



Searches for heavy resonances with the ATLAS detector

Madalina Stanescu-Bellu (DESY, Germany)

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HUMBOLDT-UNIVERSITÄT ZU BERLIN



Heavy Resonances

- excited states of heavy particles
- decay fast (10^{-23} s) into lighter particles before it reaches our detectors
- Relativistic Breit-Wigner distribution:

$$f(s) = \frac{k}{(s - M^2)^2 + M^2 \Gamma^2}$$

k =constant

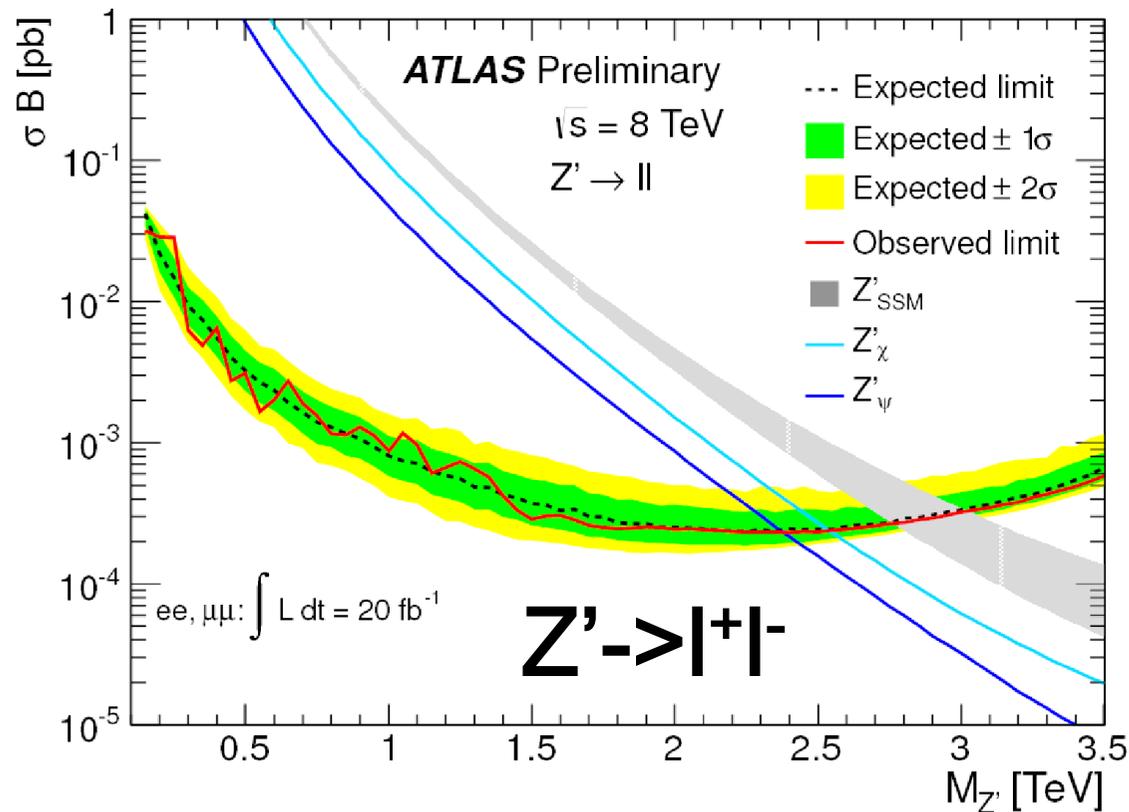
\sqrt{s} =center-of-mass energy

Γ = width= \hbar/τ

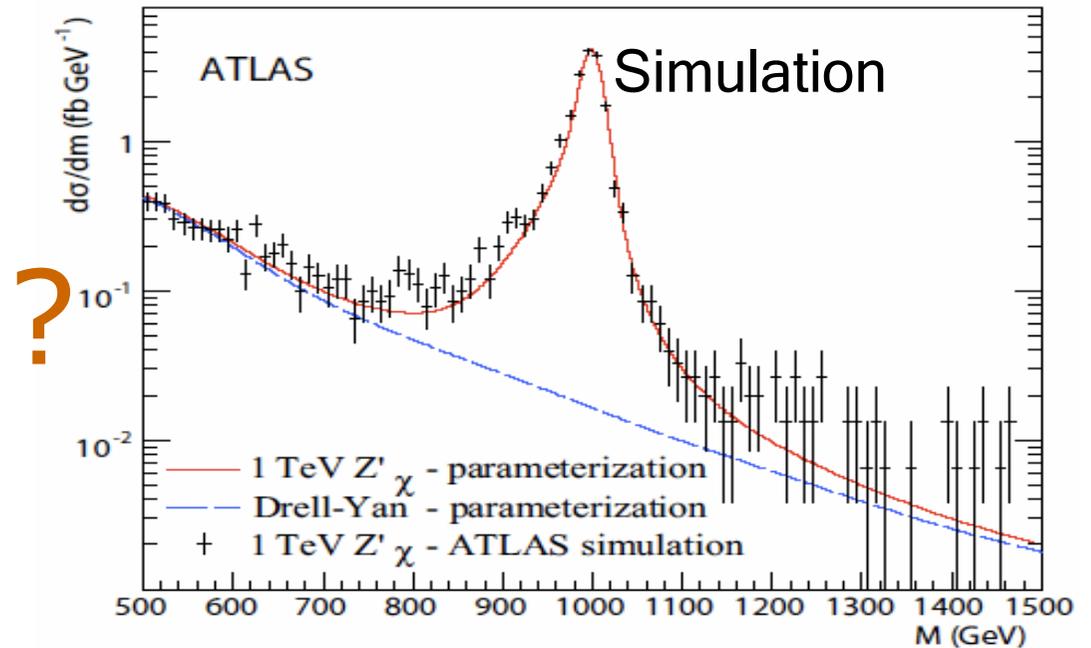
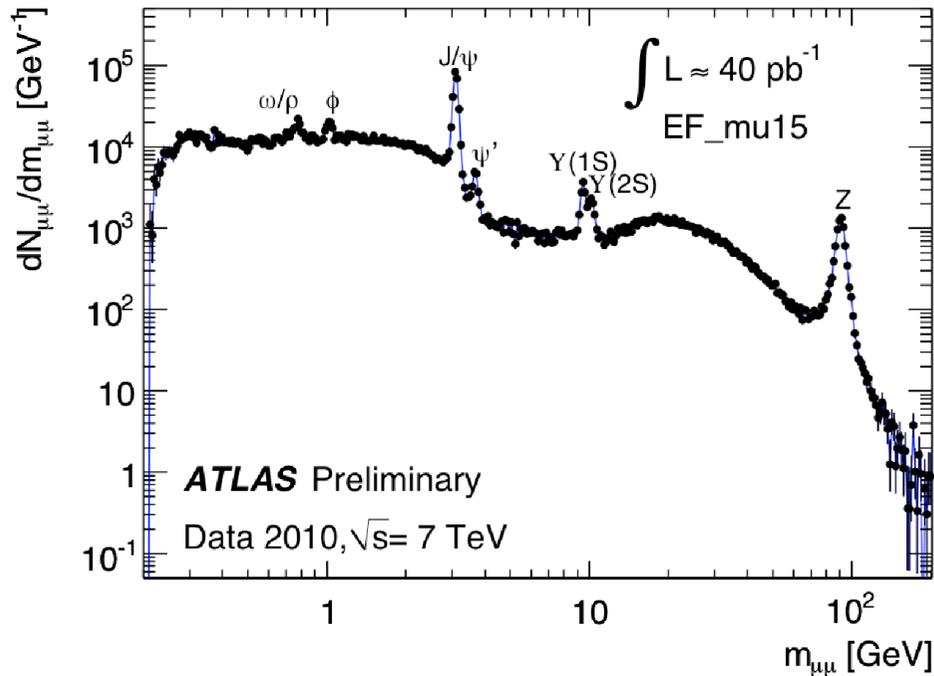
M =mass

Heavy Resonances

- If no discovery made:
 - Set upper limit of $\sigma_{\text{production}} * \text{BranchingRatio}_{\text{decay}}$
 - Find exclusion limit for masses by intersecting:
 - the observed σ limit
 - with theory σ prediction



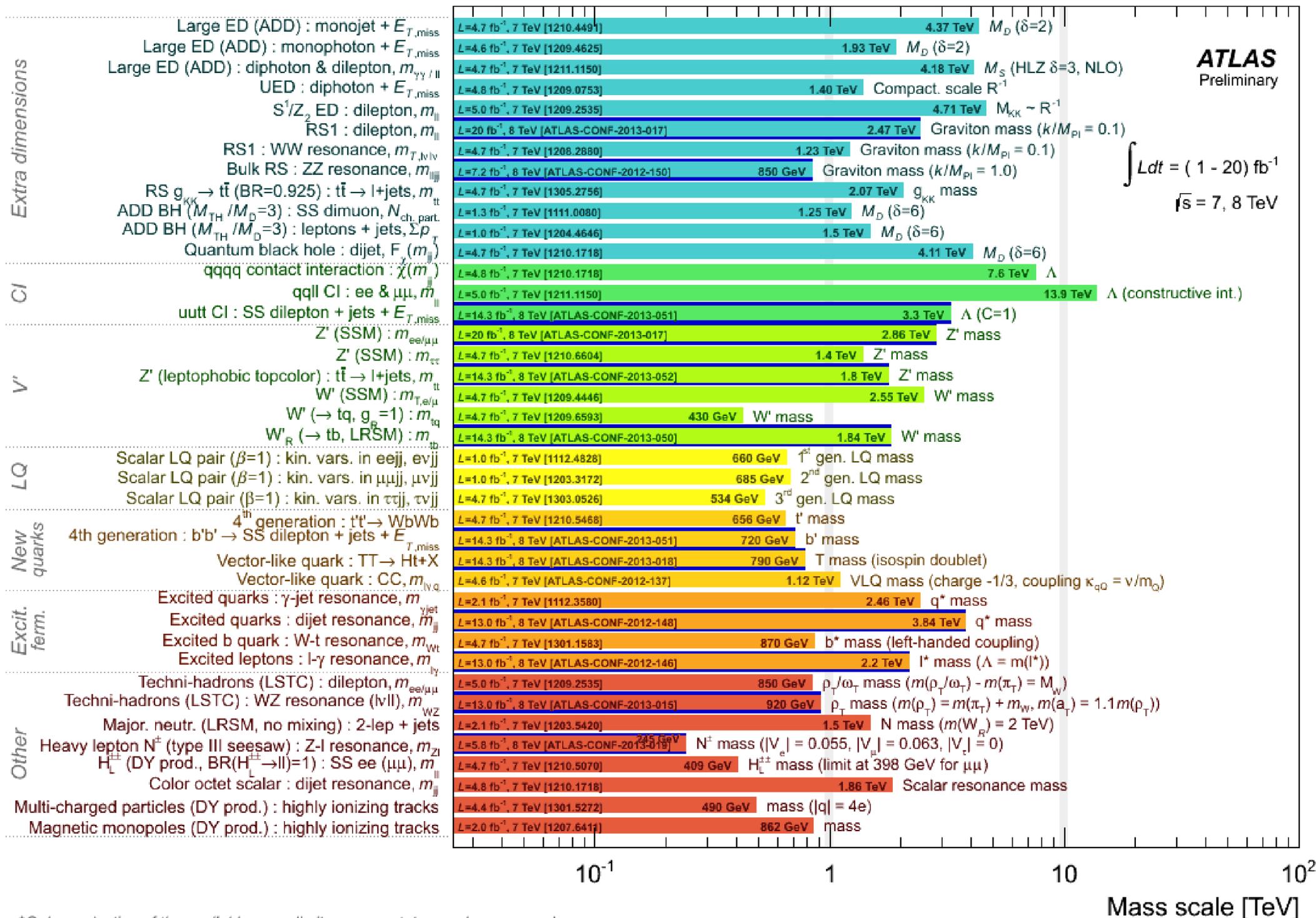
ATLAS Searches for Resonances



- One of the most common techniques: **BUMP HUNTING**
 - smooth background (from MC or fit)
 - search for excesses

ATLAS Exotics Searches* - 95% CL Lower Limits (Status: May 2013)

ATLAS
Preliminary

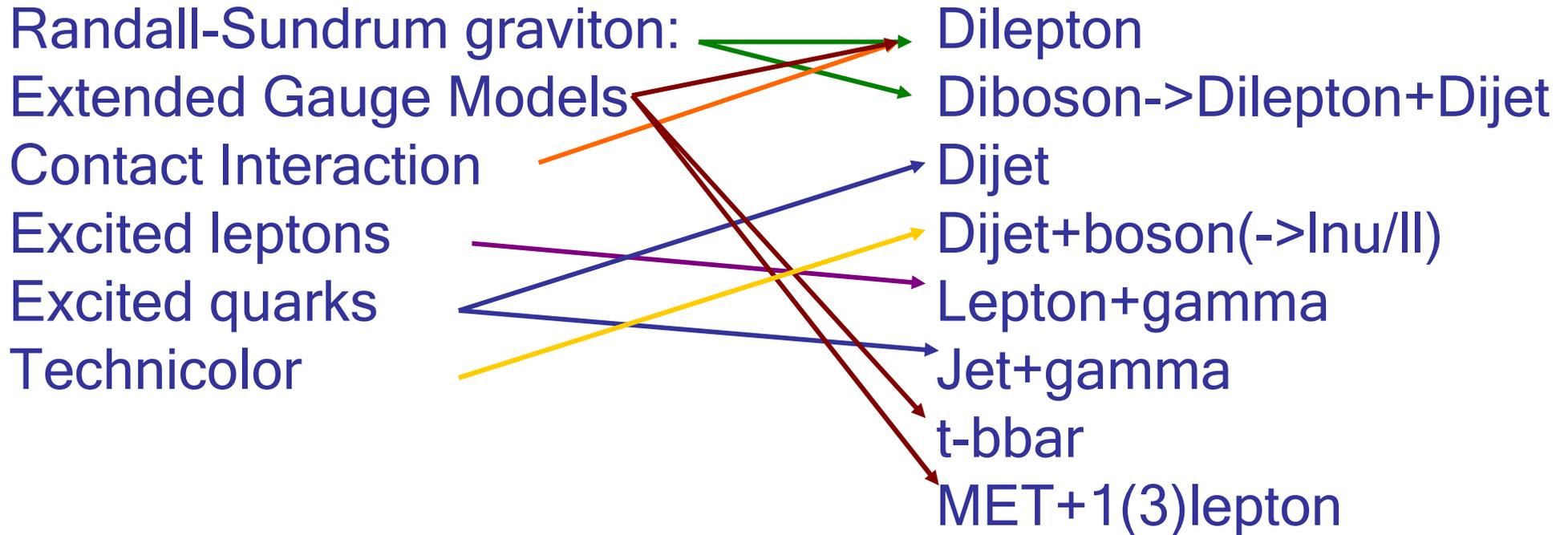


*Only a selection of the available mass limits on new states or phenomena shown

Signature driven searches

MODELS COVERED in this talk:

SIGNATURES:



MODELS NOT COVERED in this talk:

Leptoquarks, 4th generation,
vector-like quarks

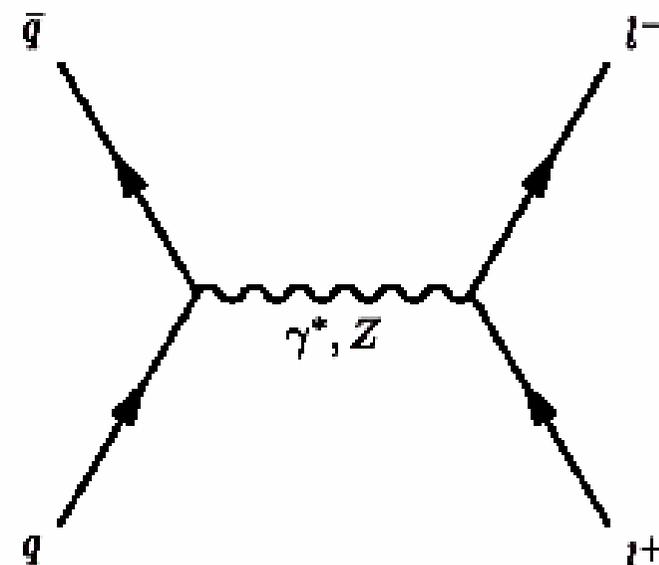
COLOR CODES:

SIGNAL

BACKGROUND

Dileptons $e^+e^-/\mu^+\mu^-$

- RS1 graviton spin2 G^*/Z' $\rightarrow l^+l^-$
- BACKGROUNDS:
- Drell-Yan: $Z/\gamma^* \rightarrow l^+l^-$
 - MC, irreducible
 - reweighted to generate signal



Drell-Yan process

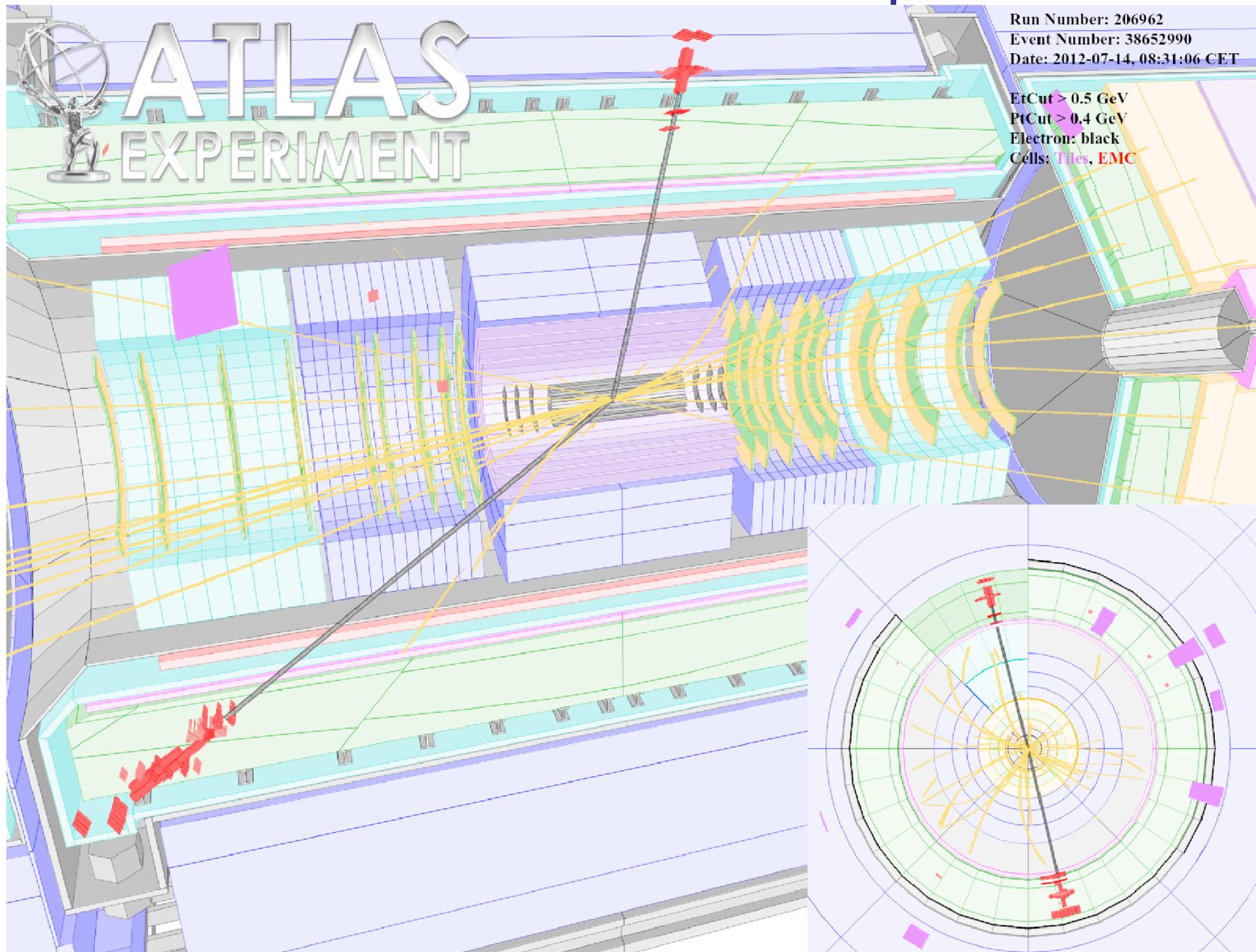
- Multijets/W+jets:
 - quark/gluon initiated jets=fake leptons
 - data driven by extrapolating from small mass area:
 - where elec tracks don't match clusters
 - where μ is not isolated $\frac{\sum p_T(\text{tracks} - \text{around} - \mu - \text{excluding} - \mu)}{pT^\mu} > 0.05$

$m(Z' \rightarrow e^+e^-) = 1.54 \text{ TeV}$

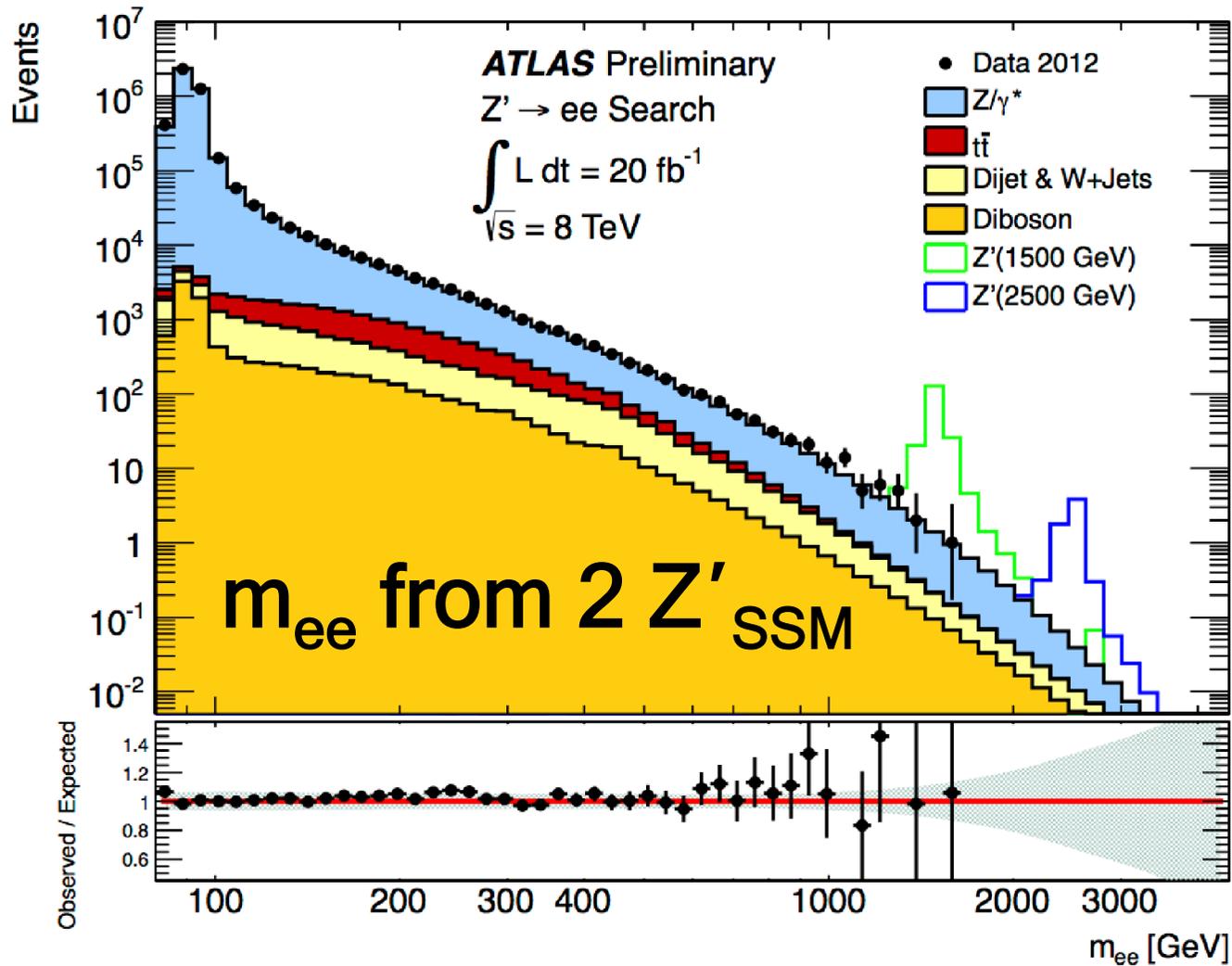
Elec: Isolated

Elec η : boost due to PDF

Elec φ : back to back



Dileptons $e^+e^-/\mu^+\mu^-$



Backgrounds: MC templates reweighted to match data in non-signal (control region)

Lower m limit @95% CL

Z'_{E6} : 2.38-2.54 TeV

Z'_{SSM} : 2.86 TeV

G^* : 2.47 TeV

Ditau in fully hadronic channel

$$Z' \rightarrow \tau_{had}^{\pm} \tau_{had}^{\mp}$$

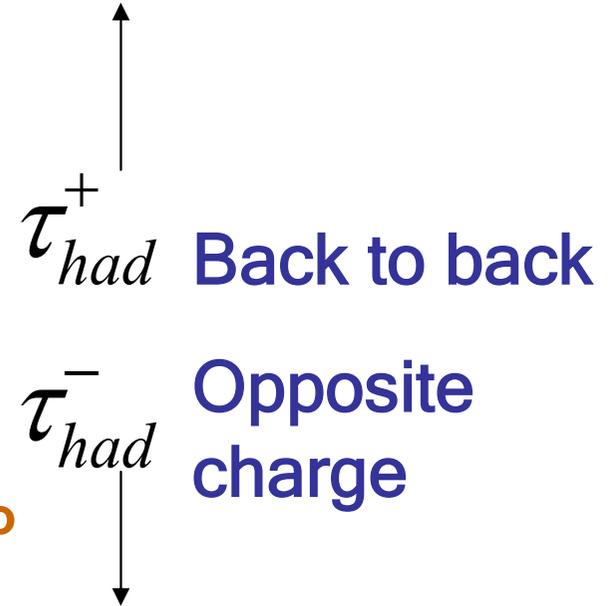
$$\tau_{had}^{\pm} \rightarrow \pi^{\pm} \nu_{\tau} + n\pi^0$$

$$\tau_{had}^{\pm} \rightarrow \pi^{\pm} \nu_{\tau} \pi^{\pm} \pi^{\mp} + n\pi^0$$

1 prong decay

3 prong decay

(at high pT difficult to reconstruct due to track merging)



➤ $\tau_{had} \tau_{had}$: 42% of BR_{τ} THE OTHER channels: $\tau_{lep}^{\pm} \rightarrow l^{\pm} \nu_l \nu_{\tau}$

➤ Mass resolution 30-50% due to undetected neutrinos

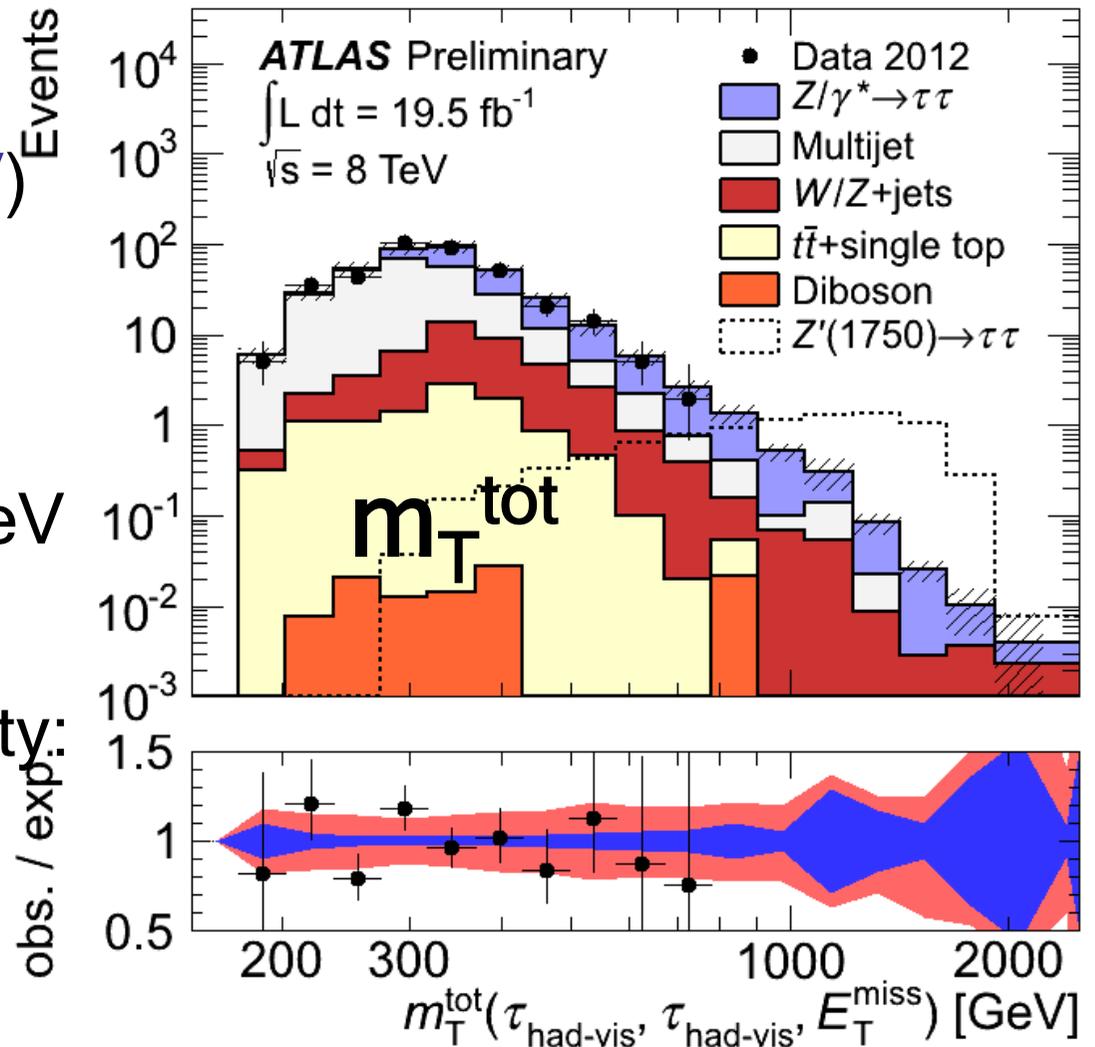
Ditau in fully hadronic channel

➤ Different m_τ cut for each m_Z ,
 ($m_\tau > 850 \text{ GeV}$ for $m_Z > 1500 \text{ GeV}$)

➤ Geometrical Acceptance *
 Efficiency: 7-9% for $m_Z \geq 750 \text{ GeV}$

➤ Highest signal syst uncertainty:
 tau ID efficiency 13%

Lower m limit @95% CL
 $Z'_{\text{SSM}} : 1.90 \text{ TeV}$



Contact Interactions in dilepton channel

$$q\bar{q} \xrightarrow{SM, CI(\Lambda)} l^+ l^-$$

Standard Model

$$\frac{d\sigma}{dm_{ll}} = \frac{d\sigma_{SM(Drell-Yan)}}{dm_{ll}} - \frac{SM-CI}{\Lambda^2} + \frac{CI}{\Lambda^4}$$

Interference SM-CI :
Destructive(-) Constructive(+)

Contact Interaction $\Lambda = g^2/M^2$

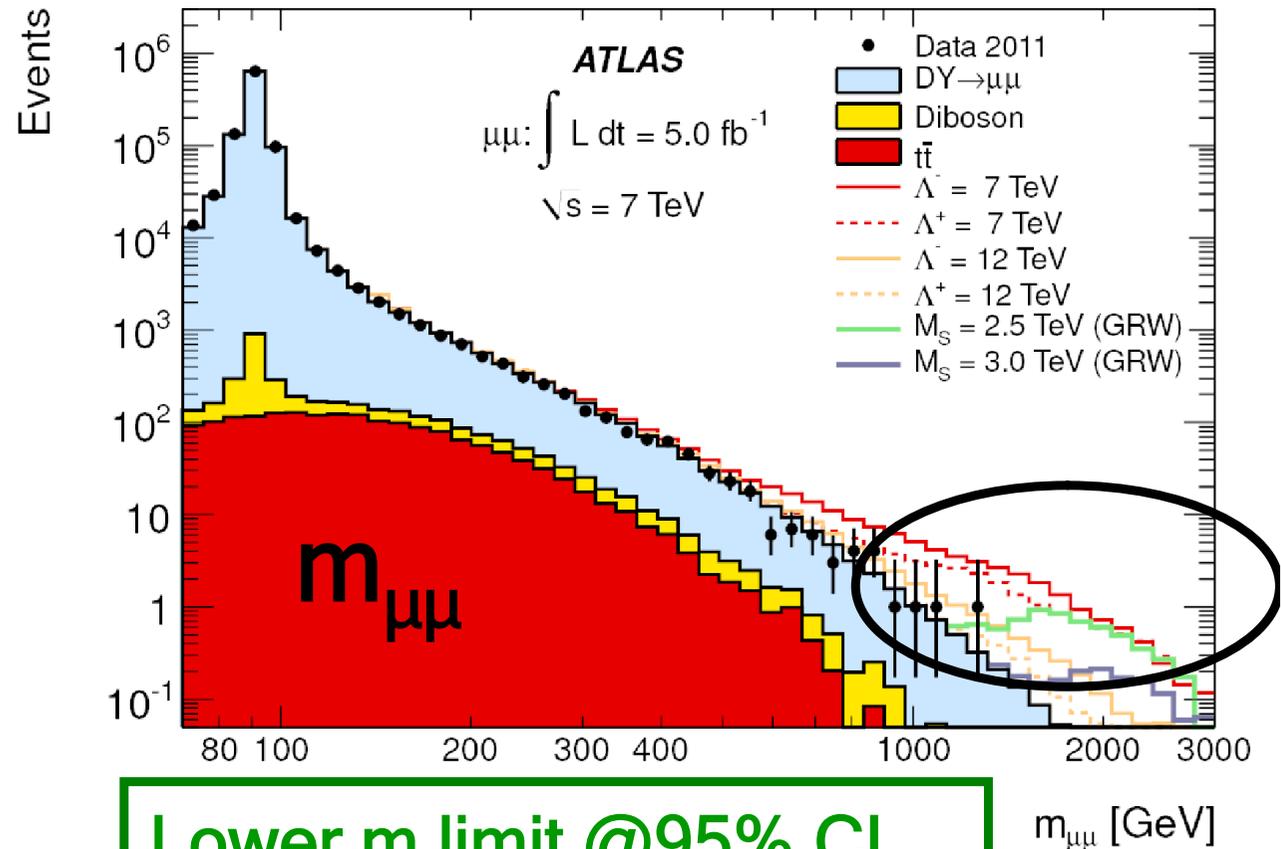
Quarks & Leptons:

➤ SM: elementary

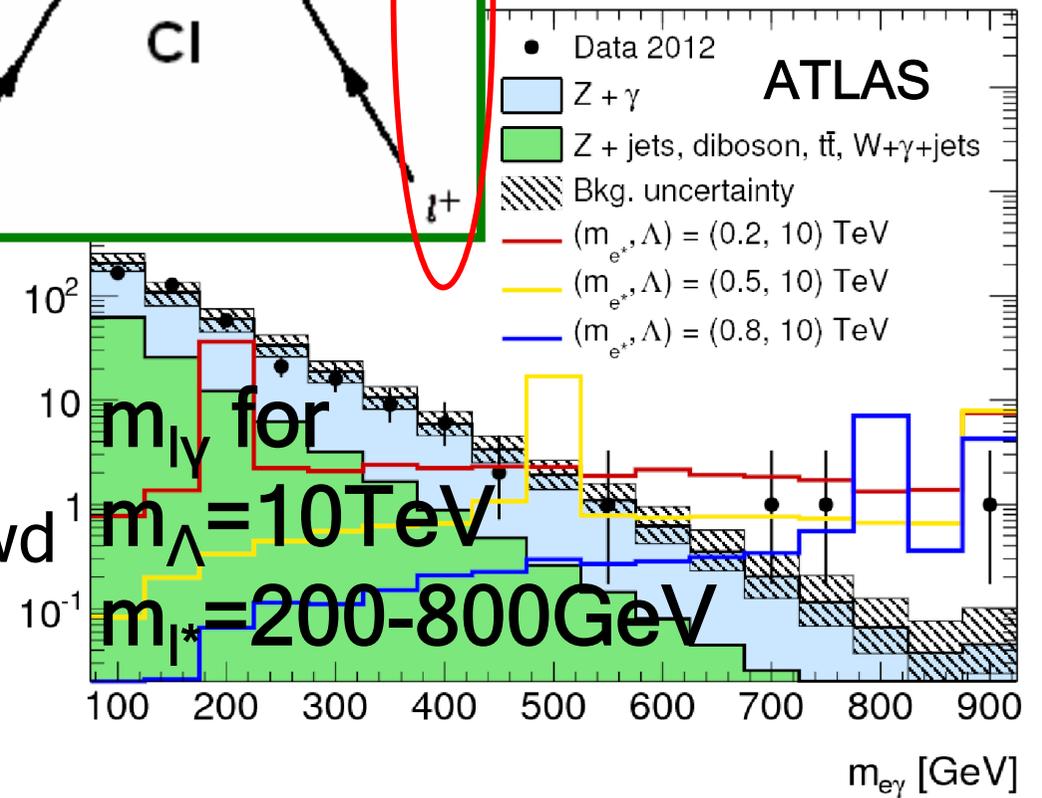
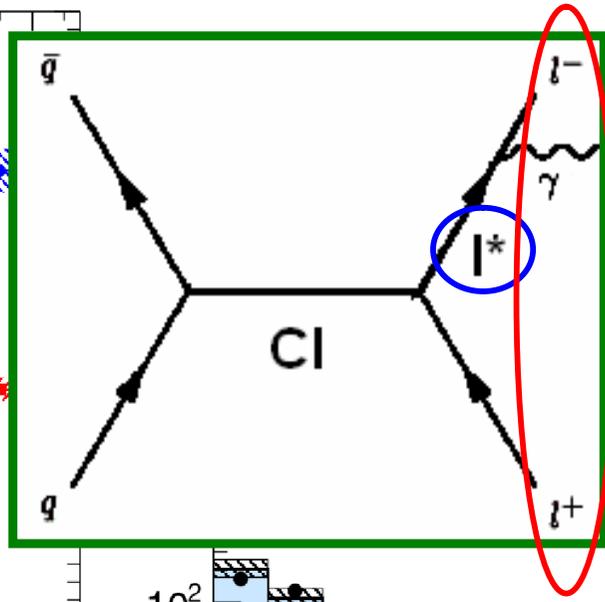
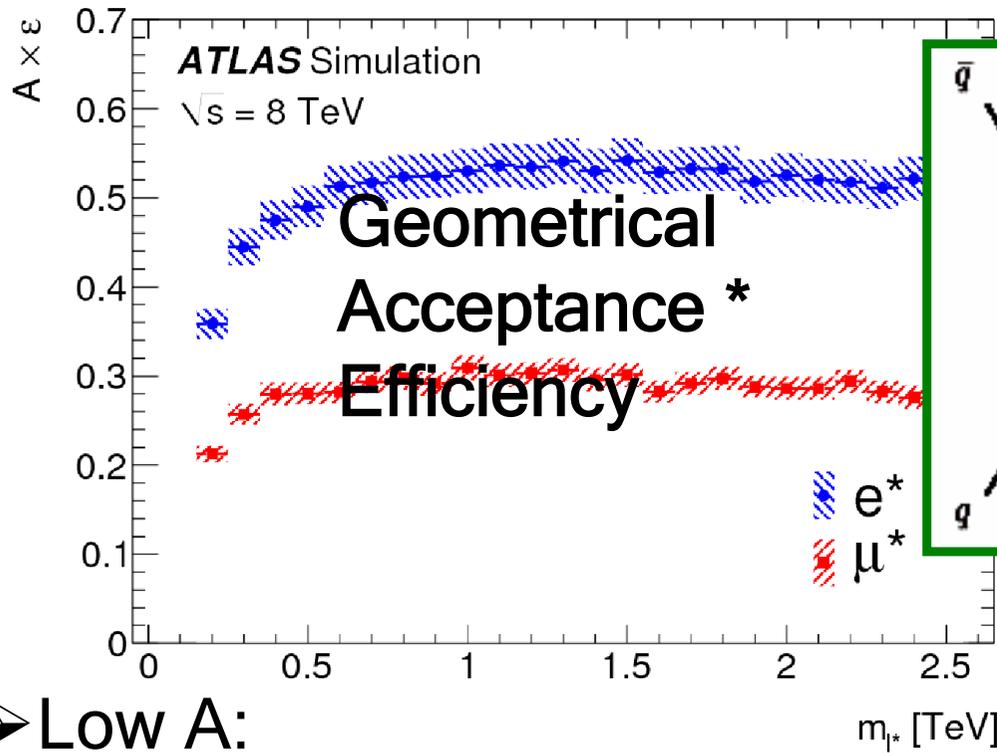
➤ BSM: composite,
constituents interact
through 4-fermion CI

➤ $\Lambda =$ compositeness
scale

➤ broad enhancement
at high M



Excited leptons l^* in $l+\gamma$ channel



- Low A:
- at low m_{l^*} due to $\gamma+l$ produced fwd
- μ due to 3 hits requirements in Tracker
- Search excesses in $m_{ll\gamma}$ instead of $m_{l\gamma}$ due to $l-\gamma$ association ambiguity

Upper $\sigma_B(l^* \rightarrow l\gamma)$ limit
0.75fb (e^*) / 0.90 fb (μ^*)
Lower m limit l^* : 2.2 TeV

Excited quarks q^* in jet+ γ channel

➤ PHOTON, isolated, $p_T > 125 \text{ GeV}$:

➤ Shower shape in EM calo

➤ Tracker info to:

➤ Reject fake γ from elec

➤ Recover $\gamma \rightarrow e^+e^-$

➤ Corrected for E loss in tracker

➤ $\Delta R(\gamma, j) > 1$

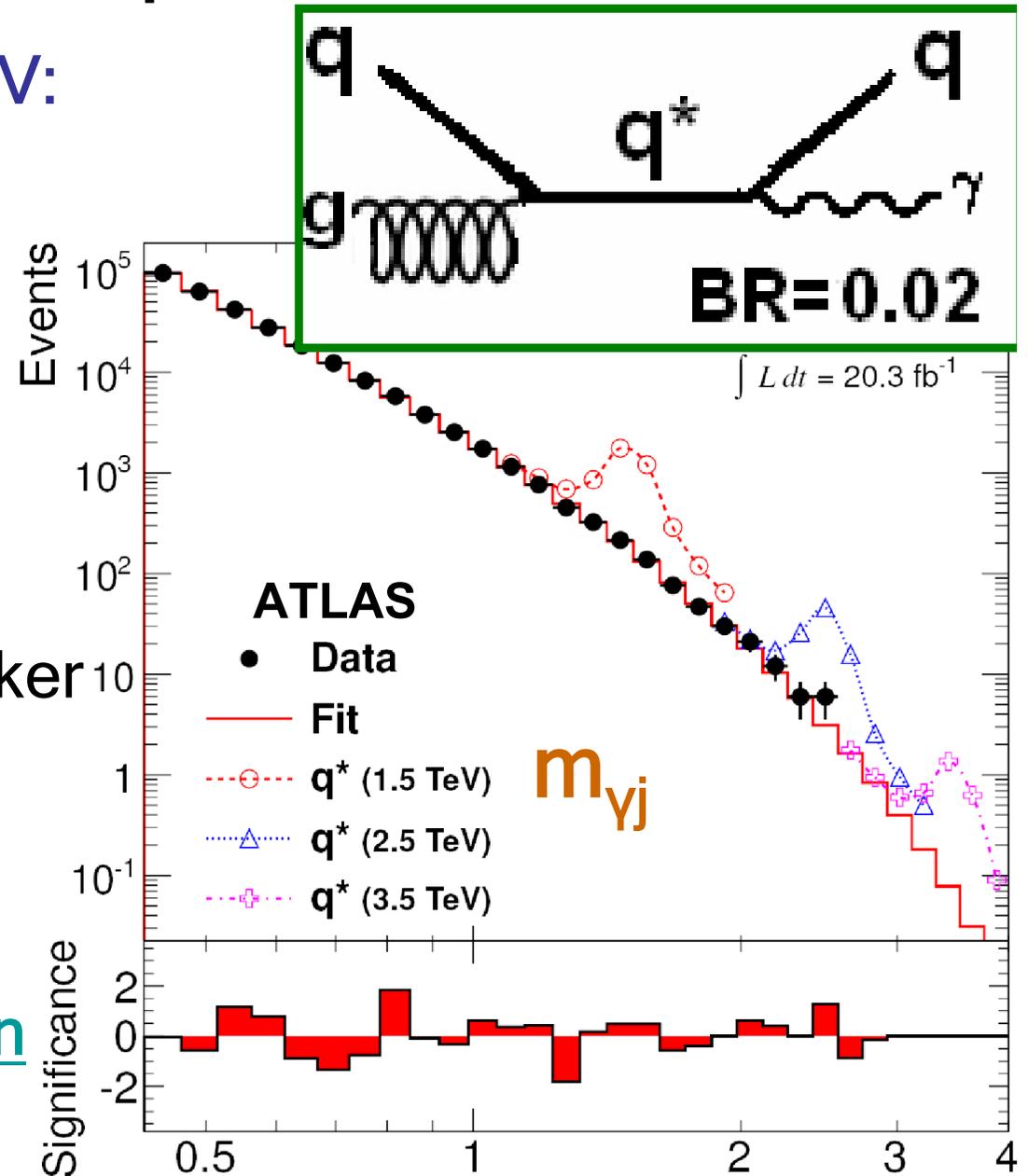
➤ BACKGROUND:

➤ quark-antiquark annihilation

➤ quark-gluon scattering

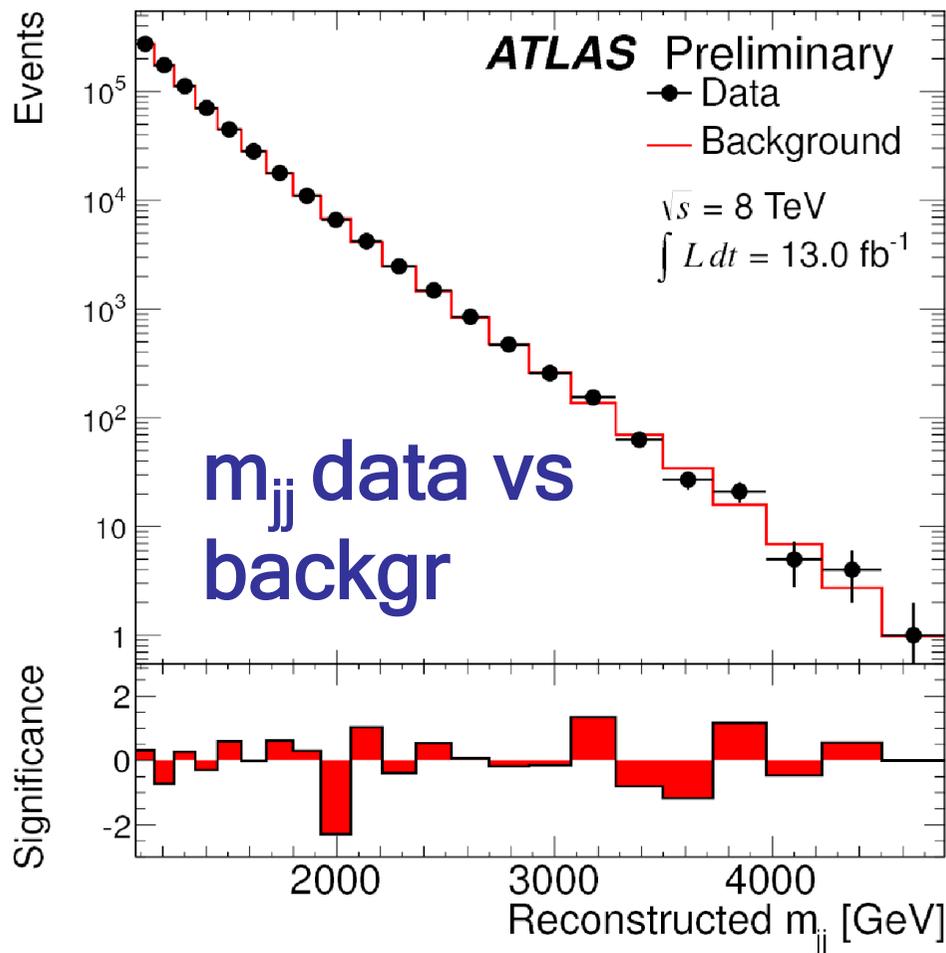
➤ radiation from final-state quarks

20 fb^{-1} , 8TeV, CERN-PH-EP-2013-126, PRD42,3(1990)



Lower m limit @95% CL
 q^* : 3.5 TeV

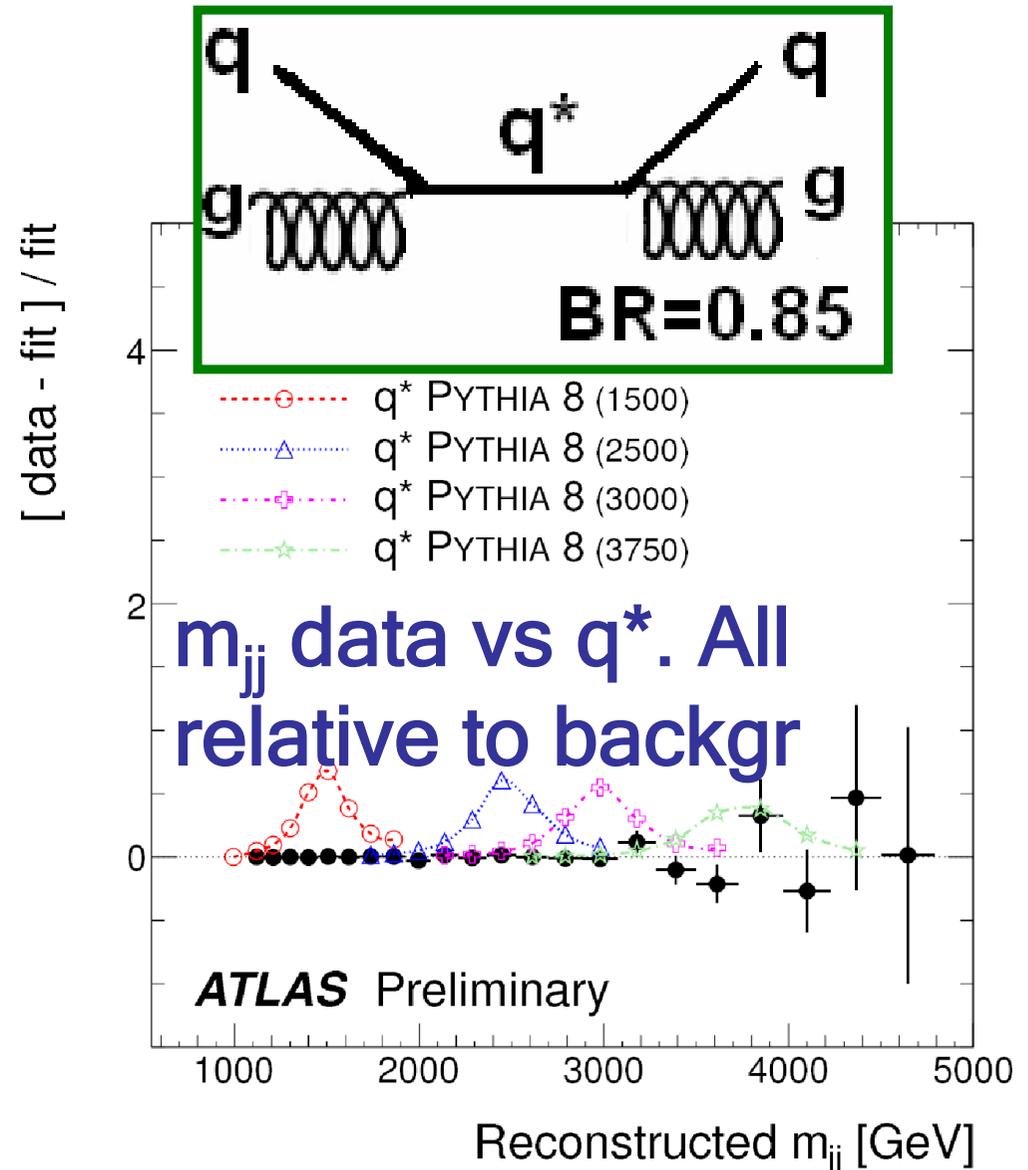
Excited quarks q^* in Dijet channel



Background estimated from data fitted with 4-param

$$f(x) = p_1(1-x)^{p_2} x^{p_3+p_4} \ln x$$

13 fb⁻¹, 8TeV, ATLAS-CONF-2012-148, PRD42,3(1990)



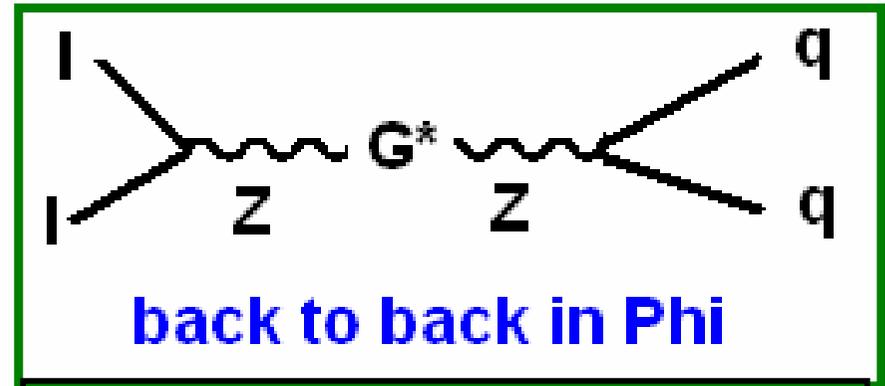
Lower m limit @95% CL
 q^* : 3.84 TeV

ZZ->llqq

- Spin 2 Bulk RS graviton

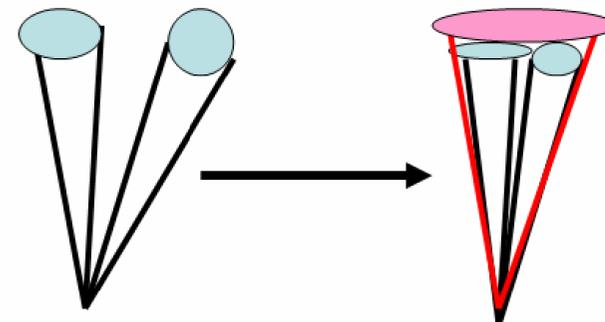
G*->ZZ->llqq

- $m_{G^*}:[300-2000\text{GeV}]$
- $k/m_{\tilde{p}_l}=1$
- Semi-leptonic final states reduces multijet, while preserving the large hadronic BR
- $\Gamma_{G^*}=3-6\% m_{G^*}$



m_{ll} around $m_Z=91\text{GeV}$
 μ : opposite charge
 e : can have charge misID

- | | |
|--|--|
| <ul style="list-style-type: none"> ➤ $p_{T_{ll}} > 50\text{GeV}$ ➤ 2 separated jets ➤ m_{jj} around m_Z ➤ LOW m_{G^*} | <ul style="list-style-type: none"> ➤ $p_{T_{ll}} > 200\text{GeV}$ ➤ 1 merged jet ➤ $p_{T_j} > 200\text{GeV}$ ➤ HIGH m_{G^*} |
|--|--|



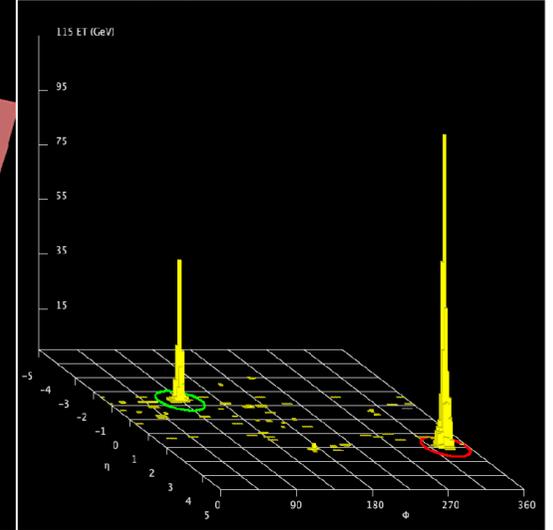
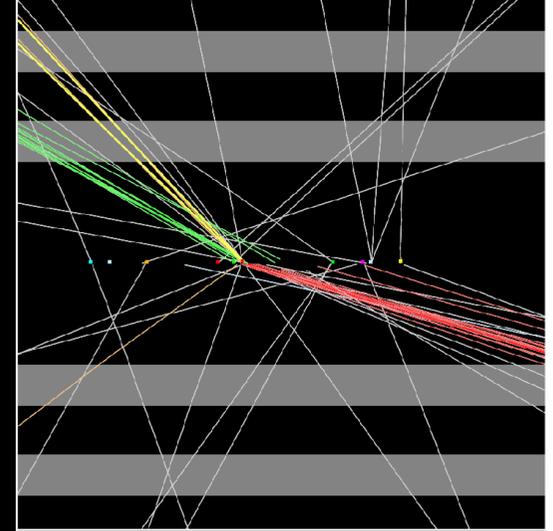
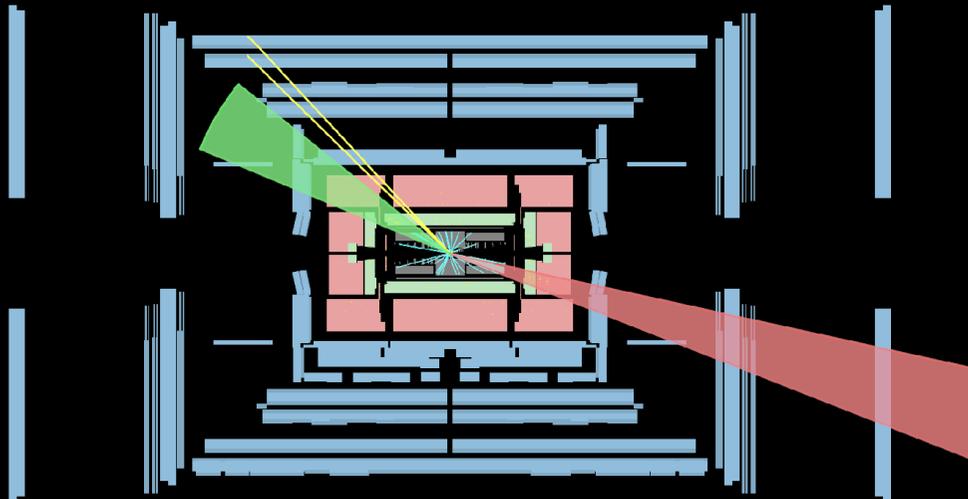
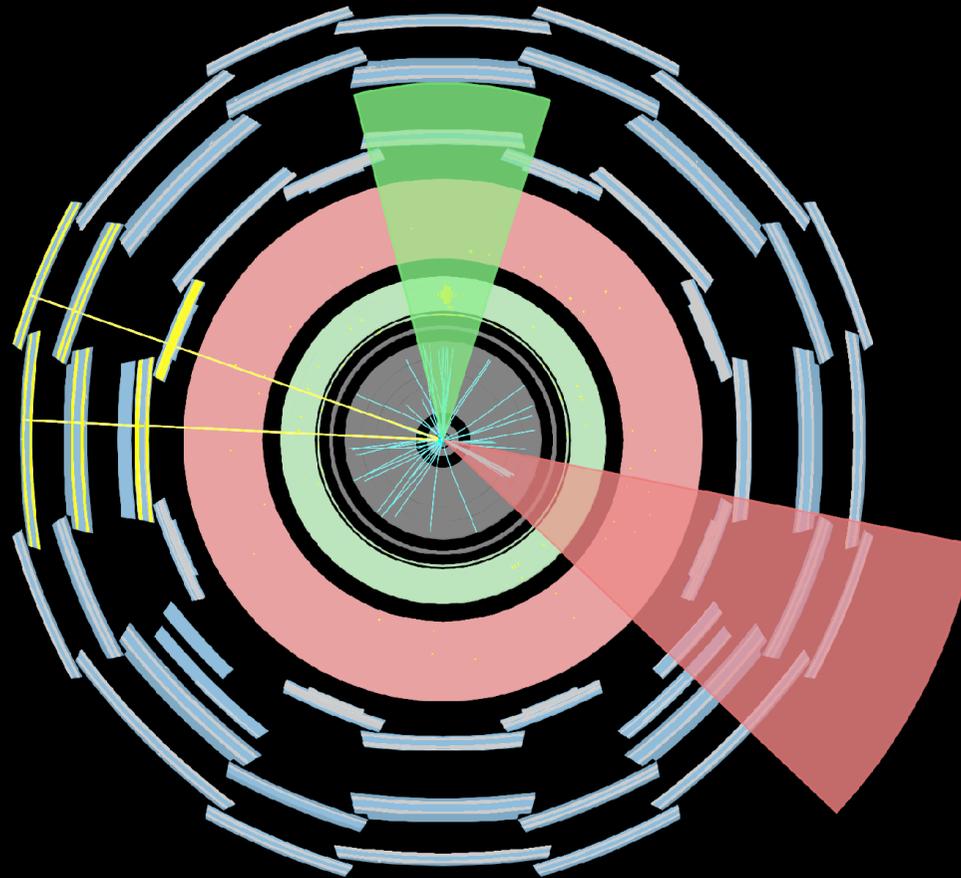
RESOLVED BOOSTED

Boosted
 $m_{ZZ}=2.9\text{TeV}$

Z $\rightarrow\mu\mu$
(2 tracks)

Z $\rightarrow qq$
(1 merged jet)

green jet:
radiation

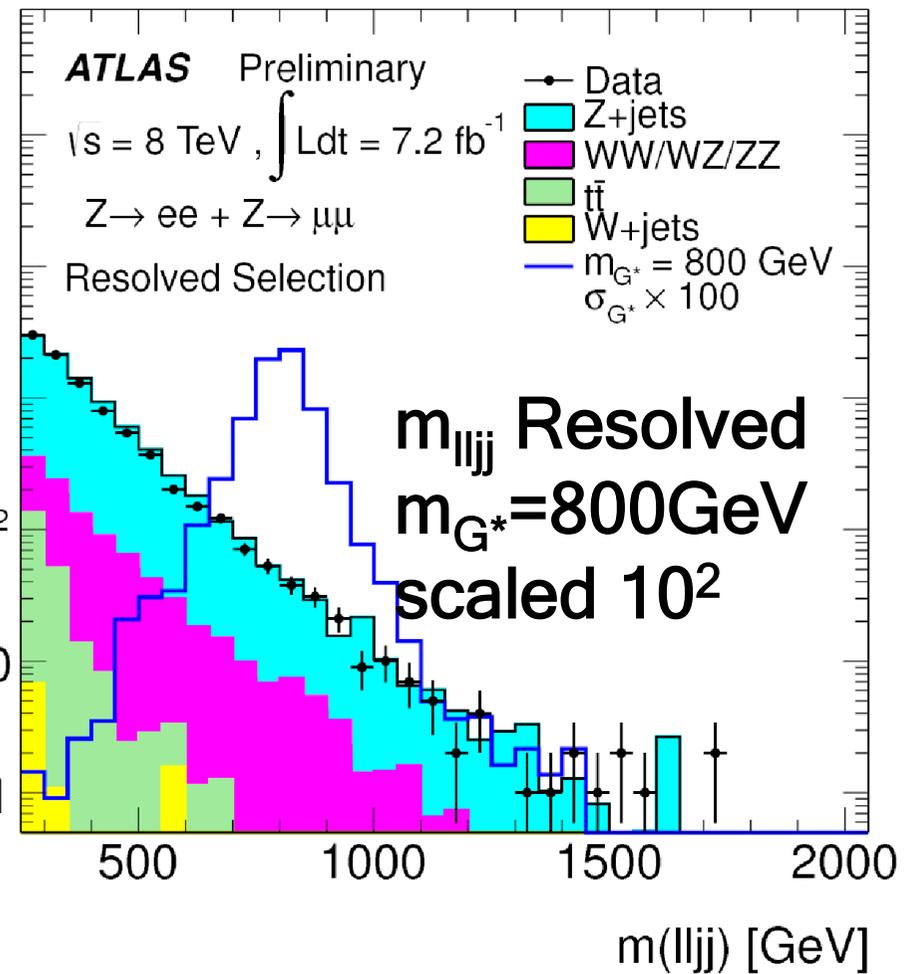
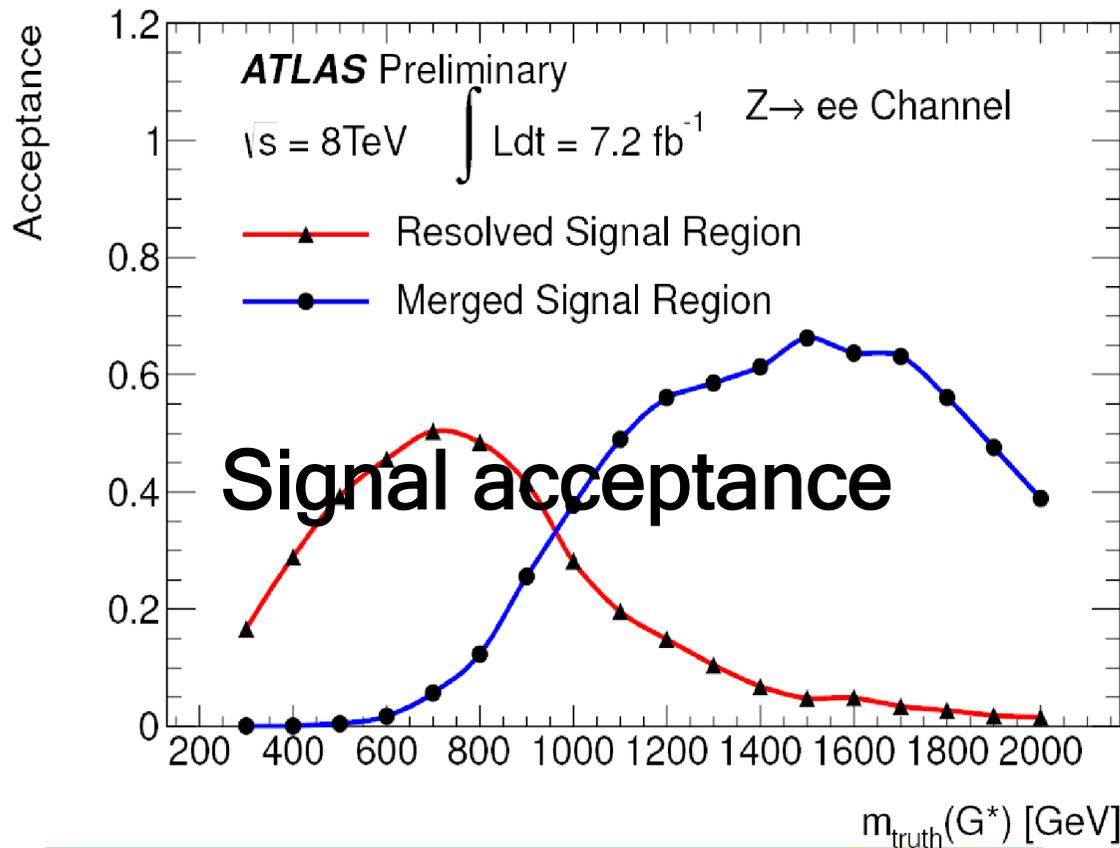


 **ATLAS**
EXPERIMENT

Run Number: 205017, Event Number: 540815

Date: 2012-06-15 07:16:45 UTC

ZZ->llqq



Upper $\sigma B(G^* \rightarrow ZZ \rightarrow llqq)$ limit:
 1.86 pb at 300 GeV
 22 fb at 2000 GeV

No exclusion mass limit, due to incorrect theory σ curve

Dijet+W/Z(->lν/l)

➤ Spin 1 vector $\rho_T^{\pm,0}$, technimeson $\pi_T^{\pm,0}$

➤ $BR(\rho_T \rightarrow \pi_T W/Z) = 100\%$

➤ require W/Z leptonic decay to **suppress multijet**

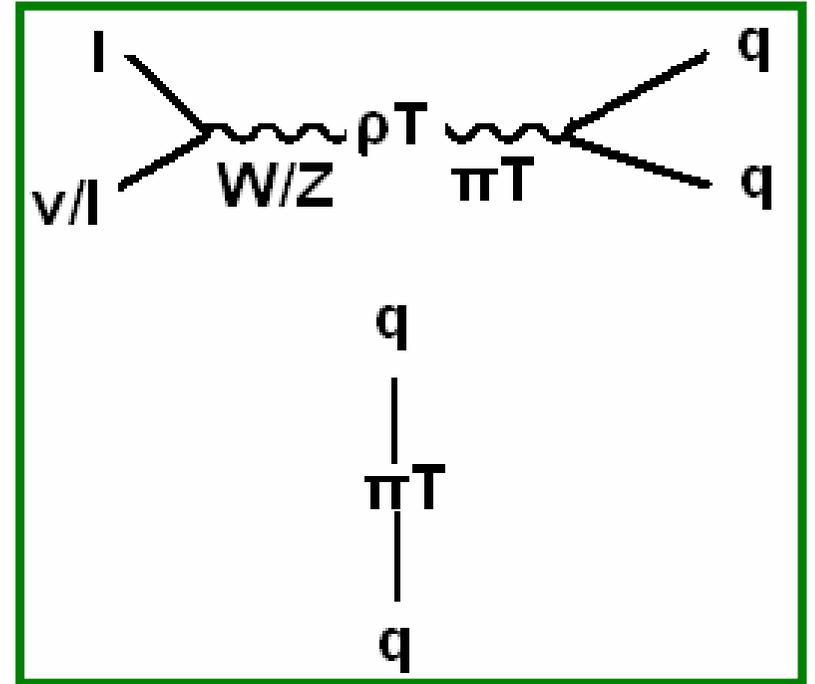
➤ #Technicolours: 4

➤ Made of techniquarks: $Q_U=1, Q_D=0$

➤ $MET > 30 \text{ GeV}$

➤ $m_T^W = \sqrt{2 p_T^l MET (1 - \cos \Delta\Phi(l, MET))} > 40 \text{ GeV}$

➤ Mass conditions (with different benchmarks): $m_{\pi T} + m_{W/Z} < m_{\rho T} < 2 m_{\pi T}$



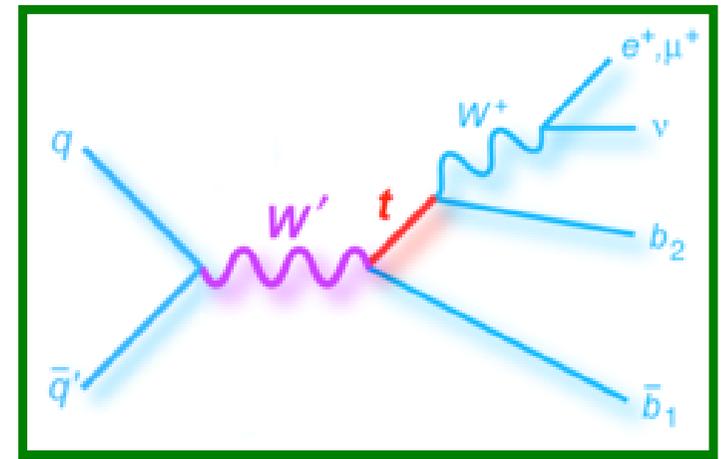
p_T (in ϕ): jets back to back
 p_z (in η) vary due to PDF

Lower $m_{\pi T}$ limit @95% CL
 Zjj channel 170 GeV
 Wjj channel 180 GeV

$t\bar{b}$

$$\begin{aligned}
 W'^+ &\rightarrow t\bar{b} \rightarrow l^+ \nu b\bar{b} \\
 W'^- &\rightarrow \bar{t}b \rightarrow l^- \nu \bar{b}\bar{b}
 \end{aligned}$$

Hadronic decay



W'_R :

➤ HADRONIC decay: YES

➤ LEPTONIC decay: NO

because $m_{\nu_R} > m_{W'}$ ~~$W'_R \rightarrow l \nu_R$~~

W'_L :

➤ both decays

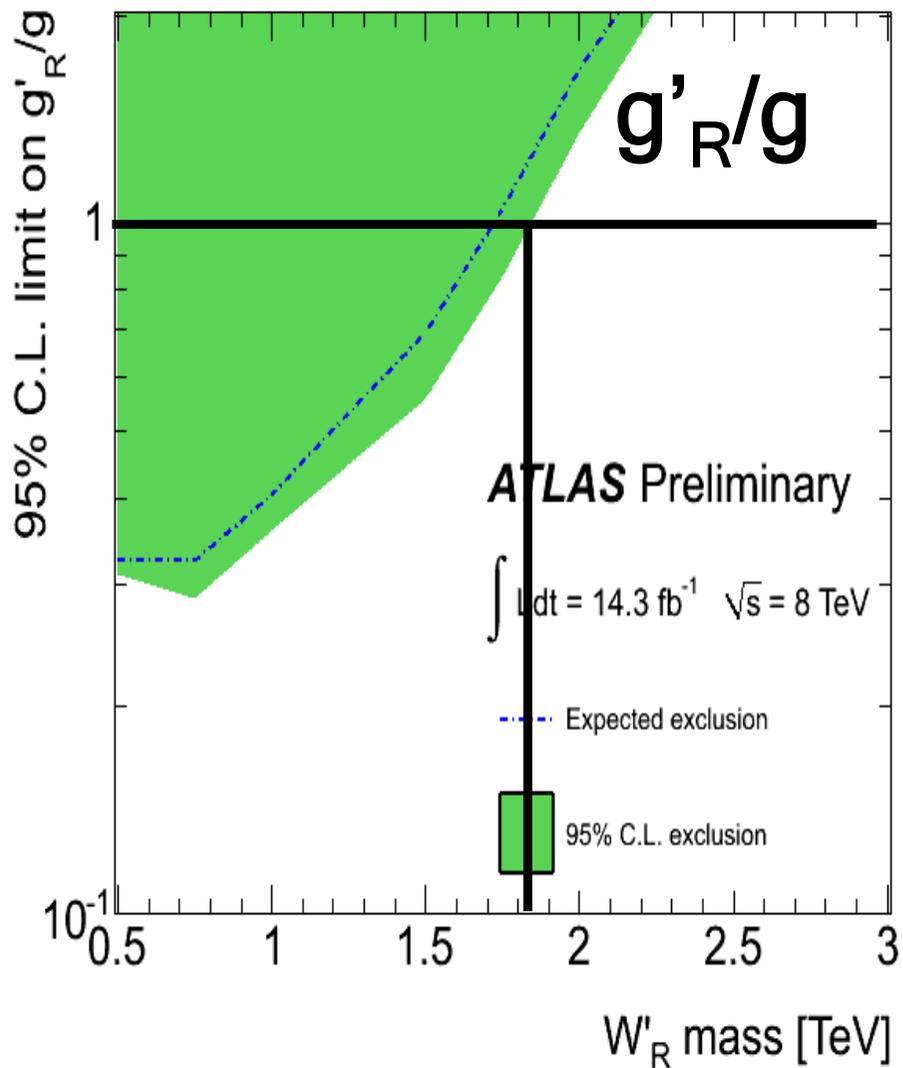
MOTIVATION HADR CHANNEL:

➤ W' couples stronger to 3rd quarks than 1st / 2nd

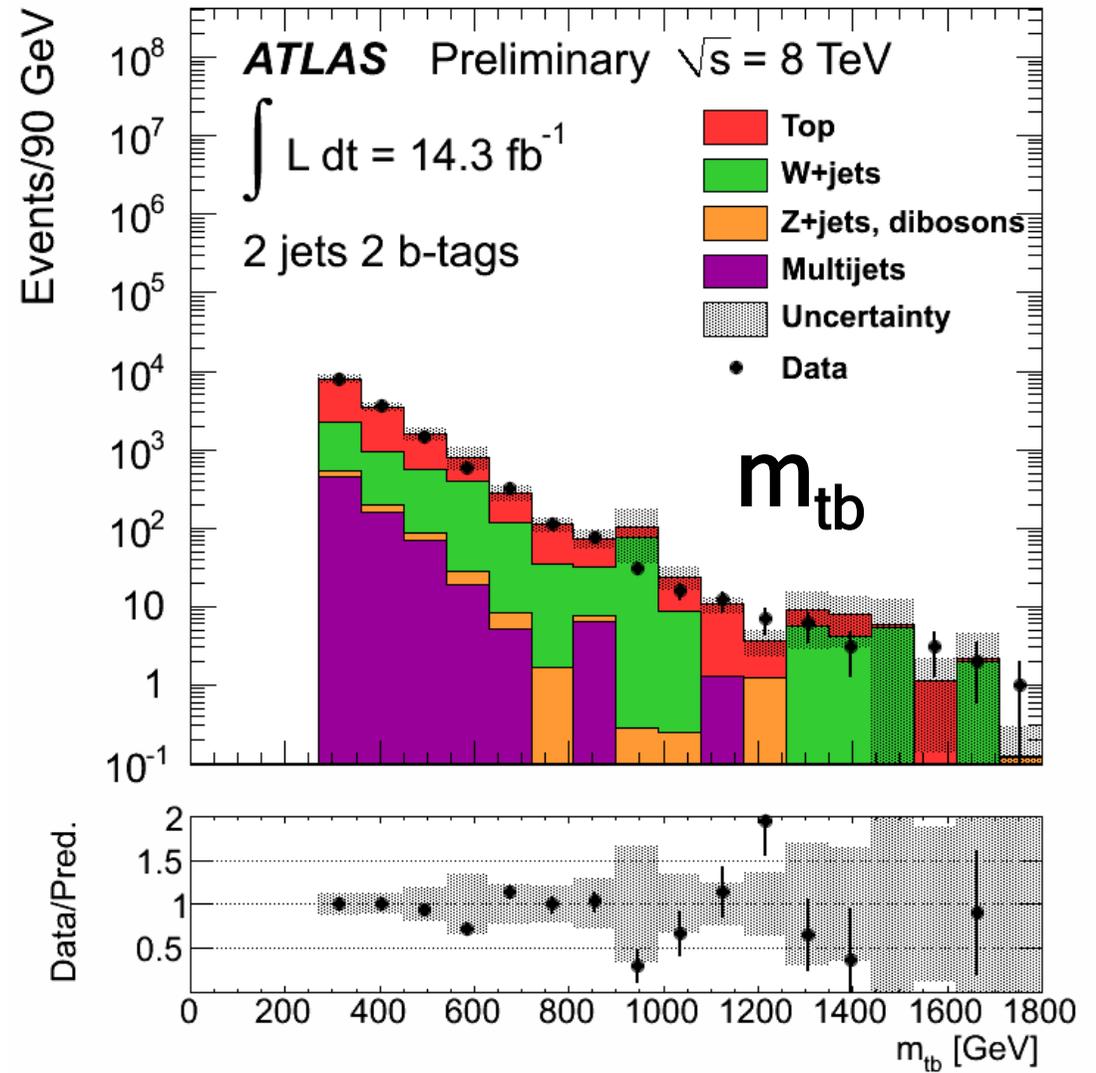
➤ $g'_R = g/0$ and $g'_L = 0/g$

➤ $g = W_{SM}$ quark coupling

➤ t distinct signature



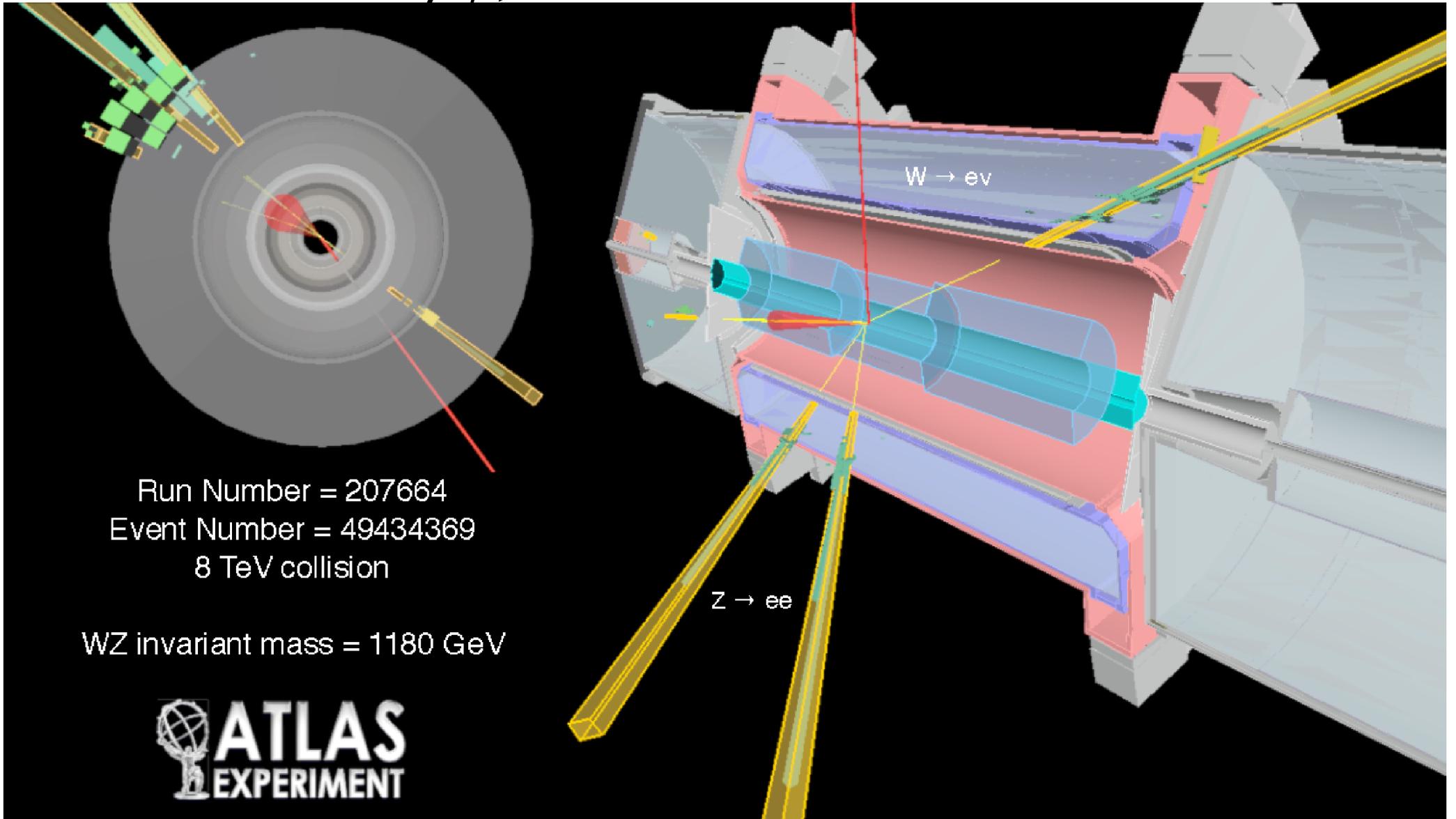
$t\bar{b}$



@95% lower m limit

W'_L : 1.74 TeV W'_R : 1.84 TeV

$$\rho_T, W' \rightarrow WZ \rightarrow l\nu l'l'$$



WZ \rightarrow $e\nu e'e'$

13 fb⁻¹ , 8TeV, ATLAS-CONF-2013-015

@95% lower m limit
W': 1180 GeV
 ρ_T : 920 GeV

Conclusions

- Presented a few exotic searches **8 TeV**
- No new physics discovery, only upper limits on the $\sigma=f(\text{mass})$
- Have covered a small part
- **Runs 13-14 TeV in 2015 will significantly increase search**

THANK YOU !



BACKUP

V' models

General model: Extended Gauge Groups

W' benchmarks:

- **Extended Gauge Model**
 - Same coupling to fermions as W_{SM}
 - $W' \rightarrow WZ \rightarrow \nu \nu'$: $g_{W'WZ} = g_{WWZ} * m_W m_Z / m_{W'}^2$
- **Sequential Standard Model**
 - Same as EGM, but
 - $g_{W'WZ} = 0$, $W' \rightarrow \nu \nu'$
- **With massive W'_R counterpart**

Z' benchmarks:

- **Grand Unification Model:**
 - E6 broken in SU(5) and $2 * U(1)$
 - $Z'(\theta_{E6}) = Z'_\psi \cos(\theta_{E6}) + Z'_\chi \sin(\theta_{E6})$,
where $0 \leq \theta_{E6} < \pi$ is mixing angle
 - $\Gamma = 0.5 - 1.3\% * m_{Z'}$
- **Sequential Standard Model**
 - Same coupling to fermions as Z_{SM}
 - $\Gamma = 3.1\% * m_{Z'}$
- **Leptophobic**
 - Switch off the lepton couplings

Ttbar resonances

➤ **Search in $t\bar{t}$ → lepton+jets :**

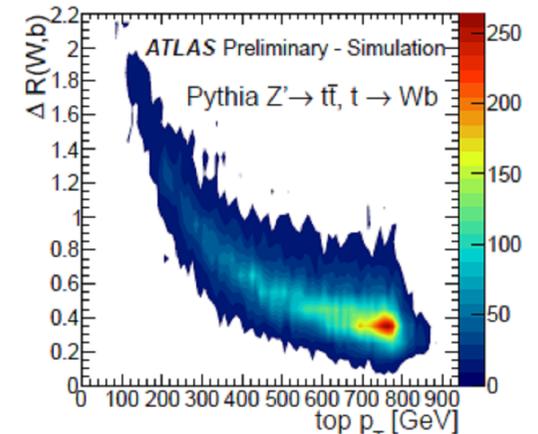
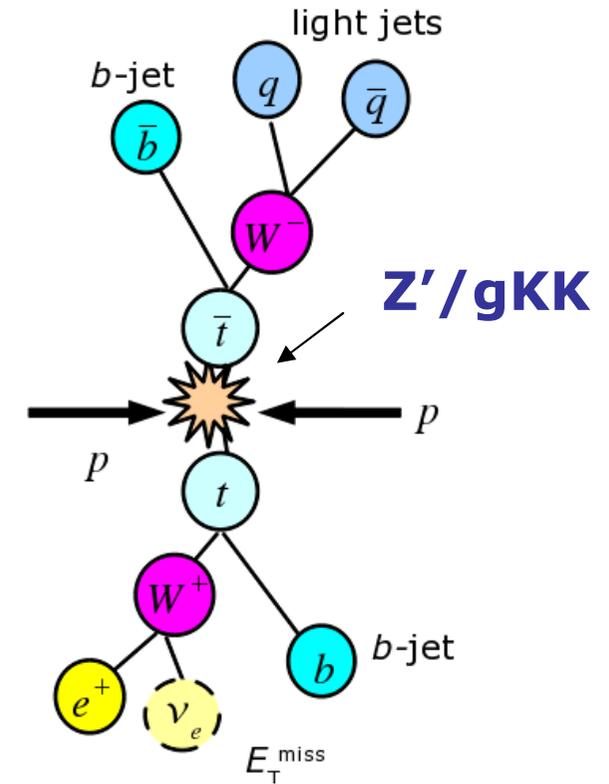
- **All jets :** hard to distinguish from multijets
- **All leptons:** hard to reconstruct 2ν from 1MET

➤ top quark: heaviest known elementary particle:
 $m = 173.5 \text{ GeV}$, 3-pronged top decay products:

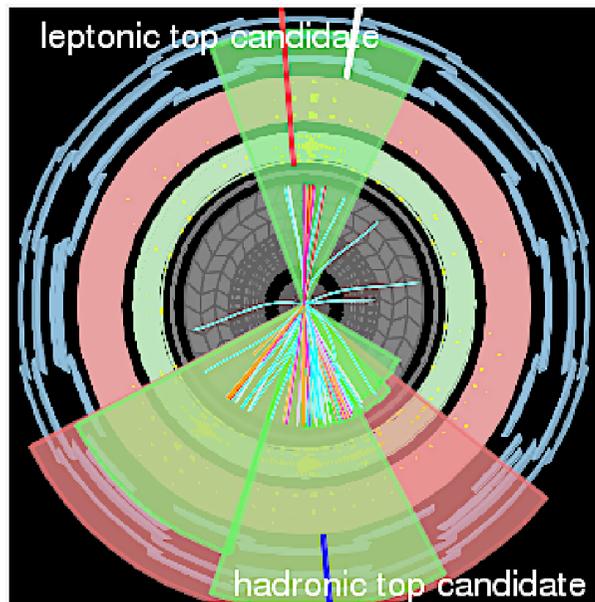
➤ **top at rest (resolved):** 3 reconstructed objects

- **Hadronic Decay:**
 - 1 b -jet + 2 light jets OR
- **Leptonic Decay :**
 - 1 b -jet + 1 charged lepton + MET

➤ **top with high p_T , $m_{t\bar{t}} > 1\text{TeV}$ (boosted):**
 decay products merge $\Delta R(W,b) \sim 2m_t / p_{T_t}$



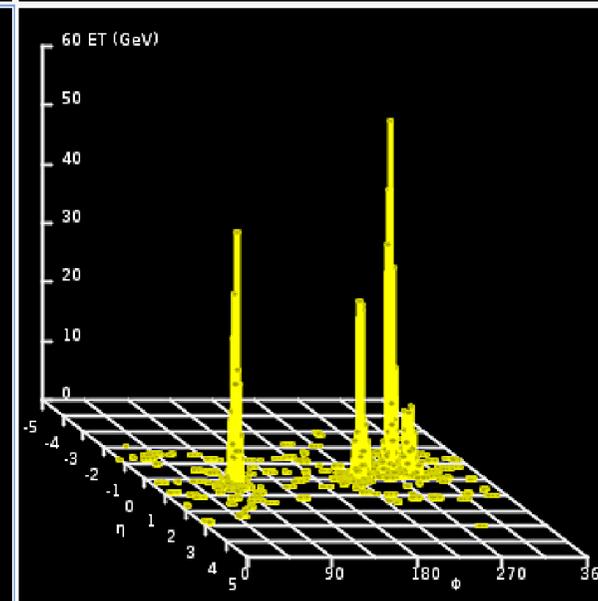
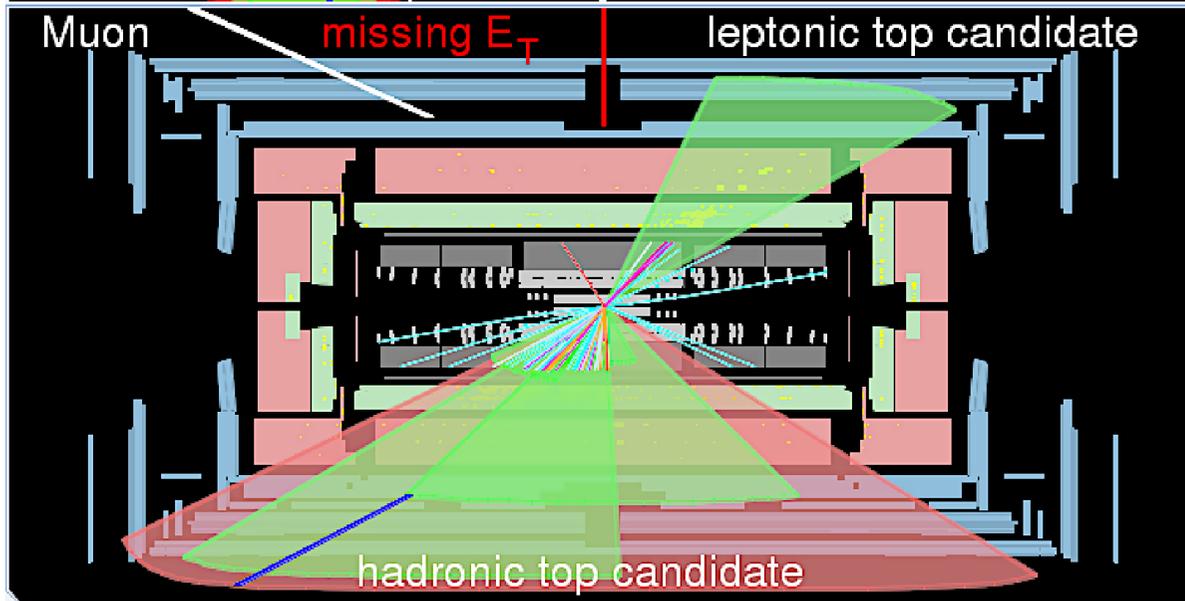
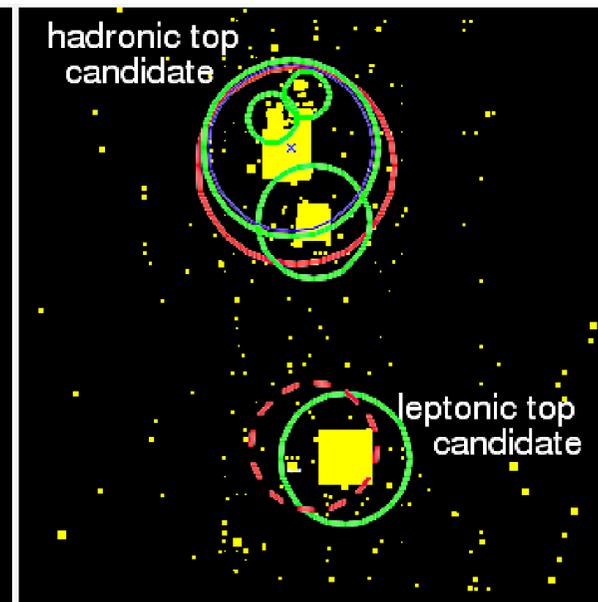
$\Delta R(W,b) m_z = 1.6\text{TeV}$
 ATLAS-CONF-2012-065

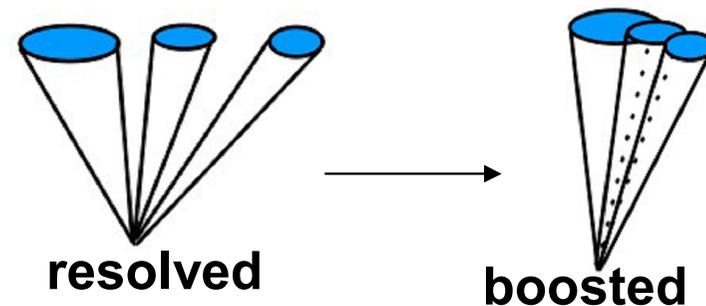


ATLAS EXPERIMENT

Run Number: 208781, Event Number: 34662984

Date: 2012-08-17 20:55:28 CEST



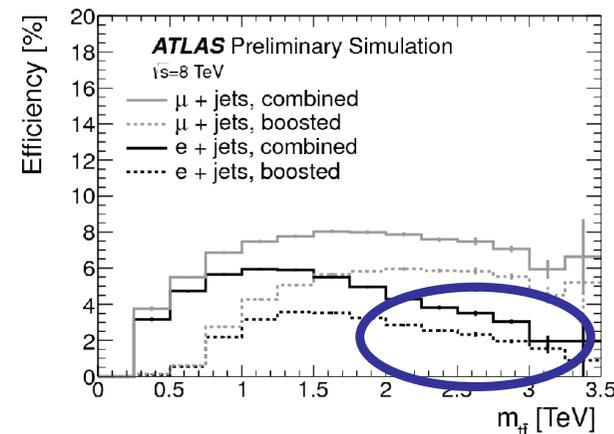
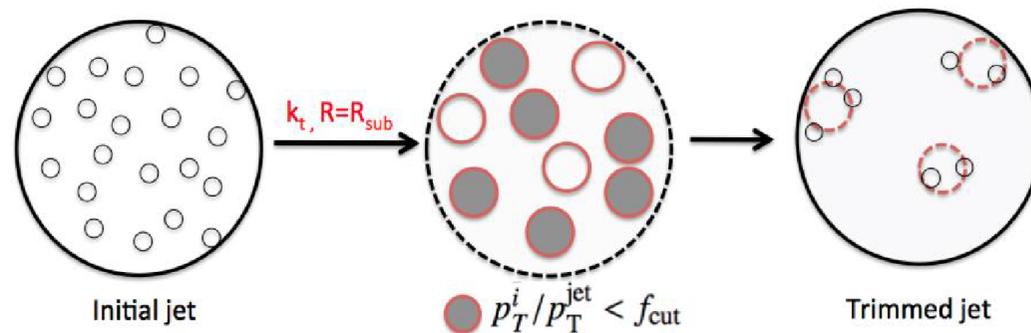


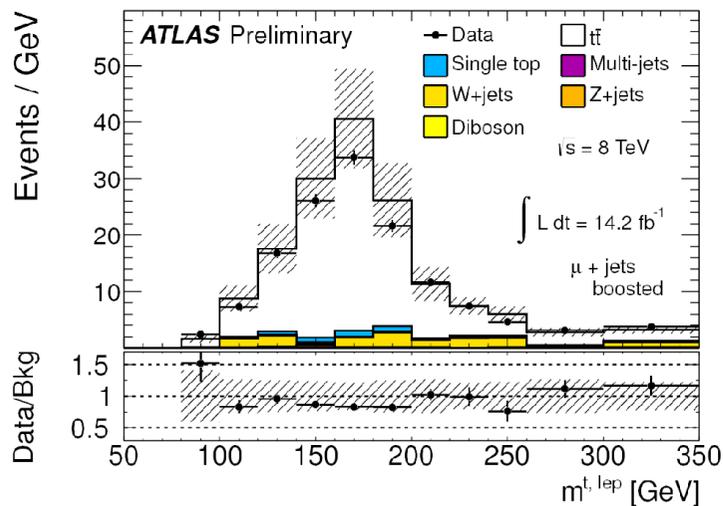
- Leptophobic topcolor Z' : $\Gamma_{Z'} = 1.2\% * m_{Z'}$
- Kaluza-Klein gluon g_{KK} : $\Gamma_{g_{KK}} = 15.3\% * m_{g_{KK}}$

➤ **Large-R Jets:**

- Used in boosted case to include the merged jets
- Good: includes FSR/ISR for $m_{Z'}$ reco
- Bad: noise from pile-up and underlying events

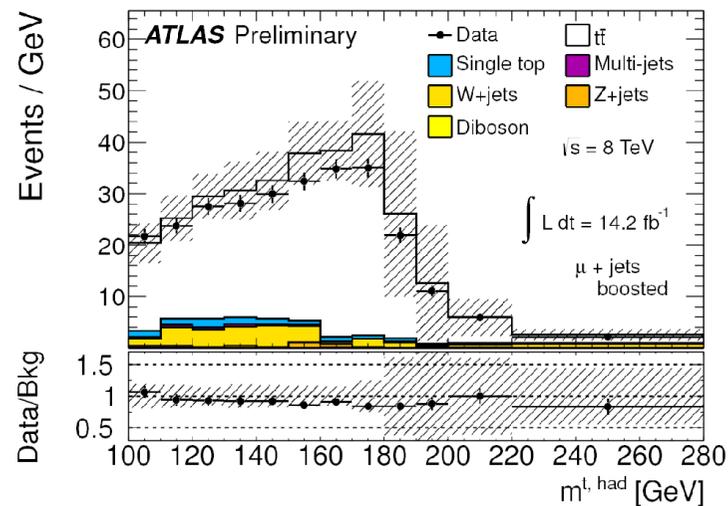
➤ **Trimming: remove soft components (pileup)**





**Slight mismatch
 $m^{t,lep}$ vs $m^{t,had}$**

@95% CL



Z':

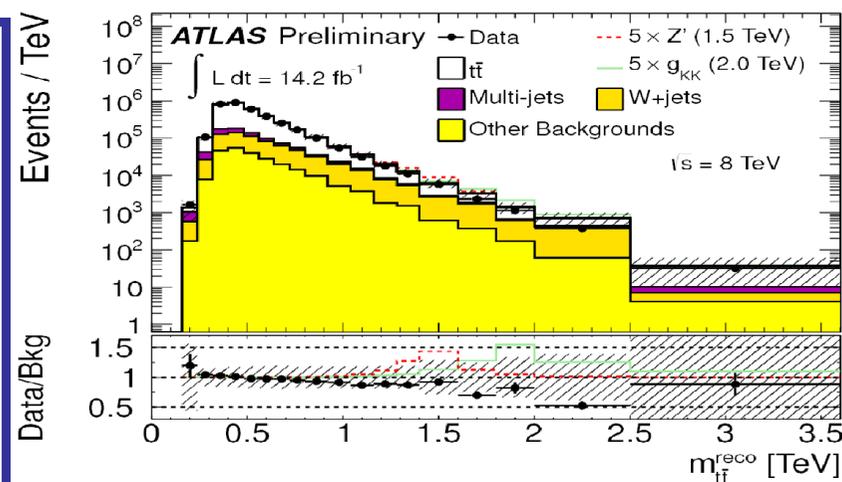
➤ Upper σ_B : **5.3pb** (for 0.5TeV), **0.08pb**(for 3TeV)

➤ Lower m limit: **1,8 TeV**

g_{KK} :

➤ Upper σ_B : **9.6pb** (for 0.5TeV), **0.152pb**(for 3TeV)

➤ Lower m limit: **2 TeV**



High pT electrons

- **Match ID track (take η, φ) with EM calorimeter clusters (take E) - 85% => combined elec $E_T > 25\text{GeV}$**
- Shower shape requirements
- Don't consider barrel-endcap transition

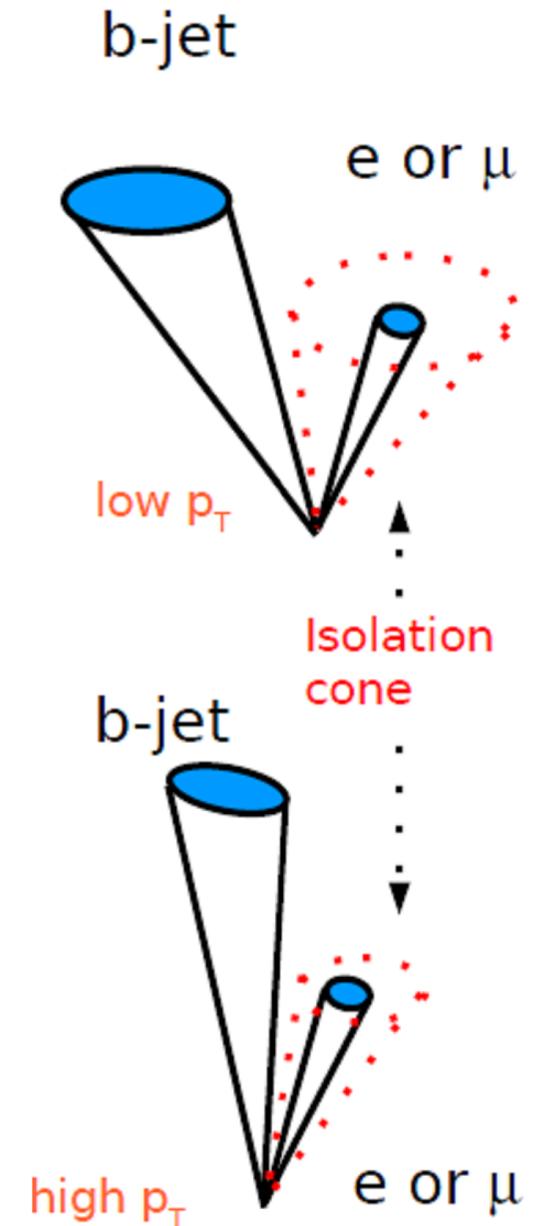
- **Fake rate: jets mis-ID as e, photon conversions, π^0 mis-ID as e**

- **ISOLATION**

$$\frac{\sum pT(\text{tracks-DR-around-lep-excluding-lep})}{pT^{\text{lep}}} < 0.05$$

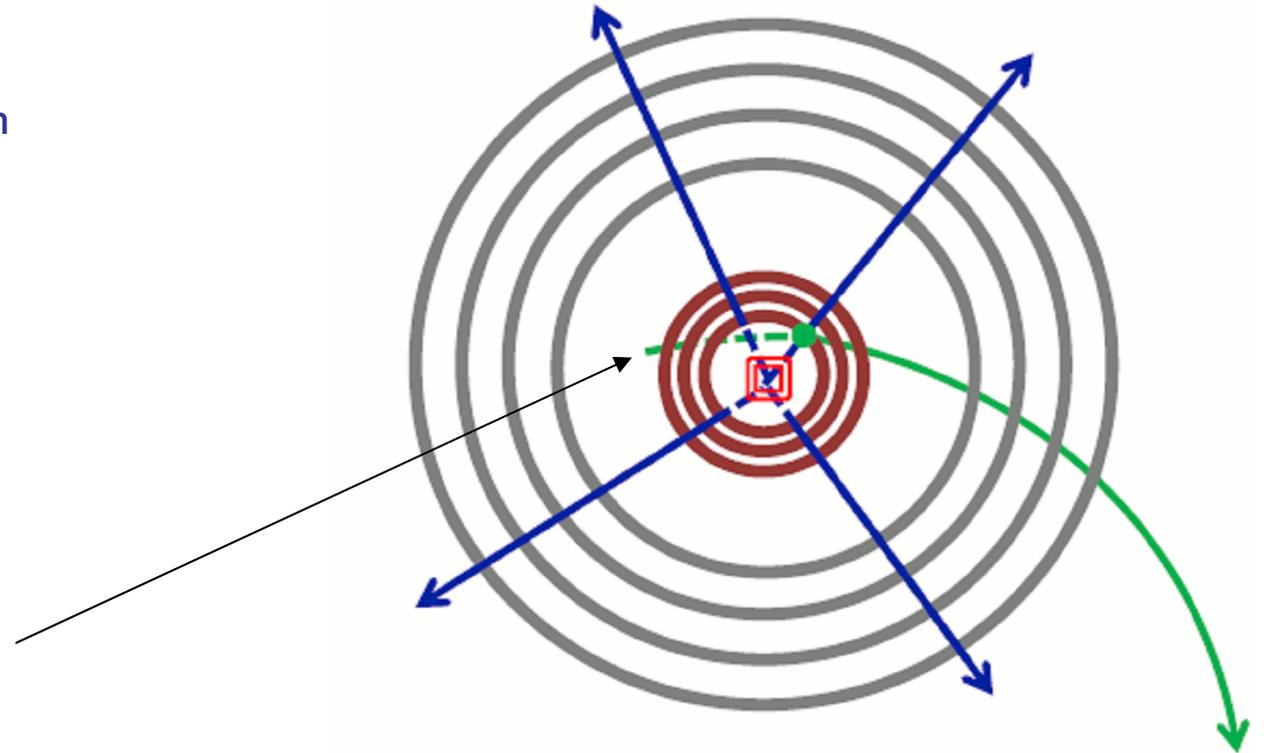
variable DR=10/pT^{lep}

- Elec included in jets calo cells:
 - **Remove if DR(Jet,e)<0.4**



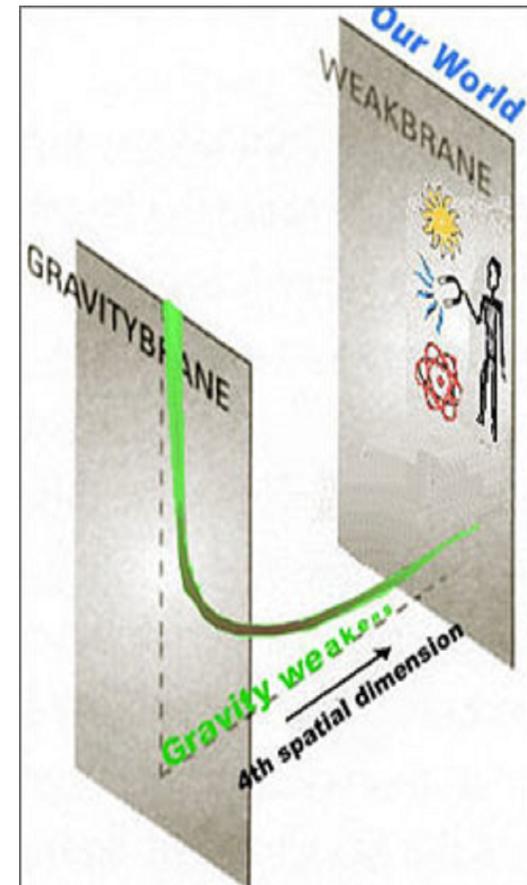
High pT muons

- Match tracks ID with Muon Spectrometer => **combined muon $p_T > 25 \text{ GeV}$**
- **Correct the energy loss through calorimeters**
- Require **3 hits** in muon stations for good measurement
- Fake rates have high d_0 :
 - η from cosmics and Non Collision Background isolation
 - Non-prompt η from B decays
 - ISOLATION



Randall-Sundrum graviton G^* (spin 2)

- 1 highly curved extradimension
- 2 branes: TeV and Planck scale
- Gravitons G propagate everywhere
- SM confined to TeV brane
- RS model: KK tower of TeV massive G^* s:
 - G^* have k/M_{Pl} coupling to SM particles
 - $\Gamma_{G^*} \sim (k/M_{Pl})^2 \Rightarrow$ narrow resonances for $k/M_{Pl} < 0.1$



RS graviton G^*

Technicolor

➤ Model for EW Symmetry breaking:

- Early theories modeled on Quantum Chromodynamics => name "color"
- Alternative to Higgs
- Hides EW symmetry and generates W/Z masses through dynamics of new gauge interactions

