Backgrounds to MultiLeptons at ATLAS

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Multi-leptons WS, Lisbon, March 25, 2010

Outline

- Multi-lepton final states are generally considered low-background / practically background-free.
  - However large x-section × minute detector effects can still bring non-negligible backgrounds.
- What is in this talk?
  - Ways to guess the size of such backgrounds without resorting to detector simulation.
    - Example $L^0L^\pm$ analysis in 3 same-sign (SS) leptons.
  - On behalf of ATLAS Collaboration: Example full-simulation multi-lepton analysis & an introduction to how ATLAS plans to extract background estimates from actual data.
- Everything is @ 14TeV…

Disclaimer: Not an official ATLAS talk…

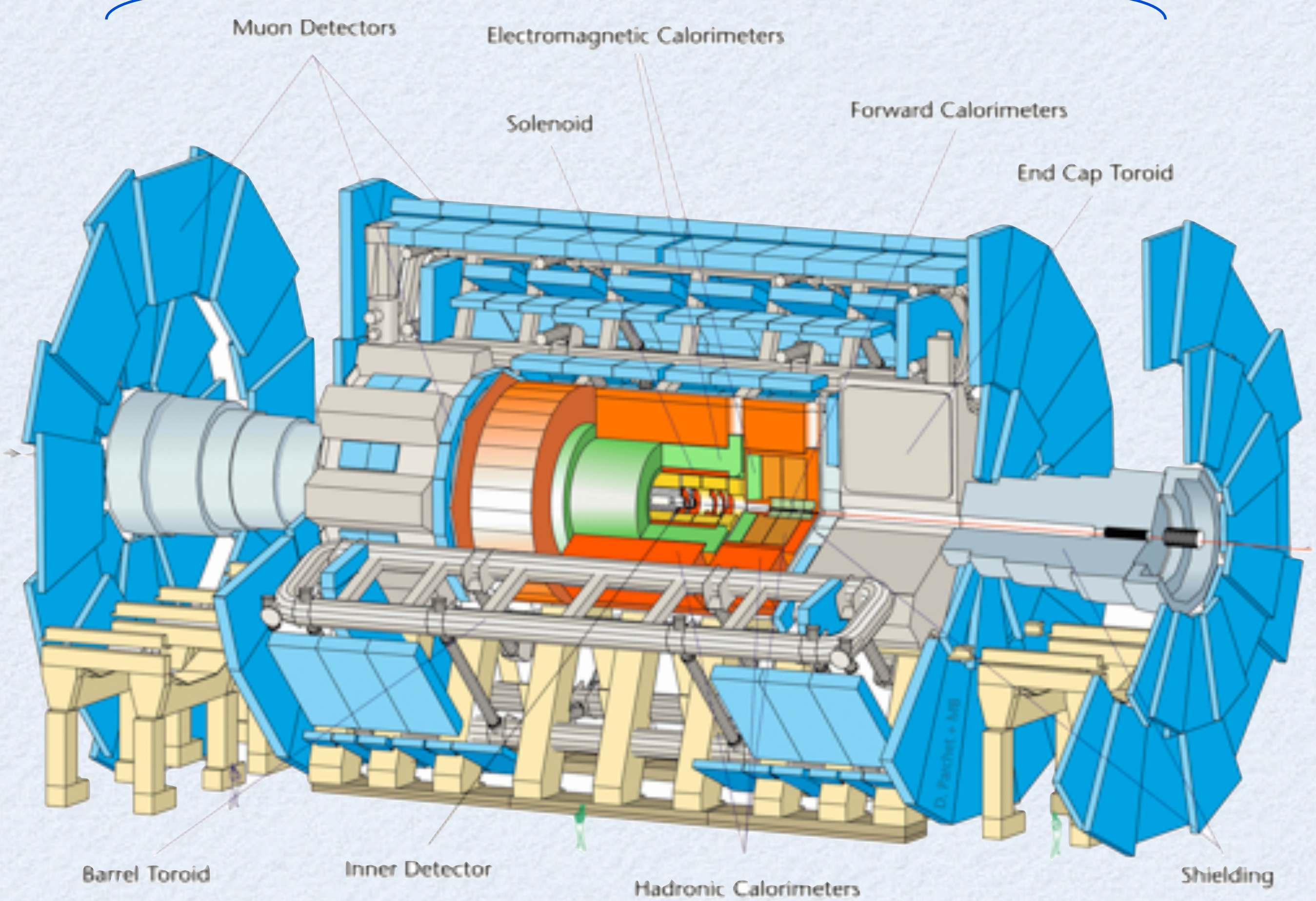
Sources

- Details on various aspects of what is in this presentation can be obtained from:
  - V. E. Özcan, S. Sultansoy, G. Ünel, A Possible Discovery Channel for New Charged Leptons at the LHC, J. Phys. G 36 (2009) 095002.
  - ATLAS Collaboration, Expected Performance of the ATLAS Experiment Detector, Trigger, Physics, CERN-OPEN-2008-020 [arXiv:0901.0512].
  - ATLAS Collaboration, The ATLAS Experiment at the CERN Large Hadron Collider, J. Instrum. 3 (2008) S08003.

ATLAS Detector

45 m

24 m



7000 tones

- Tracking and muon coverage: $|\eta|<2.5$
- Calorimeters with presamplers: $|\eta|<1.8$
- Forward calorimeters : $3.2<|\eta|<5.9$

- e/γ energy resolution

  $\sigma/E \approx 10\text{–}15\%/\sqrt{E} \oplus \sim 1\%$

- Central jet energy resolution

  $\sigma/E \approx 60\%/\sqrt{E} \oplus 3\%$

- Missing $E_{x,y}$ resolution

  $\sigma \approx 0.55\text{GeV} \times \sqrt{(\Sigma E_T)}$

- Track inverse-P_T resolution

  $\sigma_{\{1/PT\}} \approx 35\text{TeV}^{-1} \times (1 \oplus 50/P_T)$

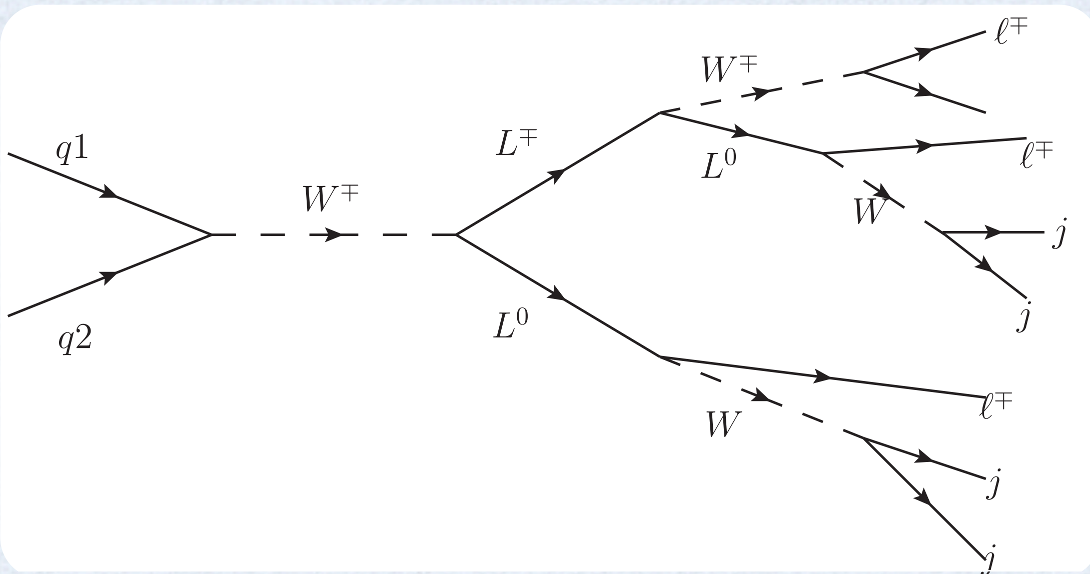
- Muon system standalone momentum resolution (with no inner detector)

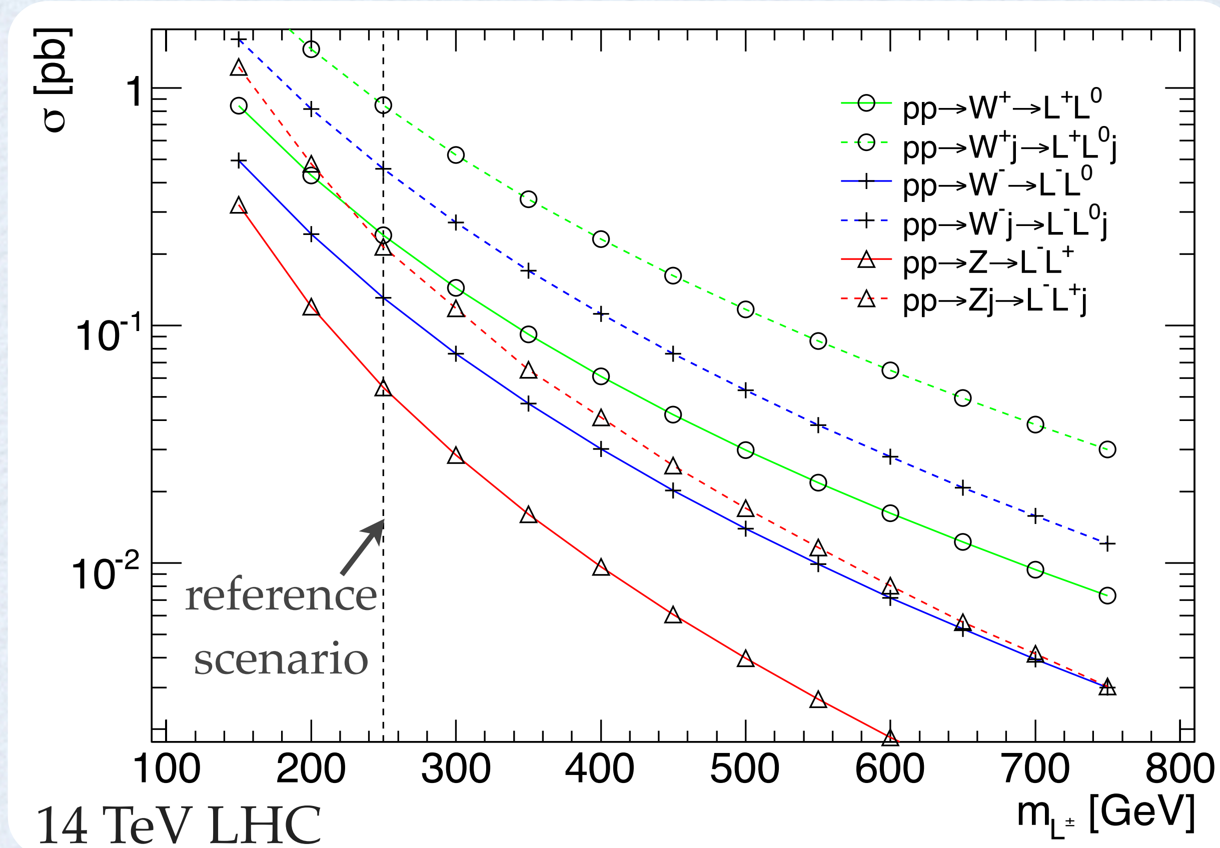
  $\sigma/P_T < 4\text{–}10\%$ up to 1 TeV

Backup slides: η dependence

Charged Leptons @ LHC

- Search for charged heavy leptons & Majorana neutrinos in final state with 3 SS leptons.





$pp \rightarrow L^{\pm}L^{0} \rightarrow WL^{0}L^{0} \rightarrow W_{l\nu}W_{jj}\mu W_{jj}\mu$

Reference scenario :

$m_{L}^{\pm}$=250 GeV , m_{L}^{0}=100 GeV

BR($L^{\pm} \rightarrow L^{0}$W)~100%

BR($L^{0} \rightarrow \mu$W)=68%

18 events/fb^{-1} with 3 SS leptons (2μ+μ/e) & 2 hadronic Ws for the reference scenario.

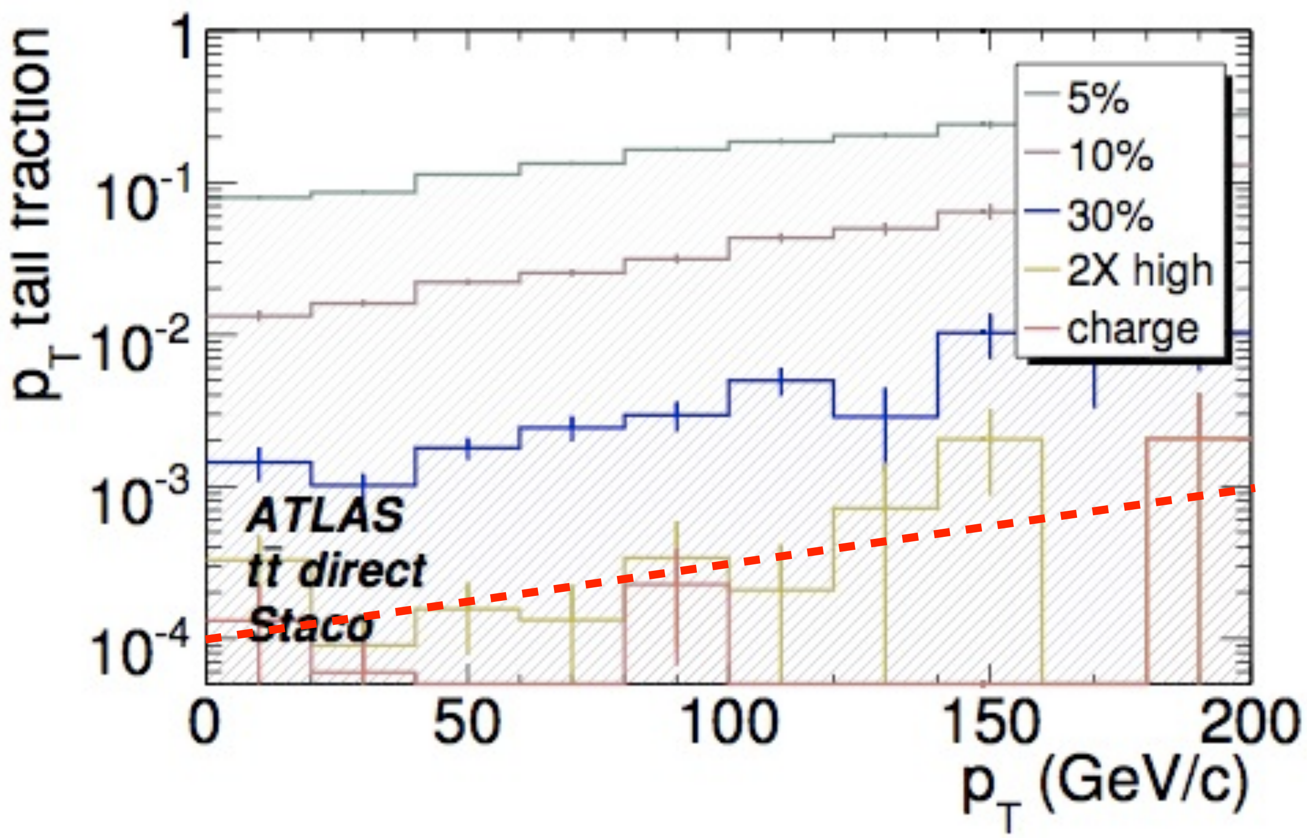
- Acceptance: $P_T^{e/\mu}$>10 GeV $|\eta^{e/\mu}|$<2.5
- For trigger: One lepton with $P_T^{e/\mu}$>20 GeV

=> 9 "backgroundless" events/fb^{-1}.

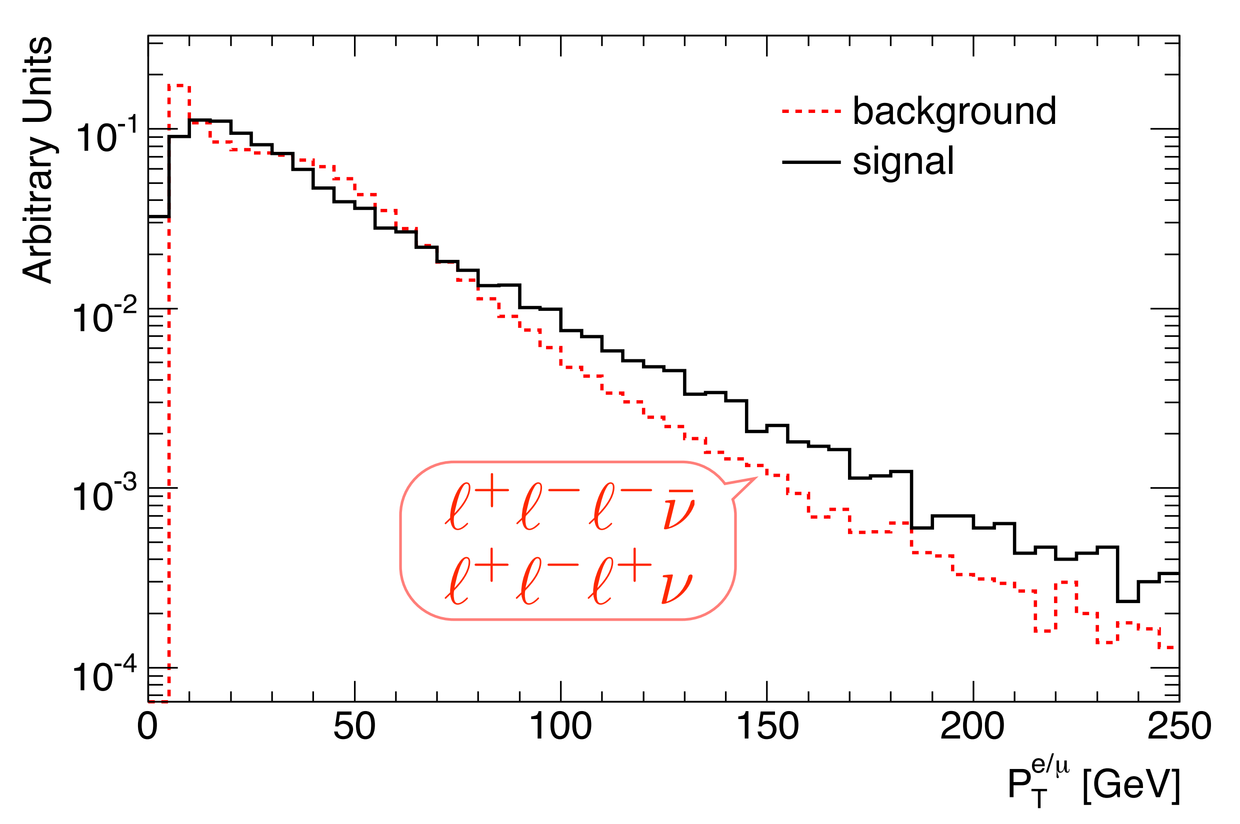
Backgroundless???

- Diboson production can provide 3 leptons, one of which is measured with the wrong charge.
- Can get jets misidentified as leptons.
  - Difficult to get all 3 jets as such, but what if you have at least one isolated true lepton? (ex. W+jets)
- tt production has a huge x-section (≈830pb^{-1} NLO).
  - Provides jets, leptons, b-jets... At moderately high momenta!
    - tt should be considered a potential background for almost all LHC analyses.
  - How to get 3 SS leptons from tt?
    - Leptonically decaying Ws + for lowish-PT leptons, b-jets are an abundant source.
- How to assess all these without going thru detector simulation?
  - Use expected performance of ATLAS from CERN-OPEN-2008-020.

3 Leptons in SM



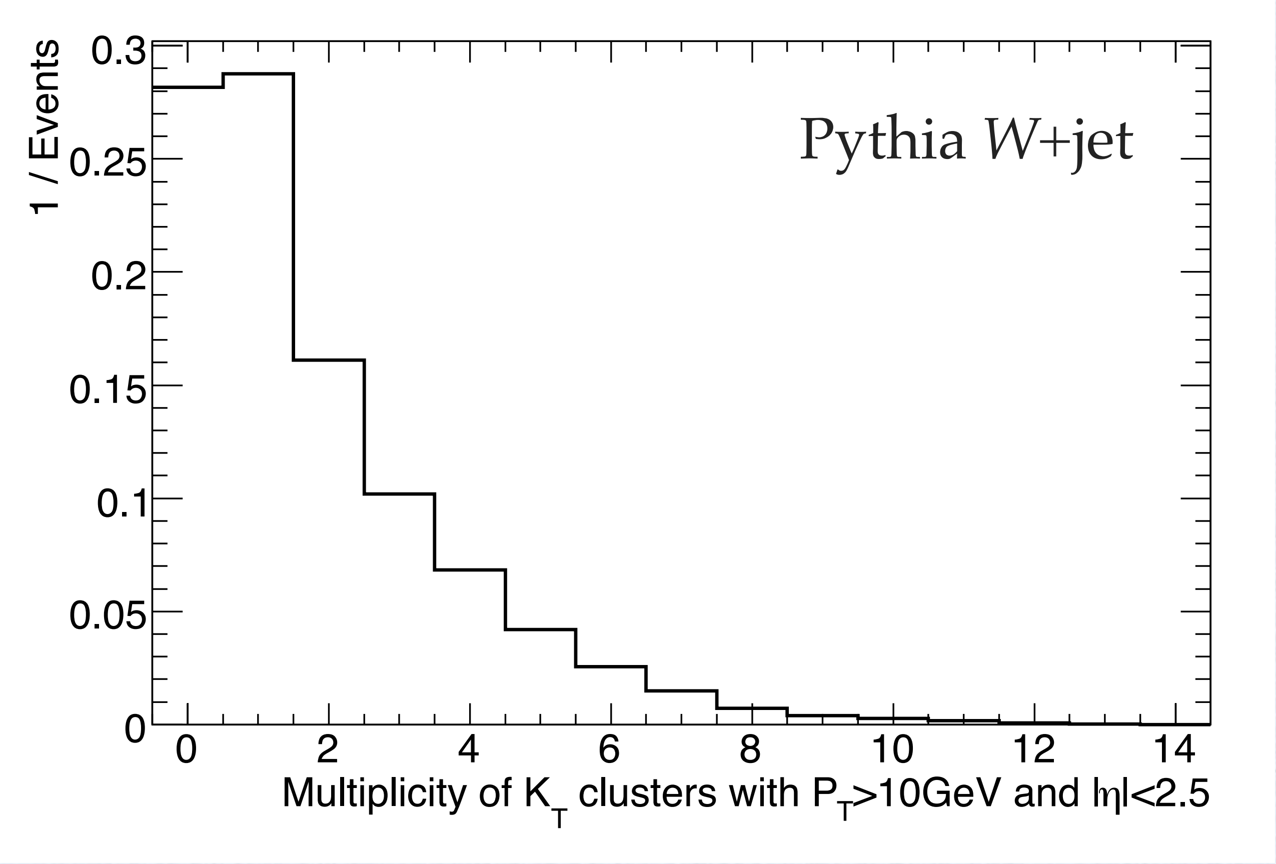
Fraction of reconstructed muons with magnitude of $\Delta P_T/P_T$ outside indicated ranges from **CERN-OPEN-2008-020**, for the combined muon algorithm with worse performance. The last tail curve ("charge"), shows charge mis-measurement fraction. In red dashed line, our parameterization.



- charge mis-measurement conservatively parameterized: $\varepsilon_{mischarge} = 10^{-4+PT/200GeV}$

- Generate 75k 3l+ν events w/MGME.
  - SM 3-lepton x-sec: 195.7±0.6 fb
  - Applying the mischarge parameterization, we get eff. background x-sec = 0.04 fb

W+Jets

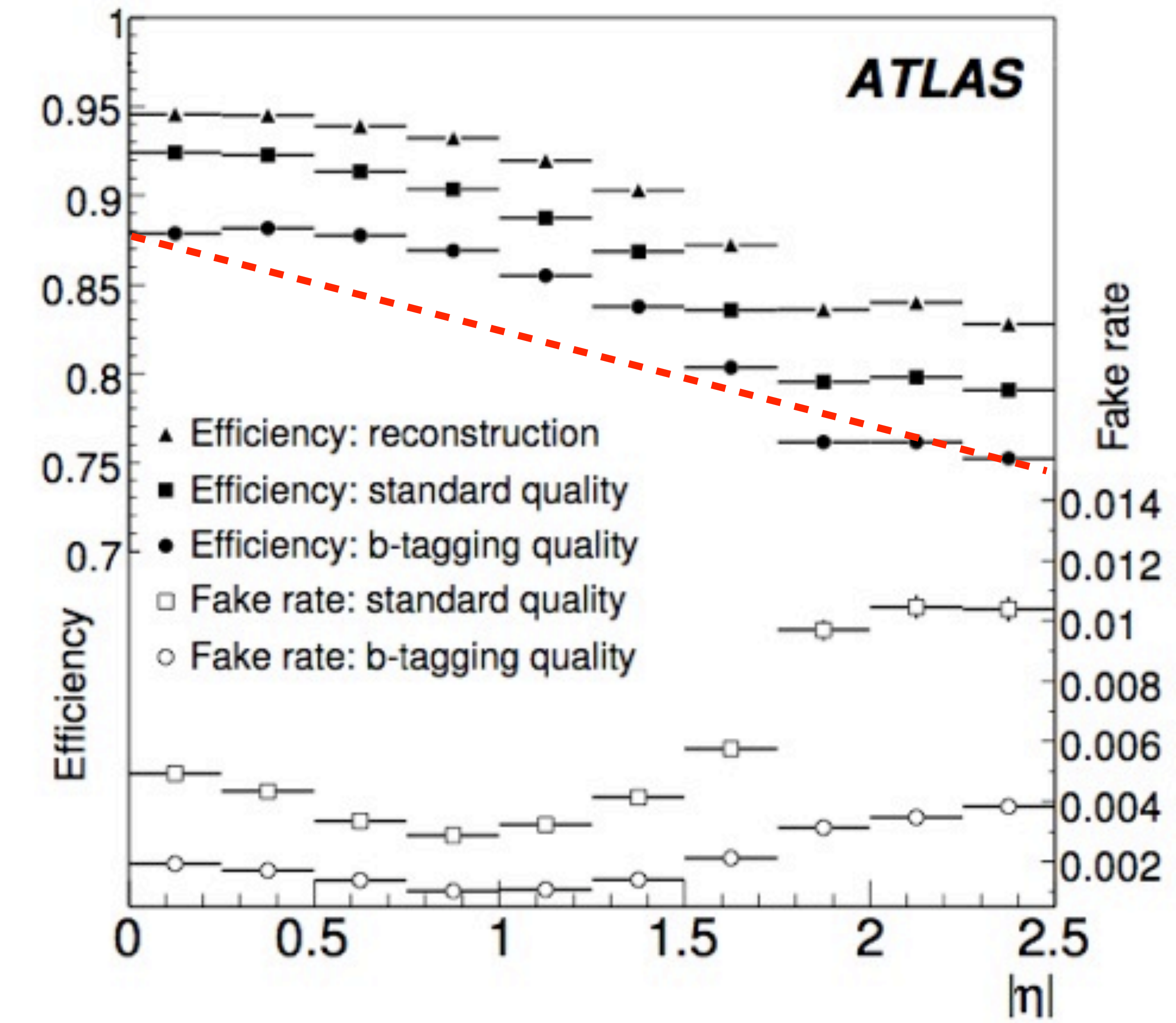


- Having all 3 leptons from fakes highly unlikely.
  - Why? Comparing W+jet vs. jet-jet backgrounds in the dilepton (Z′) analysis in CERN-OPEN-2008-020.

- A true e/μ from a W & two fakes from jets.
- Electrons more prone to jet fakes than μs.
  - CERN-OPEN-2008-020, max-likelihood based electron ID: For 77% electron ID efficiency, jet rejection factor = 3.77×10^4.
- Generate 10k $W_{e/\mu\nu}$+jets with Pythia, with e/μ satisfying acceptance.
  - x-sec = 19.9±0.2 nb
- Run k_T jet algo & extract multiplicity of clusters within acceptance.
  - Compute expected effective background x-sect = 0.01 fb.

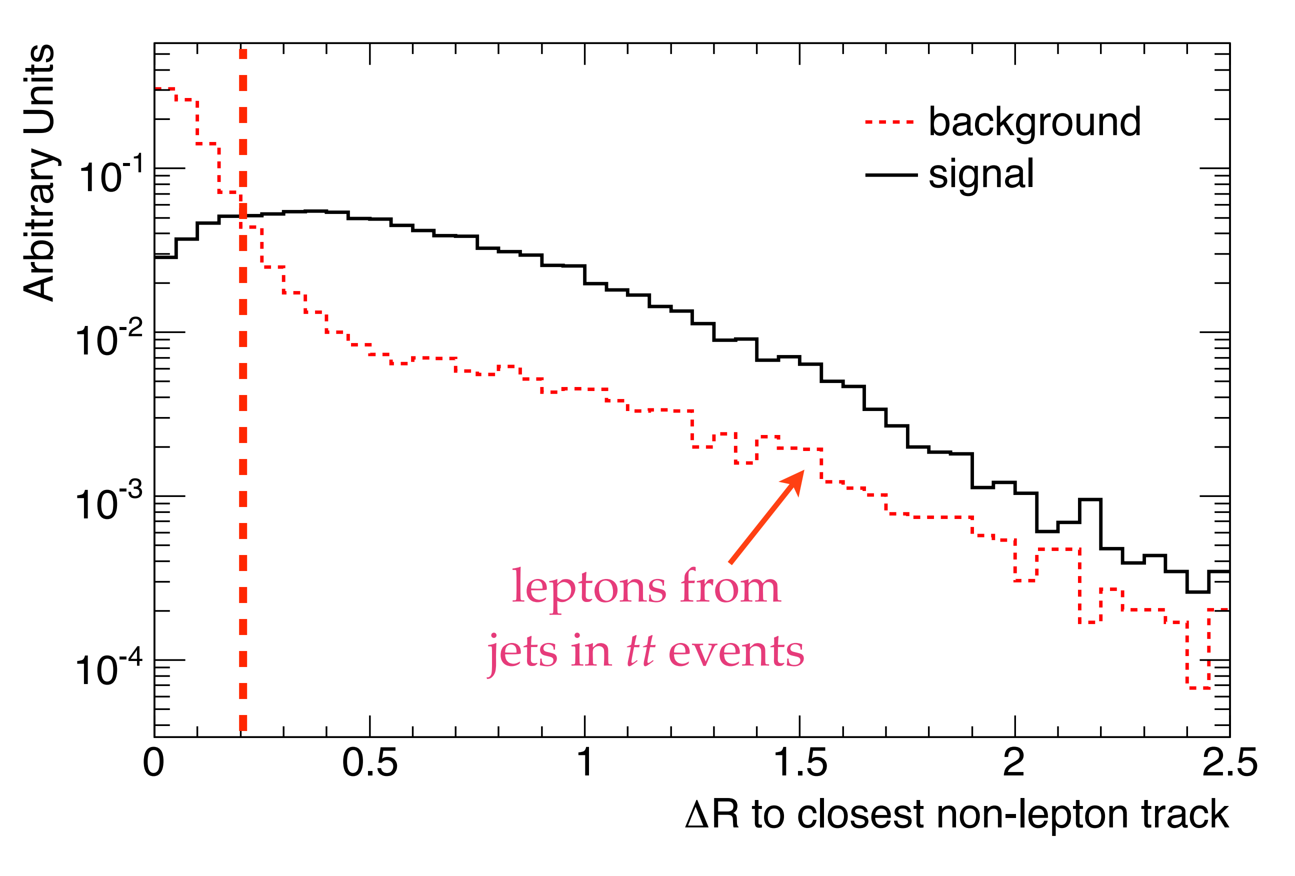
$t\bar{t}$ Background

- To get 3 relatively-low PT SS leptons from tt background:
  - 1 lepton from a W and 2 from b-jets.
  - Rejection by lepton isolation.
    - Calo-based isolation difficult to do at generator level.
    - Track based isolation => Need to parameterize tracking inefficiency.
    - CERN-OPEN-2008-020 has tracking eff. for pions in jets in tt events!



Track reconstruction efficiency and fake rates for charged pions in jets in tt events as a function of |η|, from **CERN-OPEN-2008-020**. In red, our conservative parameterization.

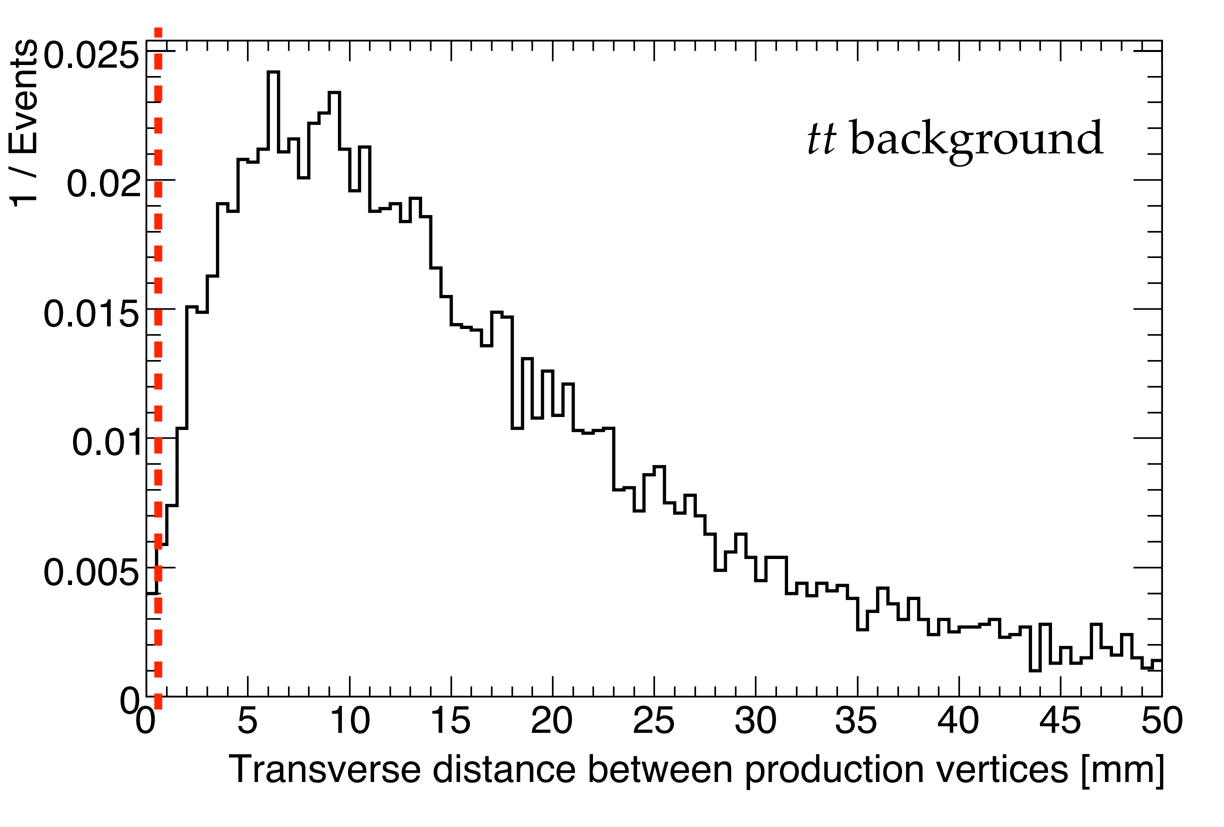
$t\bar{t}$ Background - Lepton Isolation



$\Delta R_{iso} \equiv$ minimum ΔR between lepton and any non-lepton track of P_T>1GeV, taking into account expected efficiency of tracking for pions in b-jets parameterized as $\varepsilon_{trk}=(88-13\cdot|\eta^{track}|/2.5)\%$.

- Require:
  - all 3 leptons: $\Delta R_{iso}>0.05$
  - $\Delta R_{iso}>0.2$ for 2 out of 3 leptons
- Why?
  - Applying the tighter cut on signal events has low eff., due to jets from 2 hadronic Ws falling close to leptons.
  - Getting 2 well-isolated leptons in tt is much more difficult.

$t\bar{t}$ Background



MTD ≡ maximum transverse distance between the production vertices of any of pair of leptons in the event

- Leptons from b-jets produced away from each other. Require 3 leptons consistent with one vertex.
  - Cannot do vertexing without full simulation & reco.
  - Instead, reject if MTD>400μm. (The secondary vertex radial position resolution in ATLAS is below 170μm for J/ψ→μμ.)

- After these requirements & taking into account also the jet fakes and charge mis-id discussed earlier: 1 event out of 5M Pythia events.
  - Effective tt background x-section = 0.17 fb.

See backup slides for vtx. pos. resolution

Signal Significance

- After the cuts, for 1 fb^{-1} of data at 14 TeV:
  - 7 signal events
  - Rudimentary background estimate = 0.22 events
  - Some other potential backgrounds, not considered:
    - Zb, with charge mis-id: Without charge mis-id, shown to be a source of multileptons comparable to tt in SUSY OSSF studies in CERN-OPEN-2008-020. If found to be large, can be suppressed with an m_{ll} veto or a loose E_T^{miss} cut.
    - ZZ, where one lepton is lost & another's charge mis-id'ed. Cannot be more than 3l+ν.
    - ...
  - Even if background larger by ×10, significance over 3.5σ

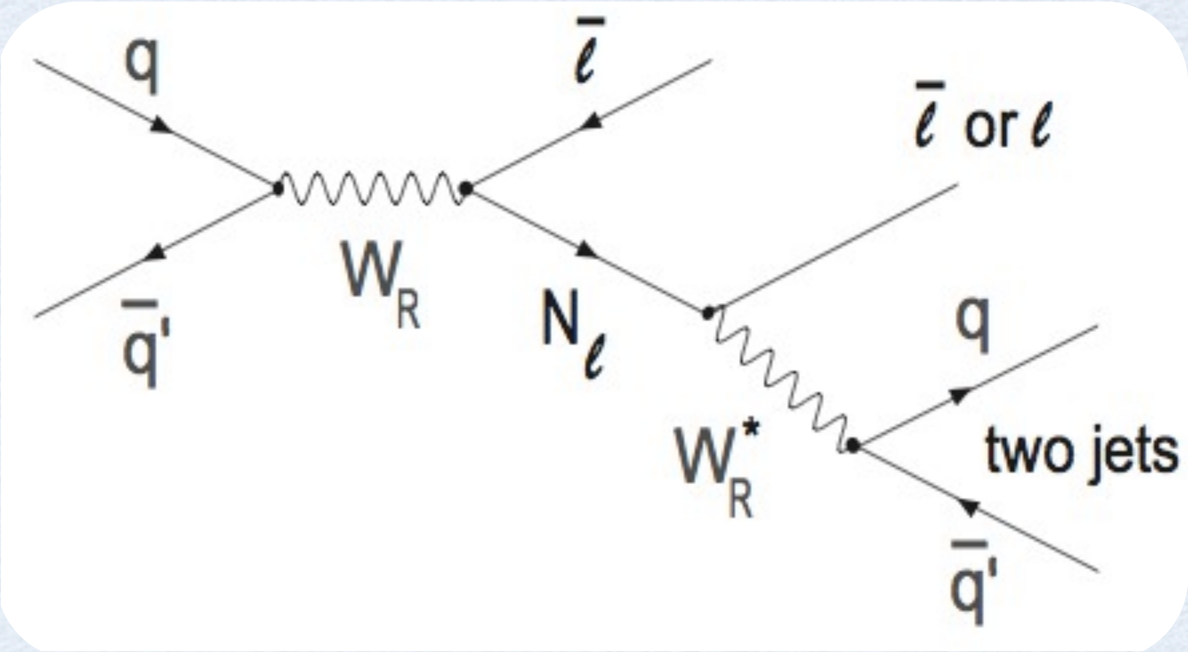
Multi-Leptons at ATLAS

- Many multi-lepton exotic final states are studied are studied at ATLAS. Some examples:
  - Leptonic decay of pairs of heavy gauginos through real or virtual W/Z or sleptons to leptons and a pair of LSPs.
  - Exotic di-lepton resonances, like Z′.
  - Pair production of heavy particles, like neutrinos, quarks, leptoquarks, etc.
  - Production of heavy particles in association of a lepton. Ex: leptoquarks, neutrinos...
  - Vector boson scattering with both bosons decaying leptonically.

Majorana Neutrinos

- Left-Right Symmetric Models (LRSMs) address non-zero masses of neutrinos and baryogenesis.
  - Introduce 3 new heavy right-handed Majorana neutrinos, new bosons W_R & Z′,...
  - Direct searches:

    $m(W_R) \gtrsim 750 GeV$.
  - W_R can be produced via the Drell-Yan process and decay to heavy neutrinos.



Signal and Backgrounds

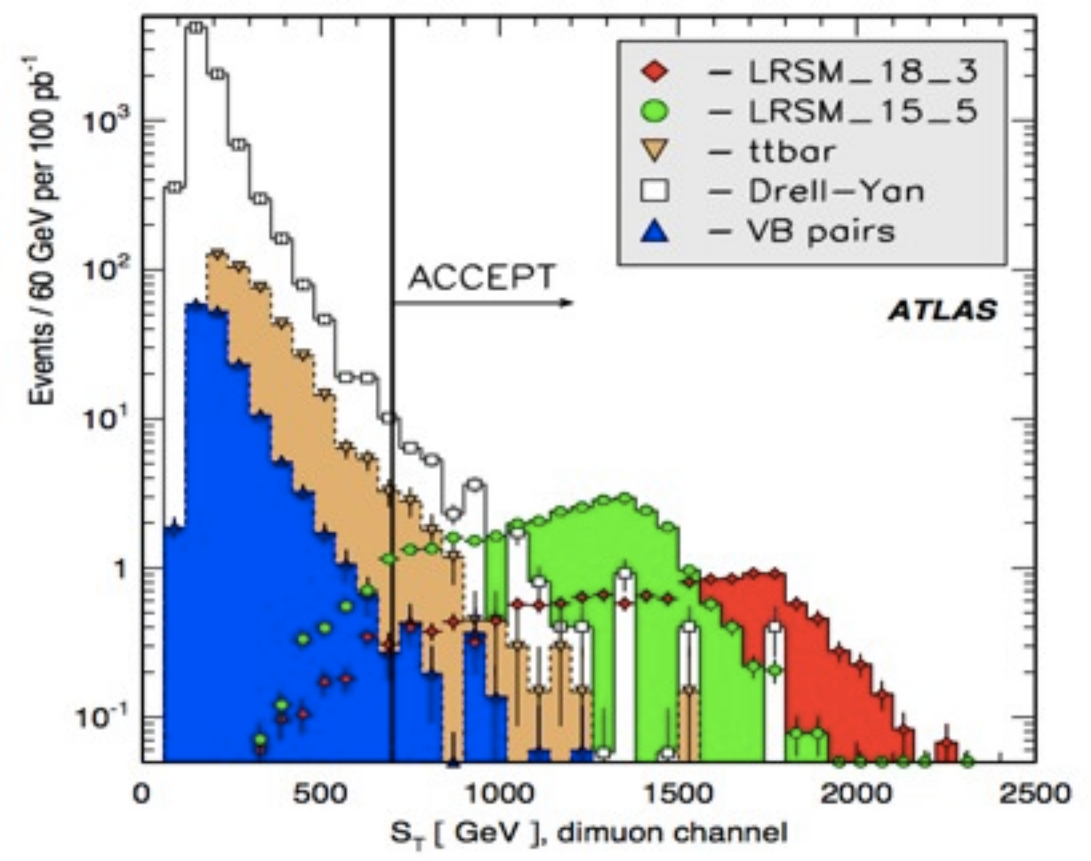
CERN-OPEN-2008-020

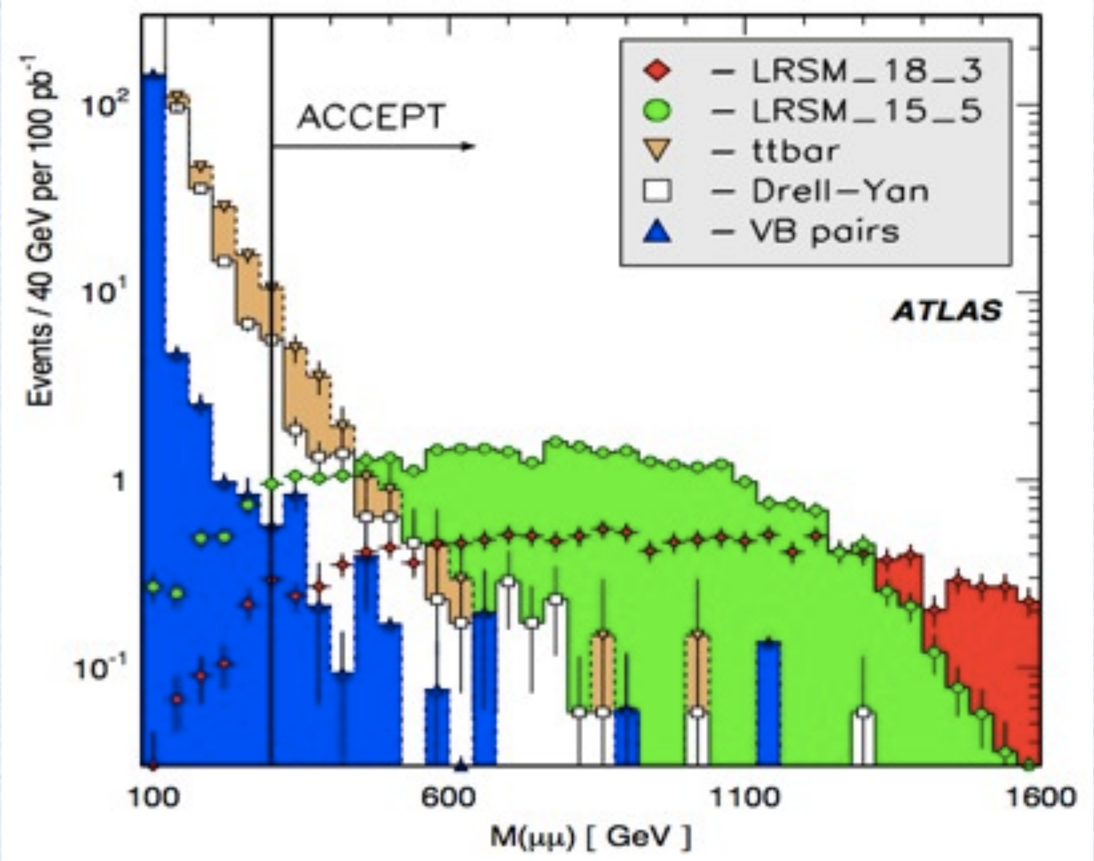
Sample ($l=e,\mu$)	Generator	x-section (pb)		
		no cuts	basic cuts, e-channel	basic cuts, μ-channel
pp->W_RX, W_R->lljj m(W_R,$N_{e,\mu}$)=1800,300 GeV	pythia	LO 0.25	0.088	0.145
pp->W_RX, W_R->lljj m(W_R,$N_{e,\mu}$)=1500,500 GeV	pythia	LO 0.47	0.220	0.328
pp->Z_{ll}X, mll>60GeV P_T^l>10GeV, $\|\eta^l\|$<2.7	pythia, herwig	NLO 1808	49.8	80.0
pp->tt, at least one e,μ with P_T^l>1GeV	mc@nlo	NLO+NLL 450	3.23	4.17
pp->VV, V=Z,W, m_{Z/γ^*}>20GeV, P_T^l>10GeV, $\|\eta^l\|$<2.8	herwig	NLO 60.9	0.610	0.876
multi-jet	pythia	10^8	20.5	0.0

- Basic cuts: 2e or 2μ well-identified, 2jets with cone0.4, ΔR(jet,any e)>0.1, $P_T^{l,j}$>20GeV, $|\eta^l|$<2.5, $|\eta^j|$<4.5, m_{ll}>70GeV

Event Selection

CERN-OPEN-2008-020





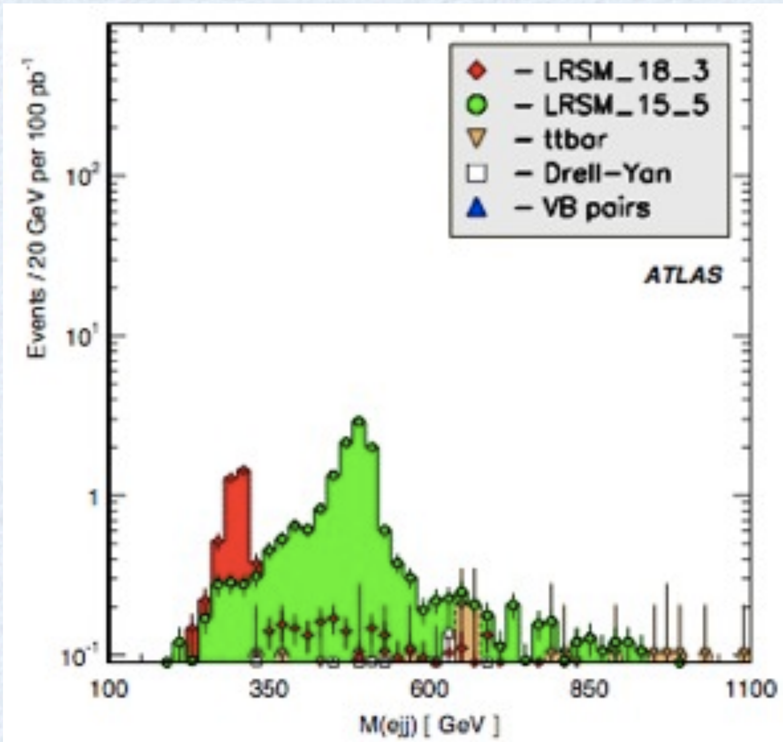
- Reconstruct from 2 highest-P_T jets and leptons
- S_T>700GeV (scalar ΣP_T of 2 jets and leptons), m_{ll}>300GeV
- Final signal region: m_{ljj}>100GeV, m_{lljj}>1000GeV

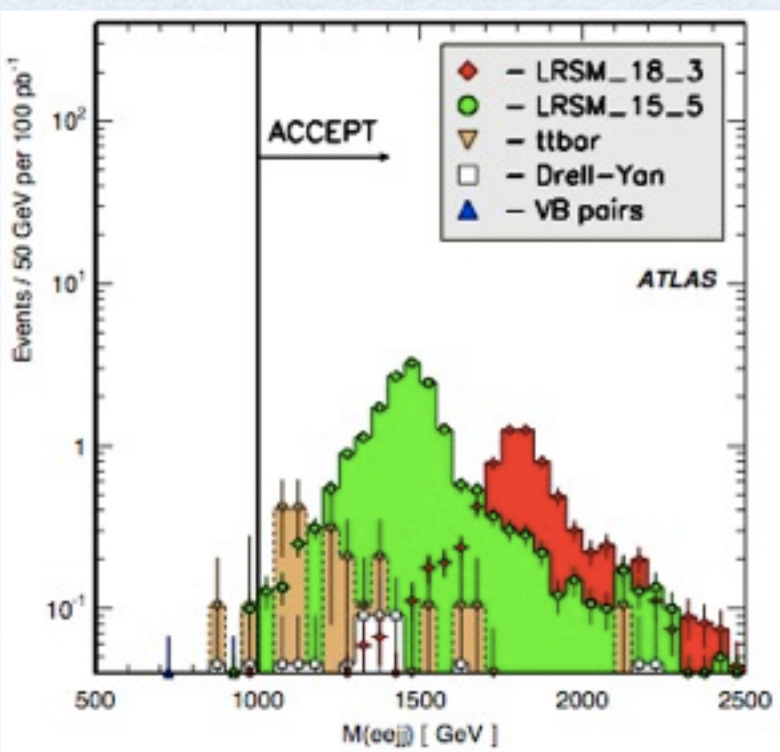
ATLAS Full Simulation

RECONSTRUCTED W_R & ν

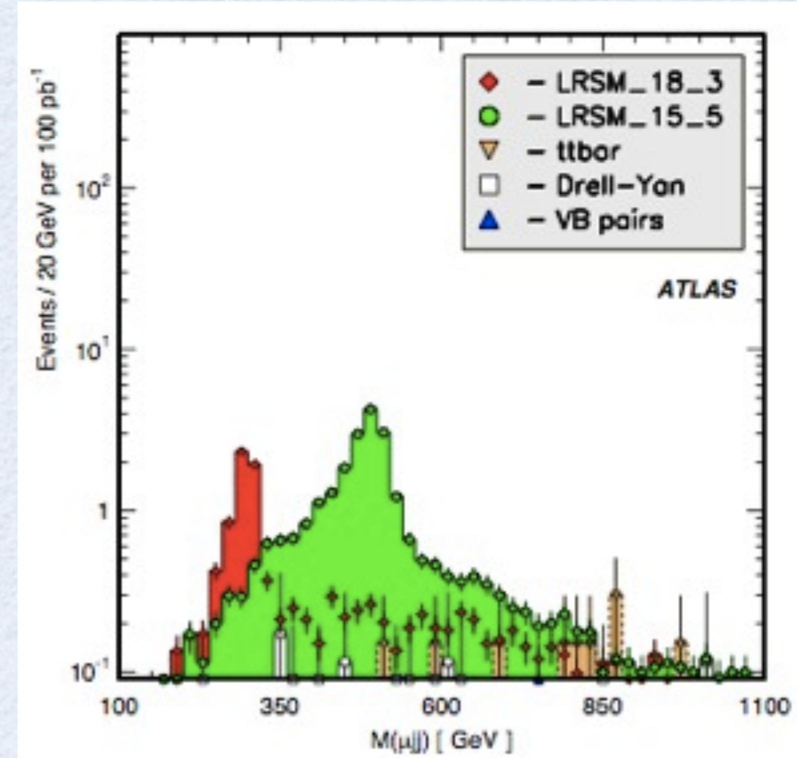
CERN-OPEN-2008-020

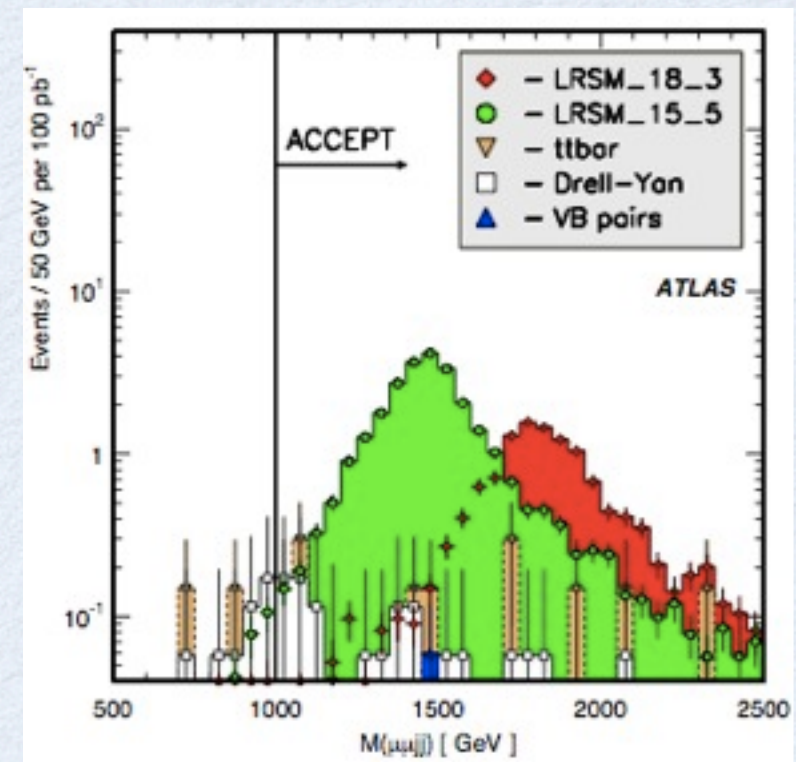
Electron channel





- After all cuts, backgrounds are about an order of magnitude smaller.
- 9-45 signal events @ 100pb^{-1}
- Multi-jet background not shown.
  - Can be important for e-channel.



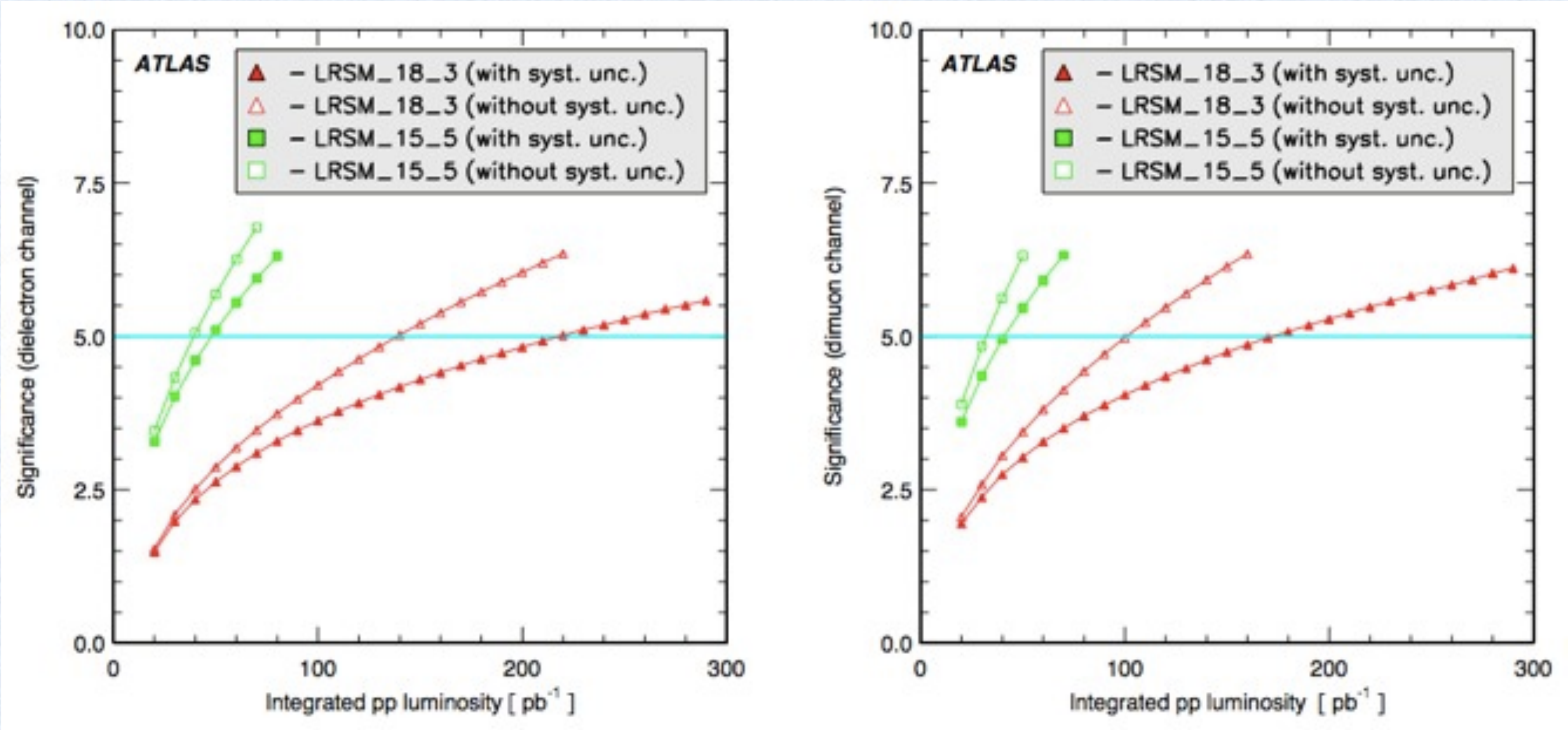


Muon channel

Results

CERN-OPEN-2008-020

- Trigger efficiency (single e or μ triggers) ≳ 95%
- Systematics on the background estimation ≈ 40-45%
  - Largest contributors: Integrated luminosity measurement, jet energy scale and resolution, limited MC statistics.
  - Pileup effect & multi-jet background in e-channel not considered!

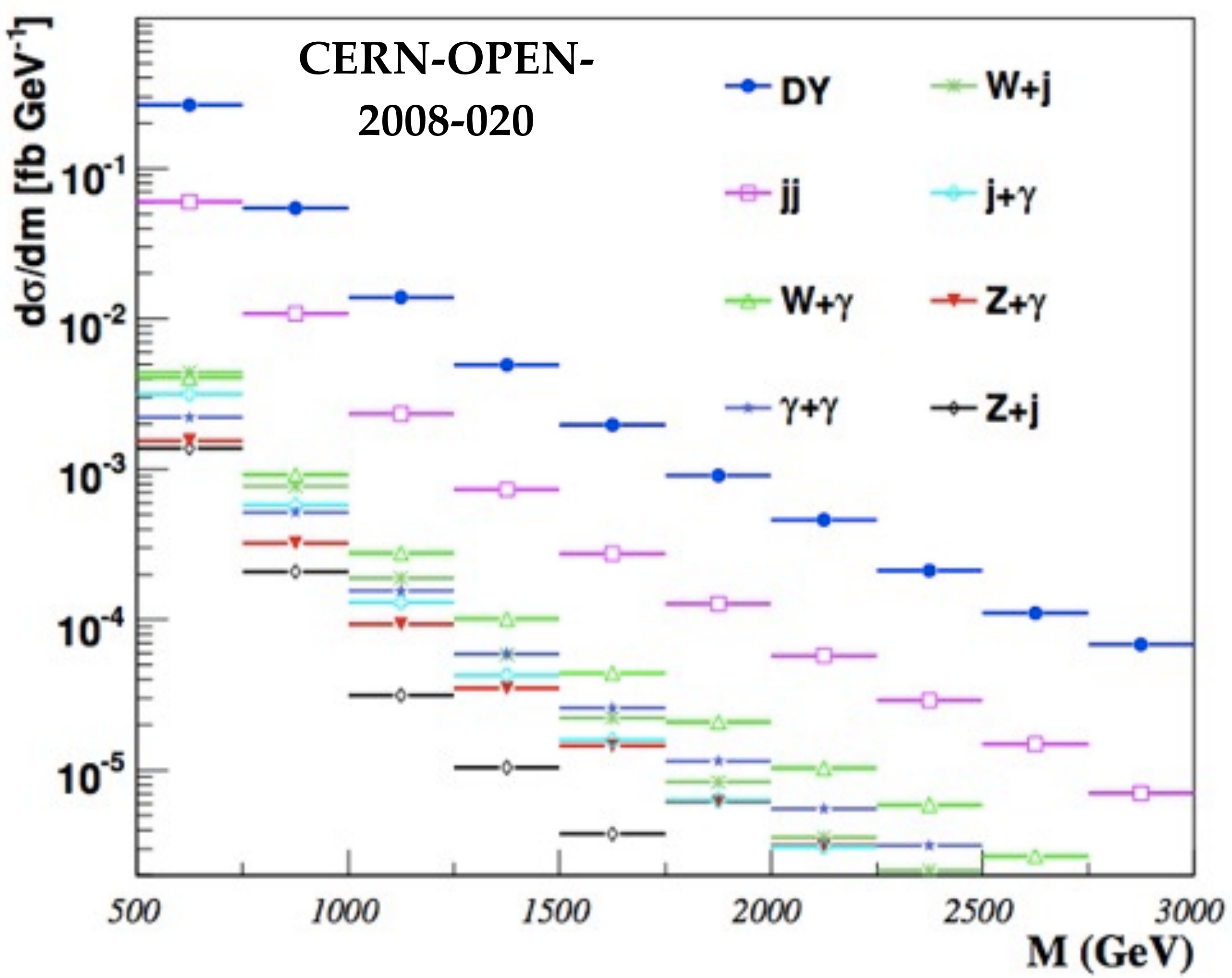


5σ discovery expected at **150pb^{-1}** and **40pb^{-1}** for m$(W_R, N_{e,\mu})$ = 1800,300 and 1500,500 scenarios respectively.

Effect of systematics is channel dependent.

DiLepton Resonances

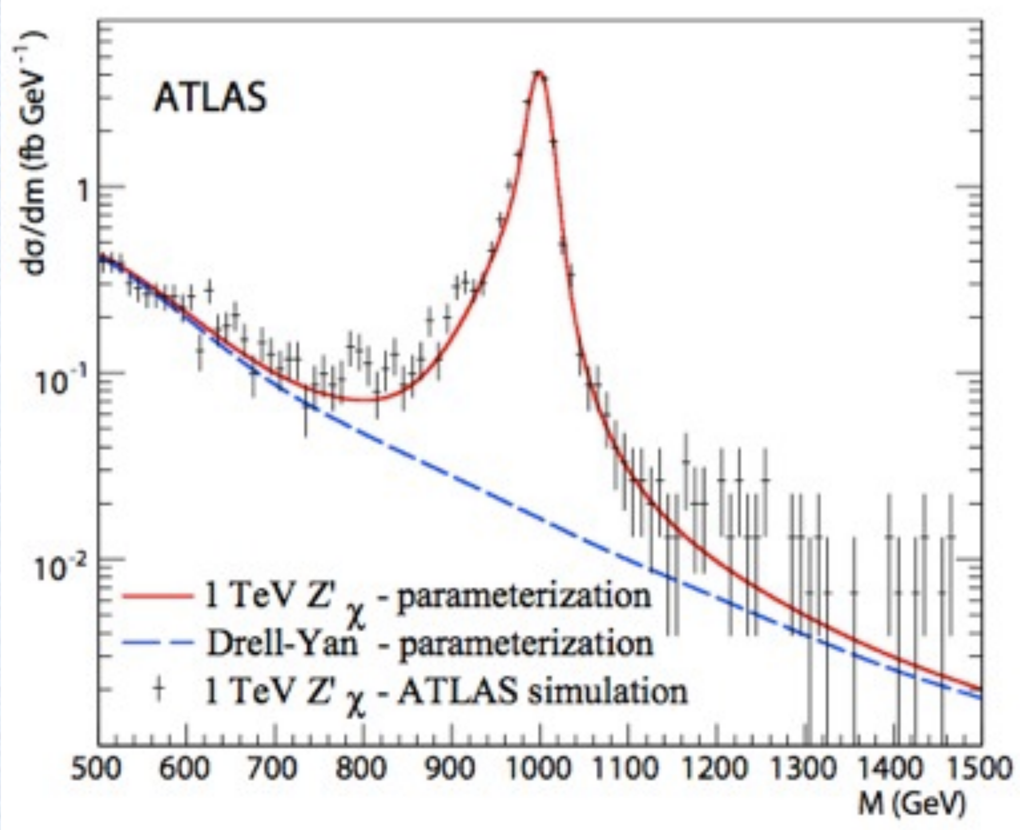
CERN-OPEN-2008-020



Differential x-section obtained from Pythia for various backgrounds to the e+e- channel. Requirements on electron candidates: $|\eta|<2.5$ and at least one with $P_T>65$GeV. Assumed rejection factors are: $R_{e\text{-}jet}=4\times10^3$ and $R_{e\text{-}\gamma}=10$.

See backup slides for uncut x-sections.

- For the search of dilepton resonances the largest background contribution is from Drell-Yan production.
  - Second largest is QCD di-jets, contributing less than 1/4th of DY.
  - tt contributes ≈10% of DY for dilepton masses above 500 GeV.



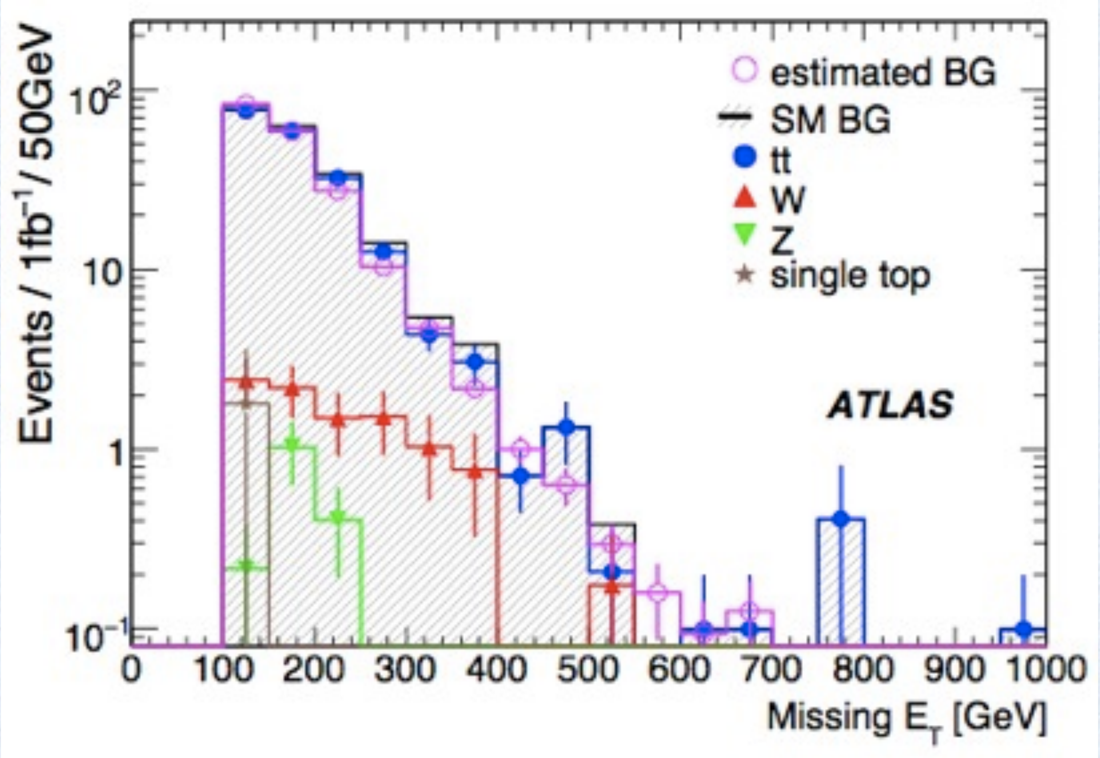
Background Control Samples

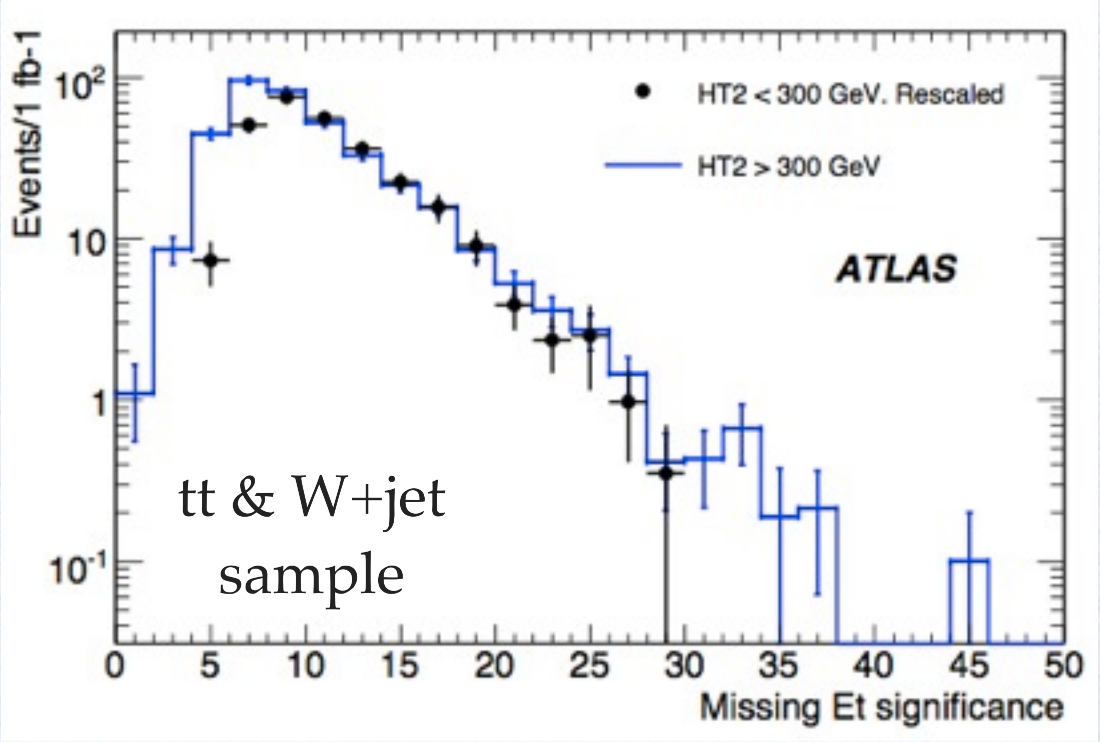
SUSY analyses in CERN-OPEN-2008-020

- To estimate the size (and shape of) backgrounds, the simplest thing to do: Look at cut-out regions.
  - Signals mostly at high M_T:

    $$M_T^2(\mathbf{p}_T^\alpha, \mathbf{p}_T^{\text{miss}}, m_\alpha, m_\chi) \equiv m_\alpha^2 + m_\chi^2 + 2\left(E_T^\alpha E_T^{\text{miss}} - \mathbf{p}_T^\alpha \cdot \mathbf{p}_T^{\text{miss}}\right)$$

  - Revert cut, for control region: M_T<100GeV
    - tt and W+jet backgrounds enhanced
- Alternatively, invent new variables which have low correlation with the cut variables.
  - Ex: HT2, a ΣP_T variable without the highest PT jet, to reduce correlation with E_T^{miss}.
  - Control region: HT2<300GeV $\text{HT2} \equiv \sum_{i=2}^{4} p_T^{\text{jet}\,i} + p_T^{\text{lepton}}$
- Issues with control regions: The composition of various background components can/will be different in signal and control samples. Signal contamination.

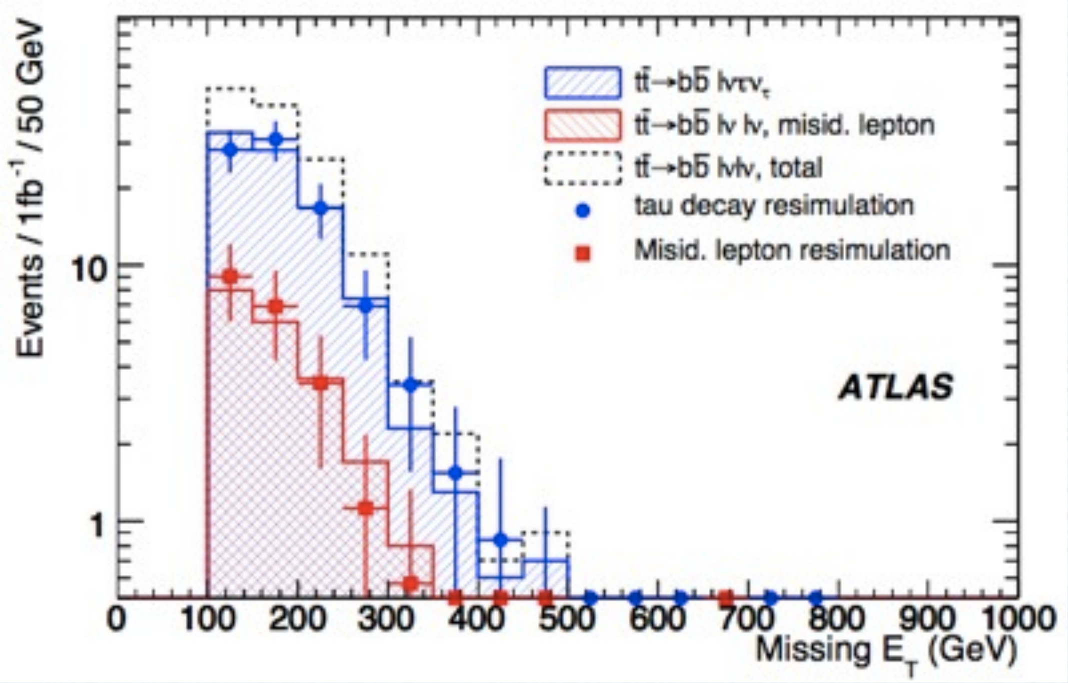


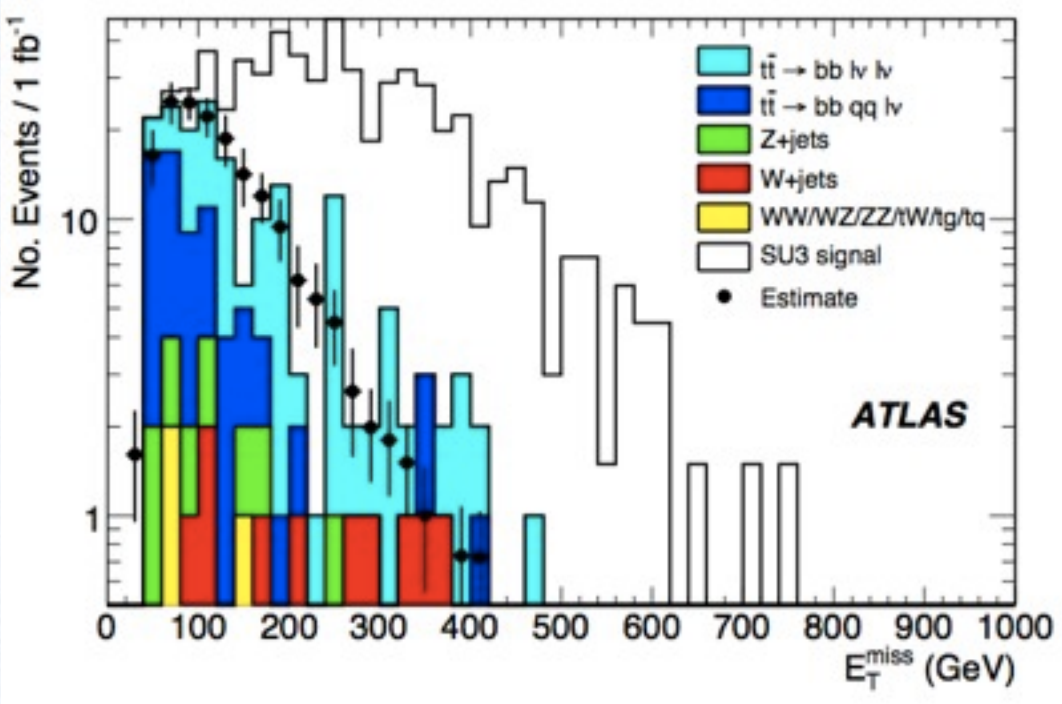


Substitution Studies

SUSY analyses in CERN-OPEN-2008-020

- Identify samples that represent your background in other decay modes & re-decay them.
- Ex: Create a clean fully-leptonic tt control sample by taking 2 OS leptons, 3+ jets, and using kinematic constraints.
  - Selectively kill a lepton or replace it with tau's generated with TAUOLA.
  - Or take out decay products of tops, including E_T^{miss} contribution and redecay the tops in whatever way you like.
- These techniques allow access to unusual parts of parameter space => one seed event can be used for generating thousands of events.





Conclusion

- Multi-lepton final states will play an important part even in the ATLAS studies targeting first hundreds of pb^{-1} of data.
- Backgrounds are not as small as mostly expected, particularly due to detector effects.
  - While they are mostly left to the interested experimentalist as homework, they can be roughly estimated without (full)detector simulation is possible.
  - Extraction of backgrounds from data, either by fits, or by uses of control regions are essential. Theory colleagues are encouraged to be innovative here as well...

Backups

Expected performance of ATLAS

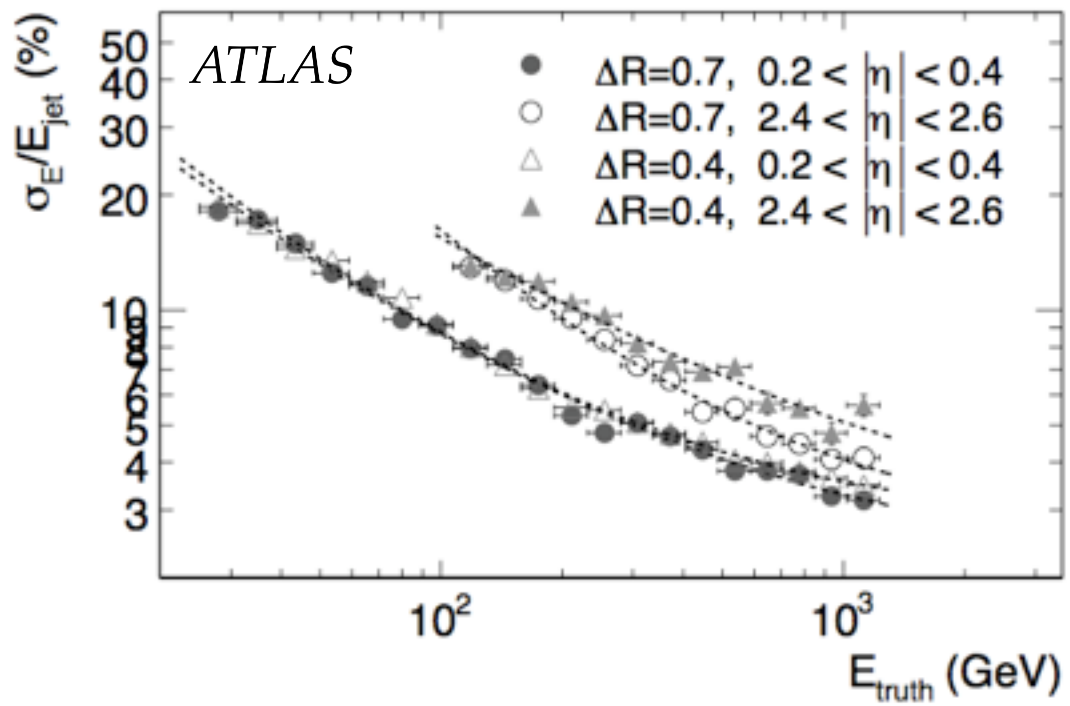
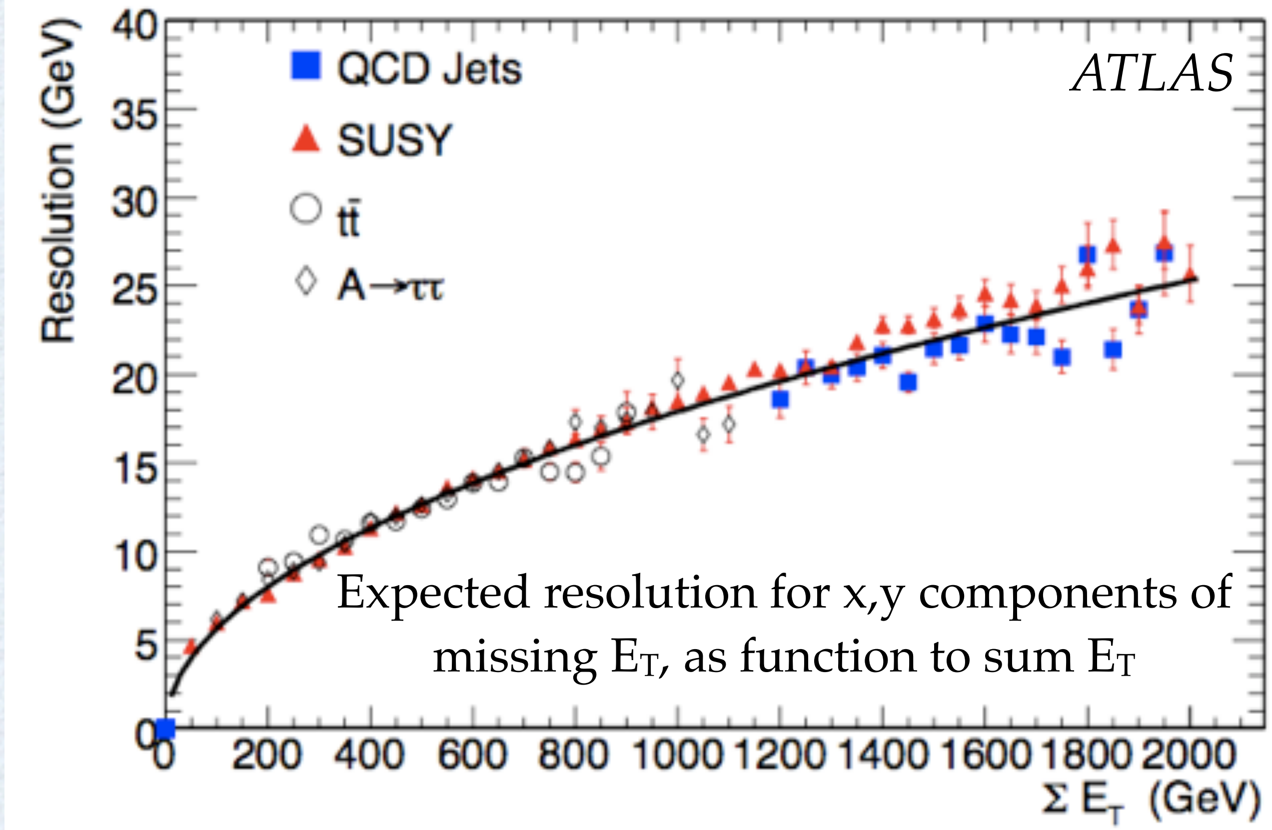


Figure 10.71: Fractional energy resolution for calibrated cone-tower jets reconstructed with $\Delta R = 0.7$ and Δ of $|\eta|$ and as a



Expected resolution for x,y components of missing E_T, as function to sum E_T

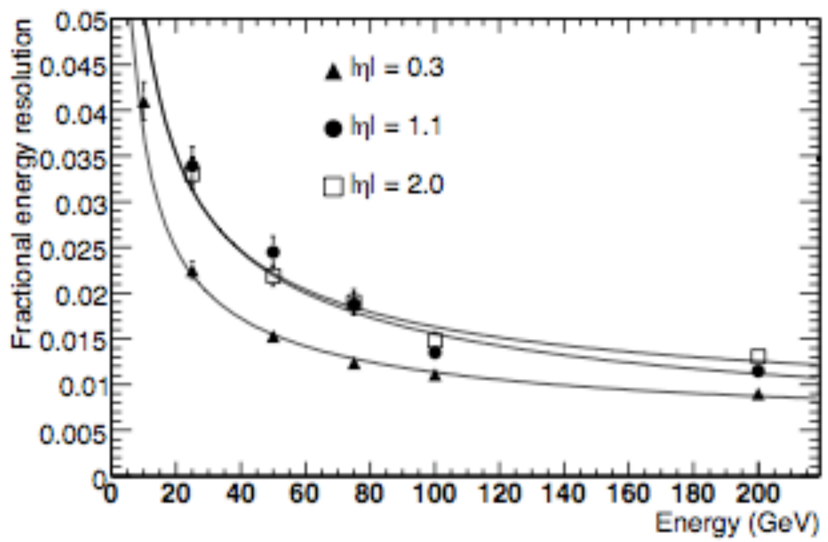


Figure 10.50: Expected relative energy resolution as a function of energy for electrons at $|\eta| = 0.3$, 1.1, and 2.0. The curves represent fits to the points at the same $|\eta|$ by a function containing a stochastic term, a constant term and a noise term.

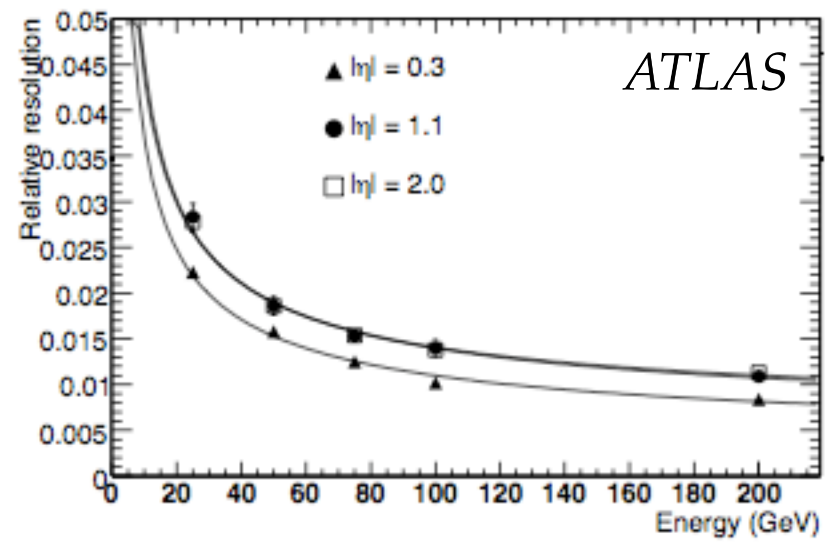


Figure 10.51: Expected relative energy resolution as a function of energy for photons at $|\eta| = 0.3$, 1.1, and 2.0. The curves represent fits to the points at the same η by a function containing a stochastic term, a constant term and a noise term.

Expected performance of ATLAS

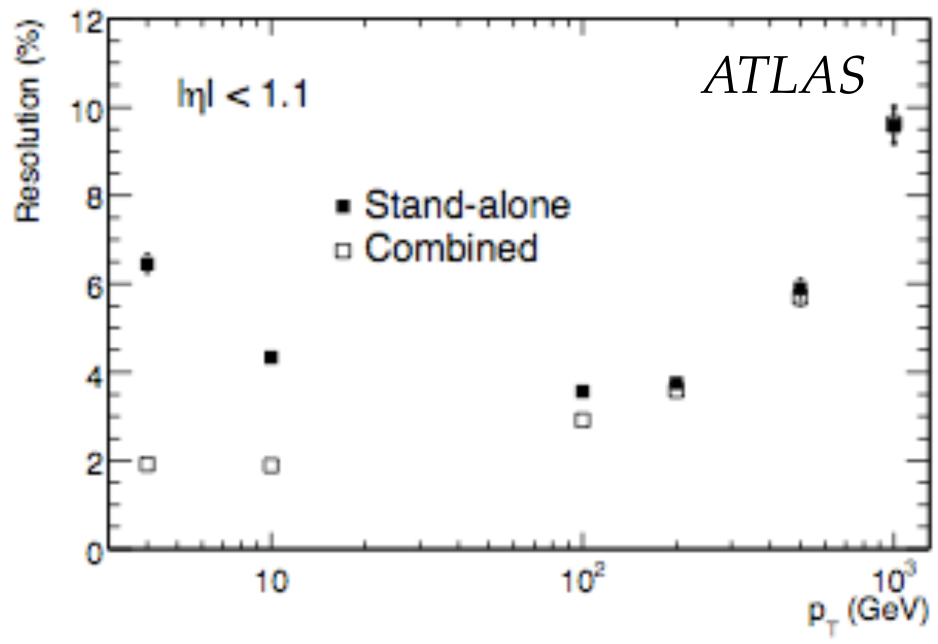


Figure 10.35: Expected stand-alone and combined fractional momentum resolution as a function of p_T for single muons with $|\eta| < 1.1$.

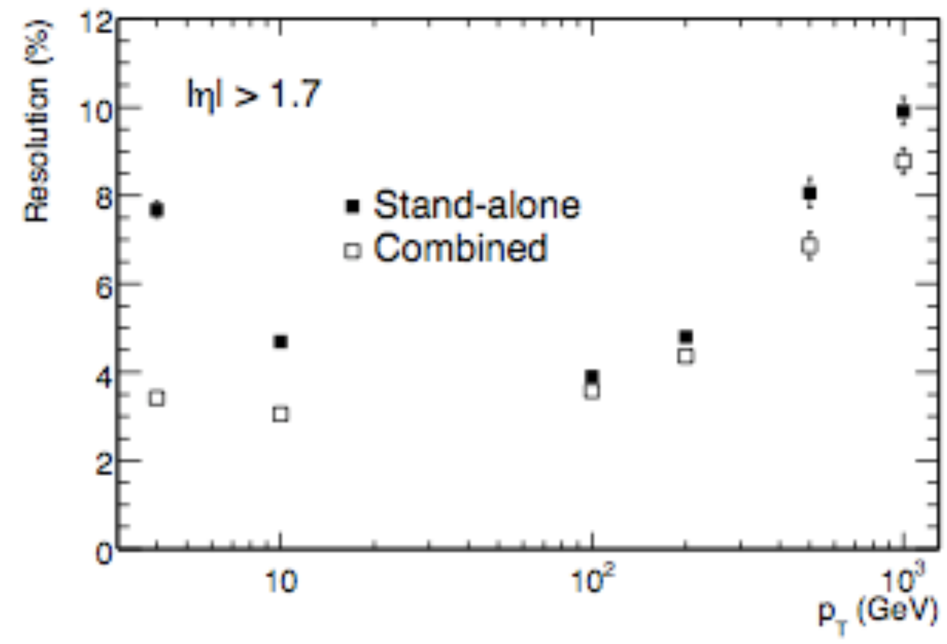


Figure 10.36: Expected stand-alone and combined fractional momentum resolution as a function of p_T for single muons with $|\eta| > 1.7$.

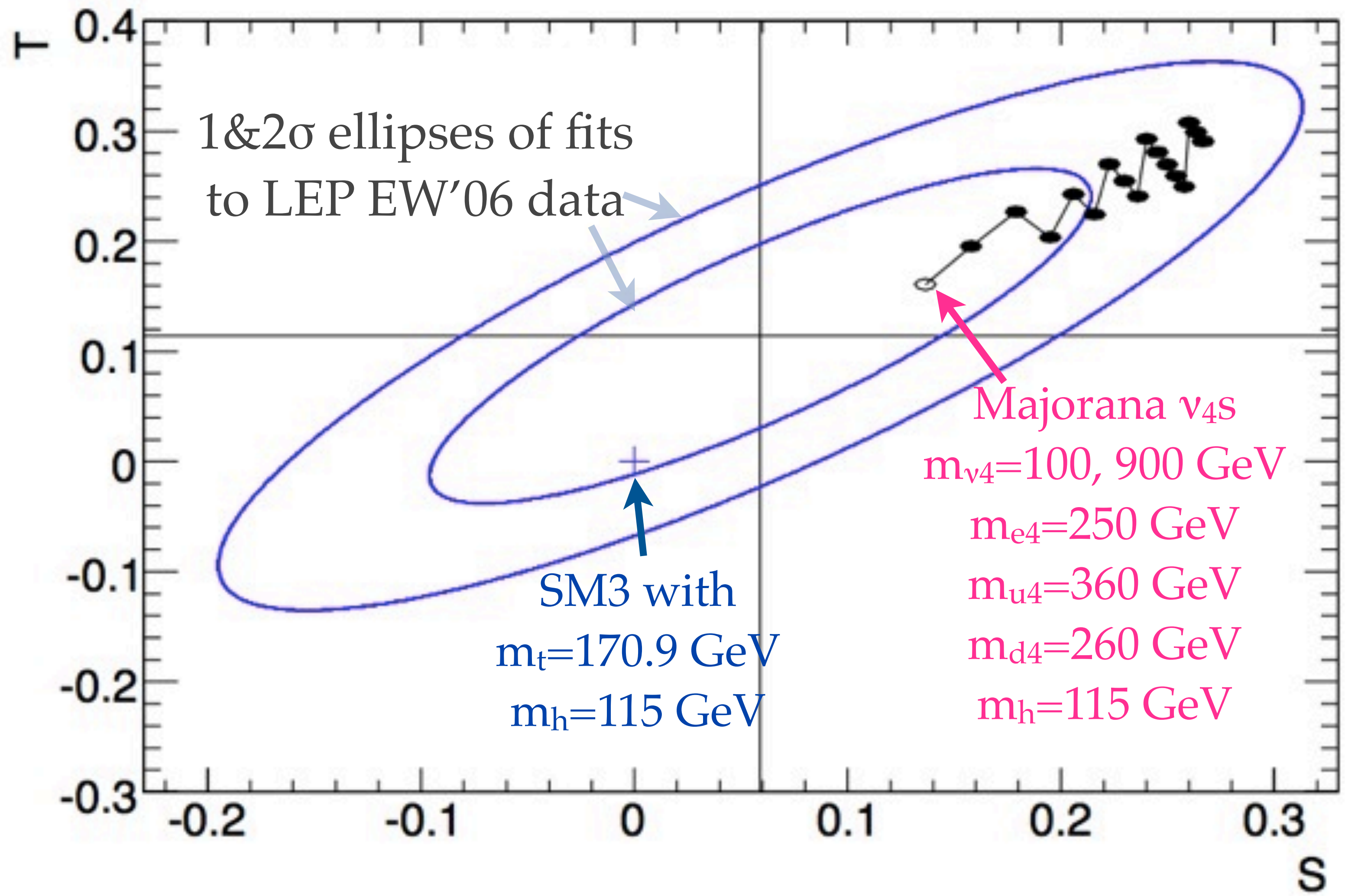
Track parameter	$0.25 < \|\eta\| < 0.50$		$1.50 < \|\eta\| < 1.75$	
	$\sigma_X(\infty)$	p_X (GeV)	$\sigma_X(\infty)$	p_X (GeV)
Inverse transverse momentum (q/p_T)	0.34 TeV^{-1}	44	0.41 TeV^{-1}	80
Azimuthal angle (ϕ)	70 μrad	39	92 μrad	49
Polar angle ($\cot\theta$)	0.7×10^{-3}	5.0	1.2×10^{-3}	10
Transverse impact parameter (d_0)	10 μm	14	12 μm	20
Longitudinal impact parameter ($z_0 \times \sin\theta$)	91 μm	2.3	71 μm	3.7

Table 3: Expected track-parameter resolutions (RMS) at infinite transverse momentum, $\sigma_X(\infty)$, and transverse momentum, p_X, at which the multiple-scattering contribution equals that from the detector resolution (see Eq. (1)). The momentum and angular resolutions are shown for muons, whereas the impact-parameter resolutions are shown for pions (see text). The values are shown for two η-regions, one in the barrel inner detector where the amount of material is close to its minimum and one in the end-cap where the amount of material is close to its maximum. Isolated, single particles are used with perfect alignment and calibration in order to indicate the optimal performance.

$$\sigma_X(p_T) = \sigma_X(\infty)(1 \oplus p_X/p_T)$$

ATLAS

STU on $L^{\pm}L^{0}$



Black solid circles represent m_h going from 150 to 900 GeV in steps of 50 GeV, while the best value of m_{u4} goes slowly up to 390 GeV.

Is the reference scenario viable?

- Viable for E6GUTs, but how about as members of a 4th SM generation?

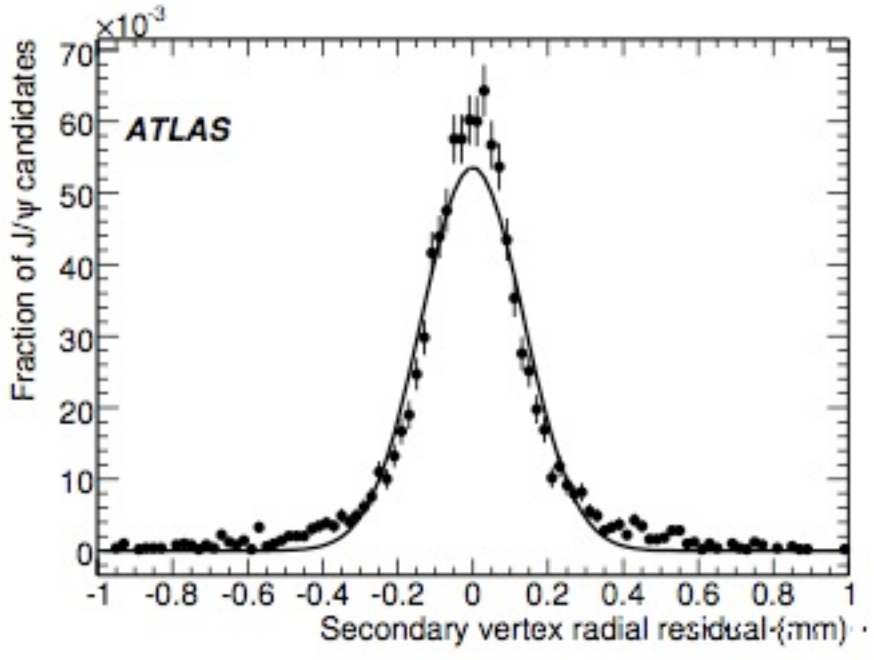
OPUCEM: Implemention exact one-loop calculations from:

- B.A.Kniehl & H.G.Khors, PRD48(1993)225.
- H.J.He, N.Polonsky & S.F.Su, PRD64(2001)053004.

=> Reference scenario can easily be accommodated for light or heavy Higgs alike.

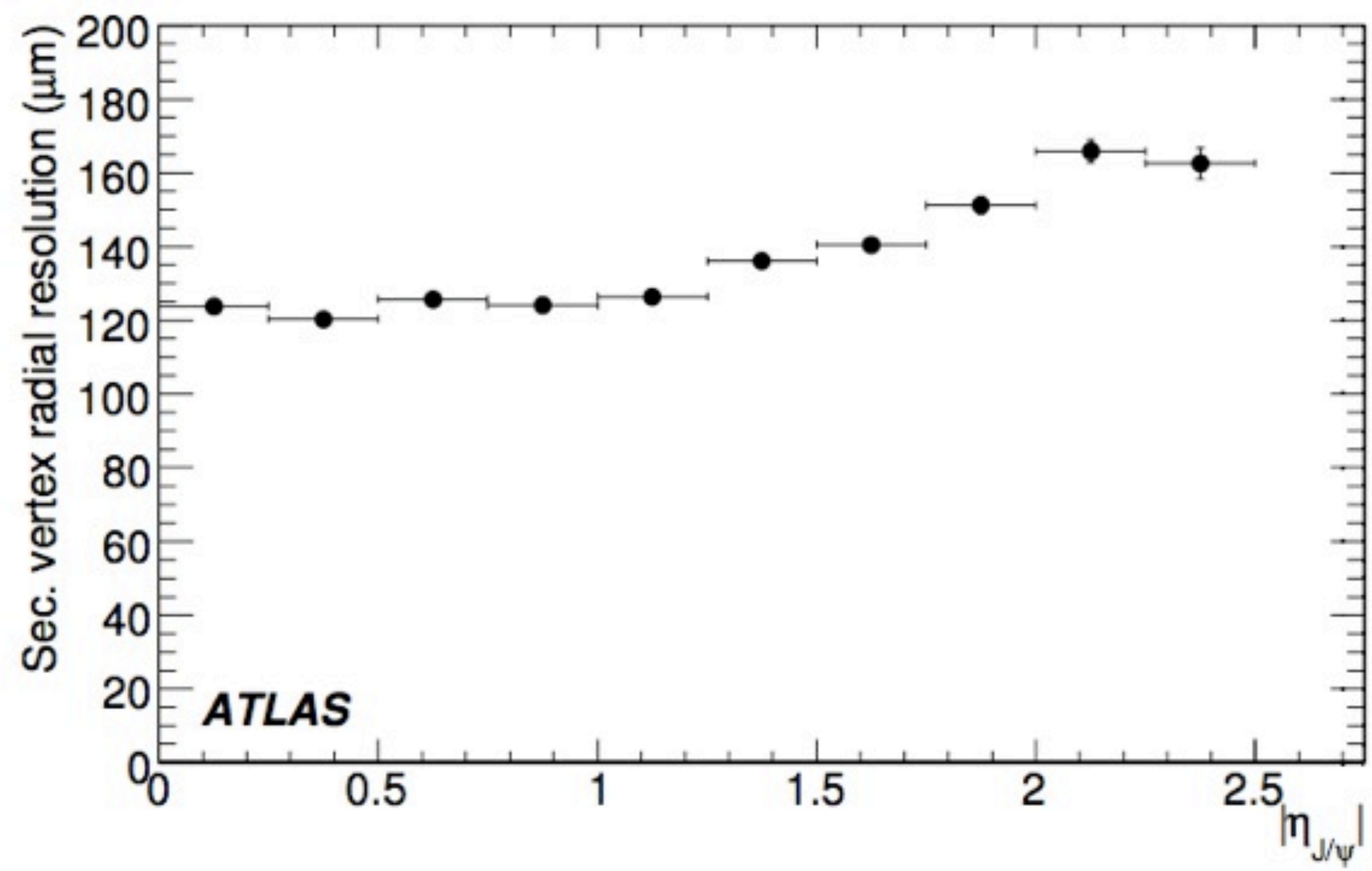
Further details in: V. E. Özcan, S. Sultansoy, G. Ünel, **A Possible Discovery Channel for New Charged Leptons at the LHC**, *J. Phys.* **G 36** (2009) 095002.

2nd Vertex Position Resolution



Resolution for the reconstruction of the radial position of the secondary vertex for $J/\psi \rightarrow \mu\mu$ decays in events containing *B*-hadron decays for tracks with $|\eta|$ around 0, from **CERN-OPEN-2008-020**.

As part of the tt background discussion

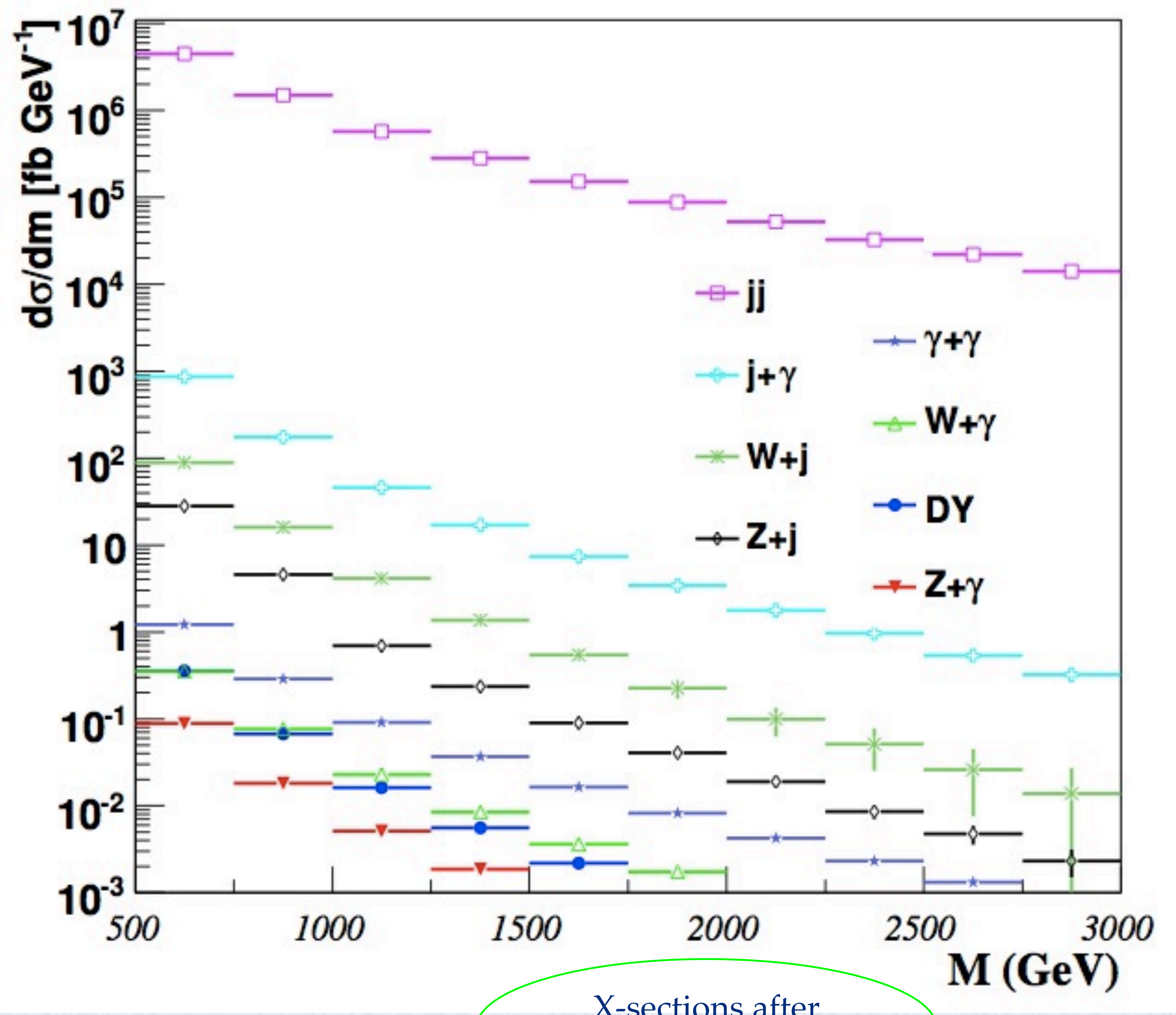


Resolution for the reconstruction of the radial position of the secondary vertex for $J/\psi \rightarrow \mu\mu$ decays in events containing *B*-hadron decays as a function of $|\eta_{J/\psi}|$, from **CERN-OPEN-2008-020**.

Backgrounds to DiLepton Resonances

CERN-OPEN-2008-020

- Differential x-sections from Pythia, for the background processes that can contribute to the e+e- invariant mass spectrum.
- W & Zs contribute true isolated leptons.
- No cuts and no lepton mis-identification rejection applied.



X-sections after cuts shown earlier.