Production of top pair events with additional radiation using the ATLAS detector at the LHC

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Overview

- **Physics motivation**
- **top-pairs production and final states at LHC**
- **Studies of MC generators and tests of pQCD**
  - Generator studies for top pairs production with extra jets
  - Associated production of top-pairs and HF
  - top-pair differential cross-section
- **top EW properties**
  - top-pairs and photon production
  - top-pairs and Z production
- **Summary and conclusions**

Physics motivation

Improving the precision of top-quark measurements

➡ top-pairs production fundamental for pQCD studies at the top scale
most measurements affected by uncertainties in the description of quark and gluon radiation in standard MC generators

✦ **Top pairs + jets allows to tune current MC generators and constraint model uncertainties**

Top quark heaviest particle, special role in the SM

➡ heavy top dominant in the Higgs self-coupling (loop corrections to m_H)
heavy top does not hadronize ($\Gamma_{top} \gg \Lambda_{QCD}$)

both due to the the large coupling O(1) to the EW sector which suggests a fundamental role in the EWSB

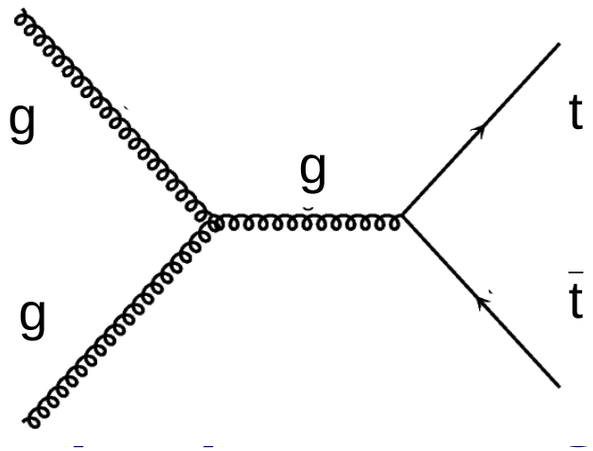
✦ **Top pairs + vector boson allows to probe top EW properties**

Top as a portal for new physics

➡ "naturalness" leads to new heavy states with favored coupling to top

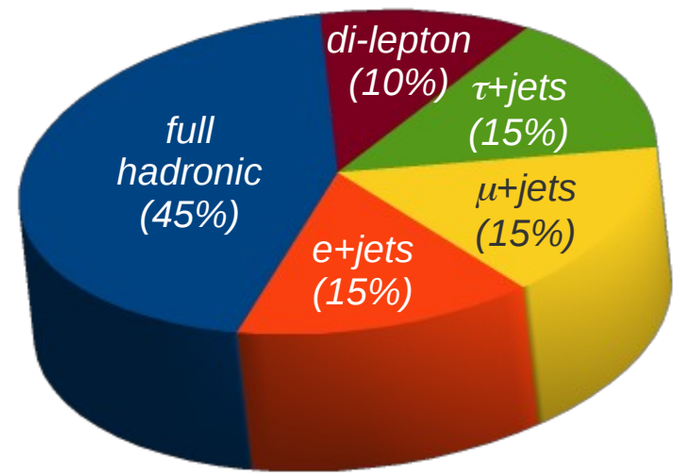
✦ **Such states decay to tops and extra radiation (not included in this talk)**

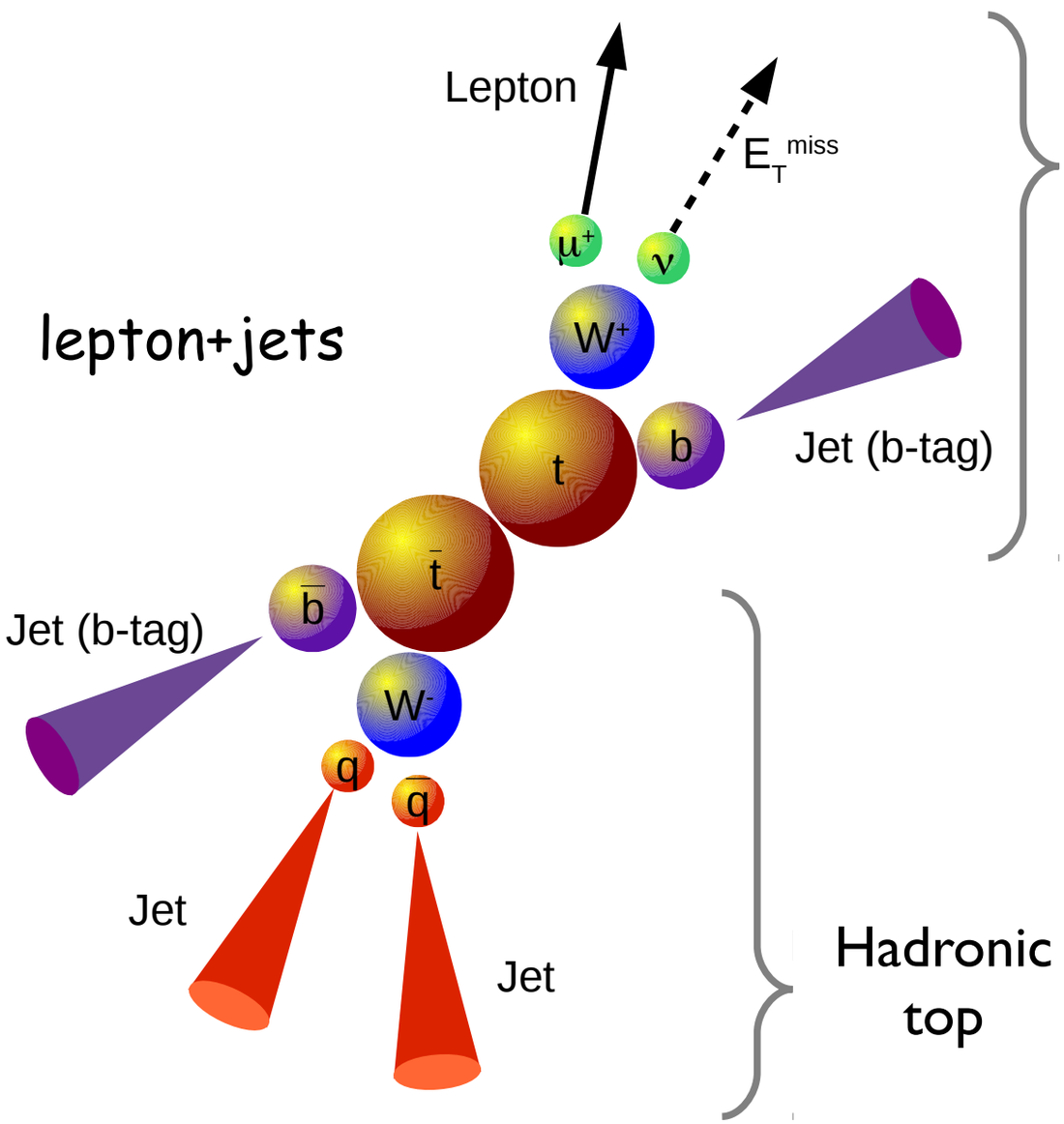
Top-pair production and decay



dominant production at LHC via gg

$\sigma_{tt} \sim 170\ (245)$ pb @ $\sqrt{s}$= 7 (8) TeV





Selection used in the presented results

lepton+jets

- one high-pt isolated lepton
- ≥ 4 jets
- E_T^{miss}, $m_T(W)$
- b-tagging

dilepton

- two high-pt isolated lepton
- ≥ 2 jets
- E_T^{miss}
- b-tagging

Top-pairs production with extra jets

- Constraint uncertainties related to QCD radiation modeling
- Test of pQCD at the LHC regime

EPJC C72 (2012) 2043, ATLAS-PHYS-PUB-2013-005

- $\sqrt{s}$=7 TeV, **dilepton** channel, 2 b-tagged jets
- variables of interest gap fractions:

$$f(Q_0) = \frac{n(Q_0)}{N} \longrightarrow \text{leading-pt emission}$$

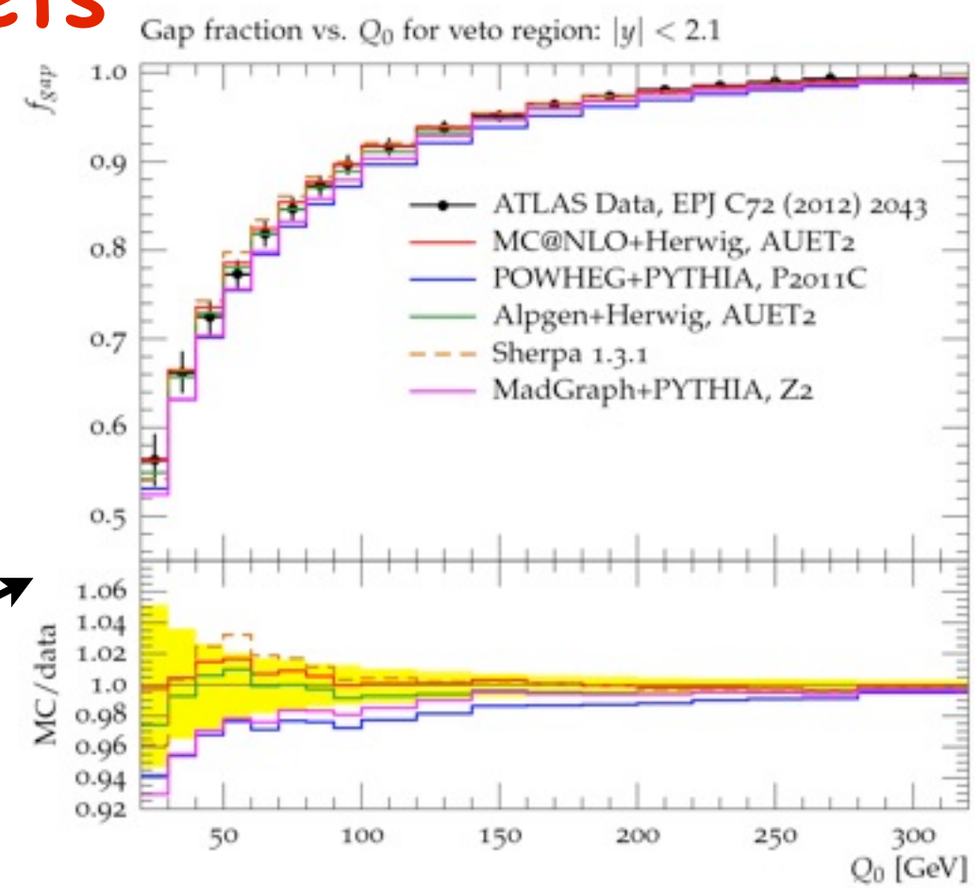
$$f(Q_{sum}) = \frac{n(Q_{sum})}{N} \longrightarrow \text{all hard emission}$$

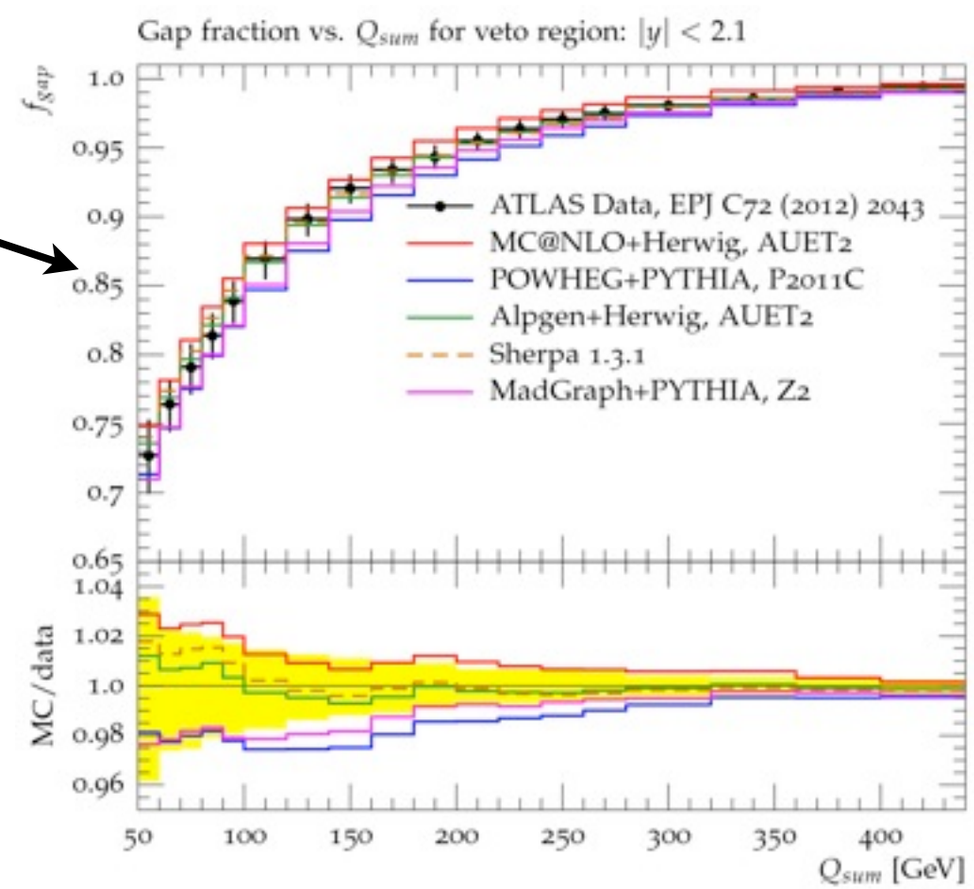
N = selected events

$n(Q_0)$ = subset of N with no additional jet with $P_T > Q_0$

$n(Q_{sum})$ = subset of N with no additional radiation with $\Sigma_j P_T > Q_{sum}$

Fraction of events surviving veto cuts in different rapidity region





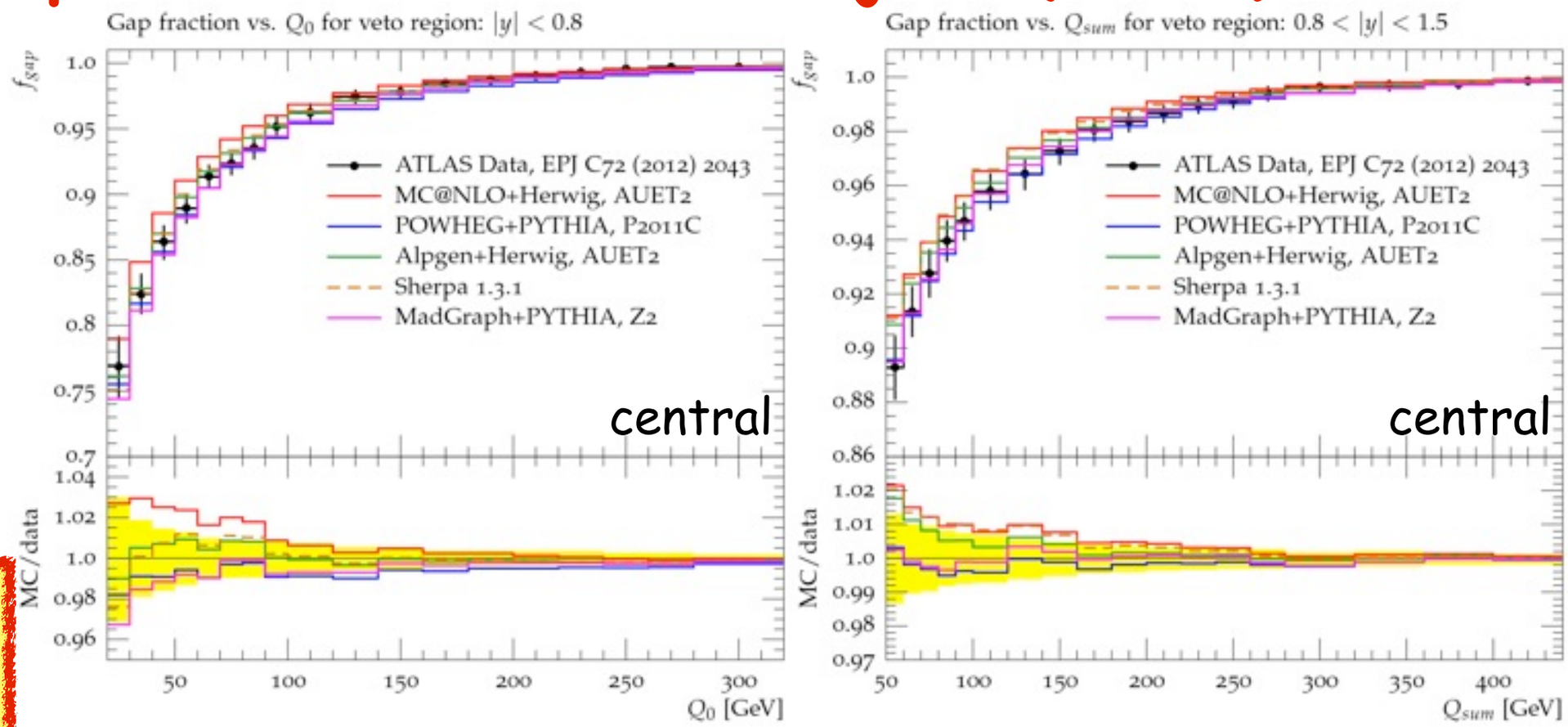
Top-pairs production with extra jets (contd)

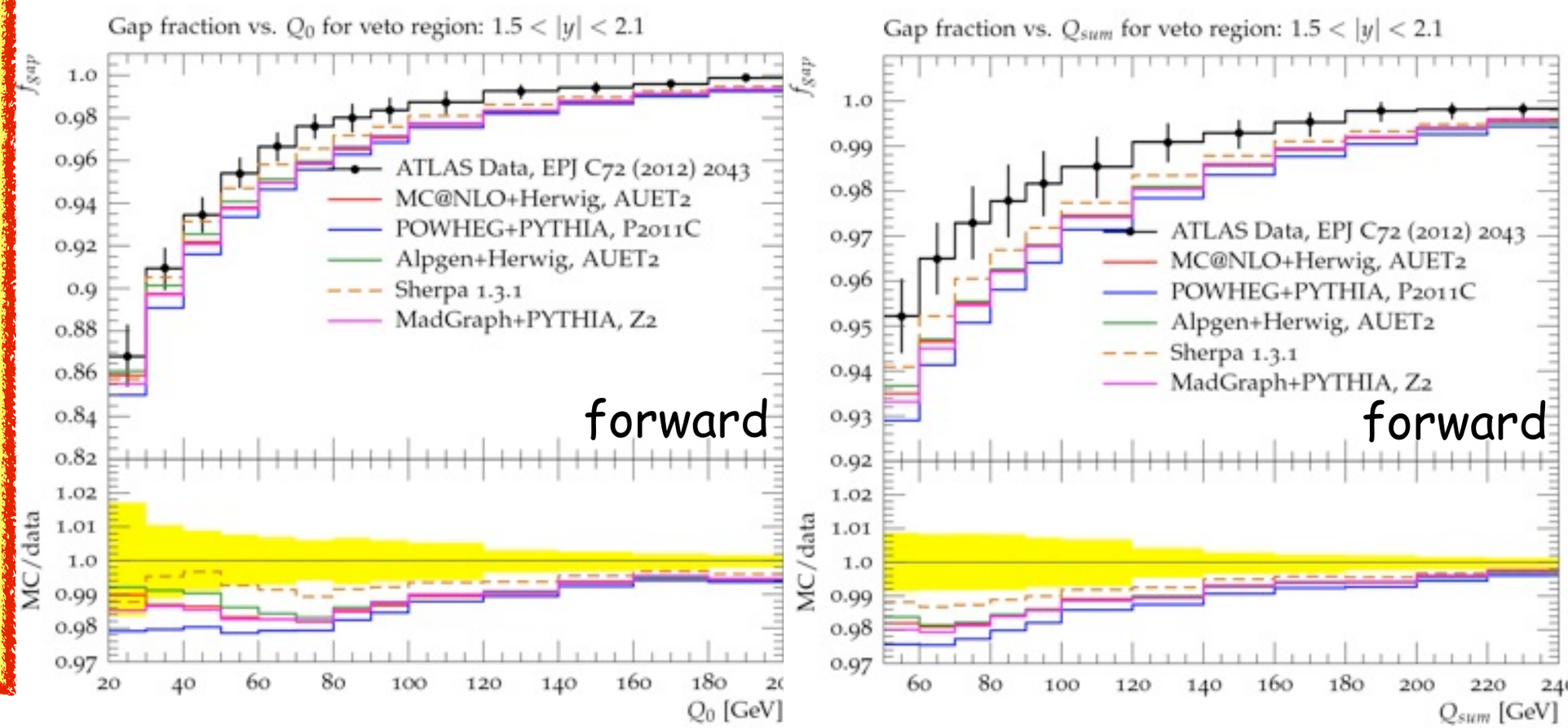
EPJC C72 (2012) 2043
ATLAS-PHYS-PUB-2013-005

- Comparison with NLO ME and LO multi-leg generators with different PS and tunings

- **Central rapidity** region: all generators but MC@NLO +HERWIG give a reasonable description of the data

- **Forward rapidity** region: all generators have difficulty in describing data especially at low Q_0 and Q_{sum}. SHERPA is the closest to data.





Top-pairs production with extra jets (contd)

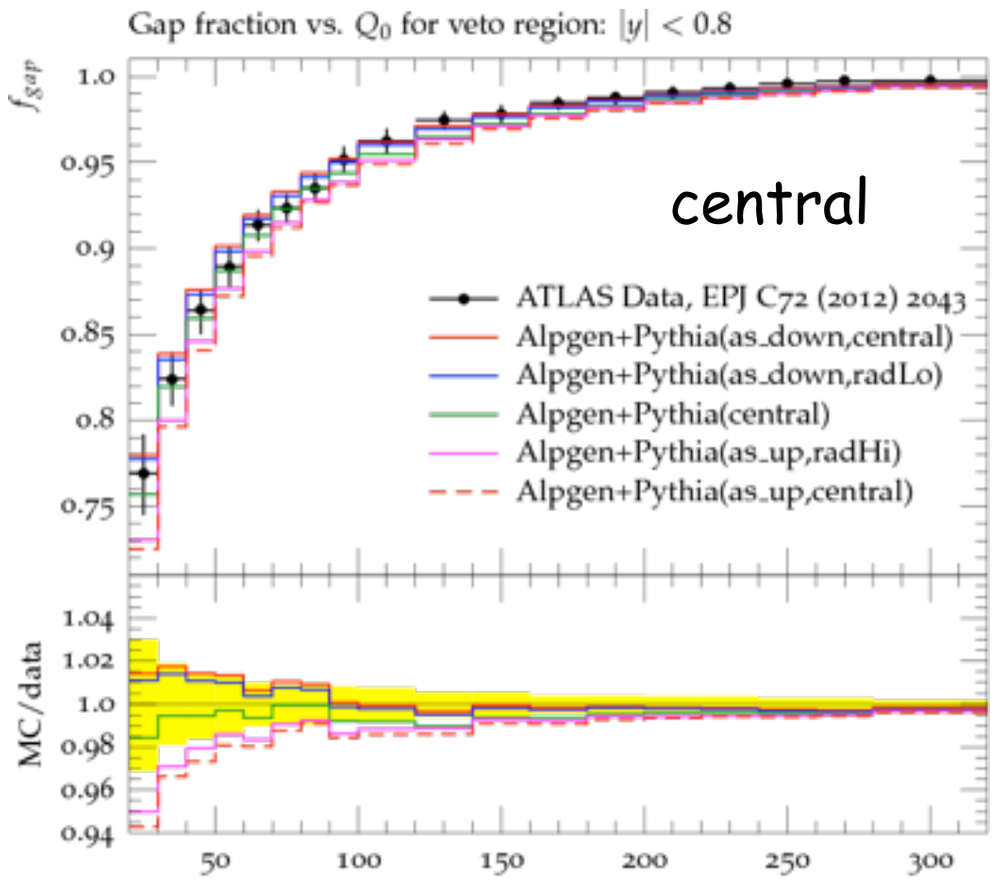
Further studies using ALPGEN+PYTHIA predictions varying the radiation settings

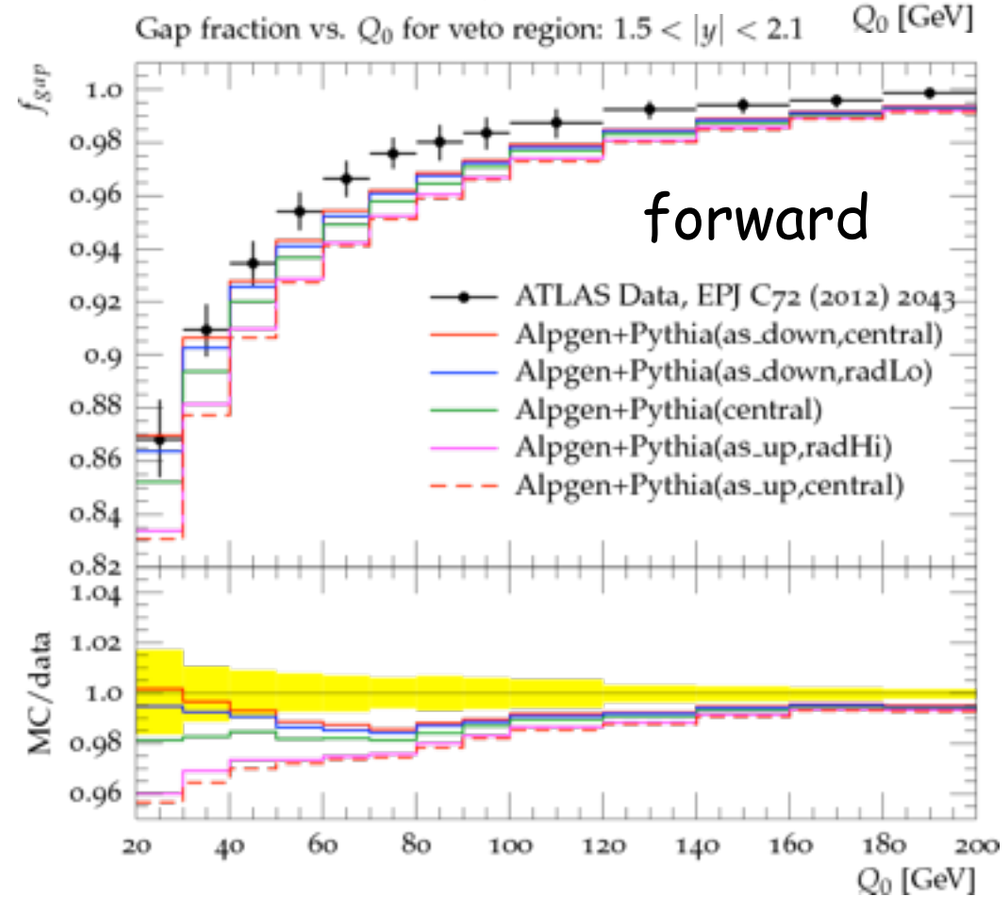
EPJC C72 (2012) 2043, ATLAS-PHYS-PUB-2013-005

✦ Radiation increased and decreased at the ME level and both at the ME and PS level

✦ **Central rapidity** region very well described, the systematic variations bracket the data.

✦ **Forward rapidity** region not well described, all variations below the data (radiation overestimated). Low-radiation settings improve the agreement with data, high-radiation settings in large disagreement with data.





Top-pairs production with extra jets (contd)

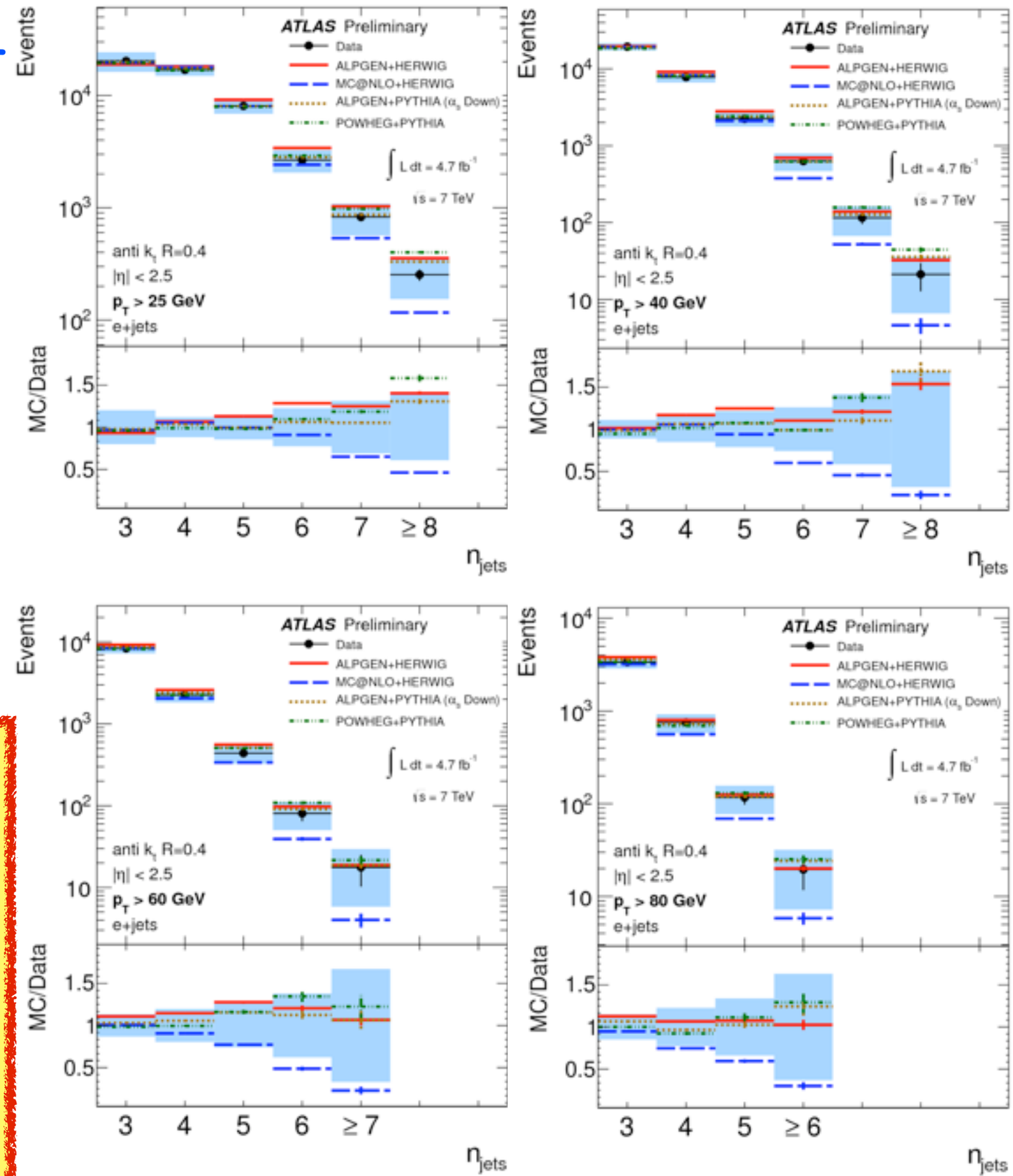
Global jet-multiplicity studied in top-pair events, full 2011 data-set

ATLAS-CONF-2012-155
ATLAS-PHYS-PUB-2013-005

- ✦ $\sqrt{s}$=7 TeV, **lepton+jets** channel
- ✦ jet multiplicities for different jet-P_T thresholds, compared to NLO and LO multi-leg MC predictions
- ✦ Measurement precision limited by systematic uncertainties:
  Bkg modeling at lower jet-multiplicities
  JES at higher jet-multiplicities

✦**Jet-P_T >25 GeV**, all generators agree with data in the 3-5 jets bin.

✦**Higher jet-PT** thresholds, MC@NLO +HERWIG lower jet-multiplicities and softer jets (as expected), ALPGEN +HERWIG/PYTHIA (decreased rad.) and POWHEG+PYTHIA better agreement with the data

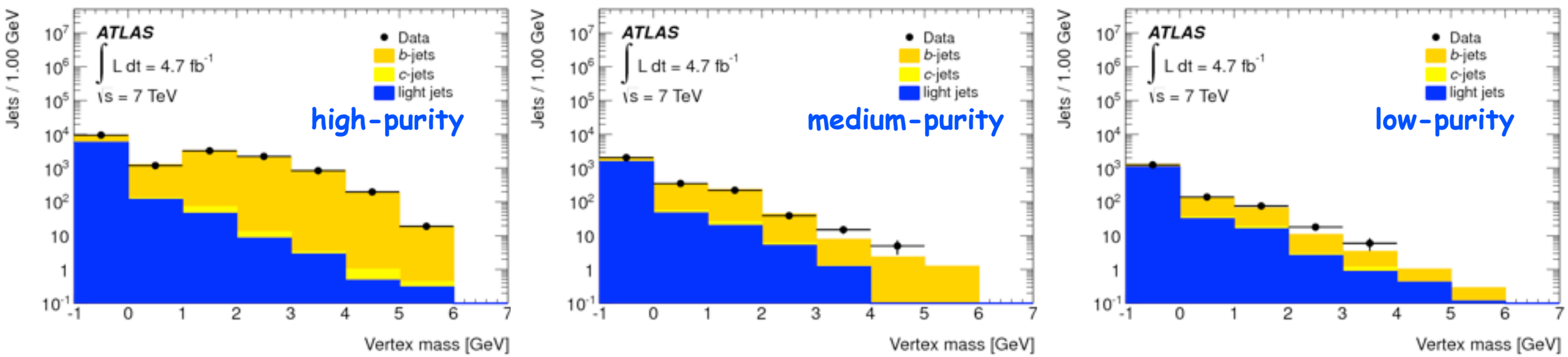


top-pairs + heavy flavor production

Irreducible background for ttH, H→bb

- ✦ √s=7 TeV, dilepton selection with at least one additional jet
- ✦ Template fit method on displaced vertex mass, using different b-tag operating point
- ✦ Measure ratio respect to tt+jets
- ✦ Main systs: HF tagging efficiency and fragmentation modeling

arXiv:1304.6386 [hep-ex], accepted by PRD



$$\frac{\sigma_{tt+HF}}{\sigma_{tt+jets}} = 6.2 \pm 1.1(stat.) \pm 1.8(syst.)\%$$

in agreement with SM MC predictions:
ALPGEN+HERWIG = 3.4% , POWHEG+HERWIG = 5.2%

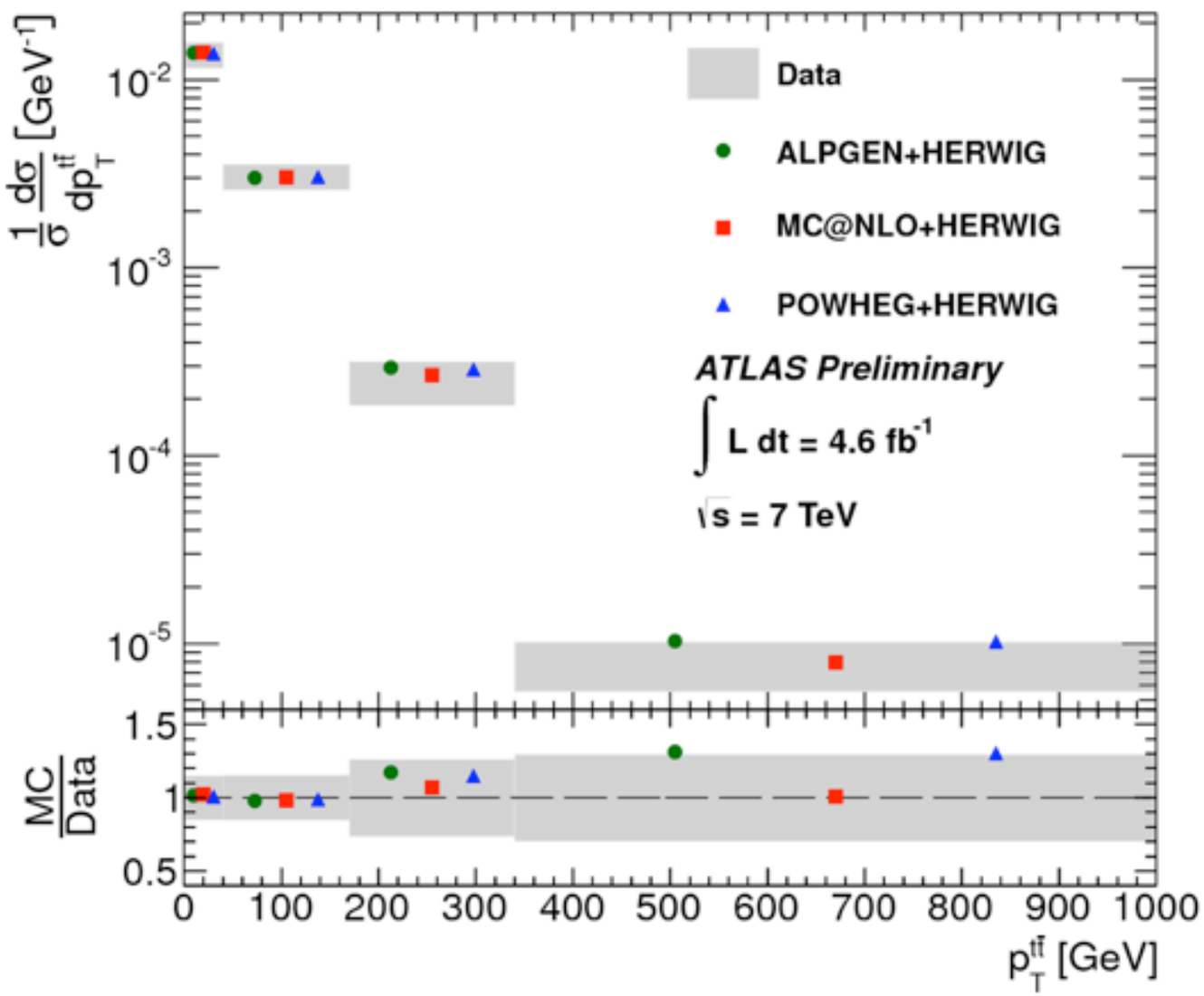
top-pair differential cross-section

Hints on the details of the production process
pQCD tests

ATLAS-CONF-2013-099

- ✦ $\sqrt{s}$=7 TeV, **lepton+jets** channel, full 2011 data-set
- ✦ P_T of the tt system only defined at NLO or higher corrections (identically null at LO)

  ➡ large sensitivity to extra QCD radiation
- ✦ Normalized differential cross section compared to NLO and LO multi-leg generators interfaced to HERWIG for the PS.



✦ MC@NLO closest to the data, reasonable agreement for all generators within uncertainty.

top-pairs + photon production

Many properties of the top quark still measured with large uncertainties:

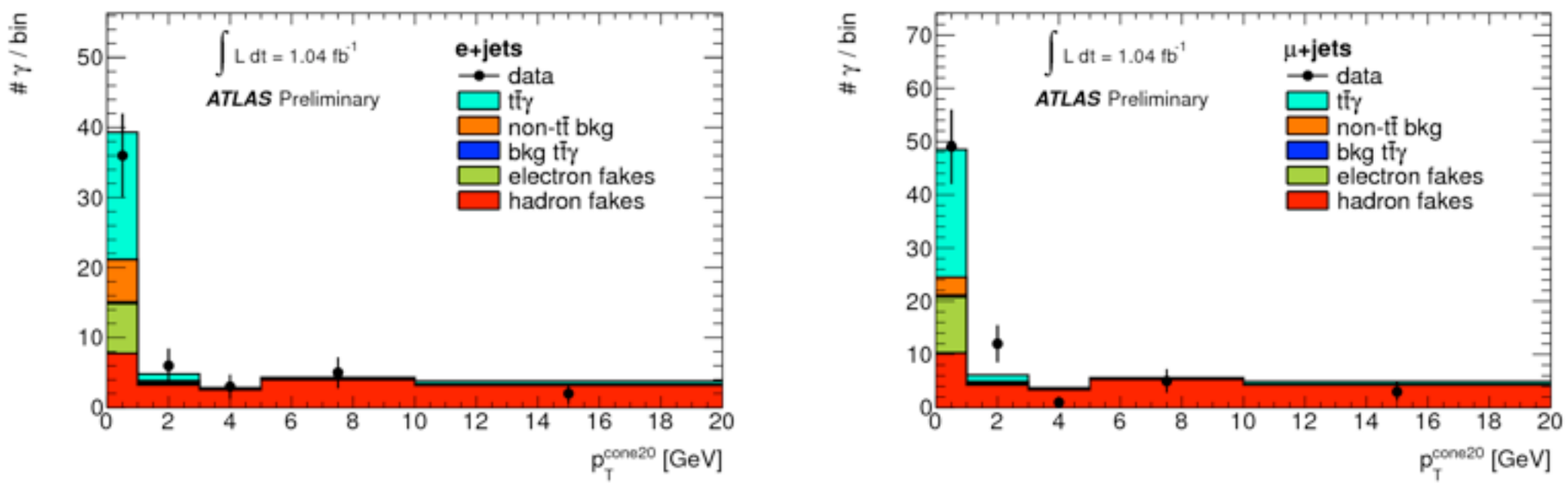
➡ **associated production of top pairs and a vector boson, sensitivity to the ttγ or ttZ vertex, test of the EW properties of the top quark**

- ✦ $\sqrt{s}$=7 TeV, lepton+jets selection + high-E_T photon (E_T >15 GeV)
- ✦ Template fit method used to evaluate the number of signal events,

photon-track isolation used as discriminate variables:

$P_T^{cone20} = \sum_{trk} P_T^{trk}$ in a cone R=0.2 around the photon

ATLAS-CONF-2011-153



$$\sigma_{tt\gamma} = 2.0 \pm 0.5(stat.) \pm 0.7(syst.) \pm 0.08(lumi.)pb$$

in agreement with the SM prediction: $\sigma_{tt\gamma} = 2.1 \pm 0.4pb$ (LO MC x NLO corr.)

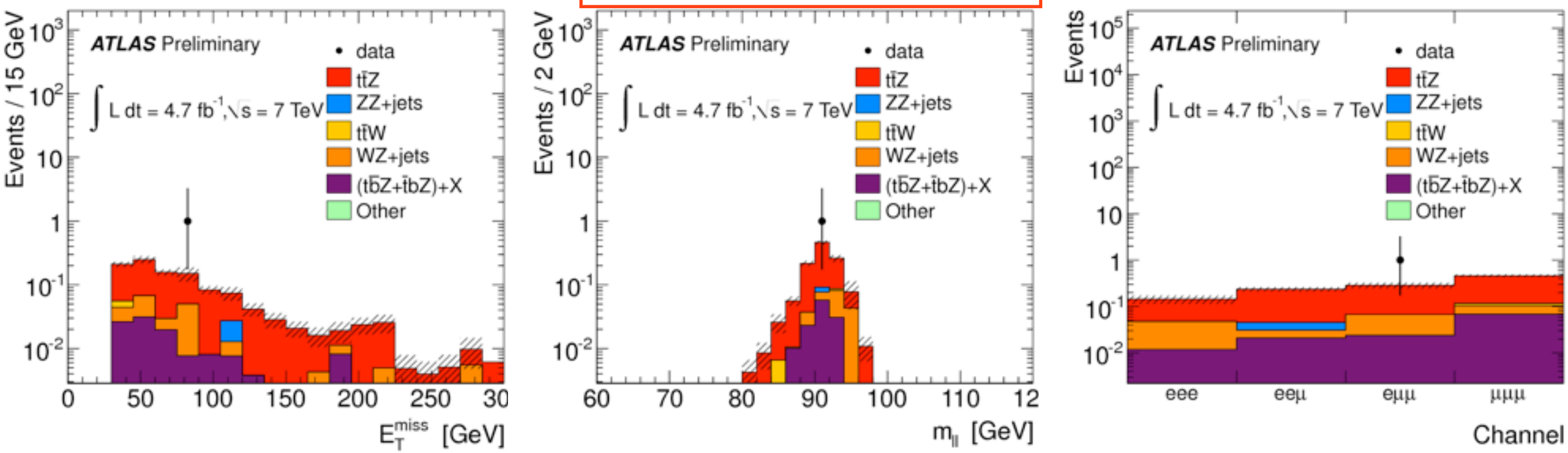
background only hypotesis: p-value=0.71% ➡ 2.7 σ significance

top-pairs + Z production

Associated production of top pairs and Z ⇨ direct probe of ttZ coupling
Can be derived from LEP data, but no direct measurements before LHC

✦ √s=7 TeV, lepton+jets selection + one lepton pair (e+e- or μ+μ-) from Z decay (three lepton channel)

ATLAS-CONF-2012-126



$N_{obs} = 1 \quad N_{sig} = 0.85 \pm 0.04 \pm 0.14 \quad N_{bkg} = 0.28 \pm 0.05 \pm 0.14$

✦ cross section upper limit evaluated with a bayesian approach using a poissonian likelihood and a flat prior

⇨

$\sigma_{ttz} =< 0.71 pb$ @ 95% CL

consistent with the SM expectation

$\sigma_{ttz}^{SM} = 0.137^{+0.012}_{-0.016}\ pb$ JHEP 11 56 (2012)

Summary and conclusions

Very rich physics content in top-pairs final states:

✦ **Precise test of pQCD at the top scale**

top-pair final states with extra QCD radiation: basic testing ground for the current MC generator, important source of infos for tuning generators and constraining model uncertainties

✦ **First studies of associated production of tops and HF**

Irreducible background for the ttH, H→bb one of the fundamental measurement to be performed in the next LHC runs

✦ **Tops + vector bosons**

Test the EW properties of the top. First results presented, large improvement expected in the next future

Large progresses done during the first LHC runs, important improvements expected for the next LHC run

Top-pair final-states physics will maintain a central role in the next years !

Back-Up

Generator parameters and tunings used in the QCD radiation studies

generator	PS,hadronization,UE	PDF gen	PDF PS	Scale	ME/PS match
mMC@NLO	HERWIG+JIMMY AUET2	CT10	CT10	(PT_t^2+PT_tbar^2)/2 + m_t^2	
POWHEG	PYTHIA P2011C	CT10	CTEQ6L1	PT_top^2 + m_t^2	
POWHEG	PYTHIA AUET2B	CT10	CTEQ6L1	PT_top^2 + m_t^2	
POWHEG	HERWIG+JIMMY AUET2	CT10	CT10	PT_top^2 + m_t^2	
ALPGEN	HERWIG+JIMMY AUET2	CTEQ6L1	CTEQ6L1	sum(m^2+pT^2) sum over HF and ligh-jets	MLM
ALPGEN	PYTHIA P2011C	CTEQ5L	CTEQ5L	sum(m^2+pT^2) sum over HF and ligh-jets	MLM
ALPGEN	PYTHIA P2011C, low/high rad	CTEQ5L	CTEQ5L	sum(m^2+pT^2) sum over HF and ligh-jets	MLM
SHERPA	default generator tune	CTEQ6L1	CTEQ6L1		CKKW
MADGRAPH	PYTHIA Z2	CTEQ6L1	CTEQ6L1		MLM

Top-pairs production with extra jets (contd)

Jet multiplicity data compared with ALPGEN+PYTHIA with variated radiation settings

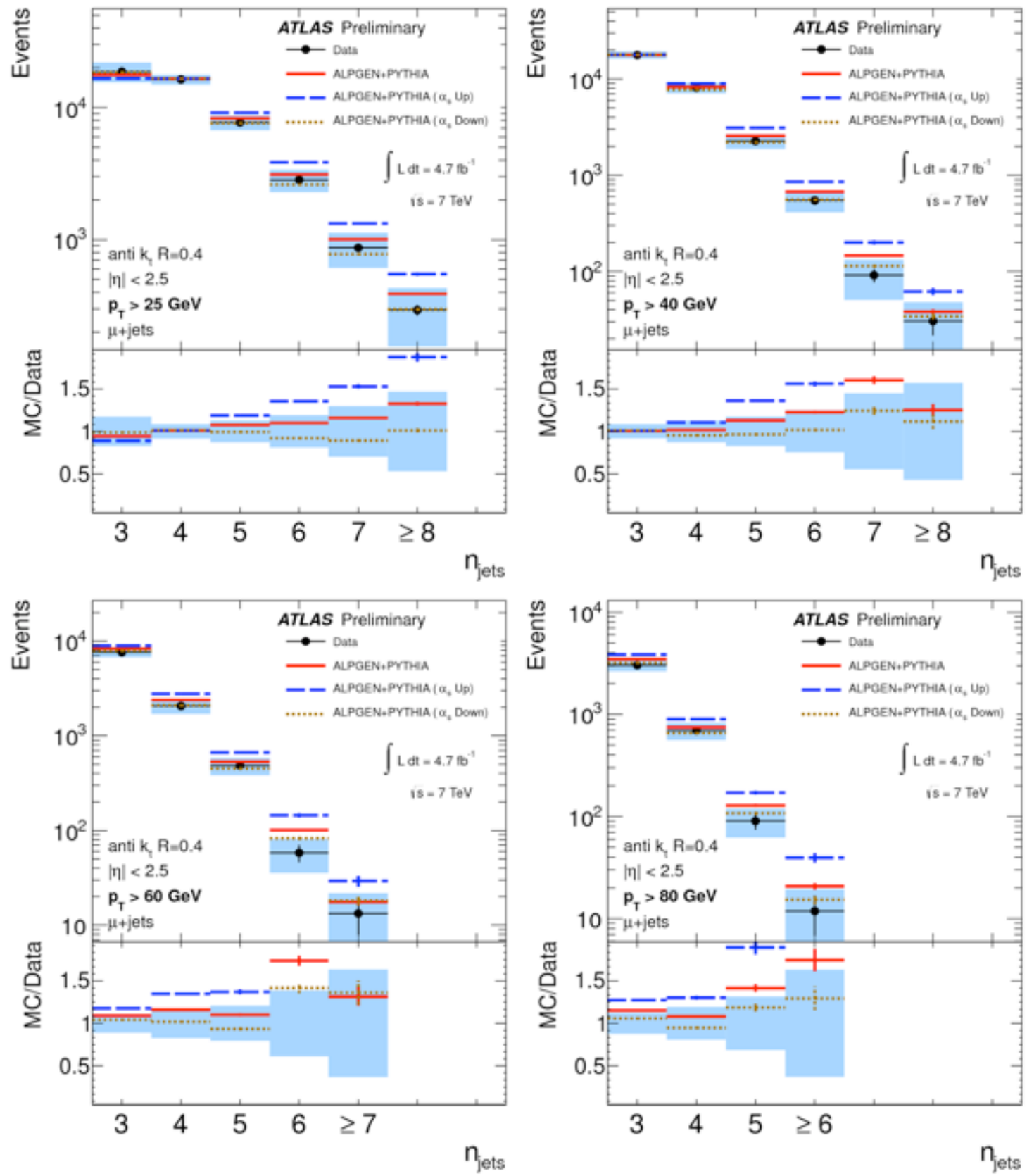
ATLAS-CONF-2012-155
ATLAS-PHYS-PUB-2013-005

✦ Radiation increased and decreased at the ME level

✦ALPGEN+PYTHIA increased radiation, larger jet multiplicities than data

✦ ALPGEN+PYTHIA nominal also overestimate the jet multiplicity for higher jet-P_T thresholds

✦ALPGEN+PYTHIA decreased radiation, in agreement with data for all jet-P_T thresholds



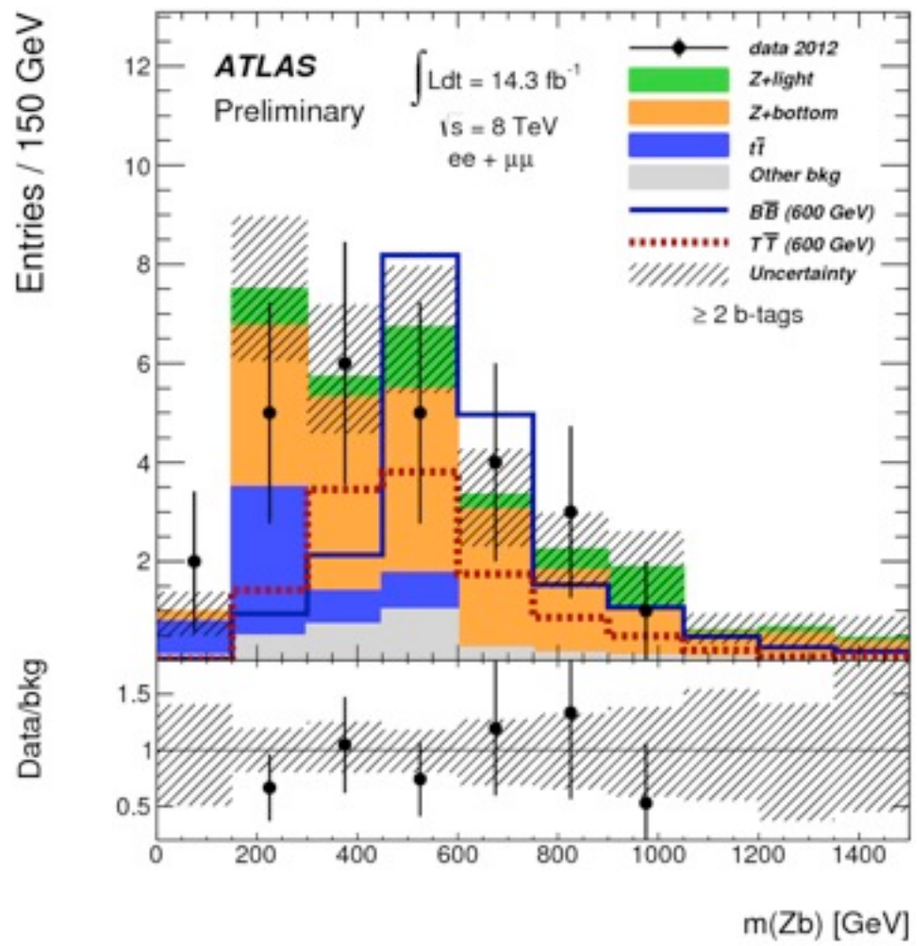
Search for new physics in top + Z production

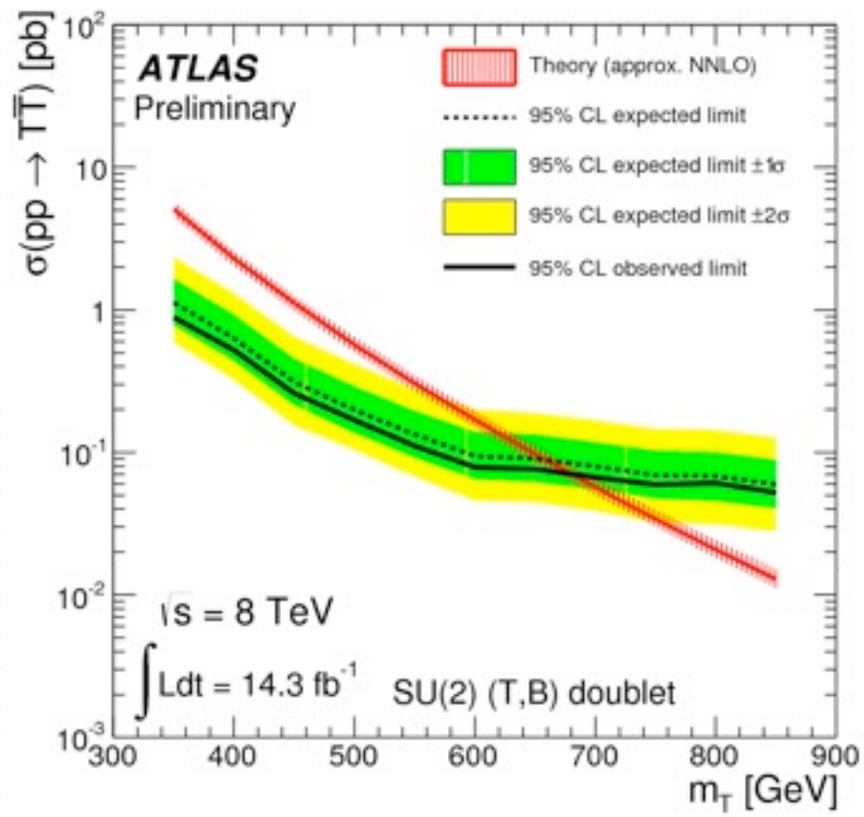
Several non SUSY natural model foreseen vector-quarks (both chiralities share same properties under SM EW gauge transformations).
Coupling with top-quark allows to control quadratic divergence of the Higgs mass.

➡ vector-quark T/B-pair production $T \to t + Z, b + W$ $B \to t + W, b + Z$

ATLAS-CONF-2013-056

- ✦ √s=8 TeV, at least one high-P_T Z + additional jets and leptons
- ✦ search strategy: one high-P_T Z (e+e-,μ+μ-) at least 2 b-tag jets, additional cut on the scalar sum of jet P_T
- ✦ ≥ 2 b-tag / < 2 b-tag used as signal/control region samples
- ✦ m(Zb) used for signal search. No significant excess, limits extracted using a binned Poisson likelihood test





SU(2) singlet: $m_T\ (m_B) < 585\ (645)$ GeV @ 95% CL

SU(2) doublet: $m_T\ (m_B) < 680\ (725)$ GeV @ 95% CL

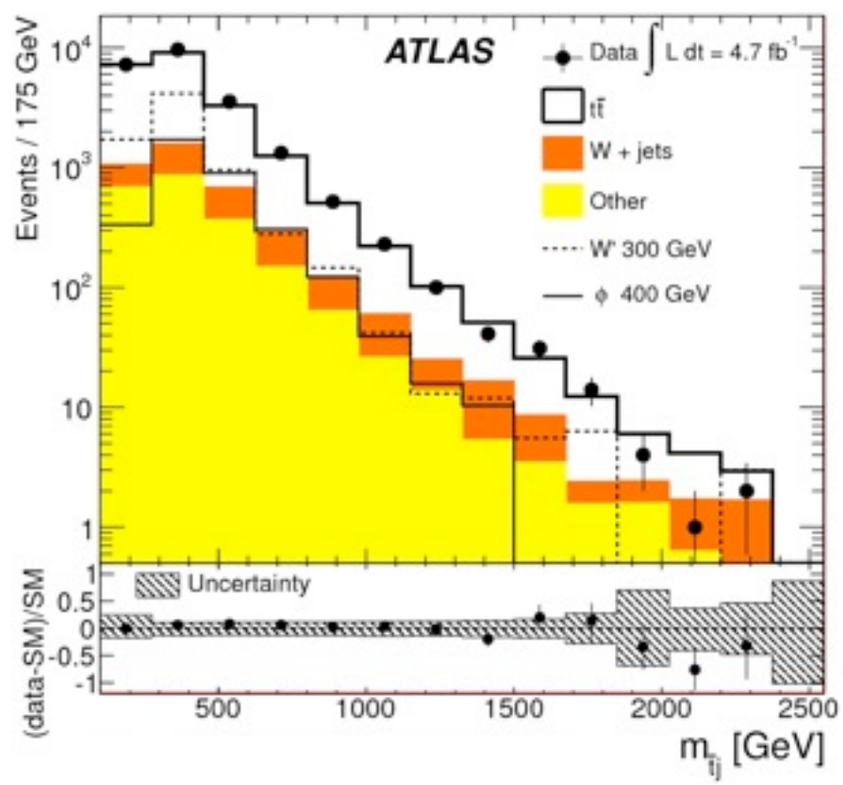
Search for resonances in top pairs + jets production

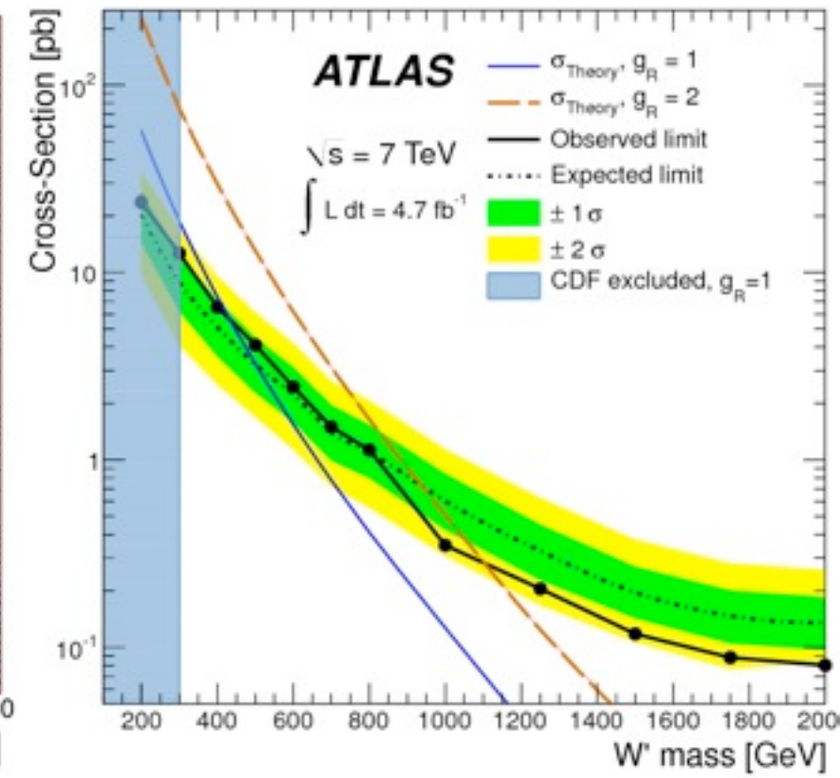
Recent measurement of top-quark forward-backward asymmetry (FBA) at Tevatron in marginal agreement with SM expectation.
Possible BSM explanations from top-flavor violating processes: production of a heavy state R=W'/ϕ (R → t+q) in association with a top-quark

PRD 86, 091103(R) (2012)

$$W'(\text{color singlet}) \to \bar{t} + q$$
$$\phi\ (\text{color triplet}) \to t + q$$

- ✦ √s=7 TeV, lepton+jets channel
- ✦ kinematic fit used to assign reconstructed lepton, jets and E_T^{miss} to top and anti-top
- ✦ The jets not associated to the top-quarks are used to construct m_{tj} and m_{tbarj}
- ✦ No significant excess observed, limits are set looking at mass windows in the m_{tj} and m_{tbarj} distributions





Assuming unit coupling g_R:

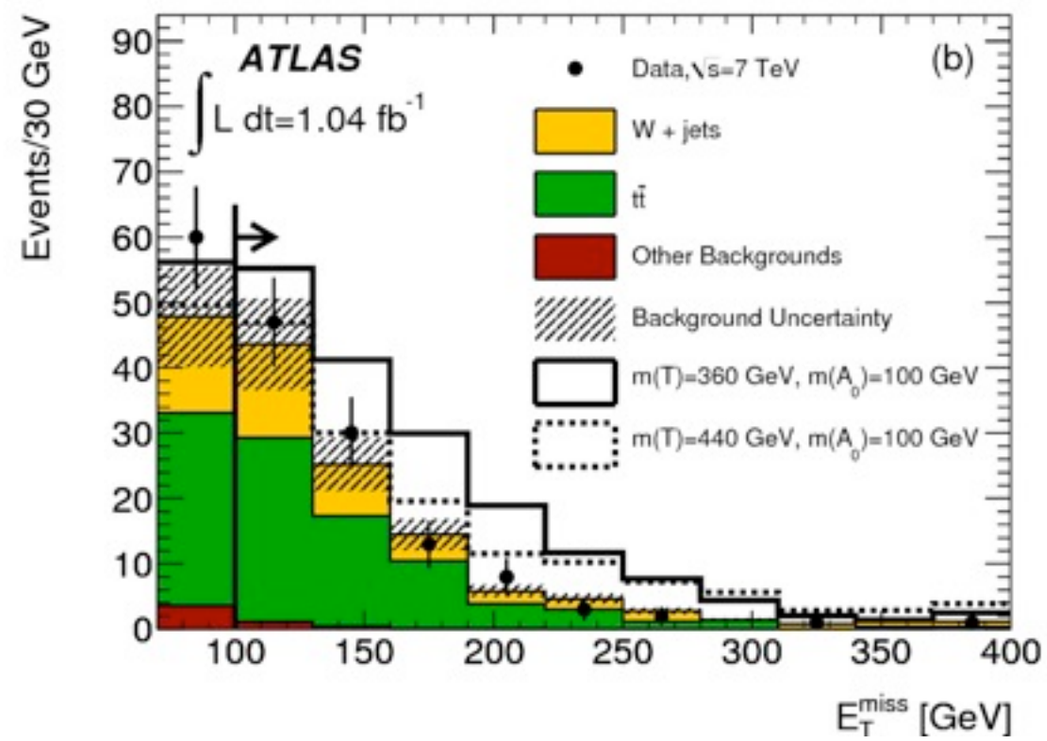
$$m_{W'/\phi} < 430 \text{ GeV @ } 95\% \text{ CL}$$

most of the parameter space consistent with the Tevatron FBA results excluded at 95% CL

Search for new physics in top pairs + E_T^{miss} production

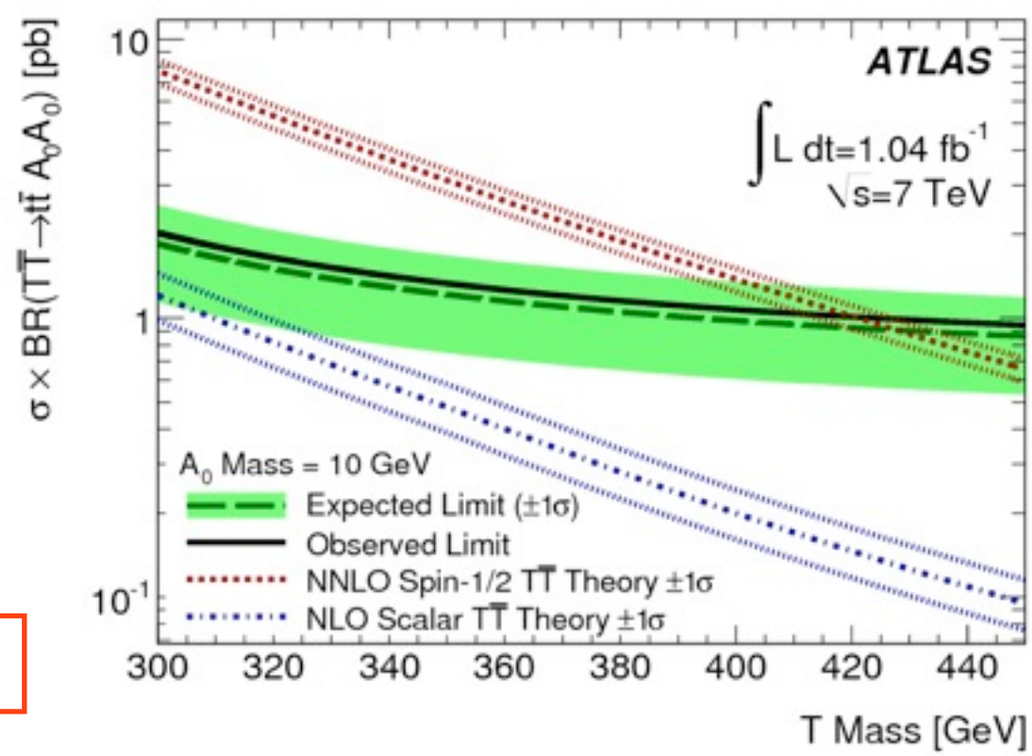
Exotic top partners T decaying to top and a WIMP foreseen by several natural BSM models with a dark-matter candidate. $T\bar{T} \to t\bar{t}A_0A_0$ final state identical to SM tt production + large E_T^{miss} due to the undetected A_0 pairs.

- ✦ $\sqrt{s}$=7 TeV, lepton+jets channel + E_T^{miss} and $m_T(W)$ cut
- ✦ No significant excess observed, a frequentist confidence interval for the signal hypothesis evaluated for various assumed T and A_0 masses



$$\sigma \times BR(T\bar{T} \to t\bar{t}A_0A_0) < 1.1 \text{ pb @ } 95\% \text{ CL}$$
$$m_T = 420 \text{ GeV}, \; m_{A_0} = 10 \text{ GeV}$$

Fourth-generation top partner model:
m_T up to 420 GeV and m_{A0} up to 140 GeV excluded at 95% CL



PRL 108, 041805 (2012)