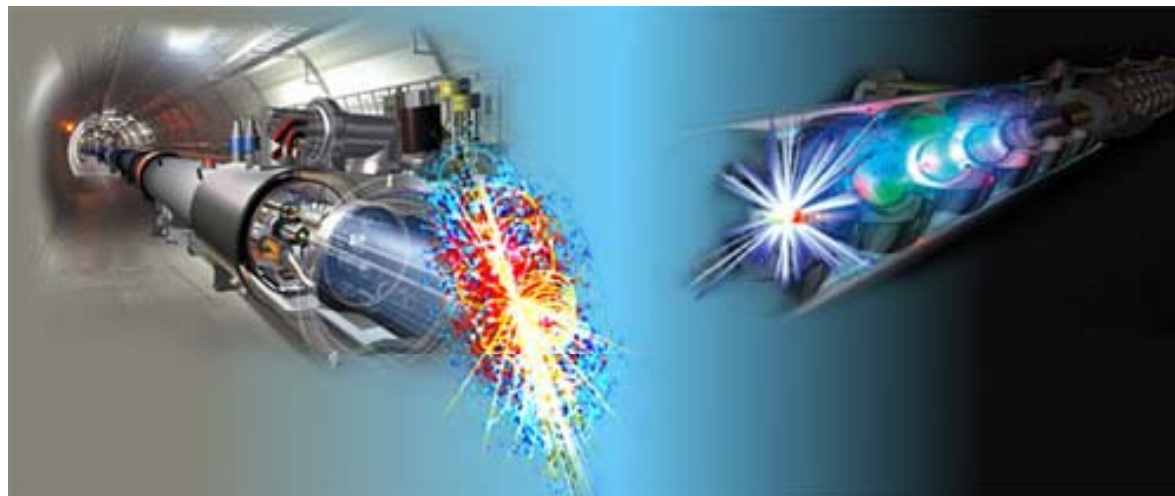


# Beyond the SM signals at the LHC

## The LHC Early Phase for the ILC

FNAL 12-14 April

Albert De Roeck  
CERN  
and University of Antwerp  
and the IPPP Durham



# Reminder: Mass Reach

Ellis, Gianotti, ADR

hep-ex/0112004+ few updates

Units are TeV (except  $W_L W_L$  reach)

☞ Ldt correspond to 1 year of running at nominal luminosity for 1 experiment

PROCESS	LHC 14 TeV 100 fb <sup>-1</sup>	SLHC 14 TeV 1000 fb <sup>-1</sup>	28 TeV 100 fb <sup>-1</sup>	VLHC 40 TeV 100 fb <sup>-1</sup>	VLHC 200 TeV 100 fb <sup>-1</sup>	LC 0.8 TeV 500 fb <sup>-1</sup>	LC 5 TeV 1000 fb <sup>-1</sup>
Squarks	2.5	3	4	5	20	0.4	2.5
$W_L W_L$	2 $\sigma$	4 $\sigma$	4.5 $\sigma$	7 $\sigma$	18 $\sigma$	6 $\sigma$	90 $\sigma$
Z'	5	6	8	11	35	8 <sup>†</sup>	30 <sup>†</sup>
Extra-dim ( $\delta=2$ )	9	12	15	25	65	5-8.5 <sup>†</sup>	30-55 <sup>†</sup>
$q^*$	6.5	7.5	9.5	13	75	0.8	5
$\Delta$ compositeness	30	40	40	50	100	100	400
TGC ( $\lambda_\gamma$ )	0.0014	0.0006	0.0008		0.0003	0.0004	0.00008

† indirect reach  
(from precision measurements)

LHC: High energy: direct mass coverage into the TeV range  
LC: Precision: large indirect mass reach

What for  
1-10 fb<sup>-1</sup>?

# This talk

- **My mission statement**

How much one will know with 1 - 10 fb<sup>-1</sup> of data in different scenarios, i.e. how much will one know about new observed states and how much scope will there be for other new physics to hide in 1 - 10 fb<sup>-1</sup> of LHC data.

The scenario that we would like you to consider is the observation of new states of physics beyond the SM. We would like you to cover **all possible scenarios of BSM physics \*except\* missing energy, leptonic resonances and multi gauge bosons**

- **So what is left?**

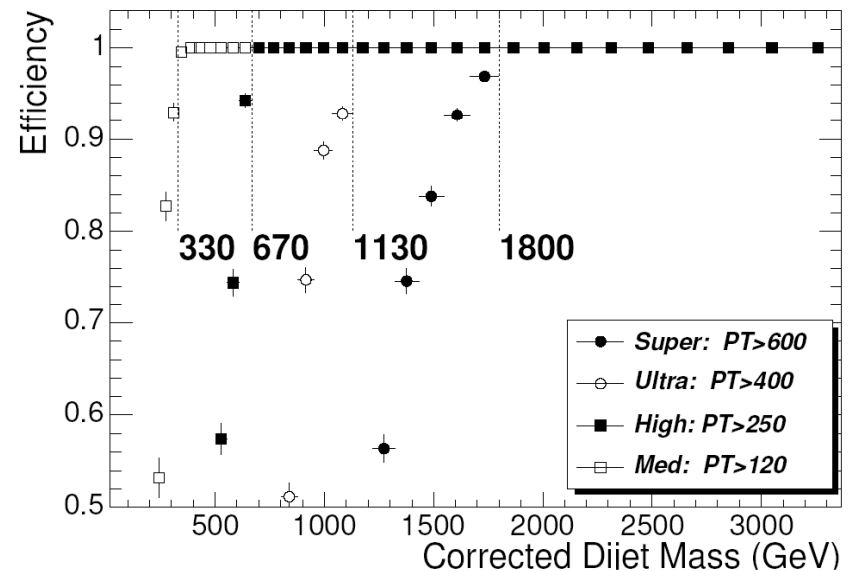
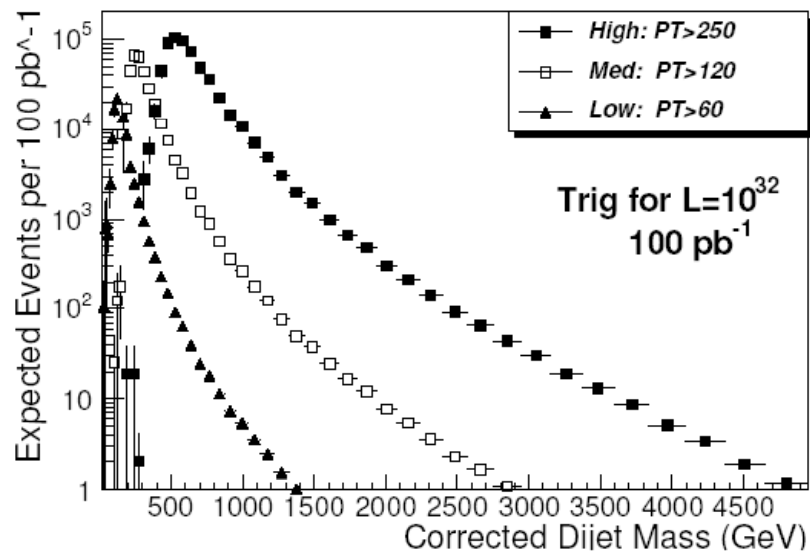
- Jets, Photons, (b/τ), top quarks, combined signatures, special signatures, eg heavy stable charged particles, r-hadrons

- **Hence: in this talk ⇒**

- New physics with (di)jets
- New physics with top quark
- RPV SUSY, Technicolor (jets + leptons, leptons)
- ED with photons and (non-resonant) leptons
- Spherical events/Black holes
- Other exotics (excited quarks & leptons,...)
- Special signatures, weird scenarios

# Initial Dijet studies

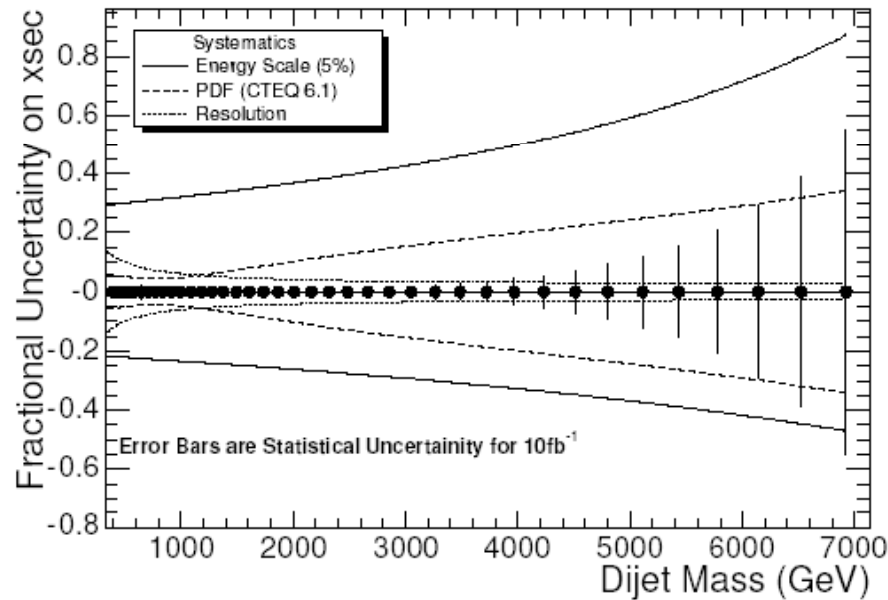
- Jets : Iterative cone algorithm with  $R = 0.5$  in  $(\eta, \phi)$
- Triggers with different thresholds to cover full dijet mass range  
Adjust dynamically during luminosity ramp-up of the LHC



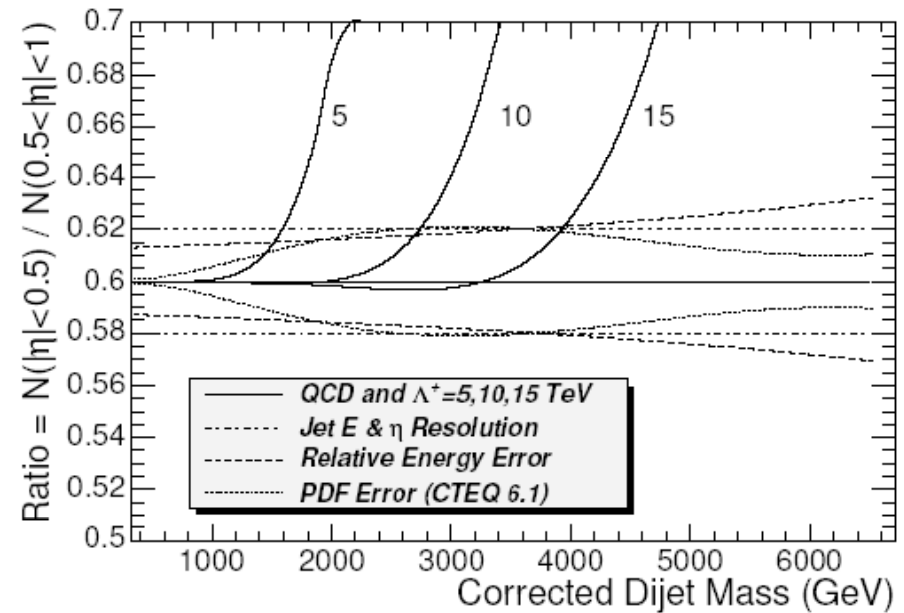
Access to high masses already for low eg 100 pb<sup>-1</sup>

# Dijets: Ratios

**Dijet ratio:**  $N(|\eta| < 0.5) / N(0.5 < |\eta| < 1.0)$



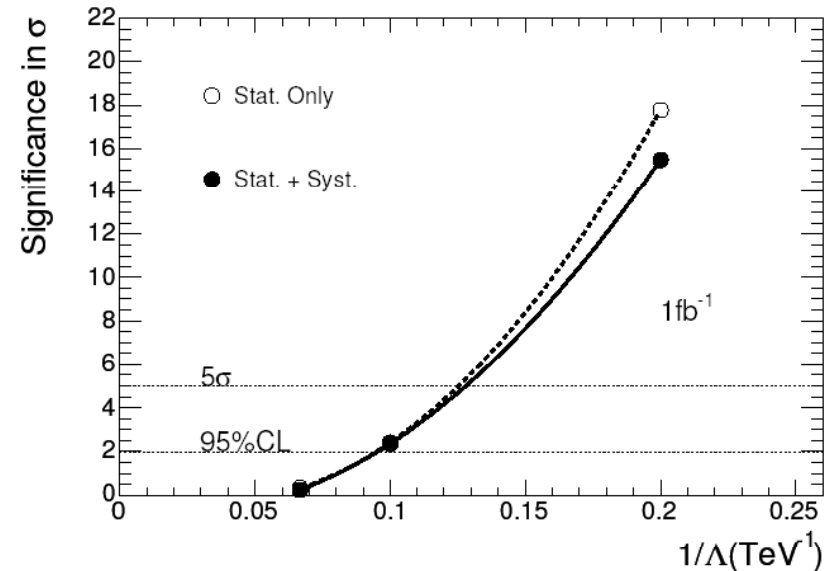
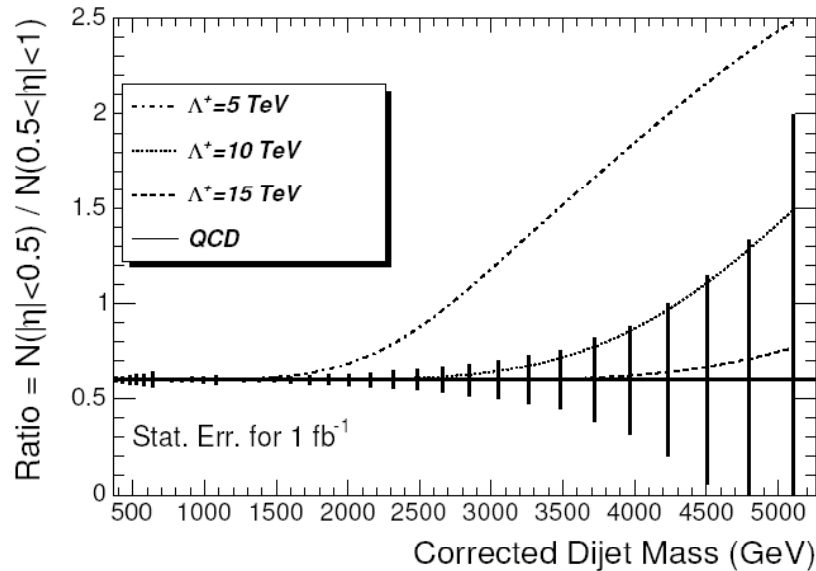
**Systematics**  
Energy scale (5%)  
PDFs (CTEQ6.1 series)  
Energy smearing (resolution)



**Sensitivity to contact interactions for 3 CI scales**

# Dijets: Contact Interactions

**Dijet ratio:**  $N(|\eta| < 0.5) / N(0.5 < |\eta| < 1.0)$



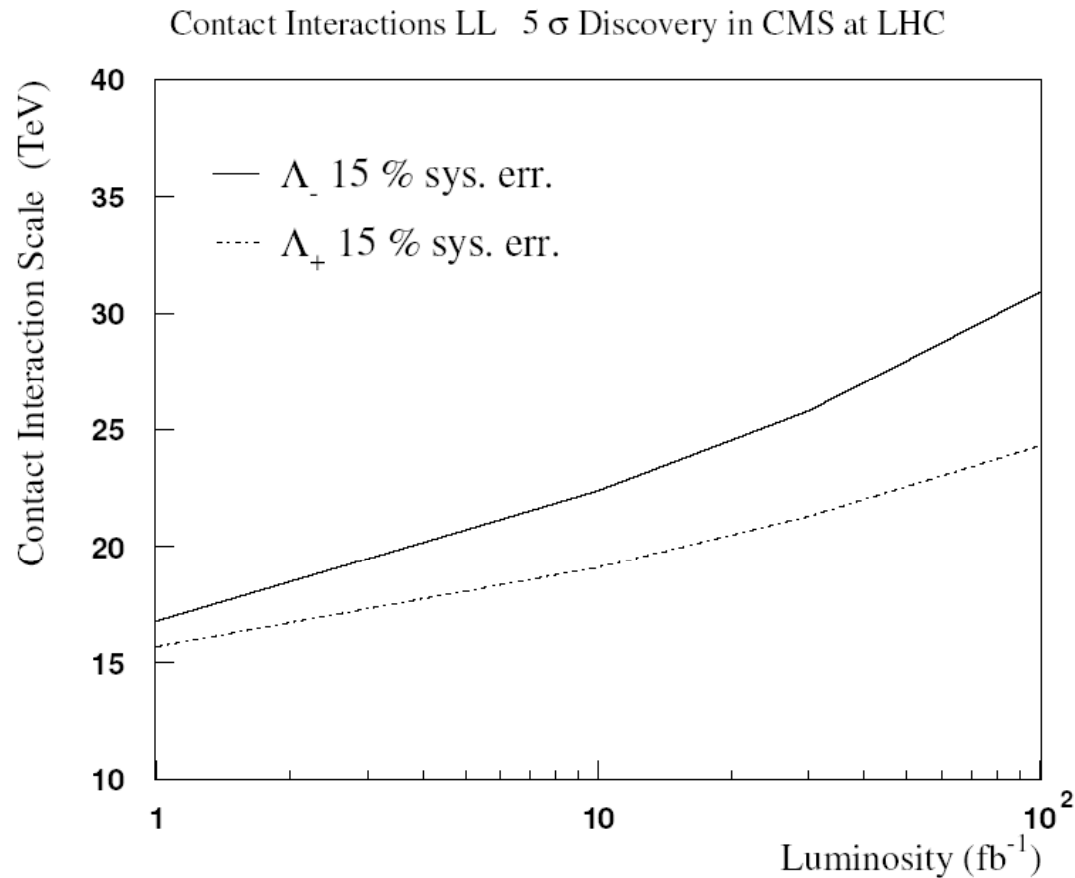
## Reach versus start up luminosities

Luminosity	95% CL Excluded Scale			5 $\sigma$ Discovered Scale		
	100 pb <sup>-1</sup>	1 fb <sup>-1</sup>	10 fb <sup>-1</sup>	100 pb <sup>-1</sup>	1 fb <sup>-1</sup>	10 fb <sup>-1</sup>
$\Lambda^+ (\text{TeV})$	<6.2	<10.4	<14.8	<4.7	<7.8	<12.0

⇒ Reach ~ 12-15 TeV with 10 fb<sup>-1</sup>

# Drell Yan muons

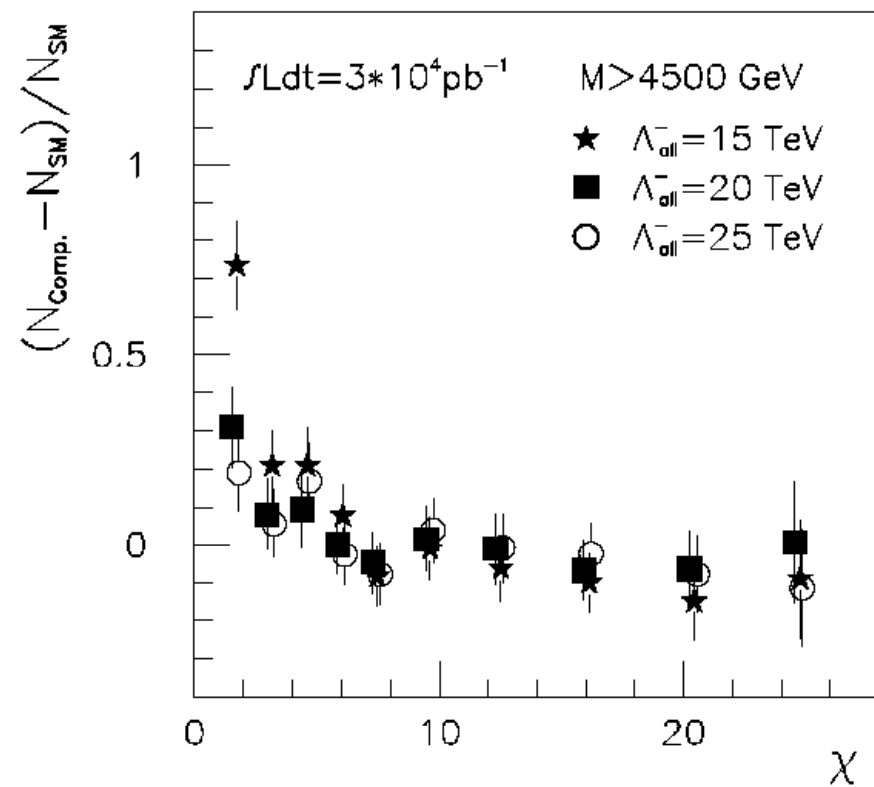
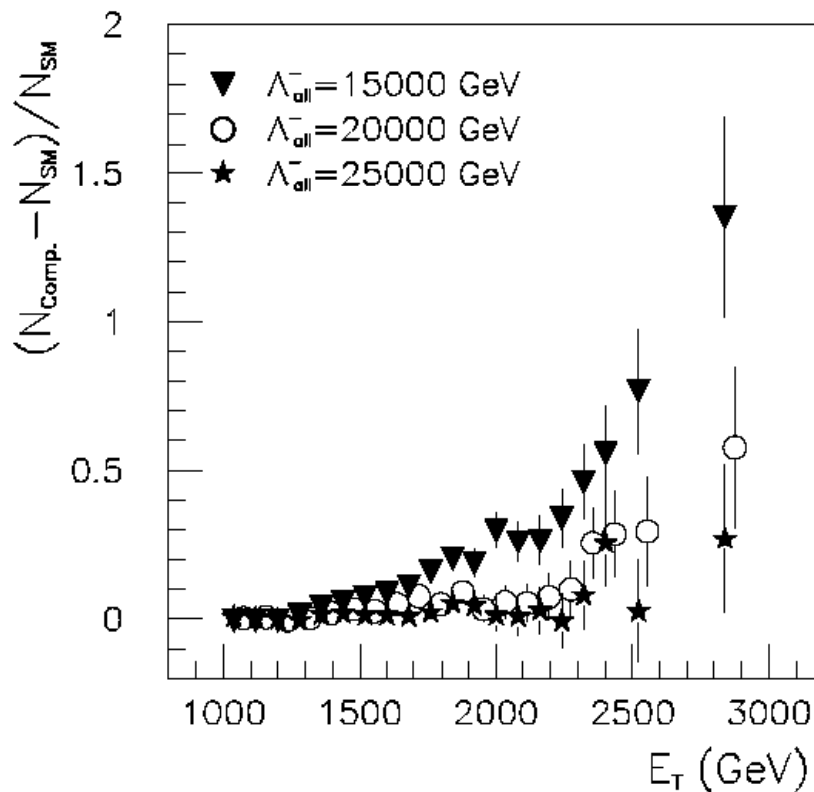
## Contact Interactions in the lepton final state channel



Reach  $\sim 20$  TeV with  $10 \text{ fb}^{-1}$

# Dijets

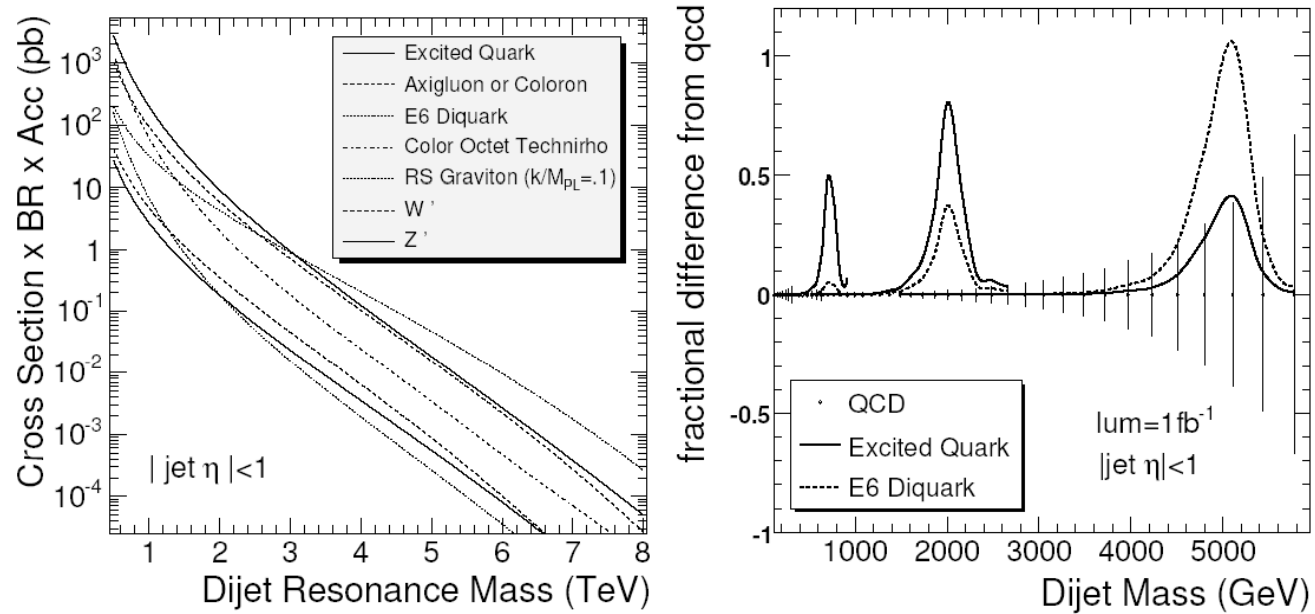
Ultimately, with the highest luminosities:



Scenario	14 TeV 300 fb <sup>-1</sup>	14 TeV 3000 fb <sup>-1</sup>	28 TeV 300 fb <sup>-1</sup>	28 TeV 3000 fb <sup>-1</sup>
$\Lambda$ (TeV)	40	60	60	85



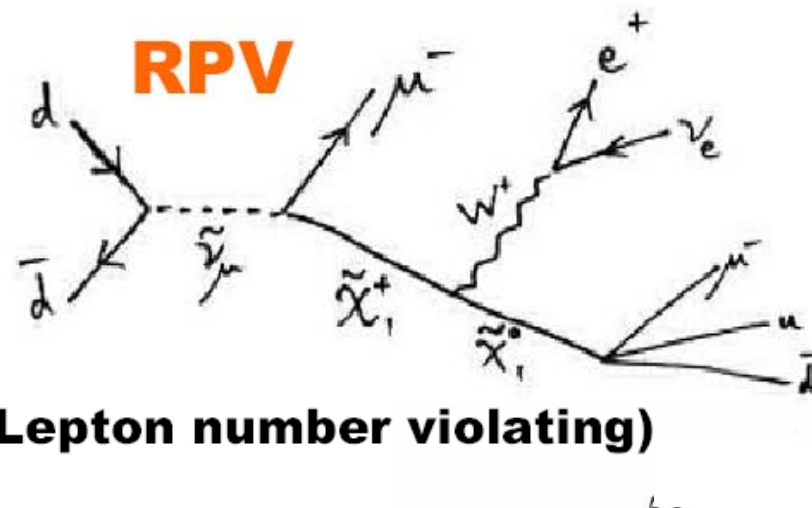
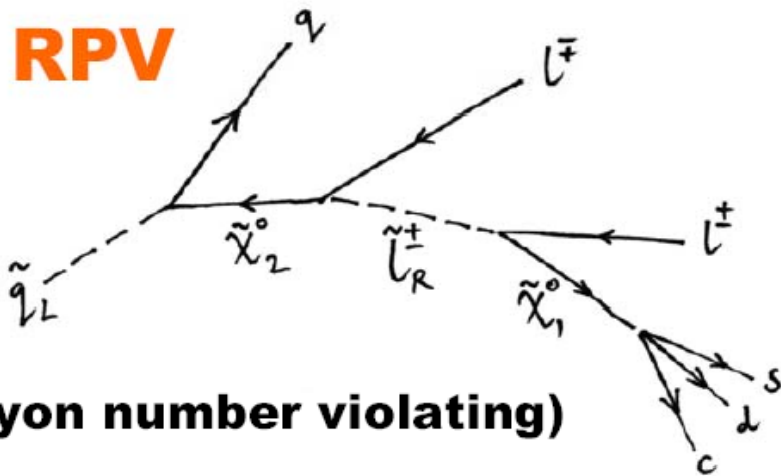
# Dijets: New Physics Reach Summary



Resonance Model	95% CL Excluded Mass ( $\text{TeV}/c^2$ )			$5\sigma$ Discovered Mass ( $\text{TeV}/c^2$ )		
	$100 \text{ pb}^{-1}$	$1 \text{ fb}^{-1}$	$10 \text{ fb}^{-1}$	$100 \text{ pb}^{-1}$	$1 \text{ fb}^{-1}$	$10 \text{ fb}^{-1}$
Excited Quark	0.7 - 3.6	0.7 - 4.6	0.7 - 5.4	0.7 - 2.5	0.7 - 3.4	0.7 - 4.4
Axigluon or Colouron	0.7 - 3.5	0.7 - 4.5	0.7 - 5.3	0.7 - 2.2	0.7 - 3.3	0.7 - 4.3
$E_6$ diquarks	0.7 - 4.0	0.7 - 5.4	0.7 - 6.1	0.8 - 2.0	0.8 - 3.7	0.8 - 5.1
Colour Octet Technirho	0.7 - 2.4	0.7 - 3.3	0.7 - 4.3	0.7 - 1.5	0.7 - 2.2	0.7 - 3.1
Randall-Sundrum Graviton	0.7 - 1.1	0.7 - 1.1 1.3 - 1.6	0.7 - 1.1 1.3 - 1.6 2.1 - 2.3	N/A	N/A	N/A
$W'$	0.8 - 0.9	0.8 - 0.9 1.3 - 2.0	0.8 - 1.0 1.3 - 3.2	N/A	N/A	N/A
$Z'$	N/A	N/A	2.1 - 2.5	N/A	N/A	N/A

# R-Parity violating Susy

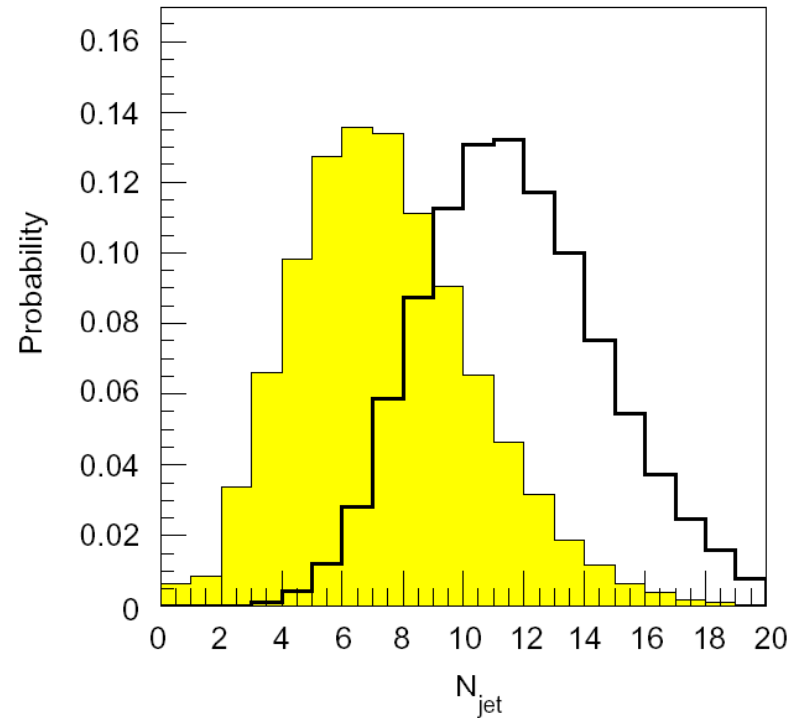
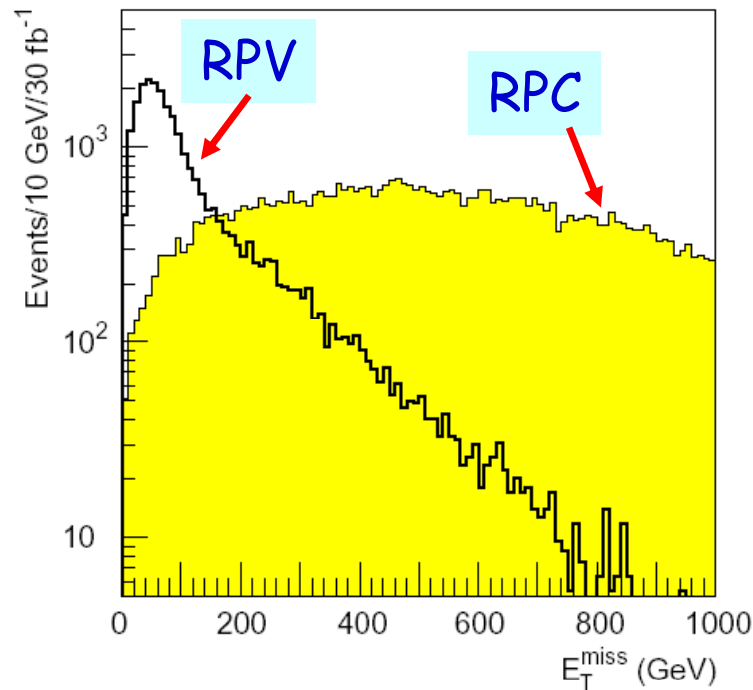
	How stable is the lightest SUSY particle (L.S.P.) ?	Large missing energy?	Event can be reconstructed fully?	Sparticle production
<b>RPC</b>	Stable	Yes	Usually not	Only in pairs
<b>RPV</b>	Unstable (decays to leptons or jets)	No	Yes	Either singly, or in pairs



Multijets + lepton events + relatively small missing  $E_T$

# R-parity violation

$M_0=100 \text{ GeV}$   $m_{1/2}=300 \text{ GeV}$   $A=300 \text{ GeV}$   $\tan\beta=2.1$   $\mu>0$

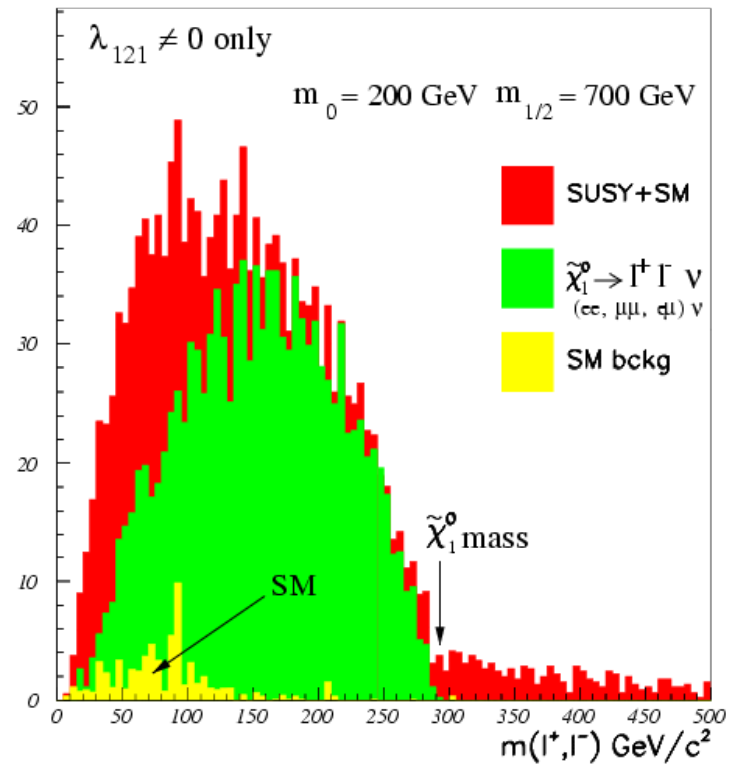
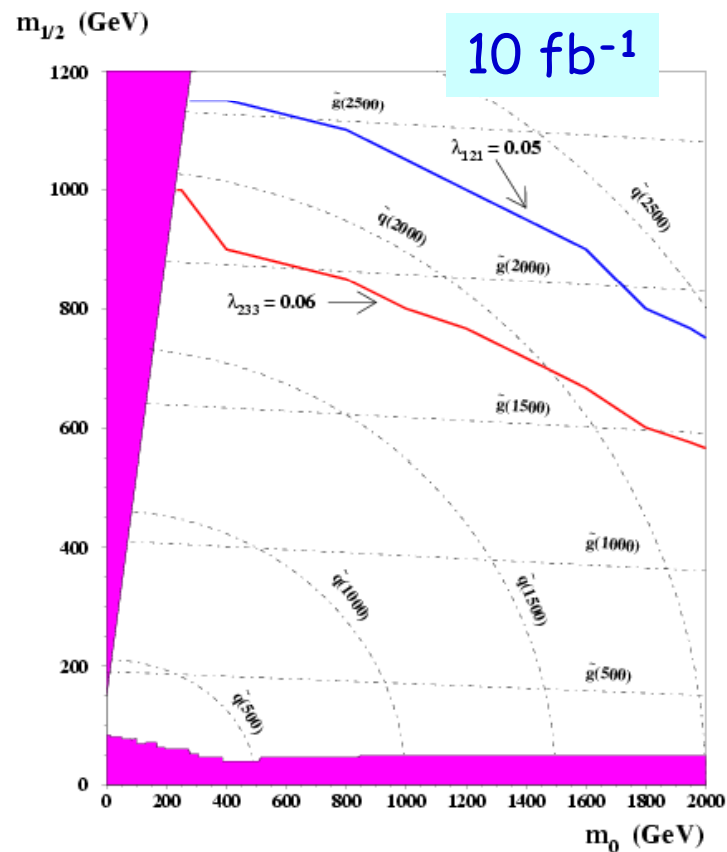


Less missing  $E_T$  More Jets and/or Leptons than RPC SUSY

# R-Parity Violating SuSY

Example! No real recent experimental studies

Selection of 3 isolated leptons + 2 jets

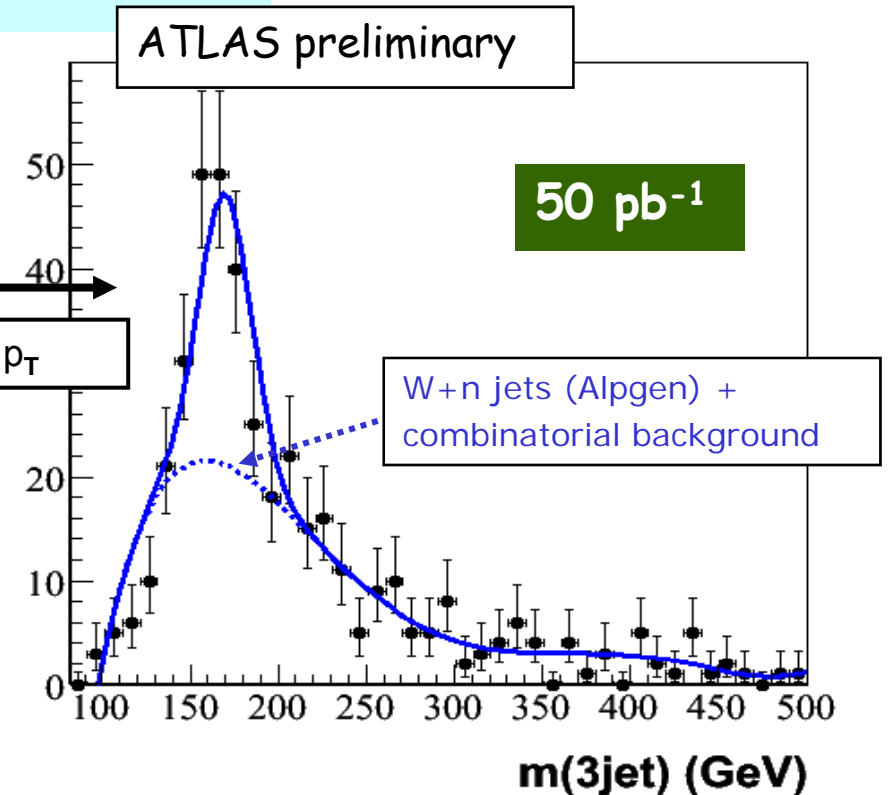
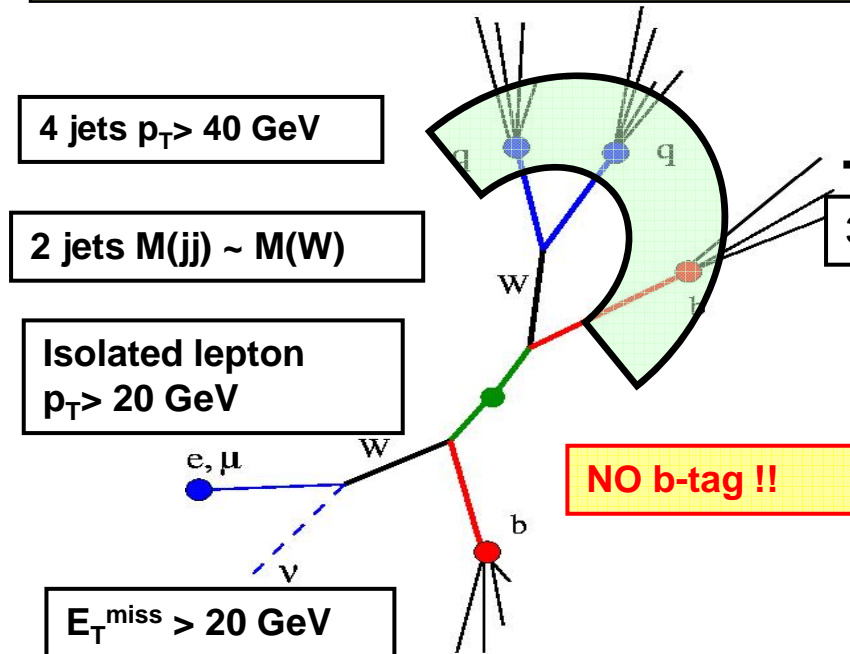


⇒ Discovery of squark/sleptons up to ~ 2 TeV with 10 fb<sup>-1</sup>

# Early Top-quark events

Can we observe an early top signal with limited detector performance?  
And use it to understand detector and physics?

$$\sigma_{t\bar{t}} \approx 250 \text{ pb for } t\bar{t} \rightarrow bW \ b\bar{W} \rightarrow b\ell\nu \ bjj$$

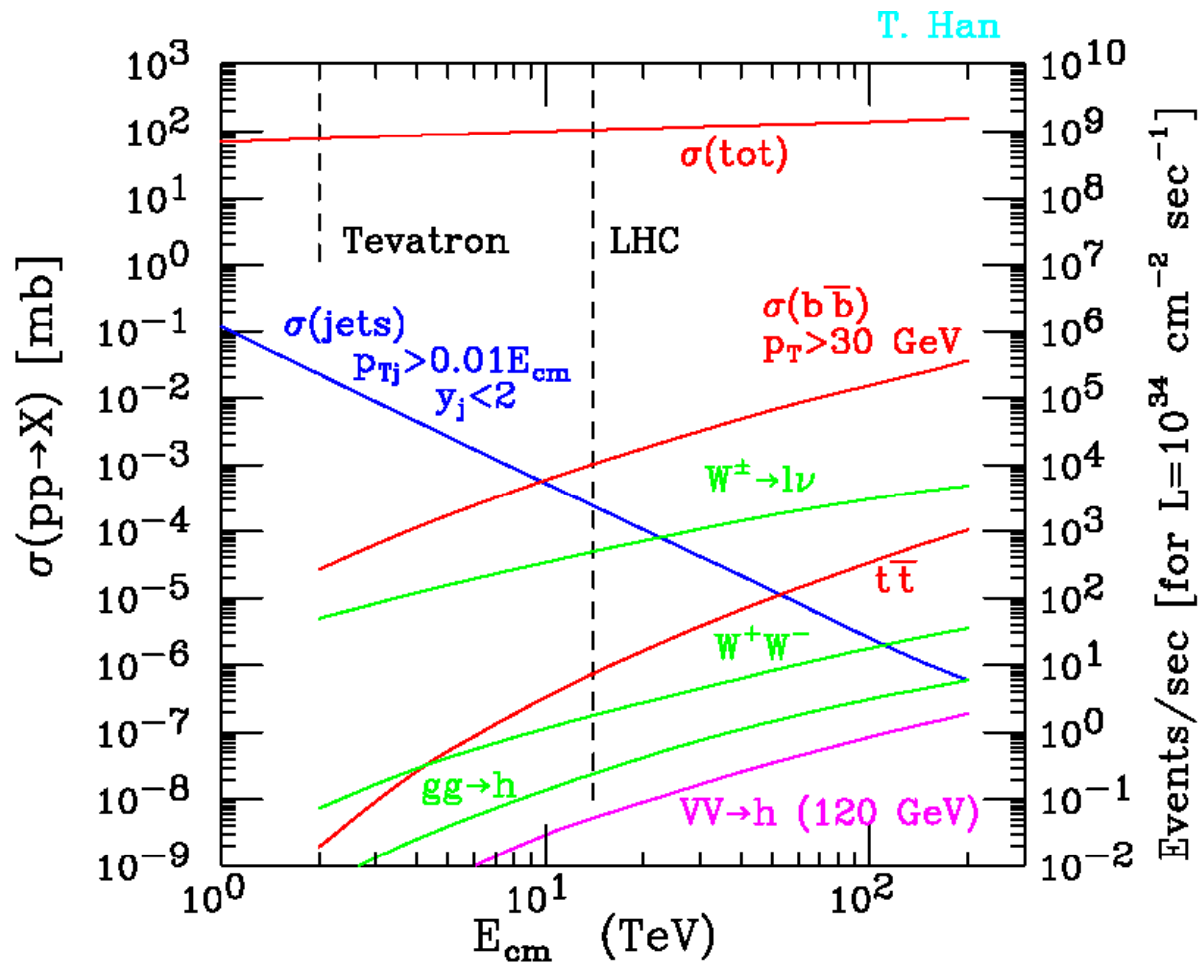


Top signal observable in early days with no b-tagging and simple analysis  
( $100 \pm 20$  evts for  $50 \text{ pb}^{-1}$ )  $\rightarrow$  measure  $\sigma_{t\bar{t}}$  to 20%,  $m$  to 10 GeV with  $\sim 100 \text{ pb}^{-1}$ ?

- commission b-tagging, set jet E-scale using  $W \rightarrow jj$  peak
- understand detector performance for  $e, \mu$ , jets, b-jets, missing  $E_T$ , ...
- understand / constrain theory and MC generators using e.g.  $p_T$  spectra

# Top Quarks at the LHC

The LHC is a top factory: 1 Hz at startup luminosity  
 Cross section rises factor 10 faster than W/Z



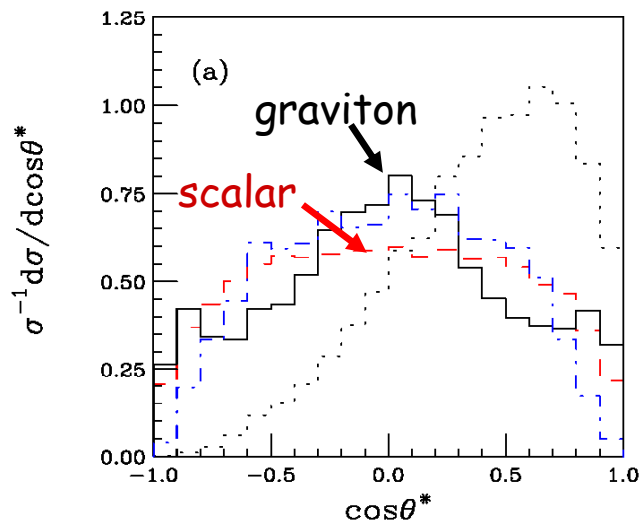
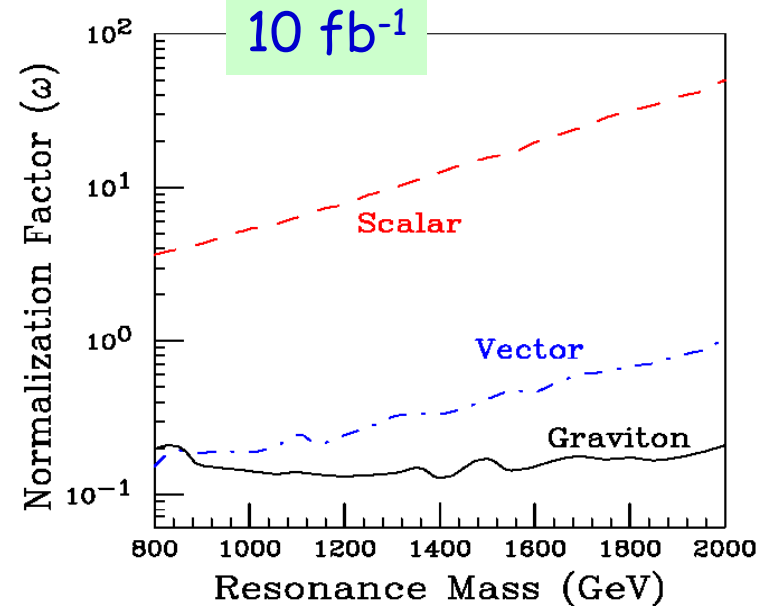
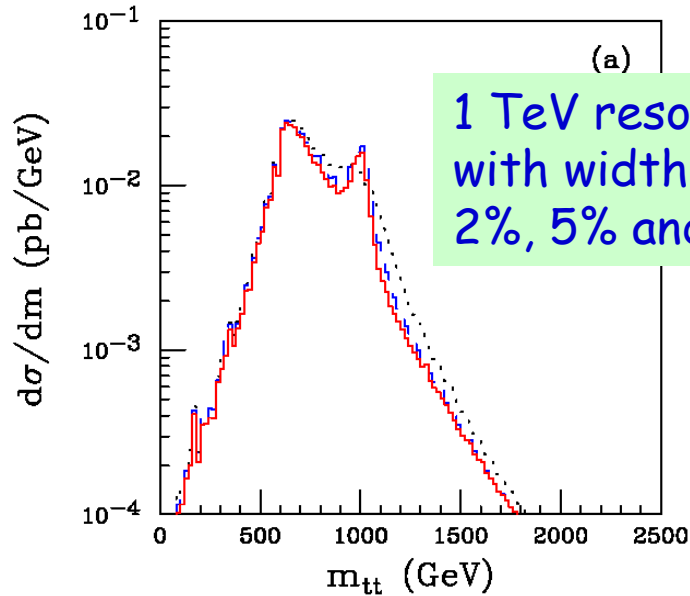
# Top: a window to new physics

- Largest Yukawa coupling (proportional to  $m_t, \cot \beta$ ):  
 $H, A \rightarrow t\bar{t}$ .
- Strong Dynamics (TC, Topcolor/Top See-Saw, Little Higgs):  
 $\rho_{TC}, \eta_{TC}, \pi_{TC}, Z_L \rightarrow t\bar{t}$ .
- Extra-dimensions (warped and universal):  
 $g_{KK}, G_{KK} \rightarrow t\bar{t}$ .
- Supersymmetry ( $\tilde{t}$  often the lightest squark):  
 $\tilde{t}_R \rightarrow t\tilde{\chi}^0$ .
- LH with T-parity (theories with naturalness argument):  
 $T \rightarrow tA^0$ .
- ... ..
- Representative features:

Model Class	Spin-0	Spin-1	Spin-2
Technicolor/Topcolor/RS	× (nrw/brd)	× (nrw/brd)	× (narrow)
MSSM	× (narrow)		
Little Higgs	× (narrow)	× (narrow)	

T. Han  
Princeton

# t-tbar Resonances



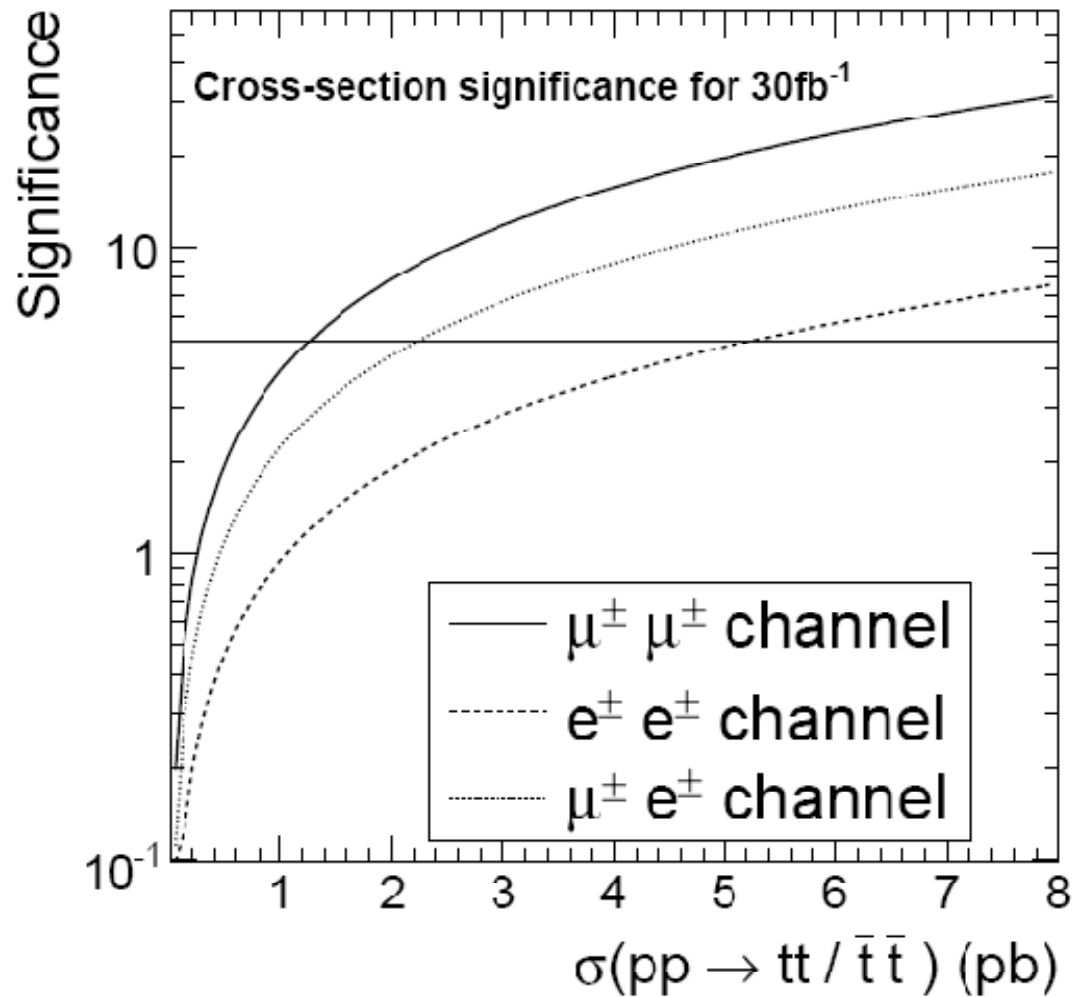
- Largest Yukawa coupling (proportional to  $m_t, \cot \beta$ ):  
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 $\rho_{TC}, \eta_{TC}, \pi_{TC}, Z_L \rightarrow t\bar{t}$ .
- Extra-dimensions (warped and universal):  
 $g_{KK}, G_{KK} \rightarrow t\bar{t}$ .

Spin analysis from polar angular distributions of the top quark in the resonance c.m. frame

Barger, Han, Walker  
Hep-ph/0612016



# Same sign top search



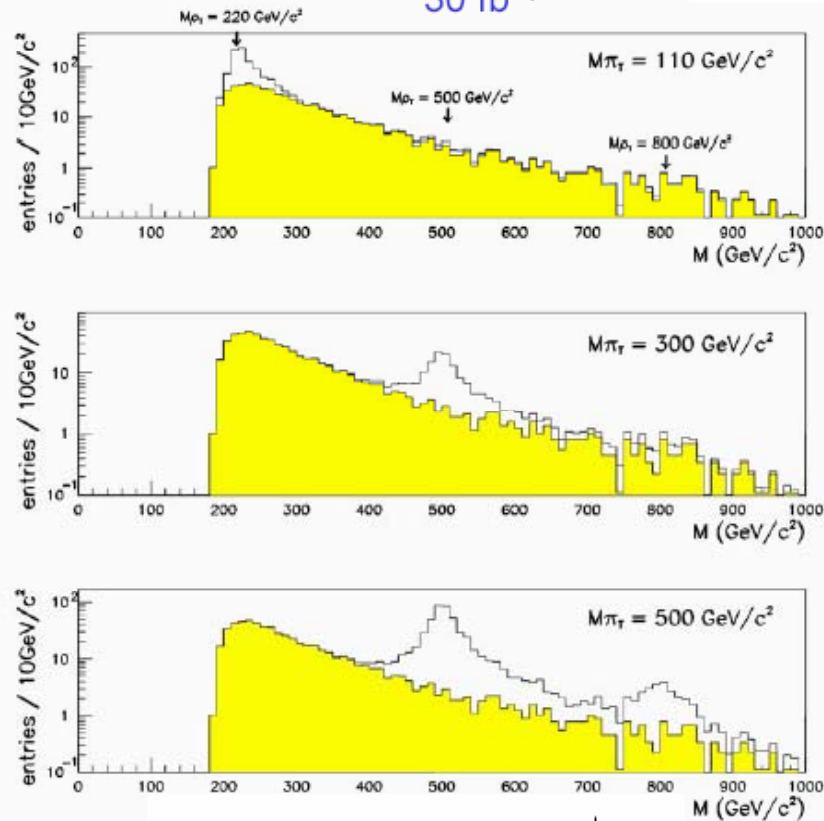
Significance of a same sign top excess over SM background as function of the cross section

# Technicolor

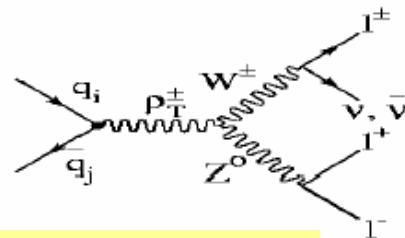
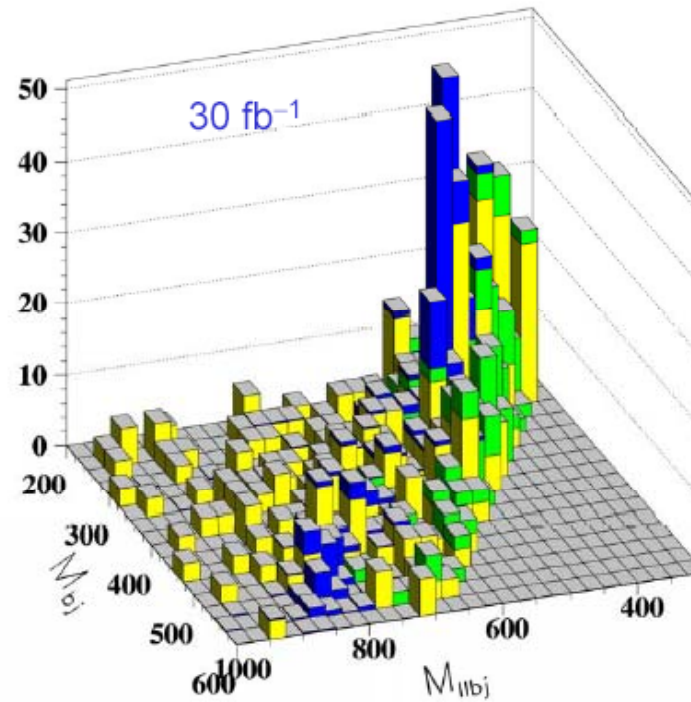
## Technicolor: leptons or leptons + jets

ATL-PHYS-99-020

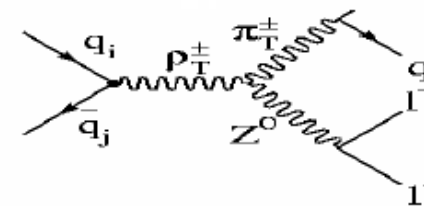
30 fb<sup>-1</sup>



results depend on parameters



3-lepton channel

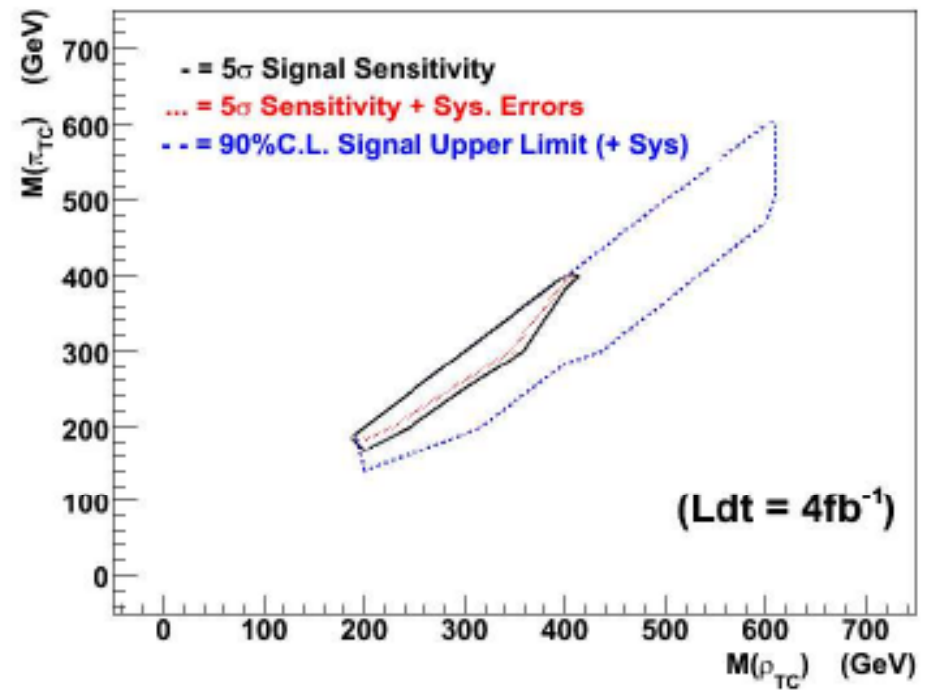
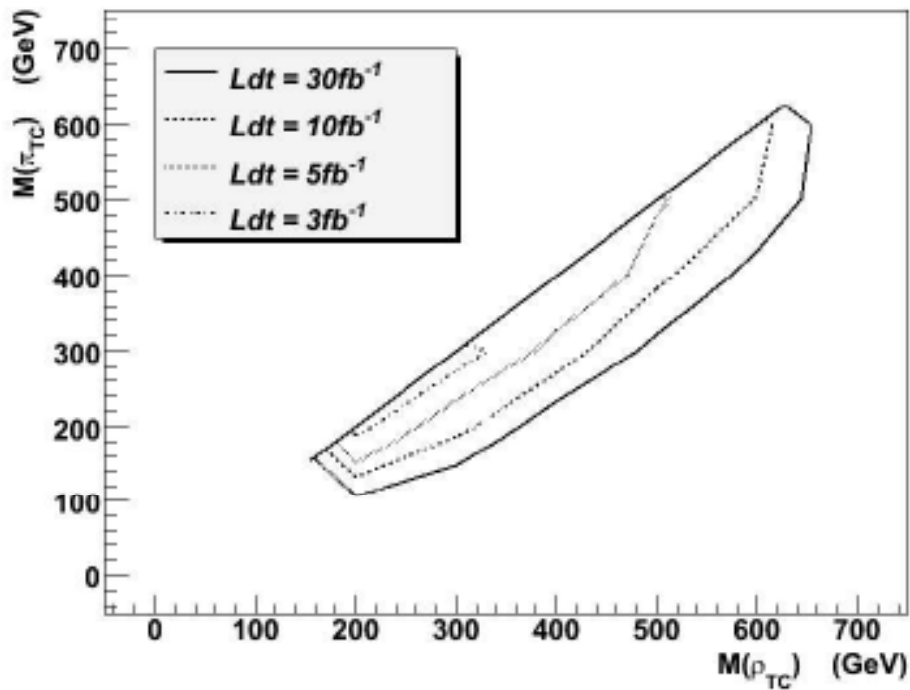


2 leptons+2jets channel

# Technicolor

5 $\sigma$  sensitivity curves for  $\rho_{TC} \rightarrow W+Z \rightarrow$  leptons channel

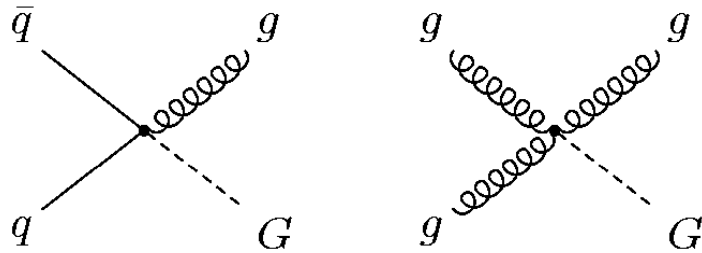
Technicolor Straw Man model



Sensitivity starting from a few  $fb^{-1}$  of data

# Photon Signals: Eg. Extra Dimensions

ADD: Arkani -Ahmed, Dimopolous,Dvali

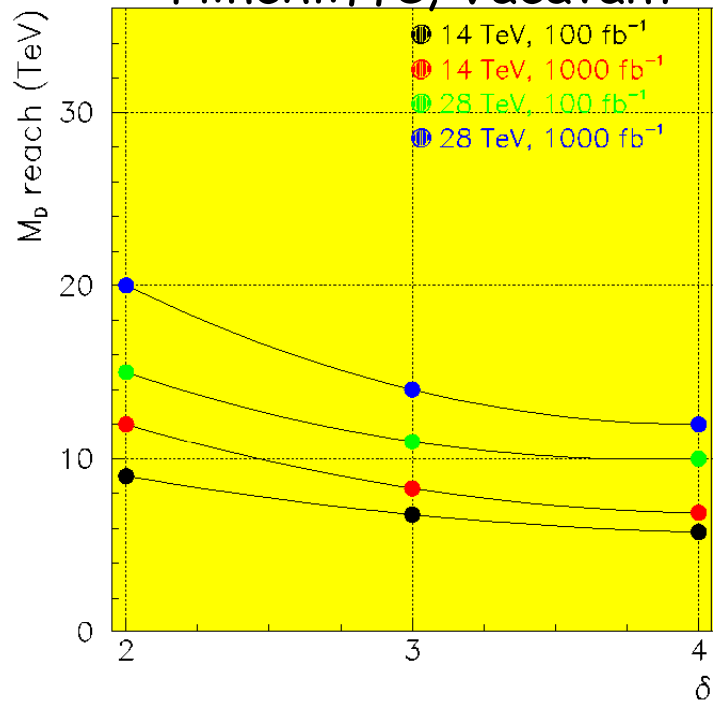


Graviton production!  
Graviton escapes detection

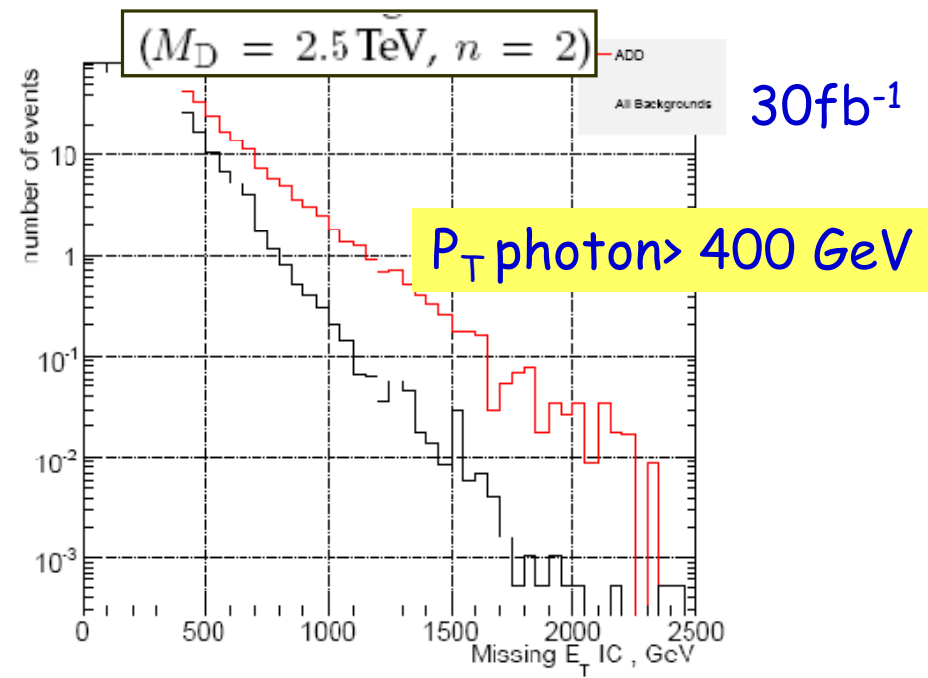
Signal: single jet + large missing ET

Signal: single photon + large missing ET

Hinchliffe, Vacavant



Test  $M_D$  to 7-9 TeV for 100 fb<sup>-1</sup>



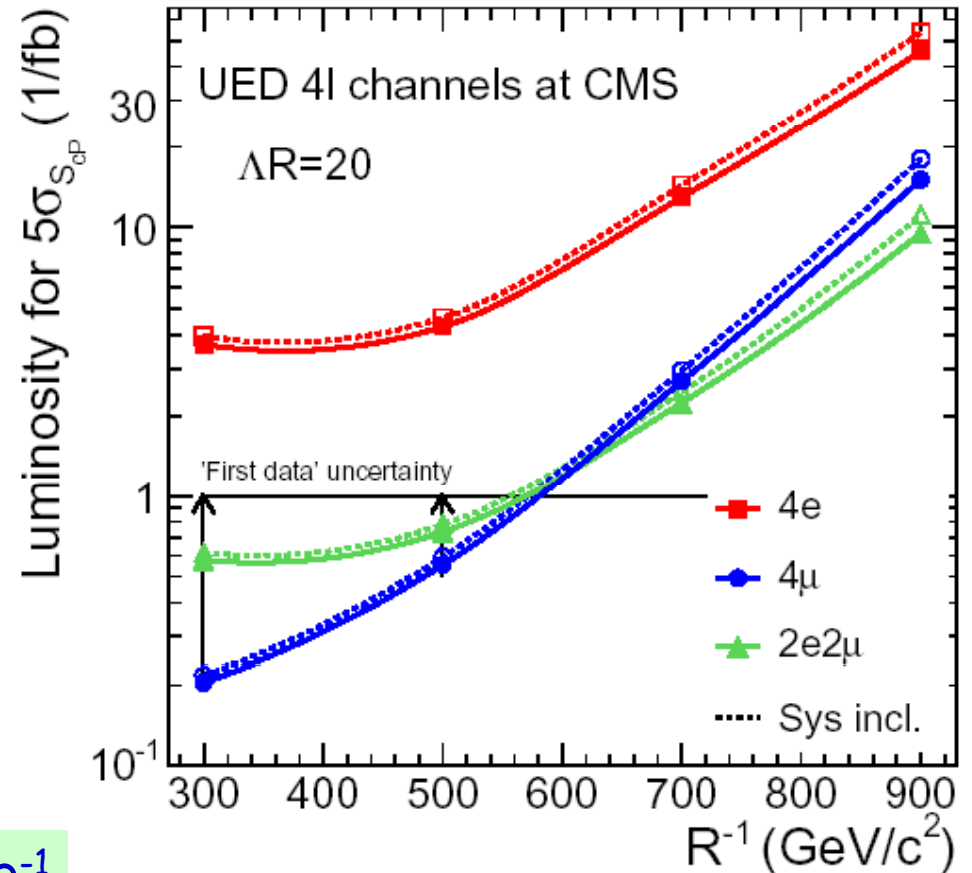
Test  $M_D$  to  $\sim 4$  TeV for 100 fb<sup>-1</sup>  
 $\sim 2.5$  TeV for 10 fb<sup>-1</sup>

# Universal Extra Dimensions

## 4 lepton channel

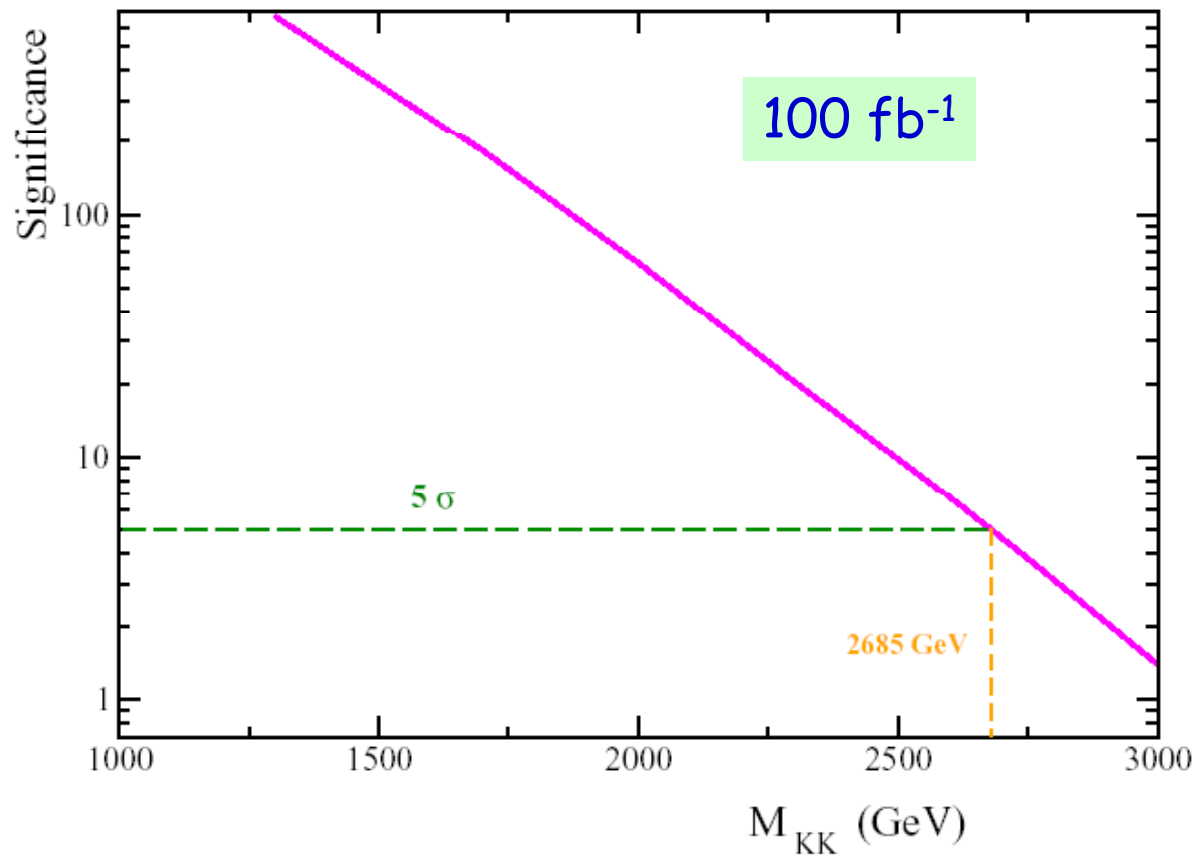
$R^{-1}$	$\sigma_{\text{Signal}}$ (fb)	$\sigma_{\text{B}}$ (fb)	$N_{\text{Signal}}$ @30/fb	$N_{\text{Background}}$ @30/fb	S/B @30/fb	$S_{12}$ @30/fb	$\mathcal{L}$ (1/fb) $S_{\text{CP}}=5\sigma$
4 electrons channel							
300	1.33E+0		40		36	11	3.7 – 4.0
500	1.19E+0		35.7		32	10 – 9.8	4.3 – 4.6
700	5.13E-1	6.75E-3	15.9	$1.10 \pm 0.22^{\text{TH}} \pm 0.06^{\text{EXP}}$	14	$6.2 - 5.9 (7.7 - 7.3)^*$	13 – 14
900	2.23E-1		6.7		6.1	$3.5 - 3.3 (4.0 - 3.7)^*$	46 – 54
4 muons channel							
300	1.72E+1		517		126	42 – 41	< 1
500	7.79E+0		234		57	27 – 26	< 1
700	2.38E+0	1.35E-1	71.4	$4.06 \pm 0.81^{\text{TH}} \pm 0.25^{\text{EXP}}$	17	13	2.7 – 3.0
900	7.28E-1		21.8		5.3	$6.1 - 5.7 (7.1 - 6.5)^*$	15 – 18
2 electrons 2 muons channel							
300	7.86E+0		236		49	27 – 26	< 1
500	6.53E+0		196		41	24 – 23	< 1
700	2.84E+0	1.60E-1	85.1	$4.80 \pm 0.96^{\text{TH}} \pm 0.28^{\text{EXP}}$	18	15 – 14	2.2 – 2.5
900	1.04E+0		31.2		6.5	7.6 – 7.2	9.5 – 11

Reach  $\sim 900$  GeV for  $R^{-1}$  with  $10 \text{ fb}^{-1}$



# Universal Extra Dimensions

Dijet + Missing  $E_T$  final state



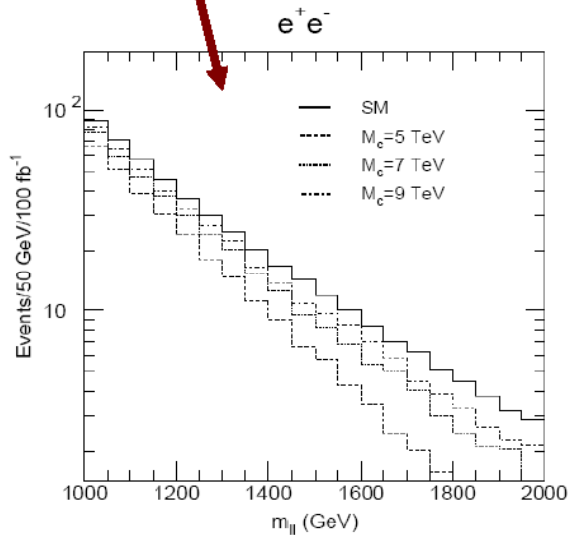
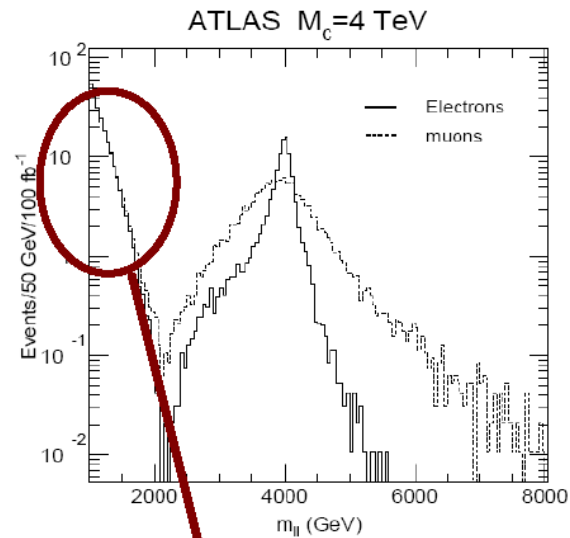
Sensitive to KK states with  $M \sim 2 \text{ TeV}$  with  $10 \text{ fb}^{-1}$

# Indirect Search for Heavy Resonances

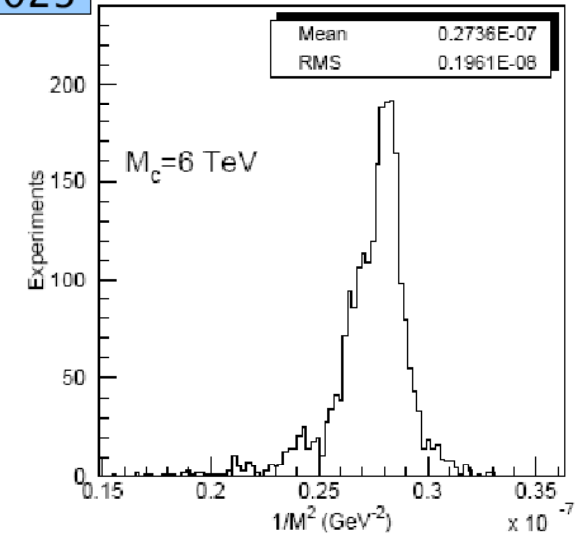
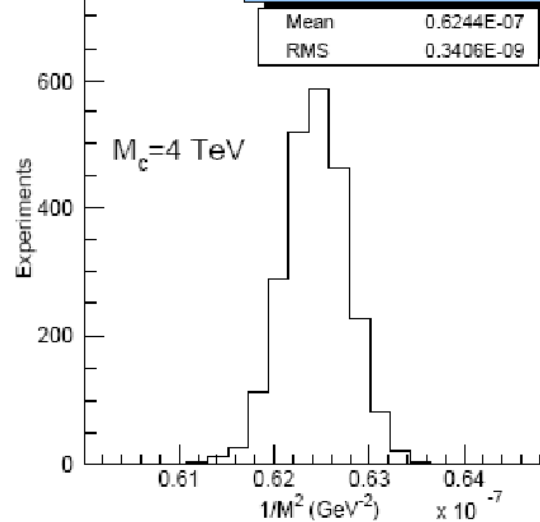
## TeV<sup>-1</sup> Extra Dimensions

Kaluza Klein excitations of a gauge boson  
Interference with the DY SM process modifies  
the high mass di-lepton spectrum

Direct:	600 fb <sup>-1</sup>	6 TeV
Interference :	600 fb <sup>-1</sup>	16 TeV



SN-ATLAS-2003-023



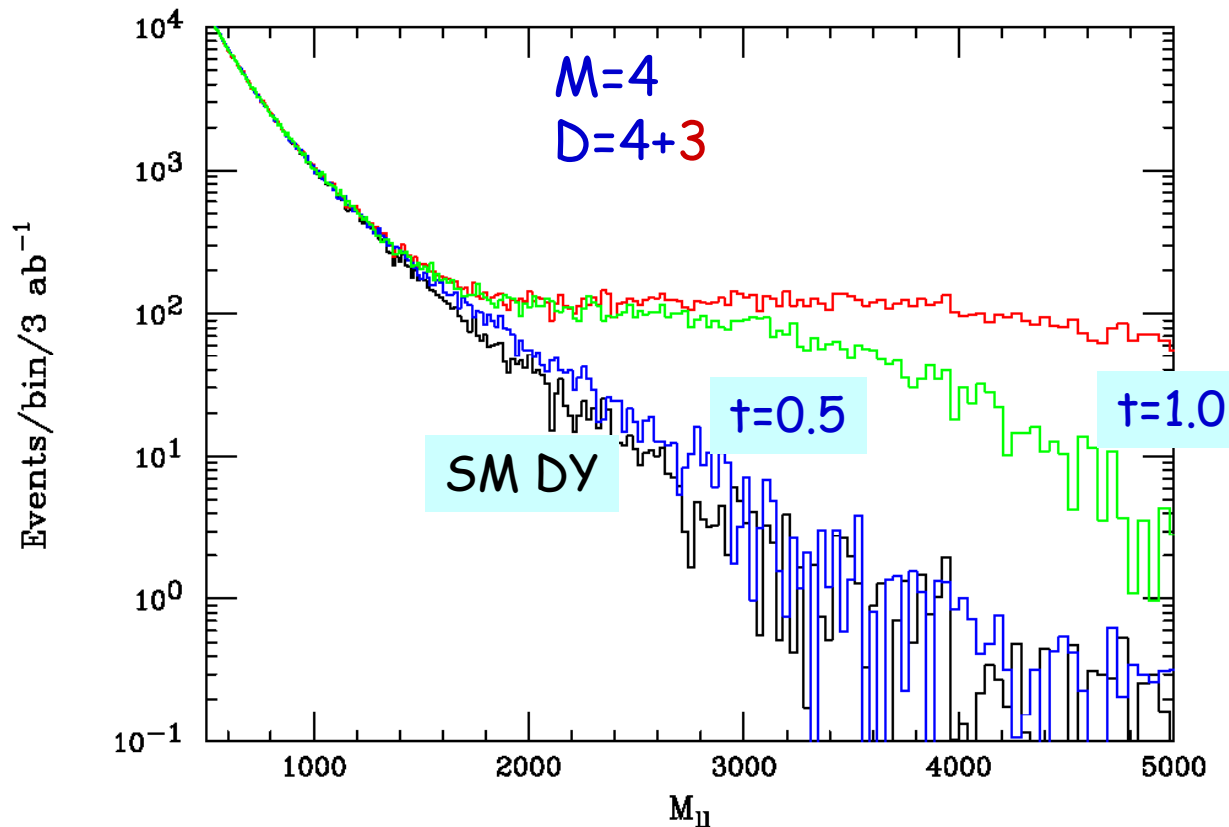
# ADD with running gravitational couplings

New!

Signatures for a running gravitational coupling in ADD scenario of extra dimensions: virtual graviton exchange

Put a form factor in the graviton KK coupling

$$M^{D-2} \rightarrow M^{D-2} [1 + q^2/t^2 M^2]^{-1}$$

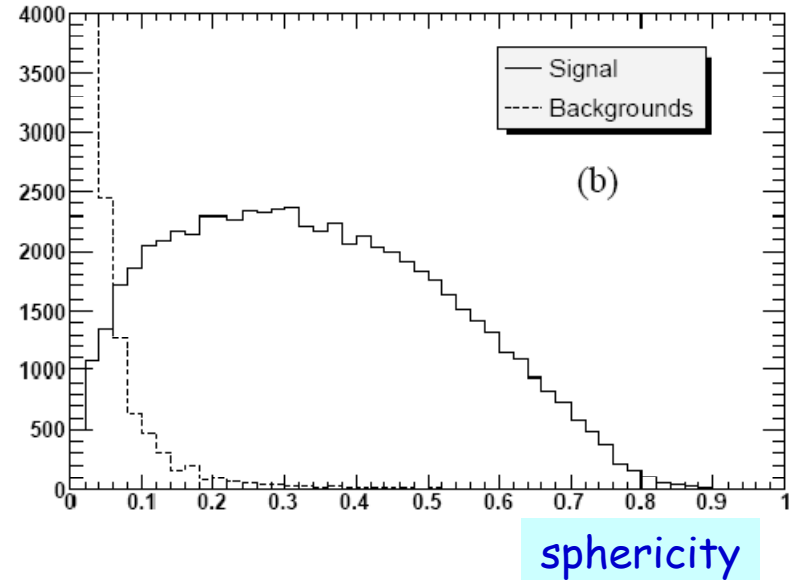
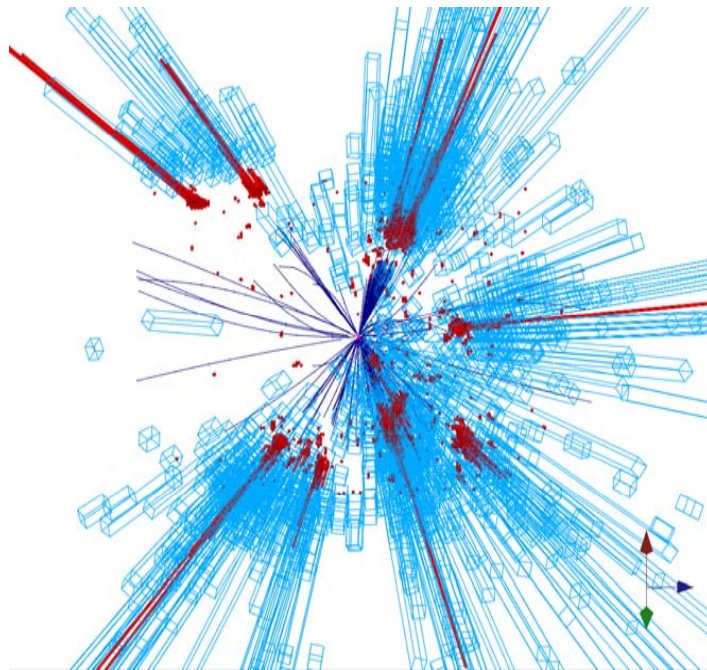
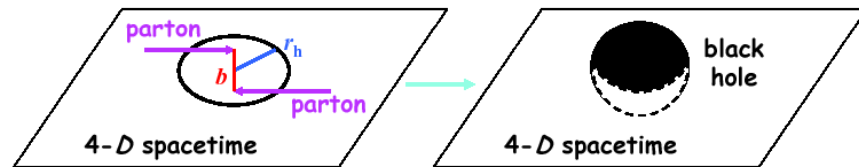


Hewett, Rizzo  
to appear



# Black Holes Production

If the Planck scale is in  $\sim$ TeV region: can expect Black Hole production



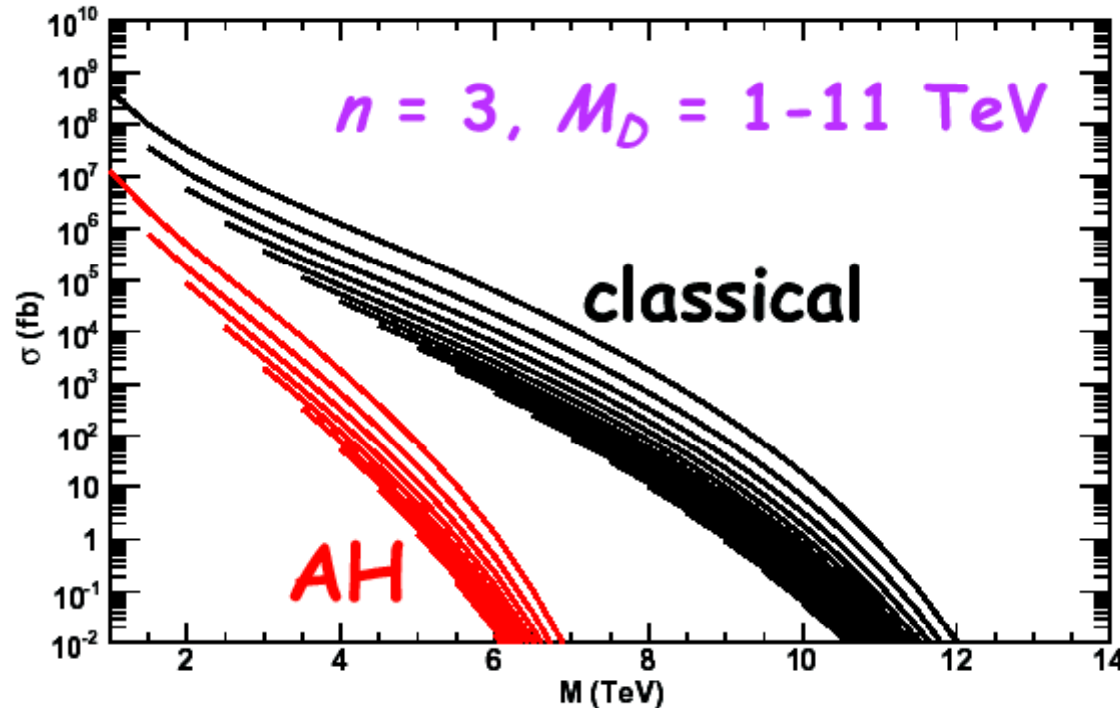
$\sim$  Spherical events: Many high energy jets leptons, photons etc.

Quantum Gravity in the lab?

Simulation of a black hole event with  $M_{\text{BH}} \sim 8$  TeV in CMS

# Black Holes

Warning: cross section could be much less than optimistic estimates



$$\sigma_{BH} \sim \pi r_h^2$$

For  $10 \text{ fb}^{-1}$

- Classical approximation to cross-section: large! Black Holes up to 8-10 TeV
- Apparent horizon (AH), not all energy trapped; see eg. [hep-ph/0609055](http://hep-ph/0609055)  
Black holes up to 4-5 TeV

# Heavy Leptons

C. Alexa

ATL-PHYS-2003-014

backgrounds:

$t\bar{t}$ , WW, WZ, ZZ

also:

6-lepton channel

Experimental considerations:

- high energy leptons, jets

Systematics:

- large NLO corrections

conclusion:

ATLAS can discover sequential charged heavy leptons up to

$M_L = 0.9 / 1.0$  TeV  
(low/high luminosity)

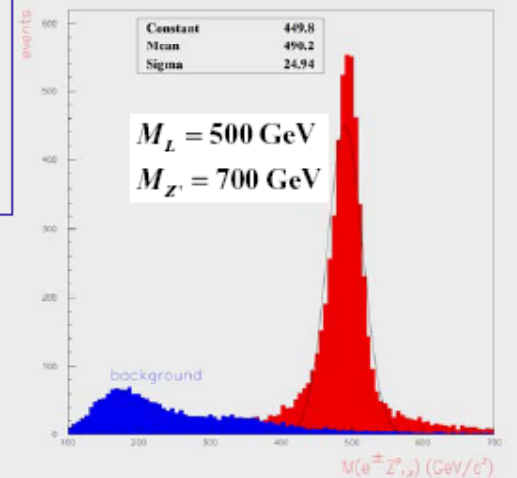
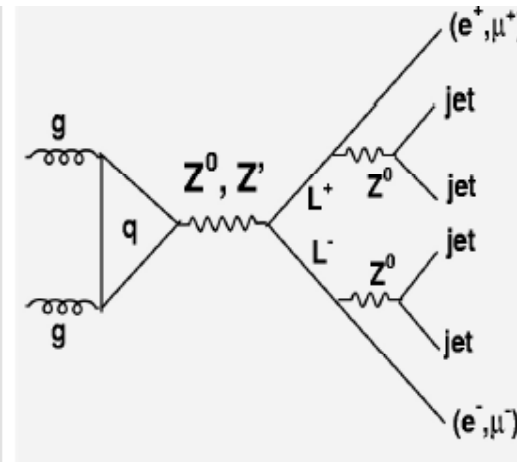
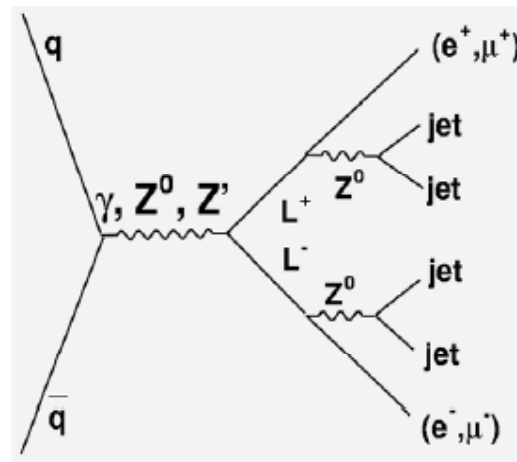
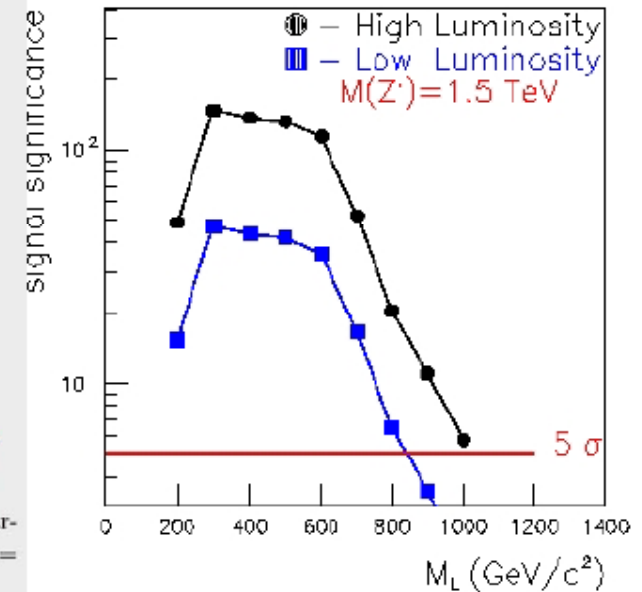
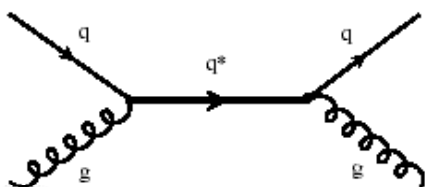


Figure 13: Signal to background comparison for  $M_L = 0.5$  TeV/ $c^2$  and  $M_{Z'} = 0.7$  TeV/ $c^2$ , for  $L \rightarrow e + Z^0$  channel.



G. Azuelos

# Excited Quarks

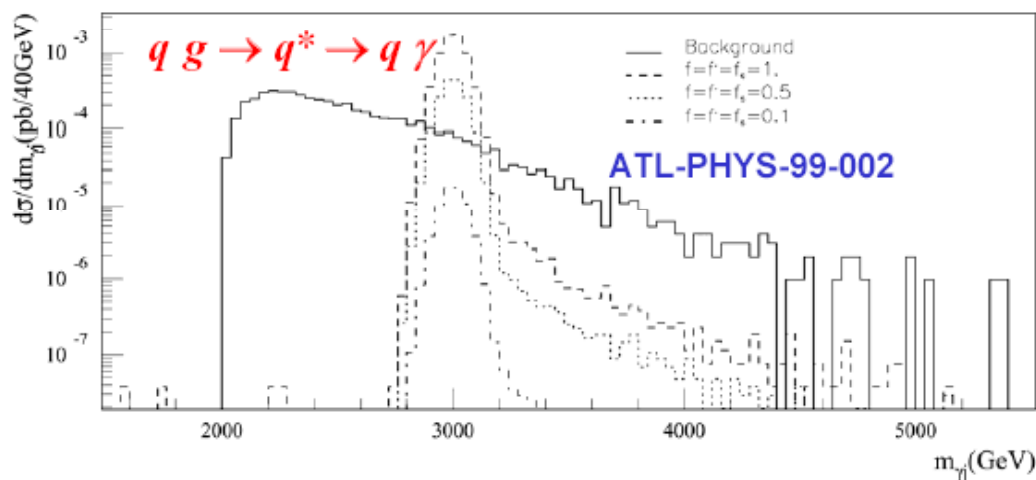
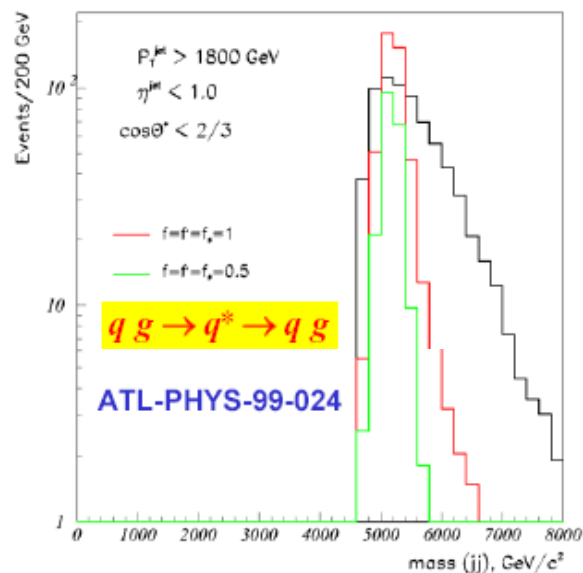


$$L = \frac{1}{2\Lambda} \bar{q}_R^* \sigma^{\mu\nu} \left( g_s f_s G_{\mu\nu}^a + g f \frac{\tau}{2} W_{\mu\nu} + g' f' \frac{Y}{2} B_{\mu\nu} \right) q_L + h.c.$$

take as reference :  $\Lambda = m^*$ ,  $f_s = f = f' = 1$

O. Çakir, C. Leroy, R. Mehdiev,  
ATL-PHYS-2002-014

$m^*(\text{GeV})$	$\Delta m_{jj}(\text{GeV})$	$S$	$B$	$S/B$	$S/\sqrt{B}$
1000	170	12396806	16870000	0.73	3018
2000	320	858214	525000	1.63	1184
3000	445	37635	23500	1.60	245
5000	705	601	325	1.85	33
6000	880	75	60	1.25	9.6



Also:  $q^* \rightarrow qZ$ ;  $q^* \rightarrow \bar{q}'W$

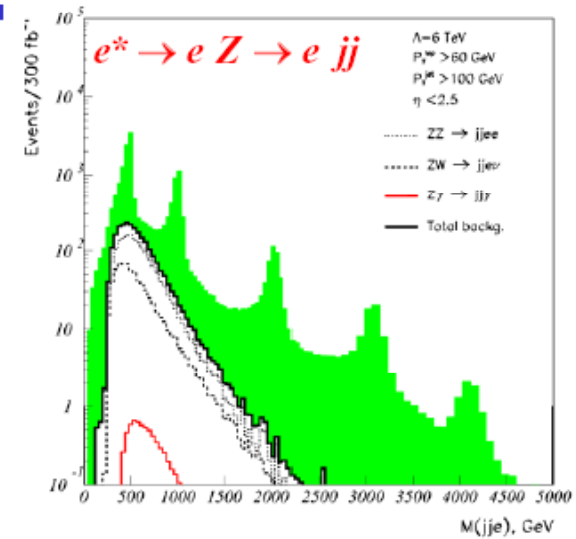
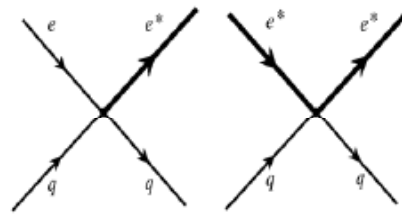
Reach  $\sim 3\text{-}5$  TeV quarks with  $10 \text{ fb}^{-1}$

G. Azuelos

# Excited leptons

G. Azuelos

contact interaction :  $L_C = \frac{g_*^2}{2\Lambda^2} J_\mu J^\mu$

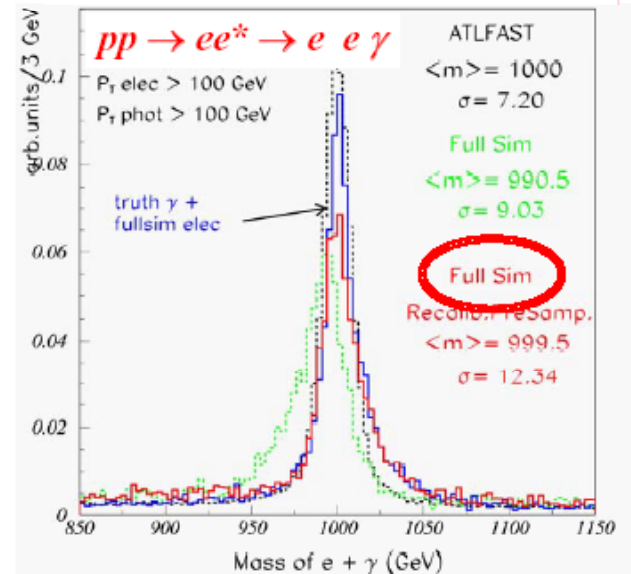


**Experimental considerations:**

- high energy e,  $\gamma$
- $Z \rightarrow jj, W \rightarrow jj$

$L = 300 \text{ fb}^{-1}, \Lambda = 6 \text{ TeV}$

$m^* \rightarrow$	500	1 TeV	2 TeV	3 TeV	4 TeV
$q\bar{q} \rightarrow e^*e \rightarrow Zee \rightarrow eeee$					
$\Delta M, \text{ GeV}$	20	38	63	84	
$S$	242	121	17	2	
$S/B$	25	76	283	333	
$S/\sqrt{B}$	77	96	69	26	
$q\bar{q} \rightarrow e^*e \rightarrow Zee \rightarrow eejj$					
$\Delta M, \text{ GeV}$	40	60	106	180	200
$S$	4725	2388	358	54	6
$S/B$	3	16	48	67	-
$S/\sqrt{B}$	121	192	131	60	-



Reach  $\sim 2 \text{ TeV}$  for  $10 \text{ fb}^{-1}$

# Recent Studies: New Signatures

Arkani-Hamed, Dimopoulos hep-th/0405159

## Split Supersymmetry

- Assumes nature is fine tuned and SUSY is broken at some high scale
- The only light particles are the Higgs and the gauginos
  - Gluino can live long: sec, min, years!
  - R-hadron formation: slow, heavy particles containing a heavy gluino.

Unusual interactions with material

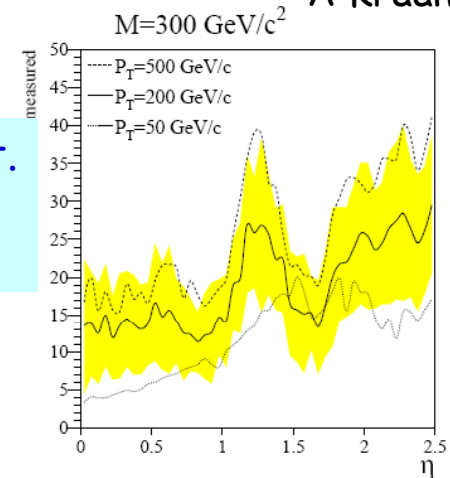
eg. with the calorimeters of the experiments!

## Gravitino Dark Matter and GMSB

- In some models/phase space the gravitino is the LSP
- Then the NLSP (neutralino, stau lepton) can live 'long'

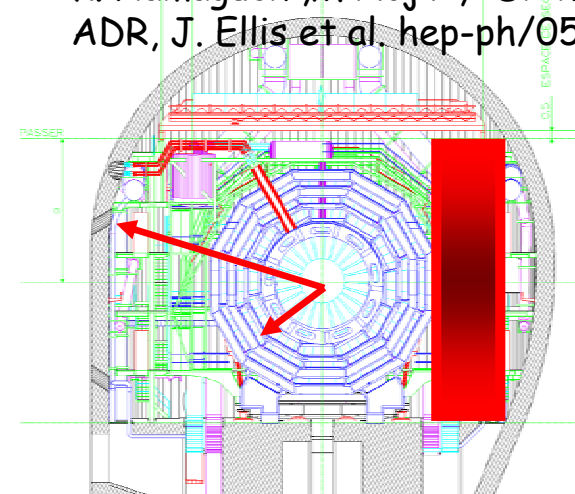
⇒ Challenge to the experiments!

A Kraan



Energy fract. deposited in calorimeter

K. Hamaguchi, M Nojiri, ADR hep-ph/0612060  
ADR, J. Ellis et al. hep-ph/0508198



~ 1000 events per year

Sparticles stopped in the detector, walls of the cavern, or dense 'stopper' detector. They decay after hours---months...

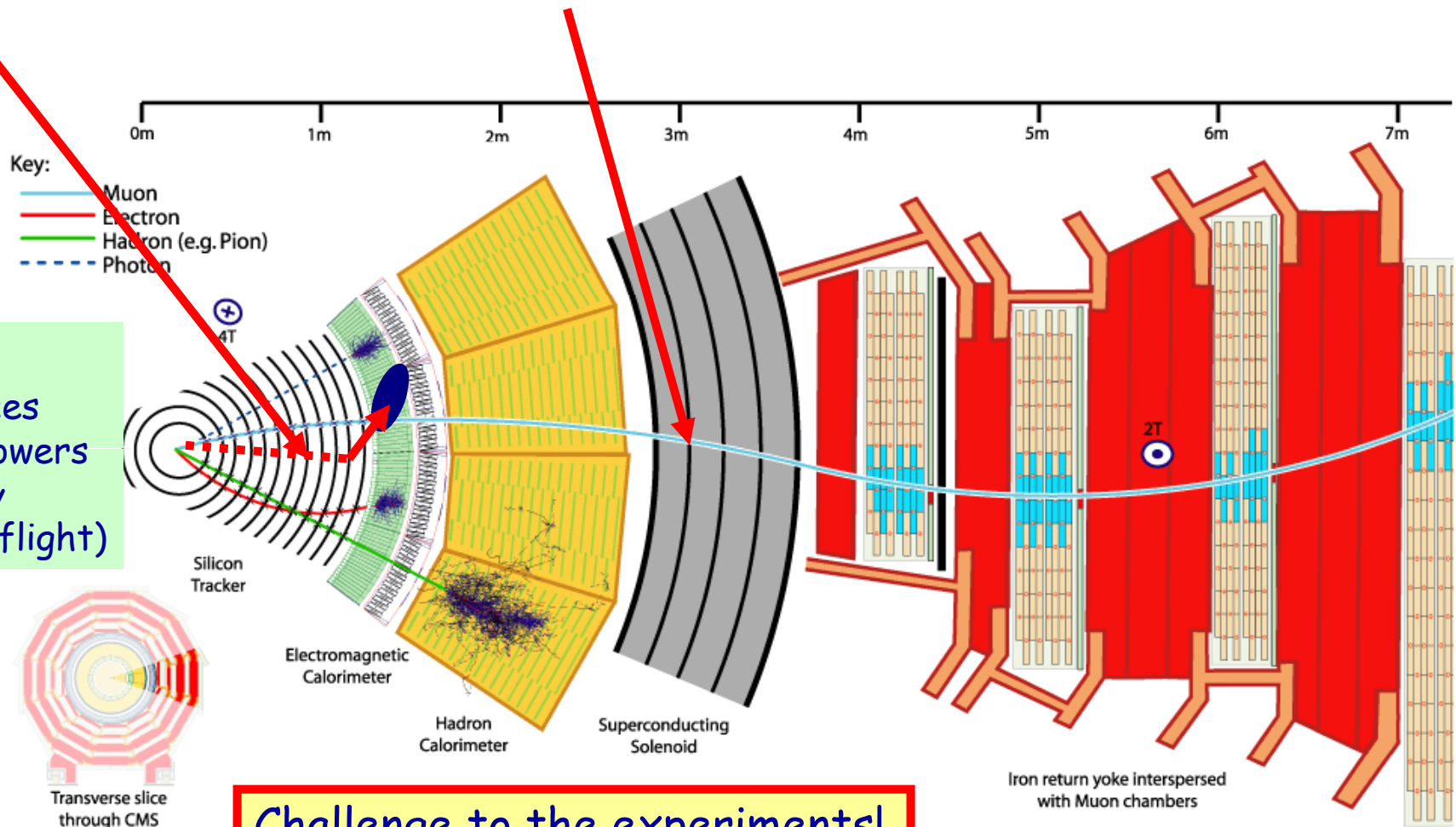


# Recent Studies: Special signatures

Eg.  $\chi \rightarrow \gamma + \text{gravitino}$  or heavy (slow) stau slepton

GMSB or  
GDM models

- Signatures**
- Displaced vertices
  - Non-pointing showers
  - Long lived 'heavy muons' (time of flight)



**Challenge to the experiments!**

# Stable Massive Particles

SMP	LSP	Scenario	Conditions	$Q_{em}$	$C_{QCD}$	$S$	Model(s)
$\tilde{\tau}_1$	$\tilde{\chi}_1^0$	MSSM	$\tilde{\tau}_1$ mass (determined by $m_{\tilde{\tau}_{L,R}}^2, \mu, \tan \beta$ , and $A_\tau$ ) close to $\tilde{\chi}_1^0$ mass.	0	<b>8</b>	1	Universal Extra Dimensions (KK gluon)
	$\tilde{G}$	GMSB	Large $N$ , small $M$ , and/or large $\tan \beta$ .	$\pm 1$	<b>1</b>	$\frac{1}{2}$	Universal Extra Dimensions (KK lepton)
		$\tilde{g}$ MSB	No detailed phenomenology studies, see [23].				Fat Higgs with a fat top ( $\psi$ fermions)
	SUGRA	Supergravity with a gravitino LSP, see [24].					4th generation (chiral) fermions
$\tilde{\tau}_1$	MSSM	Small $m_{\tilde{\tau}_{L,R}}$ and/or large $\tan \beta$ and/or very large $A_\tau$ .					Mirror and/or vector-like fermions
	AMSB	Small $m_0$ , large $\tan \beta$ .				0	Fat Higgs with a fat top ( $\psi$ scalars)
	$\tilde{g}$ MSB	Generic in minimal models.		$\pm \frac{4}{3}$	<b>3</b>	$\frac{1}{2}$	Warped Extra Dimensions with GUT parity (XY gaugino)
$\tilde{\ell}_{i1}$	$\tilde{G}$	GMSB	$\tilde{\tau}_1$ NLSP (see above). $\tilde{e}_1$ and $\tilde{\mu}_1$ co-NLSP and also SMP for small $\tan \beta$ and $\mu$ .			0	5D Dynamical SUSY-breaking (xyon)
	$\tilde{\tau}_1$	$\tilde{g}$ MSB	$\tilde{e}_1$ and $\tilde{\mu}_1$ co-LSP and also SMP when stau mixing small.	$-\frac{1}{3}, \frac{2}{3}$	<b>3</b>	$\frac{1}{2}$	Universal Extra Dimensions (KK down, KK up)
$\tilde{\chi}_1^+$	$\tilde{\chi}_1^0$	MSSM	$m_{\tilde{\chi}_1^+} - m_{\tilde{\chi}_1^0} \lesssim m_{\pi^+}$ . Very large $M_{1,2} \gtrsim 2 \text{ TeV} \gg  \mu $ (Higgsino region) or non-universal gaugino masses $M_1 \gtrsim 4M_2$ , with the latter condition relaxed to $M_1 \gtrsim M_2$ for $M_2 \ll  \mu $ . Natural in O-II models, where simultaneously also the $\tilde{g}$ can be long-lived near $\delta_{GS} = -3$ .				4th generation (chiral) fermions
	AMSB	$M_1 > M_2$ natural. $m_0$ not too small. See MSSM above.		$\epsilon < 1$	<b>1</b>	$\frac{1}{2}$	GUT with $U(1) - U(1)'$ mixing
							Extra singlets with hypercharge $Y = 2e$
$\tilde{g}$	$\tilde{\chi}_1^0$	MSSM	Very large $m_{\tilde{q}}^2 \gg M_3$ , e.g. split SUSY.				Millicharged neutrinos
	$\tilde{G}$	GMSB	SUSY GUT extensions [25–27].				
	$\tilde{g}$	MSSM	Very small $M_3 \ll M_{1,2}$ , O-II models near $\delta_{GS} = -3$ .				
		GMSB	SUSY GUT extensions [25–29].				
$\tilde{t}_1$	$\tilde{\chi}_1^0$	MSSM	Non-universal squark and gaugino masses. Small $m_{\tilde{q}}^2$ and $M_3$ , small $\tan \beta$ , large $A_t$ .				
$\tilde{b}_1$			Small $m_{\tilde{q}}^2$ and $M_3$ , large $\tan \beta$ and/or large $A_b \gg A_t$ .				
				?	?	$0/\frac{1}{2}/1$	“Technibaryons”

hep-ph/06110402

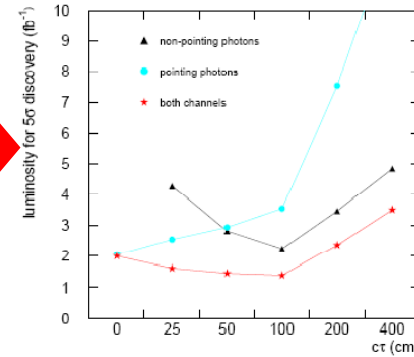
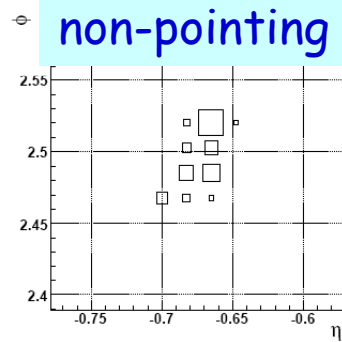
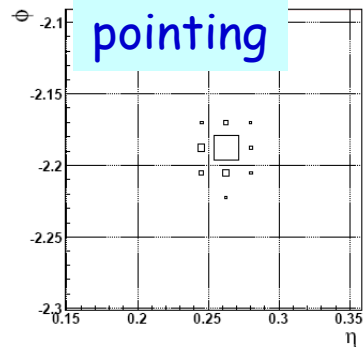
Stable Massive Particles are not a rarity at all (it seems)...



# Recent analyses

## GMSB: Non-pointing photons

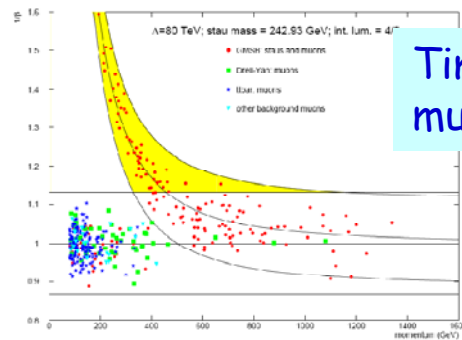
GMSB parameters  $N = 1$   $\tan \beta = 1$   $\text{sgn } \mu = 1$   $M_m = 2\Lambda$



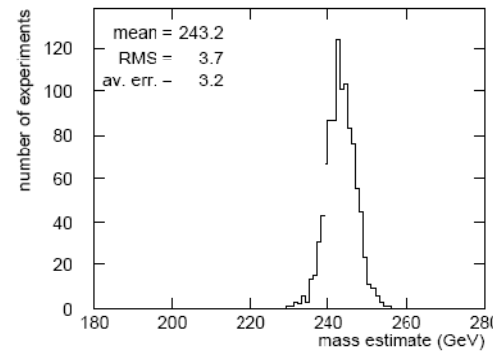
$\chi$  ct lifetime extraction with ~20% precision

## GMSB: long living staus

GMSB parameters  $N = 3$   $\tan \beta = 3$   $\text{sgn } \mu = 1$   $M_m = 2\Lambda$



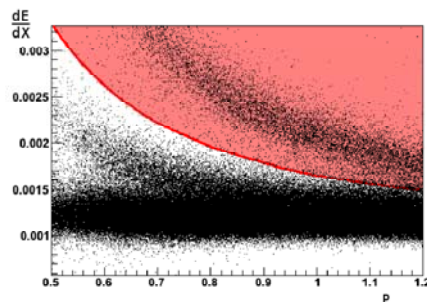
Timing ( $\beta$ ) in muon detectors



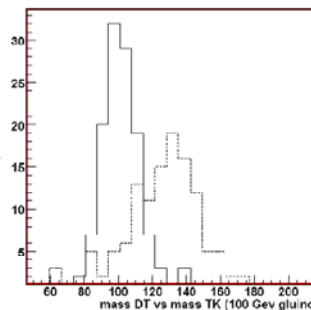
stau mass extraction with a few % precision

## R-hadrons

trigger/mass meas. for region  $\beta > 0.6$



dE/dx in the tracker



$\beta$ -tracker  $\neq \beta$  muons

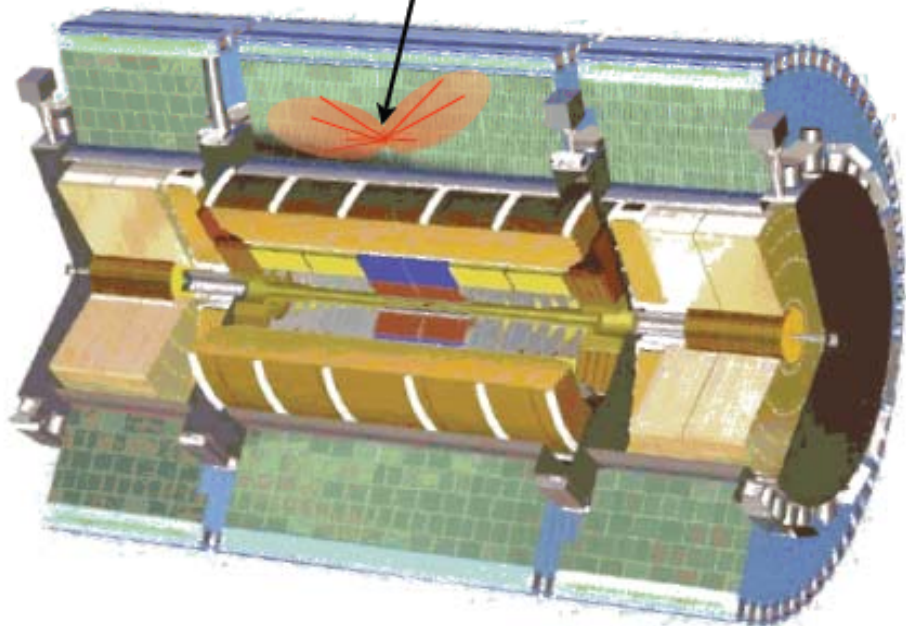
# Split SUSY

## Long Lived Gluinos

$$\tau_{\tilde{g}} > 100 \text{ ns}$$

looking for stopped gluinos that later decay

$$100\text{s GeV Unbalanced} = \cancel{E}_T$$

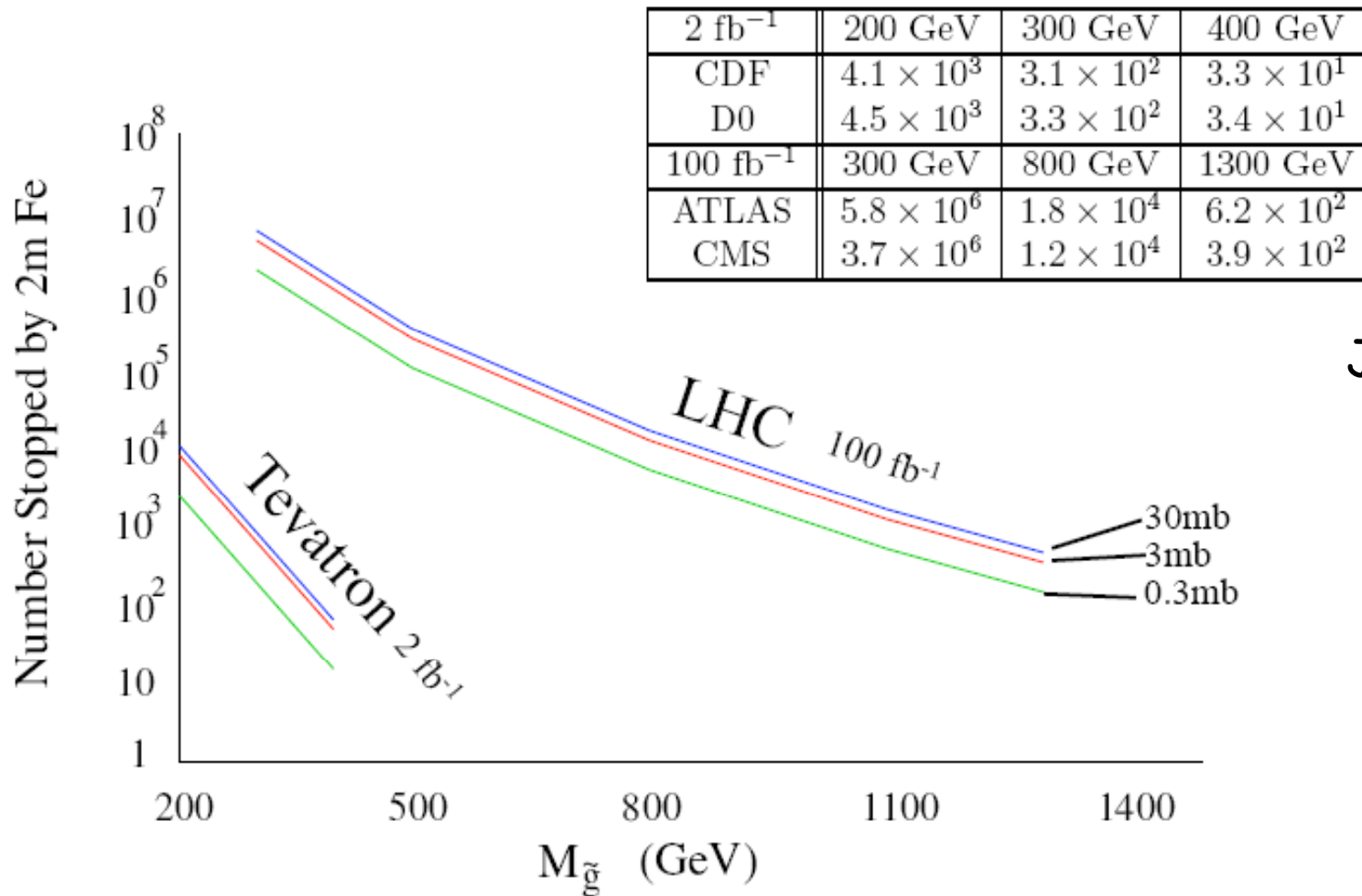


Uncorrelated with any beam crossing  
No tracks going to or from activity

# Split Susy

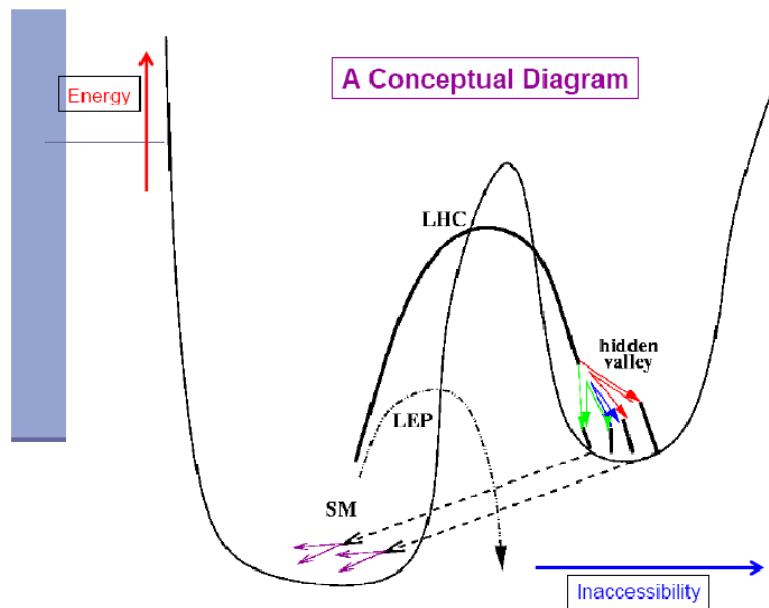
## Total Number of Stopped Gluinos

Arvanitaki, Dimopoulos, Pierce, Rajendran, JW hep-ph/0506242



J. Wacker

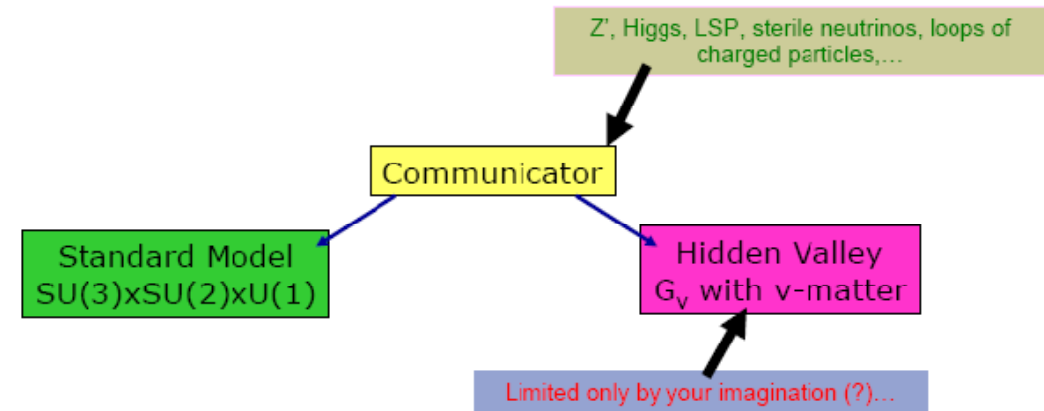
# Hidden Valley Physics?



String Theory inspired (M. Strassler)

Eg. Strassler & Zurek hep-ph/0604261

## Basic minimal structure

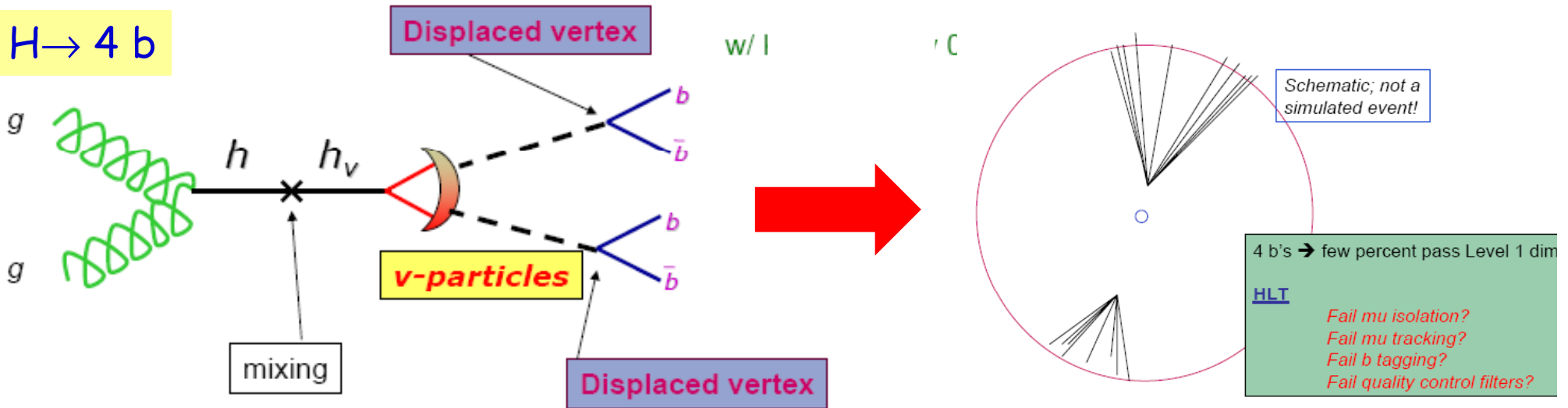


New possible phenomena that could occur in these models

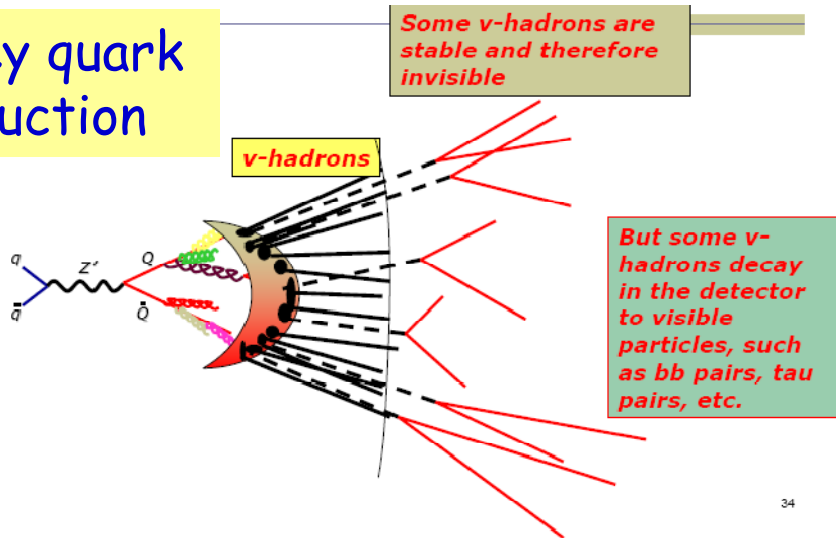
- **Higgs** decays to two [or more] long-lived particles
  - **Aside** on classes of possible decays of new particles
- **Z'** decays to the  $\nu$ -sector:
  - Final state with many particles, possibly long-lived
- **LSP** decays to the  $\nu$ -sector
  - Degradation of MET signal
  - Wide array of complex final states

# Some Hidden Valley Signals

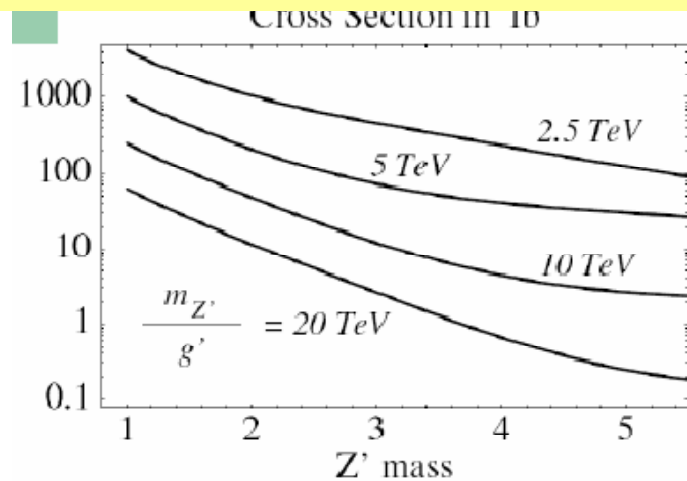
$H \rightarrow 4b$



Valley quark production



Production rates for  $v$ -hadrons



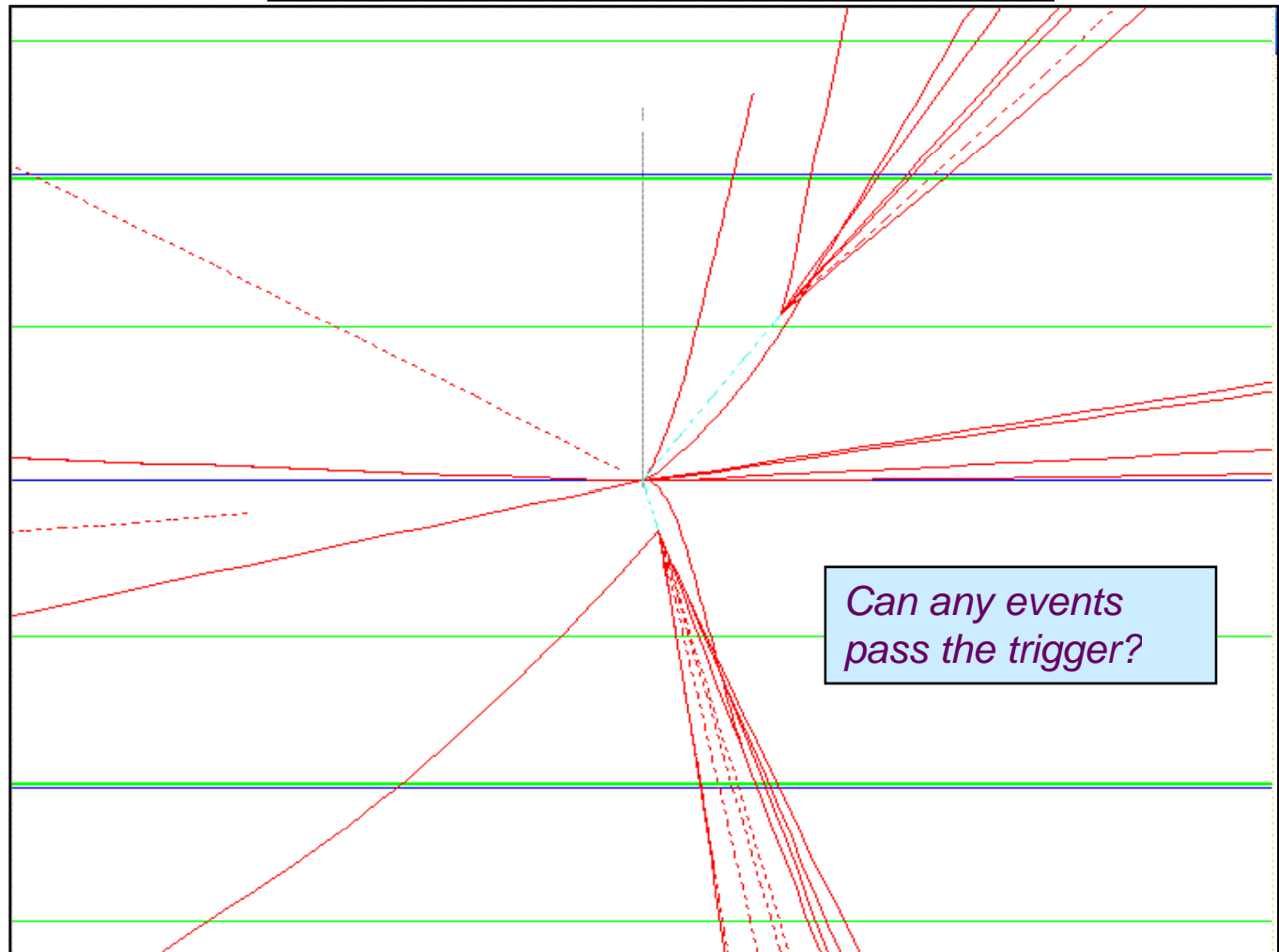
The Fear Factor: A real challenge for the triggers at the LHC

# New Discovery Mode for the Higgs?

M. Strassler & K. Zurek 5/2006

Higgs Decays to Long-Lived Particles

ATLAS Rome-Seattle  
working group:



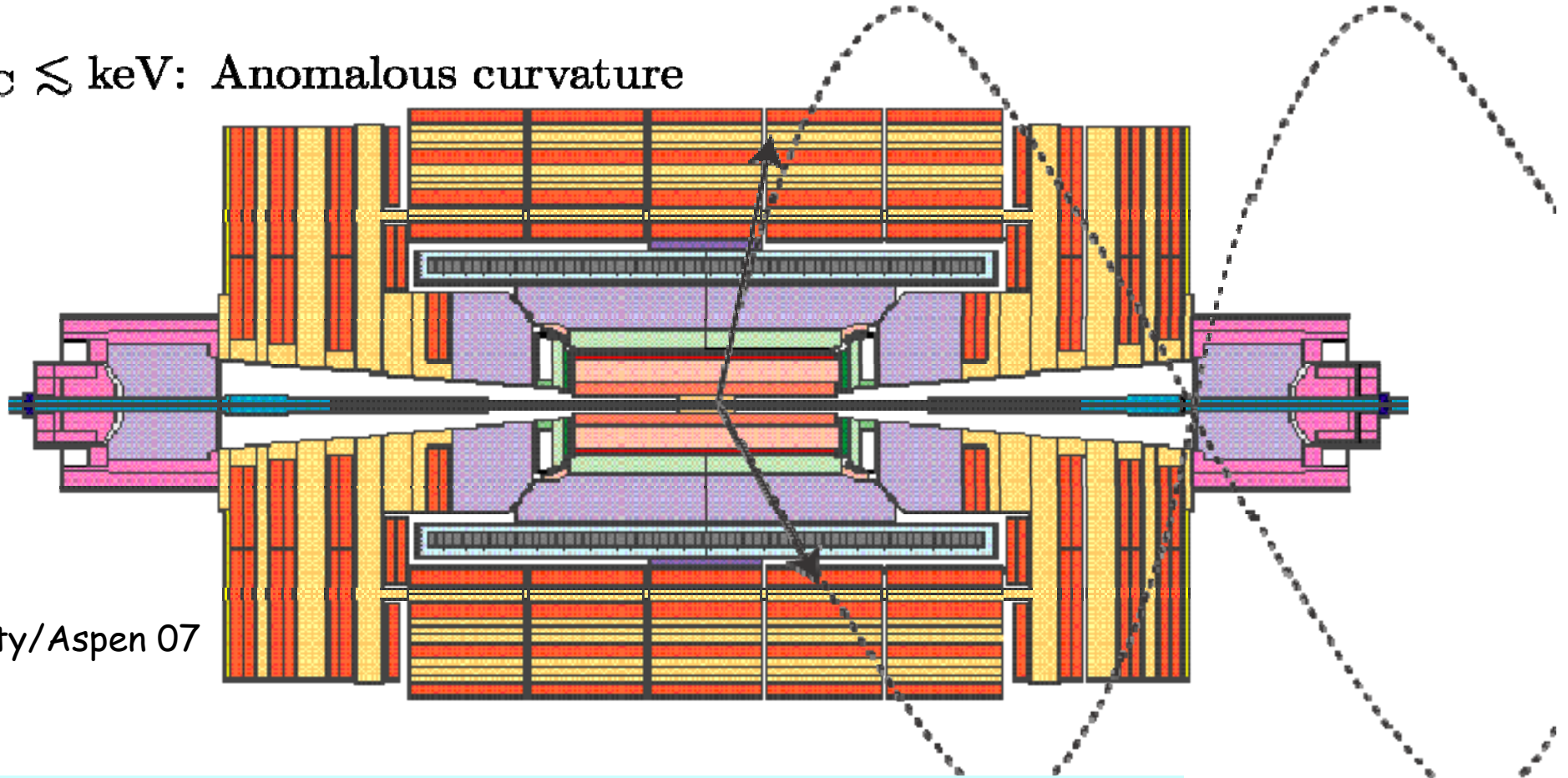
Can any events  
pass the trigger?



# New: (Colour) Strings at the LHC

Macro-strings: new strong interactions & new quarks  $m_Q >$  several hundreded GeV

$\Lambda_{IC} \lesssim \text{keV}$ : Anomalous curvature

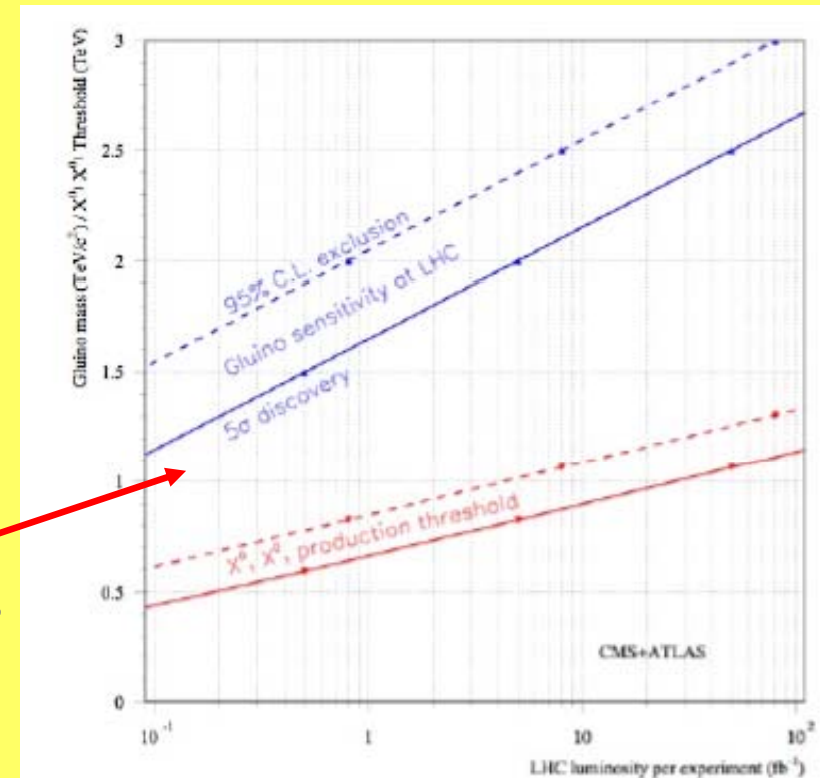


Markus Luty/Aspen 07

- Strings do not break up  $\Rightarrow$  Stringy objects in the detector.
- End points are massive quarks (quirks)
- The strings can oscillate  $\Rightarrow$  strange signature in detectors

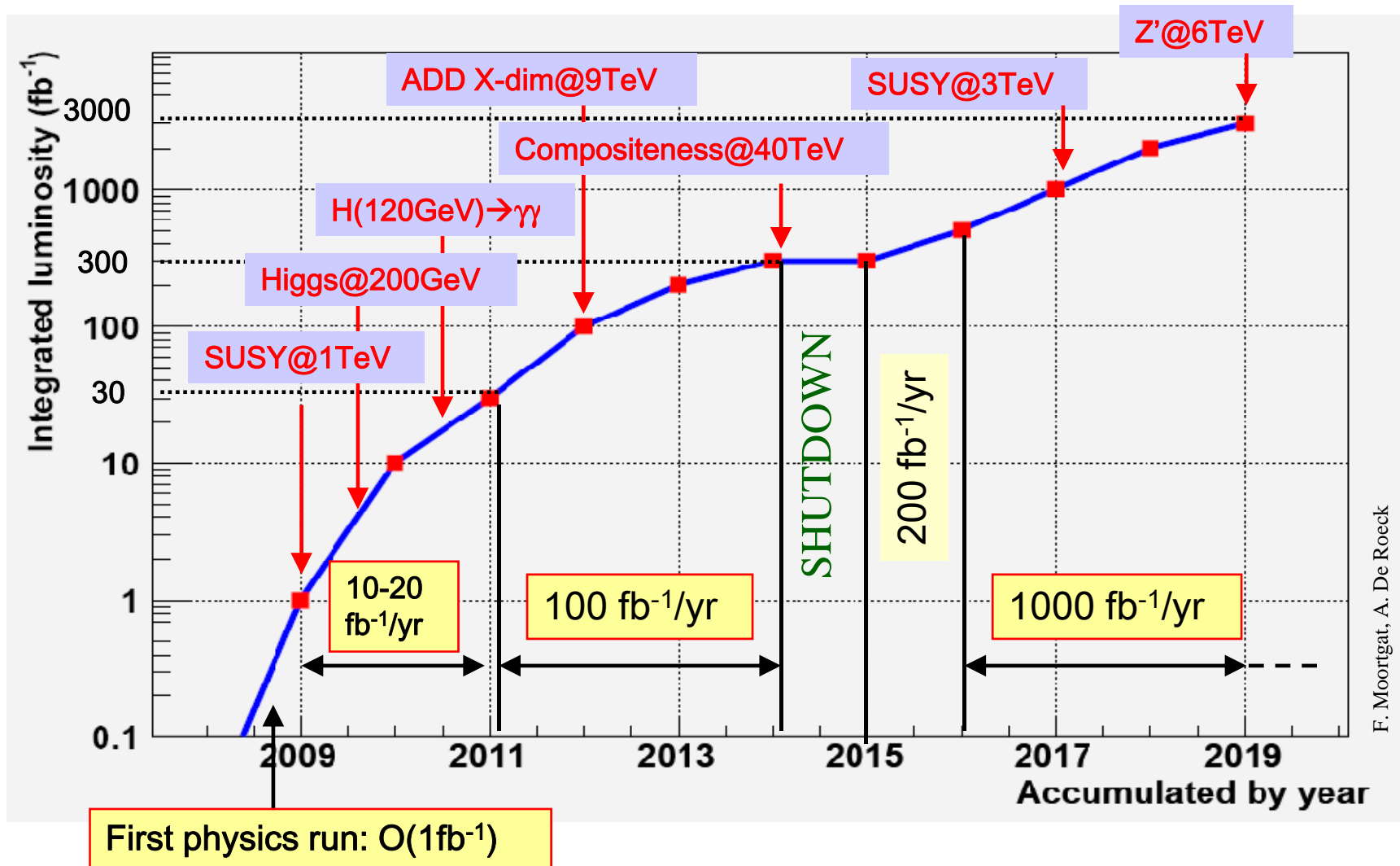
# Summary

- LHC: prepared for searches for many new scenarios
- Already with  $10 \text{ fb}^{-1}$  the region covered will be for massive particles with mass more than 1 TeV (several TeV in most cases)
  - Both for discovery or exclusion.
- Note that new experiments are new  $\Rightarrow$  Ramping up will take time  
Be patient!
- Early findings obviously very relevant for the ILC
  - may set initial energy for a LC
  - may affect detector choices
- For this workshop:
  - What do we learn from the (non) observation of new particles?





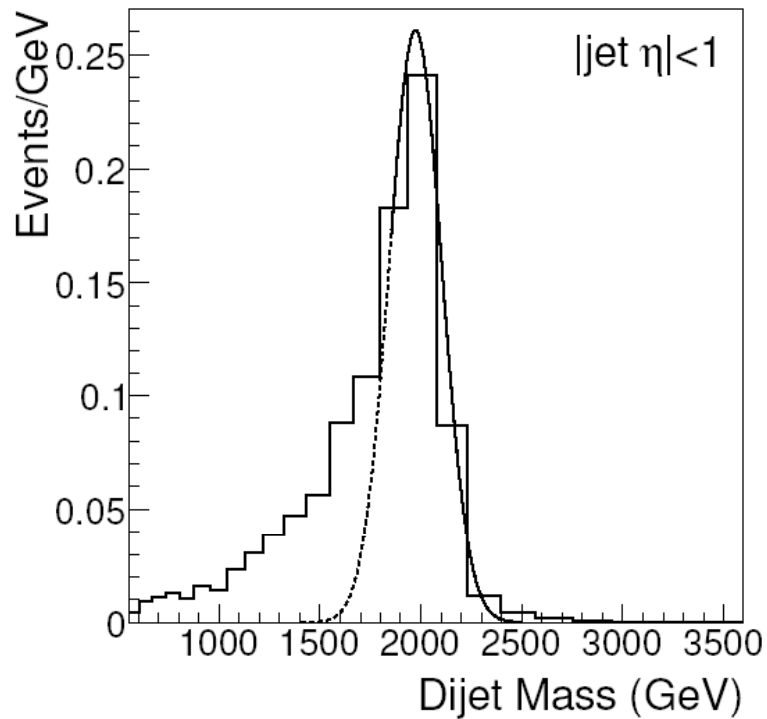
# Discovery/Luminosity Roadmap?



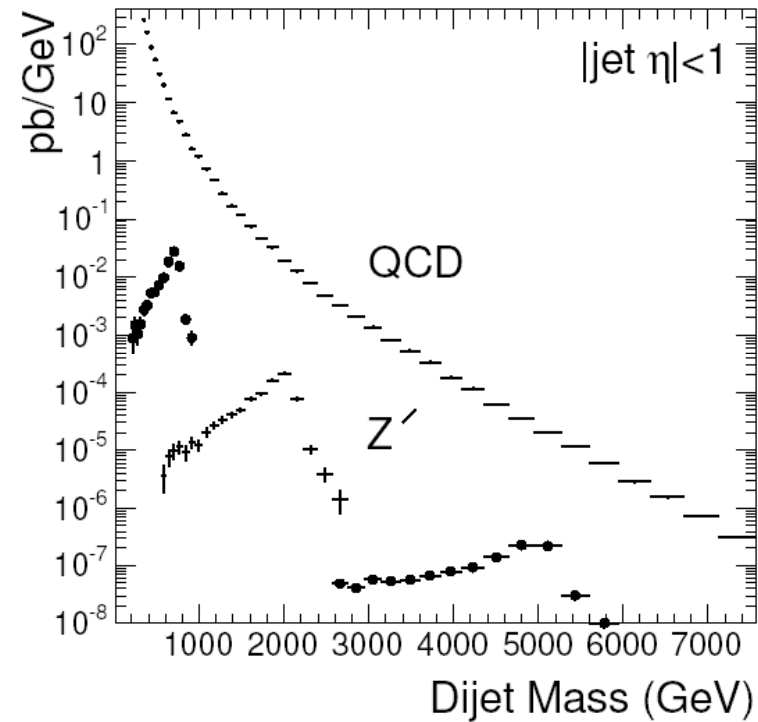
## Backup slides

# Dijets: $Z'$ resonances

With the CMS detector



Mass distribution 2 TeV  $Z'$

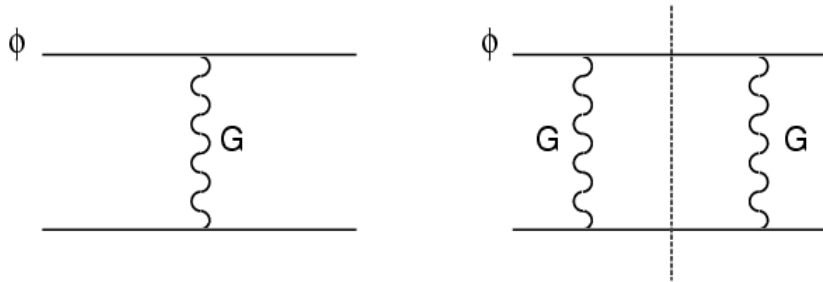


QCD background (PYTHIA)  
+ 0.7, 2 and 5 TeV  $Z'$

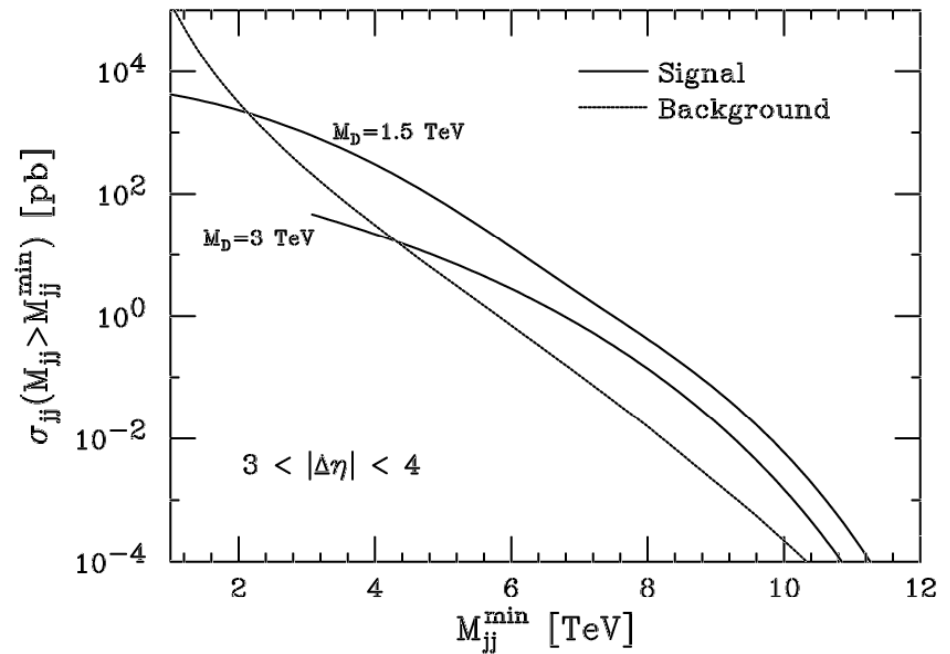
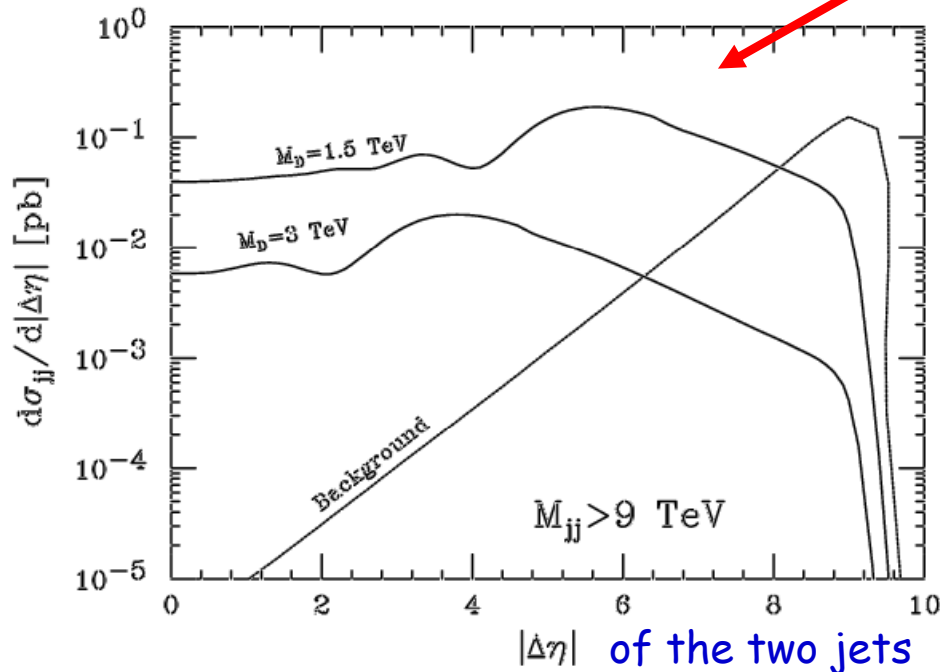
# Transplanckian effects

Once you pass the Planck scale  $\sqrt{s} \gg M_D \dots$

Processes with small momentum transfer e.g. :  
Elastic transplanckian collisions:  
Study gravity propagation in ED's  
**Signal: dijets with large  $M_{jj}$**

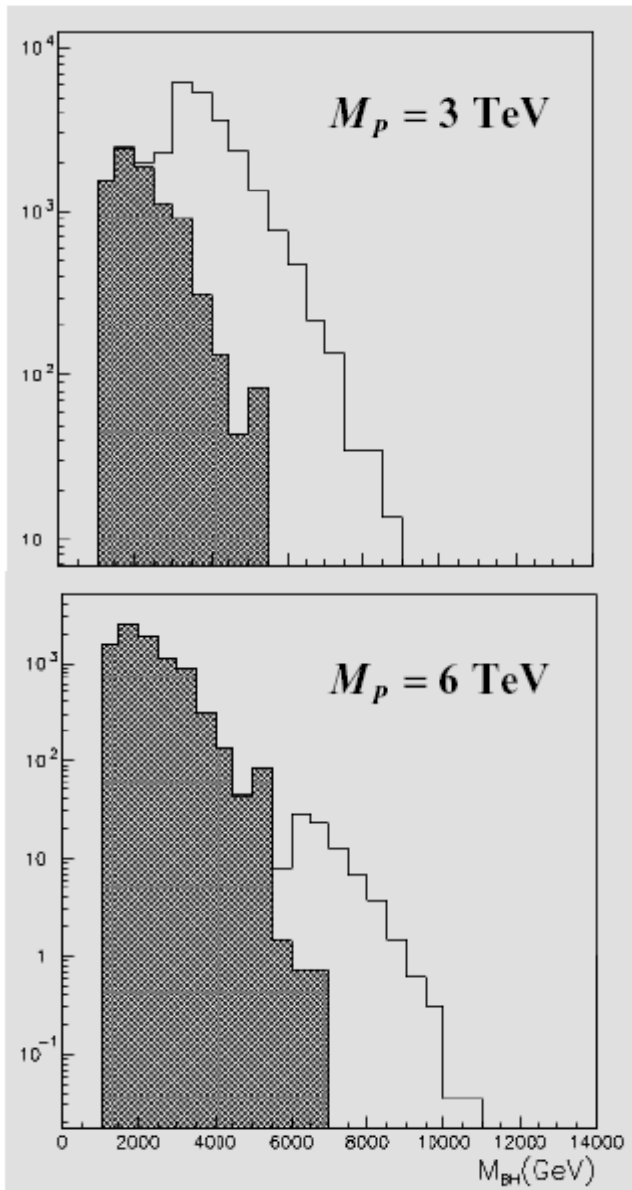


Guidice, Rattazzi, Wells



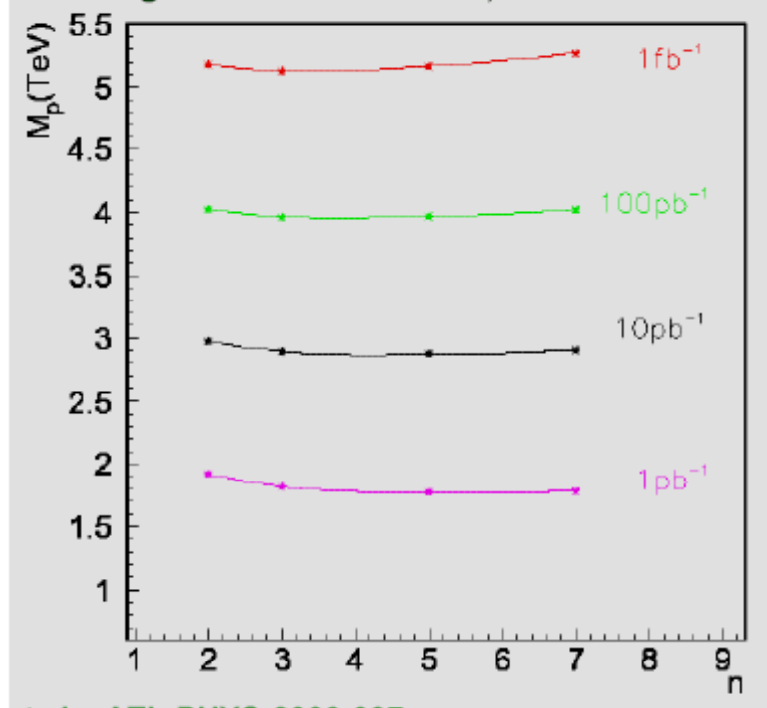
Full experimental study still missing

# Black Holes



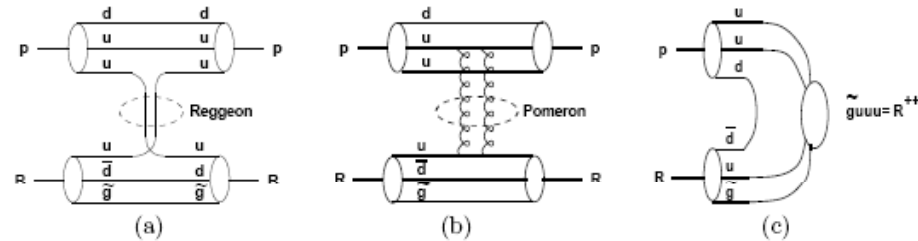
simulation in ATLAS

- selection of spherical events
  - $M_{\text{BH}}$  reconstructed for each event
  - reconstruction of  $M_P$  from the cross section  $ds/dM_{\text{BH}}$
  - given the energy distribution for  $M_{\text{BH}} \Rightarrow T_{\text{H}}$
- $n$  deduced from  $T_{\text{H}}$ ,  $M_{\text{BH}}$  and  $M_P$   
(Hawking radiation formula)



J. Tanaka et al., ATL-PHYS-2003-037

# How do these R-hadrons interact with matter?



## R-Hadrons

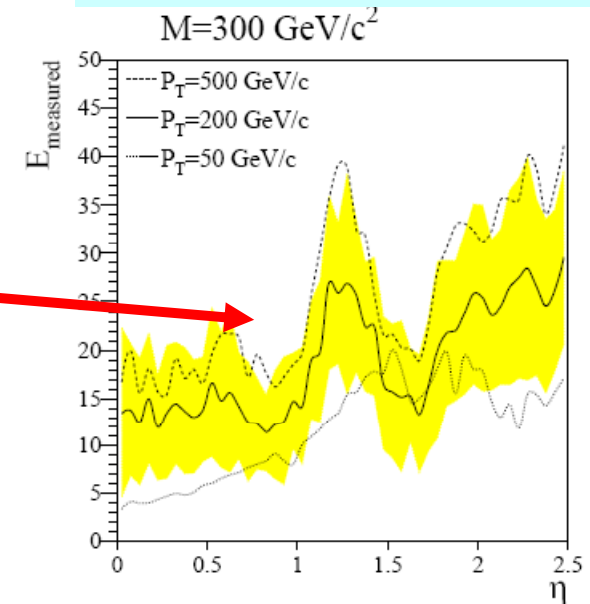
(e.g. A Kraan hep-ph/0404001)

- Gluino interactions suppressed as  $1/M^2$
  - u,d quarks interact but with a kinetic energy of order 1 GeV
- ⇒ deposit only 10-15% of energy while passing through ATLAS/CMS calorimeters

**This will be a remarkable signature**  
**Also: charge flip while passing through matter**

Understanding of travel of heavy particles through matter good enough?

Need to modify the detector simulation toolkit (Geant4)



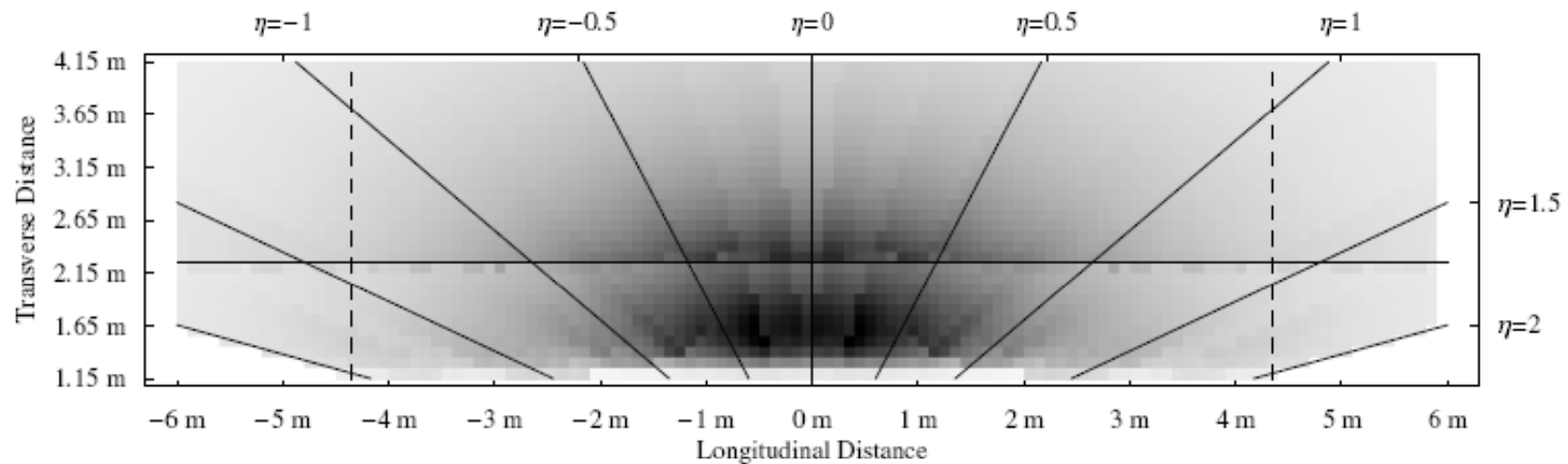
Further: anomalous  $dE/dx$ , time-of-flight measurements. Trigger is a challenge

# Split Susy

## Density of Stopped Gluinos

300 GeV gluino

Atlas Detector



Beamline

Not uniformly distributed in detector

No tracks going into or out of calorimeter

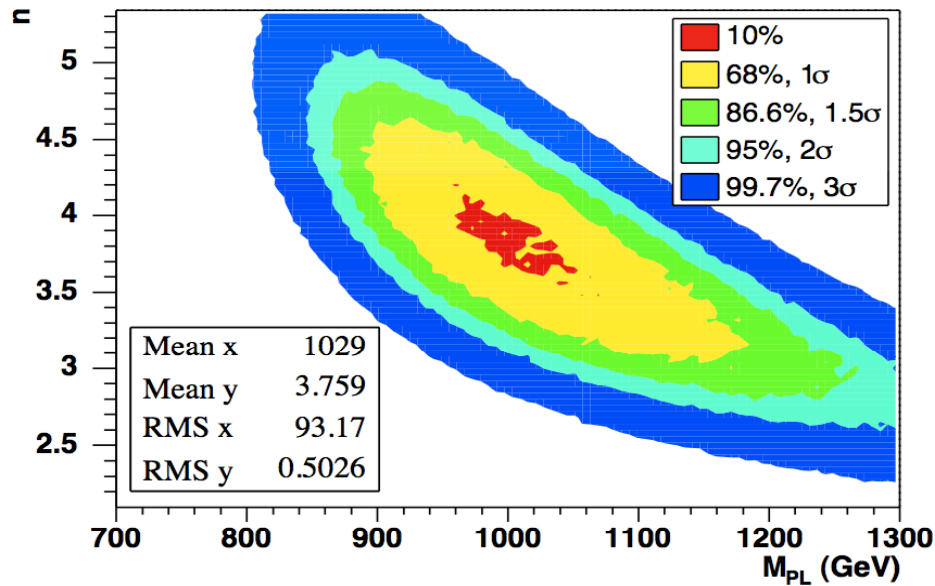
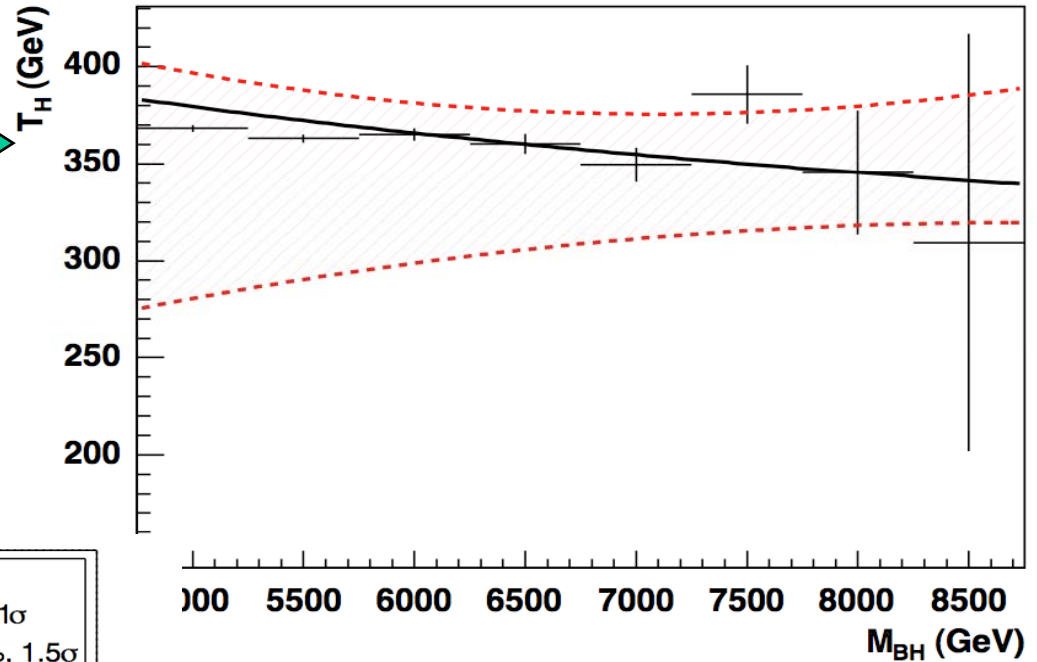
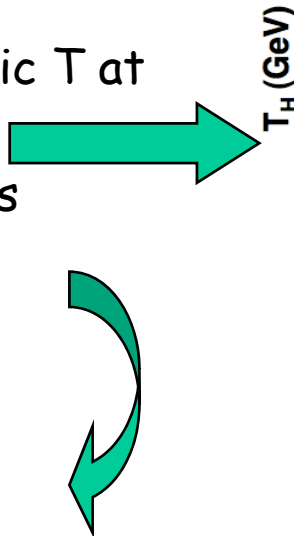
Arvanitaki, Dimopoulos, Pierce, Rajendran, JW hep-ph/0506242

# Black Hole Searches

Can measure characteristic  $T$  at average mass

-> combine this with cross section data to extract  $n$ .

Assume 20% error on  $\sigma$



Area of interest  
for **Alberta Group!**



# Extra dimensions

Hypothesize that there are extra space dimensions

Volume of bulk space  $\gg$  volume of 3-D space

Hypothesize that gravity operates throughout the bulk

SM fields confined to 3-D

Then unified field will have "diluted" gravity, as seen in 3-D

With n-D gravity mass scale=weak mass scale  $\rightarrow$  no hierarchy problem!

Can experimentally access quantum gravity!

Missing energy signatures

Black hole production

But extra dimension is different length scale from "normal" ones

$\rightarrow$  new scale to explain

