The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

2263-16

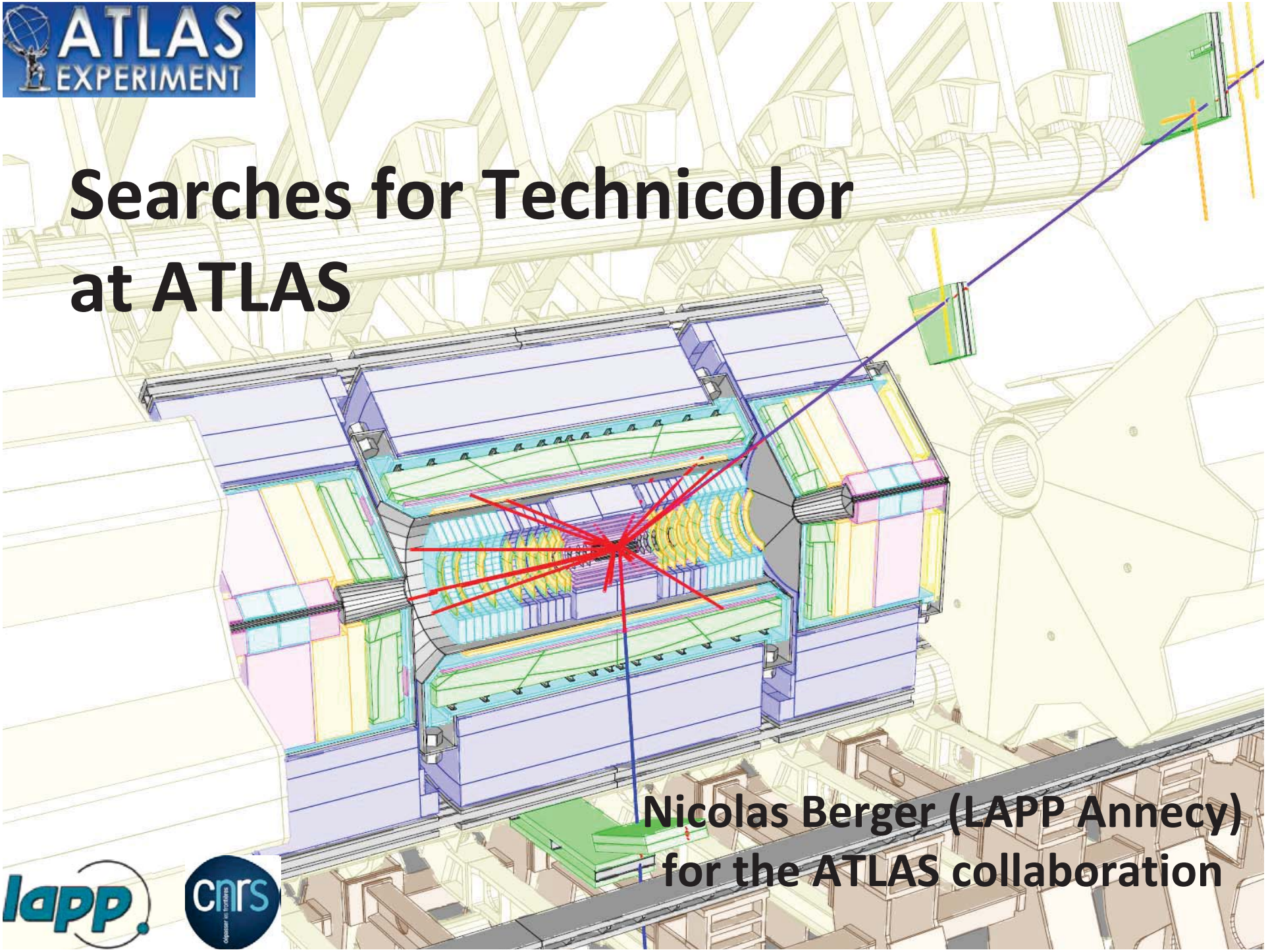
Beyond the Standard Model: Results with the 7 TeV LHC Collision Data

19 - 23 September 2011

Search for "Technicolour" at ATLAS

Nicolas Berger
LAPP, Annecy
France

Searches for Technicolor at ATLAS



Nicolas Berger (LAPP Annecy)
for the ATLAS collaboration

Contents

→ Presentation of TC models relevant for this talk

→ Search in dilepton channels

→ Search in ttbar channel

→ Study of Wjj production

Technicolor overview

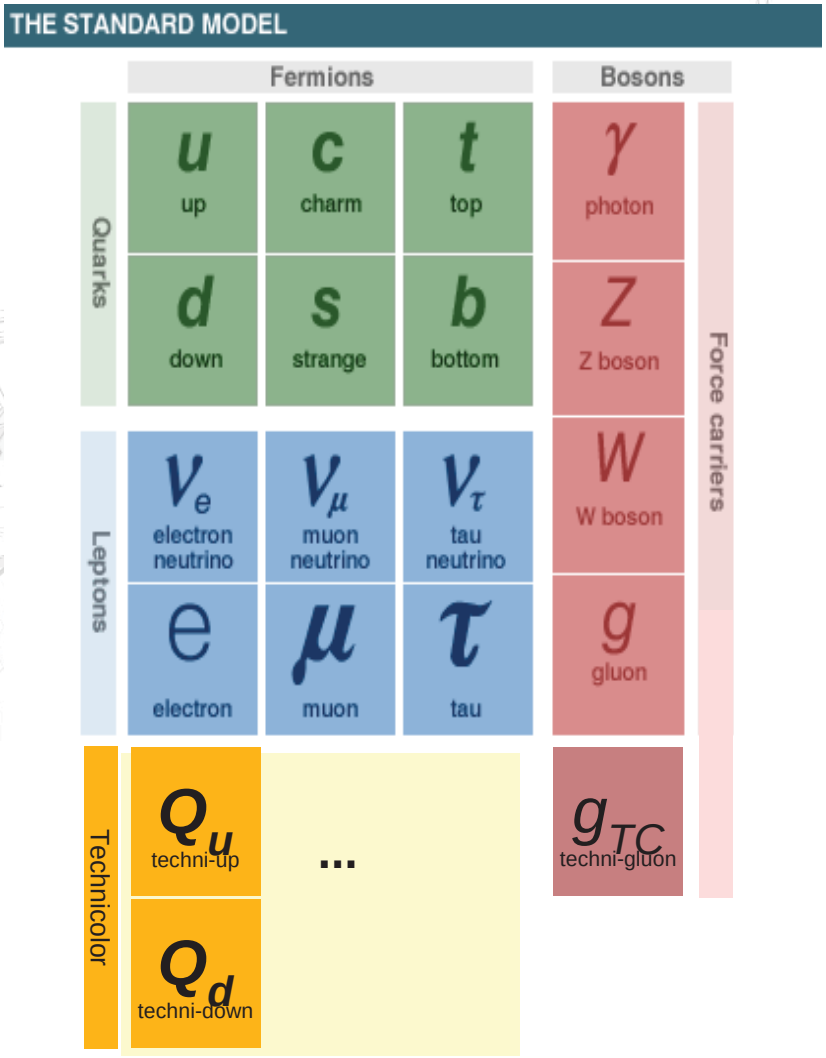
Technicolor: Alternate mechanism of EWSB
→ **No fundamental Higgs boson**

Introduce:
A **new strong gauge interaction**
→ typically some $SU(N_{TC})$.

New fermions sensitive to TC ("**techniquarks**")
→ typically N isospin doublets

EWSB:
TC coupling becomes large for Λ_{TC} ~ O(100 GeV):
⇒ **chiral symmetry breaking** : $\langle Q_L Q_R \rangle \neq 0$, ~ Λ_{TC}.

$\langle Q_L Q_R \rangle$ not invariant under $SU(2) \otimes U(1) \Rightarrow$ **EWSB**



EW precision constraints, FCNC:
→ "scaled-up QCD" models are excluded, but TC with a "**walking**" coupling is OK.

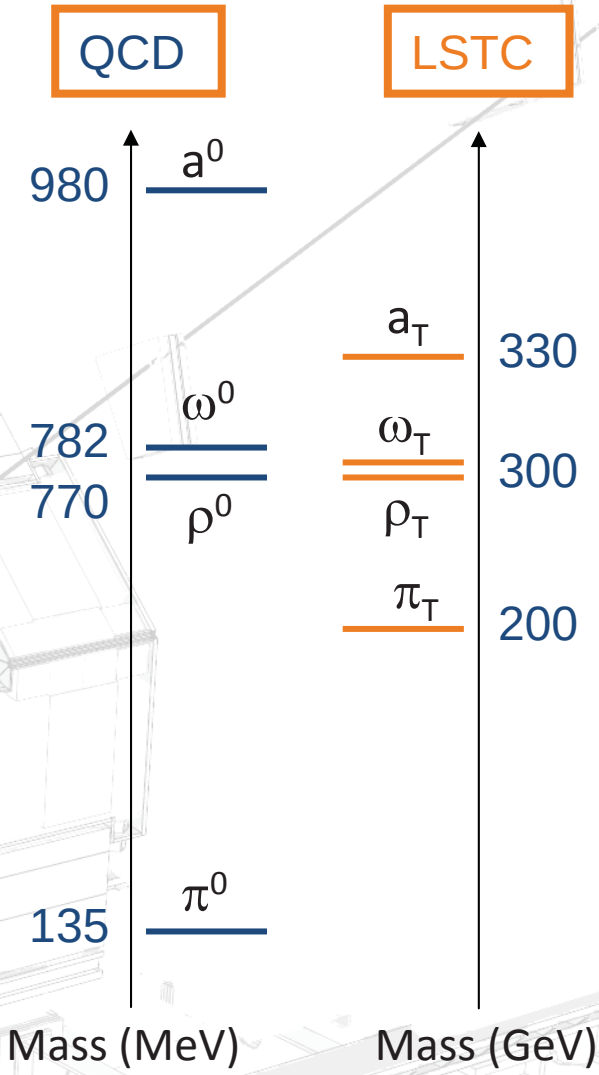
LSTC model

Low-scale Technicolor
→ SU(**N_{TC}=4**)
→ **N_D=9** isospin doublets of techniquarks
→ Λ_{TC} ~ 246GeV/$\sqrt{N_D}$ ~ **100 GeV**
Chosen N_{TC}, N_D ⇒ walking coupling

Lane and Eichten, Phys. Lett. **B222,** 274)

Particle spectrum
→ assume only lowest-lying doublet matters
→ assume TC respects isospin
⇒ QCD-like spectrum with scale O(Λ_{TC}):
→ **technipions** π_T (except 3 that give mass to W,Z)
→ **technimesons** : near-degenerate ρ_T, ω_T, a_T, …

Walking decreases M(ρ_T)/M(π_T)
⇒ V → nπ_T decays are typically forbidden
⇒ **Narrow resonances**
Main decay modes :
→ π_T → jj
→ ρ_T^0, ω_T^0, a_T^0 → l^+l^-, Zγ
→ $\rho_T^\pm$, $\omega_T^\pm$, $a_T^\pm$ →W$^\pm$Z, W$^\pm\gamma$



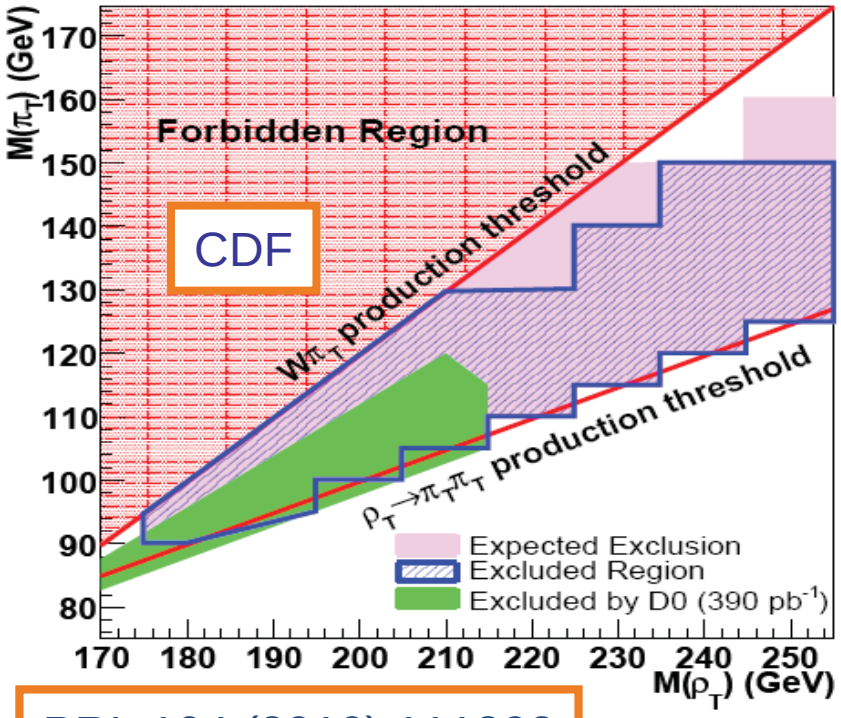
In what follows:
→ assume **degenerate ρ_T, ω_T,**
→ **ignore a_T**, higher resonances

LSTC limits from Tevatron

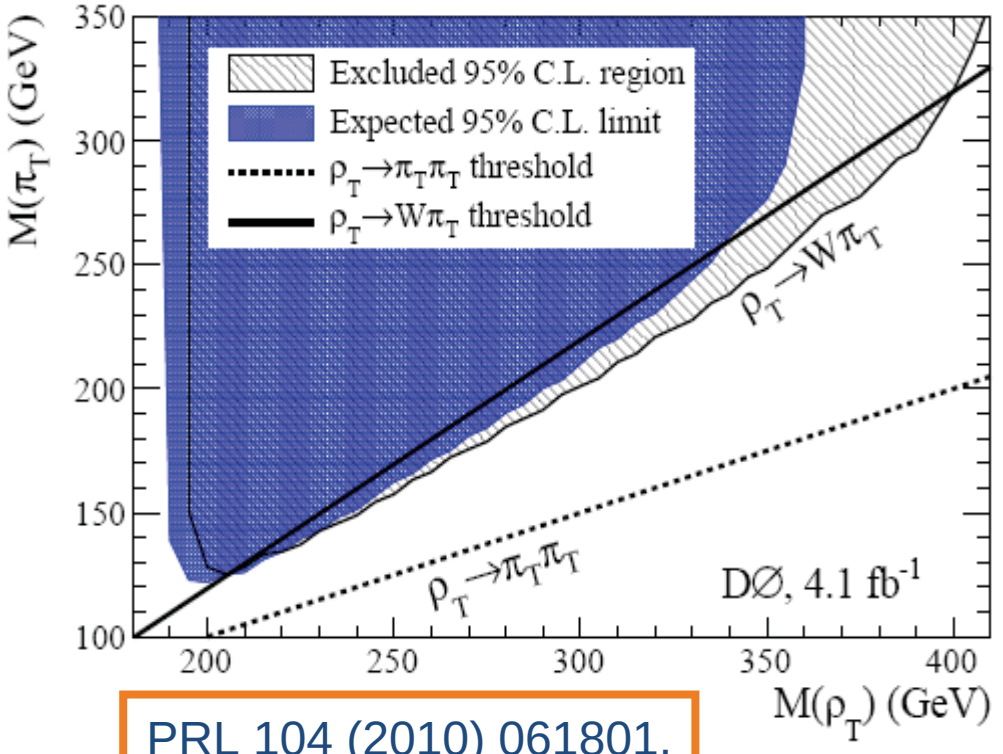
→ ρ_T, ω_T technimesons are easiest target

→ Limits usually presented in **($M(\rho_T)$, $M(\pi_T)$)** plane

– π_T mass affects allowed decay channels, BFs.



PRL 104 (2010) 111802



PRL 104 (2010) 061801,

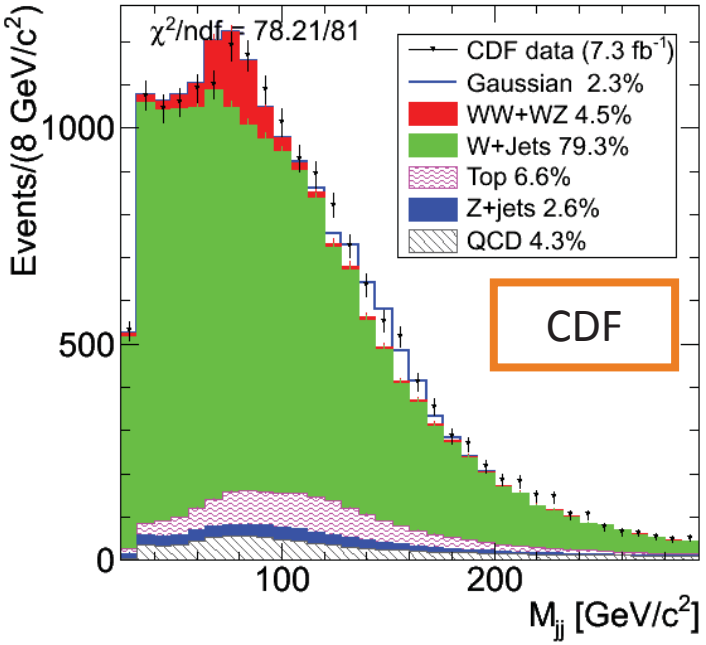
→ For lower $M(\pi_T)$, look for $\rho_T \to W\pi_T$. Best limit from CDF : $M(\rho_T) <$ **250 GeV**

→ For higher $M(\pi_T)$, use $\rho_T \to$ **WZ**. Best limit from DØ : $M(\rho_T) <$ **400 GeV.**

Technicolor at Tevatron ?

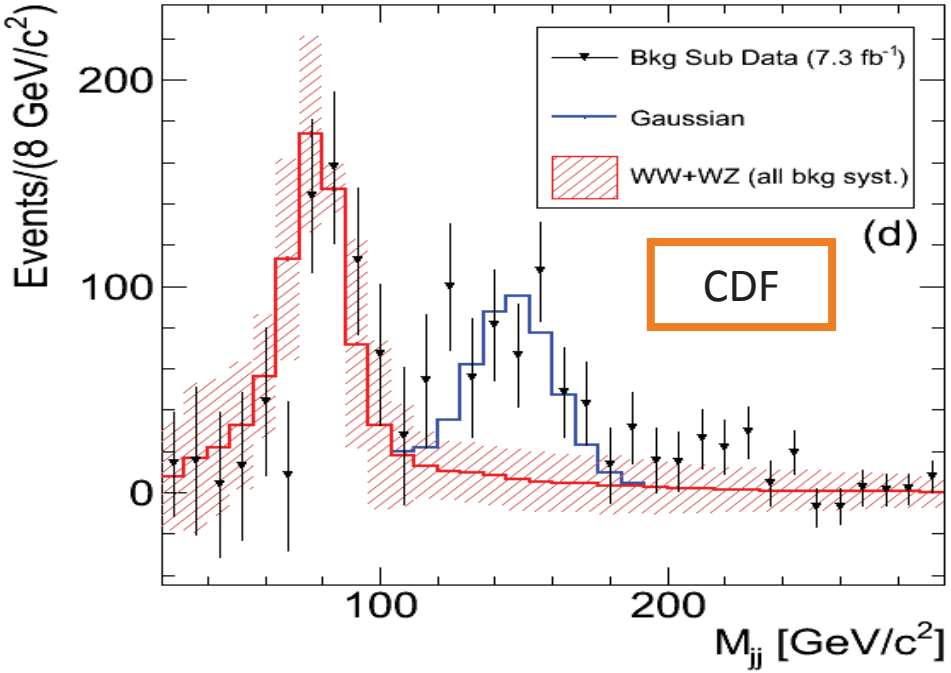
Excess in Wjj production seen by CDF for
m_{jj} = 144±5 GeV
→ **4.8σ** deviation with 7.3 fb^{-1}
→ width ~ detector resolution

PRL 106 (2011), 171801

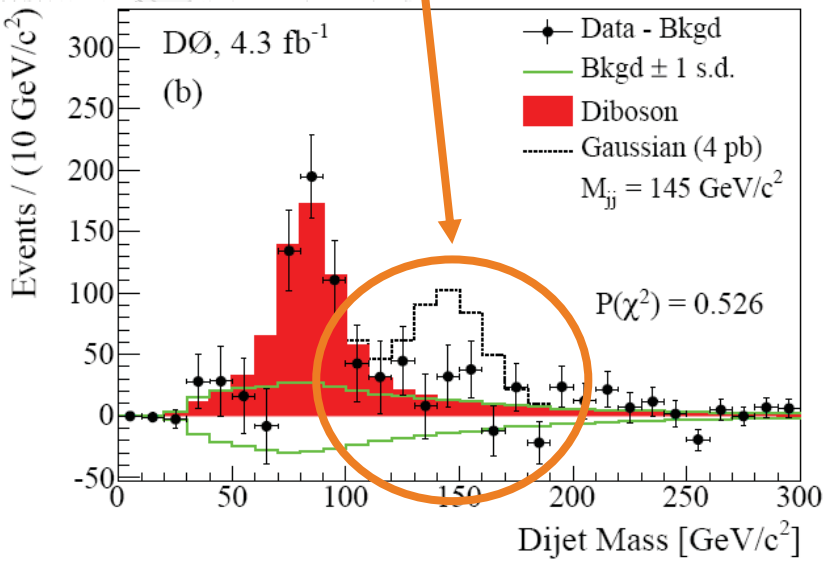


Can be interpreted as $\rho_T \rightarrow W + (\pi_T \rightarrow jj)$
→ **$M(\rho_T)$ ~ 290 GeV, $M(\pi_T)$ ~160 GeV**

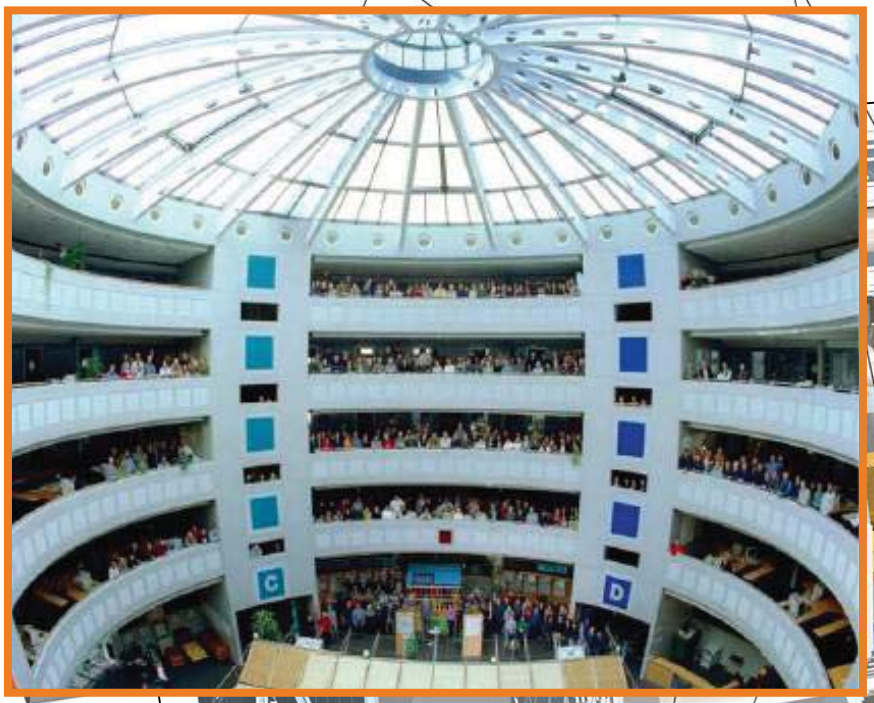
PRL 106 (2011), 251803



Not seen by DØ (p-value = **0.53**)



The ATLAS detector



Muon Detectors

Tile Calorimeter

Liquid Argon Calorimeter

~3000 physicists, ~1000 students, 174 institutes, 38 countries

Toroid Magnets

Solenoid Magnet

SCT Tracker

Pixel Detector

TRT Tracker

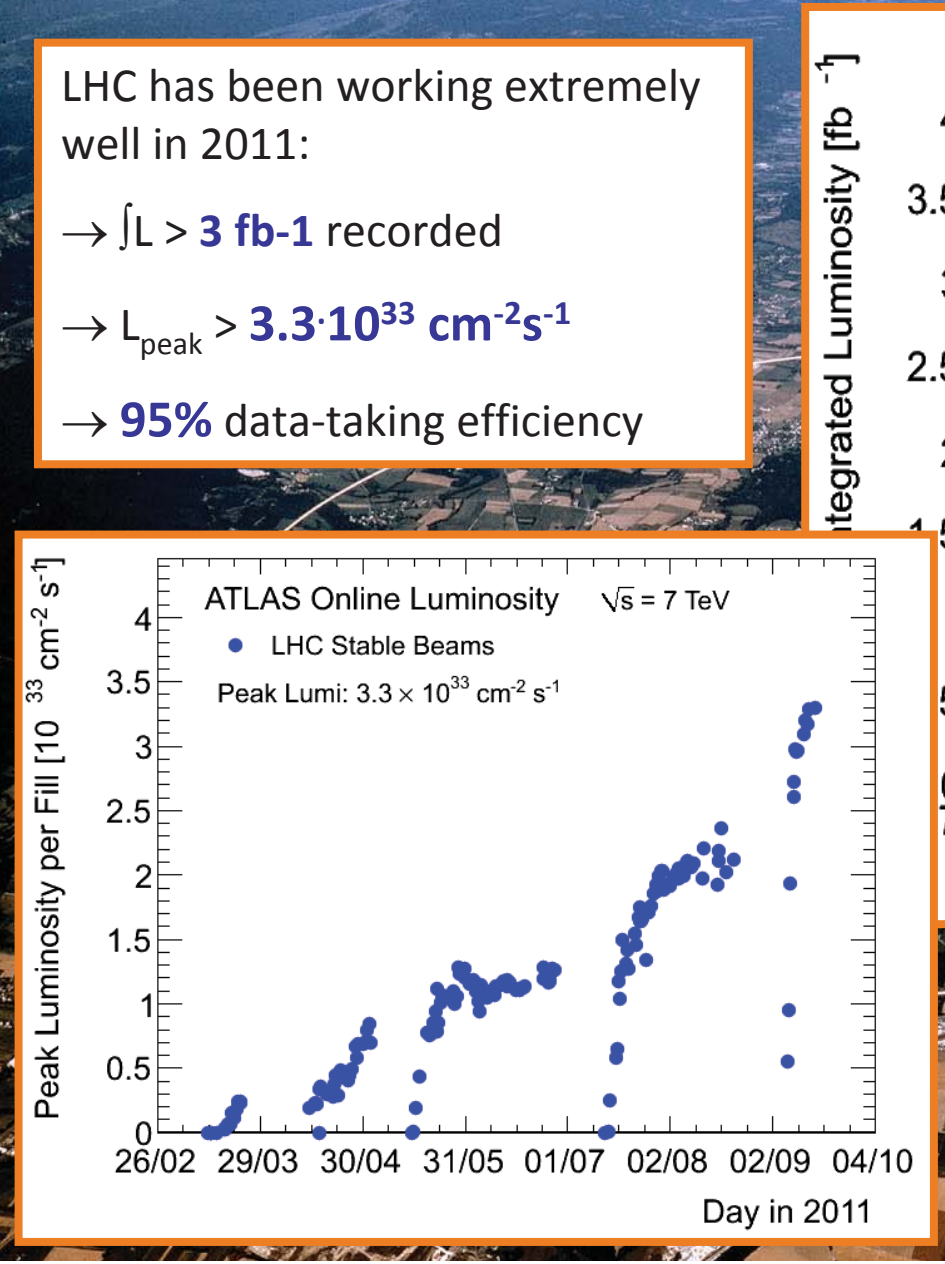
LHC 2011 Dataset

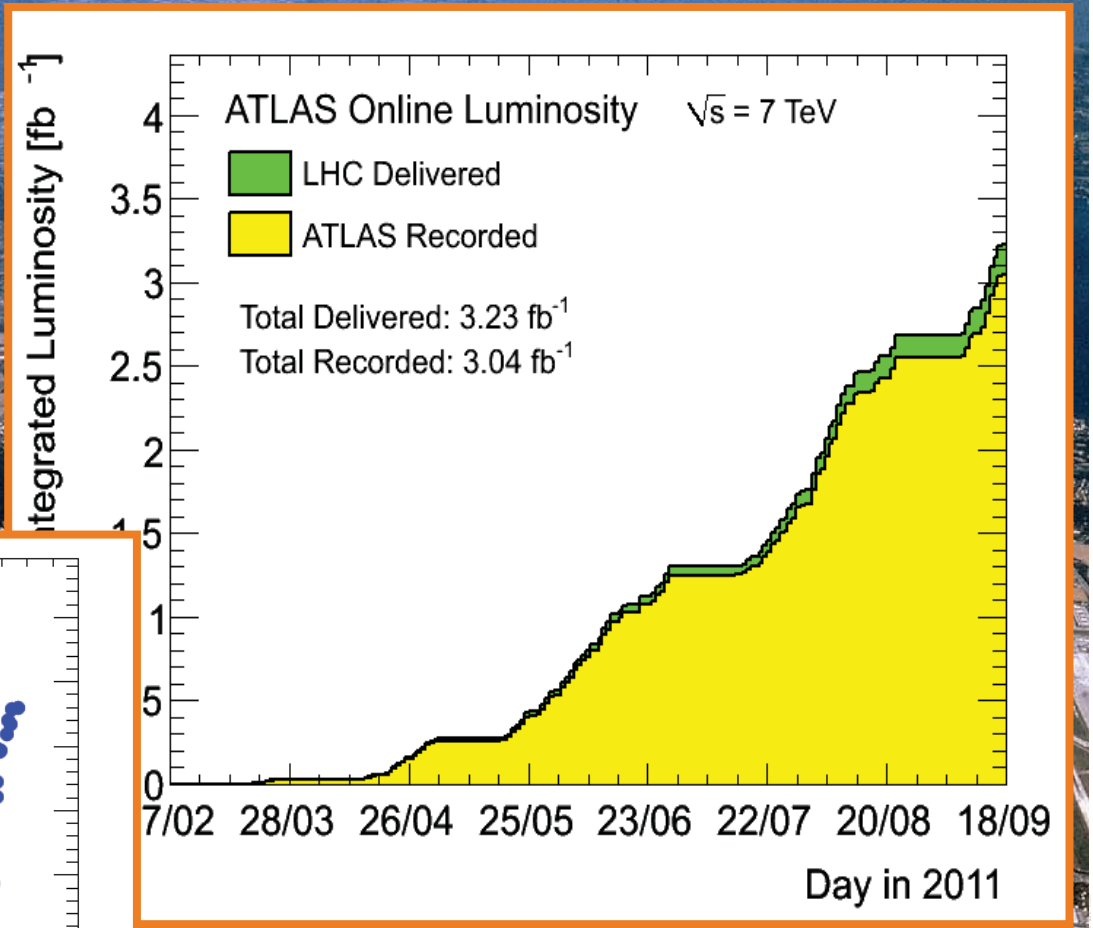
LHC has been working extremely well in 2011:

→ ∫L > **3 fb-1** recorded

→ L_{peak} > **$3.3 \cdot 10^{33}$ cm^{-2}s^{-1}**

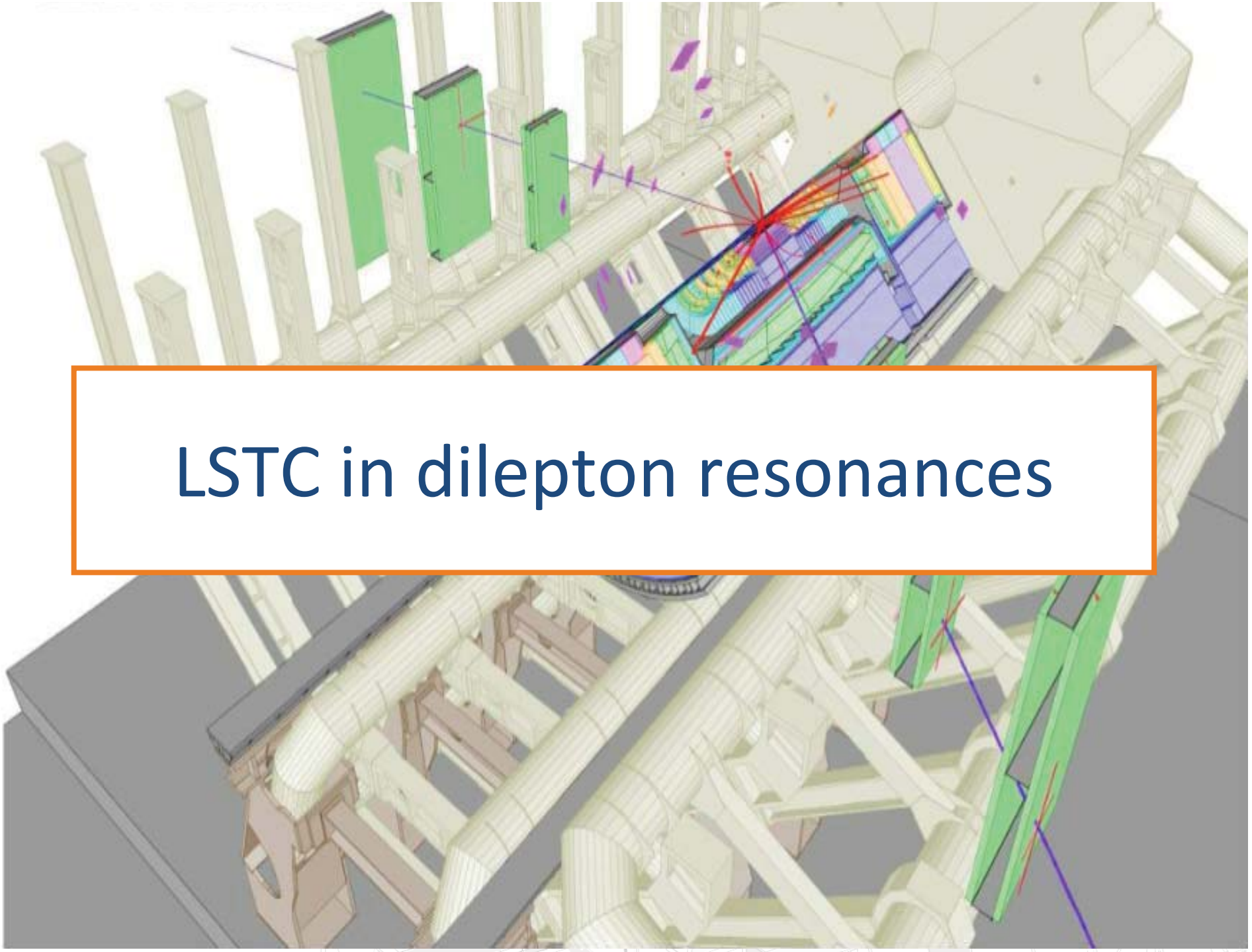
→ **95%** data-taking efficiency





→ 4-5 fb^{-1} by end of year ?

→ **<~1 fb^{-1}** in results shown here

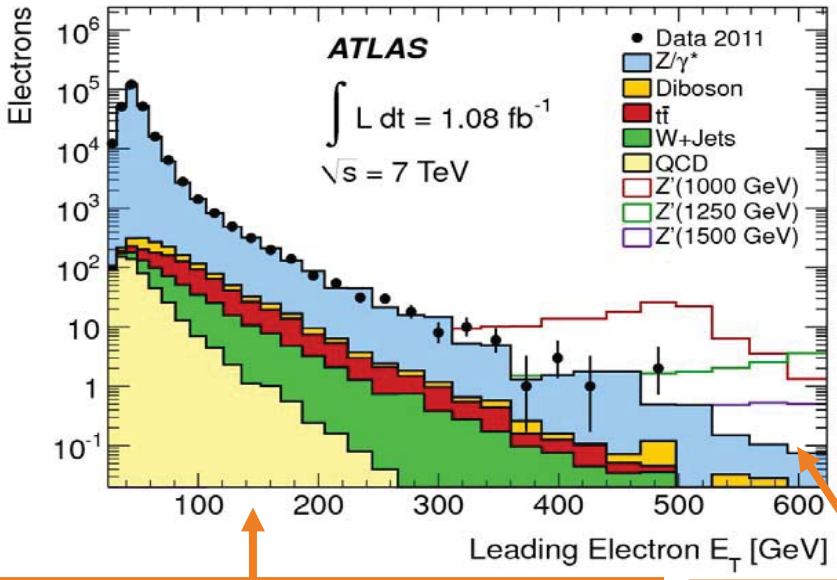


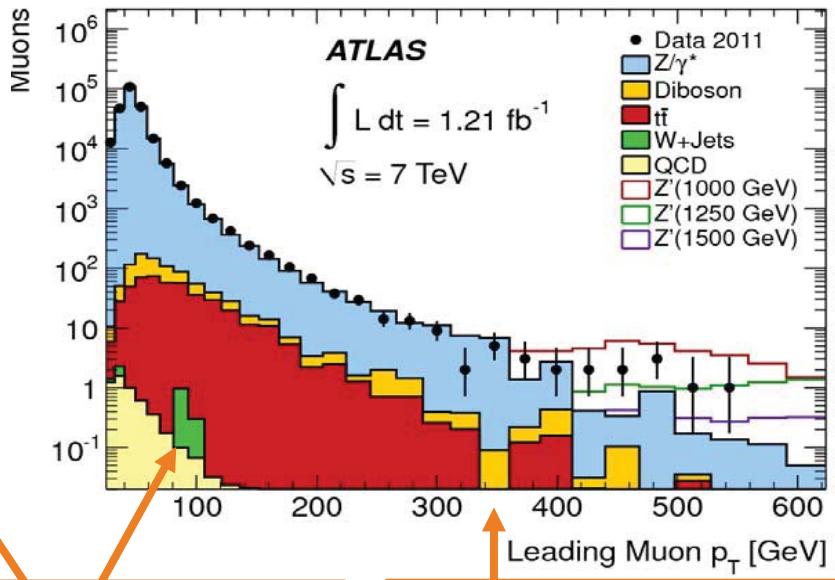
LSTC in dilepton resonances

Search for resonances in l^+l^- channel

General search for **narrow resonances** in e^+e^- and $\mu^+\mu^-$ final states performed.
→ See presentation by Oliver Stelzer-Chilton yesterday
→ Analysis mostly geared towards high-mass region (1 TeV)
Limits can be reinterpreted in terms of LSTC
→ **smaller signals at lower masses**, but included in scope of original search

arXiv:1108.1582, submitted to PRL





Electrons
→ E_T>25 GeV,
→ ID cuts on track, EM shower
→ Isolation E < 7 GeV in ΔR<0.2, corrected for pileup and leakage from electron cluster

Backgrounds
→ Main bkg : Drell-Yan
→ DY, WW/WZ/ZZ, W+jets, top from MC
→ Data-driven method for QCD

Muons
→ p_T > 25 GeV
→ Combined track: Inner tracker + Muon spectrometer
→ Track Isolation: Sum of track p_T within (ΔR<0.3) < 0.05 p_T

Search in LSTC region

New **Result (shown first time here)**

→ Excellent agreement between MC and the data in "LSTC region" (m_{ll} ~ **200-600 GeV**)

→ Quantify in terms of LSTC models with various $M(\rho_T)$, $M(\pi_T)$ values

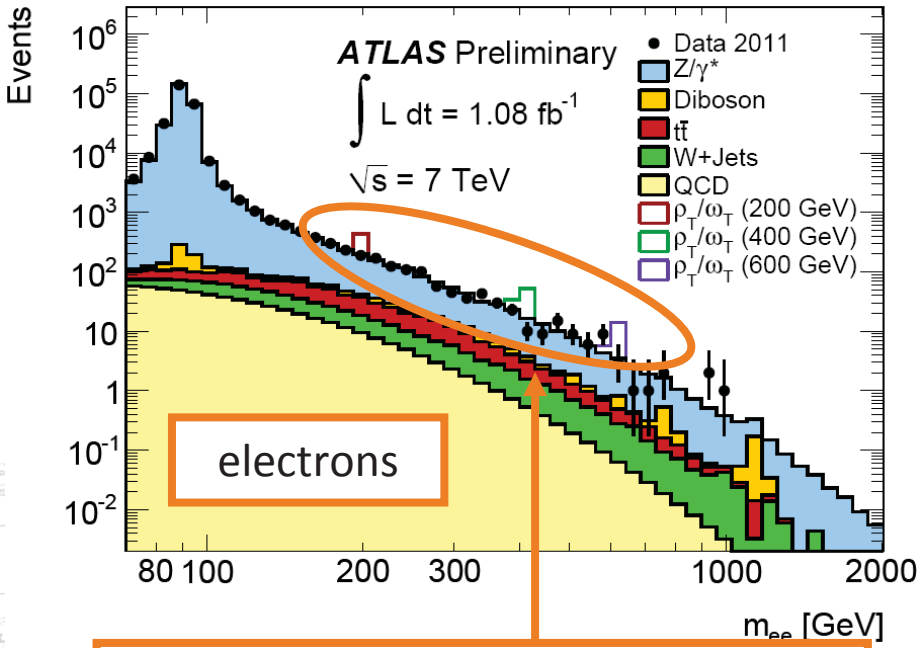
→ assume **$M(\omega_T) = M(\rho_T)$, ignore a_T**

→ Since no excess observed, set limits

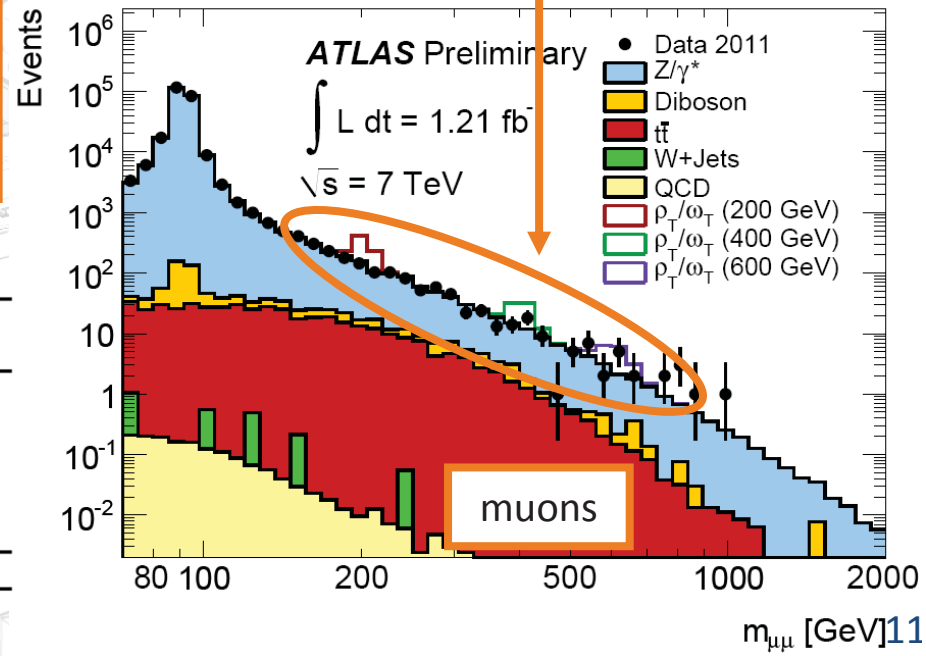
→ use a Bayesian method

ATLAS-CONF-2011-125

Source	dielectrons		dimuons	
	signal	background	signal	background
Normalization	5%	NA	5%	NA
PDFs/α_S	NA	10%	NA	10%
QCD K-factor	NA	3%	NA	3%
Weak K-factor	NA	4.5%	NA	4.5%
Trigger/Reconstruction	negligible	negligible	4.5%	4.5%
Total	5%	11%	7%	12%



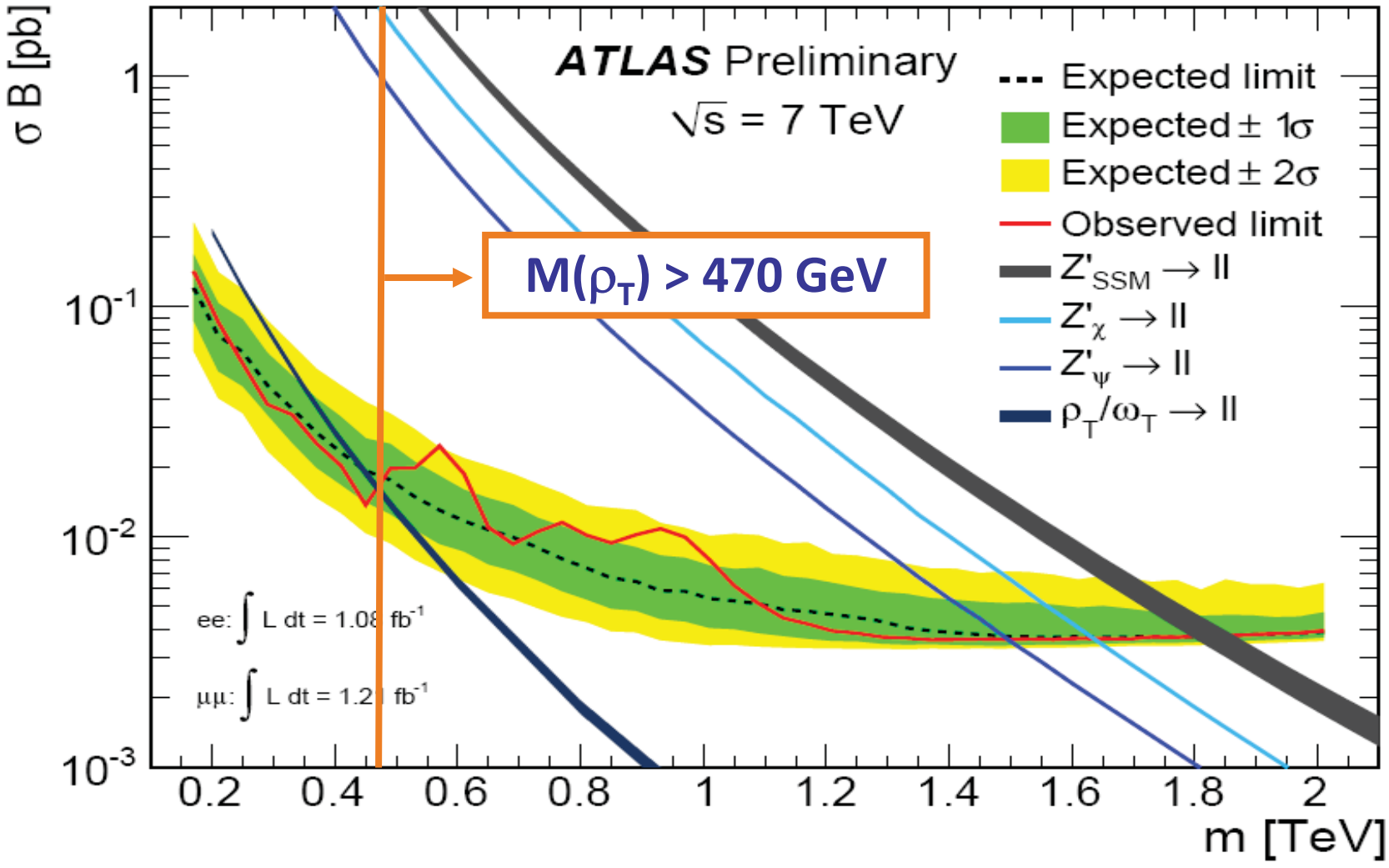
Examples of expected signal peaks



Limit on $M(\rho_T)$

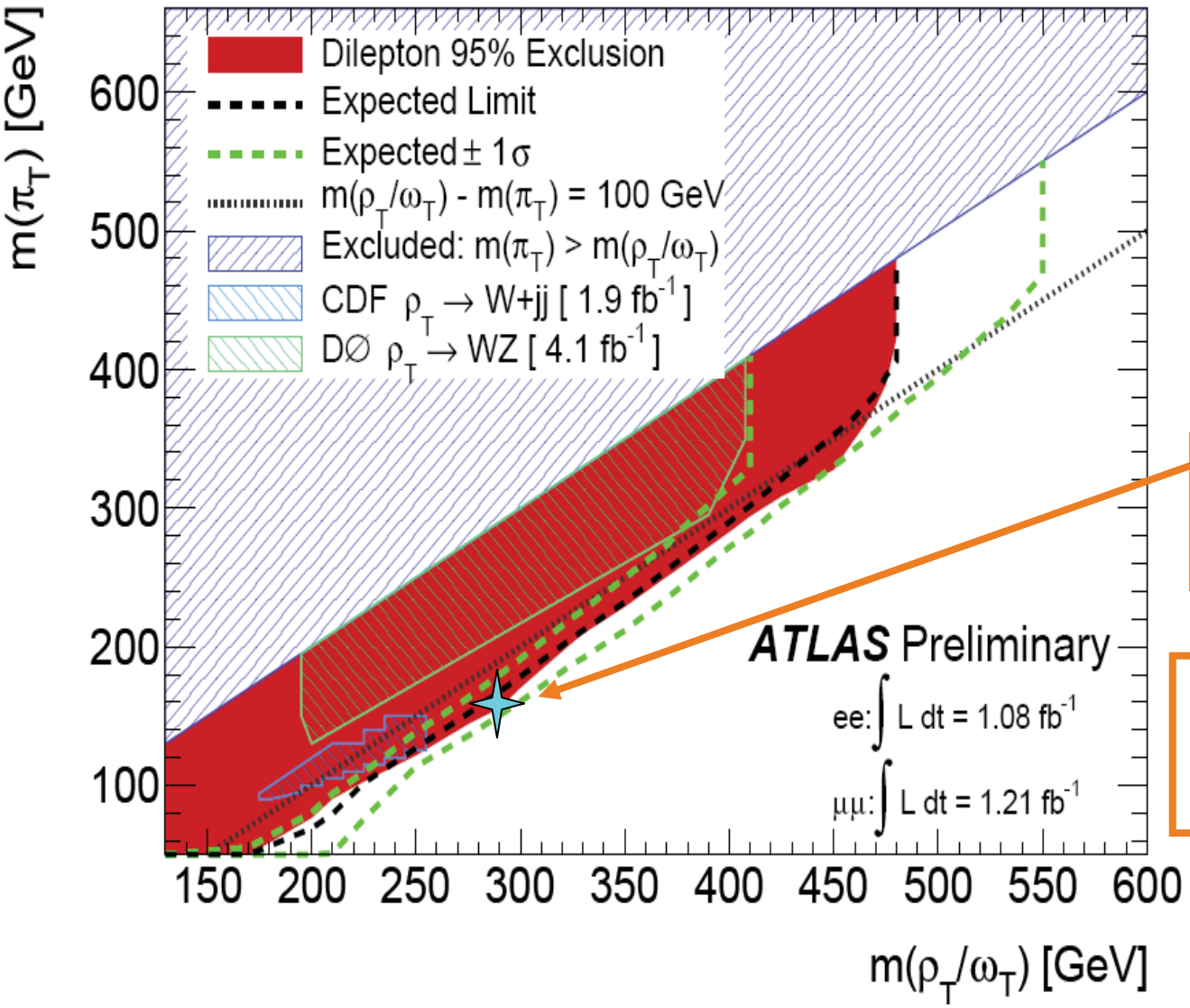
→ Assume **$M(\pi_T) = M(\rho_T) - 100$, GeV** scan $M(\rho_T)$ values

→ Set 95% UL on $M(\rho_T)$ using the limit on production $\sigma.BR(l^+l^-)$



Limit in $M(\rho_T)$, $M(\pi_T)$ plane

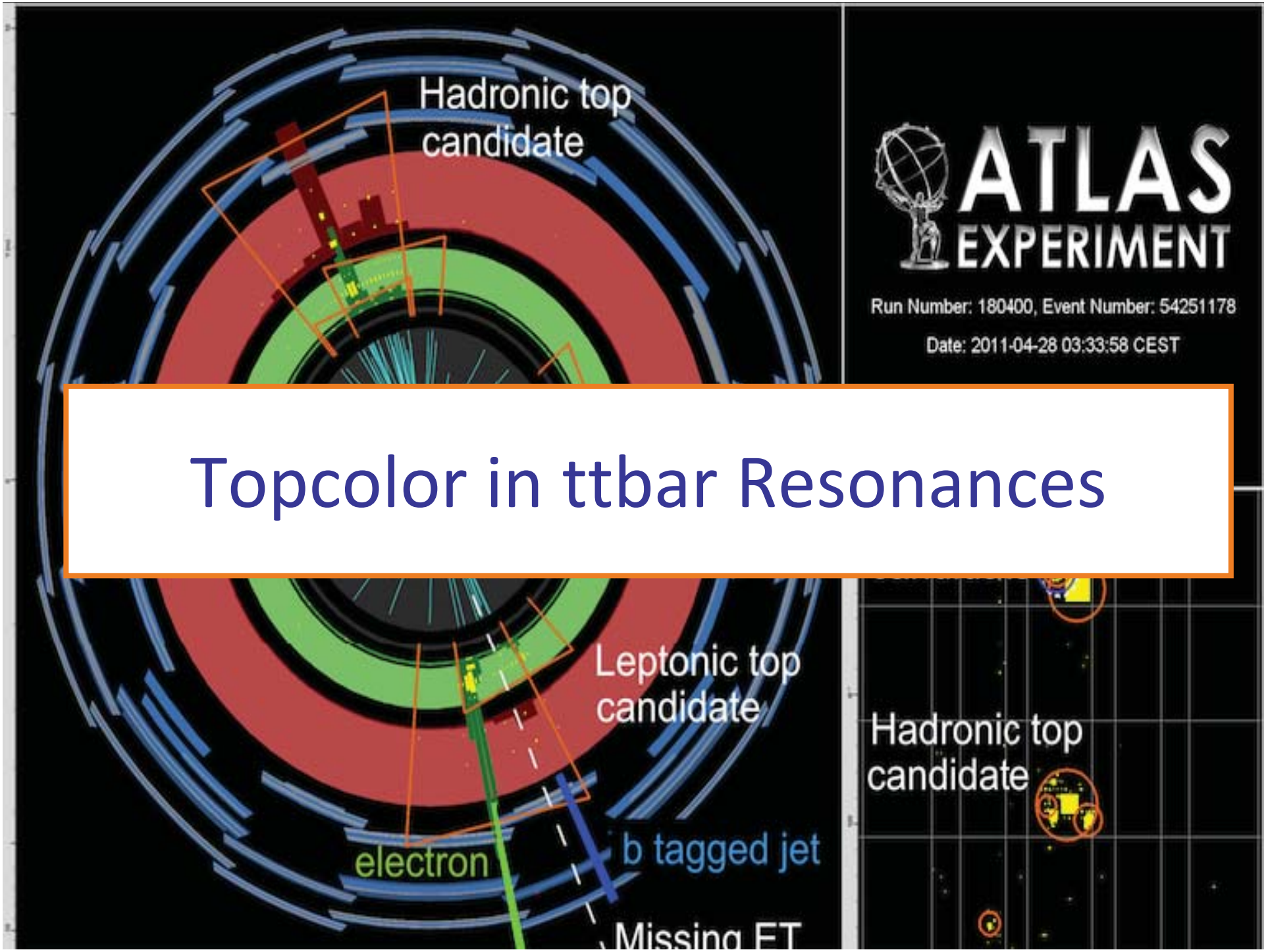
→ Same with scan on both $M(\rho_T)$ and $M(\pi_T)$, limit in $(M(\rho_T), M(\pi_T))$ plane



Significant improvement over Tevatron results

LSTC interpretation of CDF Wjj excess

Values for Wjj excess just inside excluded region



Topcolor in ttbar Resonances

Topcolor

Topcolor: mechanism to account for $m_t >> m_{udscb}$ via top condensation

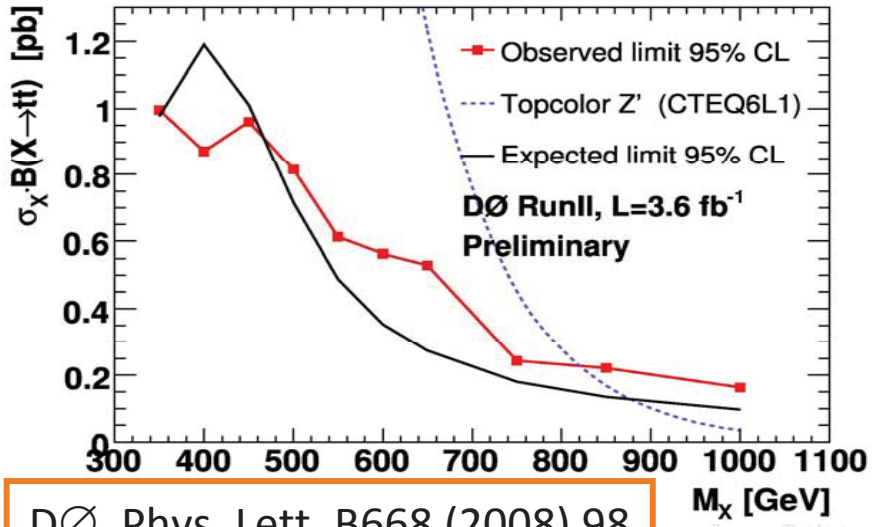
$\rightarrow$ Typically $SU(3)_{12} x SU(3)_3 x U(1)_{12} x U(1)_3$, broken to $SU(3)_C x U(1)_Y$

mainly for **1st & 2nd** gen

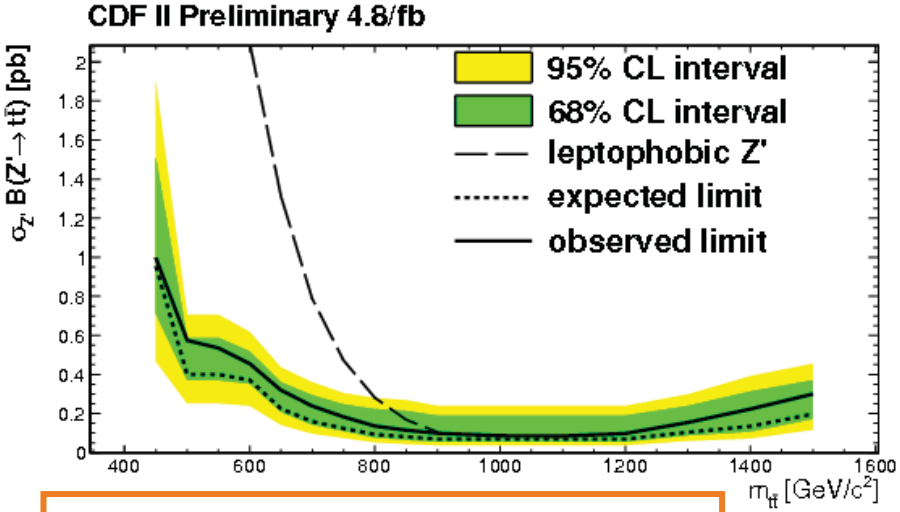
mainly for **3rd** gen

Extra U(1) factor $\Rightarrow$ **extra Z'** with O(TeV) mass after SSB.

Here use model from **hep-ph/9911288 (**Model IV) : Leptophobic Z' coupling only to quarks, width = 1.2% · M(Z')



DØ, Phys. Lett. B668 (2008) 98



CDF, Phys. Lett. B691 (2010) 183

Limits from DØ (840 GeV, same model) and CDF (900 GeV)

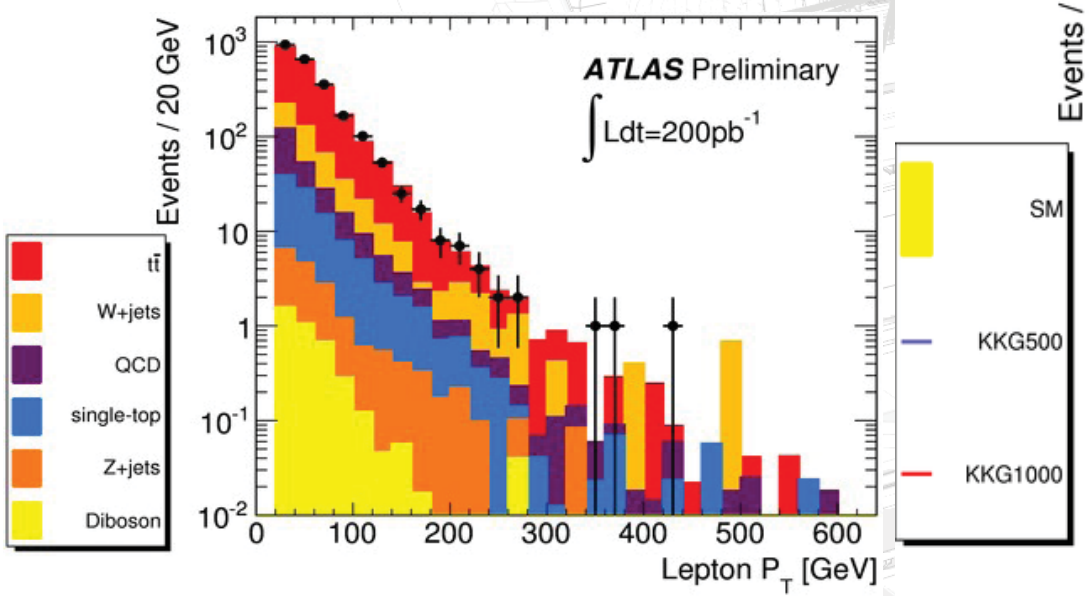
ttbar Resonance Search

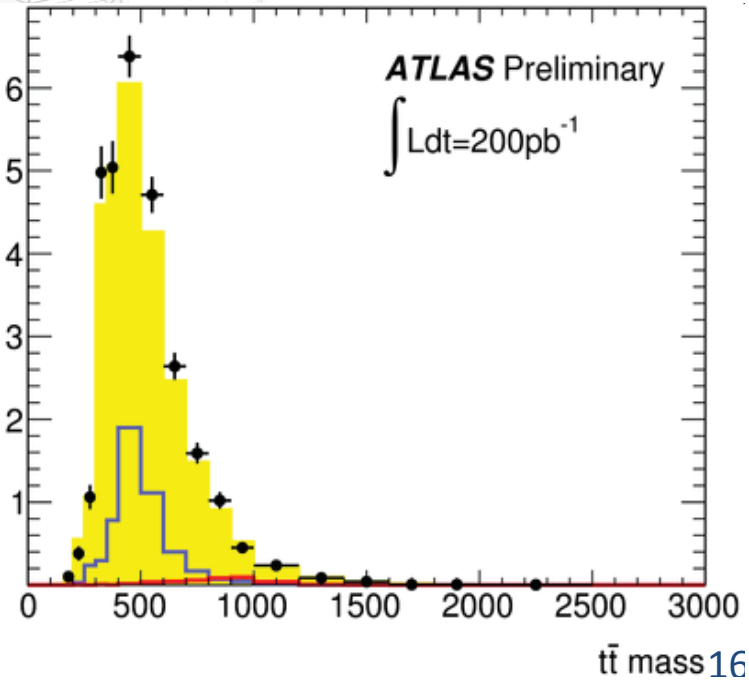
ATLAS-CONF-2011-087

→ Search for Z'→tt in **l+jets mode**: 1 hadronic + 1 leptonic top
→ Use m_{tt} as search variable (Use W mass constraint to fix $p_z(\nu)$)
→ See talk by Nuno Castro earlier today for more details

Selection:
- 4 jets, 1 b-tagged
- 1 lepton, p_T > 25 GeV (e), 20 GeV (μ)
- E_T^{miss} > 35 GeV (e), 20 GeV (μ)
- $M_T(l,E_T^{miss})$ > 25 GeV (e)
- E_T^{miss} + $M_T(l,E_T^{miss})$> 60 GeV (μ)

Backgrounds
- Main backgrounds top, W+jets
- data-driven QCD bkg
- scale factors for W+ n jets from data
- other bkgs from MC



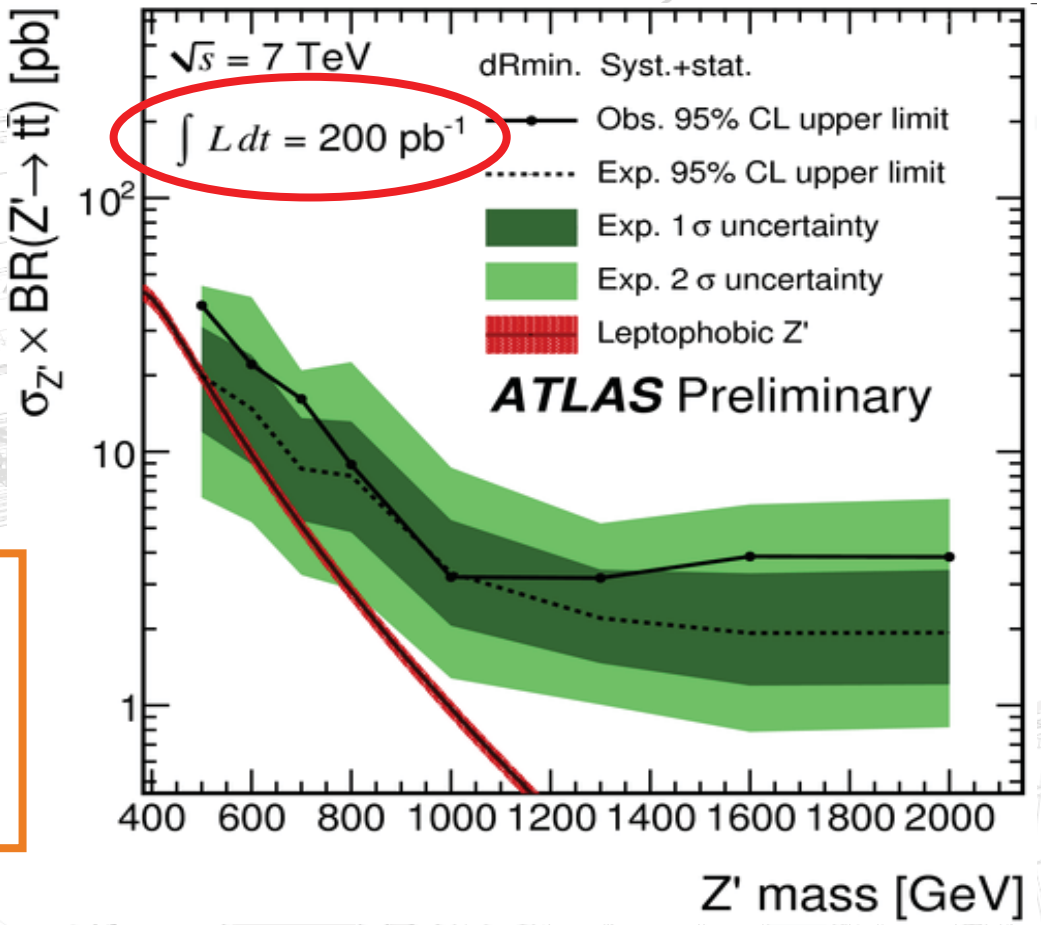


Topcolor Z' Results

→ No data excess over expectations

⇒ Set limits : use Bayesian method, profiling systematics

Systematic errors	
Luminosity	4.5%
tt bkg	10%
b-tagging	10%
JES	9%
ISR/FSR modeling	7%



Expected exclusion: **500 GeV**, but…

→ Stat. fluctuation in low-mass region

⇒ No observed exclusion…

→ **10x** larger dataset now available, should provide competitive results

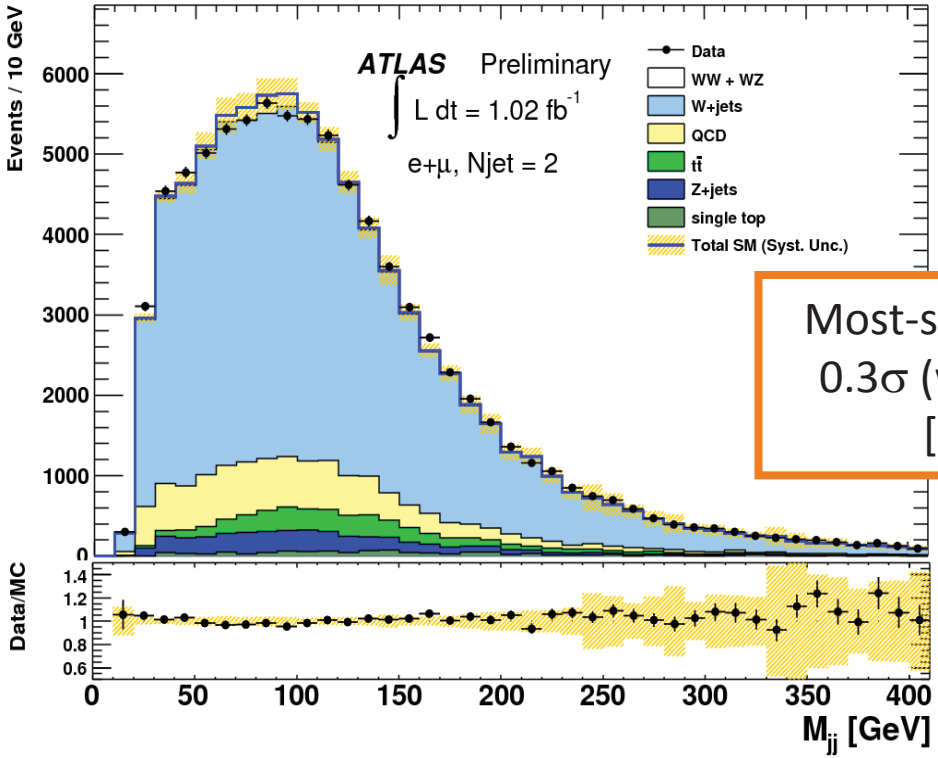
Wjj at ATLAS

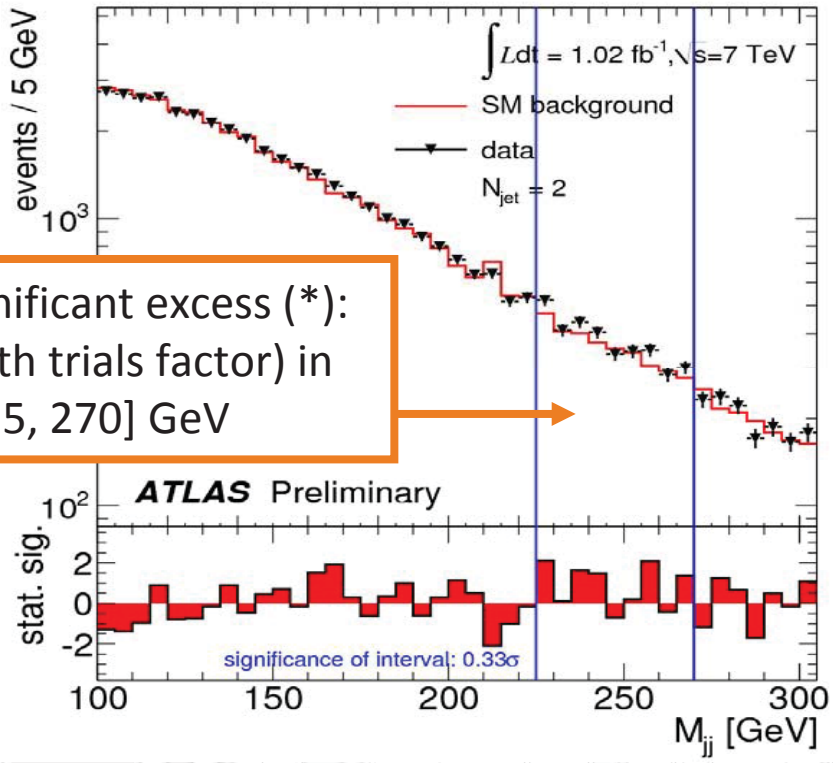
(*) For details about the method, see talk by G. Choudalakis yesterday

→ Repeat CDF study of W + 2 jets production
→ Keep selection as close as possible to CDF
→ Less favorable than at TeVatron: signal **x4** but W+jets bkg **x20**

ATLAS-CONF-2011-097

Selection:
- $E_T > 25$ GeV (e), $p_T > 20$ GeV (μ)
- $E_T^{miss} > 25$ GeV, $m_T > 40$ GeV
- p_T(jet) > 25 GeV in in $|\eta|<2.8$
- $p_T^{jj} > 40$ GeV, $|\Delta\eta^{jj}| > 2.5$





Most-significant excess (*): 0.3σ (with trials factor) in [225, 270] GeV

p-value in "CDF region" [120, 160] GeV = 0.3 (0.5σ), no excess seen

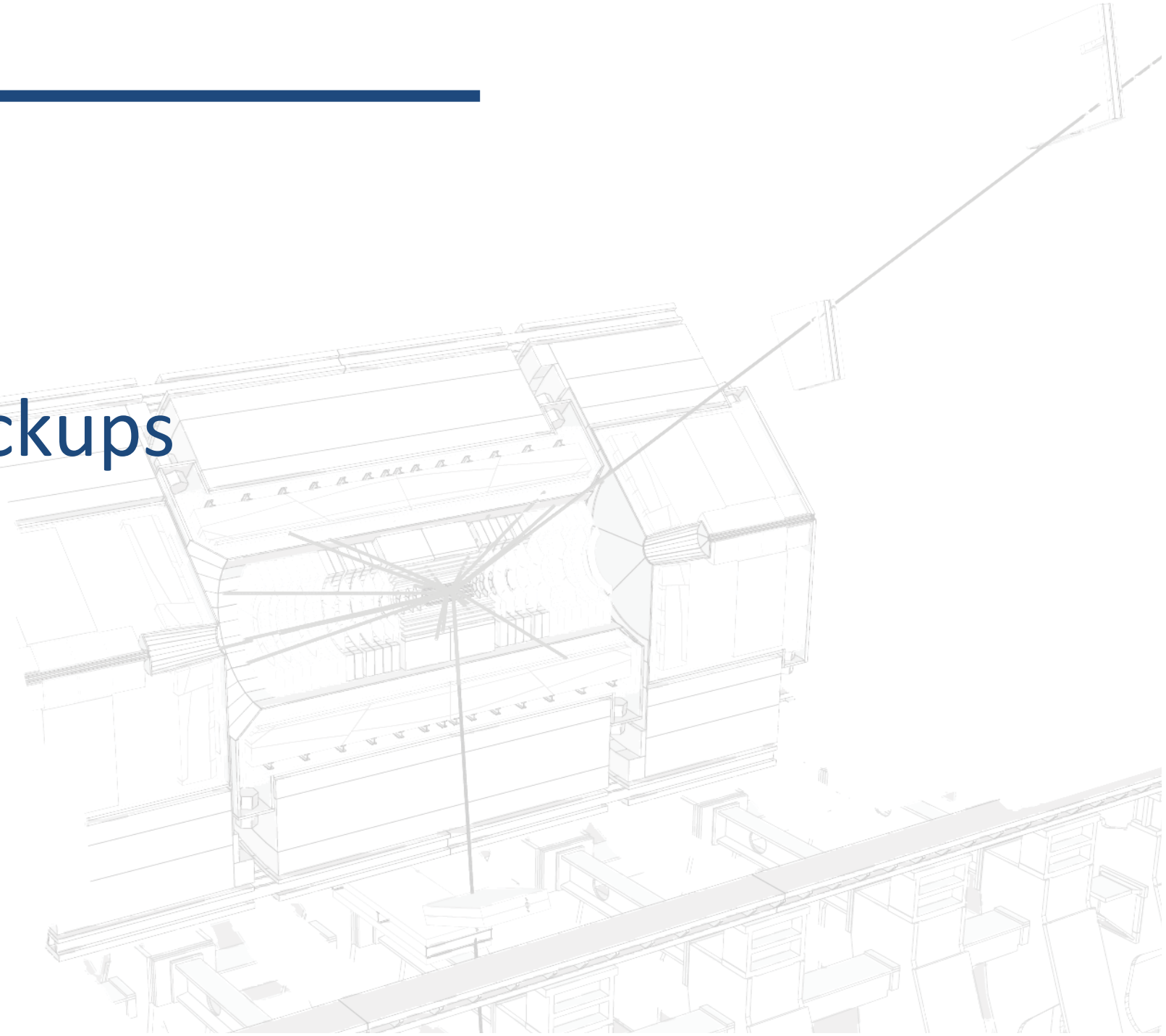
Conclusion

→ Technicolor models are important benchmarks for ATLAS exotic analyses

→ Some exclusion limits already beyond those of Tevatron experiments

→ Many more results to come as integrated luminosity keeps increasing…

Backups



Walking TC coupling ?

"Phase diagram" of SU(N) gauge theories with N_f fermions:

2-loop RGE: $$-\frac{d\alpha}{d(\log Q)} = b\alpha^2 + c\alpha^3$$

→ suggests an IR fixed point for some values of N, N_f.

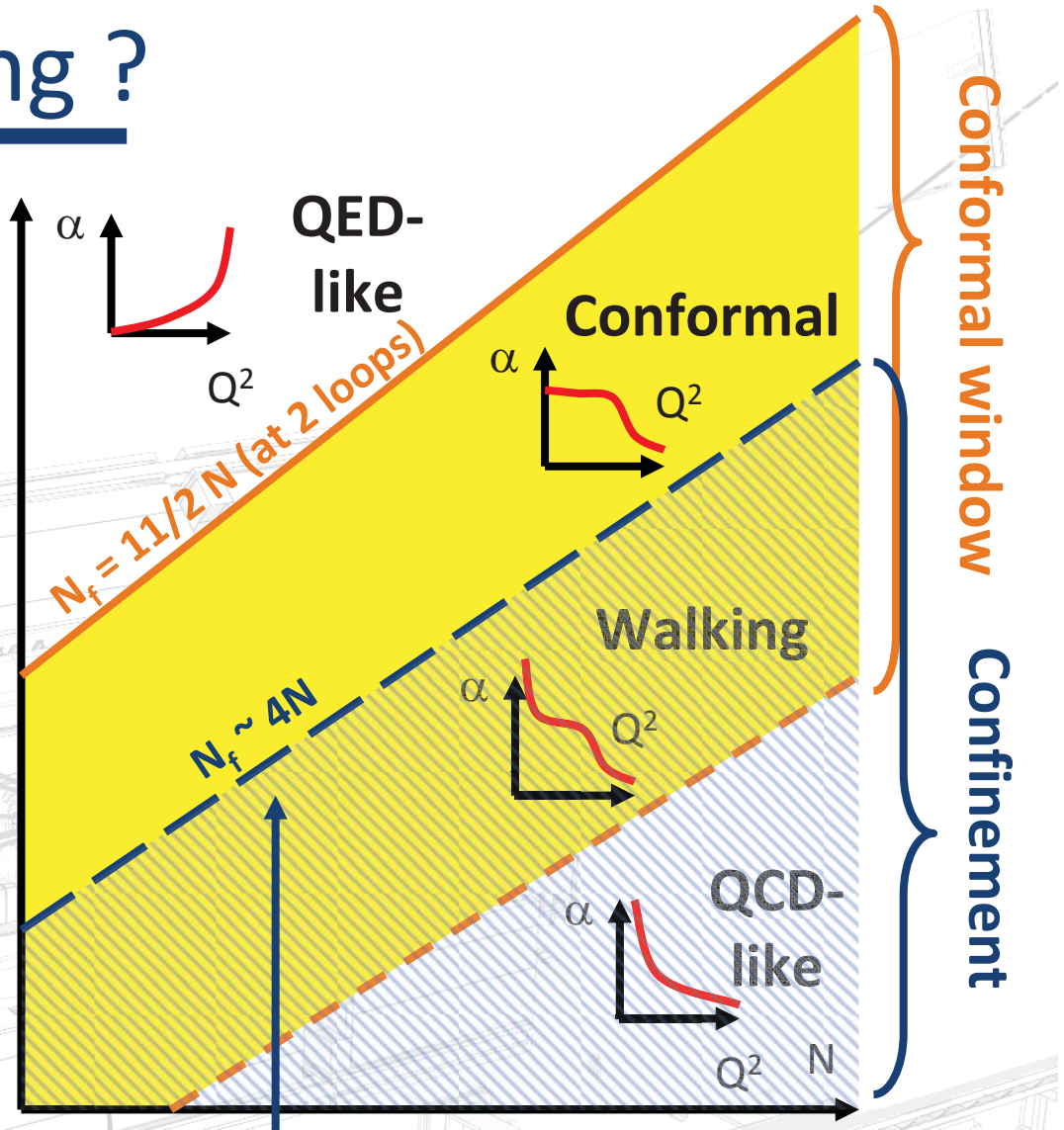
⇒ Theory is **conformal** in the IR

→ it is likely that the onset of confinement occurs inside this conformal window

⇒ Can have theories which are both **conformal** and **confining** :
the **walking** regime.

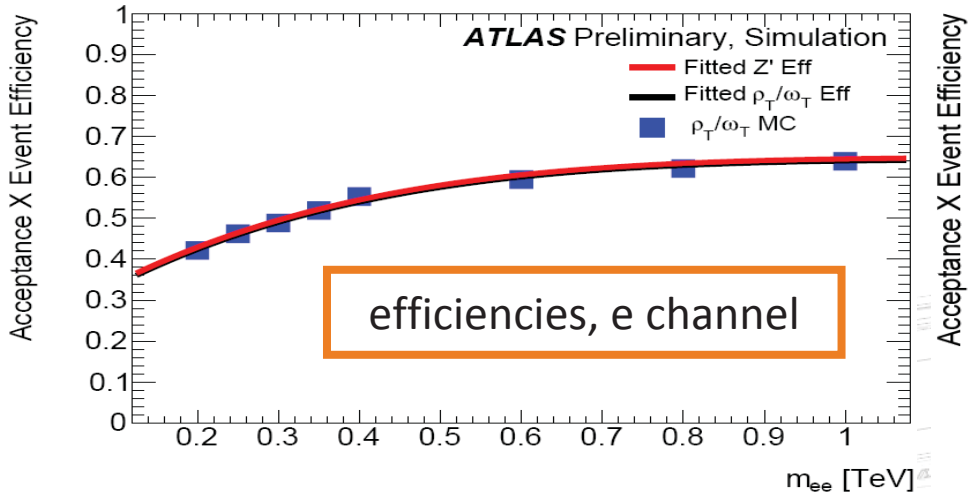
Strong couplings in lower part of the plot
⇒ need lattice for firm predictions…

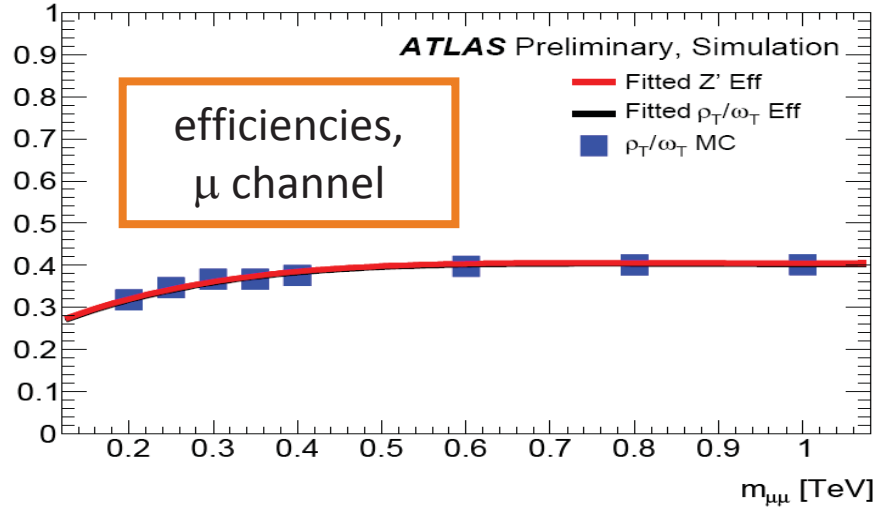
Some estimations shown here for illustration

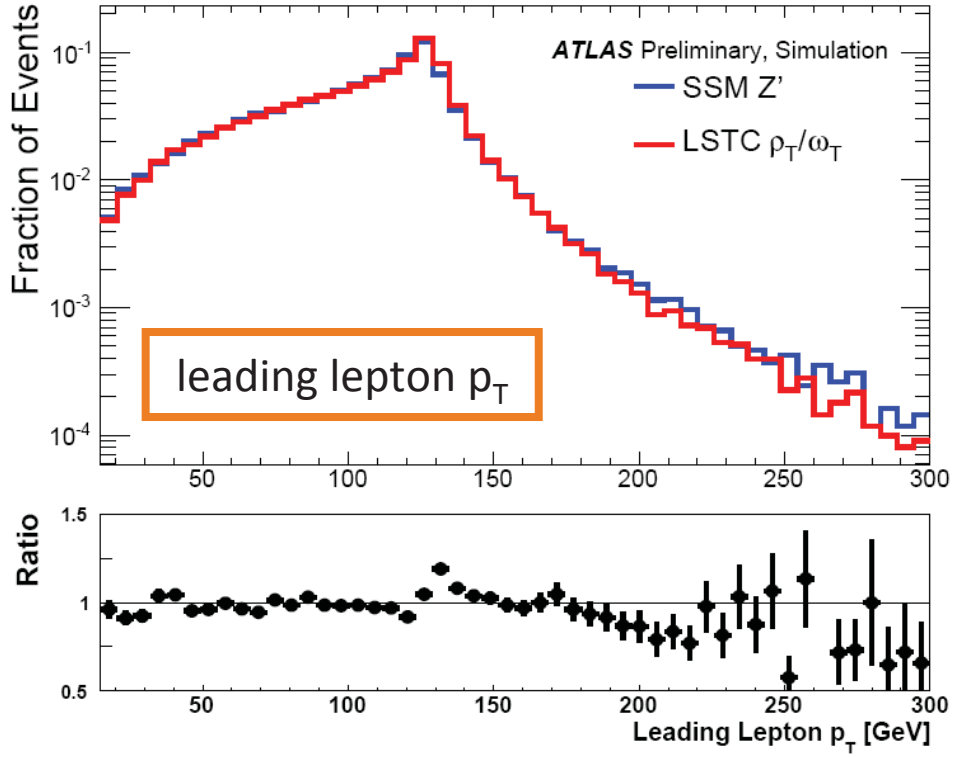


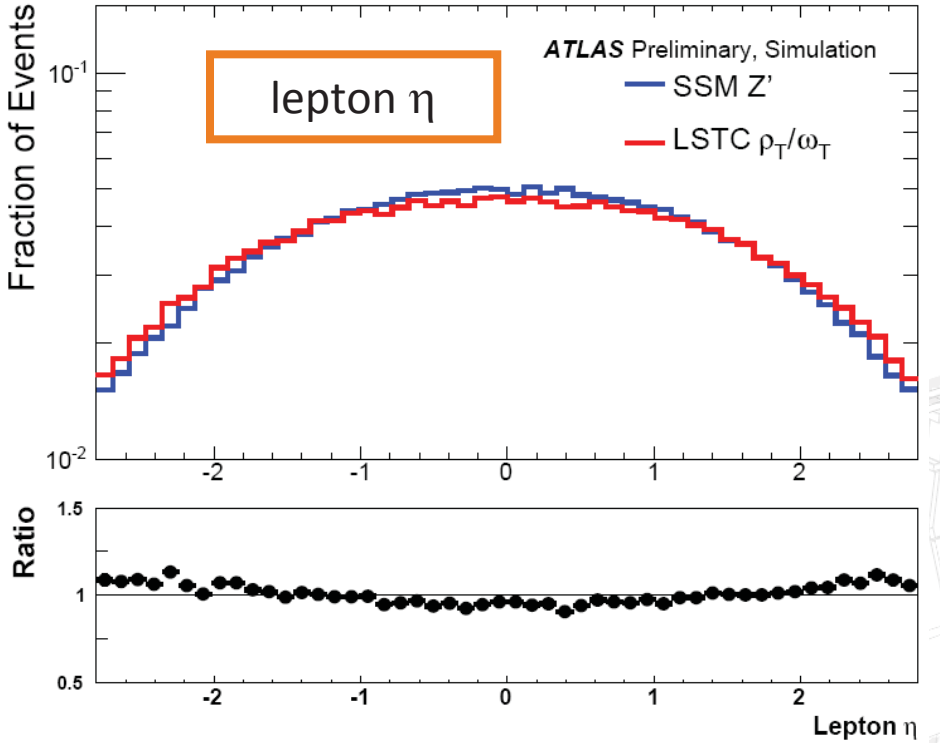
T. Appelquist et al.
PRD 58 (1998) 105017

Comparison of TC and Z'

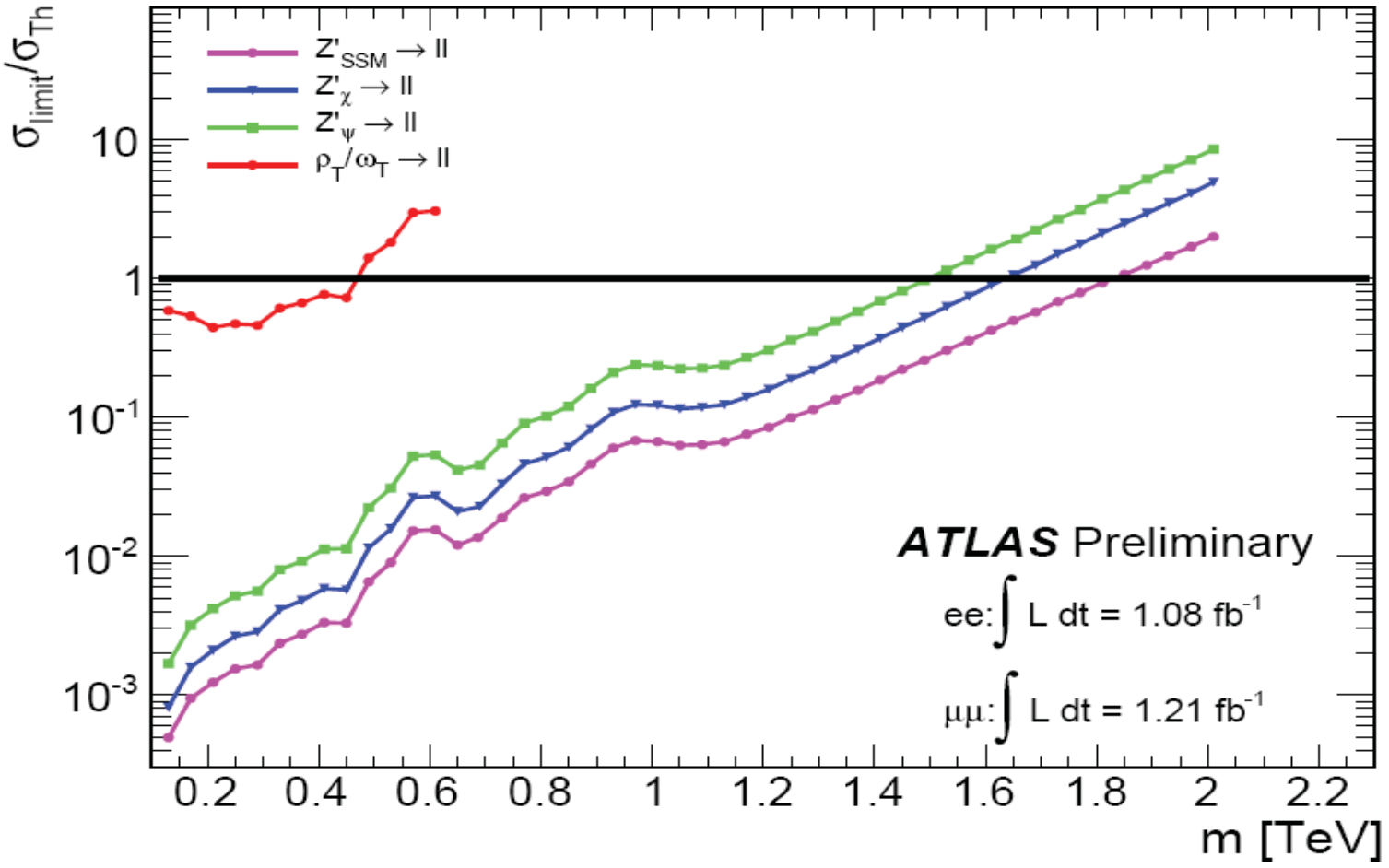






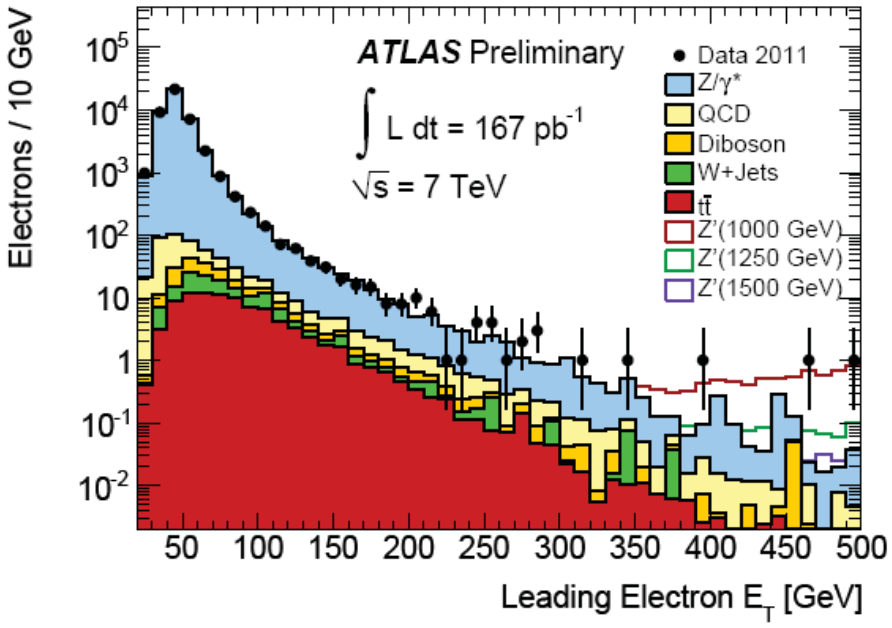


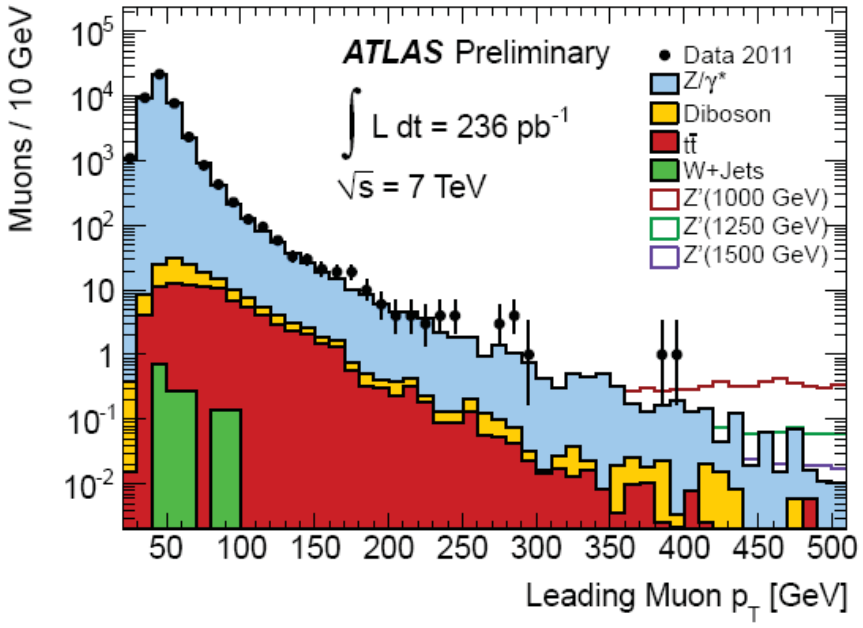
Alternate ρ_T limit plot

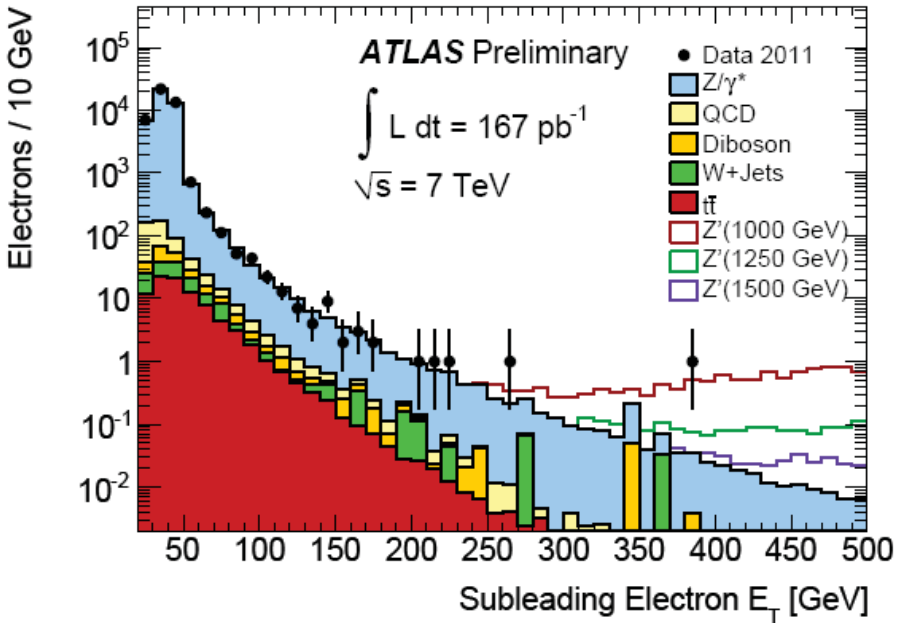


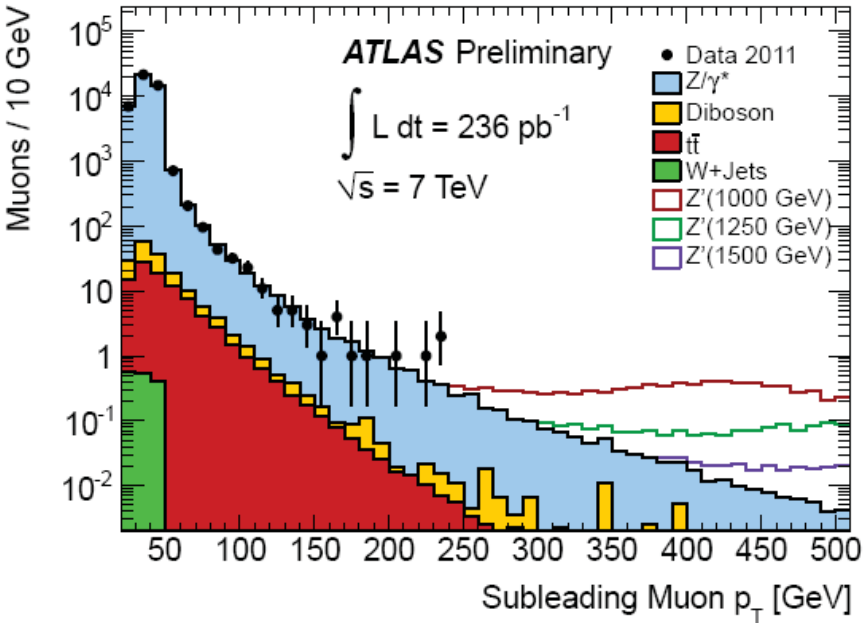
Channel	Observed mass exclusion [GeV]	Expected mass exclusion [GeV]
$\rho_T/\omega_T \rightarrow e^+e^-$	$m < 323$ and $386 < m < 445$	$m < 345$
$\rho_T/\omega_T \rightarrow \mu^+\mu^-$	$m < 280$ and $304 < m < 376$	$m < 330$
$\rho_T/\omega_T \rightarrow \ell^+\ell^-$	$m < 470$	$m < 442$

Extra Z' plots : p_T

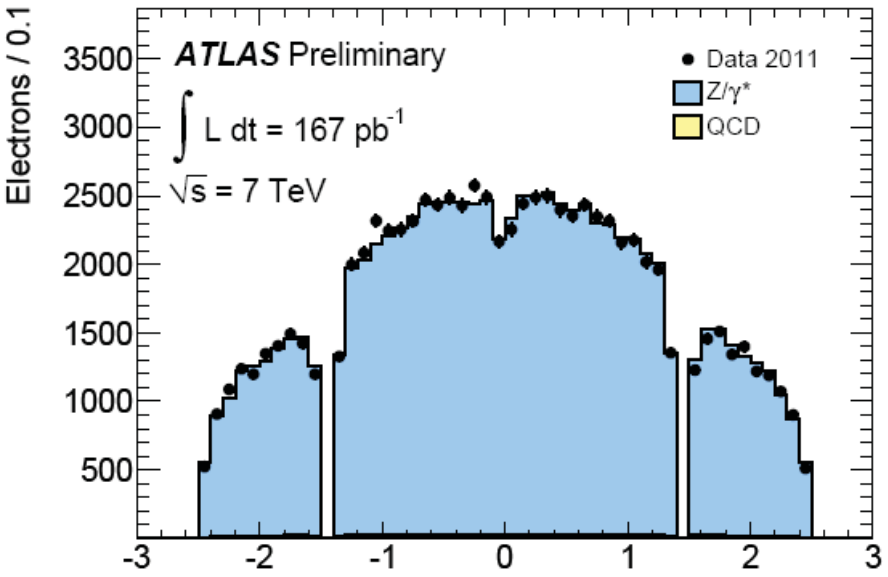


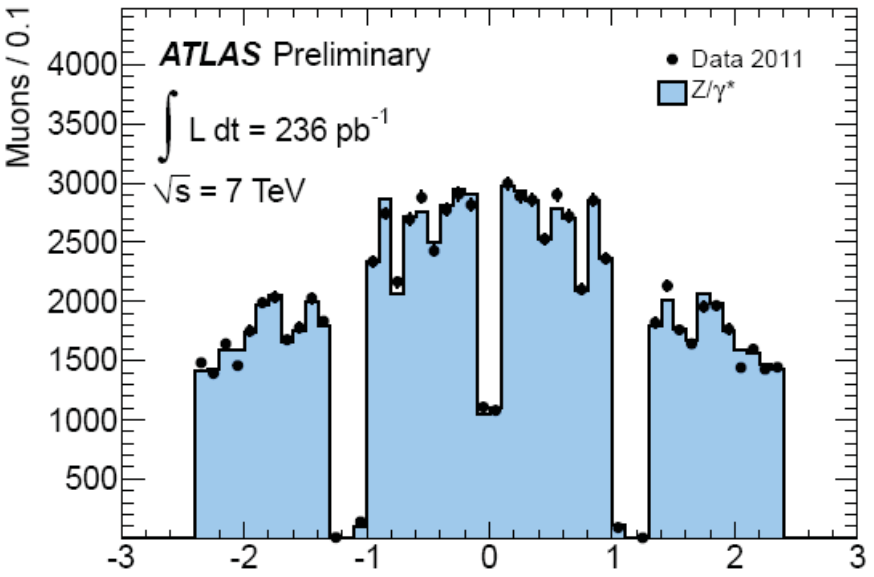


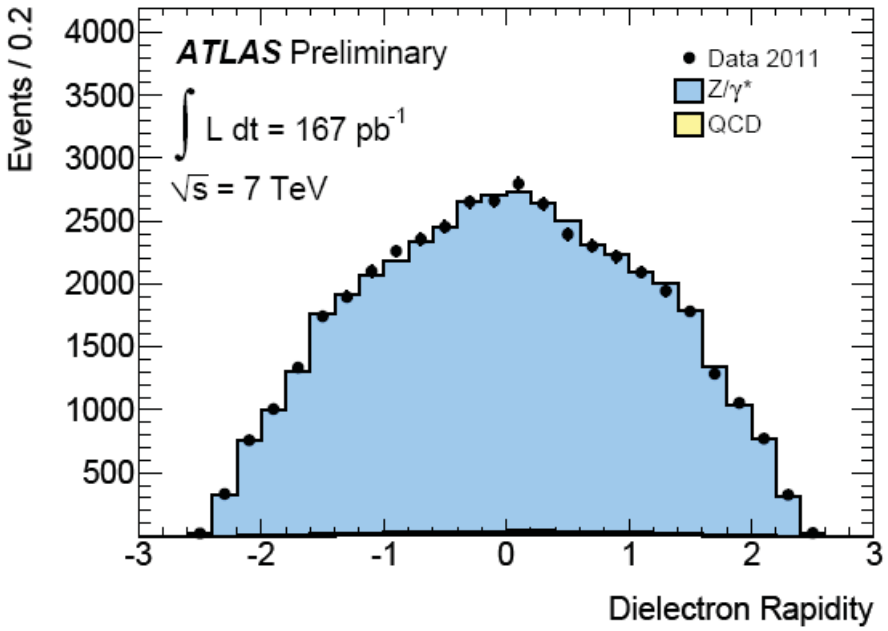


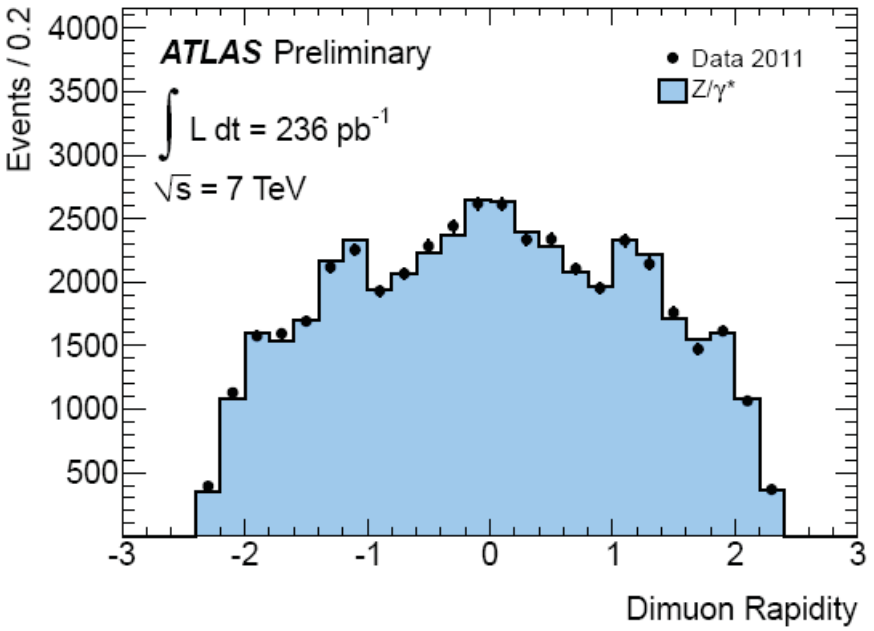


Extra Z'plots : rapidities

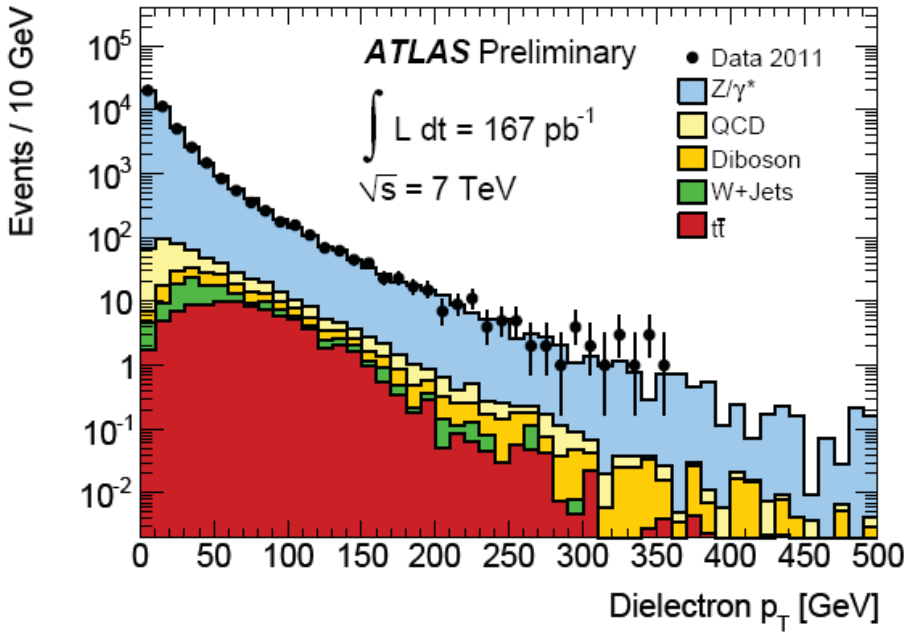


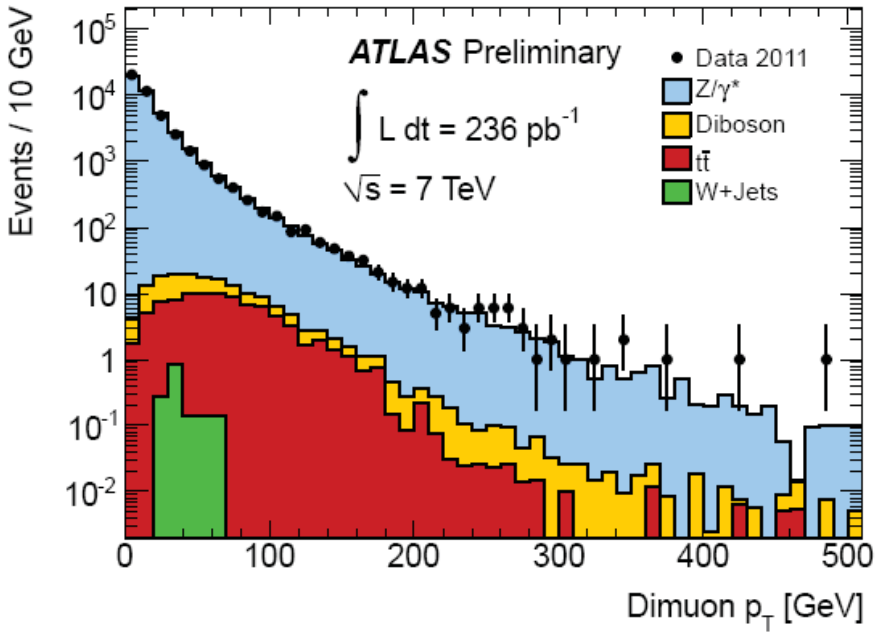


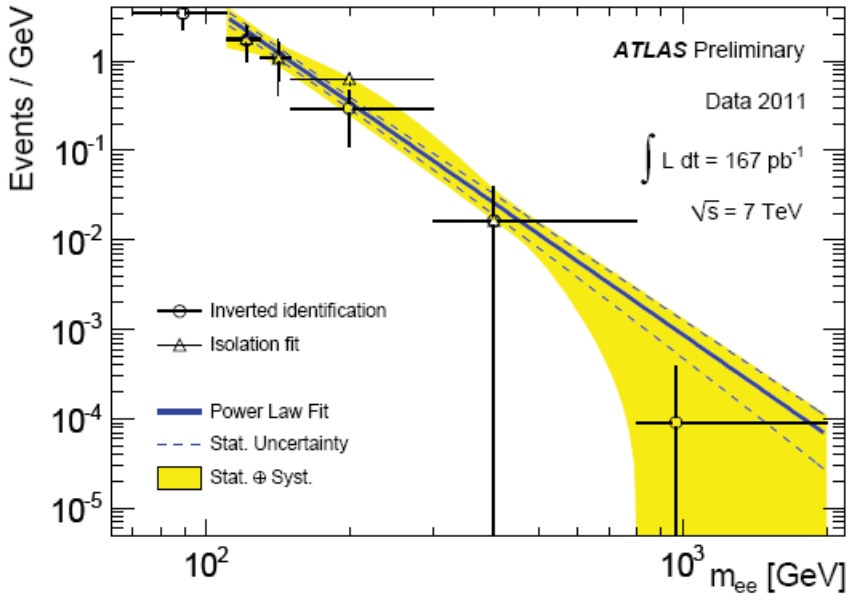




Extra Z' Plots







Background estimate

W+jets data-driven scale factors

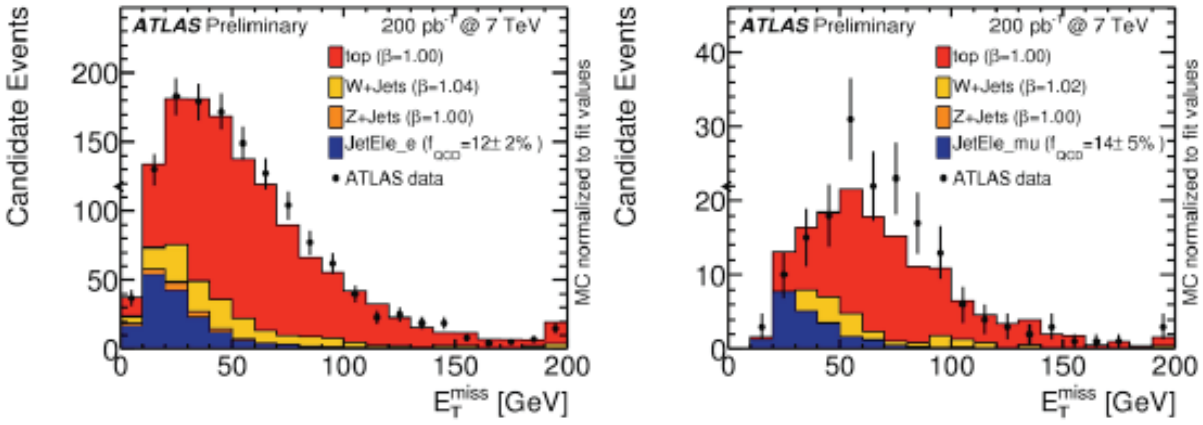
Control region with
30 < MET < 80 GeV
40 < M_T^W < 80 GeV
b-tagging veto

Fit of the jet multiplicity distribution to determine a scale factor for each parton multiplicity sample

Shape from MC

Multijet QCD data-driven shape and scale

Jet-triggered events
Jet with high EM fraction used as fake lepton
Same model for fake e and μ
Normalisation from fit of MET distribution before cut



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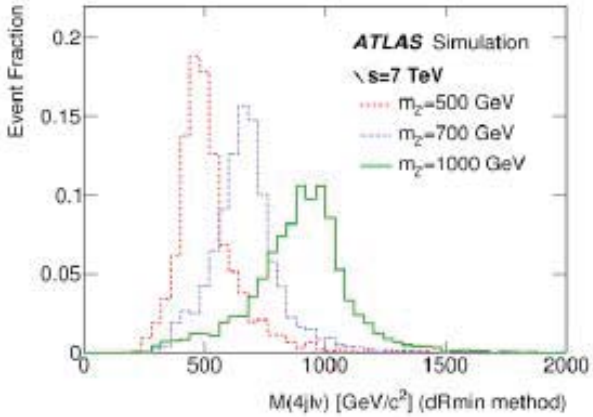
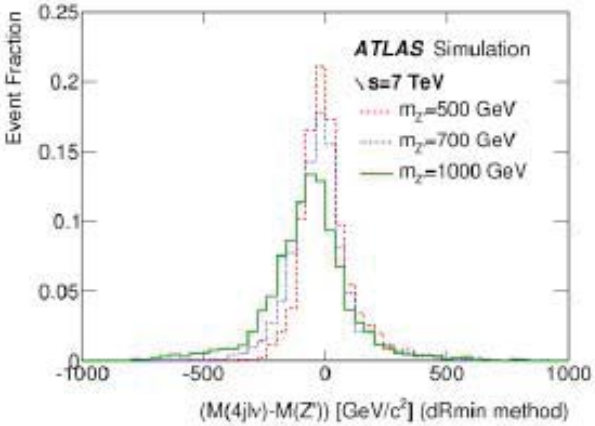
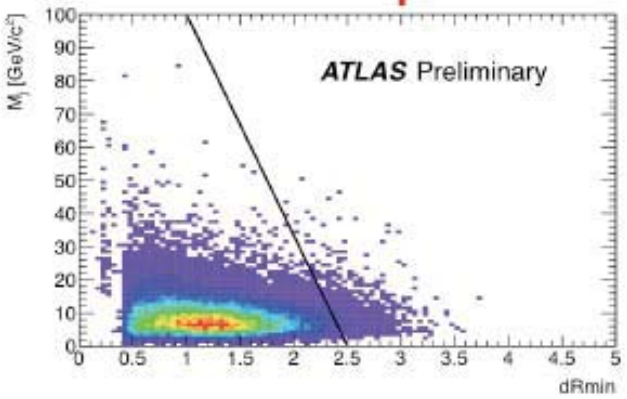
Mass reconstruction

- **Neutrino**
  MET identified with neutrino p_T
  p_z from quadratic equation imposing W mass
  If no real solution, MET corrected to get null discriminant
  If two real solutions, smallest $|p_z|$ chosen
- **No assignment of jets to top or antitop**
  3 or 4 hardest jets added to leptonic W
  Jets compatible with ISR excluded (far from other objects)

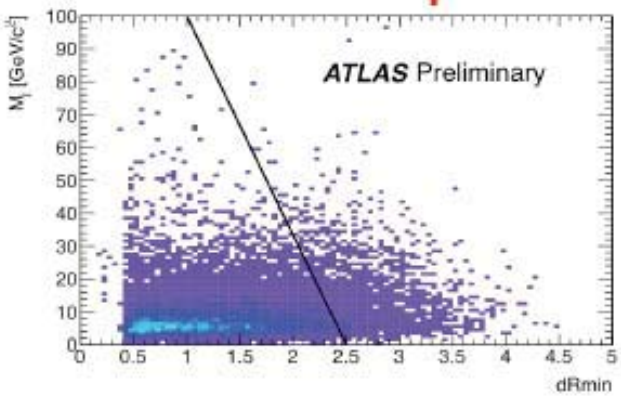




Matched jets



Unmatched jets



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