Early SM physics and early discovery strategy in ATLAS

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for the ATLAS Collaboration

- Physics potential of the first few fb^{-1}:
  - – underlying event
  - – PDFs, Z,W production
  - – top measurements
  - – early SUSY discovery
  - – Higgs, Z’ searches

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ATLAS Detector Layout

Inner Detector (ID) tracker:

- Si pixel and strip + transition rad. tracker
- $\sigma(d_0)$ = 15µm@20GeV
- $\sigma/p_T \approx 0.05\% p_T \oplus 1\%$

Calorimeter

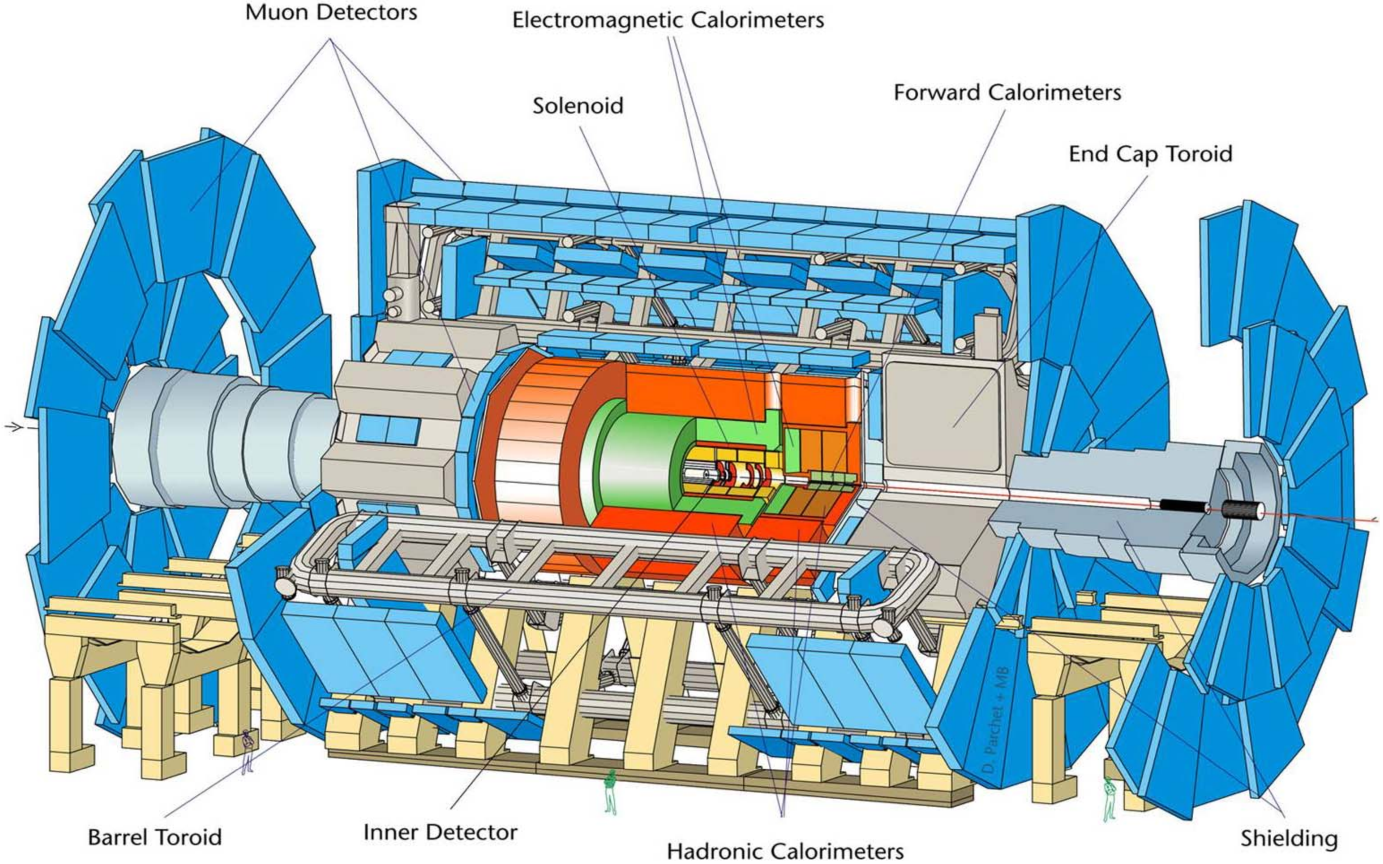
- Liquid Ar EM Cal, Tile Had.Cal
- EM: $\sigma_E/E = 10\%/\sqrt{E} \oplus 0.7\%$
- Had: $\sigma_E/E = 50\%/\sqrt{E} \oplus 3\%$

Muon spectrometer

- Drift tubes, cathode strips: precision tracking +
- RPC, TGC: triggering
- $\sigma/p_T \approx 2\text{-}7\%$

Magnets

- Solenoid (ID) → 2T
- Air toroids (muon) → up to 4T



Full coverage for $|\eta|<2.5$, calorimeter up to $|\eta|<5$

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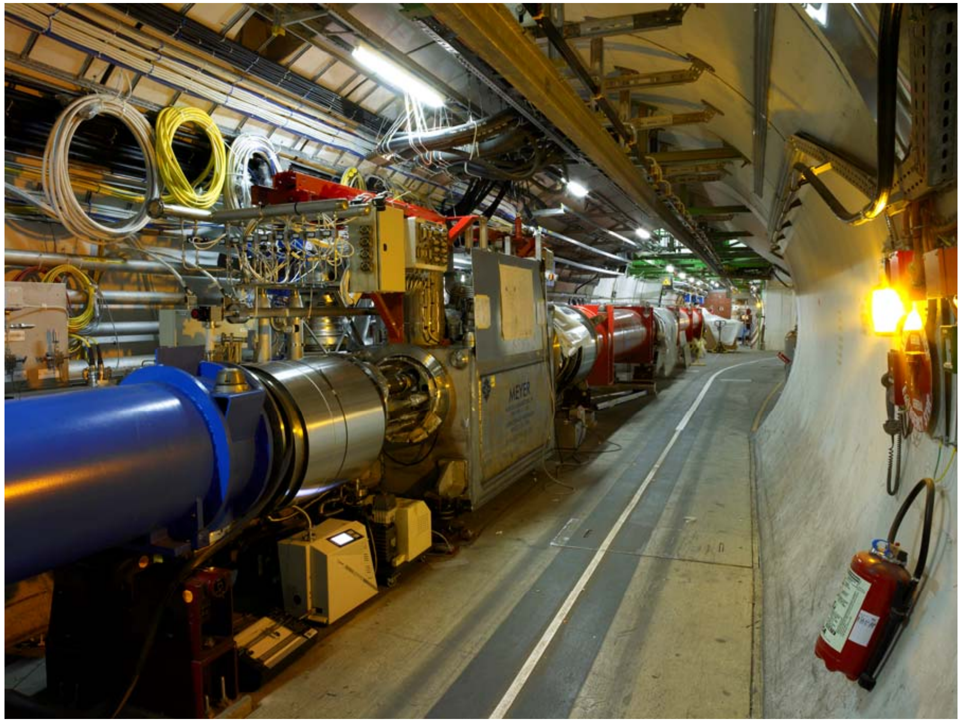
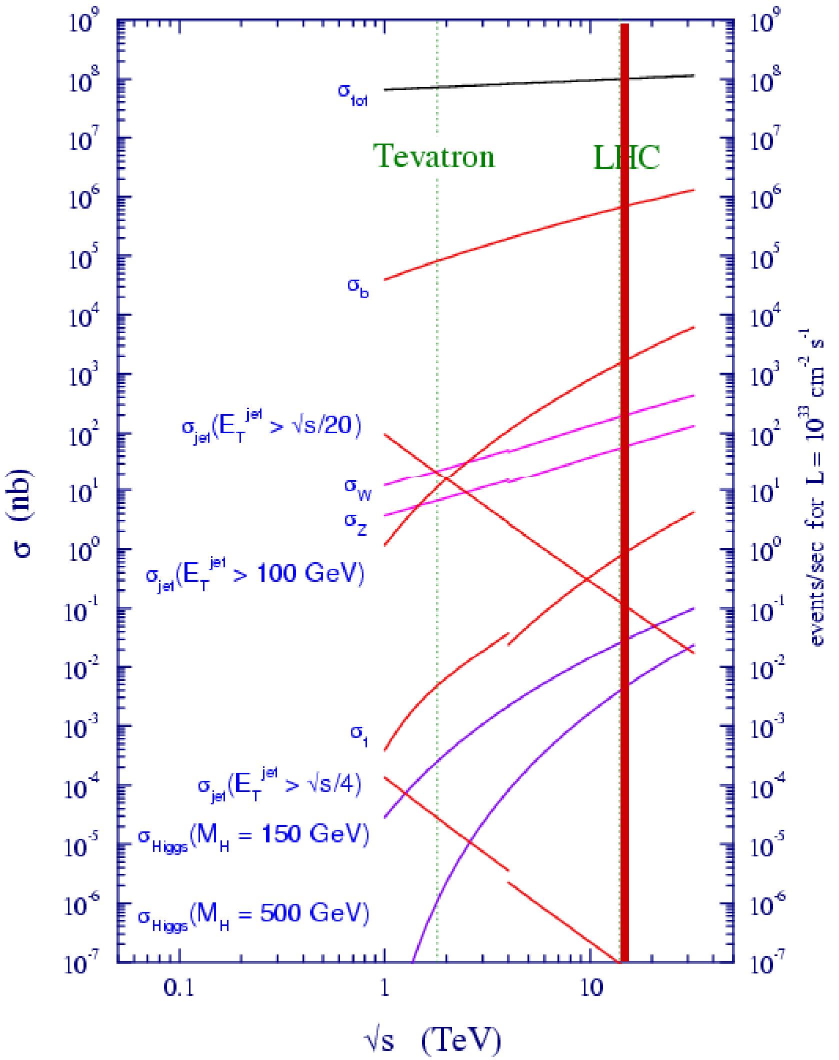
Initial Data Taking

- Full pp-collisions at $\sqrt{s}$=14 TeV from summer 2008 on
- Anticipated luminosity per experiment:
  - 2008 $\mathcal{L} < 10^{33}$ cm^{-2}s^{-1}, integrated by end of year: up to 1 fb^{-1}
  - 2009 $\mathcal{L} = 1 \ldots 2 \cdot 10^{33}$ cm^{-2}s^{-1}, integrated by end of year: up to 10 fb^{-1}



- Will focus on physics which is accessible with a few fb^{-1} or less in this talk

Cross Section and Events Rate

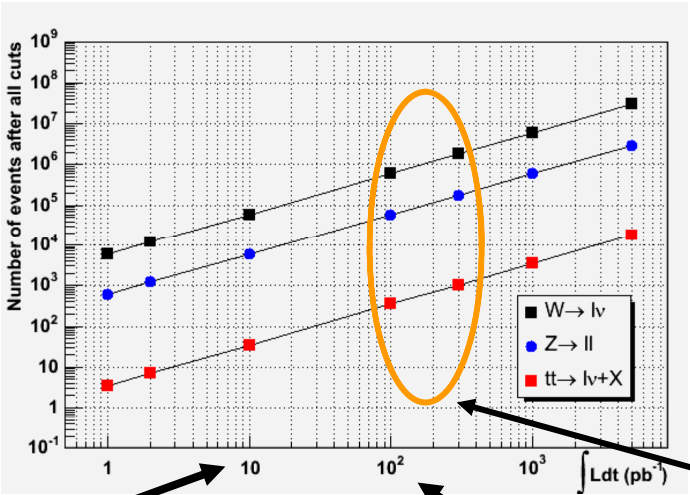


Process	σ(nb)	L=10pb^{-1}	L=10fb^{-1}
Minimum bias	10^8	$\sim 10^{12}$	$\sim 10^{15}$
Inclusive jets – p_T>200GeV	100	$\sim 10^6$	$\sim 10^9$
$W \rightarrow e\nu$	15	$\sim 10^5$	$\sim 10^8$
$Z \rightarrow e^+e^-$	1.5	$\sim 10^4$	$\sim 10^7$
$t\bar{t}$	0.85	$\sim 10^3$	$\sim 10^6$

cross-sections of “basic” hard processes ~1-2 orders of magnitude larger than at Tevatron – can be even more for searches

The First 10-100 pb^{-1}

How many events in the beginning ?



~10 pb^{-1} ≡ 1 month at 10^{30} and < 2 weeks at 10^{31}, ε=50%

100 pb^{-1} ≡ few days at 10^{32} , ε=50%

statistics similar to CDF, D0 today

- Assumed selection efficiency:
W→ ℓν, Z→ ℓℓ : 20%
tt → ℓν+X : 1.5% (no b-tag, inside mass bin)

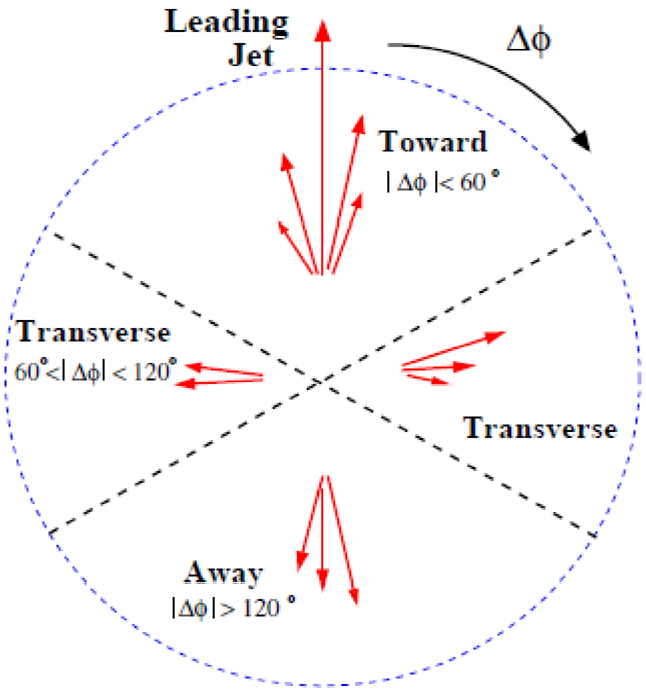
- lots of minimum-bias and jets (10^{7} events in 2 weeks of data taking if 20% of trigger bandwidth allocated)

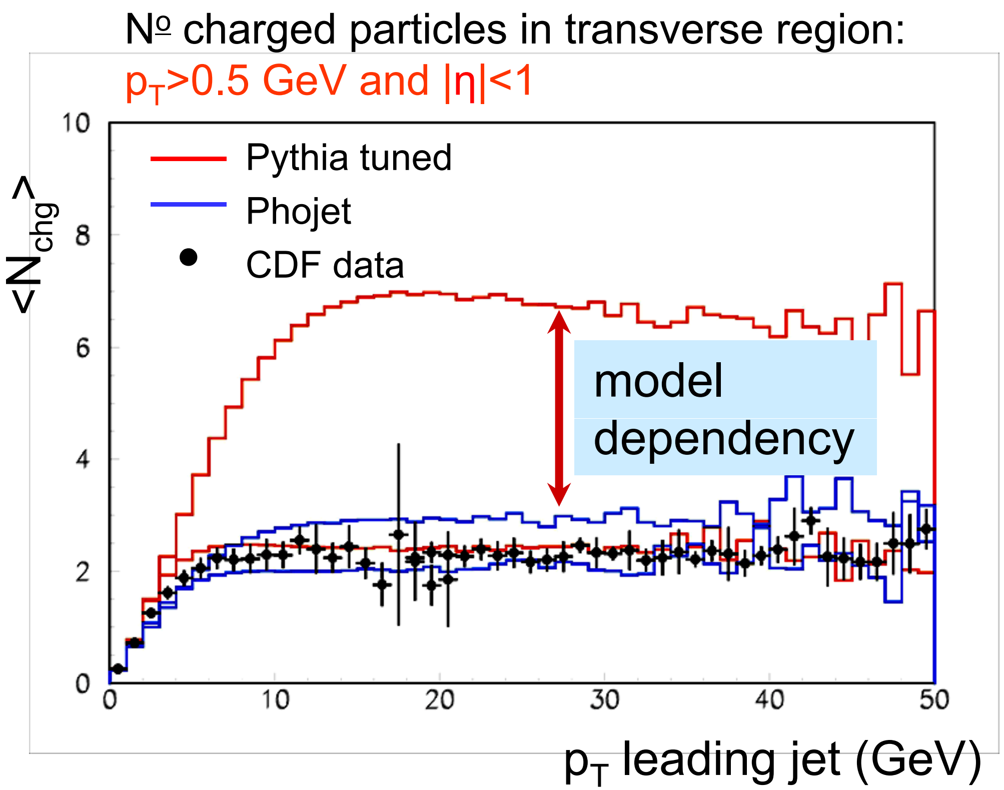
LHC is a W,Z,top factory:

- small statistical errors in precision measurements
- can search for rare processes
- large samples for studies of systematic effects

Underlying Event

region transverse to the leading jet: particles come from underlying event





Underlying event also uncertain at LHC :

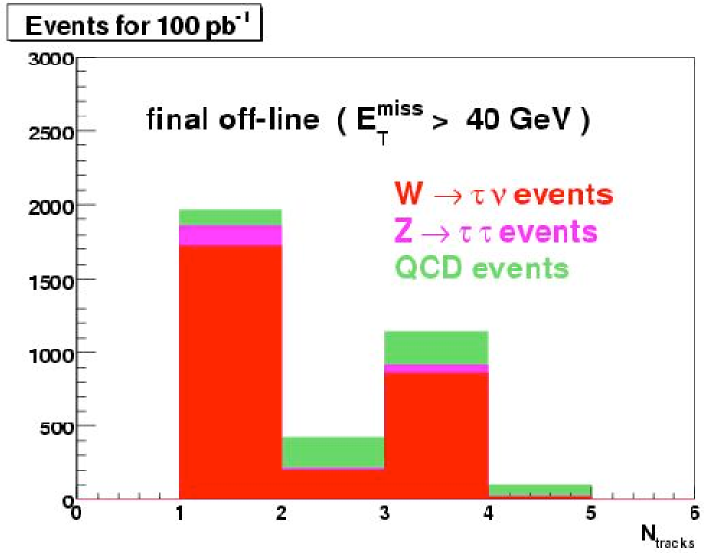
- Depends on: multiple interactions, PDFs, gluon radiation
- Important ingredient for isolation of jets and leptons, energy flow, jet tagging …

Z and W Production

- Low luminosity runs ($\mathcal{L}$=0.5 10^{30} - 10^{33} $cm^{-2}s^{-1}$) → trigger early on large samples of SM candles :
  - $Z \rightarrow \ell\ell$
  - $W \rightarrow \ell\nu$

  ℓ = e/μ but also τ (hadronic τ + E_T^{miss} trigger)

- Energy and momentum scale calibration from $Z \rightarrow \ell\ell$ (ℓ = e/μ)
- E_T^{miss} calibration from $W \rightarrow \mu\nu$ and $Z \rightarrow \tau\tau$
- Understand W+jets and Z+jets:
  - important background for searches
- Measure the $W \rightarrow \tau\nu$ cross section:
  - validation of τ-ID needed for searches



Signal evidence through N_{track} spectrum after selection:

- τ trigger
- full off-line τ-ID
- E_T^{miss} cut

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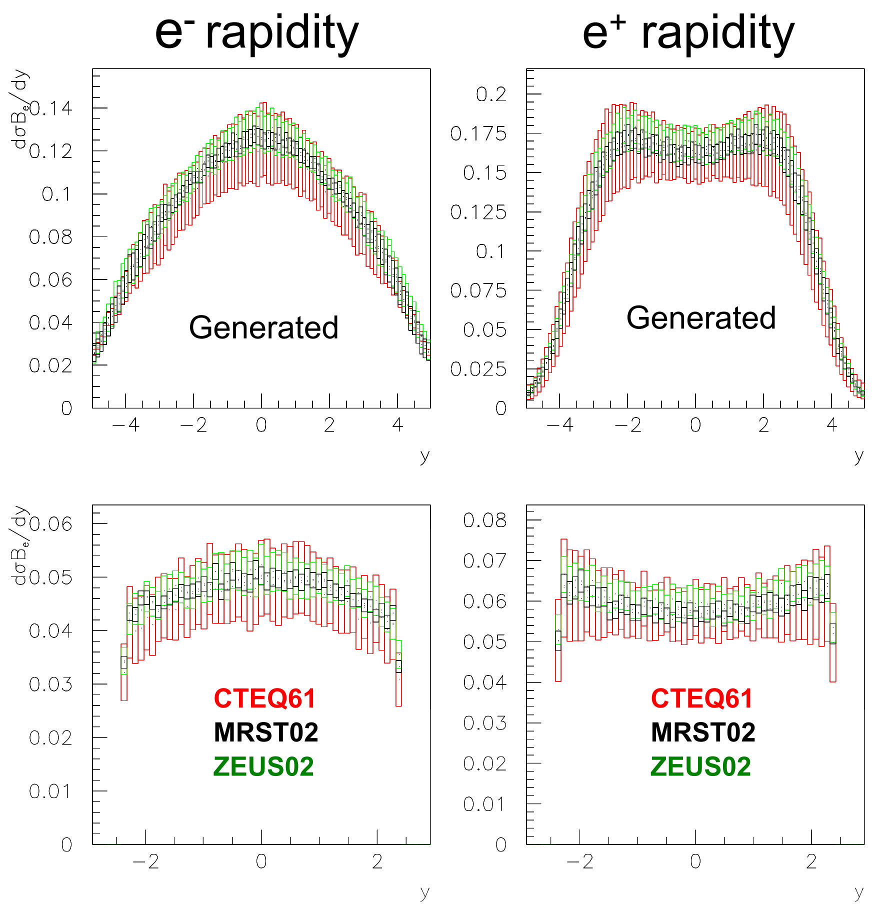
W Rapidity

- Constrain PDF using $W \rightarrow \ell\nu$ ATLAS early data

$$u\bar{d} \rightarrow W^+ \rightarrow e^+\nu$$

$$d\bar{u} \rightarrow W^- \rightarrow e^-\bar{\nu}$$

  – $e^{\pm}$ rapidity spectrum shape: sensitive to gluon shape parameter - valence quark density
- Probe low-x gluon PDF at $Q^2=M_W{}^2$



The selection:

- Isolated electron p_T>25 GeV, |η|<2.4
- E_T^{miss}>25 GeV
- no jets with E_T>30 GeV
- p_T^{recoil}<20 GeV
- BKG <1% W/Z→τ, Z→e^+e^-, QCD

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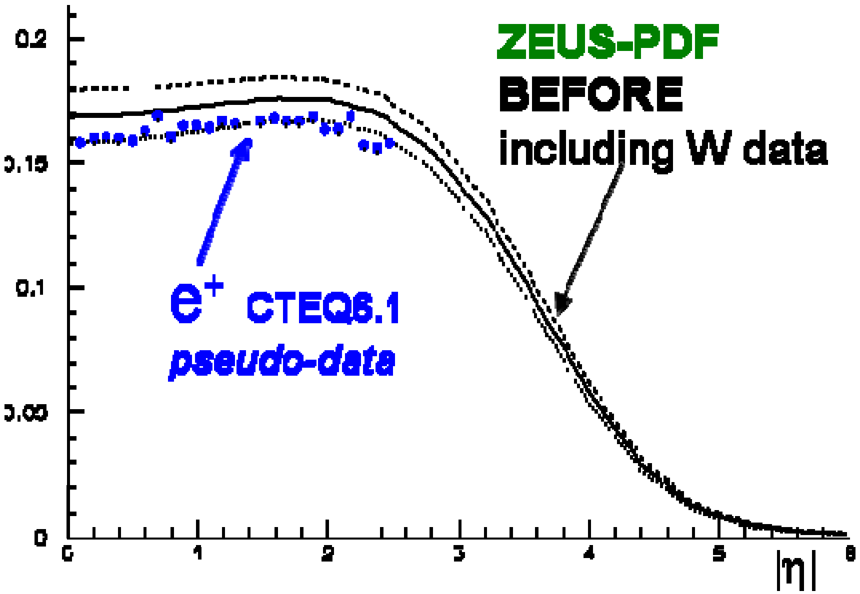
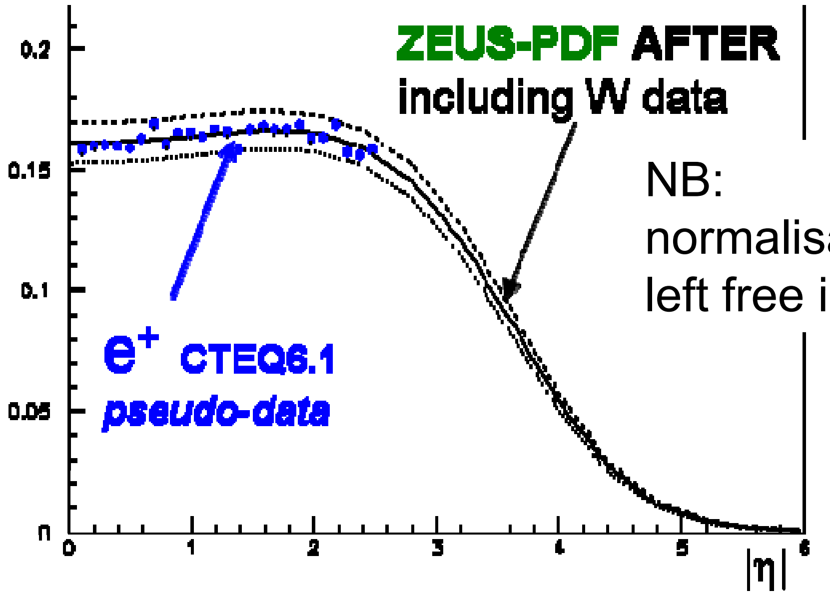
W Rapidity

1M simulated(CTEQ6.1) pseudo-data sample
(~100pb^{-1}) including 4% sys. error



λ = -0.199±0.046



NB:
normalisation
left free in fit

λ = -0.181±0.030

for $xg(x) = x^{-\lambda}$

Central value of ZEUS–PDF prediction shifts and reduced error on low-x gluon shape parameter λ by 35%

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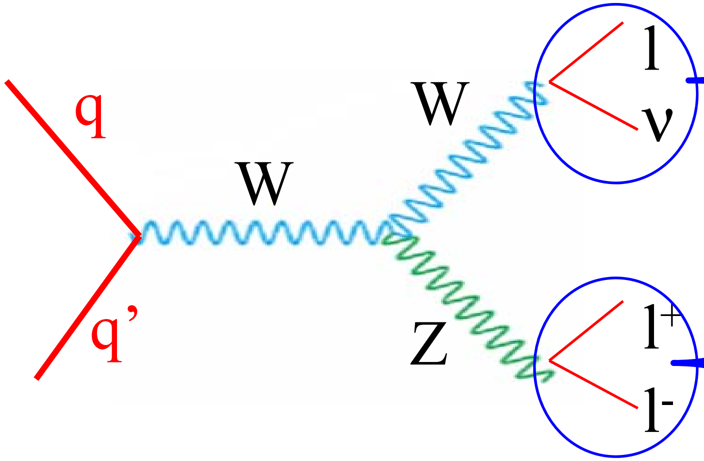
WZ Production at Low Luminosity



- $40 < M_T(W) < 120$ GeV
- $E_T^{Miss} > 25$ GeV

- $|M(\mu^+\mu^-) - M_Z| < 12$ GeV
- $|M(e^+e^-) - M_Z| < 9$ GeV

	N_{eee}	$N_{ee\mu}$	$N_{\mu\mu e}$	$N_{\mu\mu\mu}$	N_{total} ($1fb^{-1}$)
N_{signal}	16.9	17.1	21.9	19.8	75.7
N_{bkg}	1.97	0.91	2.35	2.25	7.47
S/B	8.57	18.9	9.33	8.80	10.13
$S/\sqrt{B}$	12.0	18.0	14.3	13.3	27.7

Background Contribution

Channel	Z+jet	ZZ→4l	Zγ	DY
Contribution(%)	45	40	10	5

Signal can be observed with $1fb^{-1}$

→ probe gauge coupling

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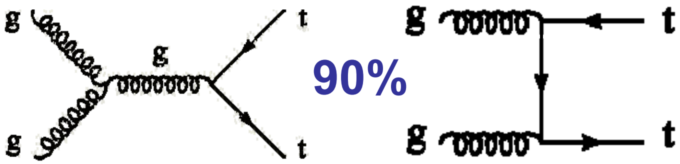
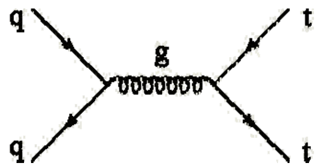
Top Production and Decay at LHC



90%



10%

σ_{tt}(LHC) ~ 830 ± 100 pb

→ millions of top quarks produced at LHC

Cross section LHC = 100 x Tevatron
Background LHC = 10 x Tevatron

↓

BR (t→Wb) ~ 100 %

↓ W→eν, μν, **qq**

$t\bar{t}$ final states (LHC,10 fb^{-1})

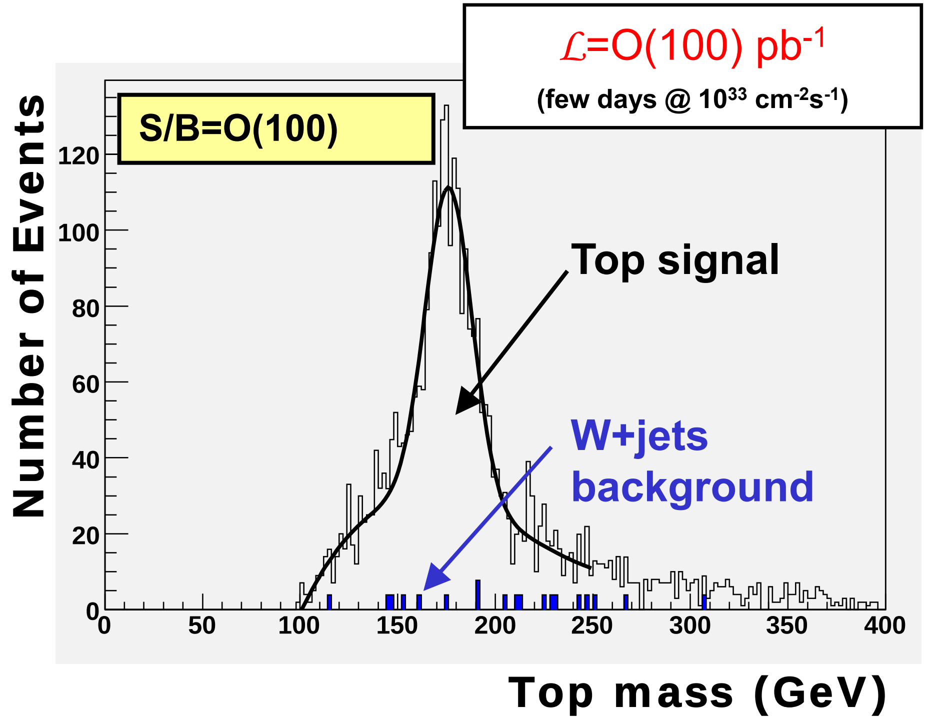
- Full hadronic **(3.7 M)** : 6 jets
- Semileptonic **(2.5 M)** : ℓ + ν + 4jets
- Dileptonic **(0.4 M)** : 2ℓ + 2ν + 2jets

→ **Golden channel**

(early physics, precision meas.)

Top Measurements (<1 fb^{-1})

…with b-tag



Selection:

- 1 Lepton
- missing E_T
- 4 (high-P_T)-jets (2 b-jets)

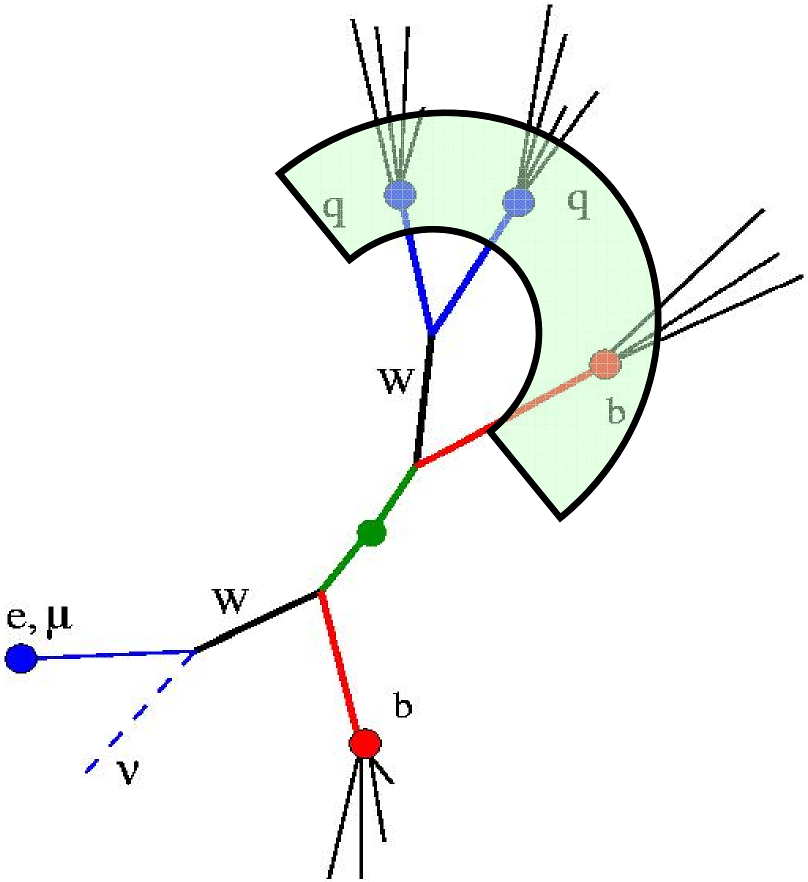
→ signal efficiency few %
→ *very* small SM background

- 'Standard' Top physics at the LHC:
  - b-tag is important in selection;
  - most measurements limited by systematic uncertainties
- 'Early' top physics at the LHC:
  - cross-section measurement (~ 20%)
  - production & decay mechanisms (spin)

Top Measurements (<1 fb^{-1})

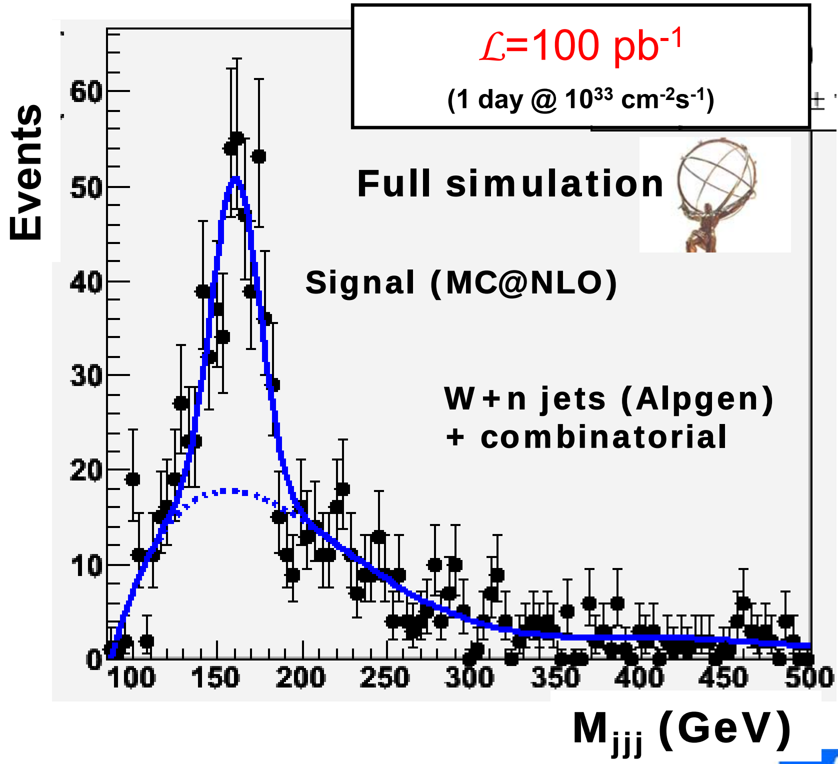
…without b-tag – b-tag might not be well understood on day one

Event toplogy: 3 jets with highest $\sum p_T$



Event selection:

- 4 jets p_T> 40 GeV
- Isolated lepton : p_T> 20 GeV
- missing E_T > 20 GeV



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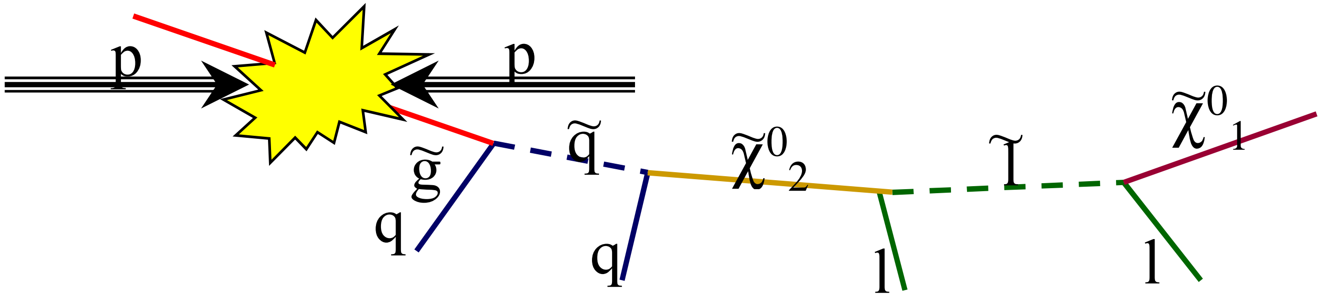
Top Measurements (<1 fb^{-1})

- Feedback on MC description and detector performance:
  - b-tagging
  - calibrate calorimeter energy jet scale ($W \rightarrow jj$ from $t \rightarrow bW$)

- With 30pb^{-1} data, δm_{top} ~ 3.2 GeV
  sys. error dominated: FSR, b-jet energy scale → those 30pb^{-1} must be well understood (ie actually need more data)!

SUSY Signatures



- Strongly interacting sparticles (squarks, gluinos) dominate production
  - ~100 events per day (for squark/gluino masses of ~1TeV at 10^{33} $cm^{-2}s^{-1}$)
  - Discovery possible with only 1 fb^{-1}
- Heavier than sleptons, gauginos etc. → cascade decays to lightest SUSY particle (LSP)
- Long decay chains and large mass differences between SUSY states
  - Many high p_T objects observed (leptons, jets, b-jets)
- If R-Parity conserved LSP (lightest neutralino in mSUGRA) stable and sparticles pair produced
  - Large E_T^{miss} signature
- Largest physics background is neutrino emission (eg Z→νν)

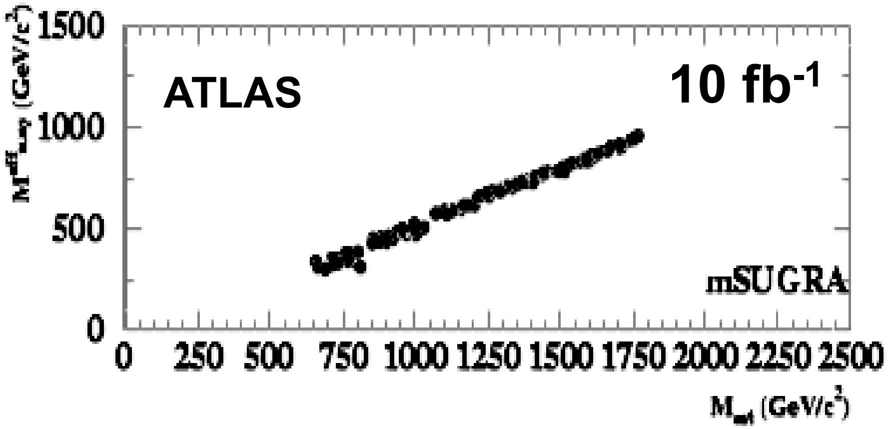
SUSY Mass Scale

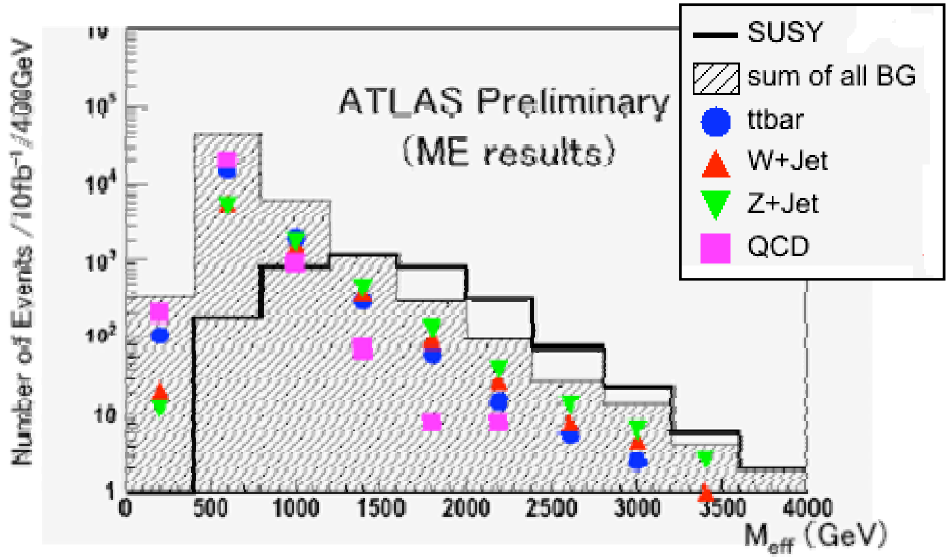
Look at hardest jets/leptons

$M_{eff}=\Sigma|p_T^i| + E_T^{miss}$

Distribution peaked at ~ twice SUSY mass scale for signal events.

- Previously: Monte Carlo generators with parton shower only
  - Cover high p_T region of phase space badly (fewer jets generated there)
- Need high p_T jets for SUSY analysis
  - Use newer matrix element-parton shower matching Monte Carlos





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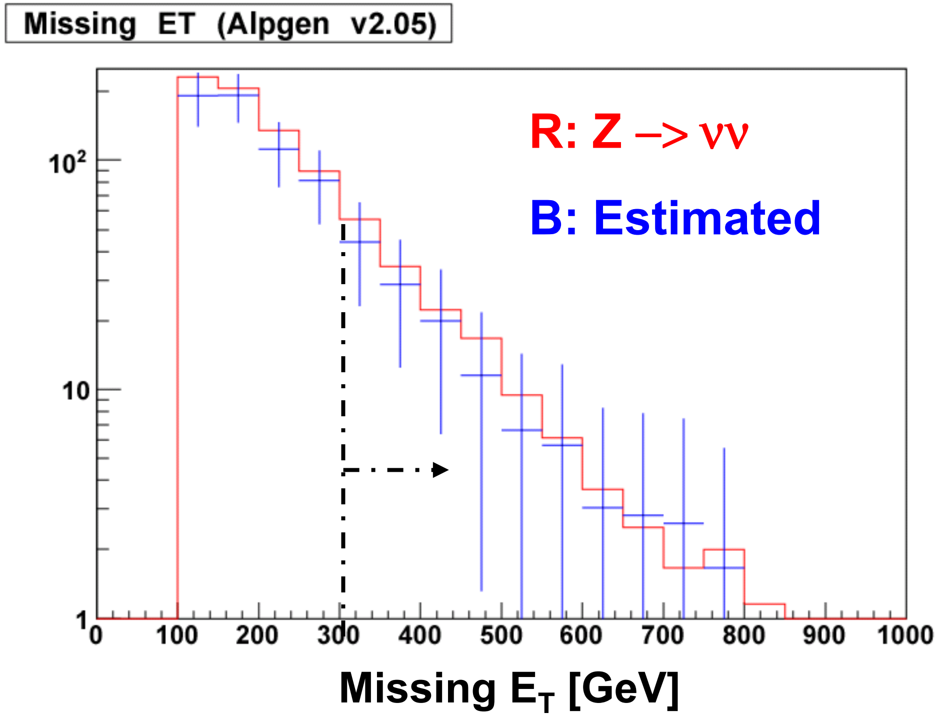
$Z \rightarrow \nu\nu$ Missing E_T Distribution



blue distribution is obtained from $Z \to \mu\mu$ events

Muon reconstruction efficiencies and Z decay branching fractions are considered

Number of events ($E_T$miss > 300GeV)

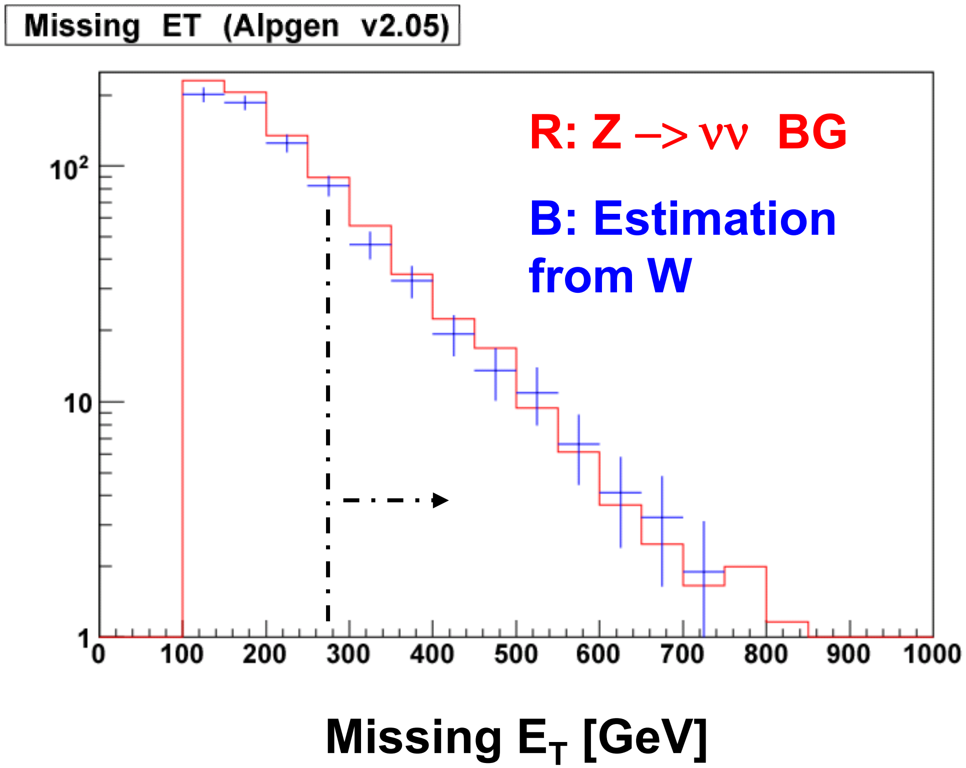
157 ± 13 ($Z \to \nu\nu$)

142 ± 39 ($Z \to \mu\mu$)

Estimation is successful,

but statistics is limited

Estimation from W+jets



Number of Event ($E_T$miss > 300GeV)

157 ± 13 (Z –> νν)

134 ± 10 (W –> μν)

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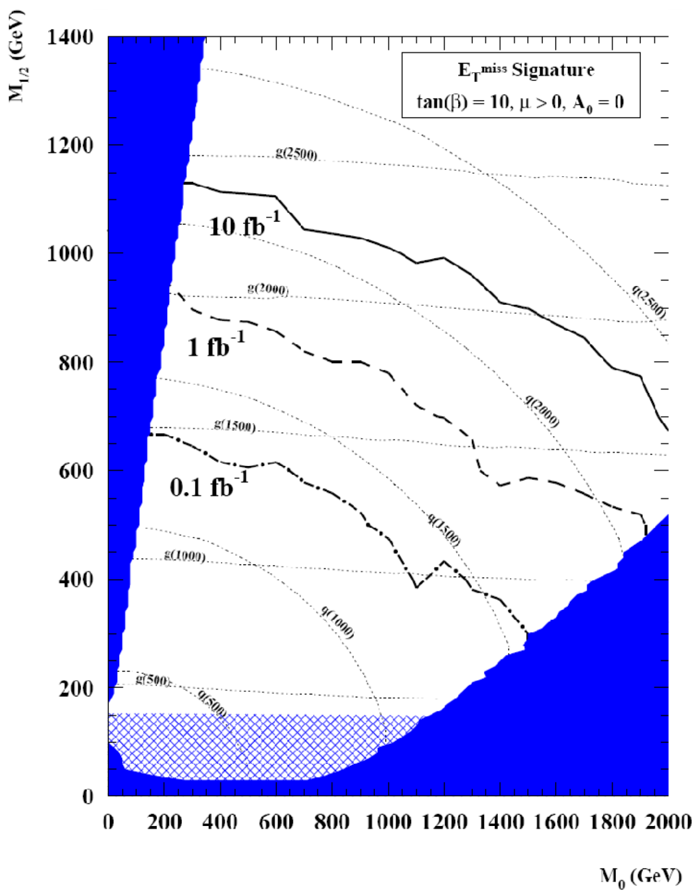
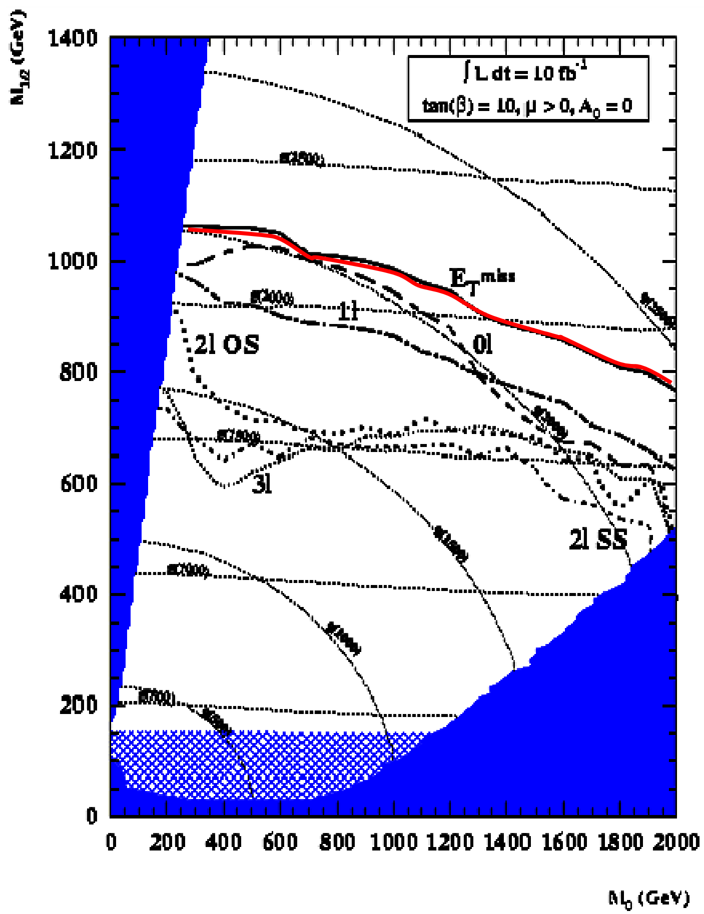
SUSY Reach



Discovery reach as a function of integrated luminosity in mSUGRA parameter space for E_T^{miss} channel



Discovery reach for multiple signatures: cover most of parameter space with $10fb^{-1}$

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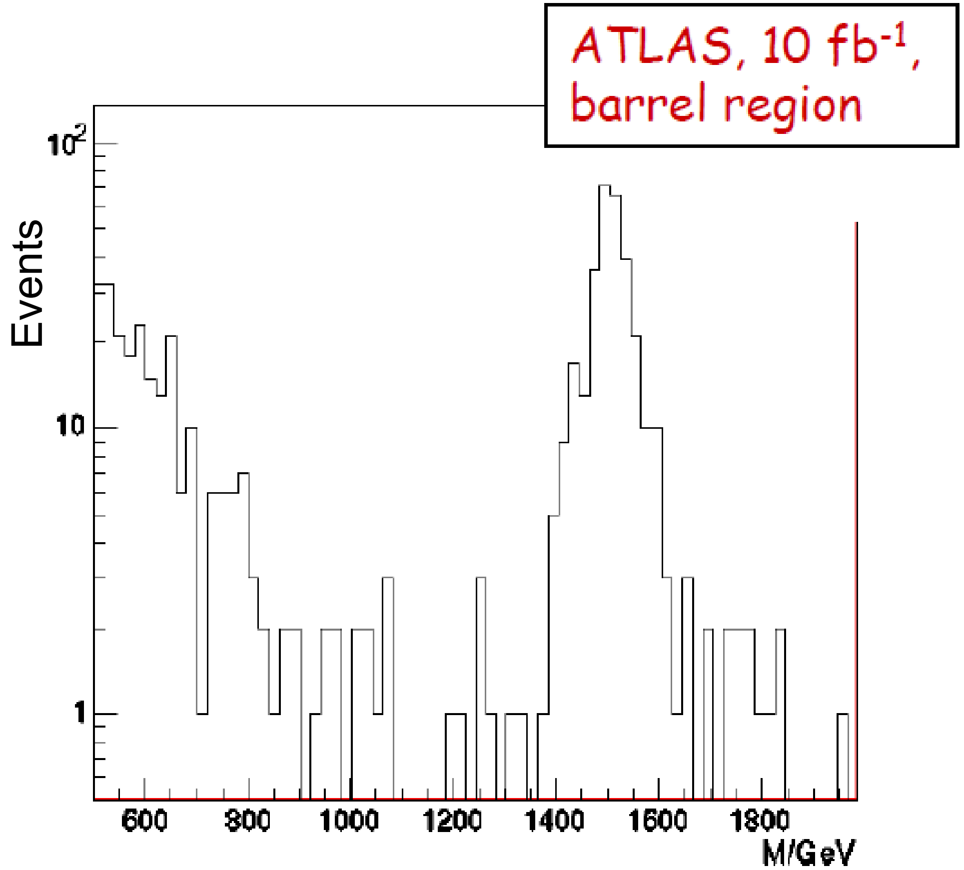
Di-Lepton Search

- Z': new heavy neutral gauge bosons
- Expected in new physics: GUT, dynamical EWSB,…
- Current mass limit (CDF) $m_{Z'}$>850GeV
- Di-lepton (e^+e^- or $\mu^+\mu^-$) resonance with $m_{Z'}=\mathcal{O}(1\ \text{TeV})$

  → large mass peak above low background:
  - Mostly Drell-Yan (irreducible)
  - ZZ, ZW, WW, tt
- Expect $Z'\rightarrow e^+e^-$ to be better than $Z'\rightarrow\mu^+\mu^-$ (better resolution of calorimeter at high energy)



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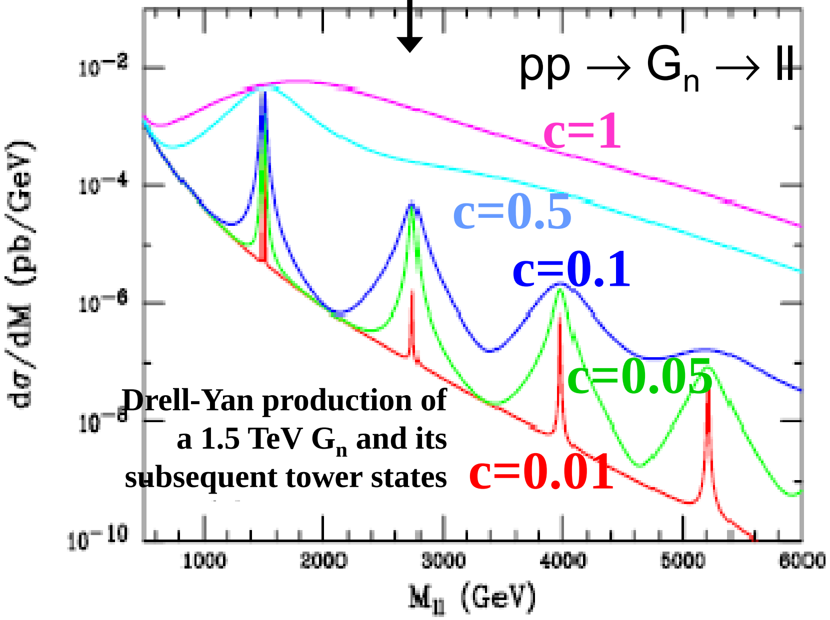
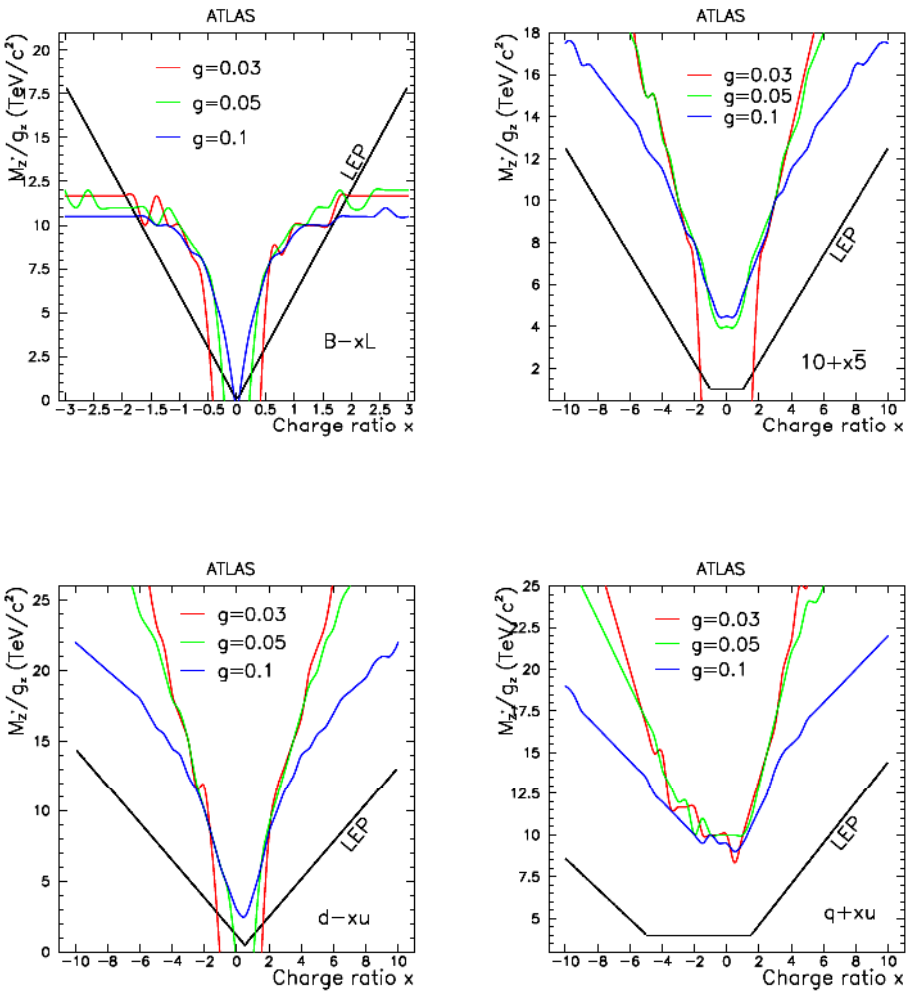
Di-Lepton Search

- Few 100pb^{-1} enough to discover for $m_{Z'}$~1 TeV
- Di-Lepton search:
  Generally good channel for searching new physics with low luminosity data
  - eg Randall-Sundrum excitations



ATLAS reach for 400pb^{-1}



rel. coupling strength to fermions

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Light SM Higgs

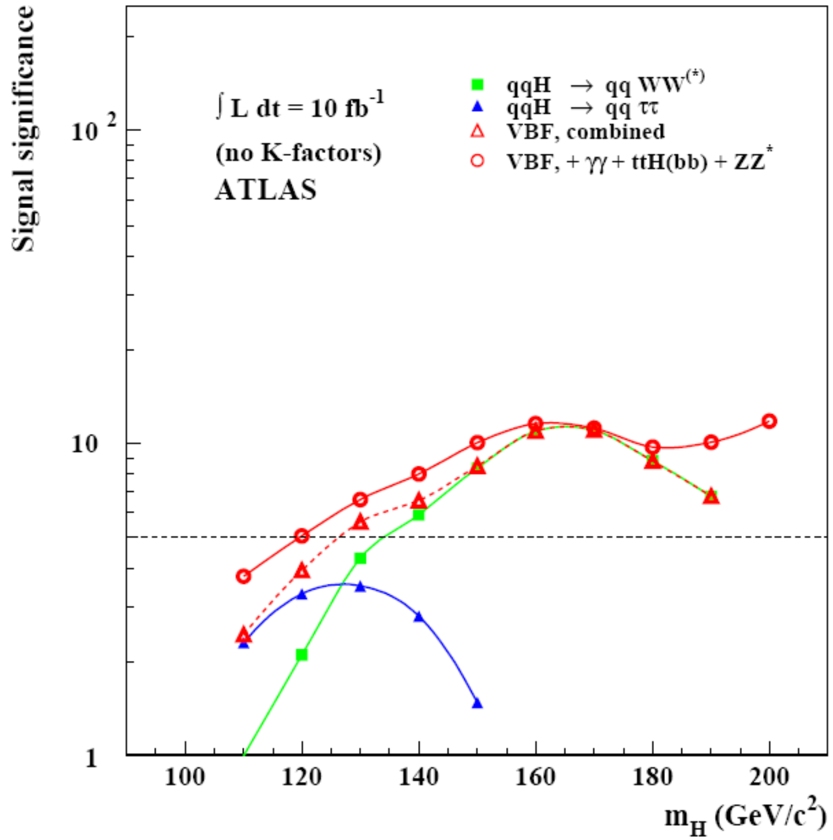
ATLAS with $10fb^{-1}$:

5σ significance for $m_H \geq 120$GeV

Important channels:

- $H \to \gamma\gamma$
- ttH, $H \to bb$
- qqH, $H \to \tau\tau$
- qqH, $H \to WW^{(*)}$
- $H \to ZZ^{(*)}$, $Z \to 4\ell$

Relies on very good detector & background understanding



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Summary

First physics at 14 TeV starting summer 2008 will allow to study on few fb^{-1}…

- Standard Model physics:
  - Underlying event, min. bias, QCD (see next talk)
  - W, Z production:
    - Use for detector, MC understanding
    - Improve knowledge of PDFs
  - Di-boson production: probe gauge coupling
  - Measure top events, use for calibration
- First searches:
  - Probe SUSY in the ~ 1 TeV scale
  - Look for di-lepton resonances
  - If lucky, discover Higgs (might need more luminosity)