Signals of Parity Restoration at ATLAS and CMS

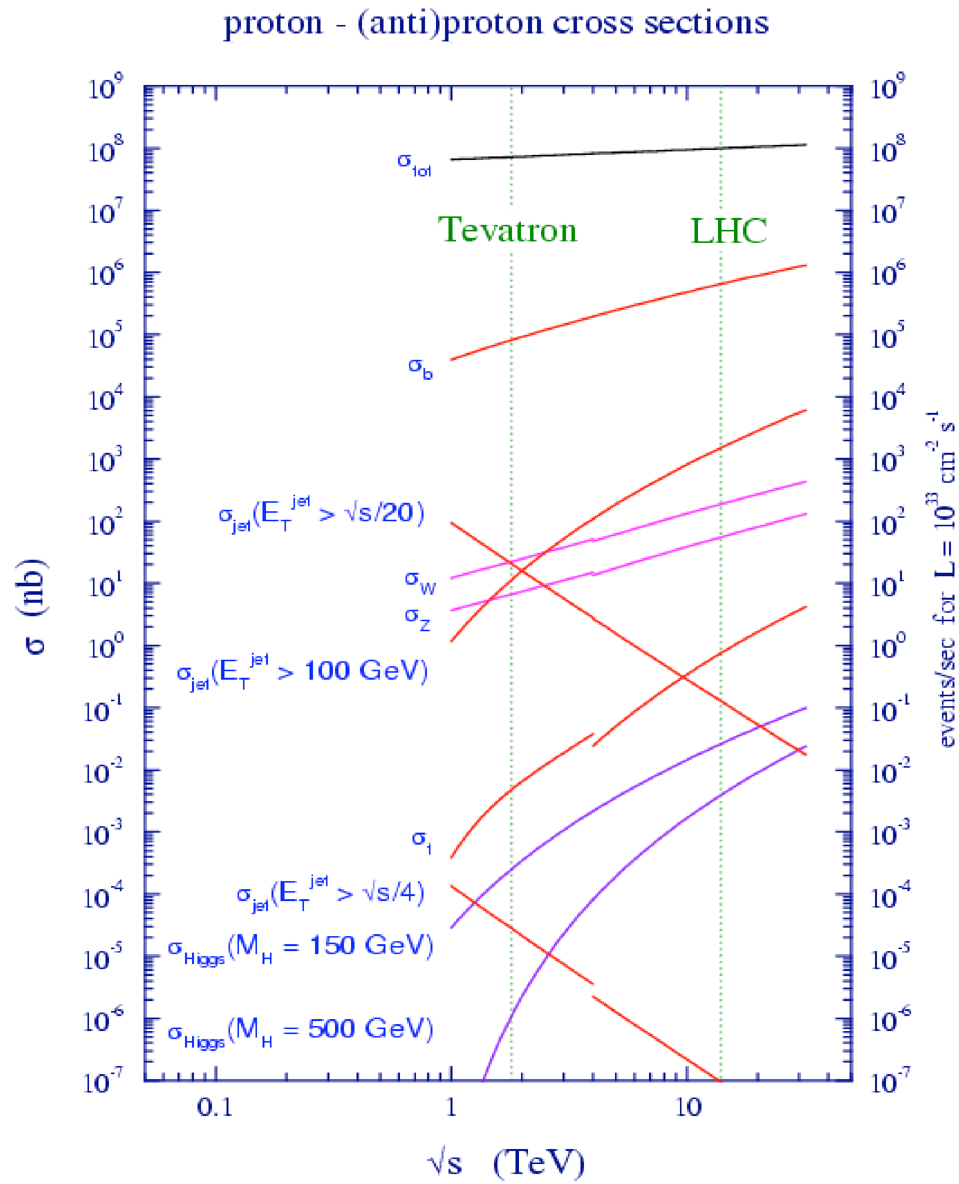
Gustaaf Brooijmans

Columbia University in the City of New York

for the ATLAS and CMS Collaborations

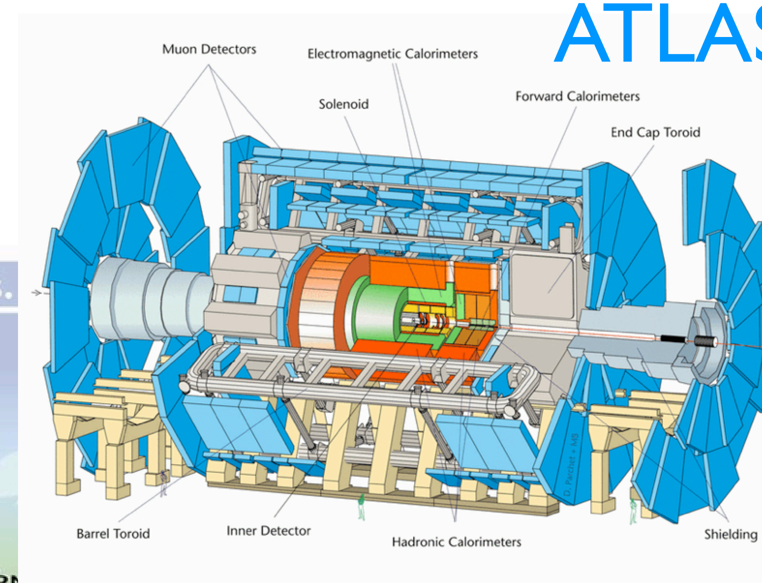
The LHC

- 14 TeV p-p
  - At this energy, contribution of sea quarks/gluons to collisions very important, no need to produce antiprotons
- At design luminosity, 20 interactions every 25 ns
- New energy domain, and very high luminosities
  - ~100 x Tevatron

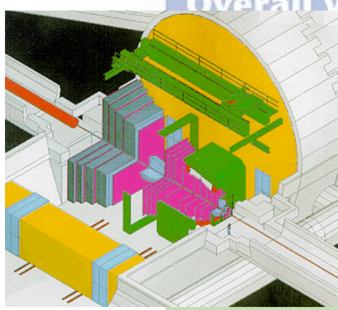


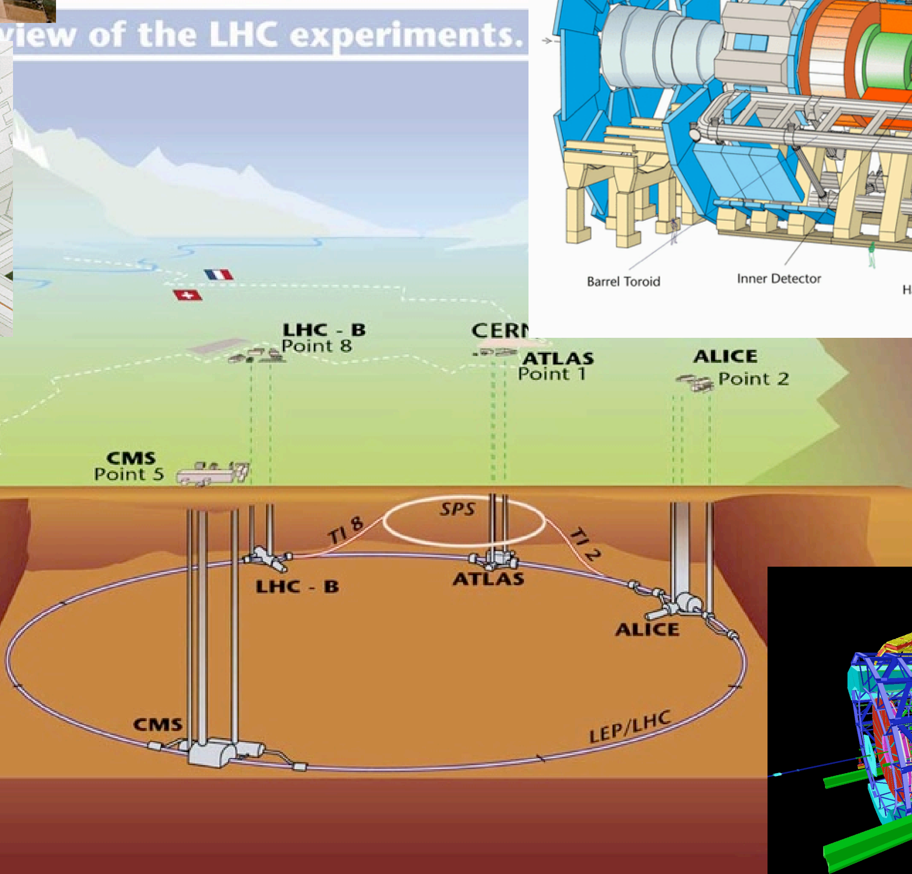
The LHC(2)

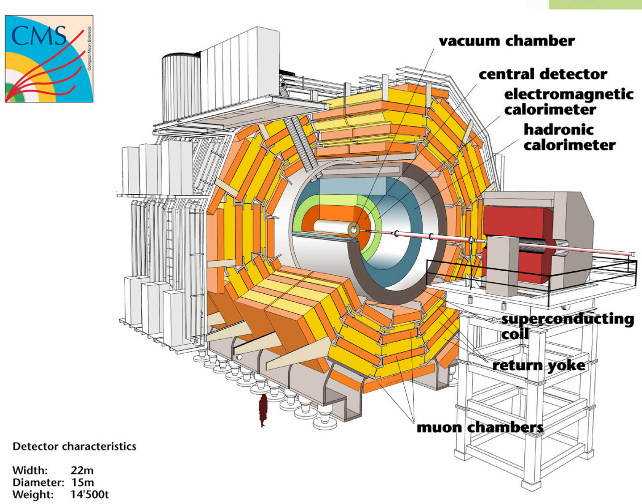
ATLAS

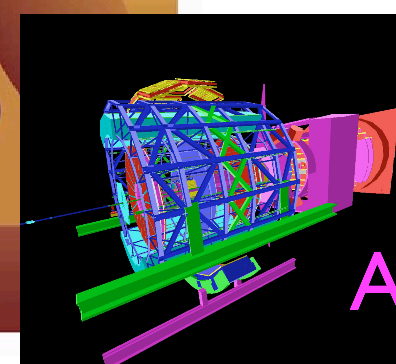


LHCb





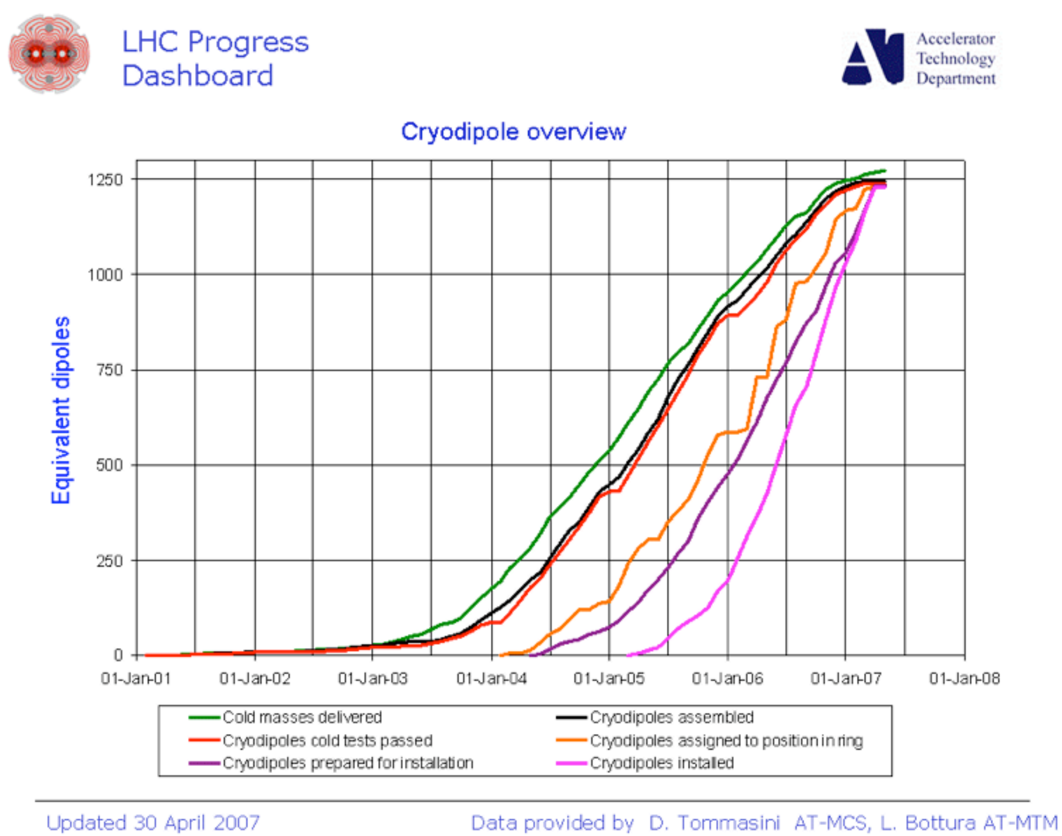




Alice

LHC Milestones

Last Magnet Lowered in Tunnel

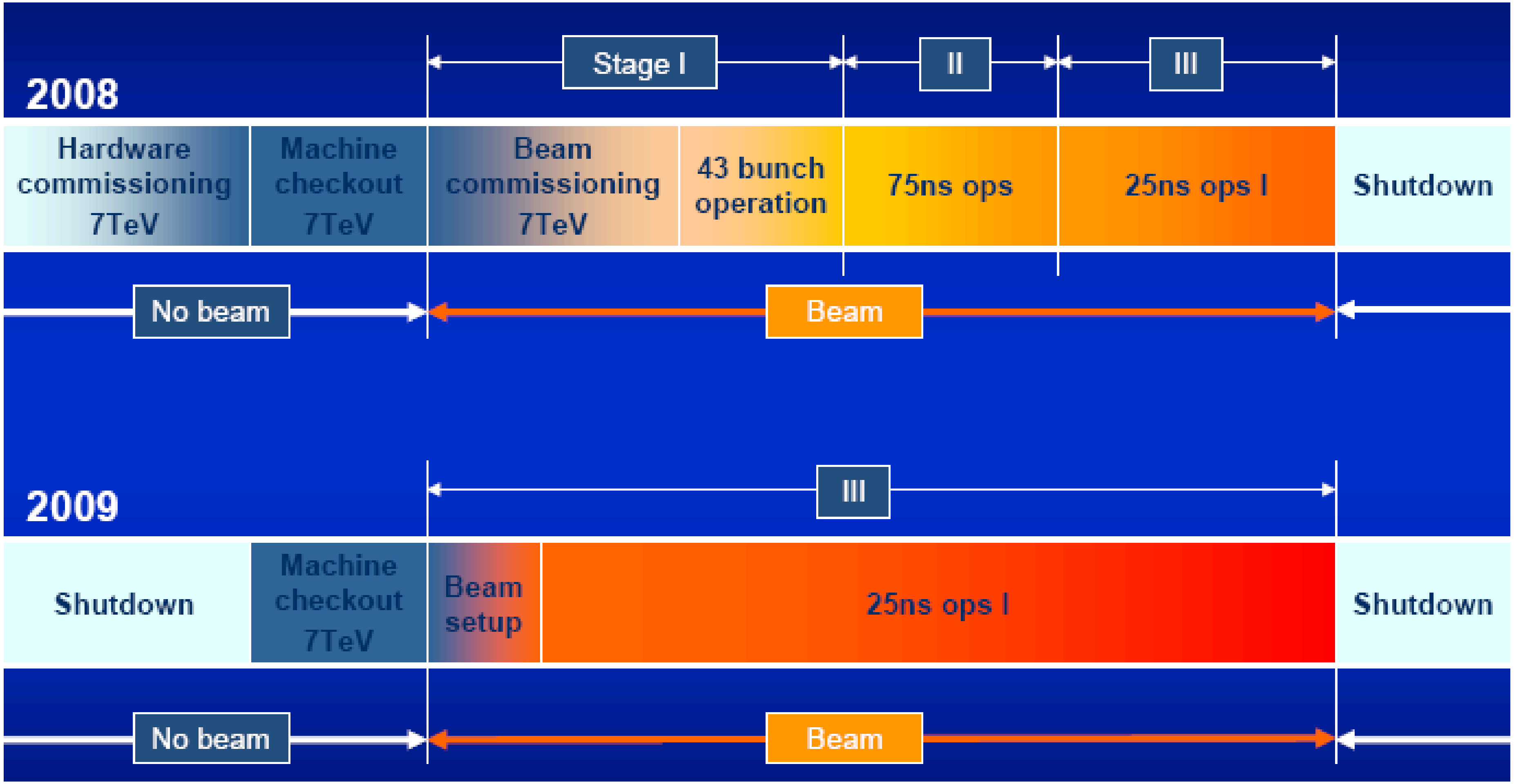


Interconnecting Last Sector

LHC Schedule

- First collisions @ 14 TeV in summer 2008
- ≥ 1 fb^{-1} in 2008, 5 fb^{-1} (?) in 2009

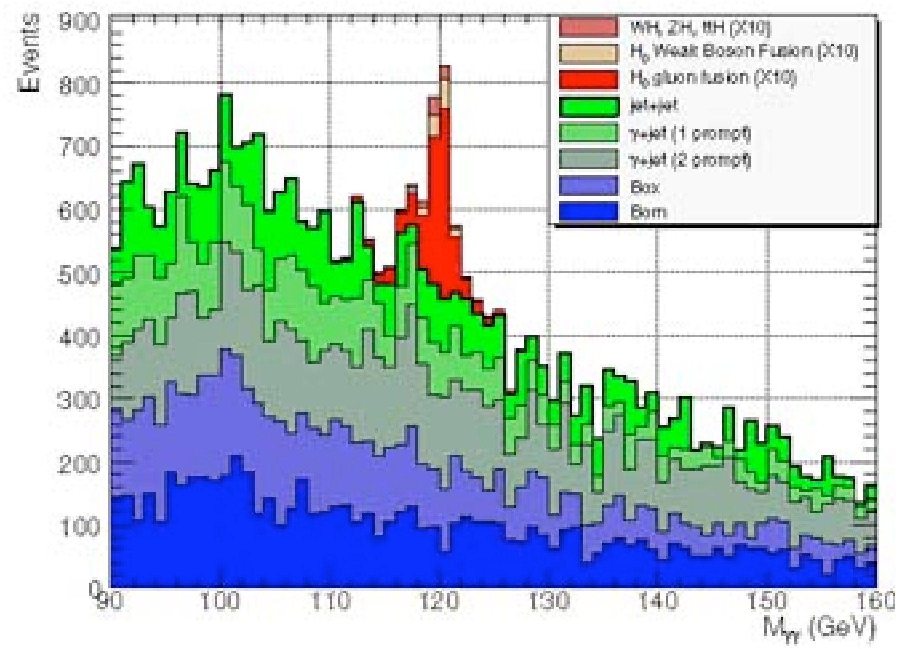
(At end of April 2007, ~1 month behind schedule)

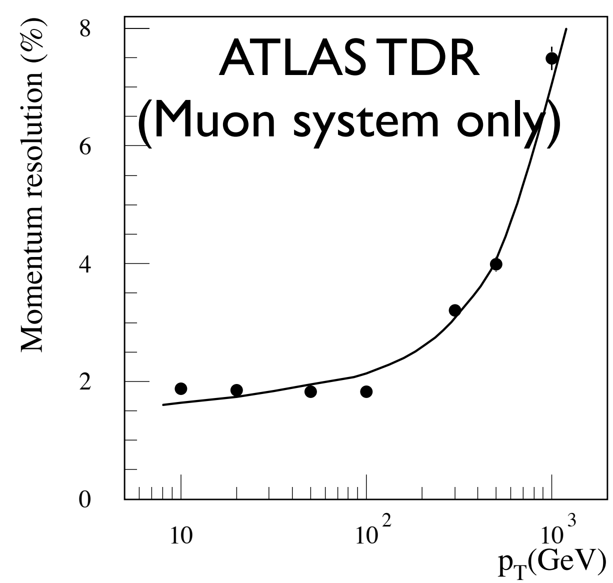


ATLAS & CMS

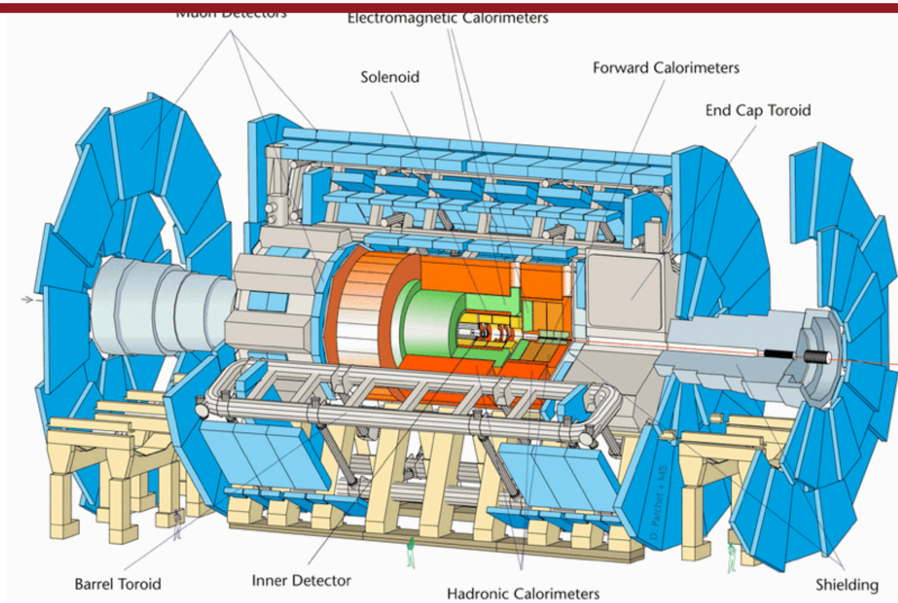
- Detector design driven by search for Higgs, study of top, search for new physics
  - Excellent calorimetry ($H \to \gamma\gamma$)
    - CMS ECAL saturates at ~1.7 TeV
  - Excellent momentum resolution at high p^T
    - Intense fields
  - Excellent b-tagging capabilities (pixel detectors)

CMS TDR, 7.7 fb^{-1}

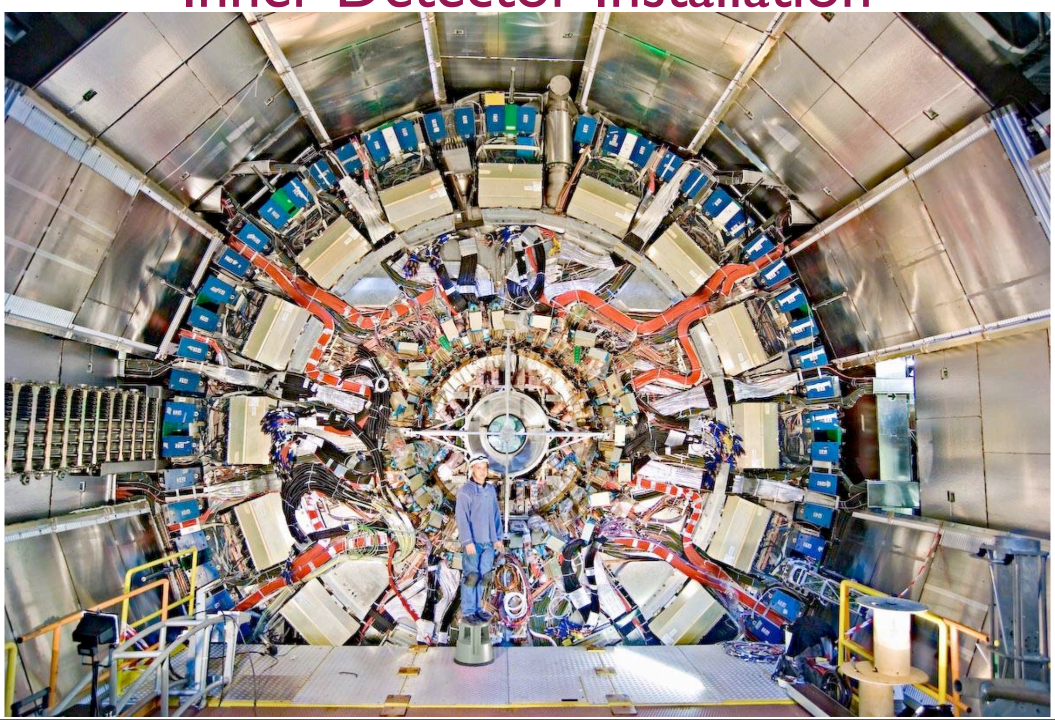


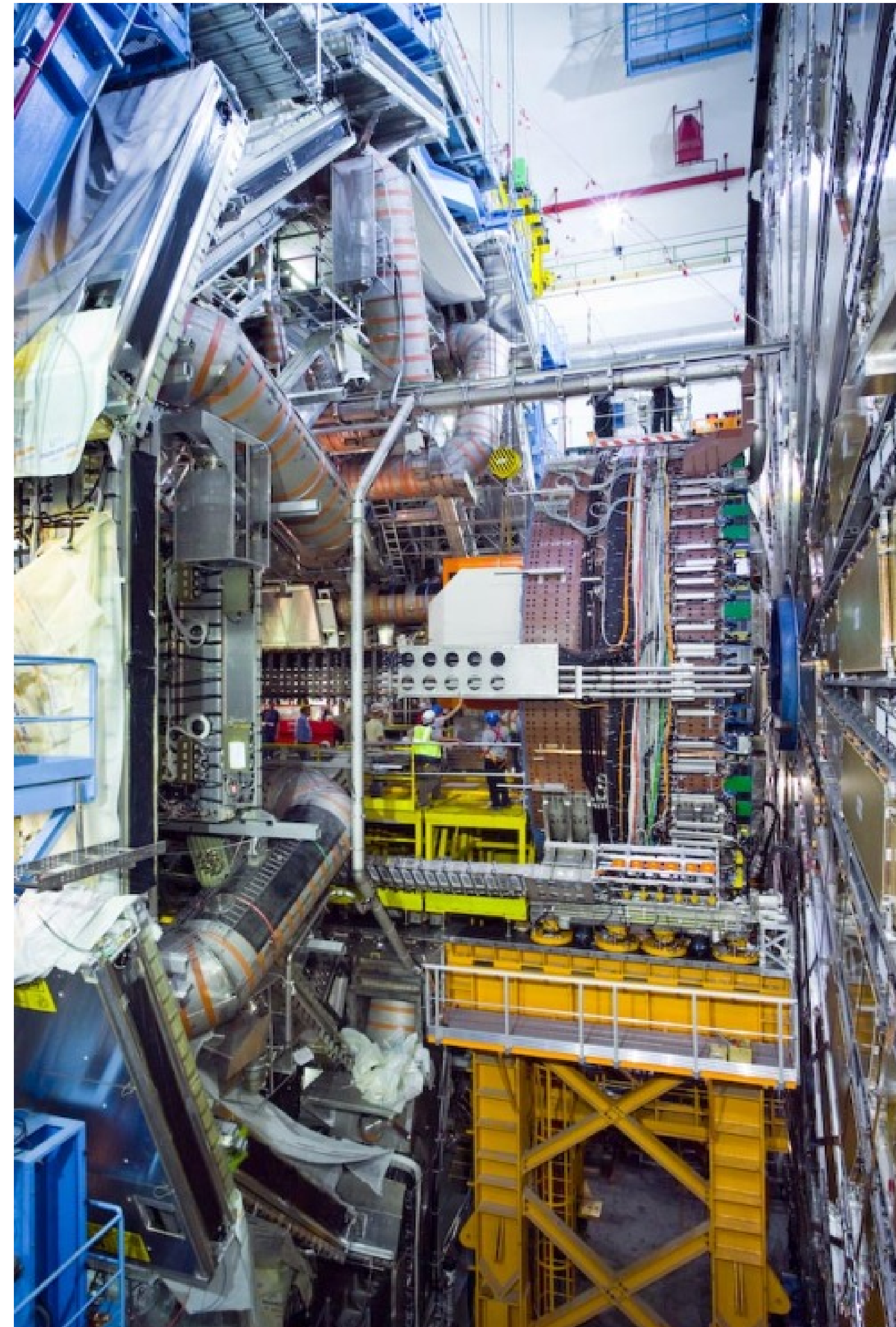


ATLAS Installation

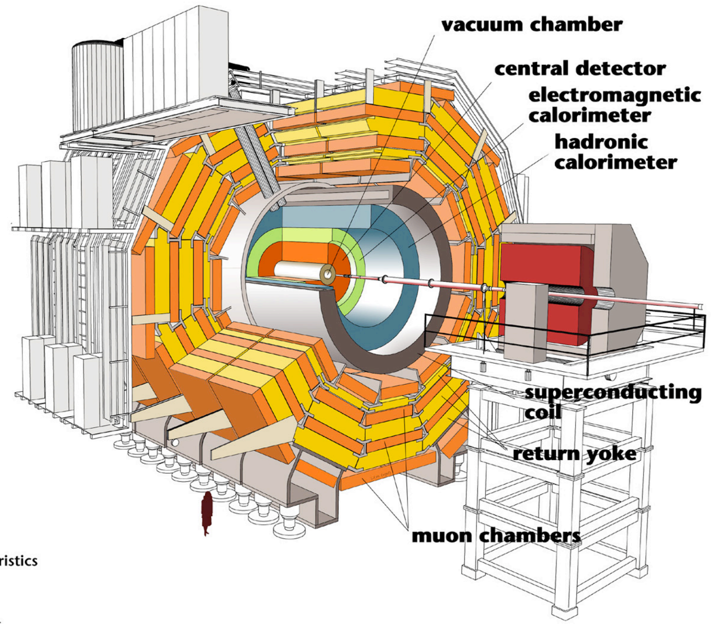


Inner Detector Installation



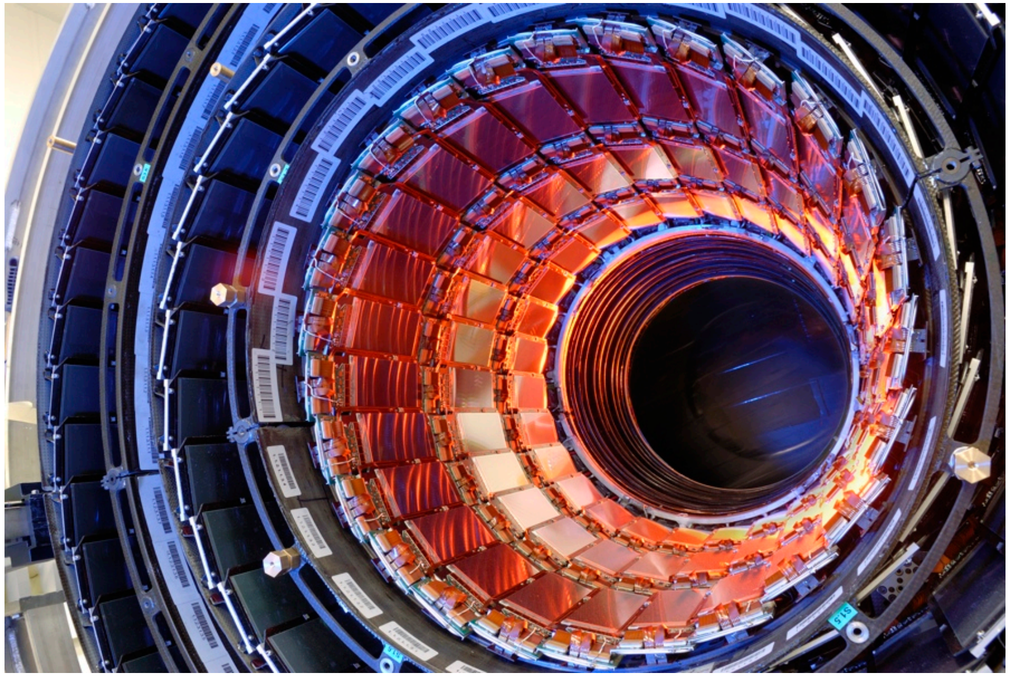


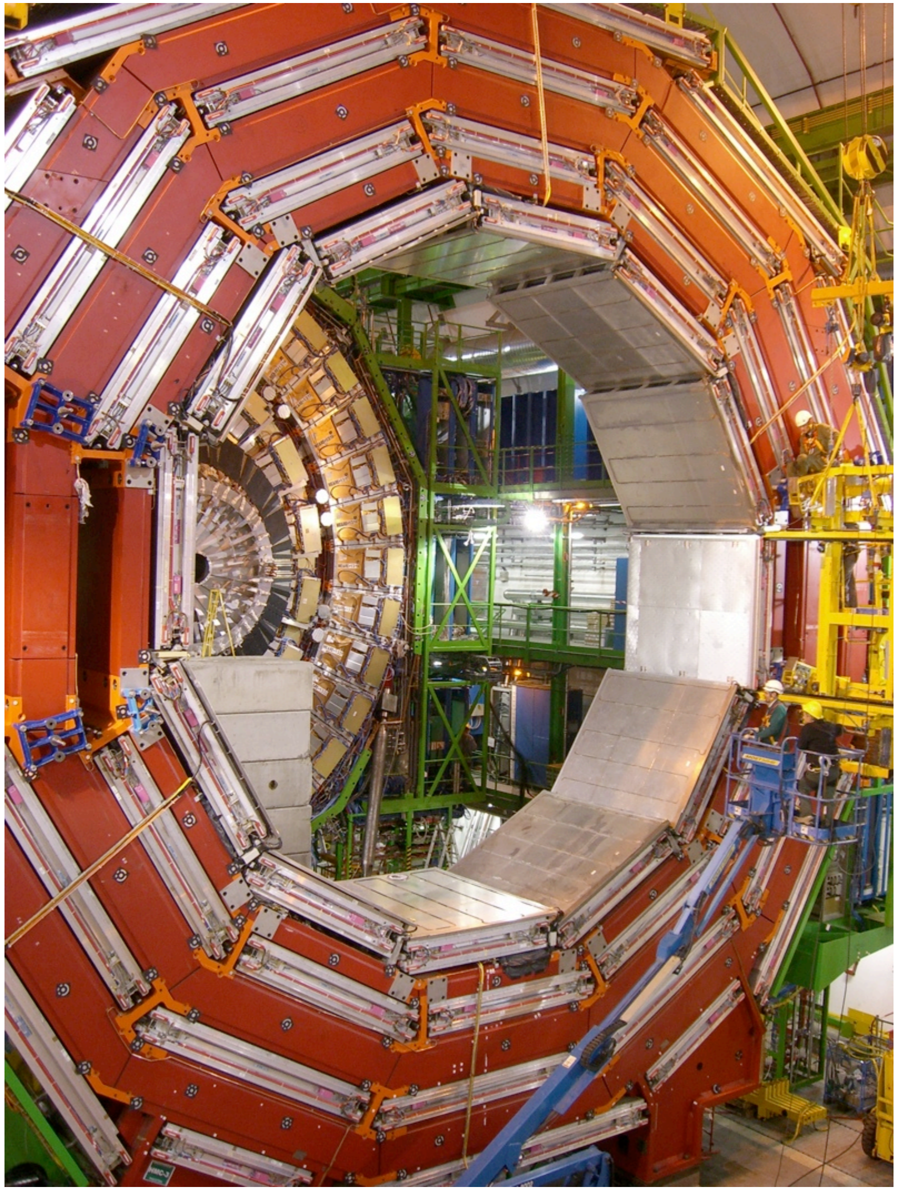
CMS Installation



Detector characteristics

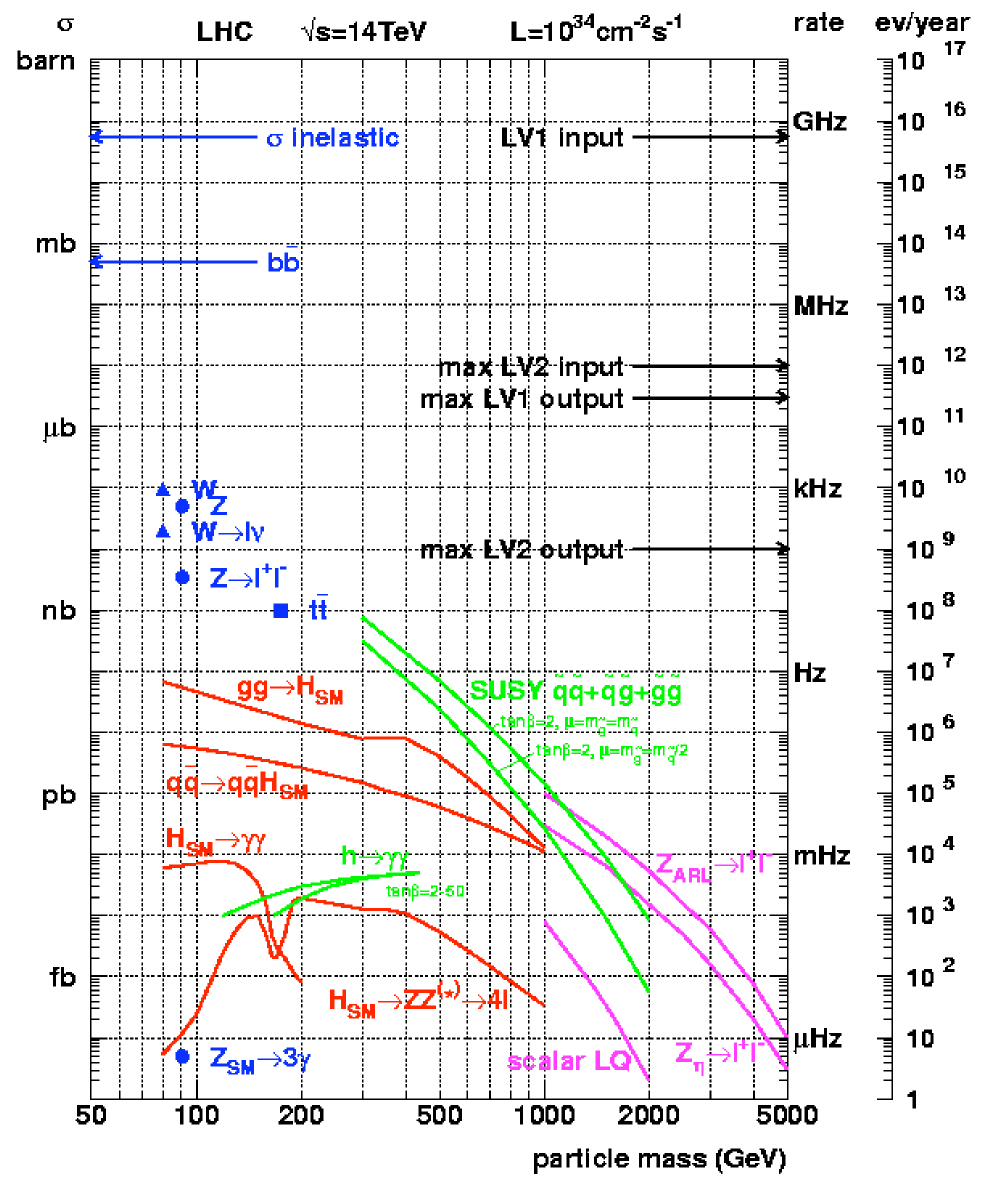
Width: 22m
Diameter: 15m
Weight: 14'500t





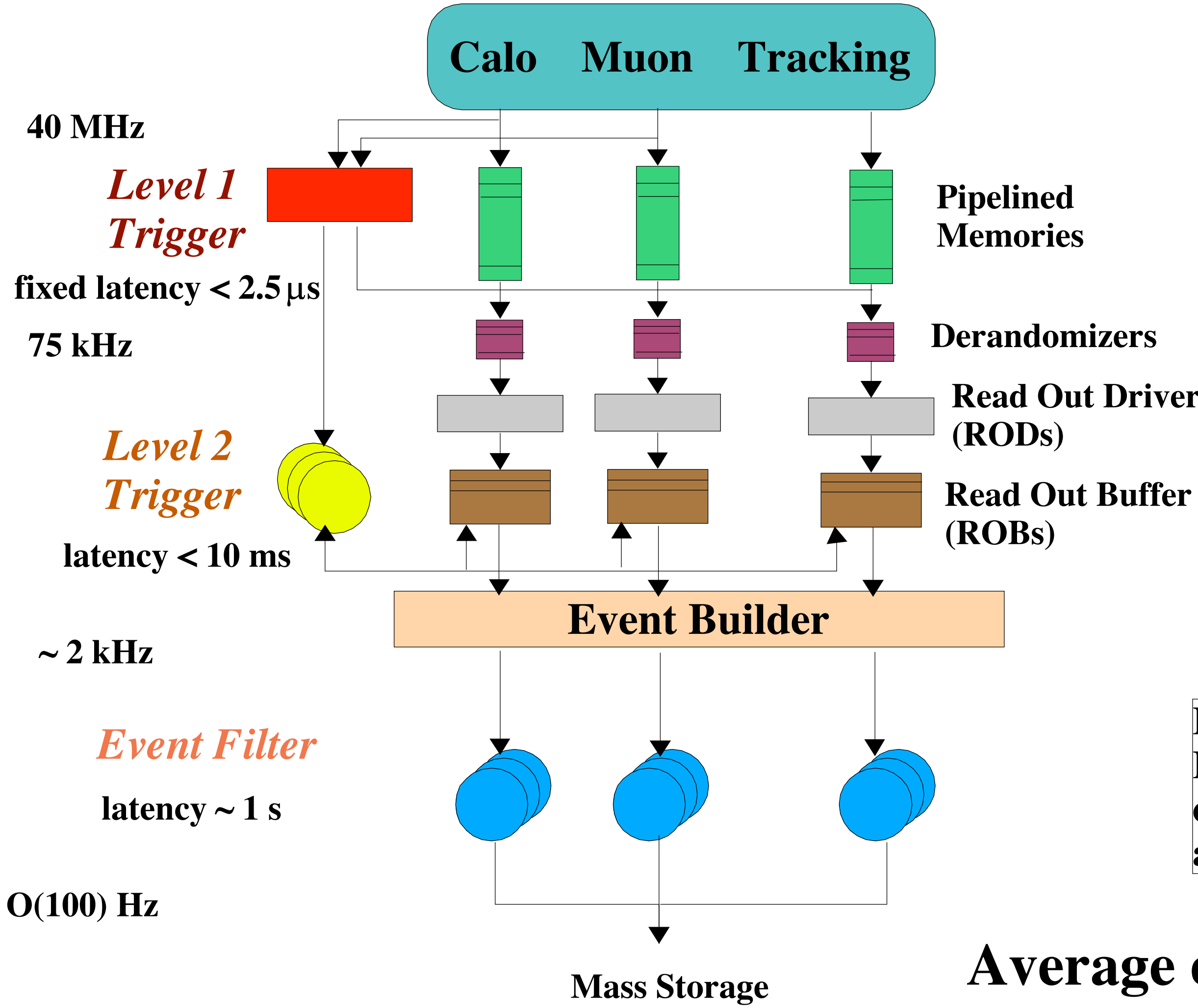
Trigger Systems

- Total inelastic cross-section ~6 orders of magnitude larger than W/Z production rate
- At design luminosity, even need to prescale W->lν events (produced at ~200 Hz)
- Need very sophisticated trigger systems



ATLAS Trigger

- Three level system, uses only calorimeter and muon system information at level 1



Level 1: coarse granularity calorimeter and muon trigger stations only

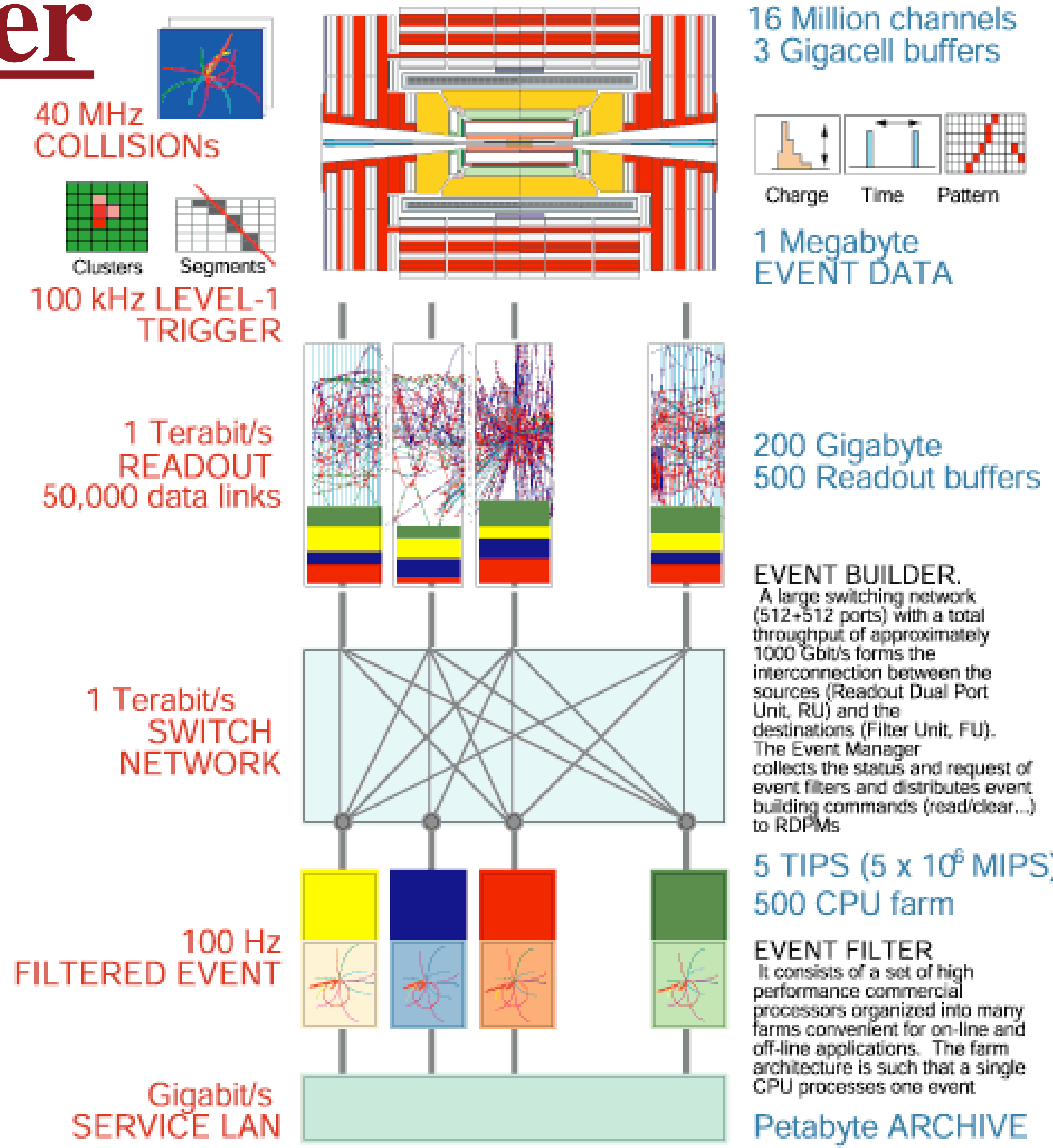
Level 2: full granularity data from all detectors; Regions of Interest (ROI) from Level 1 to reduce data access to ROBs (~2 % of full event)

Eventfilter: access to full event data. Refine LVL2 selection; event classification; monitoring, best available alignment and calibration data;

Average event size: ~1.5 MByte

CMS Trigger

- 2-level
- Level 1 also only calorimeter + muon system
- Similar level 1 and event filter accept rates



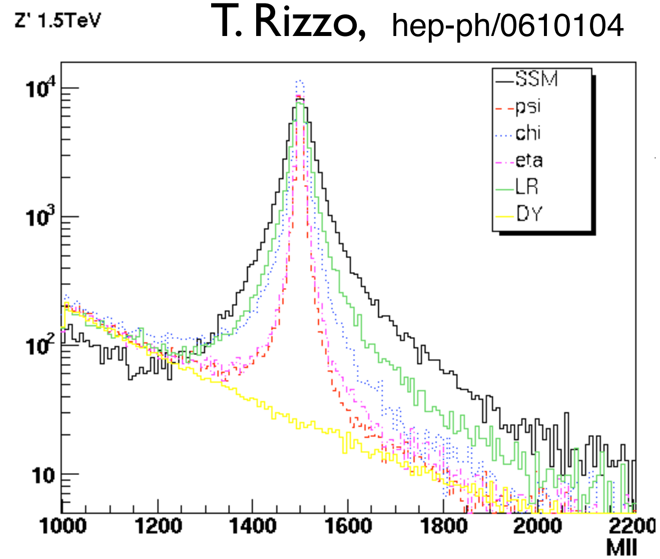
Signals of Parity Restoration

- Primary signals are right-handed W', Z'
  - Dilepton resonances offer clean signals, well-understood backgrounds
    - At LHC, some concern about extrapolation of calibration from Z to very high energies
    - Electron/muon resolution improves/degrades with p^T
  - $t\bar{t}$ decays visible
  - ν_R is presumably heavy, W' may only decay to quarks
    - If ν_R lighter than W', ν_R decays become important
- Of course, many models predict Z', W'-like resonances -> measure properties

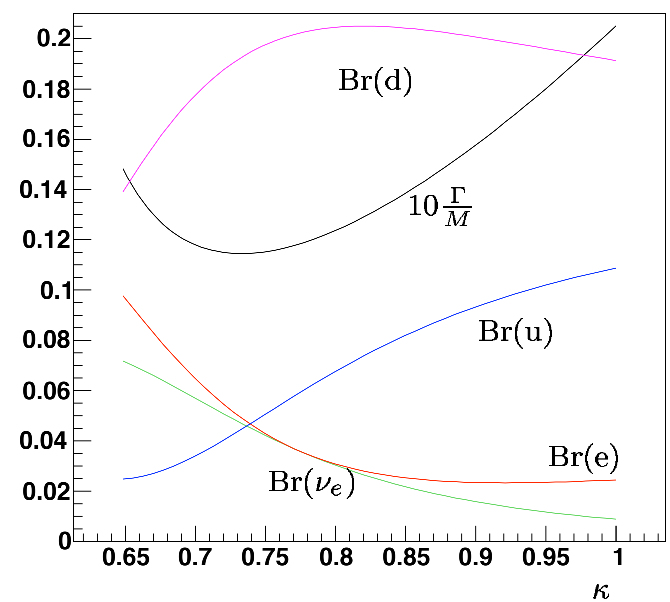
Z' Production and Decay

- Production from u, d quarks is dominant at LHC
  - Couplings vary by model
  - E.g. for LR symmetric models, $\varkappa = g_R/g_L$ drives production cross-section (convolute with PDFs) and branching ratios
- Decays somewhat similar to Z (but no BR to light neutrinos, decays to top open up), plot assumes ν_R heavier

T. Rizzo, hep-ph/0610104



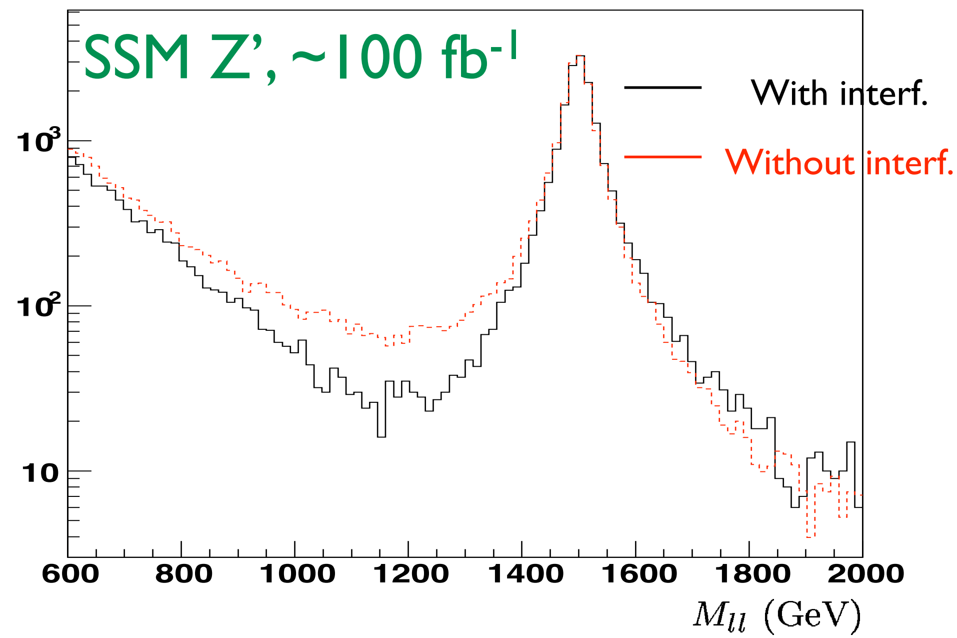
ATL-PHYS-PUB-2005-010

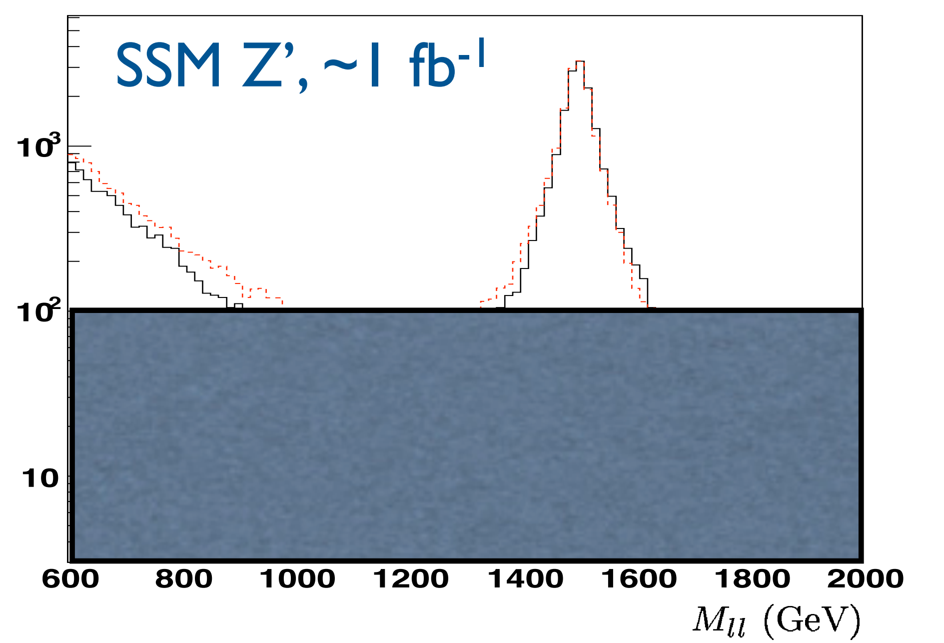


Z’ -> ee

ATL-PHYS-PUB-2005-010

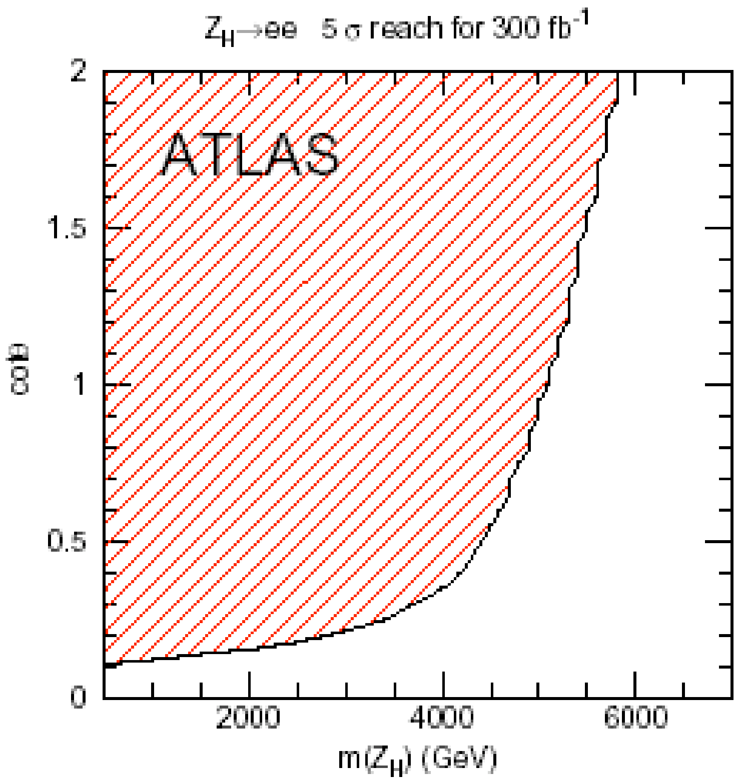
- Most promising channel:
  - At Z’ masses, energy resolutior dominated by constant term
    - 10 GeV for 1.5 TeV electron
    - Could measure width!
  - CMS ECAL saturation will require reweighting
- Extend Tevatron reach as soon as understand data
  - 10 events needed for discovery





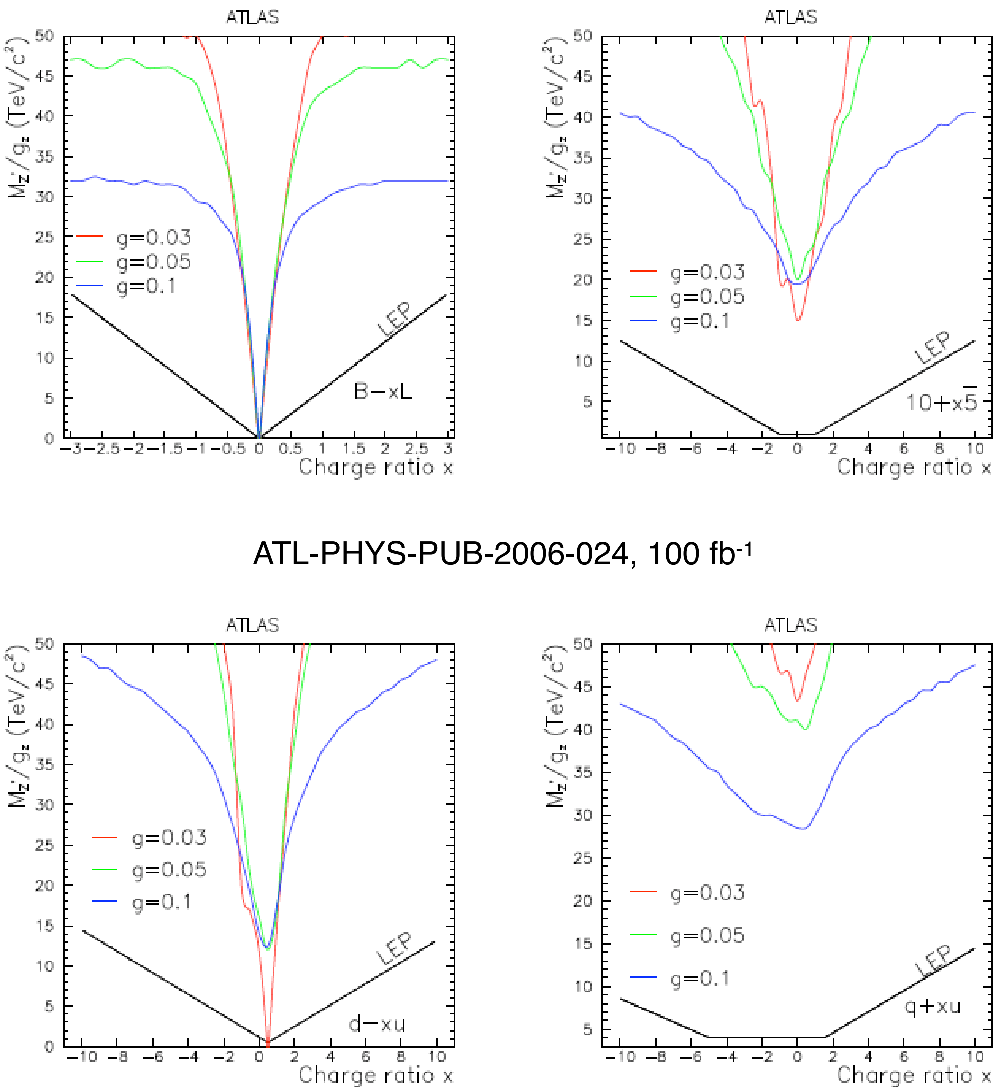
Z' -> ee (2)

- Then up to 5-6 TeV for "typical" models



Azuelos et al., hep-ph/0402037

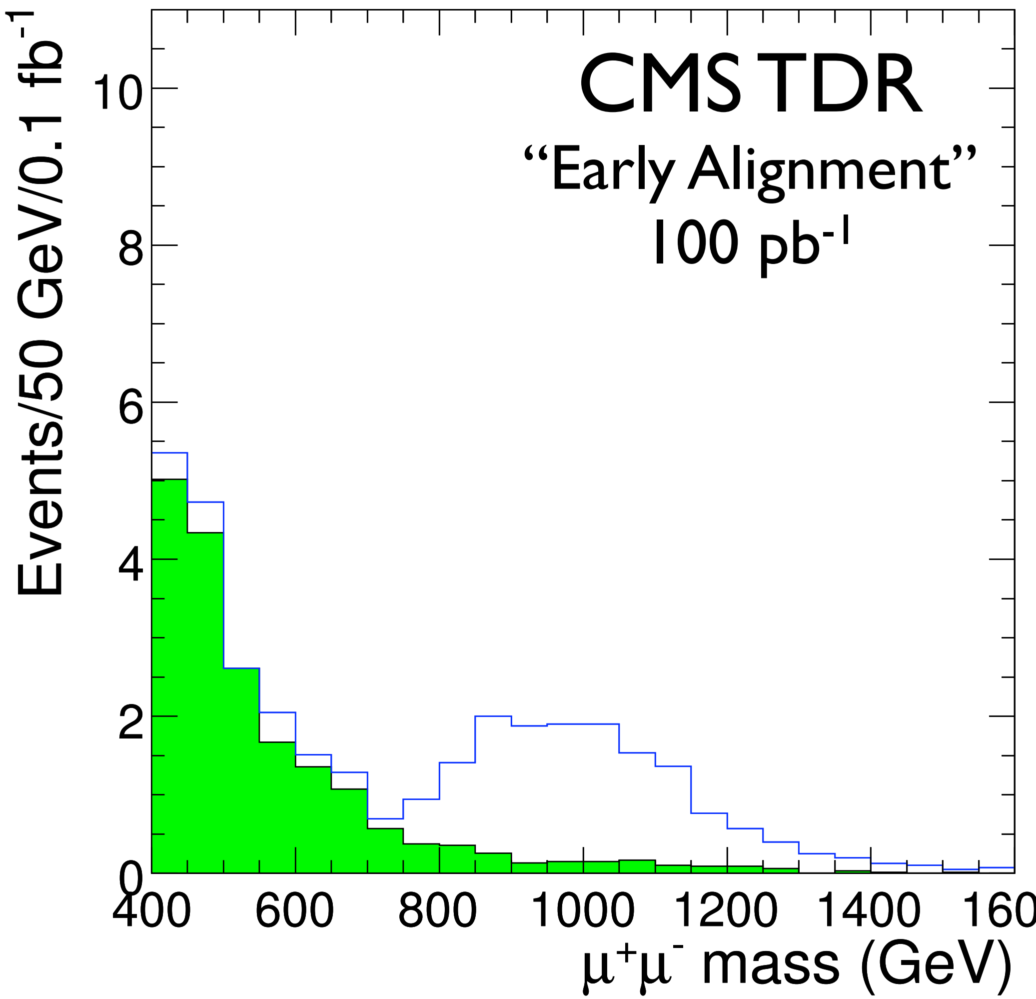
CDDT parametrisation, Phys.Rev.D70:093009,2004



ATL-PHYS-PUB-2006-024, 100 fb^{-1}

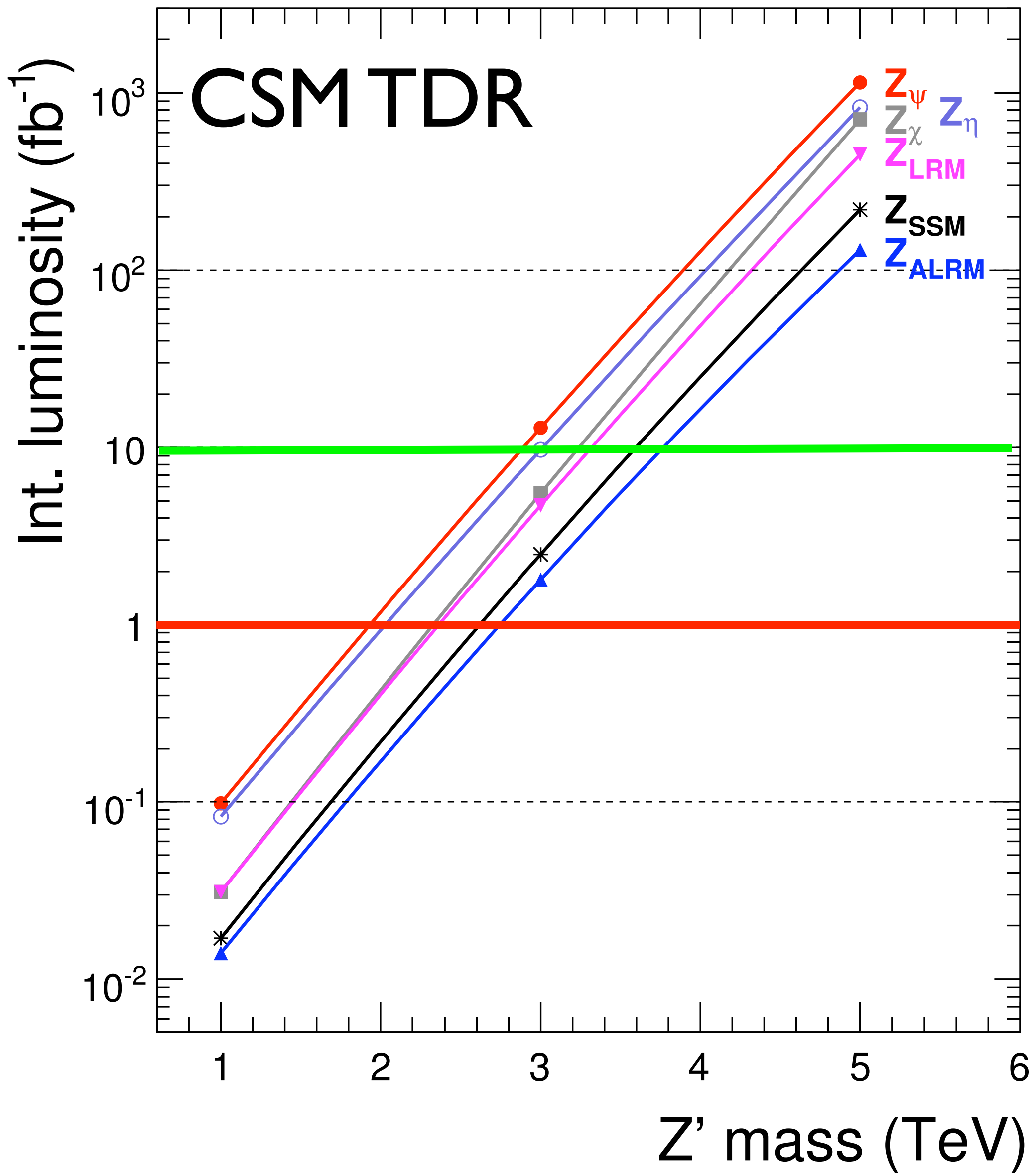
Z’ -> μμ: Early Potential

- CMS 1 TeV Z_η study
  - Narrower than SSM (7 vs 31 GeV), but dominated by detector anyway
  - Cross-section 2-3 times smaller than SSM
  - Note: statistics scaled down, so fluctuations “not to scale”



Z’ -> μμ Reach

- 5σ discovery reach
- Systematics don’t change these results much
- 2-3 TeV with 1 fb^{-1}
- 3-4 TeV with 10 fb^{-1}
- Again, assumes no “exotic” decays
- Discovery reach about 700 GeV below 95% CL limit at highest masses



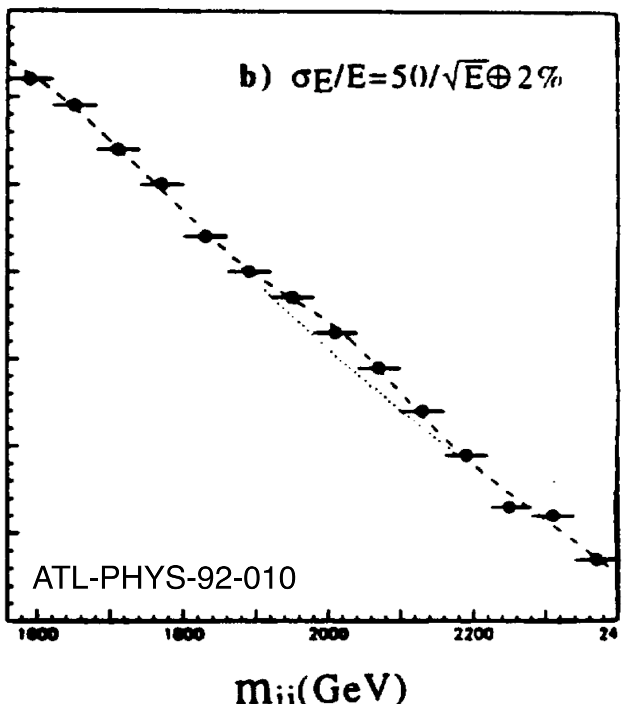
Z’ -> $\tau\tau$

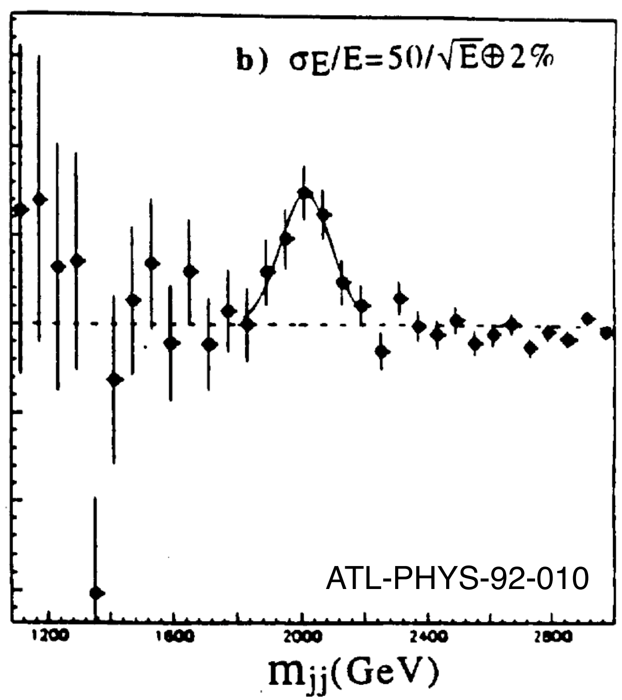
- Studies underway, no public results
- Sensitivity substantially smaller
  - But if Z’ preferentially coupled to 3rd generation...
- At the Tevatron, di-tau searches use channels with one tau decaying leptonically, the other hadronically
  - Projecting MET to reconstruct resonance mass diverges when τ’s are back-to-back
    - “Visible mass” found to be more sensitive: some loss in resolution but can “rescale” mass

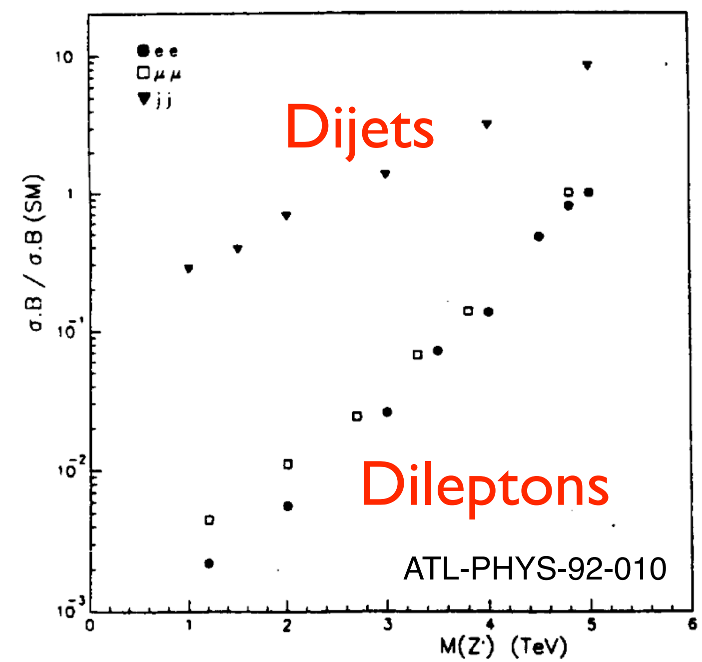
Z' -> jj

- In the dijet channel, the backgrounds are obviously much larger
  - But not necessarily unmanageable: DØ published a Run 1 search for resonances in the dijet channel

(PRD Rapid Comm. {69}, 111101 (2004))



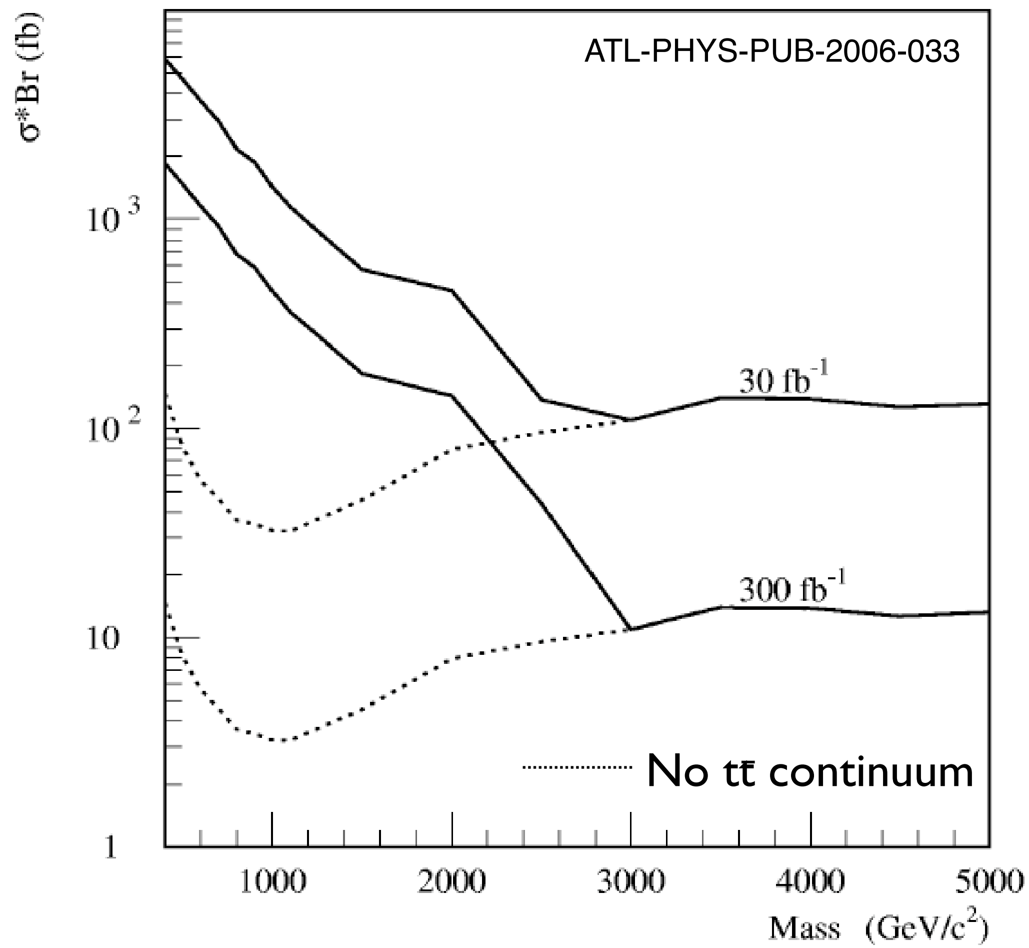




Z’ -> $t\bar{t}$

- So far, only events in which top decay jets are distinguishable have been studied in detail
  - Loss of efficiency at higher masses
- Studies using jet mass, substructure, etc. underway
- Continuum $t\bar{t}$ background dominant up to ~3 TeV

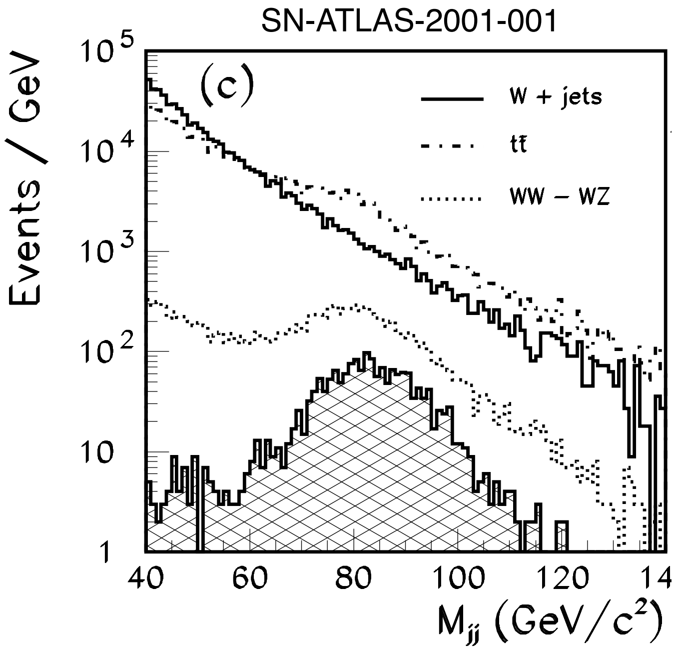
Limit on cross-section x BR



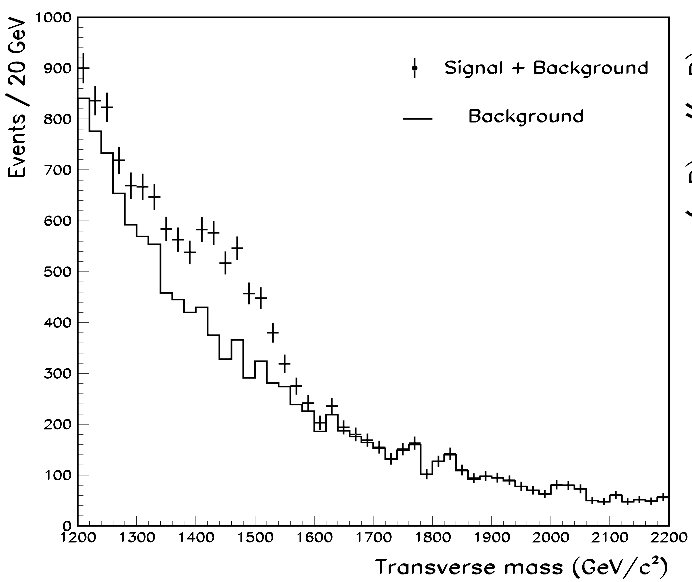
Z’ -> WW

- BR very model-dependent, for SSM it’s ~1%
- “Lepton + Jets” channel has the best rate/background ratio (as for $t\bar{t}$ production)

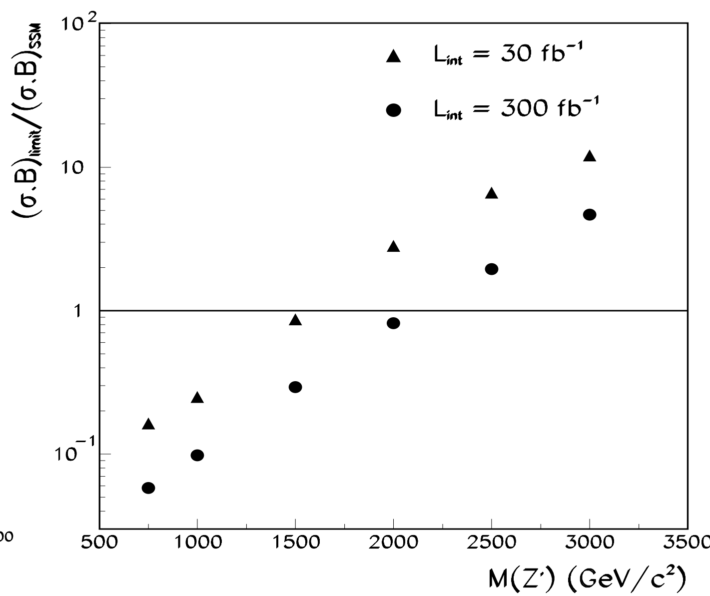
Jets from W are usually merged



jjlMET transverse mass

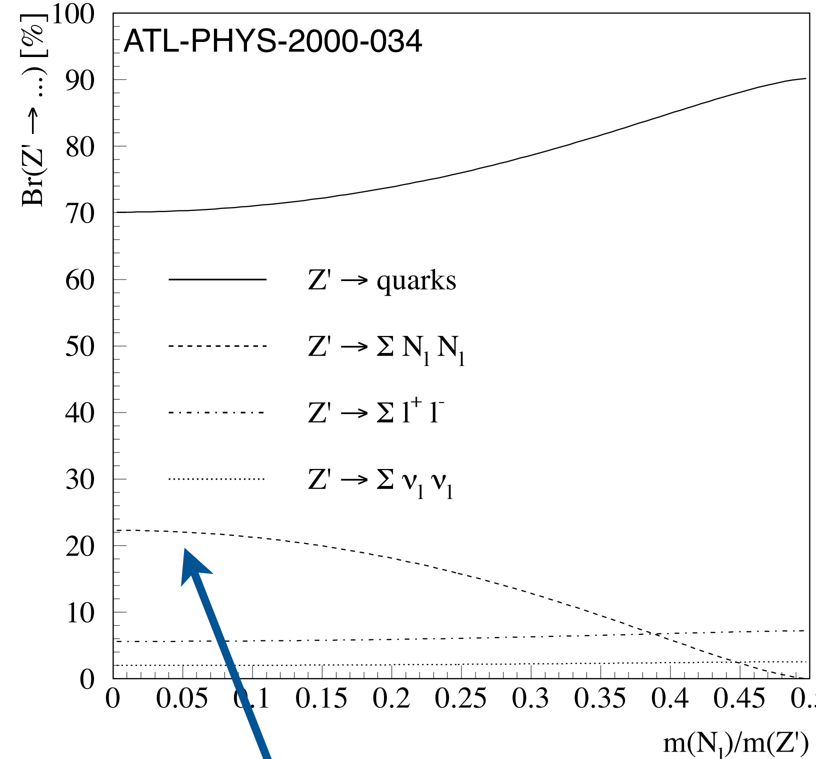


Discovery reach (compared to SSM discovery reach)



$Z' \to \nu_R \nu_R$

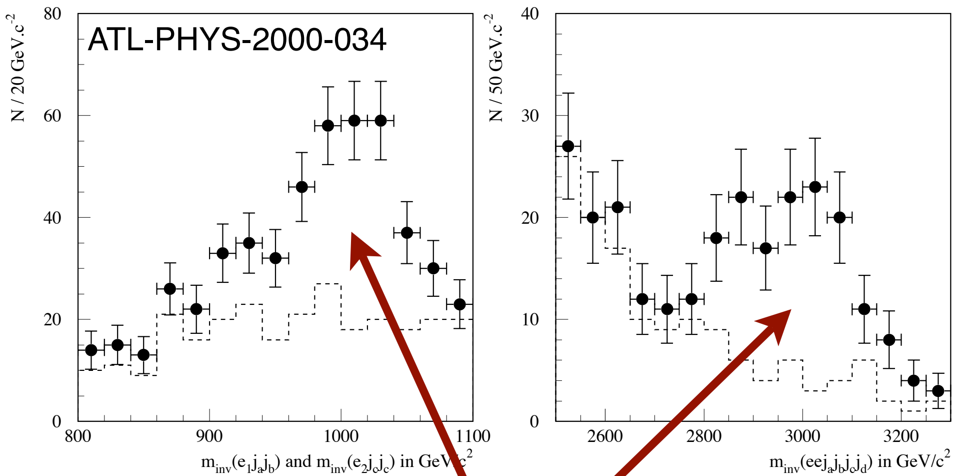
- If ν_R is lighter than m(Z')/2, decay channel opens up
- ν_R subsequently decays to lW_R^* (assuming W_R is heavier than ν_R), leading to signature with two leptons and 4 jets
    - Or other combinations if $m(\nu_R') < m(\nu_R)$, for example more leptons
    - If ν_R is majorana, can get same-sign leptons!



If ν_R is light, lepton and jets collimated $\to$ leptons embedded in merged jets

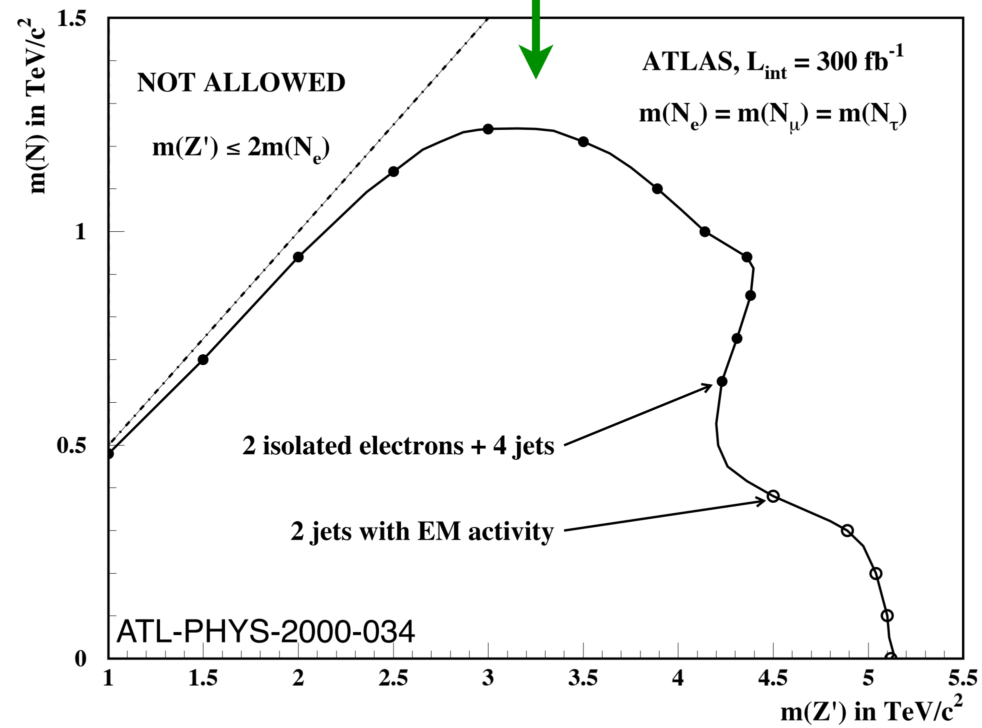
Z' -> $\nu_R \nu_R$ (2)

- Backgrounds include $t\bar{t}$, ZZ, ... + jets, but also W_R!



Reconstruction of ν_R (ejj) and Z' (eejjjj) masses

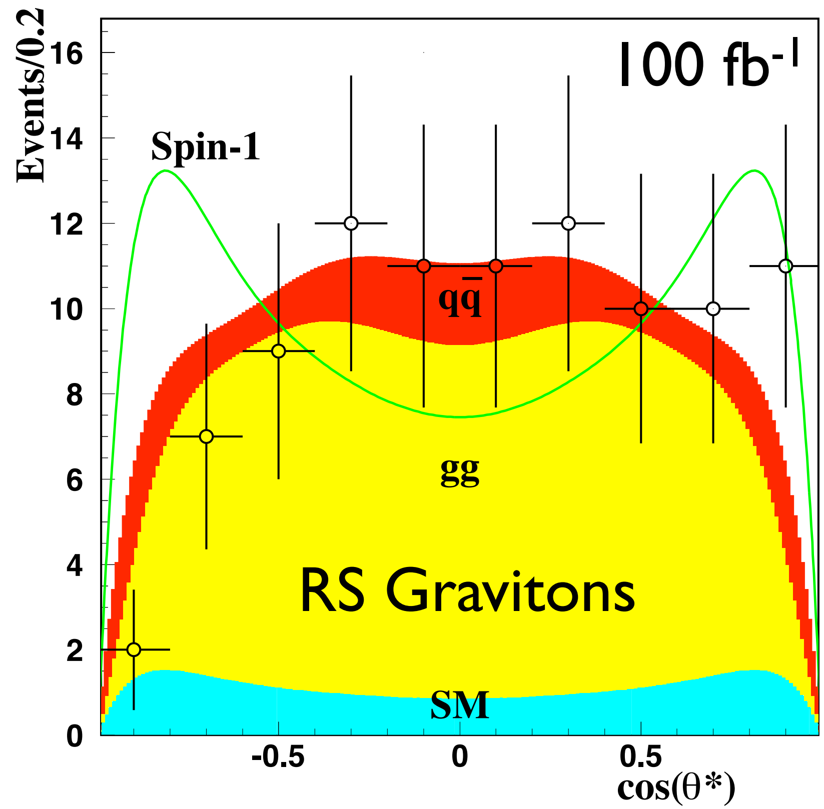
Discovery Potential



Spin Determination

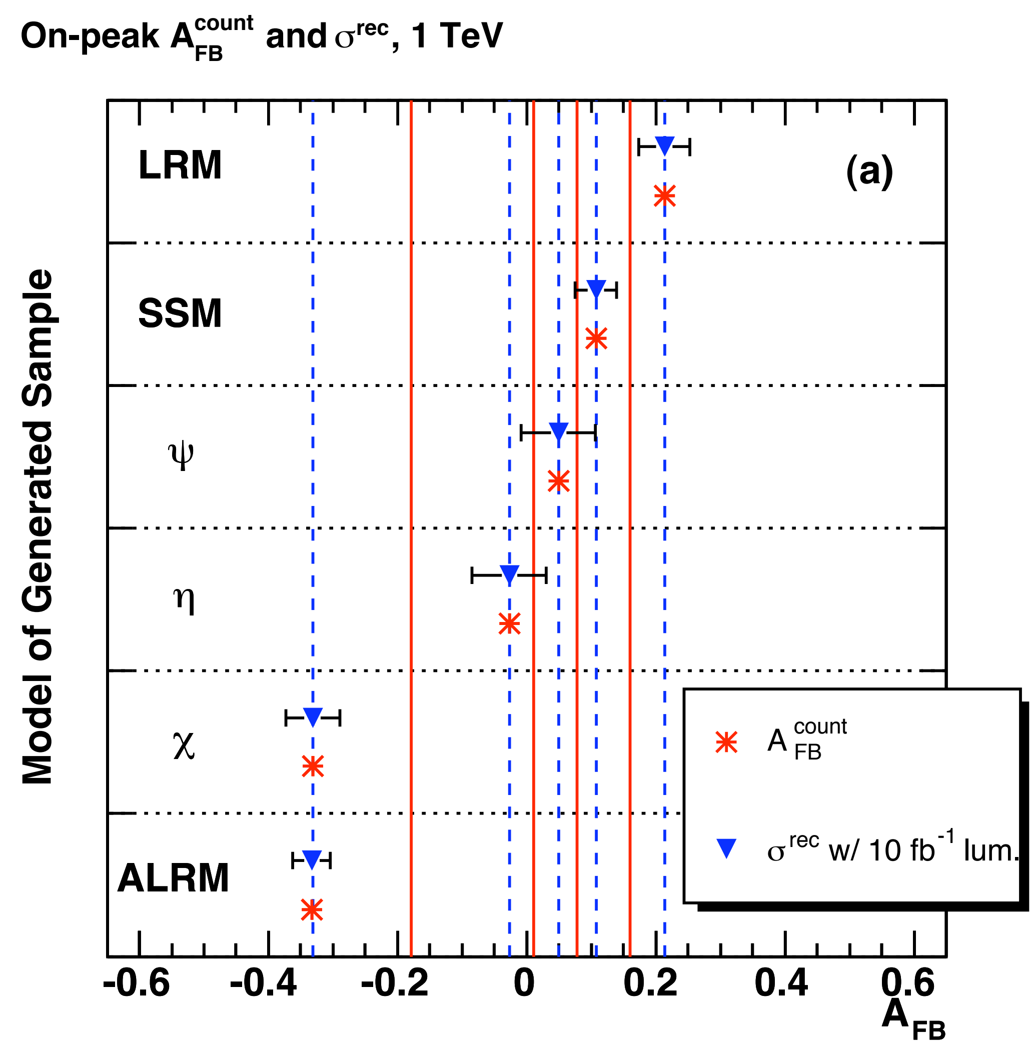
- Look at angle between lepton and beam direction
  - Spin 1 particles tend to emit leptons closer to beam
- Plot is potentially optimistic: sensitivity is in the forward region where lepton identification not nearly as efficient or pure

B. Allanach et al, JHEP 0009:019,2000



Model Determination

- Angular distribution gives excellent handle on g_V, g_A for various fermions
  - Charm may be possible
- This will come after an initial determination of branching ratios (obviously)
  - Complementary information in determining nature of resonance



CMS Note 2005/022

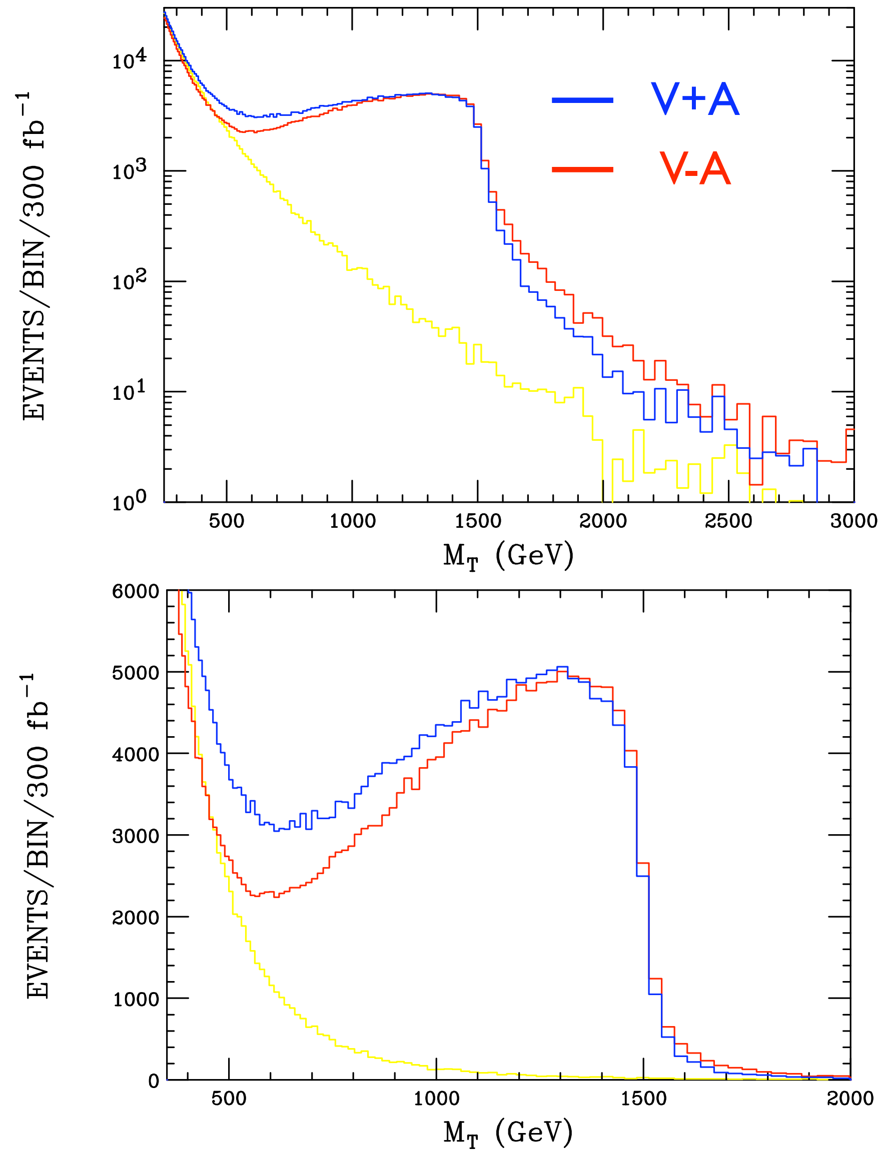
W' Production

- W' production rate not very dependent on couplings
- But interference with W important (and not in experimental studies)!
  - Key in identifying W' coupling helicity in fact

(T. Rizzo, hep-ph/0704.0235)

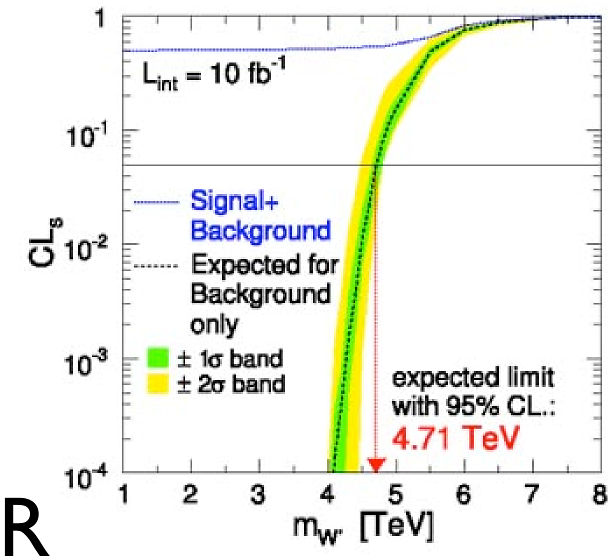
- (This plot is for e+MET transverse mass, which may not be a signature)

T. Rizzo, hep-ph/0704.0235

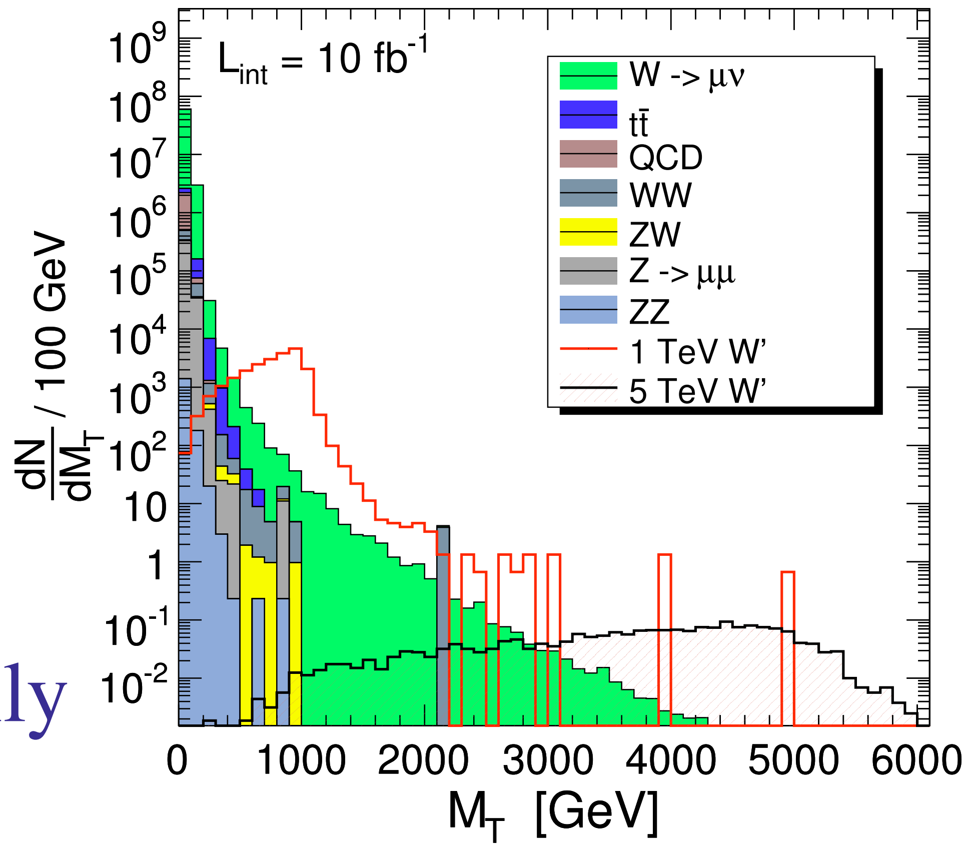


W' -> $\mu\nu_{(R)}$

- SSM W'
  - "Standard" M_T plot
- Discovery reach ~4.5 TeV with 10 fb^{-1}
- Similar reach with electrons
  - Note very different resolution effects in electrons vs muons
- Decay does not necessarily exist!



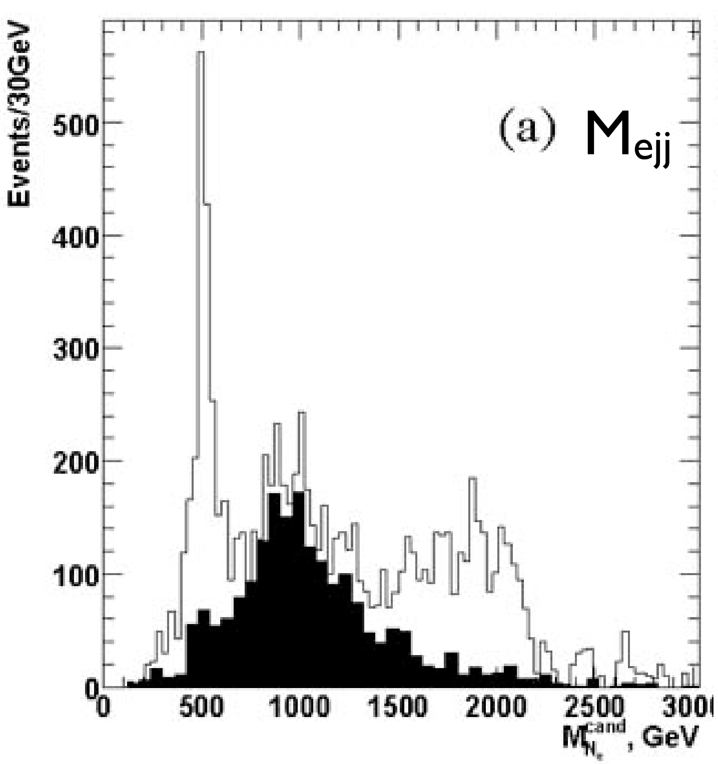
CMS TDR



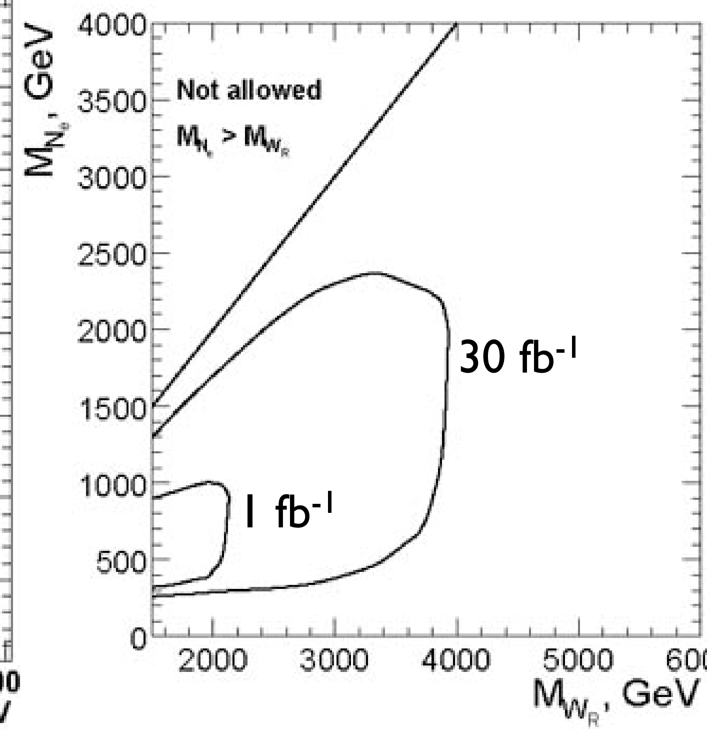
W_R -> l l j j

- ν_R mass critical in determining W_R decays
  - If $W_R \to l\, \nu_R$ open, and $\nu_R \to l\, W_R^* \to l\, \bar{q}\, q'$ open, get dilepton-dijet final state (similar to leptoquark pairs)

CMS TDR (30 fb^{-1})

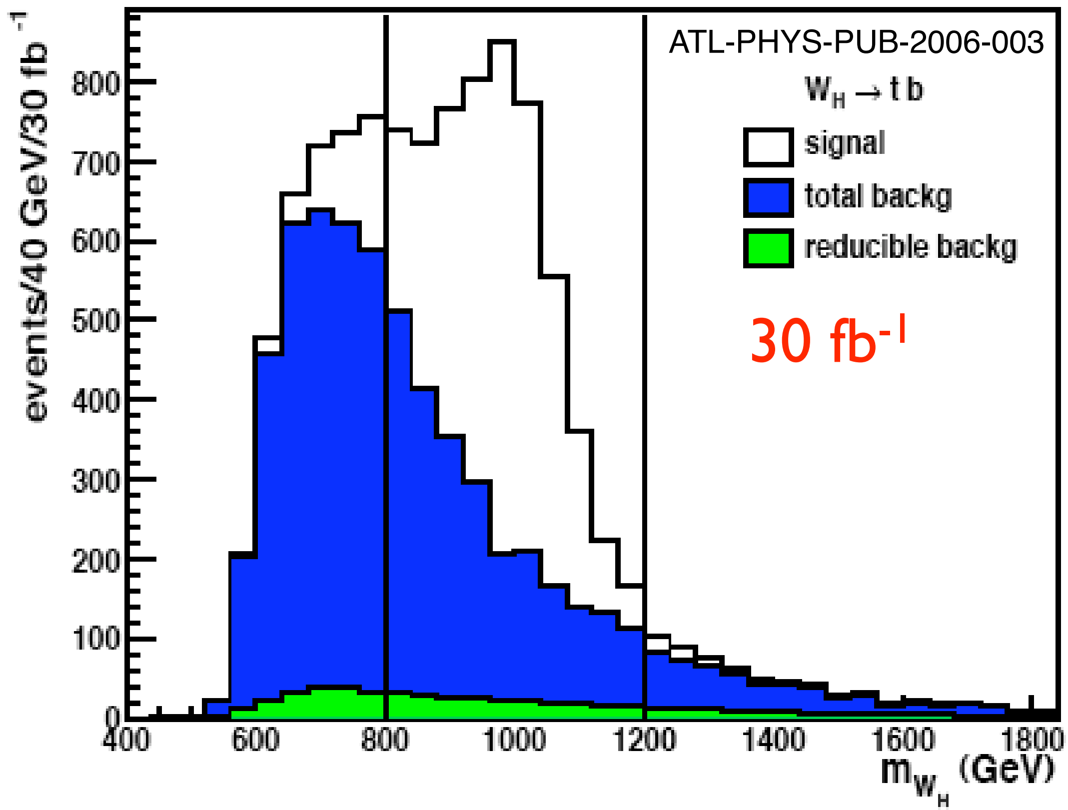


Discovery Reach



W' -> tb

- ATLAS fast simulation study
  - Use of very high pT b-tagging
  - B meson decays *outside* first pixel layer! More studies needed to confirm efficiencies
- Overall, could already make a (BR) statement very early on

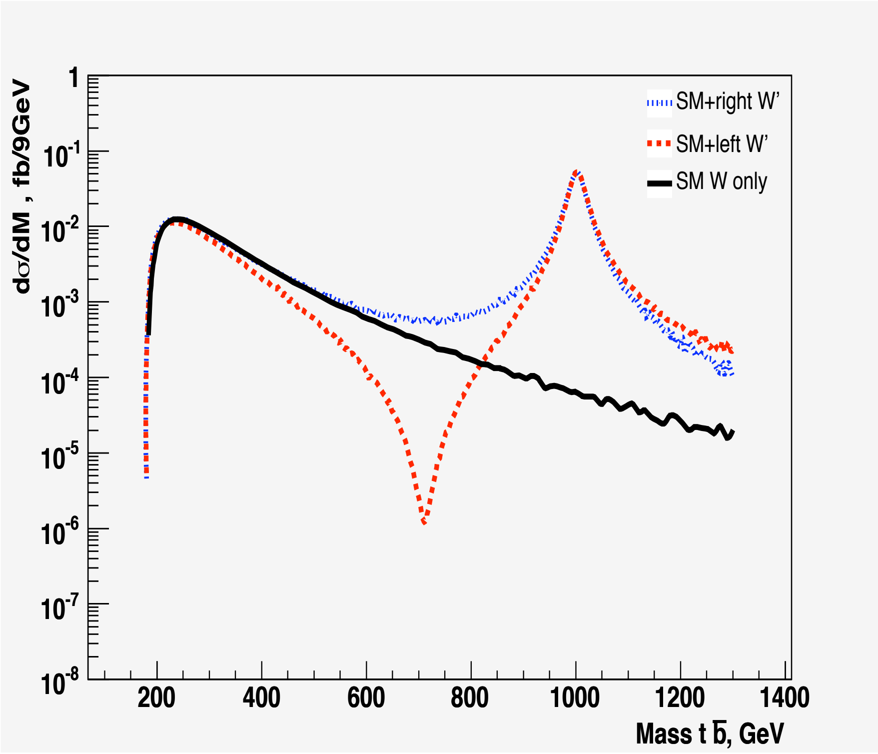


Note: This is for W_H from Little Higgs

W-W' Interference!

- $t\bar{b}$ resonance search suffers from interference with single top
  - Again, W coupling helicity important (destructive interference for m < $m_{W'}$ if W' LH)
- Current experimental studies do not take this into account!

E.Boos et al., hep-ph/0610080

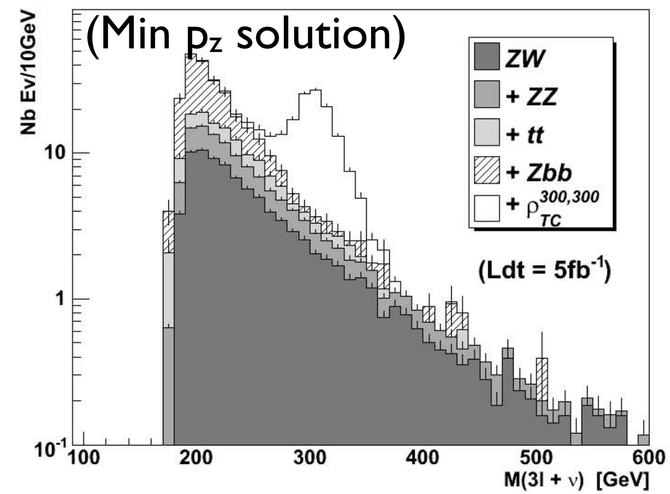


(No experimental resolution effects)

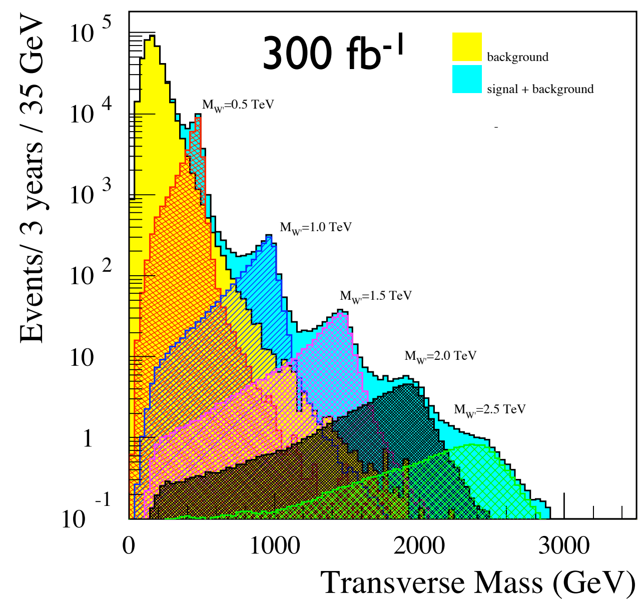
W' -> WZ

- Require at least one of the W, Z to decay leptonically to suppress backgrounds
  - Then use mass constraints to improve S/B further
- Cleanest channel is obviously when both decay leptonically (but BR only 1.4%)
  - Studied in the context of a technicolor study by CMS
  - LR model by ATLAS

CMS TDR



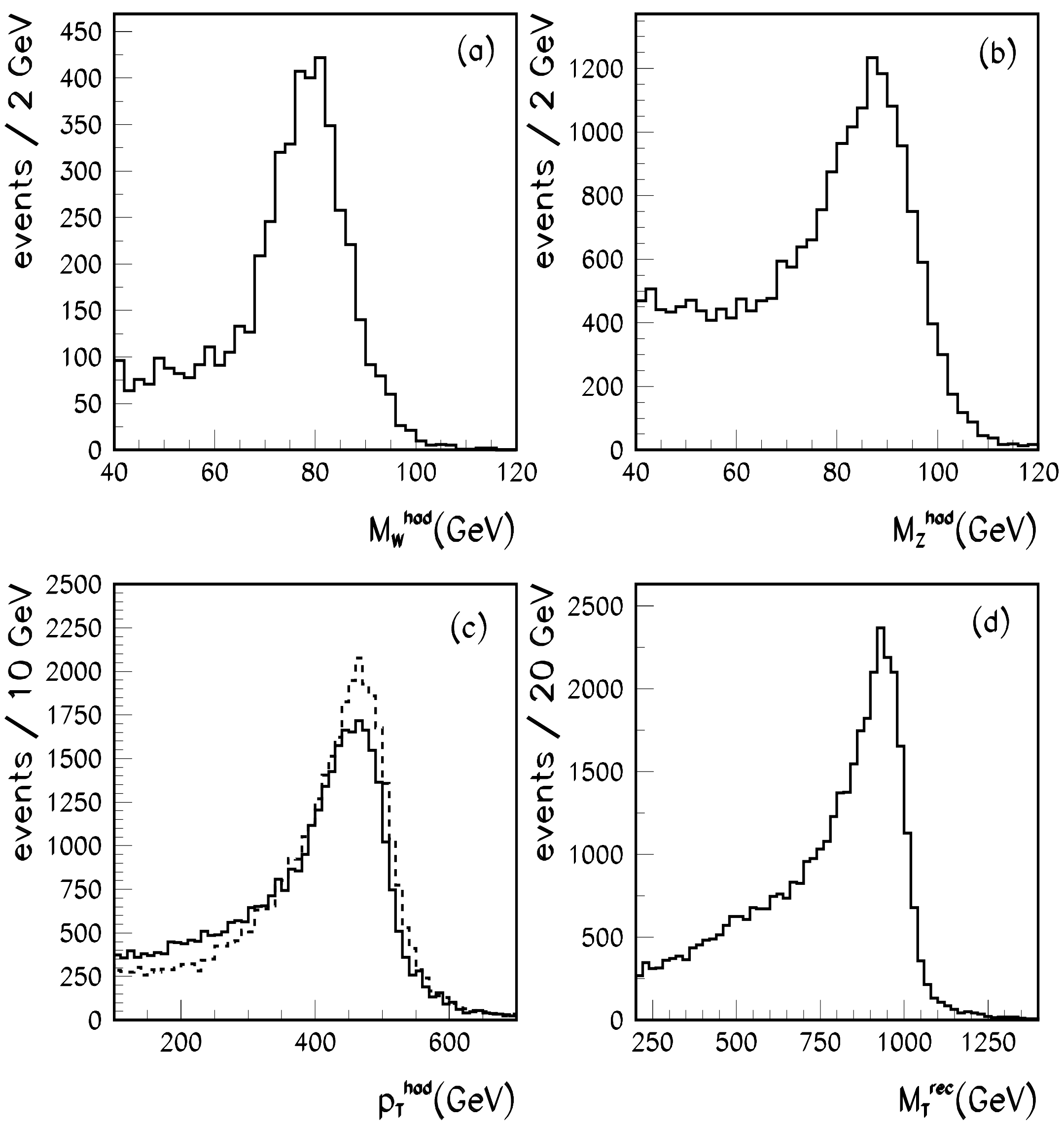
ATL-PHYS-2001-005



W' -> WZ (2)

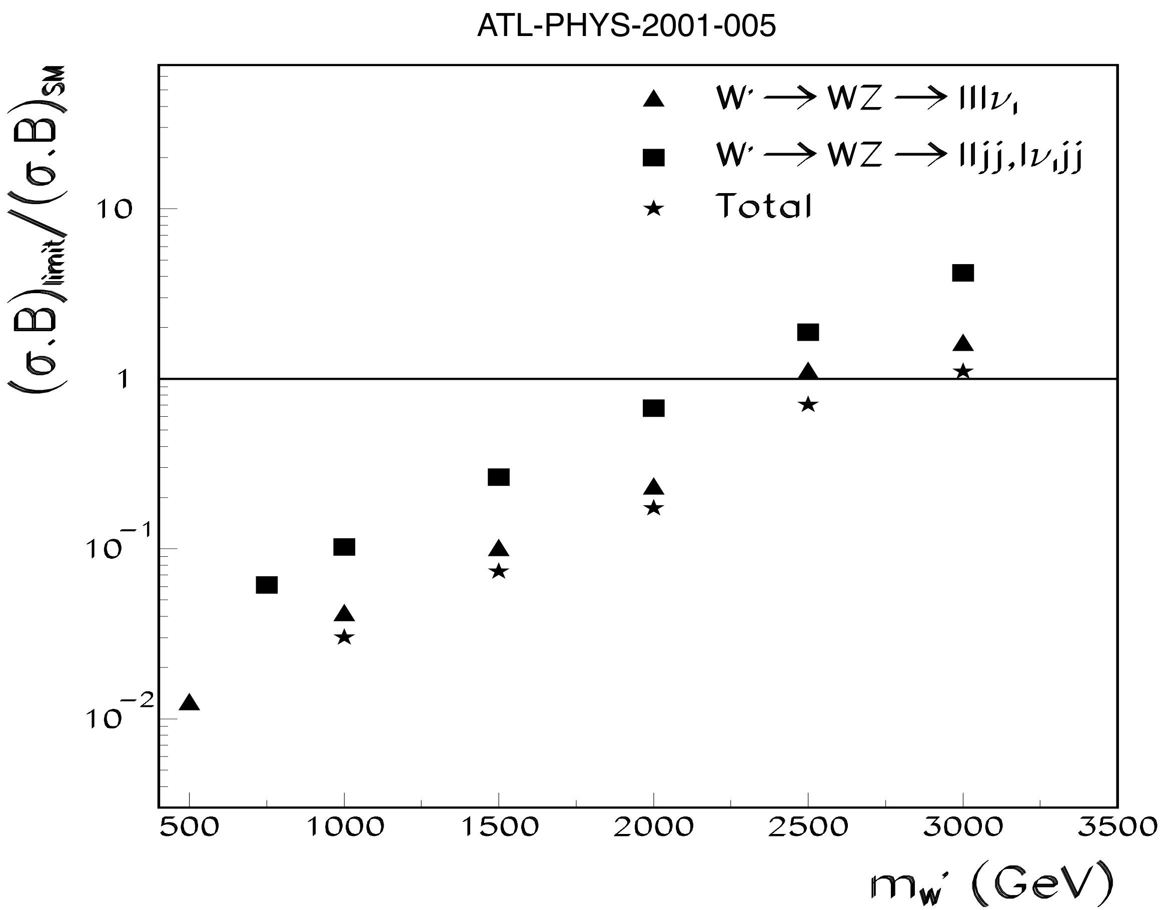
- If allow one boson to decay hadronically, higher BR (4.6/15%) but higher backgrounds
  - Hadronically decaying boson has large boost, so jets are merged -> rely on jet mass
  - W/Z + jets background not well known

ATL-PHYS-2001-005



W' -> WZ (2)

- Overall discovery potential with 300 fb^{-1} for W' with BR (W'->WZ) = 1% (SM-like situation)
  - Larger if leptonic W' decays forbidden?



A Few Words of Caution

- ATLAS and CMS are some of the most complex pieces of equipment ever built
  - It will take time to understand the response, determine the failure modes
    - Some failures can generate artificial signals (correlated noise effects, unexpected saturation, ...)
- Poor knowledge of a number of important backgrounds
  - W/Z + jets (see Tevatron struggles)
  - $t\bar{t}$ + jets
  - ...

- Combination of challenge in determining the detector response precisely and limited a priori knowledge of the behavior of a number of SM processes leads experimenters to be cautious
  - When we don't "give" our data right away, it's usually because we're uncertain about our interpretation and want to run more checks before publishing
    - Tevatron experiments currently publish ~30 papers/year
- I fear some unrealistic expectations have been generated regarding the speed with which the LHC experiments will confirm discovery of new physics

Conclusions

- The LHC will explore a new energy domain starting in 2008
- For W', Z' bosons the reach in leptonic decay channels will typically be in the 5-6 TeV range
  - And 2-3 TeV will be reachable early on
- Hadronic decay channels are accessible as well, but with smaller reach
- Multiple handles on determining the nature of a resonance:
  - spin, A_{FB}, BRs