Physics Results from ATLAS

(EXCEPT HIGGS!)

G. Compostella
on behalf of the ATLAS MPP group

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

MPP in ATLAS

MPP ATLAS group director: Prof. Siegfried Bethke

Performance studies

With contributions by: Teresa Barillari, Johanna Bronner, Daniele Capriotti, Michael Flowerdew, Maximilian Goblirsch-Kolb, Andrey Kiryunin, Oliver Kortner, Alessandro Manfredini, Sven Menke, Martin Nagel, Denis Salihagic, Rikhard Sandstrom, Peter Schacht, Federico Sforza, Sebastian Stern, Marco Vanadia, Daniele Zanzi

Standard Model measurements

With contributions by: Daniele Capriotti, Katharina Ecker, Maximilian Goblirsch-Kolb, Oliver Kortner, Hubert Kroha, Robert Richter, Fabian Spettel, Stefan Stonjek, Marco Vanadia

Top quark physics

With contributions by: Gabriele Compostella, Giorgio Cortiana, Andreas Maier, Thomas McCarthy, Richard Nisius, Stefan Kluth, Andreas Wildauer

Supersymmetry searches

With contributions by: Michael Flowerdew, Maximilian Goblirsch-Kolb, Hubert Kroha, Federico Sforza

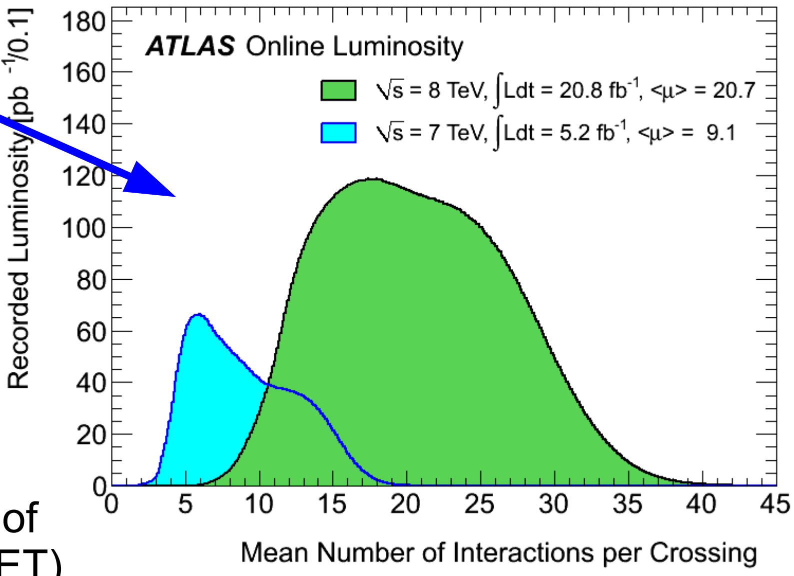
Missing Transverse Energy (MET) performance

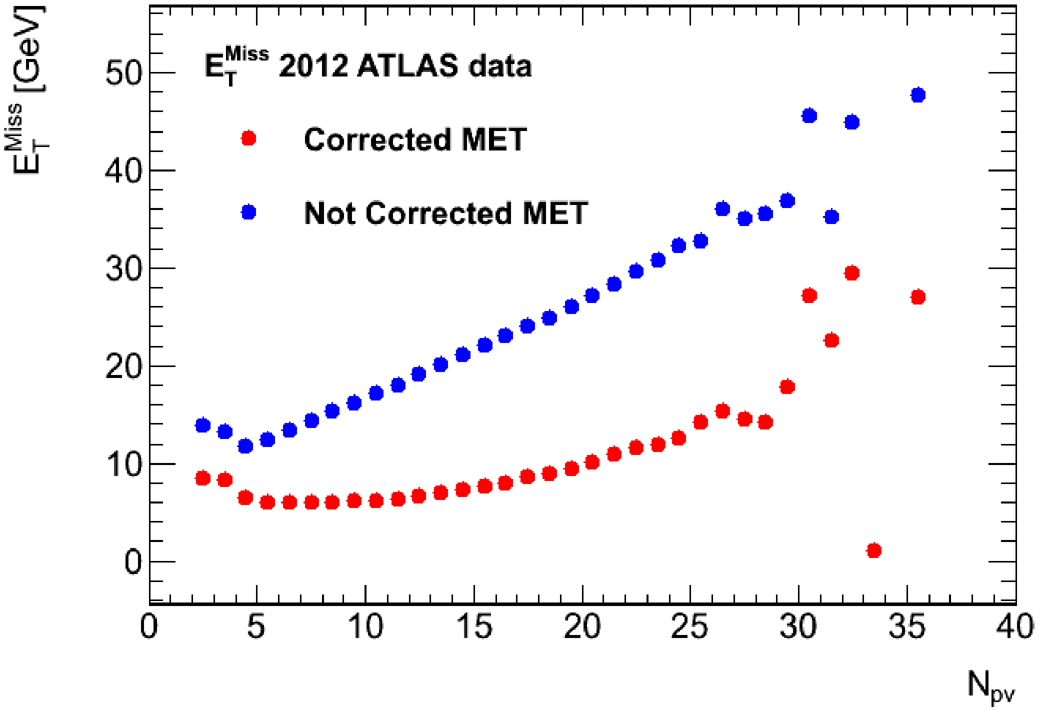
Pile-up conditions drastically changed during 2012!

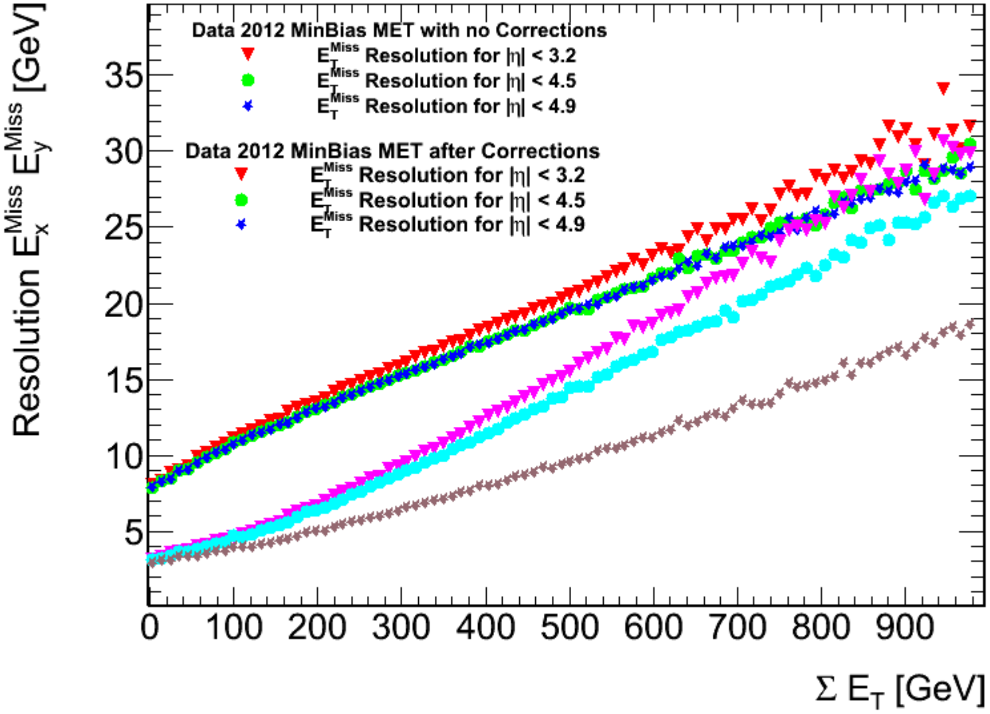
MET performance is the key for many analyses

Studied 2012 MinBias data in 3 different calorimeter regions
    |η| < 3.2, |η| < 4.5, and |η| < 4.9

MET resolution is improved using the "STVF correction method" (ATLAS-CONF-2012-101)
(The fraction of tracks from the primary vertex pointing to soft terms of the MET is used to reweight the terms and recalculate the overall MET)

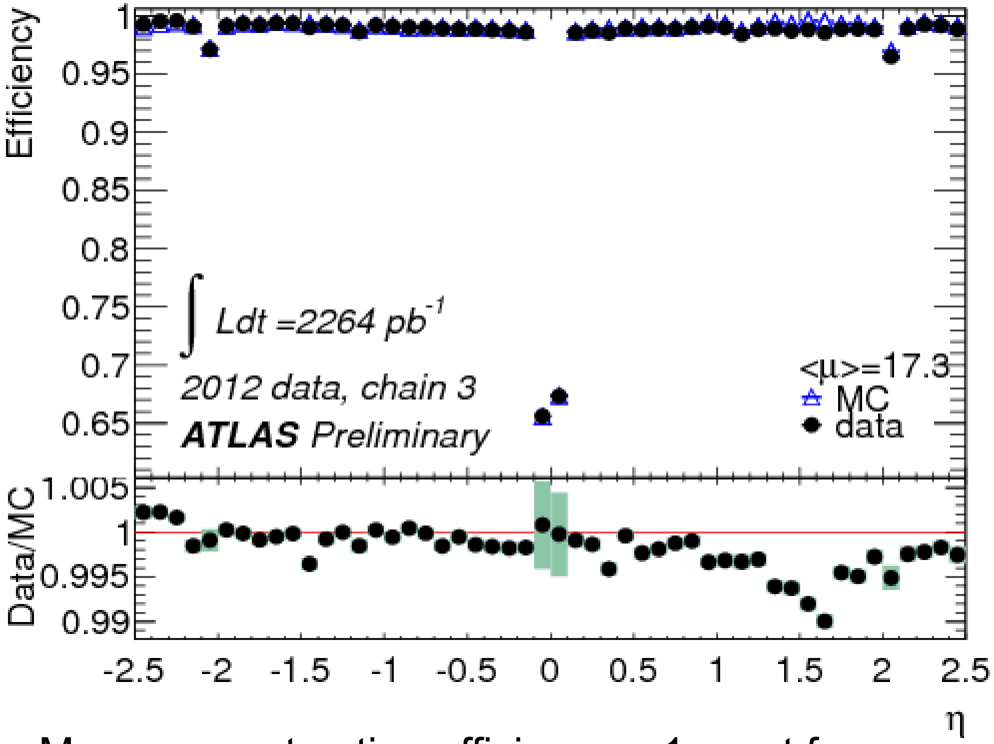




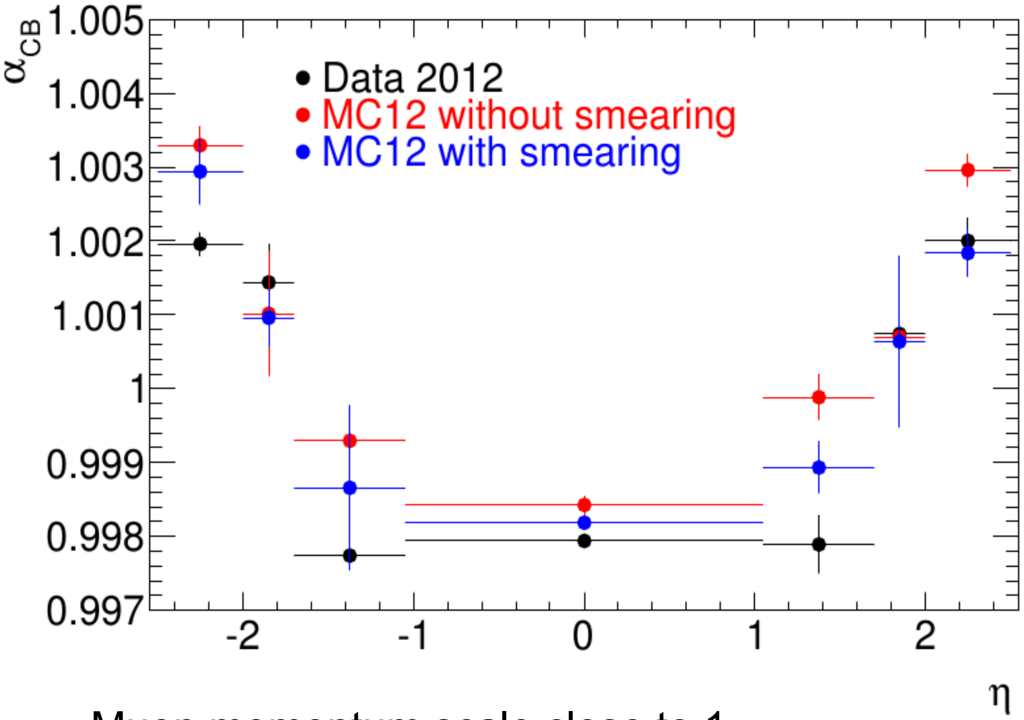


Muon performance in pp→Z→μμ collision data

Muon reconstruction efficiency



Muon momentum scale



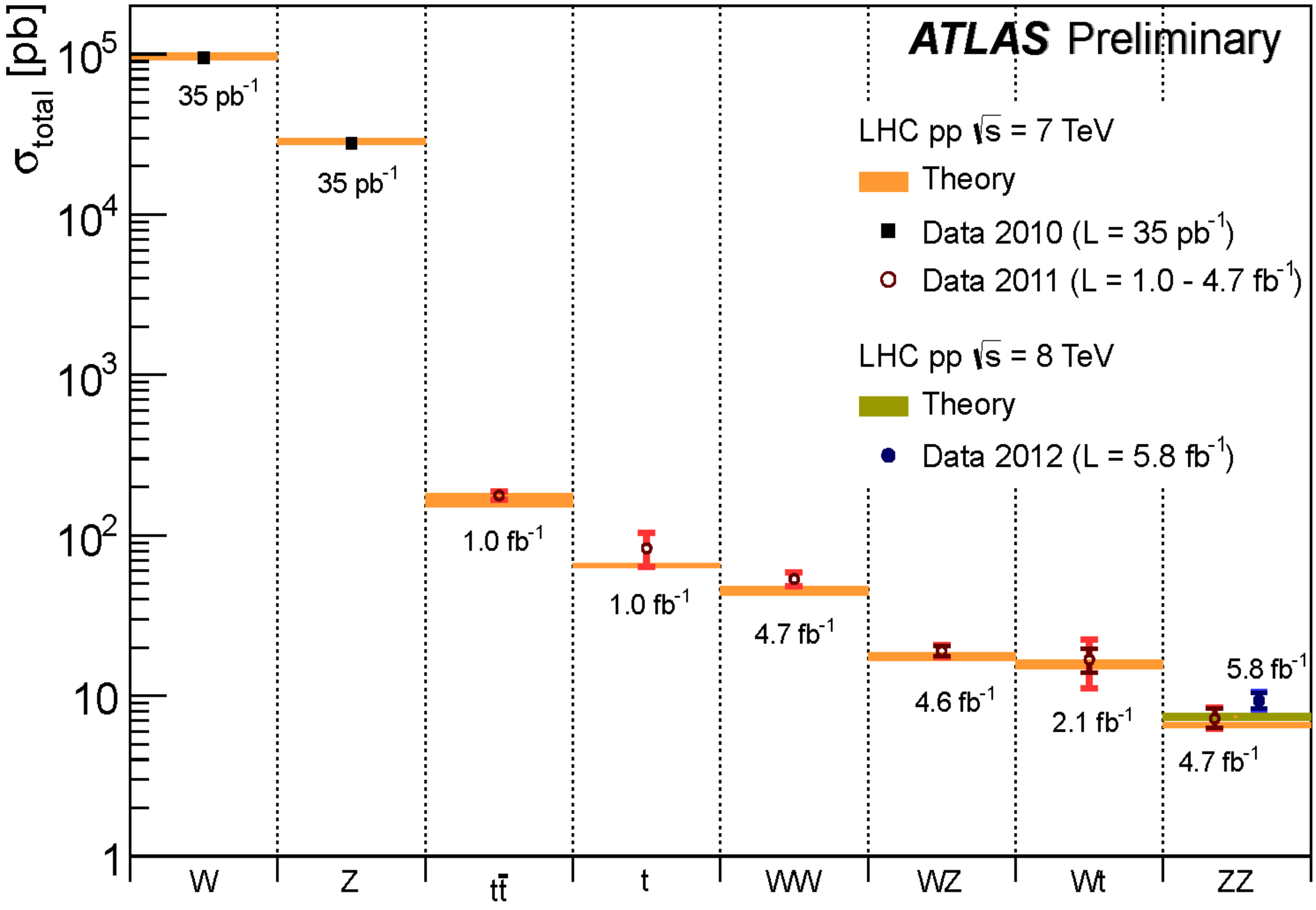
- Muon reconstruction efficiency ~ 1 apart from regions with limited muon spectrometer coverage
- Agreement with the Monte-Carlo prediction at <<1%

- Muon momentum scale close to 1
- Deviations modelled by the Monte-Carlo simulation

Many more performance studies ongoing:

- τ identification and reconstruction
- b-jet reconstruction optimization with track jets
- local hadron calibration method for jet energies (standard for 2012 analyses)

Standard Model at ATLAS



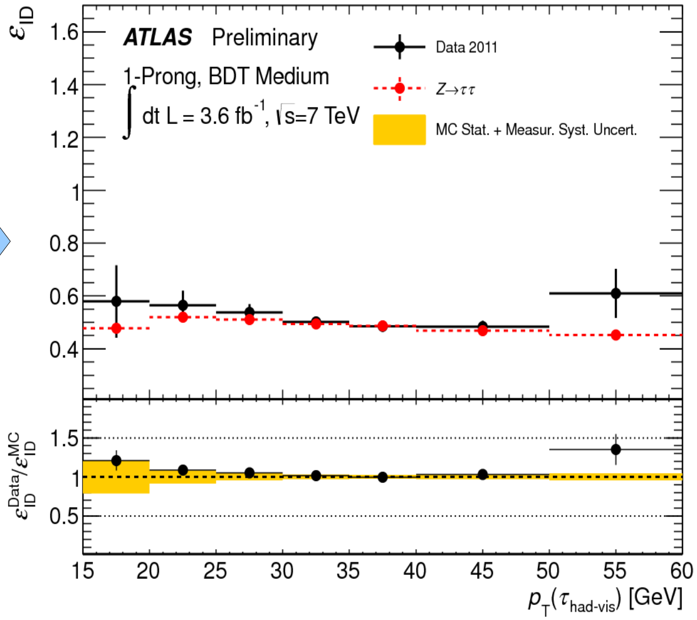
...H?

ATLAS is sensitive to a large number of SM processes, with cross sections spanning multiple orders of magnitude... **MPP presence all over this plot!**

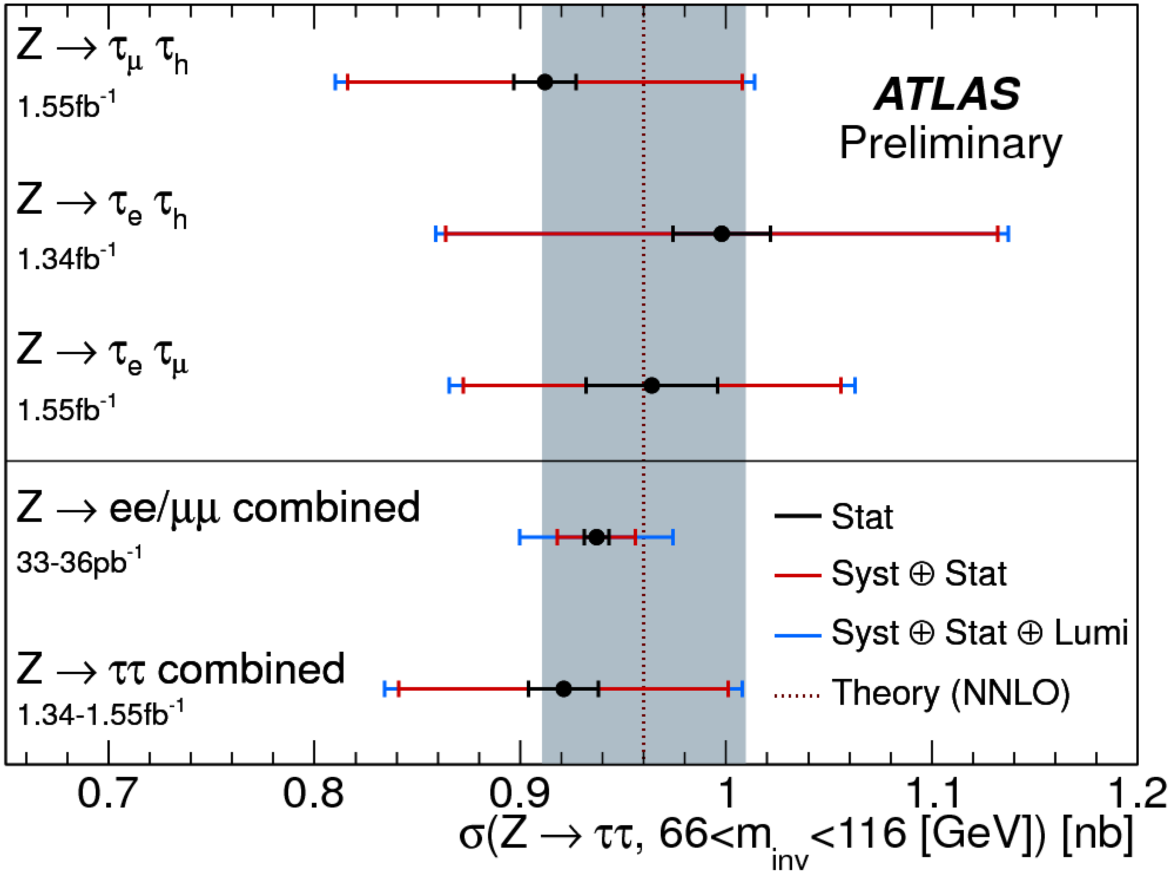
Measurement of the $pp \to Z \to \tau\tau$ production

- Test of τ lepton identification
- Irreducible background to $pp \to H \to \tau\tau$
- Complemented with extensive τ reconstruction and identification performance studies

1 prong τ



Excellent Data/MC agreement in τ ID!

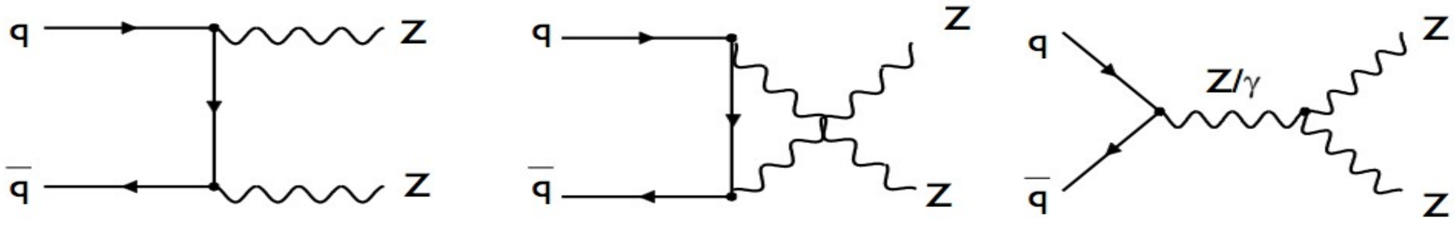


Excellent agreement of $pp \to Z \to \tau\tau$ cross sections with $pp \to Z \to ee/\mu\mu$ cross sections!

ATLAS-CONF-2012-006, Phys.Rev. D84 (2011) 112006

Measurement of the $pp \to ZZ \to 4l$ production

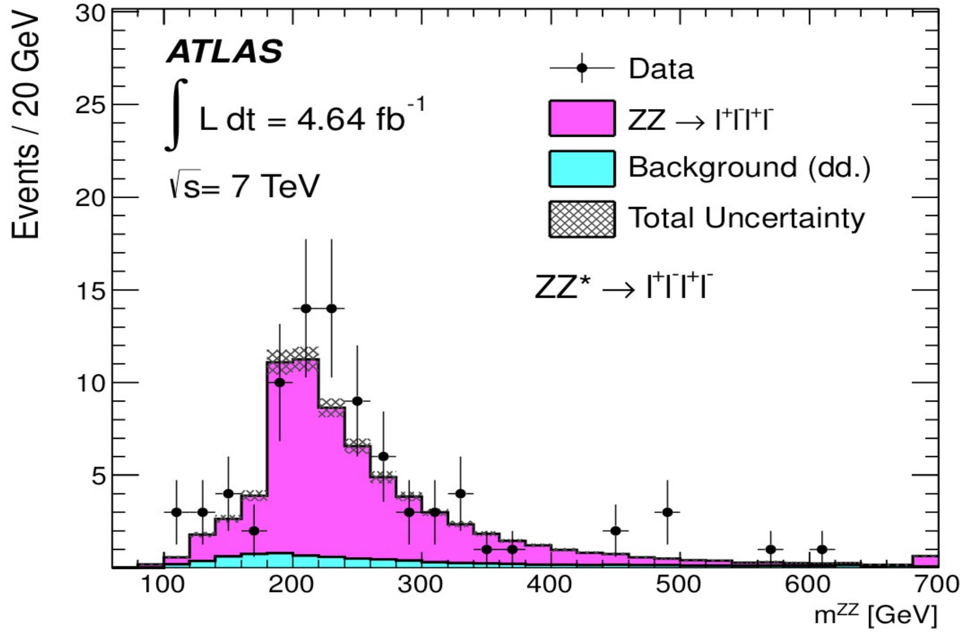
- Search for anomalous triple gauge couplings which are forbidden in the Standard Model at leading order:



Standard Model Production

SM Forbidden

- $pp \to ZZ \to 4l$ irreducible background to $pp \to H \to ZZ \to 4l$



Standard Model prediction

$$5.89^{+0.22}_{-0.18}\ \text{pb}$$

ATLAS ($\int L dt = 4.7\ \text{fb}^{-1}$)

$$\sigma^{\text{tot}}_{ZZ} = 6.7 \pm 0.7\ (\text{stat.})\ ^{+0.4}_{-0.3}\ (\text{syst.}) \pm 0.3\ (\text{lumi.})\ \text{pb}$$

Standard Model compatible
with result on data

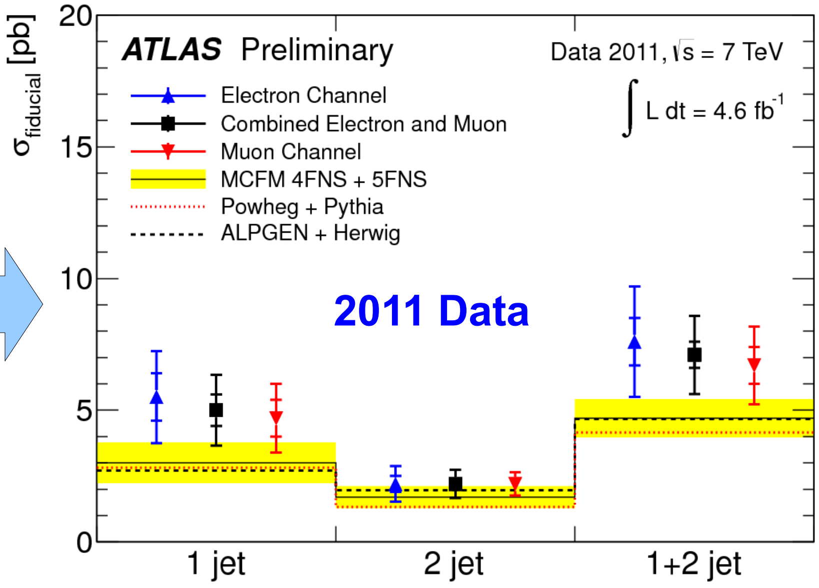
ATLAS-CONF-2012-026, arXiv:1211.6096

Other Standard Model measurements at MPP

Measurement of the pp→W+b jets production:

- Test of higher order QCD predictions
- *pp→W+bb* important reducible background to *pp→H→WW*

ATLAS-CONF-2012-156,
Phys.Lett. B707 (2012) 418-437



2011 Data

Ongoing Activities:

Measurement of the pp→W+c jet production

- *pp→W+c jet* is sensitive to the *s* quark and gluon density inside the proton

Measurement of the pp→WW→ jets production

- Very challenging
- Important test of the Standard Model
- dominant background to H → WW

Top quark overview

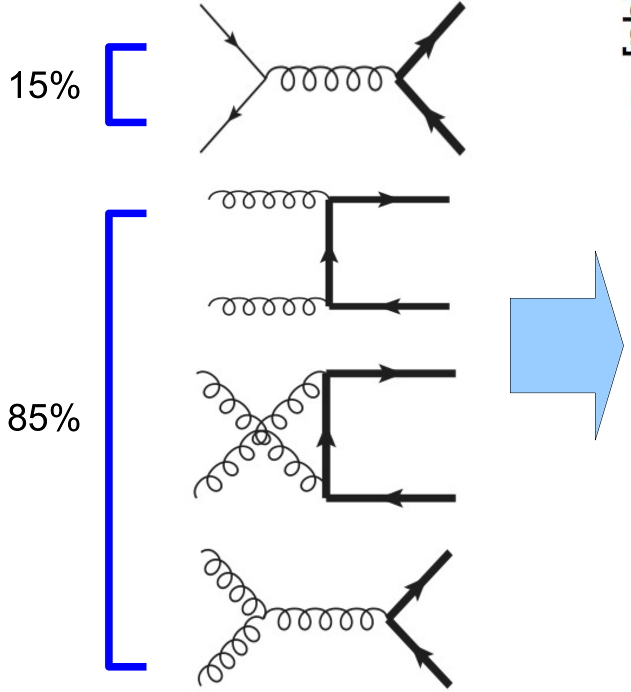
The top quark plays a central role in LHC physics:

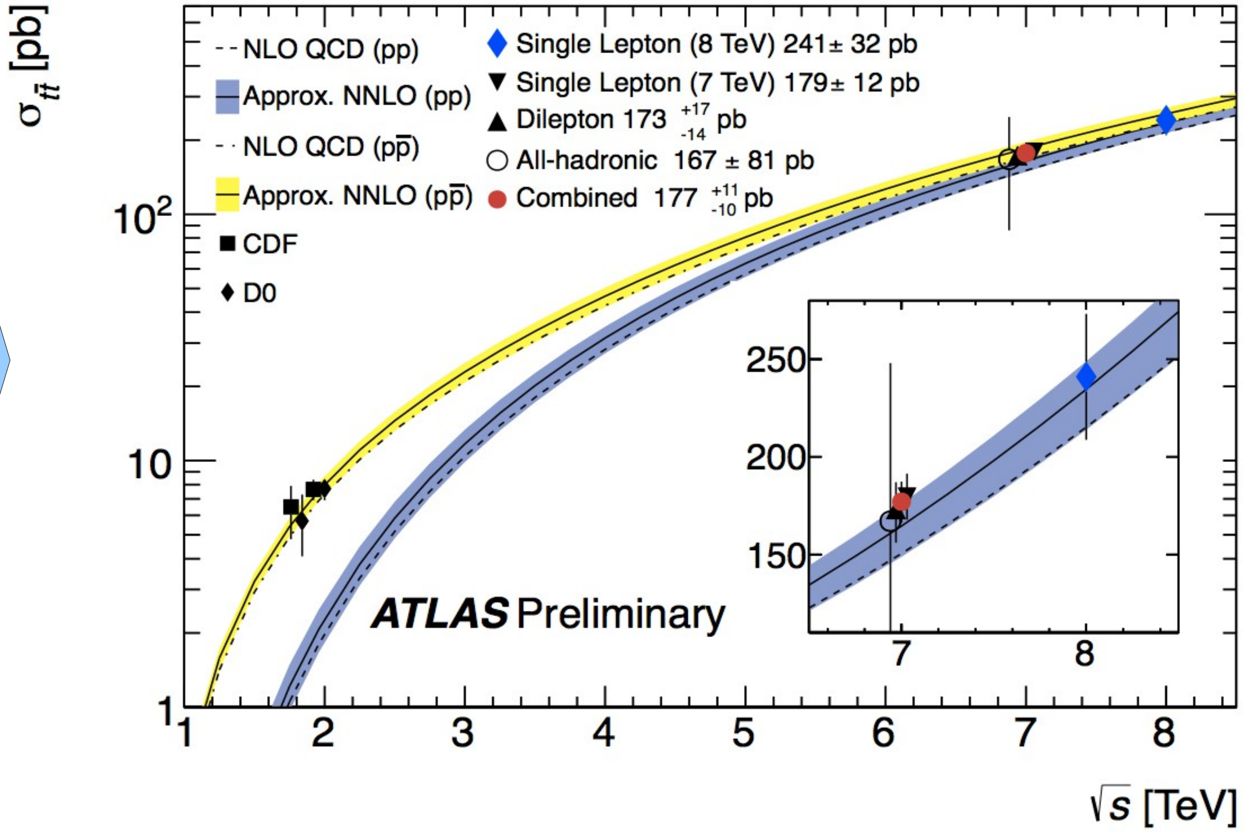
- its mass is a fundamental parameter of the Standard Model
- the top quark is ~40x heavier than the bottom quark:
  the only SM fermion with mass at the Electroweak scale

→ Large contribution in virtual fermionic loops

- top quark decays before hadronization, provides a unique opportunity to study a "bare" quark

- Important background to direct searches, large $t\bar{t}$ pair production cross section at the LHC:

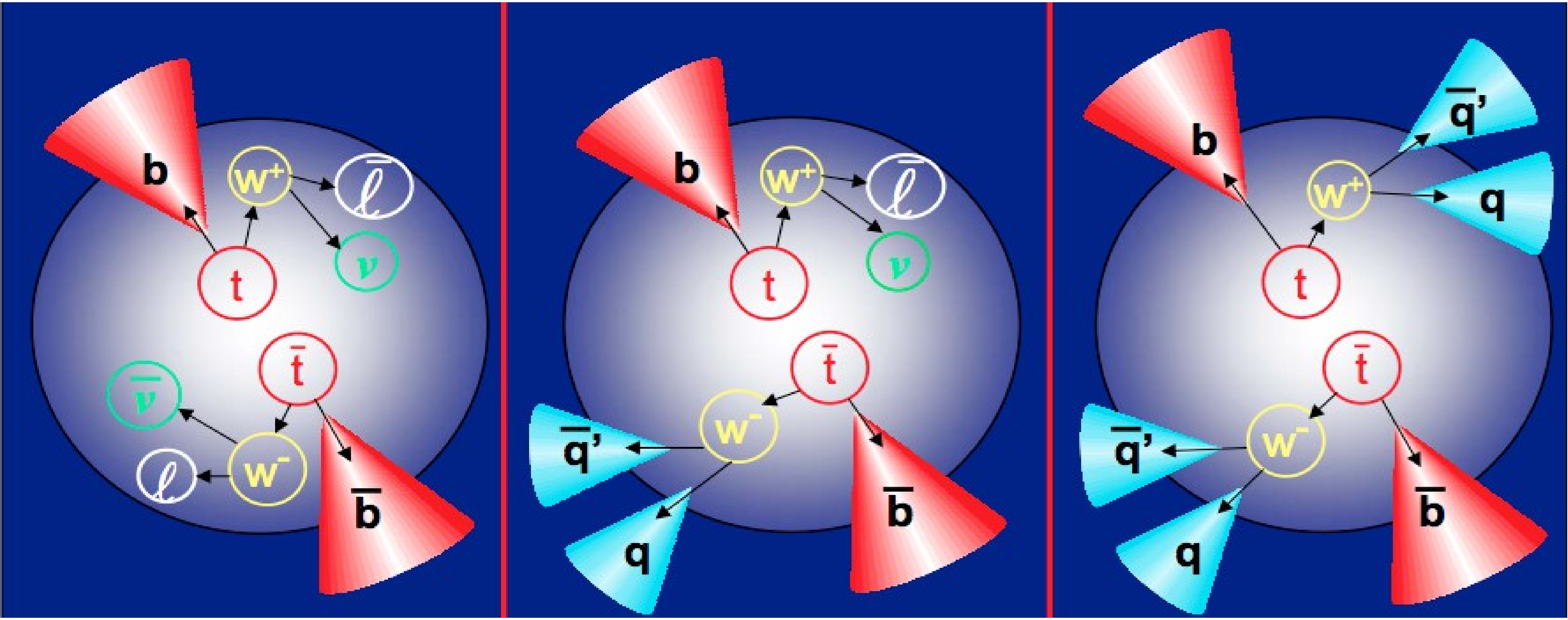




Top quark pair decay signatures

Top quark decays almost exclusively to Wb, $t\bar{t}$ pair decay signatures categorized from W decay

Dilepton (e or μ) 5% | Lepton (e or μ) +jets 30% | All hadronic 44%



low rate, low background (mainly Drell-Yan)
High purity
2 high-p_T leptons + MET

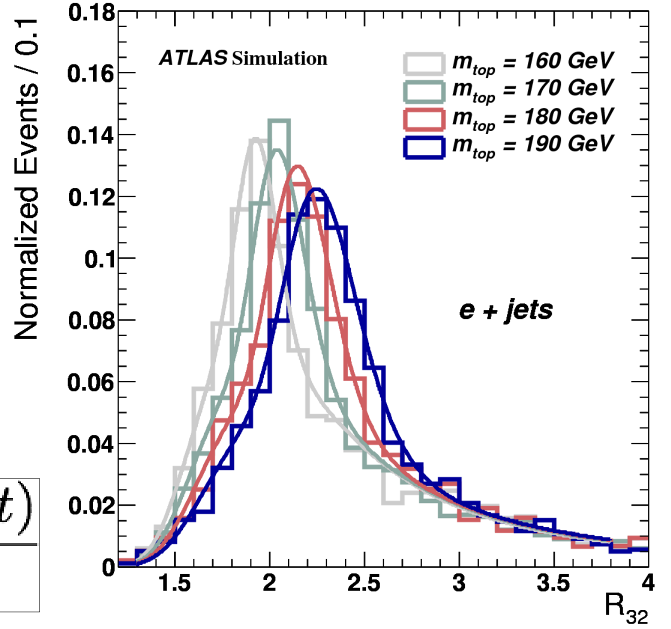
higher rate, manageable background (mainly W+jets)
Golden Channel
1 high-p_T lepton + MET + jets

large rate, large background (mainly QCD)
Lowest purity
6 Jets + b-tagging

(other signatures involve at least one τ)

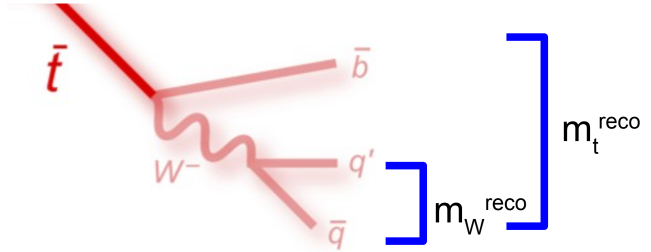
Our institute has ongoing analyses in each of the 3 channels!

ATLAS 2012 top quark mass paper



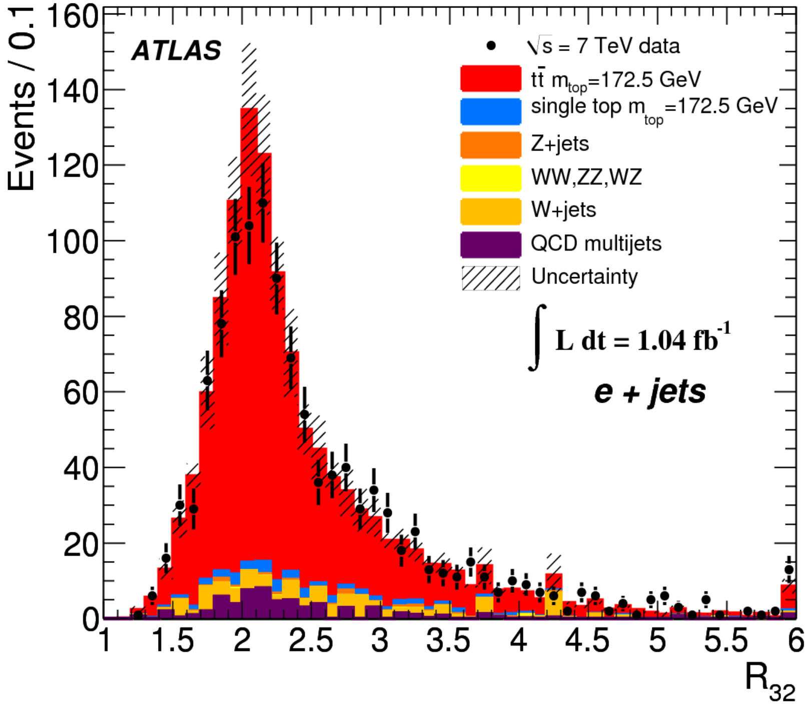
Template method in the lepton+jets channel, 1.04 fb^{-1} of 2011 LHC Data:

- Perform jet-parton assignment using a kinematic likelihood fitter
- Use R_{32} as estimator for top quark mass
- Derive signal and background templates of R_{32} from simulation
- Fit templates to data to extract the top quark mass

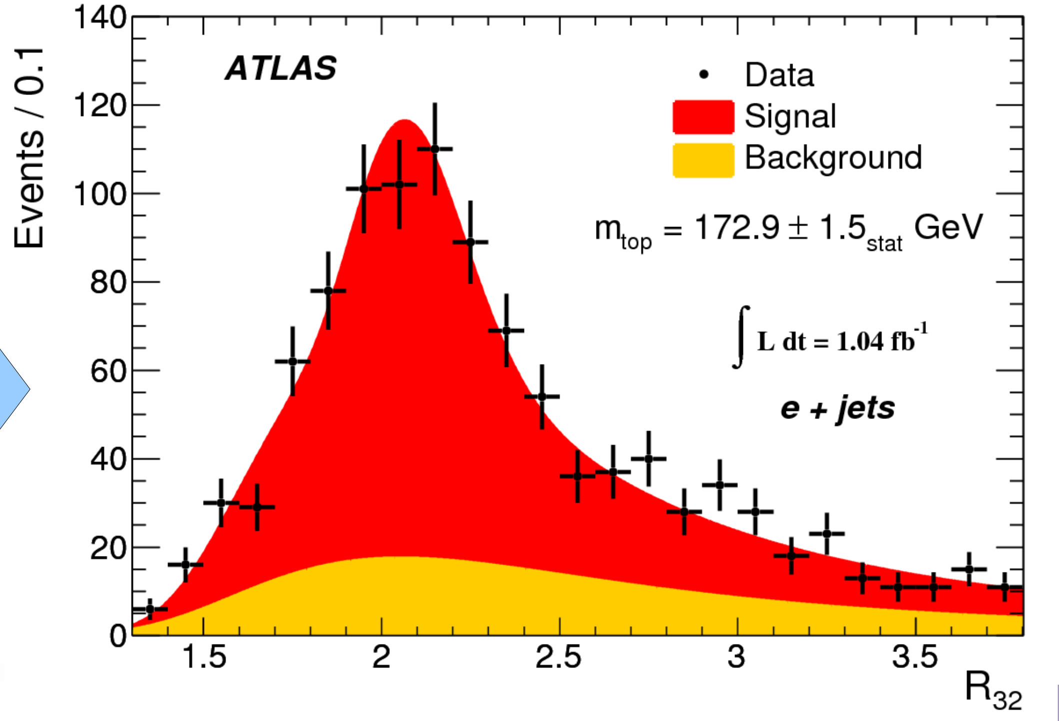


$$R_{32} = \frac{m_t^{reco}}{m_W^{reco}} = \frac{m(jet, jet, bjet)}{m(jet, jet)}$$

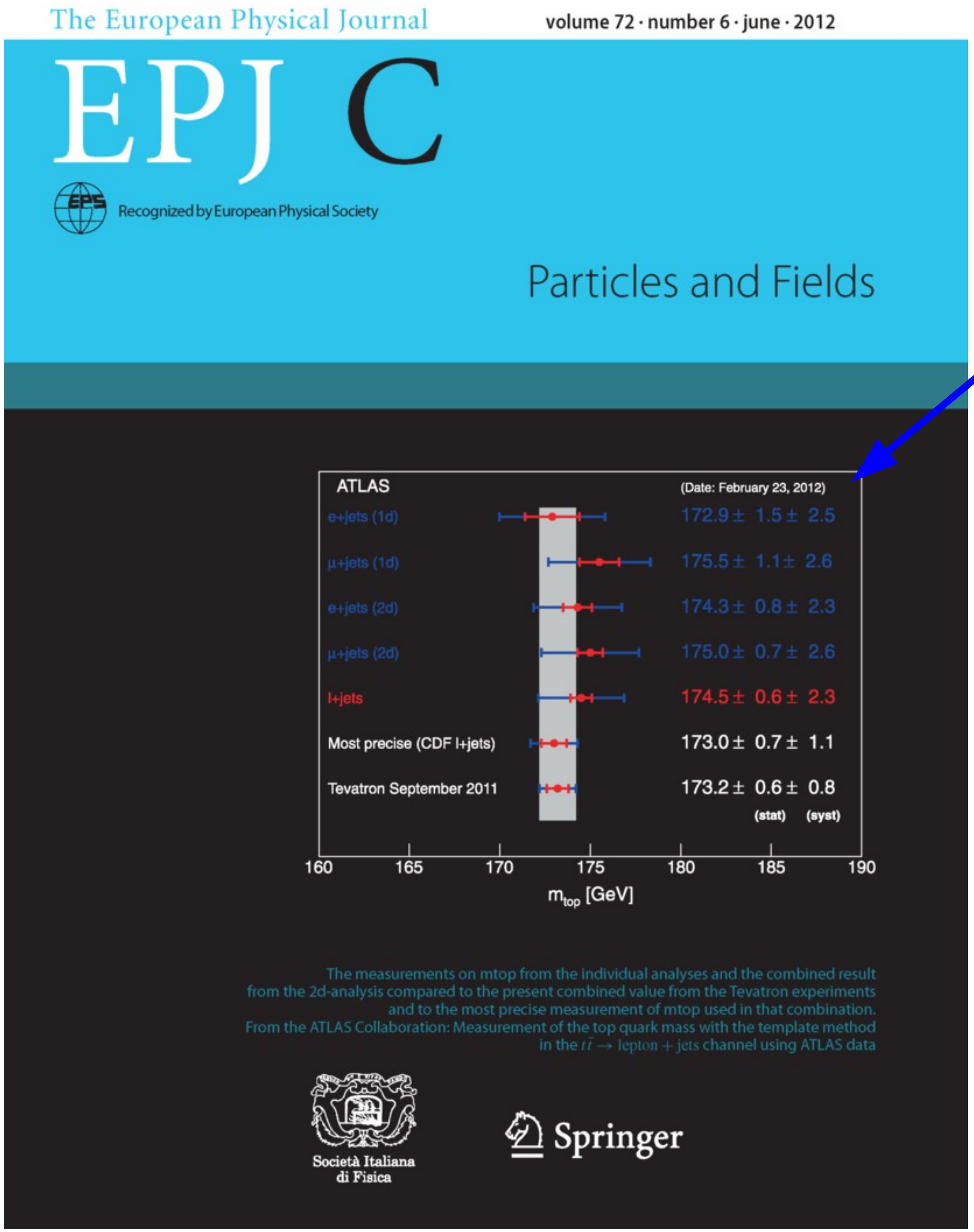
→ use jets to determine the top quark mass, minimizing uncertainties from Jet Energy Scale (JES)



Template fit



ATLAS 2012 top quark mass paper



The European Physical Journal

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EPJ C

Recognized by European Physical Society

Particles and Fields

The measurements on mtop from the individual analyses and the combined result from the 2d-analysis compared to the present combined value from the Tevatron experiments and to the most precise measurement of mtop used in that combination.
From the ATLAS Collaboration: Measurement of the top quark mass with the template method in the $t\bar{t} \rightarrow$ lepton + jets channel using ATLAS data

Società Italiana di Fisica

Springer

Results published in
Eur.Phys.J. C (2012) 72:2046

Major MPP contribution,
made the cover of EPJ!

Results from different channels (e/mu) and methods (1D/2D template)
Getting closer to Tevatron precision, but still limited by large systematic uncertanties

Major sources of uncertainties for this measurement (~80%): JES, bJES, modelling of Initial and Final state radiation (ISR/FSR)

In 2012 MPP contributed to the efforts in reducing these uncertainties:
bJES: study the calorimeter/tracker jet p_T ratio r_{trk} in the lepton +jets sample
ISR/FSR: tune simulations to data using jet track shapes

A 3D template analysis fitting simultaneously m_t^{reco}, m_W^{reco} and an r_{trk}-like variable is in the final stages of development: it will measure the top quark mass, fixing JES and bJES to data!

First LHC top quark mass combination

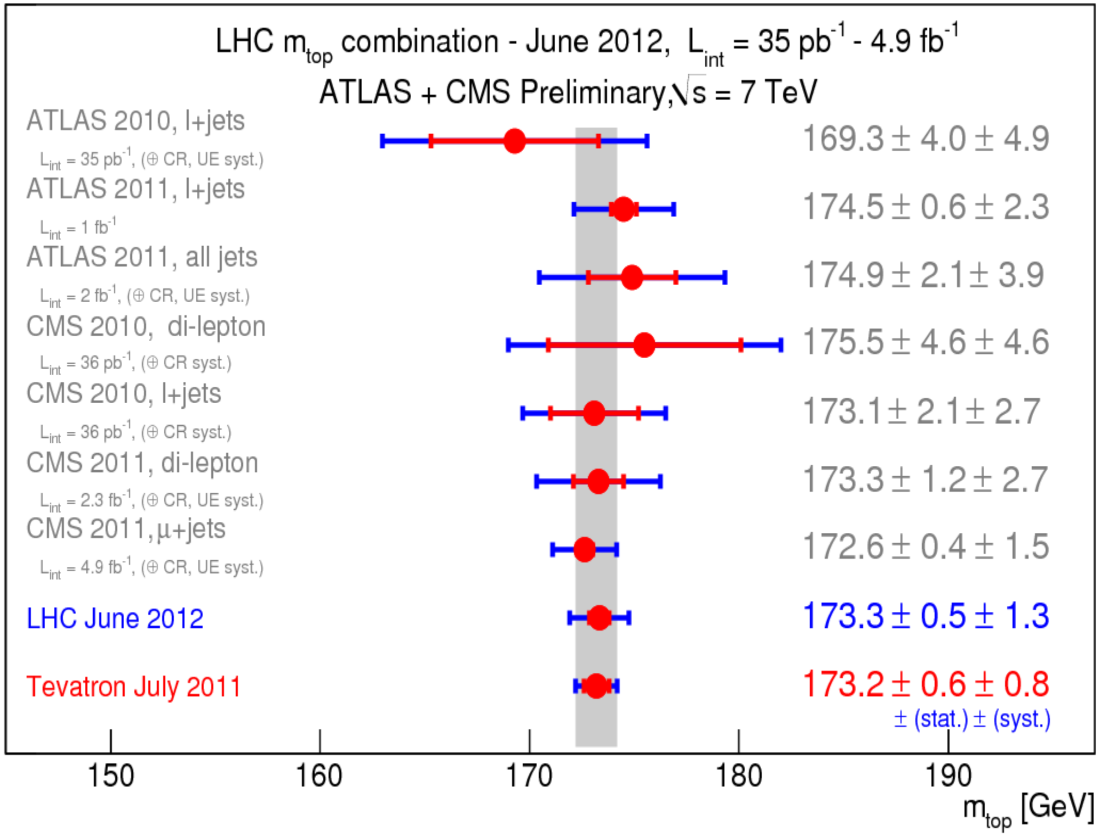
Many measurements of the top quark mass already available at the LHC:
- different top decay channels and techniques
- different assumptions and sensitivity to various systematic effects

Combination is not easy!

- Needs deep understanding of systematic uncertainties and their correlations between ATLAS and CMS

- Work is ongoing towards harmonization of the treatment of the different uncertainties

- Experience gained was successfully ported to the first LHC top quark pair production cross section combination



ATLAS-CONF-2012-095 (mass combination)
ATLAS-CONF-2012-134 (cross section combination)

Other top physics measurements at MPP

Ongoing Activities:

Measurement of the top quark mass in the dilepton channel MPP-2012-160

- Underconstrained kinematics due to the presence of 2 undetected neutrinos
- Studied performance of 3 different m_t estimators with a template method
- Public result coming soon

Measurement of the top quark mass in the all-hadronic channel

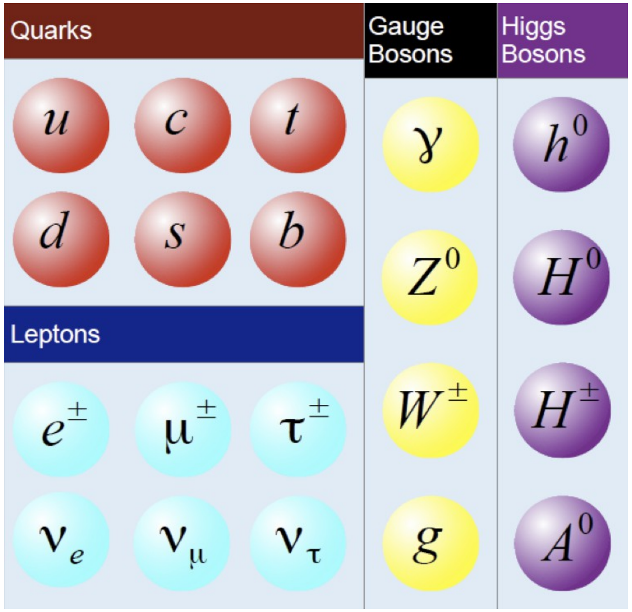
- Very challenging to reconstruct: 6 jets, no leptons, no MET!
- Studied different algorithms for jet-parton assignment

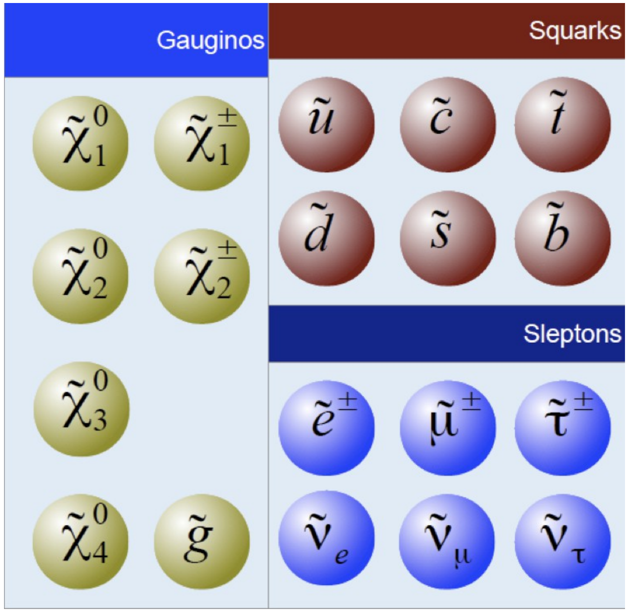
Search for New Physics in single top quark decays

- Probe anomalous couplings in the Wtb vertex
- Public result almost ready

Supersymmetry (SUSY)

- SUSY postulates a boson field for every fermion field, and vice versa
- Exact SUSY stabilizes the Higgs mass canceling loop corrections from fermions
- If SUSY exists, it must be a broken symmetry → sparticles gain mass ~TeV





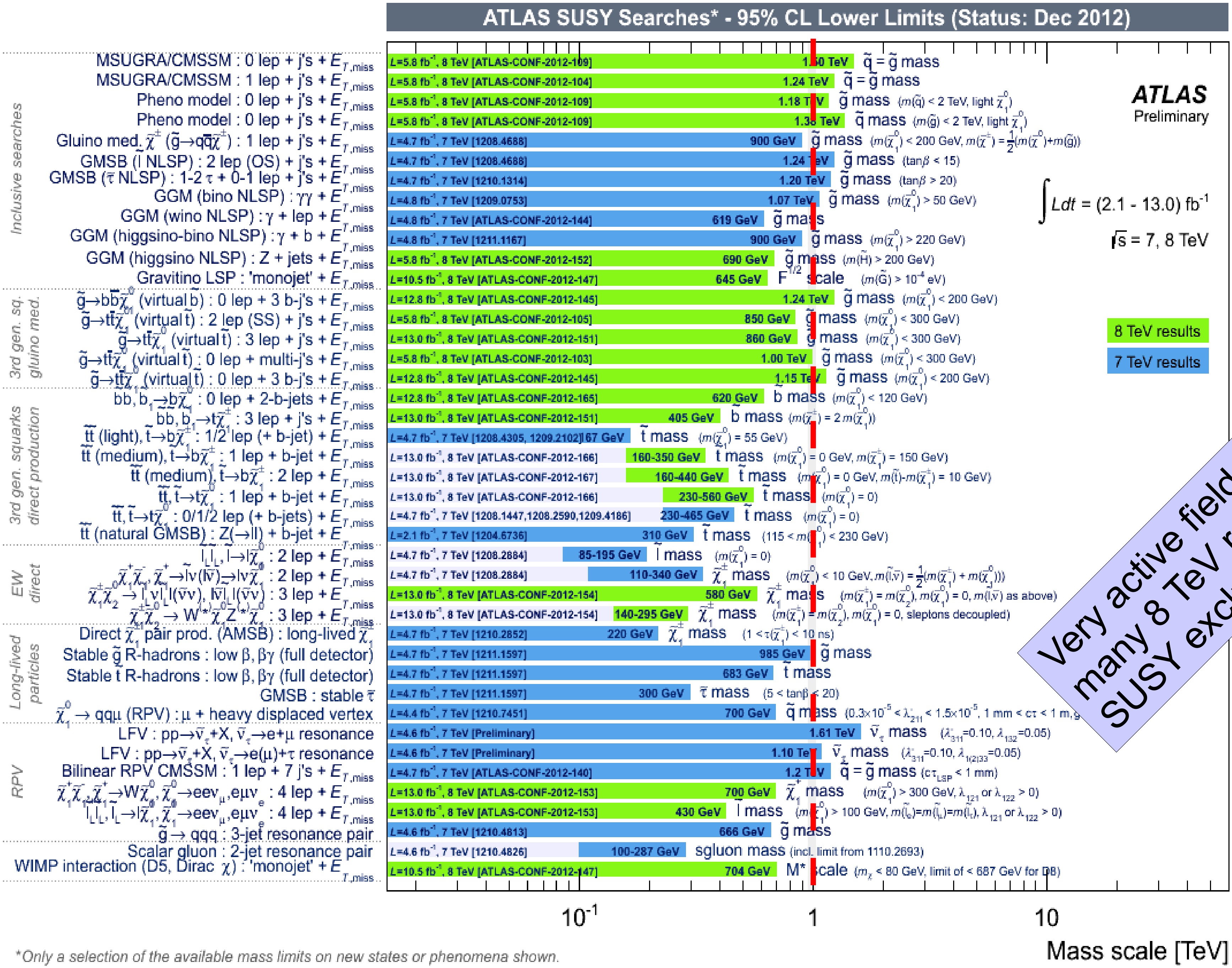
- To prevent rapid proton decay, many SUSY models assume R-Parity is conserved:

$$R_P = (-1)^{2s+3B+L} = \begin{cases} +1(\textit{particles}) \\ -1(\textit{sparticles}) \end{cases}$$

→

Lightest SUSY particle (LSP) stable,
Experimental signature: large MET

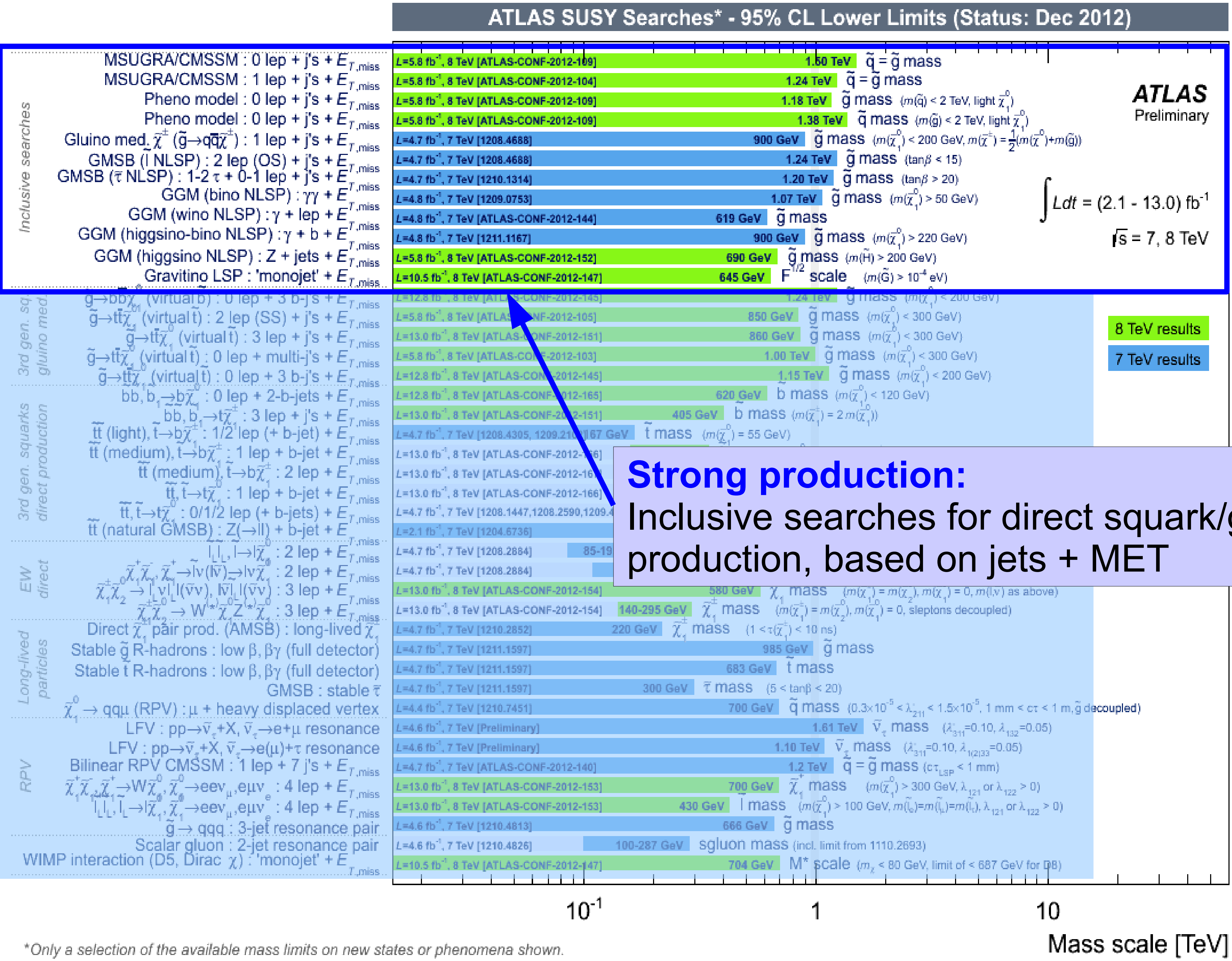
SUSY searches at ATLAS



*Only a selection of the available mass limits on new states or phenomena shown.
All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

Very active field in ATLAS,
many 8 TeV results,
SUSY excluded up to ~1 TeV!

SUSY searches at ATLAS



Strong production:
Inclusive searches for direct squark/gluino production, based on jets + MET

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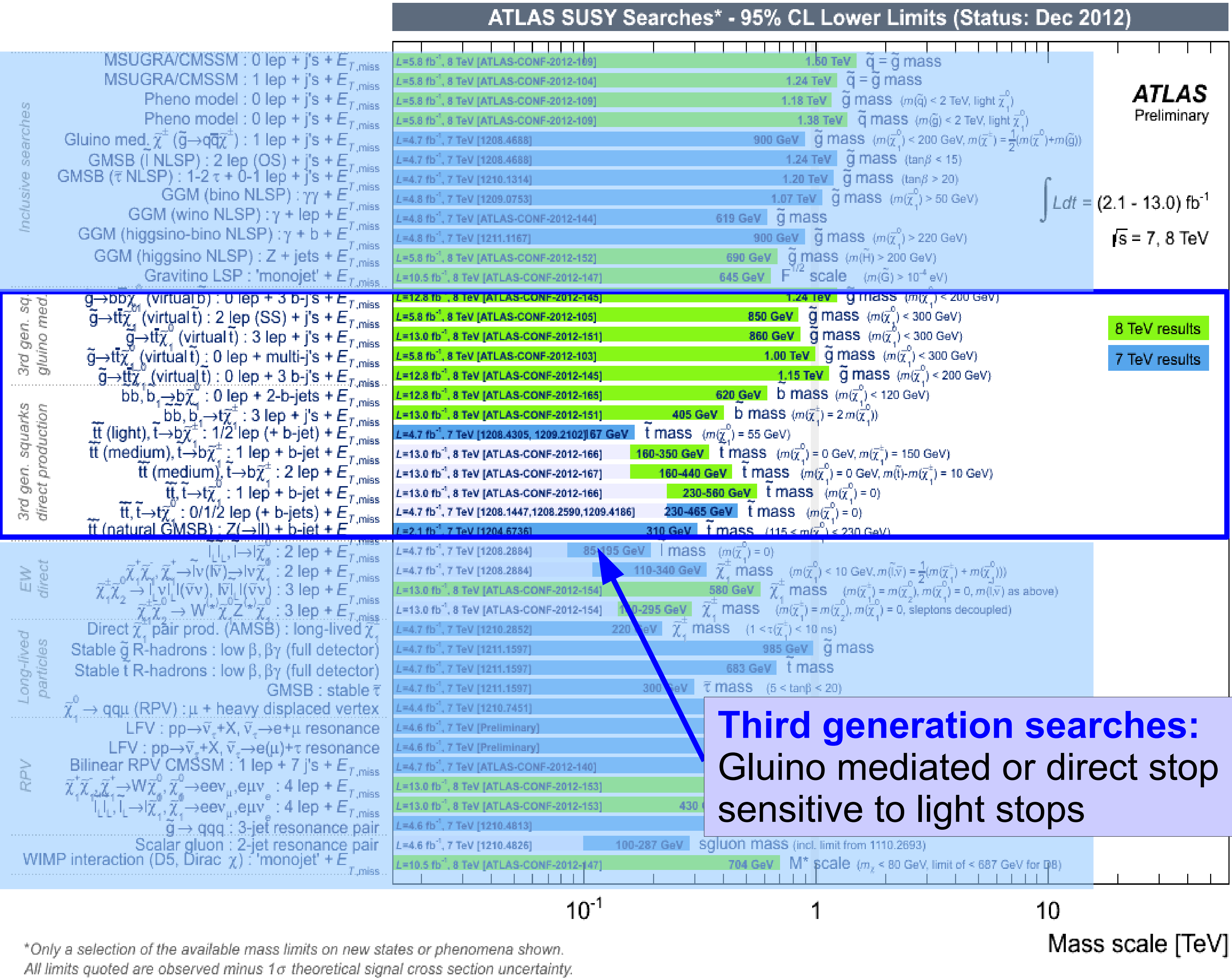
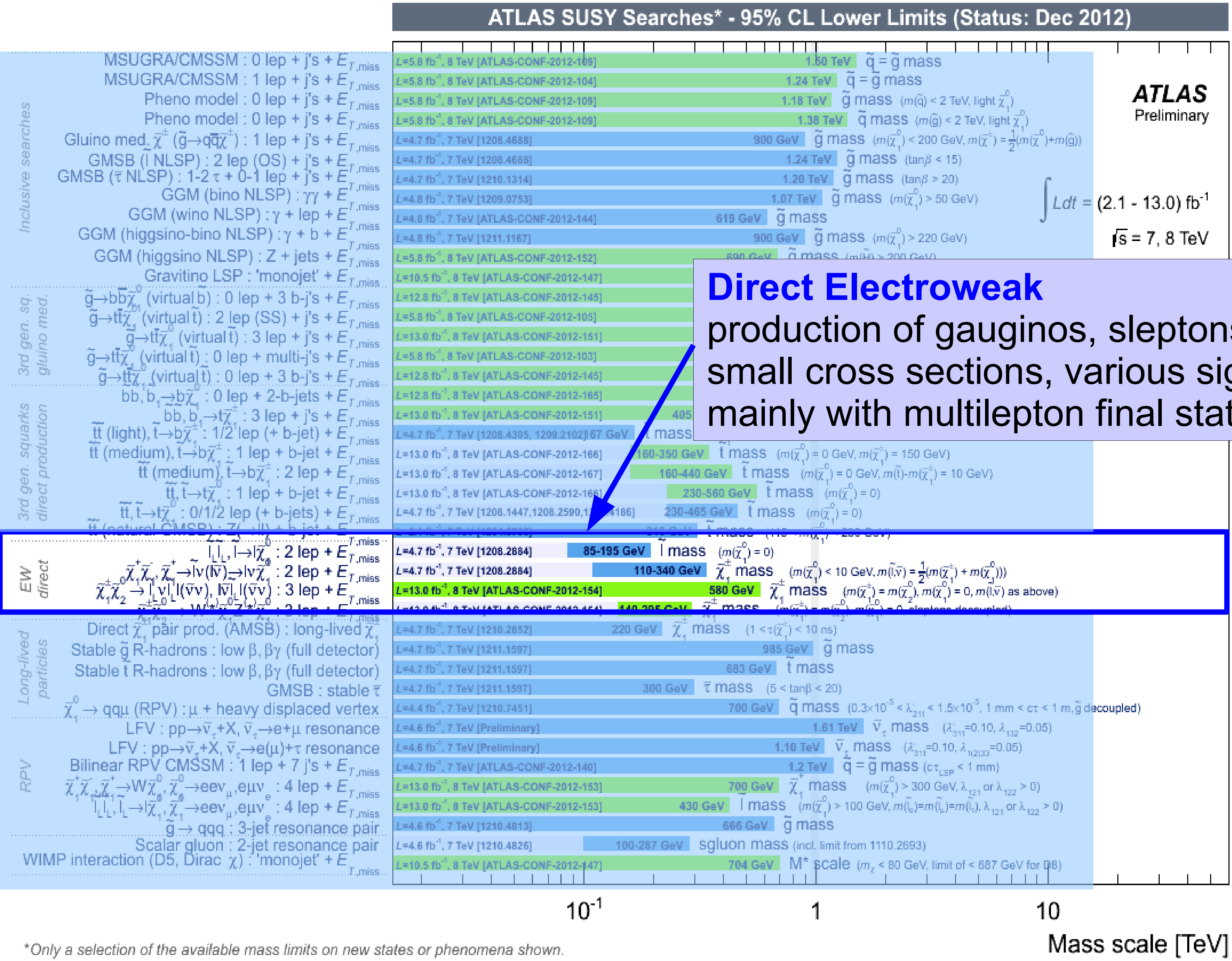
SUSY searches at ATLAS



Third generation searches:
Gluino mediated or direct stop production, sensitive to light stops

SUSY searches at ATLAS



Direct Electroweak
production of gauginos, sleptons,
small cross sections, various signatures,
mainly with multilepton final states

*Only a selection of the available mass limits on new states or phenomena shown.
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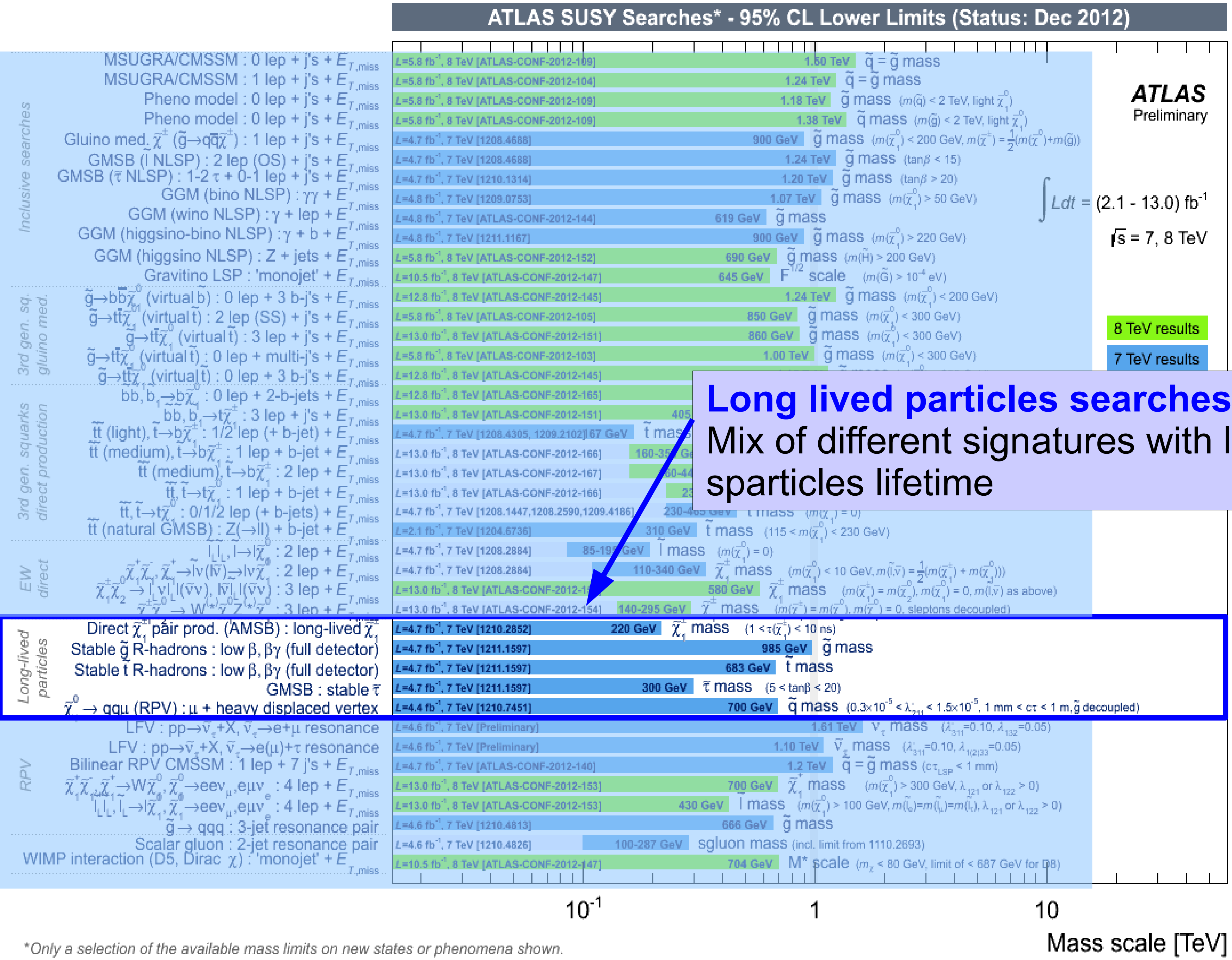
SUSY searches at ATLAS



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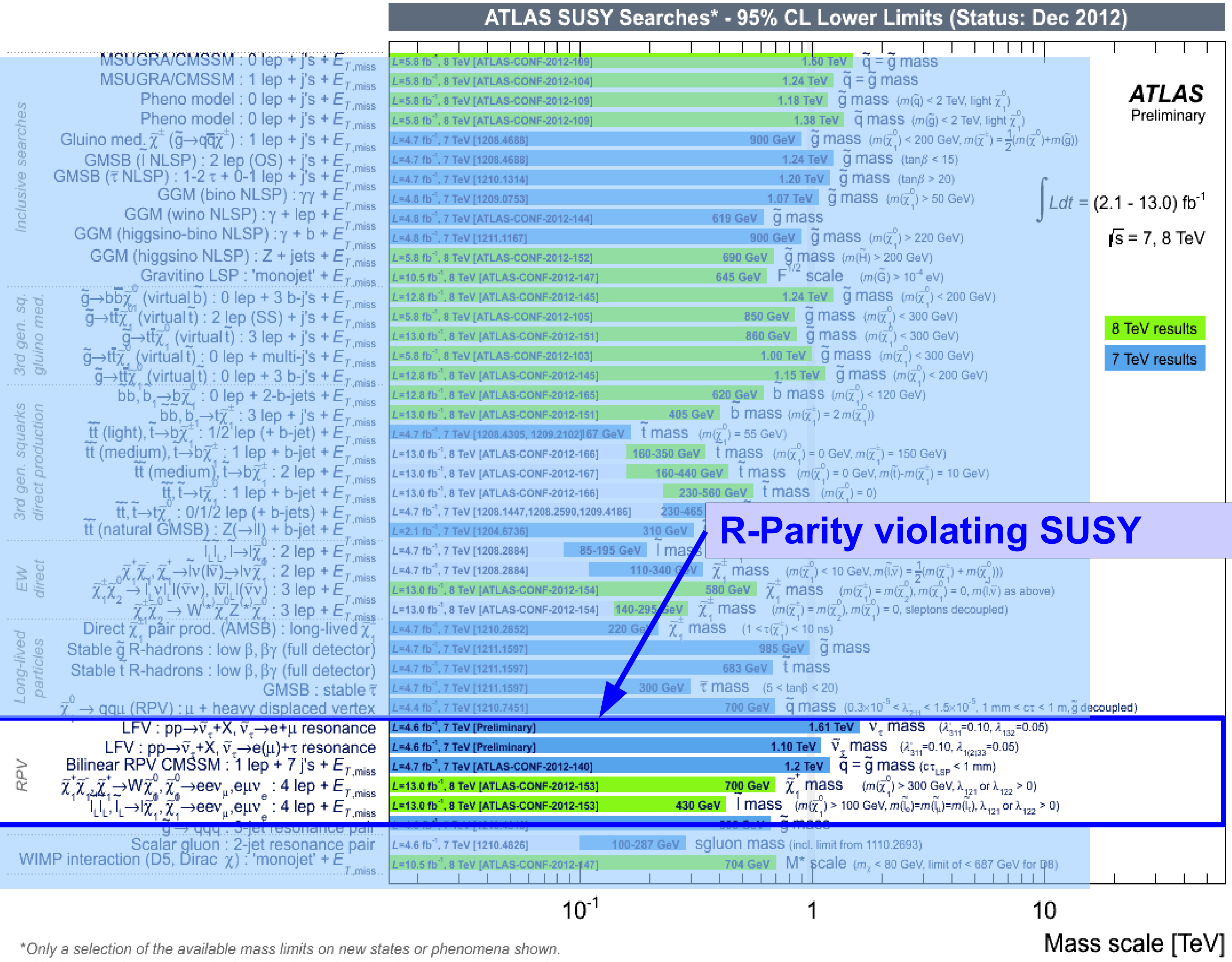
All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

Long lived particles searches
Mix of different signatures with longer sparticles lifetime

SUSY searches at ATLAS



R-Parity violating SUSY

*Only a selection of the available mass limits on new states or phenomena shown.

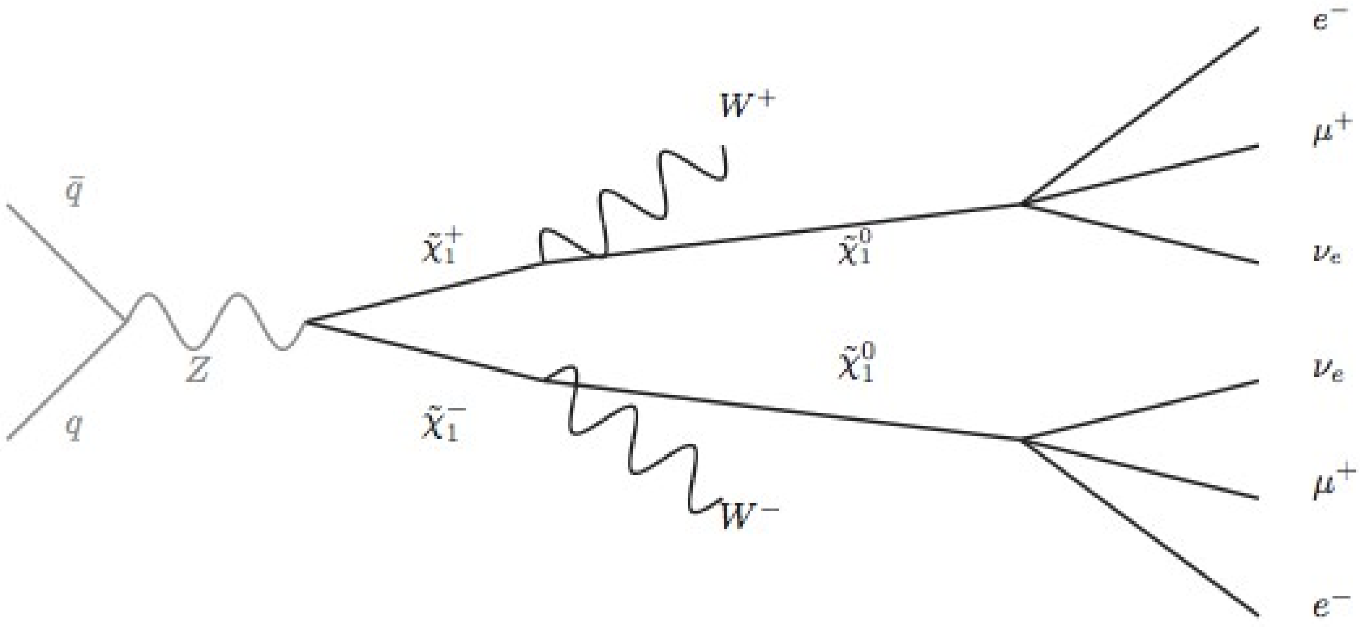
All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

R-Parity violation

- What if we relax R-Parity and protect the proton with other simmetries?
  - LSP now can decay violating lepton/baryon number conservation:

$$W_{RPV} = \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k + \kappa_i L_i H_2$$

Assuming a simplified R-Parity Violating (RPV) model with neutralino-like LSP and $\lambda_{121}>0$:

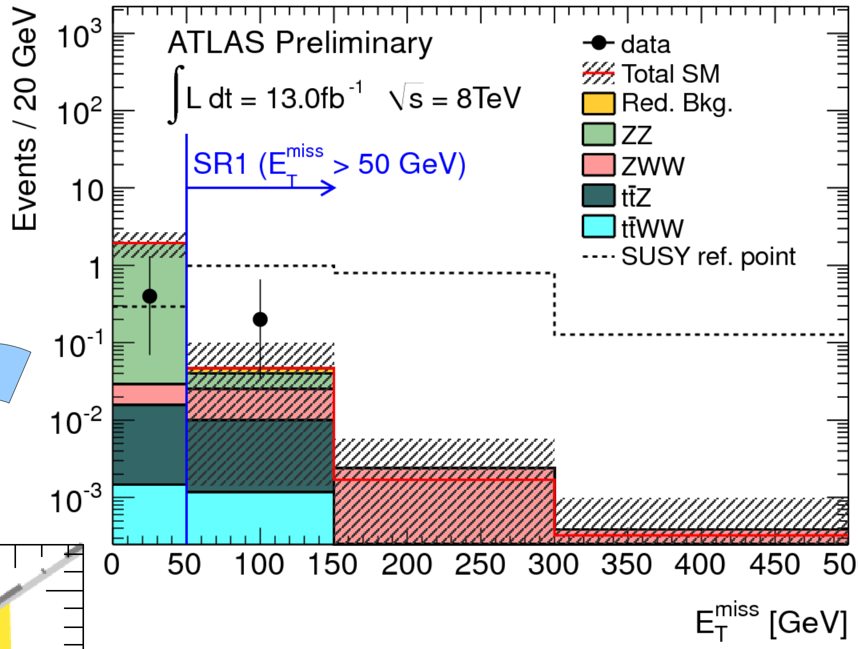


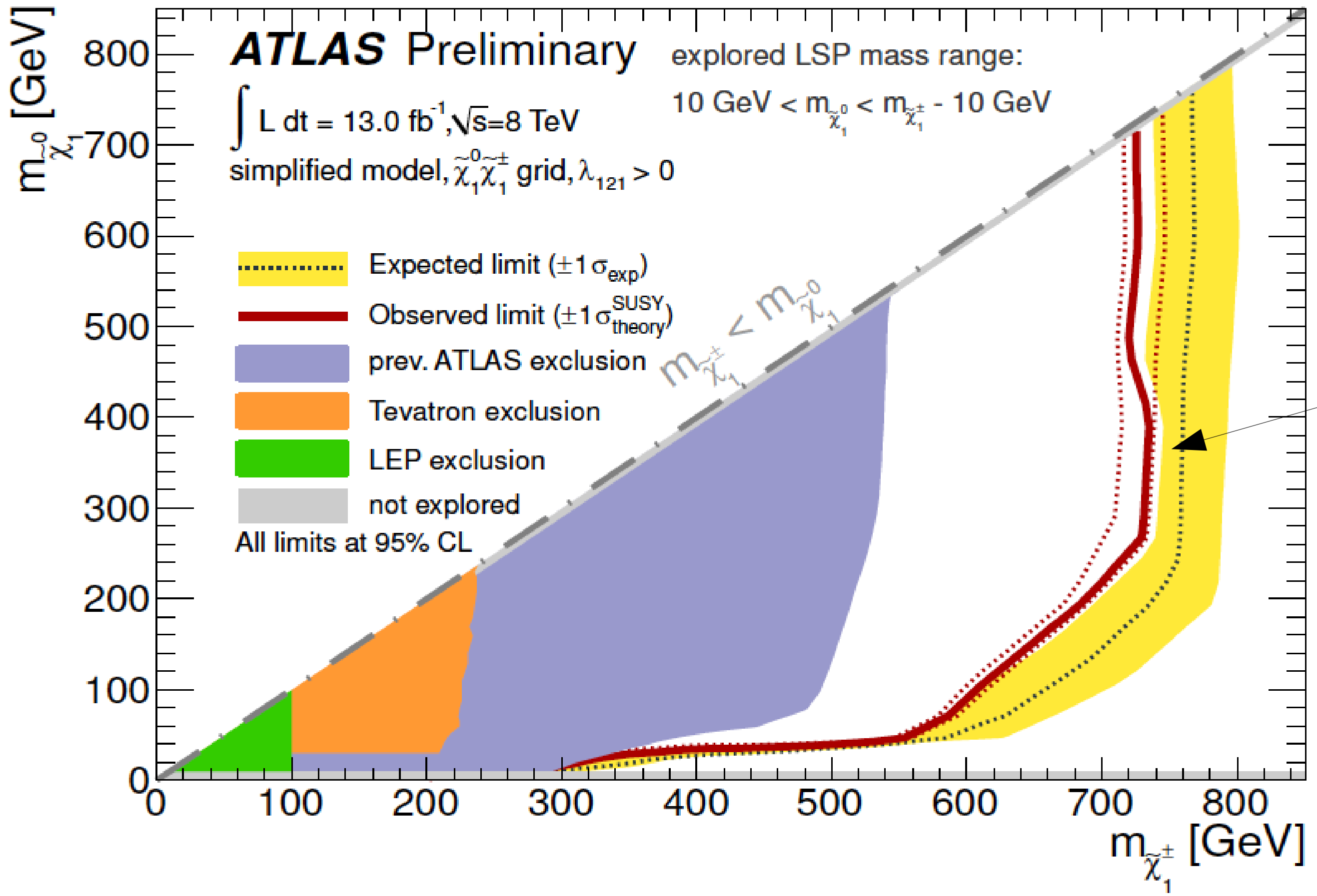
➡ Multilepton
experimental signature

Analysis of ≥ 4l events at MPP

Search for events with ≥ 4 isolated e/μ

- Veto Z→ l^+l^- candidates
- Reducible background from simulation
- Irreducible background from data-driven studies, validated in non-isolated control regions
- Null result interpreted as 95% CL mass limit in simplified RPV model





Exclude Wino masses up to 700 GeV

ATLAS-CONF-2012-153
...and:
ATLAS-CONF-2012-001
ATLAS-CONF-2012-035
arXiv:1210.4457 [hep-ex]

Conclusions

I gave a (somehow personal) overview of the analysis activities at MPP within the ATLAS collaboration

A lot of work is ongoing, both measurements and performance studies to improve our understanding of the detector
...couldn't show all of them in detail!

For more informations on ATLAS results: https://twiki.cern.ch/twiki/bin/view/AtlasPublic

- 2012 hasn't been only about Higgs!

- Standard Model analyses are the base for searches of new phenomena

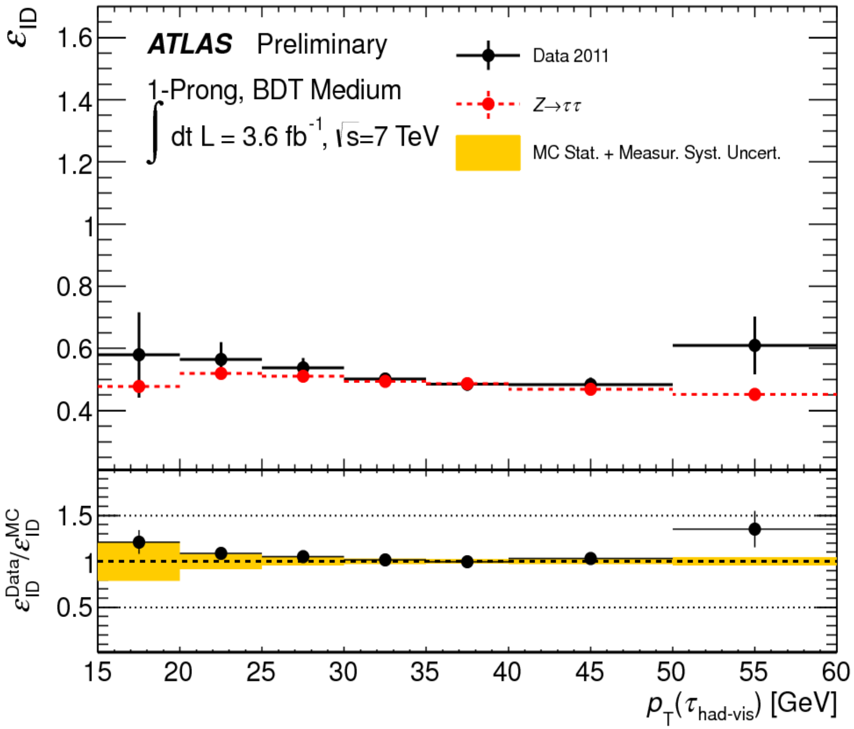
- Encouraging prospects for:
  - precision measurements in top quark physics
  - Beyond the Standard Model searches

MPP has a strong presence in all these activities and continues to play a central role in the ATLAS collaboration!

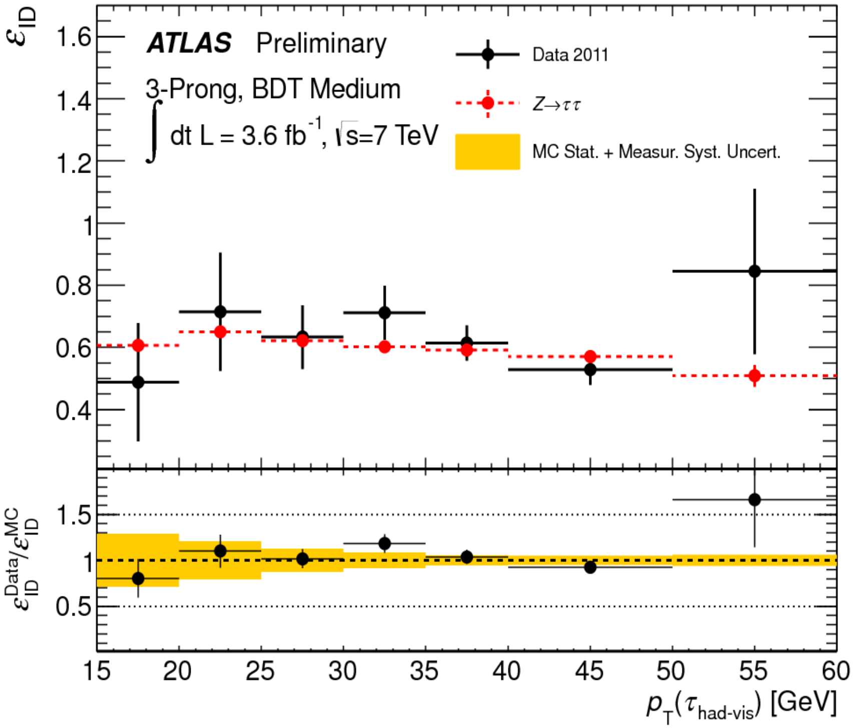
- Additional Material -

τ identification performance in pp→W/Z collision data

Jets with 1 prong



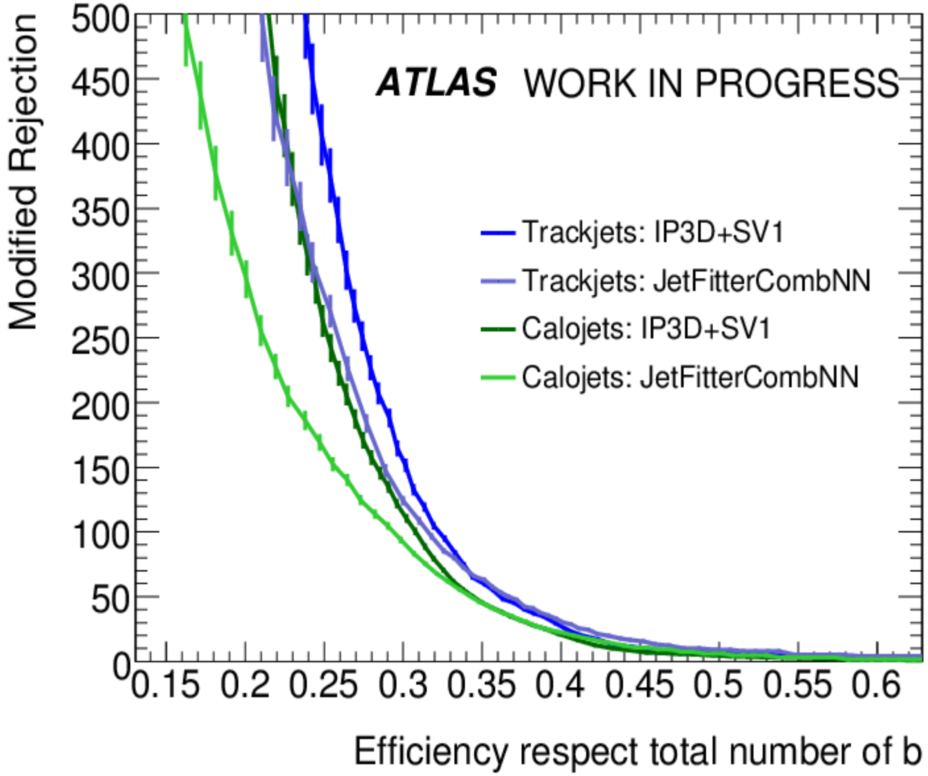
Jets with 3 prongs



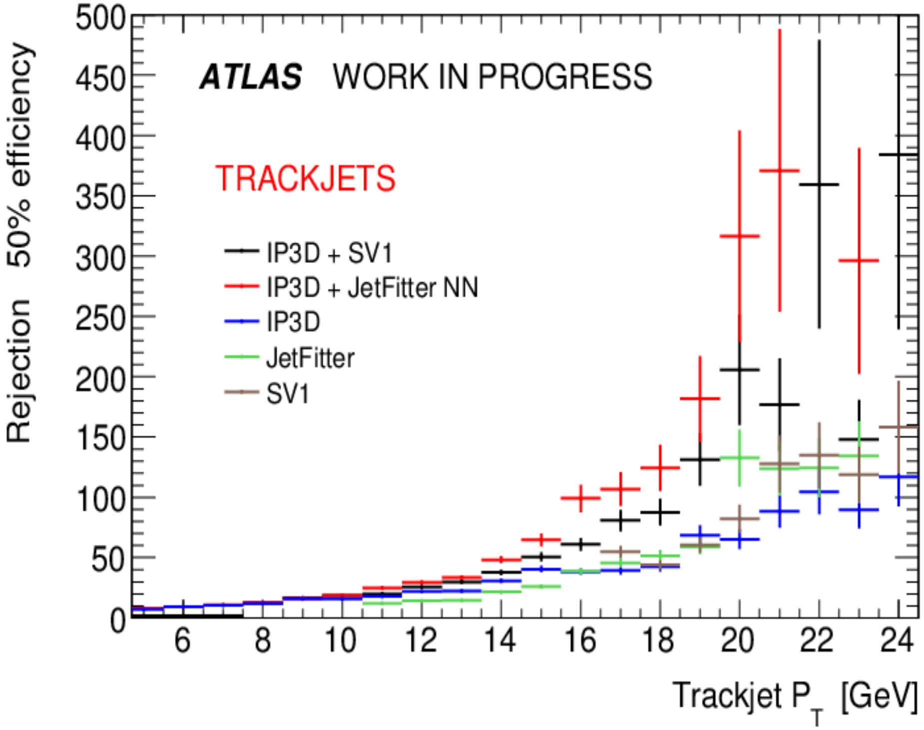
Excellent agreement of τ lepton reconstruction and identification efficiency in experimental and simulated data!

b jet reconstruction optimization with track jets

Rejection versus efficiency



Rejection at 50% efficiency



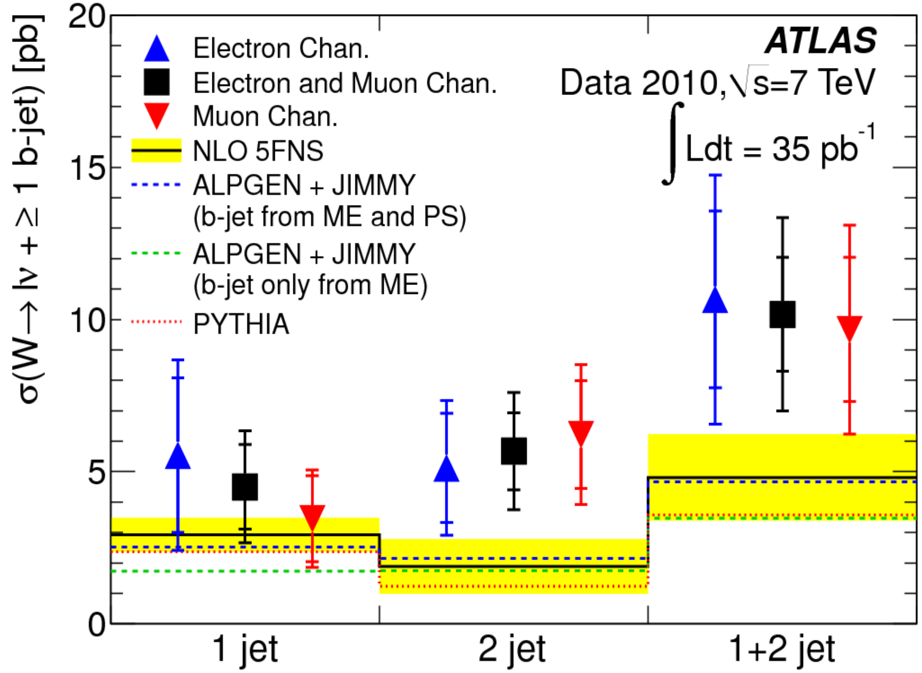
- Significantly better rejection for track jets than for standard calorimeter jets at a given efficiency
- High rejection of *b*-quark track jets event at low transverse momenta as required for the low p_T *b* quarks in $pp \rightarrow bbA/H$.

Measurement of the *pp→W+b jets* production

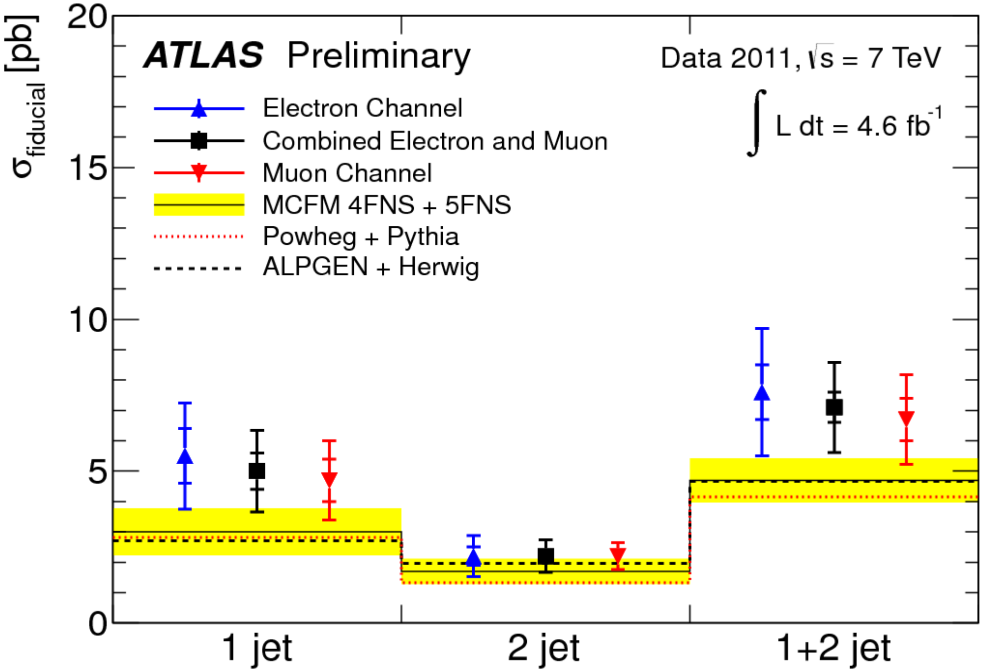
Motivation:

- Test of higher order QCD predictions
- *pp→W+bb* important reducible background to *pp→H→WW*

2010 Data



2011 Data



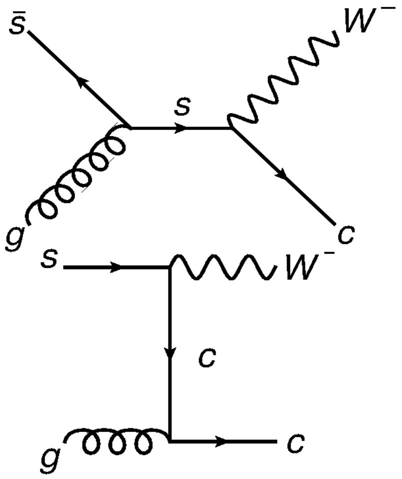
Initial indication for a discrepancy between NLO predictions and experimental measurement have disappeared with the full 2011 data set

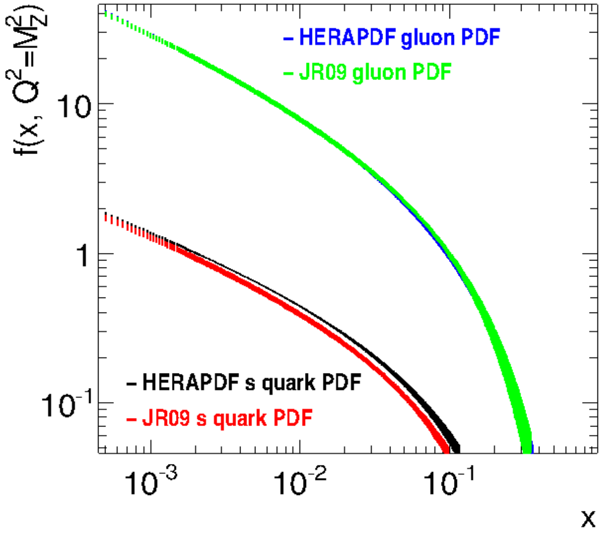
ATLAS-CONF-2012-156, Phys.Lett. B707 (2012) 418-437

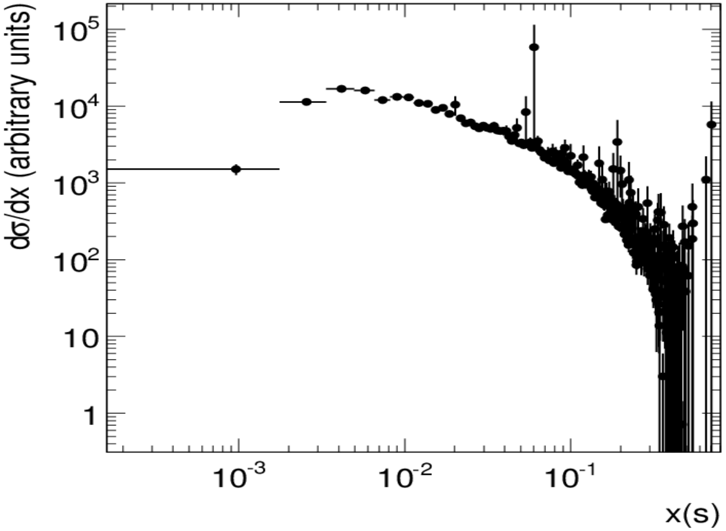
Measurement of the *pp→W+c jet* production

Motivation:

- Significant differences in *s* quark densities in different PDF sets
- *pp→W+c jet* is sensitive to the *s* quark and gluon density inside the proton for approx. 0.002<x<0.2







Analysis Strategy:

- Use anticorrelation of lepton charges to indentify the final state:

  $W^- \rightarrow l^- \nu,\ c \rightarrow W^+ s' \rightarrow l^+ X$
- Strategy applicable because
  - *pp→W+b jet* is Cabibbo suppressed
  - Production of leptons in light jets of *pp→W+light jets* rare and has same and opposite signs of lepton charges with equal probability
- Publication planned for upcoming winter conferences

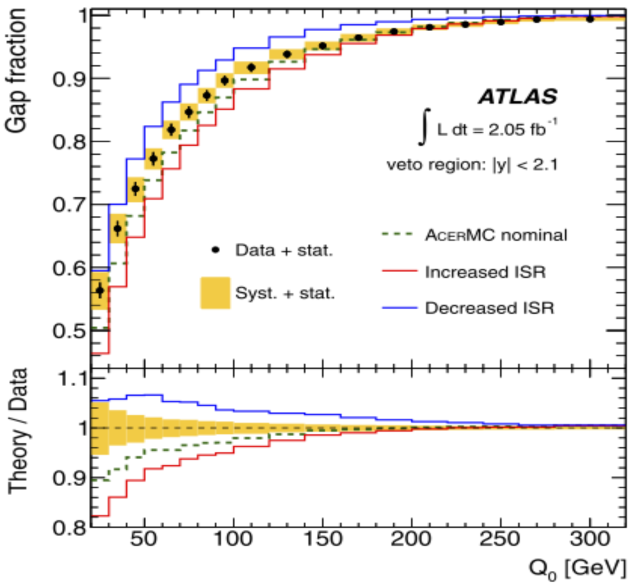
Reducing systematics on the top quark mass measurement

ISR/FSR:

• find observables sensitive to the effect and tune simulations using data, current investigations cover:

- jet shapes
- jet track shapes (MPP contribution)
- jet veto analysis

Eur.Phys.J. C72 (2012) 2043



bJES:

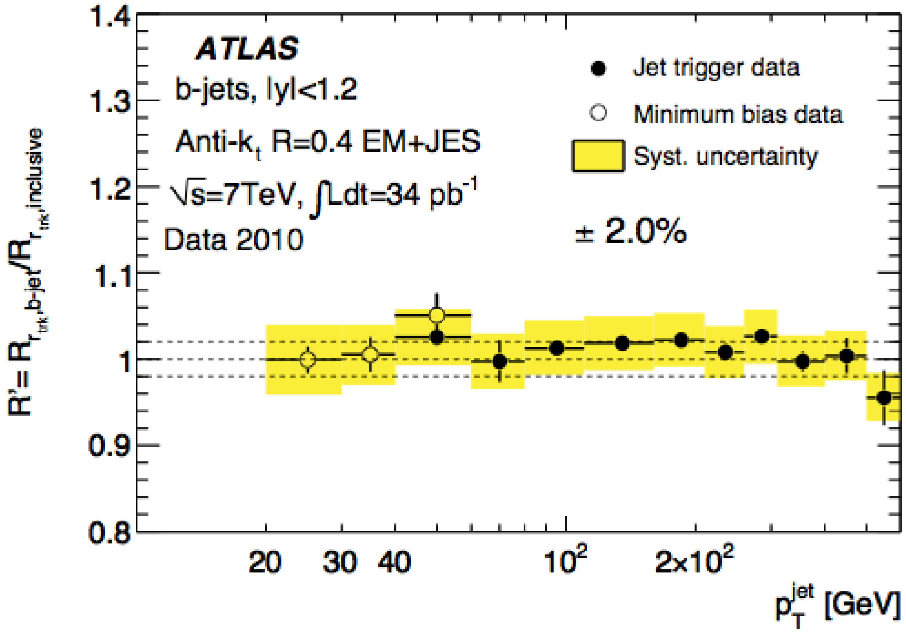
• MPP contribution to validate the bJES using tracks associated to jets in 2011 data:

$$r_{trk} = \frac{|\sum \vec{p_T}^{track}|}{|\vec{p_T}^{calo}|}$$

$$R_{r_{trk}} = \frac{[< r_{trk} >]_{data}}{[< r_{trk} >]_{MC}}$$

$$R' = \frac{R_{r_{trk},b-jet}}{R_{r_{trk},light}}$$

relative additional JES uncertainty of b-jets with respect to the light JES



Top quark mass analyses in other channels

dilepton channel, underconstrained kinematics due to the presence of 2 undetected neutrinos

- determined the performance of 3 different mtop estimators using the template method

- analysis on 4.7 fb^{-1} data being finalized, public result coming soon!

Master Thesis in MPP-2012-160

m_{lb} Method: invariant mass of the lepton-b-jet system

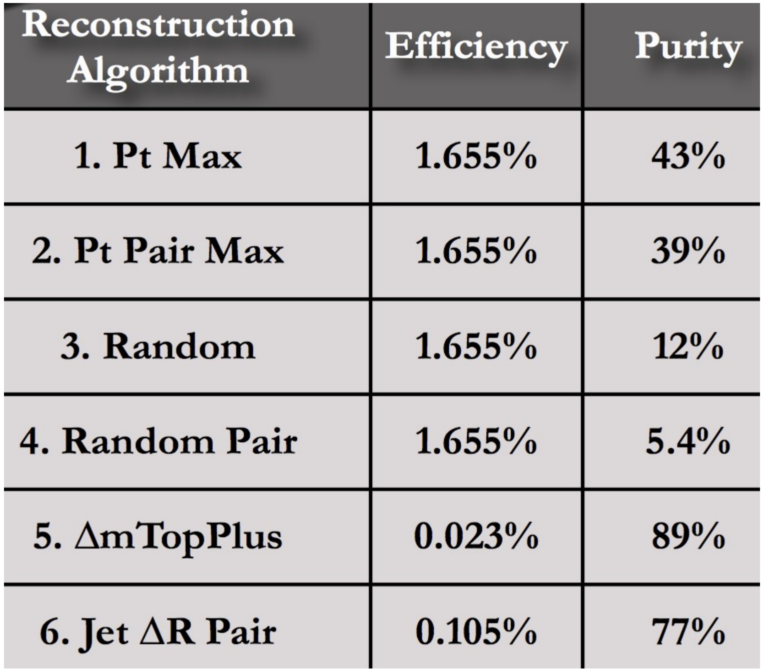
m_{T2} Method: transverse mass of the t-quark using MET information to scan transverse neutrino momenta.

Neutrino Weighting Method (νWT):
Scan over trial m_{top} and neutrino pseudo-rapidities η_1, η_2
Use the level of agreement of reconstructed neutrino momenta with MET for weighting the trial m_{top}

all-hadronic channel,
very challenging to reconstruct: 6 jets, no leptons or MET!

- evaluated the performance of many different algorithms for jet-parton assignment

- plan to use the known W mass to constrain the light jets energy scale with an iterative method



Reconstruction Algorithm	Efficiency	Purity
1. Pt Max	1.655%	43%
2. Pt Pair Max	1.655%	39%
3. Random	1.655%	12%
4. Random Pair	1.655%	5.4%
5. ΔmTopPlus	0.023%	89%
6. Jet ΔR Pair	0.105%	77%

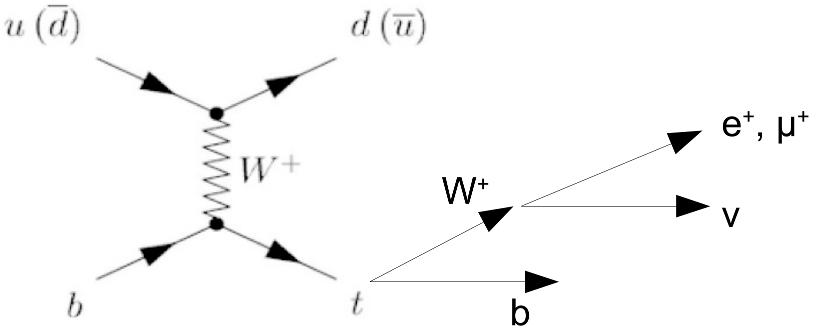
Search for New Physics in single top decays

The effects of New Physics on the Wtb vertex can be parameterized using effective operators:

$$\begin{aligned}\mathcal{L}_{Wtb} &= -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}\left(\underline{V_L}P_L + \underline{V_R}P_R\right)t\,W_{\mu}^{-}\\ &\quad -\frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}\left(\underline{g_L}P_L + \underline{g_R}P_R\right)t\,W_{\mu}^{-} + \text{h.c.}\end{aligned}$$

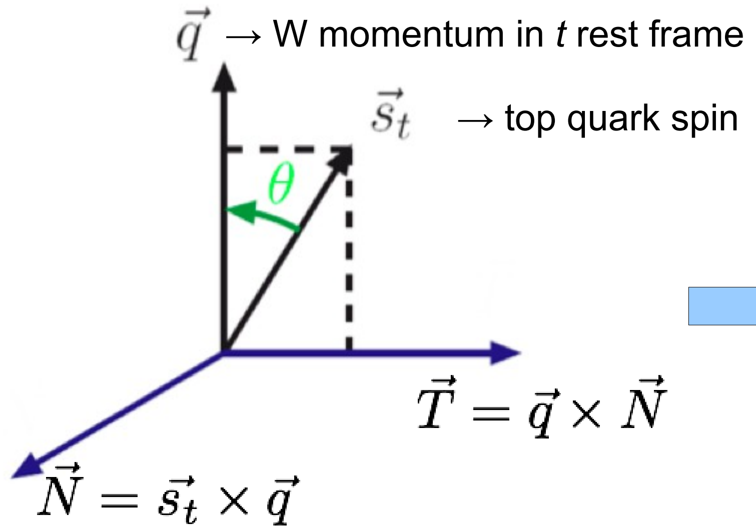
...in the Standard Model **$V_L = V_{tb} \approx 1$** and the **anomalous couplings V_R, g_L, g_R** are **zero**

In single top quark t-channel production, top quark polarized in the direction of the spectator quark



t-channel
σ ~ 66 pb

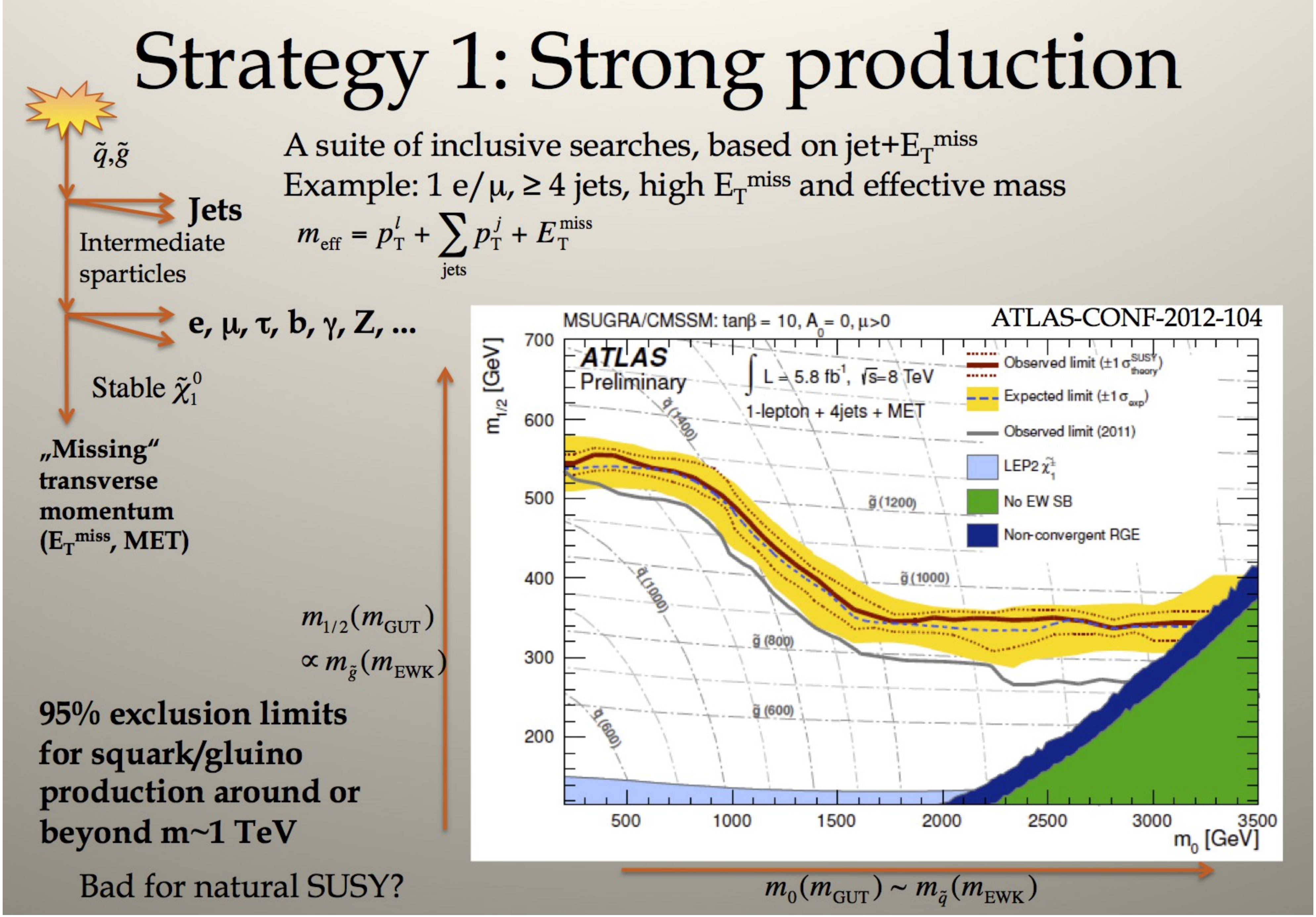
Can define two directions **N, T**:



arxiv.org/abs/1005.5382

The forward–backward asymmetry with respect to **N** (A_{FB}^{N}) is very sensitive to *Im* **g_R**, and $A_{FB}^{N} \neq 0$ would imply CP violation

ATLAS measurement of A_{FB}^{N} in 4.7 fb^{-1} of lepton+2 jets data in final stages of approval, public result expected soon!



Strategy 1: Strong production

A suite of inclusive searches, based on jet+E_T^{miss}

Example: 1 e/μ, ≥ 4 jets, high E_T^{miss} and effective mass

$$m_{\mathrm{eff}} = p_T^l + \sum_{\mathrm{jets}} p_T^j + E_T^{\mathrm{miss}}$$

$\tilde{q}, \tilde{g}$

Jets

Intermediate sparticles

e, μ, τ, b, γ, Z, ...

Stable $\tilde{\chi}_1^0$

„Missing“ transverse momentum (E_T^{miss}, MET)

$m_{1/2}(m_{\mathrm{GUT}}) \propto m_{\tilde{g}}(m_{\mathrm{EWK}})$

$m_0(m_{\mathrm{GUT}}) \sim m_{\tilde{q}}(m_{\mathrm{EWK}})$

95% exclusion limits for squark/gluino production around or beyond m~1 TeV

Bad for natural SUSY?

Direct stop search results