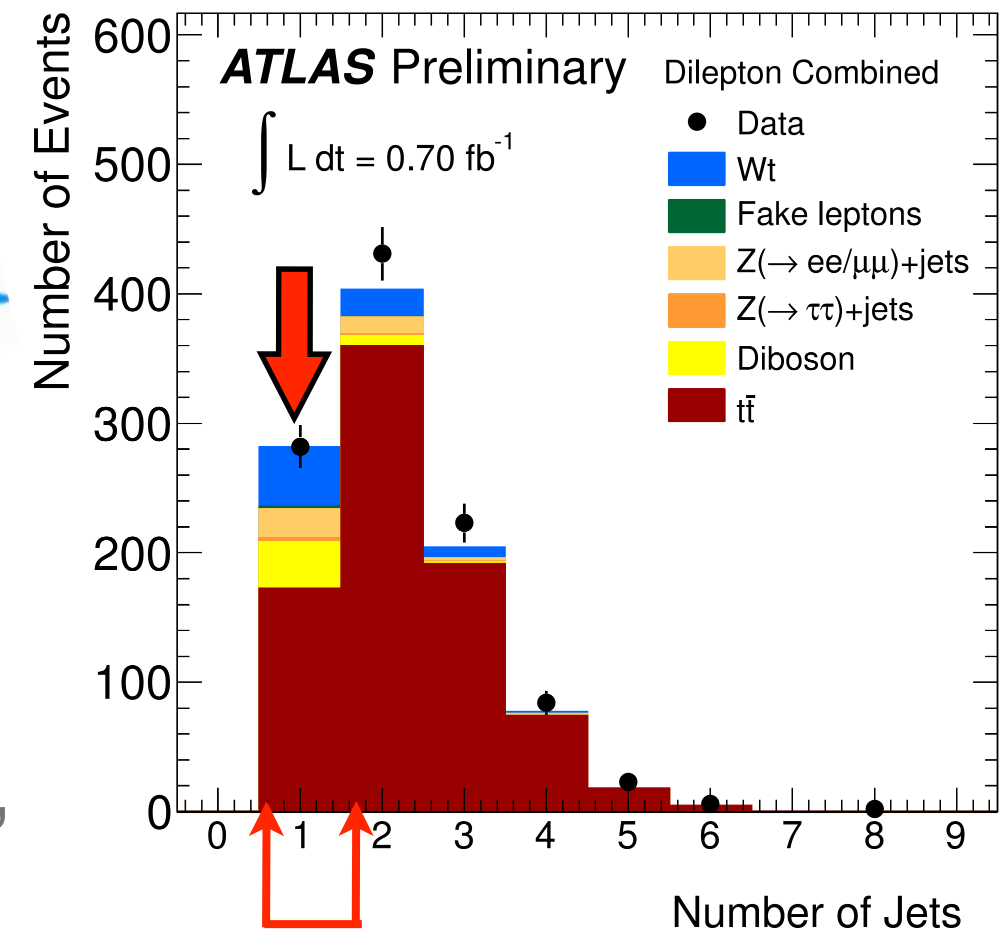
A=ATLAS, C=CMS

ATLAS-CONF-2011-014



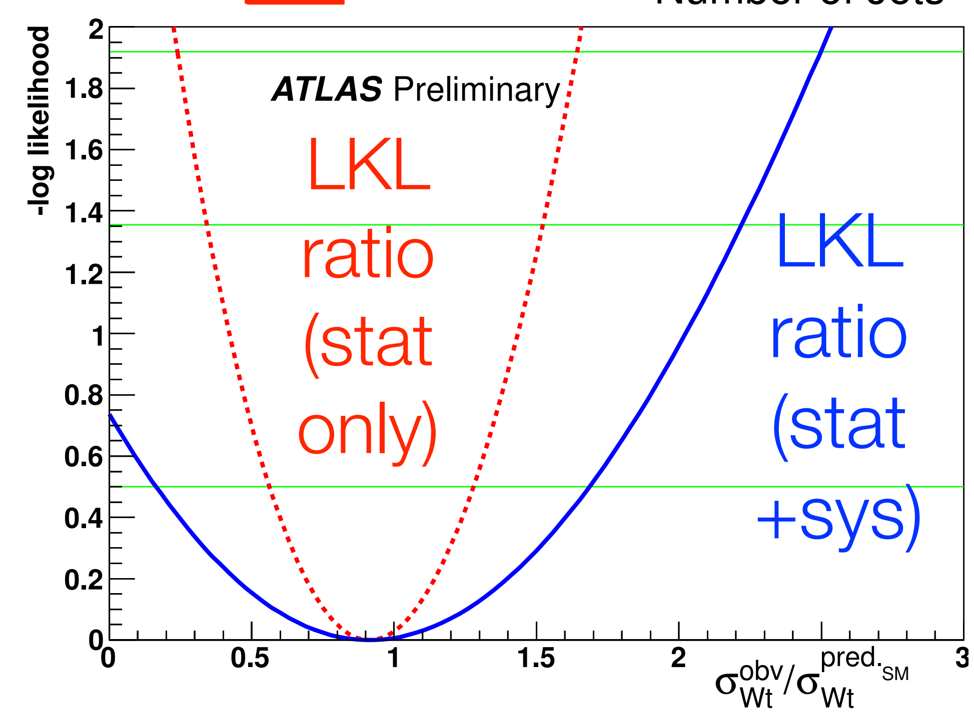
Wt-chan: qqℓνb,ℓνℓνb

- Standard di-lepton (e,μ) selection with
  - **exactly 1 high p_T central jet**
  - cut on $\sum_{lep} \Delta\phi(lep, E_T^{miss})$ to reject $Z\to\tau\tau$



- **Data-driven QCD** *(loose/tight matrix method)*, **Z/γ*+jets** *(extrapol. in (E_T^{miss},M(ℓℓ)) plane)*, **Z→ ττ** *(extrapol. from low $\sum_{lep} \Delta\phi(lep, E_T^{miss})$ region)*, dominant **top pair** *(extrapol. from 2-jet bin)*

- **Cut/count and combine** channels **with max lkl fit. Systematics fitted** as nuisance pars *(jet dominated) in profile lkl.*



95% CL obs(exp) upper limit

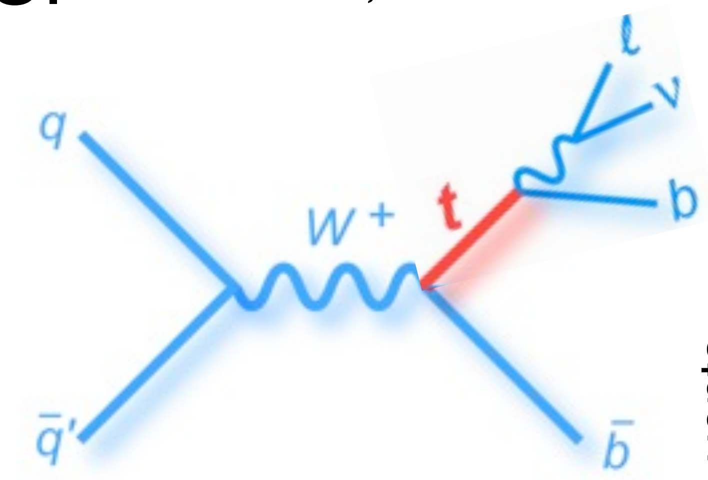
$$\sigma(pp \to Wt + X) < 39\ (41)\ \text{pb}$$

NEW!

$$\sigma(pp \to Wt + X) = 14.4^{+5.3}_{-5.1}(\text{stat})^{+9.7}_{-9.4}(\text{syst})$$

Single top - s channel *A=ATLAS, C=CMS*

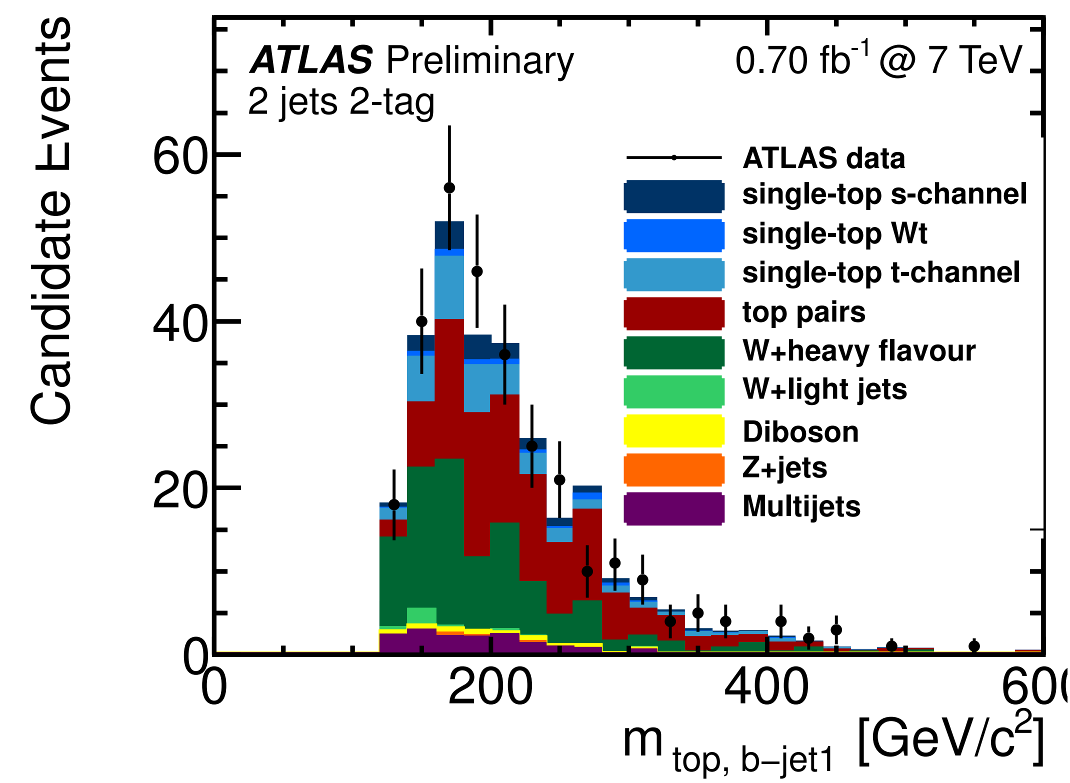
s-chan: ℓvbb

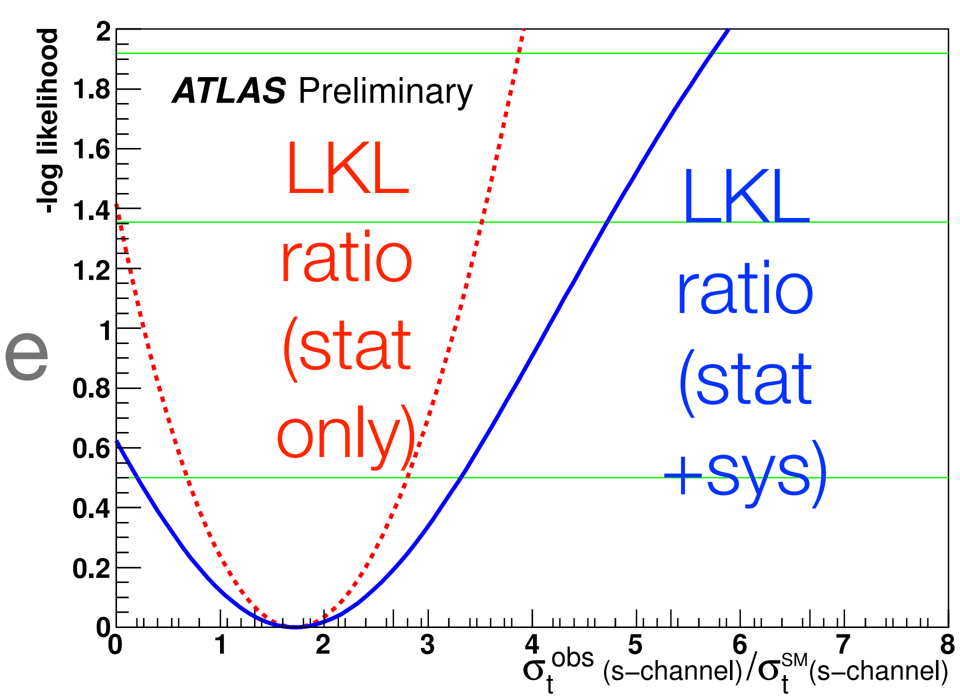


$\int L dt$ = **0.7 fb^{-1}** (***A***) *(2011)*

- Standard single lepton (e,μ) selection with
  - **2 high p_T central jets**
  - **only triangular cut** *(M_T^W > 60GeV - E_T^{miss})* **vs QCD**
- *3 samples: pre-tag,1 b-tag,**2 b-tag (for analysis)***
- Data-driven **QCD** (*electron-like jets shape fitted to E_T^{miss}*), **W+jets normalization** (*extrapol. from pre-tag & 1-tag 2&1-jet bins*)
- **Cut/count and combine** channels **with max lkl fit. Systematics fitted** as nuisance pars *(MC generator dominates) in profile lkl.*

ATL-CONF-2011-118



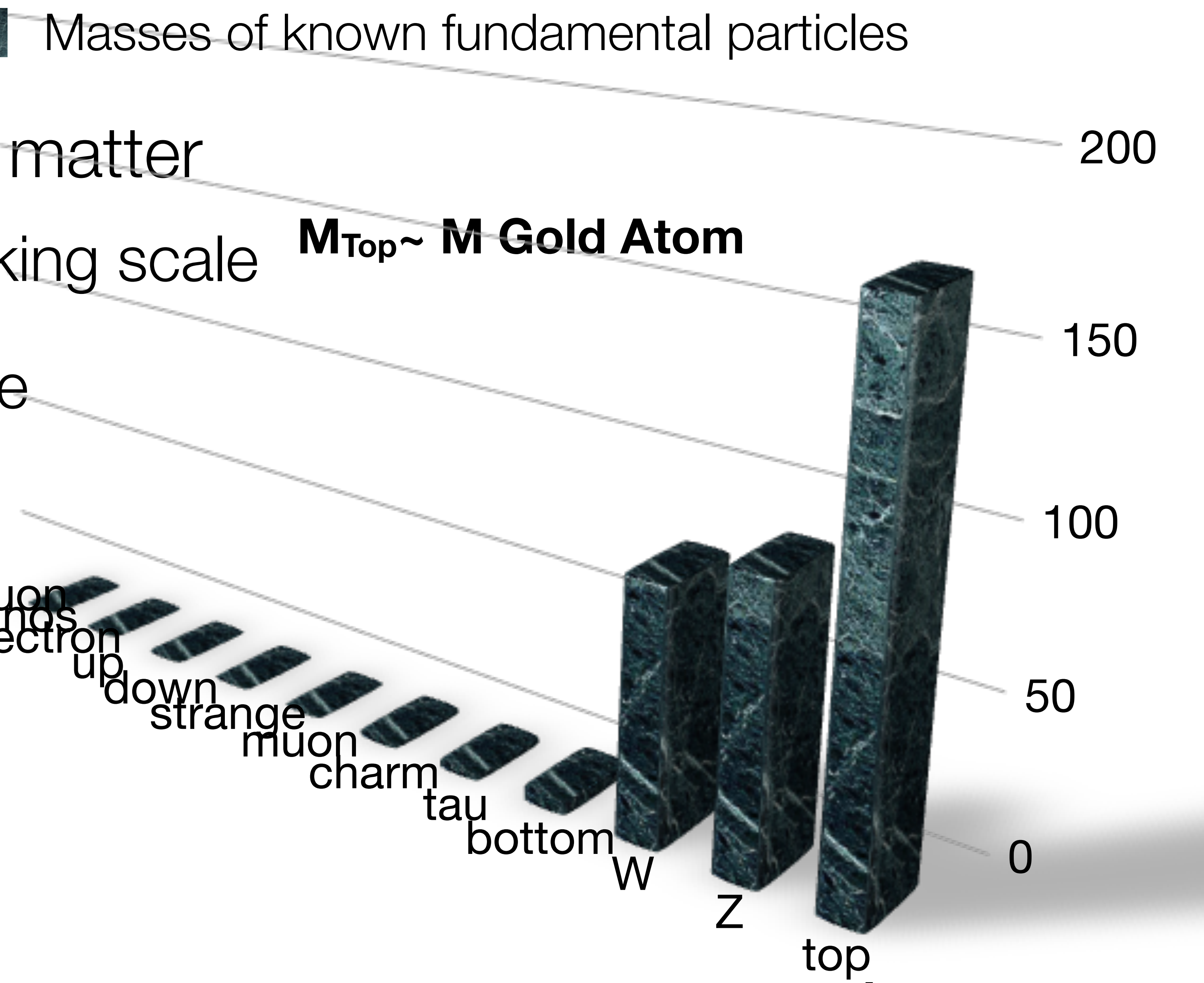


NEW!

95% CL obs(exp) upper limit

$$\sigma_t \text{ (s-channel)} < 26.5 \ (20.5) \text{ pb}$$

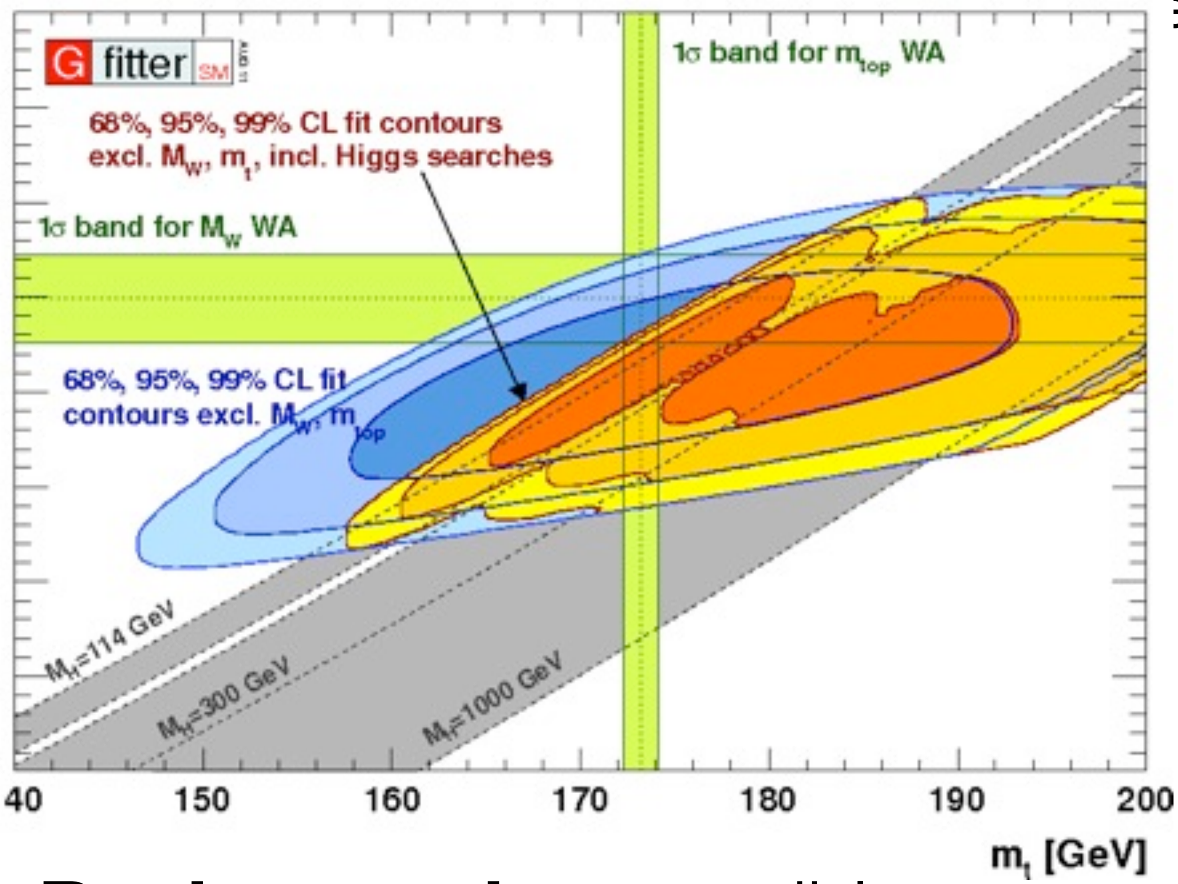
Why Top (quark)?



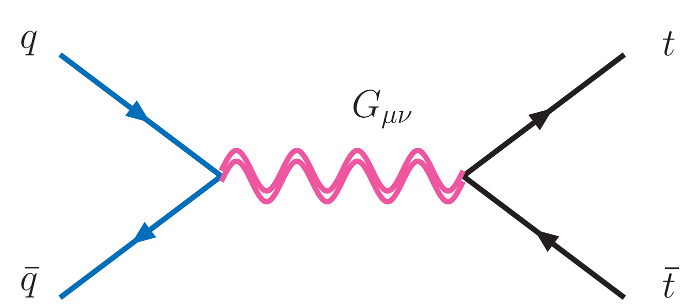
Most massive constituent of matter

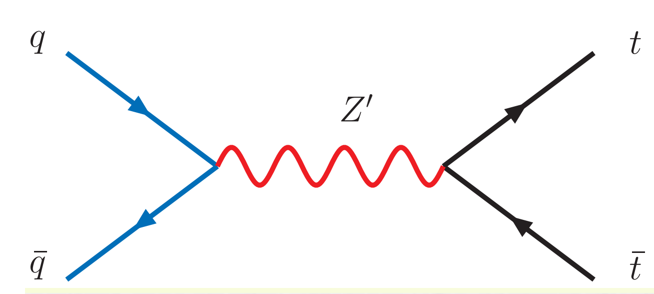
$M_{top}\sim$ electroweak symmetry breaking scale

Decay and strong production rate are **tests of standard model**



Various scenarios with **direct/indirect coupling to new physics:**
from extra dimensions to new strong forces

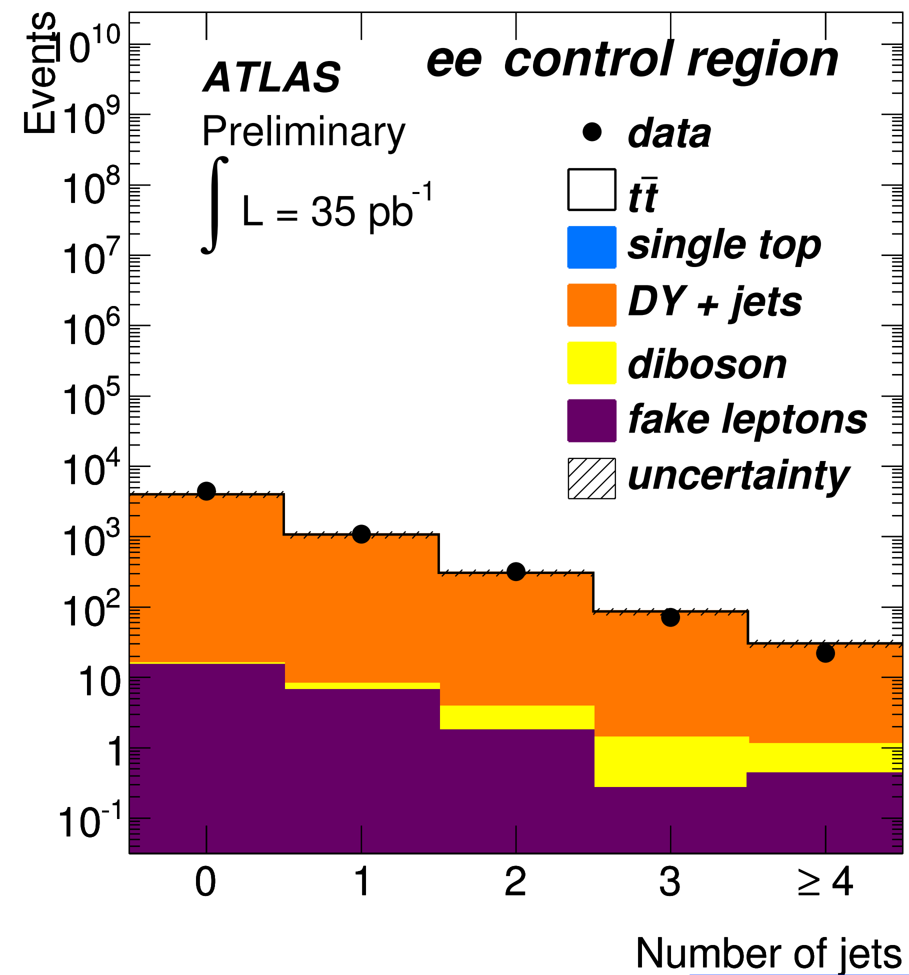




Background to possible **new physics** (Higgs, SUSY)

Data Driven estimate of Non-Z bkg - di-lepton

- Define tight (standard) and loose lepton samples relaxing
  - calo and track isolation for μ
  - calo isolation, TRT hits, E/p cuts for **e**
- Express measured (tight,loose) samples in terms of unknown (**real**, ***fake***) and estimated probabilities **r** (***f***): for **real** (***fake***) leptons passing loose also to pass tight cuts
- Extract ***fake*** content by matrix inversion

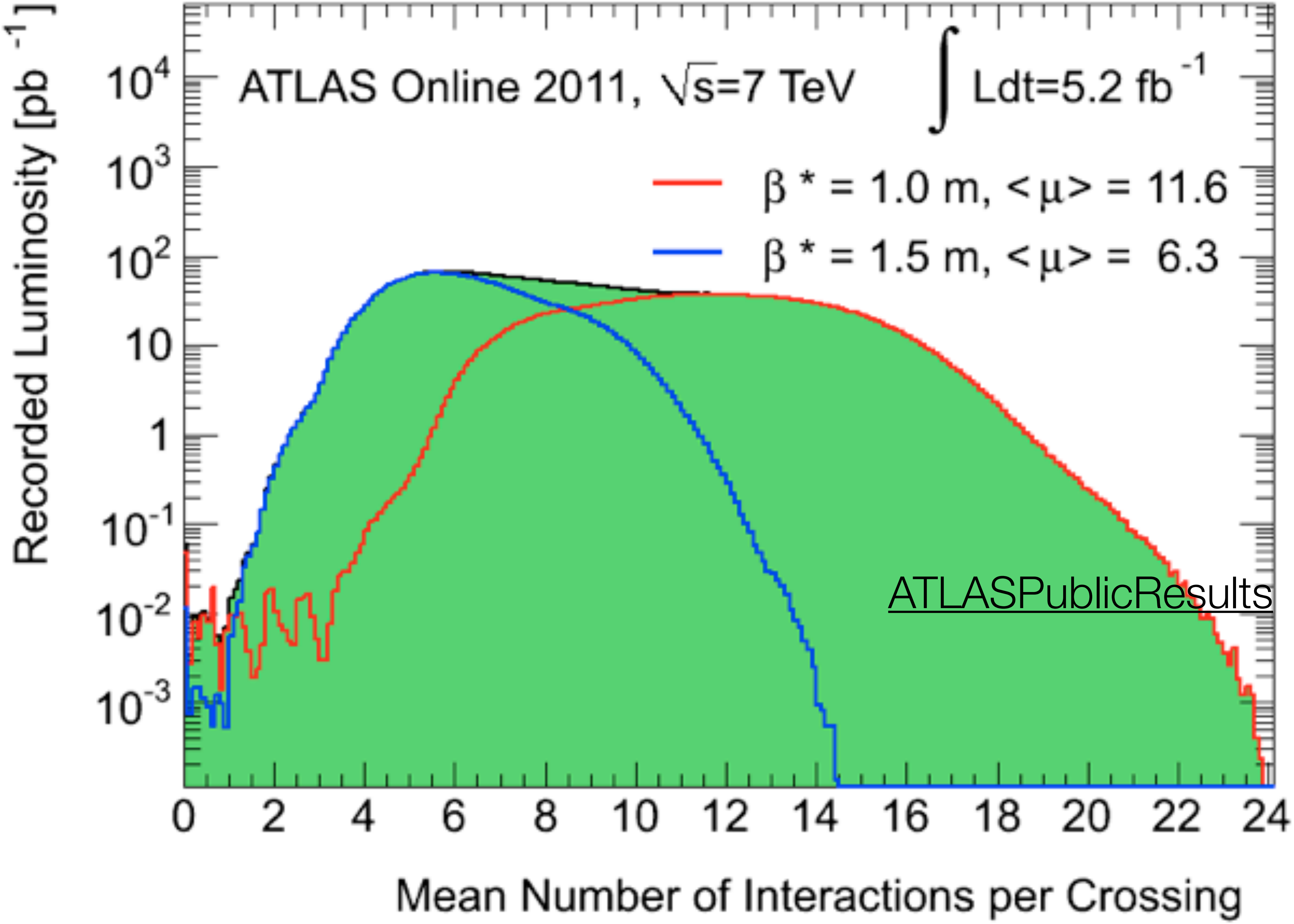


$$\begin{bmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \\ N_{LL} \end{bmatrix} = \begin{bmatrix} rr & rf & fr & ff \\ r(1-r) & r(1-f) & f(1-r) & f(1-f) \\ (1-r)r & (1-r)f & (1-f)r & (1-f)f \\ (1-r)(1-r) & (1-r)(1-f) & (1-f)(1-r) & (1-f)(1-f) \end{bmatrix} \begin{bmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{bmatrix}$$

Measure **r** in $Z \rightarrow ll$

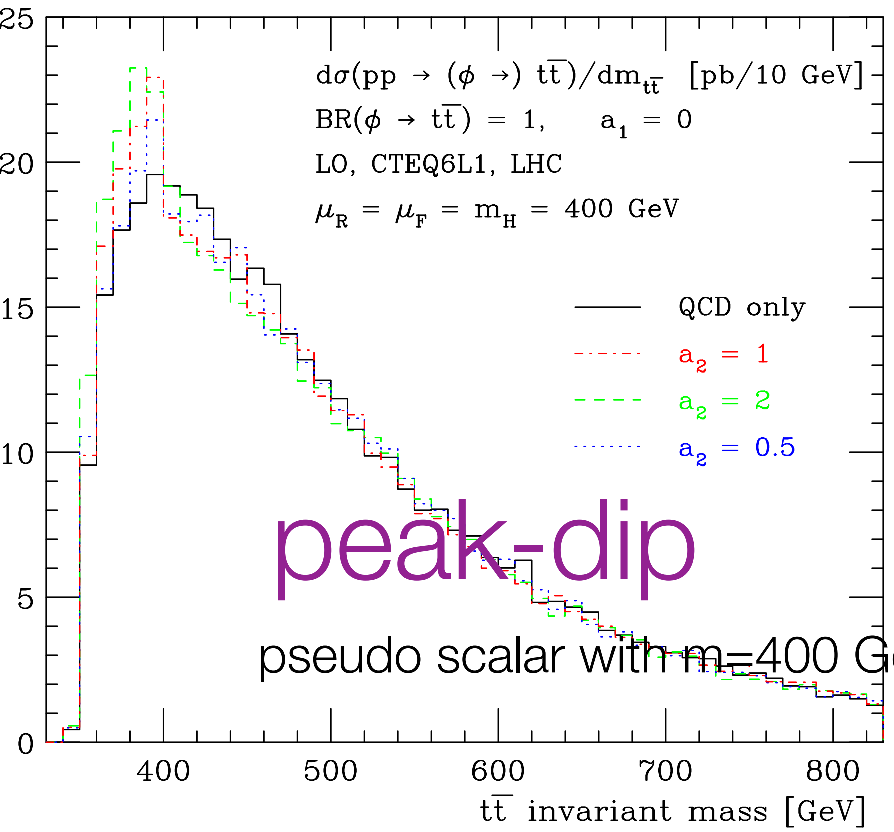
Measure ***f*** in QCD enriched sample: single loose lepton, low E_T^{miss}

(W+jets subtracted using simulation)



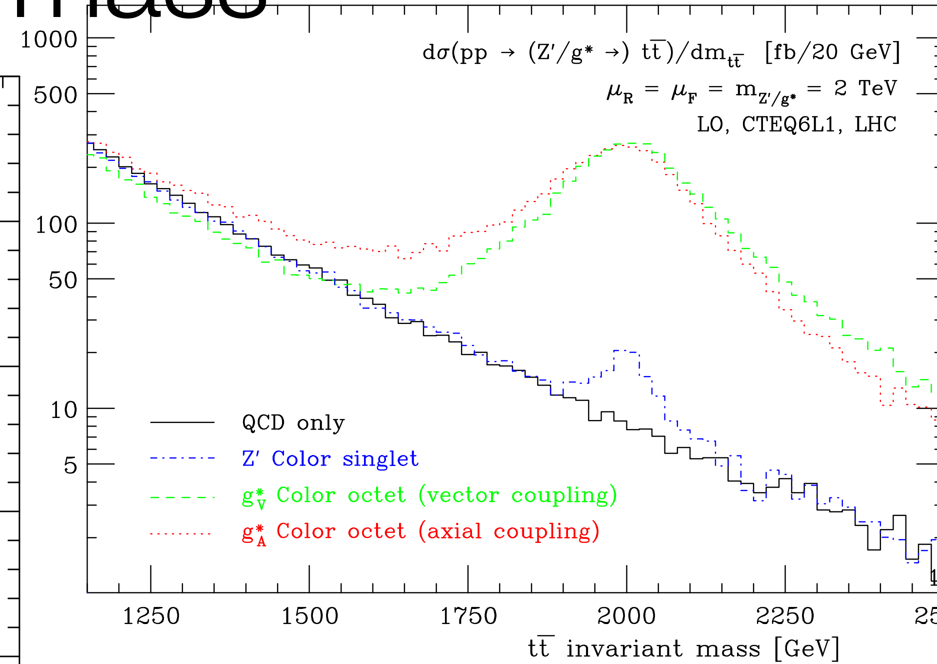
also see arxiv:1101.2185

New phys in ttbar mass



peak-dip

pseudo scalar with m=400 GeV

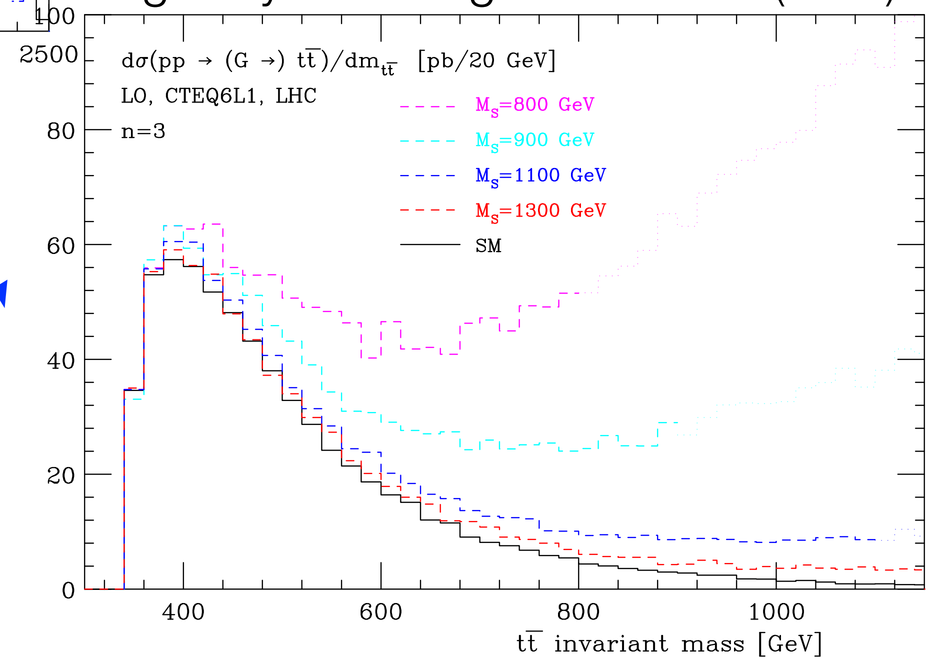


one peak

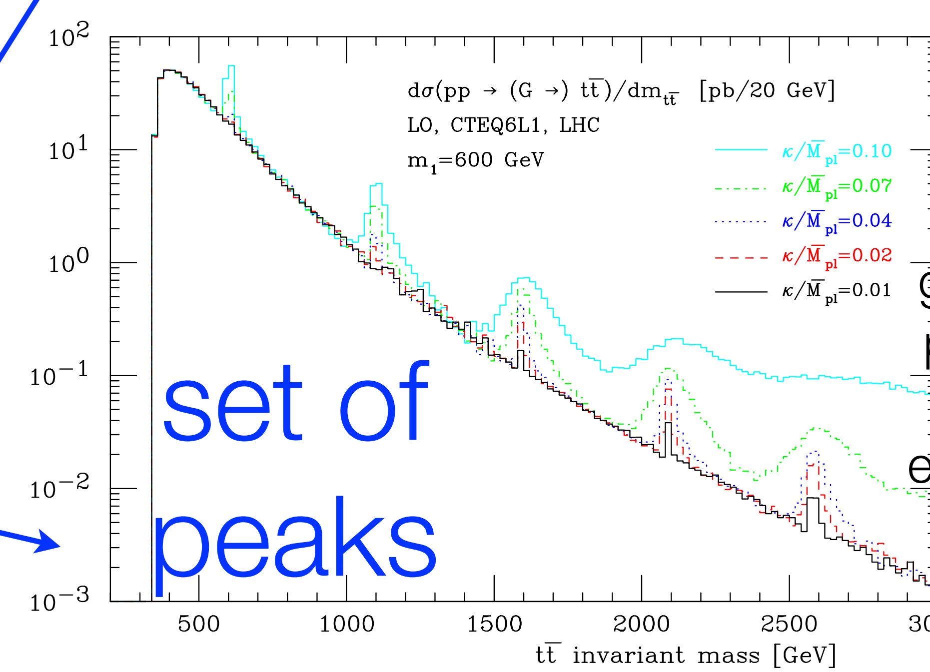
Z' or
new strong bosons

enhancements

tower of degenerate KK gravitons ; only gravity in N "large" extra dim (ADD)



Spin	color	parity $(1, \gamma_5)$	some examples/Ref.
0	0	(1,0)	SM/MSSM/2HDM, Ref. [51, 52, 53]
0	0	(0,1)	MSSM/2HDM, Ref. [52, 53]
0	8	(1,0)	Ref. [54, 55]
0	8	(0,1)	Ref. [54, 55]
1	0	(SM,SM)	*Z′*
1	0	(1,0)	vector
1	0	(0,1)	axial vector
1	0	(1,1)	vector-left
1	0	(1,-1)	vector-right
1	8	(1,0)	coloron/KK gluon, Ref. [56, 57, 58]
1	8	(0,1)	axigluon, Ref. [57]
2	0	–	graviton "continuum", Ref. [17]
2	0	–	graviton resonances, Ref. [18]



set of peaks

tower of KK gravitons ; all particles in 1 "warped" extra dim (RS)

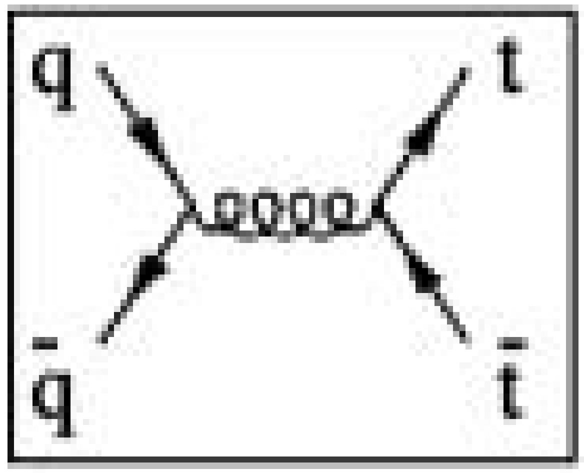
arxiv:0712.2325

Top spin correlation

$^{2L+1}S_J$

- Top quark decays before hadronization: $1/\Gamma_{top} < 1$ fm → top polarization preserved in angular distrib of decay products

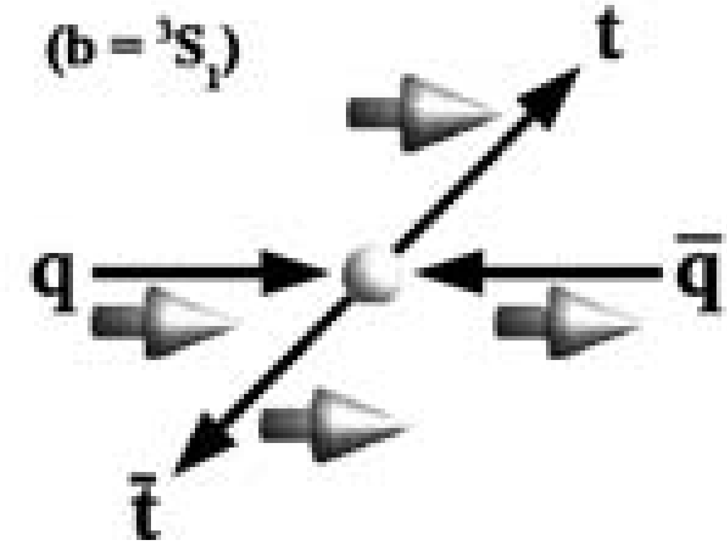
massless fermions: fixed helicity=chirality + QCD conserves chirality



dominant at Tevatron

$s \sim 2m_{top}$

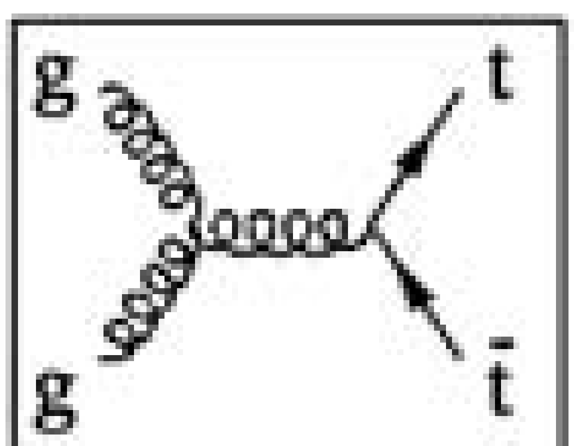
mostly $^3S_1$



L=0,J=1 → **parallel** spins *along given axis*

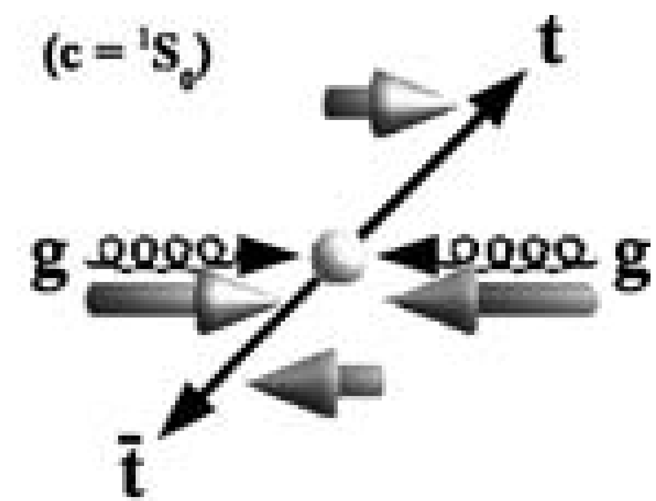
opposite helicity

tt is produced unpolarized



dominant at LHC

mostly $^1S_0$



L=J=0 → anti-**parallel** spins *along given axis*

same helicity

if m -> 0 chirality -> helicity = projection of spin along direction of motion