The Top Quark Charge Asymmetry at the LHC

Recent ATLAS measurements and strategies for the LHC

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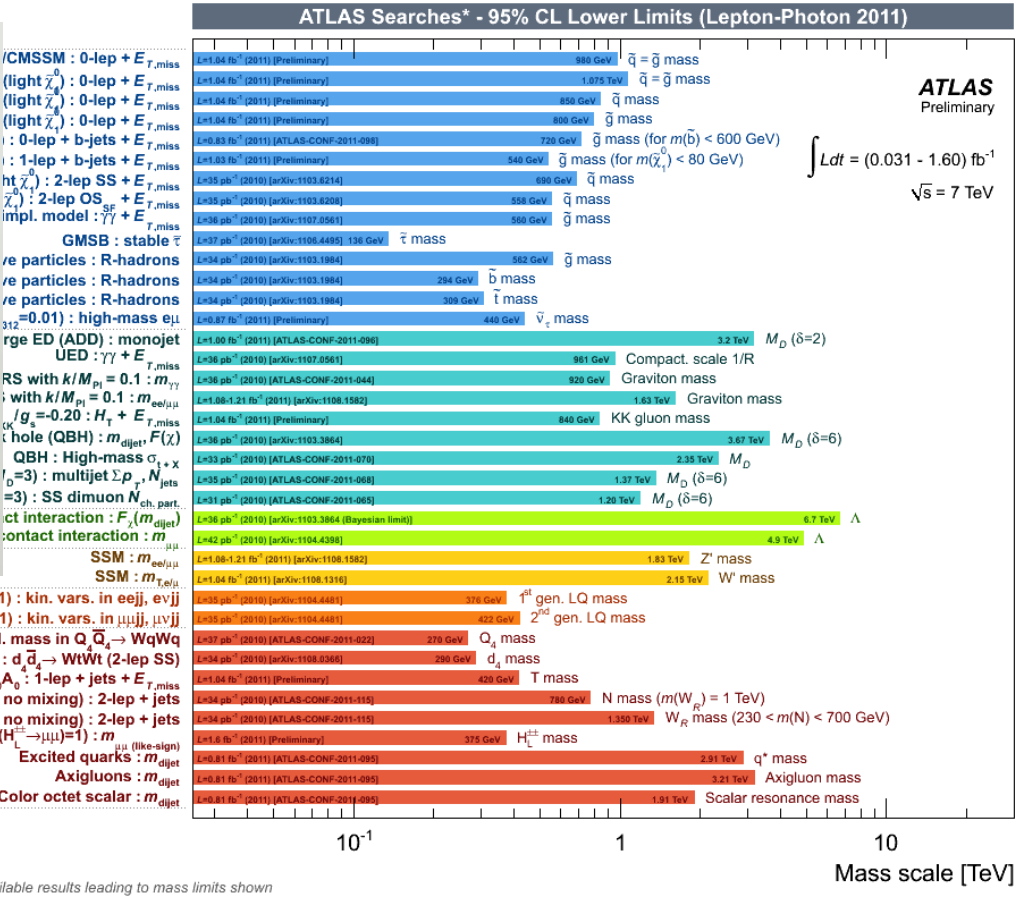
Status after LHC@7-8 TeV

The Higgs discovery completed the Standard Model at the ElectroWeak scale

Null results from direct beyond-SM searches up to ~1 TeV

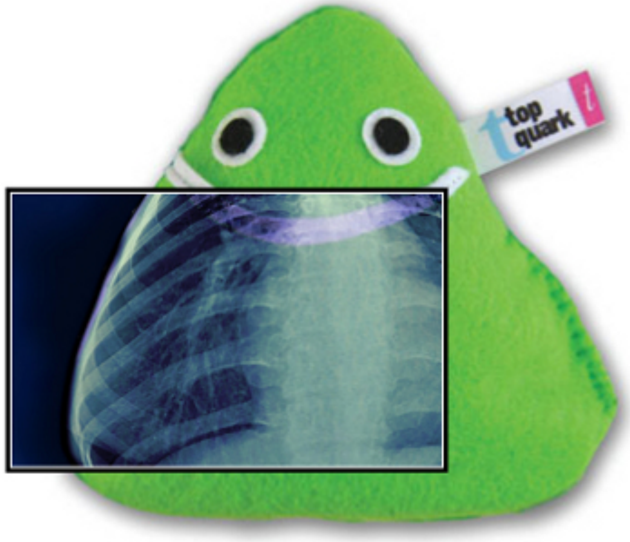


*Only a selection of the available results leading to mass limits shown

The Top Quark – gateway towards New Physics

- Heaviest particle, m_{top}~173 GeV
- Yukawa coupling ~1

Important role in EW symmetry breaking and BSM models.



Measurements of top quark properties, such as the charge asymmetry in the production of top quark pairs, might provide hints of new physics beyond the Standard Model.

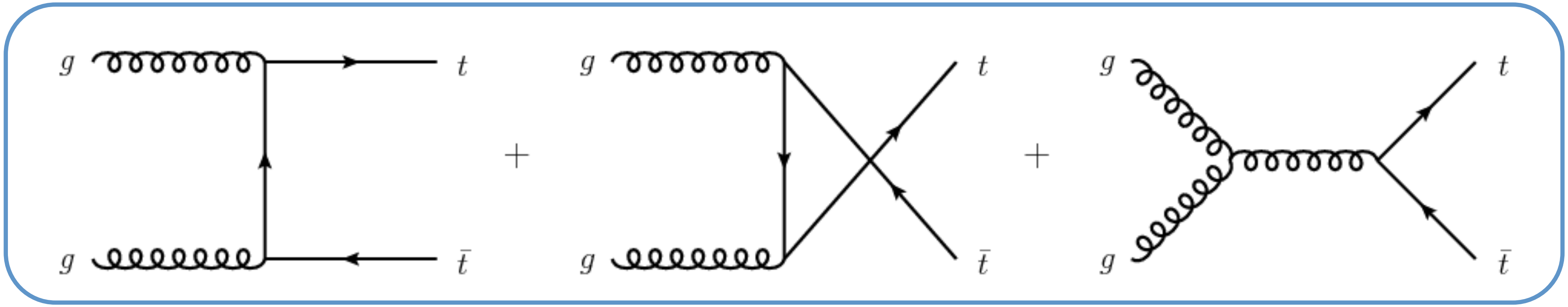
The Top Quark – Pair production at the LHC

Large rate: ~5M of top pair events in Run-I

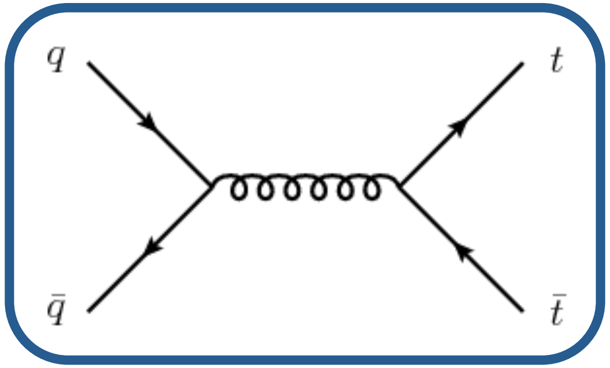
Main production modes:

- gluon fusion $gg \rightarrow t\bar{t}$
- quark-antiquark annihilation $q\bar{q} \rightarrow t\bar{t}$

$$\sigma(pp \rightarrow t\bar{t}) \approx 200\,pb$$



~85% of σ_{tt}



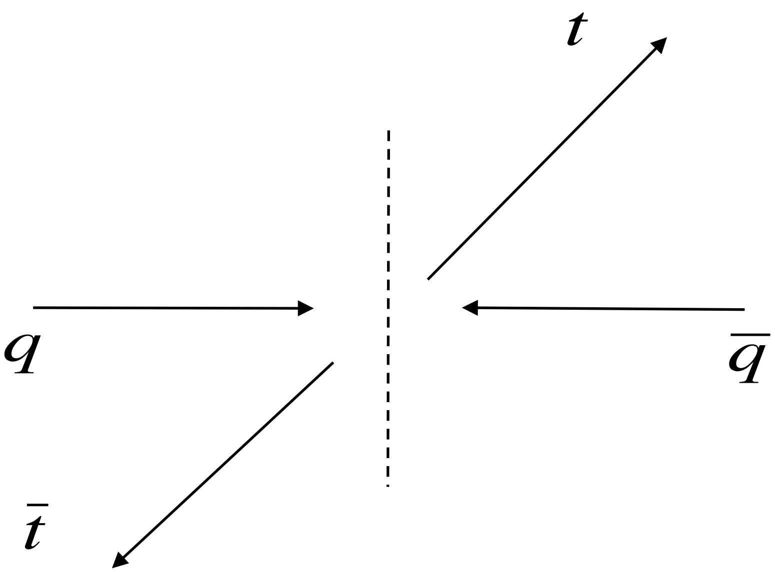
~15% of σ_{tt}

Relevant events to measure asymmetry

Top Quark Pair Charge Asymmetry

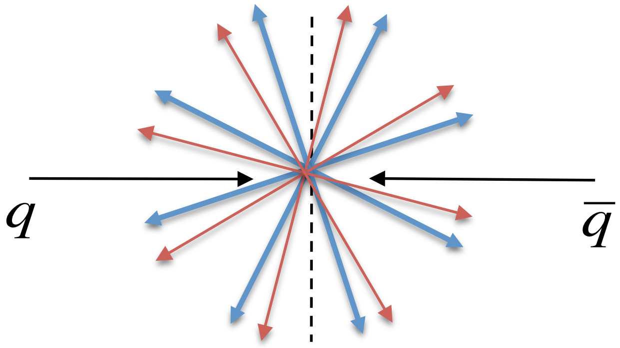
<u>What is the Top Charge Asymmetry:</u>

Measure anisotropy in (anti-)top production wrt incoming (anti-)quark direction.



C.M. reference frame

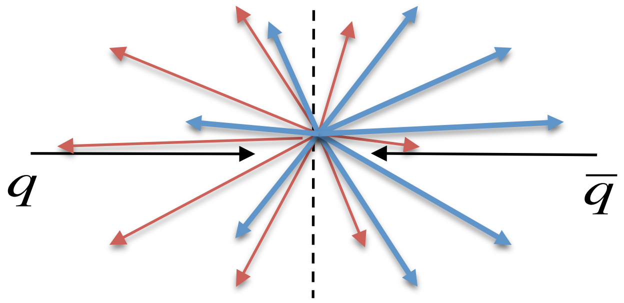
NO ASYMMETRY



top directions

anti-top directions

ASYMMETRY



N.B. requires **asymmetric initial state** (e.g. **quark-antiquark annihilation**)

Outline

- Motivation – the A_{FB} puzzle
- The asymmetry at the LHC - A_C
- Early measurements at the LHC:
  ATLAS lepton+jets 1.04 fb^{-1} at √s=7 TeV — Eur.Phys.J. C72 (2012) 2039
- Boosting the charge asymmetry — Phys.Lett. B707 (2012) 92-98
- Charge asymmetry at ATLAS:
  lepton+jets 4.7 fb^{-1} at √s=7 TeV — JHEP 02 (2014) 107
- A_C at √s=14 TeV with a photon handle — arxiv:1402.3598

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A_{FB} @ Tevatron

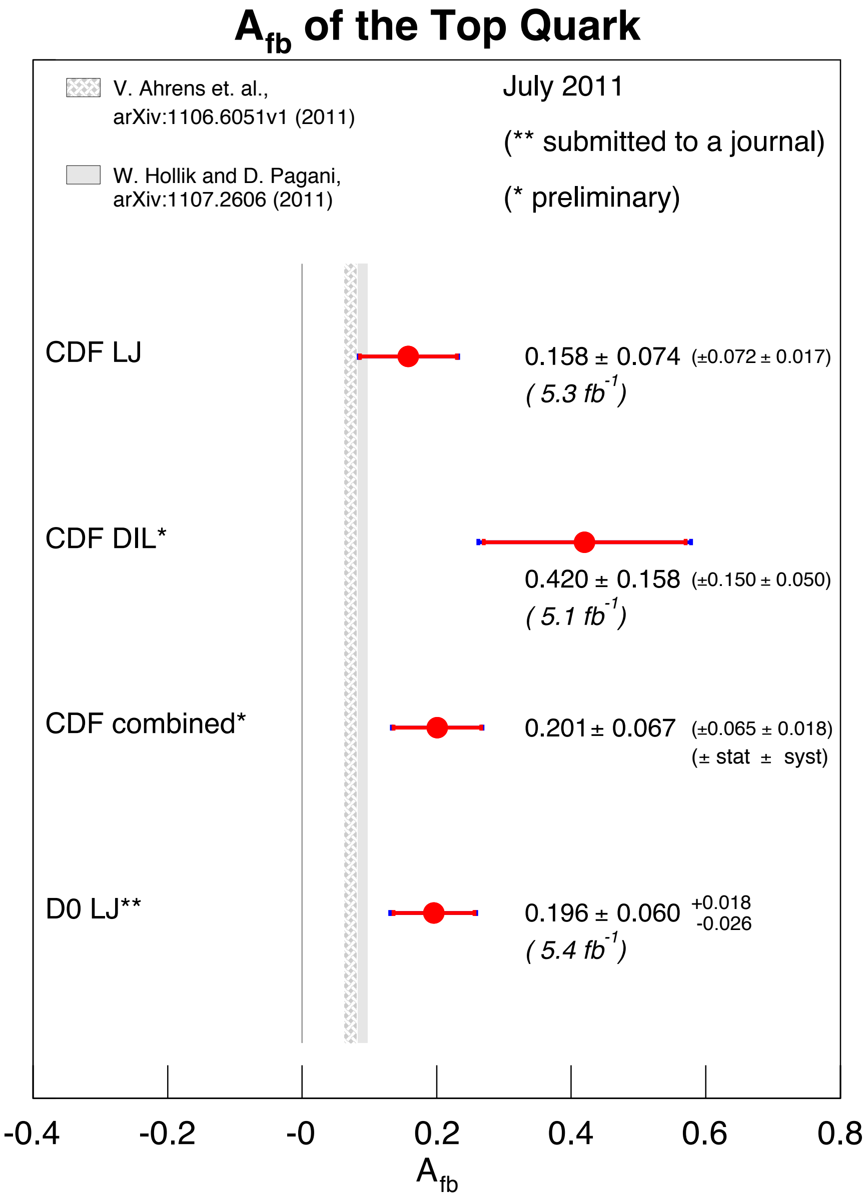
In 2011 both CDF and D0 collaborations reported a non-zero forward-backward asymmetry in top quark pair production defined as:

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

rapidity

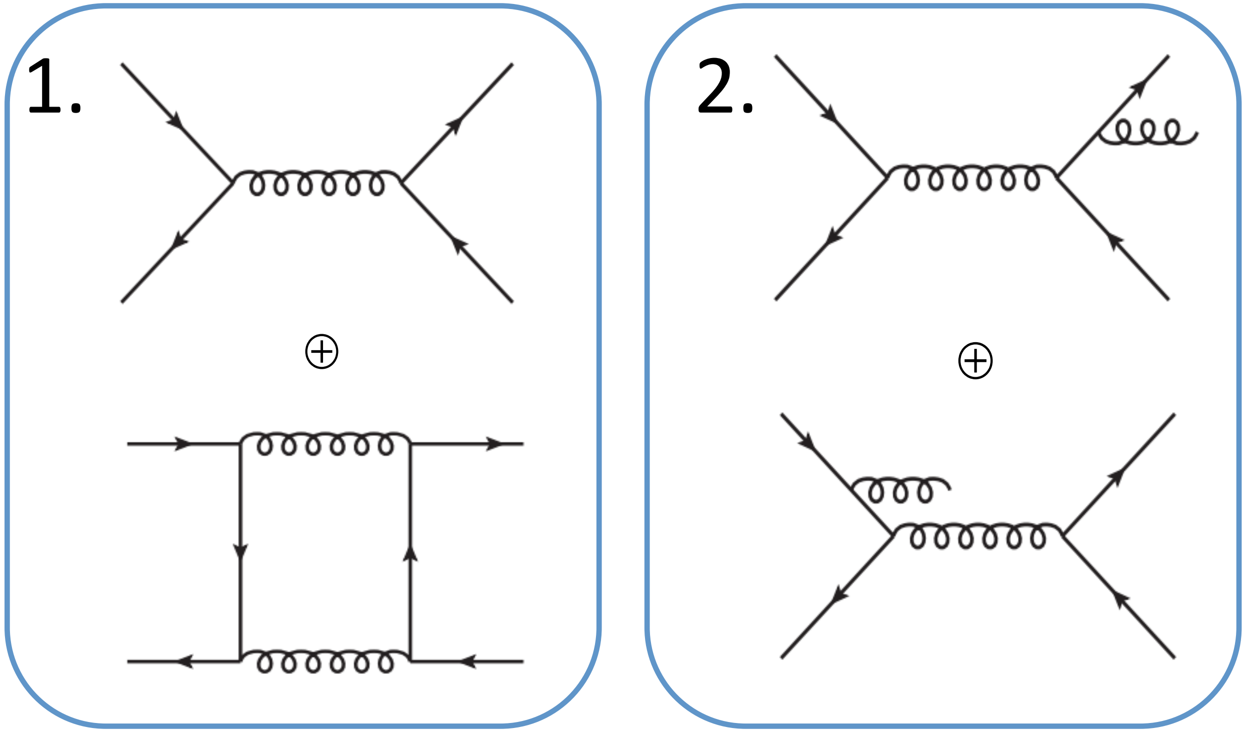
with $\Delta y = y_{top} - y_{anti\text{-}top}$

- Triggered theoretical activity for precise SM predictions and BSM hypotheses (axigluons,Z',..).



The SM charge asymmetry

- SM top quark pair production is charge asymmetric at NLO.
- Main source of asymmetry is the QCD quark-antiquark annihilation process.



asymmetric QCD

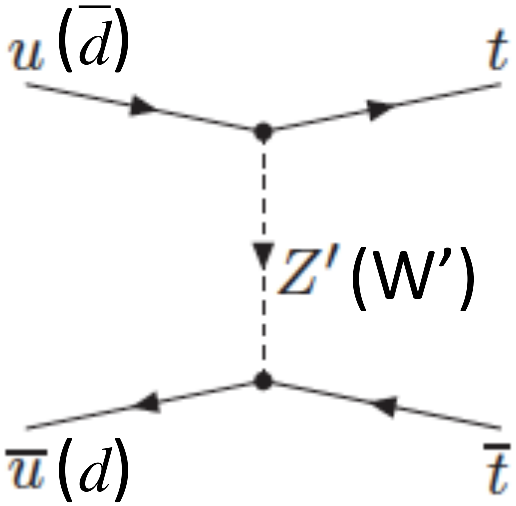
The SM QCD asymmetry in $q\bar{q} \rightarrow t\bar{t}$ originates from:

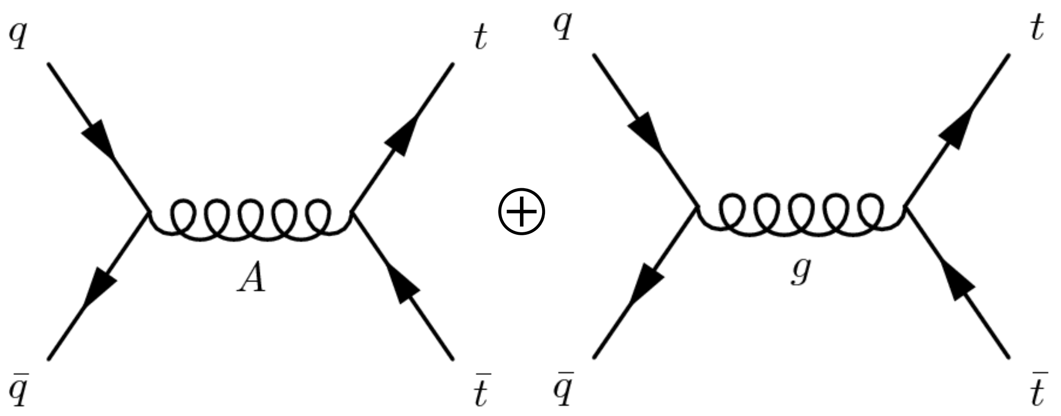
1. Interference between tree and box diagram $A_{FB}>0$
2. Interference between gluon ISR and FSR diagrams $A_{FB}<0$

BSM asymmetry

Z’ / W’

Axigluon



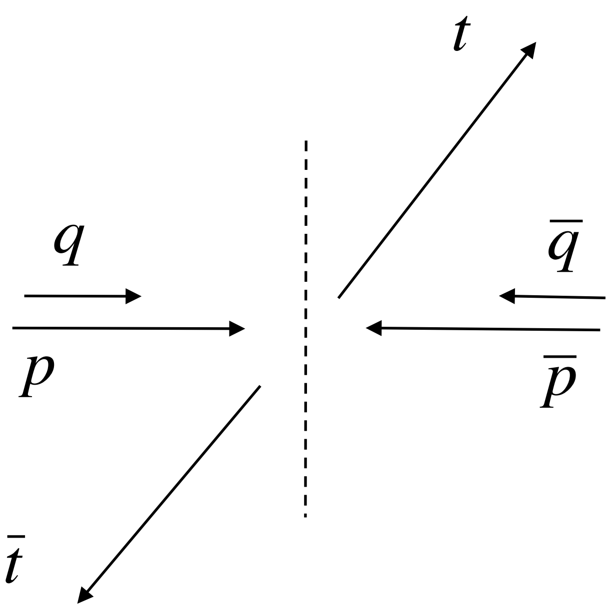


t-channel:
exotic flavor changing vector bosons

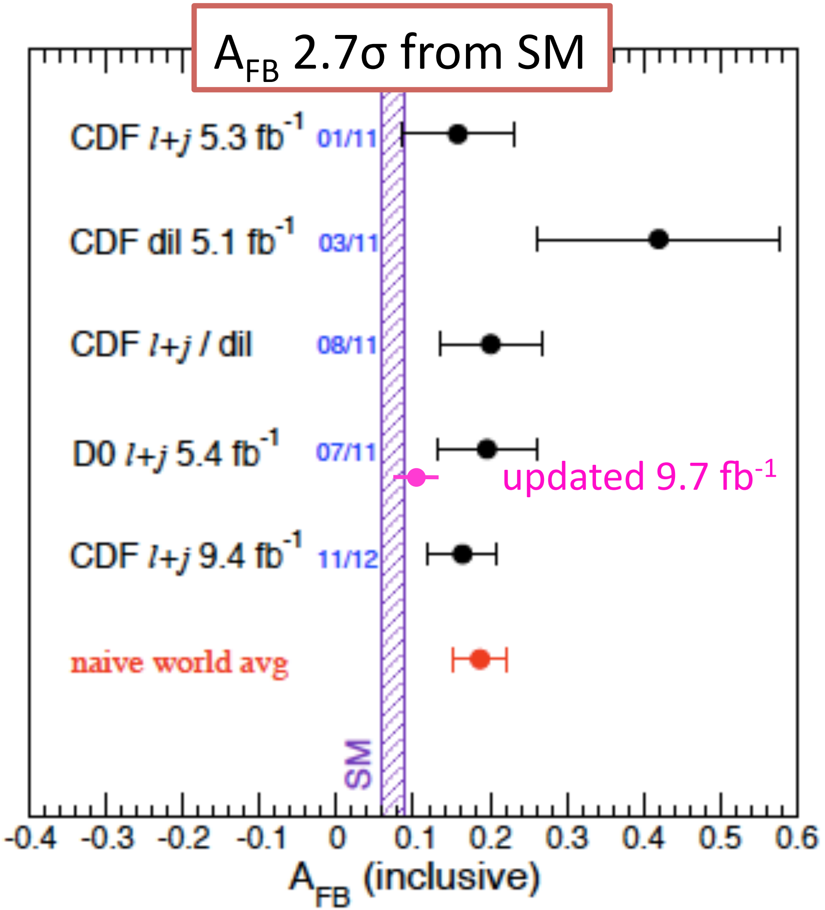
s-channel:
interference between SM QCD and exotic gluons with axial coupling

A_{FB} @ Tevatron

- $p\bar{p}$ initial state → forward-backward asymmetry
- $q\bar{q} \rightarrow t\bar{t}$ dominant process (~85%)→ small dilution
- updated results with full datasets (~10 fb^{-1}) still report A_{FB} consistently larger than SM prediction.



Lab reference frame


A_{FB} 2.7σ from SM

updated 9.7 fb^{-1}

J.A. Aguilar-Saavedra et al. - arxiv:1302.6618

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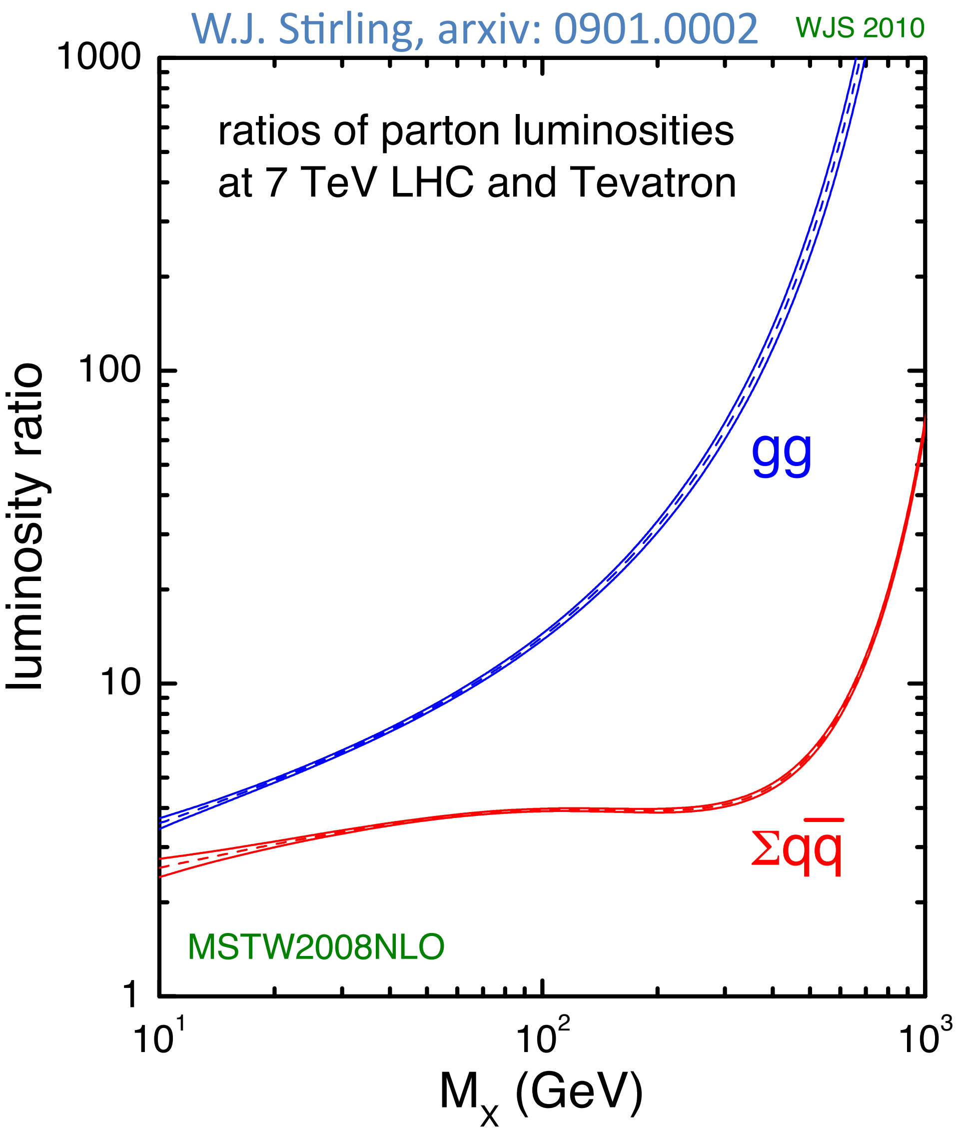
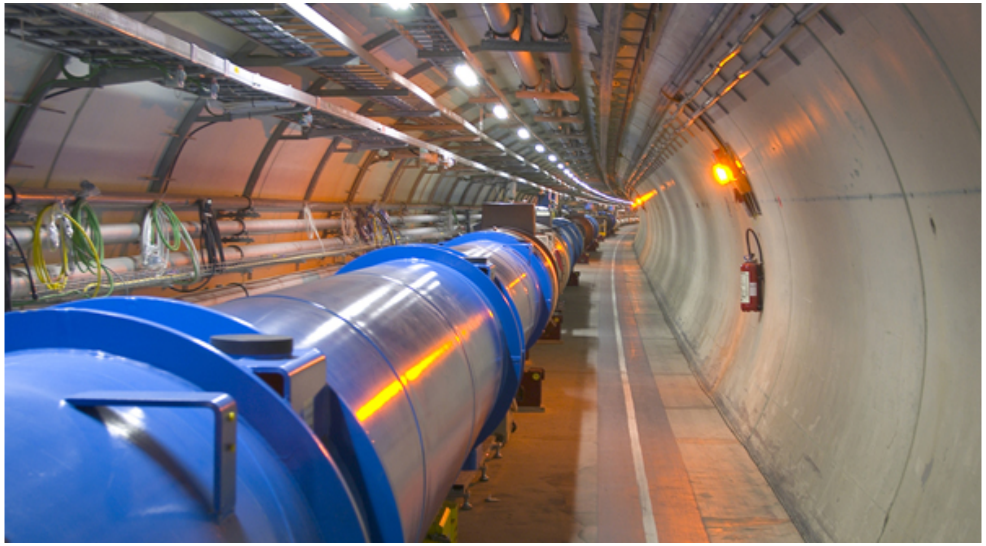
Overview of the LHC

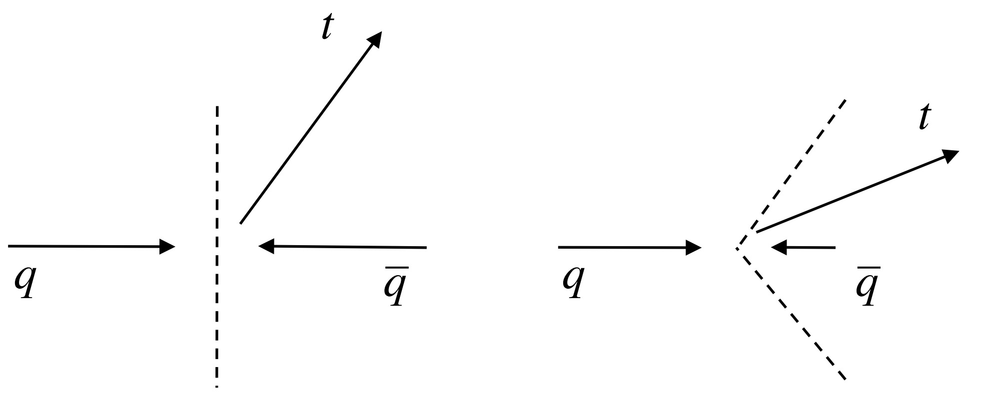




- p-p collisions: charge symmetric initial state
- dominated by gluon-gluon fusion:
  ~85% at √s=7,8 TeV
  >90% at √s=14 TeV
- average momentum imbalance in $q\bar{q}$ events (anti-quarks from sea)

Asymmetry @ LHC

- More diluted: $q\bar{q} \rightarrow t\bar{t}$ only ~15% at 8 TeV
- (anti)top is preferentially produced along the direction of the incoming (anti)quark.



CM reference frame

Lab reference frame

- Direction of the incoming quark not known in pp collisions

\- BUT -

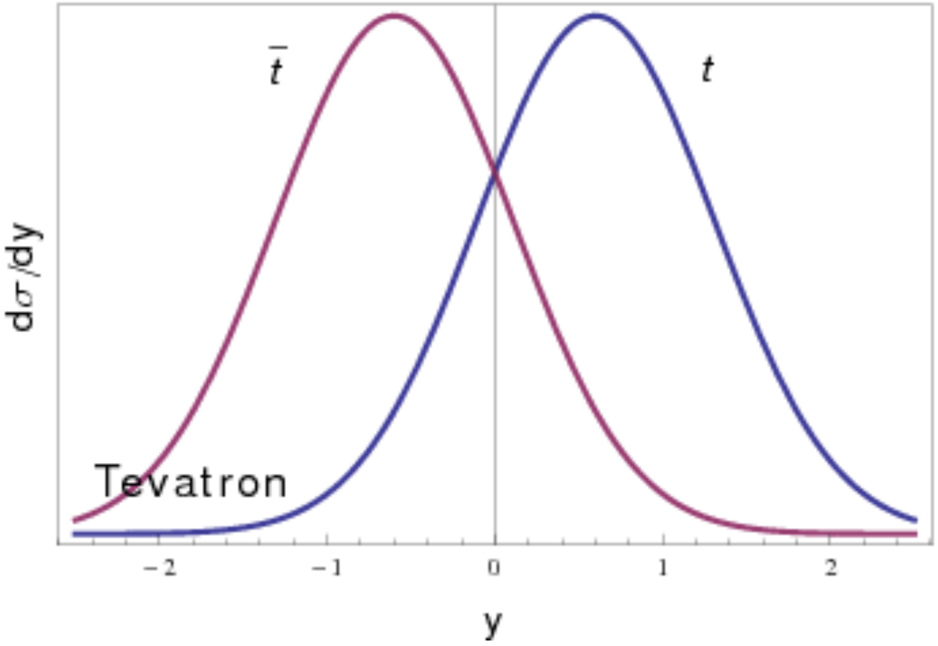
- Quarks more likely to be valence quarks (→larger fraction of momentum)
- only sea anti-quarks available
- top quarks more forward than antitops

Asymmetries

Tevatron - $p\bar{p}$ collisions

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

with $\Delta y = y_{top} - y_{anti\text{-}top}$

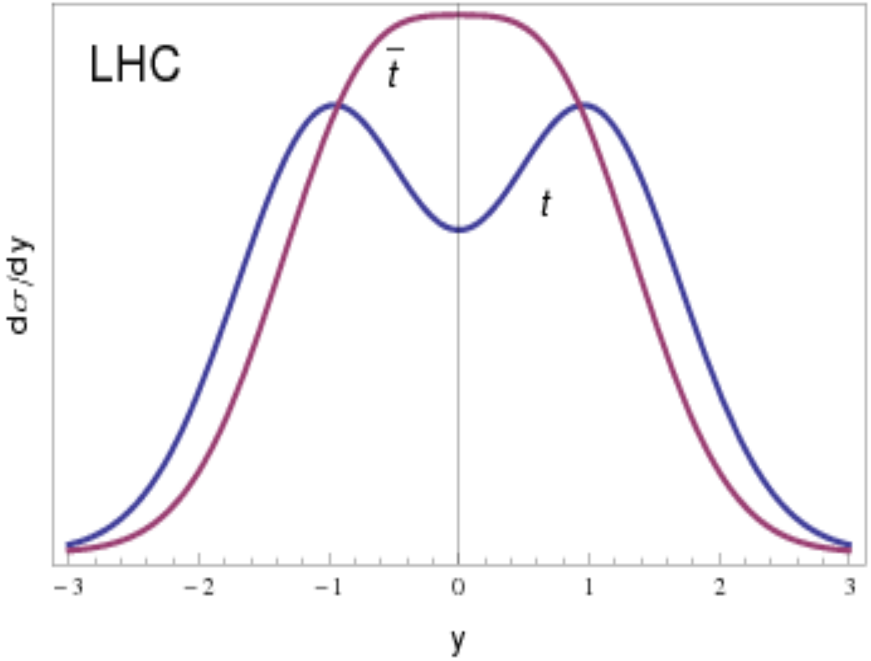


figures from G.Rodrigo, arxiv:1207.0331

LHC - pp collisions

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

with $\Delta|y| = |y_{top}| - |y_{antitop}|$



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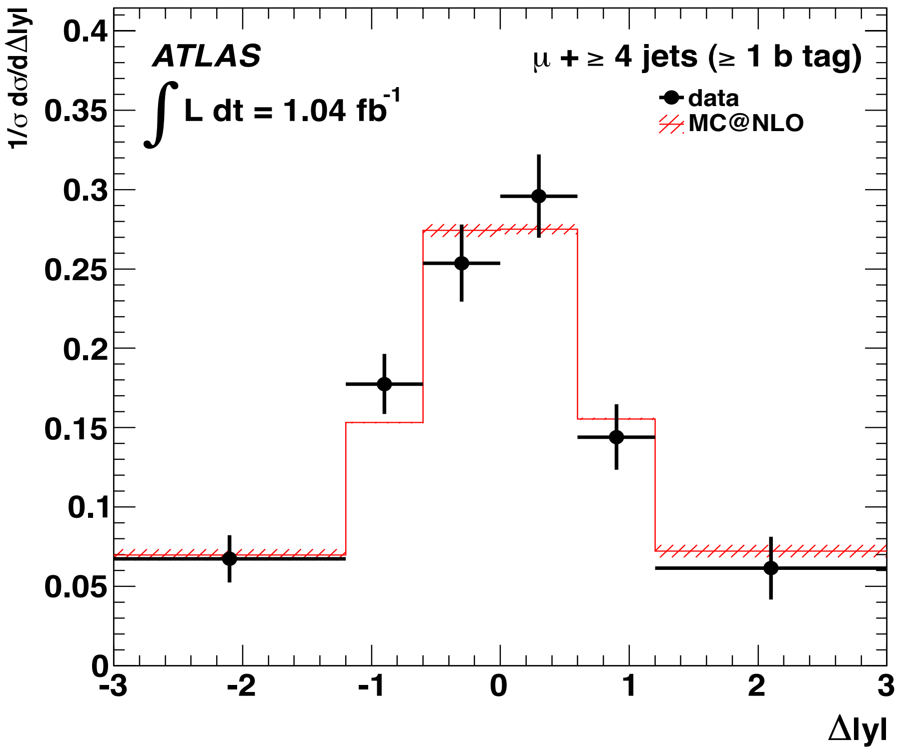
Charge asymmetry – l+jets



ATLAS - l+jets Eur.Phys.J. C72 (2012) 2039

$\sqrt{s}$ = 7 TeV, 1.04 fb^{-1}

$A_C = -0.019 \pm 0.028(\mathit{stat.}) \pm 0.024(\mathit{syst.})$

Theory: A_C = 0.0123 (5)

W. Bernreuther et al., Phys. Rev. D 86 (2012) 034026

- First measurements at LHC7 compatible with 0 asymmetry (and SM)
- Large statistical and systematic uncertainties
- The expected SM asymmetry is very small (~1%).

Experimental challenge

- Small fraction of quark-antiquark annihilation
- Direction of the incoming quark not known in pp collisions

small $A_C \sim 1\%$

- Measured A_C distorted by resolution and acceptance.

Need to extrapolate to parton-level asymmetry to compare with theory.

- Large systematic effects from parton-level extrapolation and from background modelling.

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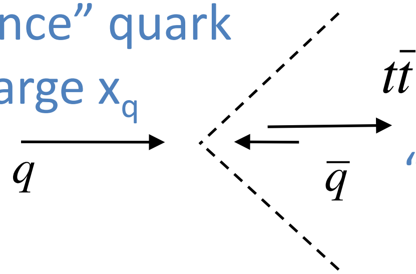
Boosted A_C

- Expected A_C is very small. Hard to measure.

- Fraction of $q\bar{q} \rightarrow t\bar{t}$ events increases with the velocity of the top quark pair along the beam axis

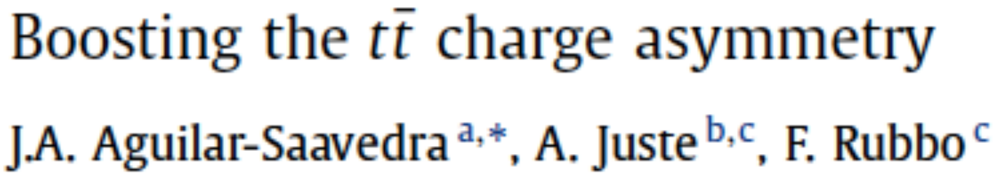
$$\beta = \frac{|p_t^z + p_{\bar{t}}^z|}{E_t + E_{\bar{t}}}$$



“valence” quark
large x_q

“sea” anti-quark
small x_q

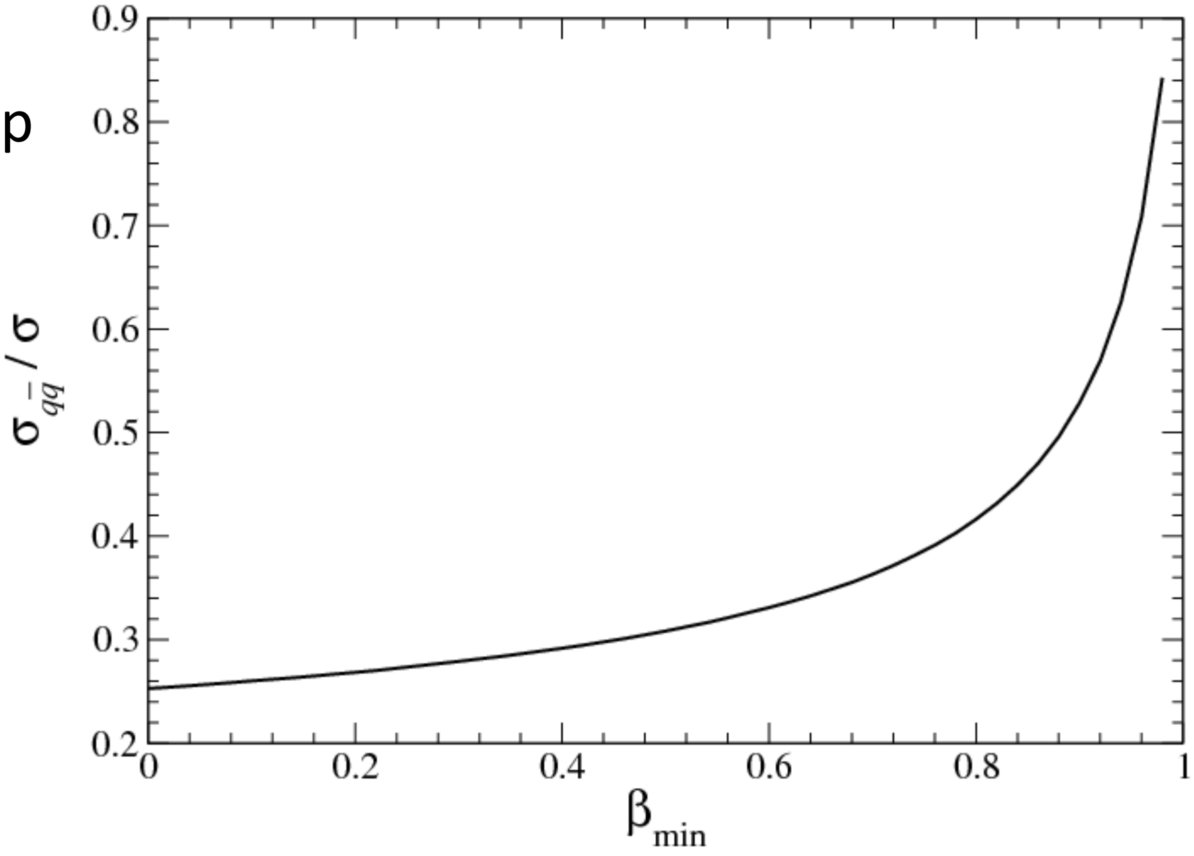
Lab reference frame



Boosting the $t\bar{t}$ charge asymmetry

J.A. Aguilar-Saavedra [a,*], A. Juste [b,c], F. Rubbo [c]

Phys.Lett. B707 (2012) 92-98



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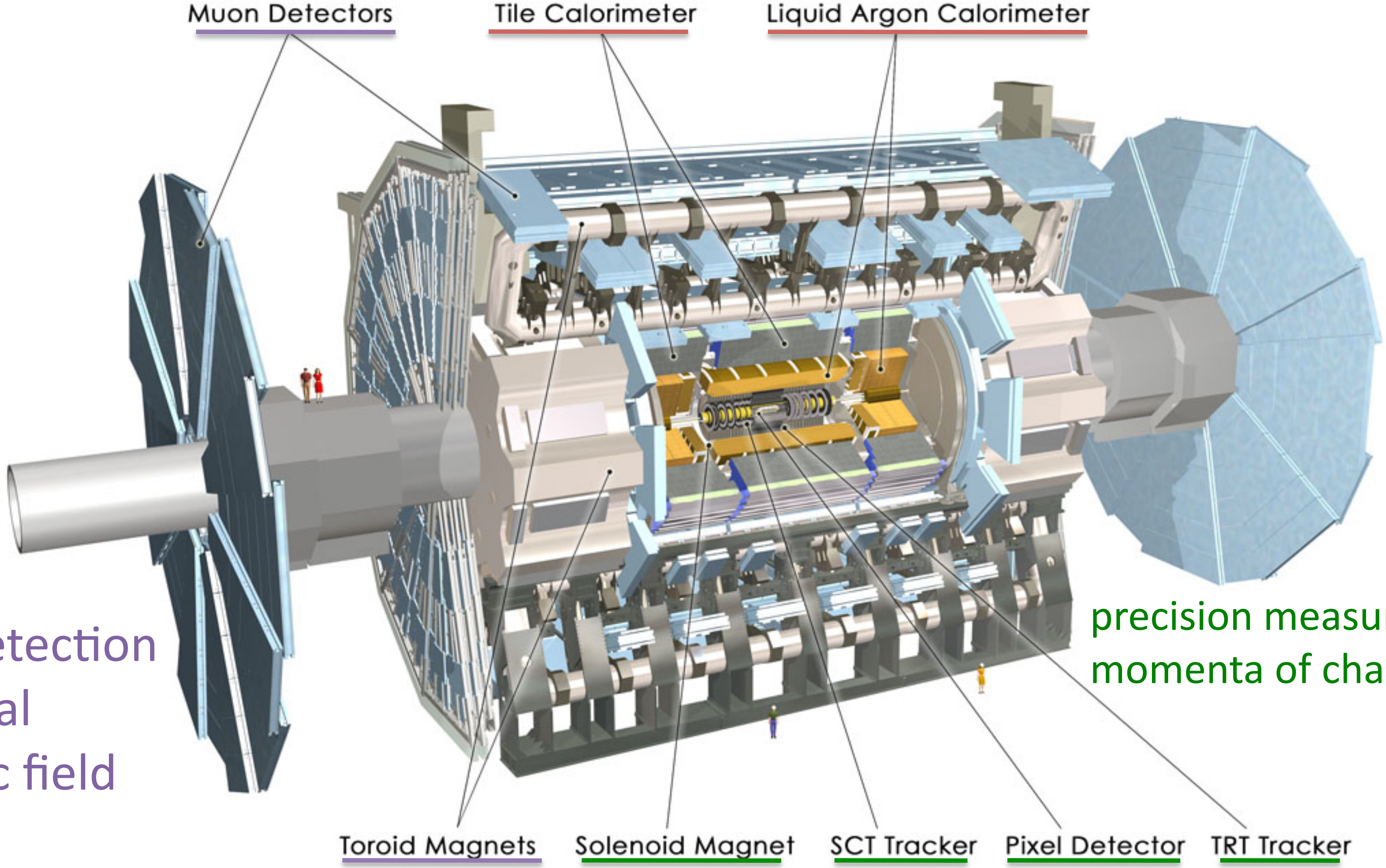
Overview of ATLAS

Efficiently collected ~20 fb^{-1} of p-p collision data



energy of jets, electrons

Muon detection in toroidal magnetic field

precision measurement of momenta of charged particles

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Measurements

Performed a complete set of measurements of the charge asymmetry:

- Inclusive measurement of A_C, $A_C(\beta_{z,tt}>0.6)$ and $A_C(m_{tt}>600$ GeV)

- Differential measurements: the dependence of A_C vs kinematics of the top quark pair might provide useful information for BSM discrimination/ understanding of the SM.

same as $\beta_{z,tt}$

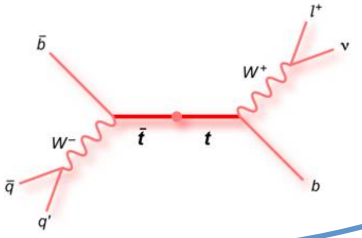
A_C vs $|y_{tt}|$: sensitive to enhancement of asymmetry at high rapidity, due to increase of the fraction of $q\bar{q} \rightarrow t\bar{t}$ events.

A_C vs m_{tt}: expected different behavior for different BSM scenarios.
Also with $\beta_{z,tt}>0.6$ to enhance $q\bar{q} \rightarrow t\bar{t}$ fraction.

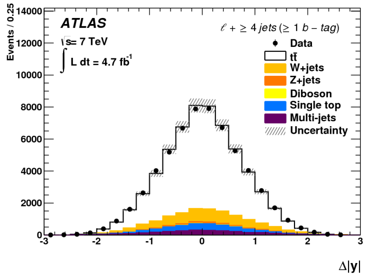
A_C vs $p_{T,tt}$: more sensitive to asymmetry from ISR/FSR interference.

Analysis flow

Selection of semileptonic top pair events



Background estimation

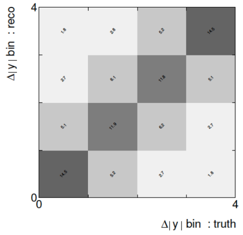


Kinematic reconstruction of the top pair:

- $\Delta|y|$
- m_{tt}
- $p_{T,tt}$
- $|y_{tt}|$, $\beta_{z,tt}$

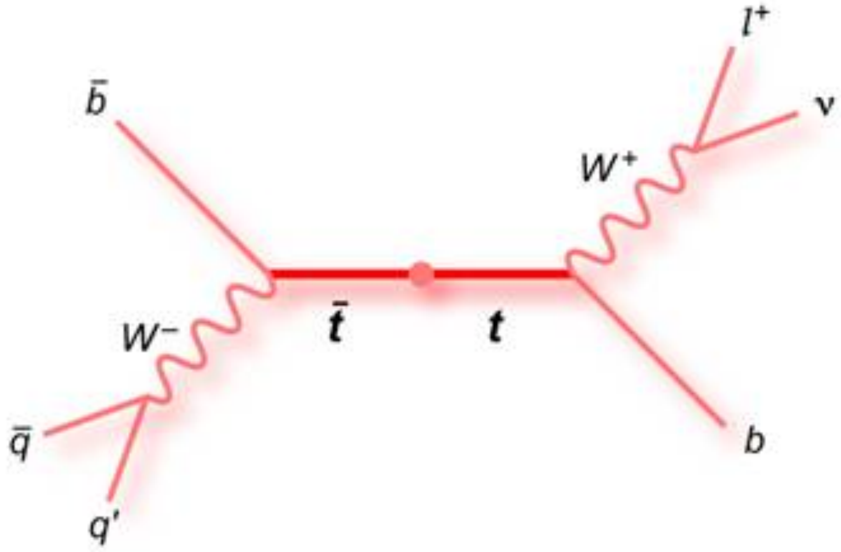
Unfolding to parton level

- resolution
- acceptance



Results

Event selection



semileptonic (lepton=μ,e) top pair decays:

- large BR (~30%)
- manageable background (W+jets,multijets)
- use lepton charge to tag top/antitop quark

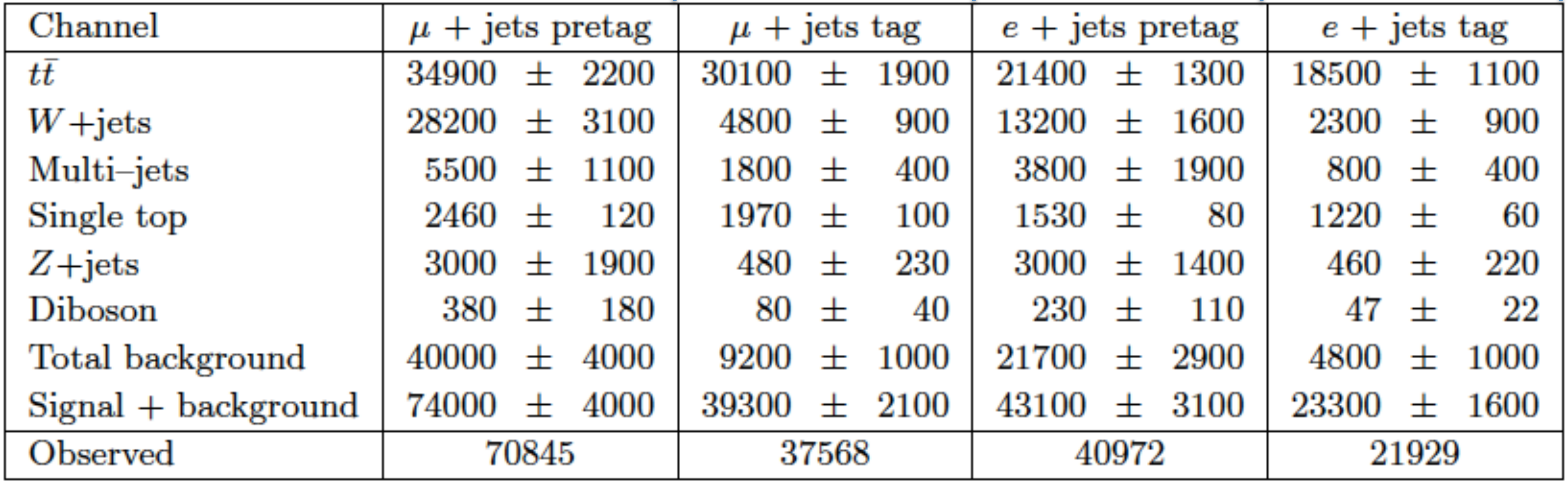
Selection:

- exactly 1 isolated lepton with p_T >20 (e), 25 (μ) GeV
- at least 4 jets with p_T>25 GeV and $|\eta|$<2.5
- at least 1 b-tagged jet (efficiencies: 70% b-jets, 20% c-jets, <1% light jets)
- additional cuts on leptonic W to reduce multijet background with fake leptons

Event yields

signal region

signal region

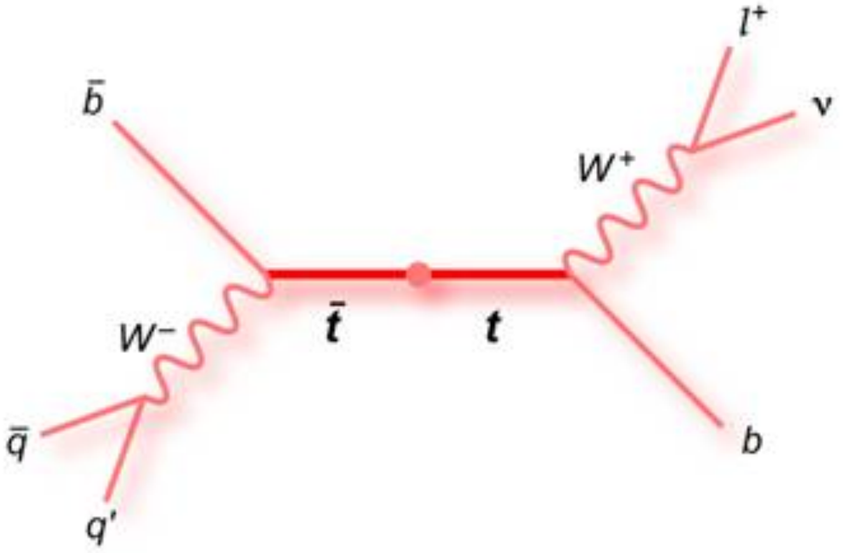


Channel	μ + jets pretag	μ + jets tag	e + jets pretag	e + jets tag
$t\bar{t}$	34900 ± 2200	30100 ± 1900	21400 ± 1300	18500 ± 1100
W+jets	28200 ± 3100	4800 ± 900	13200 ± 1600	2300 ± 900
Multi–jets	5500 ± 1100	1800 ± 400	3800 ± 1900	800 ± 400
Single top	2460 ± 120	1970 ± 100	1530 ± 80	1220 ± 60
Z+jets	3000 ± 1900	480 ± 230	3000 ± 1400	460 ± 220
Diboson	380 ± 180	80 ± 40	230 ± 110	47 ± 22
Total background	40000 ± 4000	9200 ± 1000	21700 ± 2900	4800 ± 1000
Signal + background	74000 ± 4000	39300 ± 2100	43100 ± 3100	23300 ± 1600
Observed	70845	37568	40972	21929

- Less events in e+jets due to tighter requirements on leptonic W to reduce the larger multijets background
- Normalization uncertainties are shown.
- Overall good agreement of data with predictions

Kinematic reconstruction

Top-antitop pair system fully reconstructed with kinematic likelihood fit.



Likelihood input:

- 4-momenta of four jets
- 4-momentum of the lepton
- missing transverse momentum

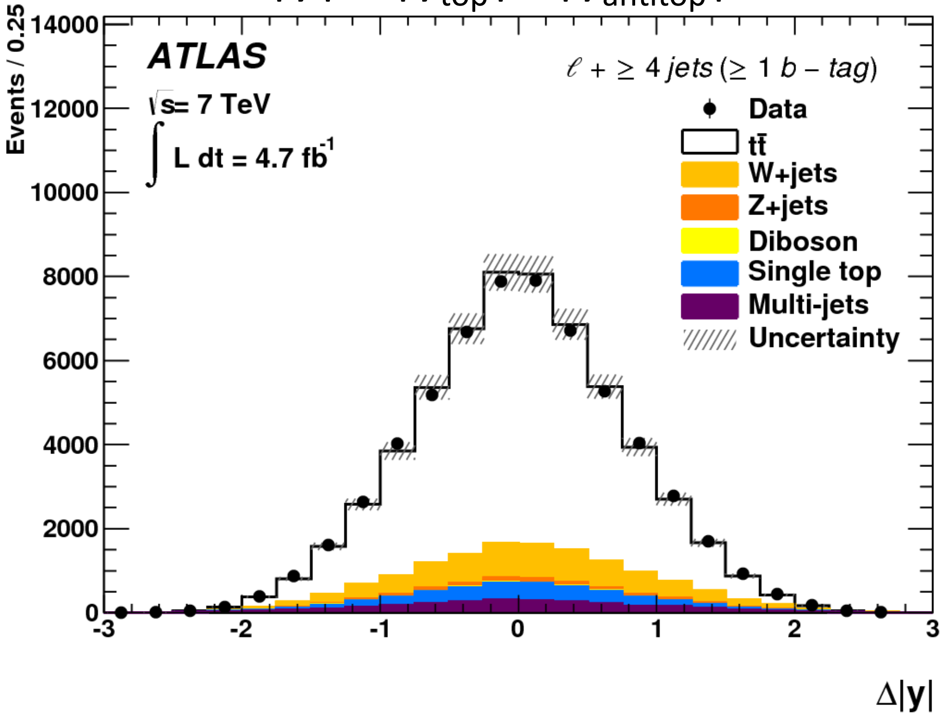
Constraints:

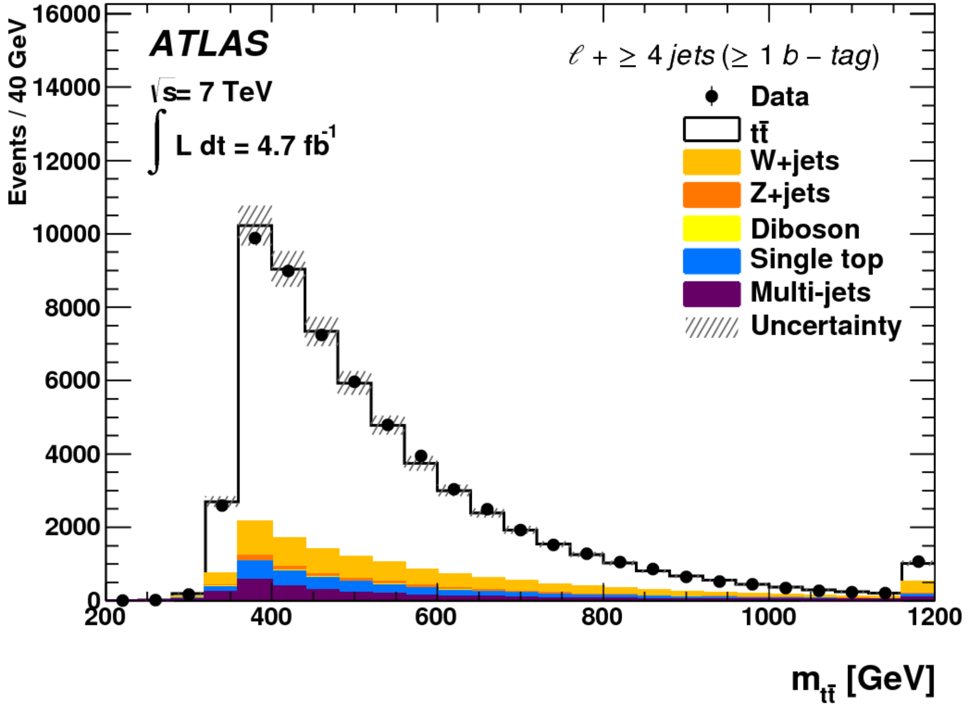
m_t=172.5 GeV, Γ_t=1.5 GeV
m_W=80.4 GeV, Γ_W=2.1 GeV

$$
\begin{aligned}
L \; = \; & \left.\begin{aligned} & \mathcal{B}(\widetilde{E}_{\mathrm{p},1}, \widetilde{E}_{\mathrm{p},2} | m_W, \Gamma_W) \cdot \mathcal{B}(\widetilde{E}_l, \widetilde{E}_\nu | m_W, \Gamma_W) \cdot \\ & \mathcal{B}(\widetilde{E}_{\mathrm{p},1}, \widetilde{E}_{\mathrm{p},2}, \widetilde{E}_{\mathrm{p},3} | m_t, \Gamma_t) \cdot \mathcal{B}(\widetilde{E}_l, \widetilde{E}_\nu, \widetilde{E}_{\mathrm{p},4} | m_t, \Gamma_t) \cdot \end{aligned}\right\} \text{Breit-Wigner's for top quarks and W bosons} \\
& \mathcal{W}(\hat{E}_x^{miss} | \widetilde{p}_{x,\nu}) \cdot \mathcal{W}(\hat{E}_y^{miss} | \widetilde{p}_{y,\nu}) \cdot \mathcal{W}(\hat{E}_{\mathrm{lep}} | \widetilde{E}_{\mathrm{lep}}) \cdot \; \rightarrow \text{energy transfer functions} \\
& \prod_{\mathrm{i}=1}^{4} \mathcal{W}(\hat{E}_{\mathrm{jet,i}} | \widetilde{E}_{\mathrm{p,i}}) \cdot \boxed{P(b \text{ tag} \mid \text{quark})}, \; \rightarrow \text{favor b-tagged jets in b-positions}
\end{aligned}
$$

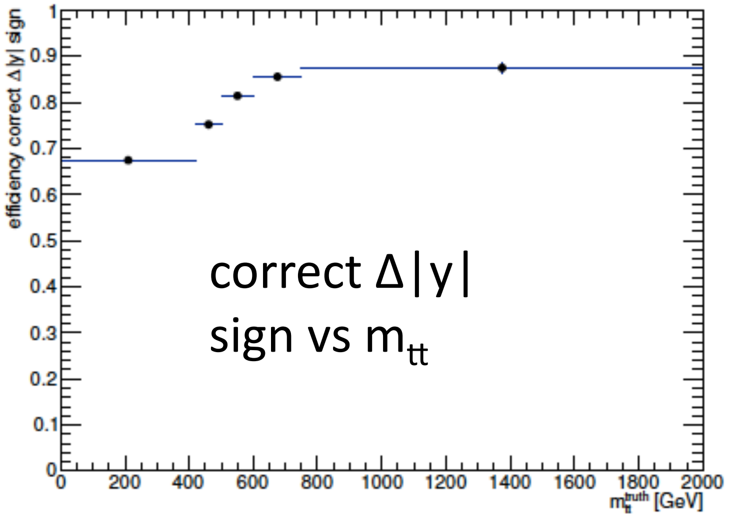
Reconstructed quantities

$\Delta|y| = |y_{top}| - |y_{antitop}|$





- Distortions from acceptance and resolution.
- Efficiency for correct sign of reconstructed Δ|y|: p~75%
  → dilution D=2·p-1~0.5 of the parton level asymmetry



correct Δ|y| sign vs m_{tt}

Unfolding

A_C in simulation (MC@NLO):
reconstructed Δ|y|: (0.3 ± 0.1)%
parton-level Δ|y|: (0.519 ± 0.030)%

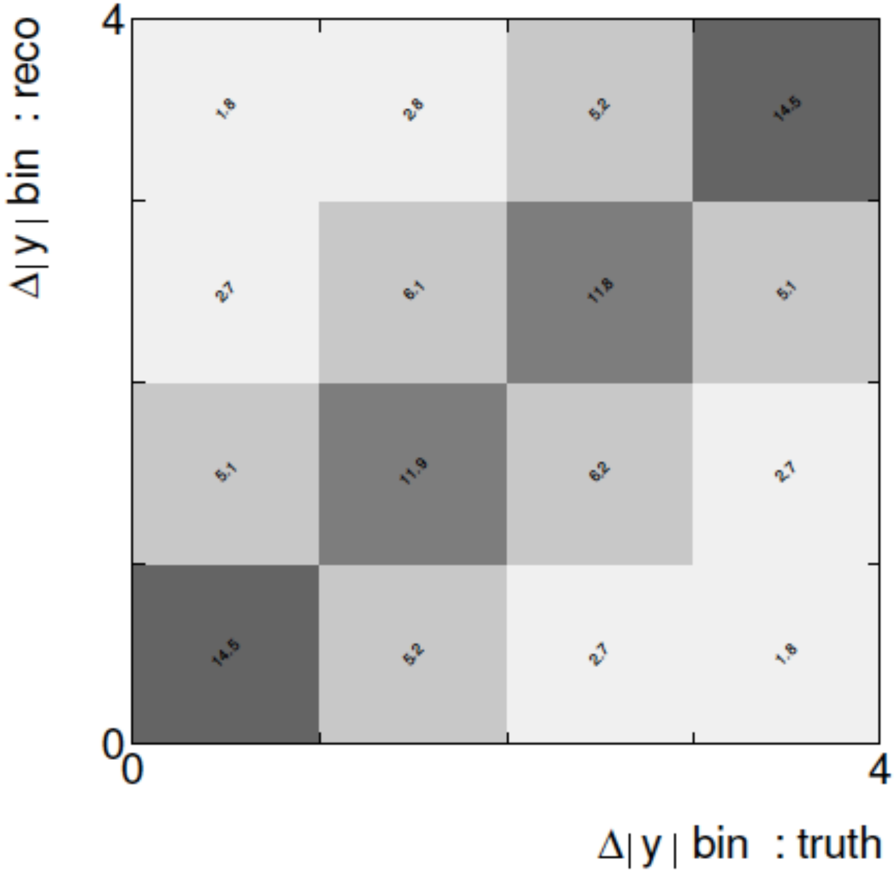
Estimates parton level A_C spectra to compare directly with theory.

map of event migrations from truth bins to reco bins

reconstructed Δ|y| distribution

$$R = M \cdot T$$

parton-level Δ|y| distribution



- Fully Bayesian Unfolding
  - no explicit matrix inversion
  - prior choice determines bias
  - “automatic” handling of systematics and correlations

Fully Bayesian Unfolding

arXiv:1201.4612
https://pypi.python.org/pypi/fbu

T: Δ|y| distribution to estimate before resolution and acceptance effects.

D: Δ|y| distribution measured in data distorted by resolution and acceptance.

$$p(\mathrm{T}|\mathrm{D}) \propto \underline{\mathcal{L}(\mathrm{D}|\mathrm{T})} \cdot \underline{\pi(\mathrm{T})}$$

***L(D|T)*: likelihood of observing D given T. Compares the effect of acceptance and resolution on a given T with what is measured in data (D).**

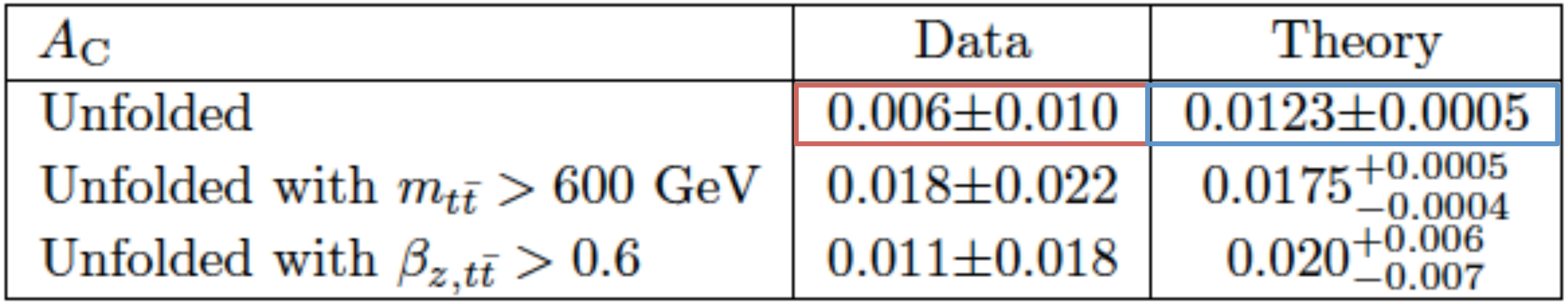
***π(T)*: prior probability for T. Encompass the prior knowledge or assumptions on the distribution T.**

The unfolding procedure estimates directly the probability density for A_C at the parton level.

Results – Inclusive A_C

- To date, most precise measurement for A_C @ √s=7 TeV.
- Measurement is limited by statistics.
- A_C compatible with 0 and SM predictions.

Theory predictions from
W. Bernreuther and Z.-G. Si, Phys. Rev. D 86 (2012) 034026



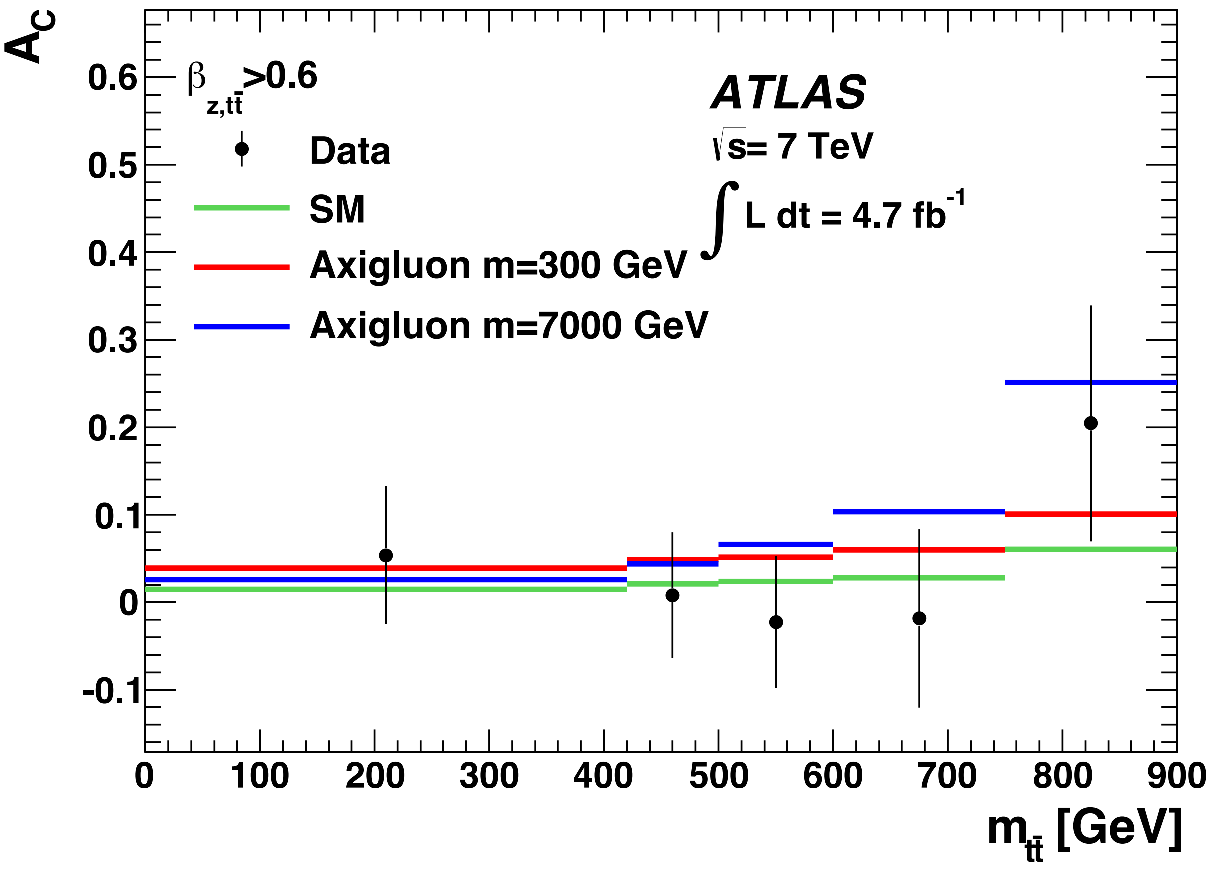
A_C	Data	Theory
Unfolded	0.006 ± 0.010	0.0123 ± 0.0005
Unfolded with $m_{t\bar{t}} > 600$ GeV	0.018 ± 0.022	$0.0175^{+0.0005}_{-0.0004}$
Unfolded with $\beta_{z,t\bar{t}} > 0.6$	0.011 ± 0.018	$0.020^{+0.006}_{-0.007}$

Uncertainties are (stat.+syst.)

- Statistical error is the dominant component.

Results – A_C vs m_{tt}

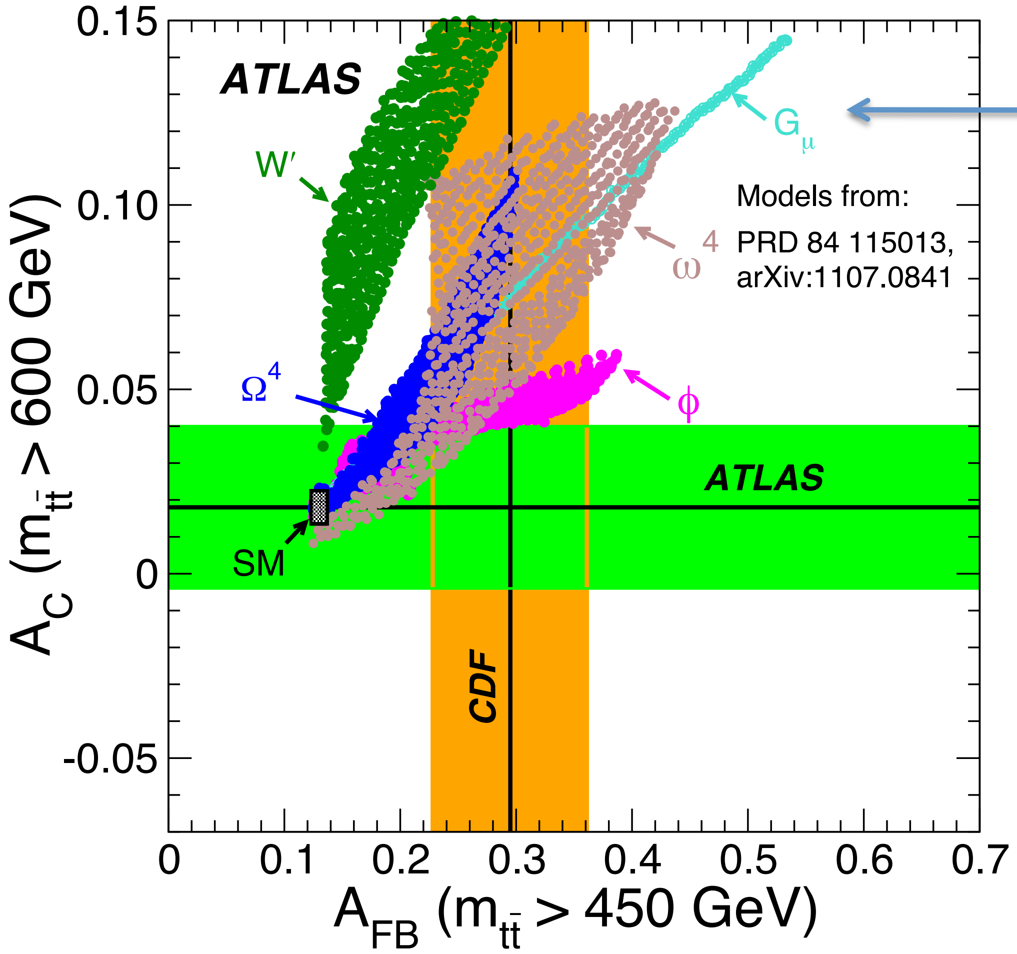
$\beta_{z,tt}>0.6$



The measured A_C spectra are compatible with both

- SM predictions
- Axigluon benchmarks with inclusive A_C/A_{FB} compatible with current Tevatron and LHC results

Results – Interpretation



NON-comprehensive set of BSM scenarios!

Axigluon models with opposite sign couplings with u and d quarks (not shown here) can be compatible with both A_C and A_{FB} (A_u/A_d cancellation at the LHC).

- Tevatron results show some tension with SM predictions
- LHC measurements are compatible with the SM predictions.
- The W' scenario is disfavored by the combination of A_C and A_{FB} measurements.

ATLAS - $\sqrt{s} = 8$ TeV

The ATLAS measurement at $\sqrt{s} = 8$ TeV will complete the A_C picture at the LHC.

A_C	$\sqrt{s} = 7$ TeV	$\sqrt{s} = 8$ TeV
Theory	0.0123 ± 0.0005	0.0111 ± 0.0004
CMS	0.04 ± 0.015 (stat. + syst)	0.005 ± 0.009 (stat. + syst.)
ATLAS	0.006 ± 0.010 (stat. + syst.)	?

6x top quark pair events
σ_A~0.5% for inclusive A_C

Expected significant reduction of statistical uncertainty wrt 7 TeV.
Understanding and constraint of systematics plays a significant role.

Outline

- Motivation – the A_{FB} puzzle
- The asymmetry at the LHC - A_C
- Early measurements at the LHC:
  ATLAS lepton+jets 1.04 fb^{-1} at √s=7 TeV Eur.Phys.J. C72 (2012) 2039
- Boosting the charge asymmetry Phys.Lett. B707 (2012) 92-98
- Charge asymmetry at ATLAS:
  lepton+jets 4.7 fb^{-1} at √s=7 TeV JHEP 02 (2014) 107
- A_C at √s=14 TeV with a photon handle arxiv:1402.3598

A_C with a photon handle

Shedding *light* on the $t\bar{t}$ asymmetry: the photon handle

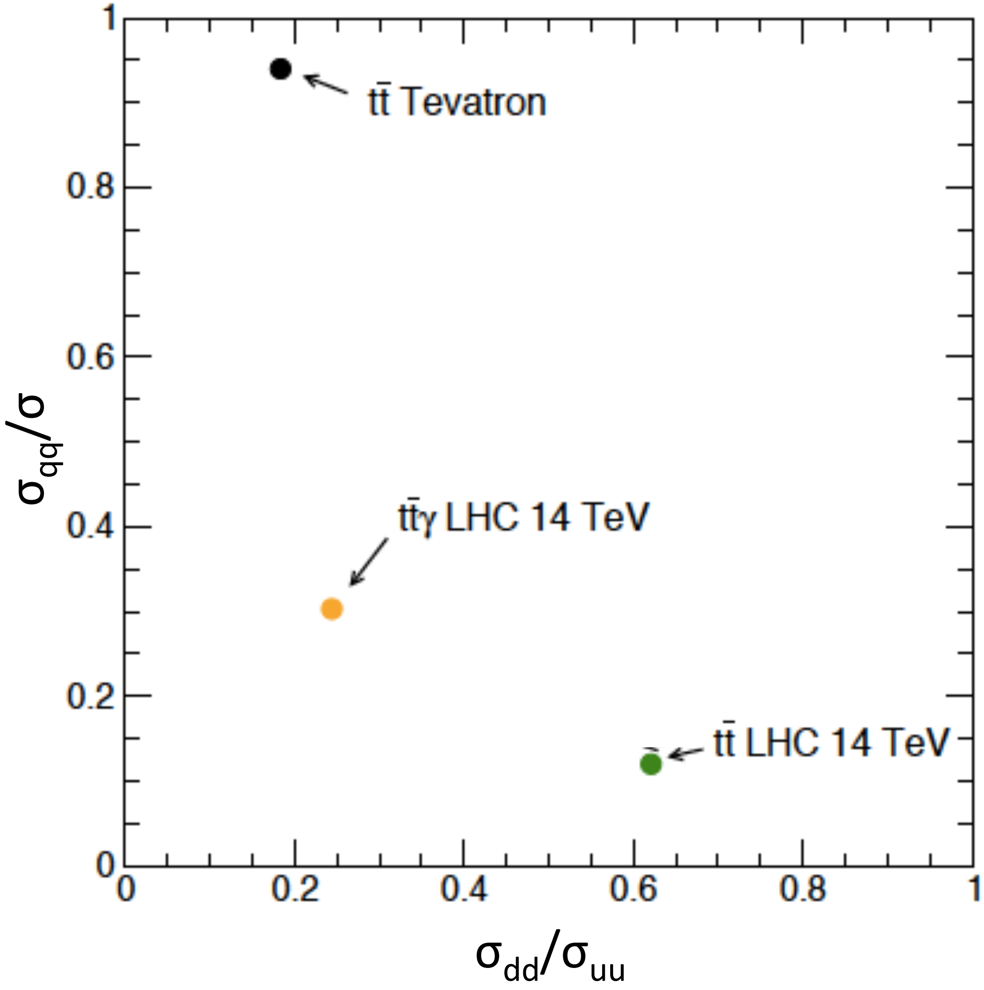
J. A. Aguilar–Saavedra[a], E. Álvarez[b], A. Juste[c,d], F. Rubbo[d]

arxiv:1402.3598

- At √s=14 TeV $q\bar{q} \rightarrow t\bar{t}$ events <10% →sensitivity for A_C washed out by gluon fusion events.
- Solution: measure A_C in $t\bar{t}\gamma$ events.
  - x2 higher $q\bar{q}$ fraction than in $t\bar{t}$
  - ~same $u\bar{u}/d\bar{d}$ as Tevatron

for $p_T(\gamma)$>20 GeV

- Small cross-section (2.73 pb) not an issue given the large amount of data expected in Run-II (100-400 fb^{-1})
- Breaks potential cancellation between $u\bar{u}$ and $d\bar{d}$ process.



Summary

- Precision top-quark phenomenology provides indirect probes of NP beyond EW scale. Production asymmetries of top quark pairs: sensitive to broad class of SM extensions, experimentally robust against systematic effects.

- First measurements at Tevatron indicated mild departure from SM predictions, raising significant interest.

- A_C @ LHC important to clarify experimental status: higher CM energy and luminosity

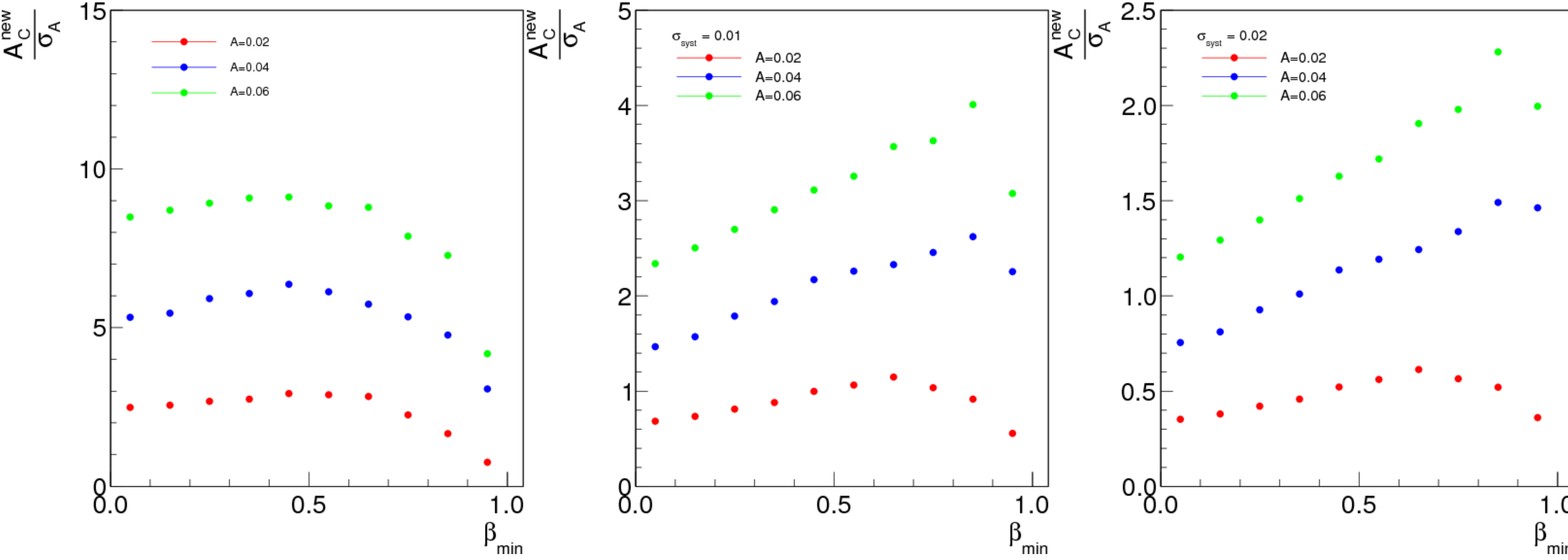
- ATLAS result most precise measurement at 7 TeV:
  - careful understanding of background modeling and associated systematics, as well as unfolding requirements.
  - differential measurements bring important additional information.
  - 8 TeV measurement underway will represent significant step forward in precision due to larger statistics and further experimental refinements.

- Measurement at 14 TeV will be challenging due to further wash out of asymmetry from increased gg fraction. Possible solutions:
  - increase $q\bar{q}$ using kinematics (already exercised in 7 TeV measurements)
  - exploit other production modes, e.g. $t\bar{t}\gamma$

- Backup -

Significance of boosted A_C

- Significant improvement in sensitivity for systematics limited results



stat. only

syst 1%

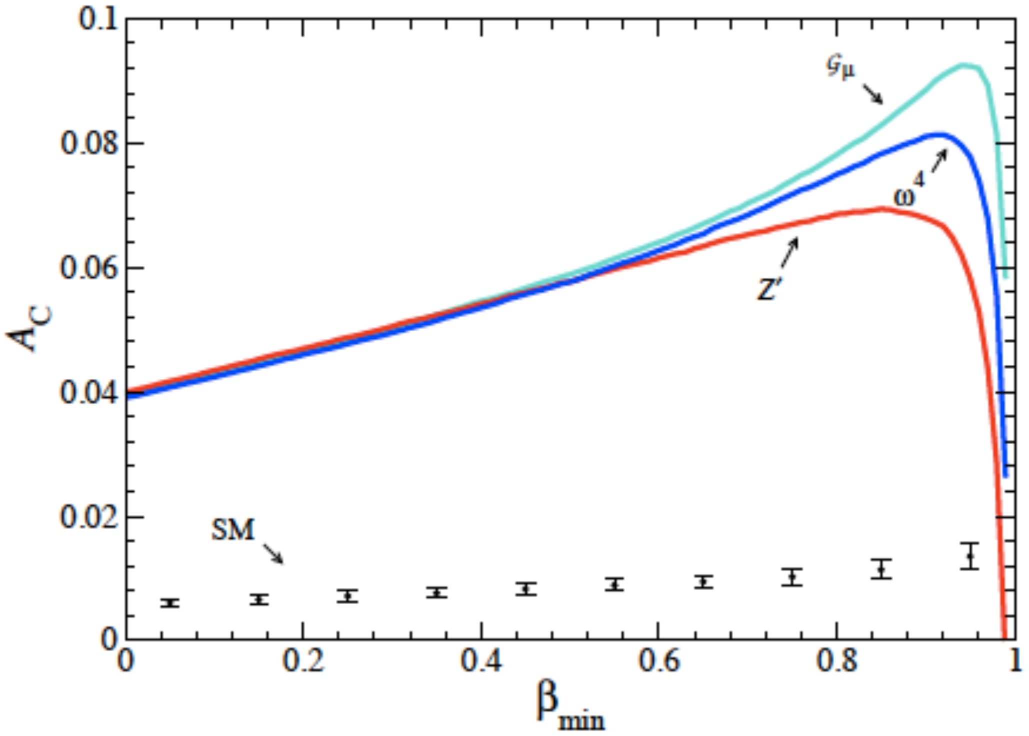
syst 2%

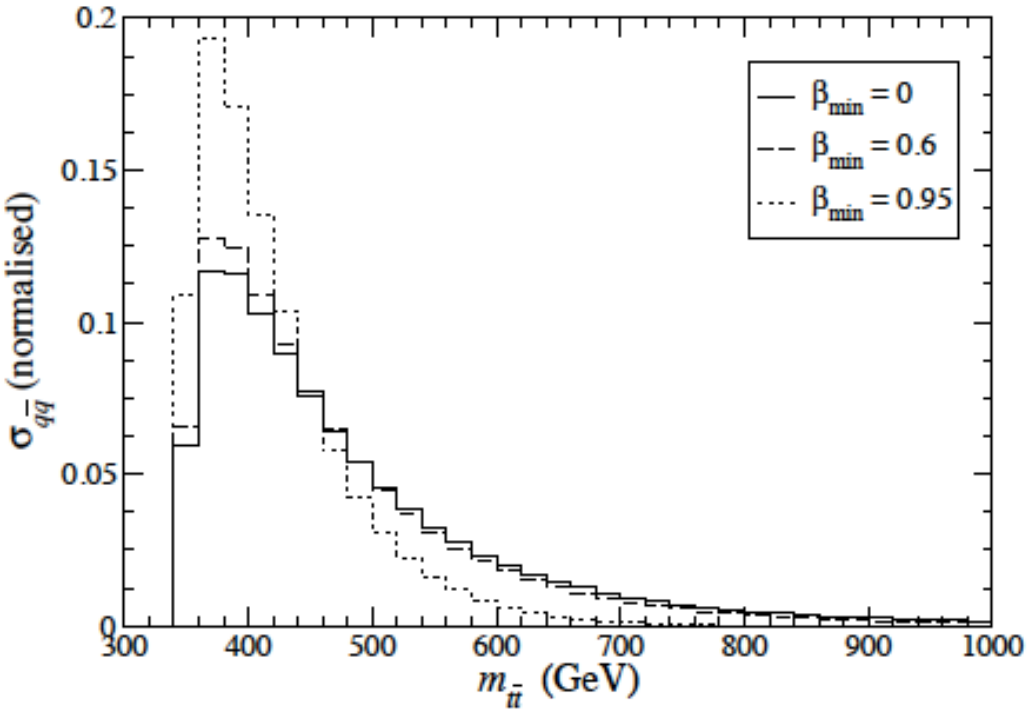
Int. luminosity: 10 fb^{-1} @ √s=7 TeV

Red: A_C=2% Blue: A_C=4% Green: A_C=6%

Boosted A_C - m_{tt}

At very high β (~0.9) the m_{tt} distribution is distorted, thus introducing model dependence.



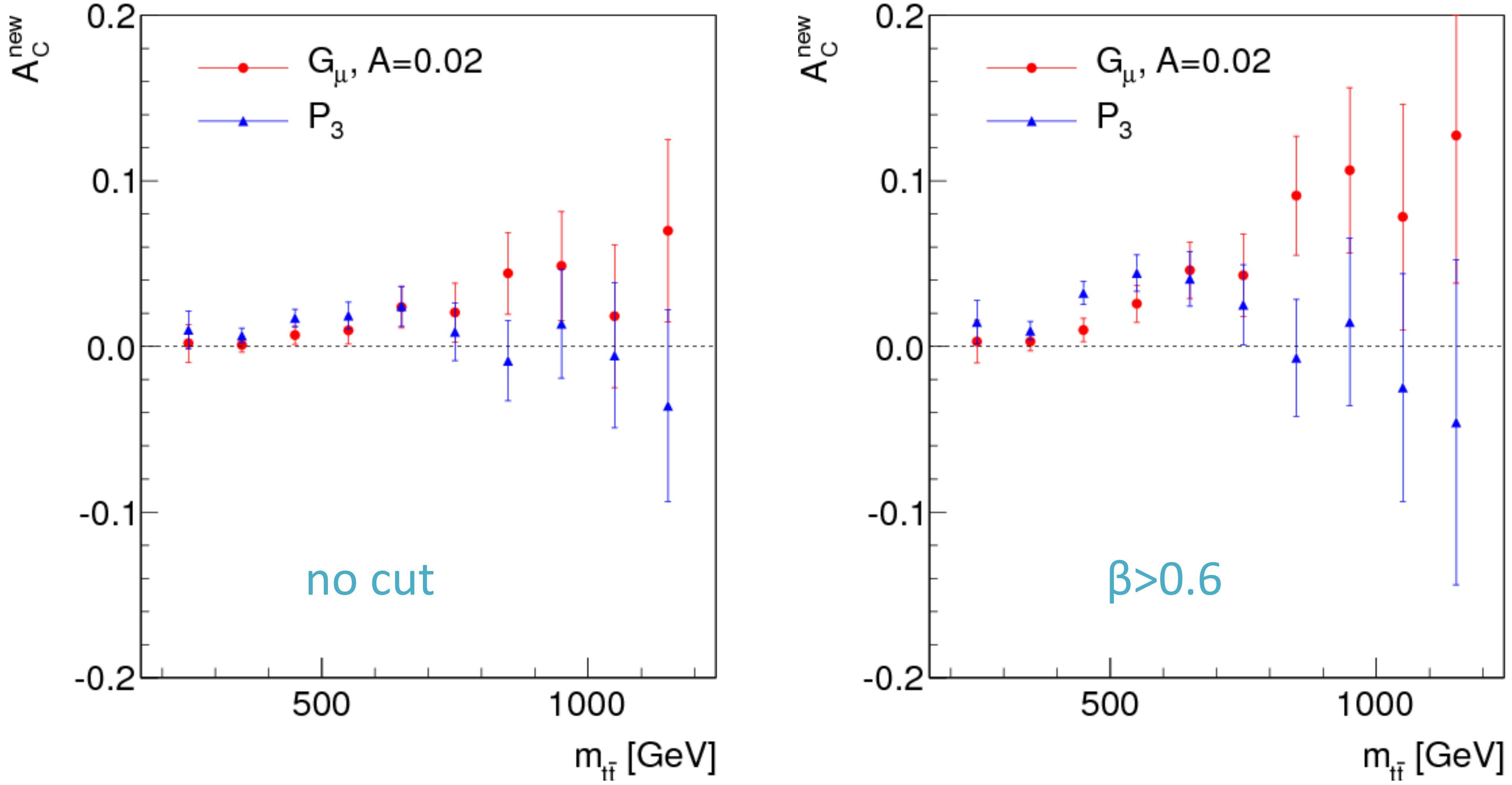


Boosted A_C

- Cutting on β improves model discrimination.

G_μ: heavy axigluon, M=7 TeV

P_3: light axigluon, M=850 GeV

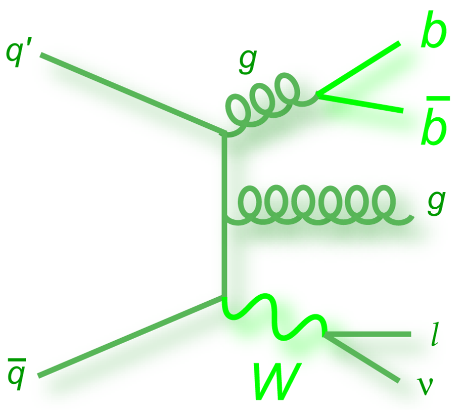


Int. luminosity: 10 fb^{-1} @ √s=7 TeV, 1% systematic uncertainty

Backgrounds

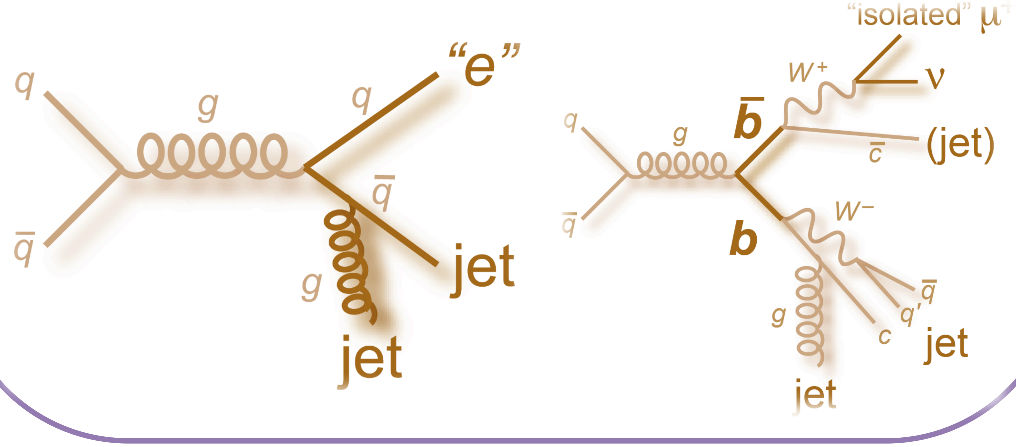
W+jets

- Largest background (~15%)
- Residual "top" charge asymmetry from $W^+/W^- \neq 1$
- Large uncertainties on predictions for overall normalization and flavor composition



Multijets

- Charge symmetric
- Huge x-sec but tiny acceptance (~5% background in l+jets selection)
- Hard to model fake lepton rates →use of simulation not practical
- Estimate rate and shape from data



Other backgrounds (<5%) from simulation: Z+jets, single top, diboson

W+jets estimation

- Shapes from simulation

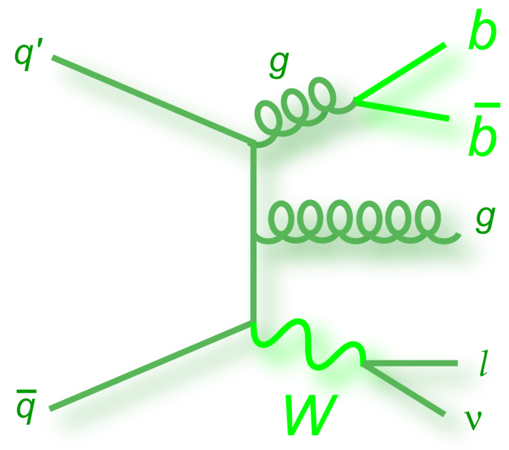
- Normalization extracted from data exploiting W charge asymmetry

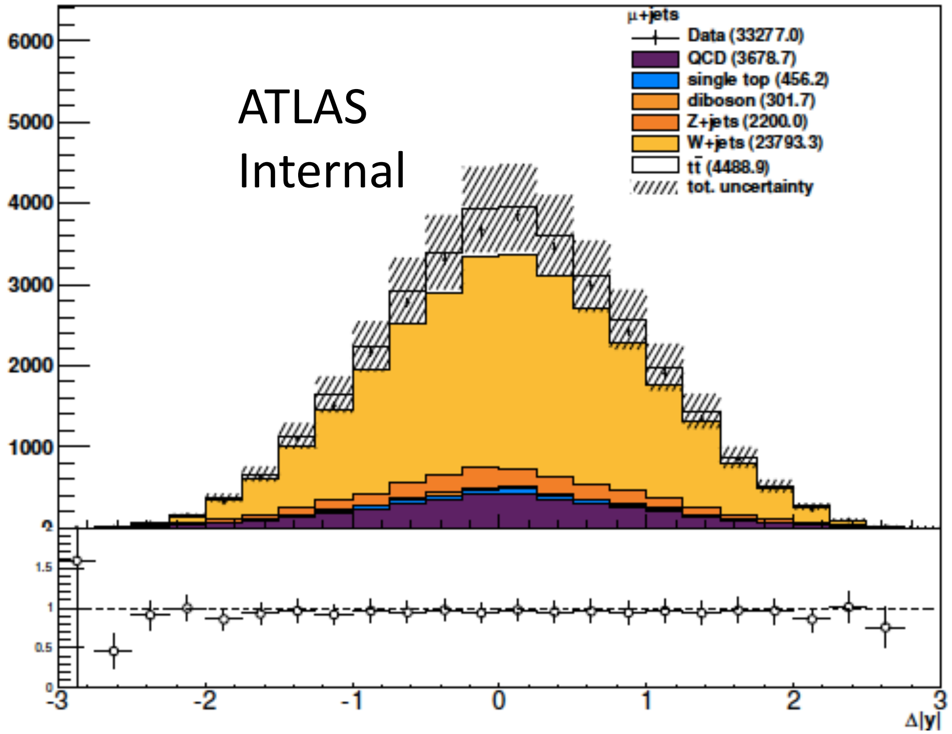
$$N_W = (N_{W^+} + N_{W^-}) = \frac{r_{MC}+1}{r_{MC}-1}\cdot (D^+ - D^-)$$

r_{MC} = W^+/W^- ratio from simulation
$D^{+(-)}$ = # of selected positive(negative) lepton events in data

- Simultaneous fit of normalization and flavor composition (W+bb/cc,W+c,W+light)

- Modeling is cross-checked in W+jets enriched control region (=0 b-jets)





Multijets estimation

- Fully data-driven estimates for shapes and rates
- Fake lepton-enriched **loose** selection

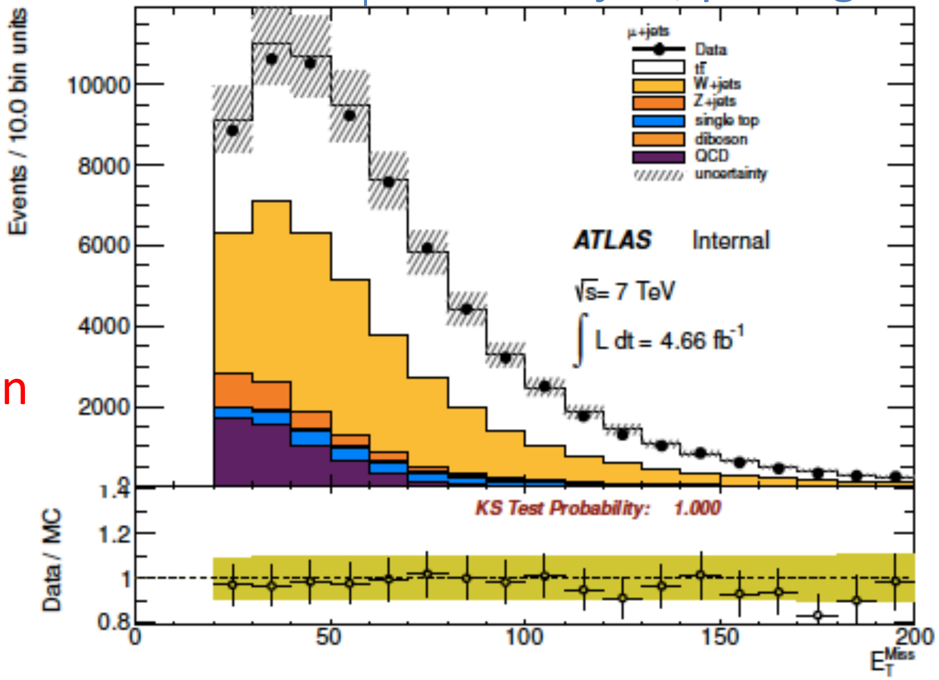
- Solve system of equations

fakes in signal region

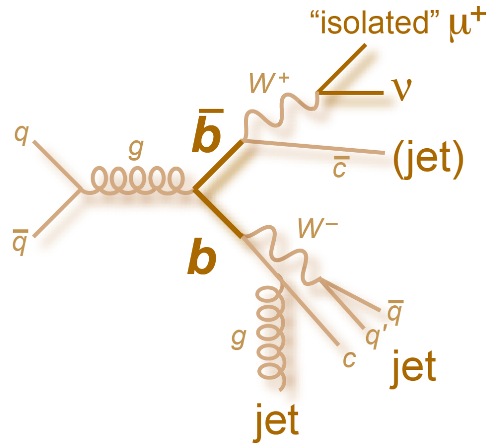
$$N^{loose} = N^{loose}_{real} + N^{loose}_{fake}$$

$$N^{tight} = \varepsilon_{real} \cdot N^{loose}_{real} + \boxed{\varepsilon_{fake} \cdot N^{loose}_{fake}}$$

E_T^{Miss} in >=4 jets, pre-tag



- N^{tight} = # of events in **tight** selection
- N^{loose} = # of events in **loose** selection
- ε_{real} = efficiency of **tight** selection on **real** leptons
- ε_{fake} = efficiency of **tight** selection on **fake** leptons



FBU - Likelihood

$$\mathcal{L}(\mathbf{D}|\mathbf{T}) = \prod_{i=1}^{n} Poisson(d_i, r_i(\mathbf{T}, \mathcal{M}))$$

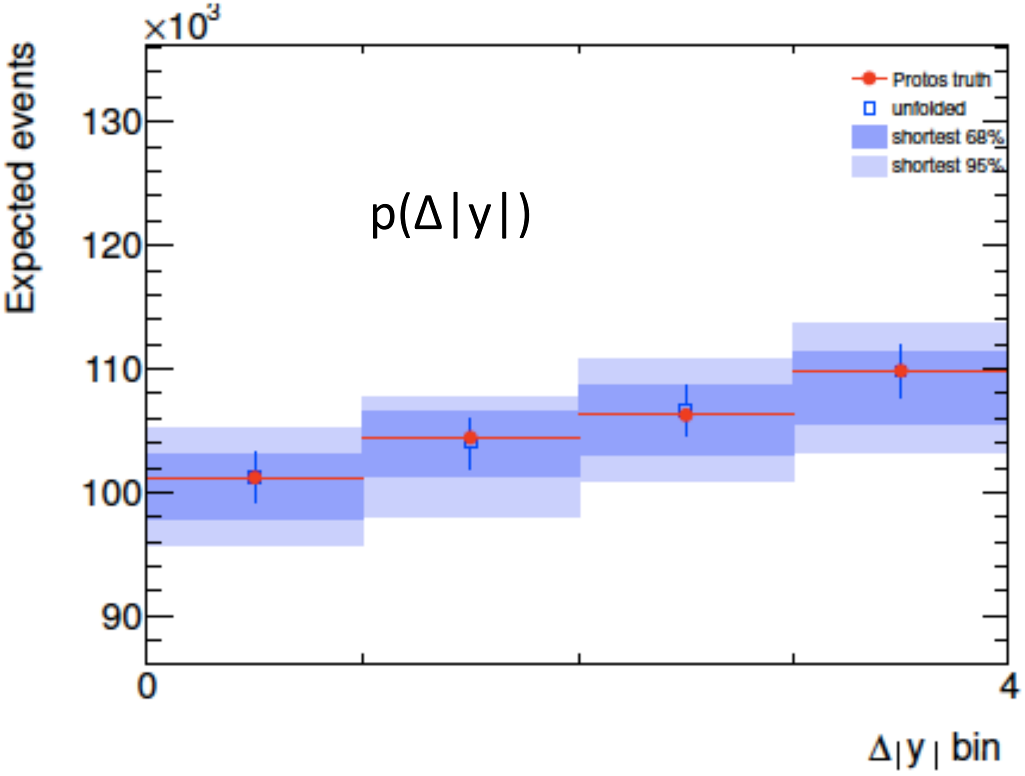
$$r_i(\mathbf{T}, \mathcal{M}) = \sum_{j=0}^{n} \epsilon(t_j) \boxed{p(r_i|t_j)}$$

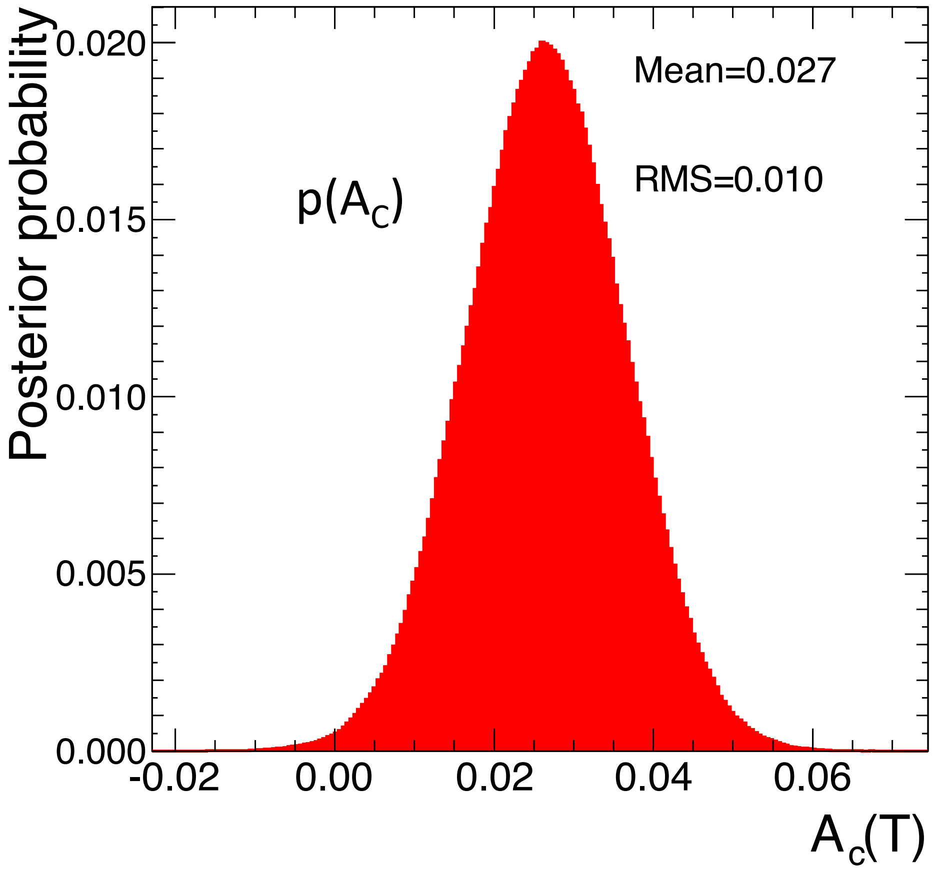
migration matrix *M*

- where d_i,r_i and t_i are the i-th bins of **D**,**R** and **T**.
- $\epsilon(t_i)$: acceptance for i-th bin.
- $p(r_i|t_j)$: probability for event in t_j to be reconstructed in r_i.

FBU – $p(A_C|D)$

The posterior probability for A_C is obtained from $p(\Delta|y|)$.





FBU - Background

The background prediction is included in the likelihood definition →NO background subtraction from distribution of data before unfolding.

$$\mathcal{L}(\mathbf{D}|\mathbf{T},\mathbf{B}) = \prod_{i=1}^{n} Poisson(d_i, r_i(\mathbf{T},\mathcal{M})+b_i)$$

FBU - Marginalization

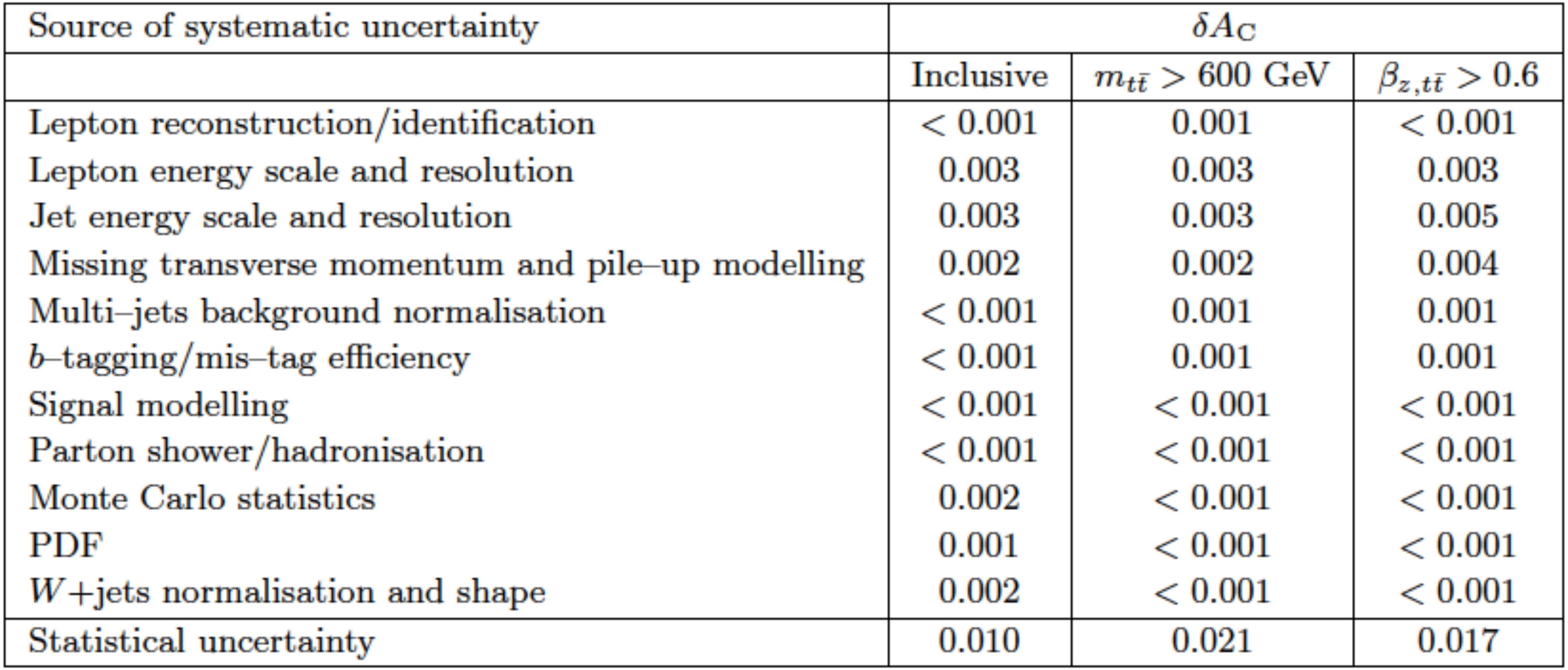
- Bayesian inference framework→ marginalization of systematics
- The posterior probability is integrated over the nuisance parameters.

$$p(\mathbf{T}|\mathbf{D}) \propto \int \mathcal{L}(\mathbf{D}|\mathbf{T}, \boldsymbol{\theta}) \cdot \pi(\mathbf{T})\, \mathrm{d}\boldsymbol{\theta}$$

nuisance parameters

- In √s=7 TeV l+jets results the integral is approximated with a weighted sum of nominal,+1σ,-1σ posterior probability distributions.

Systematics √s=7 TeV



Source of systematic uncertainty	δA_C		
	Inclusive	$m_{t\bar{t}} > 600$ GeV	$\beta_{z,t\bar{t}} > 0.6$
Lepton reconstruction/identification	< 0.001	0.001	< 0.001
Lepton energy scale and resolution	0.003	0.003	0.003
Jet energy scale and resolution	0.003	0.003	0.005
Missing transverse momentum and pile–up modelling	0.002	0.002	0.004
Multi–jets background normalisation	< 0.001	0.001	0.001
b–tagging/mis–tag efficiency	< 0.001	0.001	0.001
Signal modelling	< 0.001	< 0.001	< 0.001
Parton shower/hadronisation	< 0.001	< 0.001	< 0.001
Monte Carlo statistics	0.002	< 0.001	< 0.001
PDF	0.001	< 0.001	< 0.001
W+jets normalisation and shape	0.002	< 0.001	< 0.001
Statistical uncertainty	0.010	0.021	0.017

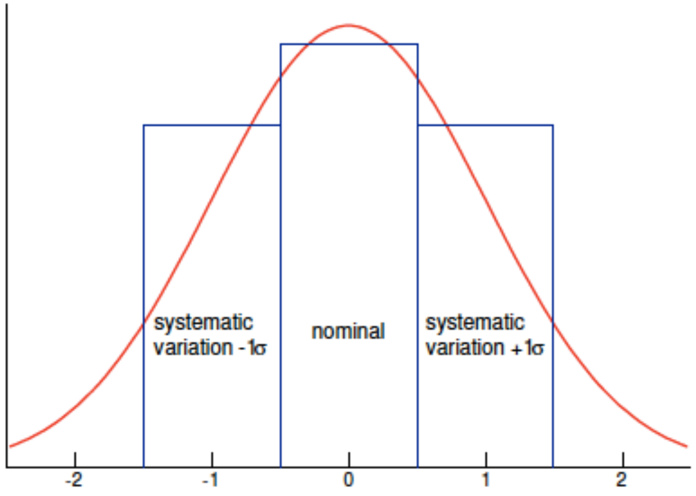
Average difference of the mean of $p(A_C)$ for +1σ/-1σ variation of the source of uncertainty.

FBU – systematics √s=7 TeV

- Statistical uncertainties $\gg$ systematics.
- Approximate marginalization as discrete weighted sum of nominal, $+1\sigma$, -1σ posteriors.

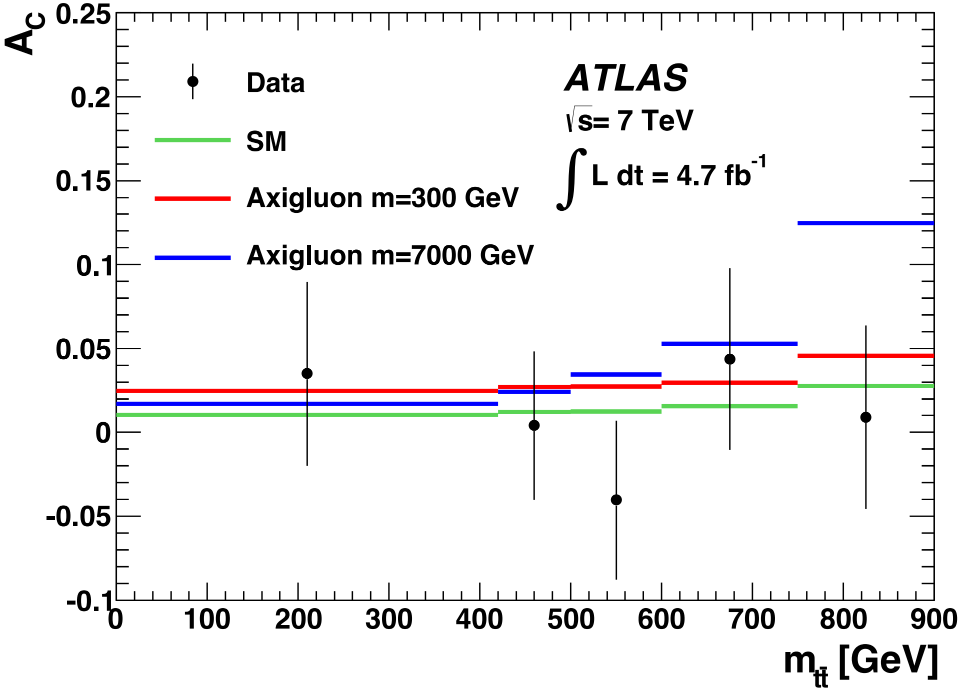
$$\int \mathrm{d}x p(x,y) \approx \sum_i p(x_i,y)\delta x_i \approx \sum_{x_i=-\sigma,0,+\sigma} p(x_i,y)\Delta x_i$$

- Compute weights Δx_i based on gaussian definition
- $\Delta x_{-\sigma} = \int_{-\infty}^{-0.5} \mathrm{d}x\, Gaus(x)$
- $\Delta x_0 = \int_{-0.5}^{+0.5} \mathrm{d}x\, Gaus(x)$
- $\Delta x_{+\sigma} = \int_{+0.5}^{+\infty} \mathrm{d}x\, Gaus(x)$



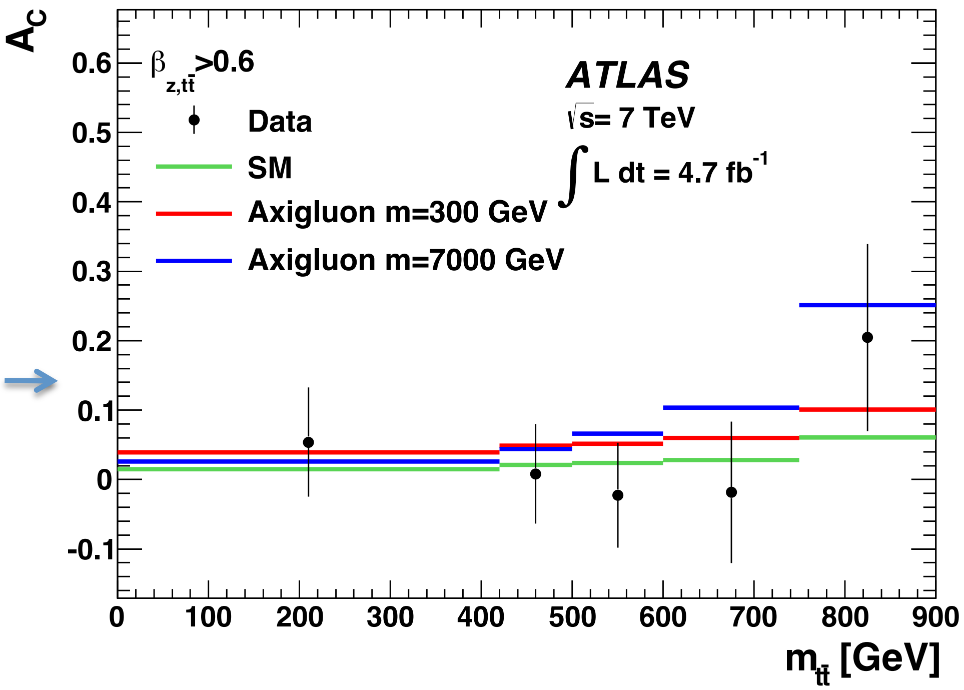
Results – A_C vs m_{tt}

no $\beta_{z,tt}$ cut



N.B. wider y-axis range →

$\beta_{z,tt}$>0.6

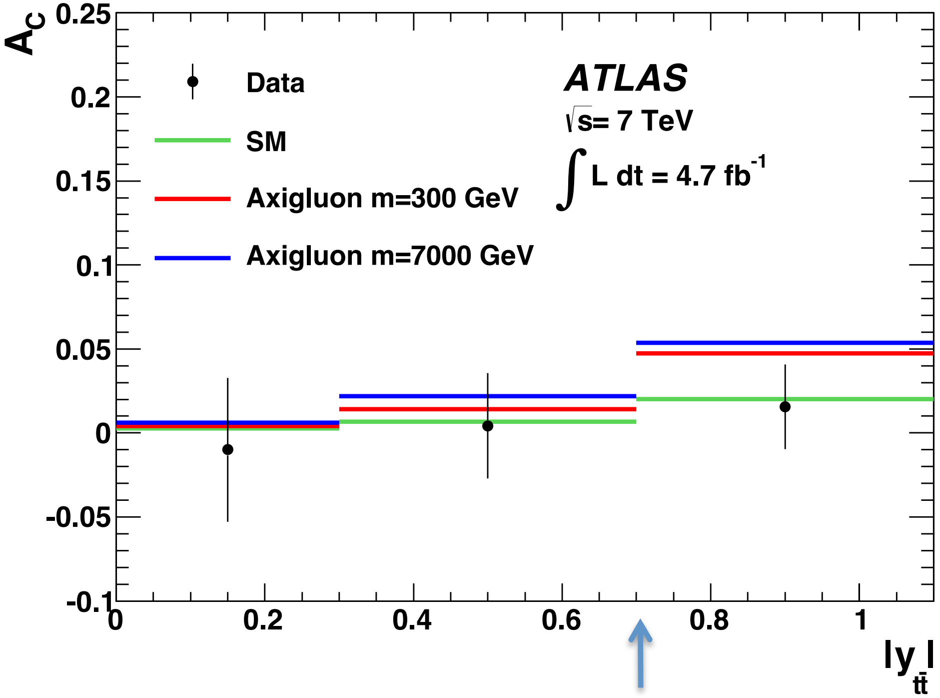


The measured $A_C(m_{tt})$ spectrum is compatible with both

- SM predictions
- Axigluon benchmarks with inclusive A_C compatible with current Tevatron and LHC results

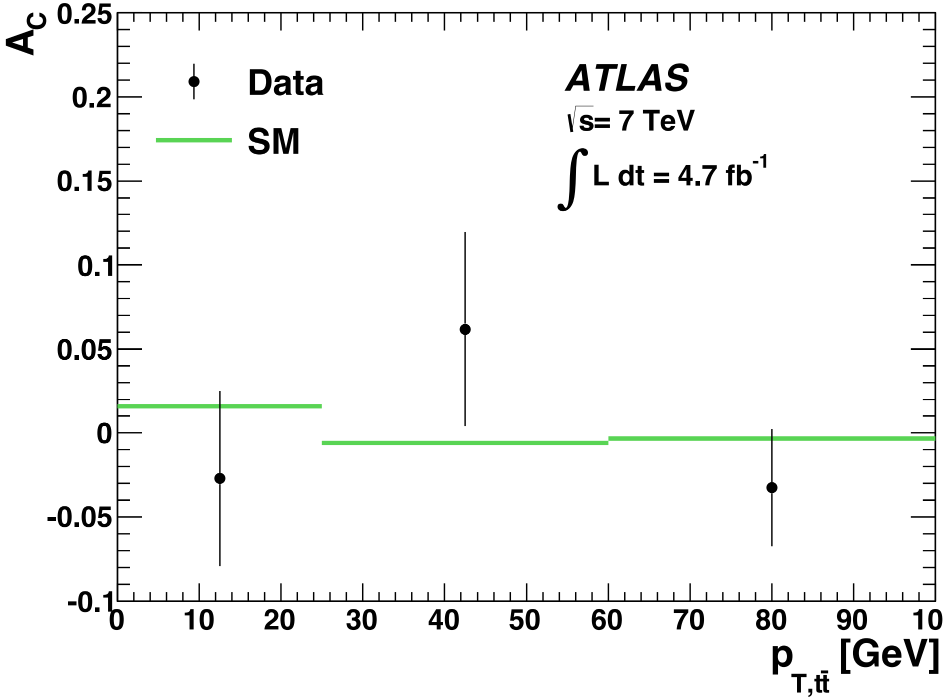
Results – A_C vs $|y_{tt}|$, $p_{T,tt}$

A_C vs $|y_{tt}|$



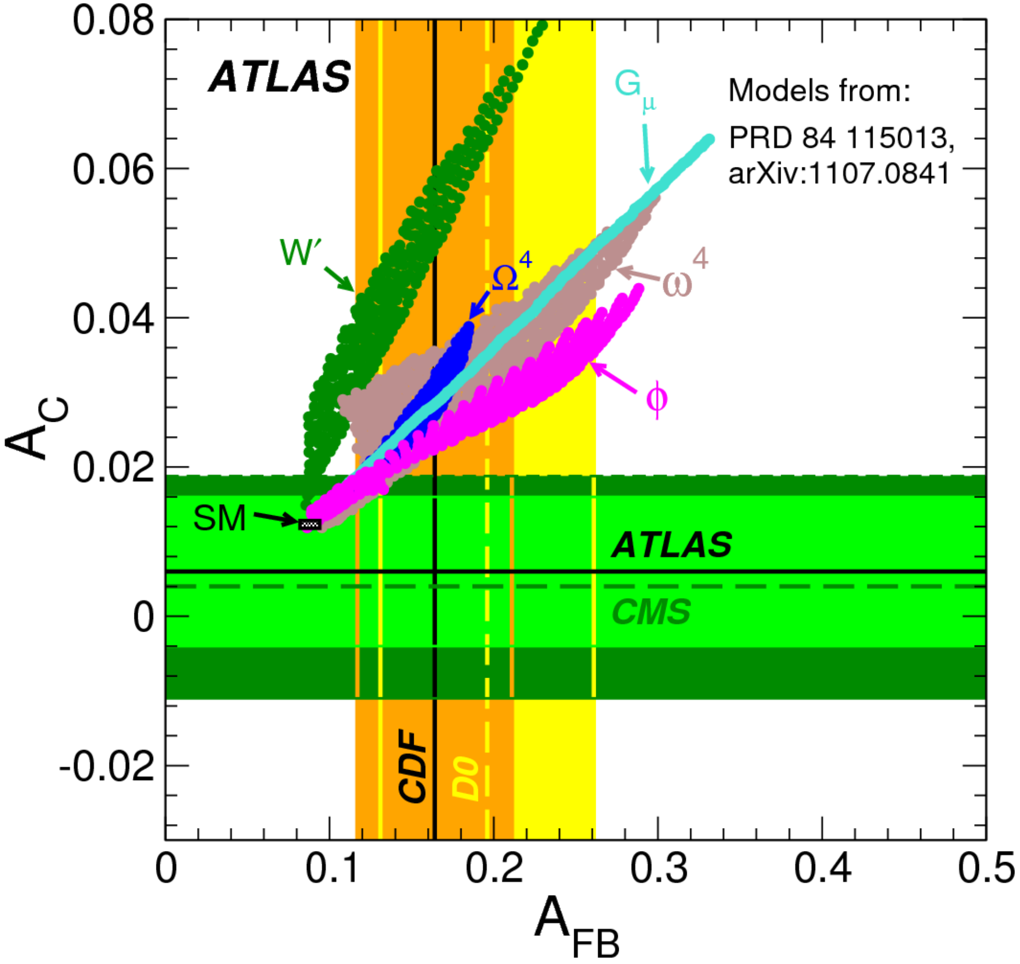
$\beta_{z,tt} \approx 0.6$

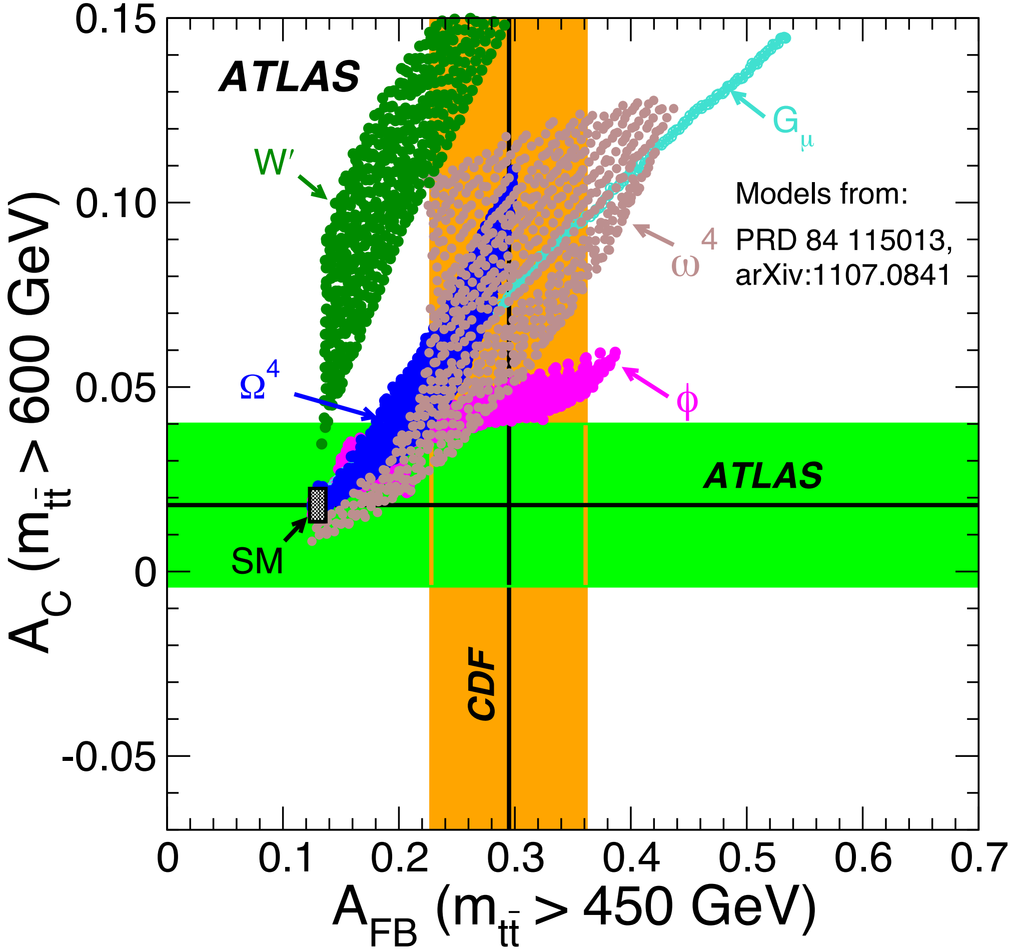
A_C vs $p_{T,tt}$



- Clear enhancement of A_C vs $|y_{tt}|$ (same as $\beta_{z,tt}$)
- Higher precision at high $|y_{tt}|$ due to better sign($\Delta|y|$) reconstruction
- Large uncertainties in A_C vs $p_{T,tt}$ due to migrations across $p_{T,tt}$ bins

Results – Interpretation





- Tevatron results show some tension with SM predictions
- LHC measurements are compatible with the SM predictions.
- The W’ scenario is disfavored by the combination of A_C and A_{FB} measurements.

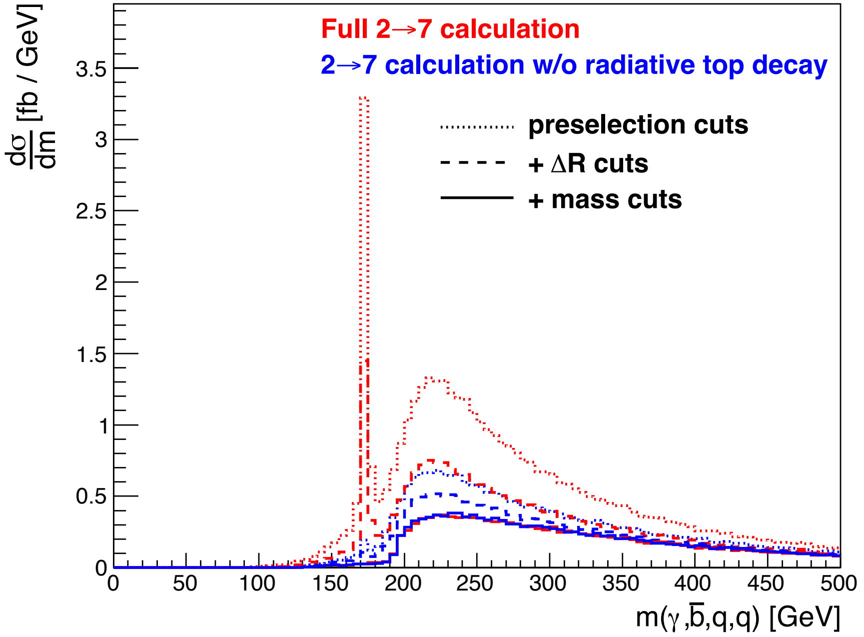
A_C with a photon handle

- veto radiative top decays: reject events satisfying either of the following conditions:

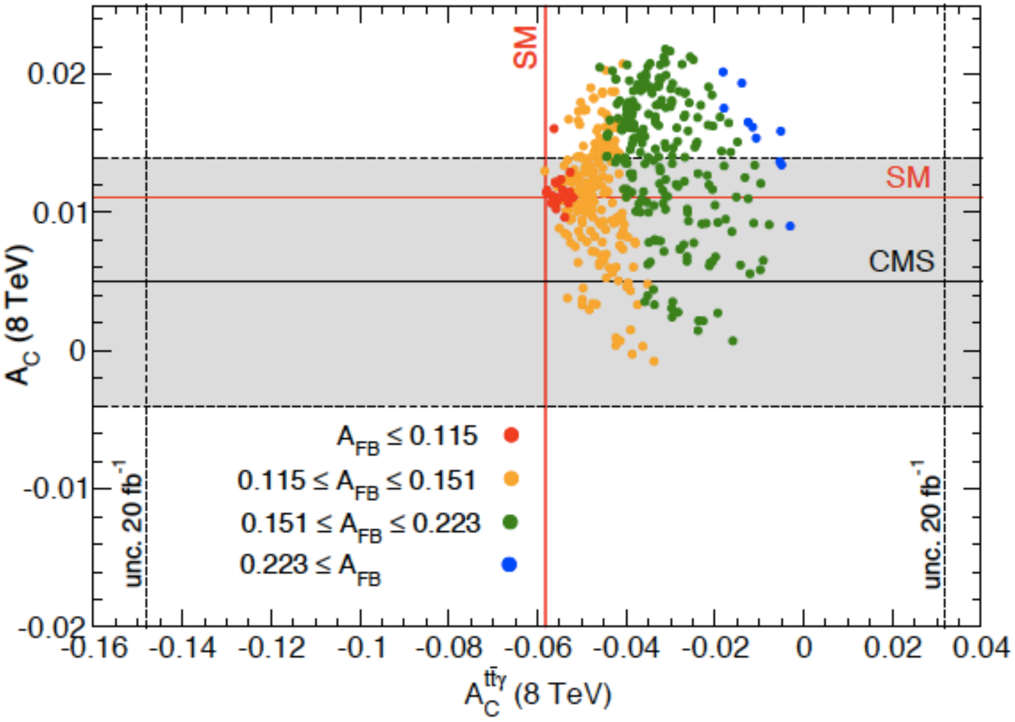
  1. $m_T(b_{1,2}\ell\gamma;\not{p}_T) < m_t + 20$ GeV and $m_t - 20$ GeV $< m(b_{2,1}jj) < m_t + 20$ GeV;
  2. $m_T(b_{1,2}\ell;\not{p}_T) < m_t + 20$ GeV and $m_t - 20$ GeV $< m(b_{2,1}jj\gamma) < m_t + 20$ GeV,

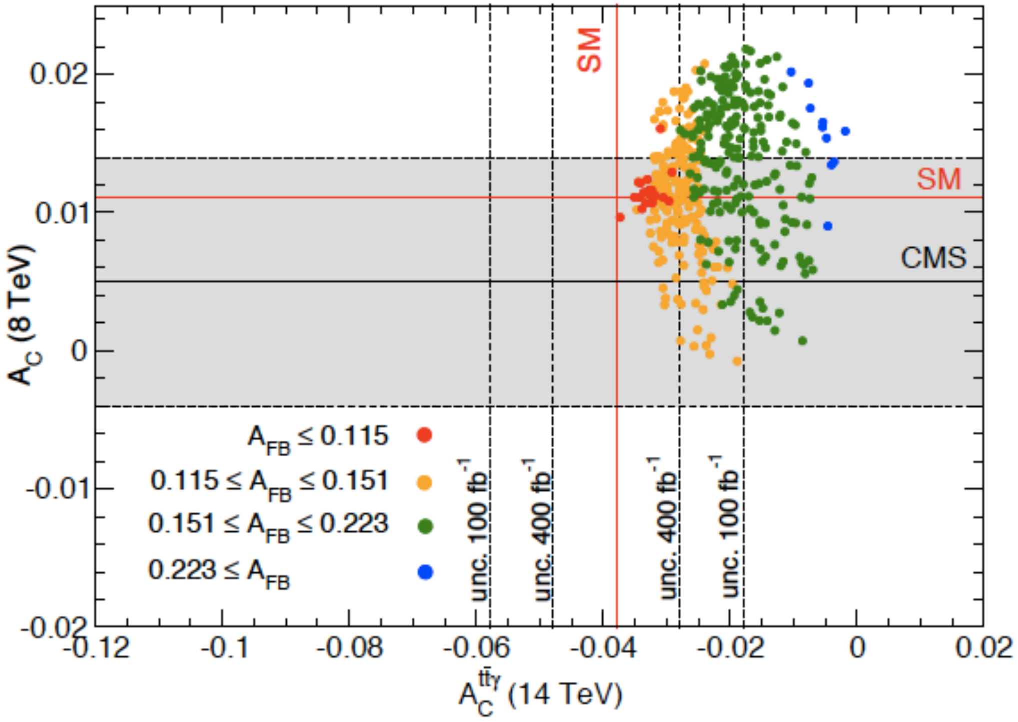
  where $b_1, b_2 = b, \bar{b}$, and $b_1 \neq b_2$;

- consistency with radiative top production: $m_T(b_{1,2}\ell;\not{p}_T) < m_t + 20$ GeV and $m_t - 20$ GeV $< m(b_{2,1}jj) < m_t + 20$ GeV.



A_C with a photon handle



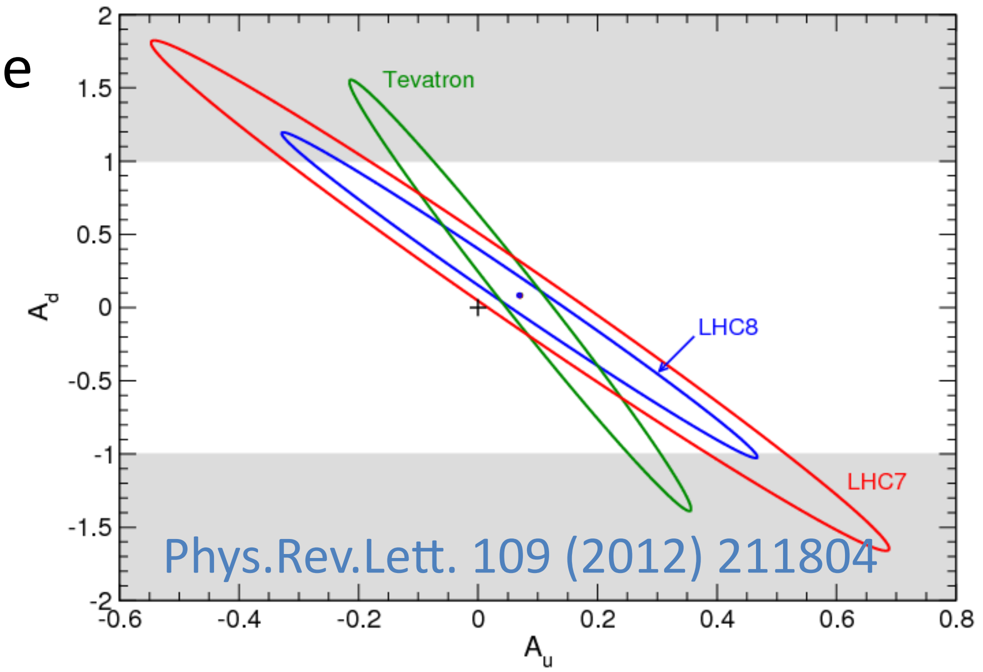


A_C relatives

Other important aspects to investigate at the LHC:

Precision measurements

- lepton asymmetry: sensitive to top polarization
- collider independent asymmetries A_u/A_d



Phys.Rev.Lett. 109 (2012) 211804

Direct searches

Run-II dataset will improve direct searches for asymmetry-related NP:

- multiple top quarks production (axigluon)
- same sign top quarks production (Z')
- top and bottom quark pairs associated production (axigluon)
- ...