Search for Extra Dimensions and Leptoquarks in Early LHC Data

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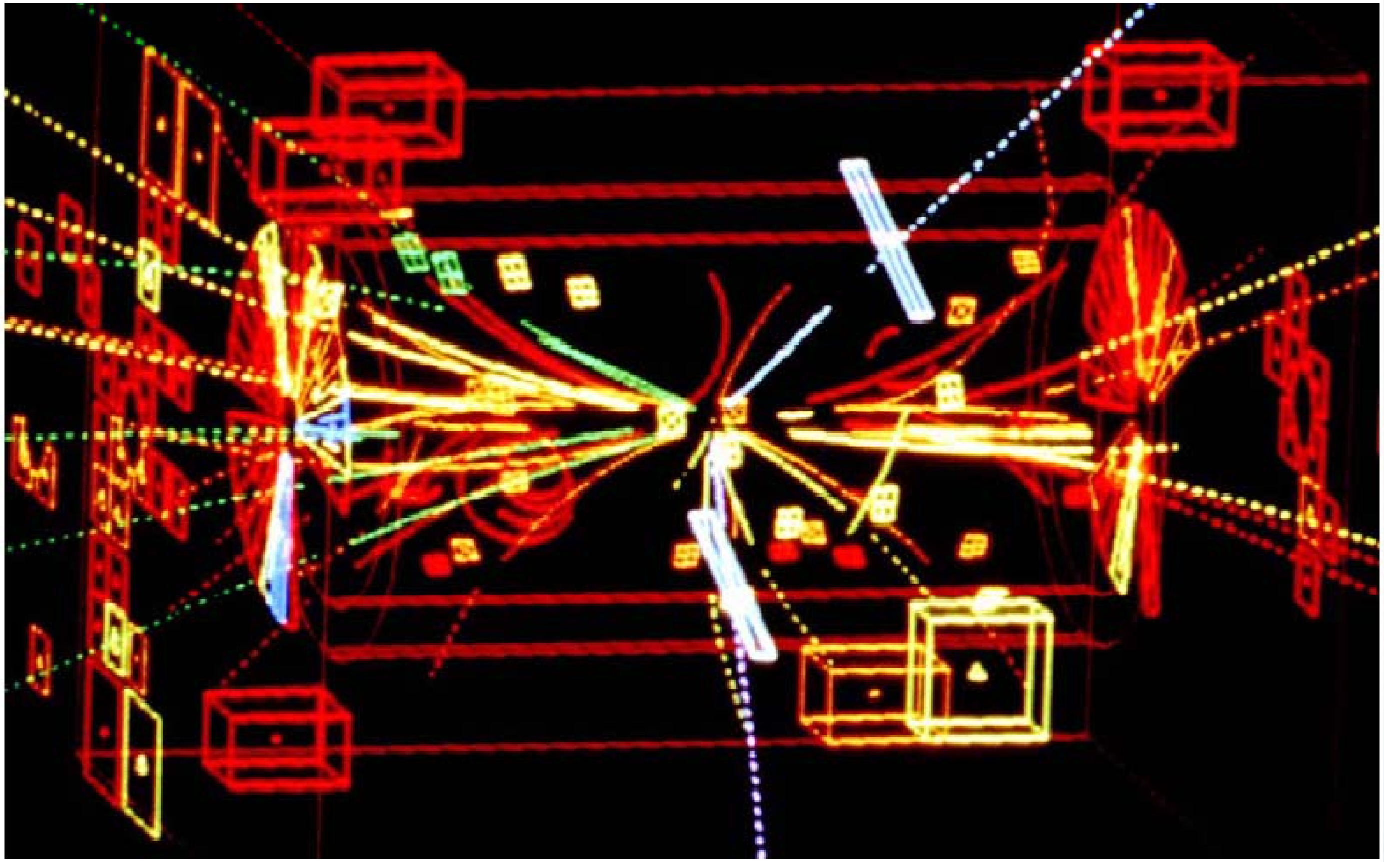
Outline

- History and General Comments
- LHC Schedule
- Challenges
- Sensitivities
- Detector-Specific Challenges
- Word of Caution
- Conclusions

History

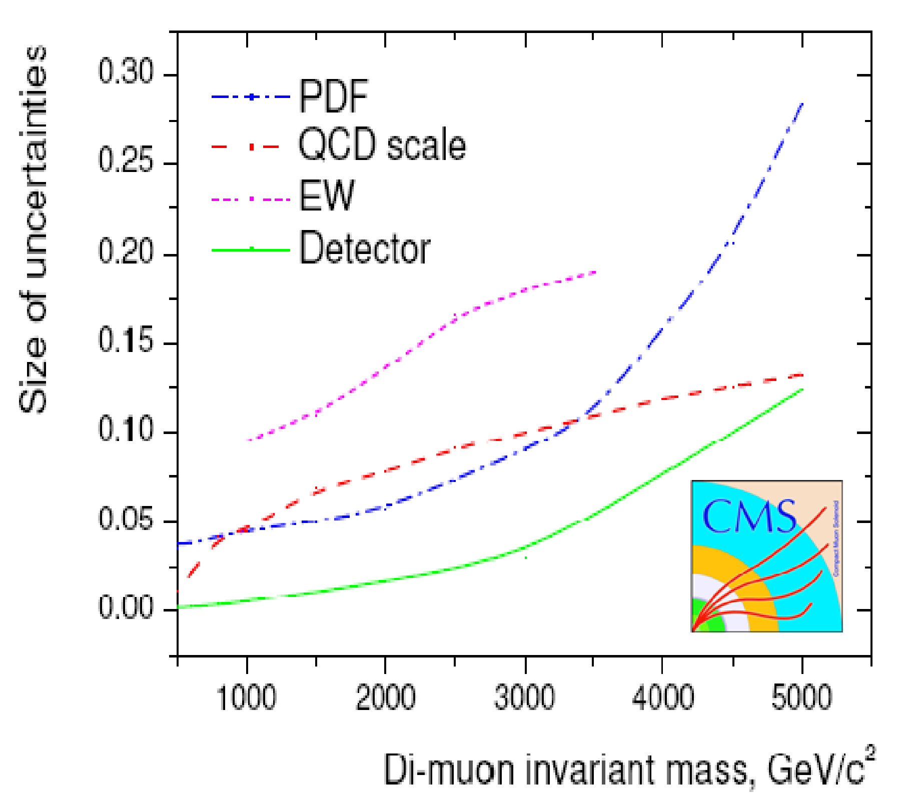
- Drell-Yan dilepton production historically has been a fruitful channel for discoveries (J/Ψ, Υ, Z)
  - So maybe the LHC case



UA1 Z(ee) candidate

History, cont'd

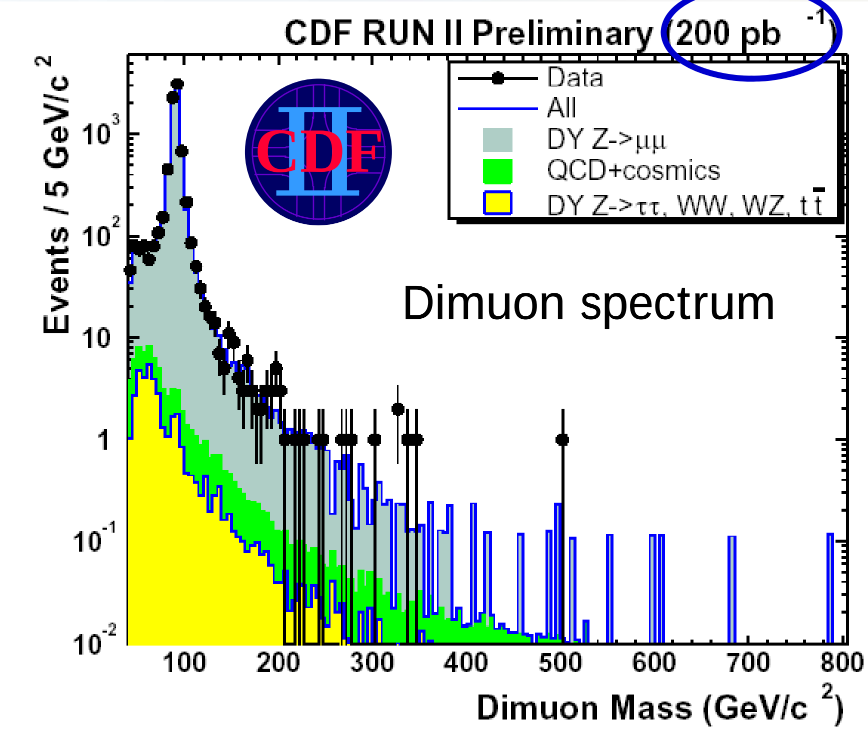
- Well-understood SM cross section (calculated to NNLO level)
- Reasonably small dependence on PDF's and other systematics (except at very low x's)

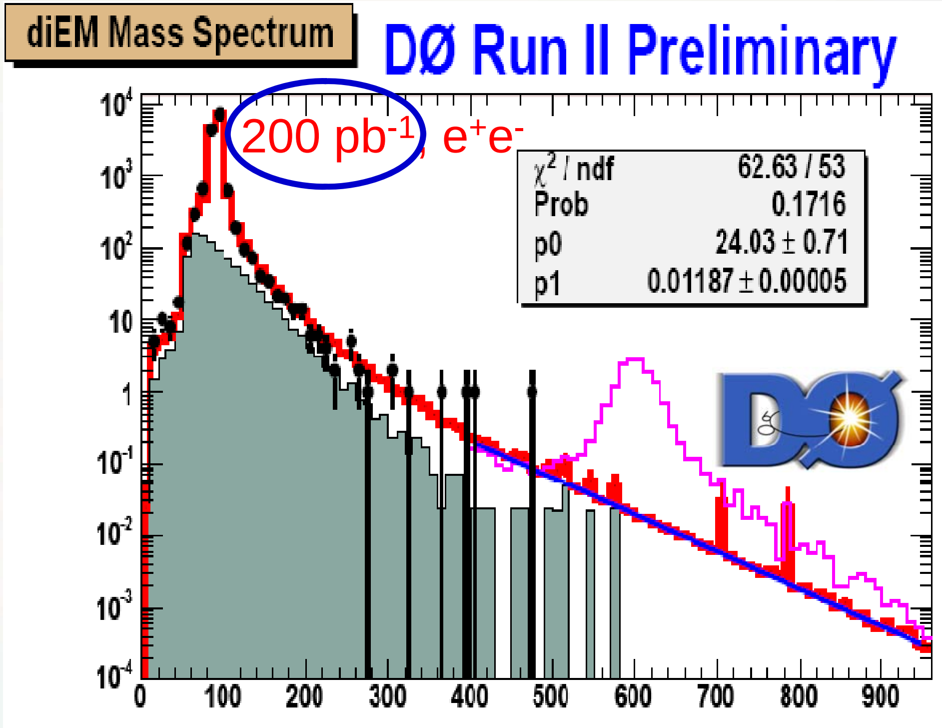


y	0	2	4	0	2	4	0	2	4
	M = 91.2 GeV/c^2			M = 200 GeV/c^2			M = 1000 GeV/c^2		
x_1	0.0065	0.0481	0.3557	0.0143	0.1056	0.7800	0.0714	0.5278	-
x_2	0.0065	0.0009	0.0001	0.0143	0.0019	0.0003	0.0714	0.0097	-

History, cont'd

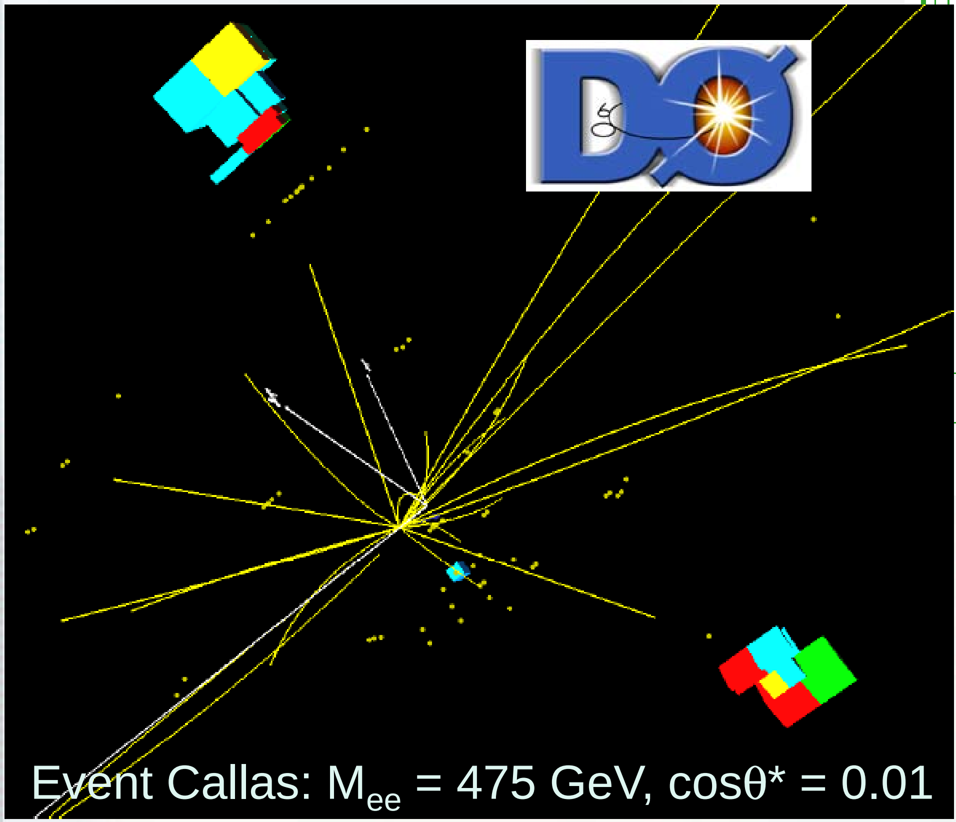
- Tevatron experience shows that these analyses can be performed fast, even with poorly understood detector:
  - Have a "standard candle" – the Z, which can be used for in situ measurement of the efficiencies and luminosity
  - Have been among the first analyses shown by the Tevatron collaborations in Run II and still yield world's best sensitivity to date to a number of new phenomena

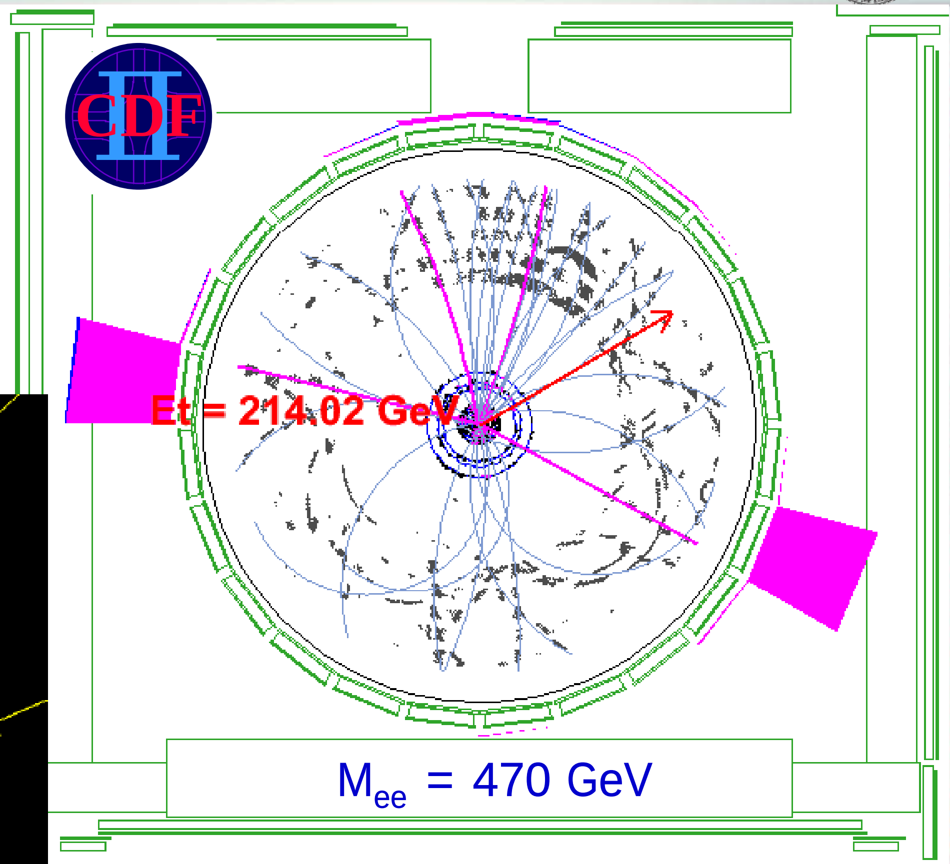




History, cont'd

- Beautifully clean events!

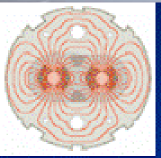




General Comments

- Lepton Resonances:
  - Very clean channel with easy triggering and possibility of a cross check ($ee/\mu\mu/\tau\tau$)
  - In situ calibration with the Z, possibly J/Ψ and Υ
  - (Largely) insensitive to precise tracking alignment, jet energy scale, precise calibration
- Leptoquarks and other gauge bosons:
  - Once dilepton channels are understood, one can start adding other objects, e.g. jets
  - More complicated final states, but still relatively clean
  - Resonant states among the final state particles
- Challenges:
  - Commissioning detectors at the same time as trying to get the first results out
  - Changing beam conditions
  - Changing trigger definition and event reconstruction

LHC Schedule, 2007



Calibration run in 2007

0

Installation Hardware Commissioning	Hardware Commissioning 450GeV	Engineering Run 450GeV	Shutdown

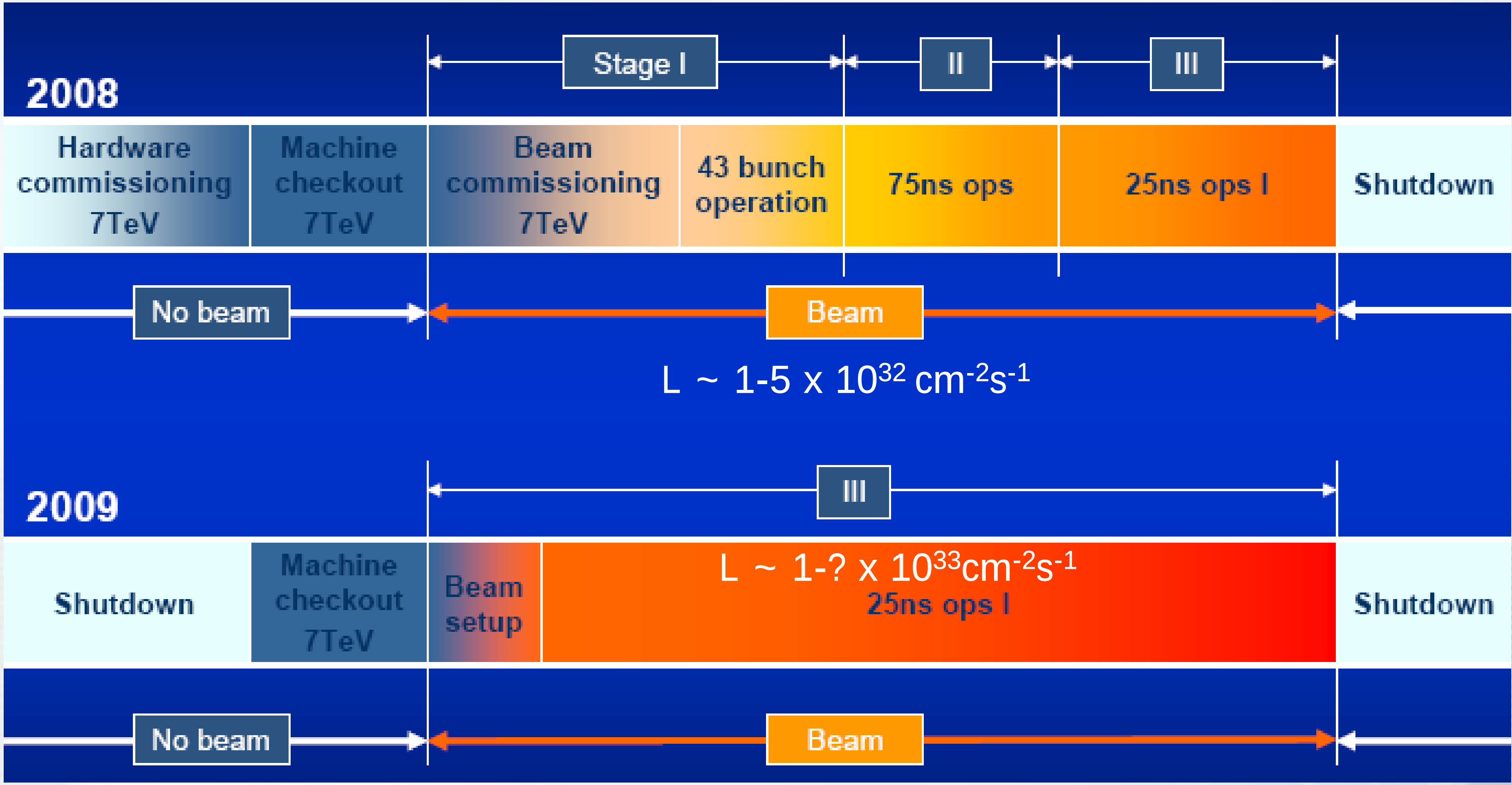
Machine checkout 450GeV	Beam commissioning 450GeV	Calibration run 450GeV

k_b	43	43	156	156
I_b (10^{10})	2	4	4	10
β^* (m)	18	4	4	4
luminosity	10^{28}	$2\ 10^{29}$	$7\ 10^{29}$	$4\ 10^{30}$
Event rate (kHz) [1]	0.4	8	28	180
W rate [2] (per 24h)	1	17	62	386
Z rate [3] (per 24h)	0.1	1.7	6.2	39

1. Assuming 450GeV inelastic cross section 40mb
2. Assuming 450GeV cross section $W \rightarrow l\nu$ 1nb
3. Assuming 450GeV cross section $Z \rightarrow ll$ 100pb

LHC Schedule

- First 14 TeV Collisions: June 2008
- Effective ATLAS/CMS running time/year: ~1000 hours ~ 4 x 10^6 s ~ 4 x 10^{39} cm^{-2} = 4 x 10^{15} b^{-1} = 4 fb^{-1} @ 10^{33} $cm^{-2}s^{-1}$
- Expected luminosity: ~1 fb^{-1} on 2008; ~5 fb^{-1} in 2009



'Early Phase' Assumptions

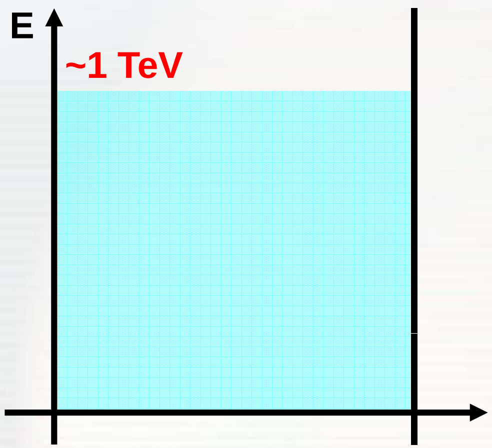
- Still large uncertainties on the delivered luminosity in 2008-2009
- Define `early physics' as 1-10 fb^{-1} of good quality data
- This is the dataset we *could* expect by the time of the Tevatron shutdown
- This may vary from channel to channel, but gives an overall guidance on what to expect from early LHC run
- Focus on dielectron and dimuon reach; will comment on di-taus as well
- Assuming typical acceptance of 50% and 80% detection efficiency expect ~2,000 events produced for a process with 1pb cross section
- Assuming at least ~5 events necessary for discovery, can probe cross sections up to ~2 fb
- Disclaimer: will use slightly more CMS than ATLAS studies, as CMS has brand new Physics TDR
  - Gustaaf will hopefully compensate this slight misbalance

ED Models: The Stage

ADD Model:

- Winding modes with energy spacing ~1/r, i.e. 1 meV – 100 MeV
- Can't resolve these modes – they appear as continuous spectrum

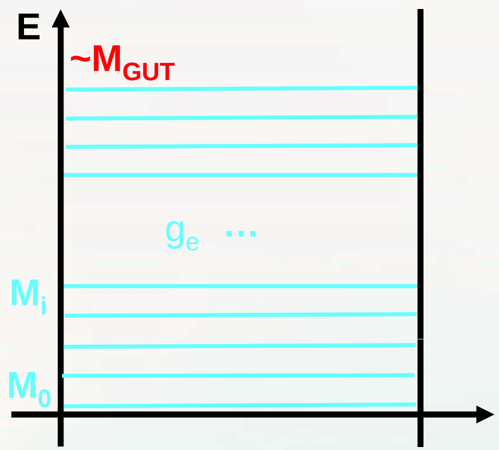
Gravitational coupling per mode; many modes



TeV^{-1} Scenario:

- Winding modes with nearly equal energy spacing ~1/r, i.e. ~TeV
- Can excite individual modes at colliders or look for indirect effects

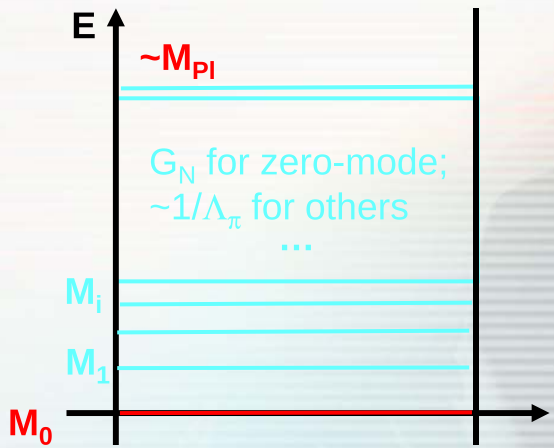
$$M_i = \sqrt{M_0^2 + i^2/r^2}$$



RS Model:

- "Particle in a box" with a special metric
- Energy eigenvalues are given by zeroes of Bessel function J_1
- Light modes might be accessible at colliders

$$M_0 = 0; M_i = M_1 x_i/x_1 \approx M_1, 1.83M_1, 2.66M_1, 3.48M_1, 4.30M_1, \ldots$$



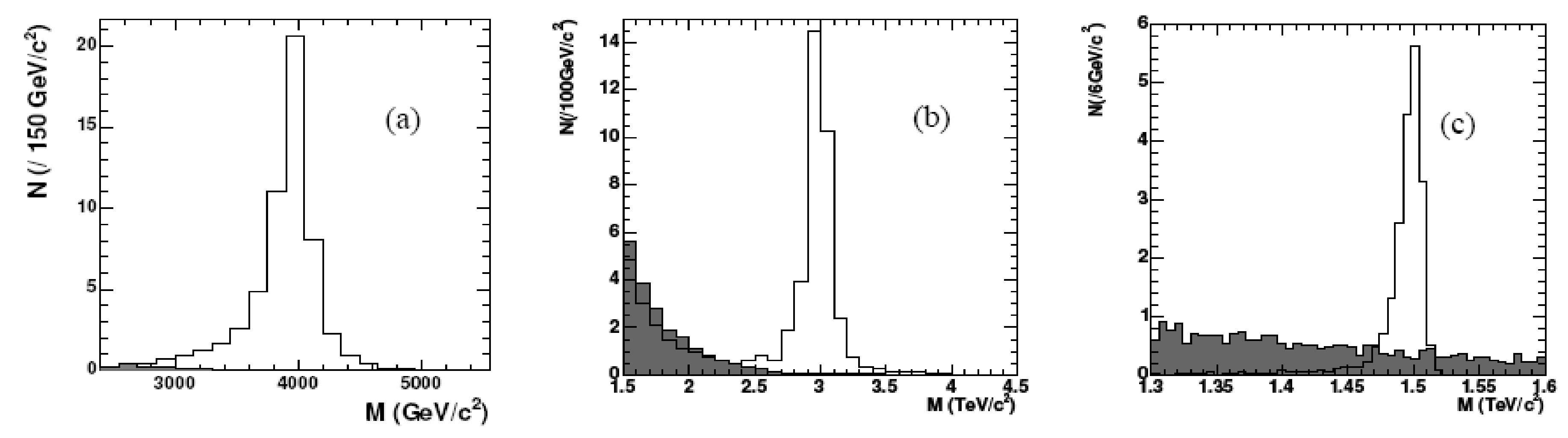
Dielectrons: Discovery Channel

- Excellent resolution 5-10%/sqrt(E, GeV) (calorimeter based) and detection efficiency
- Low background above ~1 TeV

	KK Z		G, $c = 0.01$	G, $c = 0.1$	SSM Z'	
M	4.0	6.0	1.5	3.5	1.0	5.0
M_w	3.5-4.5	5.0-6.7	1.47-1.52	3.30-3.65	0.92-1.07	4.18-5.81
N_s	50.6	1.05	18.8	7.30	72020	0.58
N_b	0.13	0.005	4.16	0.121	85.5	0.025
S	22.5	3.0	6.39	6.83	225	1.63

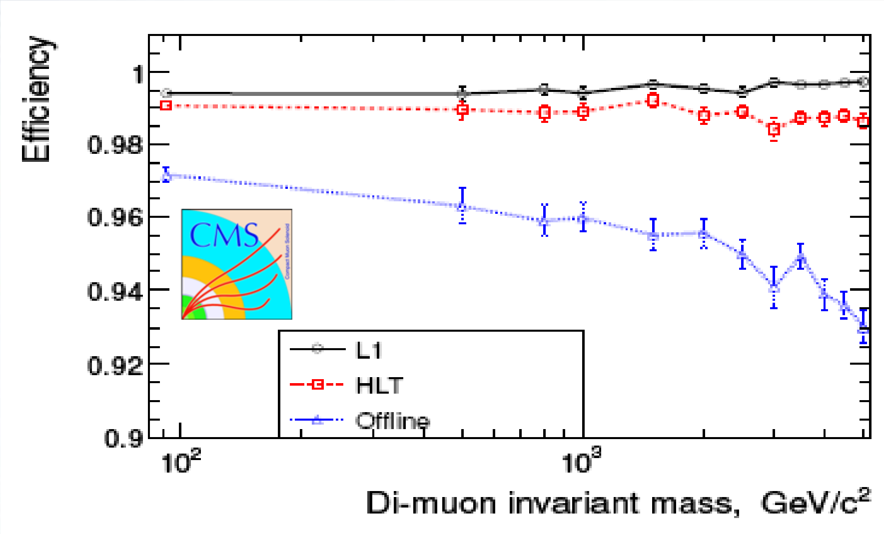
CMS, 30 fb^{-1}

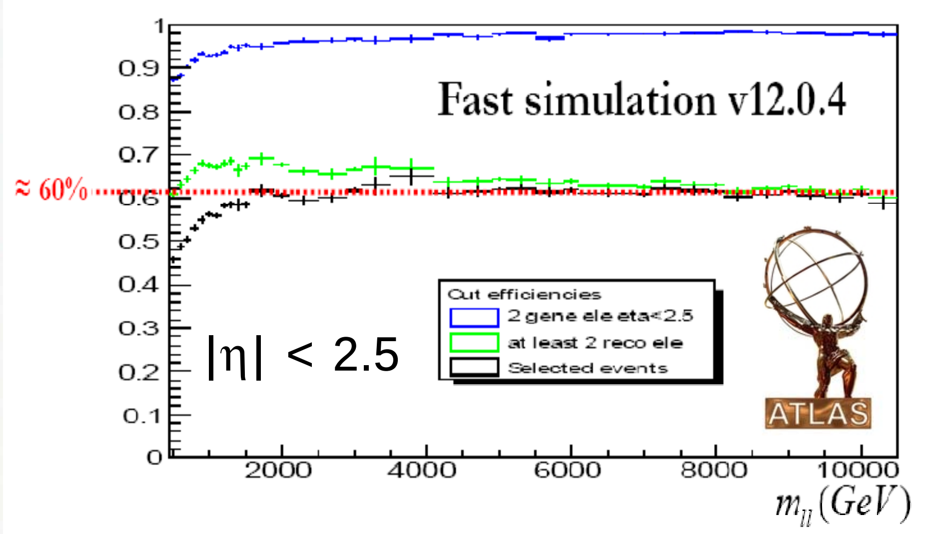
Z_{KK} production



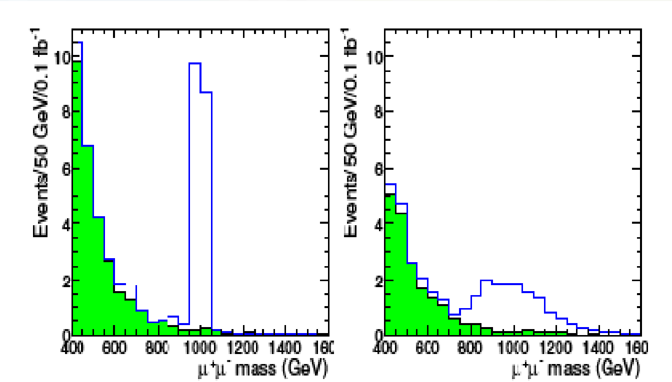
Dimuons: Confirmation Channel?

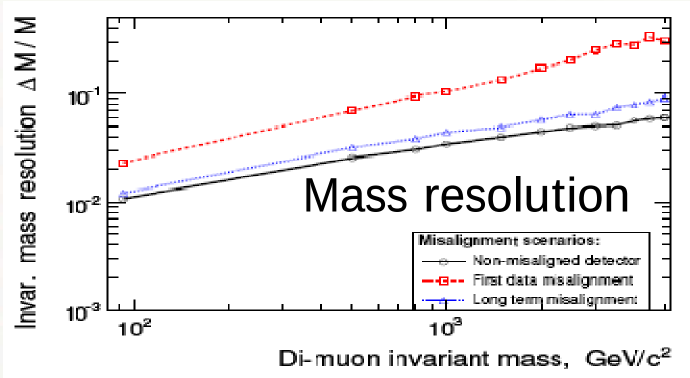
- Generally worse rapidity coverage, detection efficiency





- Significantly worse momentum resolution than for electrons

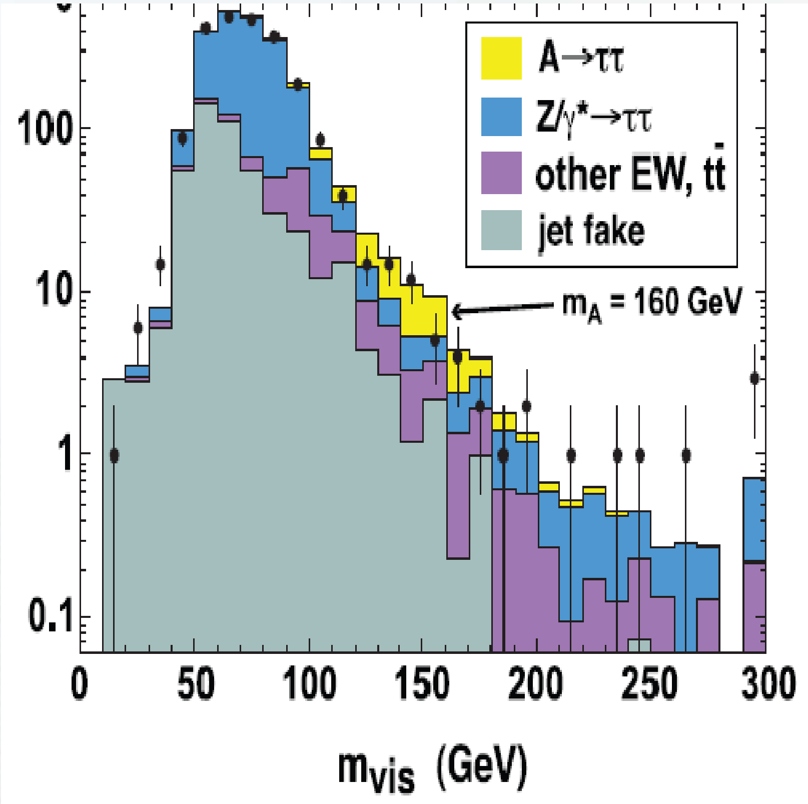


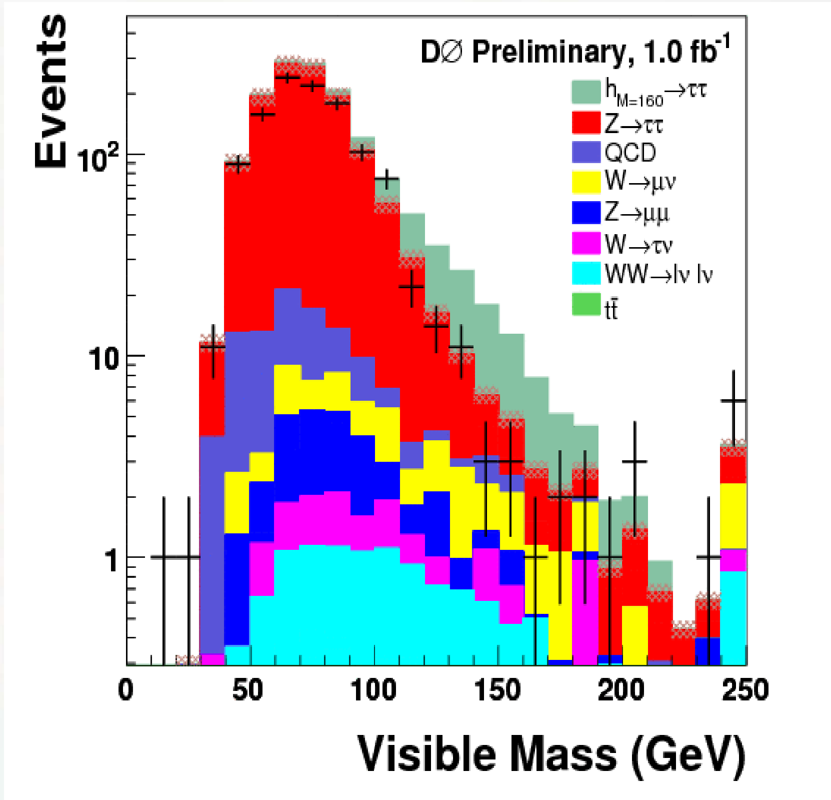


- Nevertheless: generally lower instrumental background may make dimuons a discovery channel along with dielectrons

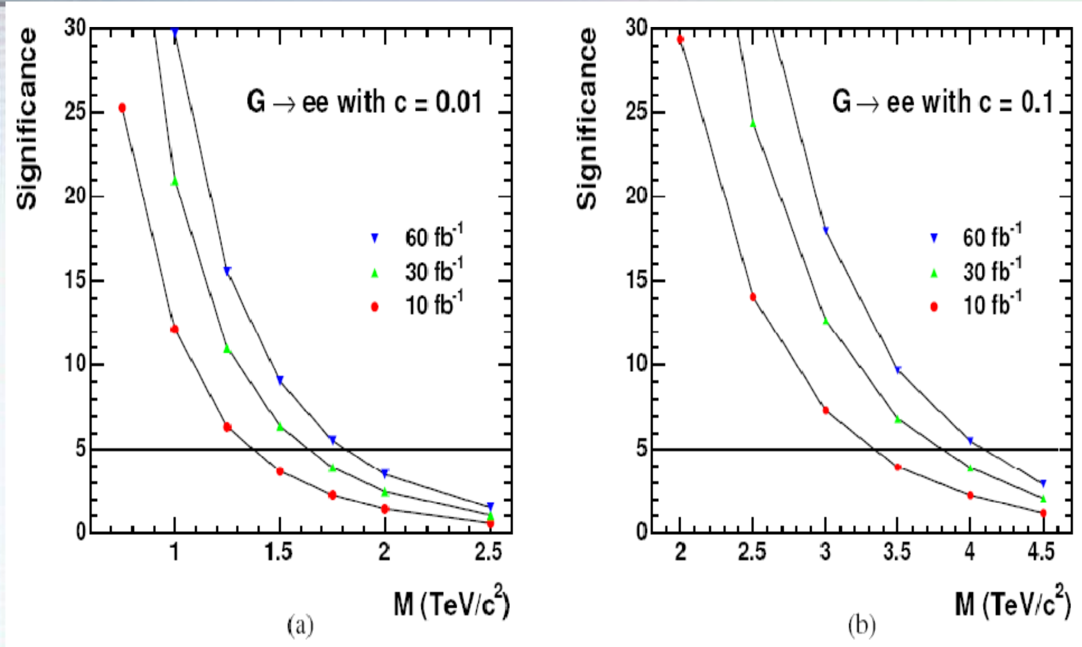
What About Tau's?

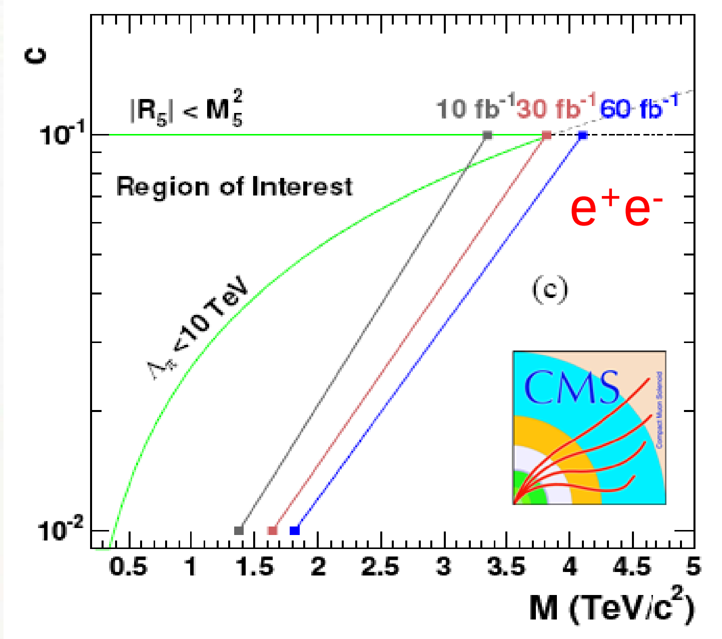
- Less studied for the discovery reach by the LHC collaborations, but still can be accessible for early physics
- N.B. The first Tevatron Run II cross section paper was DØ Z(ττ) measurement
- Very interesting reach for MSSM Higgs and other resonances; could also be tricky?

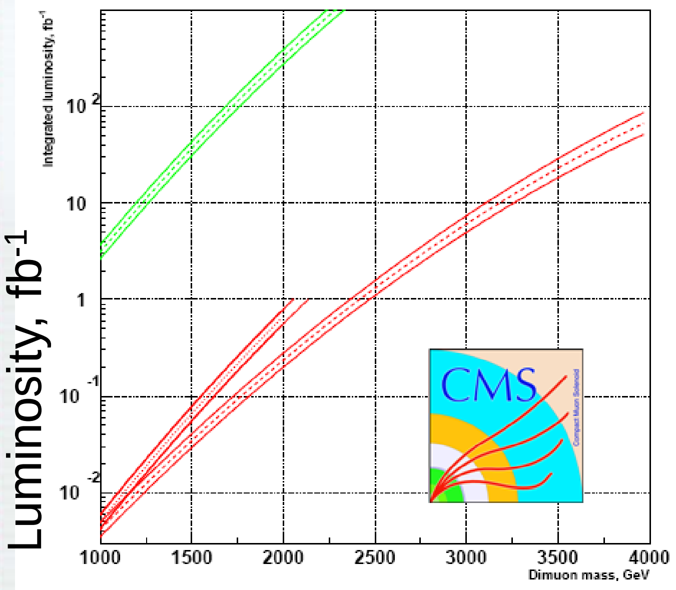




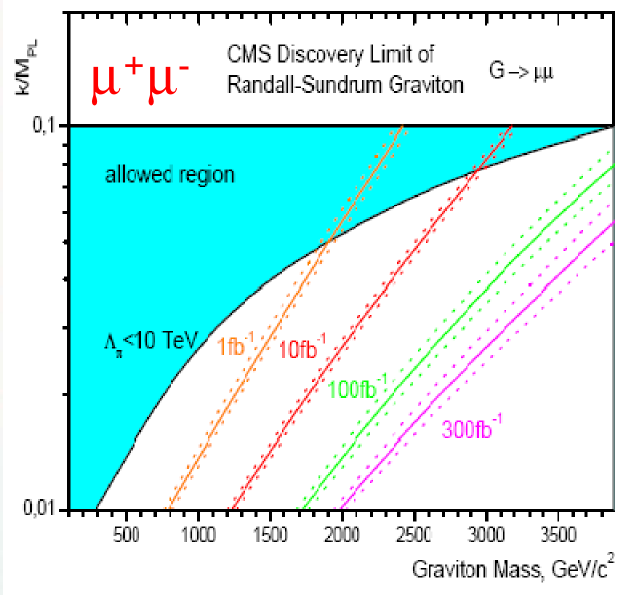
Randall-Sundrum Graviton Reach





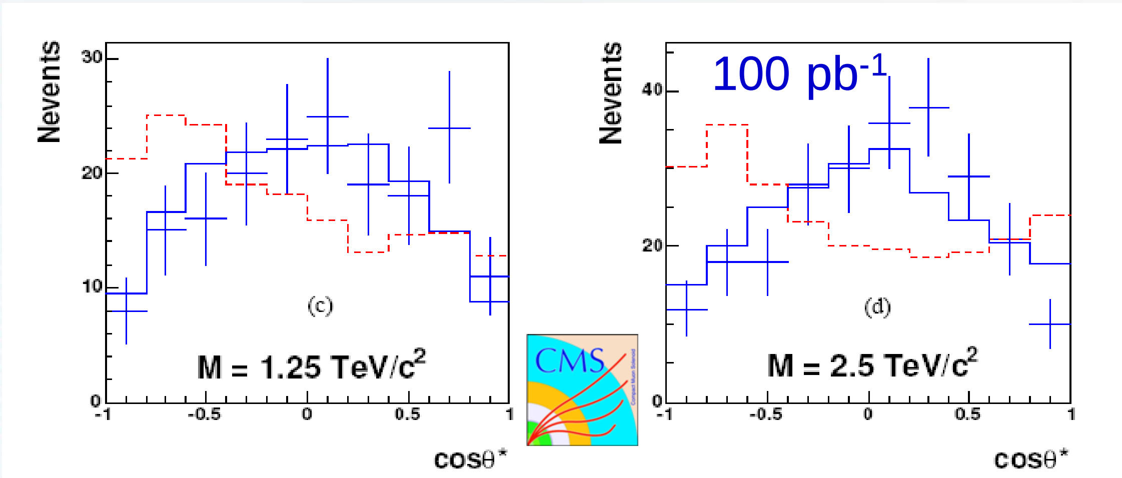


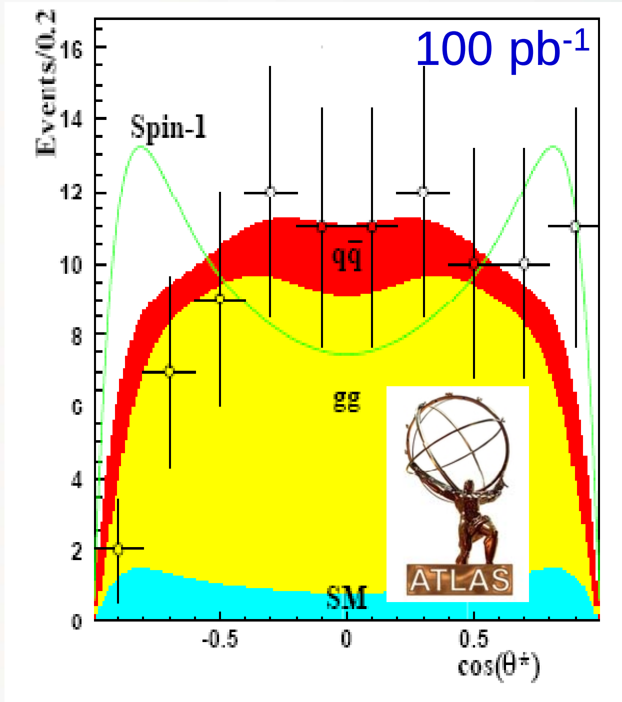
Coupling constant c	Estimator	1 fb^{-1}	10 fb^{-1}
0.01	S_{cP}	0.75	1.20
	S_{cL}	0.77	1.21
	S_L	0.78	1.23
0.02	S_{cP}	1.21	1.72
	S_{cL}	1.22	1.72
	S_L	1.22	1.74
0.05	S_{cP}	1.83	2.48
	S_{cL}	1.85	2.49
	S_L	1.85	2.51
0.1	S_{cP}	2.34	3.11
	S_{cL}	2.36	3.13
	S_L	2.36	3.16

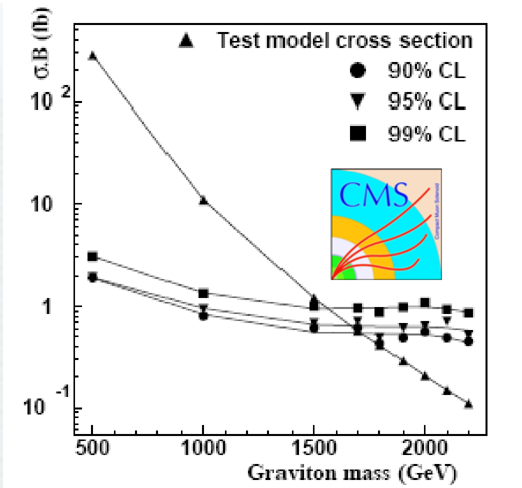


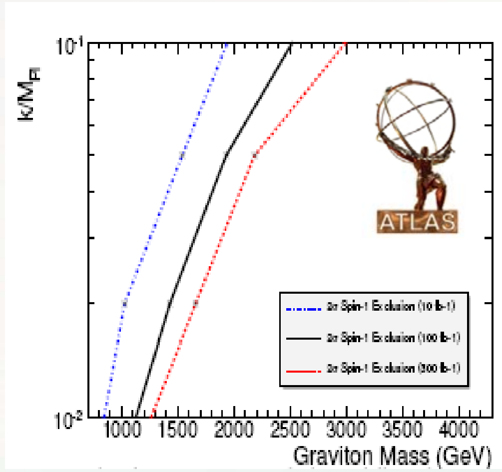
Angular Distributions?

- Not in the early running!
  - "One event – discovery; two events – cross section measurement; three events – angular distributions"



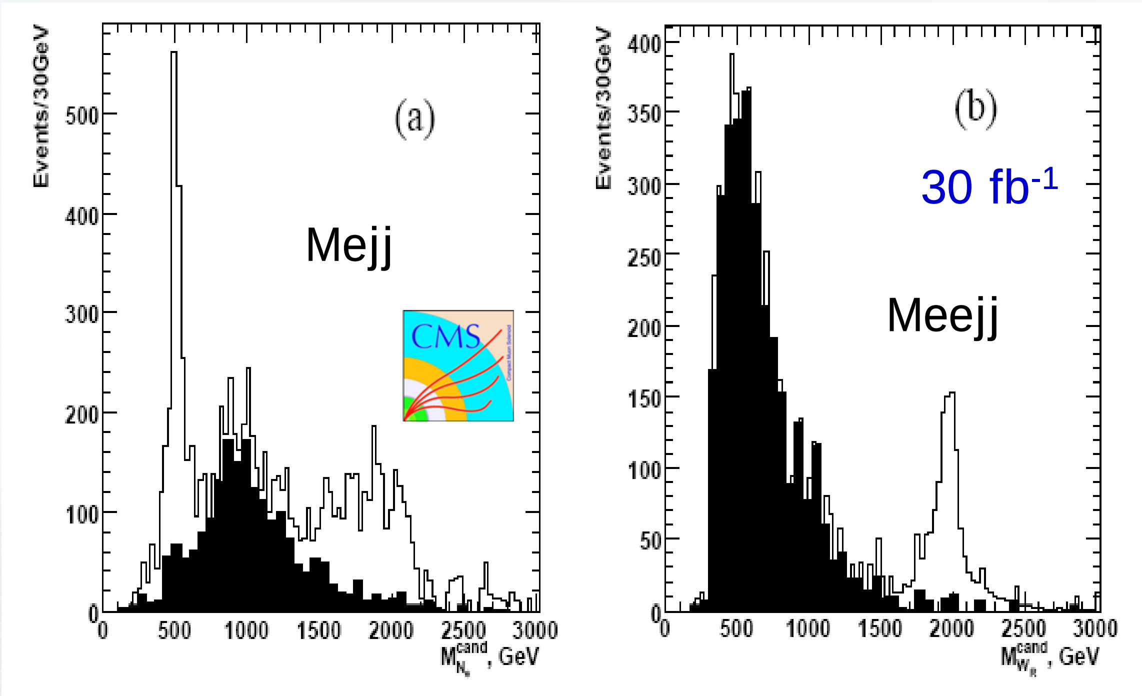


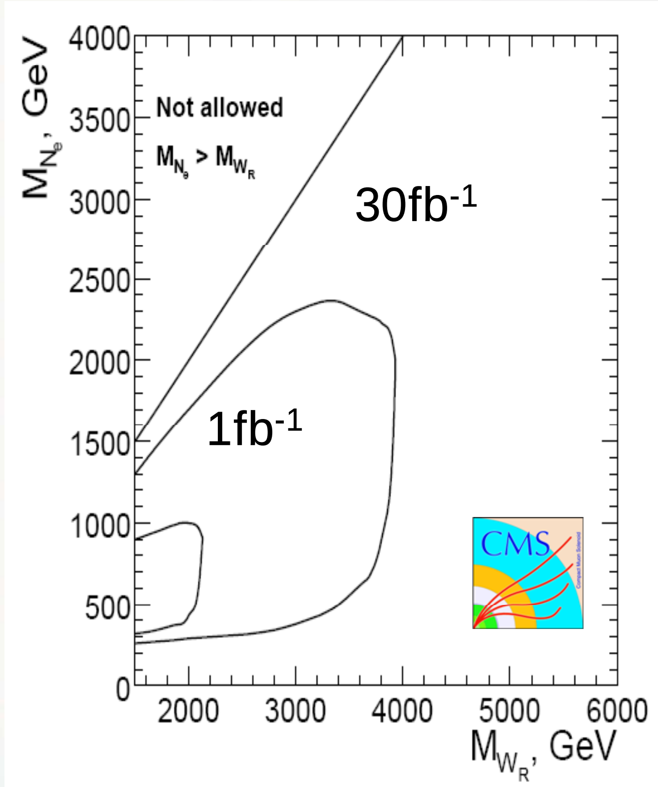




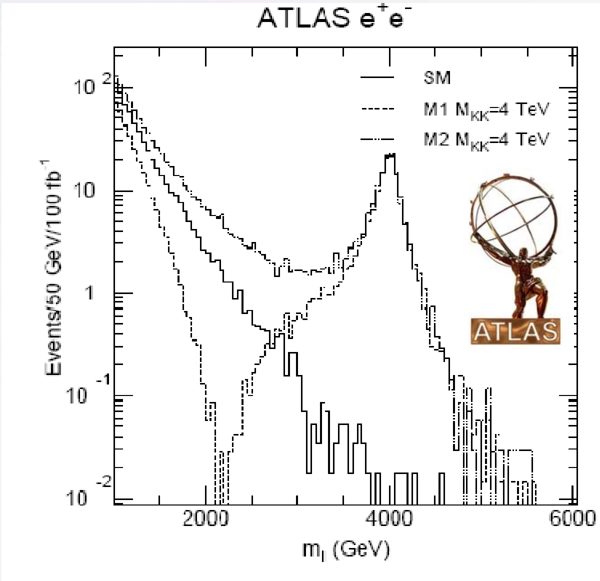
Right-handed W

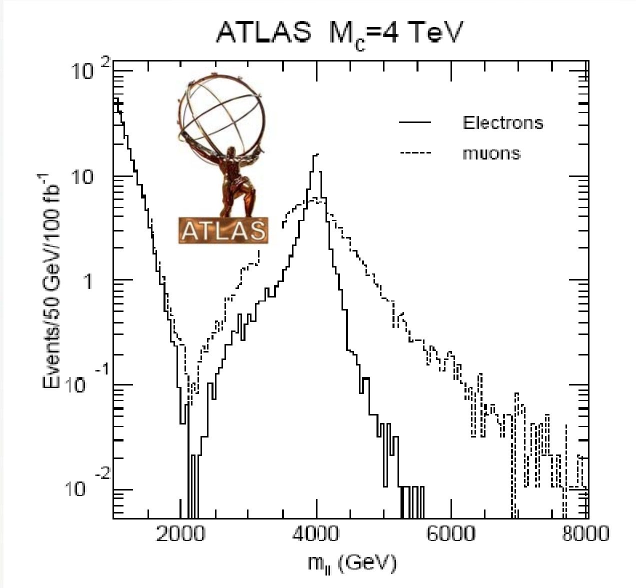
- W_R production, with $W_R \rightarrow l + N \rightarrow l + ljj$
- Interesting reach even with ~1 fb^{-1}

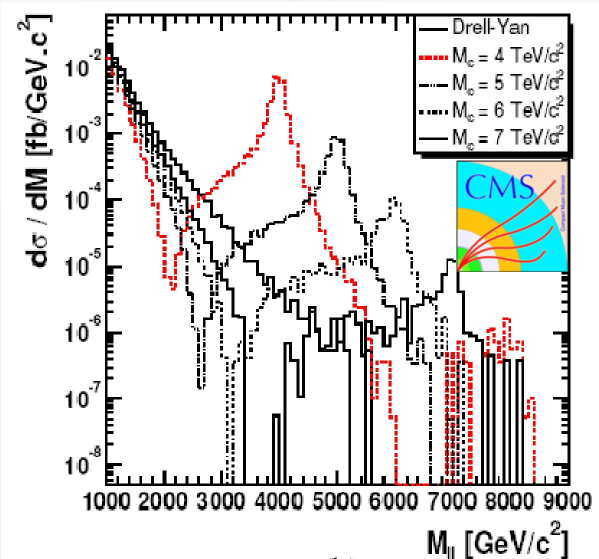




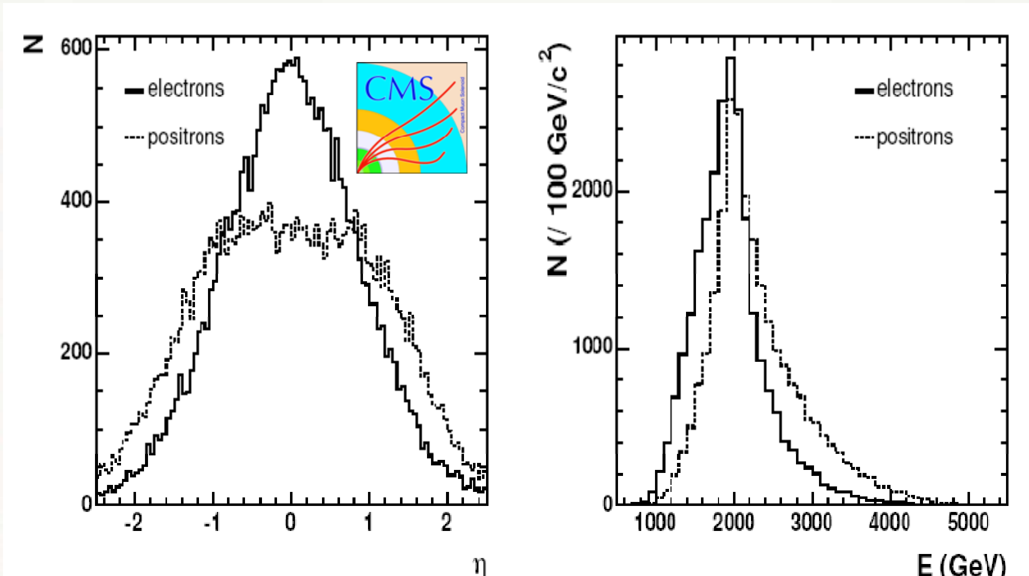
KK Excitations of the Z Boson







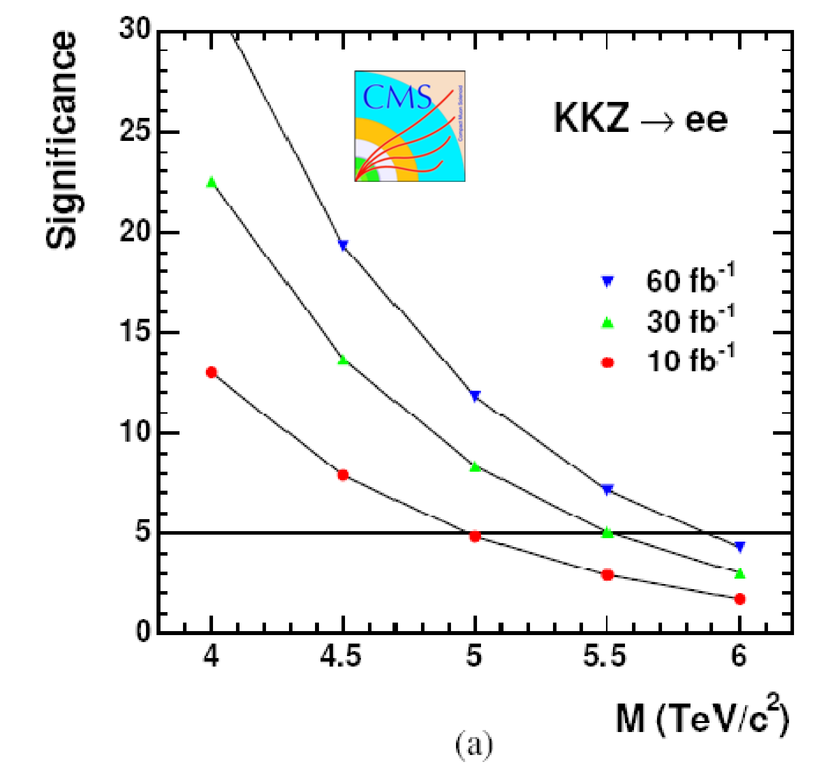
(b)

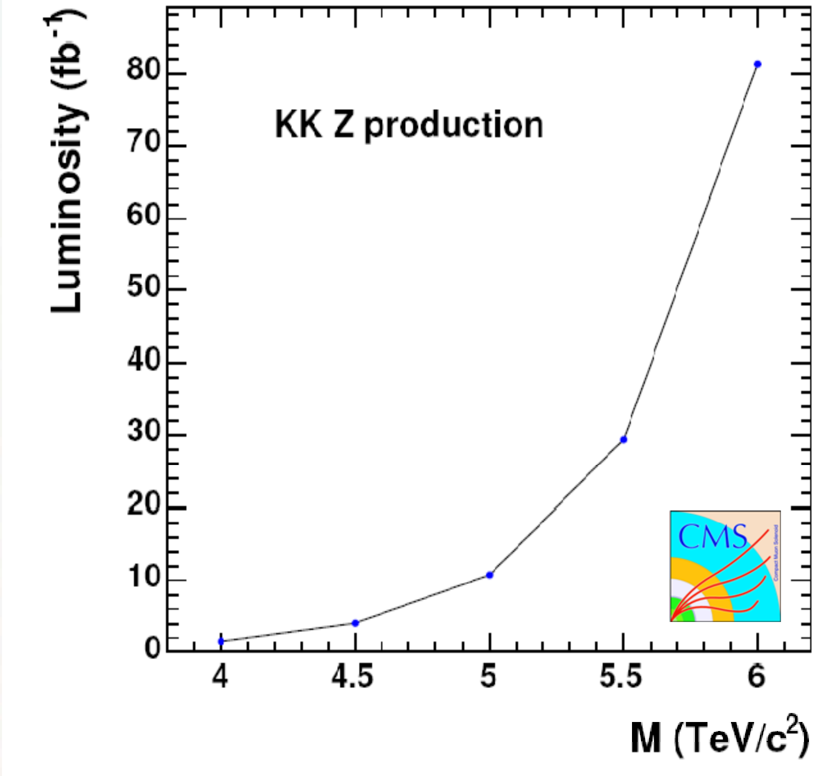


(a) (b)

KK Reach

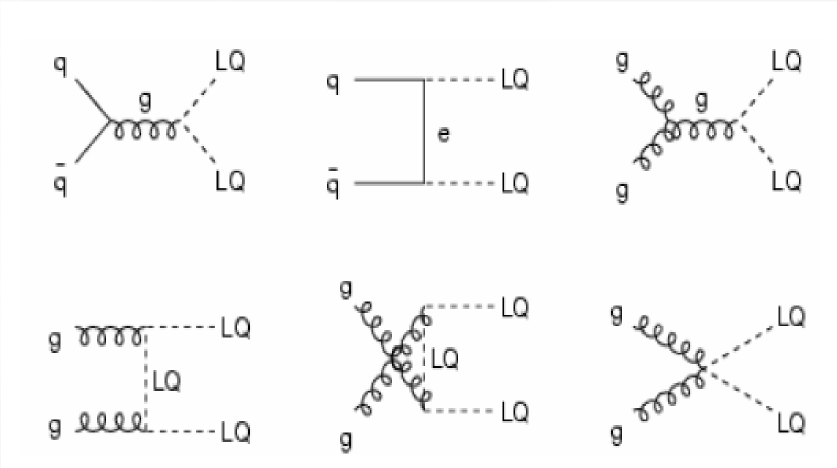
- Dramatic reach even with ~1 fb^{-1}



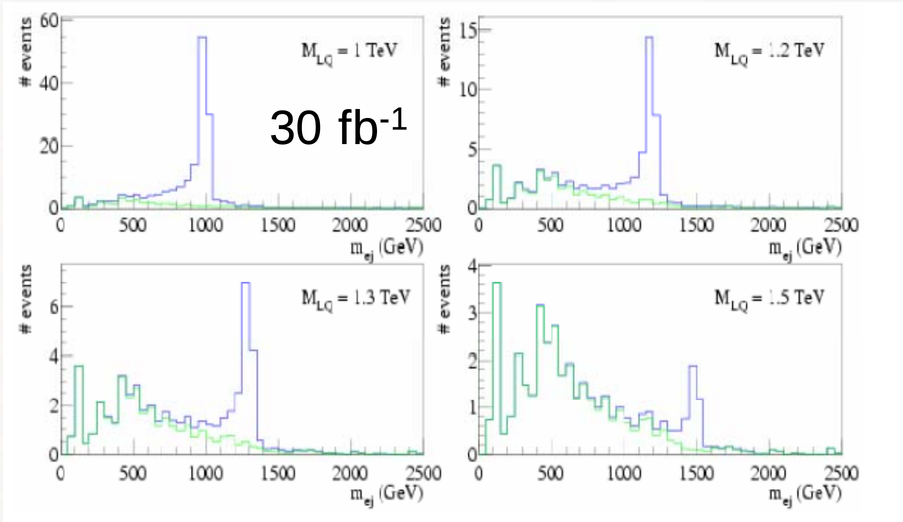


Leptoquarks

- Once ll channel is understood, adding extra objects is easy, even if they are as messy as jets!
- Focus on the lljj channel
  - eνjj is a possibility, but no existing studies
  - νν jj will take long time

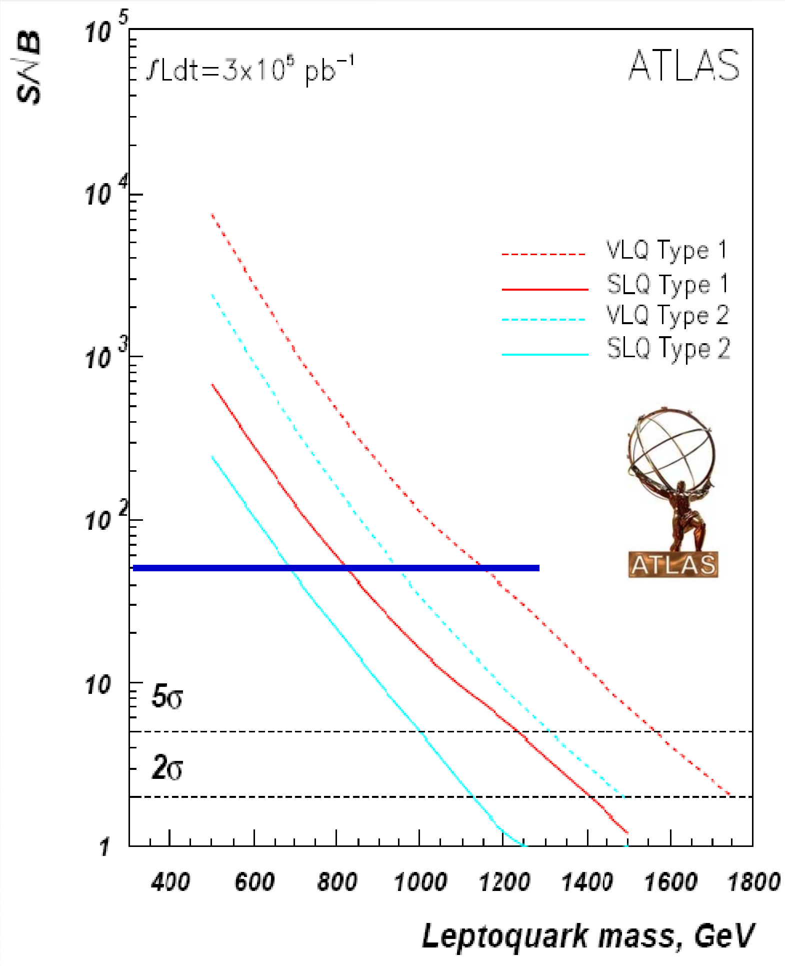


M_{LQ} (TeV)	σ (fb)	Signal	Background	$S/\sqrt{B}$
1.0	4.96	98.5	2.84	58
1.2	1.33	22.0	2.43	14
1.3	0.713	12.8	1.44	11
1.5	0.223	3.62	0.376	5.9



Leptoquarks: Reach

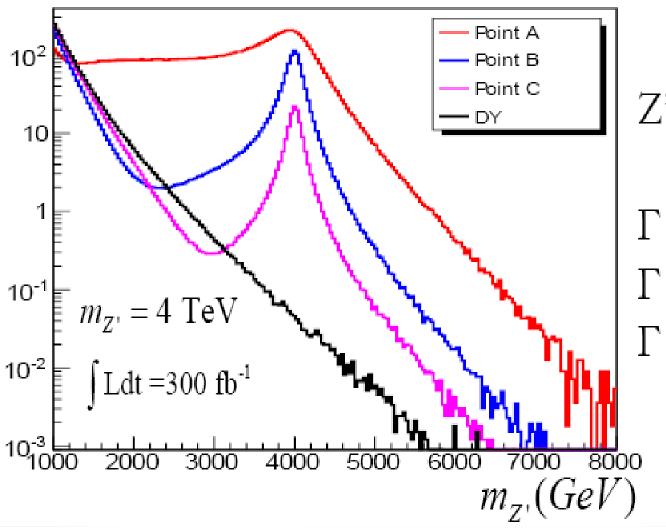
- Reach plot available for 300 fb^{-1}
  - Scale significance as sqrt(L)
  - S/sqrt(B) of 50 correspond to 5 sigma at 3 fb^{-1}



Challenges: General

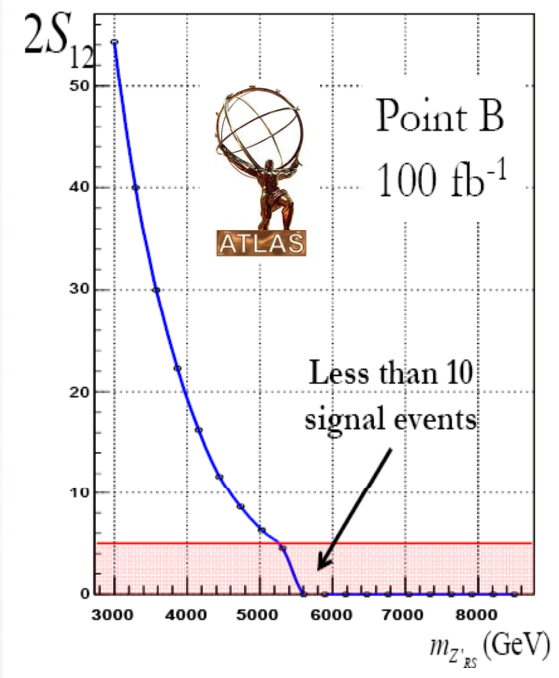
- Broad resonance are possible at high masses; signal start looking compositeness (or instrumental effect!) like
- Reduces the reach; requires different optimization of the search

Example: bulk Z_{KK} in RS model



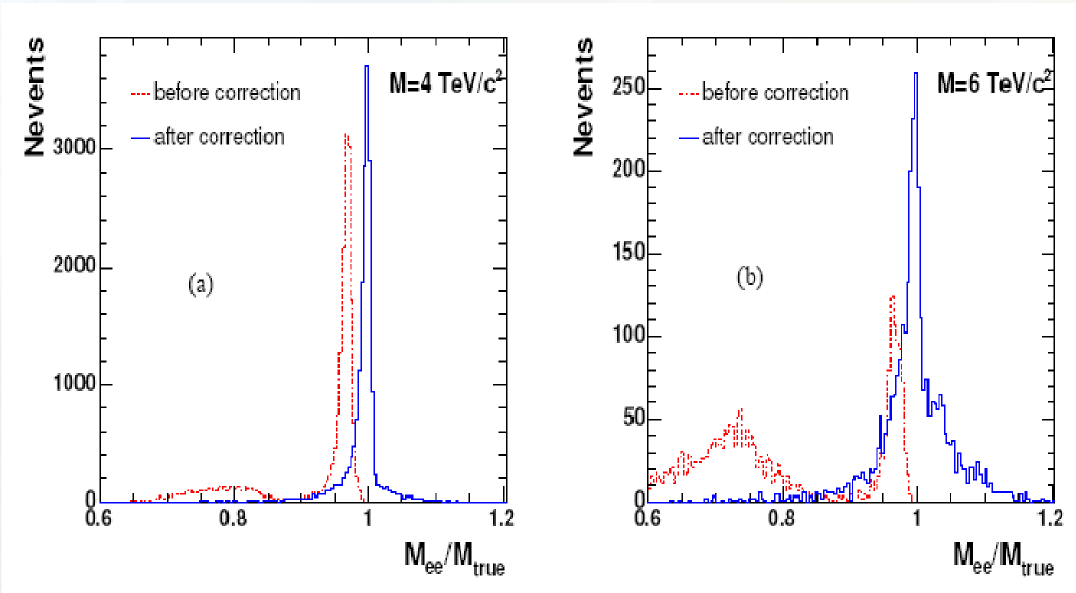
Z' Width @ $M_{Z'}$=4 TeV

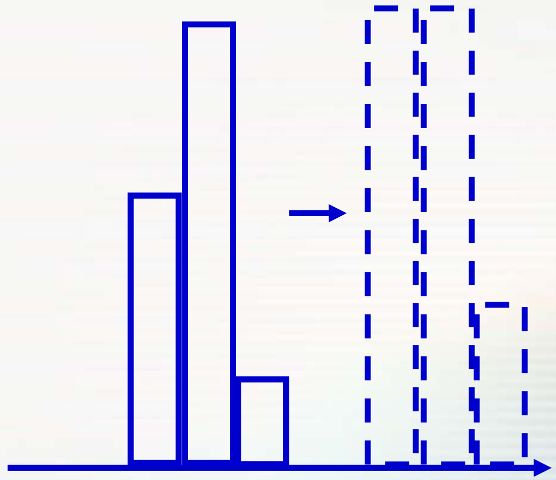
Γ = 800 GeV for point A (0.2 $M_{Z'}$)
Γ = 200 GeV for point B (0.05 $M_{Z'}$)
Γ = 170 GeV for point C (0.04 $M_{Z'}$)



Challenges: CMS

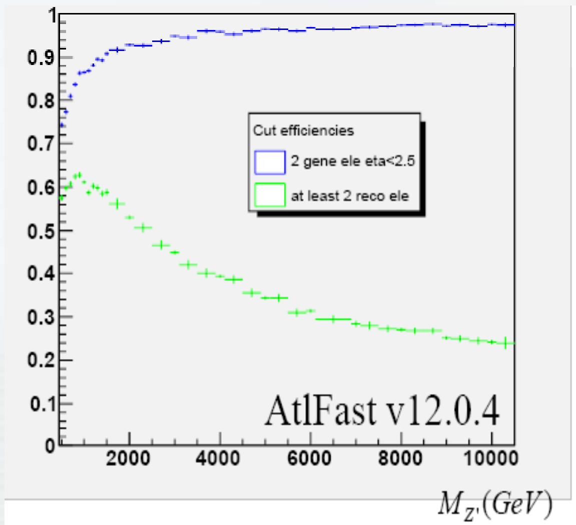
- ECAL saturation: a single crystal saturates at ~1.7 TeV; start seeing effect for >4 TeV Z'
- Correct energy at a slight resolution loss using "charge-sharing" technique
- Triggering with saturation could present another challenge!

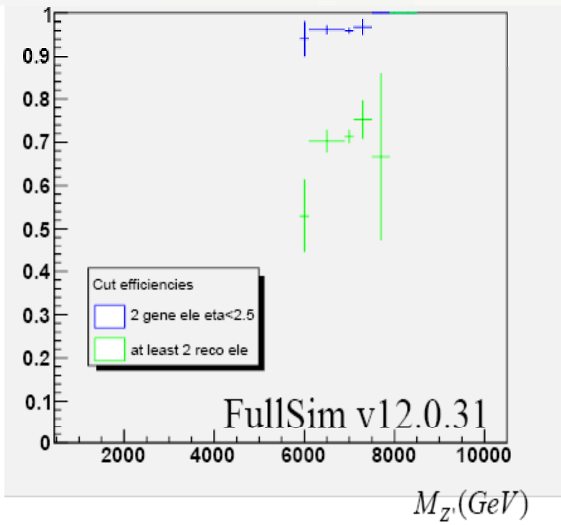


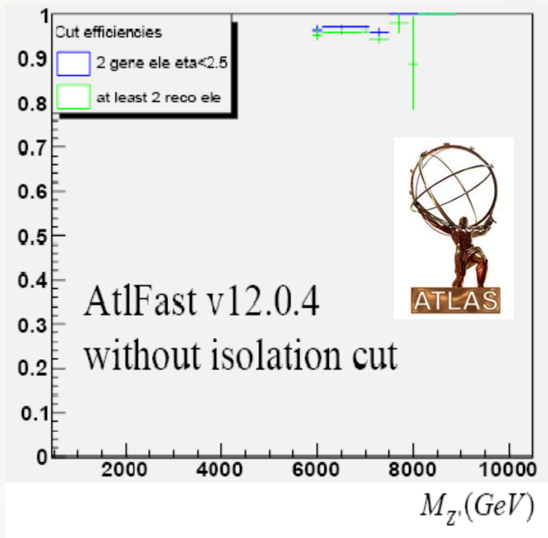


Challenges: ATLAS

- Electron efficiency drops fast with mass when "standard" isolation cut is used
  - Loosely confirmed by full simulation
- New set of isolation cuts is being developed to recover efficiency at high masses

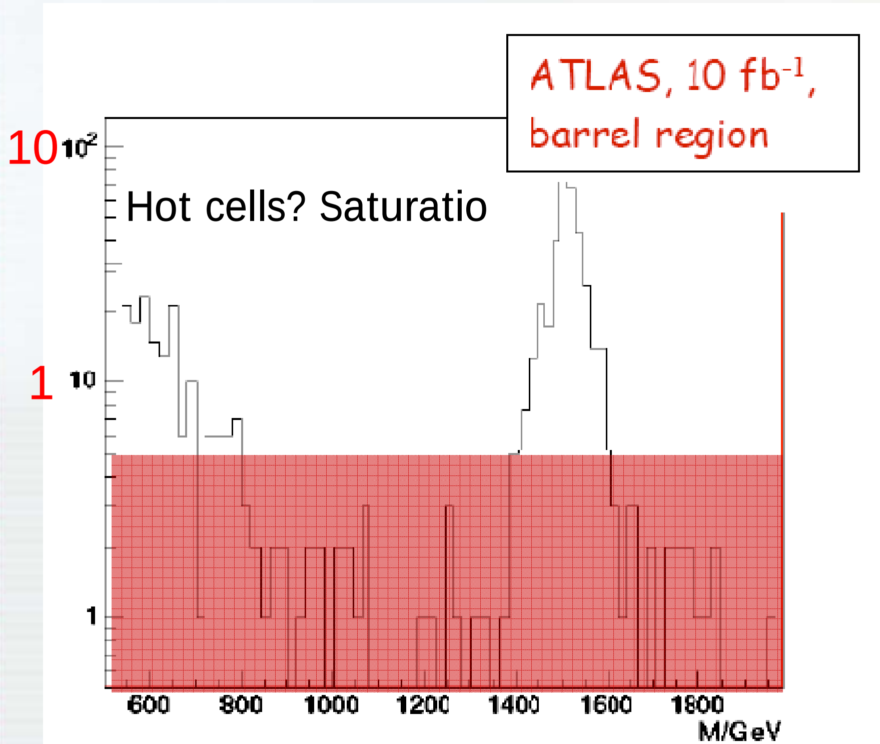


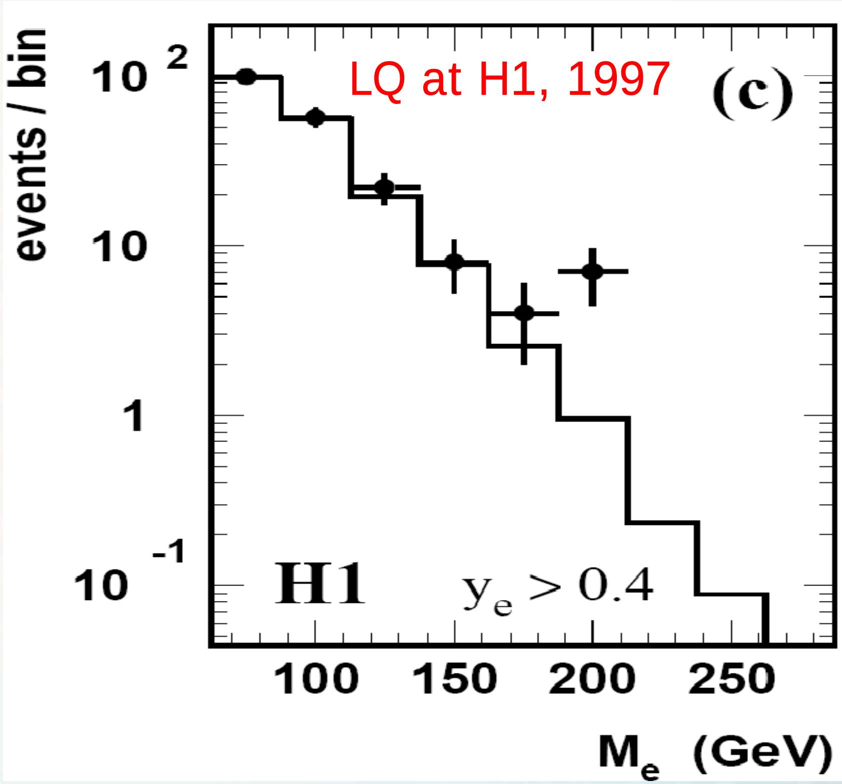




Last-Bin Effect

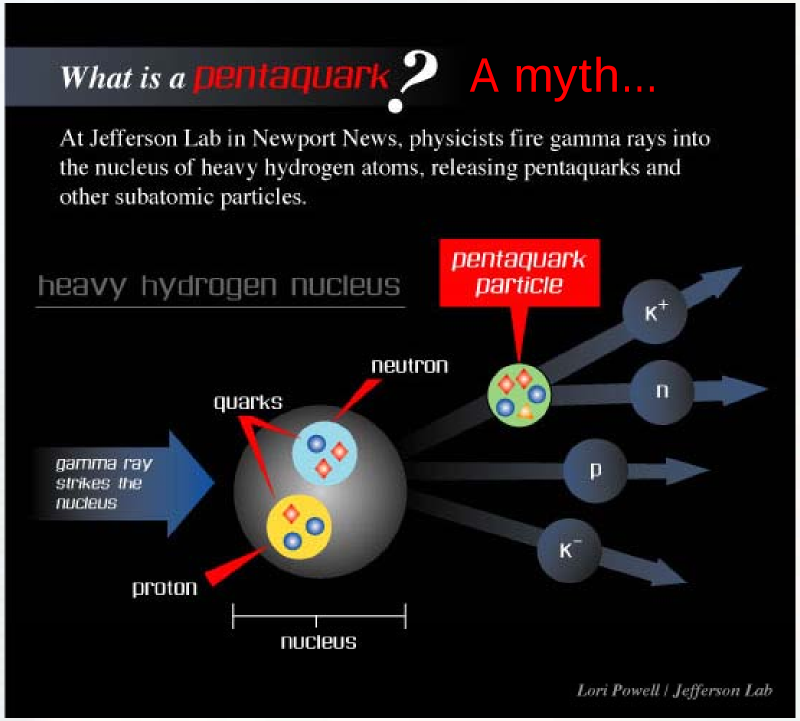
- Note the last-bin effects: saturation can easily cause a peak
  - Unlikely that confirmation could come from the dimuon (resolution) or ditau (ID, trigger, Z(ττ) first!) channel at the time of discovery
  - Thus many cross checks will be required





Memento Pentaquarks…

- Involved about a dozen (!) of groups all over the globe!
- Generated about 400 references in the literature
- Net result: every single claim of 2003 has been disputed by at least one other group
- IMHO: quite a shame for the field, which is over 100 years old and so proud of the widely-accepted 5σ discovery standard
- Unfortunately follows a long trail of "miscoveries" from split A_2 to the Heidelberg-Moscow $0\nu\beta\beta$ decay claim and DAMA story



Experiment	Reaction	State	Mode
LEPS(1)	$\gamma C_{12} \to K^+K^-X$	θ^+	K^+n
LEPS(2)	$\gamma d \to K^+K^-X$	θ^+	K^+n
CLAS(d)	$\gamma d \to K^+K^-(n)p$	θ^+	K^+n
CLAS(p)	$\gamma p \to K^+K^-\pi^+(n)$	θ^+	K^+n
SAPHIR	$\gamma p \to K^0_S K^+(n)$	θ^+	K^+n
COSY	$pp \to \Sigma^+ K^0_S p$	θ^+	$K^0_S p$
JINR	$p(C_3H_8) \to K^0_S pX$	θ^+	$K^0_S p$
SVD	$pA \to K^0_S pX$	θ^+	$K^0_S p$
DIANA	$K^+Xe \to K^0_S p(Xe)'$	θ^+	$K^0_S p$
νBC	$\nu A \to K^0_S pX$	θ^+	$K^0_S p$
NOMAD	$\nu A \to K^0_S pX$	θ^+	$K^0_S p$
HERMES	quasi-real photoproduction	θ^+	$K^0_S p$
ZEUS	$ep \to K^0_S pX$	θ^+	$K^0_S p$
NA49	$pp \to \Xi\pi X$	Ξ_5	$\Xi\pi$
H1	$ep \to (D^*p)X$	θ_c	D^*p

[Dzierba et al, hep-ex/0412077]

Peaks Are Not Easy to Fake?

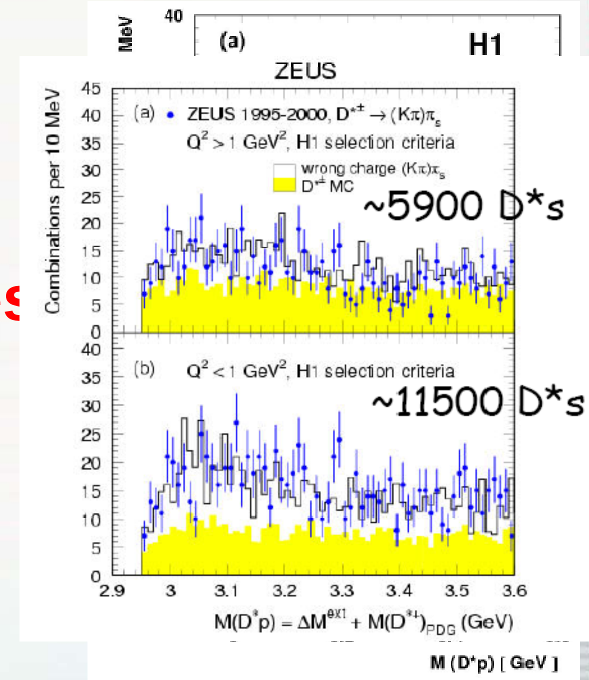
Lee Ann Womack – "Now You See Me, Now You Don't"

Better take a good look before I disappear
Because I'm just about to be your used-to-be
You might catch a glimpse of my taillights in the dust
And if you notice something missin', well it's me
'Cause I tried and you lied

…

Now you see me, now you don't
First you do but then you won't
Watch me vanish right before your eyes
You might think you see me there
In a cafe on a street somewhere
Yeah, that might be me but I'll be gone
Now you see me, now you don't

…



Conclusions

- Early LHC Physics certainly hold many surprises: both pleasant and unpleasant ones
- The machine and detector will come online and will be commissioned in parallel, which adds to the challenges
- Nevertheless, dilepton channel was historically very discovery-rich, and if history is any guide, we should be able to discover multi-TeV resonances in these channels relatively fast
- This is a brand new territory, where Tevatron doesn't have any reach, so surprises may come very early
- Both ATLAS and CMS collaborations are well aware of challenges and have formed dilepton working groups looking at realistic scenarios and developing discovery strategy
  - While a discovery can't be planned, it can and should be prepared for and accelerated!

The LHC Surprise ?

- LHC vs. Tevatron:
  - Nearly an order of magnitude higher c.o.m. energy (SSC would have been even better!)
  - Significantly reduced relative rate of important SM backgrounds due to the pp initial state
  - Consequently, surprises are possible literally on Day One of operations
  - Nevertheless, how likely are they?
- LHC event yield per 10 fb^{-1}:

channel	recorded events per experiment for 10 fb^{-1}
$W \to \mu\nu$	7×10^7
$Z \to \mu\mu$	1.1×10^7
$t\bar{t} \to \mu + X$	0.08×10^7
QCD jets p_T >150 GeV	$\sim 10^7$ (assuming 10% of trigger bandwidth)
minimum bias	$\sim 10^7$ (assuming 10% of trigger bandwidth)
$\tilde{g}\tilde{g}$, m $(\tilde{g})$~1 TeV	$10^3 - 10^4$

[Gianotti & Mangano, hep-ph/0504221]

- What are the Tevatron lessons in some of these channels?

[Gianotti & Mangano, hep-ph/0504221]