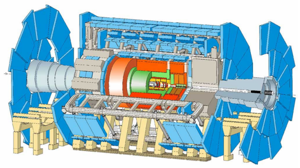
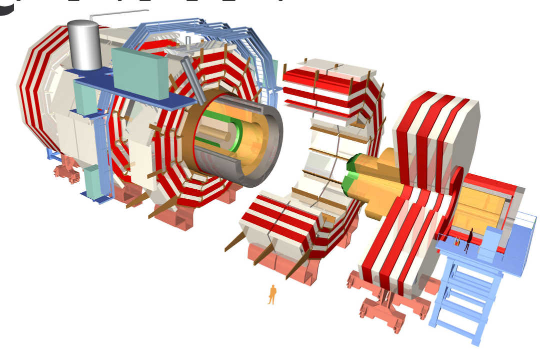


Prospects for the observation of new physics at the LHC

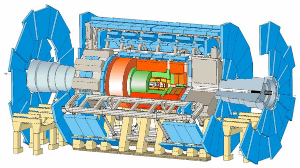


Tracey Berry

University of Royal Holloway, London

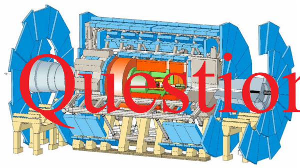
Flavour in the era of the LHC, CERN

27th March 2007



Overview

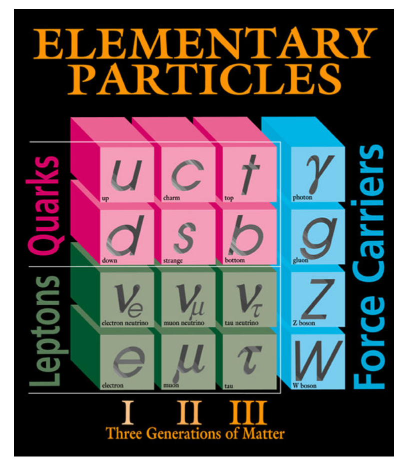
- Beyond the Standard Model
- Fundamental Symmetries
    - Heavy Gauge Bosons W′ and Z′
- Electroweak Symmetry Breaking
    - SUSY, Little Higgs, Technicolor
- Leptons & Quarks, Other New Particles
    - Left-right symmetry, E6 quarks
- Extra Dimensions
- Summary and Outlook



Questions remaining with the Standard Model

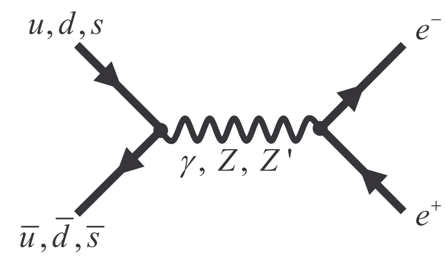
→ Reasons to search for new physics…

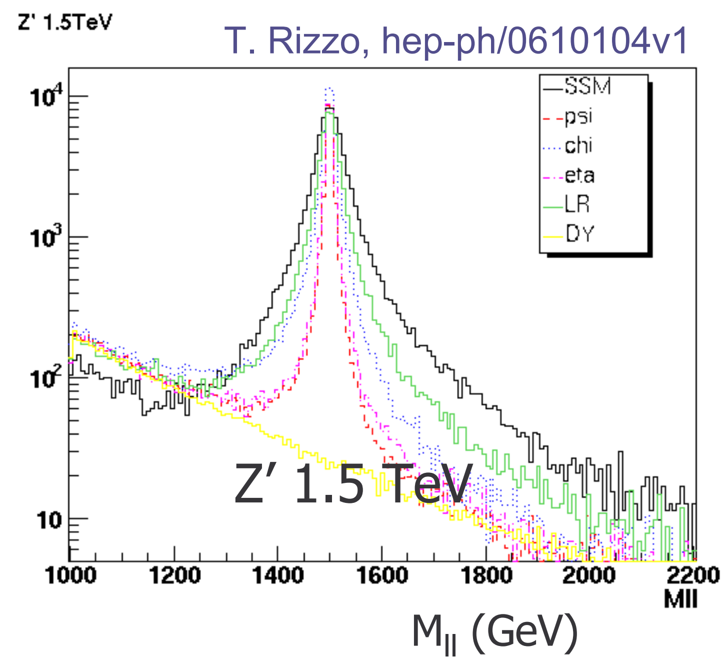
- Fundamental symmetries:
  - Are there more symmetries beyond $SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$?
    → GUTs with larger symmetry group? Left-right symmetry?
- ElectroWeak Symmetry Breaking (EWSB):
  - Unitarity violation in longitudinal WW scattering at high E
    solution: Higgs boson or other new particle with mass < 1 TeV
  - If Higgs → *hierarchy problem:* fine tuning in rad corr to Higgs mass
    solution: new physics at TeV scale (SUSY, Little Higgs, etc…)
  - If NO Higgs
    solution: new strong interactions (Technicolor, etc…)
- Quark and lepton generations:
  - Why are there 3 generations? → Fermions composite?
  - Is there a lepto(n)-quark symmetry?
  - More than 3 generations of quarks & leptons?



Heavy Gauge Bosons

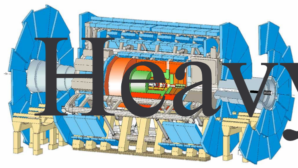
- Many extensions of the SM rely on larger symmetry groups
  (GUTs, string-inspired, left-right, little Higgs models, etc…)
  → predict existence of new gauge bosons W′ and Z′ (or KK modes)
- Production: s-channel
- Clean decay channels:
  W′ → e ν_e or μ ν_μ
  Z′ → e^+e^- or $\mu^+\mu^-$
- Tevatron searches: M up to ~1 TeV
- Z′ models considered:
  - Sequential SM (SSM) with same Z′ couplings to fermions as for Z
  - Models based on different patterns of E6 symmetry breaking (ψ, χ and η)
  - Left-right (LR) symmetry models



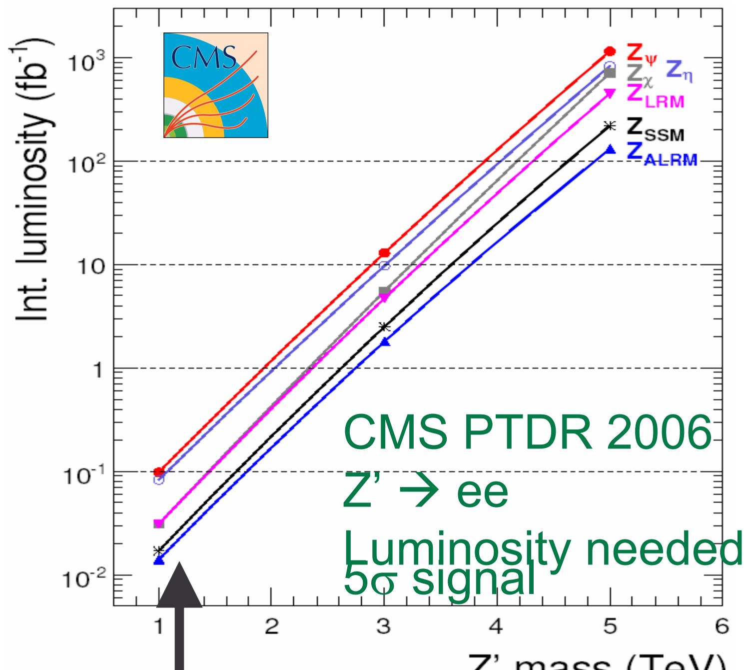


T. Rizzo, hep-ph/0610104v1

Heavy New Gauge Bosons Z’



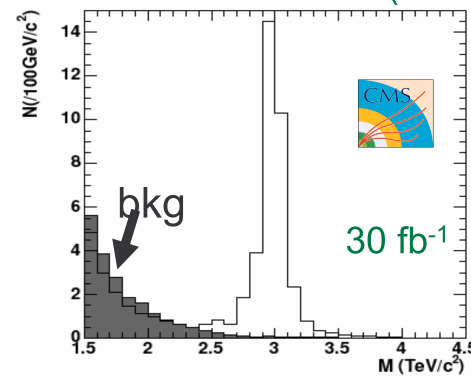
- Selection: pairs of isolated e or μ
- Bkg: dominated by dileptons from Drell-Yan
- 5σ discovery up to ~5 TeV (model dependent) for both ATLAS and CMS



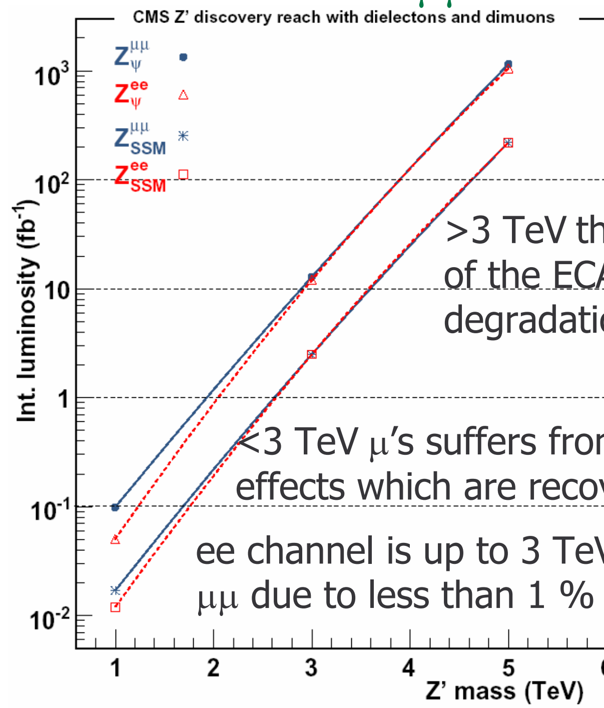
CMS PTDR 2006
Z’ → ee
Luminosity needed for 5σ signal

A very low luminosity, < 0.1 fb^{-1}, should be sufficient to discover Z’ bosons at 1 TeV For all models and in a single channel (e/m)

CMS PTDR Z’ → ee (SSM)



Z’ 5σ reach ee vs. μμ channels



>3 TeV the saturation of the ECAL causes a degradation of the ee

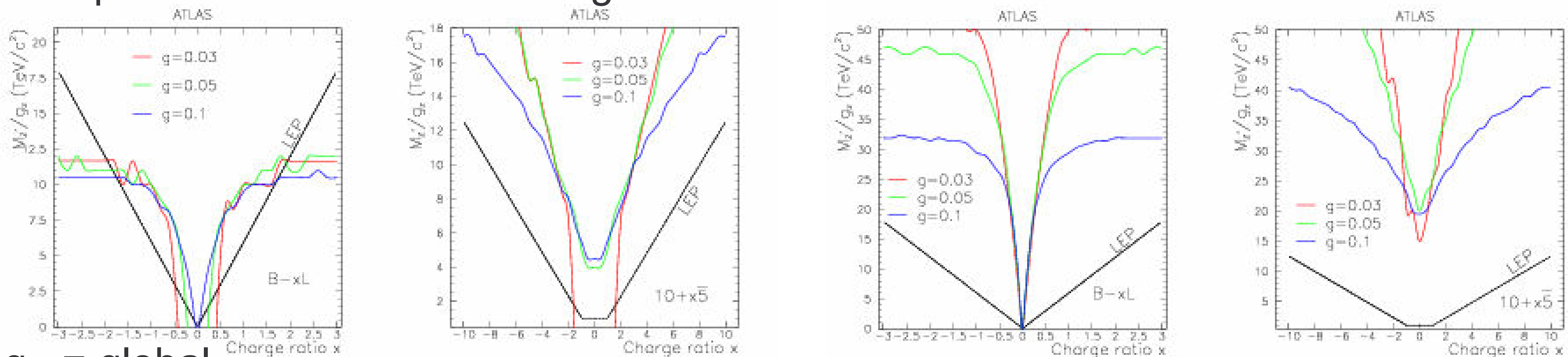
<3 TeV μ’s suffers from misalignment effects which are recovered after 10fb^{-1}

ee channel is up to 3 TeV better than the μμ due to less than 1 % resolution

Z' ATLAS reaches

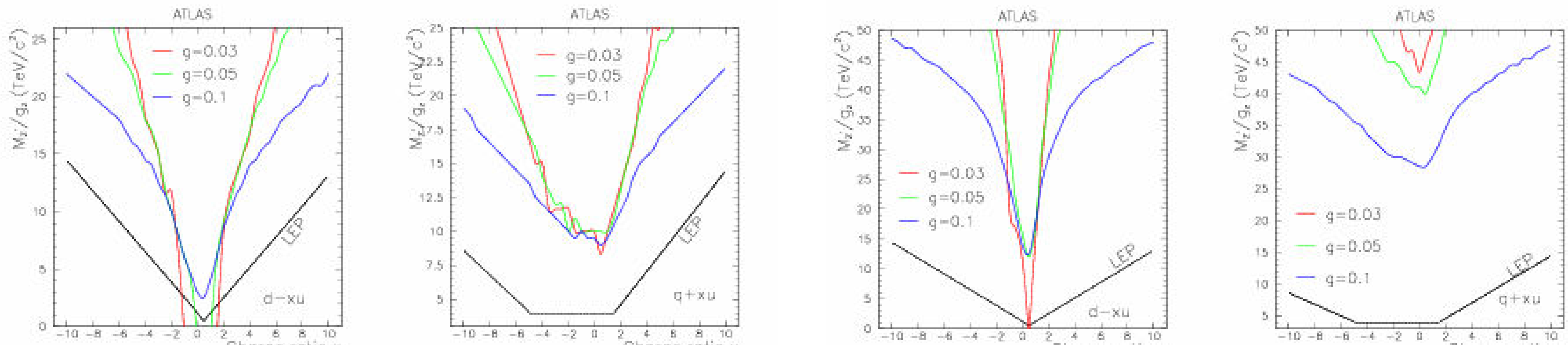
ATLAS discovery reaches in CDDT models of Z'

L=400pb^{-1} : first months of running at LHC — L=100fb^{-1}



$g_{Z'}$ = global coupling strength

x= describes relative coupling strength to different fermions



With only 400 pb^{-1} : can go beyond LEP exclusion limits and probe regions of parameter space not yet excluded by CDF.

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Discrimination between Z' models

- Models differ in the Z' couplings to fermions
  especially parity-violating couplings to leptons + couplings to initial u/d
- Distinguish by measuring:
  - $\sigma \times \Gamma$: Decay width (ee only due to worse $\mu\mu$ resolution)

    ATLAS: $\sigma(p_T)/p_T \approx 0.7\%$ (e), 10% (μ) at $p_T = 1$ TeV
  - Forward-backward asymmetry
  - Z' rapidity

→ Also provides discrimination against other models like extra-D, little Higgs, …

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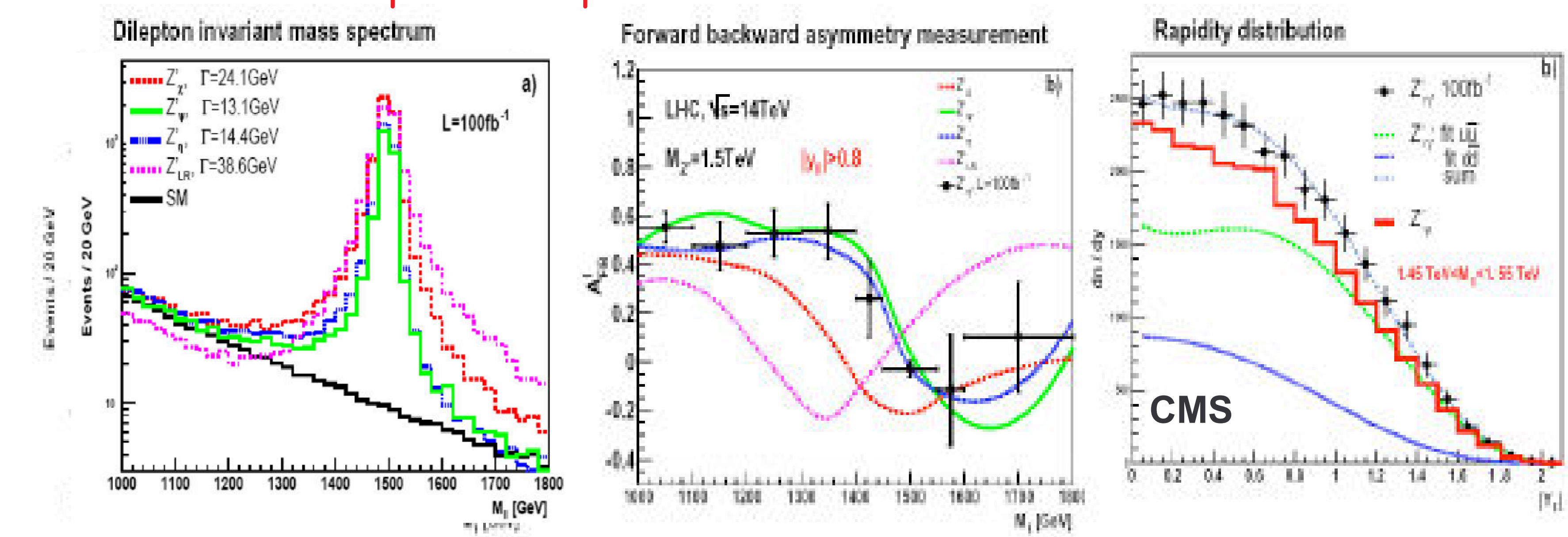
M = 1.5 TeV 100 fb^{-1}

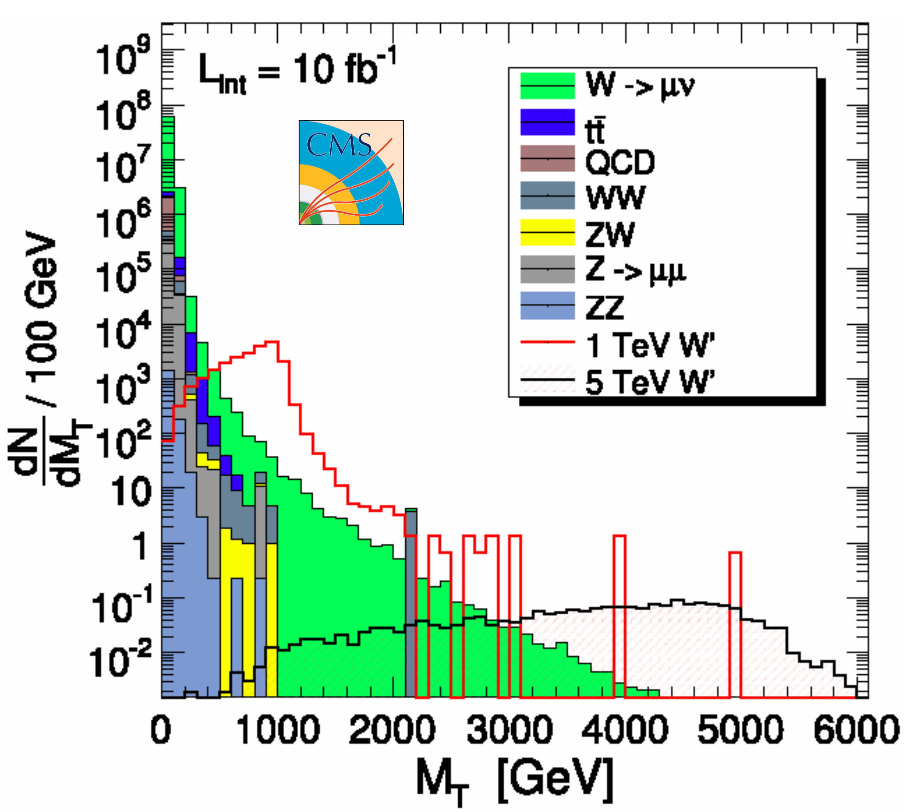
Model Z' → ee 100 fb^{-1}	$\sigma_{ll} \times \Gamma_{ll}$ (fb x GeV)	Corrected A_{FB} at Z' peak
SSM	3668 ± 138	+0.108 ± 0.027
χ	828 ± 48	-0.361 ± 0.030
LR	1515 ± 75	+0.186 ± 0.032

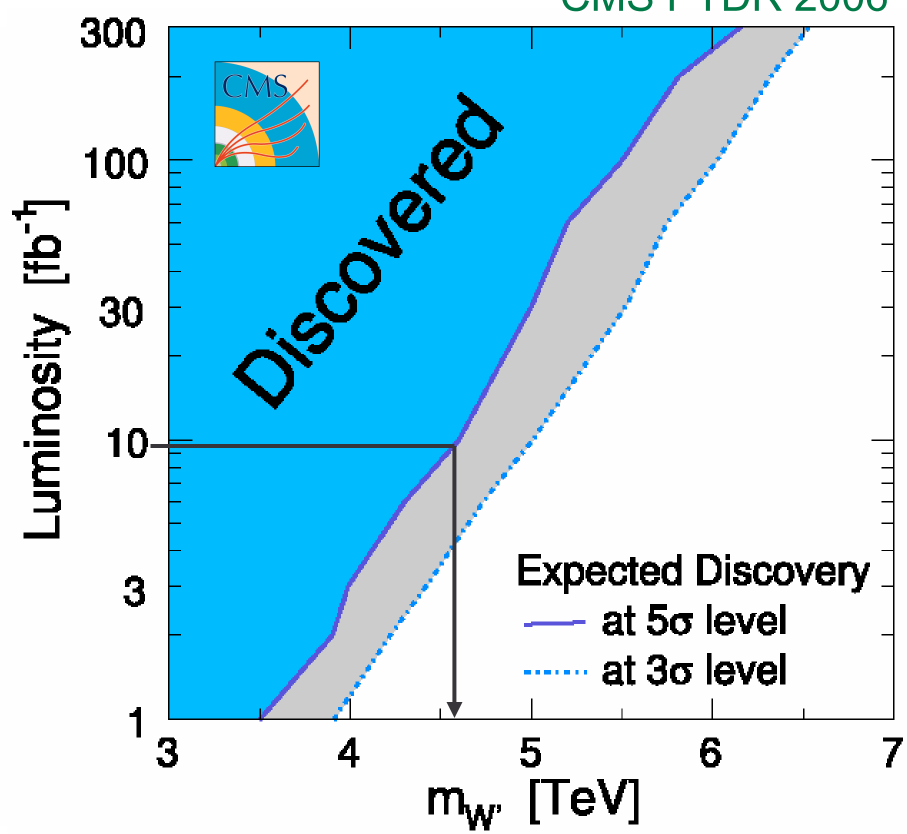
In one year at 10^{34}: reach 4-5 TeV & discriminating between models possible up to m~2.5 TeV



Heavy Gauge Bosons: W’

- General Model by Altarelli, Mele, Ruiz-Altaba with same W’ couplings to fermions as for W
- Selection: one-muon event with track isolation req[t] around μ + missing transverse energy
- Background: mostly W $\rightarrow \mu\ \nu$

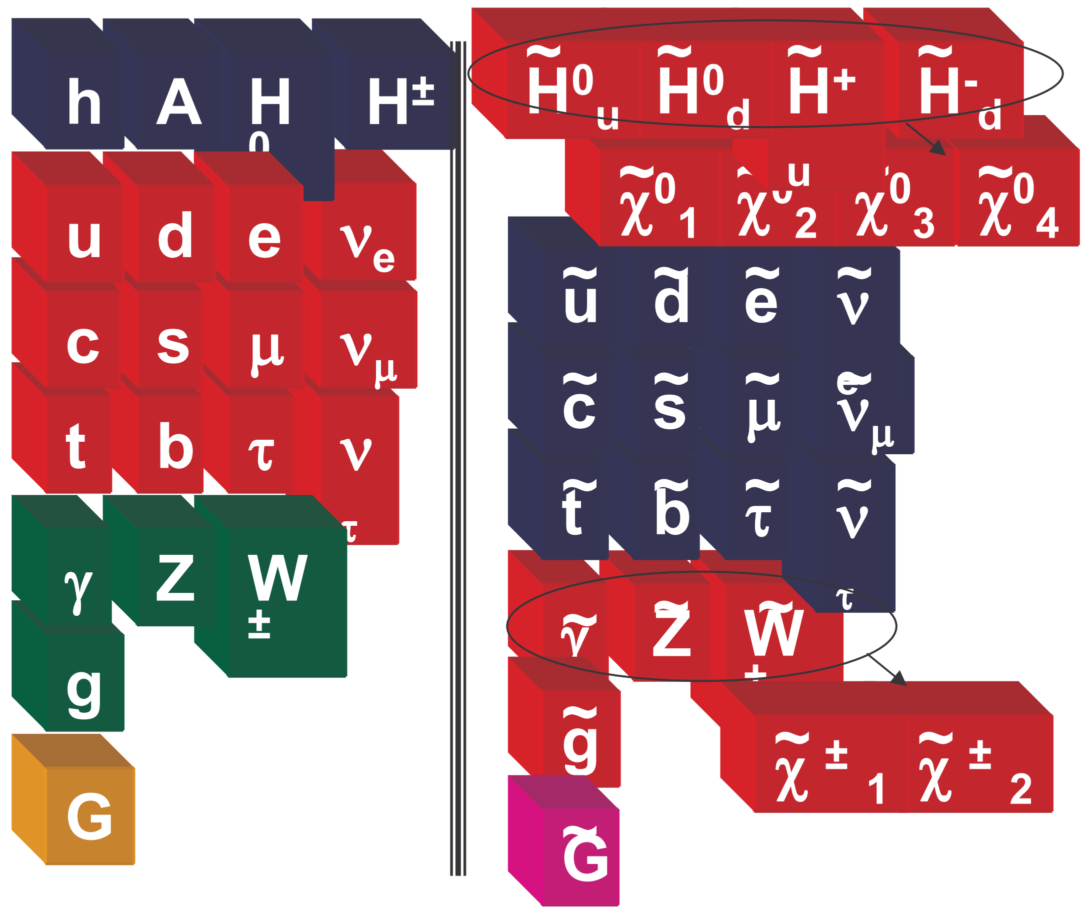




SUSY Spectrum

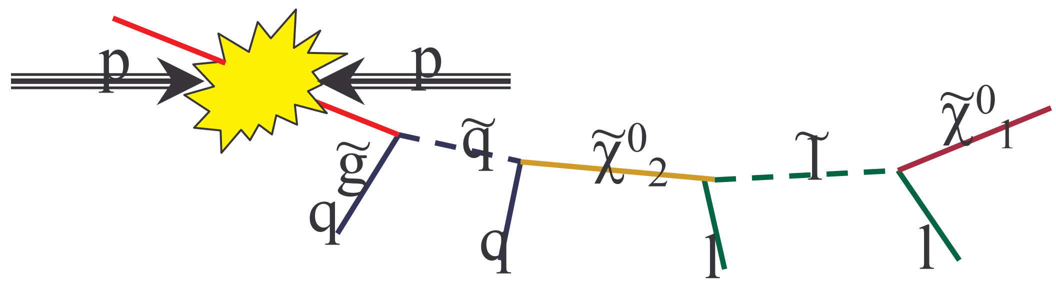
- SUSY gives rise to partners of SM states with opposite spin-statistics but otherwise same Quantum Numbers.
  spin-1/2 matter particles (fermions) <=> spin-1 force carriers (bosons)
- Expect SUSY partners to have same masses as SM states
  - Not observed
  - SUSY must be a broken symmetry
- Different mechanisms of SUSY breaking lead to different models

  MSSM, mSugra, MSSM, GMSB, AMSB
- R-Parity $R_p = (-1)^{3B+2S+L}$
- Conservation of R_p causes LSP to be stable



LHC SUSY Searches

Typical Signature/decay chain:



- Strongly interacting sparticles (squarks, gluinos) dominate production.
- Heavier than sleptons, gauginos etc. g cascade decays to LSP.
- Potentially long decay chains and large mass differences
  - **Many high p_T objects observed (leptons, jets, b-jets).**
- If R-Parity conserved LSP (lightest neutraliño in mSUGRA) stable and sparticles pair produced.
  - **Large E_T^{miss} signature (c.f. W g lν).**

SUSY Searches

- Inclusive searches to detect SUSY with first data
- Exclusive studies – performed with more data to determine model parameters e.g. masses etc from end point measurements…

SUSY discovery with first data

Inclusive searches to detect SUSY with first data
Look for deviations from SM predictions – requires good knowledge of SM processes at that energy scale and on an understanding of the detectors' performances

Best reach obtained with the most inclusive channels:

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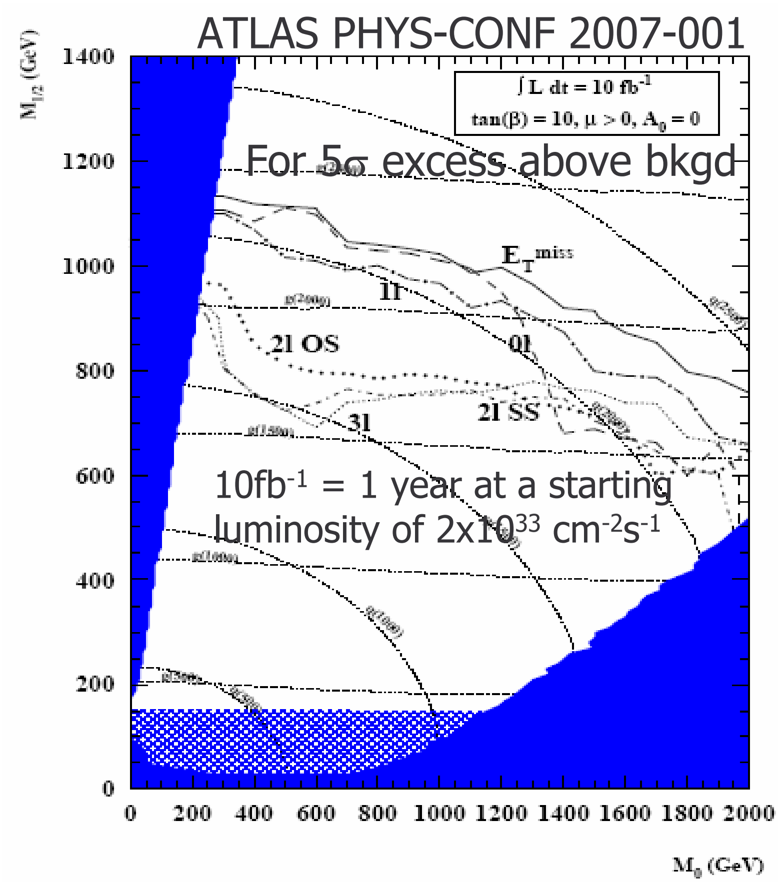
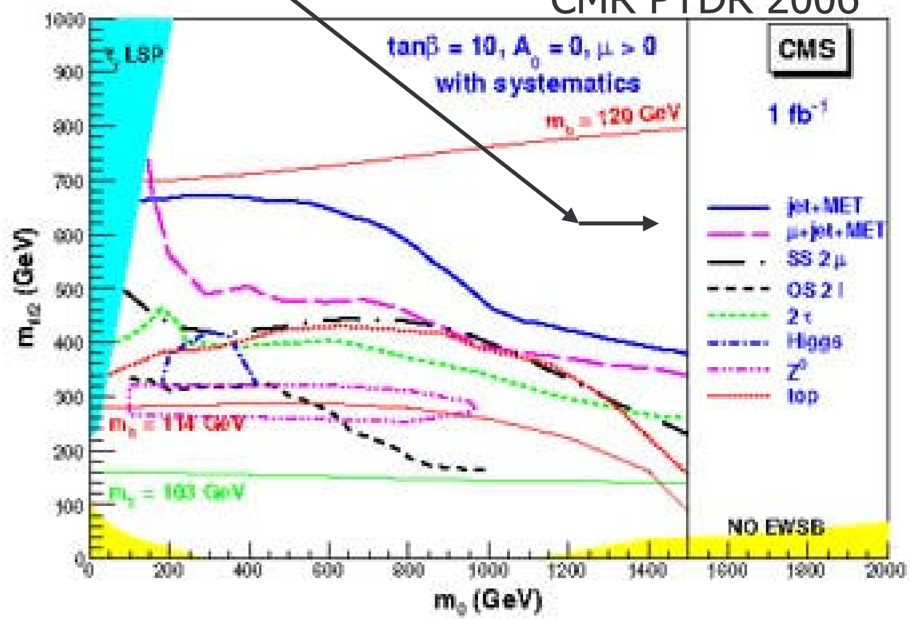


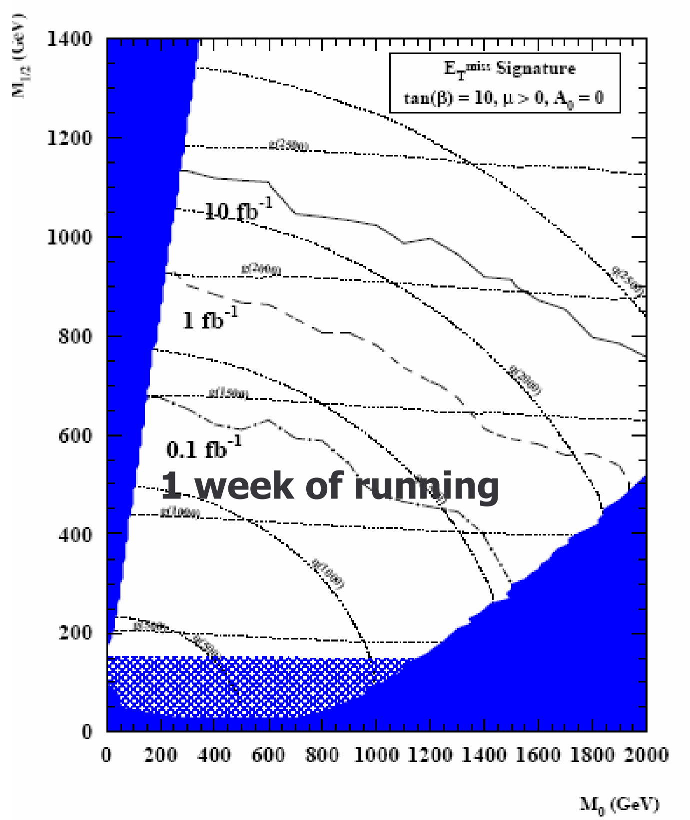
CMR PTDR 2006



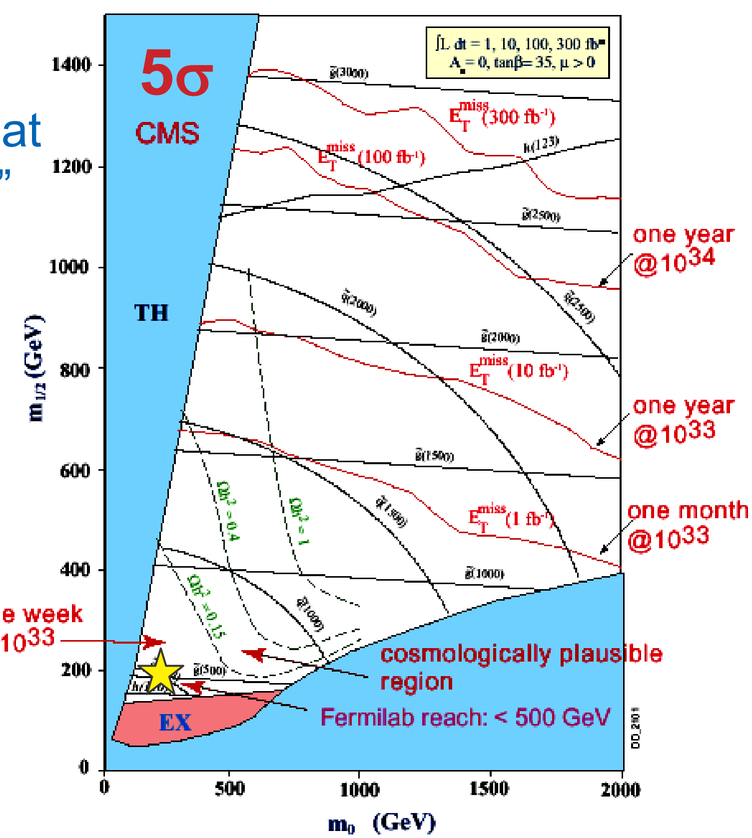
The range of gluino and squark masses up to about 1.5 TeV can be probed with $L=1fb^{-1}$ and up to about 2 TeV with $10fb^{-1}$

LHC: Jets + E_T^{miss}

- Inclusive searches with Jets + n leptons + E_T^{miss} channel.
- Map statistical discovery reach in mSUGRA m_0-$m_{1/2}$ parameter space.
- Sensitivity only weakly dependent on A_0, tan(β) and sign(μ).



"Golden channel at the LHC"



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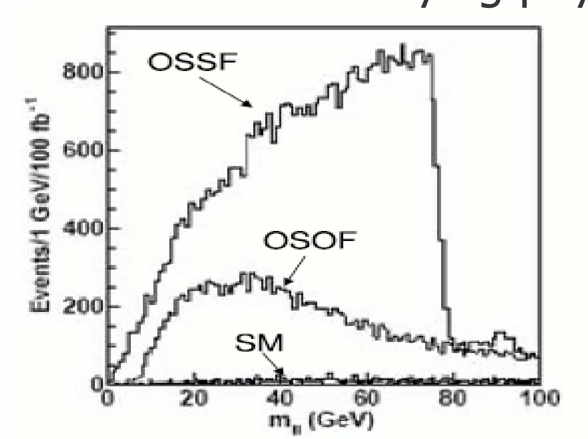
Exclusive SUSY Searches

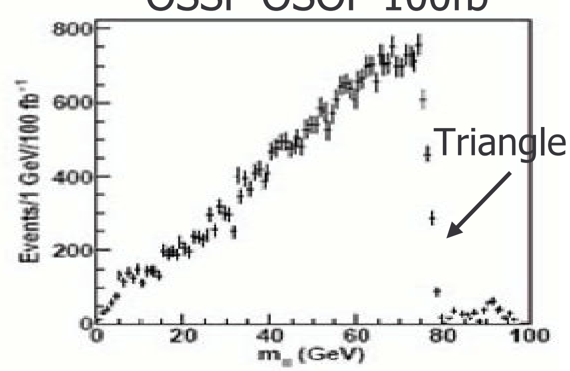
• Exclusive studies – reconstruct specific decay channels in order to estimate physical parameters characterising the decay:

e.g. reconstructing kinematic endpoints (edges & thresholds) in invariant mass distributions to extract masses

Simultaneous observation of a signal in various topologies would allow measurements of cross-sections of sub-processes and their ratios and help to determine the underlying physics.



OSSF-OSOF 100fb^{-1}



Dilepton channel is the "golden channel" for exclusive studies

Cleanest signature is the opposite sign same flavour invariant mass distributions of lepton (e/μ) pairs. From its endpoints can extract precise constraints on difference in masses between s-particles in decay chain with a statistical precision of 0.1% or better with L=100fb^{-1}

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EWSB: Little Higgs

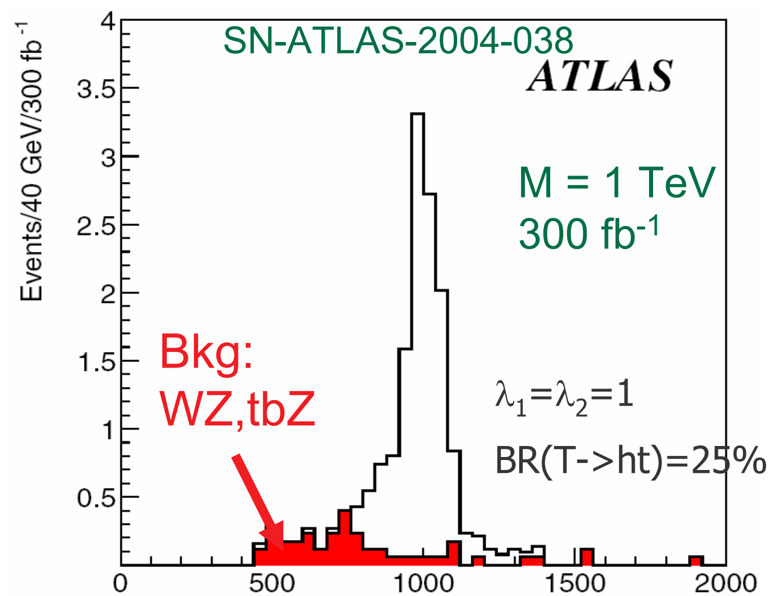
- Models with Higgs as pseudo-Goldstone boson from a broken global symmetry (SU(5) in "littlest Higgs model")
  - Extra Q=2/3 heavy quark (T) and heavy gauge bosons (A_H, W_H, Z_H)
  - Quadratic divergences cancel top and VB divergences to Higgs mass

Heavy Quark T

- Production: via QCD ($gg \to T\bar{T}$, $q\bar{q} \to T\bar{T}$)
  via W exchange ($qb \to q' T$) dominant for $M_T > 700$ GeV
- Decays: $T \to t Z$, $T \to t H$, $T \to b W$

Parameters: λ_1, λ_2 & f determine masses of T, t-quark & their couplings

- cleanest is $T \to t Z \to b l \nu l^+ l^-$ →
  main bkg is tbZ
  5σ signal up to ~1.0-1.4 TeV $\lambda_1/\lambda_2=1(2)$
- $T \to t H \to b l \nu \bar{b} b$ $< 5\sigma$
- $T \to b W \to b l \nu$
  main bkg is t t
  5σ signal up to ~2.0-2.5 TeV $\lambda_1/\lambda_2=1(2)$



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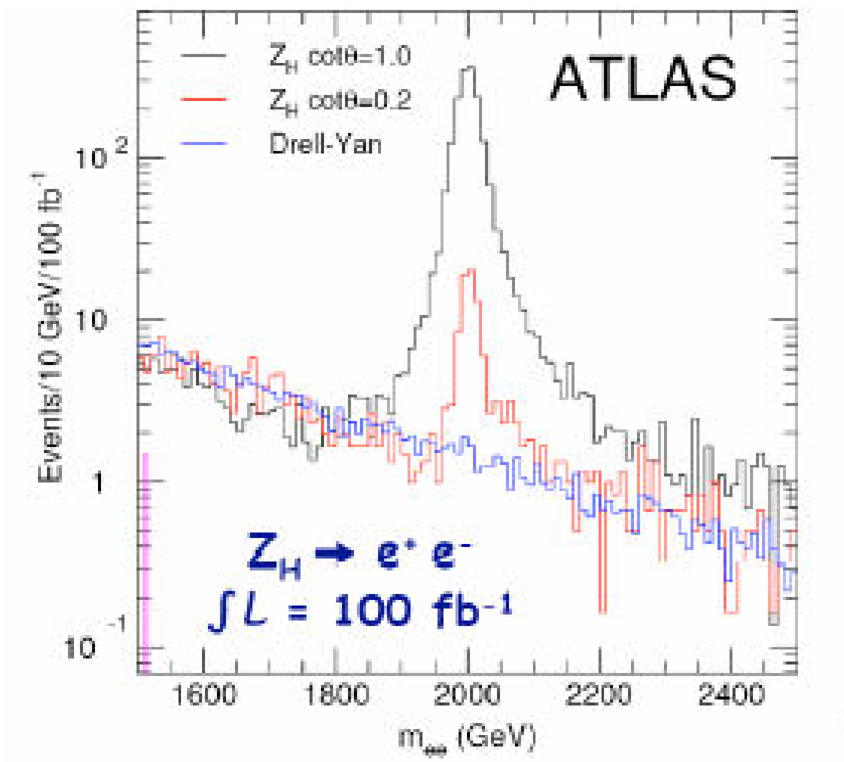
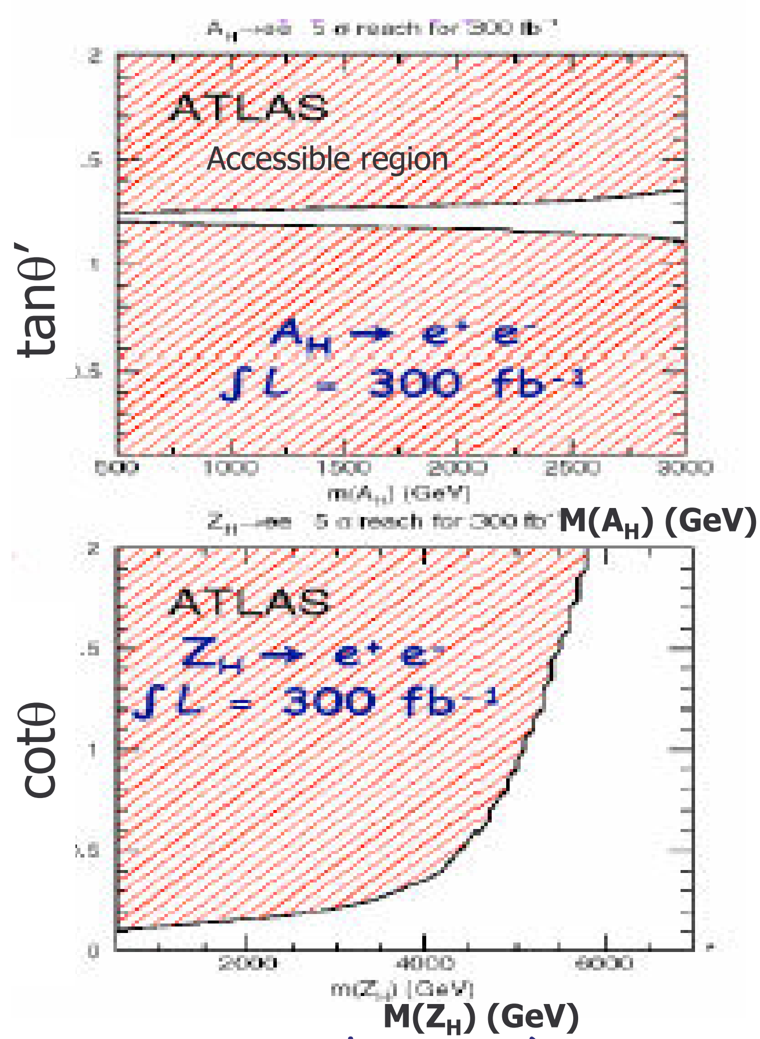
Little Higgs

- A_H and Z_H discovery in lepton modes

Signal: dilepton resonance



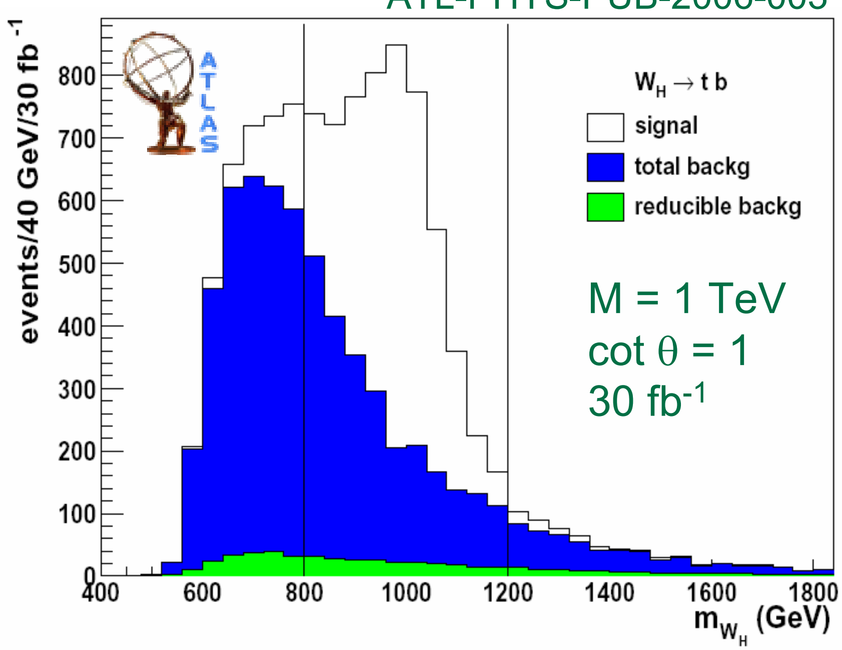


- Reach up to M ~ 6 TeV (depending on mixing angle cot θ)
- New gauge bosons observable over almost the entire mass range

ittle Higgs

- Discrimination against other models predicting dilepton resonances via observation of decay modes like $W_H \rightarrow W H$, $Z_H \rightarrow Z H$, and $W_H \rightarrow t \bar{b}$ (important at $\cot\theta \approx 1$, where $BR(W_H/Z_H \rightarrow W/Z\ H)$ vanishes)

ATL-PHYS-PUB-2006-003



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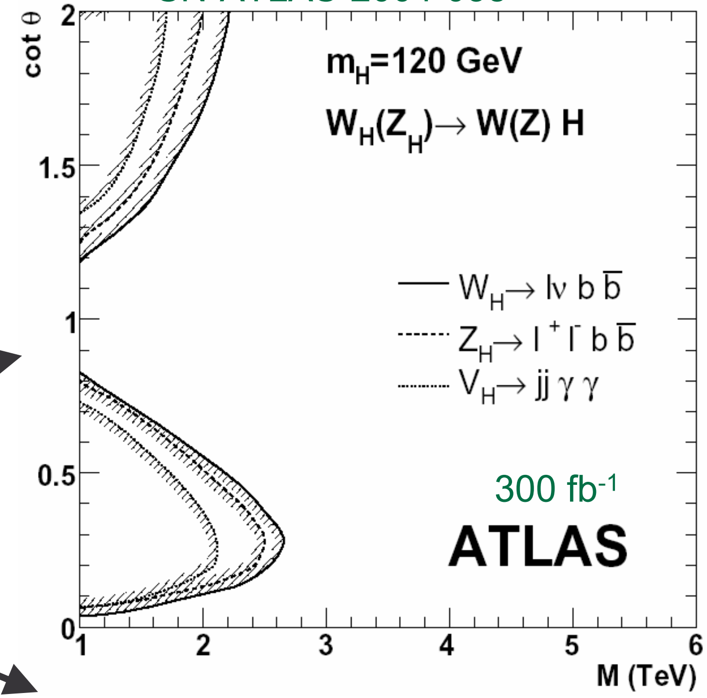
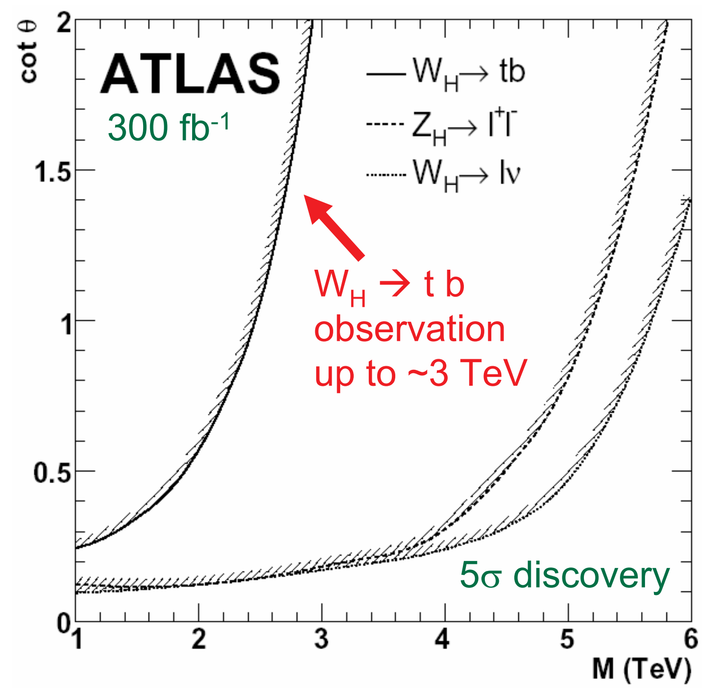
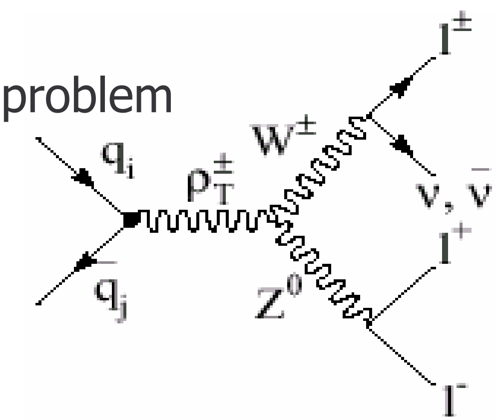
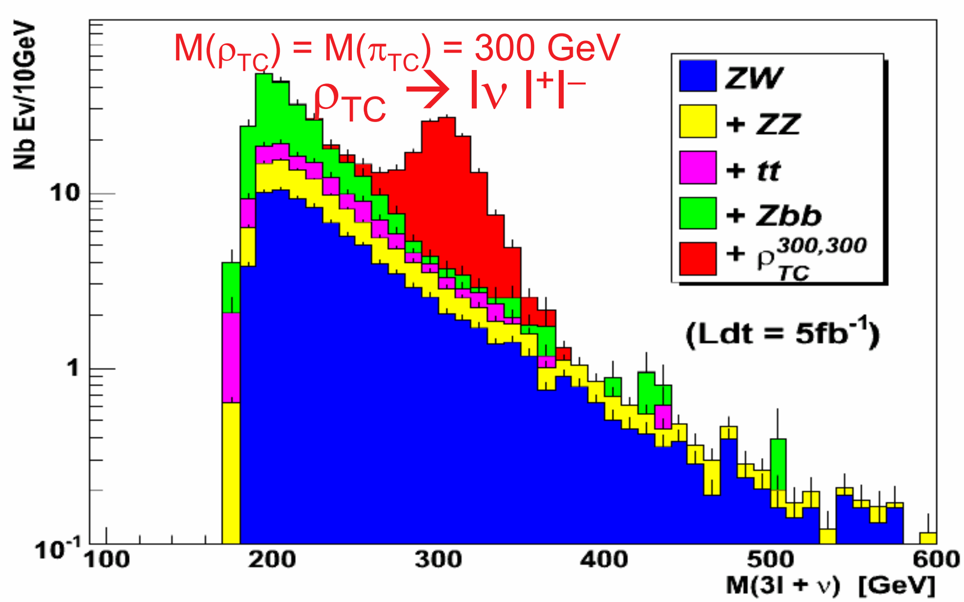


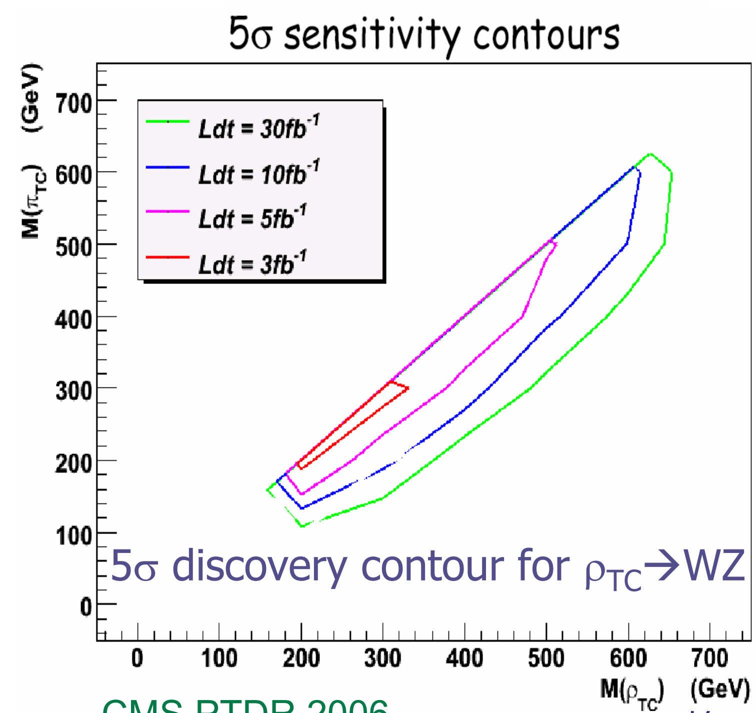


Dynamical EWSB: Technicolor

- Dynamical EWSB via new strong interaction
  - No need for Higgs boson ➔ removes fine tuning problem
  - Predict new technifermions, technihadrons
- Study $\rho_{TC} \rightarrow W\,Z$ process
- Select isolated leptons, measure missing E_T & apply W and Z kinematical constraints
- Bkg: WZ, ZZ, $Zb\bar{b}$, $t\bar{t}$



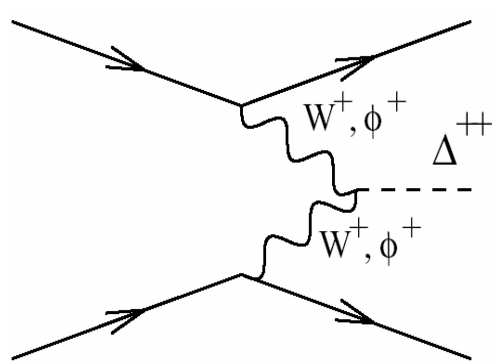




CMS PTDR 2006

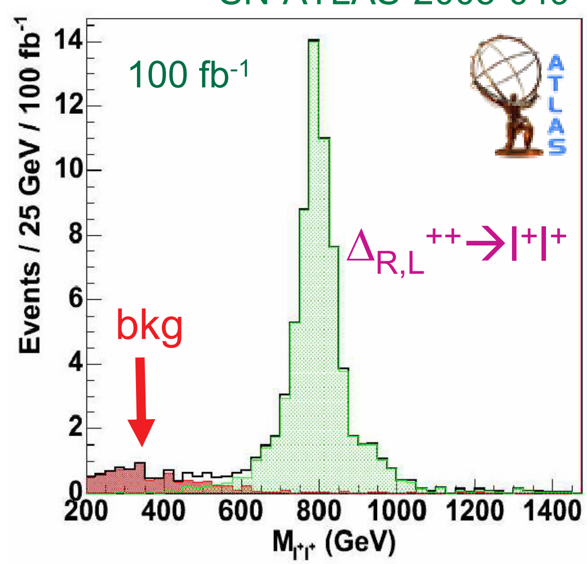
Doubly Charged Higgs in the L-R Symmetric Model

- Left-Right Symmetric Model based on $SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$
  - Features triplet of Higgs fields (Δ_R^0, Δ_R^+, Δ_R^{++}) + two doublets ϕ
  - Predicts new gauge bosons (W_R and Z_R) & new fermions (heavy Majorana ν, ν_R)
  - Addresses origin of pure left-handed charged weak interaction
    + origin of light neutrino masses (via see-saw mech. & heavy ν_R)
- Production: $q\bar{q} \rightarrow q'q' W_{R,L}^+ W_{R,L}^+ \rightarrow q'q' \Delta_{R,L}^{++}$
  $q\bar{q} \rightarrow \gamma^*/Z/Z_{R,L} \rightarrow \Delta_{R,L}^{++} \Delta_{R,L}^{--}$
- Decay: $\Delta_{R,L}^{++} \rightarrow l^+ l^+$
- Selection (WW fusion):
  2 like-sign leptons (e, μ, τ)
  + "forward" jets
- Bkg: $W^+ W^+ q q$, $W t \bar{t}$



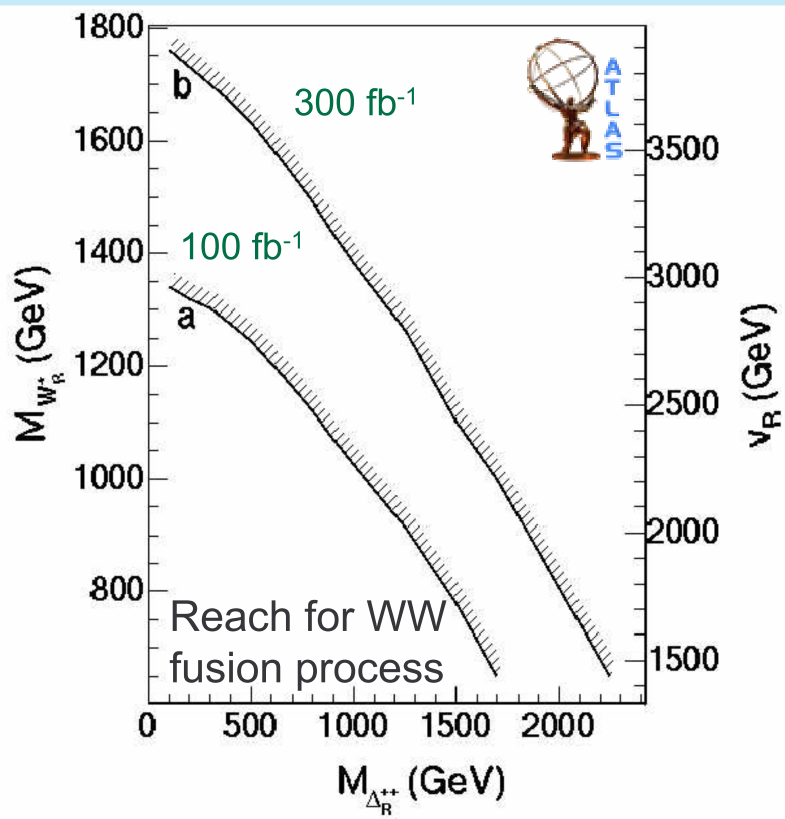
$g_R = g_L$
$m(W_R) = g_R v_R / \sqrt{2}$

SN-ATLAS-2005-049



Doubly Charged Higgs
in the L-R Symmetric Model

- Selection ($\Delta_{R,L}^{++}\ \Delta_{R,L}^{--} \rightarrow 4l$ process):
  2 pairs of like-sign leptons (e, μ, τ)
- Bkg: negligible
- Contours for 10 signal events



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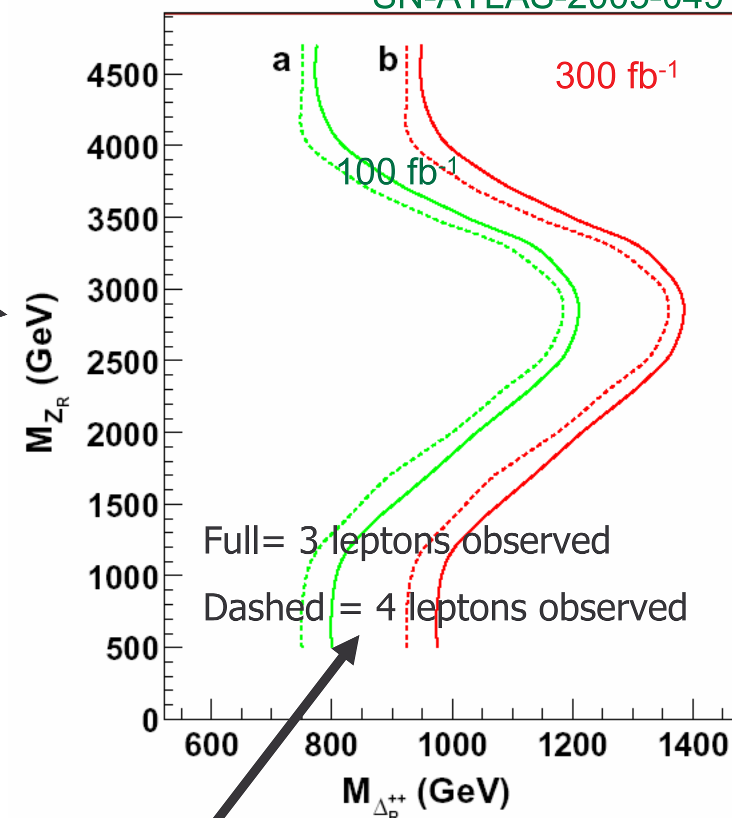
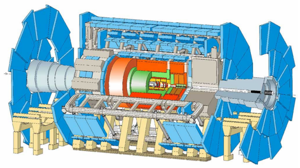


Reach improves if only
3 leptons are required (solid lines)

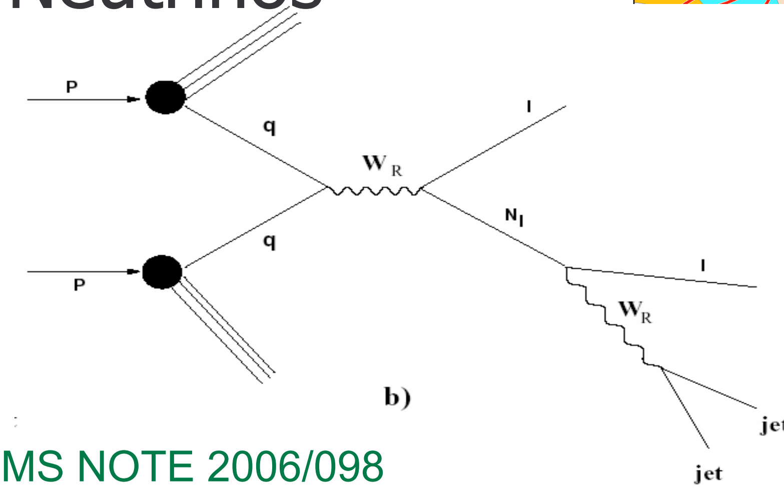
➔ Δ_R^{++} *Mass reach* 0.8 – 1.2 TeV (100 fb^{-1})
0.9 – 1.4 TeV (300 fb^{-1})

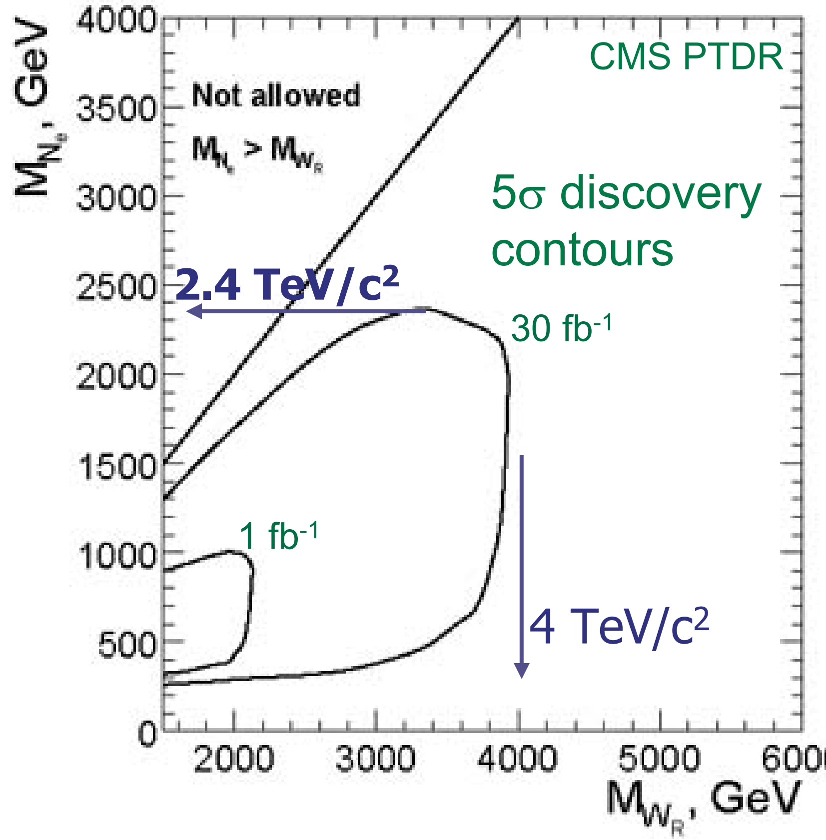
(RHUL)



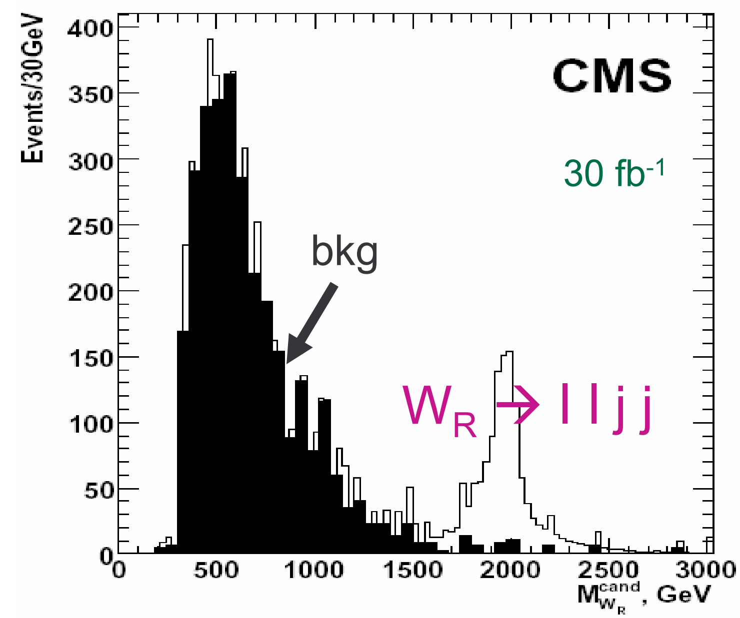
W_R and Majorana Neutrinos

- Left-right Symmetric Model
- Signature:
  lepton + 2 jets for heavy neutrino N_l
  dilepton + 2 jets for W_R





CMS NOTE 2006/098



Even after just 1 month of running at low lum. can achieve W_R=2 TeV N_e 500 GeV/c^2

Leptoquarks

SM extension: lepton-quark symmetry

Generic prediction of GUTs, composite models, technicolor schemes, superstring-inspired E_6 models & SUSY with R-parity violation

$\Rightarrow$LQ: color triplets with couplings to quarks and leptons

Study: Pair Production of Scalar LQ

$LQ\overline{LQ} \rightarrow l^+ q l^- q$

Signature: 2jets+2 leptons: 1st and 2nd gen.

Sensitivity: M_{LQ}~1.3 TeV β=1

M_{LQ}~1 TeV β=0.5 L=30fb^{-1}

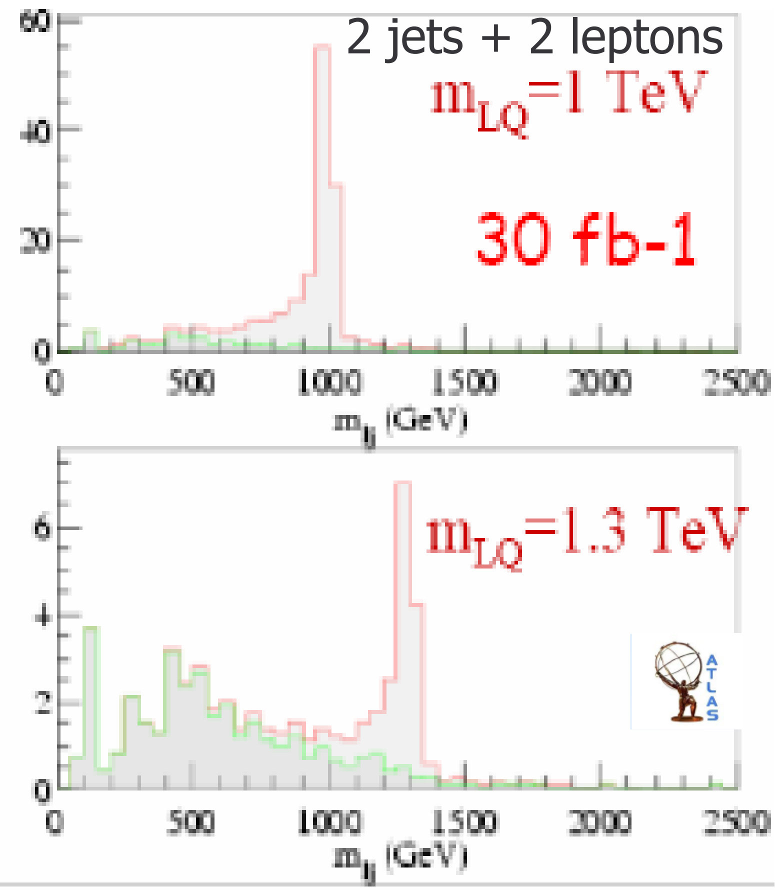
β = BR(LQ$\rightarrow$lq)

$LQ\overline{LQ} \rightarrow \nu_\tau b \bar{\nu}_\tau \bar{b}$

Signature 2 jets + Et : 3rd generation

Sensitivity: M_{LQ} ~ 1 TeV β=0.5

M_{LQ} ~ 1.3 TeV β=0



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Excited Quarks

If quarks & leptons have substructure…
there should exist new interactions among them at the scale of the constituents binding energies

$\rightarrow$ a possible consequence is the existence of excited quarks/leptons with masses of order the compositeness scale Λ.

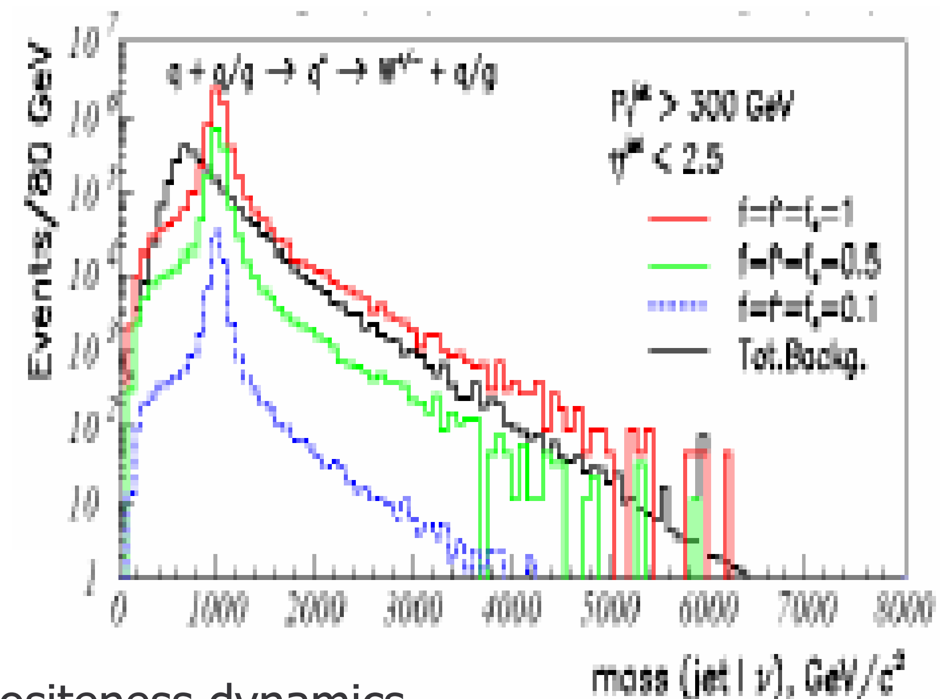
Excited Quarks

Production: quark-gluon fusion

Decay Signature: photons+jets
quarks + gauge bosons
quarks + gluons

L=300fb^{-1}, Λ=m*,f=f′=1

- Reach limit for $q^* \rightarrow q\gamma$: 6.5 TeV
- Reach limit for $q^* \rightarrow qW$: 7 TeV
- Reach limit for $q^* \rightarrow qZ$: 4.5 TeV
- Reach limit for $q^* \rightarrow gq$: 6 TeV



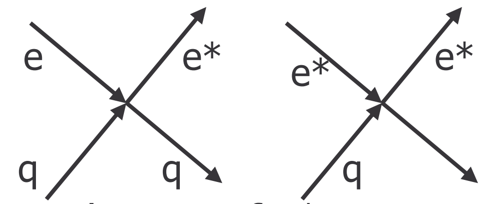
f= Coupling determined by the compositeness dynamics
ATL-PHYS-PUB-2006-027

Excited Leptons

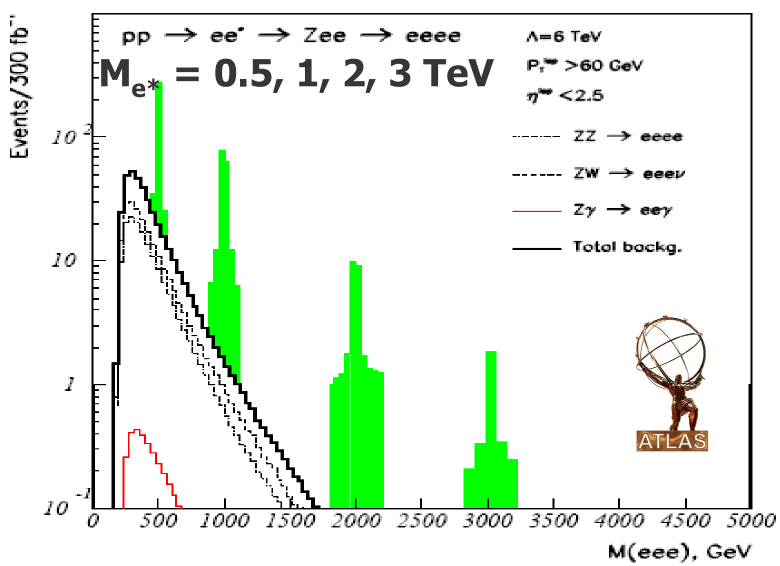
Excited Electrons

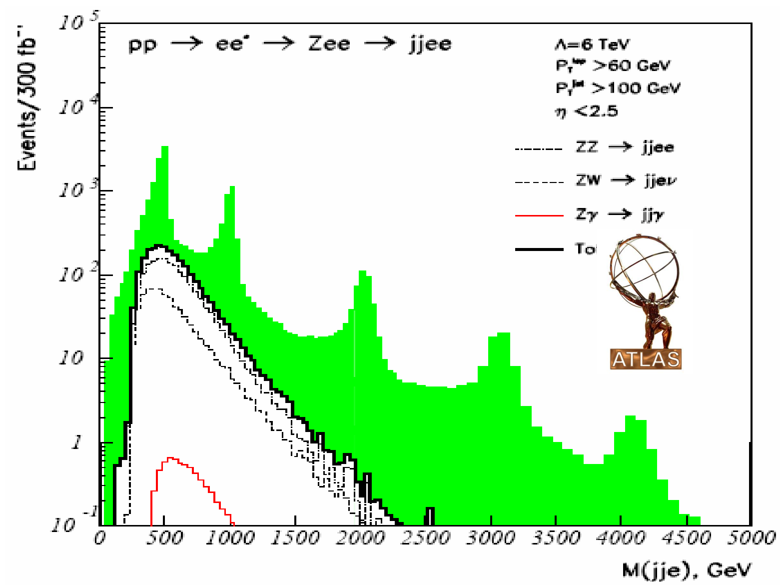
At E<< Λ compositeness scale Λ, quark-lepton interactions can be effectively approximated by contact interactions

- Production and decay: qq → e*e → Zee & Z → ee or jj
- Primary backgrounds: ZZ, Z + photon



Single production of e* via contact interactions
Decay via gauge interactions





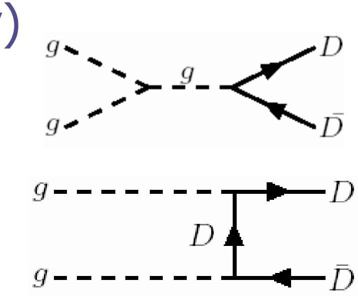
f=f′=1

Reach ~3-4TeV for L=6 TeV 300 fb^{-1}

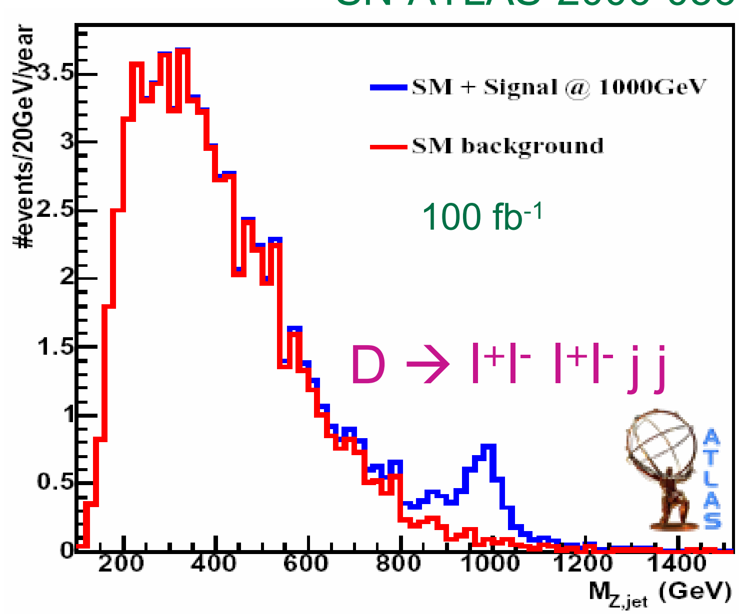
ATLAS-PHYS-2002-014

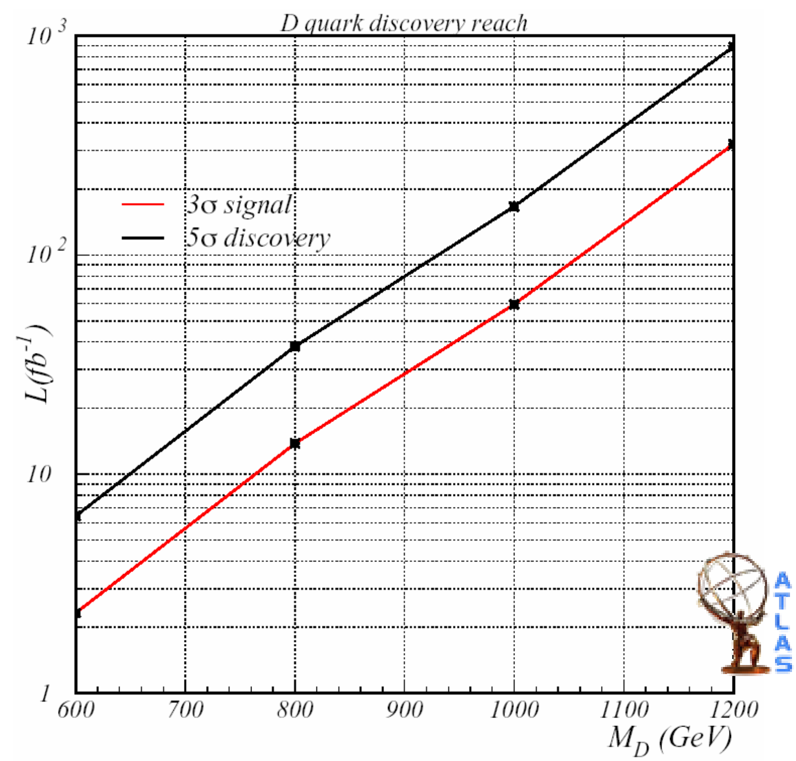
Heavy Quarks

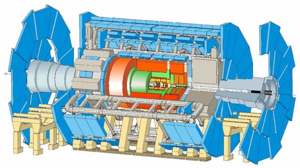
- Symmetry group E_6 favored by string-inspired GUTs (supergravity)
  - Predicts new Q=-1/3 quark
- Production: $gg \rightarrow D\bar{D}$ (dominant for M_D < 1.1 TeV)
  $\bar{q}q \rightarrow D\bar{D}$ (dominant for M_D > 1.1 TeV)
- Decay: $D \rightarrow W u$ or $D \rightarrow Z d$ (for this study)
- Selection: 4 leptons (from Z)
  + 2 jets



SN-ATLAS-2006-056



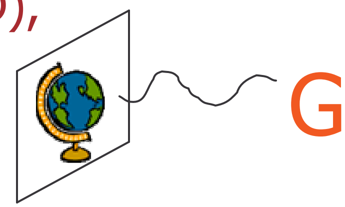


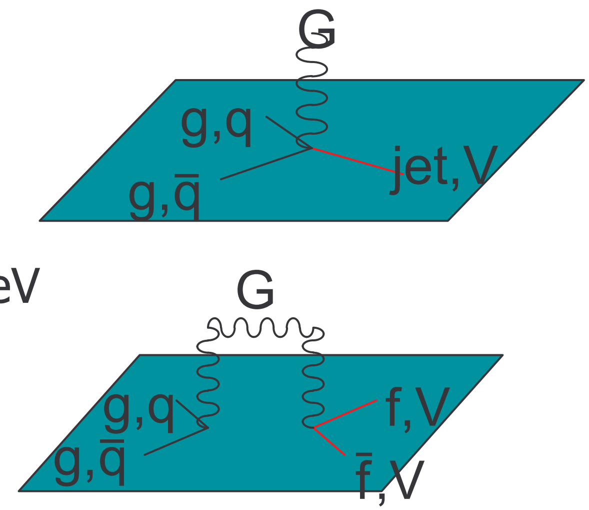


Extra Dimensions ADD Model

Arkani-Hamed, Dimopoulos, Dvali, Phys Lett B429 (98), Nuc.Phys.B544(1999)

(Many) Large flat Extra-Dimensions (LED),
could be as large as a few μm
G can propagate in ED
SM particles restricted to 3D brane
The fundamental scale is not planckian: $M_D = M_{Pl(4+\delta)} \sim$ TeV





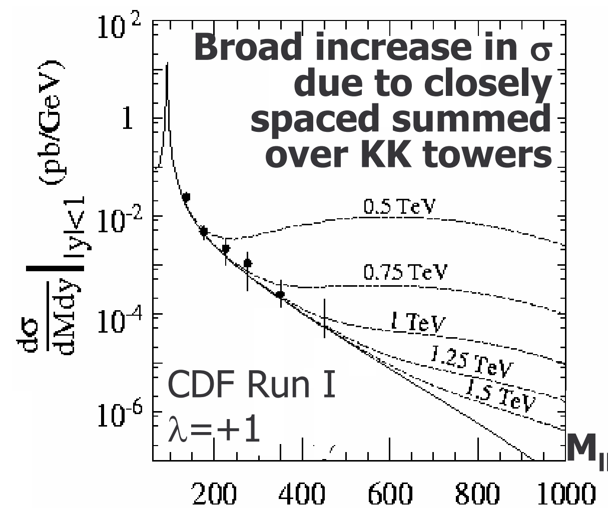
Model parameters are:
- δ = number of ED
- $M_{Pl}(4+\delta)$ = Planck mass in the 4+δ dimensions

$$M_{Pl}^2 \sim R^\delta M_{Pl(4+\delta)}^{(2+\delta)}$$

Signature:

❖ Real graviton emission: in association with a vector-boson
jets + missing ET, V+missing ET

❖ Or deviations in virtual graviton exchange
e.g. Excess above di-lepton continuum



ADD Discovery Limit: Real G Emission

J. Weng et al. CMS NOTE 2006/129

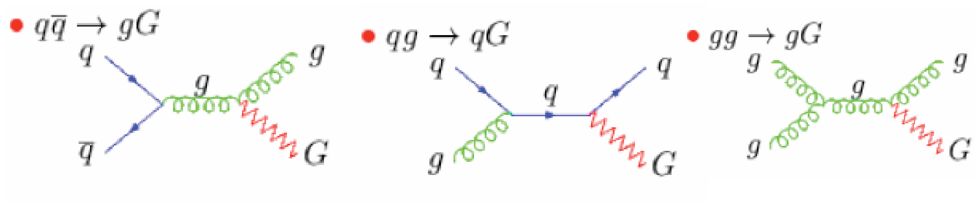
$pp \to \gamma + G^{KK}$

Signature: high-p_T photon + high missing E_T

Main Bkgd: irreducible $Z\gamma \to \nu\nu\gamma$,
Also $W \to e(\mu,\tau)\nu$, $W\gamma \to e\nu$, γ+jets,
QCD, di-γ, Z^0+jets

M_D = 1– 1.5 TeV for 1 fb^{-1}
2 - 2.5 TeV for 10 fb^{-1}
3 - 3.5 TeV for 60 fb^{-1}

Rates for $M_D \geq$ 3.5TeV are very low – too low for 5σ discovery



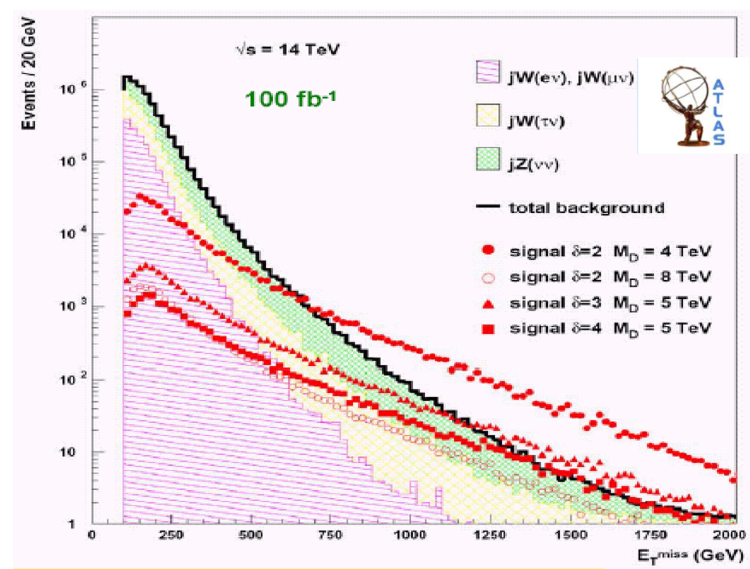
M_D^{MAX} (TeV)	δ=2
HL 100fb^{-1}	4

$pp \to jet + G^{KK}$

Signature: high E_T jet + large missing E_T
Bkgd: irreducible jet+Z/W $\to$jet+$\nu\nu$ /jet+lν
vetos leptons: to reduce jet+W bkdg mainly

Discovery limits

$M_{Pl(4+d)}^{MAX}$(TeV)	δ=2	δ=3	δ=4
LL 30fb^{-1}	7.7	6.2	5.2
HL 100fb^{-1}	9.1	7.0	6.0

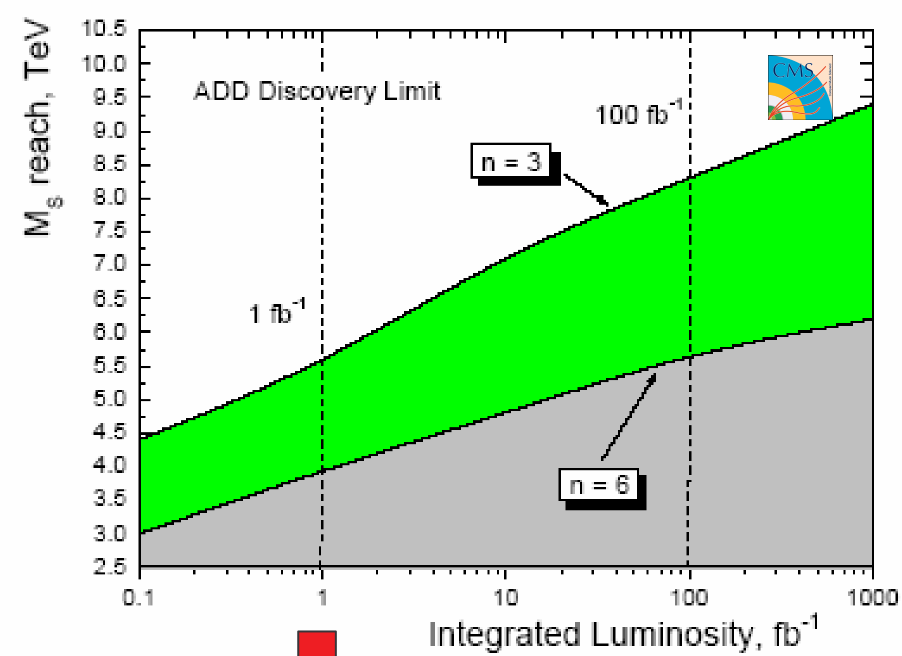


L.Vacavant, I.Hinchcliffe, ATLAS-PHYS 2000-016
J. Phys., G 27 (2001) 1839-50

ADD Discovery Limit: G Exchange

$pp \to G^{KK} \to \mu\mu$

- Two opposite sign muons & $M_{\mu\mu}$>1 TeV
- Bkg: Irreducible Drell-Yan, also ZZ, WW, WW, tt (suppressed after selection cuts)



channel	n / luminosiy		2	3	4	5
$\gamma\gamma$	10 fb^{-1}	M_S^{max} (TeV)	6.3	5.6	5.1	4.9
		S/B	36/18	36/18	39/25	34/13
	100 fb^{-1}	M_S^{max} (TeV)	7.9	7.3	6.7	6.3
		S/B	50/53	62/96	55/72	51/53
l^+l^-	10 fb^{-1}	M_S^{max} (TeV)	6.6	5.9	5.4	5.1
		S/B	33/11	31/8	30/6	30/6
	100 fb^{-1}	M_S^{max} (TeV)	7.9	7.5	7.0	6.6
		S/B	49/48	38/21	36/16	29/6
Fast MC $\gamma\gamma + l^+l^-$	10 fb^{-1}	M_S^{max} (TeV)	7.0	6.3	5.7	5.4
	100 fb^{-1}	M_S^{max} (TeV)	8.1	7.9	7.4	7.0

1 fb^{-1}: 3.9-5.5 TeV for n=6..3
10 fb^{-1}: 4.8-7.2 TeV for n=6..3
100 fb^{-1}: 5.7-8.3 TeV for n=6..3
300 fb^{-1}: 5.9-8.8 TeV for n=6..3

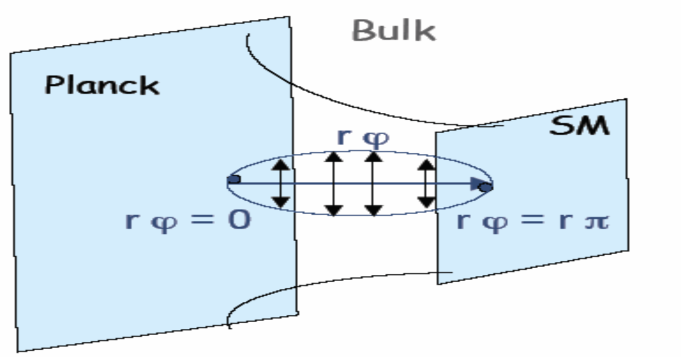
V. Kabachenko et al. ATL-PHYS-2001-012

Belotelov et al., CMS NOTE 2006/076, CMS PTDR 2006

L)

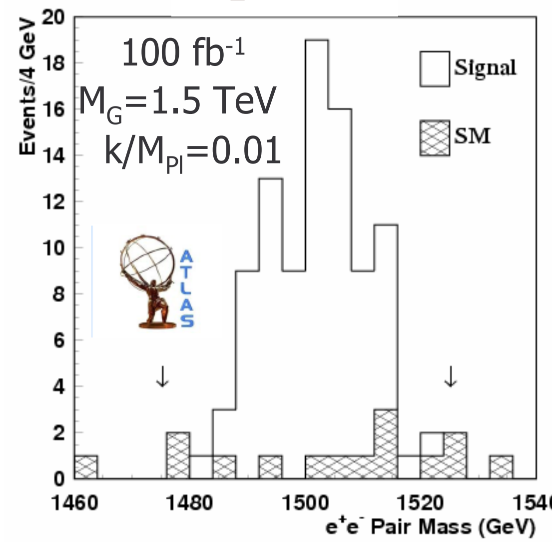
Model RS

1 extra warped dimension



Signature:
Narrow, high-mass resonance states in dilepton/dijet/diboson channels

$G_1 \rightarrow e^+e^-$



Model parameters:

- Gravity Scale: $\Lambda_\pi = \overline{M}_{pl} e^{-kR_c\pi}$

  1st graviton excitation mass: m_1 → **Resonance position**

  $\Lambda_\pi = m_1 \overline{M}_{pl}/kx_1$, & $m_n = kx_n e^{krc\pi} (J_1(x_n)=0)$
- Coupling constant: $c = k/M_{Pl}$

  $\Gamma_1 = \rho m_1 x_1^2 (k/\overline{M}_{pl})^2$ → width

k = curvature, R = compactification radius

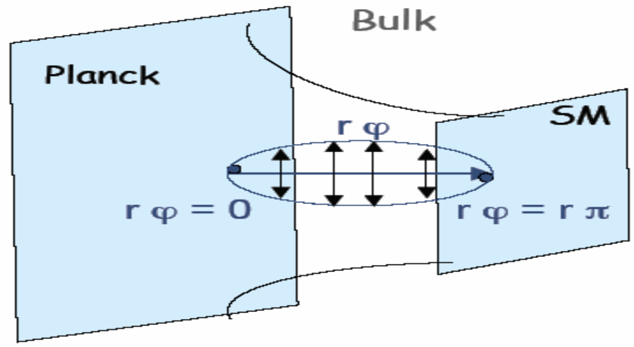
Best channels to search in are $G(1) \rightarrow e^+e^-$ and $G(1) \rightarrow \gamma\gamma$ due to the energy and angular resolutions of the LHC detectors

$G(1) \rightarrow e^+e^-$ best chance of discovery due to relatively small bkdg, from Drell-Yan

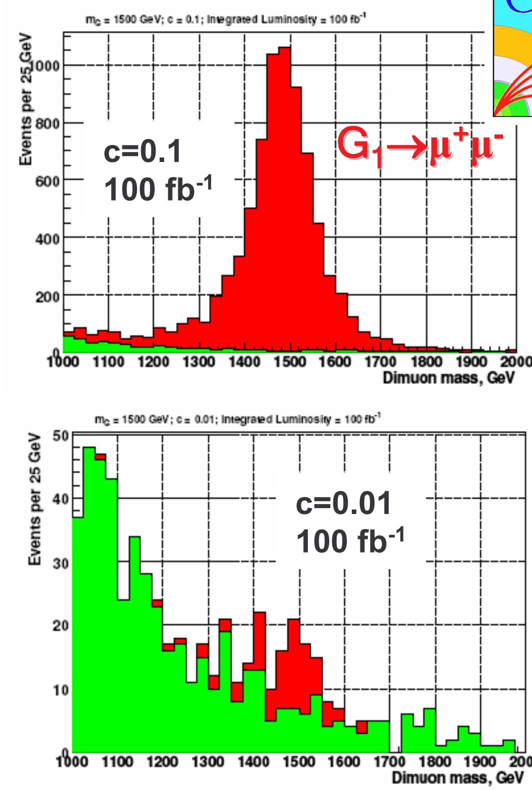
Allenach et al, hep-ph0211205 Allenach et al, hep-ph0006114

Model RS

1 extra warped dimension



Signature:
Narrow, high-mass resonance states in dilepton/dijet/diboson channels



Model parameters:

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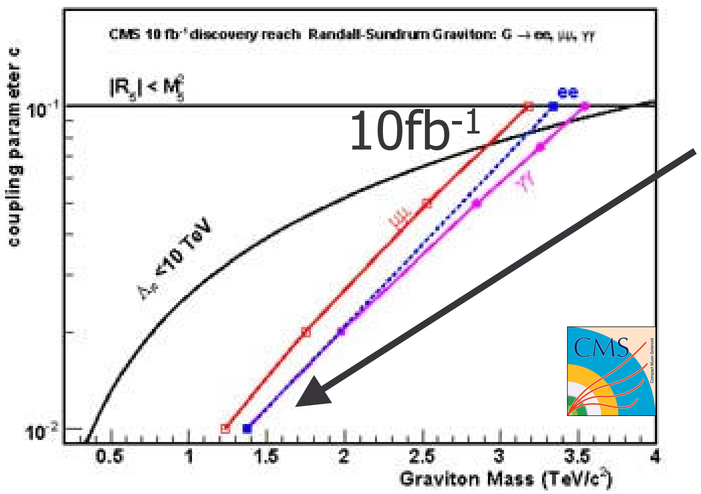
Best channels to search in are $G(1) \to e^+e^-$ and $G(1) \to \gamma\gamma$ due to the energy and angular resolutions of the LHC detectors

$G(1) \to e^+e^-$ best chance of discovery due to relatively small bkdg, from Drell-Yan

I. Belotelov et al. , CMS NOTE 2006/104, CMS PTDR 2006
Allenach et al, hep-ph0211205 Allenach et al, hep-ph0006114

RS1 Discovery Limit

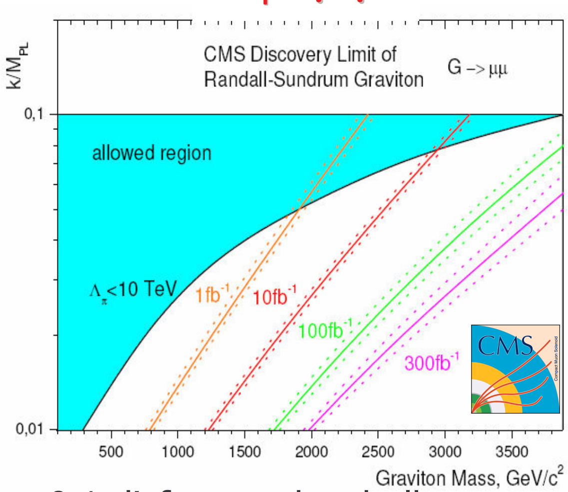


BR(G->γγ) = 2* BR(G->ee/μμ)

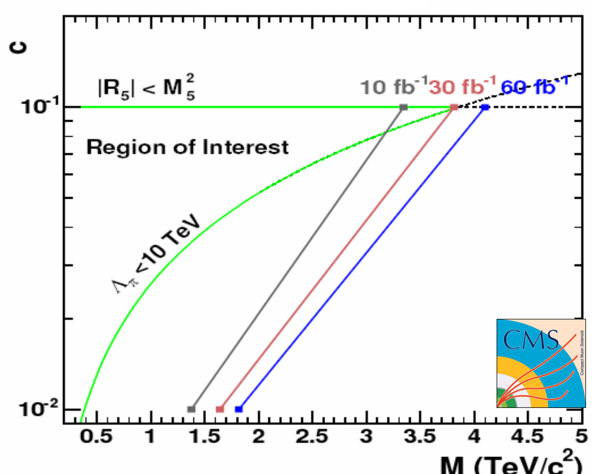
Reach for e and γ is comparable for low coupling and G mass due to the QCD and prompt photon bkgds in the γγ channel which are harder to efficiently suppress μμ channel trails ee chanel due to resolution

< 60 fb⁻¹ LHC completely covers the region of interest

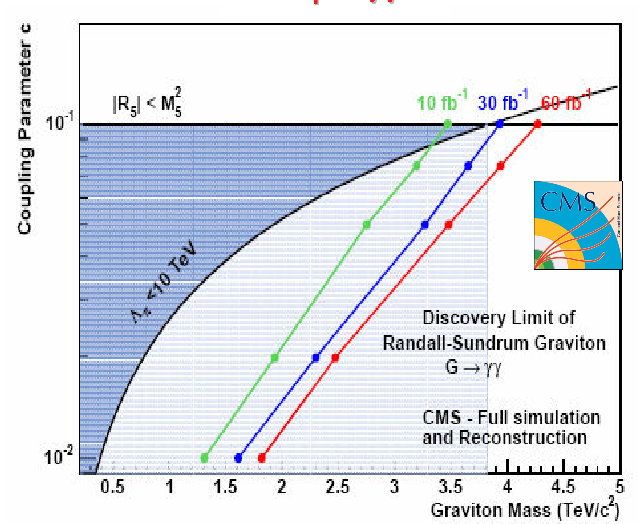
$G_1 \to \mu^+\mu^-$



$G_1 \to e^+e^-$



$G_1 \to \gamma\gamma$



c>0.1 disfavoured as bulk curvature becomes to large (larger than the 5-dim Planck scale)

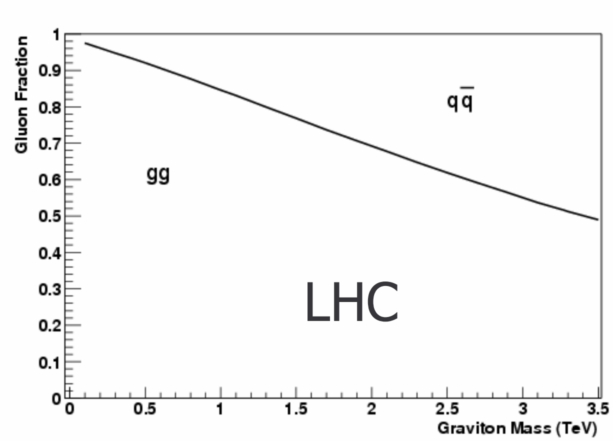
CMS PTDR 2006

RS1 Model Determination

How could a RS G resonance be distinguished from a Z′ resonance?

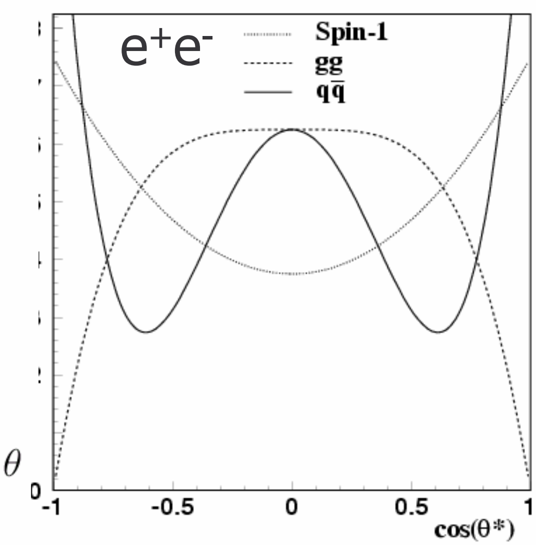
Potentially using Spin information:

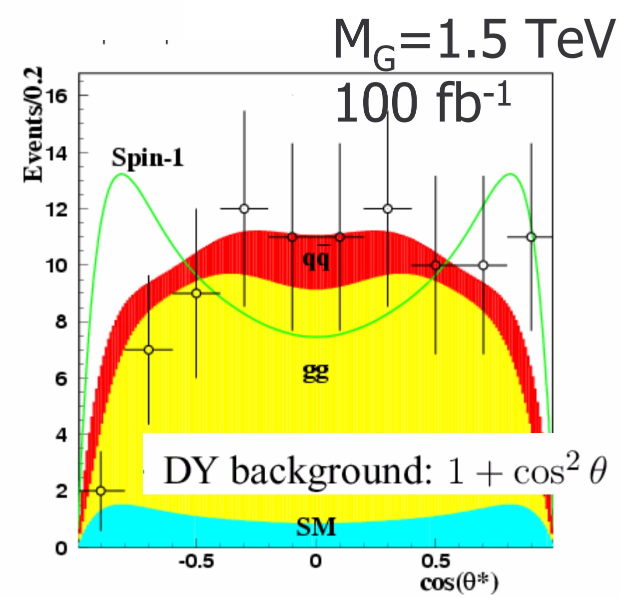
G has spin 2: pp→G→ee has 2 components: gg→G→ee & $q\bar{q}$→G→ee: each with different angular distributions:



$qq \to G \to f\bar{f}$: $1 - 3\cos^2\theta + 4\cos^4\theta$

$gg \to G \to f\bar{f}$: $1 - \cos^4\theta$





Spin-2 could be determined (spin-1 ruled out) with 90% C.L. up to M_G = 1720 GeV with 100 fb^{-1}

Note: acceptance at large pseudo-rapidities is essential for spin discrimination (1.5<|eta|<2.5)

Allanach et al, hep-ph 0006114

TeV^{-1} Sized Extra Dimensions

I. Antoniadis, PLB246 377 (1990)

- One extra dimension compactified on a S^1/Z^2 orbifold
- Radius of compactification small enough ->
  Gauge bosons can travel in the bulk

- Fermions (quarks/leptons) localized
  - at a fixed point (M1) or
  - opposite (M2) points

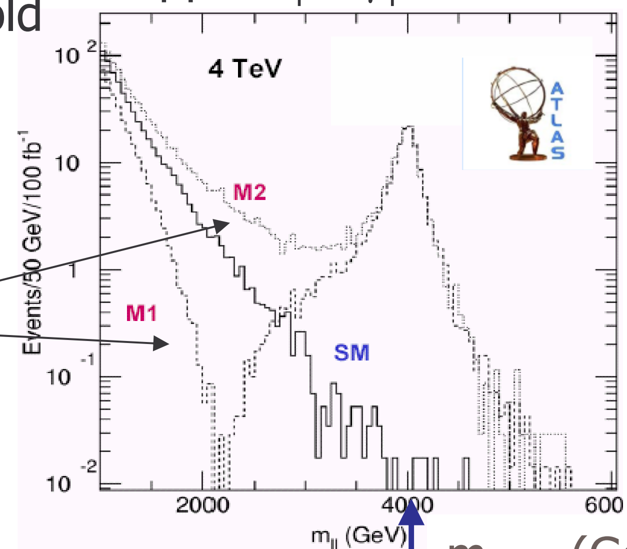
  ⇒ destructive (M1) or constructive (M2) interference of the KK excitations with SM model gauge bosons

Signature:

KK excitations of the gauge bosons ($Z^{(k)}, W^{(k)}$) appear as resonances with masses :
$M_k = \sqrt{(M_0^2+k^2/R^2)}$ where (k=1,2,...) & also interference effects!

- Look for l^+l^- decays of γ and Z^0 KK modes.
  Also in decays (m_T) of $W^{+/-}$ KK modes.
  Or evidence of g* via dijet σ or bb, tt s

$pp \to Z_1^{KK}/\gamma_1^{KK} \to e^+e^-$

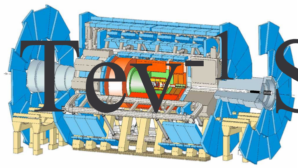


m_{e+e-} (GeV)

$M_n = M_0$

New Parameters
$R=M_C^{-1}$: size of compact dimension
M_C : compactification scale
M_0 : mass of the SM gauge boson

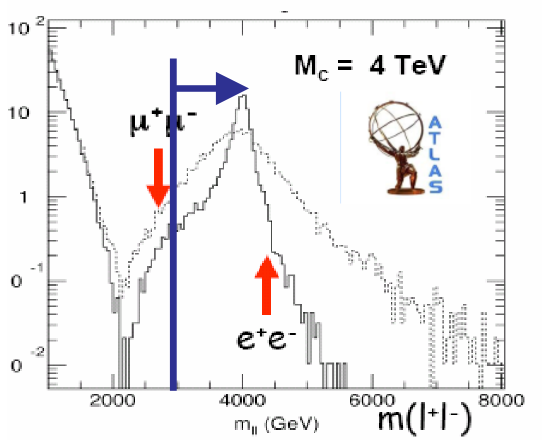
G. Azuelos, G. Polesello
EPJ Direct 10.1140 (2004)

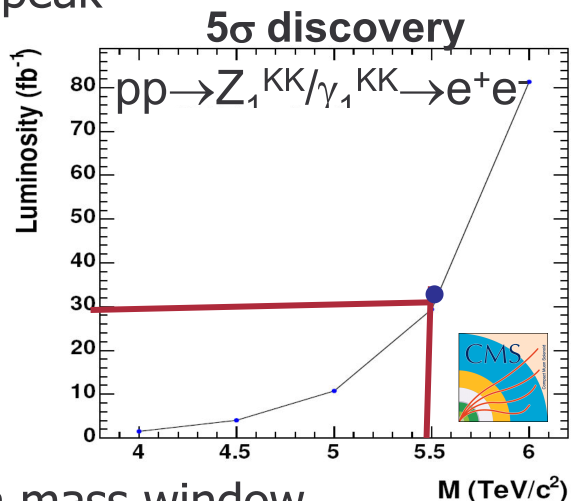


TeV^{-1} Sized Extra Dimensions

Look for resonances/deviations in the ll spectrum

1) Search for the resonance peak

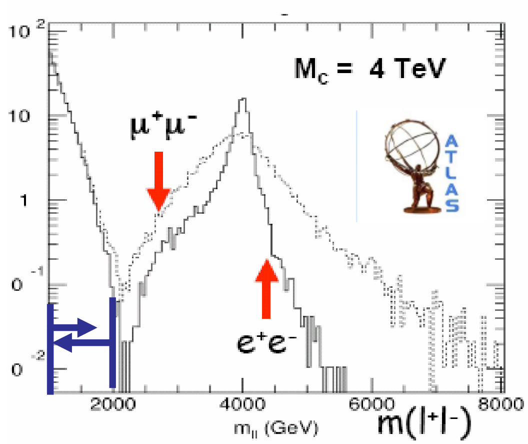


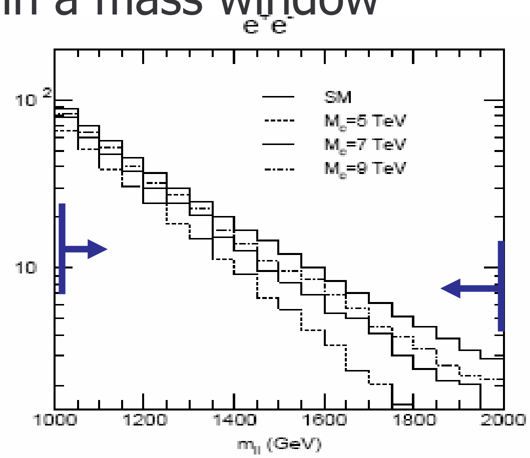


$\mathcal{L}$=30/80 fb^{-1} CMS will be able to detect a peak in the e^+e^- invar. M_{ll} if M_C<5.5/6 TeV.

ATLAS: $\mathcal{L}$=100 fb^{-1} M_C (R^{-1})<5.8 TeV (ee+μμ)

2) Search for interference in a mass window





3) Fit to kinematics of signal

With 300 fb^{-1} can reach 13.5 TeV (ee+μμ)

ee+μμ: ATLAS 5σ reach is ~8 TeV for $\mathcal{L}$=100 fb^{-1} and ~10.5 TeV for 300 fb^{-1}

Distinguishing $Z^{(1)}/\gamma^{(1)}$ from Z′, RS G

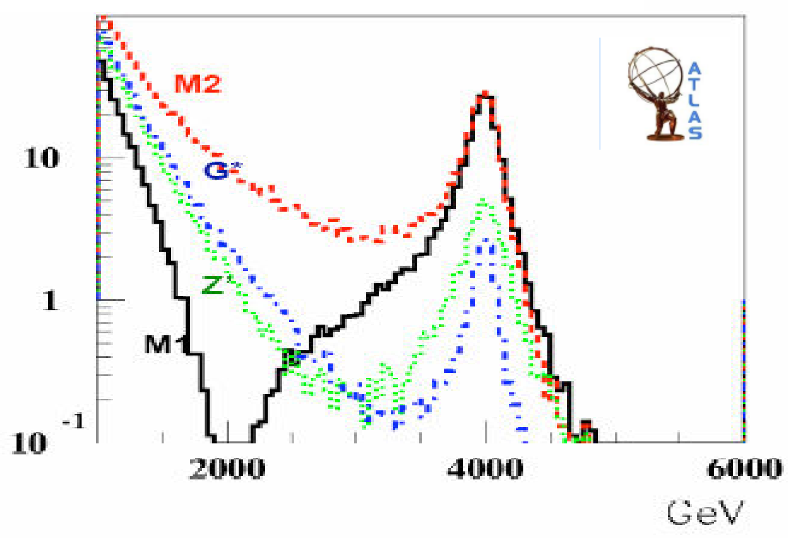
Distinguish

- spin-1 $Z^{(1)}$ from spin-2 G: angular distribution of decay products
- spin-1 $Z^{(1)}$ from spin-1 Z′ with SM-like couplings: forward-backward asymmetry

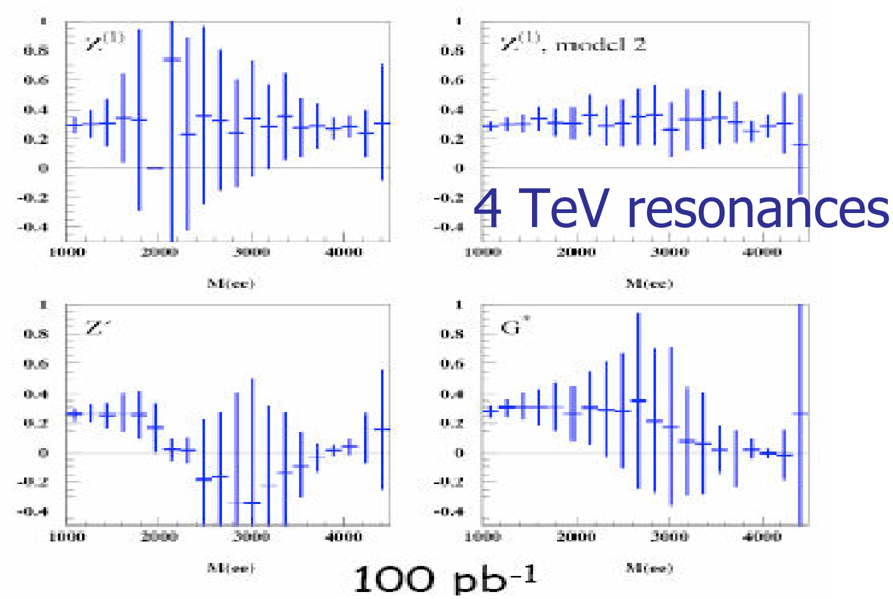
  due to contributions of the higher lying states, interference terms and additional √2 factor in its coupling to SM fermions.

The $Z^{(1)}$ can be discriminated for masses up to about 5 TeV with L=300fb^{-1}.

4 TeV $Z^{(1)})/\gamma^{(1)}$ or Z′ or RS Graviton?



Forward-backward asymetries:



G. Azuelos, G. Polesello
EPJ Direct 10.1140 (2004)

TeV^{-1} ED Discovery Limits

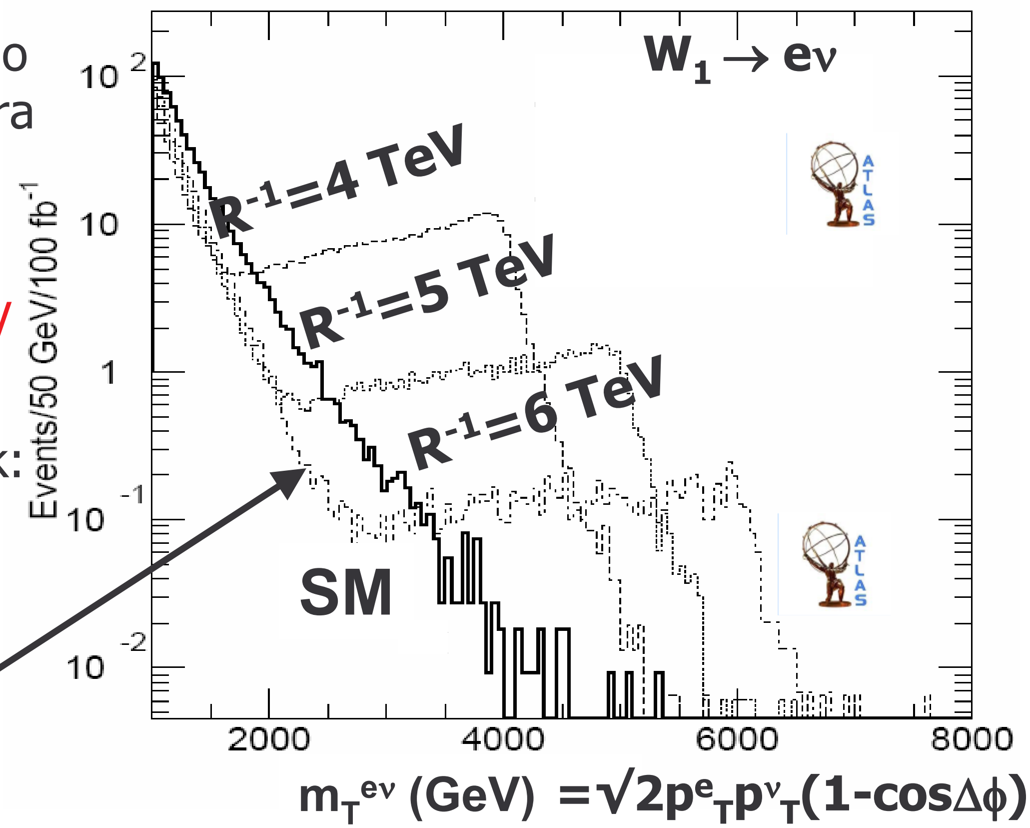
W_{KK} decays

Search for deviations in lepton-neutrino transverse invariant mass ($m_T^{l\nu}$) spectra

1) Search for peak:
L=100 fb^{-1} detect a peak if compactification scale ($M_C = R^{-1}$)<6 TeV
Sum over 2 lepton flavours

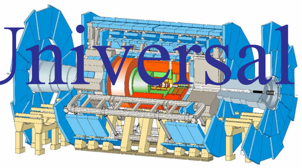
2) Studying distribution below the peak: in $m_T^{e\nu}$ spectra
L= 100 fb^{-1} a limit of M_C > 11.7 TeV

-ve interference sizable even for M_C above the ones accessible to a direct detection of the mass peak.



If a peak is detected, a measurement of the couplings of the boson to the leptons and quarks can be performed for M_C up to ~ 5 TeV.

G. Polesello, M. Patra
EPJ Direct, ATLAS 2003-023
G. Polesello, M. Patra
EPJ Direct C 32 Sup.2 (2004) pp.55-67

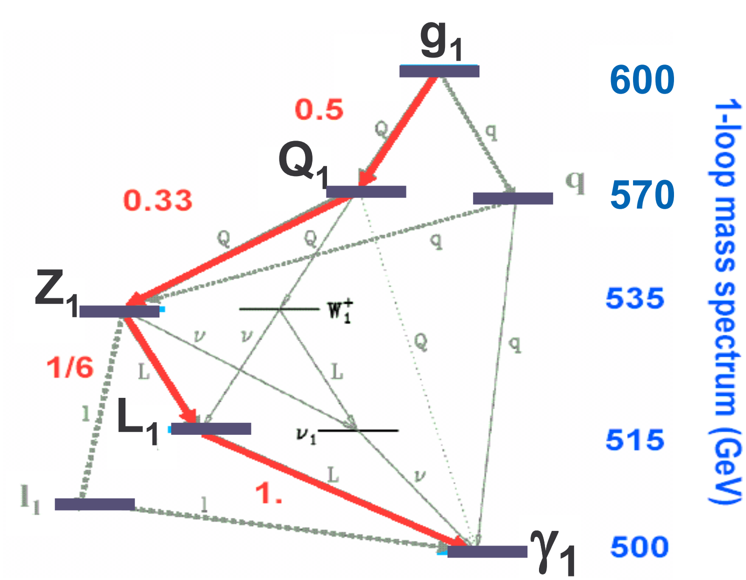


Universal Extra Dimensions

Standard/Minimal UED

- ❑ All particles can travel into the bulk, so each SM particle has an infinite tower of KK partners
- ❑ Spin of the KK particles is the same as their SM partners
- ❑ In minimal UED: 1 ED compactified in an orbifold (S1/Z2) of size R
  - ❑ KK parity conservation → the lightest massive KK particle (LKP) is stable (dark matter candidate).
  - ❑ Level one KK states must be pair produced
- ❑ Mass degeneration except if radiative corrections included

The model parameters: compactificaton radius R, cut-off scale Λ, m_h

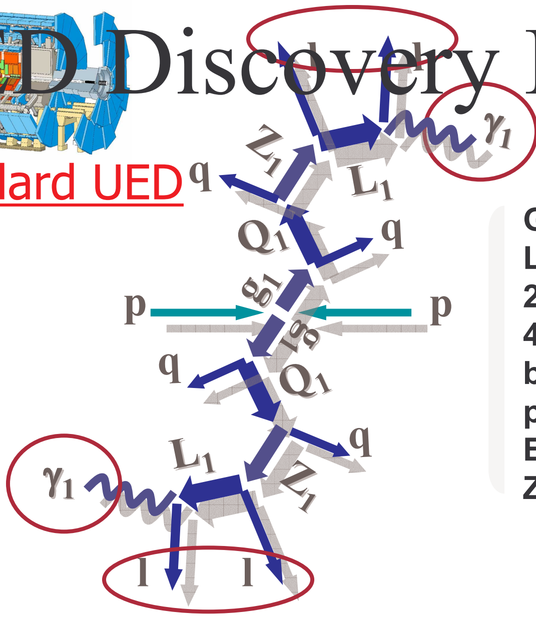


Thick/Fat brane

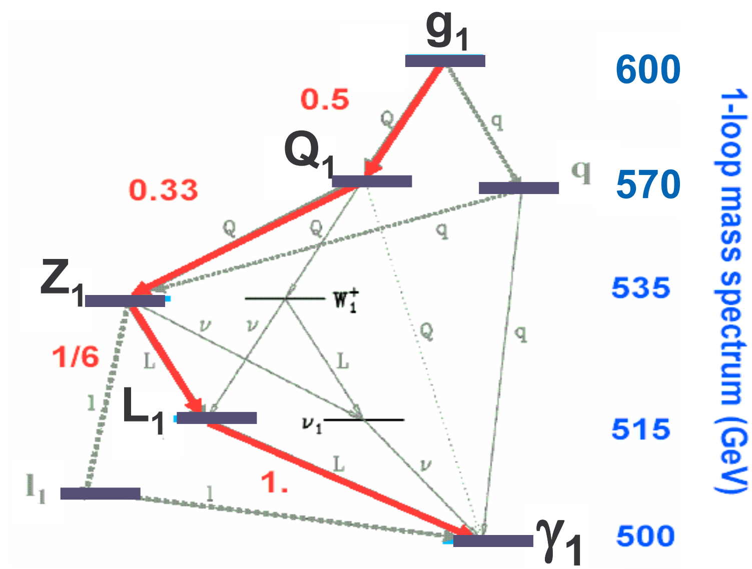
- ❑ SM brane is endowed with a finite thickness in the ED
- ❑ Gravity-matter interactions break KK number conservation:
  - 1st level KK states decay to G+SM.
  - If radiative corrections → mass degeneracy is broken and γ and leptons are produced.

UED Discovery Limit

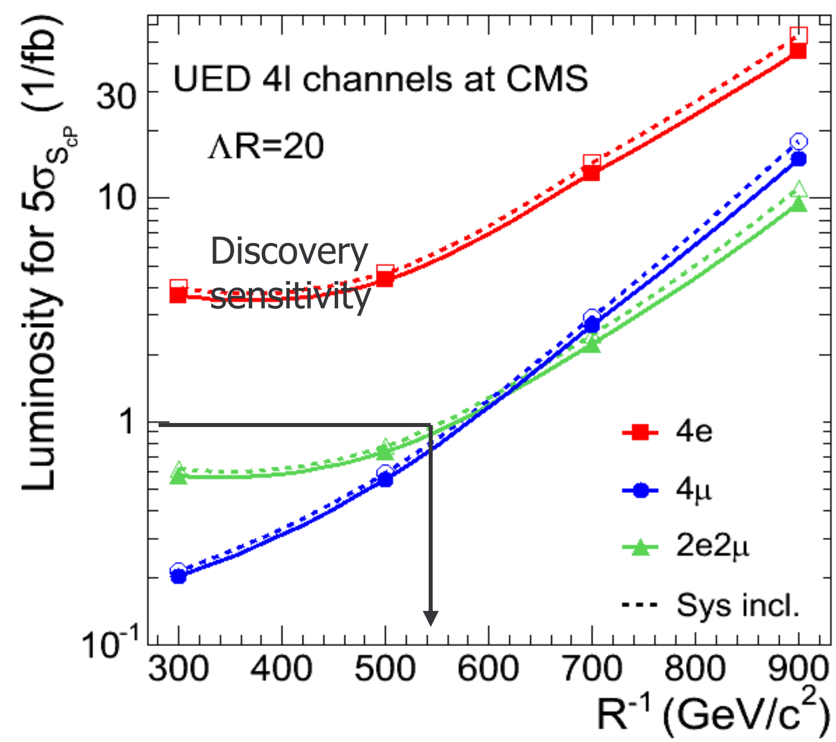
Standard UED



Geo accep
L1,HLT
2 OSSF
4 ISO
b-tag veto
p_T^l<
E_T^{miss}
Z veto



$$pp \rightarrow g_1 g_1 \rightarrow 4l + 4q + 2\,LKP \rightarrow 4l + 4\ jets + \not{P}_T$$
$$pp \rightarrow g_1 Q_1 \rightarrow 4l + 3q + 2\,LKP \rightarrow 4l + 3\ jets + \not{P}_T$$
$$pp \rightarrow Q_1 Q_1 \rightarrow 4l + 2q + 2\,LKP \rightarrow 4l + 2\ jets + \not{P}_T$$



Signature: 4 low-p_T isolated leptons (2 pairs of opposite sign, same flavour leptons) + n jets + missing E_T (from 2 undetected γ_1)

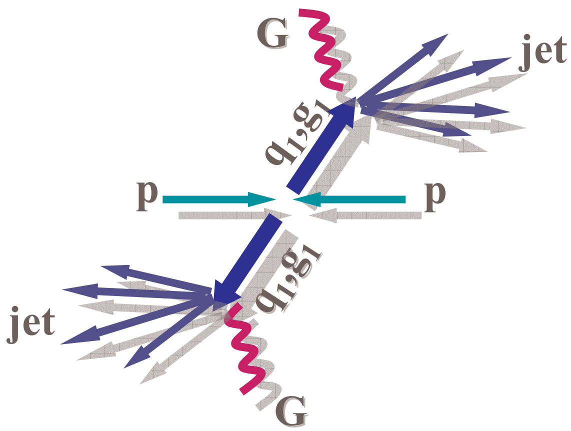
Irreducible Bckg: ttbar + n jets(n = 0,1,2), 4 b-quarks, ZZ, Zbbar

Studied for low lum run ~$2\times10^{33} cm^{-2}s^{-1}$

UED Discovery Limit

Thick brane in UED with TeV^{-1} size

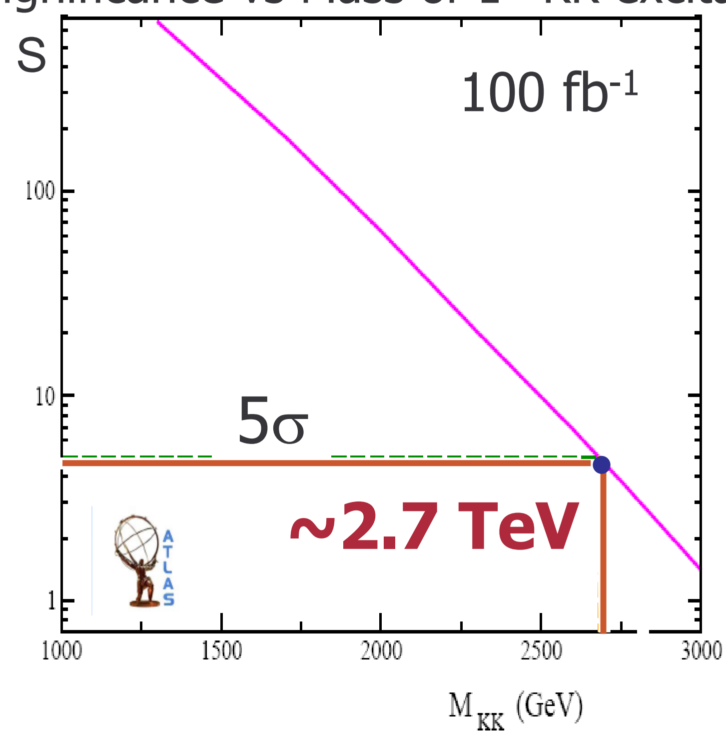
$$pp \rightarrow g_1 g_1 / q_1 g_1 / q_1 q_1 \rightarrow 2\,jets + \not{E}_T$$



Signature:
2 back-to back jets + missing E_T (>775 GeV)

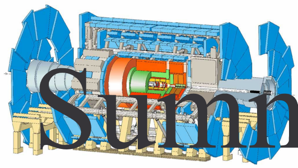
Irreducible Bckg: $Z(\rightarrow\nu\nu)$ jj, $W(\rightarrow l\nu)$ jj

Significance vs Mass of 1st KK excitation



5σ discovery possible at ATLAS with 100 fb^{-1} if first KK excitation mass < 2.7 TeV

P. H. Beauchemin, G. Azuelos
ATL-PHYS-PUB-2005-003



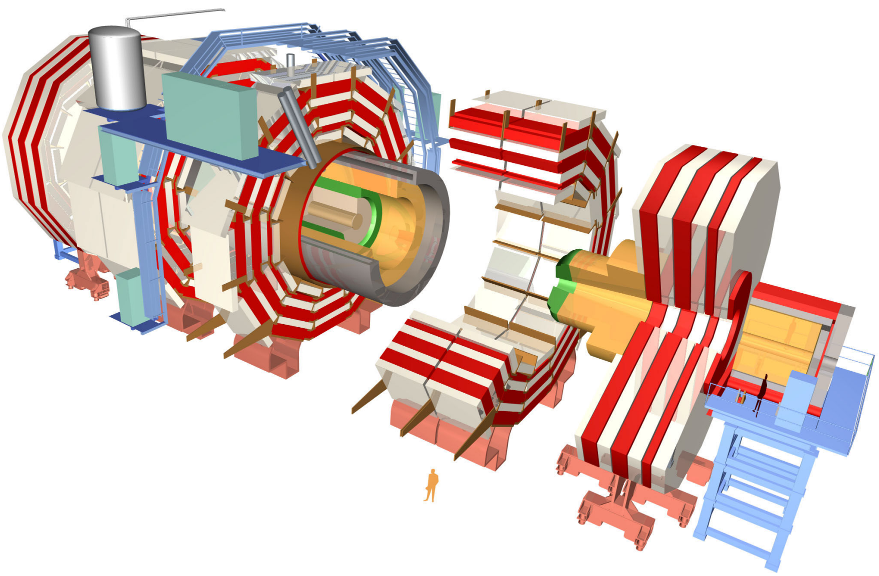
Summary & Outlook

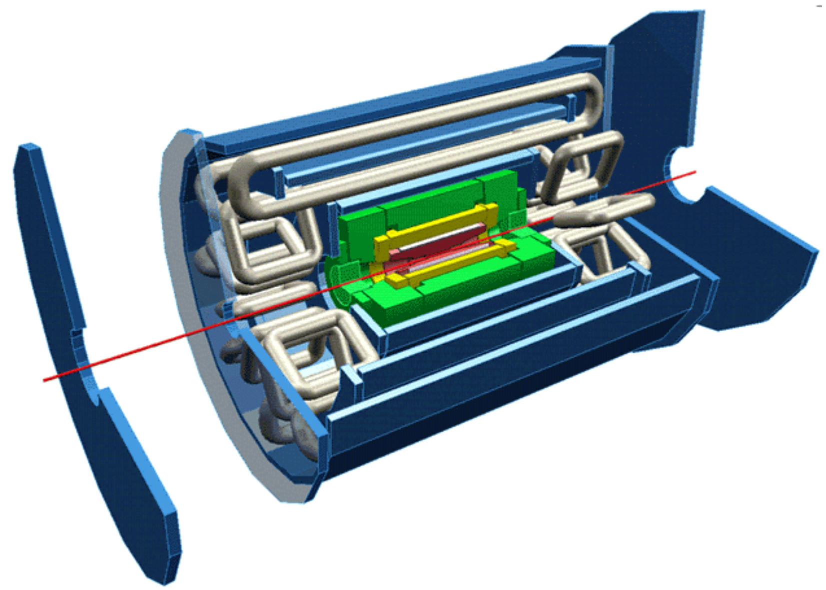
- ATLAS & CMS have significant discovery potential related to fundamental symmetries, Electroweak symmetry breaking, quark-lepton family structure and extra dimensions.
  - Heavy gauge bosons up to ~5-6 TeV
  - Little Higgs T quark up to ~2 TeV
  - Vector boson resonances; Technihadron ρ_{TC} mass up to ~600 GeV
  - Doubly-charged Higgs up to ~2 TeV
  - Heavy neutrino up to ~2.5 TeV,
  - RS Model ED up to ~4 TeV, $Z^{(KK)}/\gamma^{(KK)}$ up to ~ 13 TeV
  - *Many more topics not covered*
- ATLAS & CMS increasing focus on first year of data taking
  - Understand/optimize detector performance (calibration, alignment, ...)
  - Understand/measure Standard Model processes (bkg sources)

Once these are achieved ATLAS could potentially have new physics results within months!

- **Eager to start exploration of TeV scale!**

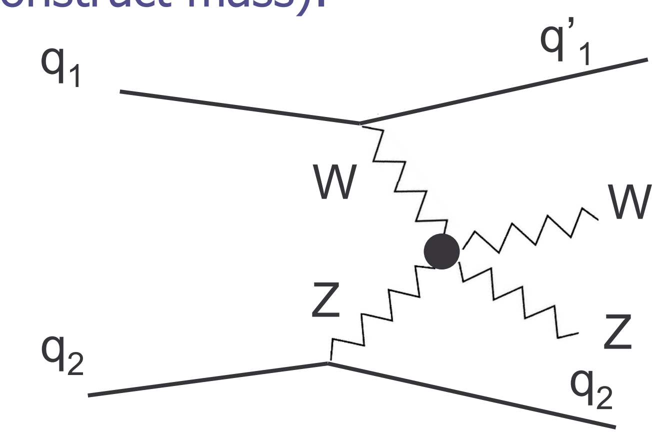
Backup Slides





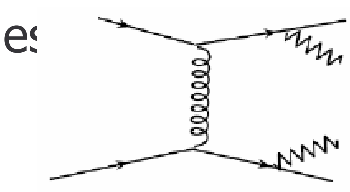
EWSB: Resonant Vector Boson Scattering

- SM cross section for W_{long} W_{long} scattering diverges at high energy if there is no Higgs ➔ new physics via diboson resonances?
- Chiral Lagrangian Model
  - low-energy effective description of electroweak interactions
    → yields interaction terms describing VB scattering with arb. coeffs.
  - respects chiral symmetry via $SU(2)_L \otimes SU(2)_R$
  - choose parameters such that new resonance M = 1.15 TeV
- Study W Z scattering (cleaner than W W + to reconstruct mass):
  - qq → qqWZ → qq lν ll (σ x BR= 1.3 fb)
  - qq → qqWZ → qq jj ll (σ x BR= 4.1 fb)
  - qq → qqWZ → qq lν jj (σ x BR= 14 fb)



Resonant Vector Boson Scattering

- Selection: 2 forward jets + central jets and/or leptons
  + missing E_T (for $W \rightarrow l\ \nu$)
  Require no additional central jet & b-jet veto (for jet modes

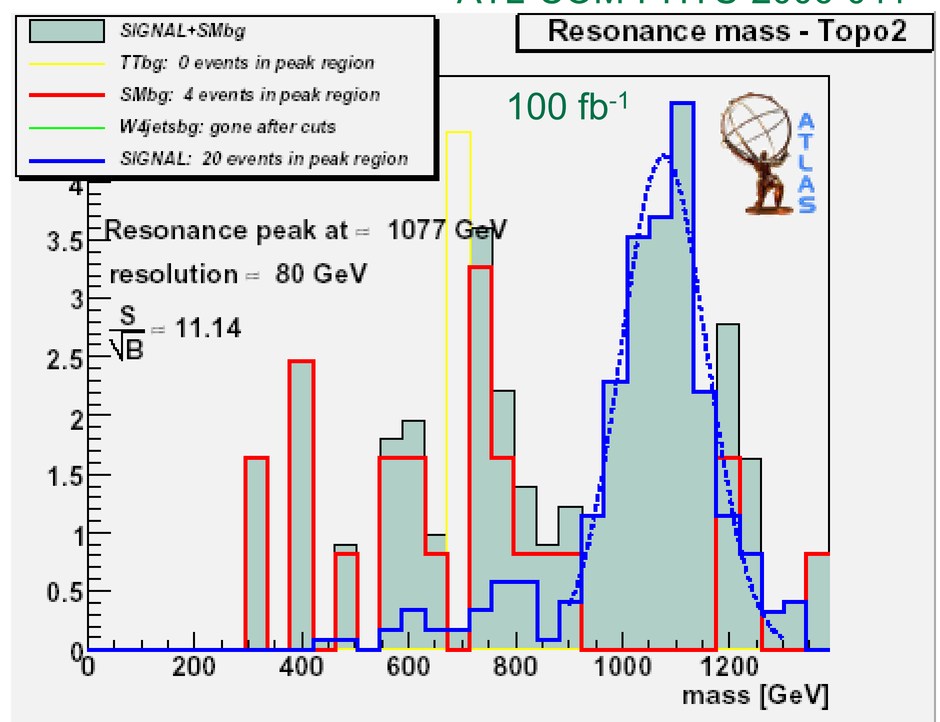


- Bkg: gluon and g/Z exchange with W and Z radiation
  also $t\bar{t}$ & W+4 jets (need more stats)

- Promising sensitivity for jet modes at 100 fb^{-1}
  (need 300 fb^{-1} for $WZ \rightarrow l\nu\ ll$)
  → study is ongoing

$W Z \rightarrow jj\ ll$

ATL-COM-PHYS-2006-041



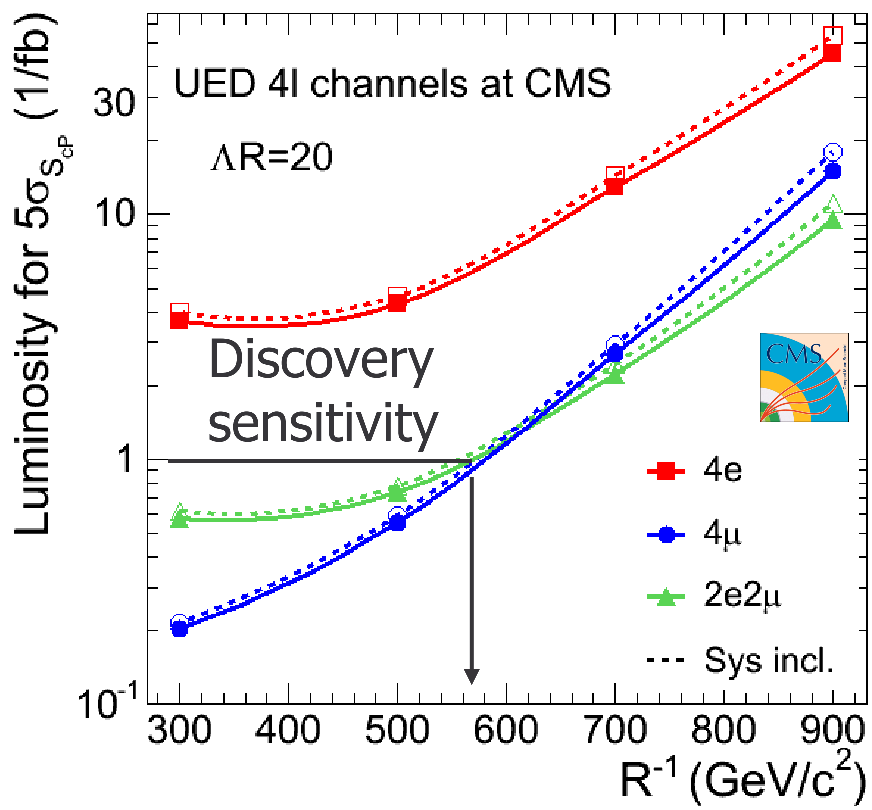
UED Discovery Limit

Standard UED

$$pp \to g_1 g_1 \to 4l + 4q + 2LKP \to 4l + 4\,jets + \not{P}_T$$
$$pp \to g_1 Q_1 \to 4l + 3q + 2LKP \to 4l + 3\,jets + \not{P}_T$$
$$pp \to Q_1 Q_1 \to 4l + 2q + 2LKP \to 4l + 2\,jets + \not{P}_T$$

- ❑ 4 leptons in the final state + missing p_T
- ❑ Irreducible Bckg: ttbar + n jets (n = 0,1,2), 4 b-quarks, ZZ, Zbbar
- ❑ To improve bkdg rejection over signal: apply b-tagging and Z-tagging vetoes
- ❑ CompHEP for signal and CompHEP, PYTHIA, Alpgen for bckg. with CTEQ5L
- ❑ Full simulation/reco + L1 + HLT(rigger) cuts
- ❑ Theoretical and experimental uncert.

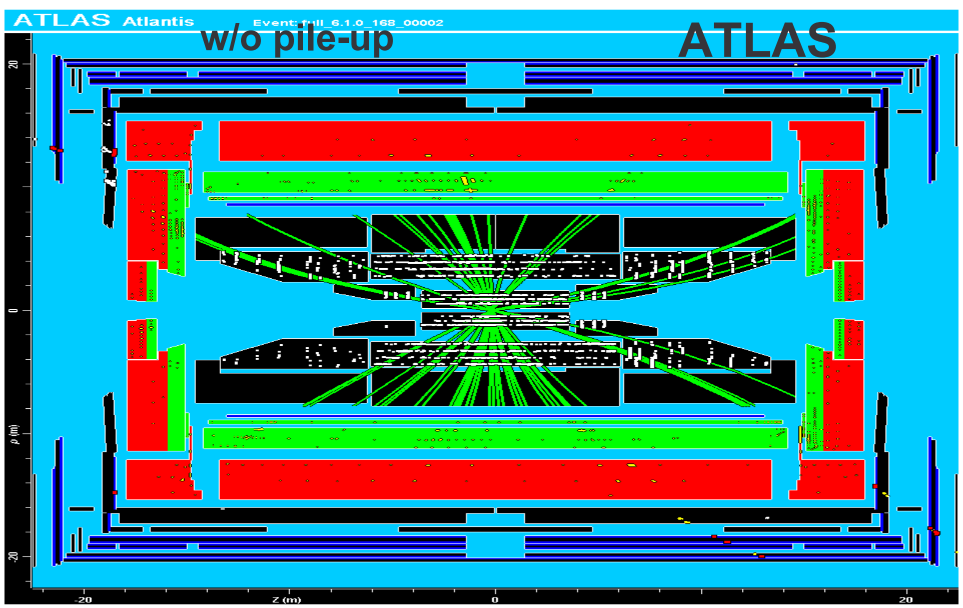
Studied for low lum run ~2×10^{33} cm^{-2}s^{-1}

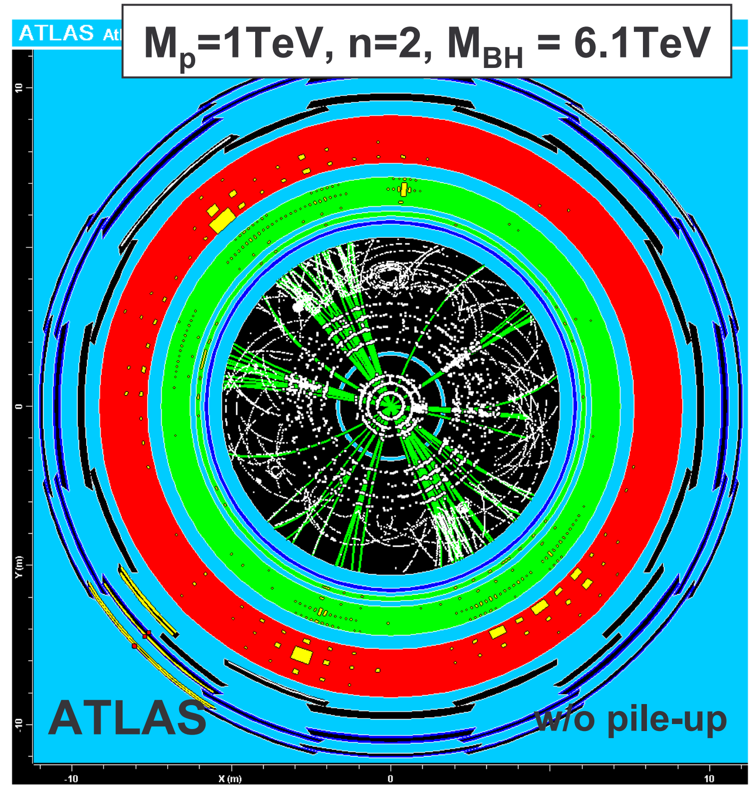


LHC: Black Hole Signatures

Dimopoulos and Landsberg PRL87 (2001) 161602

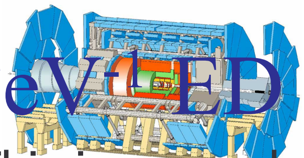
- In large ED (ADD) scenario, when impact parameter smaller than Schwartzschild radius Black Hole produced with potentially large x-sec (~100 pb).
- Decays democratically through Black Body radiation of SM states – Boltzmann energy distribution.





- Discovery potential (preliminary)
  - $M_p < \sim 4$ TeV → < ~ 1 day
  - $M_p < \sim 6$ TeV → < ~ 1 year
- Studies continue …

TeV⁻¹ ED g* Discovery Limits



This is more challenging than Z/W which have leptonic decay modes

Detect KK gluon excitations (g*) by reconstructing their hadronic decays (no leptonic decays).

Detect g* by (1) deviation in dijet σ

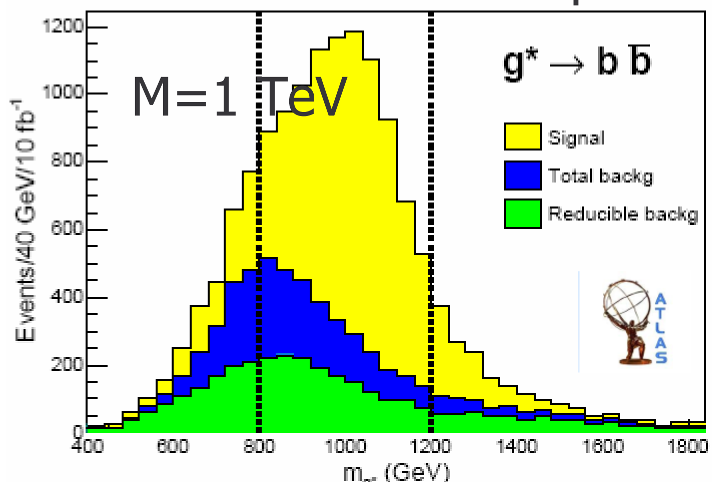
(2) analysing its decays into heavy quarks

Gluon excitation decays

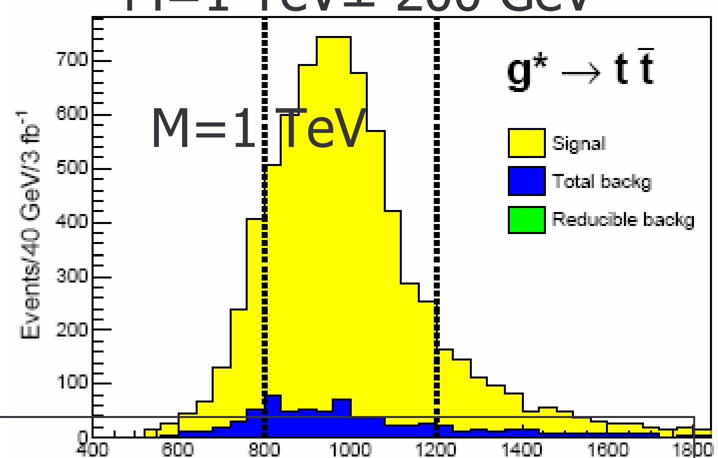
$$q\bar{q} \to g^* \to b\bar{b}, q\bar{q} \to g^* \to t\bar{t}$$

- ❑ bbar or ttbar jets
- ❑ For ttbar one t is forced to decay leptonically
- ❑ Bckg: SM continuum bbar, ttbar, 2 jets, W +jets
- ❑ PYTHIA
- ❑ Fast simulation/reco

Reconstructed mass peaks



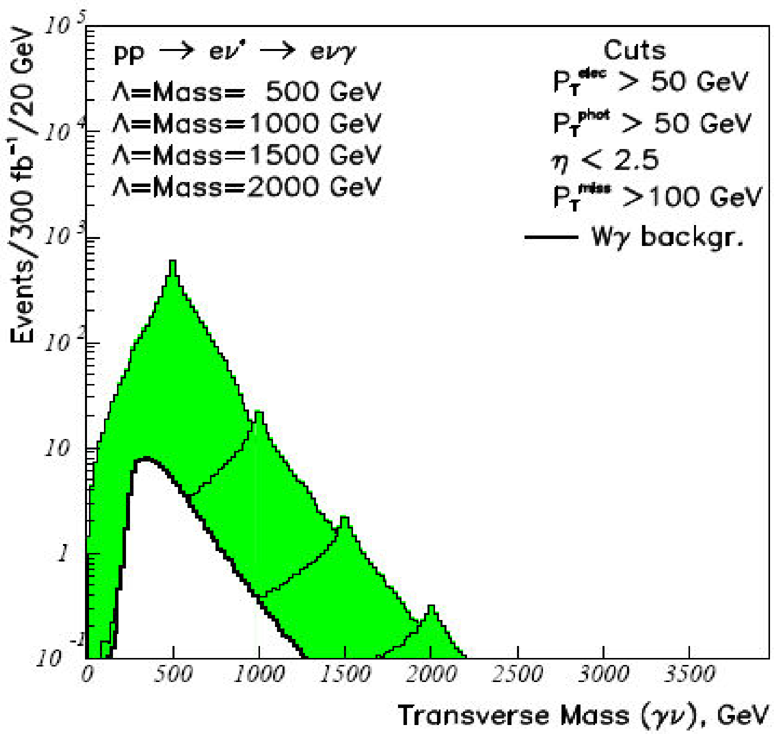
M=1 TeV± 200 GeV

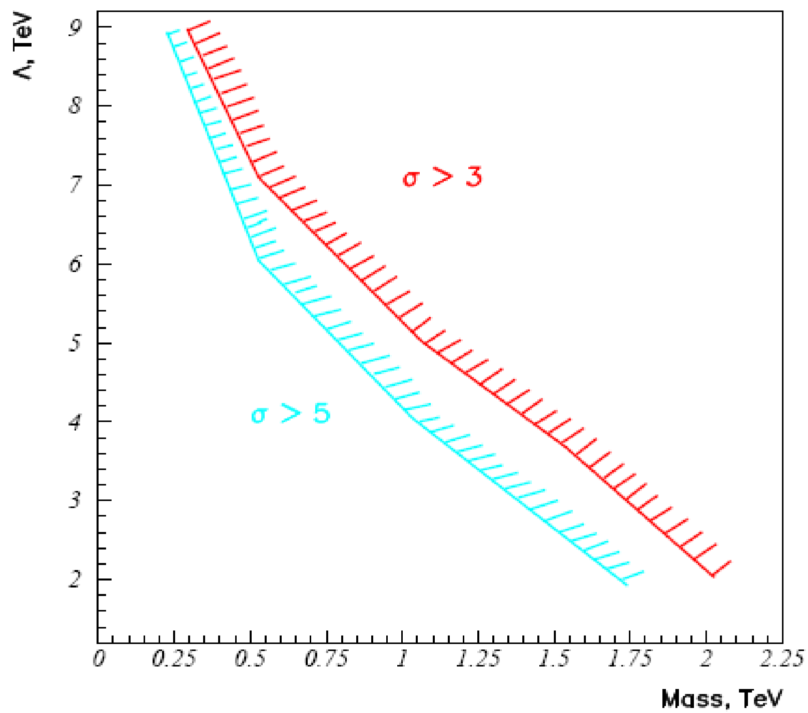


With 300 fb^{-1} Significance of 5 achieved for:
bbar channel: R^{-1} = 2.7 TeV   ttbar channel: R^{-1} = 3.3 TeV

L. March, E. Ros, B. Salvachua, ATL-PHYS-PUB-2006-002

Excited Neutrino Discovery Potential



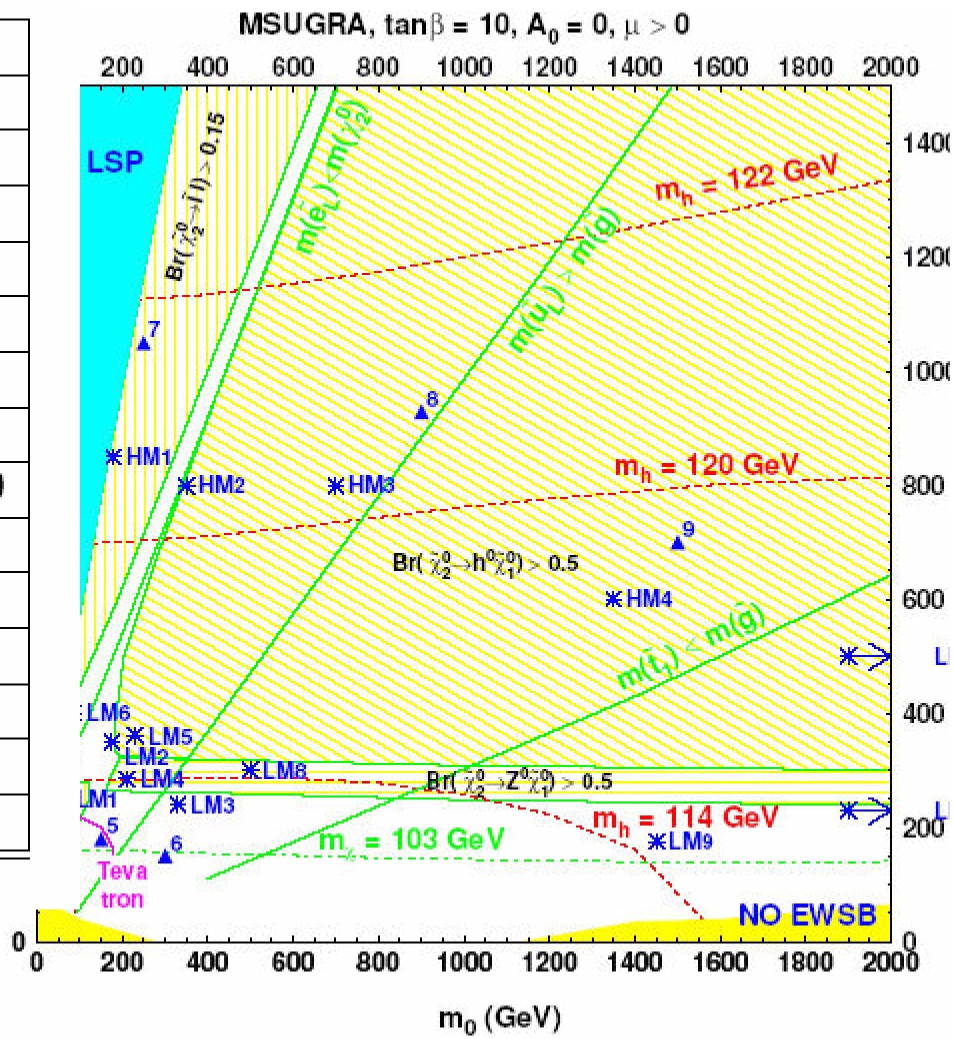


With 300 fb^{-1}

CMS SUSY

GeV/c²

Point	m_0	$m_{1/2}$	$\tan\beta$	$\mathrm{sgn}(\mu)$	A_0
LM1	60	250	10	+	0
LM2	185	350	35	+	0
LM3	330	240	20	+	0
LM4	210	285	10	+	0
LM5	230	360	10	+	0
LM6	85	400	10	+	0
LM7	3000	230	10	+	0
LM8	500	300	10	+	-300
LM9	1450	175	50	+	0
LM10	3000	500	10	+	0
HM1	180	850	10	+	0
HM2	350	800	35	+	0
HM3	700	800	10	+	0
HM4	1350	600	10	+	0



A Toroidal LHC AppartuS (ATLAS) DETECTOR

EM Calorimeters, $\sigma/E \approx 10\%/\sqrt{E(GeV)} \oplus 0.7\%$

excellent electron/photon identification

Good *E* resolution (e.g., $H \to \gamma\gamma$)

Precision Muon Spectrometer,

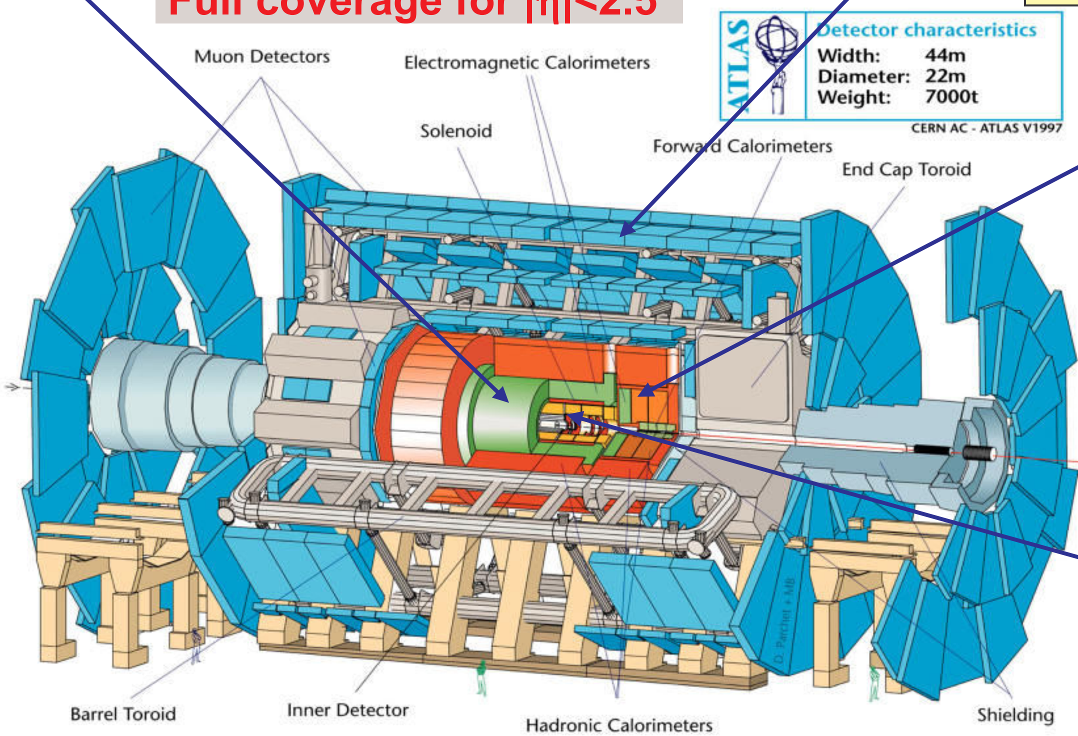
$\sigma/p_T \approx 10\%$ at 1 TeV/c

Fast response for trigger

Good *p* resolution

(e.g., $A/Z' \to \mu\mu$, $H \to 4\mu$)

Full coverage for |η|<2.5



Hadron Calorimeters,

$\sigma/E \approx 50\% / \sqrt{E(GeV)} \oplus 3\%$

Good jet and E_T miss performance

(e.g., $H \to \tau\tau$)

Inner Detector:

Si Pixel and strips (SCT) &

Transition radiation tracker (TRT)

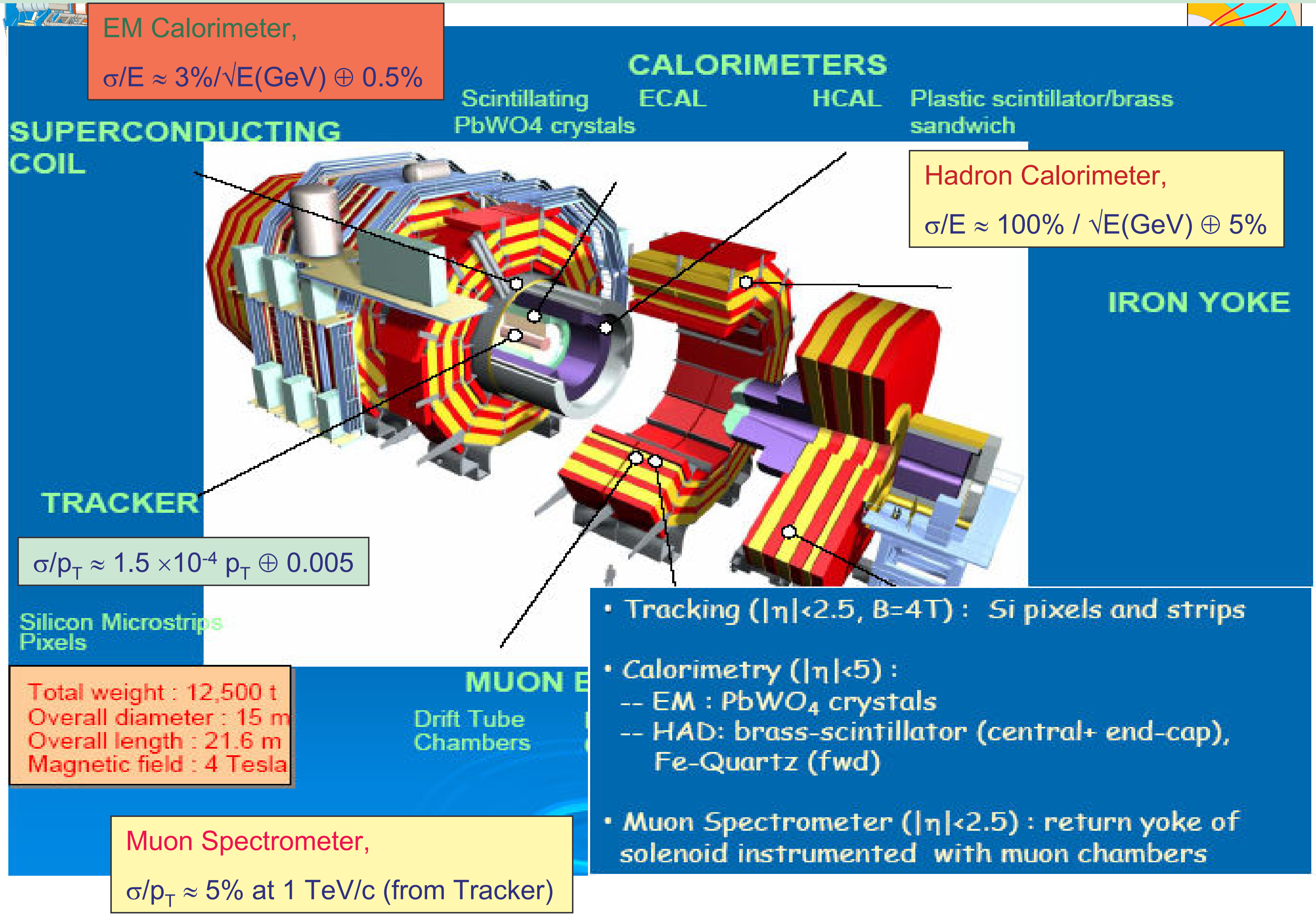
$\sigma/p_T \approx 5 \times 10^{-4}\, p_T \oplus 0.001$

Good impact parameter res.

$\sigma(d_0)=15\mu m$@20GeV (e.g. $H \to b\bar{b}$)

Magnets: solenoid (Inner Detector) 2T, air-core toroids (Muon Spectrometer) ~0.5T

Compact Muon Solenoid (CMS) DETECTOR



- Tracking (|η|<2.5, B=4T) : Si pixels and strips
- Calorimetry (|η|<5) :
  -- EM : $PbWO_4$ crystals
  -- HAD: brass-scintillator (central+ end-cap), Fe-Quartz (fwd)
- Muon Spectrometer (|η|<2.5) : return yoke of solenoid instrumented with muon chambers

ATLAS Inclusive Trigger Selection Signatures

- To select an extremely broad spectrum of "expected" and "unexpected" Physics signals (hopefully!).
- The selection of Physics signals requires the identification of **objects** that can be **distinguished** from the high particle density environment.

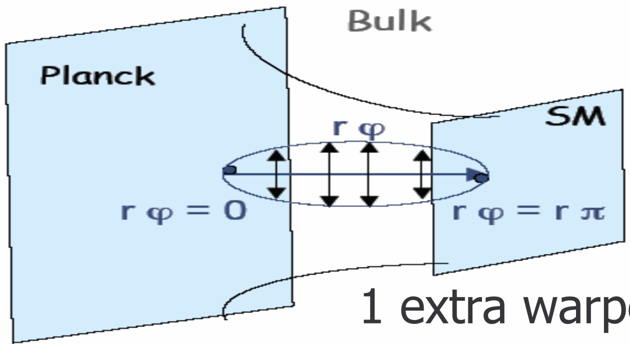
Object	Examples of physics coverage	Nomenclature
Electrons	Higgs (SM, MSSM), new gauge bosons, extra dimensions, SUSY, W/Z, top	e25i, 2e15i
Photons	Higgs (SM, MSSM), extra dimensions, SUSY	γ60i, 2γ20i
Muons	Higgs (SM, MSSM), new gauge bosons, extra dimensions, SUSY, W/Z, top	μ20i, 2μ10
Jets	SUSY, compositeness, resonances	j360, 3j150, 4j100
Jet+missing E_T	SUSY, leptoquarks, "large" extra dimensions	j60 + xE60
Tau+missing E_T	Extended Higgs models (e.g. MSSM), SUSY	τ30 + xE40

also inclusive missingET, SumET, SumET_jet

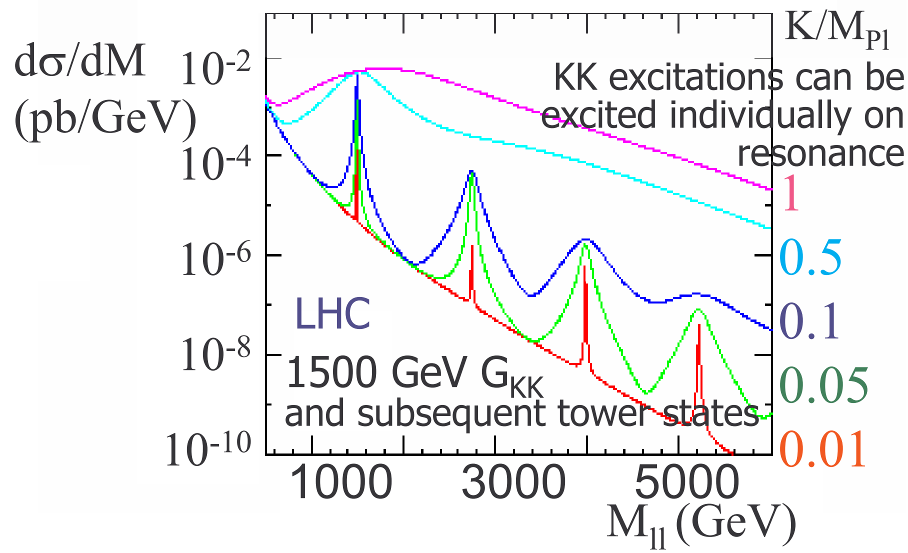
& many prescaled and mixed triggers

The list must be non-biasing, flexible, include some redundancy, extendable, to account for the "unexpected".

Experimental Signature for RS Model

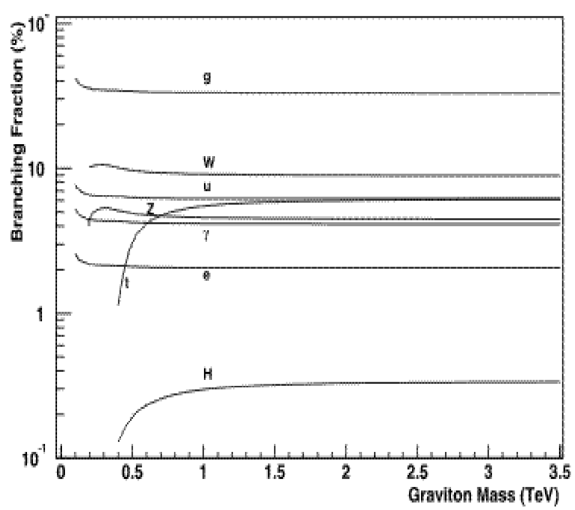


1 extra warped dimension



Signature:
Narrow, high-mass resonance states in dilepton/dijet/diboson channels

$q\bar{q}, gg \rightarrow G_{KK} \rightarrow e^+e^-, \mu^+\mu^-, \gamma\gamma, jet + jet$



Model parameters:

- Gravity Scale: $\Lambda_\pi = \overline{M}_{pl} e^{-kR_c\pi}$

  1^{st} graviton excitation mass: m_1 → position **Resonance**

  $\Lambda_\pi = m_1 \overline{M}_{pl}/kx_1$, & $m_n = kx_n e^{krc\pi} (J_1(x_n)=0)$
- Coupling constant: $c = k/M_{Pl}$

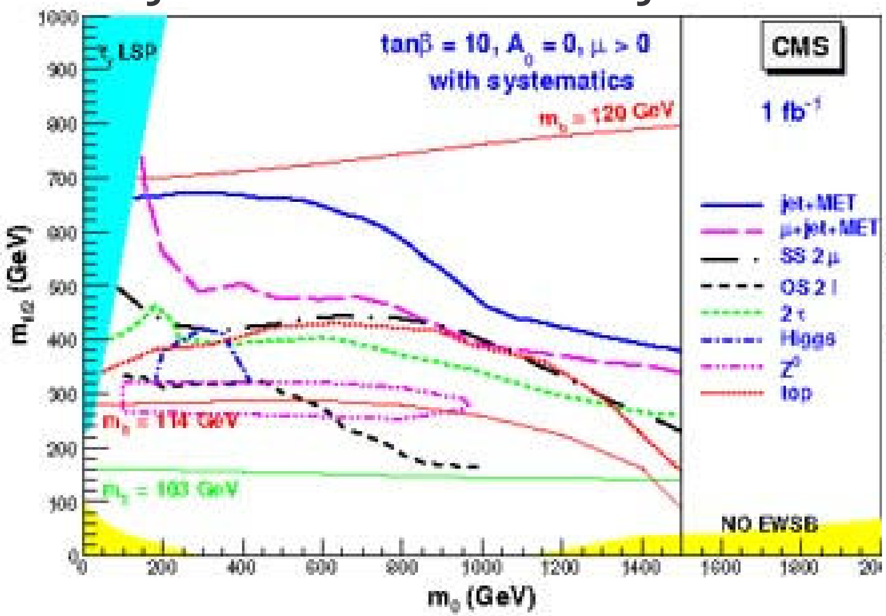
  $\Gamma_1 = \rho m_1 x_1^2 (k/\overline{M}_{pl})^2$ → width

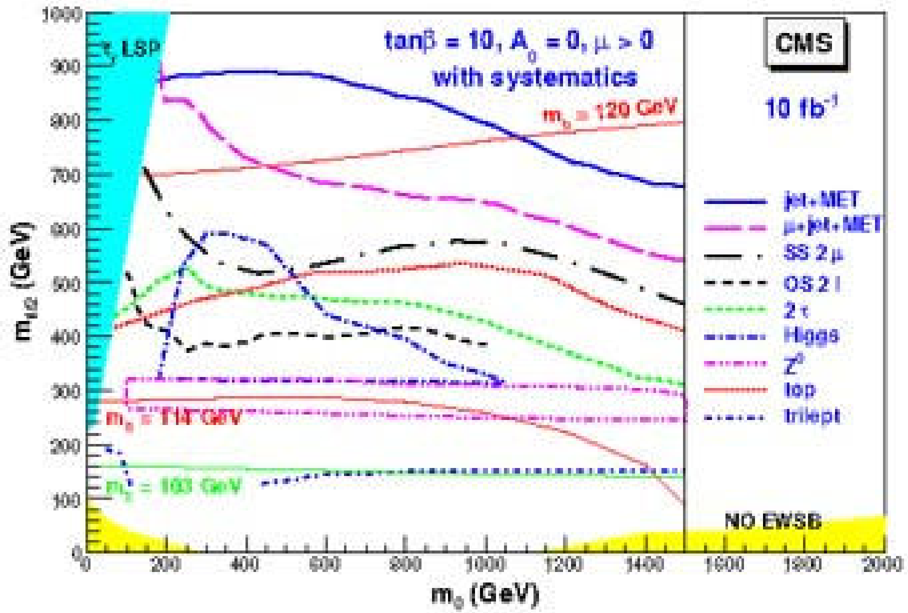
k = curvature, R = compactification radius

Davoudiasl, Hewett, Rizzo
hep-ph0006041

CMS SUSY

Best reach obtained with the most inclusive channels:
jets+MET & muons+jet+MET





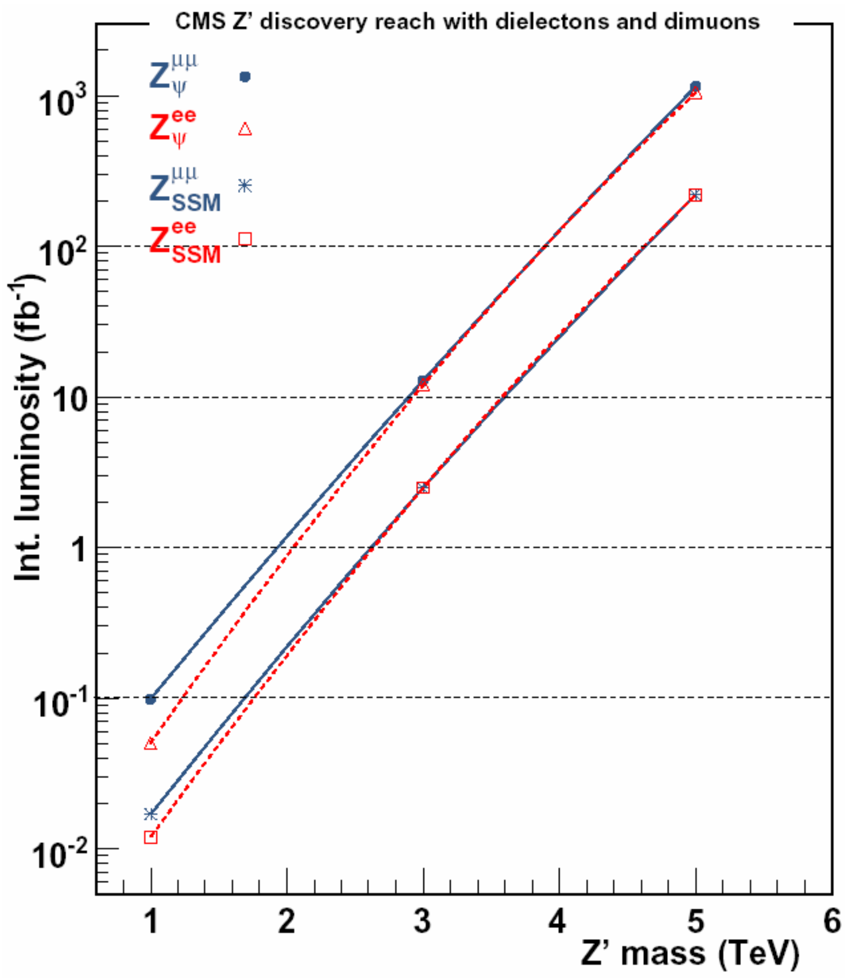
The range of gluino and squark masses up to about 1.5 TeV can be probed with L=1fb^{-1} and up to about 2 TeV with 10fb^{-1}

Simultaneous observation of a signal in various topologies would help determine the underlying physics. E.g. triangular dilepton mass distribution.

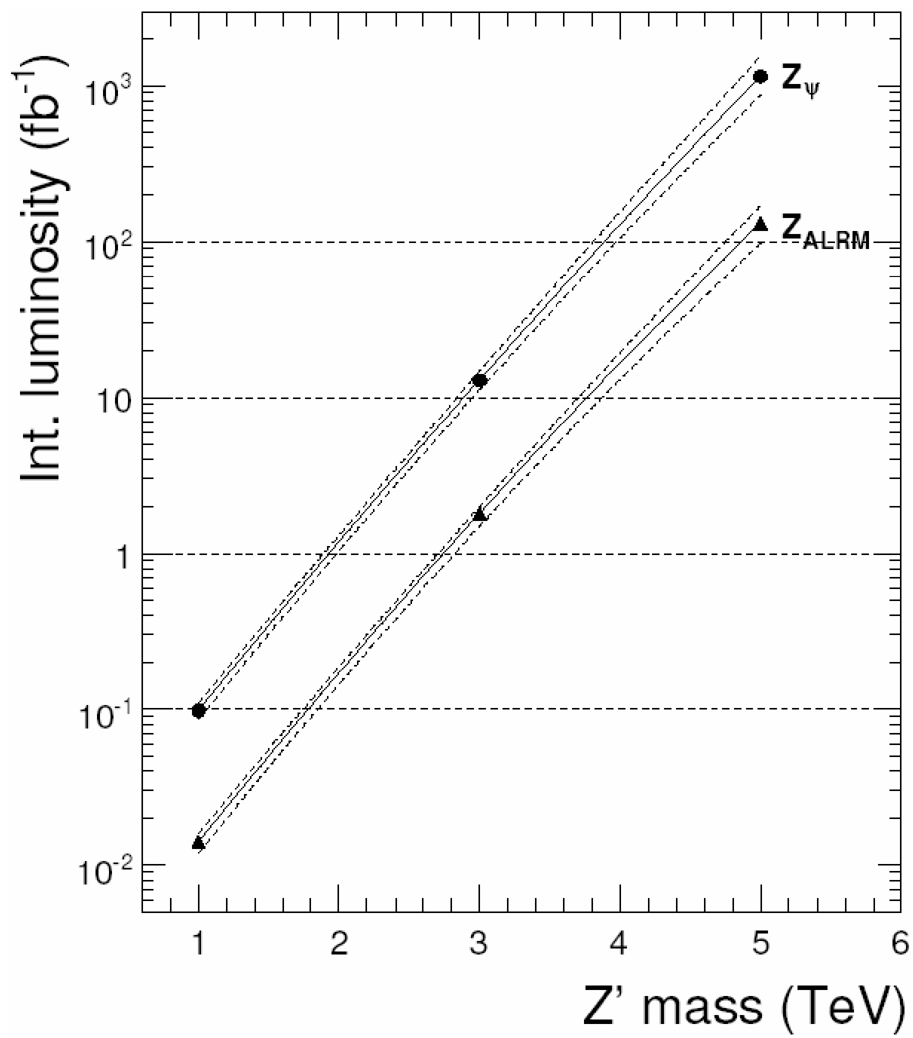
If discovered plan would be to do more exclusive analyses to reconstruct the sparticle masses and measure cross-sections of sub-processes and their ratios

Heavy Gauge Bosons: Z’

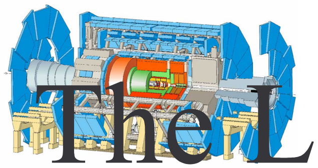
- CMS Z’ studies (TDR): integrated luminosity needed for 5σ signal



Z’ 5σ reach ee vs. μμ channels



Z’ 5σ reach: impact of theory uncertainties



The LHC Machine Schedule

year	*energy*	*luminosity*	*physics beam time*
2007	**450+450 GeV**	**5x10^{30}**	**protons - 26 days at 30% overall efficiency ➔ 0.7*10^{6} seconds**
2008	7+7 TeV	**0.5x10^{33}**	**protons - starting beginning July 4*10^{6} seconds** **ions - end of run - 5 days at 50% overall efficiency ➔ 0.2*10^{6} seconds**
2009	7+7 TeV	**1x10^{33}**	**protons:50% better than 2008 ➔ 6*10^{6} seconds** **ions: 20 days of beam at 50% efficiency ➔10^{6} seconds**
2010	7+7 TeV	**1x10^{34}**	**TDR targets:** **protons: ➔ 10^{7} seconds** **ions: ➔ 2*10^{6} seconds**

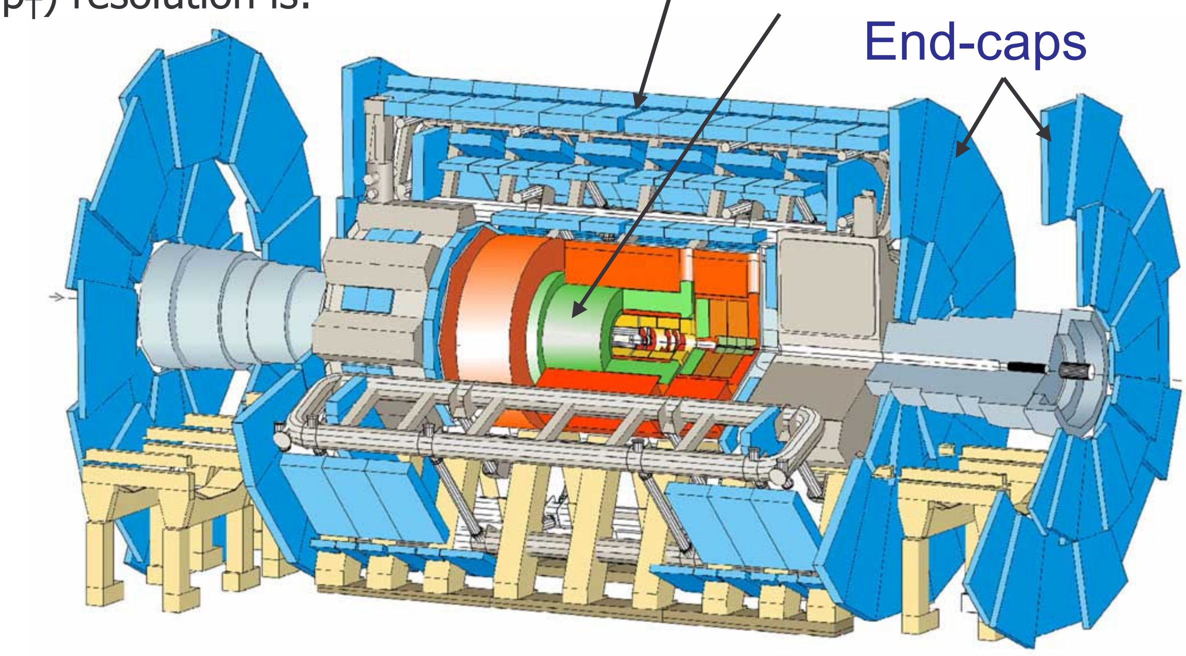
See many other talks at this meeting for ATLAS experimental details

ATLAS detector

- High energy electrons are detected by LAr calorimeter.
- Muons are detected by the Muon System.
- Expected electron energy resolution is:
  - ~0.6% for E=500GeV,
  - ~0.5% for E=1000GeV.
- Muon transverse momentum (p_T) resolution is:
  - ~6% for p_T=500GeV,
  - ~11% for p_T=1000GeV.

Electron energy resolution

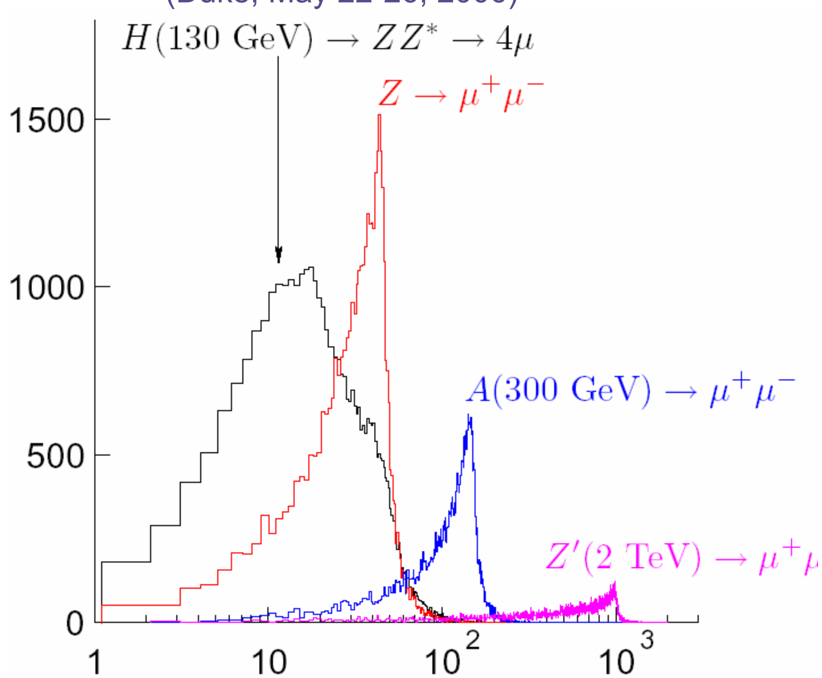
$$\frac{\sigma(E)}{E} = \frac{9.5\%}{\sqrt{E}} \oplus 0.45\%$$



High p_T leptons from Z' decay

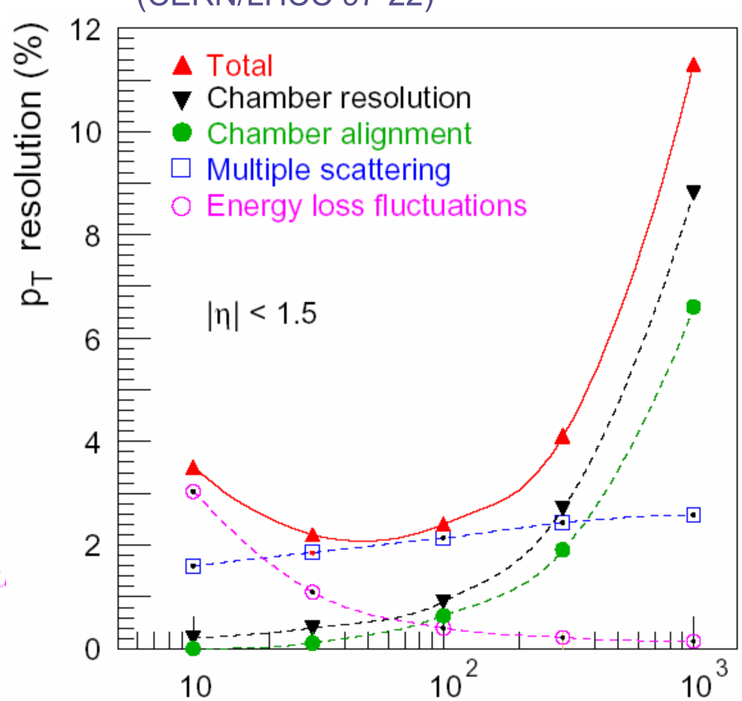
- The leptons p_T distribution from Z′ decay has a Jacobian peak.
- At high p_T, the muon momentum resolution degrades.
- For the muon p_T resolution, calibration and alignment are critical.

Oliver Kortner (MPI), HCP2006 (Duke, May 22-26, 2006)



Lepton p_T distribution

Muon spectrometer TDR (CERN/LHCC 97-22)



Muon p_T resolution

Forward-backward asymmetry

- As a probe of the underlying model, one can measure the forward-backward asymmetry.
- The differential cross section of Z′ depends on $cos\theta^*$.
- And if Z′ has spin 1, the differential cross section is given by:

$$\frac{d\sigma}{d\cos\theta^\star} \propto \frac{3}{8}(1+\cos^2\theta^\star) + A_{FB}\cos\theta^\star$$

θ^* is angle between l^- and quark in the CMS of the colliding partons.

- $A_{FB}(M_{ll}$ … d:

$$A_{FB}(M_{ll}) = \frac{N_+ - N_-}{N_+ + N_-}$$

- This qua… ndent.

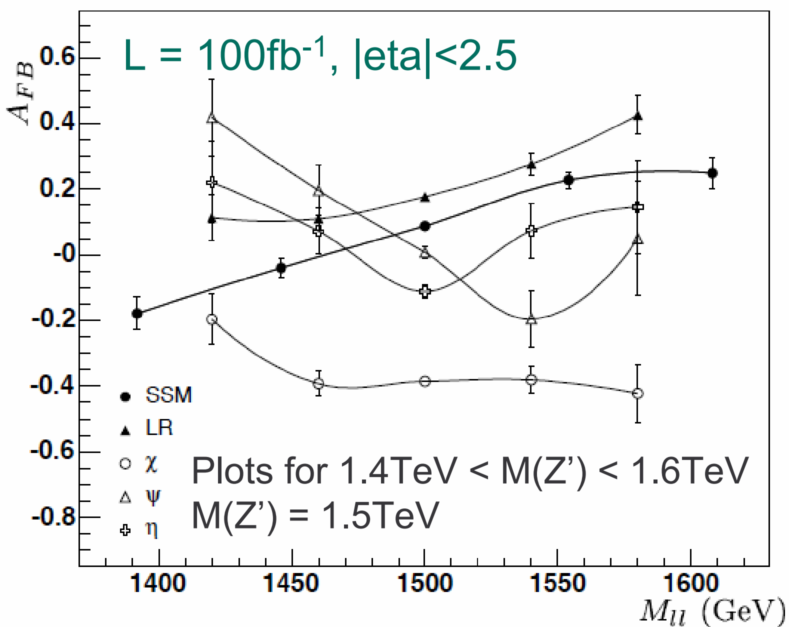
N_+: number of events with the lepton in the forward
N_-: number of events with the lepton in the backward

- One can discriminate between the underlying models by measuring $A_{FB}(M_{ll})$.

Ref: ATL-PHYS-PUB-2005-010

$A_{FB}(M_{ll})$ measurement(1)

- $Z' \to e^+e^-$:
  - high discriminating power of the asymmetry.



Asymmetry at generation level

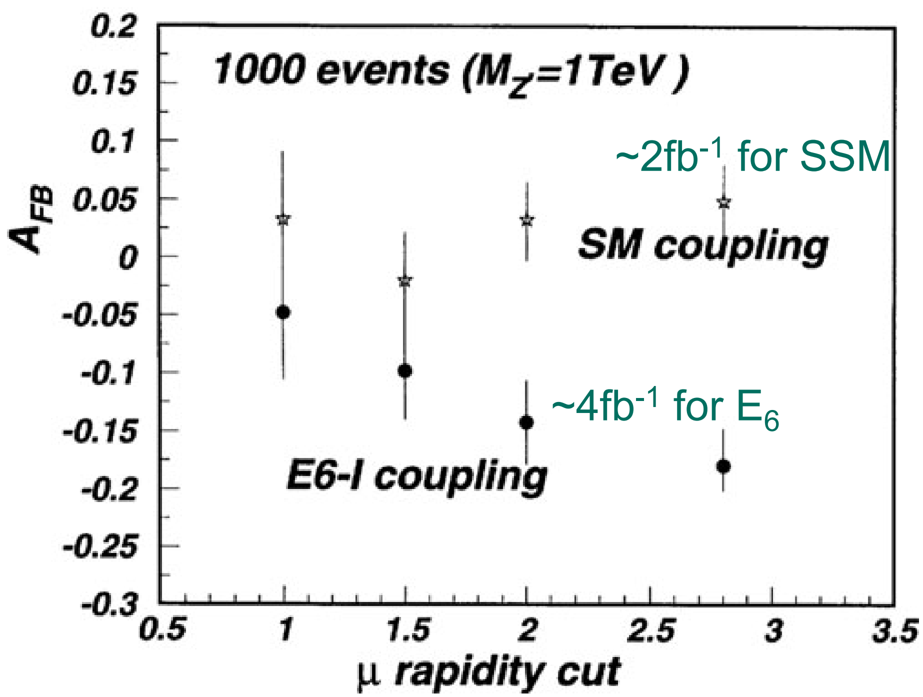
- Correction:
  - Taking into account mis-estimation of quark direction.
  - Fractions of the mis-estimation of quark direction is parameterized by simulation.

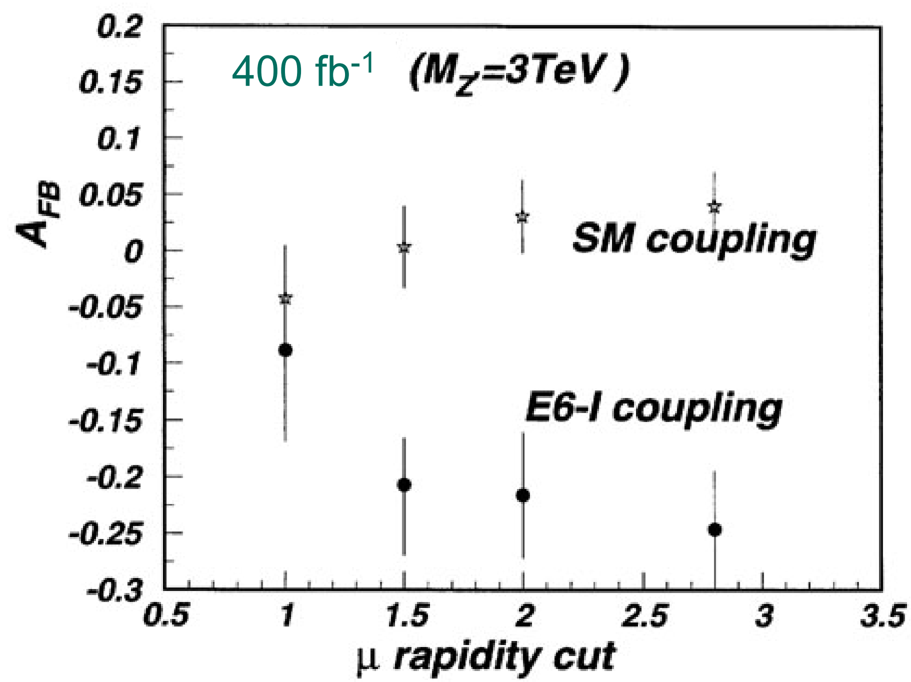
Model	$\int \mathcal{L}(fb^{-1})$	Generation	Observed	Corrected
1.5 TeV				
SSM	100	$+0.088 \pm 0.013$	$+0.060 \pm 0.022$	$+0.108 \pm 0.027$
χ	100	-0.386 ± 0.013	-0.144 ± 0.025	-0.361 ± 0.030
η	100	-0.112 ± 0.019	-0.067 ± 0.032	-0.204 ± 0.039
η	300	-0.090 ± 0.011	-0.050 ± 0.018	-0.120 ± 0.022
ψ	100	$+0.008 \pm 0.020$	-0.056 ± 0.033	-0.079 ± 0.042
ψ	300	$+0.010 \pm 0.011$	-0.019 ± 0.019	-0.011 ± 0.024
LR	100	$+0.177 \pm 0.016$	$+0.100 \pm 0.026$	$+0.186 \pm 0.032$
4 TeV				
SSM	500	$+0.138 \pm 0.099$	$+0.006 \pm 0.183$	$+0.265 \pm 0.260$
KK	500	$+0.491 \pm 0.028$	$+0.189 \pm 0.057$	$+0.457 \pm 0.073$

Ref: ATL-PHYS-PUB-2005-010

$A_{FB}(M_{ll})$ measurement(2)

- $Z' \to \mu^+ \mu^-$
  - With 200fb^{-1}, the ATLAS can distinguishes the underlying theories with accuracy better than 3% using the asymmetry for M(Z') less than 2TeV.
  - At higher masses, we need much more luminosity.



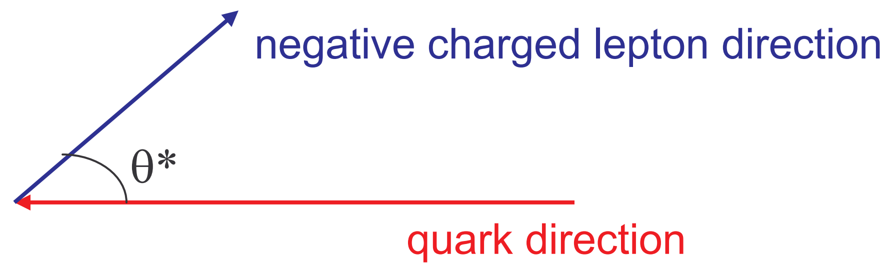


Ref: ATLAS Internal Note Muon-NO-161 23 May 1997

Forward and backward

Forward

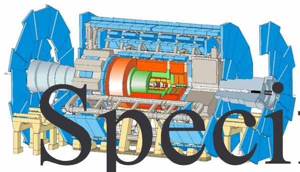
$$\cos\theta^* > 0$$



Backward

$$\cos\theta^* < 0$$

When cos theta* is positive, we call forward, and when cos theta* is negative we call backward.
The quark direction is not directly accessible in the data.
Therefore the Z' momentum defines the quark direction,
because of the quark generally being at a higher momentum than the antiquark



Specific models

- A popular model is:
  - Effective $SU(2) \times U(1)_Y \times U(1)'_{Y'}$
    - There are two additional neutral gauge bosons.
  - The new gauge boson uniquely determined by:

$$Z' = \cos\theta Z'_\psi - \sin\theta Z'_\chi$$

θ is a new mixing angle.

2 independent U(1) bosons.

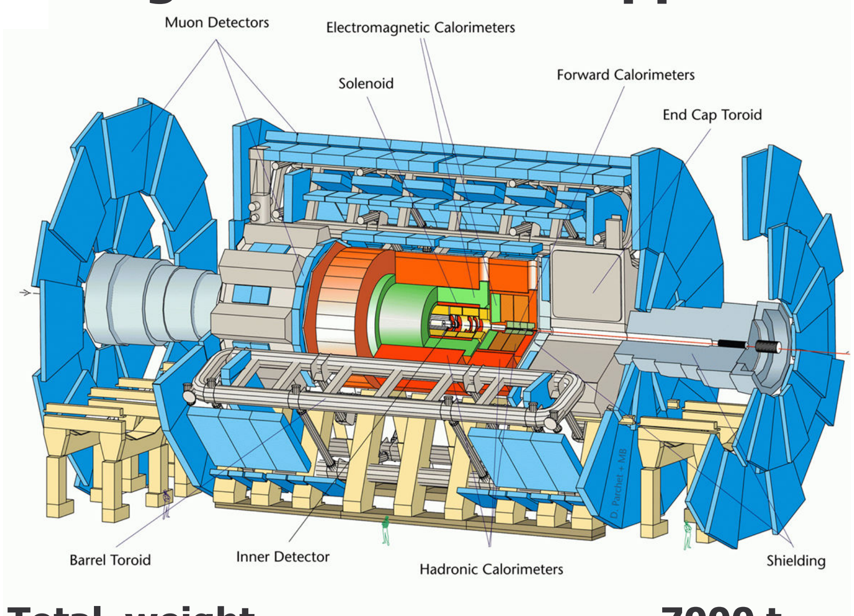
  - There are 3 special cases:
    - Z'_ψ model: $\theta=0$, $E_6 \to SO(10) \times U(1)_\psi$
    - Z'_χ model: $\theta=-\pi/2$, $E_6 \to SO(10) \times U(1)_\psi \to SU(5) \times U(1)_\chi \times U(1)_\psi$
    - Z'_η model: $\theta=\arctan(-\mathrm{sqrt}(5/3))+\pi/2$, $E_6 \to SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_\eta = SM \times U(1)_\eta$ (E_6 breaks directly down to a rank 5 model.)
- Other popular models:
  - The Left-Right model from the breaking of the *SO(10)* group,
  - The Kaluza-Klein model (Extra Dimension).
  - etc…

Ref: ATL-PHYS-PUB-2005-010

ATLAS and CMS Experiments

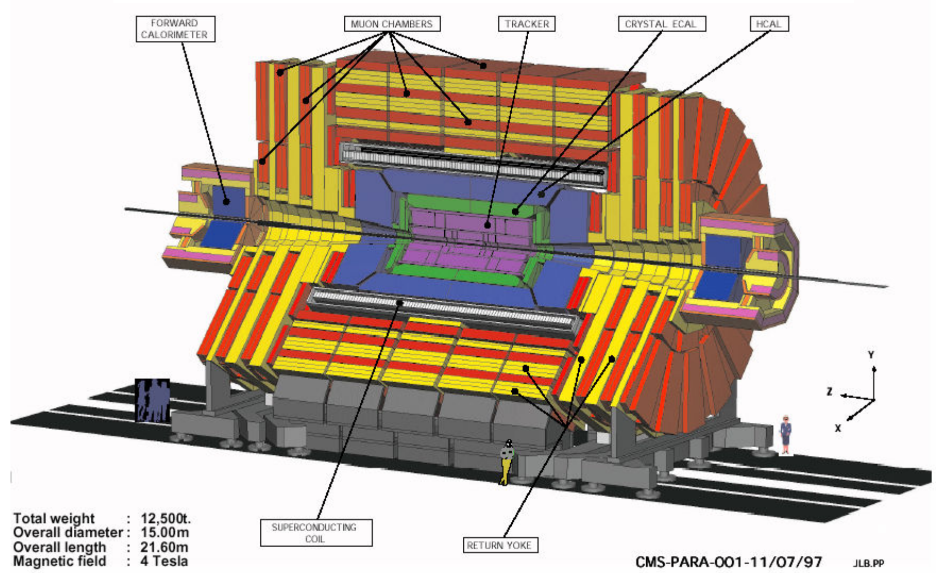
Large general-purpose particle physics detectors

A Large Toroidal LHC ApparatuS



Total weight	7000 t
Overall diameter	25 m
Barrel toroid length	26 m
End-cap end-wall chamber span	46 m
Magnetic field	2 Tesla

Compact Muon Solenoid



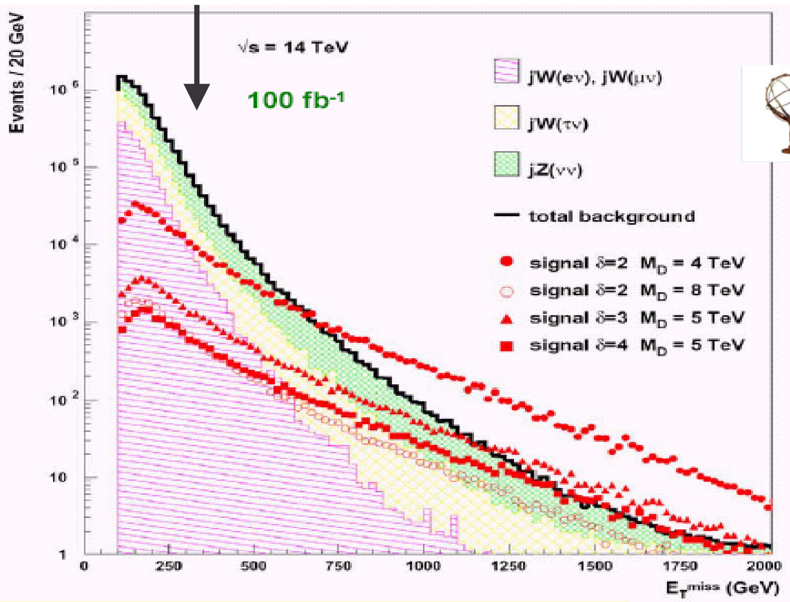
Total weight	12 500 t
Overall diameter	15.00 m
Overall length	21.6 m
Magnetic field	4 Tesla

Detector subsystems are designed to measure:
energy and momentum of γ ,e, μ, jets, missing E_T up to a few TeV

ADD Parameters: jet+G Emission

To characterise the model need to measure M_D and δ

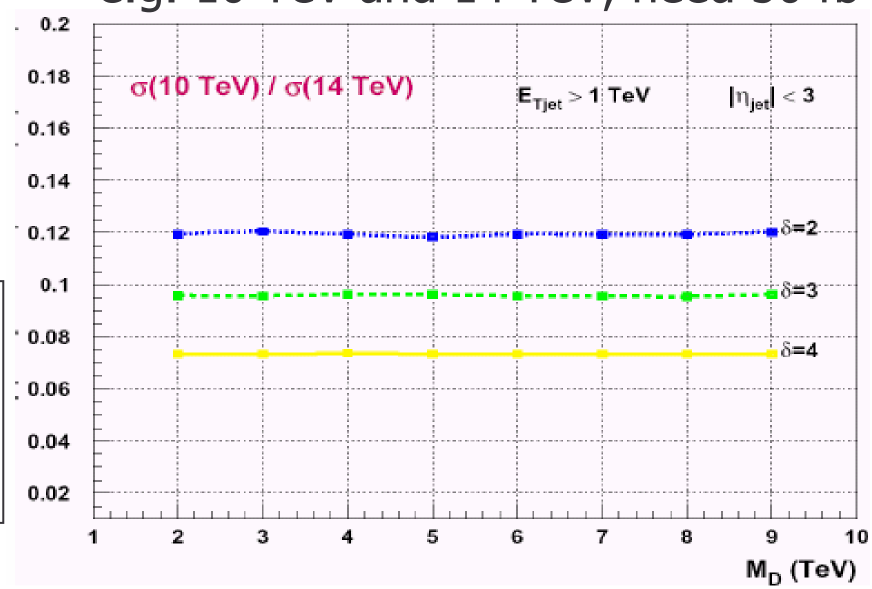
Measuring $\sigma(pp \rightarrow jet+G^{KK})$ gives ambiguous results



Rates at 14 TeV of δ=2 M_D=6 TeV very similar to δ=3 M_D=5 TeV whereas
Rates at 10 TeV of (δ=2 M_D=6 TeV) and (δ=3 M_D=5 TeV) differ by ~ factor of 2

Use variation of σ on $\sqrt{s}$
σ at different $\sqrt{s}$ almost independent of M_D, varies with δ

Run at two different $\sqrt{s}$
e.g. 10 TeV and 14 TeV, need 50 fb^{-1}



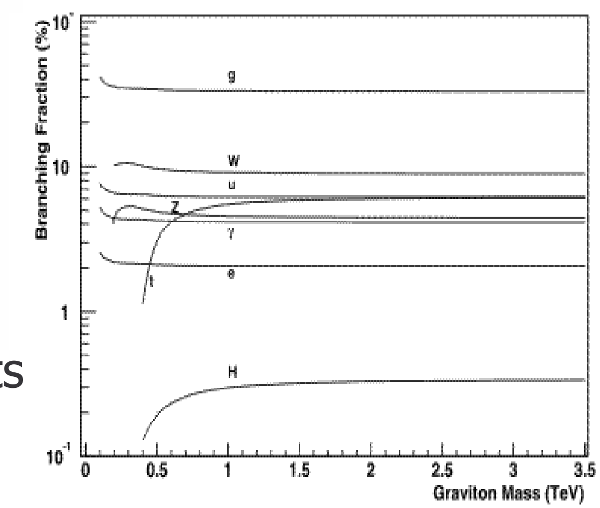
L.Vacavant, I.Hinchcliffe, ATLAS-PHYS 2000-016
J. Phys., G 27 (2001) 1839-50

Model Parameters

A resonance could be seen in many other channels: μμ, γγ, jj, bbbar, ttbar, WW, ZZ, hence allowing to check universality of its couplings:

Channel	Point m_G, Λ_π (TeV)							
	1,10	1,20	1,30	2,10	2,20	2,30	3,10	3,20
e^+e^-	1.6	3.3	5.3	5.4	11.0	17.1	15.1	30.7
$\mu^+\mu^-$	1.9	4.5	8.2	6.2	15.2	28.2	15.1	32.7
$\gamma\gamma$	1.2	2.9	5.2	3.9	8.8	15.2	10.5	23.0
WW	11.6	44.9	-	38.2	-	-	-	-
ZZ	13.7	50.1	-	52.7	-	-	-	-
jj	19.0	77.0	-	31.0	-	-	59.0	-

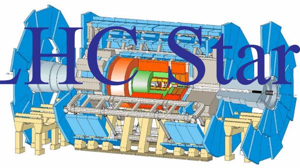
Relative precision achievable (in %) for measurements of σ.B in each channel for fixed points in the M_G,Λ_π plane. Points with errors above 100% are not shown.



Also the size (R) of the ED could also be estimated from mass and cross-section measurements.

Allenach et al, hep-ph0211205

Allenach et al, JHEP 9 19 (2000), JHEP 0212 39 (2002)



LHC Start-up Expectations

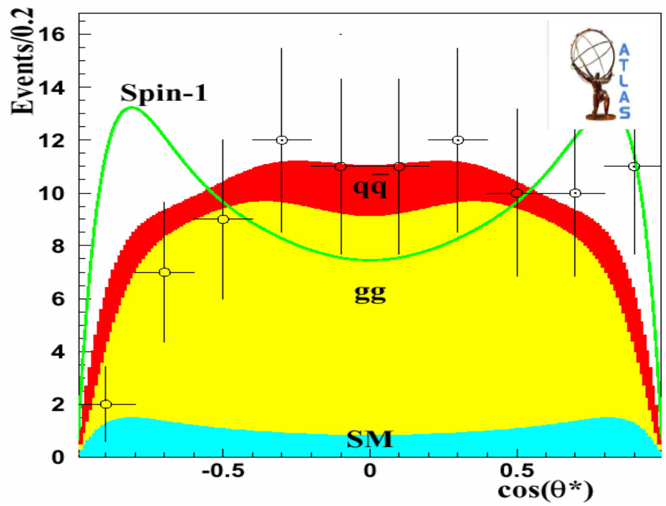
Model	Mass reach	Integrated Luminosity (fb^{-1})	Systematic uncertainties
ADD Direct G_{KK}	M_D~ 1.5-1.0 TeV, n = 3-6	1	Theor.
ADD Virtual G_{KK}	M_D~ 4.3 - 3 TeV, n = 3-6 M_D~ 5 - 4 TeV, n = 3-6	0.1 1	Theor.+Exp.
RS1 di-electrons di-photons di-muons di-jets	 M_{G1}~1.35- 3.3 TeV, c=0.01-0.1 M_{G1}~1.31- 3.47 TeV, c=0.01-0.1 M_{G1}~0.8- 2.3 TeV, c=0.01-0.1 M_{G1}~0.7- 0.8 TeV, c=0.1	 10 10 1 0.1	 Theor.+Exp. (only stat. for di-jets)
TeV^{-1} ($Z_{KK}^{(1)}$)	M_{z1} < 5 TeV	1	Theor.

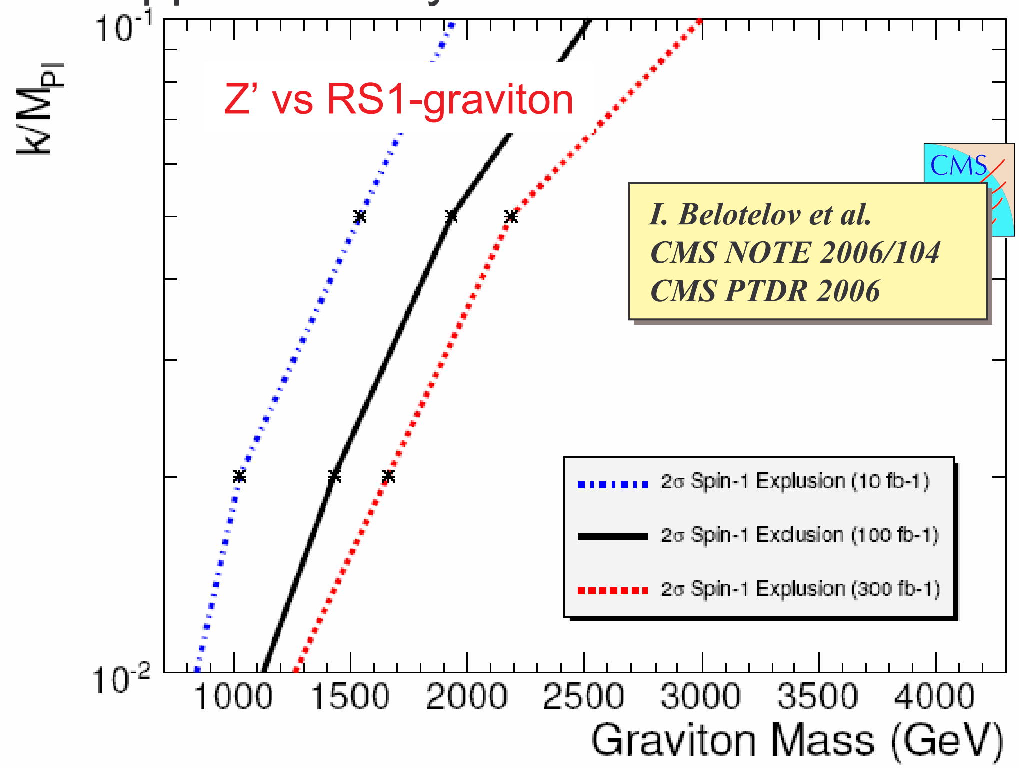
Spin-1/Spin-2 Discrimination

Spin-1 States: Z′ from extended gauge models, Z_{KK}
Spin-2 States: RS1-graviton
Method: unbinned likelihood ratio statistics incorporating the angles in of the decay products the Collins-Soper farme (R.Cousins et al. JHEP11 (2005) 046). The statististical technique has been applied to fully simu/reco events.

Angular distributions

- $qq \to G \to ff: 1 - 3\cos^2\theta + 4\cos^4\theta$
- $gg \to G \to ff: 1 - \cos^4\theta$
- $qq \to G \to VV: 1 - \cos^4\theta$
- $gg \to G \to VV: 1 + 6\cos^2\theta + \cos^4\theta$
- DY background: $1 + \cos^2\theta$



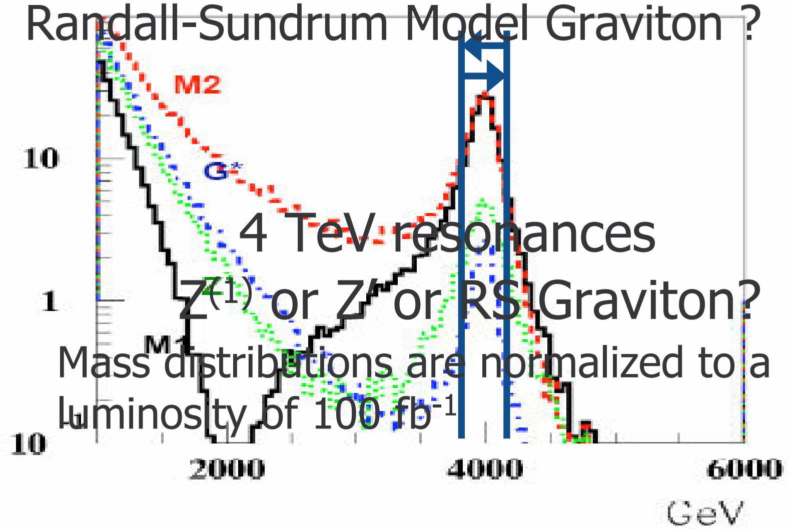


Older results on spin discrimination from ATLAS can be found

B.C. Allanach et al, JHEP 09 (2000) 019; ATL-PHYS-2000-029

Distinguishing $Z^{(1)}$ from Z′, RS G

How could a 4 TeV $Z^{(1)}/\gamma^{(1)}$ resonance be distinguished from a 4 TeV Z′ or Randall-Sundrum Model Graviton ?



4 TeV resonances

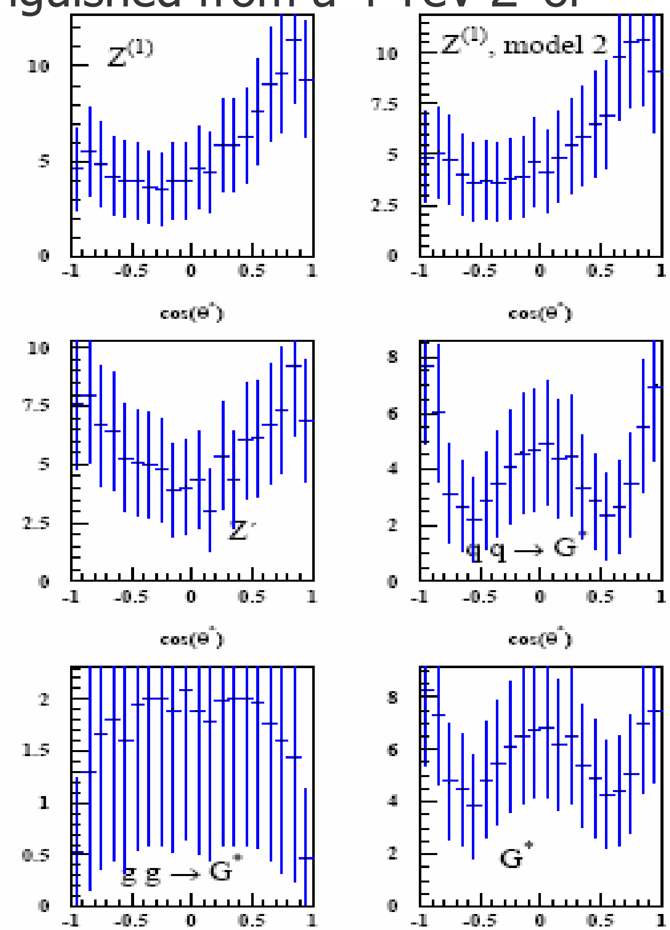
$Z^{(1)}$ or Z′ or RS Graviton?

Mass distributions are normalized to a luminosity of 100 fb^{-1}

Select events around the peak of the resonance 3750 GeV < M_{ee} < 4250 GeV

Plot cosine of the angle of the lepton, w.r.t the beam direction, the frame of the decaying resonance.

(+ve direction was defined by the sign of reconstructed momentum in the dilepton system.)



Angular distributions are normalized to 116 events, the number predicted with a luminosity of 100 fb^{-1} for the $Z^{(1)}/\gamma^{(1)}$ case

G. Azuelos, G. Polesello EPJ Direct 10.114… (2004)