Standard Model Measurements with the ATLAS Detector

Matthew Rudolph

University of Toronto

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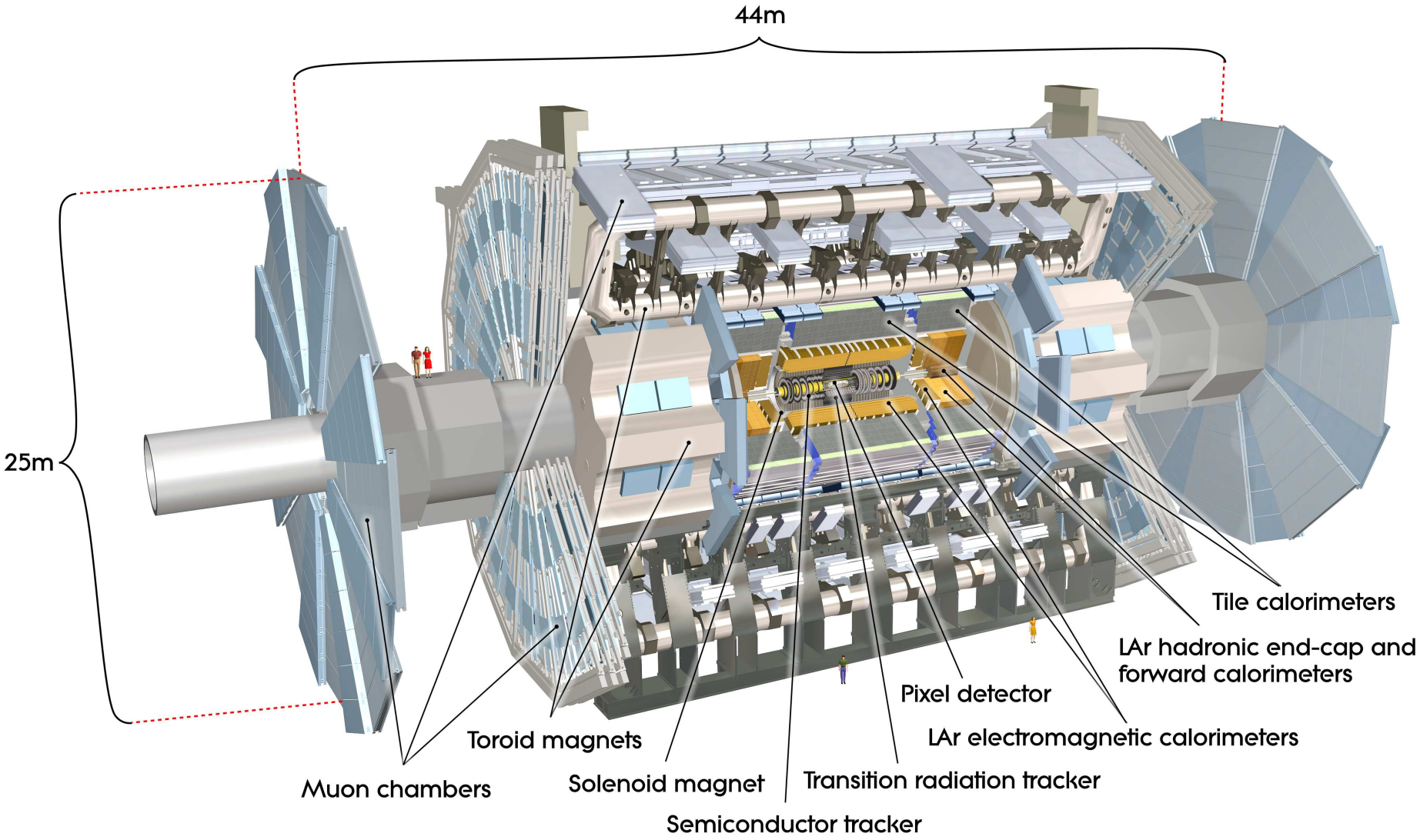
Introduction

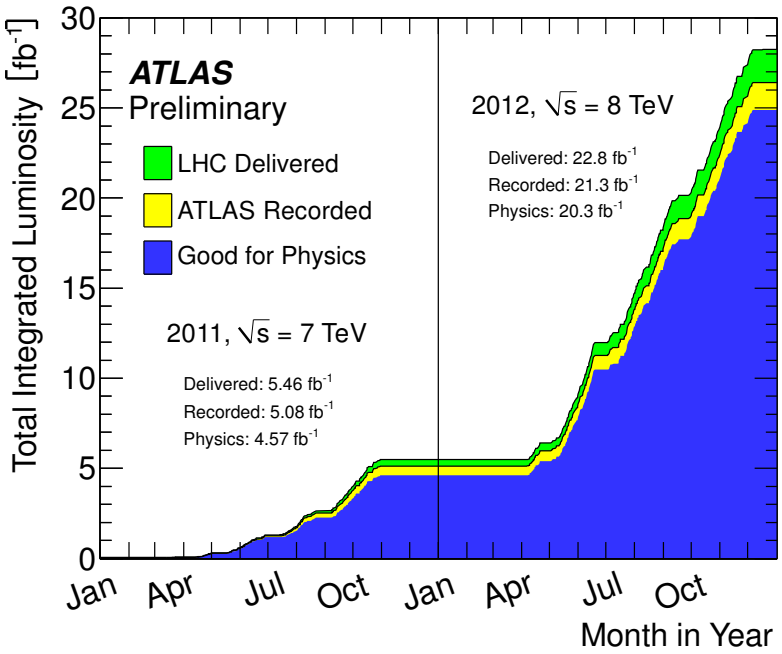
- ATLAS and the LHC unique position to probe the Standard Model
- High energy; high intensity; high precision
- Precision tests of Standard Model have the potential to reveal new physics without doing specific searches
- Many new results coming out even over long shutdown
- Detector understanding is key to getting the best results

The big picture



High energy – high intensity

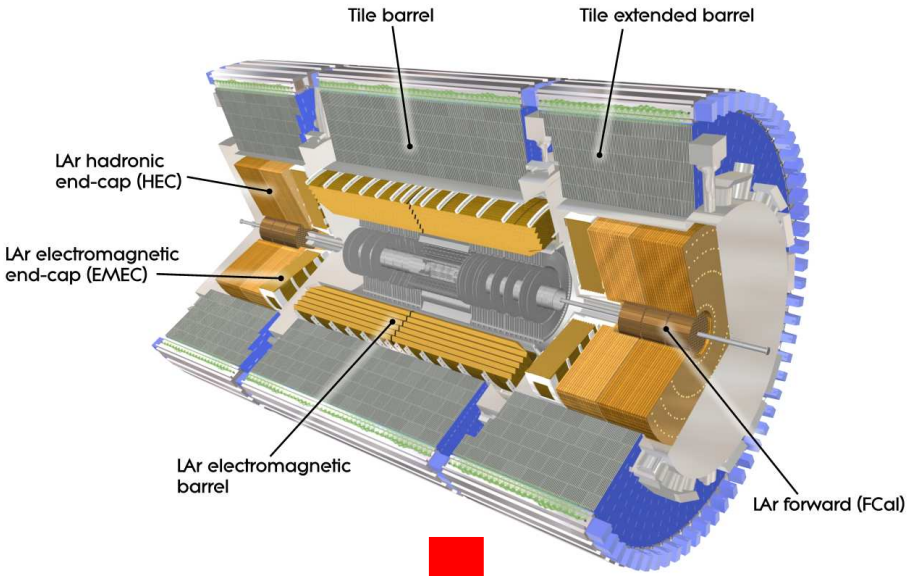
- Large datasets collected at 7 and 8 TeV
- $> 10^{15}$ collisions
- Detailed heavy particle production – vector boson (W, Z) and top quark
- Rare production and decay analyses possible

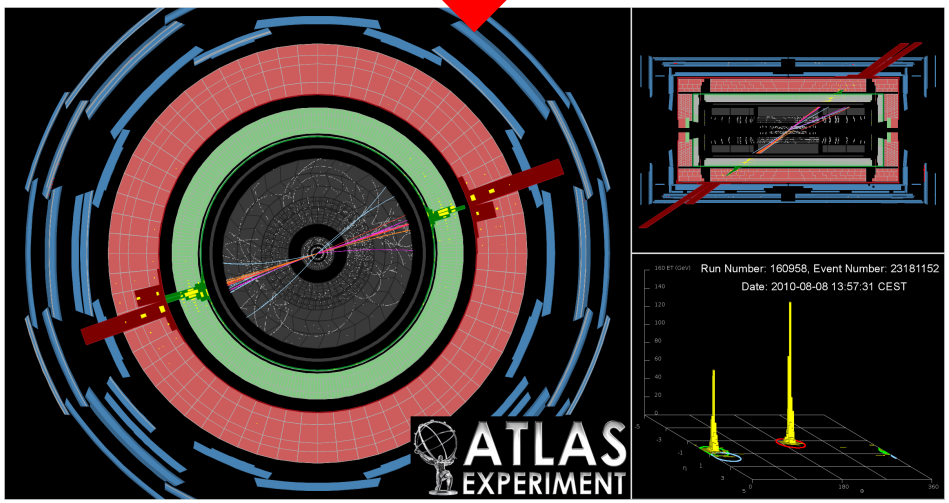


Eur.Phys.J. C73 (2013) 2518

plus preliminary 2012 result

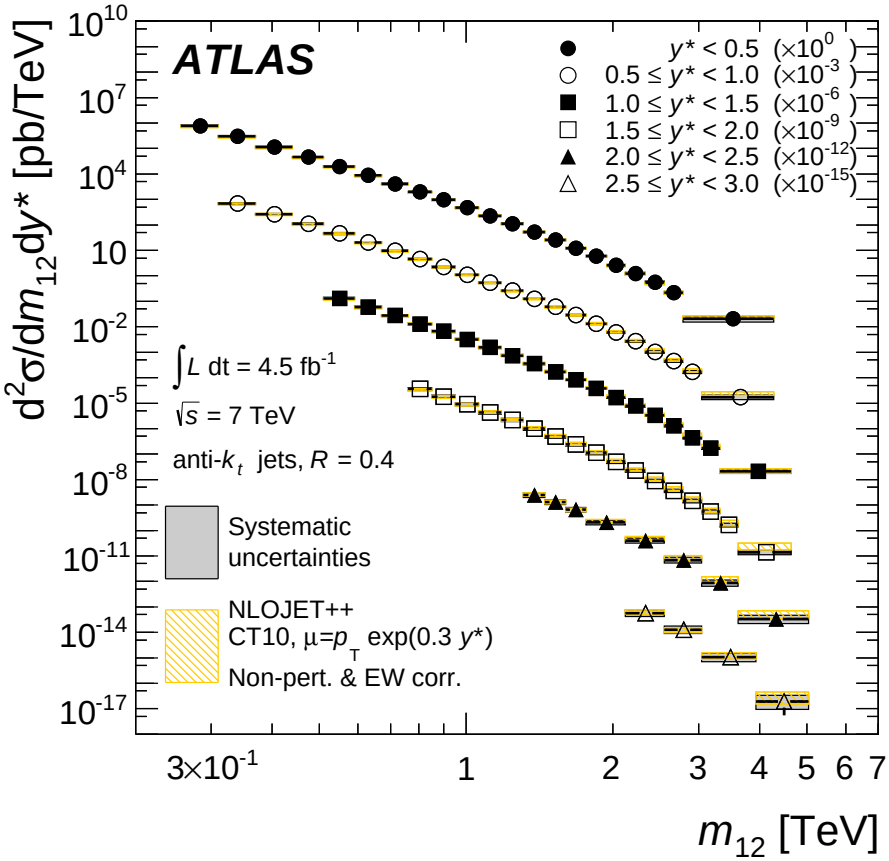
Calorimeters and jets





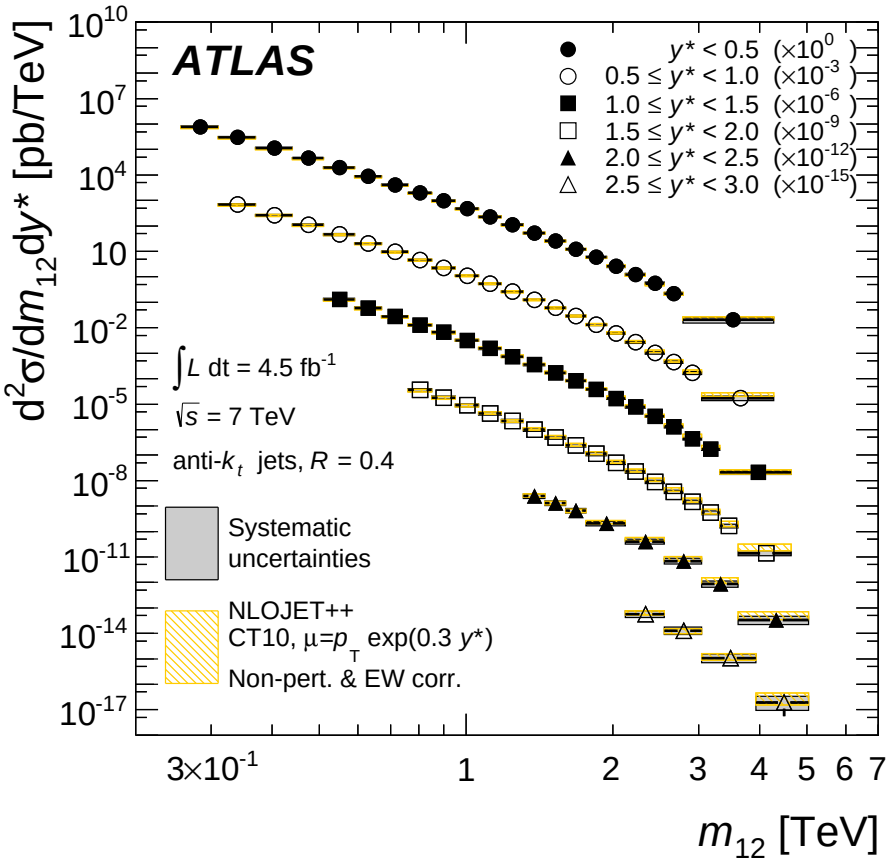
- Energy in calorimeter clustered into jets

Calorimeters and jets

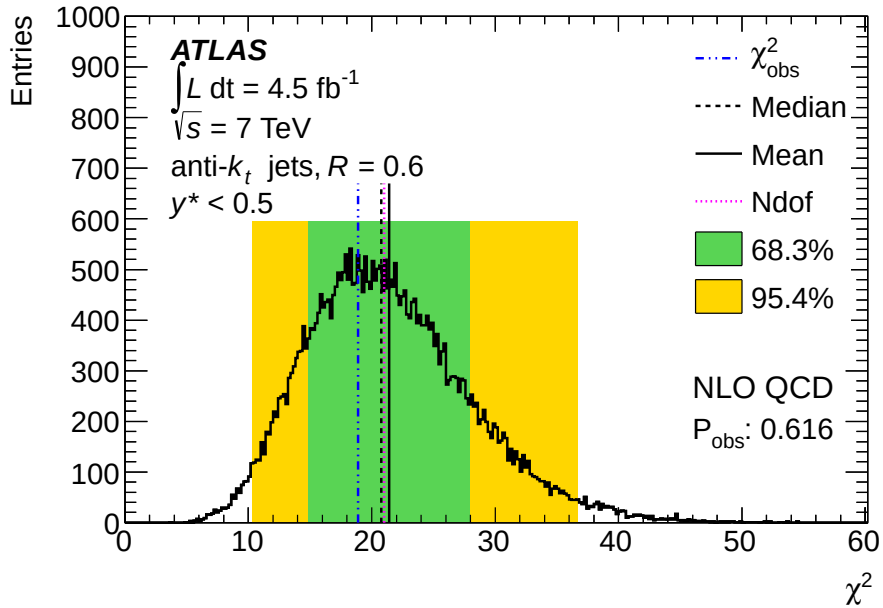


- Energy in calorimeter clustered into jets
- Measure dijet cross sections

Calorimeters and jets



- Energy in calorimeter clustered into jets
- Measure dijet cross sections
- Quantify agreement with QCD with χ^2 distribution of pseudodata



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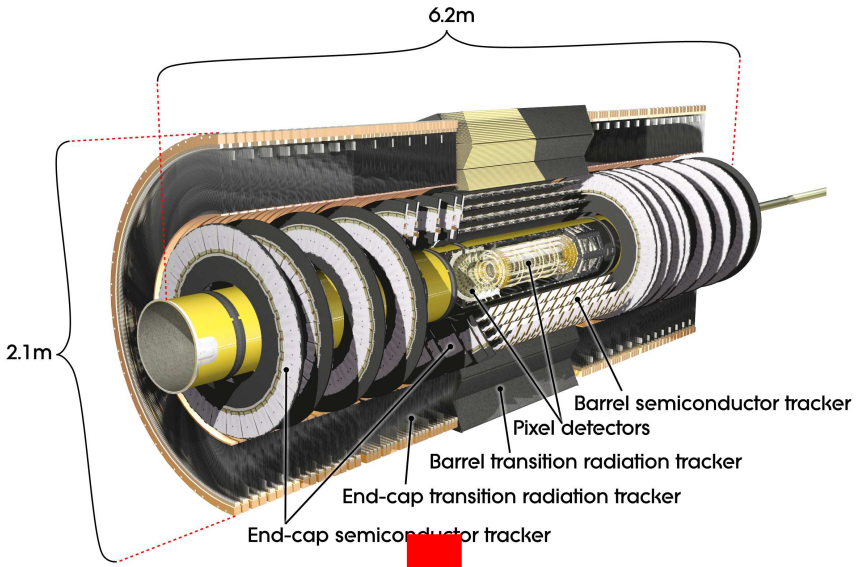
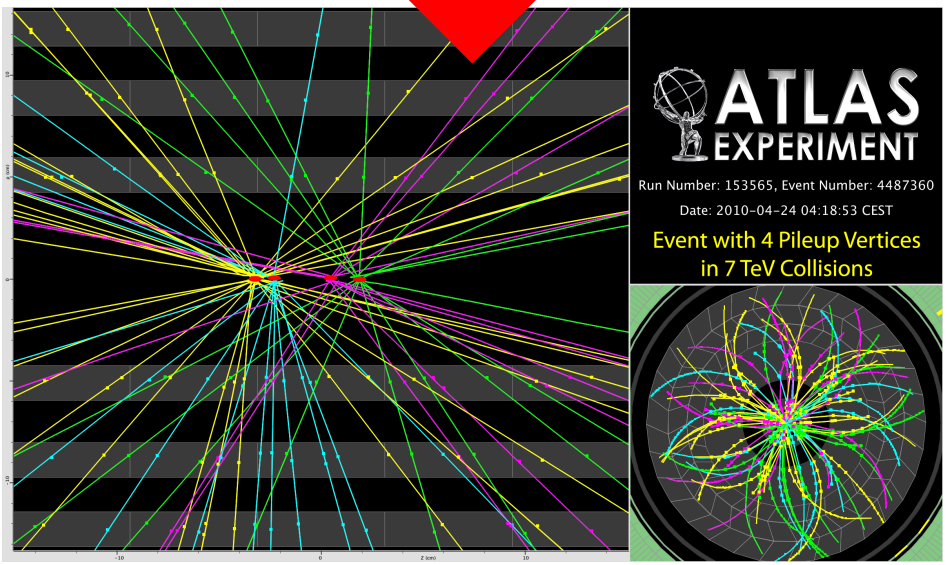
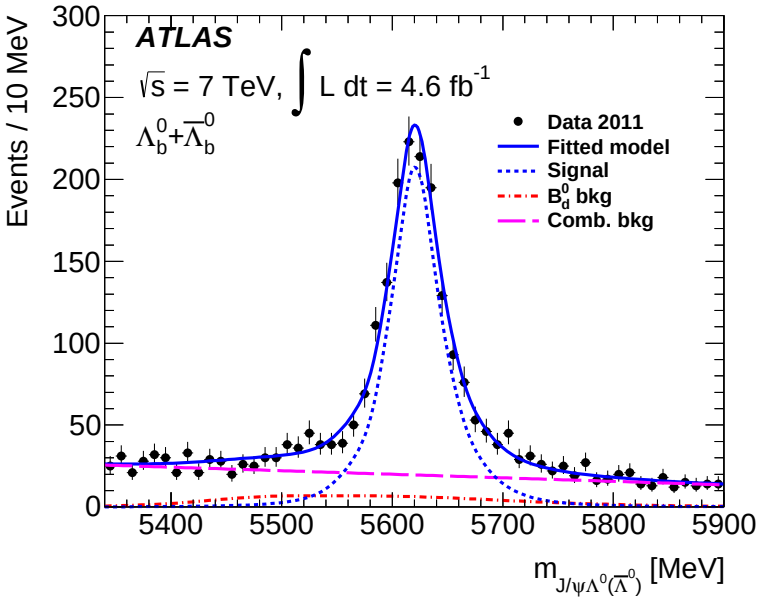
Inner detector tracking





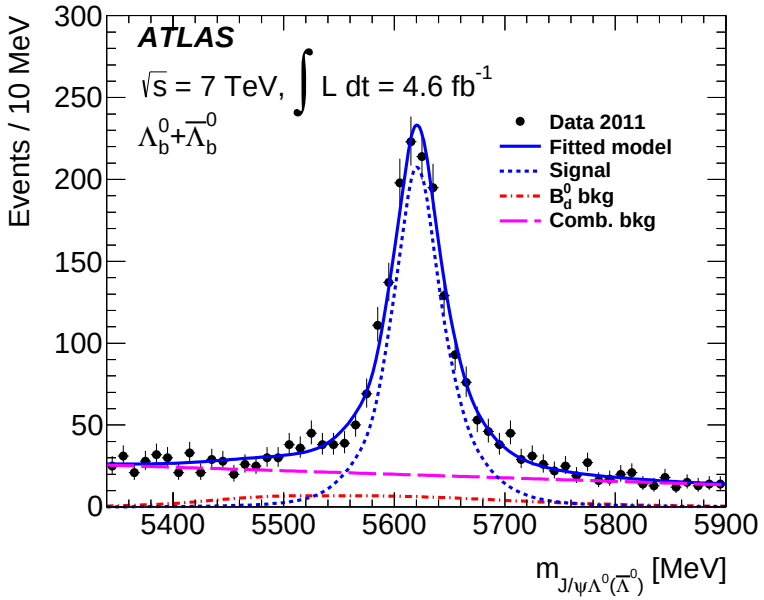
- Measure charged particle tracks
- Identify collision points

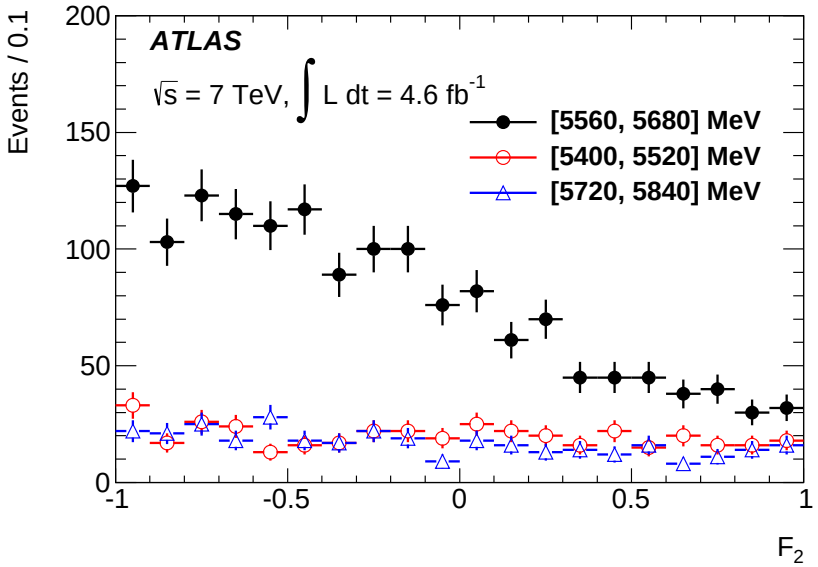
Inner detector tracking



- Measure charged particle tracks
- Identify collision points
- Or reconstruct particle decays

Inner detector tracking





- Measure charged particle tracks
- Identify collision points
- Or reconstruct particle decays
- Parity violation in Λ_b^0 decay

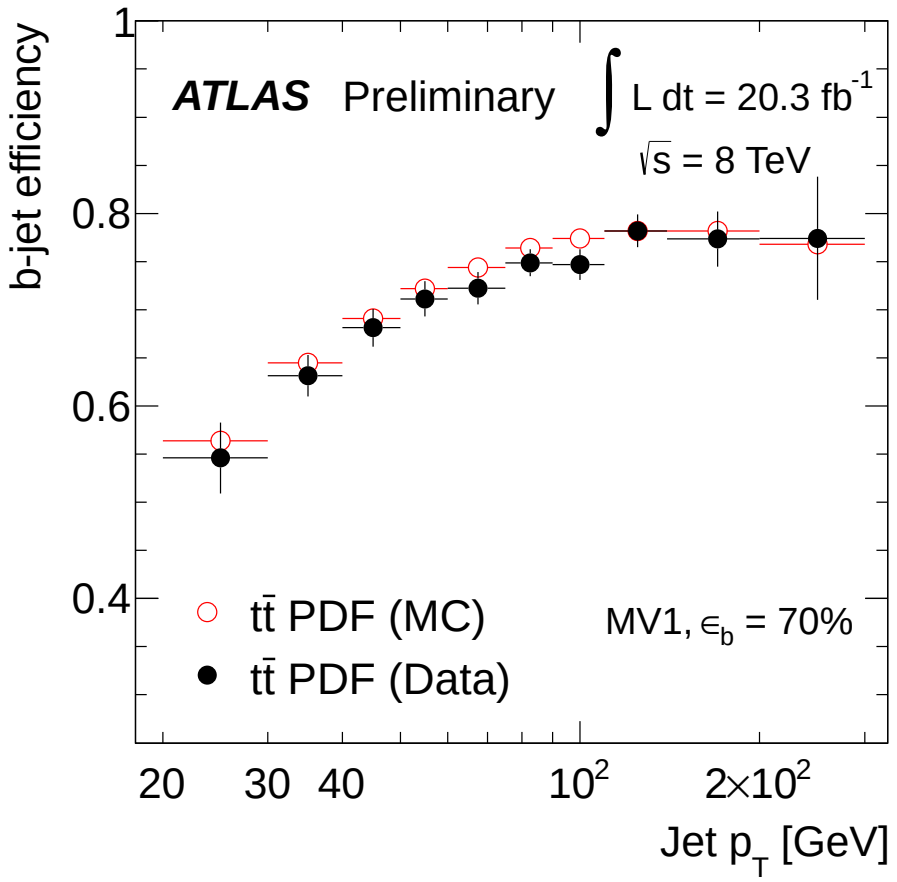
$$\alpha_b = 0.30 \pm 0.16(\text{stat.}) \pm 0.06(\text{syst.})$$

- Agrees with LHCb, but some tension with calculations in perturbative QCD and heavy quark effective theory

PRD 89 (2014) 092009

b-Tagging

- Use tracking to identify jets from *b*-quarks
- Light flavor jets rejected with factor ~ 100



b-tagging calibration using $t\bar{t}$ events

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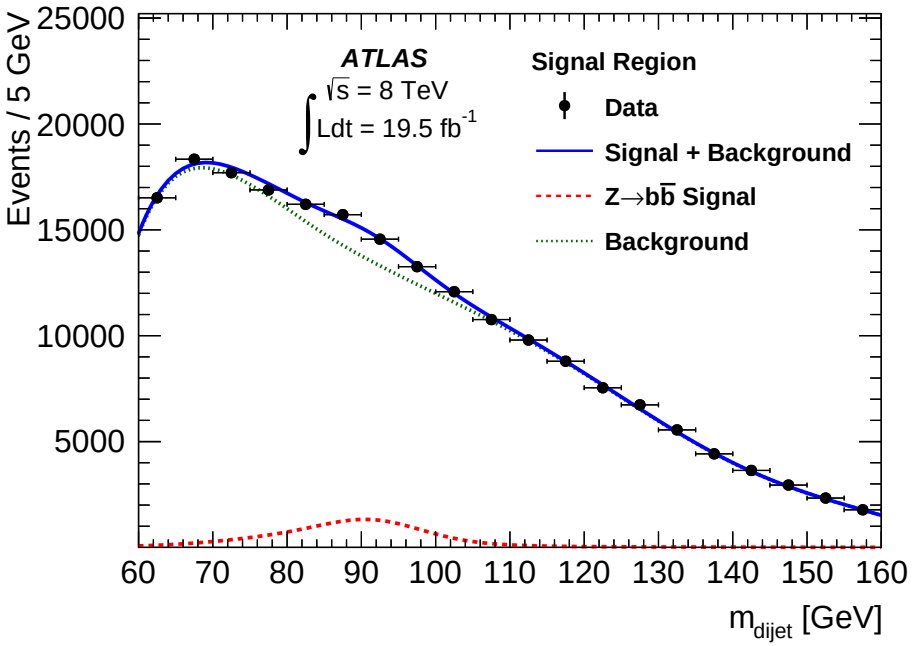
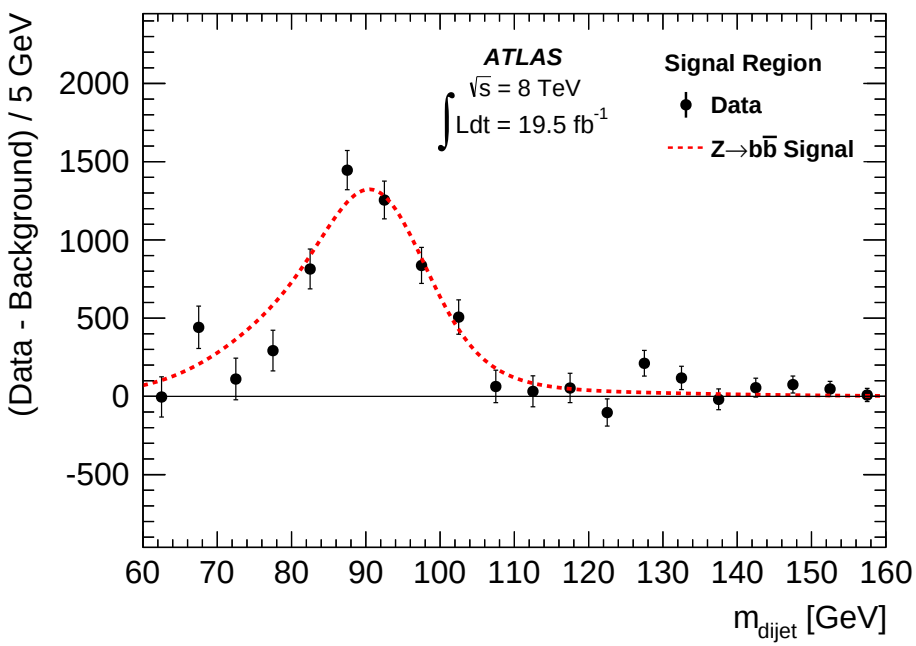
- b tagging for $Z \to b\bar{b}$ cross section $p_{\mathrm{T}}(\mathrm{dijet}) > 200$ GeV

$$\sigma^{\mathrm{fid.}}_{Z\to b\bar{b}} = 2.02 \pm 0.20(\mathrm{stat.}) \pm 0.25(\mathrm{syst.}) \pm 0.06(\mathrm{lumi.})\,\mathrm{pb}$$

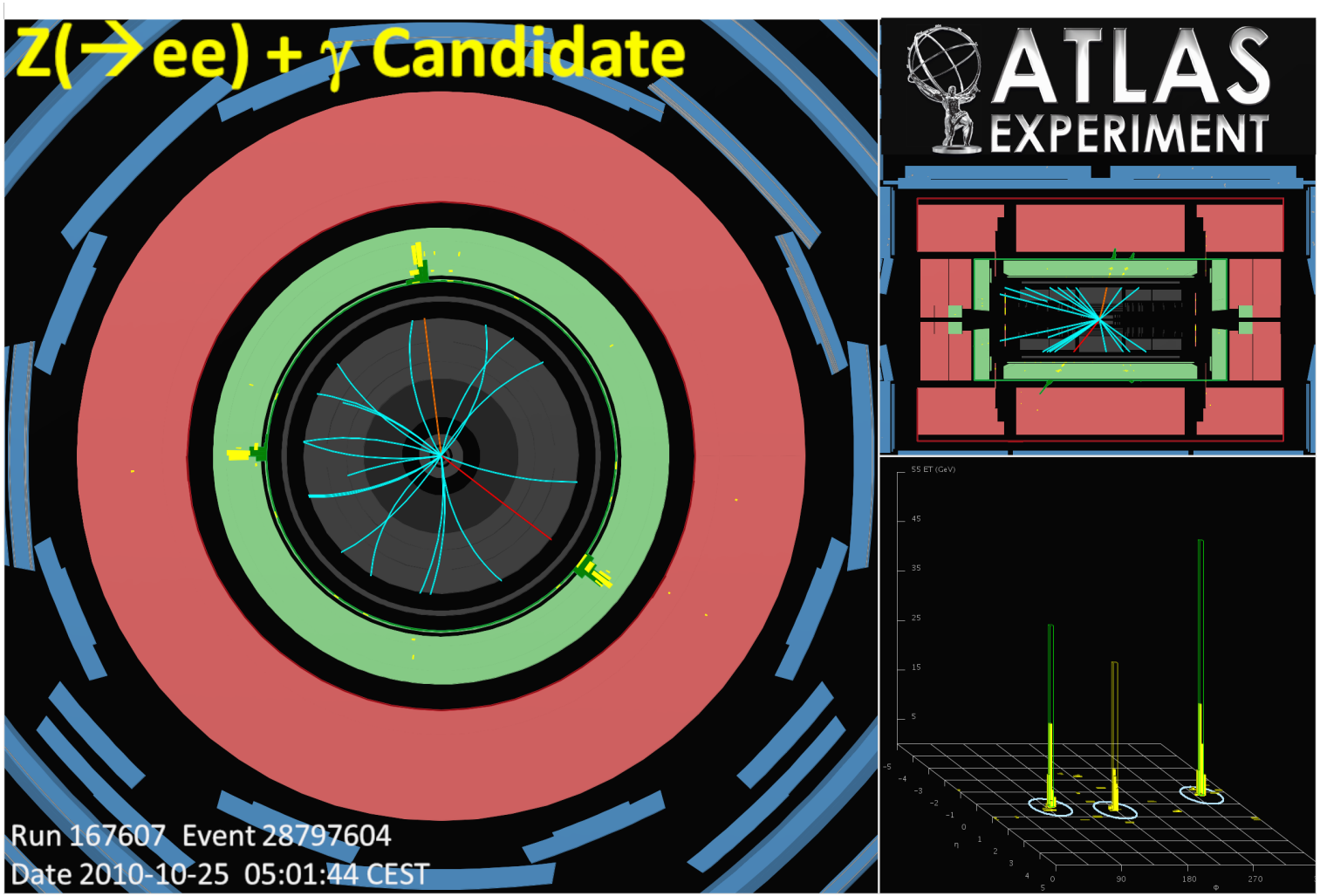




arXiv link (Submitted to PLB)

Electrons and Muons

- Showers in electromagnetic calorimeter
- Tracks in outer muon chambers



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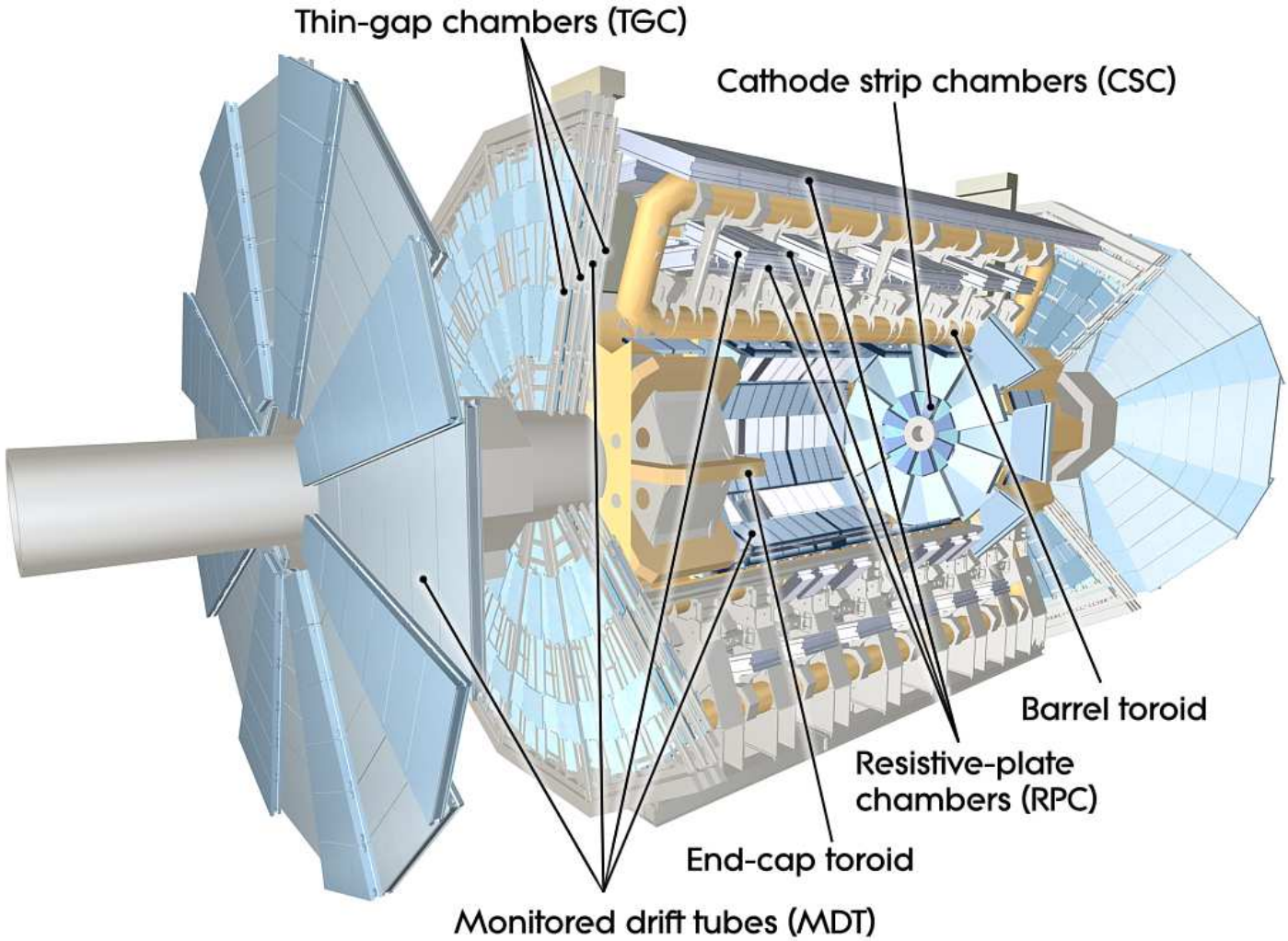
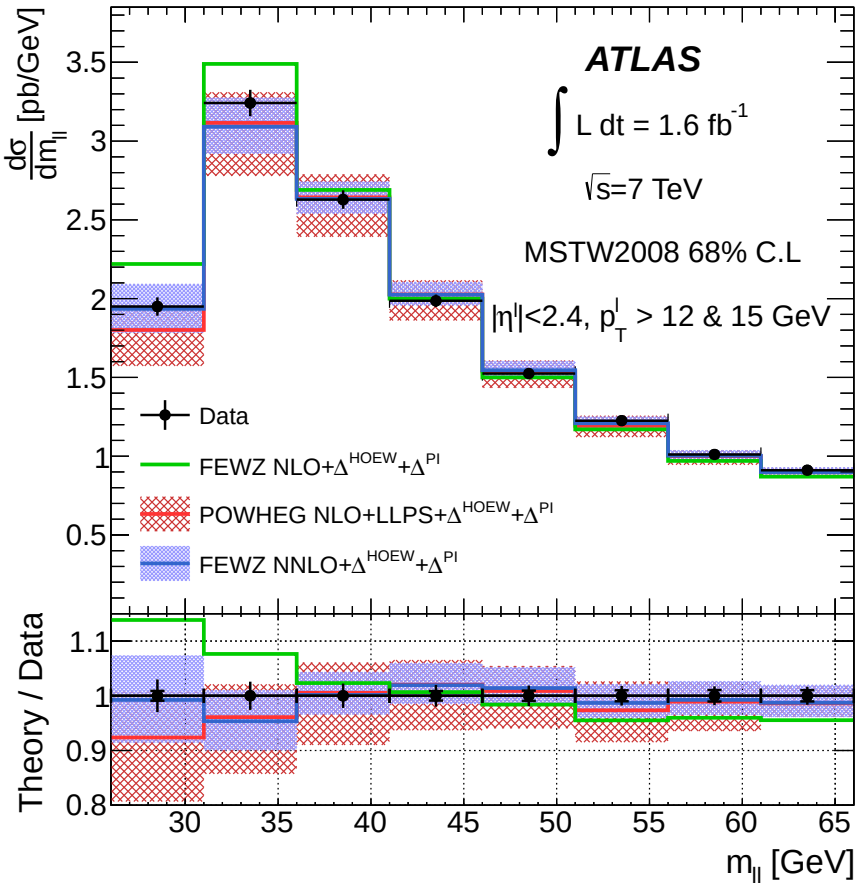


Low mass Drell-Yan cross section

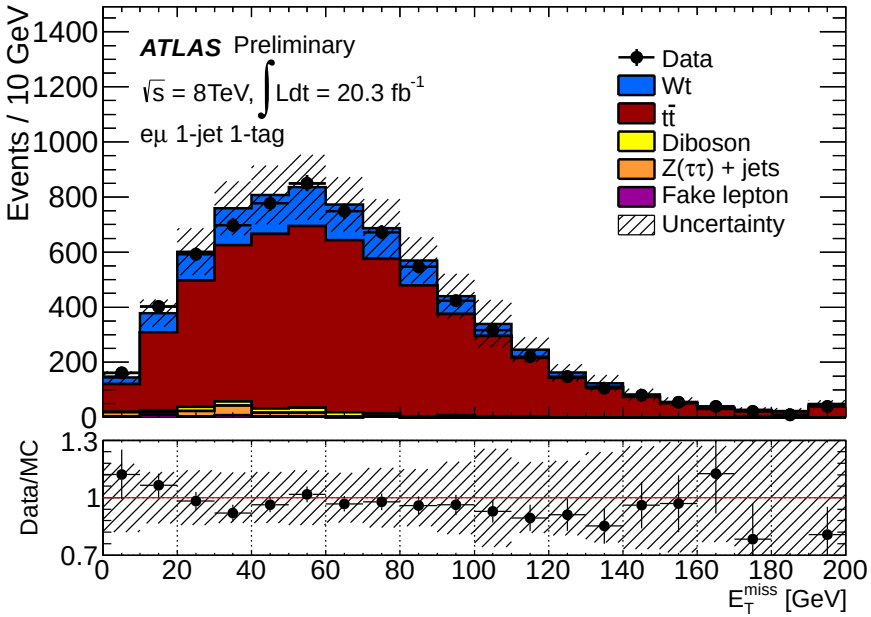
- Muons and electrons often analyzed together as “charged leptons”
- Example is low mass Drell-Yan pair production



arXiv link (Accepted by JHEP)

Missing transverse energy

- Undected particles like neutrino inferred from missing momentum
- Measure negative vector sum of energy in the event
- Analyses like single top $W + t$ production depend on it
- $Wt \to e^{\pm}\mu^{\mp}\nu\bar{\nu}b$



$$\sigma_{Wt} = 27.2 \pm 5.8\text{pb}$$

- 4.2σ evidence agrees with expectation

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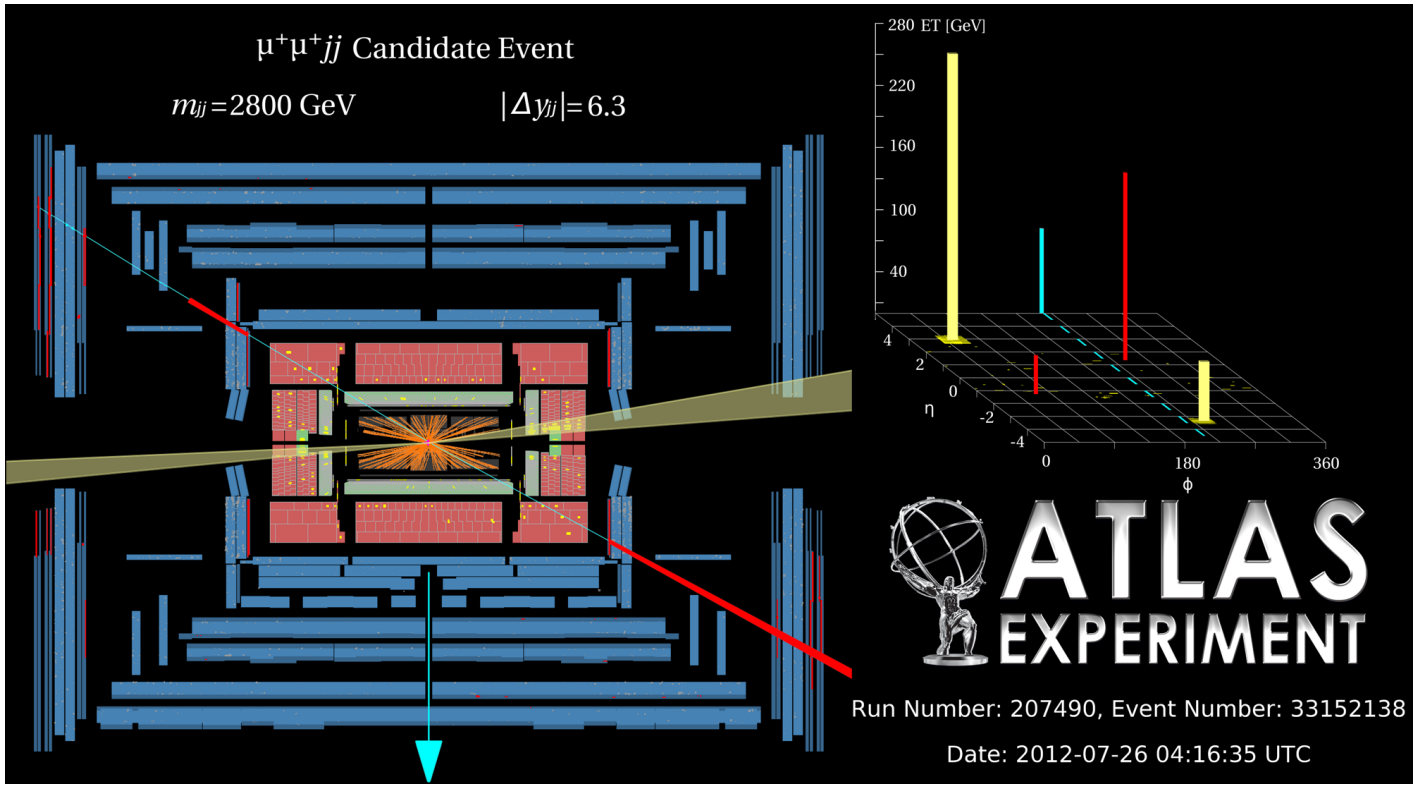
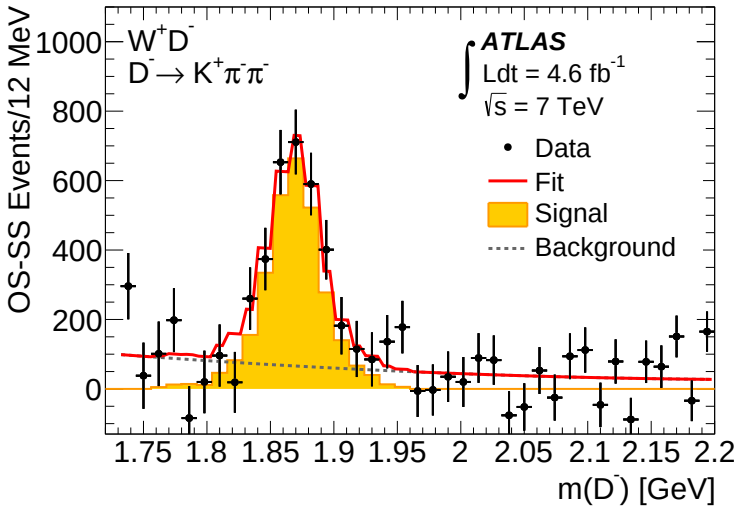
Leveraging the dataset

- Current results for rare production modes, rare decays, and precision measurements
- Example of a rare event:



W plus charm

- *W*+ *c* quark probes strange content of proton
- Uses both mesons and jets



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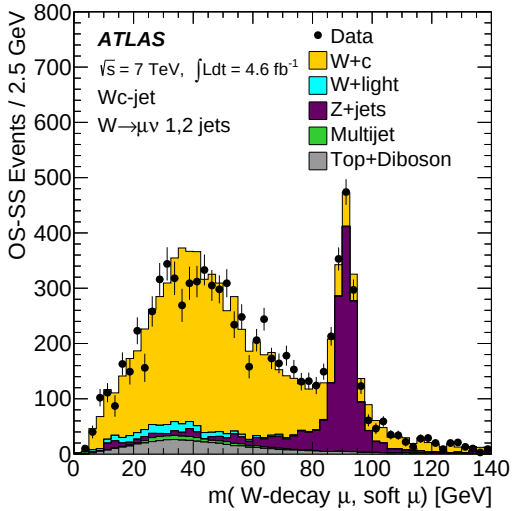
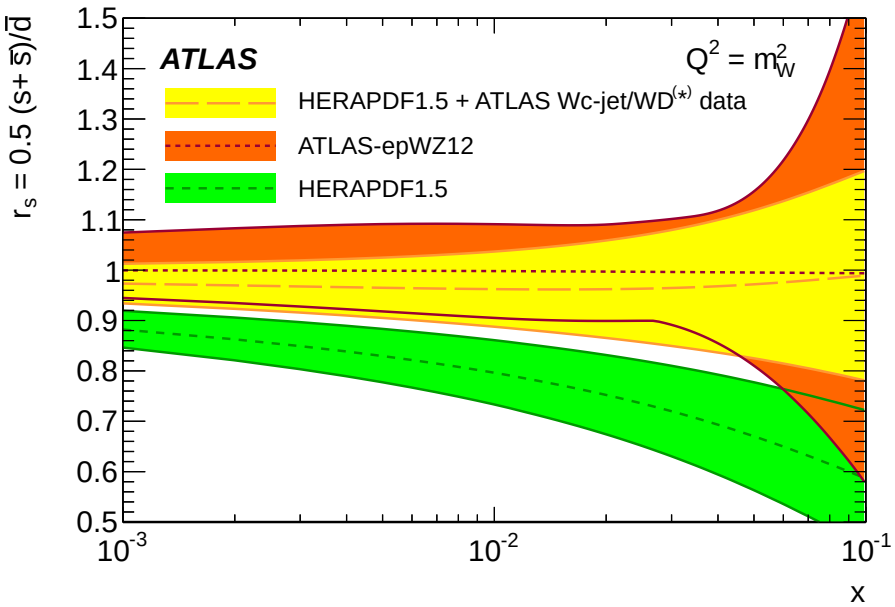
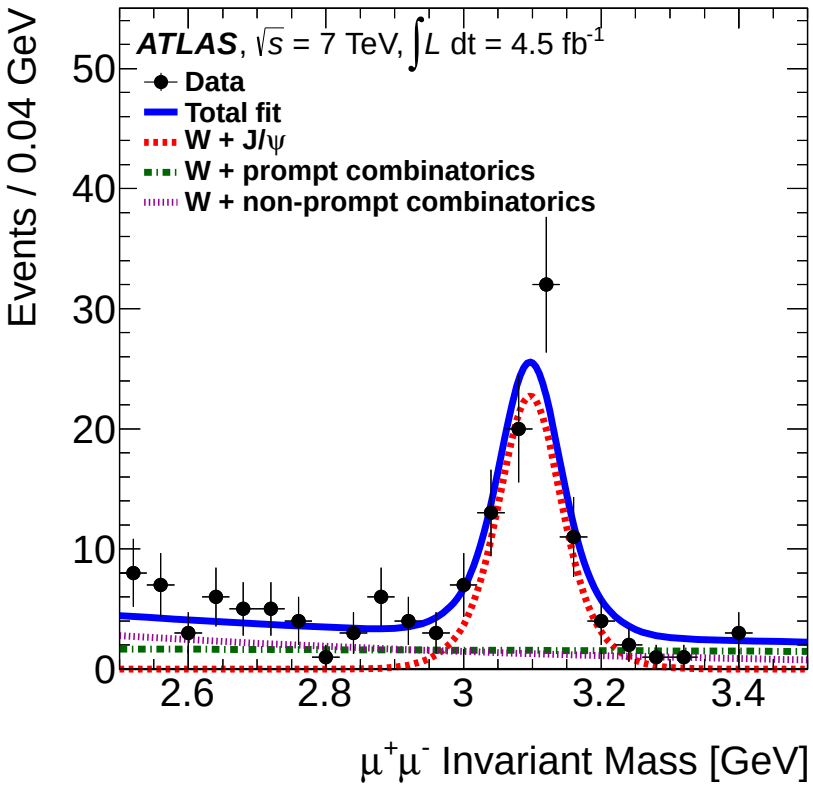
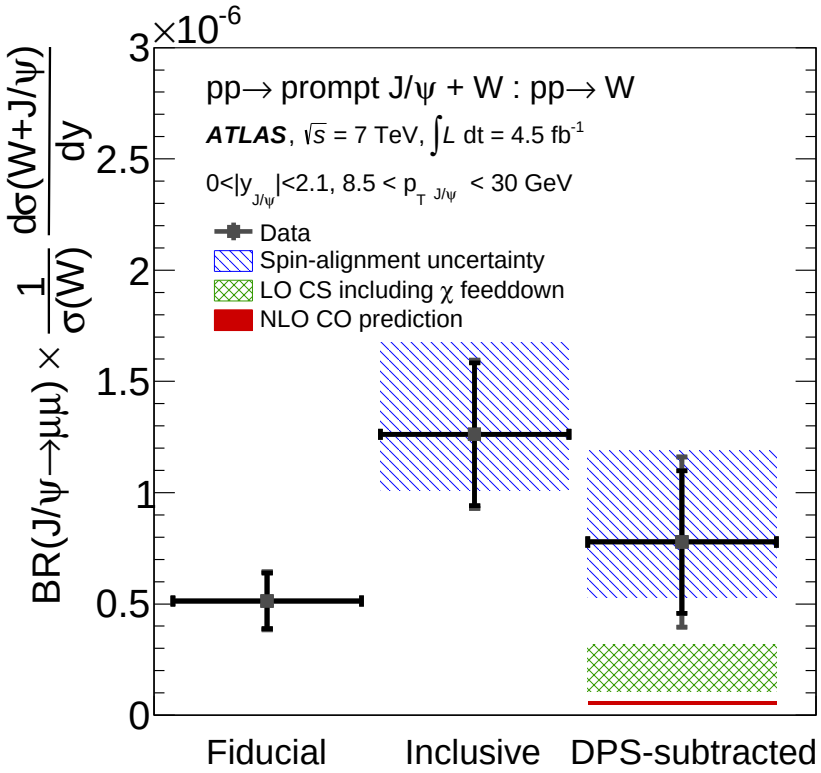




W plus J/ψ

- Probe charmonium production and double parton interactions with $pp \to W^{\pm} J/\psi$





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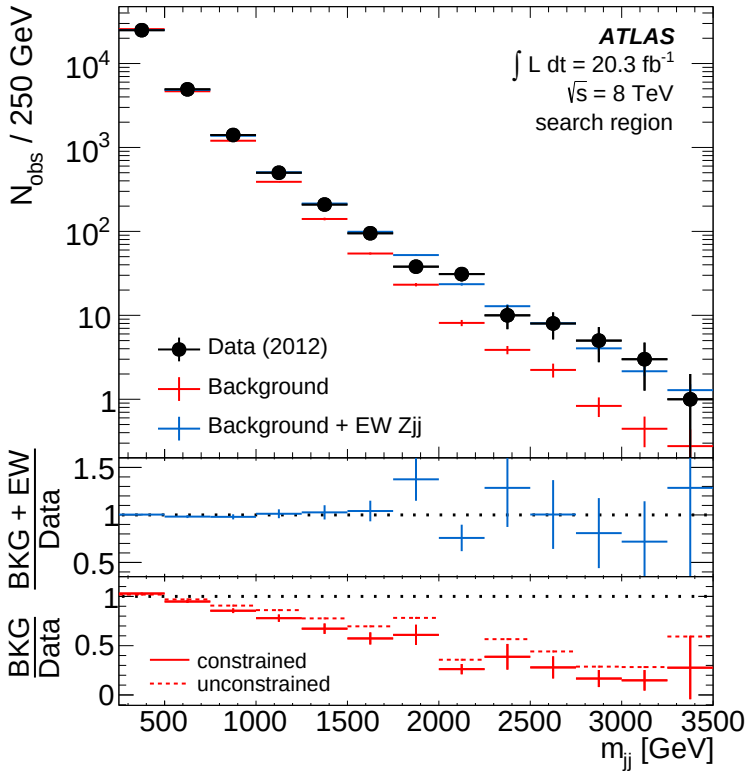
Electroweak *Zjj*

- Study Z with 2 jets - and separate out t-channel exchange of vector boson
- Includes vector boson fusion interaction with WWZ coupling

JHEP 04 (2014) 031

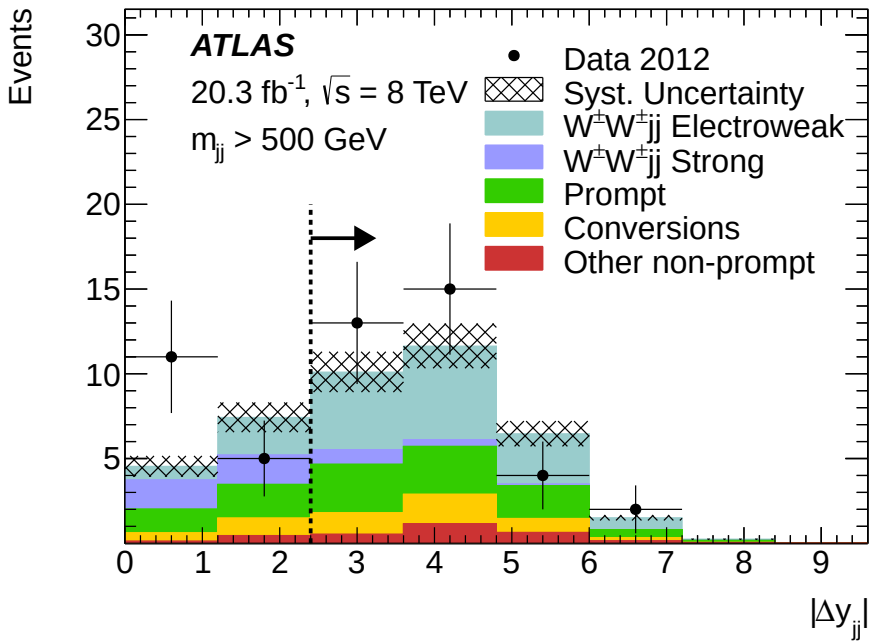


$$\sigma_{\mathrm{EW}}^{\mathrm{fid.}} = 54.7 \pm 4.6(\mathrm{stat.})^{+9.8}_{-10.4}(\mathrm{syst.}) \pm 1.5(\mathrm{Lumi.})\ \mathrm{fb}$$
$$\sigma_{\mathrm{EW}}^{\mathrm{fid.}}(m_{jj} > 1\ \ \mathrm{TeV}) = 10.7 \pm 0.9(\mathrm{stat.}) \pm 1.9(\mathrm{syst.}) \pm 0.3(\mathrm{Lumi.})\ \mathrm{fb}$$

Same sign *WW* plus jets

- Enhances electroweak production
- Used to set limits on anamolous four boson coupling

arXiv link (Submitted to PRL)



$$\sigma^{\text{fid.}} = 2.1 \pm 0.5(\text{stat.}) \pm 0.3(\text{syst.})\ \text{fb}$$
$$\sigma^{\text{fid.}}_{\text{EW}} = 1.3 \pm 0.4(\text{stat.}) \pm 0.2(\text{syst.})\ \text{fb}$$

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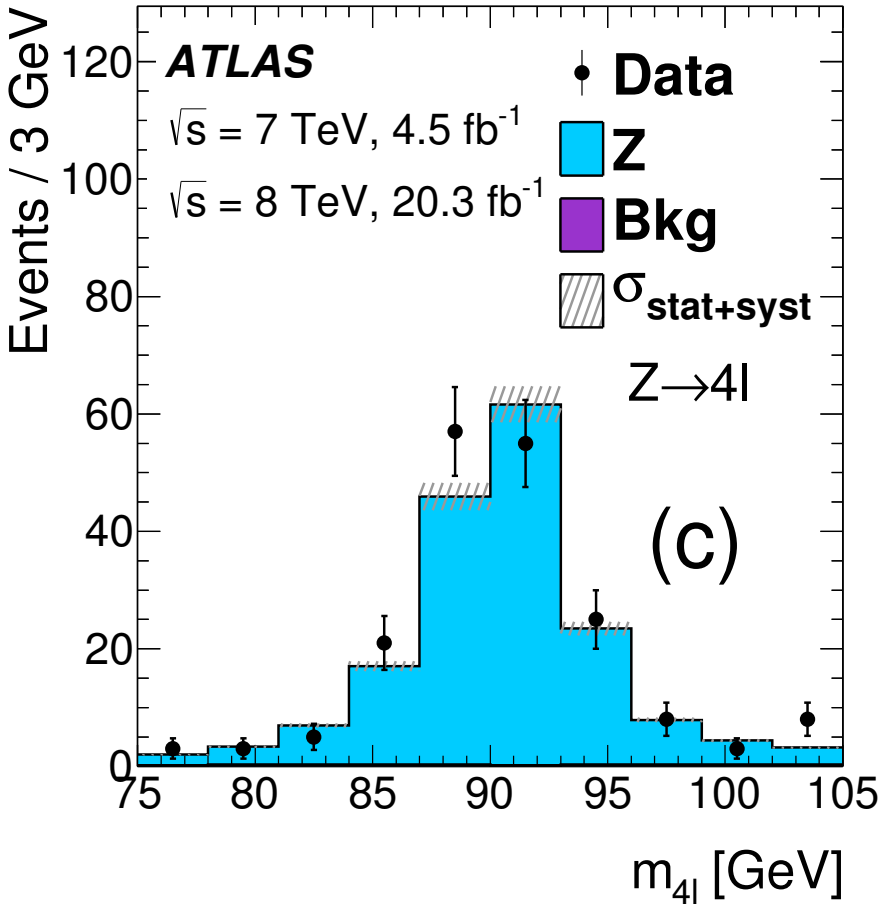
- Measure 4 charged lepton decays at Z resonance

arXiv link (Accepted by PRL)



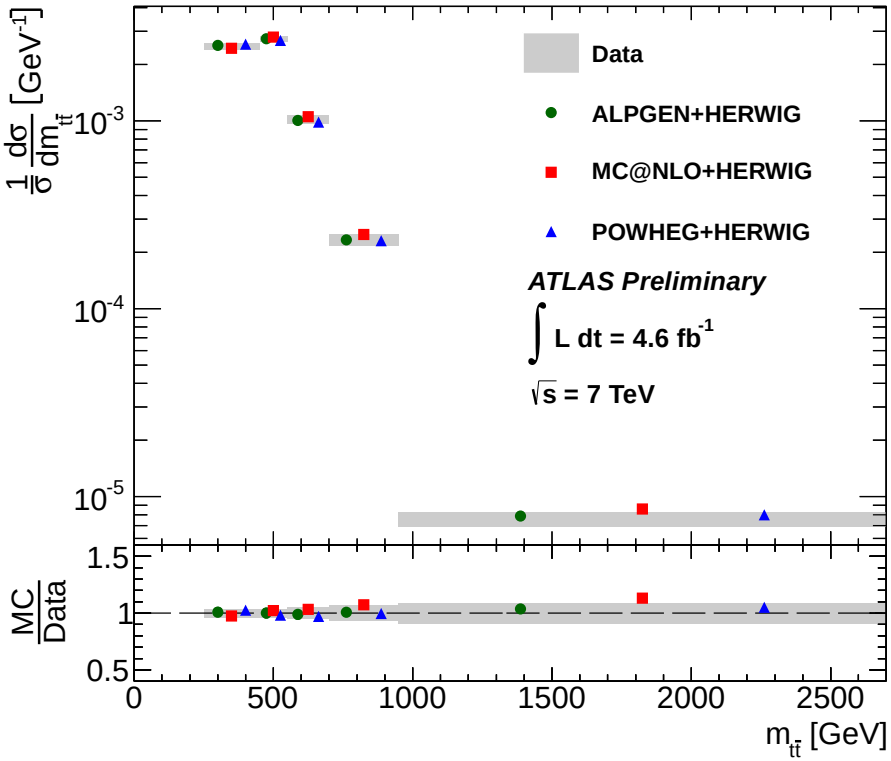
$$\Gamma_{Z\to 4\ell}/\Gamma_Z = (3.2 \pm 0.25(\text{stat.}) \pm 0.13(\text{syst.})) \times 10^{-6}$$

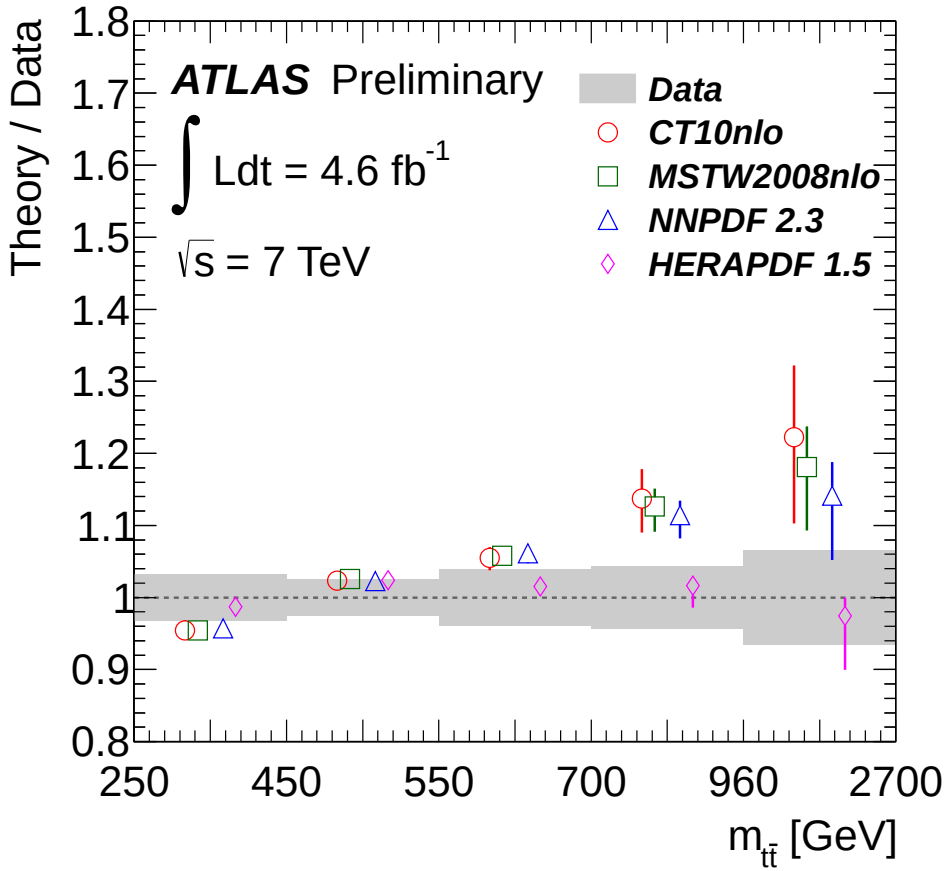
Top quark production and properties

- Very large datasets of top quark events available
- Precise measurement of production possible
- Perform new properties measurements
- High mass makes it possible to study quark properties with less dependence on hadronization

$t\bar{t}$ differential cross section

- Top cross section measurements sensitive to parton density functions and new physics contributions





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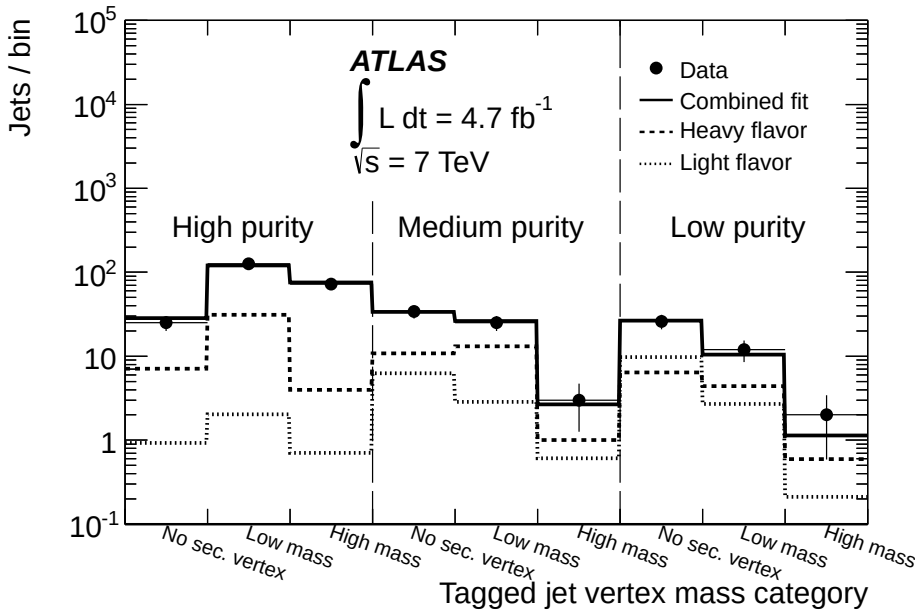
$t\bar{t}$ + heavy quarks

- $t\bar{t} + b + X$ and $t\bar{t} + c + X$ probes models of heavy flavor production at top mass scale
- Important background for $t\bar{t}H$ production

PRD 89 (2014) 072012

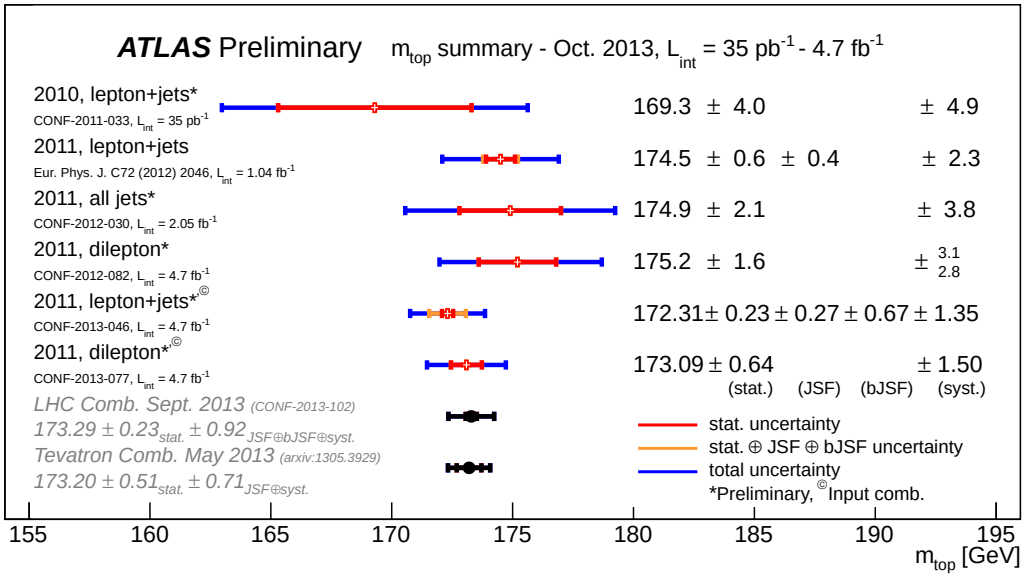
- Categorize and fit additional jets:

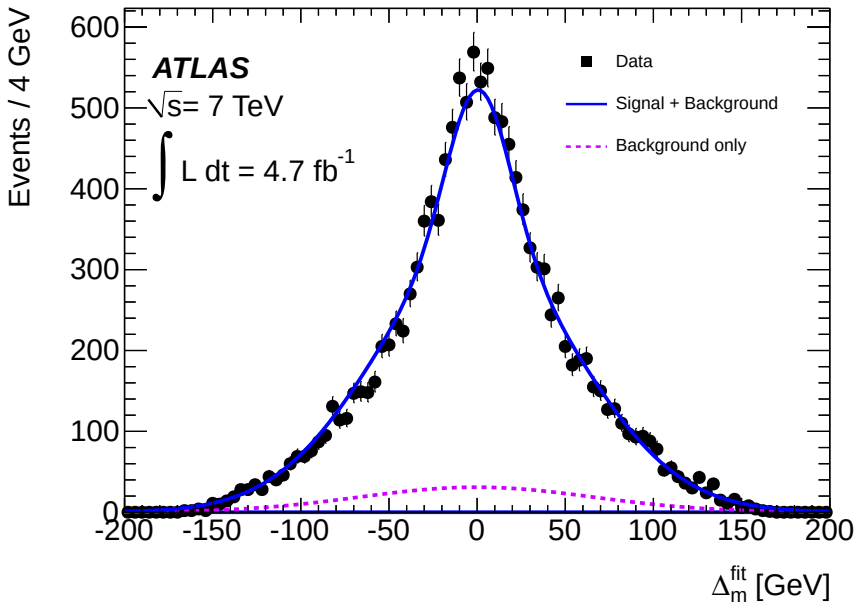


$$R_{HF} = 6.2 \pm 1.1(\text{stat.}) \pm 1.8(\text{syst.})\%$$

Top mass difference

- Measure top quark mass, but also difference between top and antitop





$$\Delta m = 0.67 \pm 0.61(\text{stat.}) \pm 0.41(\text{syst.})\ \text{GeV}$$

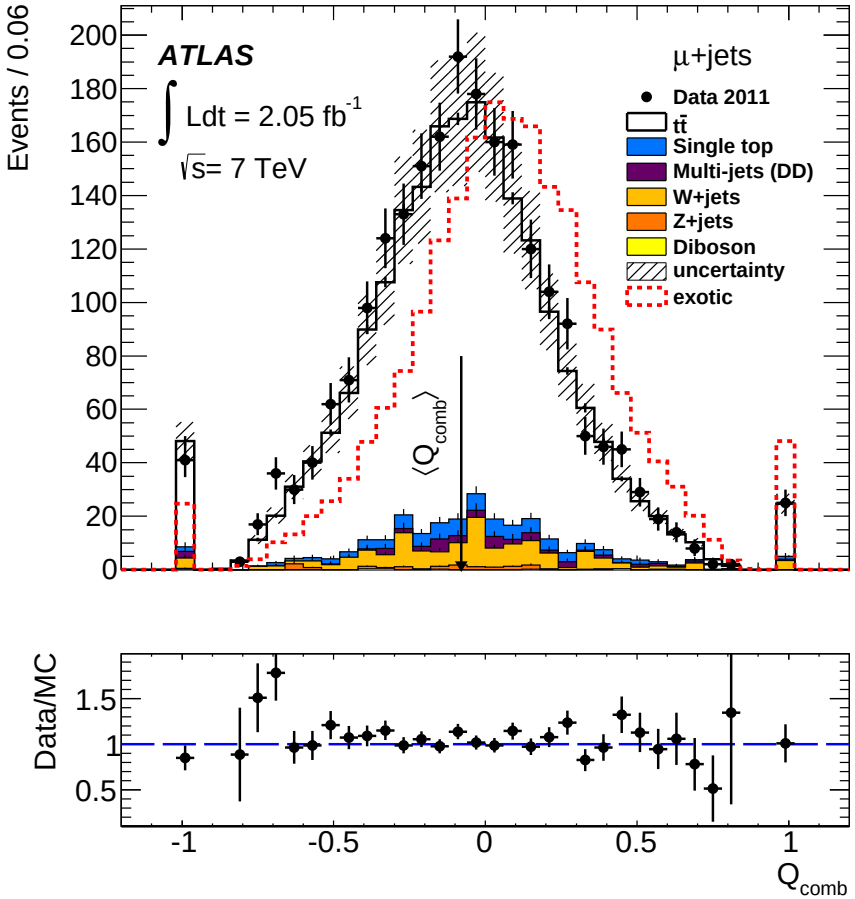
PLB 728 (2014) 363-379

Top quark charge

- Measure top quark charge by assigning jet charge to *b*-jet with momentum weighted average of tracks
- Excludes exotic $-4/3$ charge

$$Q_{\text{comb.}} = Q_b \cdot Q_\ell$$

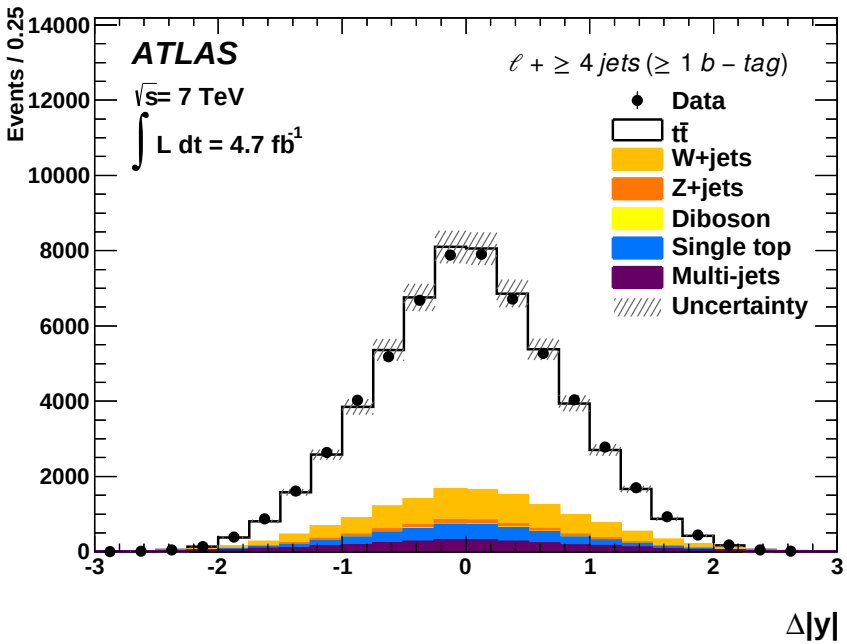
JHEP 11 (2013) 031

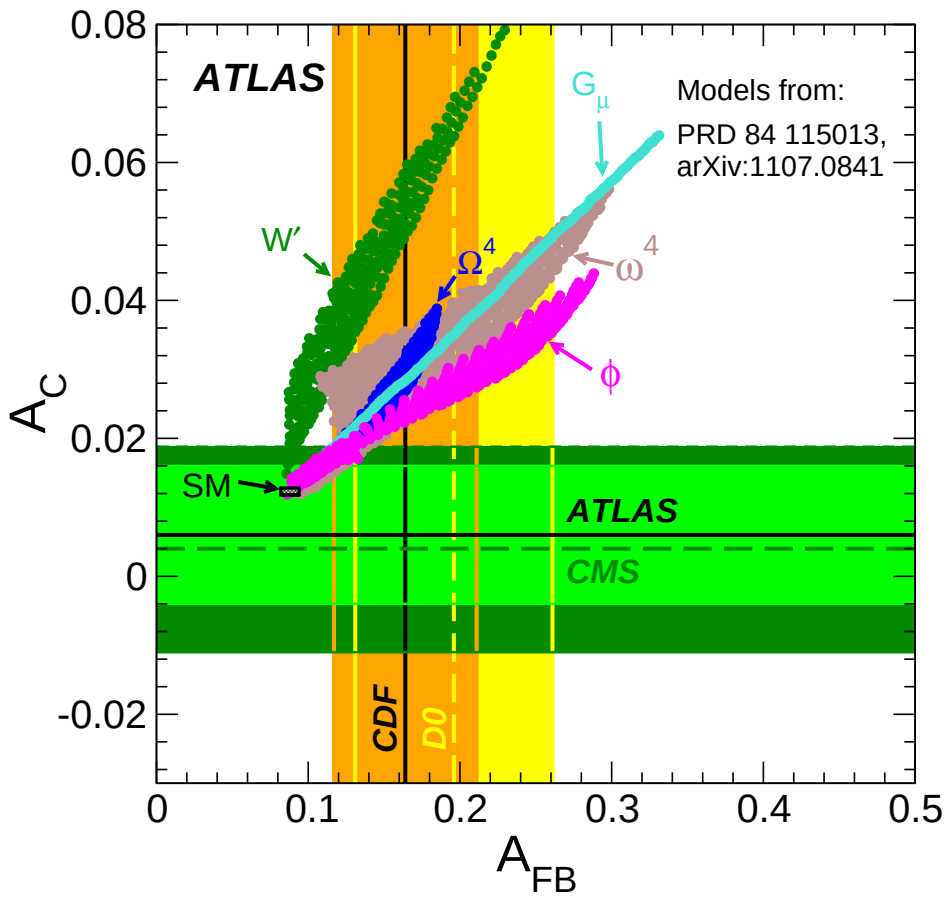


$$Q_t = 0.64 \pm 0.02(\text{stat.}) \pm 0.08(\text{syst.})$$

Top charge asymmetry

- Similar to forward-backward asymmetry A_{FB} at Tevatron
- Measure asymmetry A_C with difference of t and $\bar{t}$ absolute rapidity



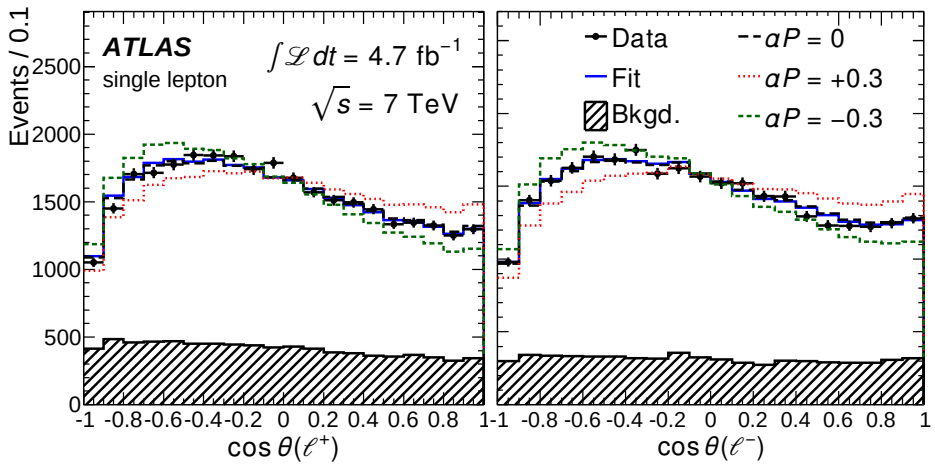


JHEP 02 (2014) 107

Top quark polarization

- Spin of top quark through angular distribution of decay daughters

PRL 111 (2013) 232002



$$\alpha_\ell P_{\mathrm{CPC}} = -0.035 \pm 0.014(\mathrm{stat.}) \pm 0.037(\mathrm{syst.})$$

$t\bar{t}$ spin correlation

- SM predicts correlated spins in $t\bar{t}$ production
- Analyze with multiple variables with sensitivity to different sources of correlation

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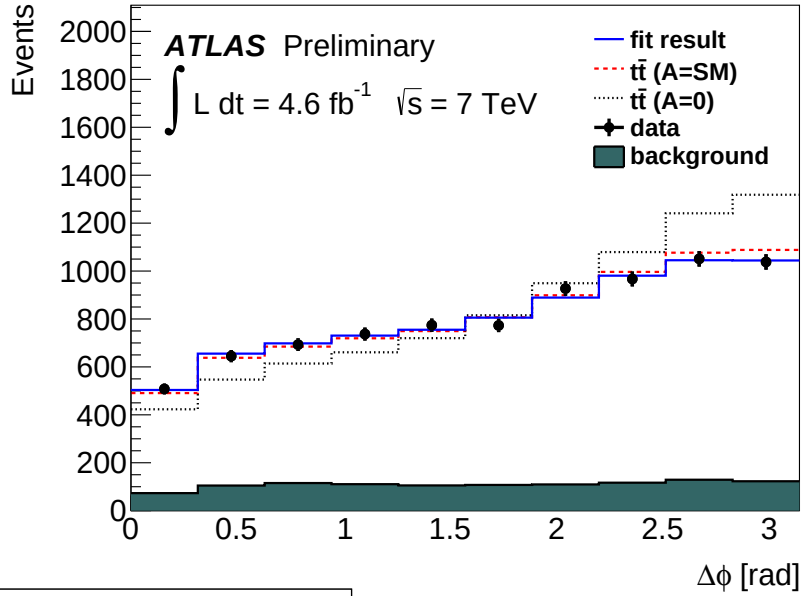
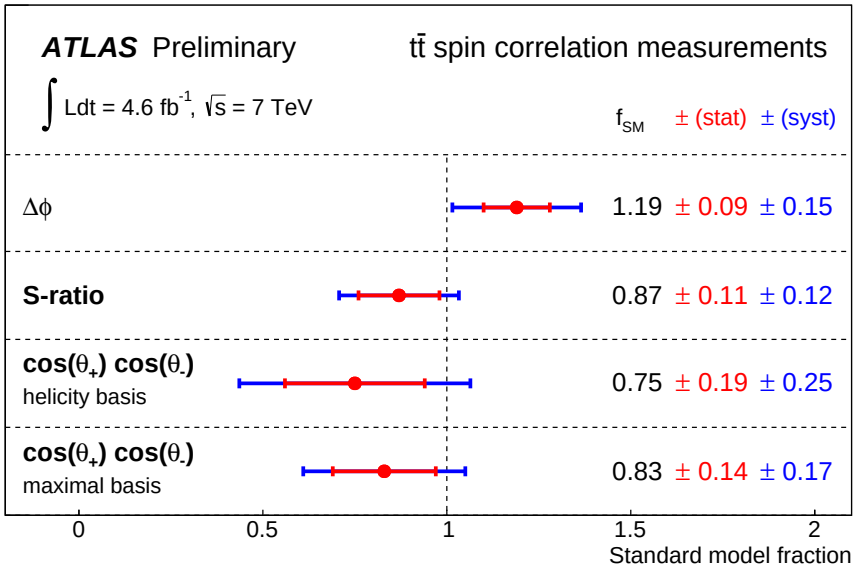




Conclusions

- Many new results on Standard Model physics released and in preparation based on 7 and 8 TeVdata taken in 2011 and 2012
- Understanding detector performance key
- Leveraging large datasets to study rare processes and detailed properties
- Test Standard Model predictions in new areas and provide essential understanding for searches for new physics
- No significant deviations found

Backup

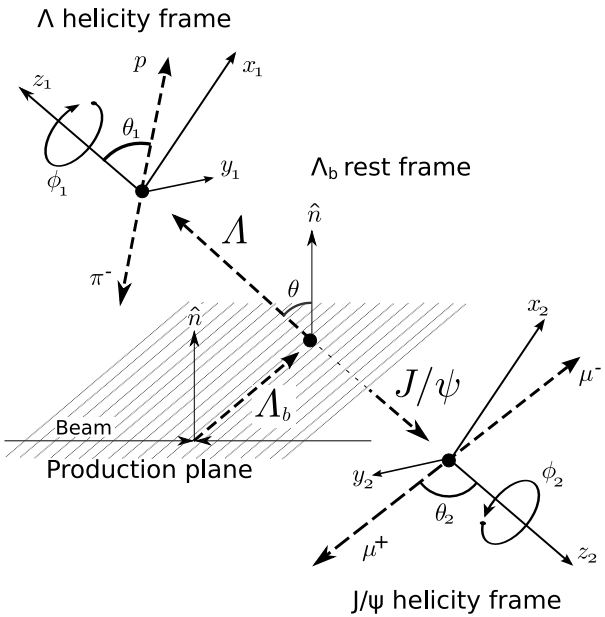
Links to public results pages

All ATLAS public results

Dijet cross sections
Λ_b parity violation
$Z \to b\bar{b}$
Low mass Drell-Yan
W plus charm
W plus J/Ψ
Electroweak Z plus jets
Electroweak same sign Ws
$Z \to 4\ell$

Single top Wt
$t\bar{t}$ b-tag calib.
$t\bar{t}$ diff. xs
$t\bar{t}$ plus heavy flavor
$t\bar{t}$ mass difference
Top quark charge
$t\bar{t}$ charge asymmetry
$t\bar{t}$ polarization
$t\bar{t}$ spin correlation

$\Lambda_b \to J/\Psi\Lambda$



$$F_2 = \cos\theta_1$$
$$F_4 = \frac{1}{2}\left(3\cos^2\theta_2 - 1\right)$$
$$F_6 = \frac{1}{2}\left(3\cos^2\theta_2 - 1\right)\cos\theta_1$$
$$F_{18} = \sin\theta_1 \sin\theta_2 \cos\theta_2 \cos(\phi_1 + \phi_2)$$
$$F_{19} = \sin\theta_1 \sin\theta_2 \cos\theta_2 \sin(\phi_1 + \phi_2)$$

- Helicity amplitudes of daughters $A(\lambda_\Lambda, \lambda_{J/\Psi})$:

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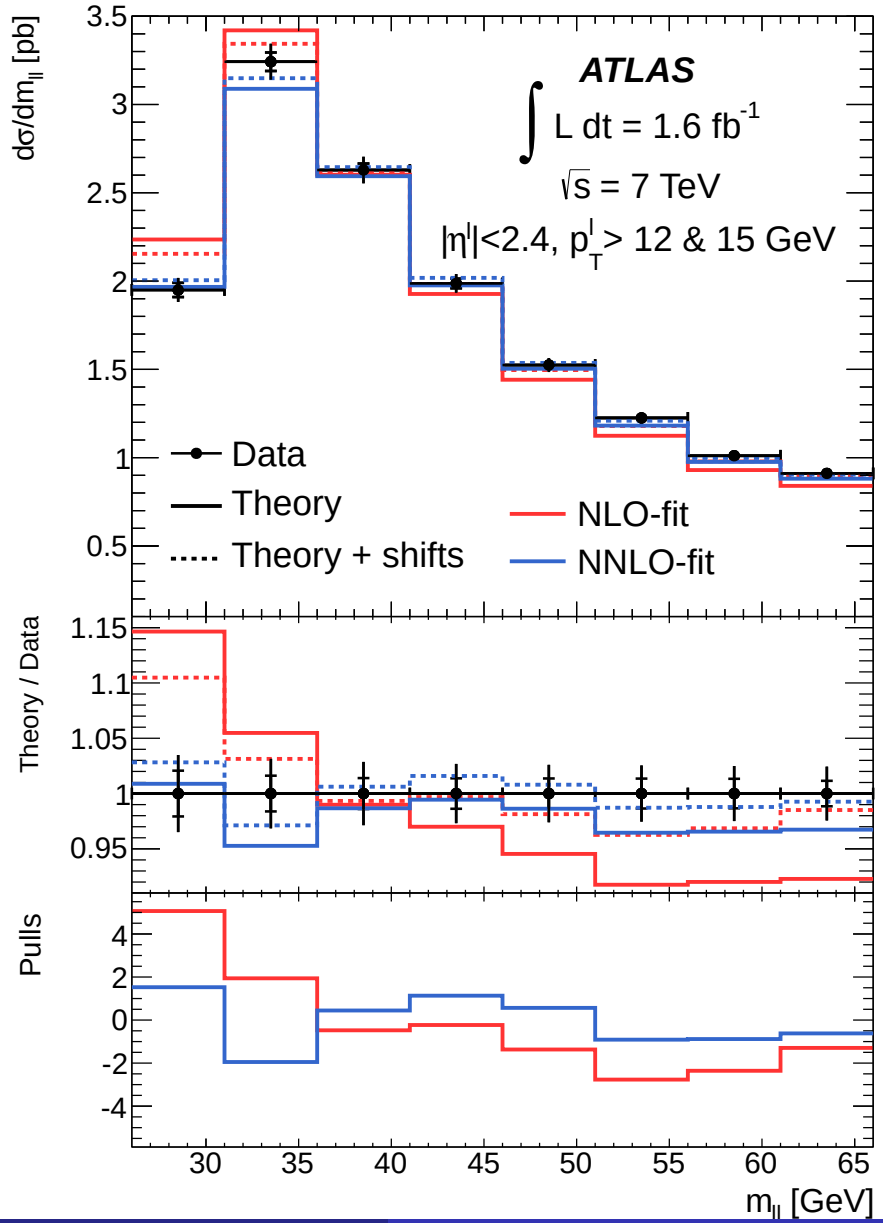
$$|A(1/2,0)| = 0.17^{+0.12}_{-0.17}(\text{stat.}) \pm 0.09(\text{syst.})$$
$$|A(-1/2,0)| = 0.59^{+0.06}_{-0.07}(\text{stat.}) \pm 0.03(\text{syst.})$$
$$|A(-1/2,-1)| = 0.79^{+0.04}_{-0.05}(\text{stat.}) \pm 0.02(\text{syst.})$$
$$|A(1/2,1)| = 0.08^{+0.13}_{-0.08}(\text{stat.}) \pm 0.06(\text{syst.})$$

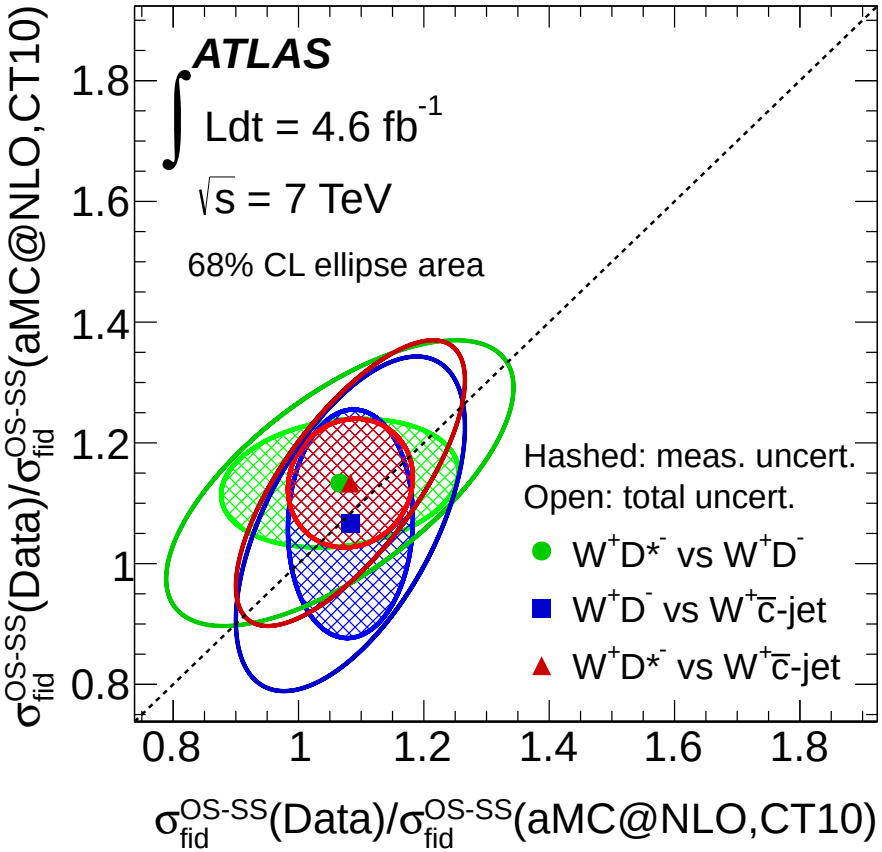
Low mass Drell-Yan

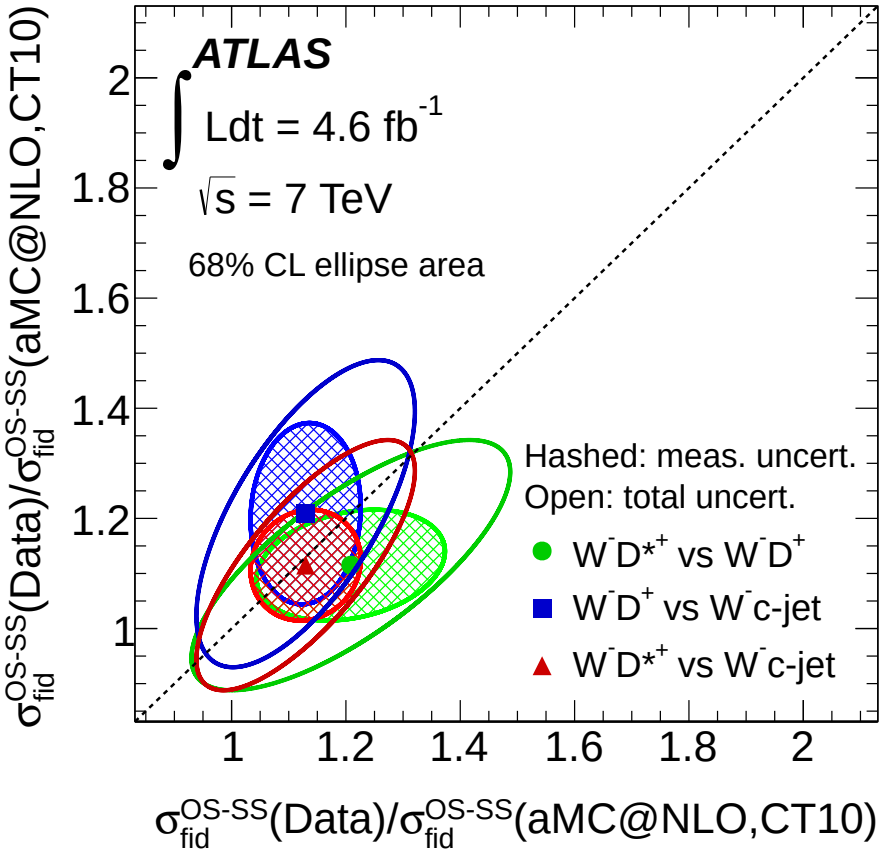
- Fit to spectrum

arXiv link (Accepted by JHEP)



W plus charm





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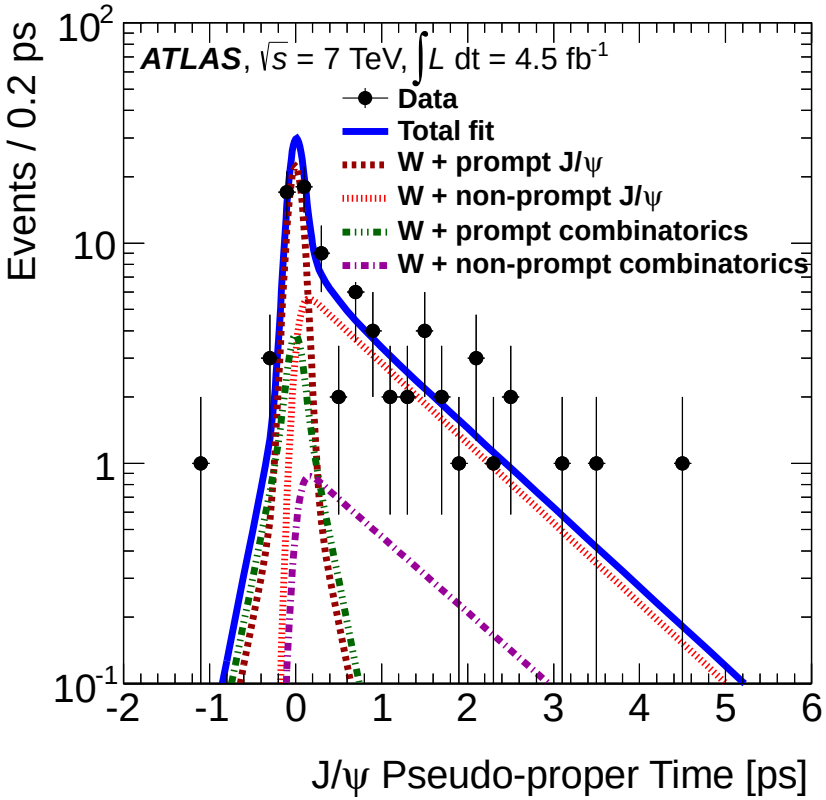
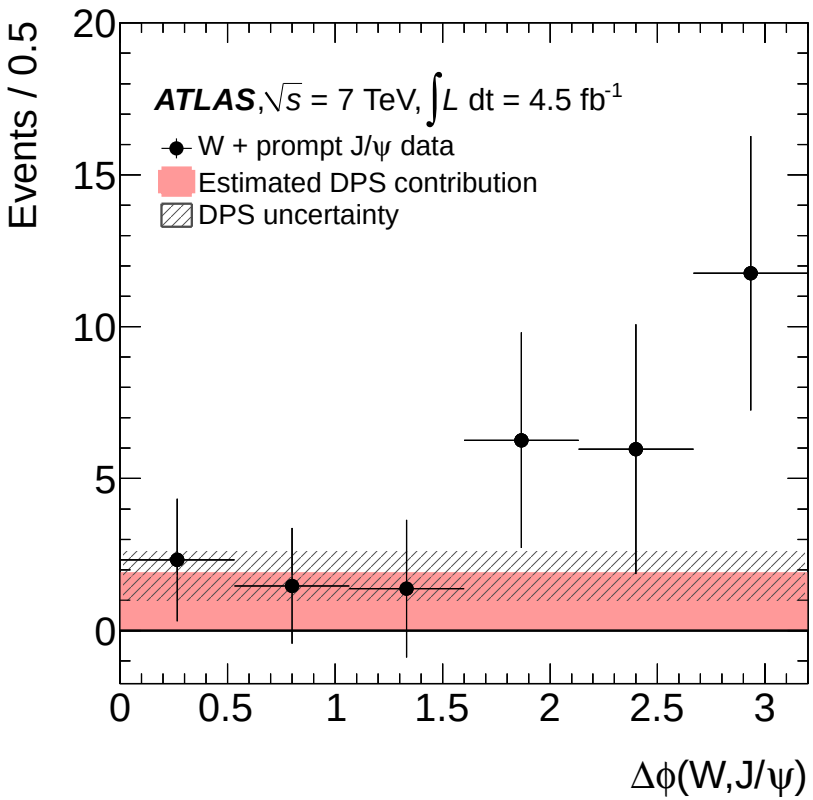
W plus J/ψ





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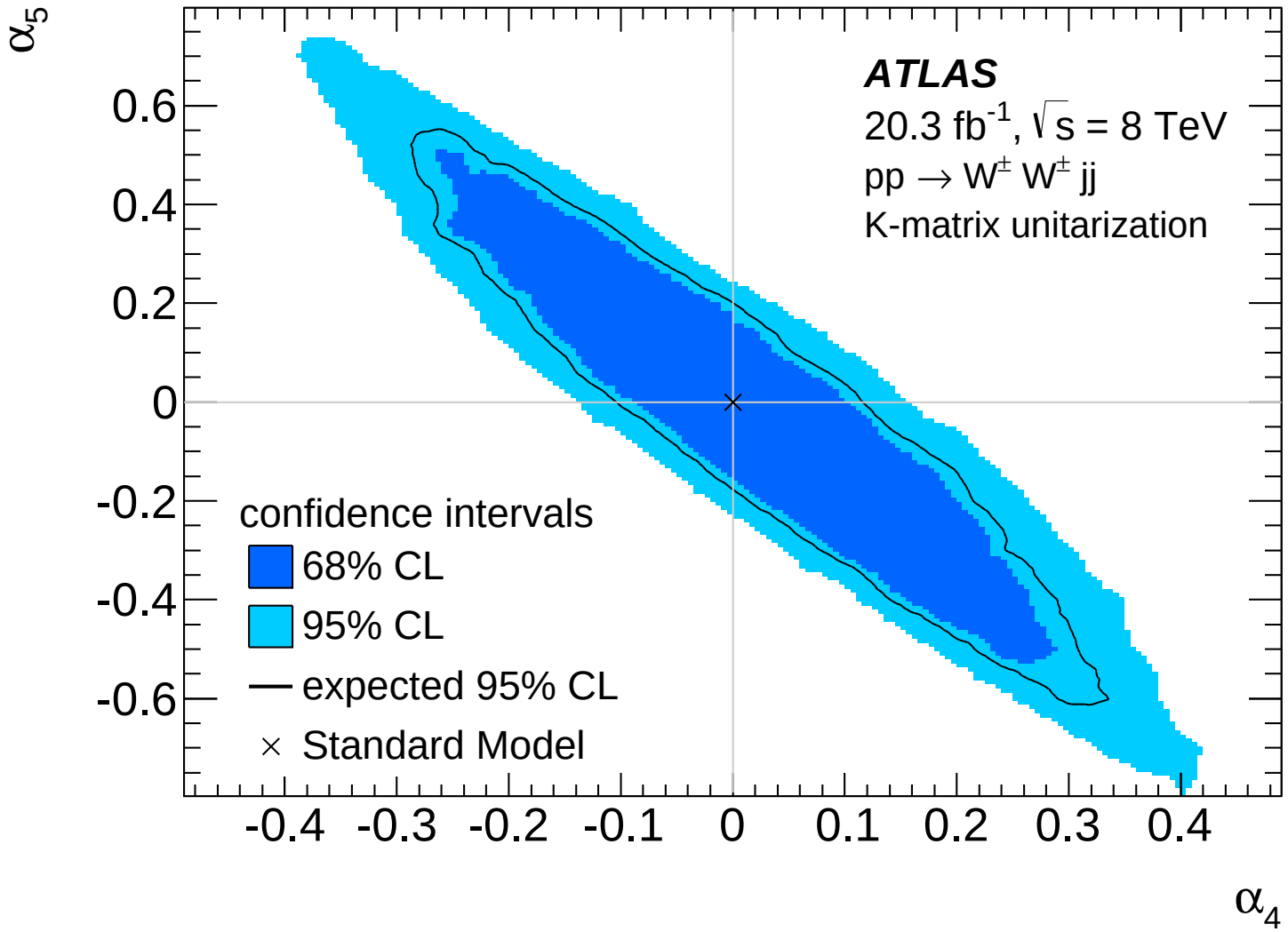
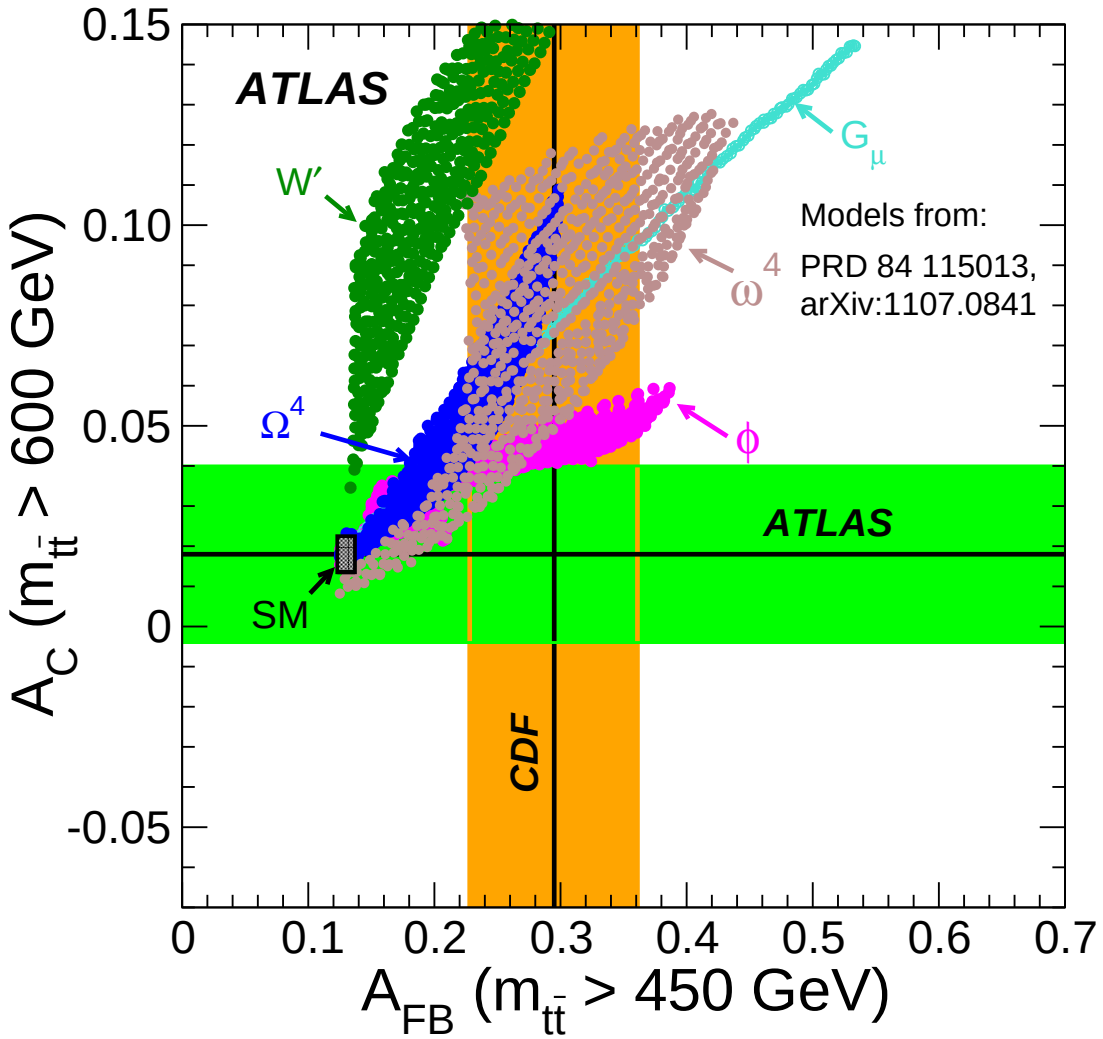


arXiv link (Submitted to PRL)

$t\bar{t}$ charge asymmetry



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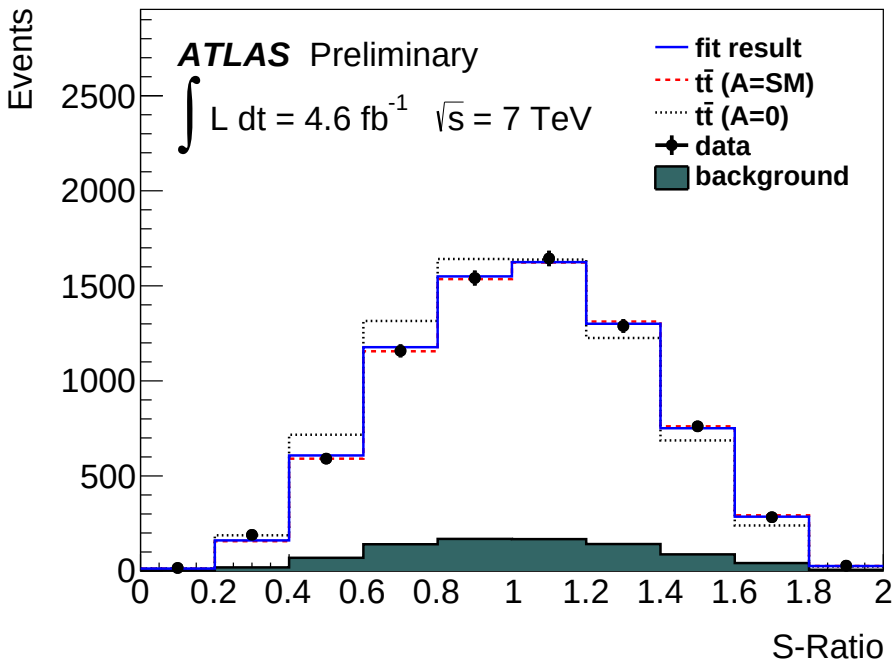
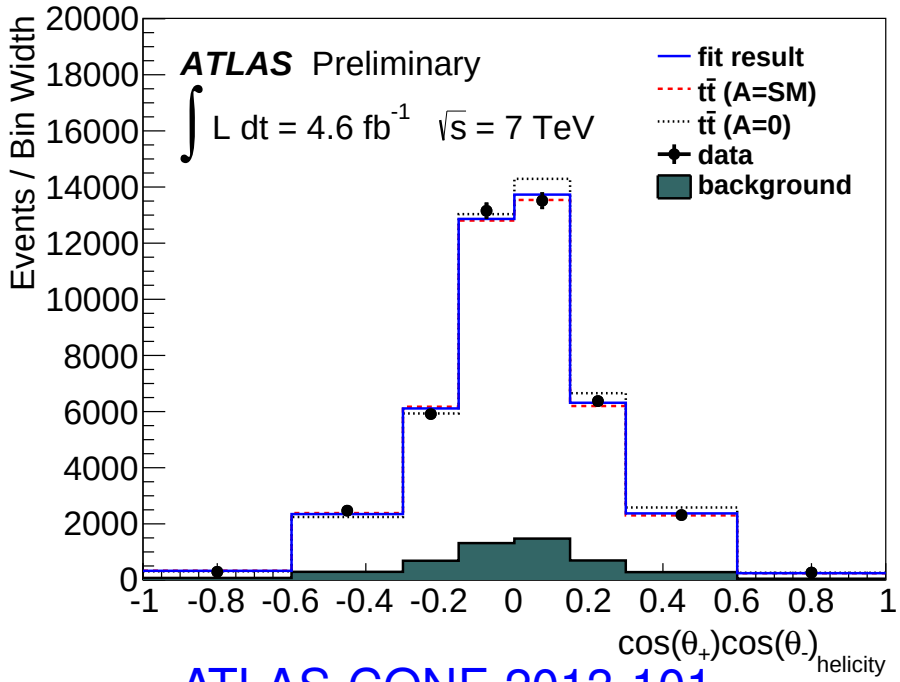
$t\bar{t}$ spin correlation





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$$S = \frac{m_t^2\left[(t\cdot\ell^+)(t\cdot\ell^-)+(\bar{t}\cdot\ell^+)(\bar{t}\cdot\ell^-)-m_t^2(\ell^+\cdot\ell^-)\right]}{(t\cdot\ell^+)(\bar{t}\cdot\ell^-)(t\cdot\bar{t})}$$