Top quark production with N-jets and jet veto with the ATLAS detector at LHC

IPPP Topical Workshop on Jet vetoes and multiplicity observables
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(On behalf of the ATLAS collaboration)

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ATLAS EXPERIMENT
http://atlas.ch

Outline

- Why top quark +Njets?
- Gap fraction measurements
- New jet multiplicity & p_T measurements
- $t\bar{t}$+heavy flavour measurement
- Conclusions

Why top quark plus jets?

- **Production of top quark plus additional jets**
  - is **sensitive to higher order pQCD** effects and a variety of energy scales
  - implies a **significant source of uncertainty in top quark precision measurement** such as m_{top}, top pair production cross section, spin correlation between top quarks, charge asymmetry
  - is a significant **background to Higgs boson** production ($t\bar{t}H$) and **new physics like supersymmetry** cascades of squarks and gluinos

Explored through measurements of differential and inclusive cross sections using data collected by ATLAS in pp collisions at $\sqrt{s}$ = 7 TeV

$d\sigma_{t\bar{t}}/dN_{jets}$	$d\sigma_{t\bar{t}}/dp_{T,jets}$	$1/\sigma_{t\bar{t}}\ d\sigma_{t\bar{t}}/dQ_X$
jet multiplicity	p_T of p_T-ordered jets	Q_0 (Q_{sum}) = (sum of) p_T of additional jet(s) required for event selection

$\sigma_{t\bar{t}+Heavy\ flavours}$

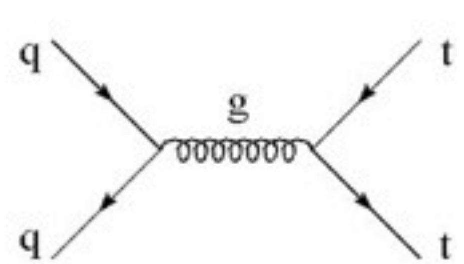
Top quark pairs @ LHC: inclusive production

pp collisions

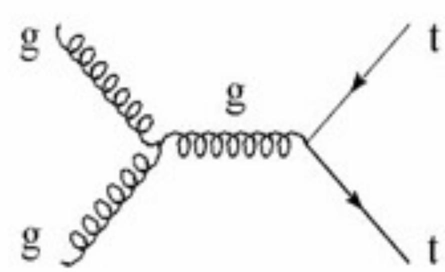
probing lower x than Tevatron → (abundant) gluon fusion dominated

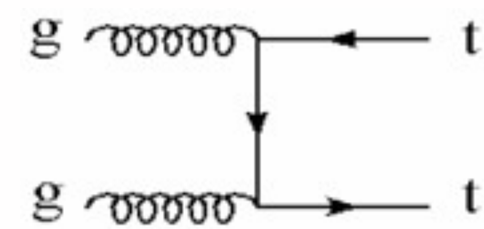
	Tevatron	LHC(7)	LHC(14)
gg	~10%	**~85%**	~90%
qq	~90%	**~15%**	~10%

qq annihilation



gluon fusion





At Tevatron

$\sigma_{t\bar{t}} \sim 7$ pb
$\sigma_t \sim 3.5$ pb

Czakon,Mitov,Fiedler 2013

NNLO+NNLL accuracy
m_{top}= 172.5

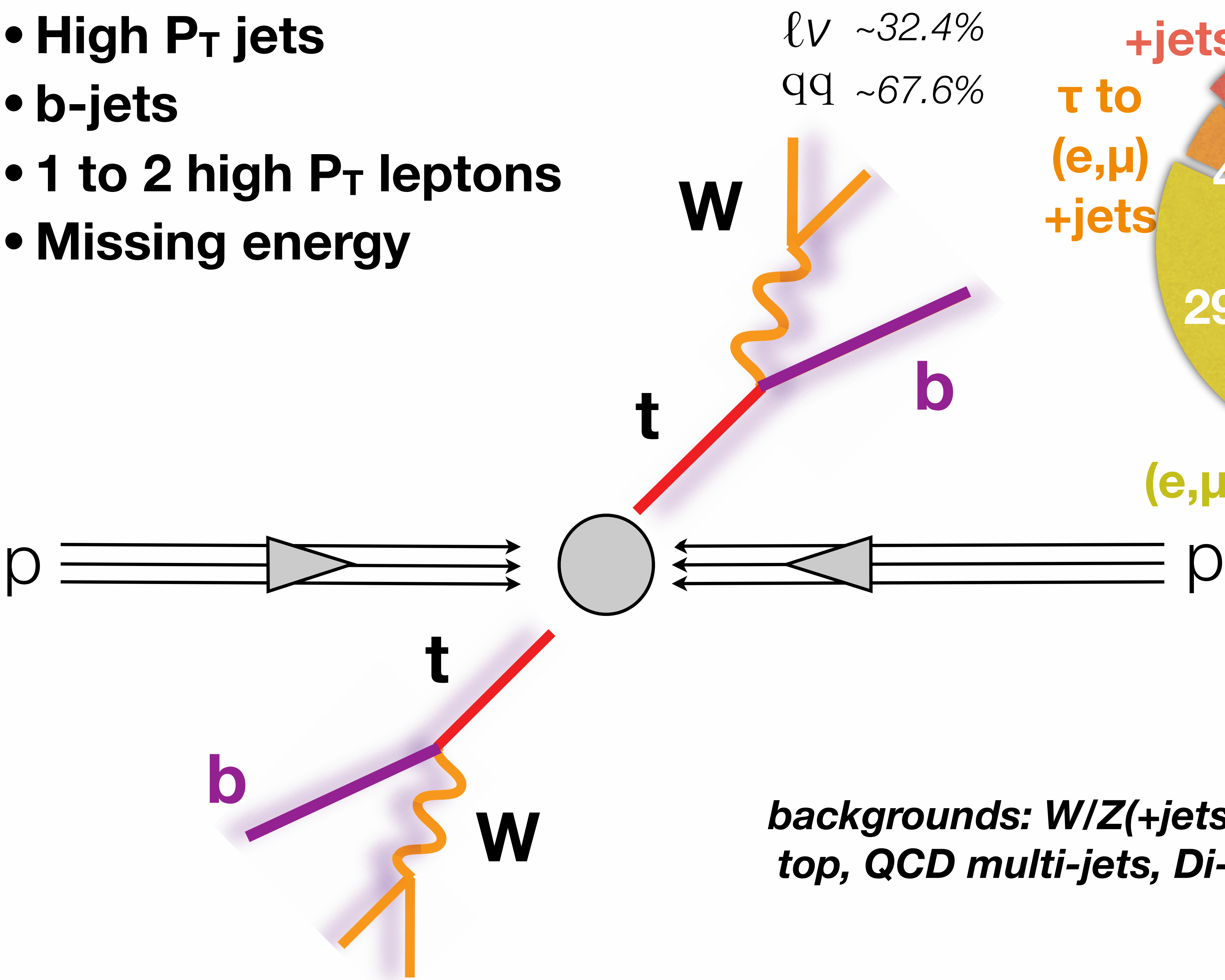
$\delta\sigma_{tt}/\sigma_{tt}$ ~4%

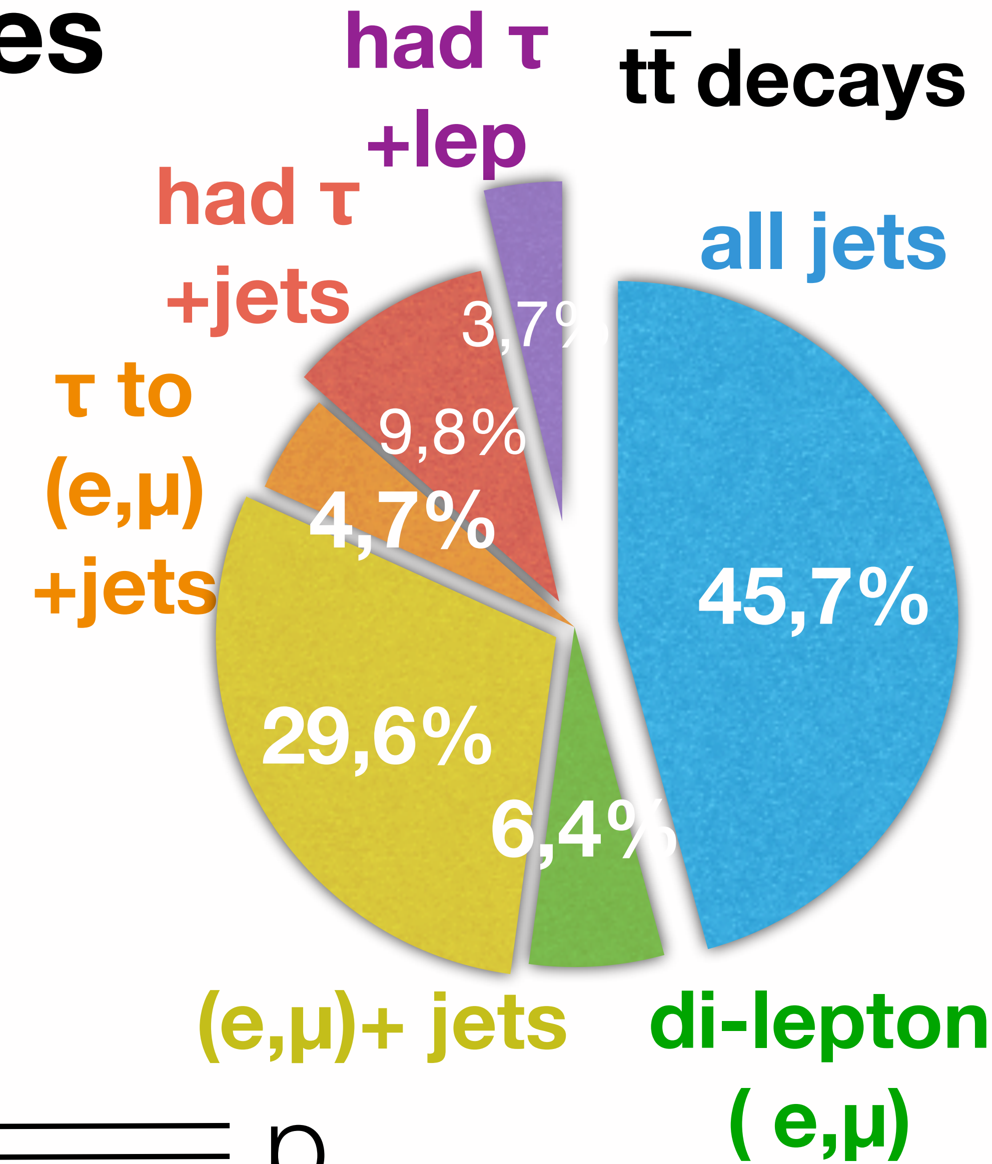
σ_{7TeV} (pb)	$172^{+4.4}_{-5.8}{}^{+4.7}_{-48}$
σ_{8TeV} (pb)	$245^{+6.2}_{-8.4}{}^{+6.2}_{-6.4}$

~0.96 M (~5.4M) $t\bar{t}$ events produced by LHC in 2011 (2012)

Top quark decay: signatures

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





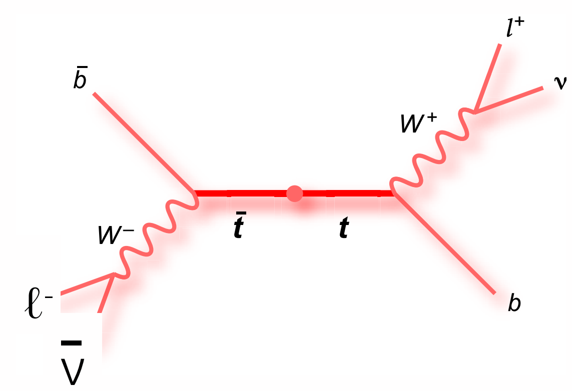
backgrounds: W/Z(+jets), single top, QCD multi-jets, Di-bosons

Differential *Jet activity*: dilepton $\sqrt{s}$ = 7 TeV

Eur. Phys. J. C72 (2012) 2043

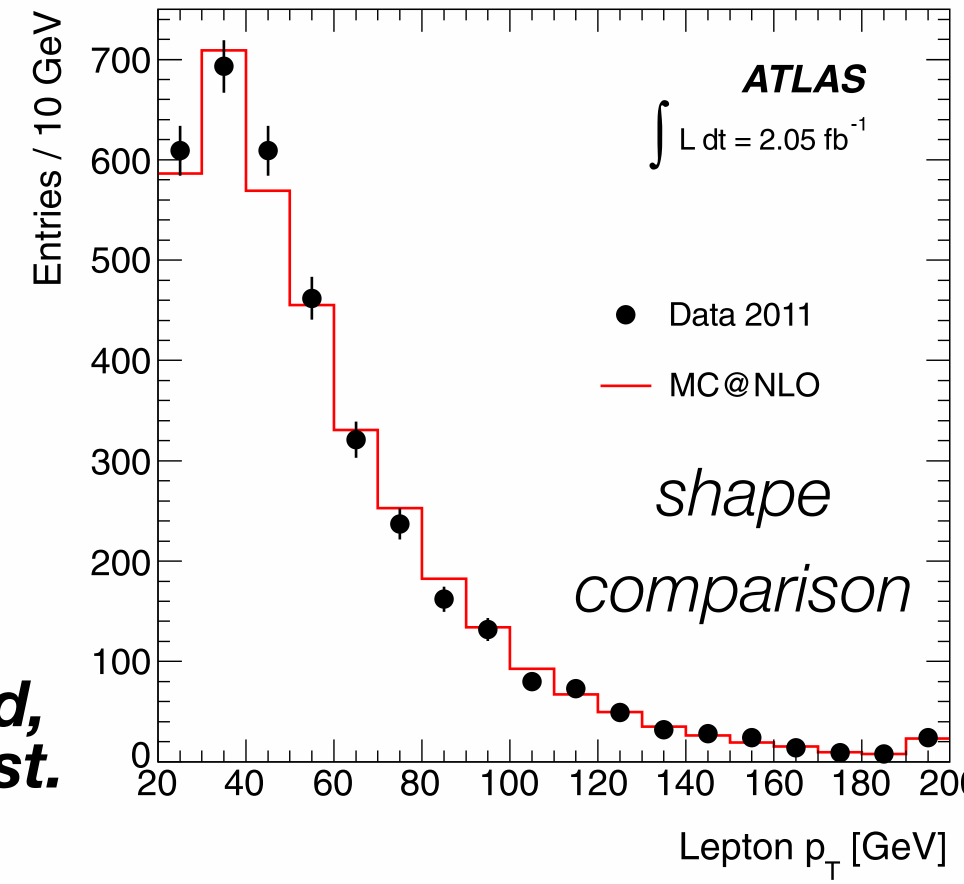
$\int L dt =$ **2.05 fb^{-1}** *(2011)*

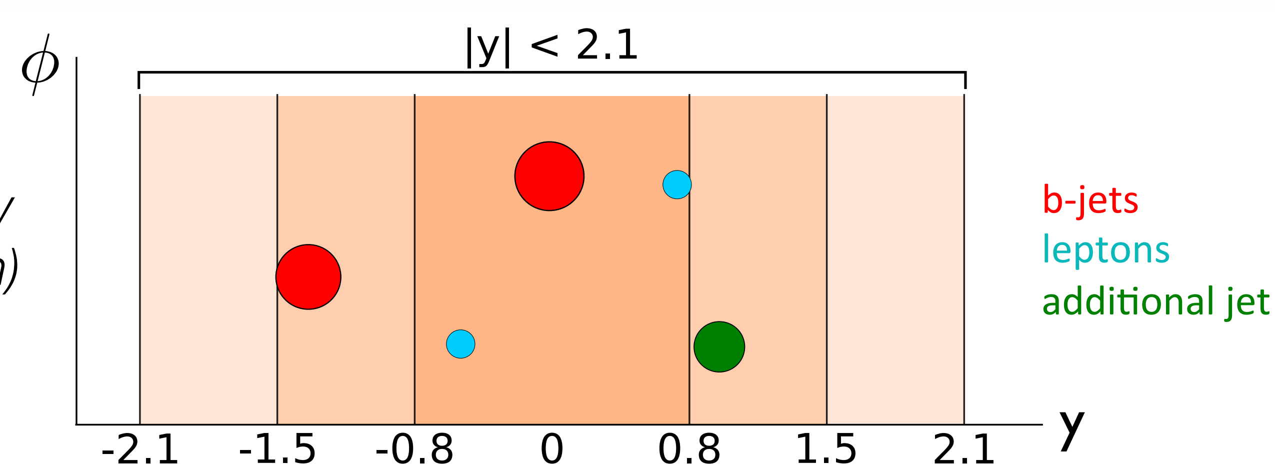
- Require 2 **opposite sign leptons, ≧ 2 b-tag jets**
- veto low M(ℓℓ) (<15 GeV)
- ee,μμ: high E_T^{miss} cut & M(ℓℓ)≠m_Z, eμ: high $H_T = \sum_{jets,lepts} p_T$ *>130 GeV*



- **Bkg(<6%): single top** (Wt) **Z+jets, diboson** *(from simul.)*, **data-driven fake leptons** *(loose/tight matrix method)* ⇨ ***Not subtracted, included in syst.***

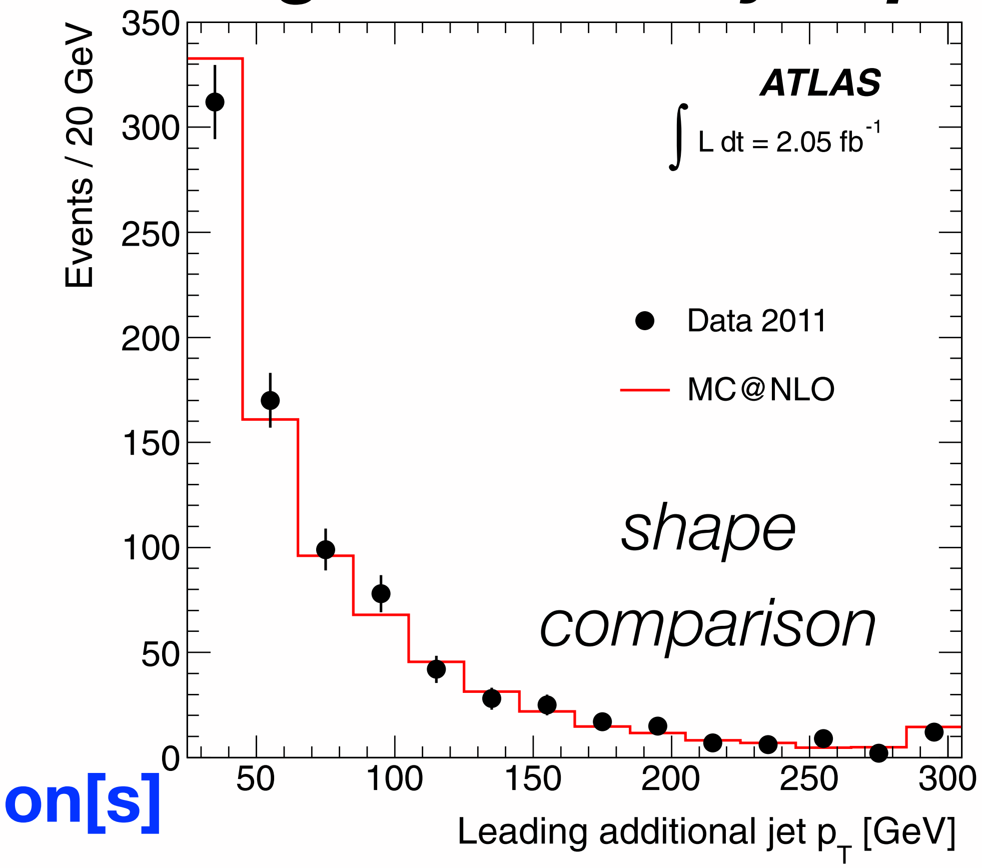
lepton p_T





(figure by M. Owen)

leading additional jet p_T



- **Derive: fraction of selected N_{ev} with**
  - **no additional** *(to 2 b-tag)* **jet with $p_T > Q_0$: $f(Q_0)$**
  - **$\sum_{\text{additional jets}} p_T$ < Q_{sum}** in given y interval: **$f(Q_{sum})$**
- **$f(Q_0)$ [$f(Q_{sum})$]: sensitive to the leading [all] p_T emission[s]**

Differential *Jet activity* : dilepton $\sqrt{s}$ = 7 TeV

Eur. Phys. J. C72 (2012) 2043

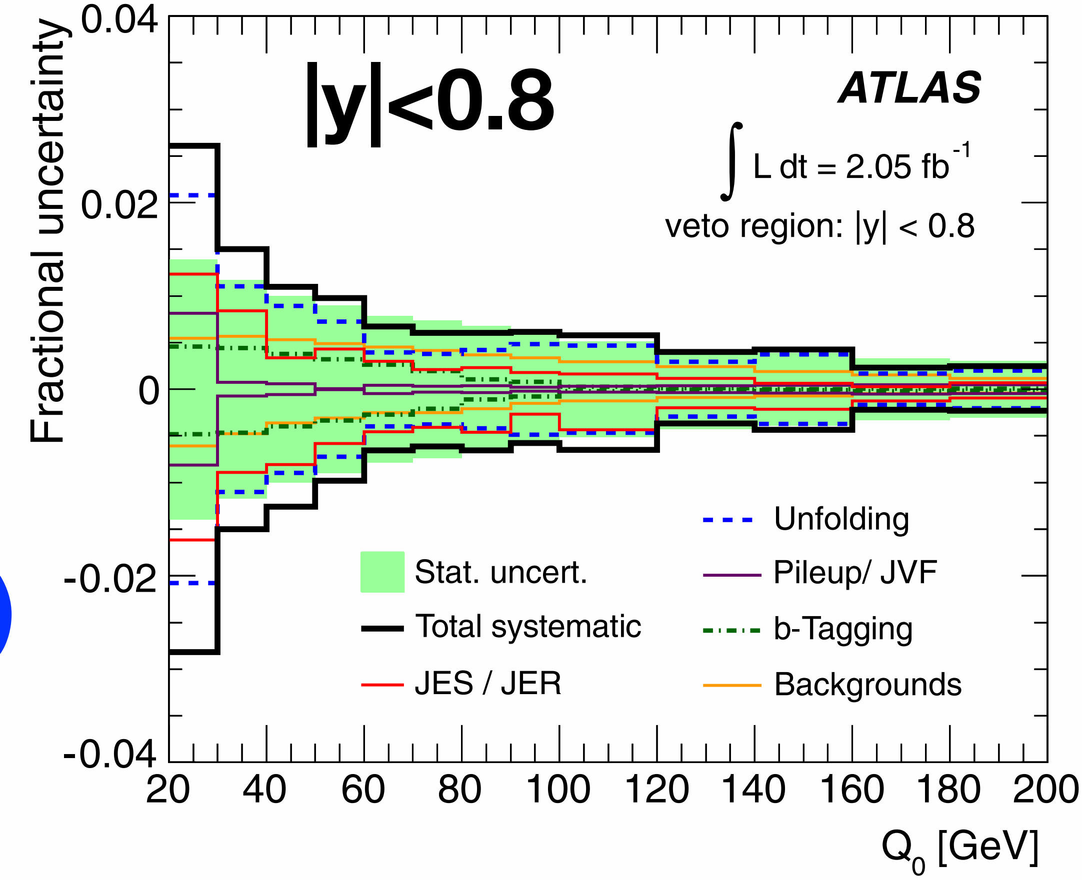
$\int Ldt$ = **2.05 fb^{-1}** *(2011)*

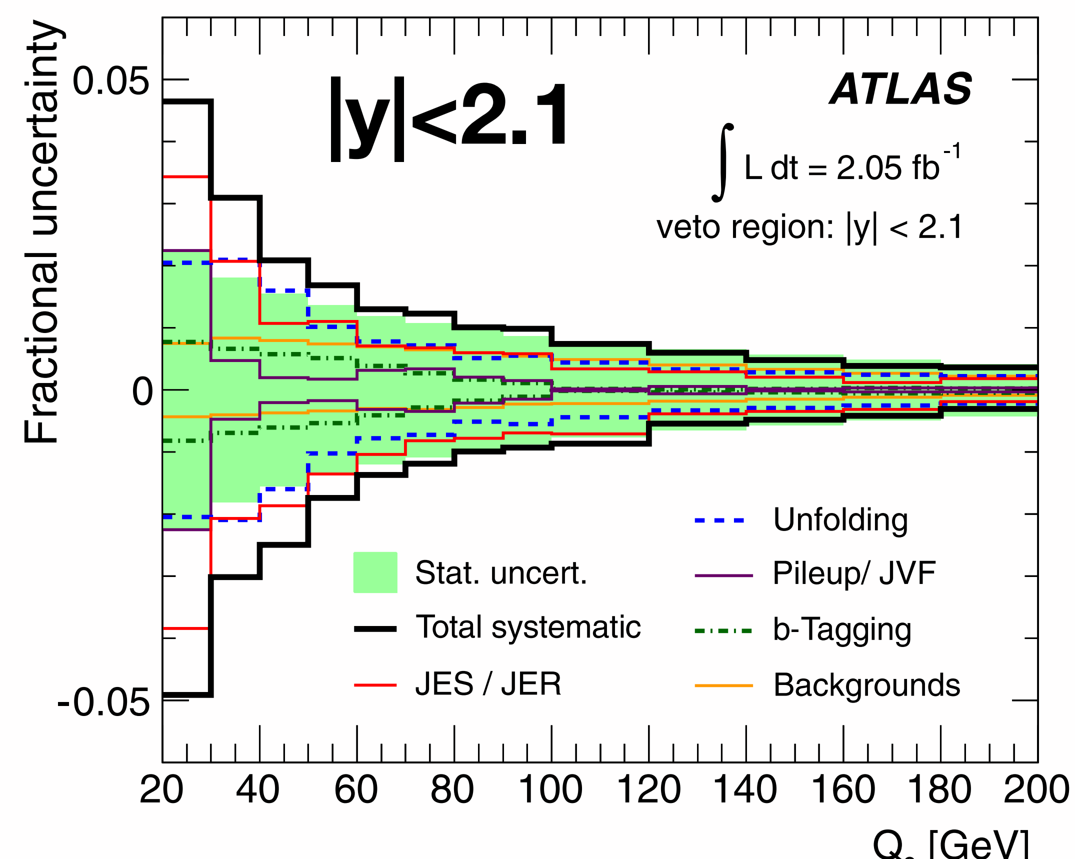
- ***Correct* f(Q_x) to fiducial phase space with correction factors *from simulation*** → *corrected gap fraction* $=1/\sigma_{tt}\, d\sigma_{tt}/dQ_X$
  X={0,sum}

$$f^{corr}(Q_x) = f^{particle,sim}(Q_X)/f^{reco,sim}(Q_X)\ f^{meas}(Q_x)$$

from MC@NLO+HW

  - **fiducial PL volume: in MC events**
    *apply ~**reco cuts to** (stable) **particle** jets, to truth e,μ,ν, from W in top decay, b-tag: spatial match of jet to B-hadron*





- ***Syst dominated for Q_X < 60 GeV,*** *stat~ sys : JES+JER~1.5% to 3.5%, slightly larger for Q_{sum}*

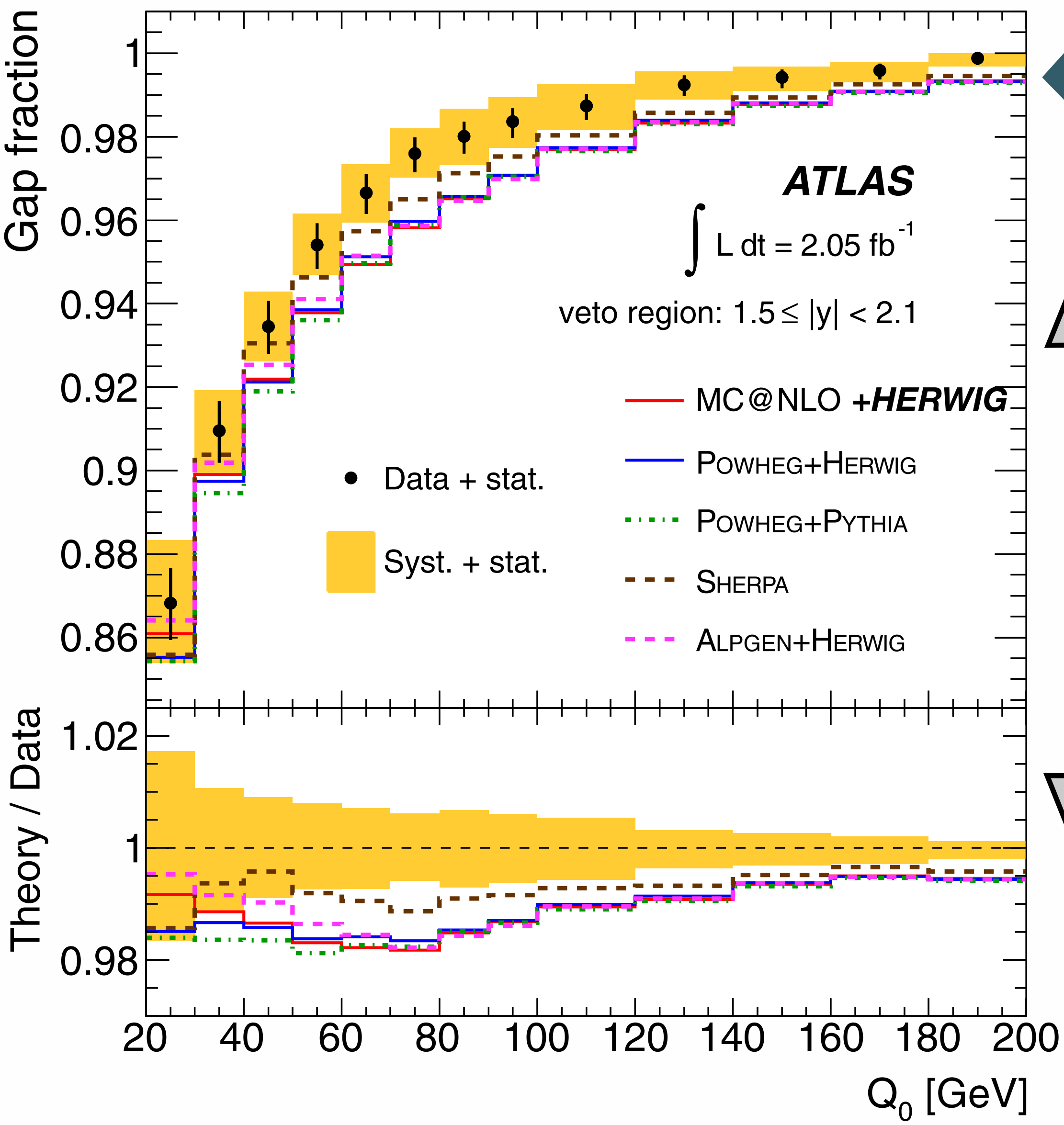
Differential *Jet activity* : dilepton √s = 7 TeV

$\int L dt =$ **2.05 fb^{-1}** *(2011)*

Eur. Phys. J. C72 (2012) 2043

- **Measure gap fractions f(Q_X)** ***X={0,sum}*** **in four rapidity regions**
  - **|y|<0.8; 0.8<|y|<1.5; 1.5<|y| <2; |y| <2.1**

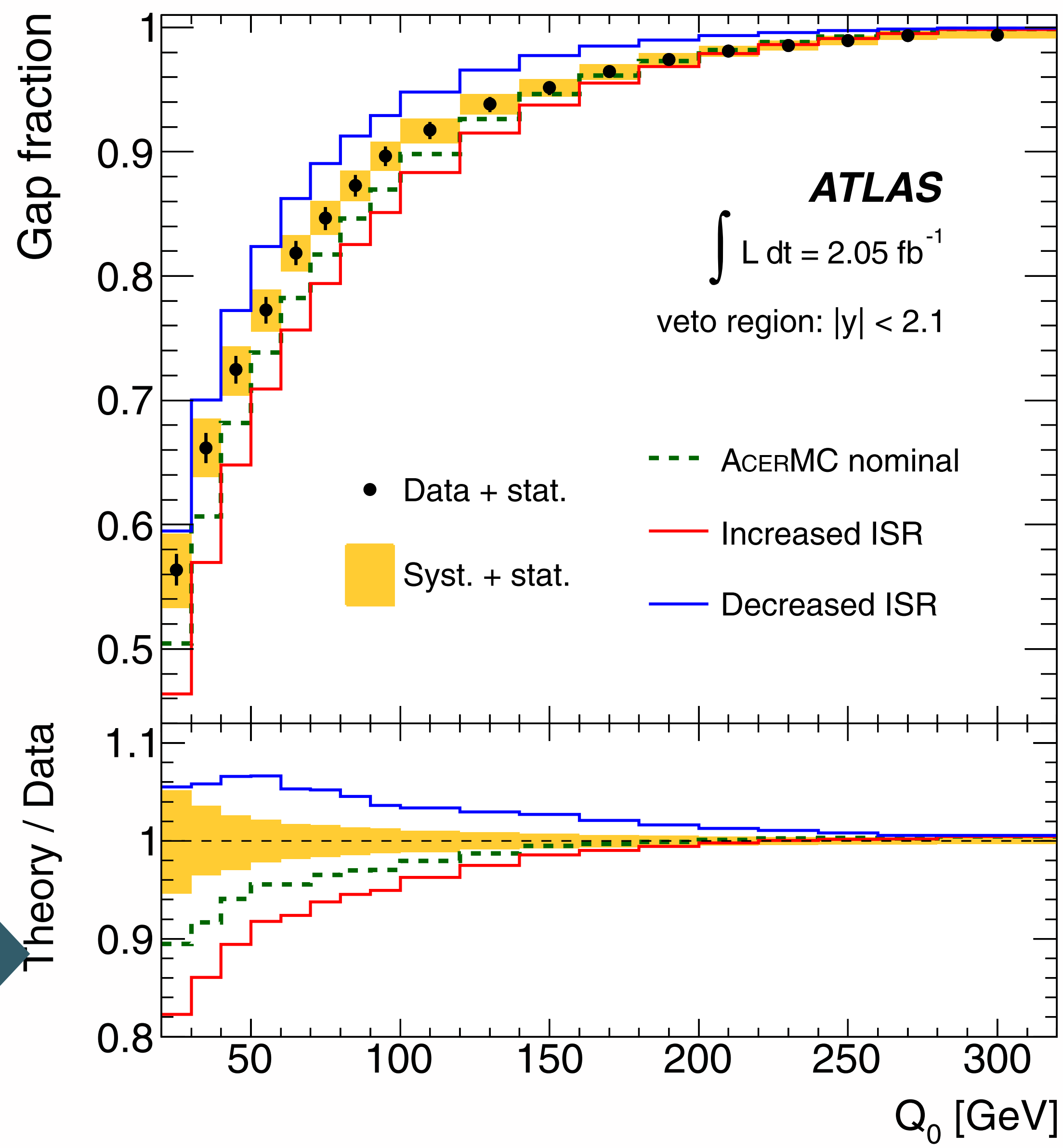
Analysis available in RIVET



- **Too much jet activity in 1.5<|y| <2.1 for all generators (LO, NLO)**
- **MC@NLO: too little jet activity in |y|<0.8**

less jet activity

more jet activity: *less events pass veto*



- **ACER+PYTHIA with more/less ISR: too large variation w.r.t. data→*reduction in model uncertainty***

Differential *Jet activity* : dilepton √s = 7 TeV ATL-PHYS-PUB-2013-005

generate — *$t\bar{t}$ predictions* — ***shower + hadronize*** Underlying event tune

LO $t\bar{t}$

ACER MC *PDF: CTEQ6L1* ⊗ ***PYTHIA*** Perugia2011C

- **with variations of ISR/FSR parameters to bracket f_{gap}**

LO $t\bar{t}$+partons

ALPGEN *PDF: CTEQ6L1* ⊗ ***HERWIG*** AUET2
PDF: CTEQ5L ***PYTHIA***

Perugia2011 +tunes for α_s up and down variations

- Merge **LO** Matrix element (ME) for $t\bar{t}$ + up to ***5 light partons***, MLM-matched to Parton Shower (PS)
- **LO** ME for exclusive $t\bar{t}+b\bar{b}$ and $t\bar{t}+c\bar{c}$
- Merge light + heavy (angular removal of overlapping events)
- **Generate events with 1) α_s variations (change reno scale) in ME only and 2) coherent α_s variations in ME and PS**

NLO $t\bar{t}$

MC@NLO *PDF: CT10* ⊗ ***HERWIG*** AUET2
POWHEG ***HERWIG*** AUET2 ***PYTHIA*** Perugia2011C AUET2B

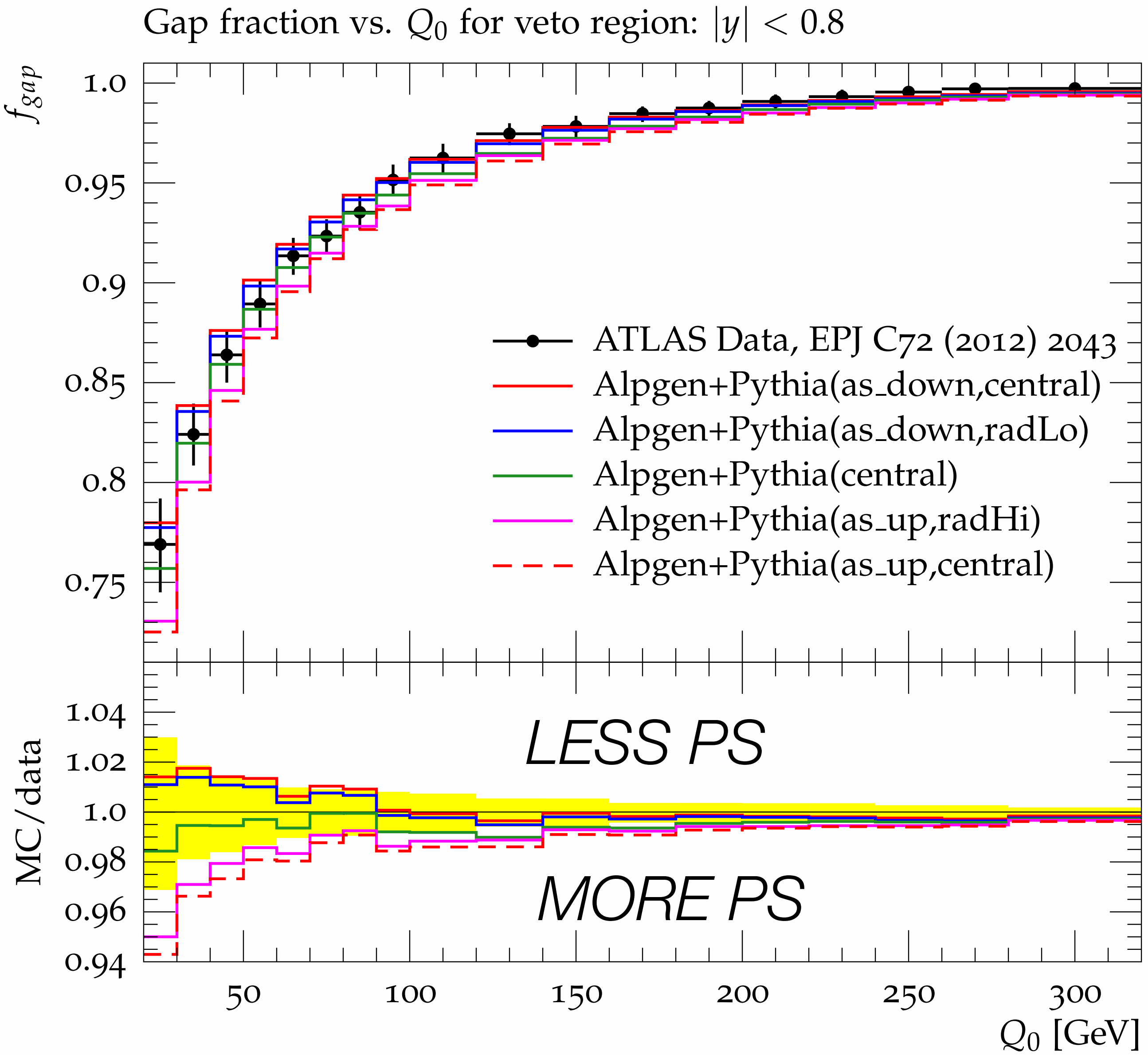
- **NLO** for $t\bar{t}$; **LO** for $t\bar{t}$+1, ~leading log for $t\bar{t}$ + >1 parton

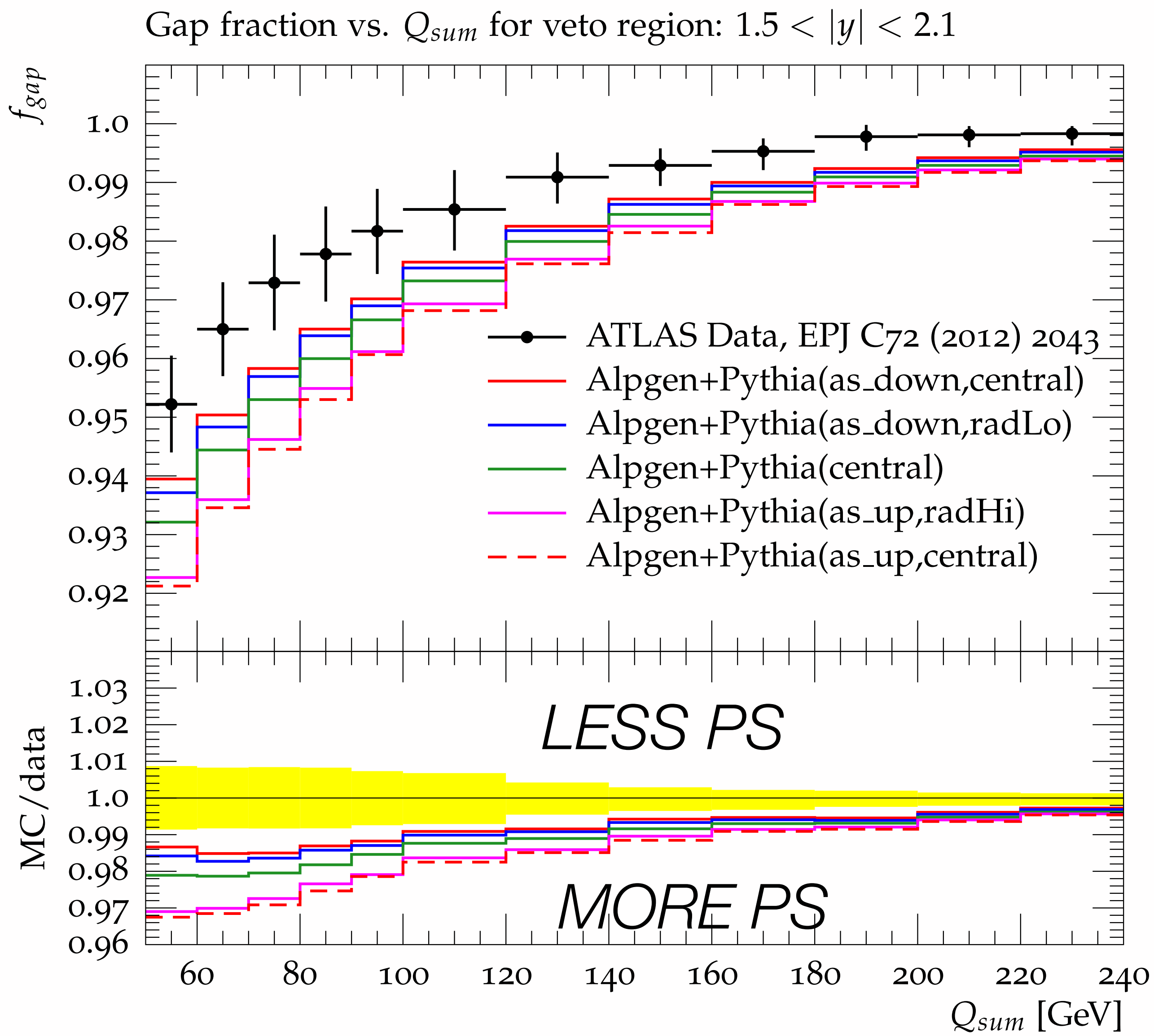
Differential *Jet activity* : dilepton √s = 7 TeV

$\int L dt =$ **2.05 fb^{-1}** *(2011)*

ATL-PHYS-PUB-2013-005

- Compare different radiation scenarios for gap fraction measurements→ tune models, constrain systematic uncertainties





- ALPGEN+PYTHIA with more (ME only, ME+PS) and less (ME only, ME+PS) radiation **bracket the data, nominal** is consistent
- Forward region: radiation is overestimated, particularly by more (ME only, ME+PS) radiation

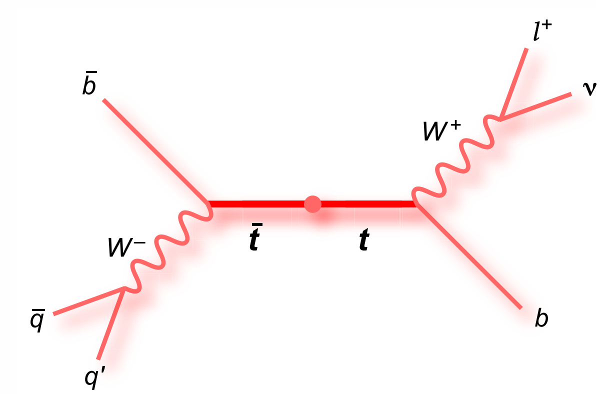
Differential $d\sigma_{t\bar{t}}/dN_{jets}$ and $d\sigma_{t\bar{t}}/dp_{T,jets}$ - l+jets $\sqrt{s}$ = 7 TeV

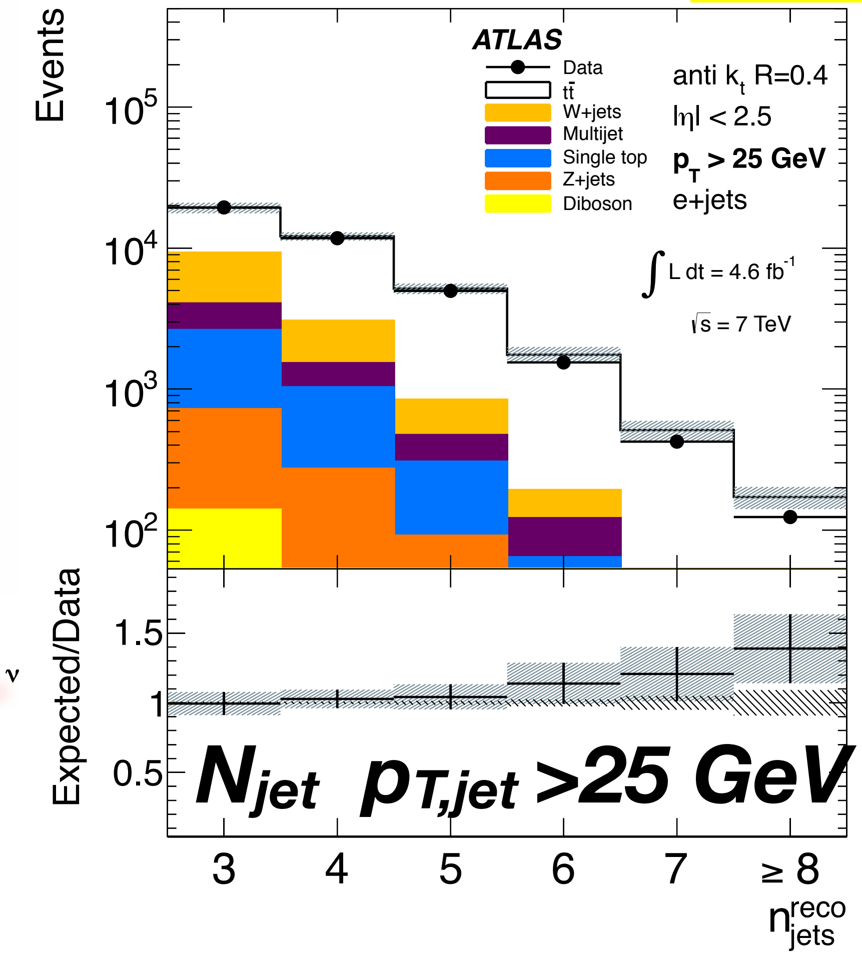
NEW!

$\int L dt$ = **4.6 fb^{-1}** *(2011)*

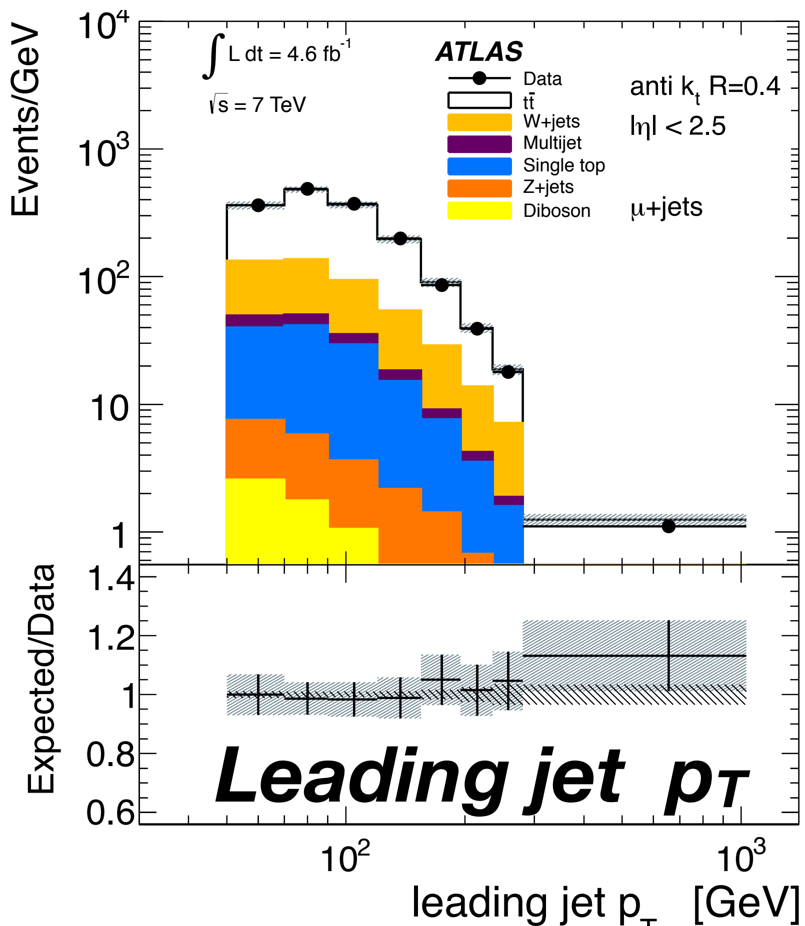
http://arxiv.org/abs/1407.0891, submitted to JHEP

- 1 isolated (e,μ), symmetric E_T^{miss} and m_T^W *cuts, **≥ 3 central jets, ≥1** b-tag
- ΔR(jet,jet)>0.5 for all jet pairs
- For jet p_T studies, leading (2nd leading) jet p_T > 50 (35) GeV → *reduce uncertainties in corrections for jet ordering*





- **Data-driven W+jets** *(normalize pre-tag with W^+/W^- asymmetry, extrapol. b-tag prob from 2-jet-bin)* **fake lep.** *(loose/tight matrix method),* ***single top, dibosons, Z+jets*** *(from sim.)*



- **Count N_{jet}** with p_T > 25,40, 60, 80 GeV
- **Derive** p_T distribution for p_T -ordered 1st to 5th jet

$$^* m_T(W) = \sqrt{2 p_T(\ell) E_T^{miss} \left[1 - \cos\Delta\phi\left(\ell, E_T^{miss}\right)\right]}$$

Differential $d\sigma_{t\bar{t}}/dN_{jets}$ and $d\sigma_{t\bar{t}}/dp_{T,jets}$ - l+jets $\sqrt{s}$ = 7 TeV **NEW!**

- **Unfold d(N-N$_{bkg}$)/dN$_{jets}$ and d(N-N$_{bkg}$)/dp$_{T,j}$ to** *final-state specific* **fiducial particle level (PL) volume +** *scale with lumi* → $d\sigma_{t\bar{t}}/dN_{jets}$, $d\sigma_{t\bar{t}}/dp_{T,jets}$

from POWHEG+PYTHIA

$$N_i^{corr} = f_{part!rec} \sum M^{part,i}_{rec,j} \; f_{mis} \; f_{rec!part} \; f_{acc,j} \; (N-N_{bkg})_j$$

jet p_T ordering migration (only for p_T)

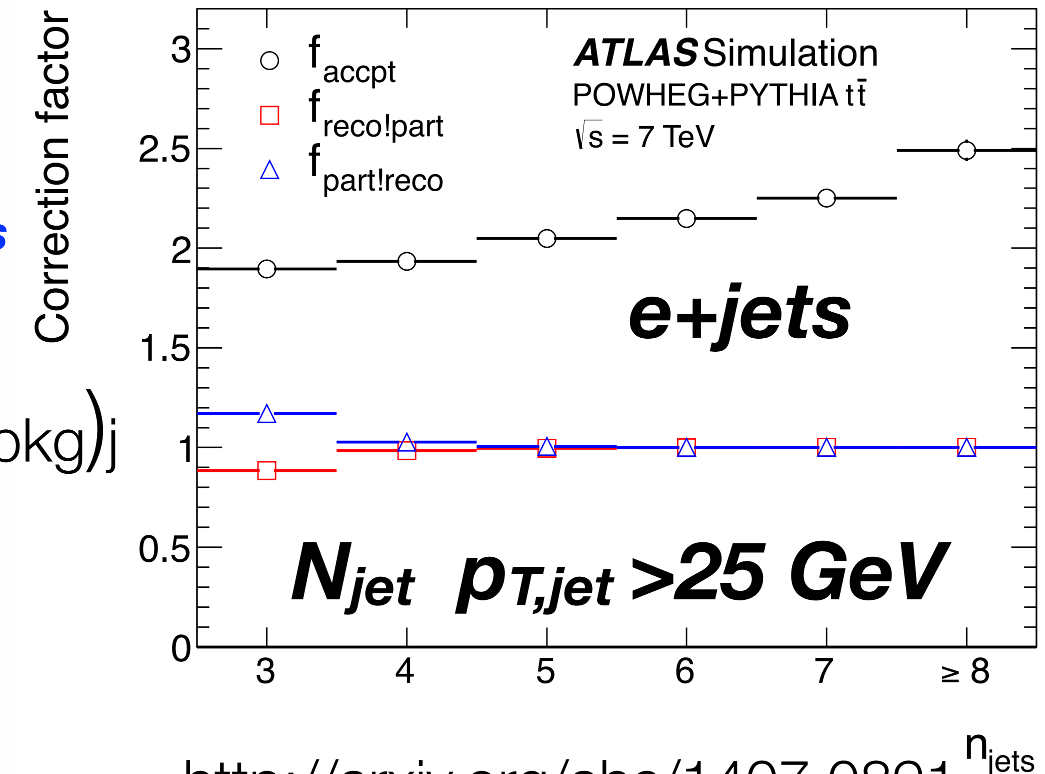
particle to reco migration (iterative unfolding)

Reco

Pass Reco, Pass PL	Pass Reco, Fail PL	Fail Reco Pass PL	Fail Reco, Fail PL

Particle level (fiducial): to correct to

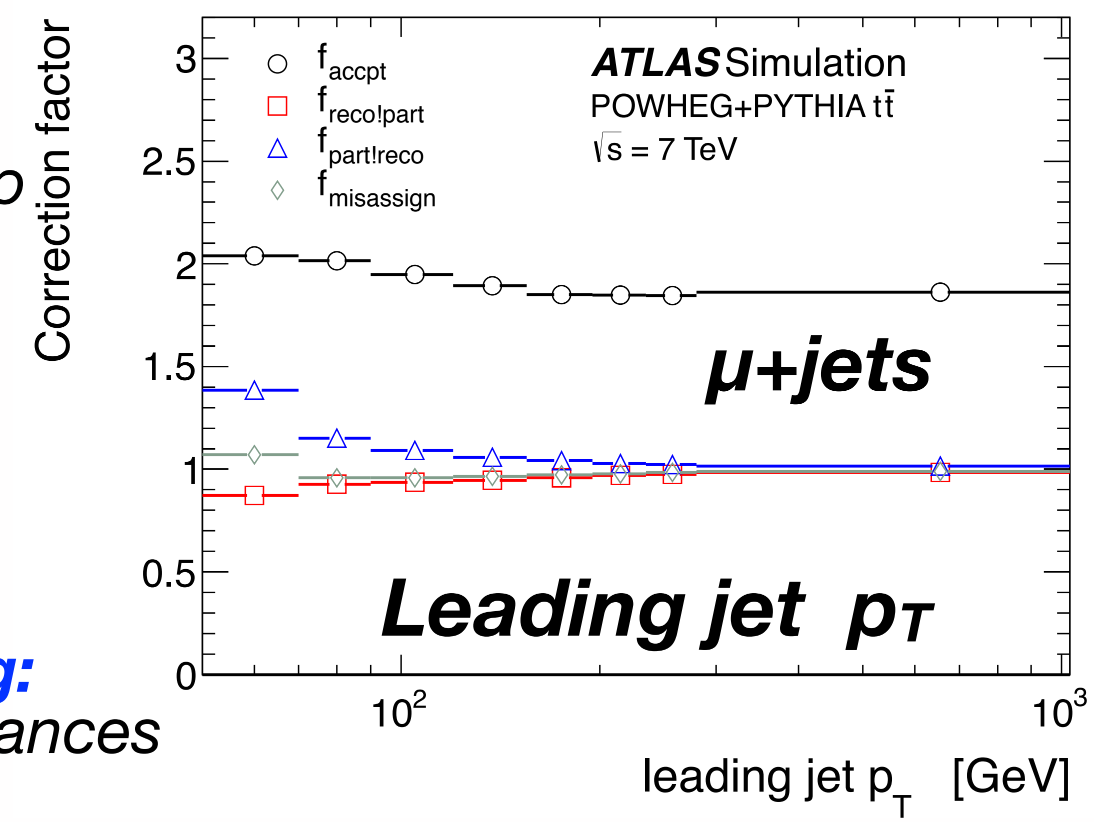
- **fiducial PL volume: in MC events** *apply* ***~reco cuts to*** (stable) ***particle*** *jets, to e,μ,ν from W in top decay, b-tag: jet that clusters "ghost"B-hadron*



http://arxiv.org/abs/1407.0891, submitted to JHEP

$\int L dt$ = **4.6 fb^{-1}** *(2011)*

- **Combine (e,μ)+jets channels** bin by bin with minimal covariance estimator (BLUE) *including correlations. Compatibility: X^2/N.d.o.f.~1*
  - ***Propagate syst uncertainties through unfolding:*** *modify pseudo-data, fix migration matrix & acceptances*



Differential $d\sigma_{tt}/dN_{jets}$ and $d\sigma_{tt}/dp_{T,jets}$ - l+jets $\sqrt{s}$ = 7 TeV NEW!

http://arxiv.org/abs/1407.0891, submitted to JHEP

$\int Ldt$ = **4.6 fb^{-1}** *(2011)*

Provide table of full breakdown of uncertainties for both results

$d\sigma_{tt}/dN_{jets}$

- ***Systematic dominated: ~10% to ~30%***
  - ***Correlated*** *effects:* ***dominant at large N_{jets} (JES****~3% to 40%* ***ISR/FSR****: 1% to 6%, MC gen.,b-jet)*
  - ***Uncorrelated*** *effects:* ***dominant at low N_{jets} (****Bkg 3% to 18%)*
  - ***Combination improves*** *by 3% (20%) on* ***μ****(****e****) chan (smaller fake lep. bkg in* ***μ*** *chan)*

$d\sigma_{tt}/dp_{T,jets}$

- ***Systematic dominated: lead p_T jet ~7%-14%, others~ up to17%***
  - ***μ*** *En. scale & ID eff.: smaller than* ***e*** *→ 20% smaller uncertainty in* ***μ*** *chan*
  - ***b-jet scale:*** *2%to 5%,* ***b-tag eff.*** *2% to7%,****W+jets bkg****~2% to 8%,* ***Stat:*** *1.5% to 14%*
  - ***Combination improves*** *by 4%-7% (15%-30%) on the* ***μ*** *(****e****) channel*

Differential $d\sigma_{t\bar{t}}/dN_{jets}$ and $d\sigma_{t\bar{t}}/dp_{T,jets}$ - l+jets $\sqrt{s}$ = 7 TeV NEW!

http://arxiv.org/abs/1407.0891, submitted to JHEP

$\int Ldt$ = **4.6 fb^{-1}** *(2011)*

generate — *$t\bar{t}$ predictions* — **shower + hadronize**

Underlying event tune

LO $t\bar{t}$+partons

ALPGEN

PDF: CTEQ6L1 ⊗ **HERWIG** AUET2

PDF: CTEQ5L ⊗ **PYTHIA** Perugia +tunes for α_s up and down variations

- **Generate events with coherent α_s variations in ME and PS settings from jet activity studies.**

NLO $t\bar{t}$

PDF: CT10

MC@NLO ⊗ **HERWIG** AUET2

POWHEG ⊗ **HERWIG** AUET2 / **PYTHIA** PerugiaC2011

- POWHEG **Finite value for** parameter **h_{damp}** → **reduced** fraction of events with **high p_T radiation. Advised v.s. underestimated scale uncertainty.** h_{damp} ~infinity (no reduction) is default.

POWHEG= baseline for unfolding

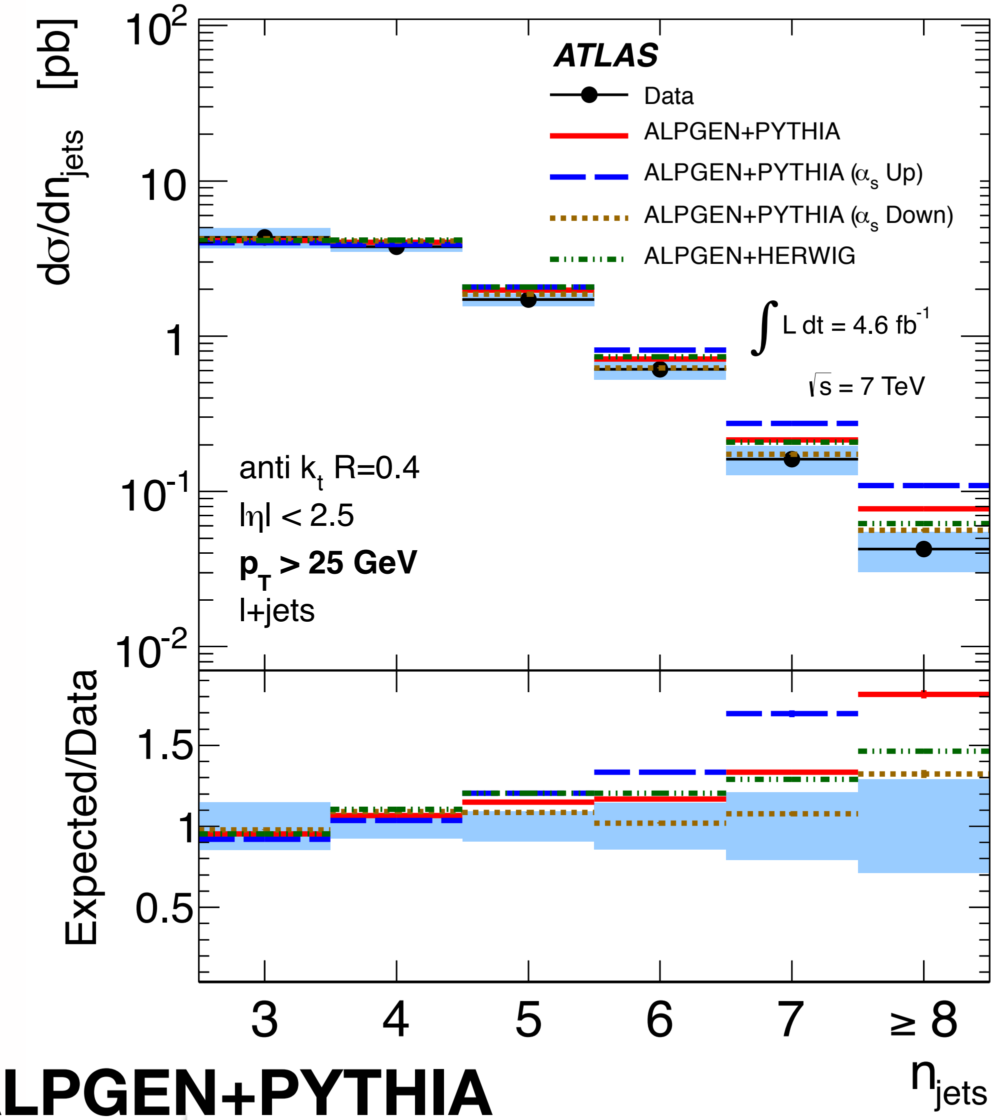
Differential $d\sigma_{t\bar{t}}/dN_{jets}$ and $d\sigma_{t\bar{t}}/dp_{T,jets}$ - l+jets $\sqrt{s}$ = 7 TeV NEW!

http://arxiv.org/abs/1407.0891, submitted to JHEP

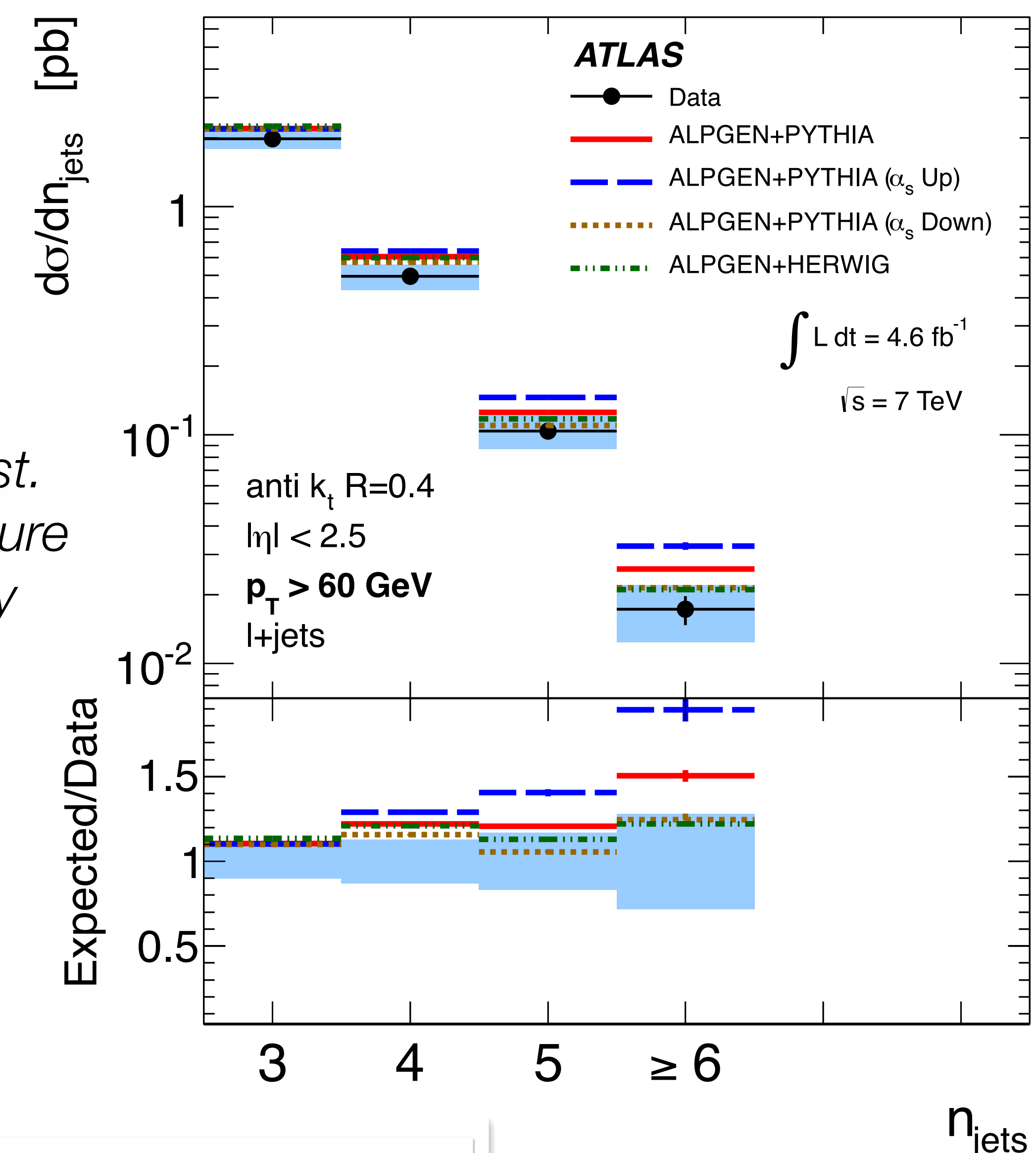
$\int L dt$ = **4.6 fb^{-1}** *(2011)*

ATLAS-CONF-2012-155

N_{jet} $p_{T,jet}$ >25 GeV



N_{jet} $p_{T,jet}$ >60 GeV



band = data stat.+syst. uncertainty in quadrature
MC: stat. uncertainty

ALPGEN+PYTHIA

CTEQ5L

- **nominal: too high cross section for ≥ 6 jets**
- **increased α_s (up) : too high cross section for ≥ 5 jets**

→ **disfavoured**

- **lower α_s (down) given best description**

ALPGEN+HERWIG *CTEQ6L1*

similar to ALPGEN+PYTHIA with α_s down (similar α_s setting)

Differential $d\sigma_{t\bar{t}}/dN_{jets}$ and $d\sigma_{t\bar{t}}/dp_{T,jets}$ - l+jets $\sqrt{s}$ = 7 TeV

NEW!

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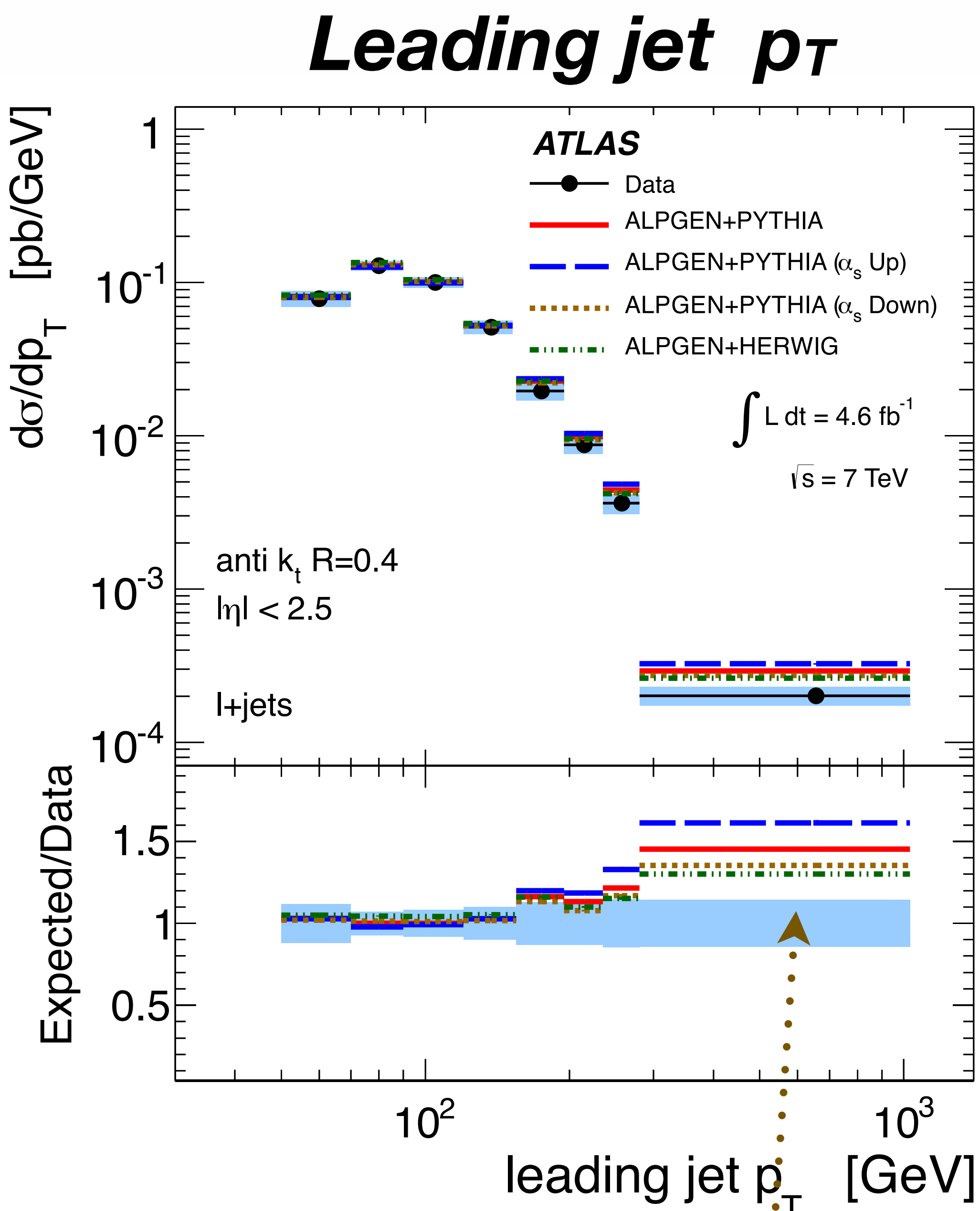
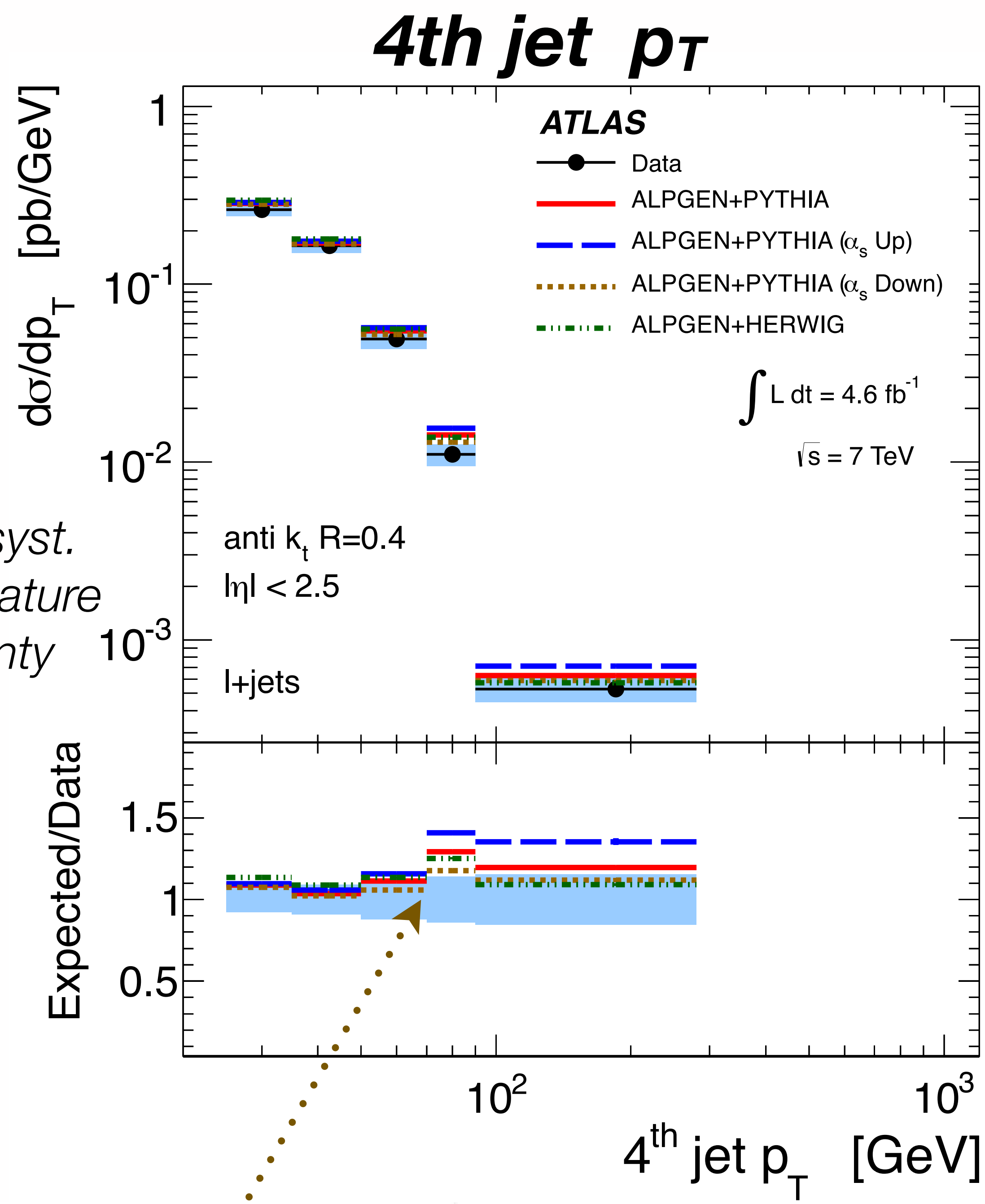
$\int L dt$ = **4.6 fb^{-1}** *(2011)*

Leading jet p_T



4th jet p_T



band = data stat.+syst. uncertainty in quadrature
MC: stat. uncertainty

ALPGEN+PYTHIA

- **nominal & α_s (up): too high cross section for p_T> O(100GeV)** ⇒ **disfavoured**
- **α_s (down) given best description**

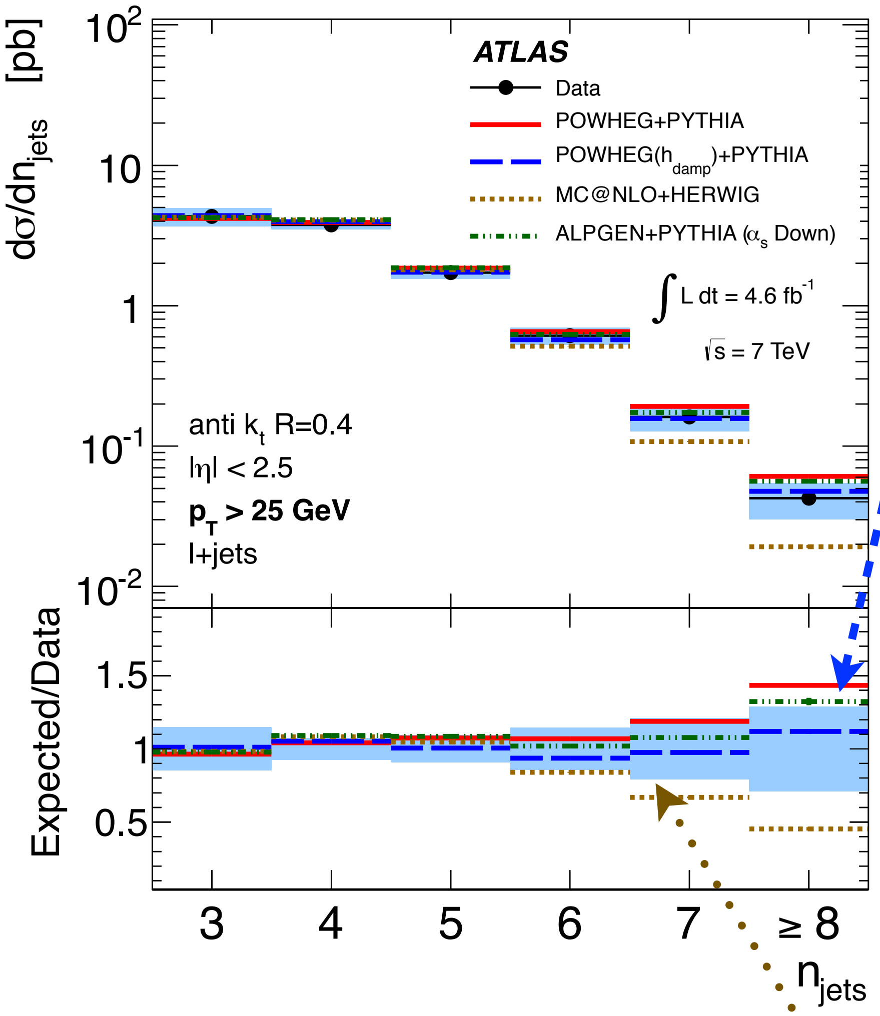
ALPGEN+HERWIG **similar to ALPGEN+PYTHIA with α_s down (similar α_s setting)**

Differential $d\sigma_{tt}/dN_{jets}$ and $d\sigma_{tt}/dp_{T,jets}$ - l+jets $\sqrt{s}$ = 7 TeV **NEW!**

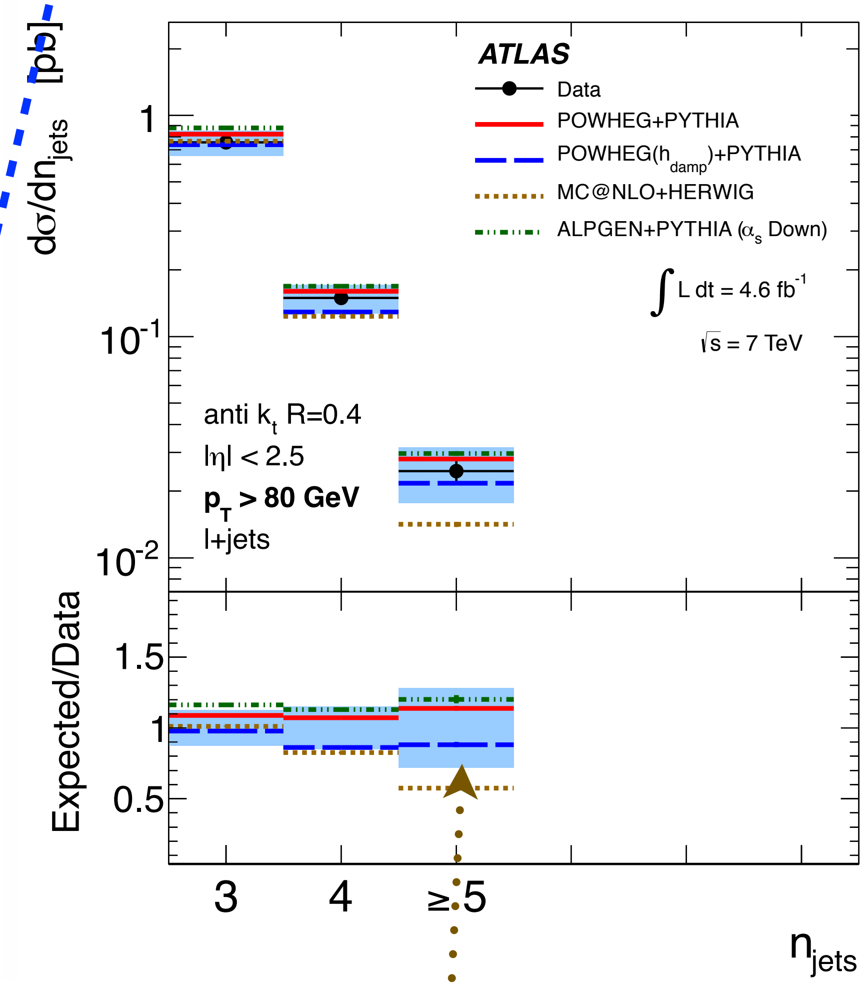
$\int Ldt$ = **4.6 fb^{-1}**
(2011)

- **POWHEG+PYTHIA: nominal in reasonable agreement, finite h_damp best for high N_{jet}** ***close to ALPGEN+PYTHIA, α_s down***

N_{jet} $p_{T,jet}$ >25 GeV



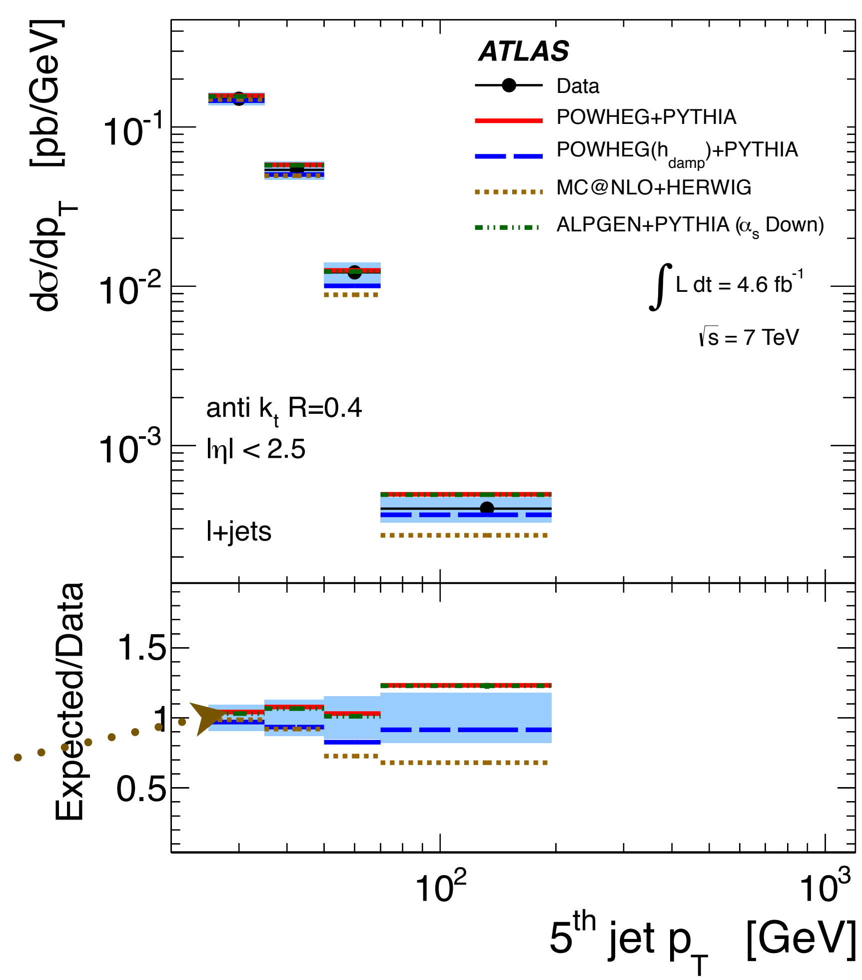
N_{jet} $p_{T,jet}$ >80 GeV



band = data stat. +syst. uncertainty
MC: stat uncertainty

http://arxiv.org/abs/1407.0891
submitted to JHEP

5th jet p_T



- **MC@NLO+HERWIG: lower cross section at high jet multiplicity[1,2] & softer spectrum for 5th jet**

[1] *dominated by PS*

[2] *JHEP071(2007) 013: MC@NLO: ttq(g) smaller than ALPGEN + larger fraction of PS additional jets*

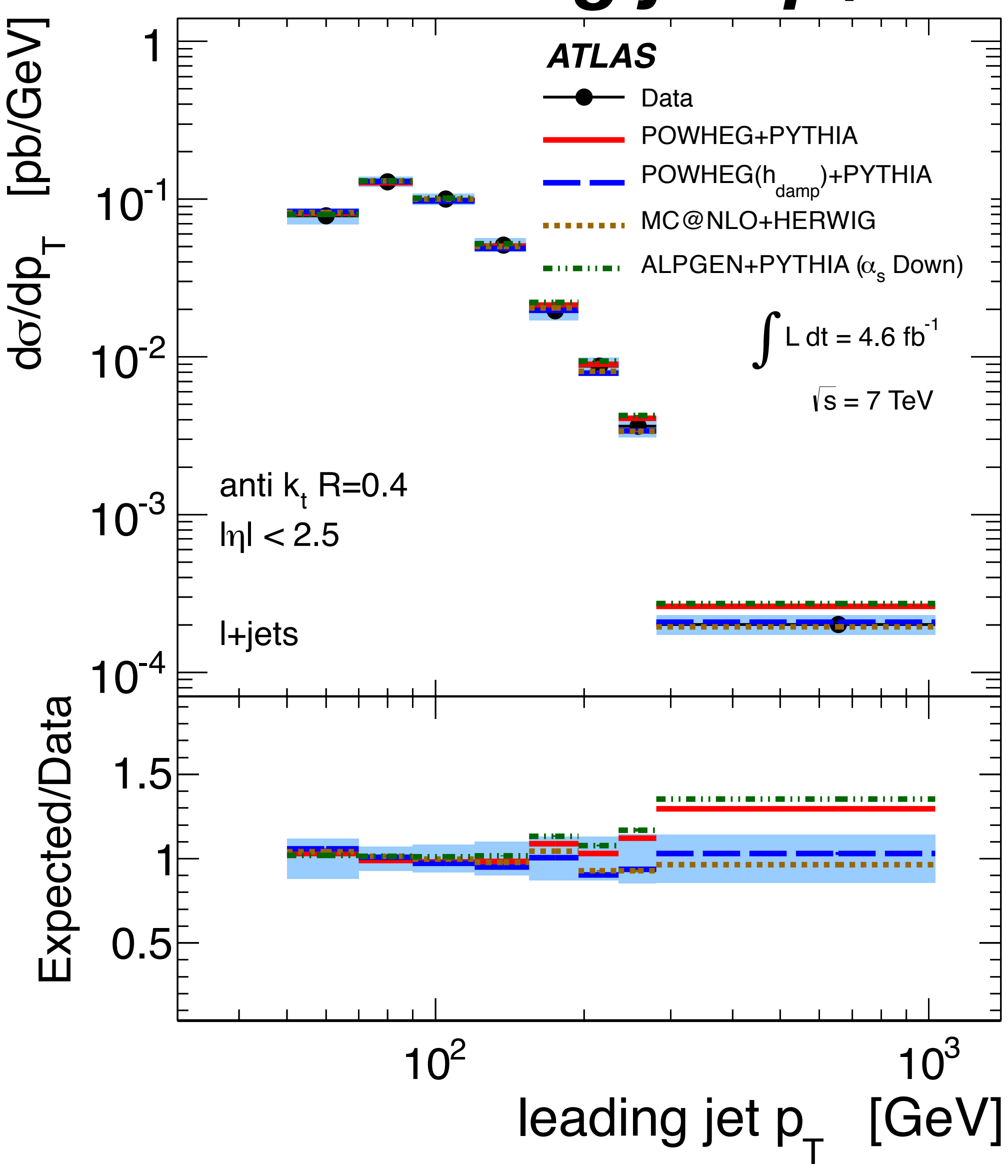
Differential $d\sigma_{tt}/dN_{jets}$ and $d\sigma_{tt}/dp_{T,jets}$ - l+jets $\sqrt{s}$ = 7 TeV

NEW!

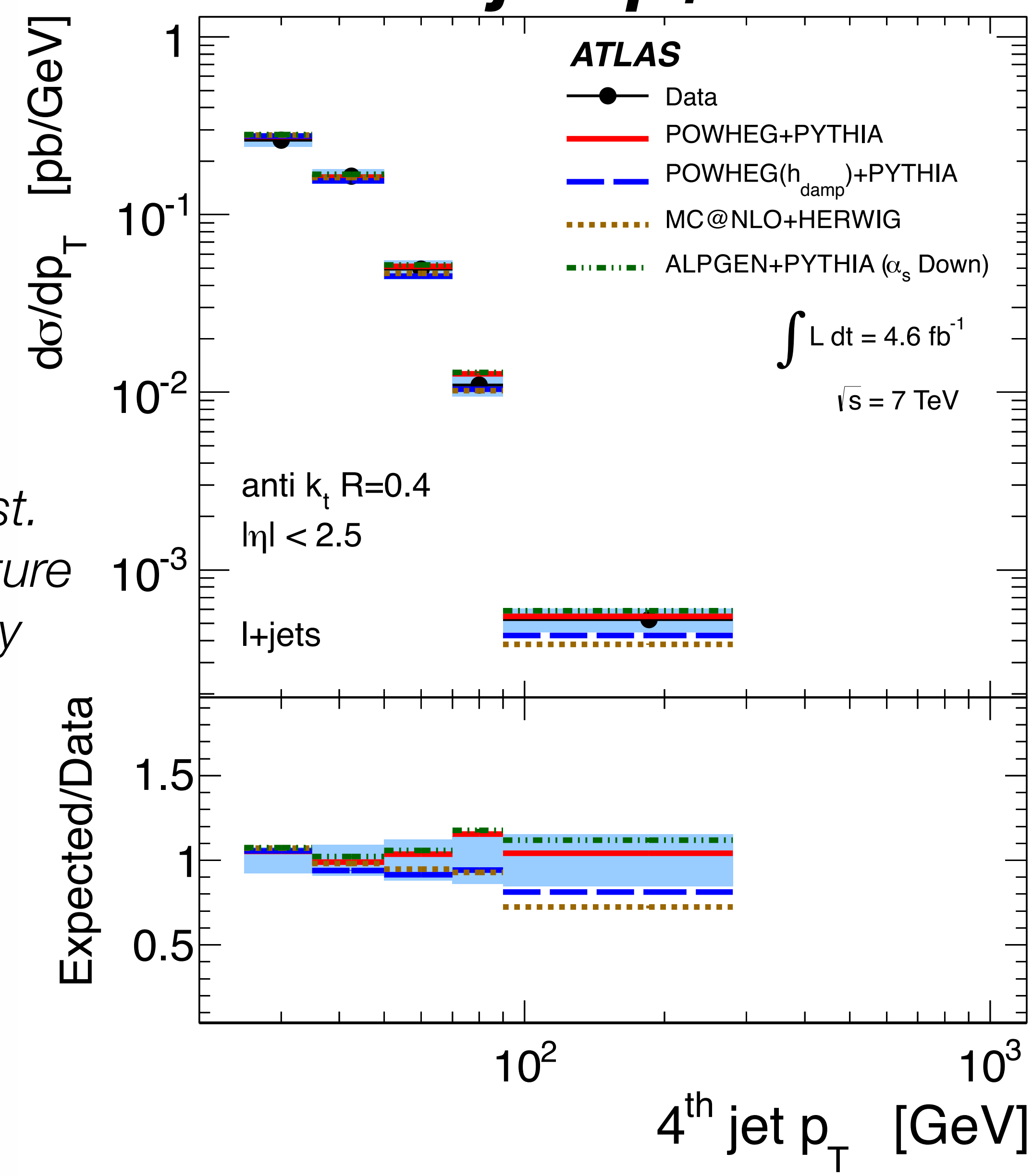
http://arxiv.org/abs/1407.0891, submitted to JHEP

$\int Ldt =$ **4.6 fb^{-1}** *(2011)*

Leading jet p_T



4th jet p_T



band = data stat+syst. uncertainty in quadrature
MC: stat. uncertainty

POWHEG+PYTHIA (similar to ***ALPGEN+PYTHIA, α_s down***)

- **nominal in reasonable agreement** **(~slightly higher)**
- **finite h_damp** *(=172.5 GeV) (less high p_T radiation):* **best for leading jet p_T**

MC@NLO+HERWIG: slightly softer at high p_T

Differential $d\sigma_{tt}/dN_{jets}$ and $d\sigma_{tt}/dp_{T,jets}$ - l+jets $\sqrt{s}$ = 7 TeV

NEW!

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$\int L dt$ = **4.6 fb^{-1}** *(2011)*

LO $t\bar{t}$+partons

ALPGEN+PYTHIA

PDF: CTEQ5L

- **nominal & α_s (up) : too high cross section for large jet multiplicity (≥ 5,6 jets)**
- **lower α_s (down) given best description**

ALPGEN+HERWIG

PDF: CTEQ6L1

similar to ALPGEN+PYTHIA with α_s down (similar α_s setting)

NLO $t\bar{t}$

MC@NLO+HERWIG

lower cross section at high jet multiplicity & softer spectrum for 5th jet

POWHEG+PYTHIA

(similar to **ALPGEN +PYTHIA with α_s down**)

- **nominal in reasonable agreement** (~slightly higher)
- **finite h_damp** *(less high p_T radiation)* **best for high N_{jet} and leading jet p_T**

inclusion in RIVET is under way

Differential *Jet activity* : dilepton $\sqrt{s}$ = 7 TeV ATL-PHYS-PUB-2014-005

generate	$t\bar{t}$ predictions	**shower + hadronize** Underlying event tune
LO $t\bar{t}$		
ACER MC: *with more or less radiation* PDF: CTEQ6L1	⊗	***PYTHIA*** Perugia AUET2B
LO $t\bar{t}$+partons		
ALPGEN *: with more or less radiation* PDF: CTEQ6L1/CTEQ5L	⊗	***HERWIG*** AUET2
	⊗	***PYTHIA*** Perugia 2011 + radiation tunes
MADGRAPH PDF: CTEQ6L	⊗	***PYTHIA***
NLO $t\bar{t}$		
MC@NLO PDF: CT10	⊗	***HERWIG*** UEEE4 LO**
POWHEG: *with ren.& fact. scale variations & damping* PDF: CT10(ME)+CTEQ6L1(PS)	⊗	***HERWIG*** AUET2 ***PYTHIA*** Perugia2011
aMC@NLO *with ren. & fact. scale variations* PDF: CT10(ME) & MRST**	⊗	***HERWIG*** AUET2,UEE4LO*

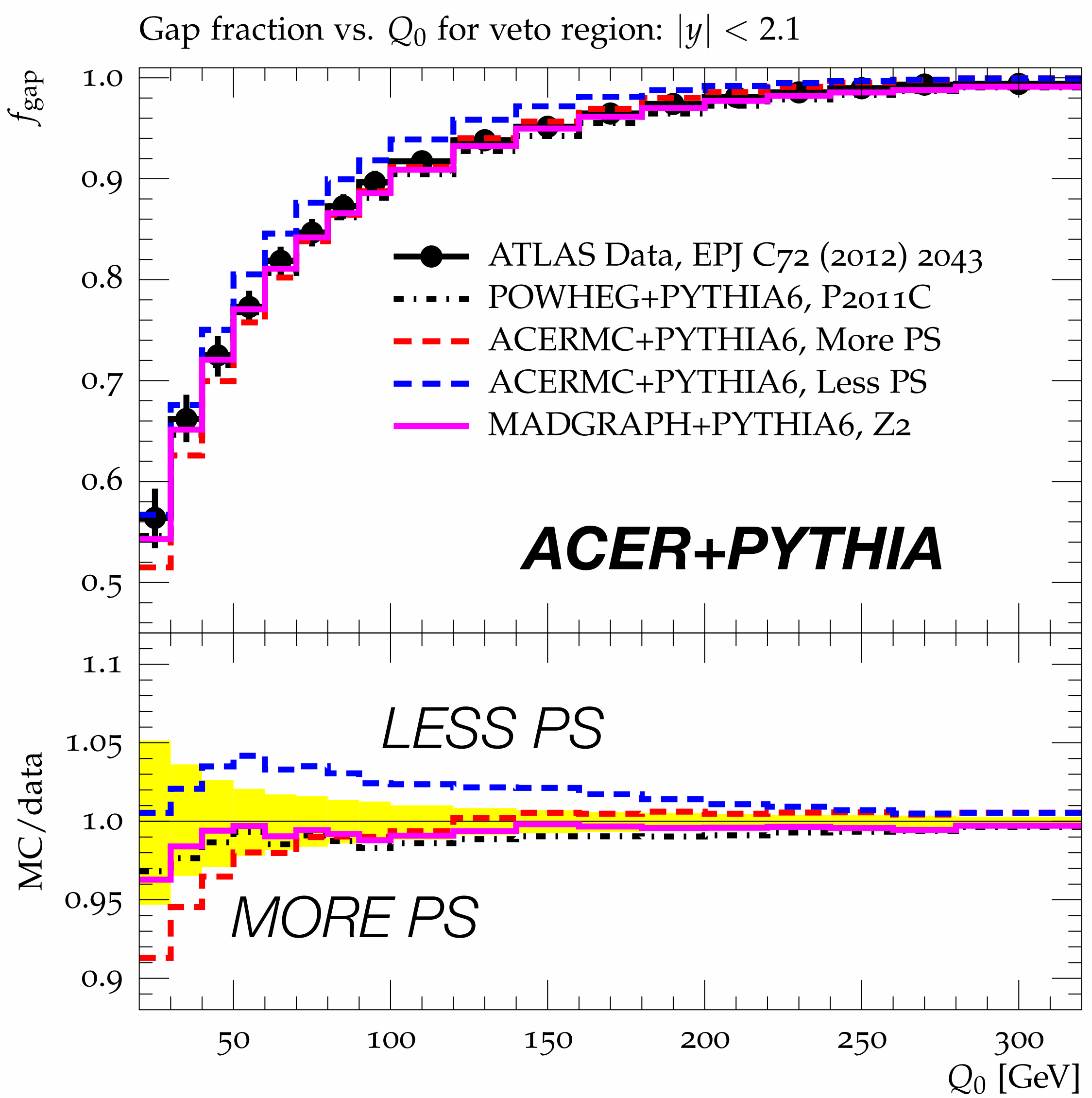
Differential *Jet activity* : dilepton √s = 7 TeV

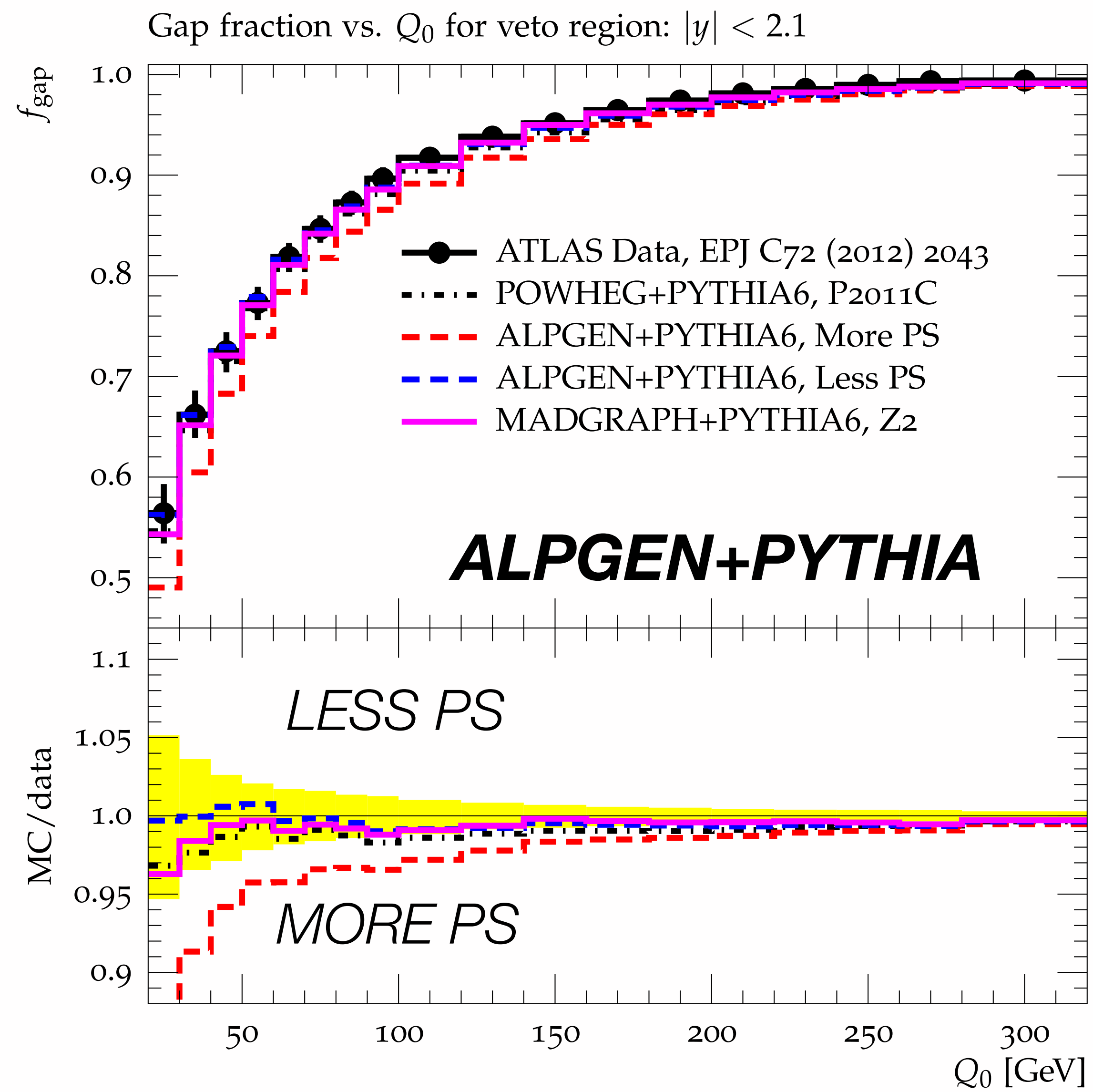
ATL-PHYS-PUB-2013-005

ATL-PHYS-PUB-2014-005

$\int L dt =$ **2.05 fb^{-1}** *(2011)*

- Compare different radiation scenarios for gap fraction measurements→ tune models, constrain systematic uncertainties





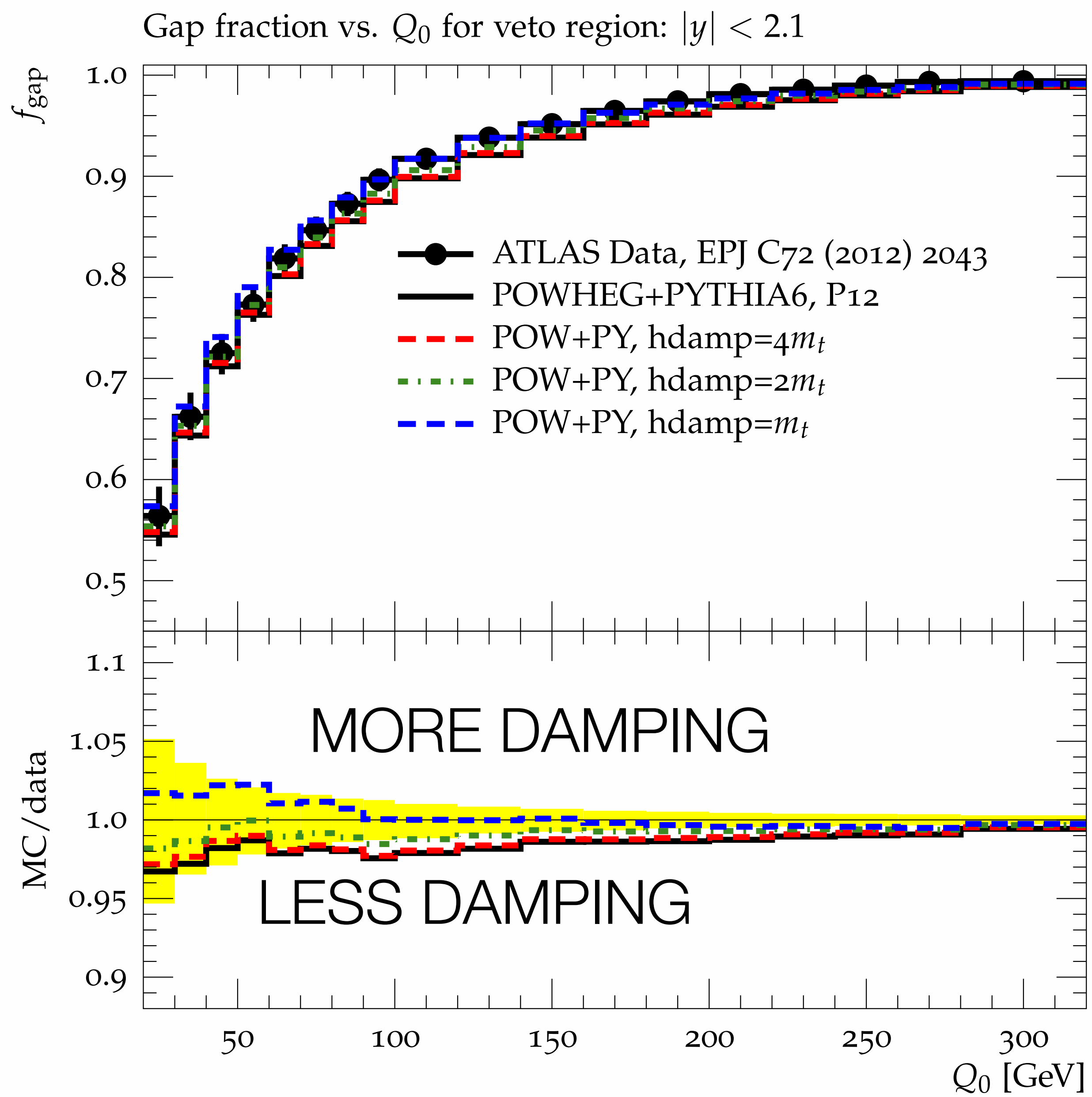
- **Comparable** more PS - less PS **differences** between
  - ACER+PYTHIA (updated after $f_{gap}(Q)$ measurement) and ALPGEN+PYTHIA
  - larger at high Q_0, Q_{sum}, large N_{jets}

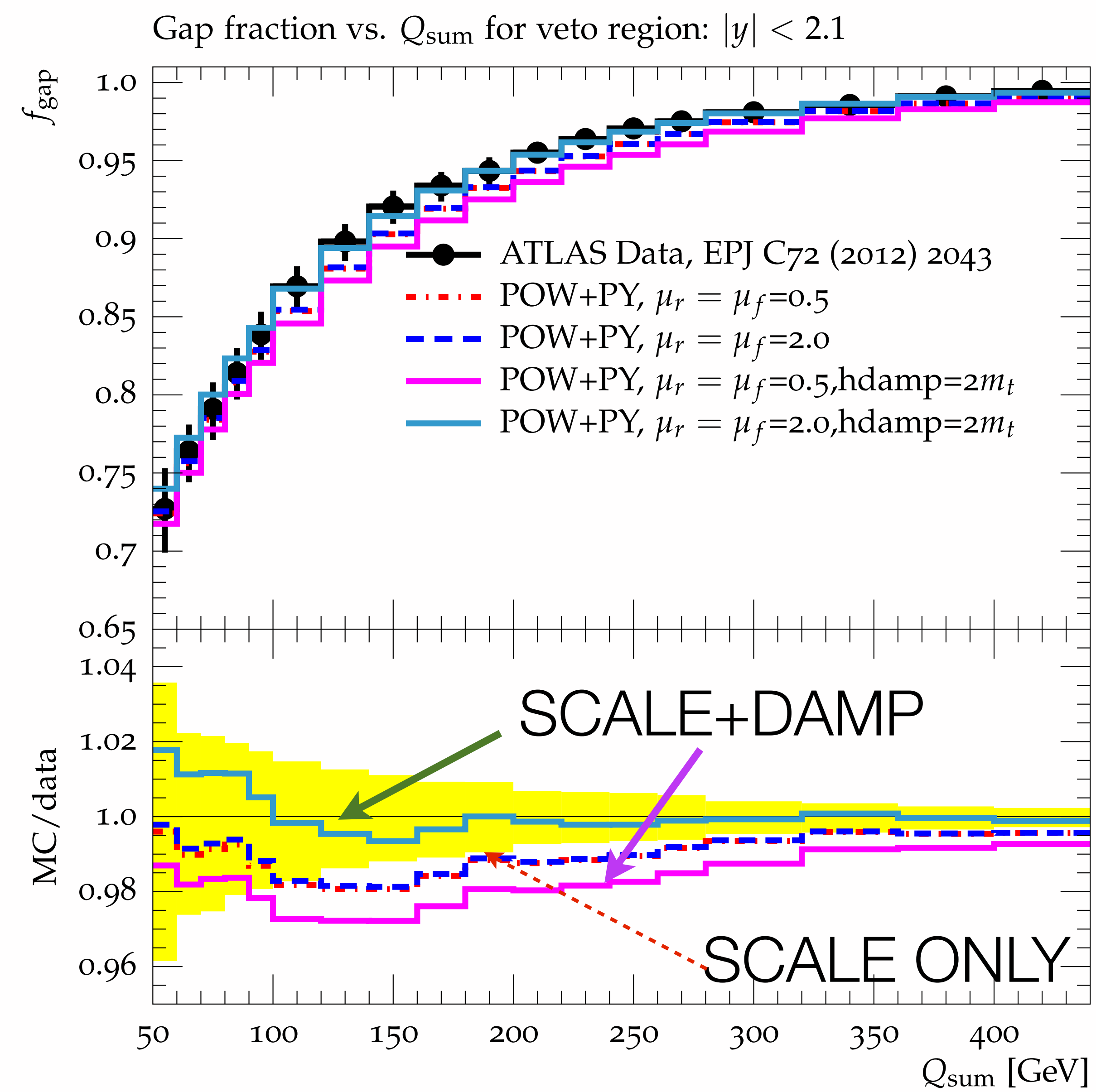
Differential *Jet activity* : dilepton $\sqrt{s}$ = 7 TeV

ATL-PHYS-PUB-2013-005
ATL-PHYS-PUB-2014-005

- Investigate tuning of NLO generators→ POWHEG with damping:p_T dependent effect on hardest emission, still at NLO

$\int L dt$ = **2.05 fb^{-1}** *(2011)*





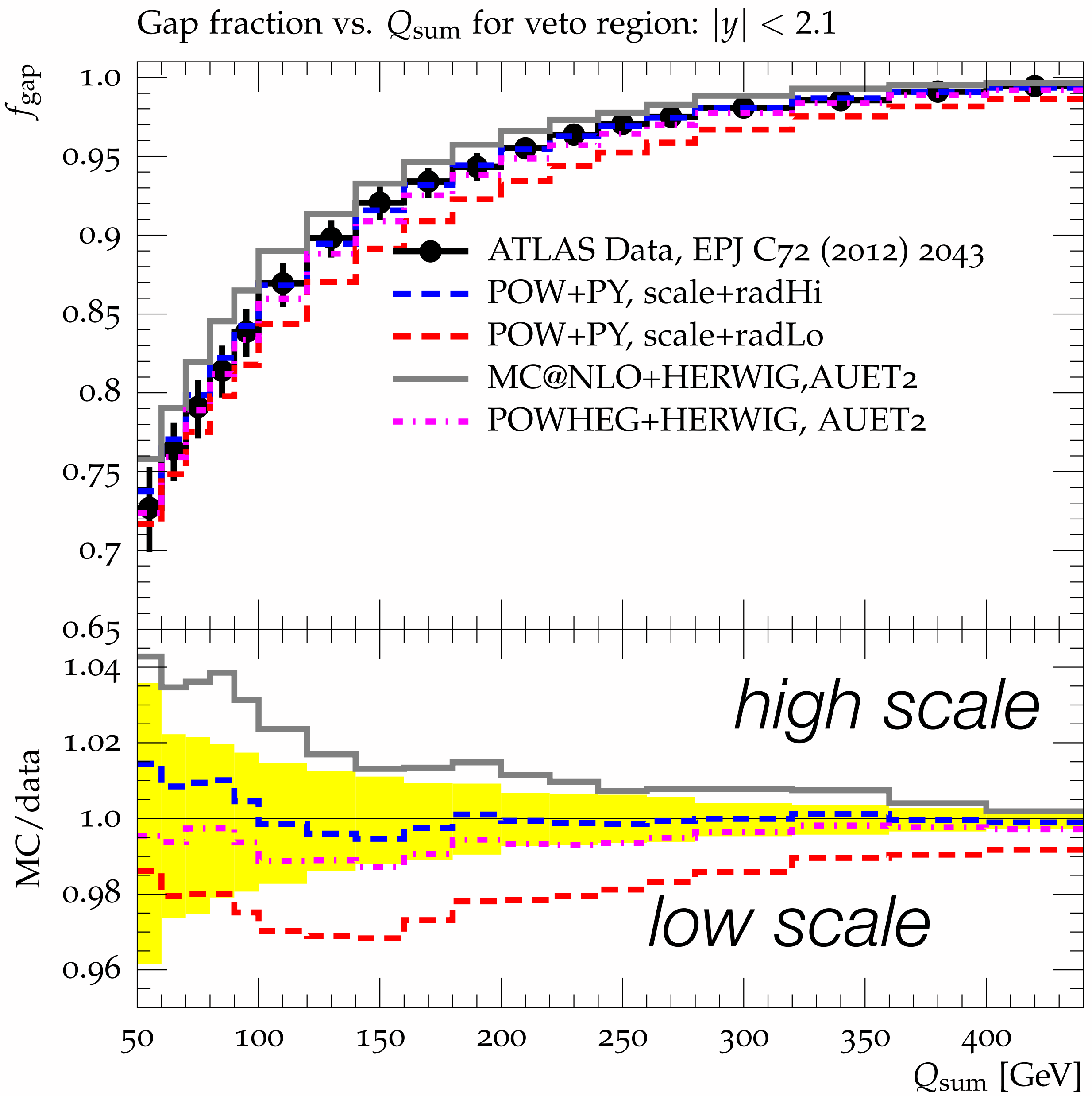
- **More damping** (lower hdamp) →**reduced** QCD **radiation activity**
- Ren. & fact. scale: **larger** *(flat)* **variation with** *(without)* **damping**

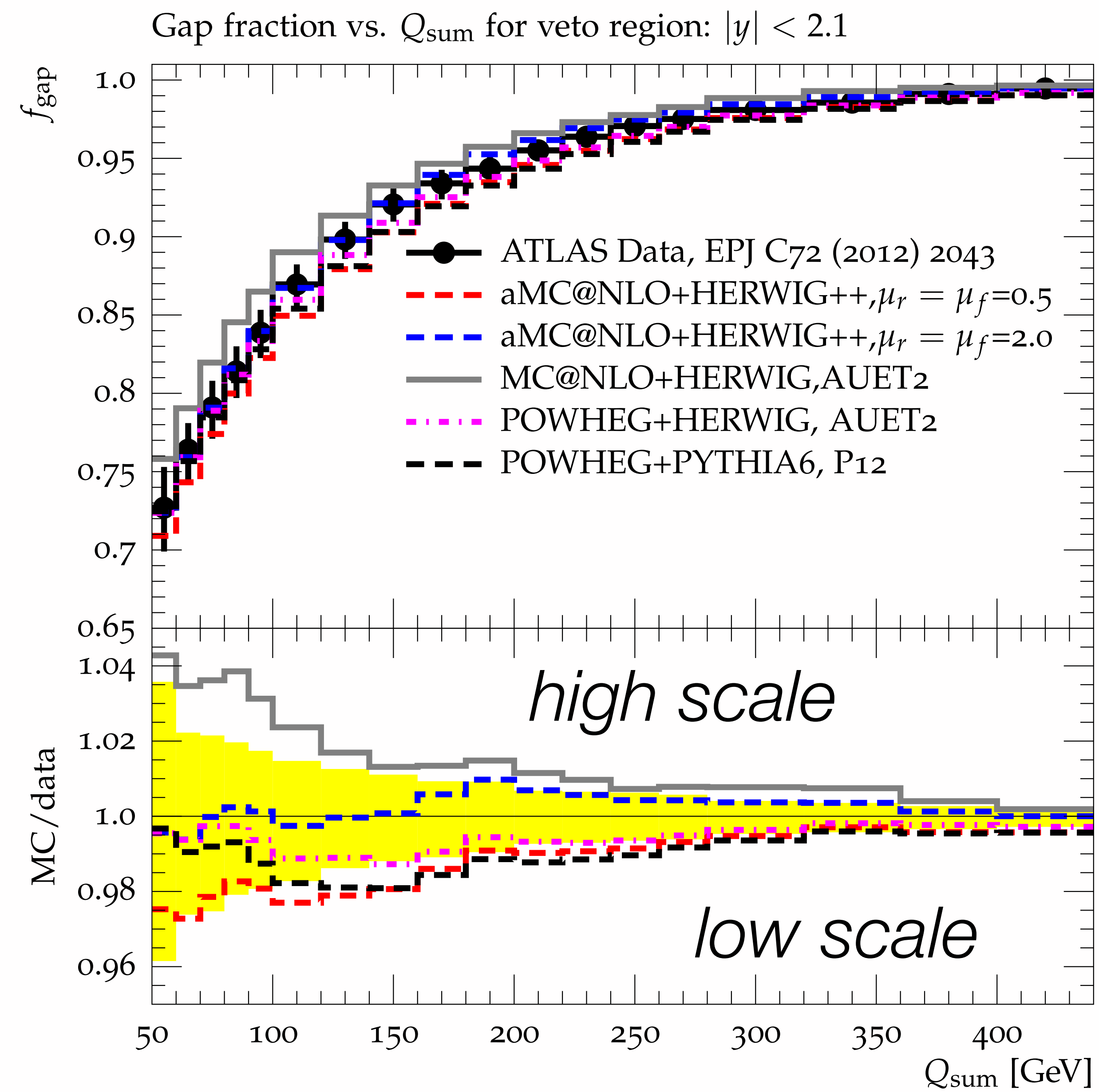
Differential *Jet activity* : dilepton √s = 7 TeV

ATL-PHYS-PUB-2013-005
ATL-PHYS-PUB-2014-005

- Investigate **new NLO generators scale variations**

$\int L dt =$ **2.05 fb^{-1}** *(2011)*



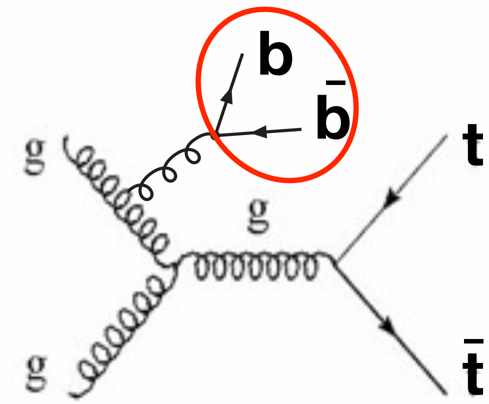


- POWHEG +PY(+ hdamp) brackets POWHEG+HW, but not MC@NLO+HW
- aMC@NLO+HW++ brackets POWHEG+HW and PY6 (not at low Q_0), but not MC@NLO+HW

Inclusive $\sigma_{t\bar{t}+heavy\ flavour}$:dilepton-$\sqrt{s}$ =7 TeV

Phys. Rev. D 89 072012 (2014)

$\int Ldt$ ~ **4.7 fb^{-1}** *(2011)*



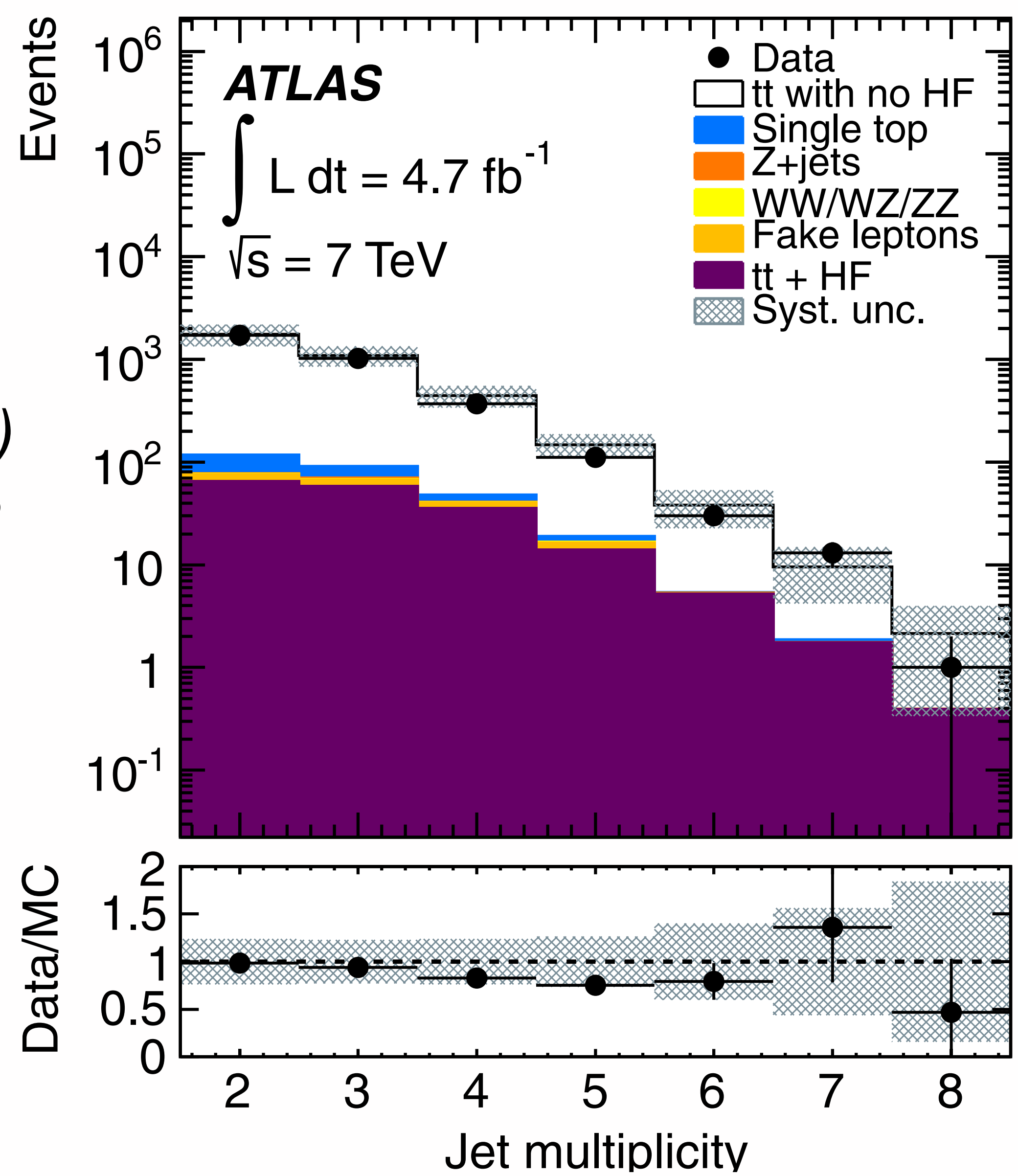
$t\bar{t}$ + b/c+X (HF) is main bkg to $t\bar{t}$+H,H→$b\bar{b}$

- 2 **OS leptons, ≧ 2 jets,** ee,μμ: high E_T^{miss} > *60 GeV* & M(ℓℓ)≠m_Z, eμ: high $H_T = \sum_{jets,lepts} p_T$ *>130GeV*

- **Bkg: $t\bar{t}$ with >1** mis-tag *(shape from simul., norm from fit in $t\bar{t}$+HF)*, **single top** and **Z+jets** *(from simul.)* **data-driven fake leptons** *(extrapol. from same sign lep. sample)*

- **objects for PL fiducial volume**: *(stable)* ***particle*** *jets, truth e,μ,ν from W in top decay, b-(c-) jet: spatial match of jet to b- (c-)quark*

2 b-tag control region



Inclusive $\sigma_{t\bar{t}+heavy\ flavour}$:dilepton-$\sqrt{s}$ =7 TeV $\int Ldt \sim$ 4.7 fb^{-1} (2011)

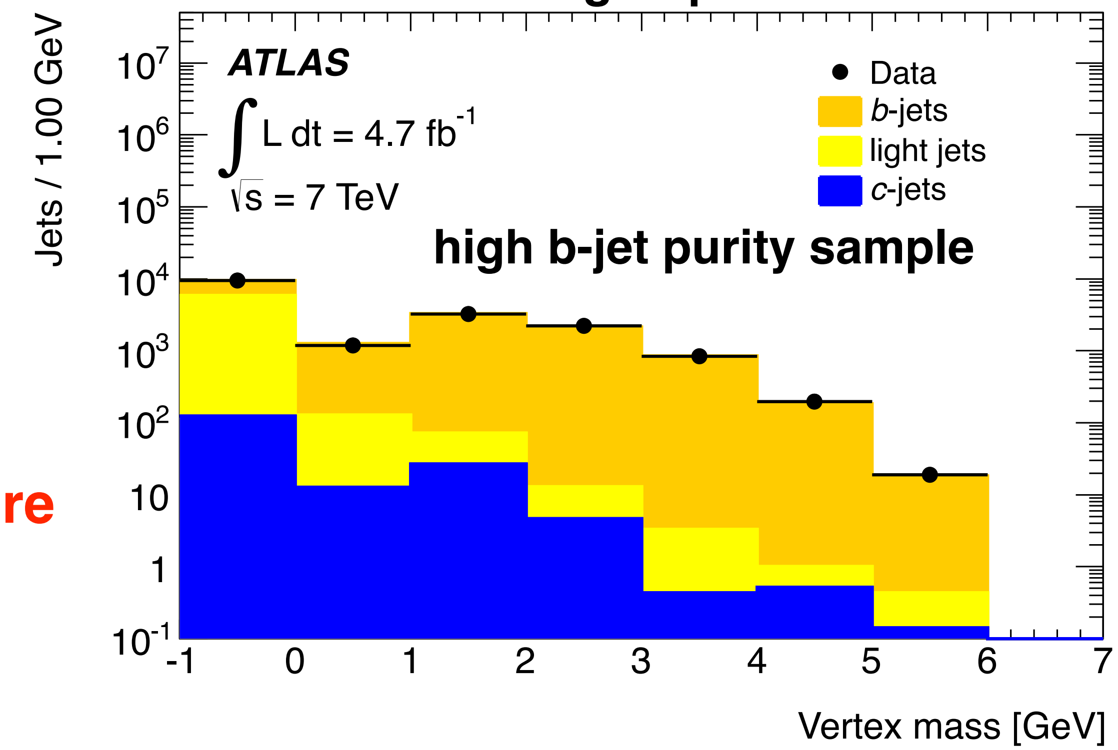
Phys. Rev. D 89 072012 (2014)

- In ≧ 3 b-tag ev. calculate $\sigma_{\rm fid}(t\bar{t}+{\rm HF}) = \frac{N_{\rm HF}}{\int \mathscr{L} dt \cdot \varepsilon_{\rm HF}}$;
  - N_{HF} =#b-tags from combined HF = 79±26←Max lkl. fit of templates *(from tt, non tt-bkg, HF (b and c), light flavour mis-tag)* to displaced vertex mass & p_T of b-tagged jets in 3 b-tag purity bins

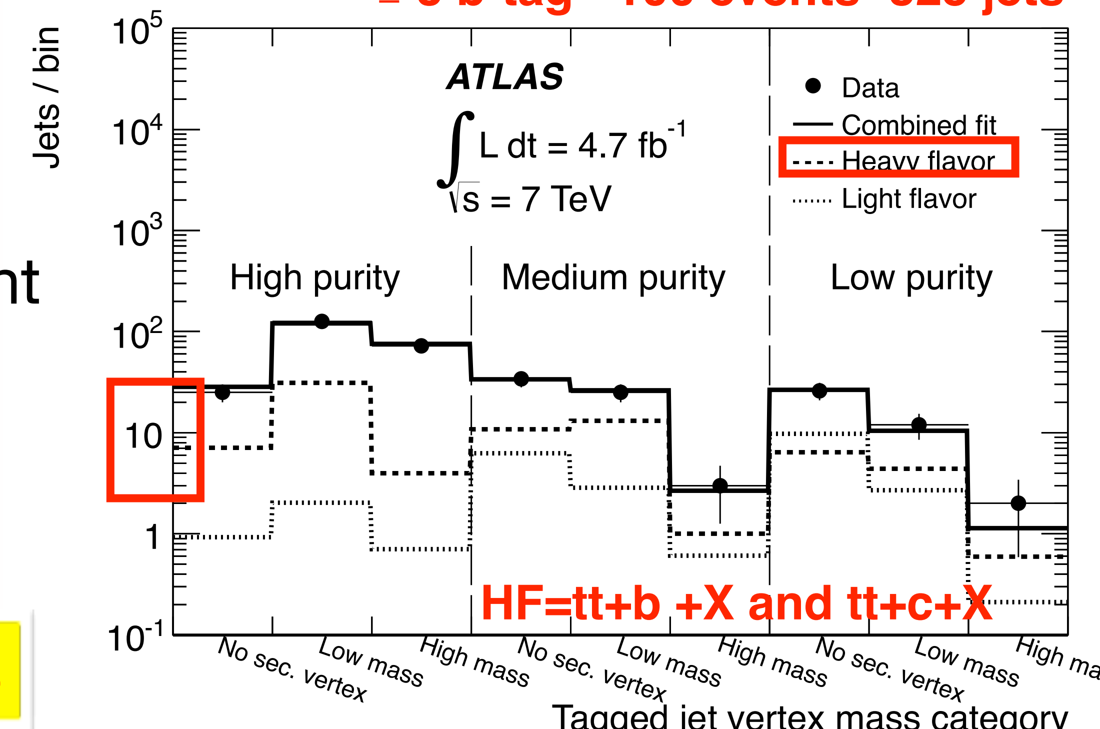
expect large uncertainty on b- to c- separation →measure only total HF *: additional b-tags not coming from light jets*

  - ε_{HF}: convert N_{HF} to #events with ≧3 true PL b-/c-jets (2 top b-jets)←MC events in fiducial volume

no # b-tag requirement



≧ 3 b-tag ~106 events~325 jets



- In ≧ 3 jets & ≧ 2 b-tags ev. get $\sigma_{\rm fid}(t\bar{t}+j) = \frac{N_j}{\int \mathscr{L} dt \cdot \varepsilon_j}$
  - N_j = #events with $t\bar{t}$ + ≧ 1 jet =1541±41 ←cut & count
  - ε_j: from N_j to #ev. with ≧3 true PL jets (2 top b-jets)←MC events in fiducial volume

$$R_{\rm HF} = \frac{\sigma_{\rm fid}(t\bar{t}+{\rm HF})}{\sigma_{\rm fid}(t\bar{t}+j)} = [6.2 \pm 1.1({\rm stat}) \pm 1.8\ ({\rm syst})]\%$$

SM: 3.4% (ALPGEN) , 5.2% (POWHEG)

- **Syst dominated**: *c-tagging (21%),fragm. (10%) flavour comp. (6%),*

Conclusions & Outlook

- ATLAS measures differential/inclusive cross sections sensitive to radiation effects in $t\bar{t}$ production using the full 7 TeV dataset in fiducial regions similar to reco space

- New measurements of $d\sigma_{t\bar{t}}/dN_{jets}$ with different p_T threshold **and $d\sigma_{t\bar{t}}/dp_{T,jets}$** for p_T-ordered jets up to the 5th show **sensitivity to parton shower modelling** for LO multi-leg and NLO generators **at highest jet multiplicities, high jet p_T of leading jet and in jet p_T of 5th jet**
  - MC@NLO+HERWIG predicts too few events at high N_{jets}

- **Measurements of gap fraction f(Q)** = fraction of events no additional jet(s) above certain p_T threshold Q, in different rapidity regions, are compared with
  - LO and multi-leg LO generators **to constrain ISR/FSR variations** in a broadly consistent manner.
  - **variations of fact. & renor. scales for several NLO generators** +different hadr. schemes: **spread of models is even wider than considered variations** → care in parameter choice & **consider use of multiple models.**

- Measurement of $t\bar{t}$+heavy flavours (b+X and c+X) production at 7 TeV shows agreement with the SM predictions

- Definitely keen on using new NLO generators so stay tuned for upcoming 8 TeV measurements and beyond!

BACK-UP

Large Hadron Collider RUN1

2012 E_{cm} =8 TeV

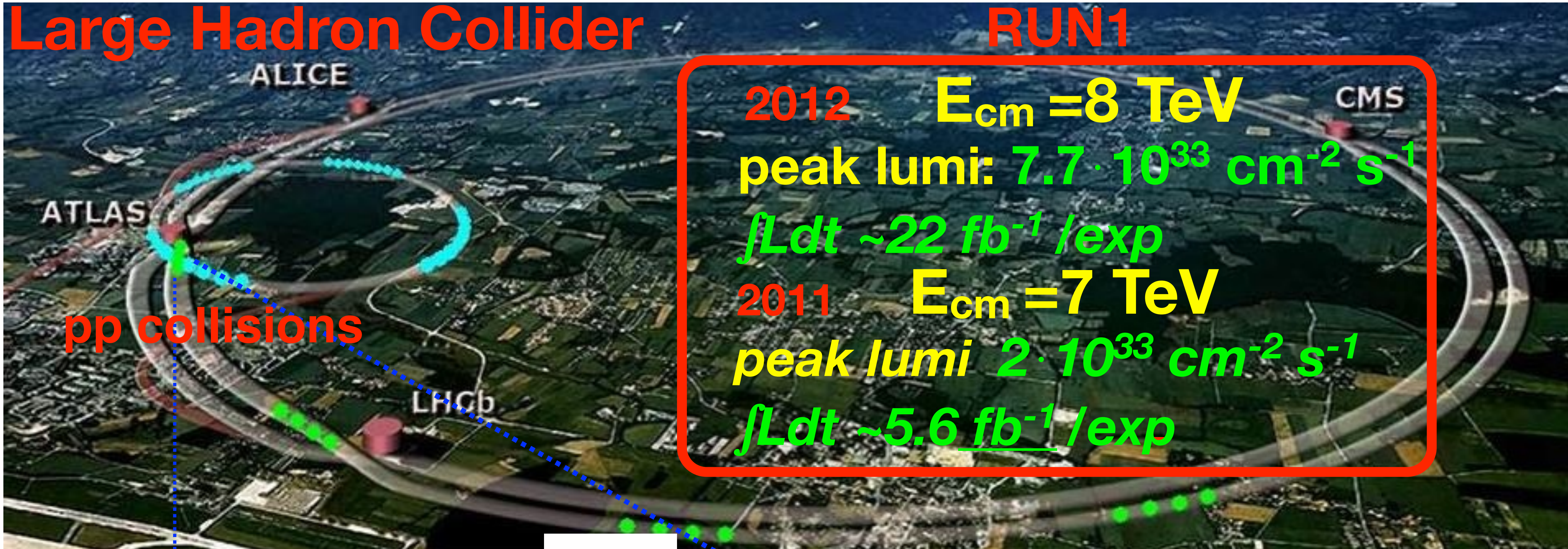
peak lumi: $7.7 \cdot 10^{33}$ cm^{-2} s^{-1}

$\int Ldt$ ~22 fb^{-1} /exp

2011 E_{cm} =7 TeV

peak lumi $2 \cdot 10^{33}$ cm^{-2} s^{-1}

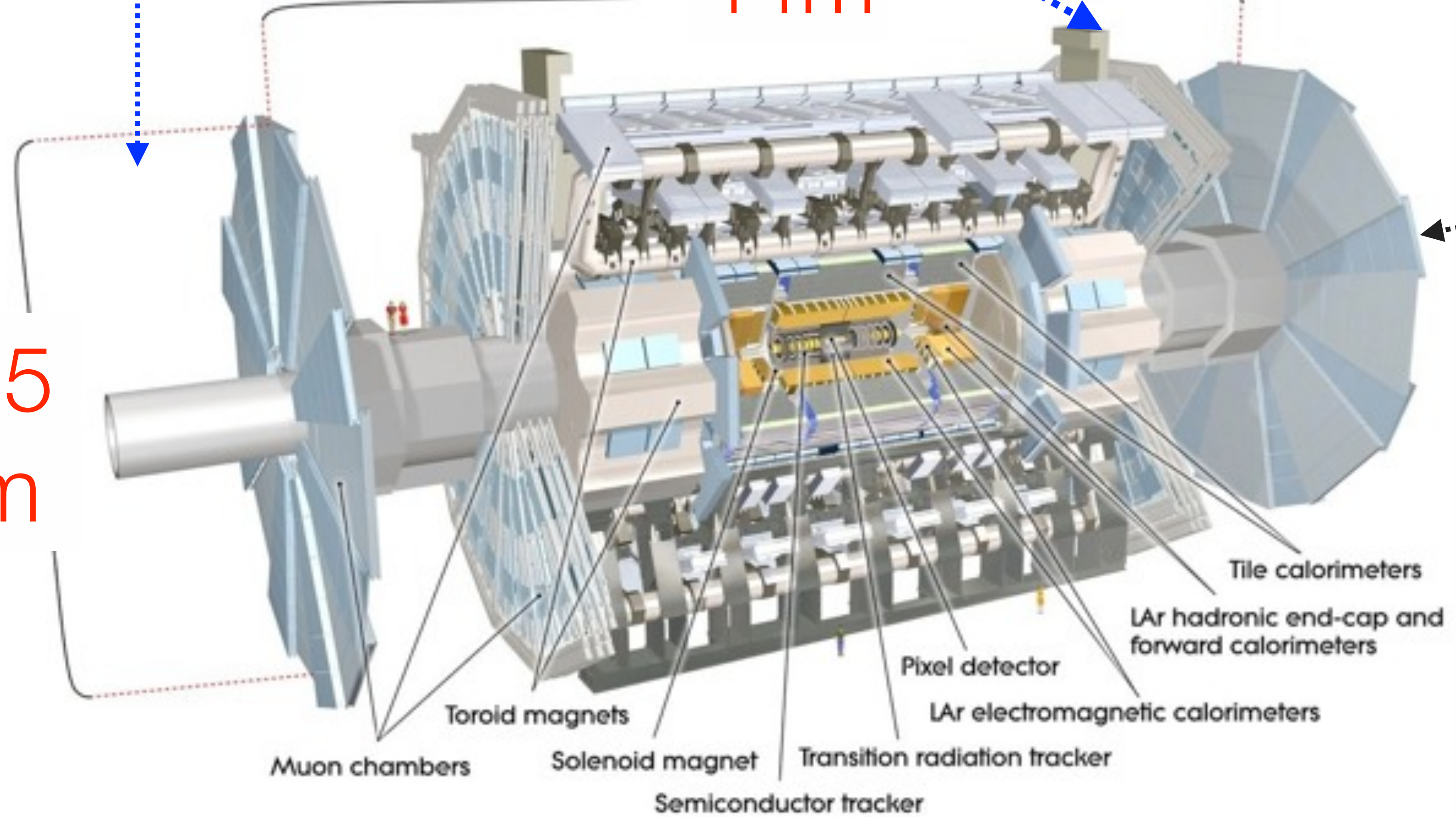
$\int Ldt$ ~5.6 fb^{-1} /exp



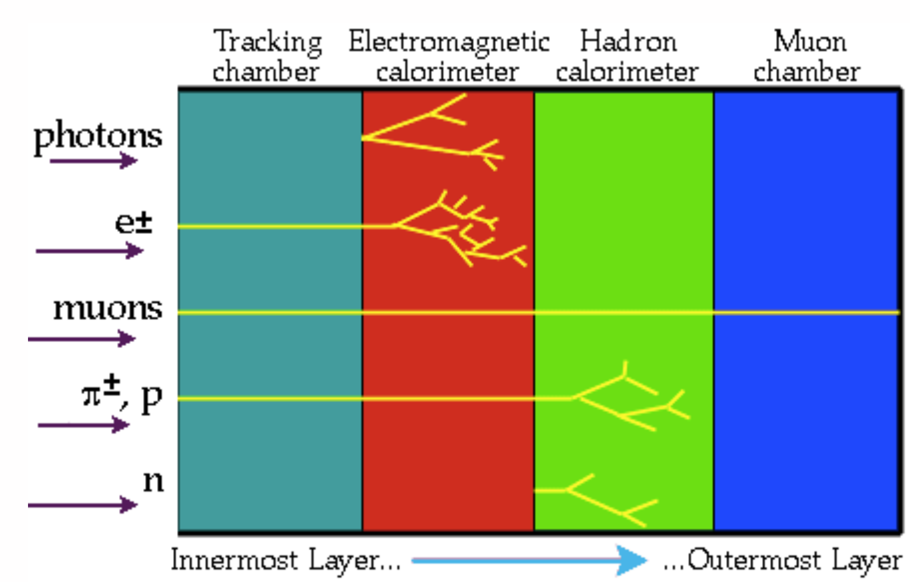
44m

25 m

p



$\bar{p}$ **tracker Calo Muon**



Top quark @ LHC: inclusive production

pp collisions

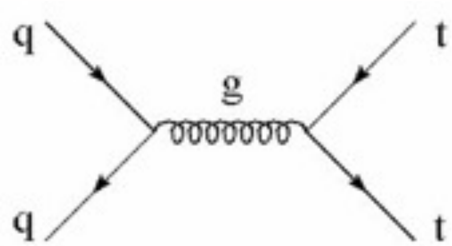
probing lower x than Tevatron → (abundant) gluon fusion dominated

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

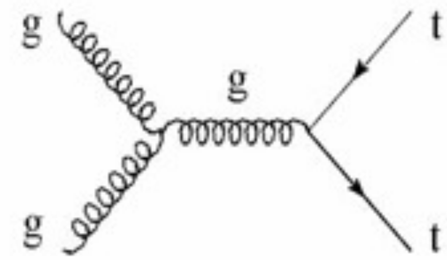
m_{top}= 172.5

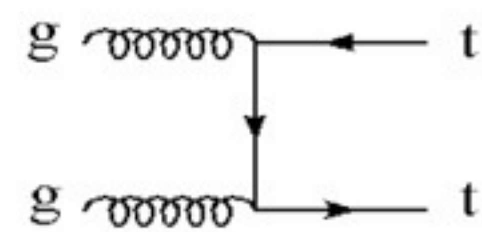
top pairs: strong

qq annihilation



gluon fusion





At Tevatron

$\sigma_{t\bar{t}} \sim 7$ pb
$\sigma_t \sim 3.5$ pb

Czakon,Mitov,Fiedler 2013

NNLO+NNLL accuracy

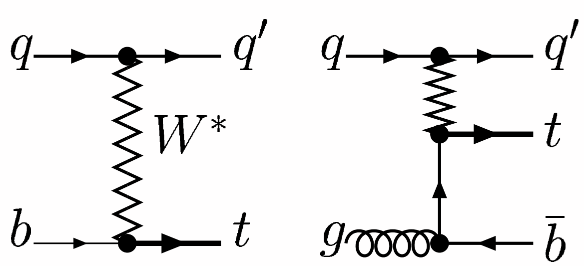
$\delta\sigma_{tt}/\sigma_{tt}$ ~4%

σ_{7TeV} (pb)	$172^{+4.4}_{-5.8}{}^{+4.7}_{-48}$
σ_{8TeV} (pb)	$245^{+6.2}_{-8.4}{}^{+6.2}_{-6.4}$

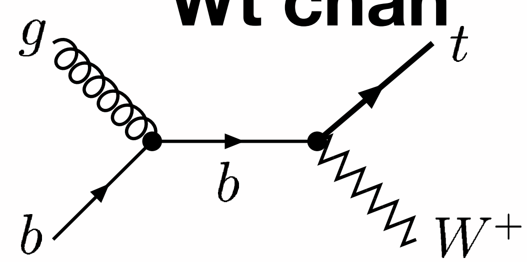
~5.4M (~0.96 M) $t\bar{t}$ events produced by LHC in 2012 (2011)

single top: electroweak

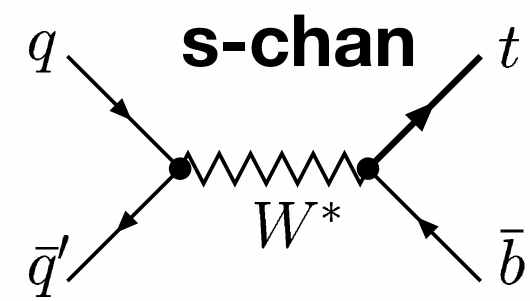
t-chan



Wt chan



s-chan



Kidonakis 2010,2011

approx NNLO

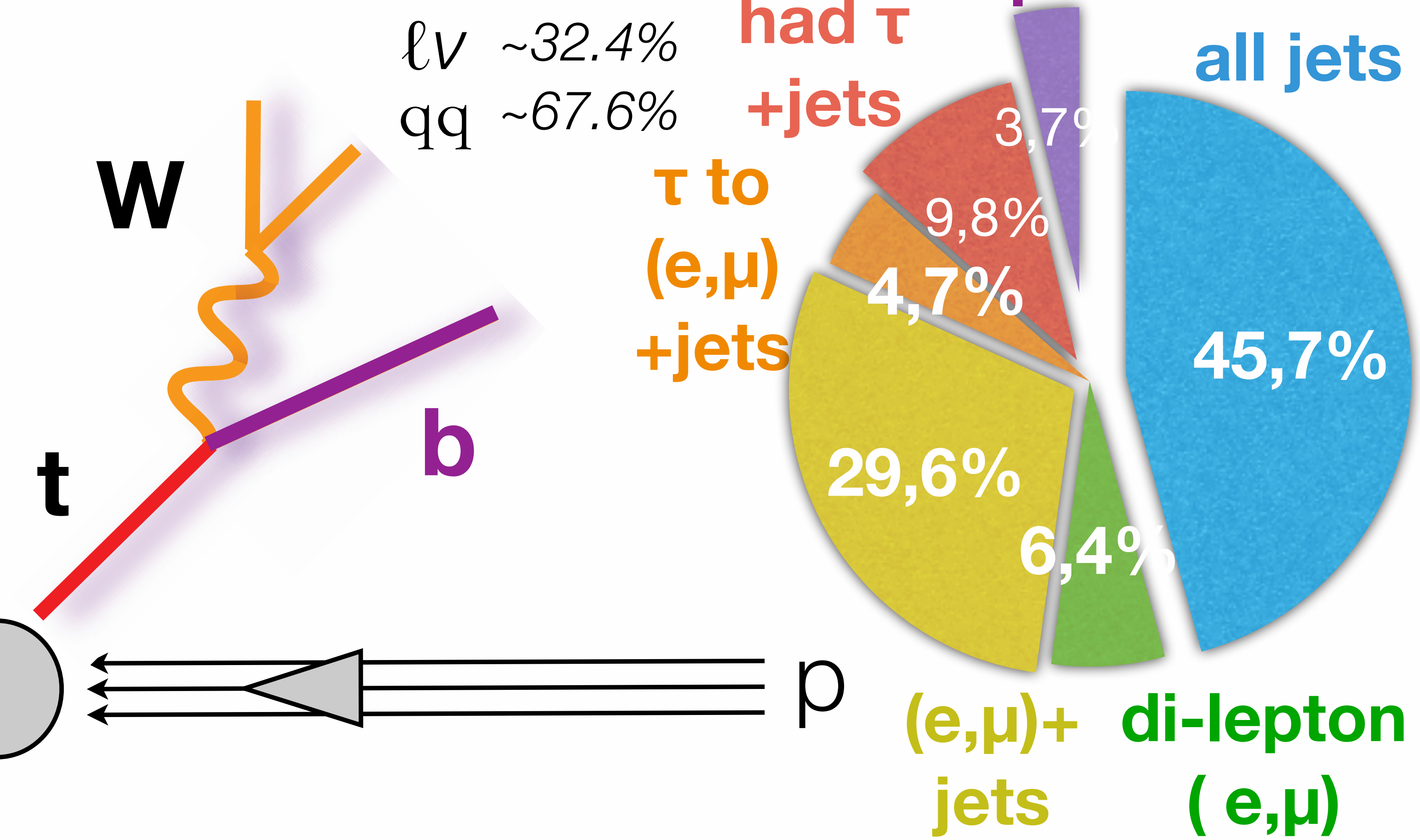
$\delta\sigma_t/\sigma_t$ ~2 to 7%

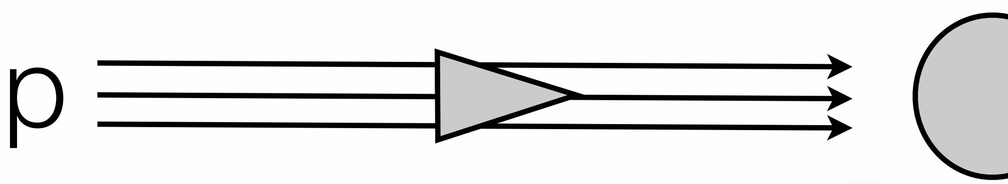
	t-chan	Wt chan	s-chan
σ_{7TeV} (pb)	64.6±2.4	15.7±1.1	4.6±0.2
σ_{8TeV} (pb)	87.8±3.4	22.4±1.5	5.6±0.2

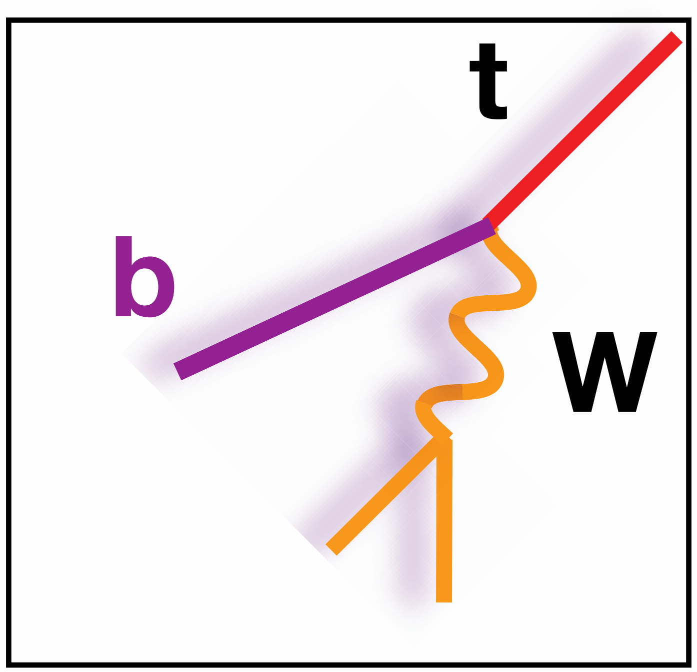
~2.5M (0.47 M) single top events produced by LHC in 2011 (2012)

Top quark decay: signatures

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

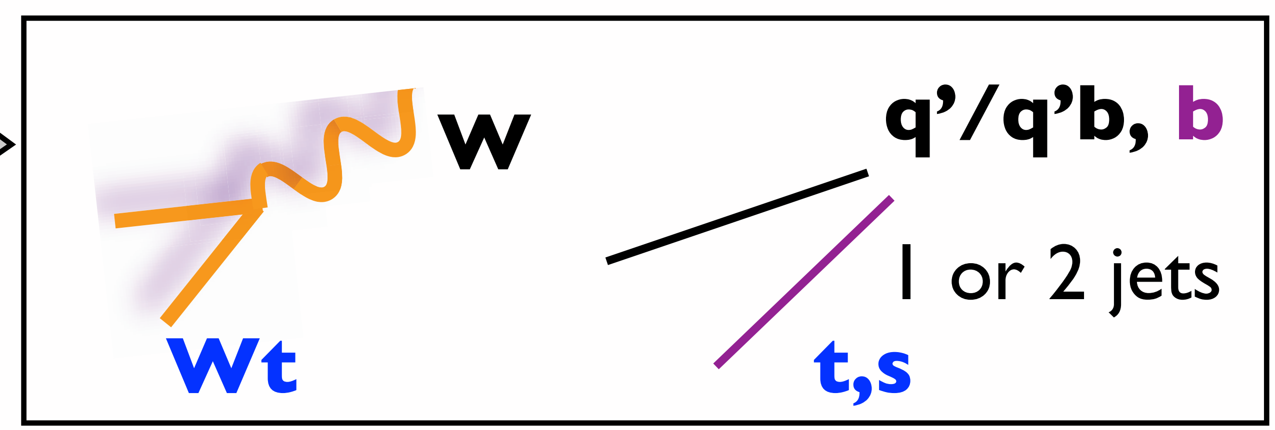






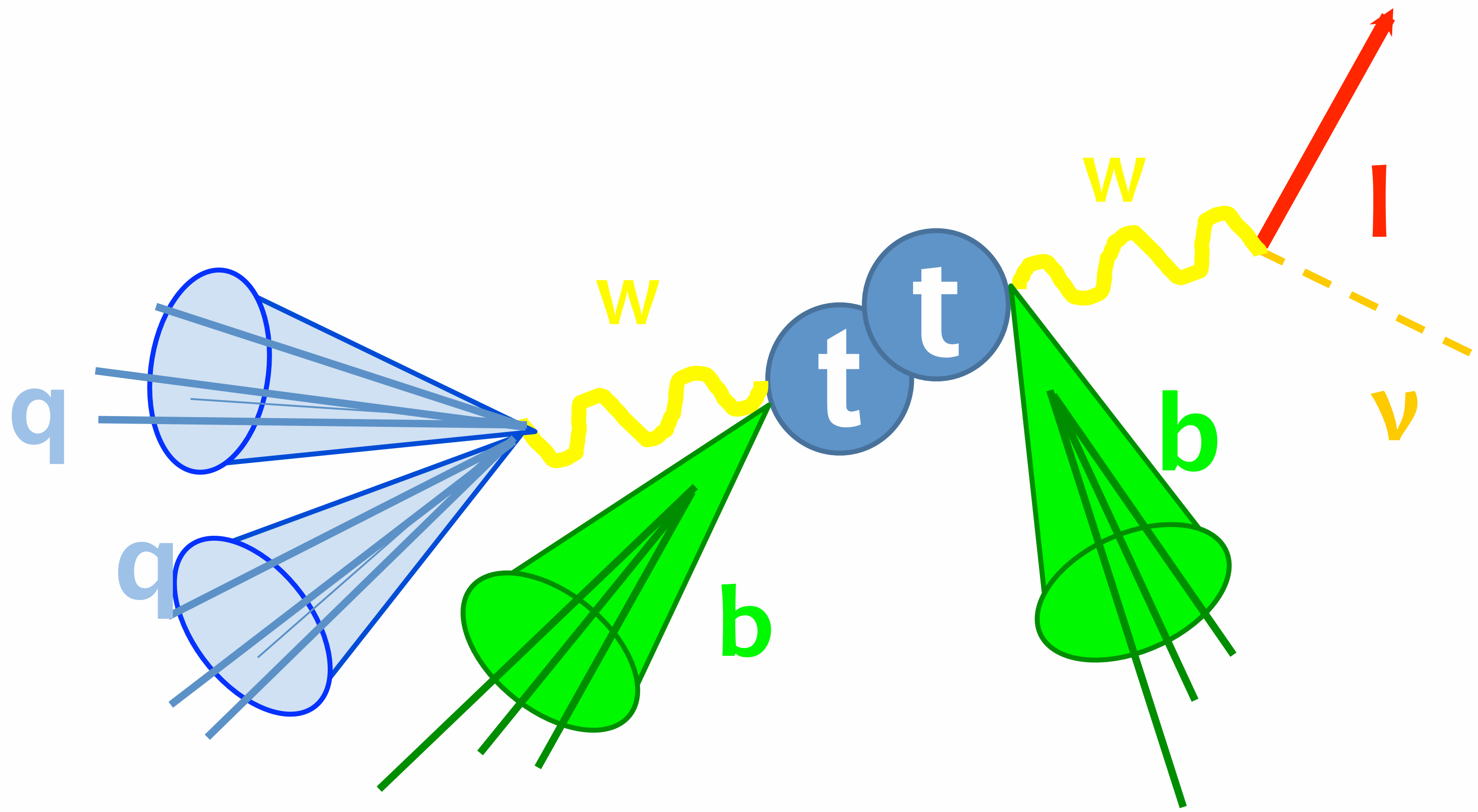
bkgs_tt̄: W/Z(+jets), single top,
QCD multi-jets, Di-bosons

single top



bkgs_single_t: tt̄ + same bkgs_tt̄

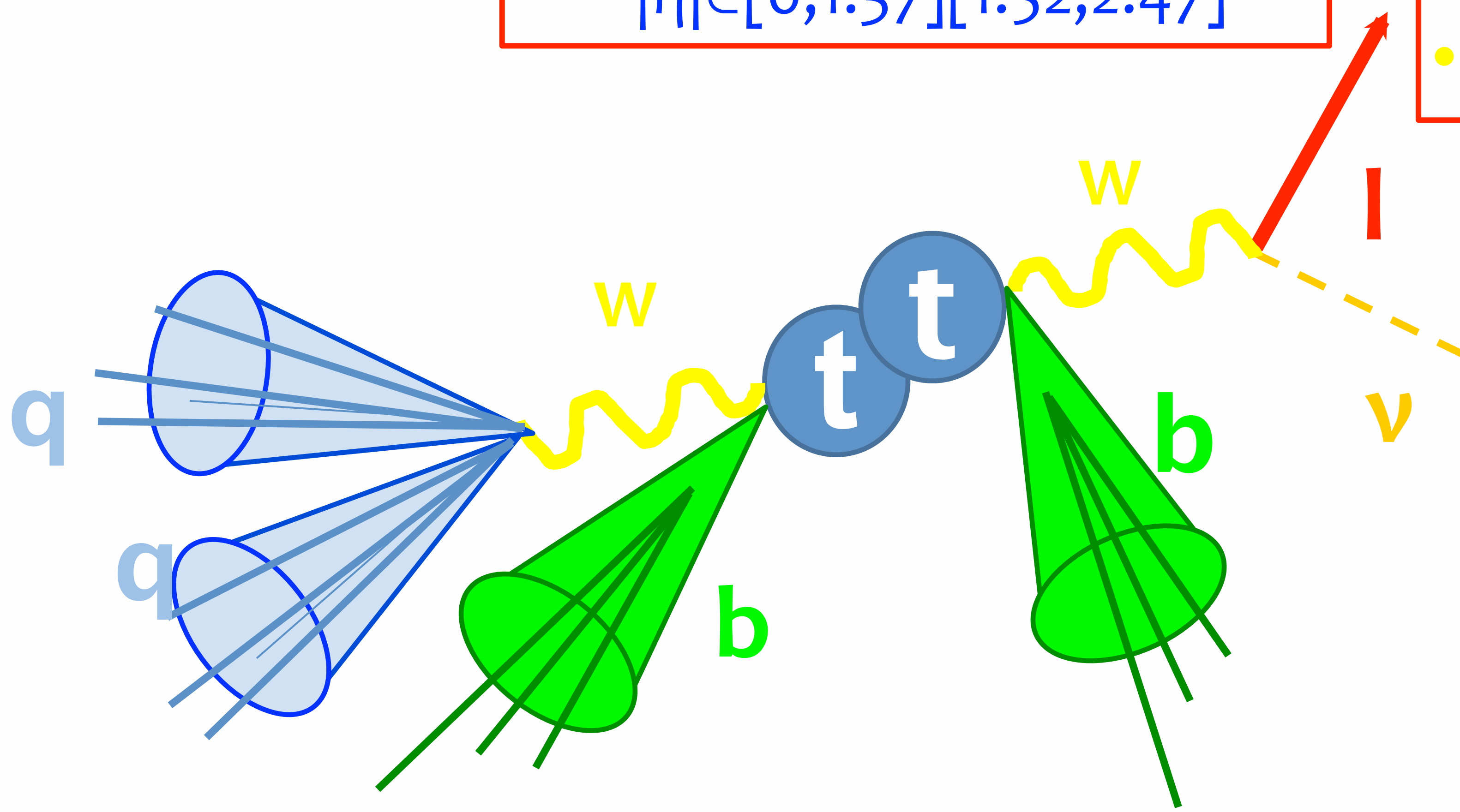
Selection/Ingredients for top quark pairs/single-top



Selection/Ingredients for top quark pairs/single-top

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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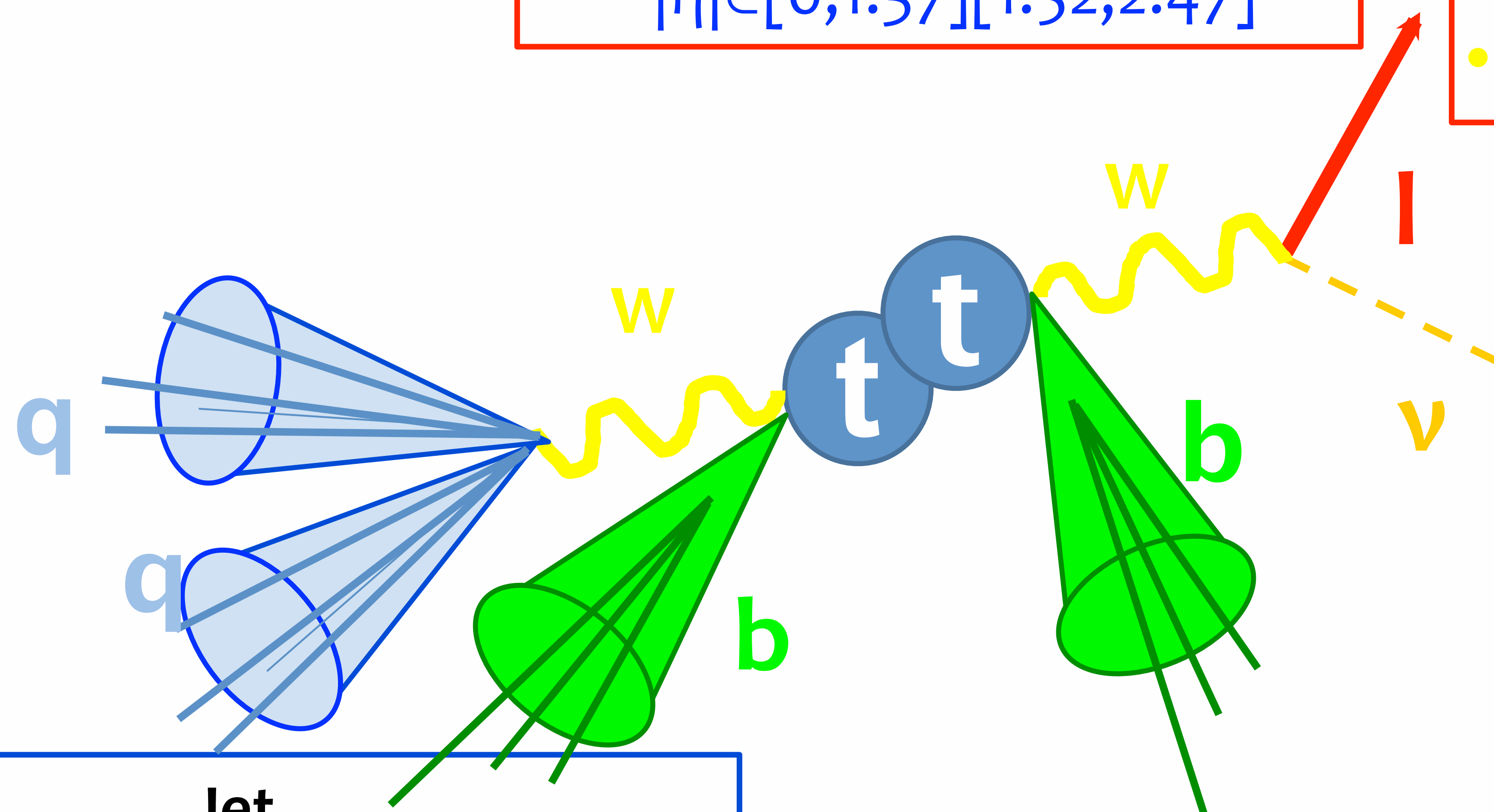

Jet
- Topological clusters, Anti-k_T (R=0.4), MC Calibration checked w/data
- $p_T > 25$ (20) GeV , $|\eta| < 2.5$
- (large JVF $=\sum_{\text{jet trk in PV}} p_T/\sum_{\text{jet trk}} p_T$ vs pile-up jets,)

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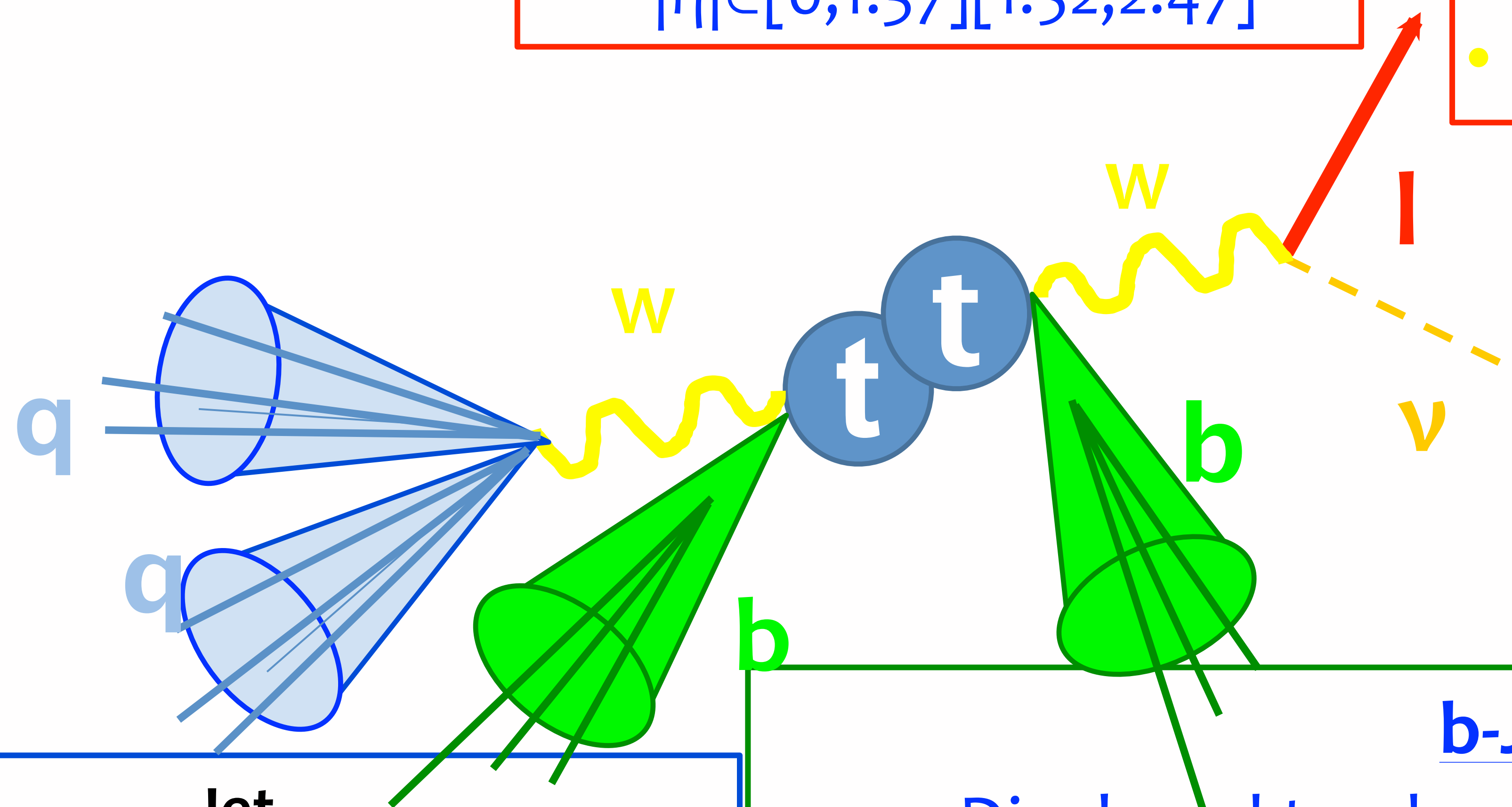

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b-Jet

- Displaced tracks or secondary lepton
- SV0: reconstruct sec.vertex
- JetProb: track/jet compatibility with prim. vertex
- MV1, IP3D+SV1 +/or JetFitter: lkl/NN taggers

Selection/Ingredients for top quark pairs/single-top

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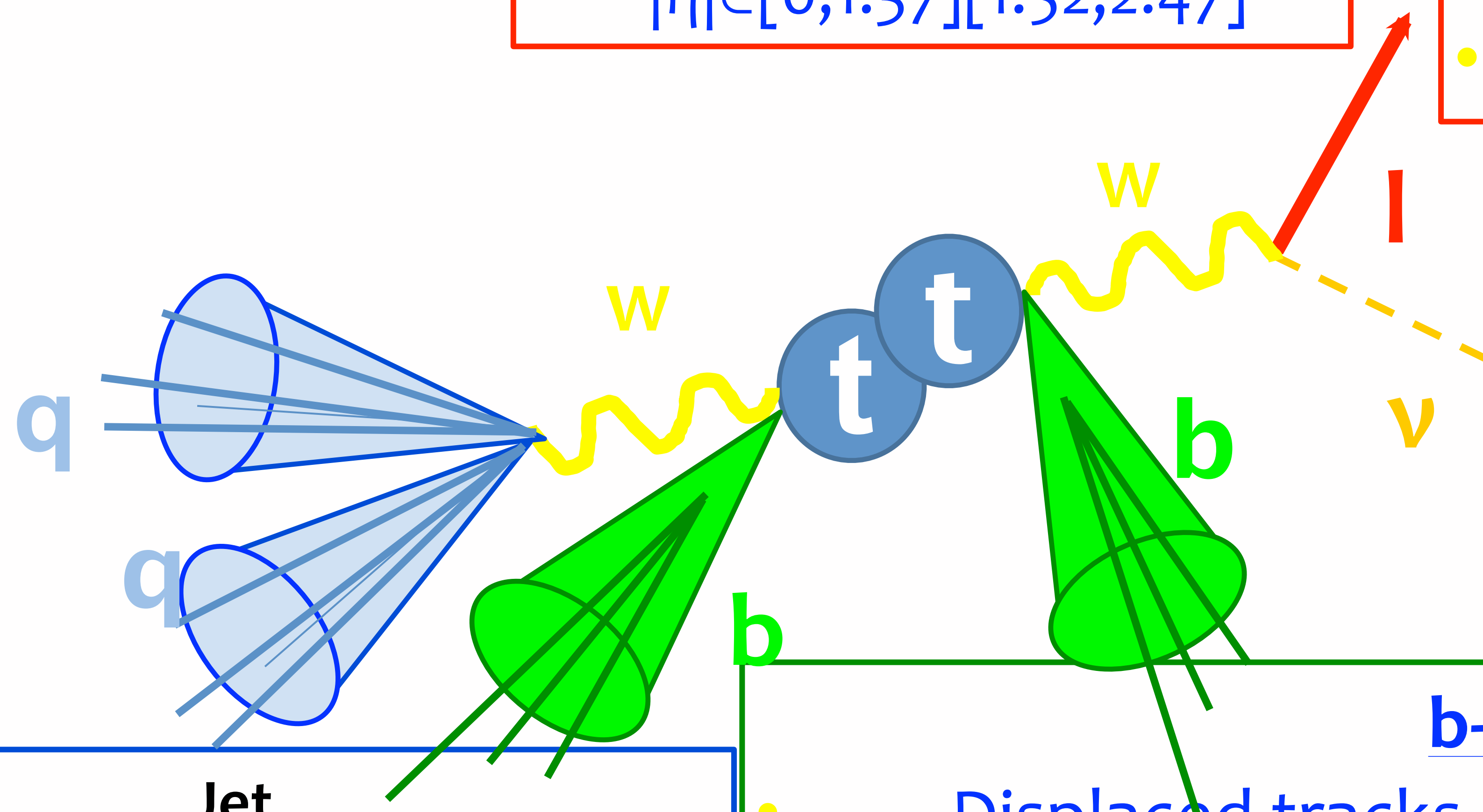

E_T^{miss}

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

Jet

- Topological clusters, Anti-k_T (R=0.4), MC Calibration checked w/data
- $p_T > 25$ (20) GeV , $|\eta| < 2.5$
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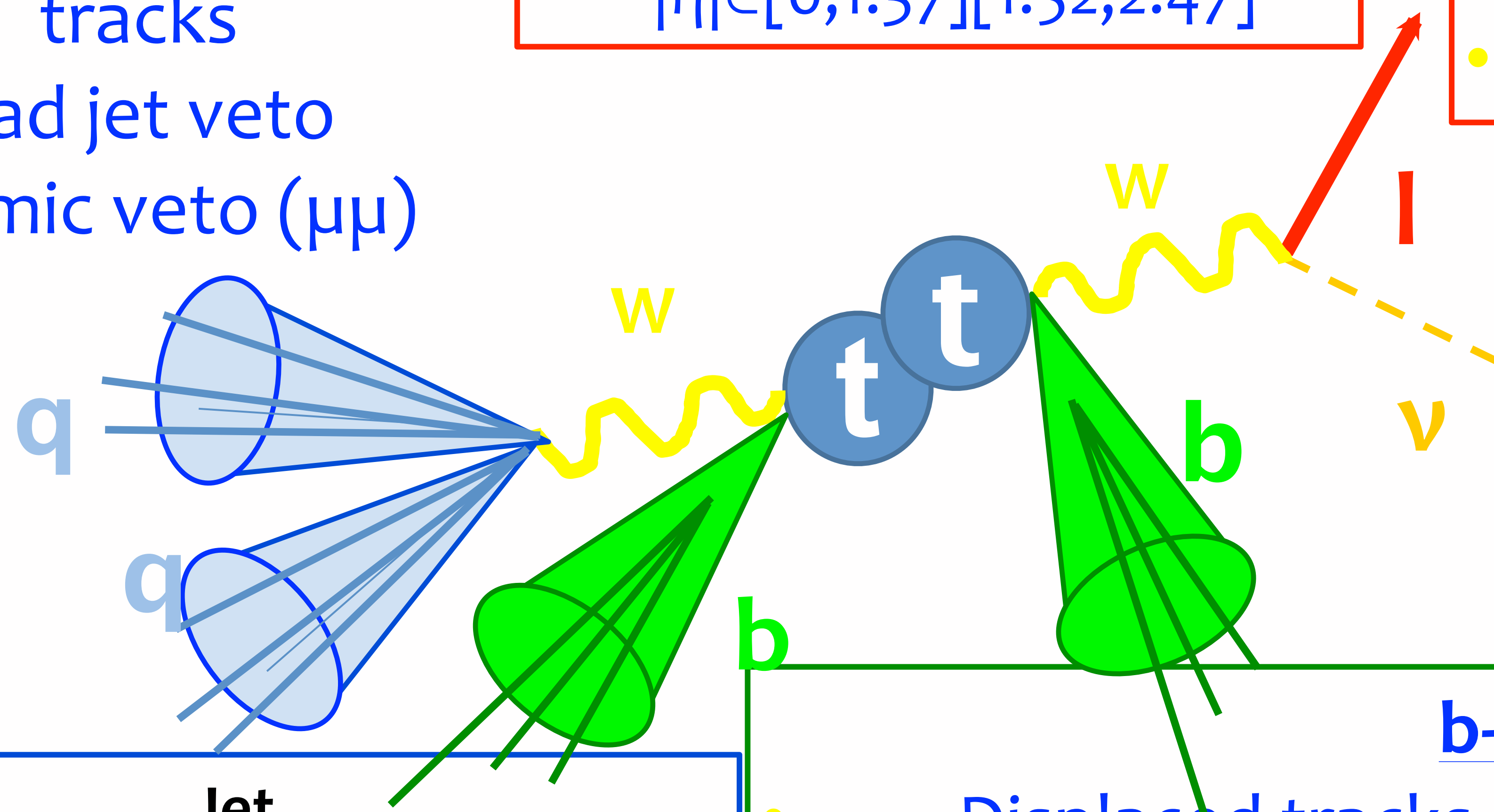
Selection/Ingredients for top quark pairs/single-top

Event cleaning
- Good run conditions
- Primary vertex (PV)with at least 5 tracks
- Bad jet veto
- Cosmic veto (μμ)

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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- Displaced tracks or secondary lepton
- SV0: reconstruct sec.vertex
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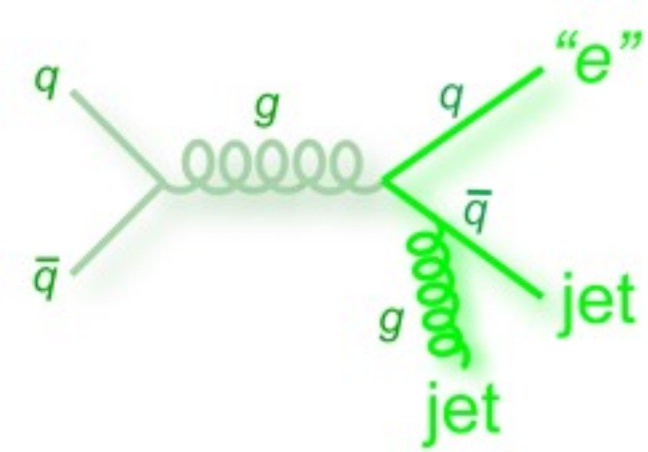
- MV1, IP3D+SV1 +/or JetFitter: lkl/NN taggers

Backgrounds estimates *(tt single lepton+jets, single top t,s-chan)*

- ***Fake leptons***



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

- *Matrix method* ***(J Boudreau, Top2012)***

$$N^{\text{loose}} = N^{\text{loose}}_{\text{real}} + N^{\text{loose}}_{\text{fake}},$$
$$N^{\text{std}} = r N^{\text{loose}}_{\text{real}} + f N^{\text{loose}}_{\text{fake}}$$

r is the marginal efficiency of standard cuts.
f is the same, for background sources

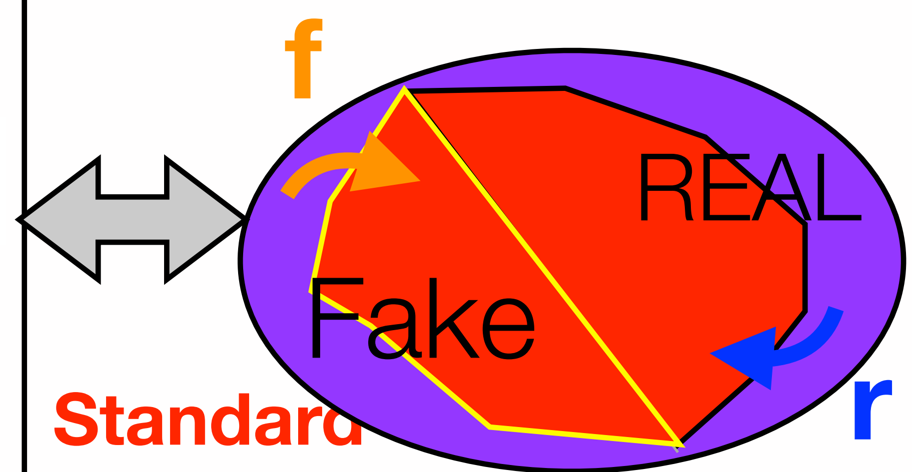
Both can be measured in pure or background event subtracted samples

- *Jet template*

Shape from jet triggered events with 1 high em. content jet.

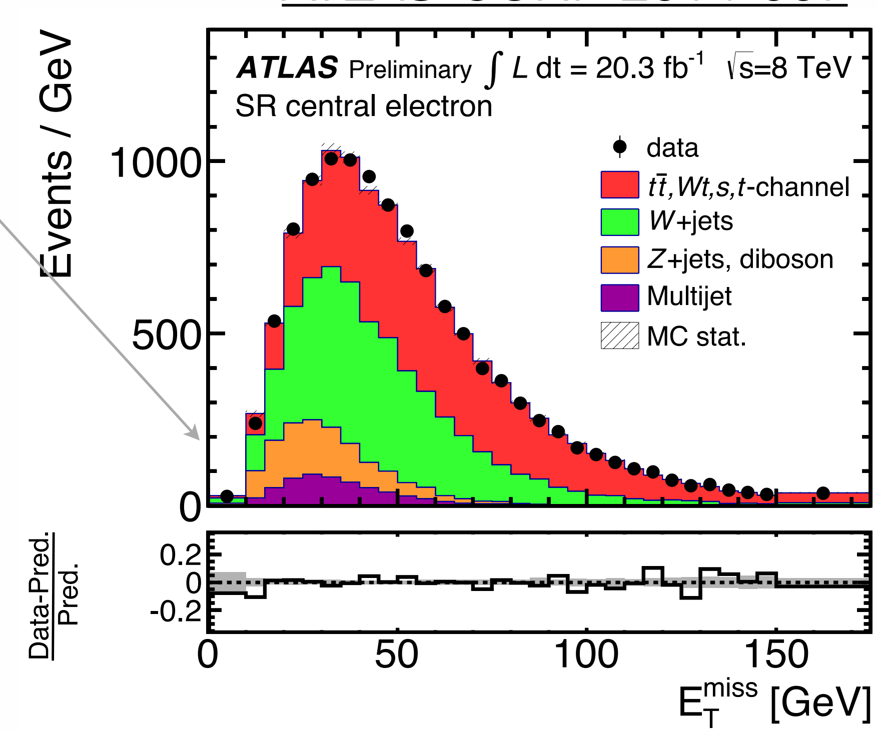
Normalize by fitting low E_T^{miss} shape to data and extrapolate

Loose selection=relax lepton isolation & identification

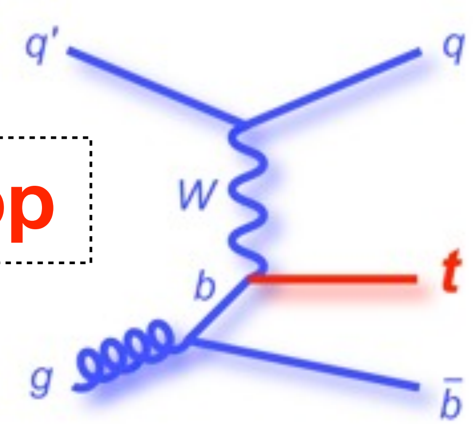


Standard selection

ATLAS-CONF-2014-007

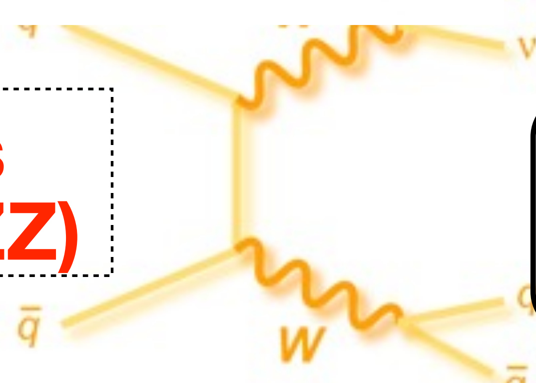


- **Single top**



Simulated shape+ rate set to approx NNLO

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



Simulated shape+ rate set to SM

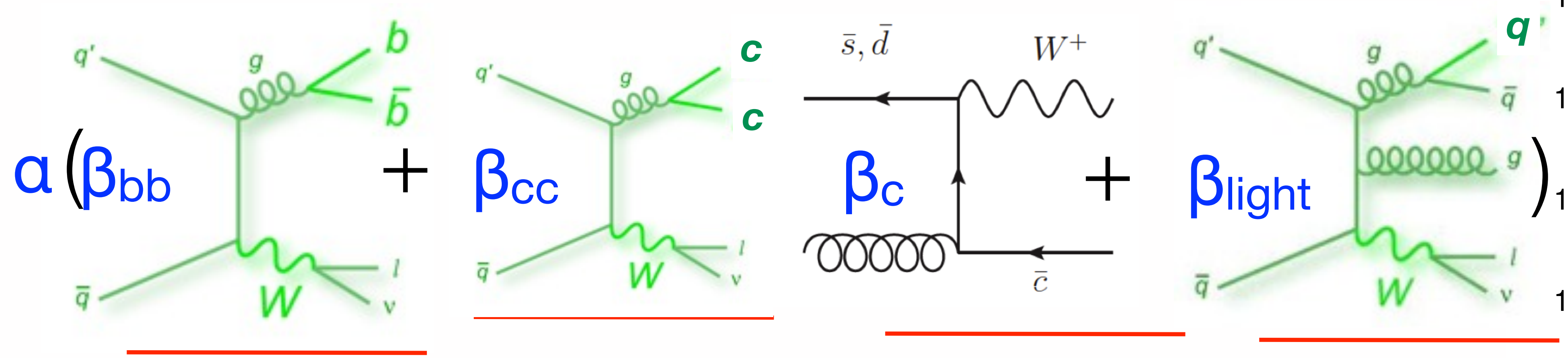
normalizations=fit parameters, estimates are starting points for fit

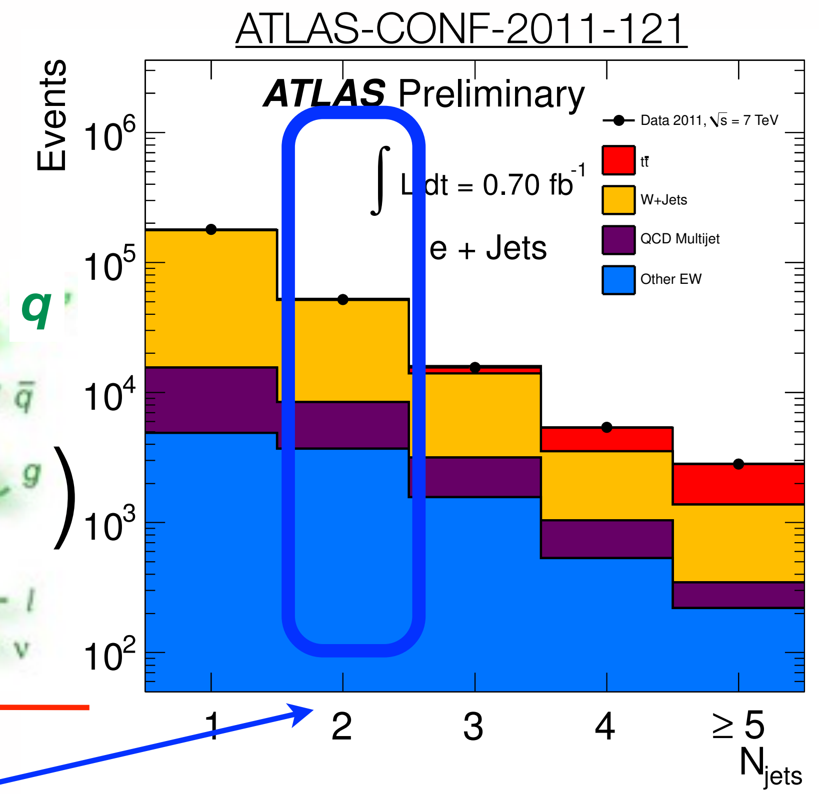
Backgrounds - single lepton+jets

- **W+jets**

simulated shapes

data-driven overall norm and flavour fractions





- Iterate: **use events with 1lep + large E_T^{miss} +2 jets to derive α and β_{xx} before b-tagging**
  1. *Derive α **as ratio of asymmetric production of W+ and W- is well known** (more u-quarks than d-quarks) in W+2jets events, no b-tag*

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

  2. *Derive β_{xx} from 3 equations using 2 data samples with positive and negative leptons in W+2 jet bin with standard sel & no b-tag + 1 normalization condition*
  3. *Derive α as in 1, but in r_{MC} use β_{xx} from step 2*

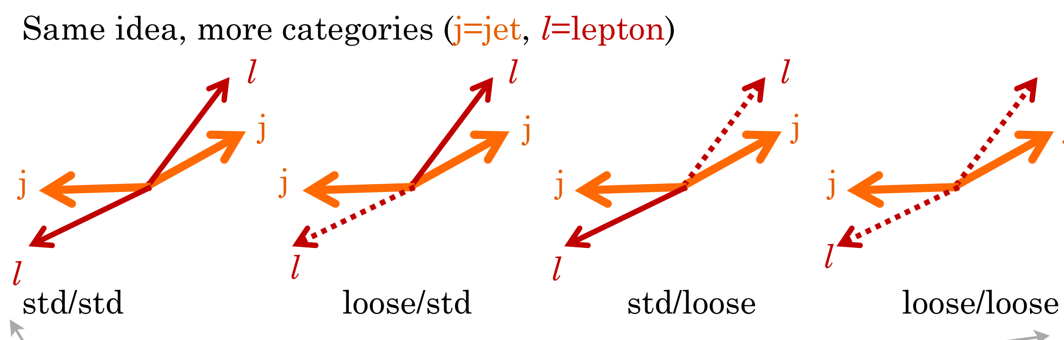
- Extrapolate shape and norm from 2 jets channel to **any jet multiplicity b-tagged** channel with

$$W^n_{\geq 1tag} = W^n_{pretag} \cdot f^{2j}_{tag} \cdot f^{2\to n}_{tag}$$

Backgrounds *(tt di-lepton, Wt single top)*

ATLAS-CONF-2011-100

- ***Fake leptons I** : generalize single lepton estimate*
  - Get **r** and **f** : **probability** for **loose** "fake" and real **leptons *to pass standard sel.*** ← **control samples** enriched with real (in Z window) or **"fake" (low E_T^{miss})** leptons
  - **Combine** with **N(di-lep)** for **all loose "fake" & real** pairs→**fake standard lepton content**



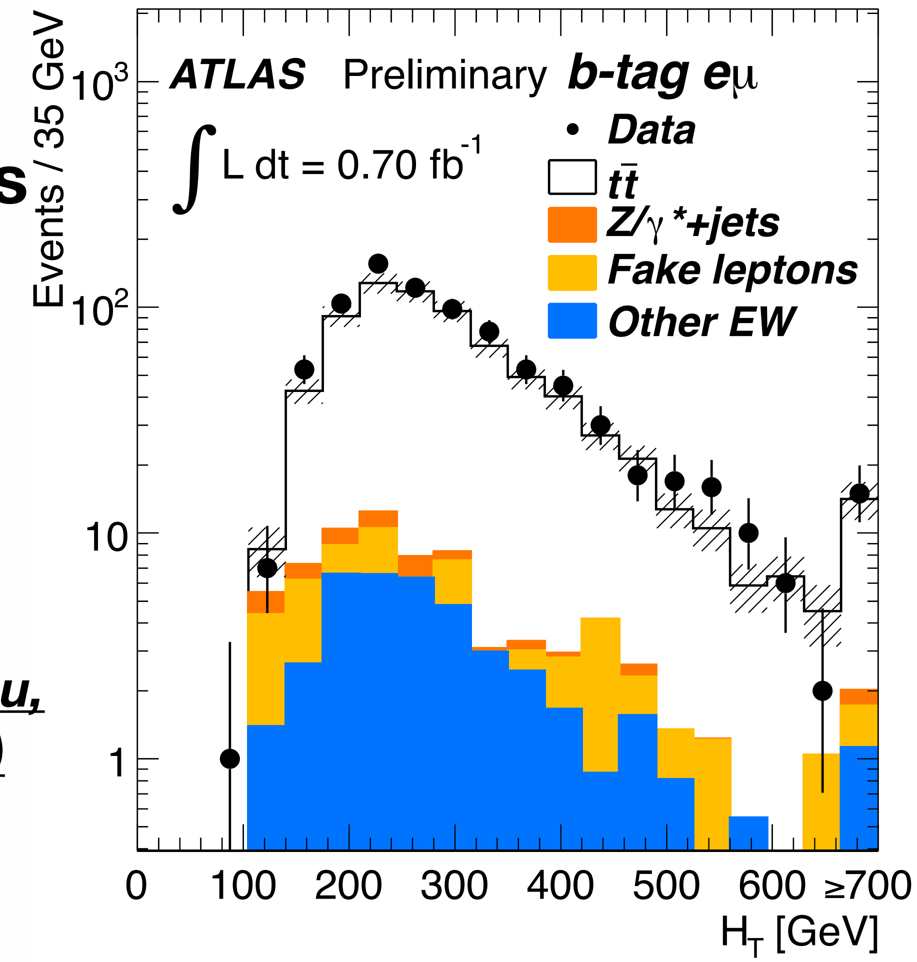
di-lep topologies

(J Boudreau, Top2012)

loose, standard

$$\begin{pmatrix} N^{l,l} \\ N^{l,s} \\ N^{s,l} \\ N^{s,s} \end{pmatrix} = \begin{pmatrix} 1 & 1 & 1 & 1 \\ r_2 & f_2 & r_2 & f_2 \\ r_1 & f_1 & r_1 & f_1 \\ r_1 r_2 & r_1 f_2 & f_1 r_2 & f_1 f_2 \end{pmatrix} \circ \begin{pmatrix} N^{l,l}_{r,r} \\ N^{l,l}_{r,f} \\ N^{l,l}_{f,r} \\ N^{l,l}_{f,f} \end{pmatrix}$$

real,fake in loose

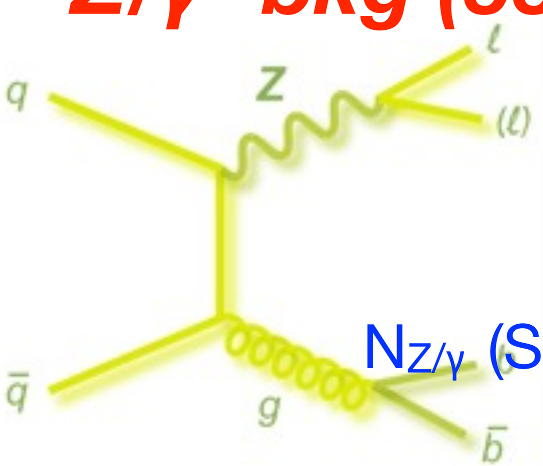


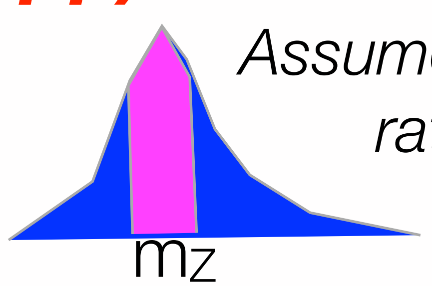
- ***Fake Leptons II***

Assume constant fake data/fakeMC in same sign/opposite sign

$N_{fakes}(OS) = [Data(SS) - NonSSBkg(SS)] * \dfrac{MC_{tt+W+jets+multijet}(OS)}{MC_{tt+W+jets+multijet}(SS)}$

- ***Z/γ* bkg (ee, μμ)***





Assume constant Z data/Z MC ratio in/out Z window

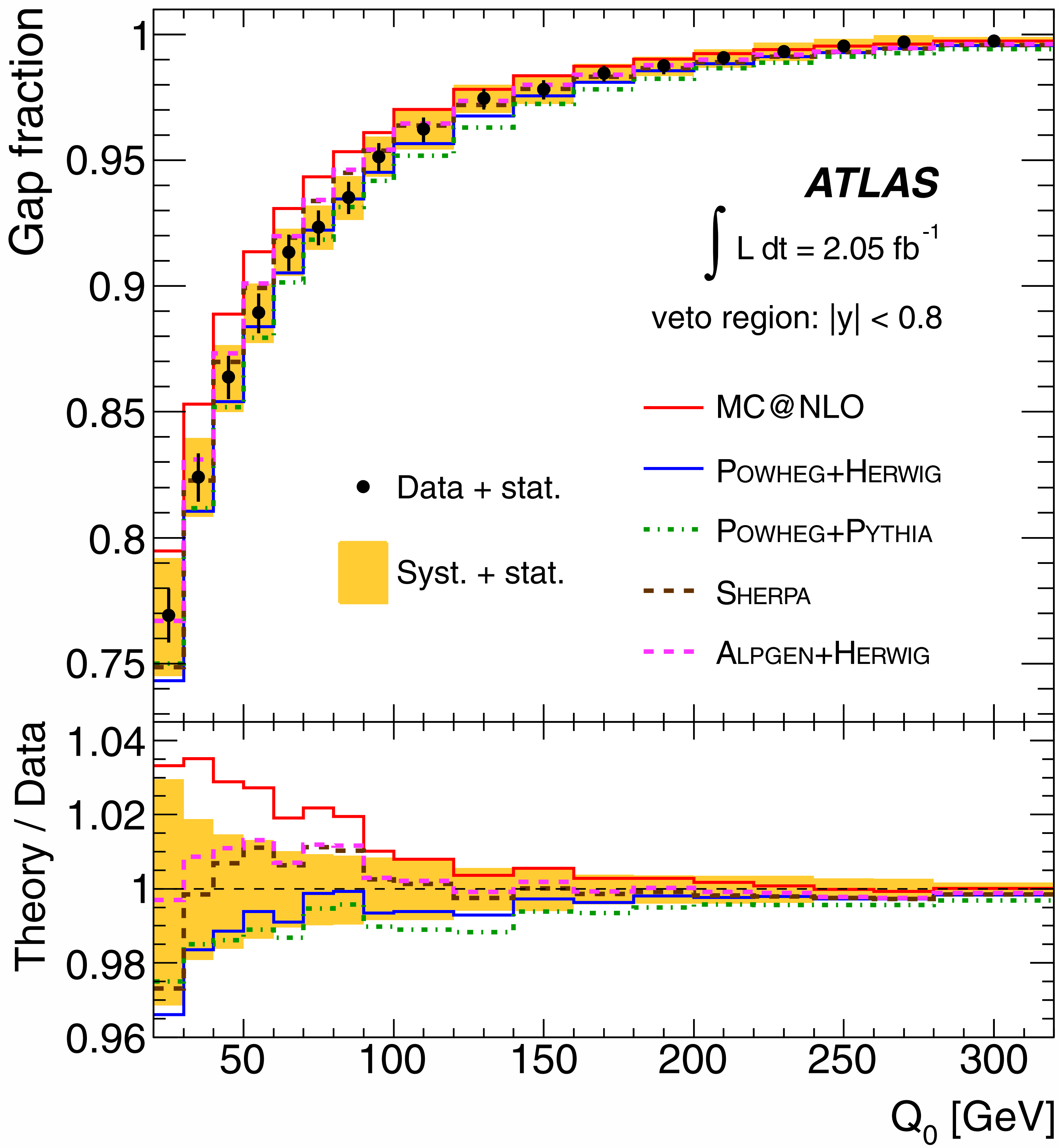
$N_{Z/\gamma}(SR) = [Data(CR) - NonZBkg(CR)] \dfrac{MC_{Z/\gamma}(SR)}{MC_{Z/\gamma}(CR)}$

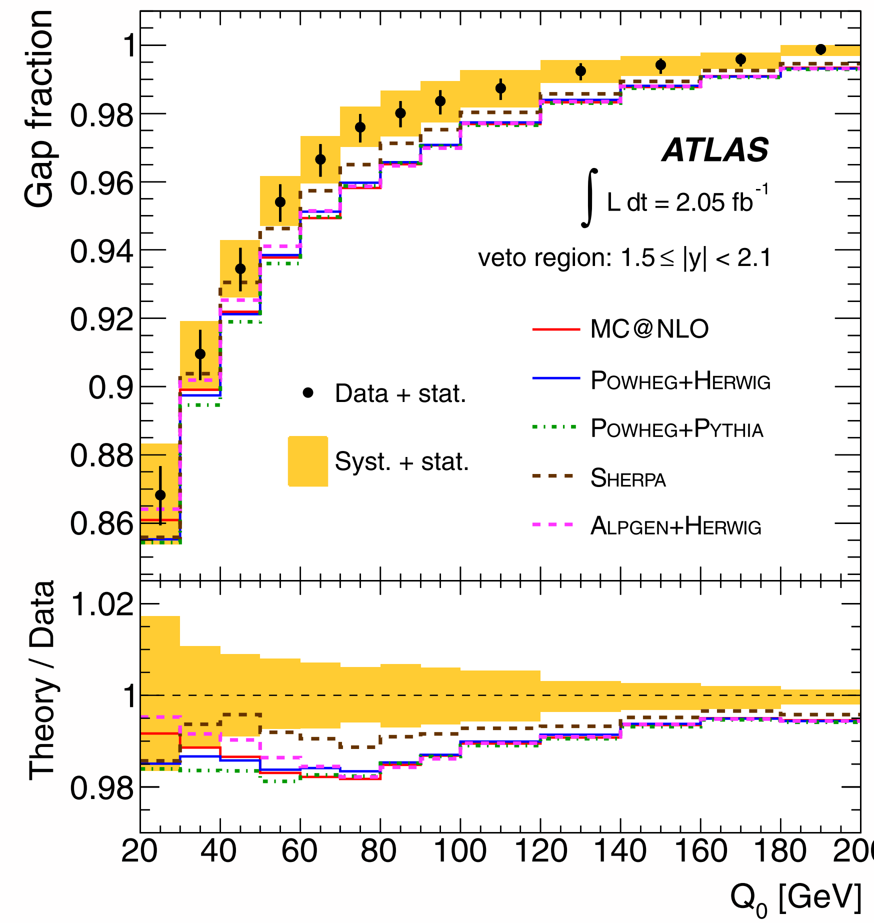
CR (SR)=in (out of) Z mass window

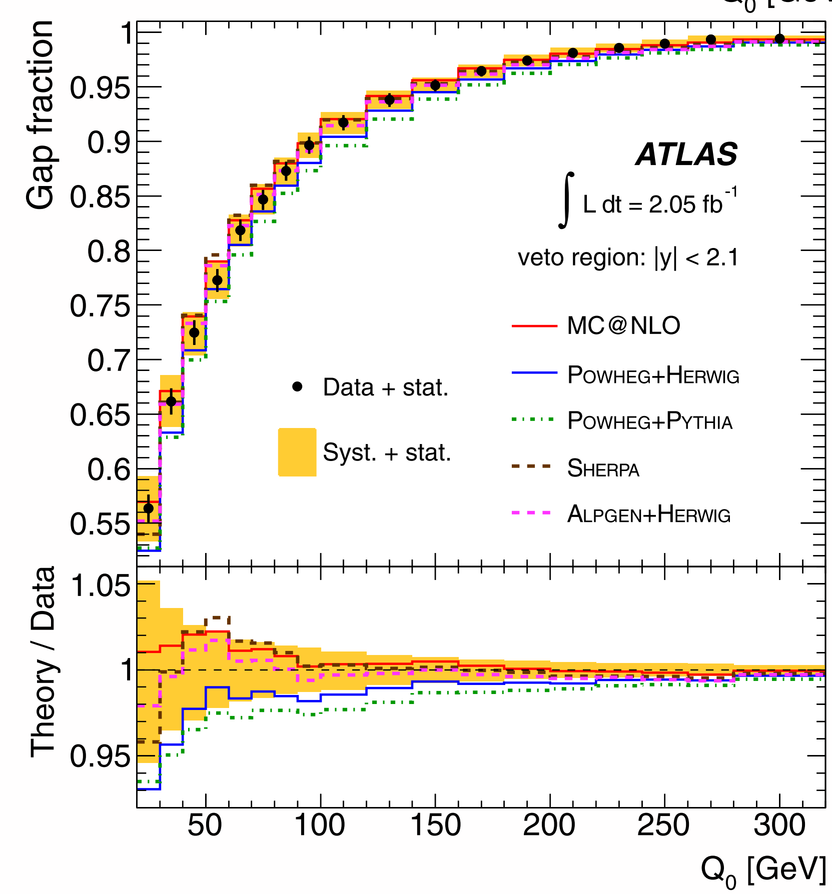
Differential *Jet activity* : dilepton √s = 7 TeV $\int L dt =$ **2.05 fb^{-1}** *(2011)*

Eur. Phys. J. C72 (2012) 2043

- **MC@NLO: too little jet activity in |y|<0.8**







Differential $d\sigma_{tt}/dN_{jets}$ and $d\sigma_{tt}/dp_{T,jets}$ - l+jets $\sqrt{s}$ = 7 TeV NEW!

Provide table of full breakdown of uncertainties for both results

http://arxiv.org/abs/1407.0891, submitted to JHEP

$d\sigma_{tt}/dN_{jets}$

- ***Systematic dominated: ~10% to ~30%***
  - ***Correlated*** *effects* ***dominant at large*** N_{jets} ***(JES****~3% to 40%* ***ISR/FSR****: 1 to 6%, MC gen.,b-jet)*
  - ***Uncorrelated*** *effects* ***dominant at low*** N_{jets} *(Bkg 3% to 18%)*
  - ***Combination improves*** *by 3% (20%) on* ***μ****(****e****) chan (smaller fake lep. bkg in* ***μ*** *events)*

$d\sigma_{tt}/dp_{T,jets}$

- ***Systematic dominated: lead p_T jet ~7-14%, others~ up to17%***
  - ***μ*** *En. scale & ID eff.: smaller than* ***e*** *→ 20% smaller uncertainty* $d\sigma_{tt}/dp_{T,jets}$ *in* ***μ*** *chan*
  - ***b-jet scale:*** *2 to 5%,b-tag eff. 2 to7%,W +jets bkg~2% to 8% Stat1.5% to 14%*
  - ***Combination improves*** *by 4-7% (15-30%) on the* ***μ*** *(****e****) channel*

example for $d\sigma_{tt}/dN_{jets}$

$\frac{d\sigma}{dn_{\text{jets}}}$ [%] / n_{jets}	3	4	5	≥ 6
MC statistics	0.8	1.2	2.8	5.9
PDF	0.6	2.1	0.8	0.8
MC generator	1.1	0.7	0.5	4.4
Fragmentation	1.2	1.1	0.4	4.1
ISR/FSR	4.9	5.3	7.4	14.6
Colour reconnection	0.4	1.4	4.2	3.1
ℓ resolution & efficiency	0.3	0.4	0.3	0.5
$E_{\text{T}}^{\text{miss}}$ cell-out	0.1	0.3	0.3	0.4
b-quark tagging efficiency	4.3	4.3	4.3	5.1
Additional interactions	0.1	0.2	0.3	0.6
Jet reconstruction efficiency	0.0	0.0	0.0	0.2
Jet energy resolution	0.1	0.9	3.0	0.8
b-quark jets (JES)	2.9	3.5	3.0	4.5
Close by jets (JES)	3.0	6.0	7.4	10.5
Effective detector NP set 1 (JES)	1.9	3.1	3.5	5.1
Effective detector NP set 2 (JES)	0.1	0.2	0.3	0.4
Effective mixed NP set 1 (JES)	0.1	0.2	0.4	0.4
Effective mixed NP set 2 (JES)	0.2	0.3	0.4	0.7
Effective model NP set 1 (JES)	1.2	1.8	2.0	4.0
Effective model NP set 2 (JES)	0.5	0.8	1.0	1.5
Effective model NP set 3 (JES)	0.7	1.0	1.3	1.8
Effective model NP set 4 (JES)	0.1	0.2	0.3	0.4
Effective stat. NP set 1 (JES)	0.2	0.4	0.4	1.1
Effective stat. NP set 2 (JES)	0.2	0.2	0.4	0.7
Effective stat. NP set 3 (JES)	0.5	0.7	0.9	1.5
η-intercalibration (JES)	2.0	3.2	4.4	5.9
η-intercalibration statistics (JES)	0.4	0.6	0.7	1.3
Flavour composition (JES)	0.8	1.4	1.8	1.7
Flavour response (JES)	0.4	2.4	3.7	2.7
Additional interactions μ (JES)	0.1	0.3	0.4	1.8
Additional interactions N_{PV} (JES)	0.2	0.3	0.7	1.0
Relative non-closure (JES)	0.3	0.5	0.8	1.1
Single particle high-p_{T} (JES)	0.0	0.0	0.0	0.0
Jet vertex fraction efficiency	0.1	0.7	0.6	1.0
W+jets normalisation	2.3	1.2	0.3	0.3
W+jets heavy/light flavour	3.0	1.3	0.0	0.0
Multijet normalisation	0.4	0.6	0.4	0.1
Multijet shape	0.2	0.3	0.2	0.4
Small backgrounds	3.0	3.4	2.6	4.0
Luminosity	1.8	1.8	1.8	1.8
Statistical uncertainty	1.8	2.8	6.3	14.5
Total uncertainty	10.2	12.9	16.8	28.0
Cross-section [pb]	1.99e+00	4.95e-01	1.04e-01	1.72e-02

Jet Veto Measurement

arXiv:1203.5015

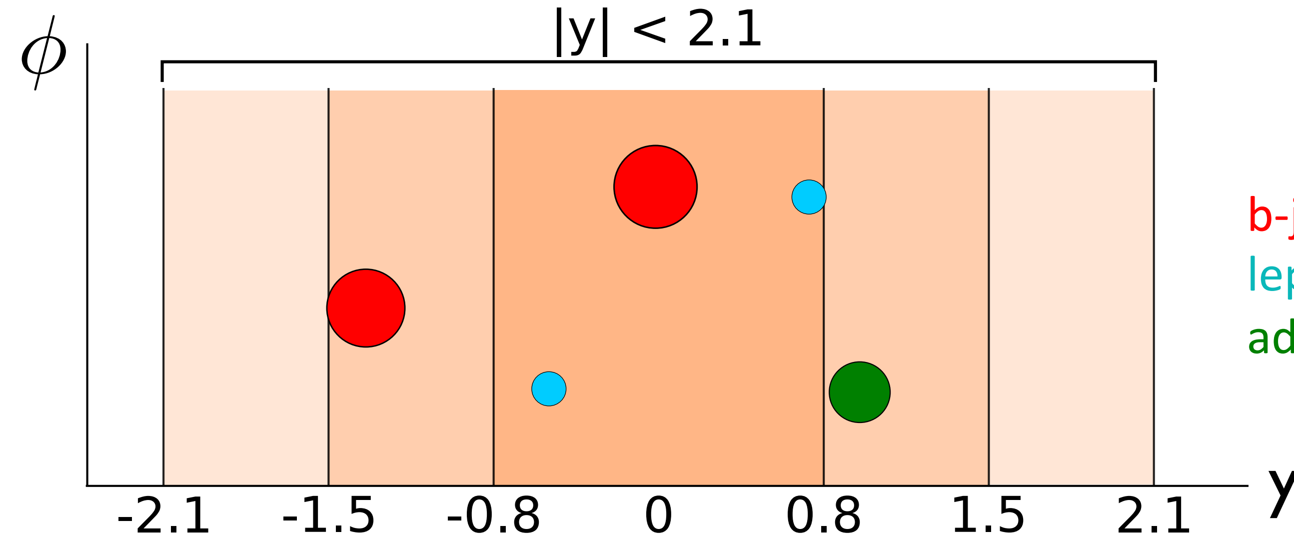
- Study the fraction of ttbar events that do not contain an additional jet, in a central rapidity region, with $p_T > Q_0$:

$$f_{\rm gap}(Q_0) = \frac{n_{\rm gap}(Q_0)}{N_{t\bar{t}}}$$

- Alternatively, we can take the sum of the p_T of the jets falling into each rapidity region and define:

$$f_{\rm gap}(Q_{\rm sum}) = \frac{n_{\rm gap}(Q_{\rm sum})}{N_{t\bar{t}}}$$

- Use dilepton events with two reconstructed b-jets to easily identify the additional jet(s).



- Four rapidity regions: |y| < 0.8   0.8 ≤ |y| < 1.5   1.5 ≤ |y| < 2.1 |y| < 2.1

- Measurement is corrected for detector effects and presented in a well defined fiducial region.

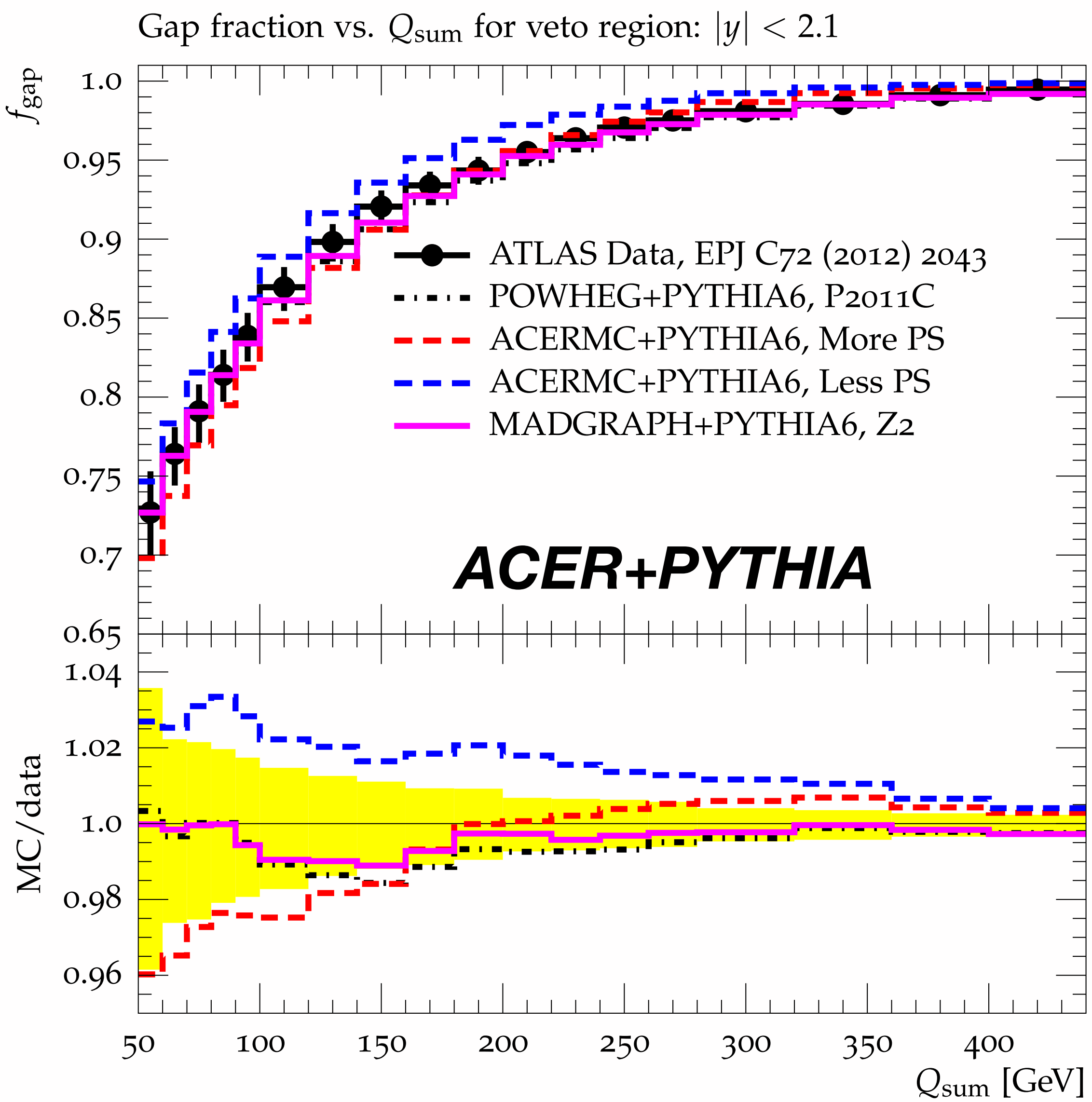
M.Owen, TopLHCWG Meeting 29th Nov 2012

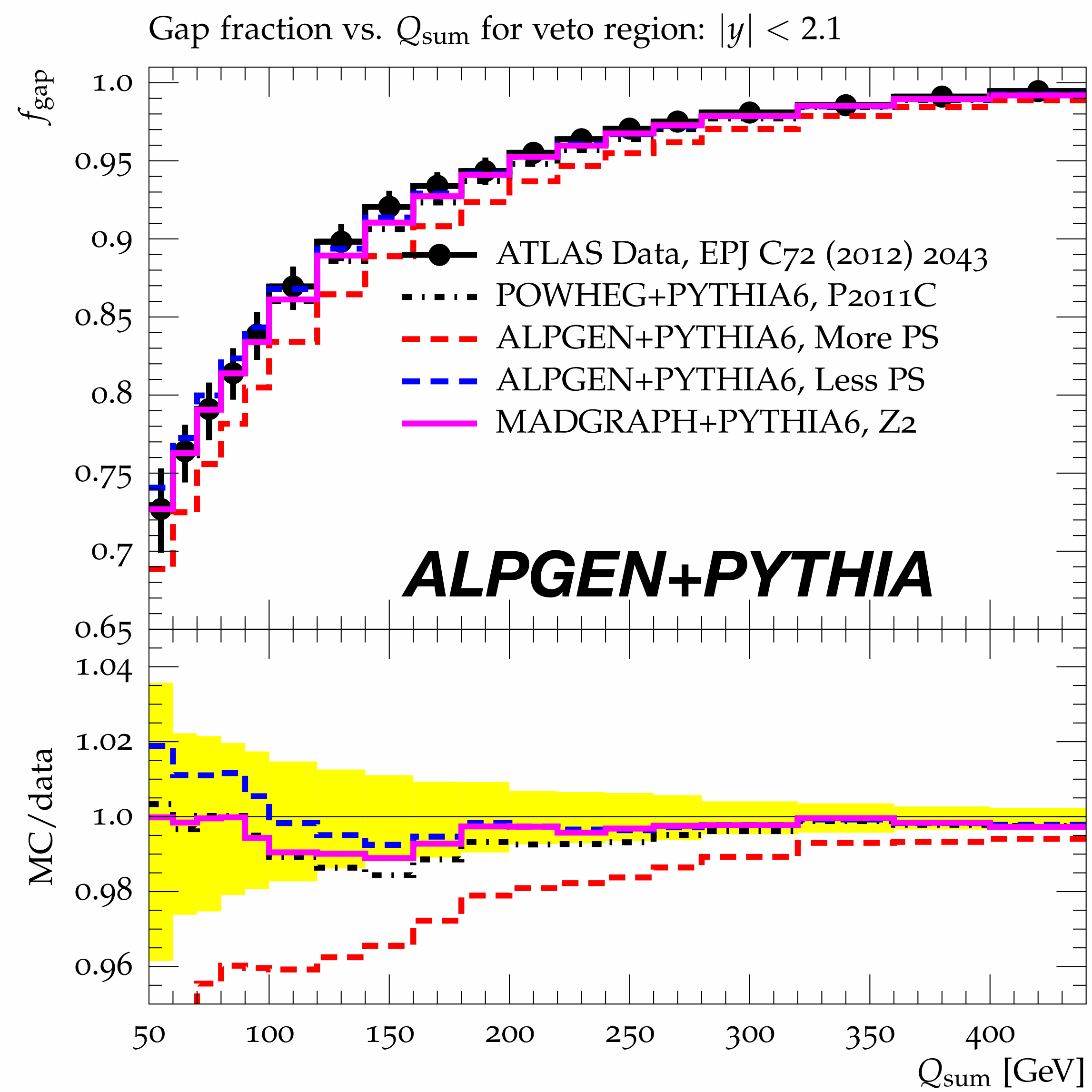
Differential *Jet activity* : dilepton √s = 7 TeV

ATL-PHYS-PUB-2013-005

ATL-PHYS-PUB-2014-005

- Compare different radiation scenarios for gap fraction measurements → tune models, constrain systematic uncertainties



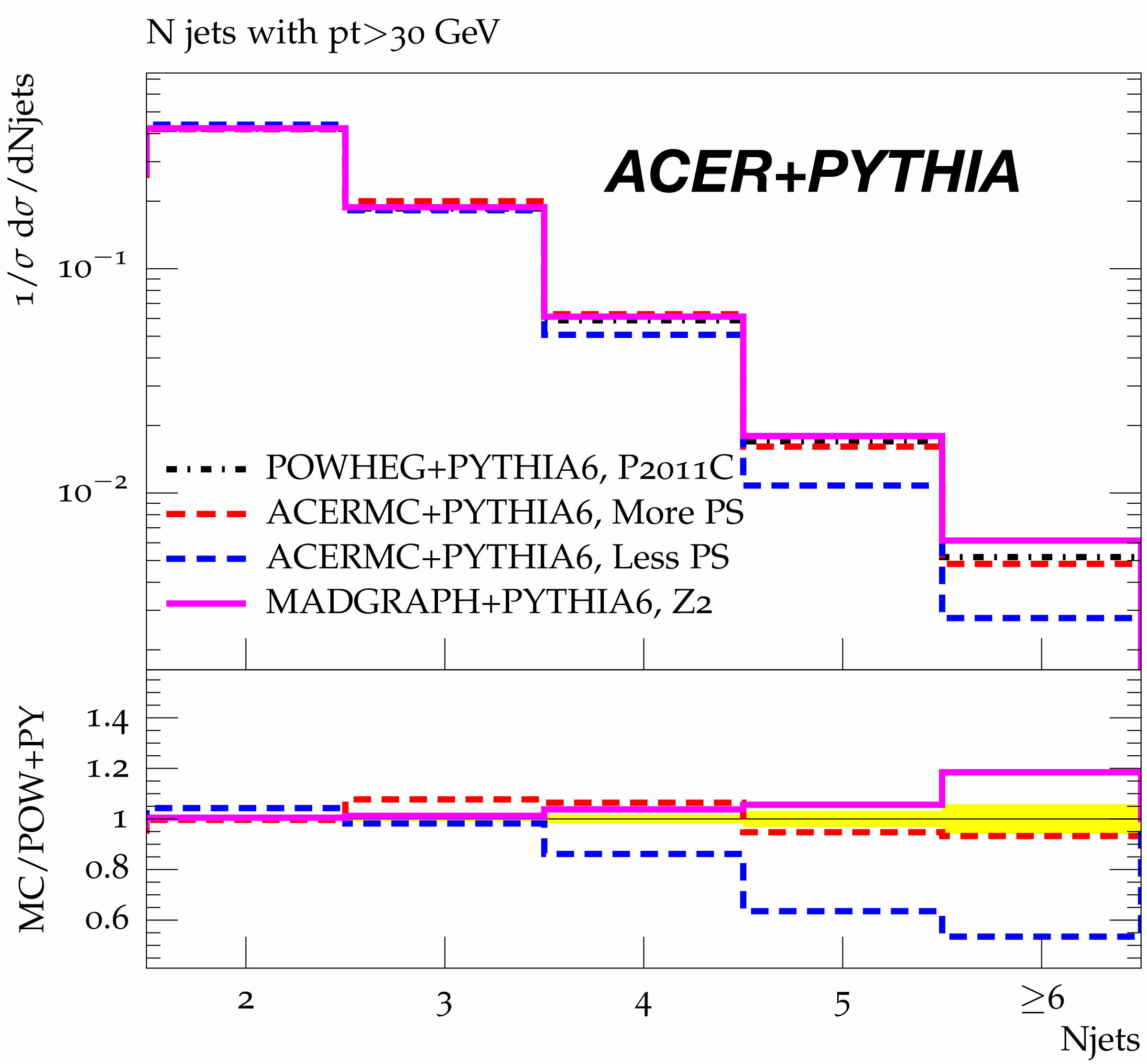


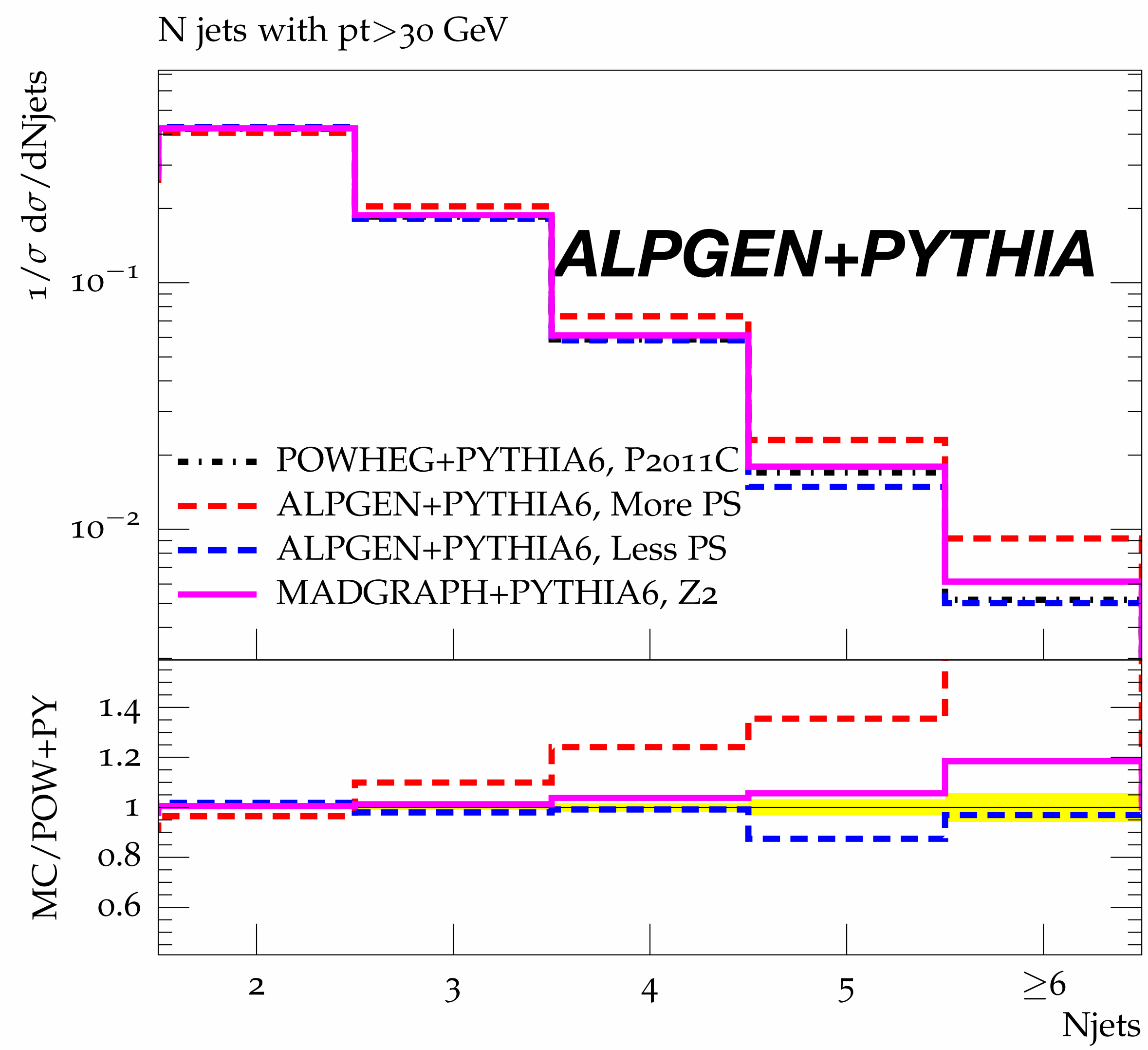
- Comparable differences between
  - (ACER+PYTHIA and ALPGEN+PYTHIA) x (more PS or less PS)
  - larger at high Q, Q_{sum}, large N_{jets}

Differential *Jet activity* : dilepton √s = 7 TeV

ATL-PHYS-PUB-2013-005
ATL-PHYS-PUB-2014-005

- Compare different radiation scenarios for gap fraction measurements → tune models, constrain systematic uncertainties

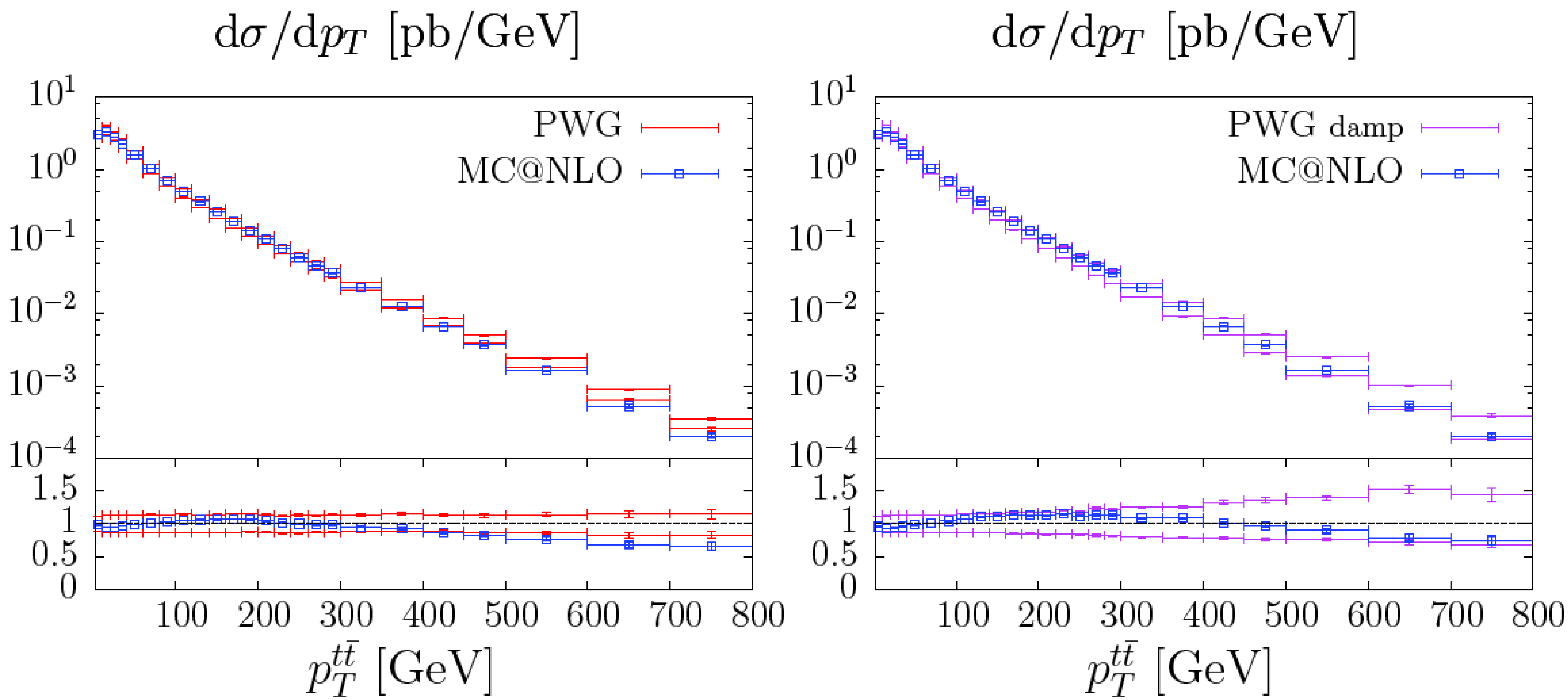




- Comparable more PS - less PS differences between
  - ACER+PYTHIA (updated after $f_{gap}(Q)$ measurement) and ALPGEN+PYTHIA
  - larger at high Q, Q_{sum}, large N_{jets}

POWHEG and hdamp

- **K. Hamilton, Top2012** http://indico.cern.ch/event/180665:
  Theory perspective on top quark signal modeling uncertainties, **parton level study**

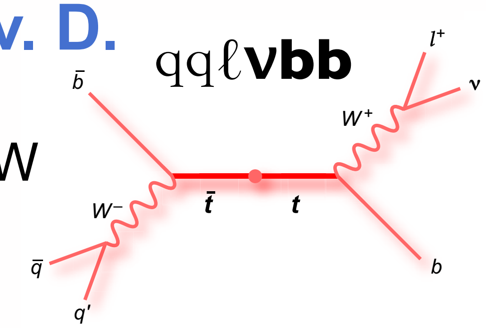


- POWHEG needs damping switched on or else scale dependence underestimated at high-p_T
- damping = p_T-dependent effect on hardest emission in POWHEG, still NLO accurate
- need to turn on damping = POWHEG-specific, no need to do it in MC@NLO

Differential $d\sigma_{t\bar{t}}/dX$: l+jets $\sqrt{s}$ = 7 TeV

$\int L dt$ = **4.7 fb^{-1}** *(2011)* ***NEW!***

arXiv:1407.0371 Submitted to Phys. Rev. D.

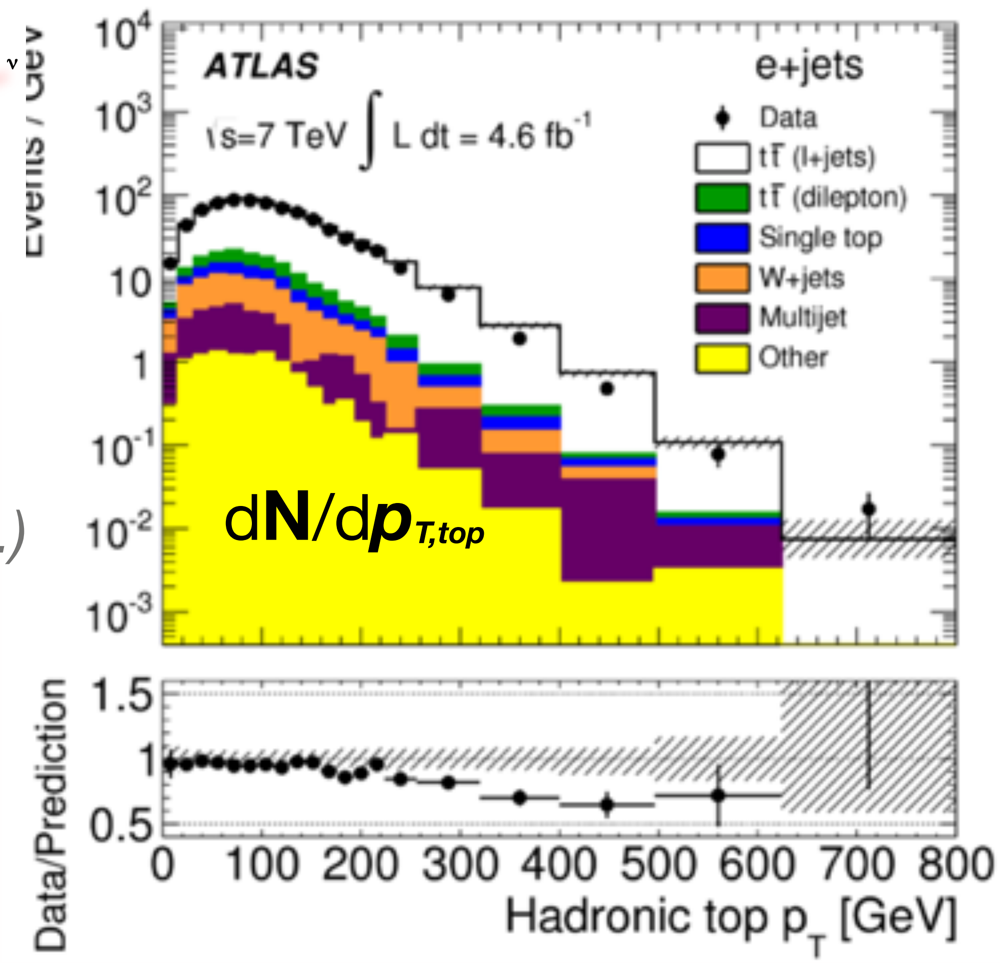


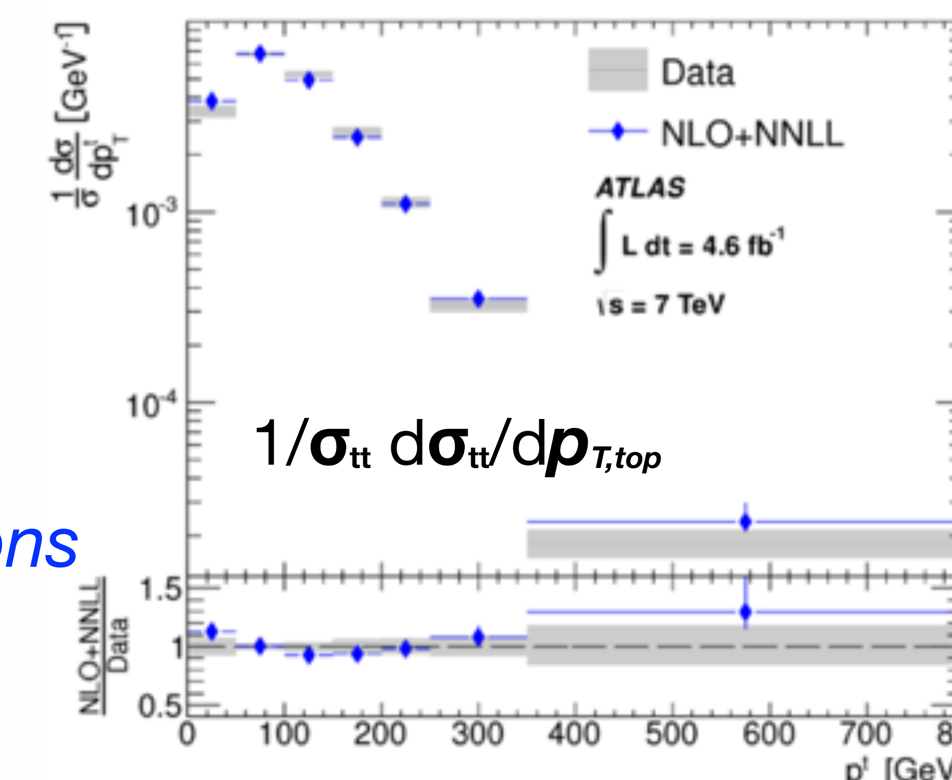
- 1 isol. (e,μ), symmetric E_T and m_T^W cuts, **≥ 4 central jets,** ≥1 b-tag
- **Data-driven W+jets** *(normalize pre-tag with W⁺/W⁻ asymmetry, extrapol. b-tag prob from 2-jet-bin)* **fake lep.** *(loose/tight matrix method),* ***single top, dibosons*** *(from sim.)*
- **Reconstruct $t\bar{t}$ with kinematic likel. fit** *(m_t,m_W constraint)* → cut on quality of kine fit
- **Unfold $d(N-N_{bkg})/dX$ to full phase space** *(regularized unfolding, linearity tests),* scale with L and $\sigma_{t\bar{t}}$ → $1/\sigma_{t\bar{t}}\ d\sigma_{t\bar{t}}/d$**X**

$$\frac{d\sigma}{dX_j} \equiv \frac{1}{\Delta X_j} \cdot \frac{\sum_i \mathcal{M}_{ji}^{-1}[D_i - B_i]}{\mathrm{BR} \cdot \mathcal{L} \cdot \epsilon_j}$$

X= $p_{T,top}$, $m_{t\bar{t}}$, $|y|_{t\bar{t}}$, $p_{T,t\bar{t}}$

- **Combine (e,μ)+jets channels** with minimal covariance estimator (BLUE) *including correlations*
  - ***Propagate syst uncertainties through unfolding:*** *modify migration matrix & acceptances, fix data*



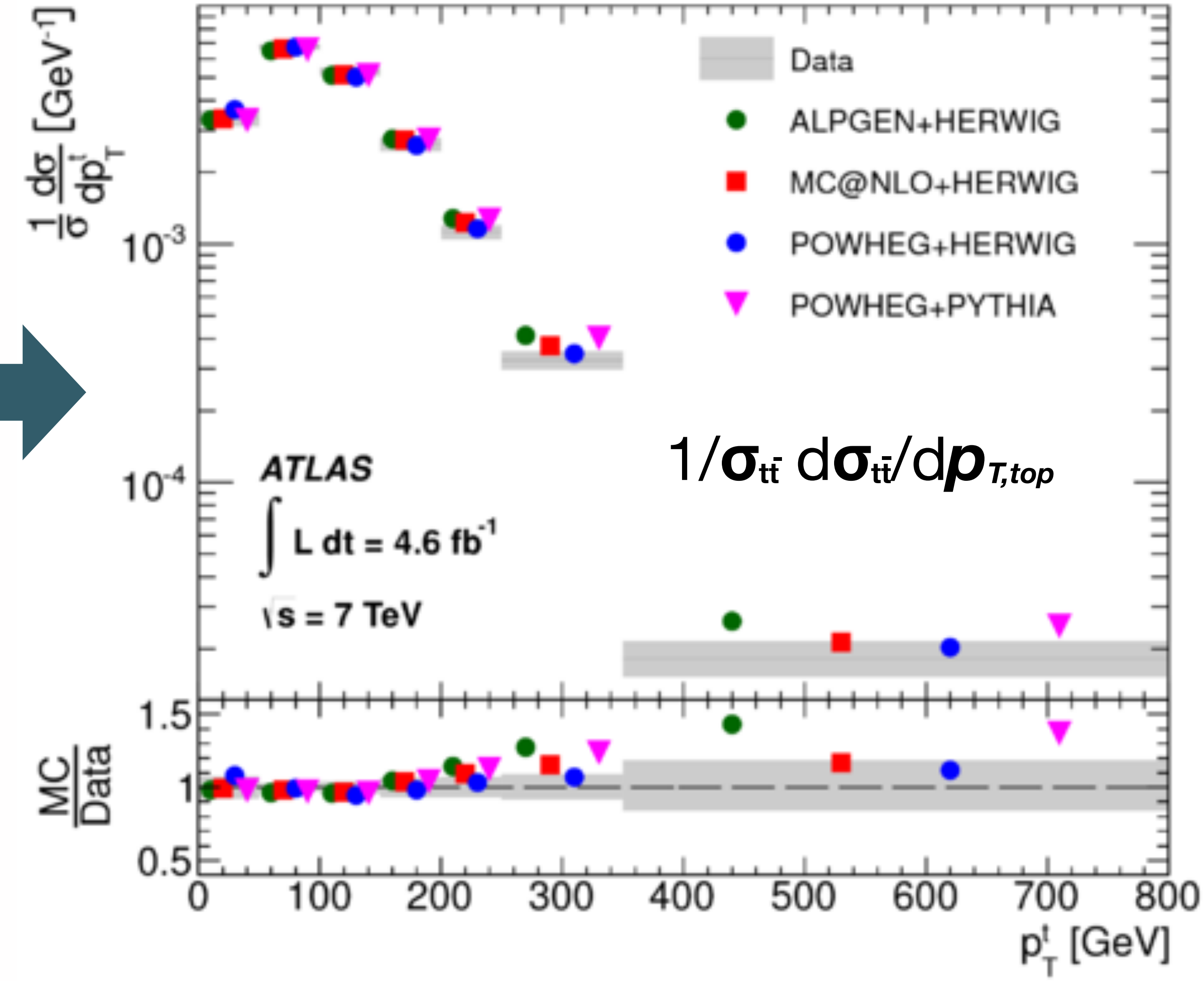


Differential $d\sigma_{t\bar{t}}/dX$: l+jets $\sqrt{s}$ = 7 TeV $\int Ldt$ = **4.7 fb^{-1}** *(2011)*   **NEW!**

- ***Syst dominated***: <7% for $y_{t\bar{t}}$, 10-20% $p_{T,t\bar{t}}$, 2% to 11% for $p_{T,top}$, 3% to 6% $m_{t\bar{t}}$

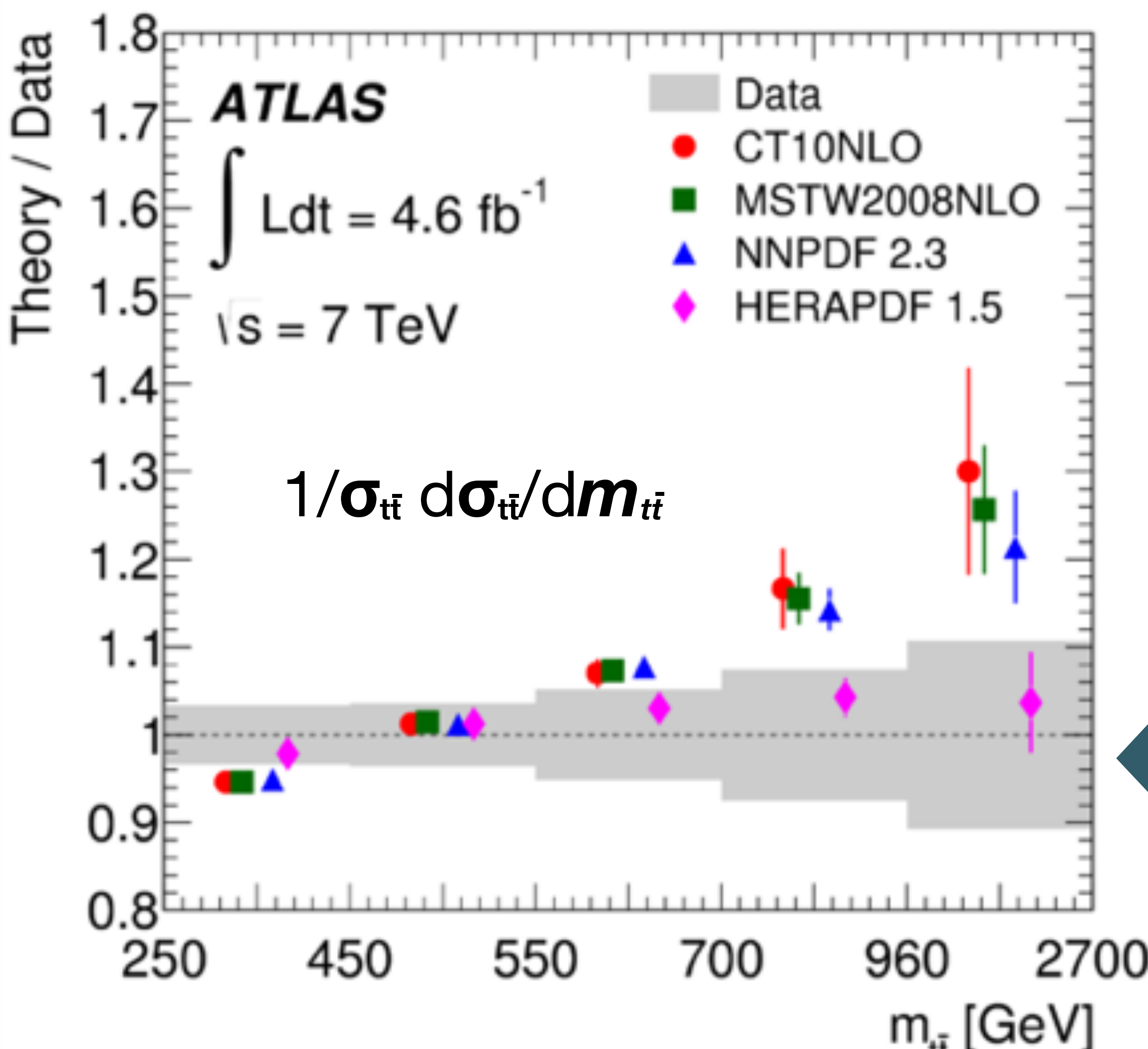
Compare with MC, NLO & approx NNLO

- **$p_{T,top}$ spectrum is softer than most predictions for $p_{T,top}$ >200 GeV**



Compare with different PDF sets

- **Data show sensitivity to PDF with some preference for HeraPDF**



arXiv:1407.0371 Submitted to Phys. Rev. D.

Fiducial definition in l+jets

http://arxiv.org/abs/1407.0891, submitted to JHEP

$E_{\mathrm{T}}^{\mathrm{miss}} > 30$ GeV & $m_{\mathrm{T}}(W) > 35$ GeV
One or more b-jets
Three or more jets with p_{T} >25 GeV & $\lvert\eta\rvert < 2.5$
e (μ) with $p_{\mathrm{T}} > 25$ GeV & $\lvert\eta\rvert < 2.5$
No additional e (μ) with $p_{\mathrm{T}} > 15$ GeV & $\lvert\eta\rvert < 2.5$
No μ (e) with $p_{\mathrm{T}} > 15$ GeV & $\lvert\eta\rvert < 2.5$
No jet-jet pair with $\Delta R < 0.5$
No jet-electron or jet-muon pair with $\Delta R < 0.4$

Table 3. Fiducial-volume definition for the electron (muon) channel of the $t\bar{t}$+jets cross-section measurement with the jet p_{T} threshold of 25 GeV. These conditions were applied on reconstruction-level and particle-level objects, with the exception of the electron where a veto on the η-region corresponding to the barrel-endcap transition region was applied on the reconstruction level (as described in section 3.1), but not included in the fiducial-volume definition. The jet p_{T} threshold in the jet multiplicity distributions was increased to 40, 60 and 80 GeV, for the corresponding cross-section measurements.

Leading jet with $p_{\mathrm{T}} > 50$ GeV & $\lvert\eta\rvert < 2.5$
2^{nd} leading jet with $p_{\mathrm{T}} > 35$ GeV & $\lvert\eta\rvert < 2.5$

Table 4. Additional fiducial-volume requirements implemented for the $t\bar{t}$ cross-section with respect to the jet p_{T}. These requirements were made in addition to those given in table 3 and were applied to the electron and the muon channel.

Details of corrections for $d\sigma_{tt}/dN_{,jets}$

http://arxiv.org/abs/1407.0891, submitted to JHEP

$$N^{i}_{\text{part}} = f^{i}_{\text{part!reco}} \cdot \sum_{j} M^{\text{part},i}_{\text{reco},j} \cdot f^{j}_{\text{reco!part}} \cdot f^{j}_{\text{accpt}} \cdot (N^{j}_{\text{reco}} - N^{j}_{\text{bgnd}})$$

after jet acceptance effects

i= bin of jet multiplicity

1) correct for all non jet related efficiencies: b-tagging, trigger, lepton reconstruction

f^{j}_{accpt} = N_{ev}(pass non jet-particle sel & jet reco sel)/ N_{ev}(pass full reco sel)

Reco

Pass Reco, Pass PL	**Pass Reco**, Fail PL	Fail Reco Pass PL	Fail Reco, Fail PL

Particle level: to correct to

2) correct for events that pass reco requirements, but fail particle level ones

3) **correct for migrations** (resolution effects) for events that pass both reco and particle level requirements

Iterative Technique (NIMA362 (1995) 487)

2) correct for events that fail reco requirements, but pass particle level ones

Details of corrections for $d\sigma_{tt}/dp_{T,jets}$

http://arxiv.org/abs/1407.0891, submitted to JHEP

i= bin of jet p_T

$$N^{i}_{\text{part}} = f^{i}_{\text{part!reco}} \cdot \sum_{i} M^{\text{part},i}_{\text{reco},j} \cdot f^{j}_{\text{misassign}} \cdot f^{j}_{\text{reco!part}} \cdot f^{j}_{\text{accpt}} \cdot \left(N^{j}_{\text{reco}} - N^{j}_{\text{bgnd}}\right)$$

1) correct for all non jet related efficiencies: b-tagging, trigger, lepton reconstruction

f^{j}_{accpt} = N_{ev}(pass non jet-particle sel & jet reco sel)/ N_{ev}(pass full reco sel)

Reco

Pass Reco, Pass PL	**Pass Reco**, Fail PL	Fail Reco Pass PL	Fail Reco, Fail PL

Particle level: to correct to

2) correct for events that pass reco requirements, but fail particle level ones

3) **correct for migrations** between different jet p_T -ordering

match reco to particle jet within ΔR=0.35
N(jets matching jet i)/ N(matched jets)

3) **correct for migrations** (resolution effects) for events that pass both reco and particle level requirements with jets having the same order

Iterative Technique (NIMA362 (1995) 487)

2) correct for events that fail reco requirements, but pass particle level ones

Why Top (quark)?

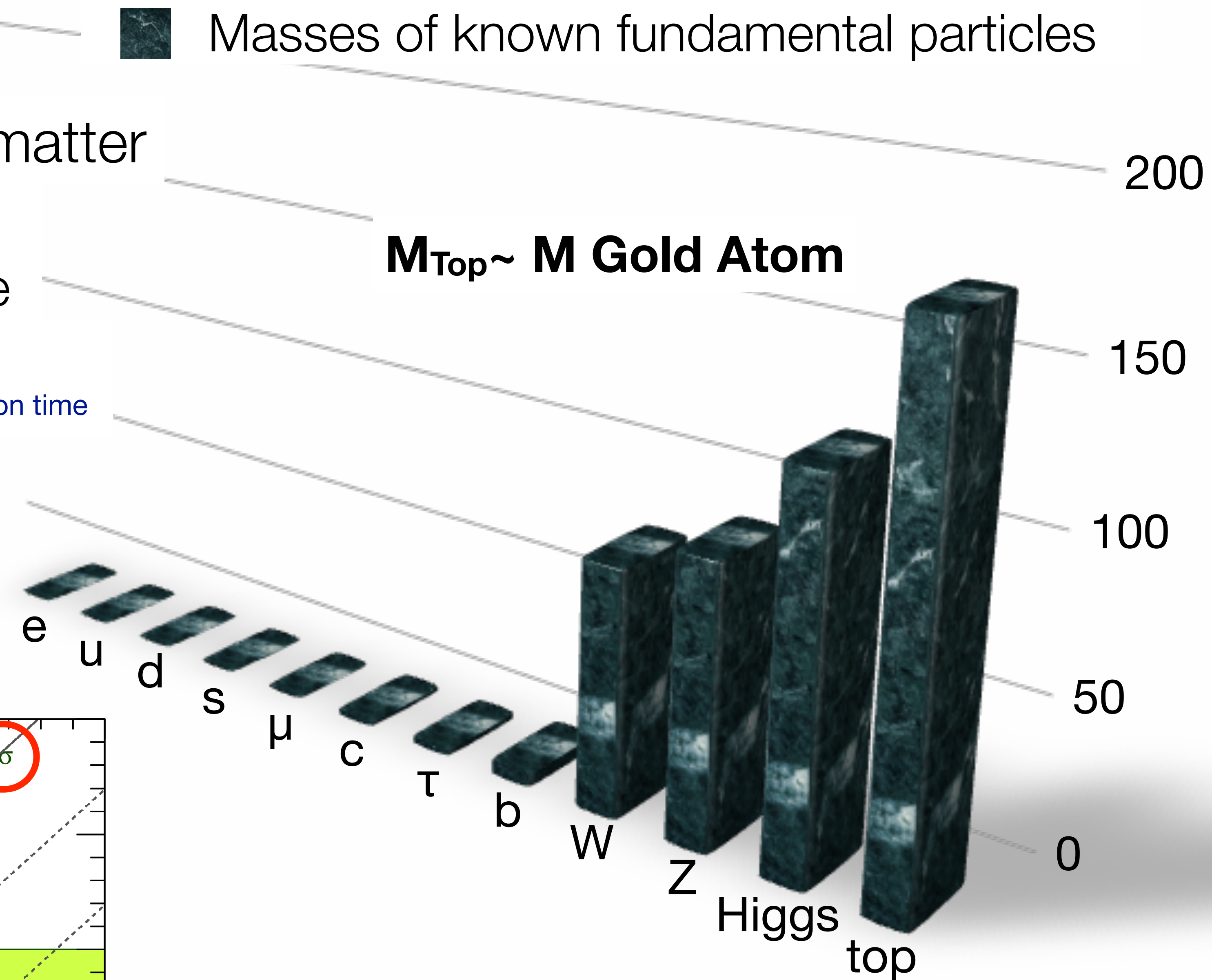
Most massive known **constituent** of matter

Large Yukawa coupling in SM: $Y_t > 0.9$

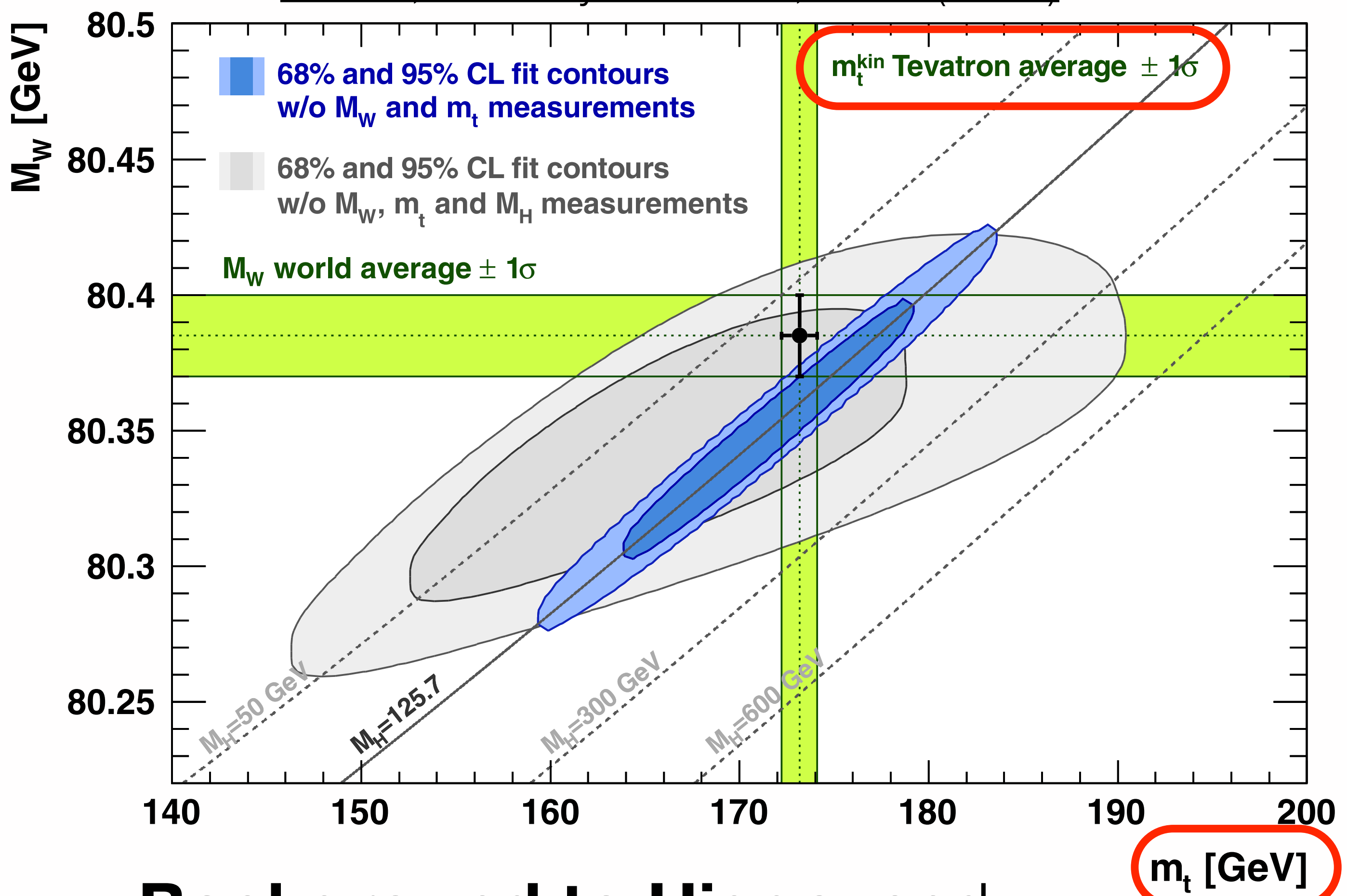
M_{top}~ electroweak symmetry breaking scale

$1/m_t$	<	$1/\Gamma_t$	<	$1/\Lambda$	<	m_t/Λ^2
Production time	<	Lifetime	<	Hadronization time	<	Spin decorrelation time

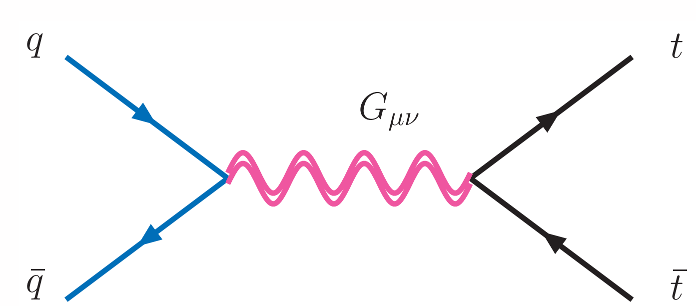
Strong, EWK production and decay rate test standard model

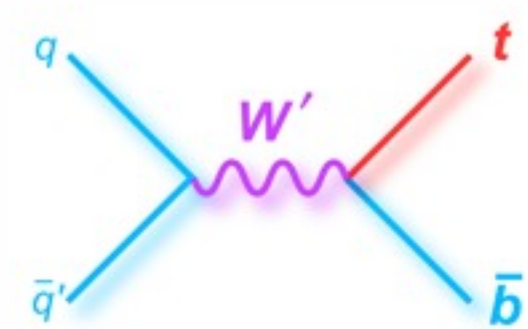


GFitter, Eur. Phys. J. C 72, 2205 (2012)



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





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

LHC : a *Top* producer

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

E_{cm}(Tevatron)= 1.96 TeV

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

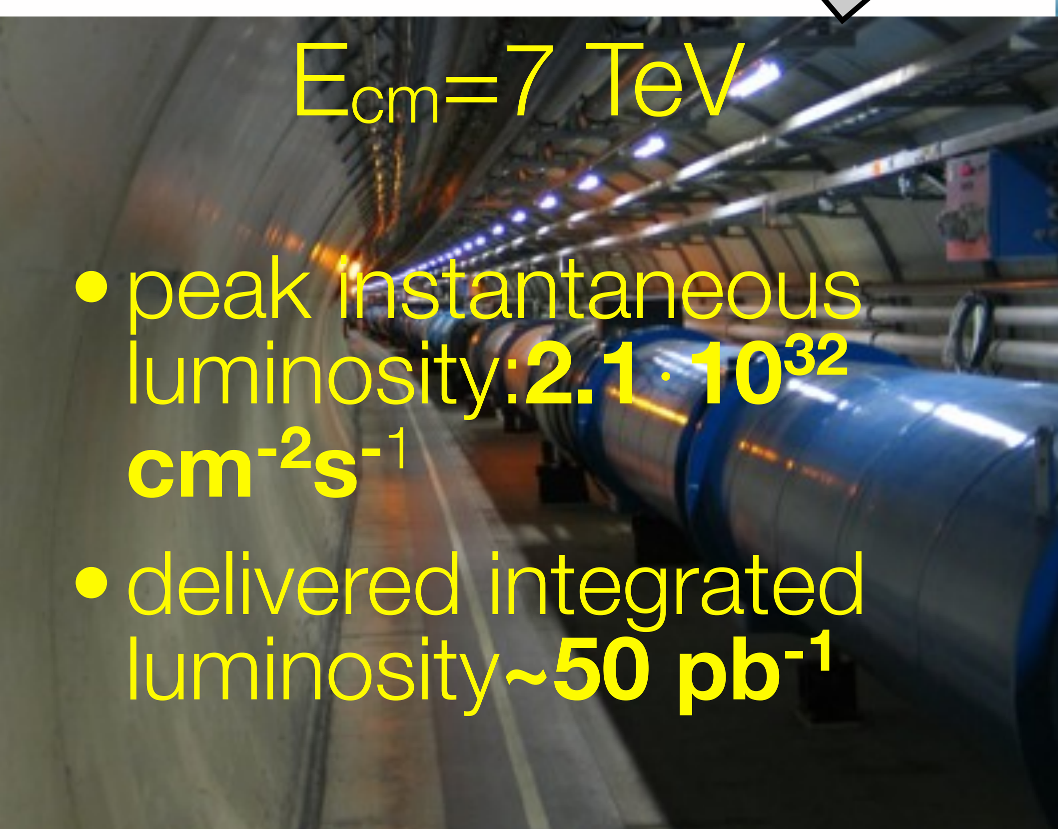
Key parameters:

N_i = bunch intensity

n_b = number of bunches

σ = colliding beam size

2010



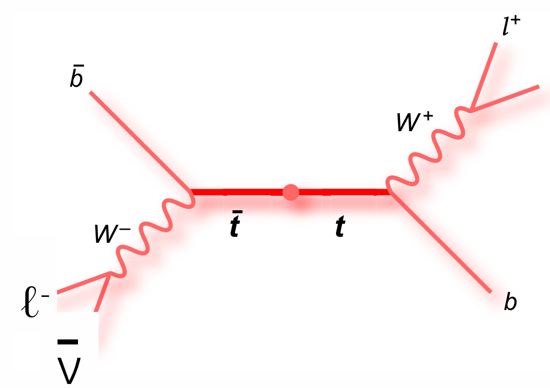
$N_{events}(\Delta t)$= *∫Ldt* * cross section

Differential *Jet activity*: dilepton $\sqrt{s}$ = 7 TeV

Eur. Phys. J. C72 (2012) 2043

$\int L dt =$ **2.05 fb^{-1}** *(2011)*

- Require 2 **opposite sign leptons, ≧ 2 b-tag jets**
- veto low M(ℓℓ) (<15 GeV)
- ee,μμ: high E_T^{miss} cut & M(ℓℓ)≠m_Z, eμ: high $H_T = \sum_{jets,lepts} p_T$ *>130 GeV*

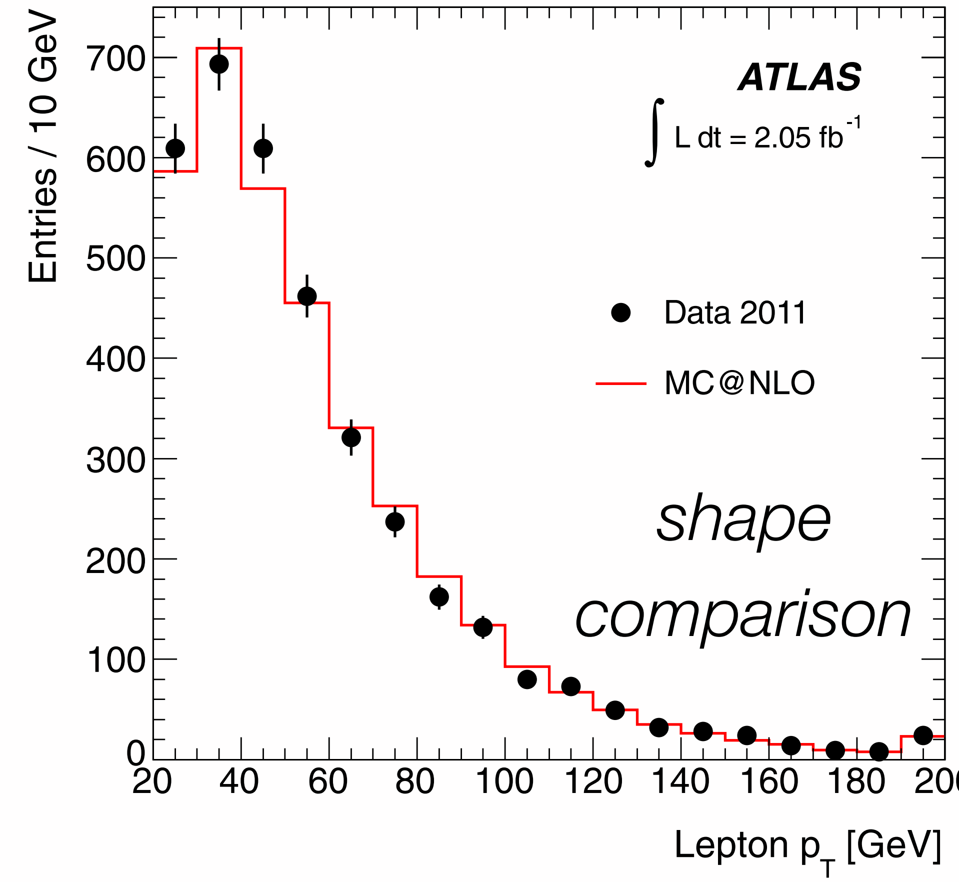


- **Bkg(<6%): single top** (Wt) **Z +jets, diboson** *(from simul.)*, **data-driven fake leptons** *(loose/tight matrix method)*

⇒ ***Not subtracted, but included in syst.***

- **Derive: fraction of selected N_{ev} with**
  - **no additional** *(to 2 b-tag)* **jet with $p_T > Q_0$: $f(Q_0)$**
  - **$\sum_{additional\ jets} p_T$ < Q_{sum}** in given y interval: **$f(Q_{sum})$**
- **$f(Q_0)$ [$f(Q_{sum})$] is sensitive to the leading [all] p_T emission[s]**

lepton p_T



leading additional jet p_T