4TH Family Quarks at ATLAS

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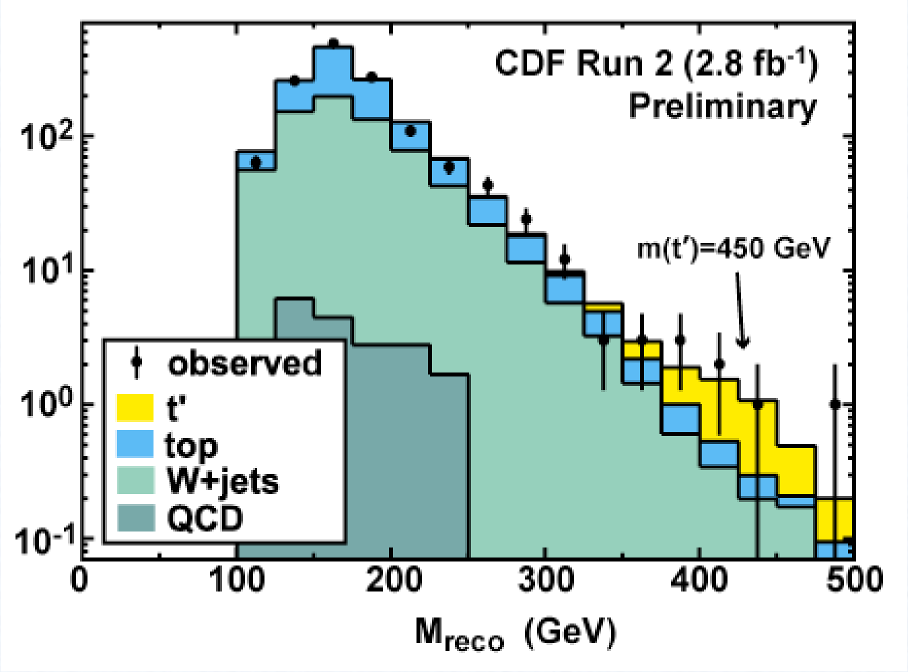
Beyond the 3SM generation at LHC era WS, CERN, Sept. 04, 2008

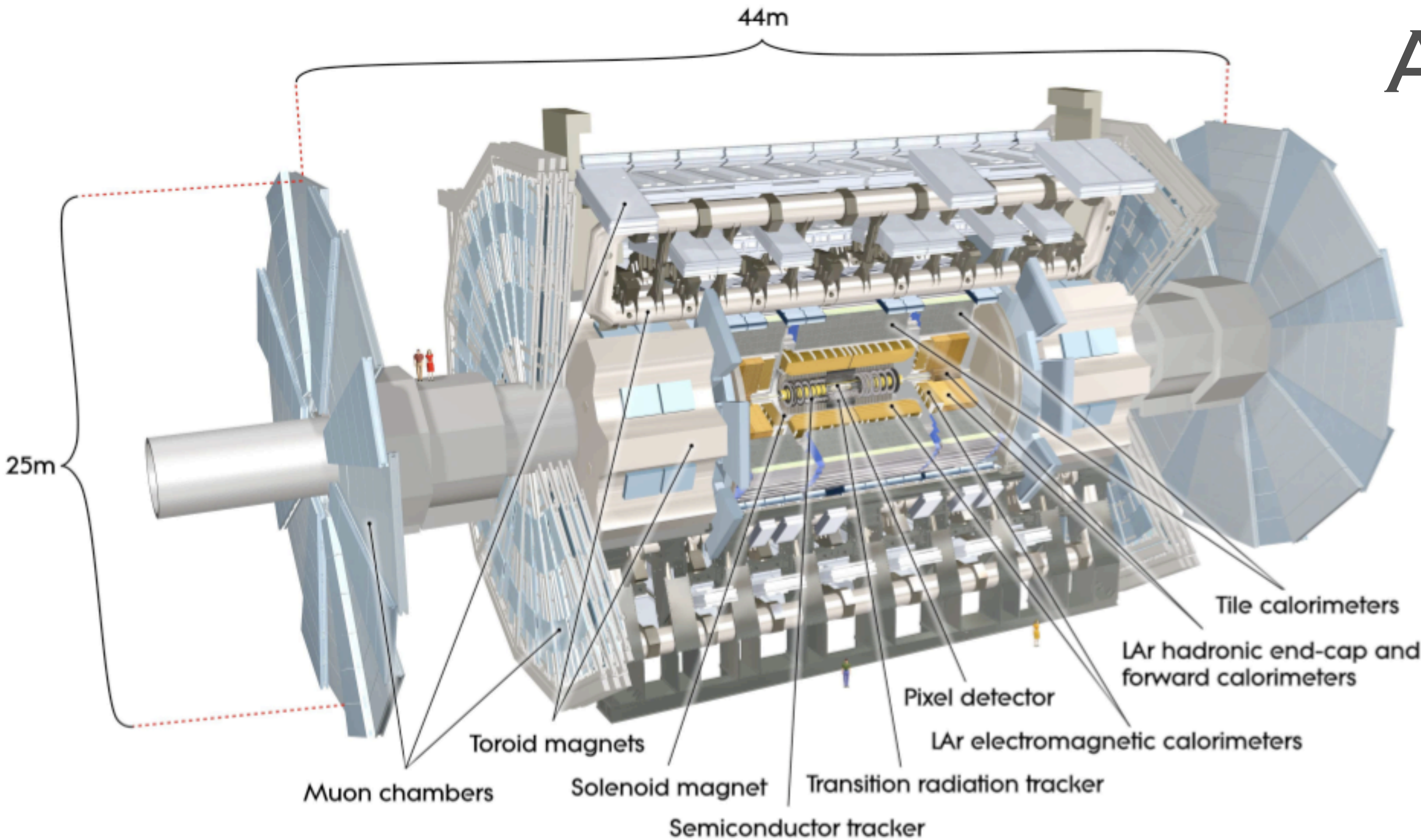
Outline / Motivation

- LHC scheduled to have first protons on Sept. 10, 2008.
- CM energy 7x larger than Tevatron, low x, gluon pdfs significant => pair production of heavy quarks…
- Recent exciting results from CDF => the first ~100pb^{-1} of data will be very interesting.



- u_4/d_4 discovery potential at ATLAS:
  - ATLAS TDR: q_4 mixing with t/b
  - Recent results: q_4 mixing with u/d/s/c
- Not in this talk - other heavy quark searches: isosinglets, FCNCs, …

ATLAS



Tracking	$|\eta|<2.5$
EM Cal.	$|\eta|<3.2$
Had. Cal.	$|\eta|<\sim 4.9$

	Start-up of LHC	Ultimate goal
Electromagnetic energy uniformity	1–2%	0.5%
Electron energy scale	∼2%	0.02%
Hadronic energy uniformity	2–3%	< 1%
Jet energy scale	< 10%	1%
Inner-detector alignment	50–100 μm	< 10 μm
Muon-spectrometer alignment	< 200 μm	30 μm
Muon momentum scale	∼1%	0.02%

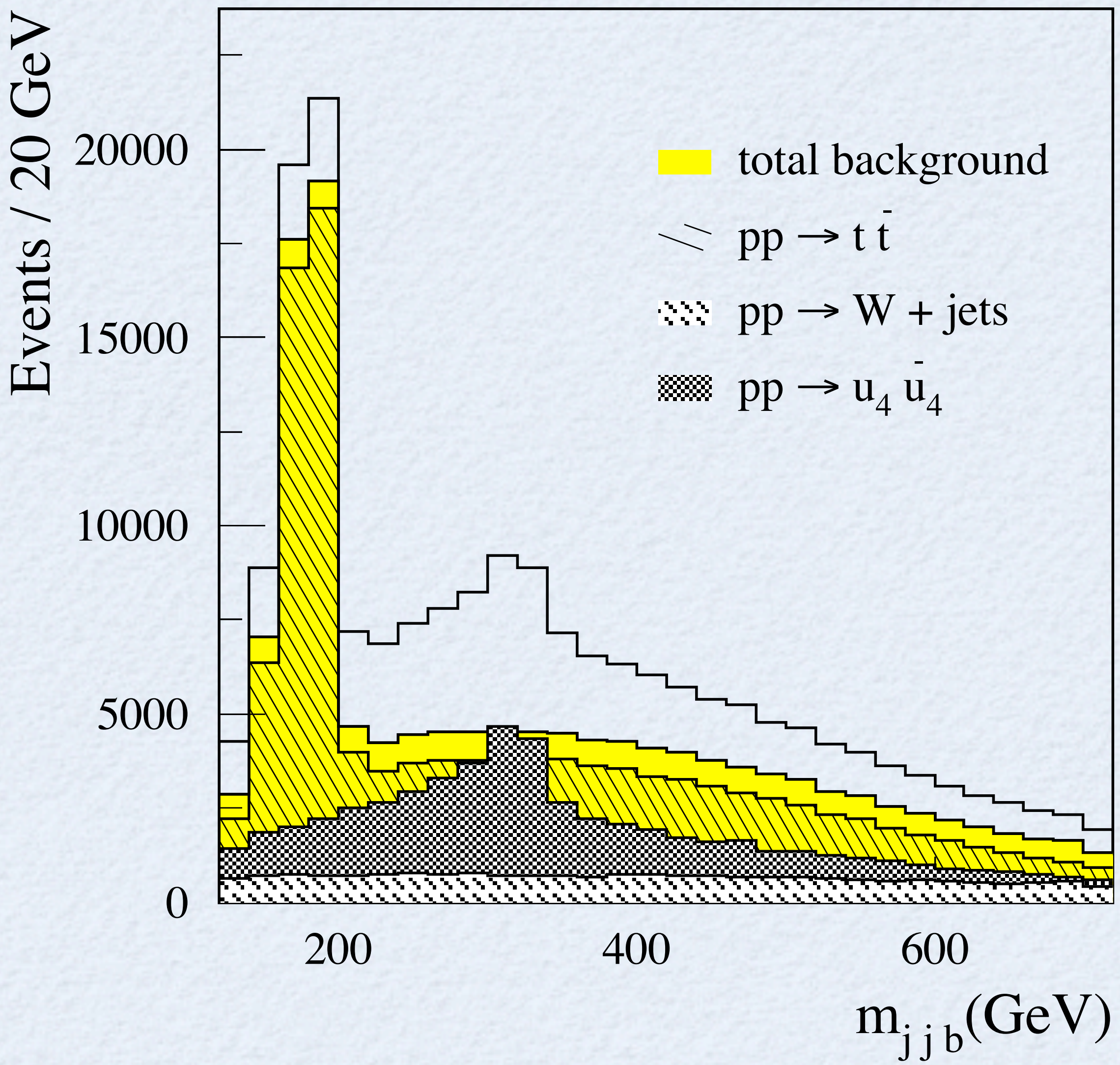
4^{th} Gen. Quarks in ATLAS TDR

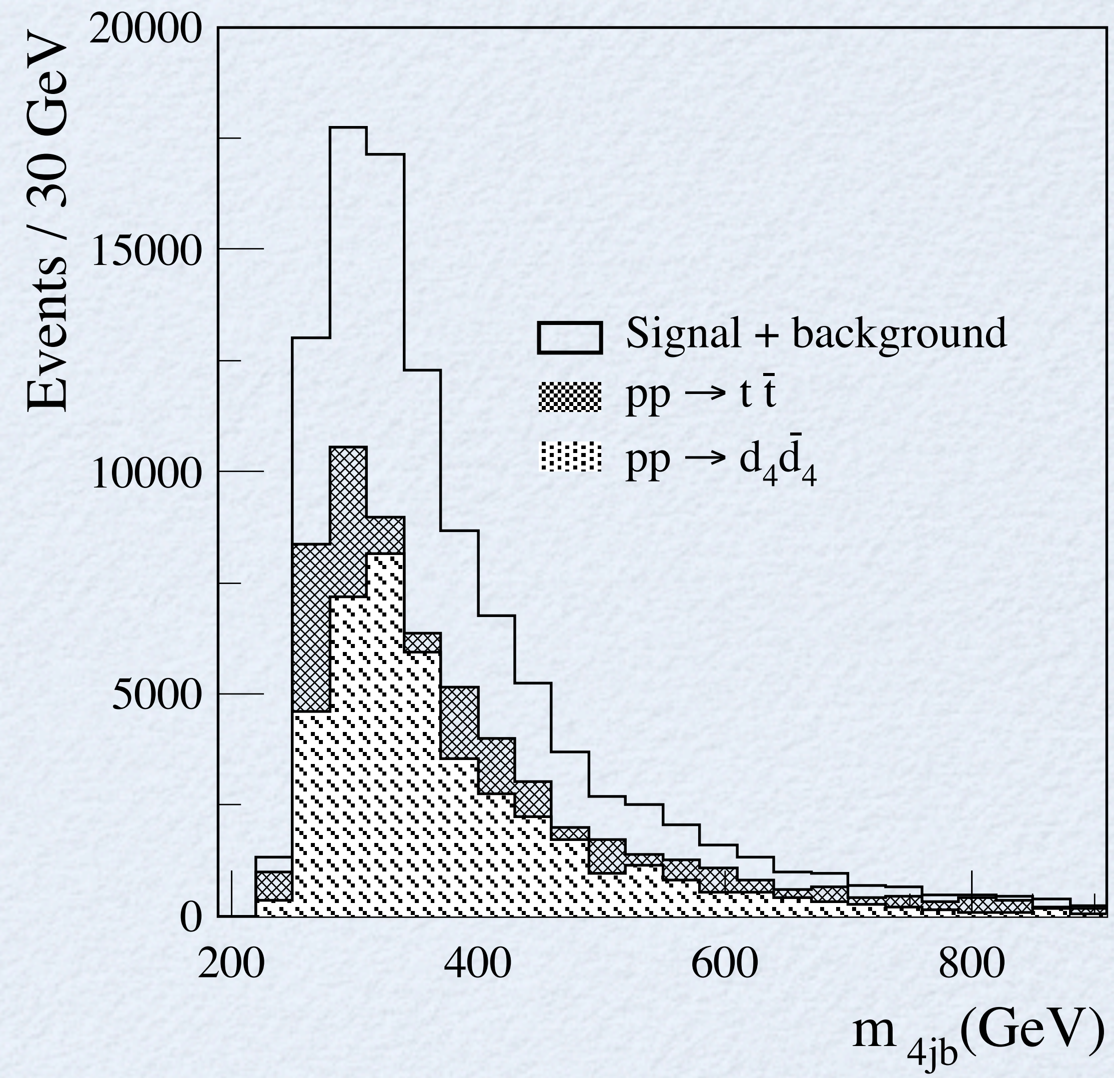
- Pair production of u_4s and d_4s and possibly a heavy quarkonium state η_4 was studied.
- **Mixing** assumed to be dominantly **with 3rd generation**
- Democratic mass matrix (DMM) approach taken; thus assuming $|m_{u4}-m_{d4}| \sim$ few GeV $< m_W$.
  - But results obtained for "generic" heavy quarks that would decay as $u_4 \rightarrow Wb$ and $d_4 \rightarrow Wt$.
  - Two mass values: 320 GeV, 640 GeV

TDR Analyses

- u_4u_4 and d_4d_4 analyses quite similar, though one involves the intermediate step of recontructing tops.
  - Primary jets (direct daughters of u_4) at high P_T
  - One of Ws in leptonic channel (with isolated μ or e), all others in hadronic channel
  - b-tagging/b-veto as expected in the final state
  - From each event only one q_4 finally reconstructed, the fact that one expects two objects of same mass is not exploited.
  - Main background from tt pair production.

TDR Conclusions





- With O(few fb^{-1}) enough for discovery.
- Next step? "Full" analysis, "recent" software…

Further details: E. Arik et al, PRD58, 117701

A Look at 4x4 CKM

- Take the measurements of the quark mixings from PDG and apply unitarity constraints for 4x4 CKM:

$$\mathrm{CKM}_{4\times4} = \begin{bmatrix} 0.97377 \pm 0.00027 & 0.2257 \pm 0.0021 & 0.00431 \pm 0.00030 & < 0.044 \\ 0.230 \pm 0.011 & 0.957 \pm 0.095 & 0.0416 \pm 0.0006 & < 0.46 \\ 0.0074 \pm 0.0008 & 0.0406 \pm 0.0027 & > 0.78 & < 0.47 \\ < 0.063 & < 0.46 & < 0.47 & > 0.57 \end{bmatrix}$$

- Assume : $|V_{d_4 u}|^2 + |V_{d_4 c}|^2 >> |V_{d_4 t}|^2$

$$|V_{u_4 d}|^2 + |V_{u_4 s}|^2 >> |V_{u_4 b}|^2$$

- The final state would be: pp→$q_4 q_4$→WjWj, j=light jet
  - Look at semileptonic channel: (lν)j(jj)j

Further details: V.E.Ozcan, S. Sultansoy, G. Unel, ATLAS SN-ATLAS-2008-069, accepted to EPJC

Event Generation

- Signal events with CompHep 4.4.3. 12k signal events each for two choices of mass.

m_{q4} (GeV)	500	750
Γ_{q4} (GeV)	8.2×10^{-3}	2.8×10^{-2}
$\sigma_{pp\to d4d4}$ (pb)	2.63	0.25

- Background events with MadGraph 3.95. A total of 280+k events at various QCD scales and jet P_T cuts.
- PDF=CTEQ6L1. Pythia 6.23 for parton showering, hadronization, etc.
- ATLFast fast simulation for detector effects.

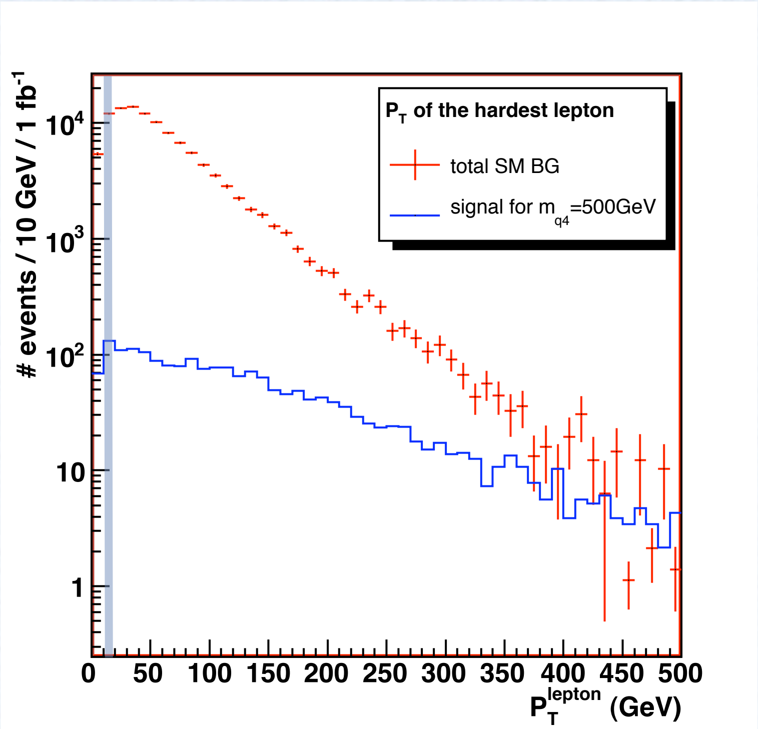
Backgrounds

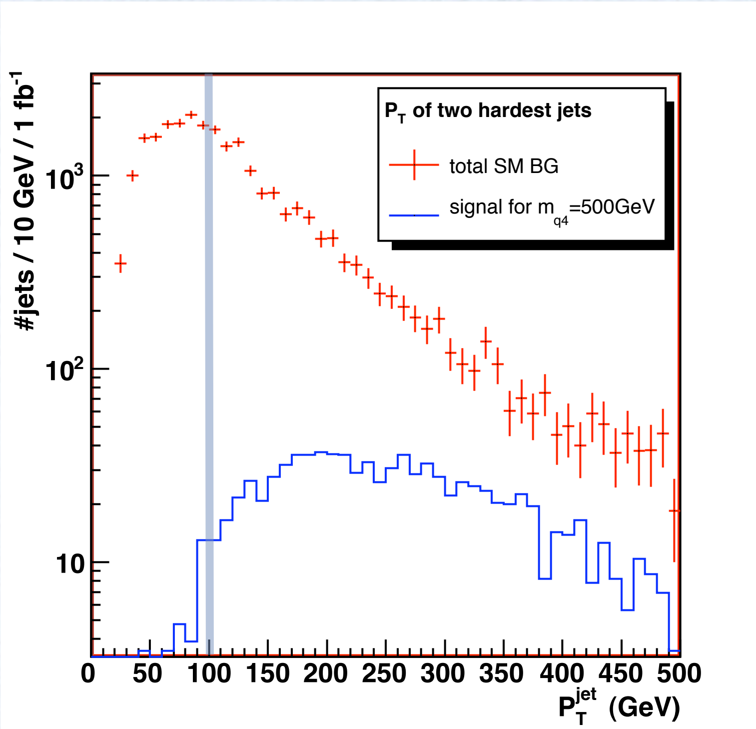
- Initially considered WbWb (mainly tt) and (W/Z)Wjj.
- However WbWbj (ttj) has similar xsec to WbWb and satisfies selection criteria with higher efficiency.
  - WbWb is the dominant background.
- tt2j xsec ~4 times smaller than ttj in the relevant jet P_T range. Neglected.
- No matching was done, WbWb and WbWbj simply added conservatively.

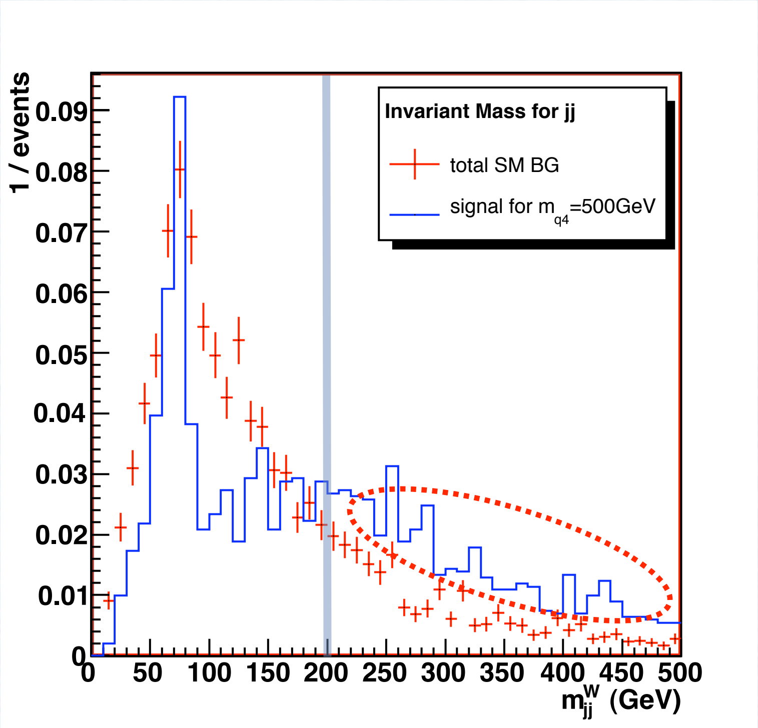
Event Selection

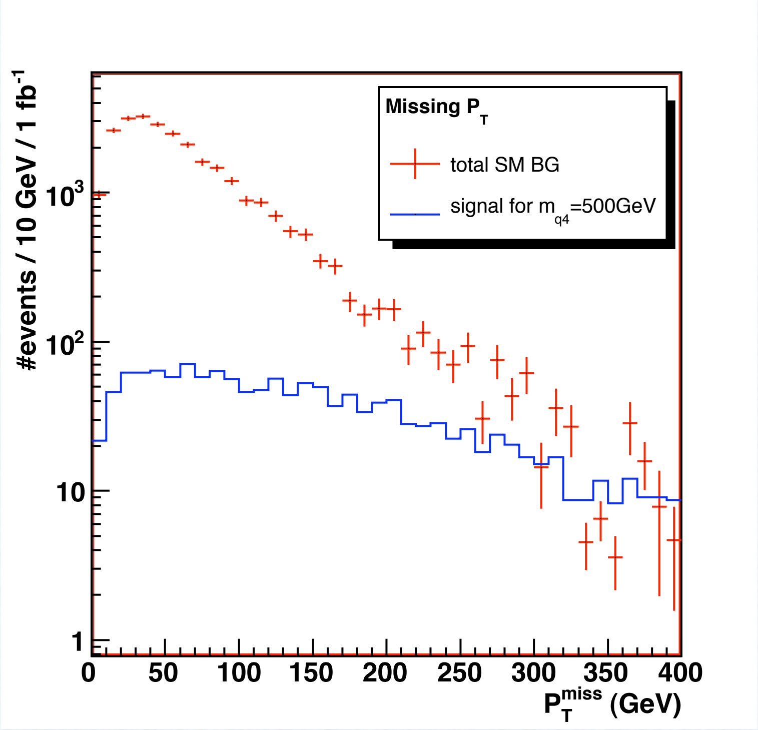
Selection Criterion	$\varepsilon_{sig.}^{m=500}$	$\varepsilon_{sig.}^{m=750}$	ε_{bkg}^{ttj}
isolated e/μ, P_T>15 GeV	32	32	29
4+ jets, P_T>20 GeV	86	84	84
4 hardest jets: b-tagging veto	92	90	33
possible neutrino solution	75	71	76
m_{jj}^W<200 GeV	50	44	75
2 hardest jets: P_T>100 GeV	94	98	35
$\lvert \Delta m_{Wj}^{q4} \rvert$<100 GeV	56	49	50
ε_{total}	5.0	3.6	0.8

Kinematic Variables



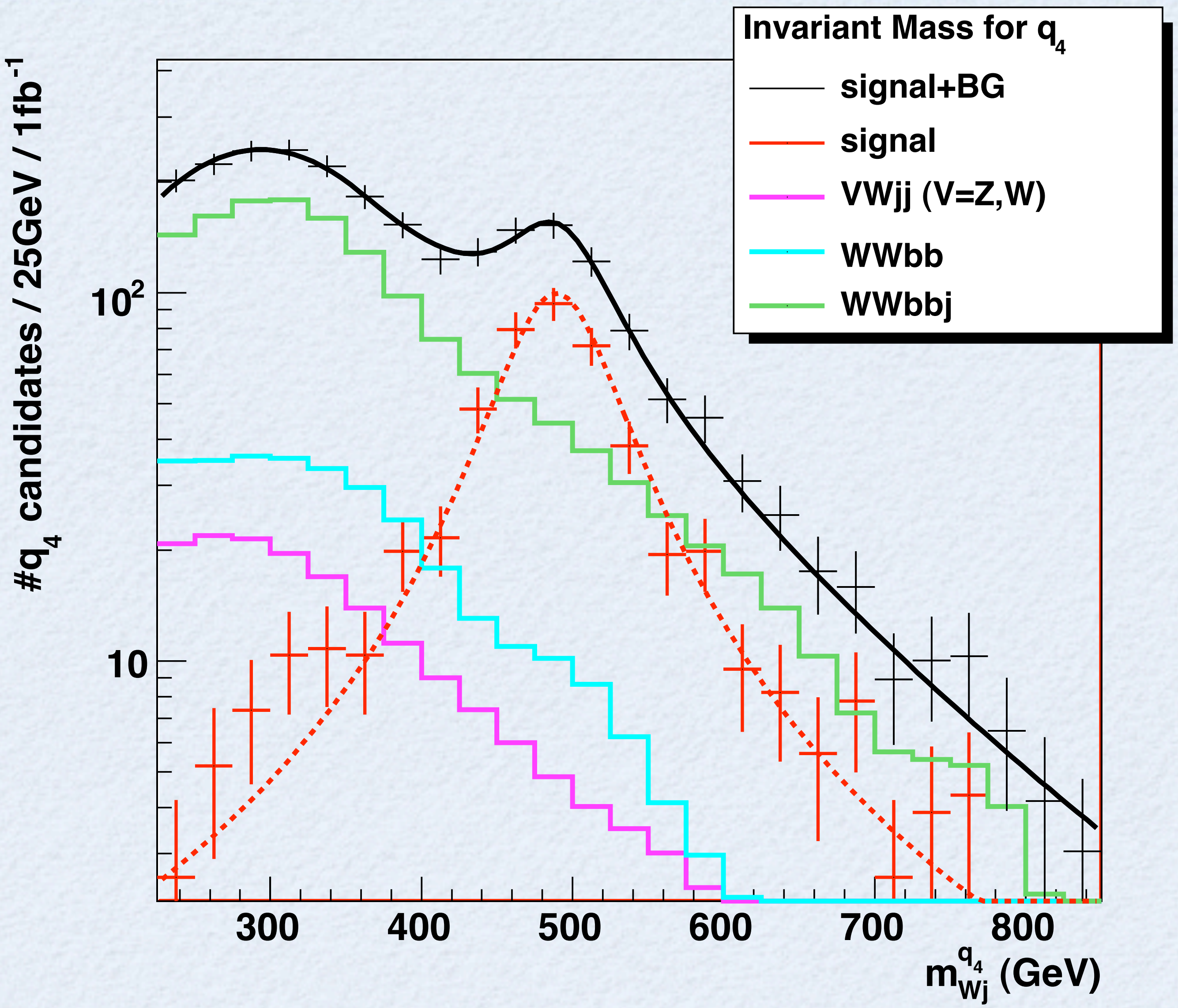


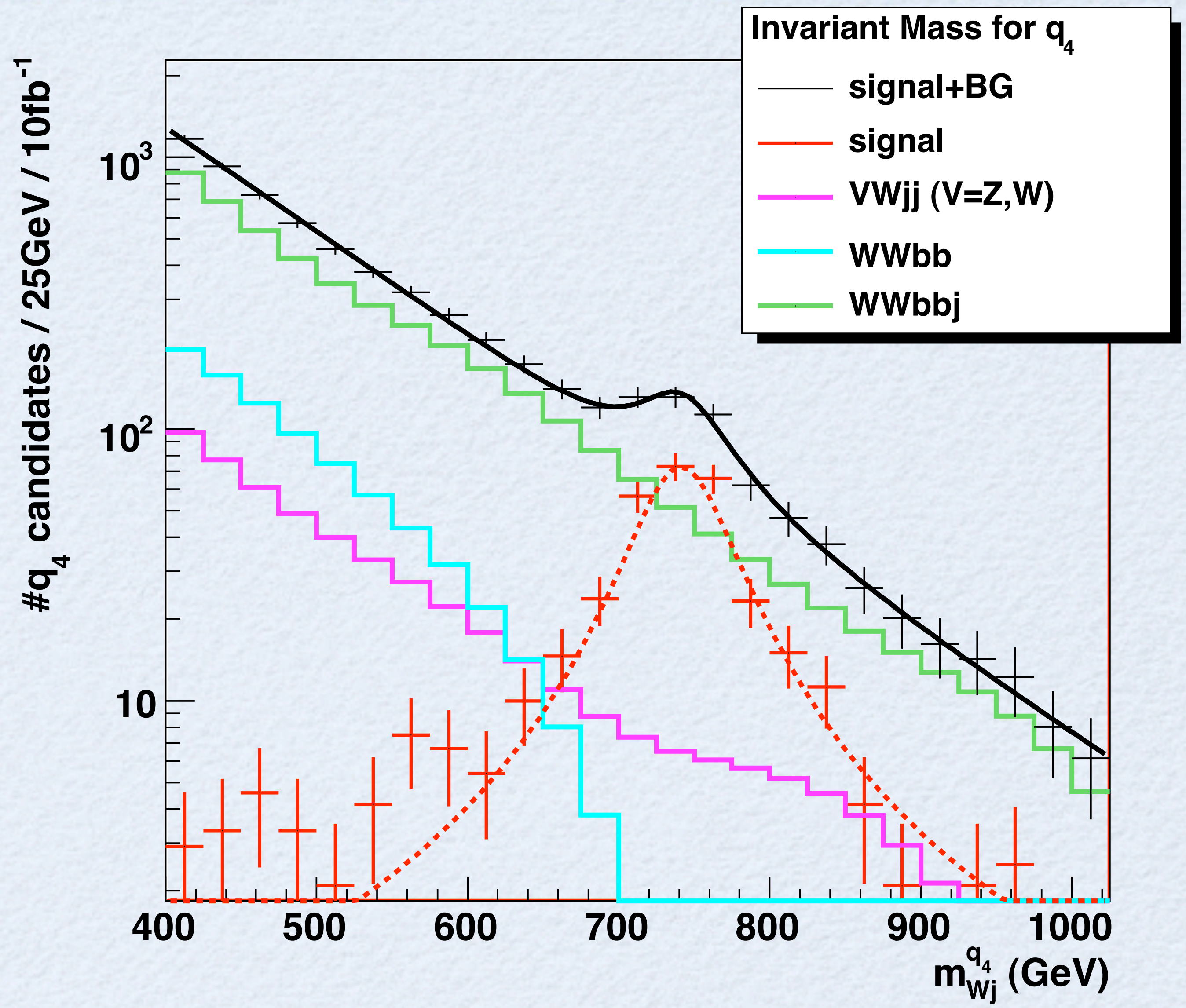




- Primary jets at high P_T, very loose cuts.
- If backgrounds are found to be more significant in data, P_T^{miss} & P_T^{lepton} cuts.
- Ws can be reconstructed from single jet (will recover the long tail in m_{jj} distribution). => *Recently shown to have excellent potential at ATLAS for P_T^W>~250 GeV, + can use jet substructure.*

Results





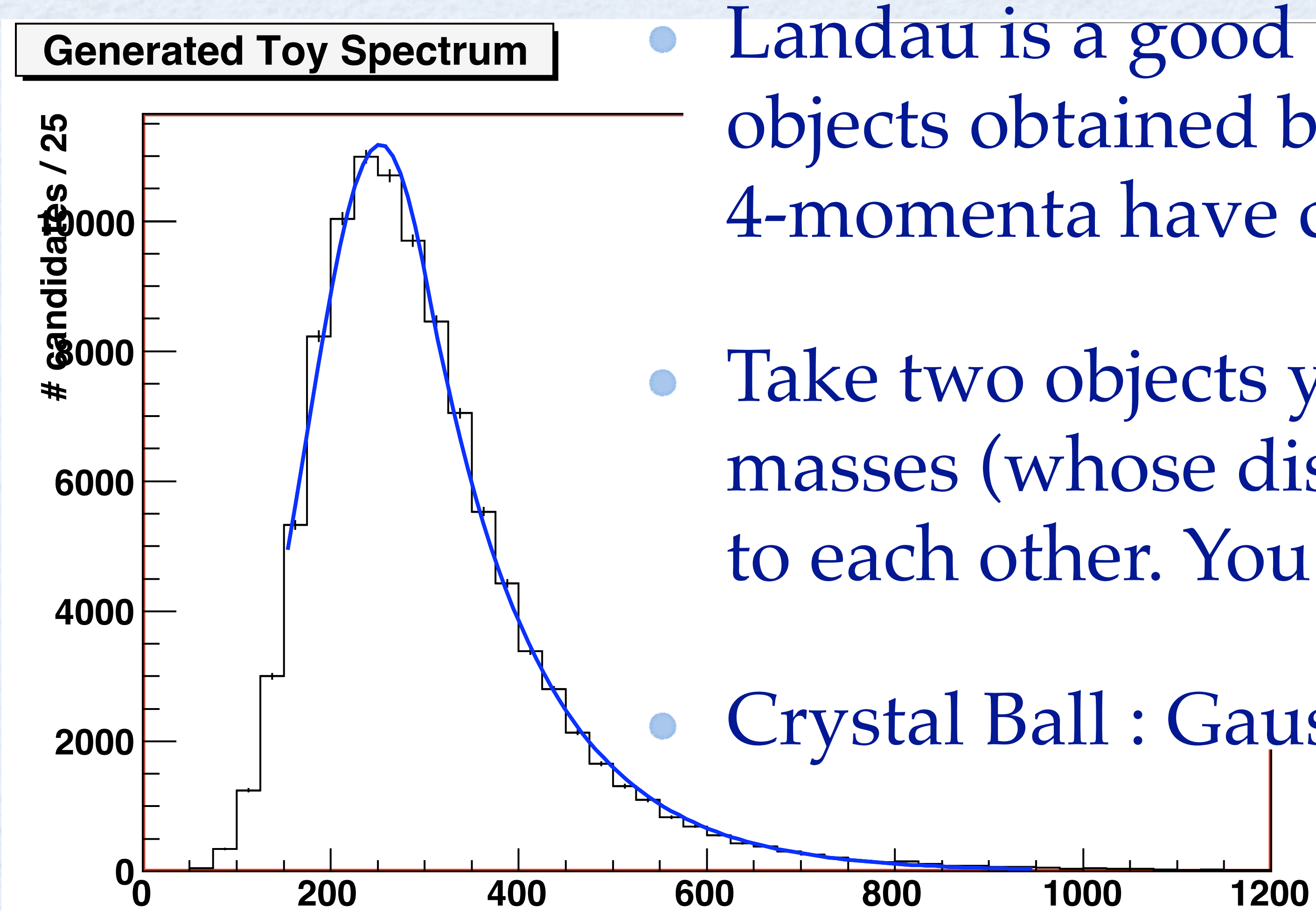
- From each event two q_4 candidates.
- Dominant background from *WbWbj,* other backgrounds an order of magnitude lower.

Fit - Why?

- Obtain a blind method to identify the signal above the background.
  - Blind = With essentially zero human input. Define one procedure to apply and irrespective of the mass of the q_4 candidate, the fit tells you the result. Fit should be robust, ie. no tuning of starting parameters for different q_4 masses.
- Backgrounds are extracted from data, ie. no dependence on background MC systematics. Also robustness against backgrounds not considered.

Fit - How?

- Breit-Wigner for the signal component.
- Crystal Ball for the sum of backgrounds:



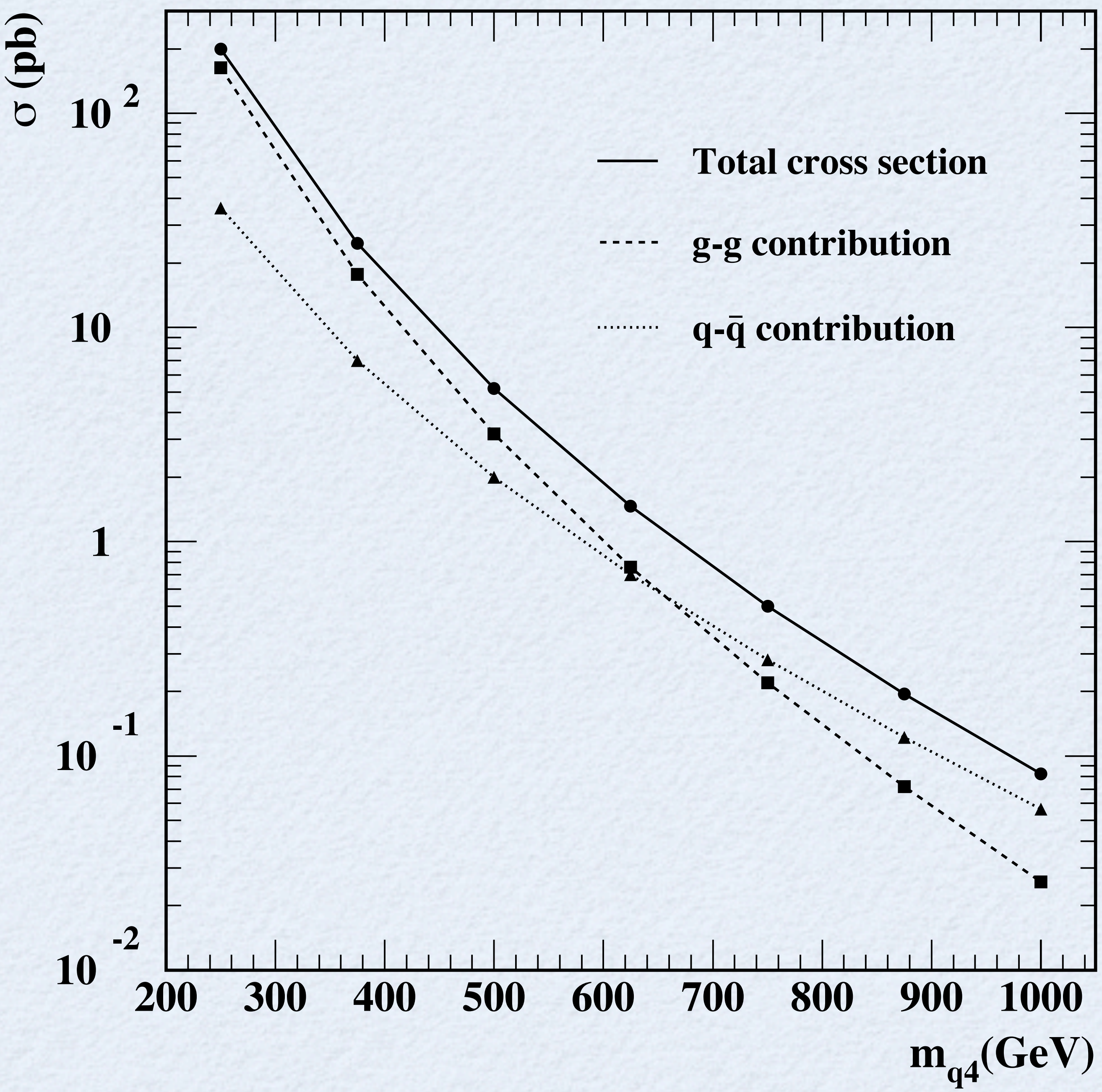
  - Landau is a good empirical definition for mass of objects obtained by adding 4-momenta when the 4-momenta have cuts from below (like min P_T etc).
  - Take two objects you reconstruct. Require their masses (whose distribution is Landau) to be close to each other. You get a “weird” distribution.
  - Crystal Ball : Gaussian + Power law tail. Smooth!

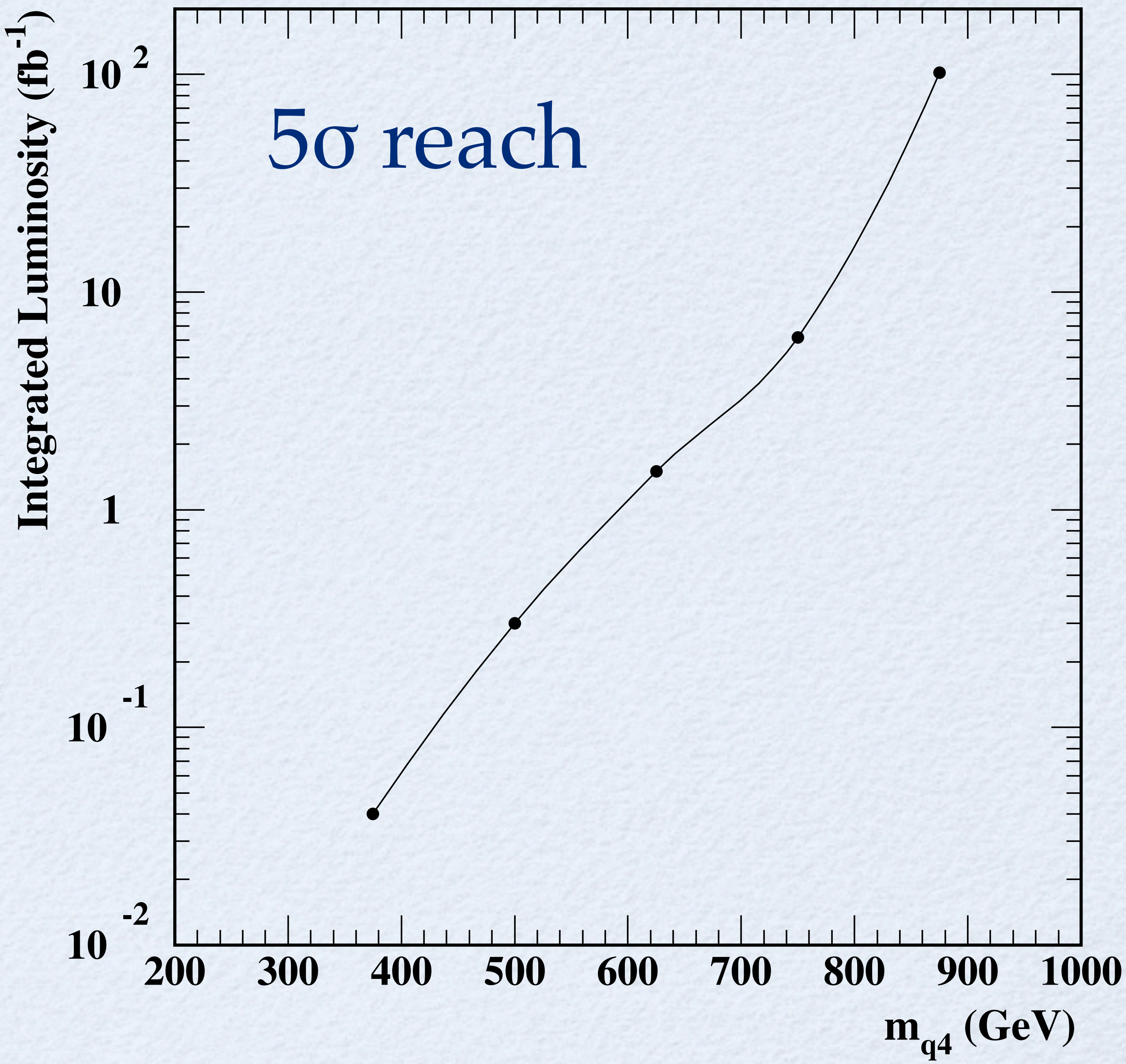
Fit Results

- Extract signal and background by integrating the fit within $\pm 2\Gamma$ of signal BW.
  - Divide by two to get number of events.
  - Fit in very good agreement with real inputs.
- Significance computed as s/sqrt(s+b).
  - Pseudo-MC to check whether reported significances.

	500 GeV	750 GeV
Luminosity	1 fb-1	10 fb^{-1}
Signal	192	134
Background	224	226
Significance	9.2	7.1

Discovery Range





- Reach plot obtained by: integrating BG fit function, extrapolating for signal efficiency and calculating the x-sec as function of mass.

Conclusion

- Recently many similar analyses (ex: search for isosinglet quarks in E6) went through the full-simulation studies and ATLFast results were found to be not too optimistic.
  - Expect the same for 4th-family quarks. Also note that not all ideas exploited yet.
- ATLAS has clear potential for 5σ discovery even with the first ~100pb-1 of data (for m_{q4} ~ 400-500 GeV).

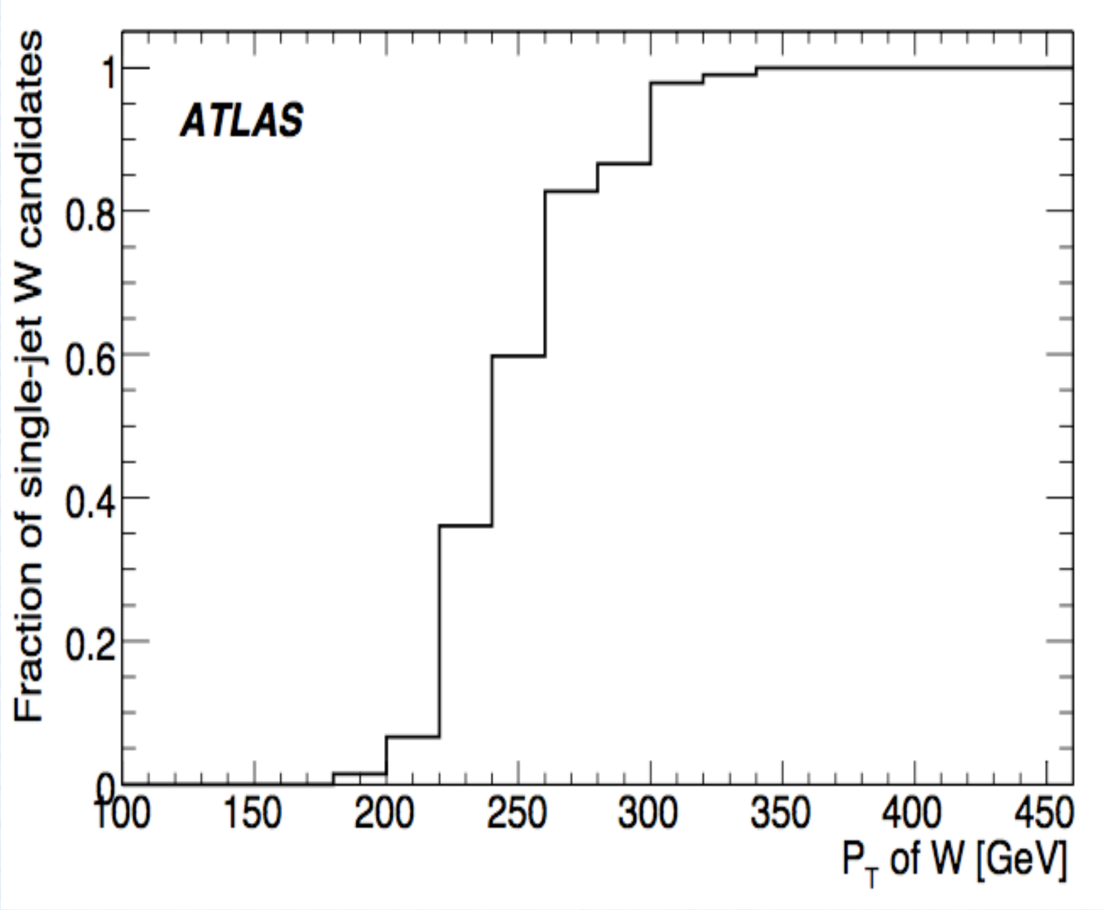
Back-up Slides

Hadronic VBs: 1 or 2 jets

- At high enough P_T, hadronic VB starts to create a single jet.
- So start by looking at each event for jets with mass close to W/Z ?

  Yes: This jet is the VB candidate. Apply cut on jet substructure.

  No: Try reconstructing your W candidates from pairs of jets.



Plot for k_T jets with R=0.6.

Jet Structure

- k_T merging intrinsically ordered in scale.
  - Undo last merging: Get the Y-scale at which the jet would split into two subjets.
  - Y-scale ~ $O(m_{VB}/2)$ ~ k_T of one subjet wrt. other

Butterworth, Ellis, Raklev
hep-ph/0702150