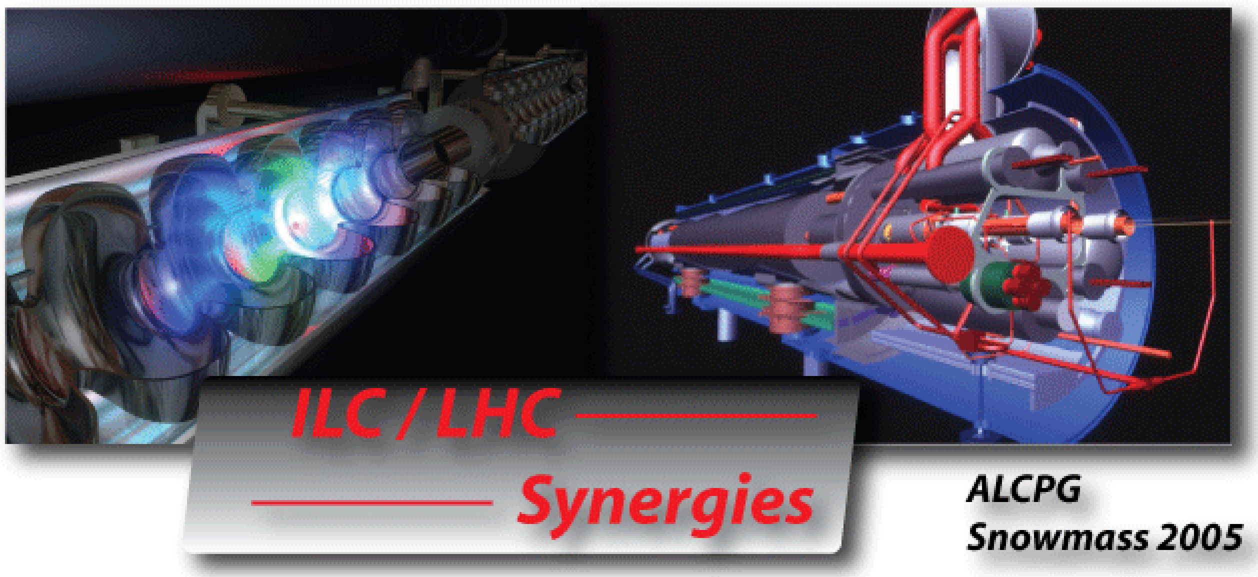
SUSY and other BSM at the (S)LHC

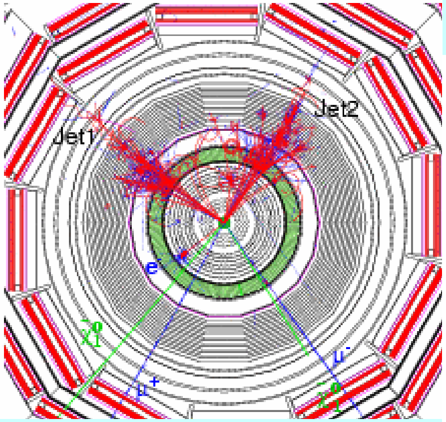
Albert De Roeck
CERN

Snowmass August 05

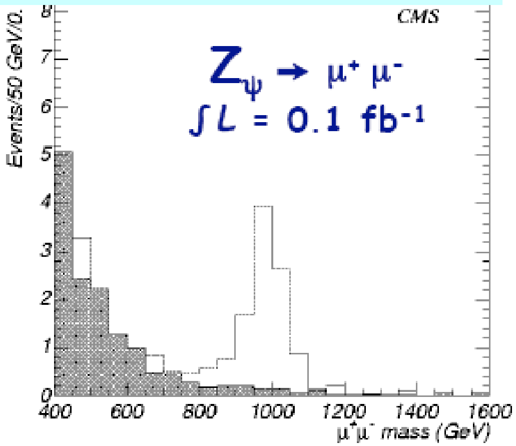


BSM Physics at the LHC: pp @ 14 TeV

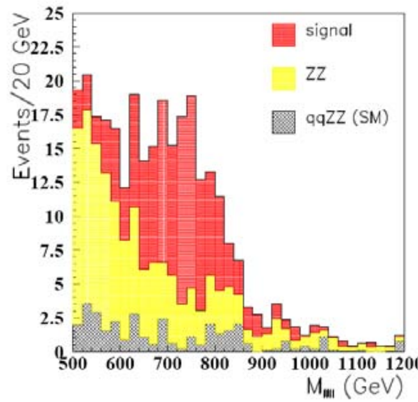
Supersymmetry?



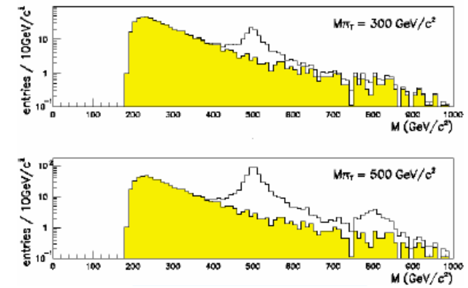
New Gauge Bosons?



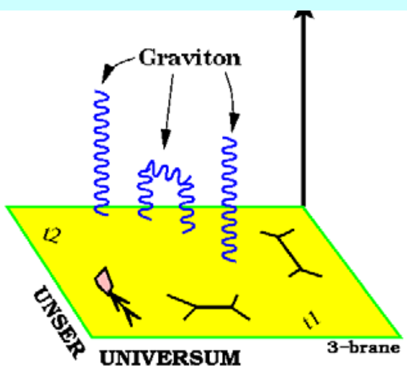
ZZ/WW resonances?



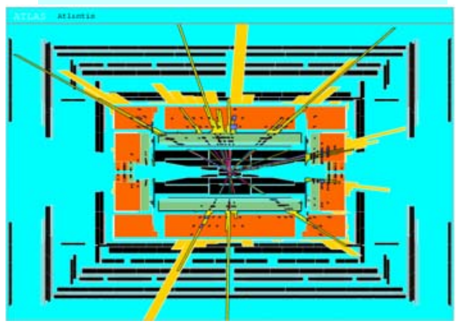
Technicolor?



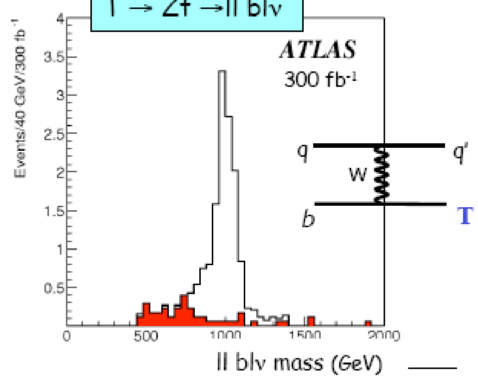
Extra Dimensions?



Black Holes???



Little Higgs?



Split Susy?

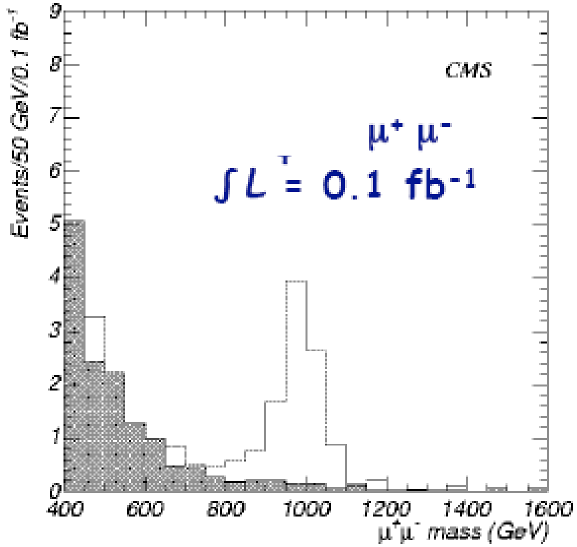
LHC	14 TeV	$10^{33}cm^{-2}s^{-1}$ - $10^{34}cm^{-2}s^{-1}$
SLHC	14 TeV	$10^{35}\ cm^{-2}s^{-1}$ ⇐
	28 TeV	$10^{34}cm^{-2}s^{-1}$ (42 TeV??)

SLHC: 2015(+)

hep-ph/0204087

Example: Di-lepton Resonance

May be seen very early: first weeks



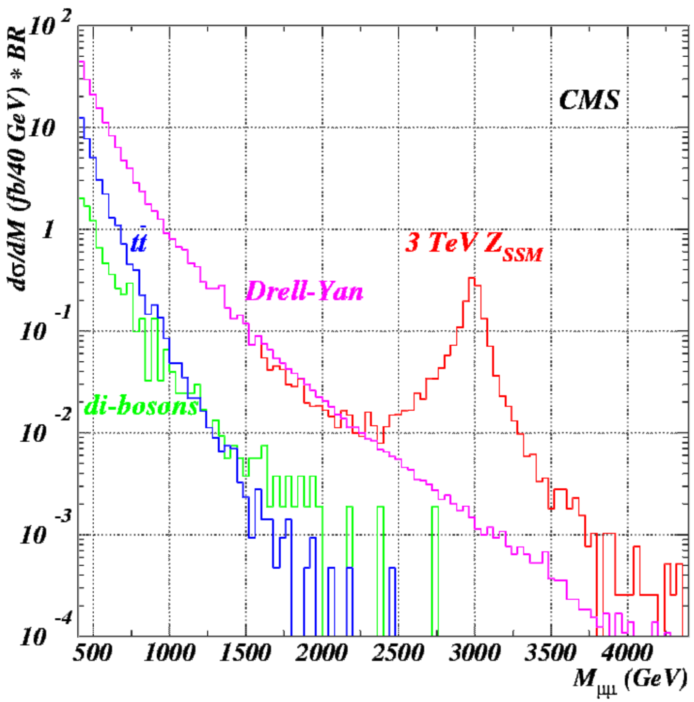
Example : The Di-lepton channel

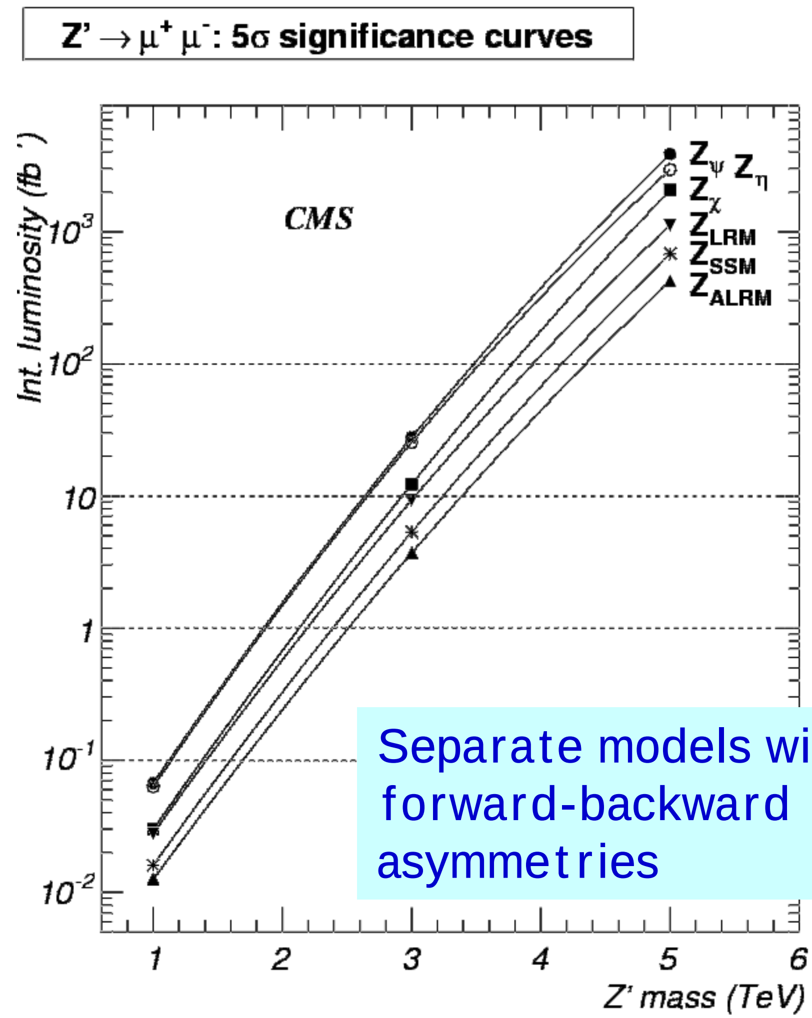
- Z' (New gauge bosons)
- A_H, Z_H (Little Higgs)
- $G^{(1)}$ (Randall-Sundrum)
- $\gamma^{(1)}/Z^{(1)}$ (TeV^{-1} Extra Dimensions)
- $G^{(KK)}$ (ADD)
- ...

New Z' Gauge Bosons

R. Cousins et al.

Z'→μμ production





Separate models with forward-backward asymmetries

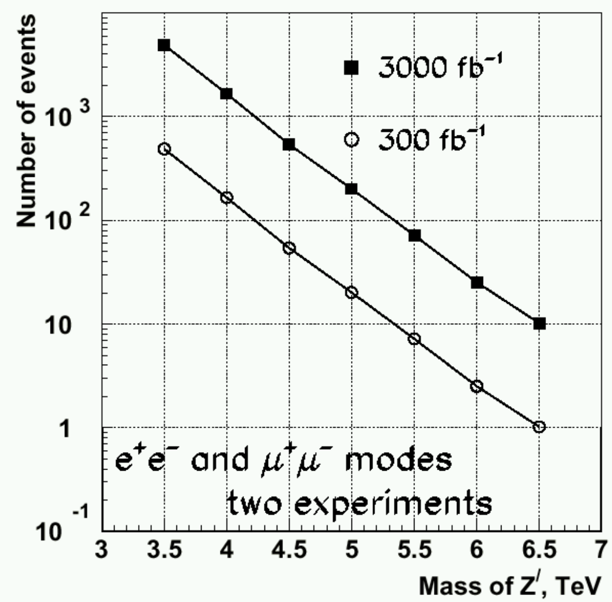
Note: Best possible theory knowledge on DY spectrum will be needed (tails!)

- Low lumi 0.1 fb^{-1} : discovery of 1-1.6 TeV possible, beyond Tevatron run-II
- High lumi 100 fb^{-1}: extend range to 3.4-4.3 TeV

SLHC: New Z' Gauge Bosons

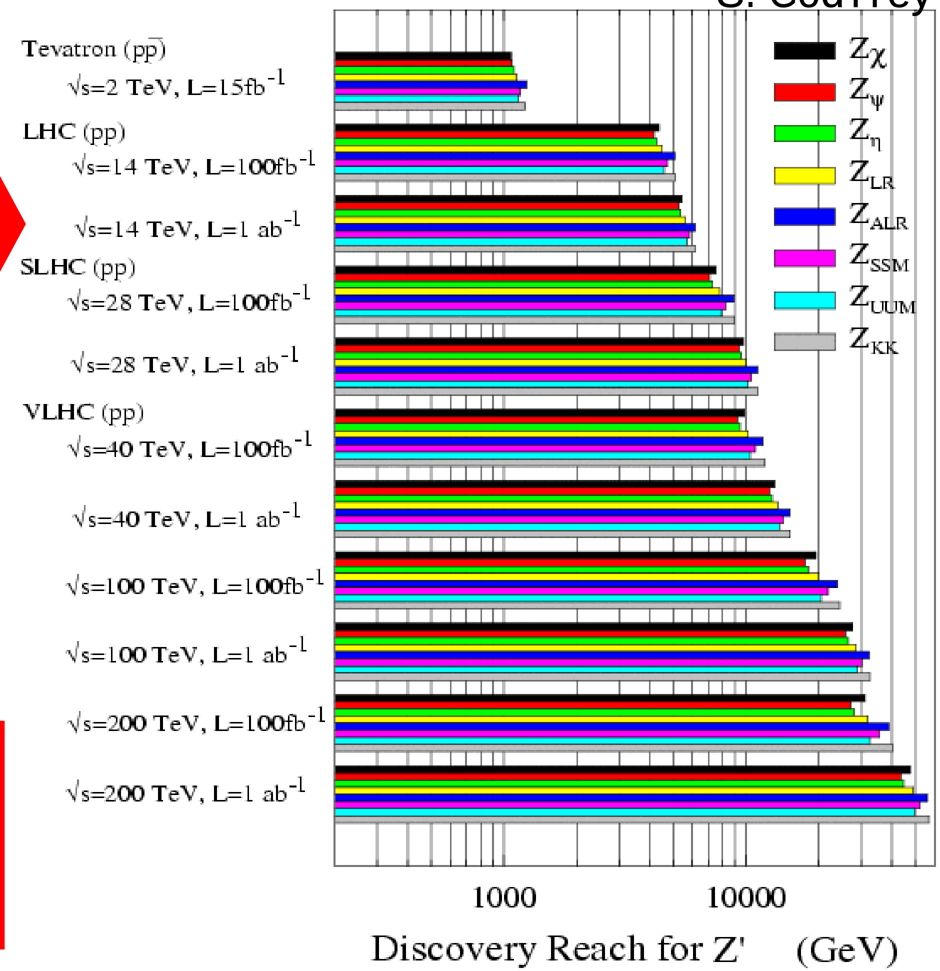
Z' mass (TeV)	1	2	3	4	5	6
$\sigma(Z' \to e^+e^-)(fb)$	512	23.9	2.5	0.38	0.08	0.026
$\Gamma_{Z'}$ (GeV)	30.6	62.4	94.2	126.1	158.0	190.0

with Z-like couplings



Includes pile-up, ECAL saturation...

S. Godfrey

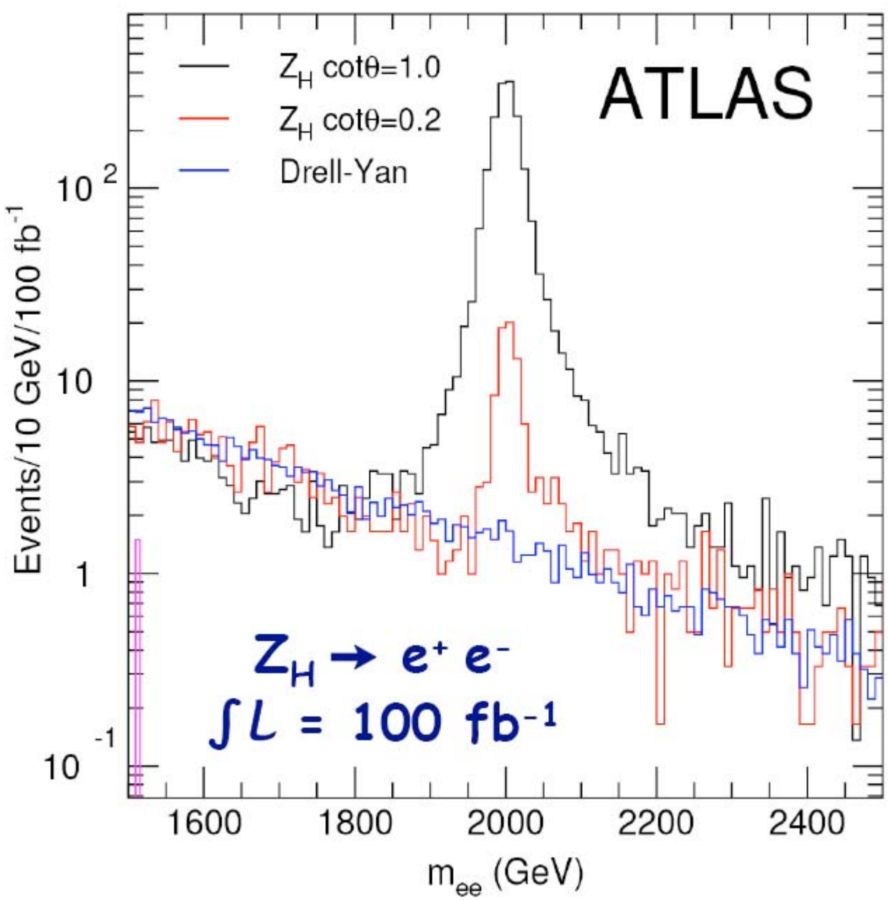


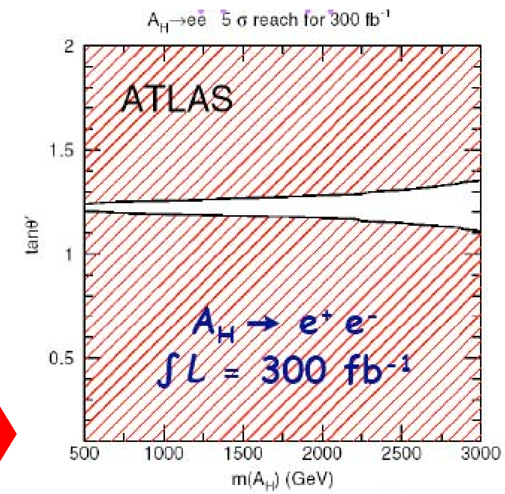
Reach:	LHC/600 fb^{-1}	5.3 TeV
	SLHC/6000 fb^{-1}	6.5 TeV
	LHC-28TeV/600 fb^{-1}	8 TeV

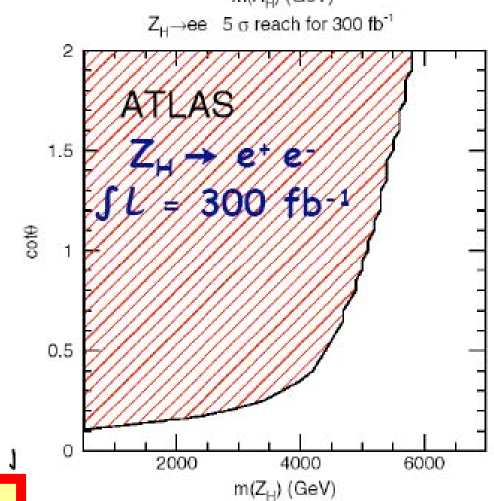
Little Higgs Model A_H and Z_H

Signal : di-lepton resonance

Littlest Higgs Model
Arkani-Hamed et al., Han et al.





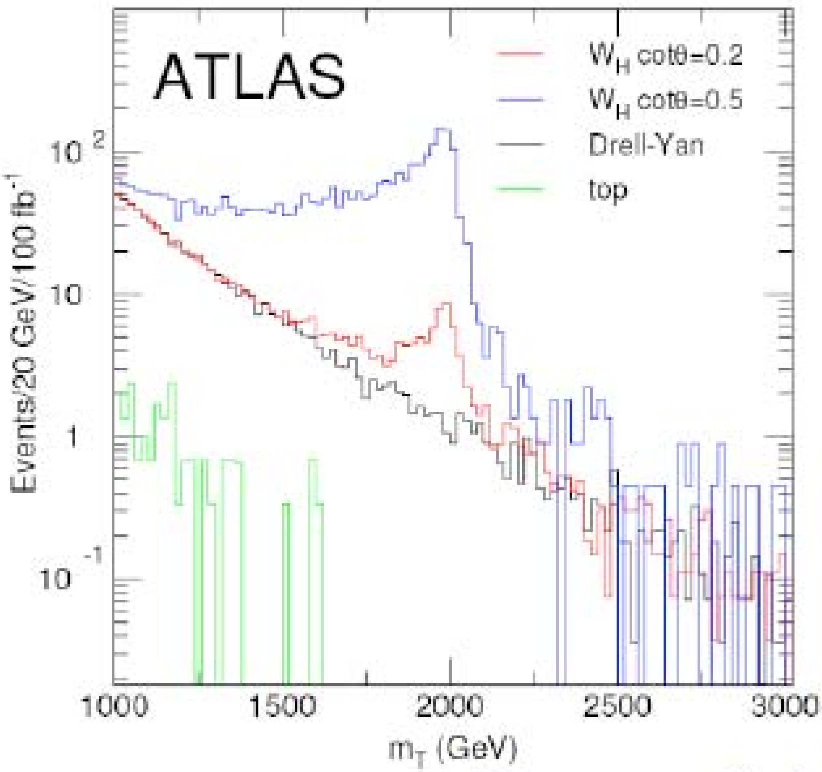


Reach up to 5.7 TeV depending on the θ angle

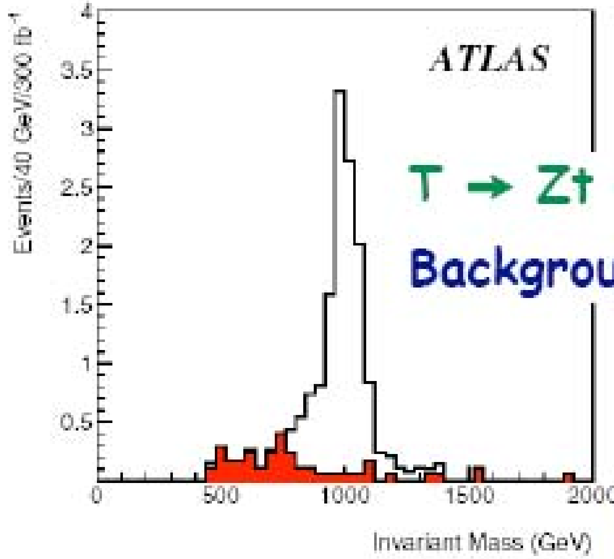
Other Little Higgs Signatures

$W_H \to e\nu$

Background: $l\nu$ via virtual W, labeled Drell-Yan



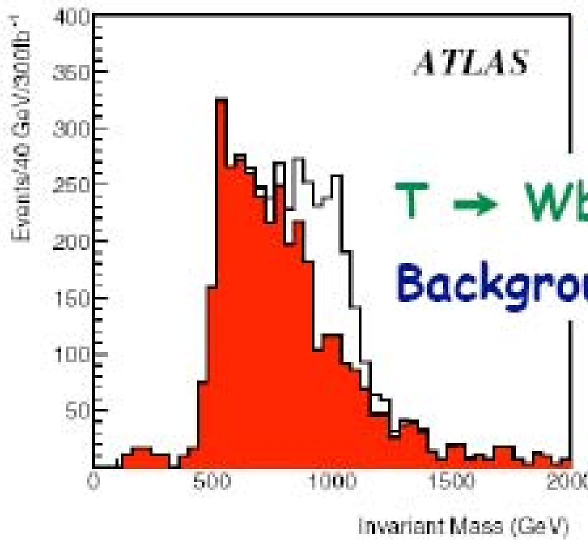
M_{WH} = 2 TeV, $\int L$ = 100 fb^{-1}



$T \to Zt \to l^+l^-l\nu b$

Background: tbZ, WZ

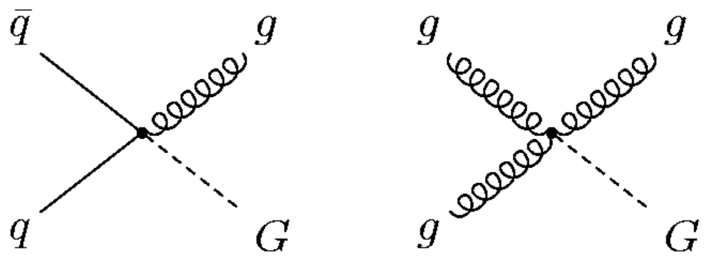
M_T = 1 TeV, $\int L$ = 300 fb^{-1}



$T \to Wb \to l\nu b$

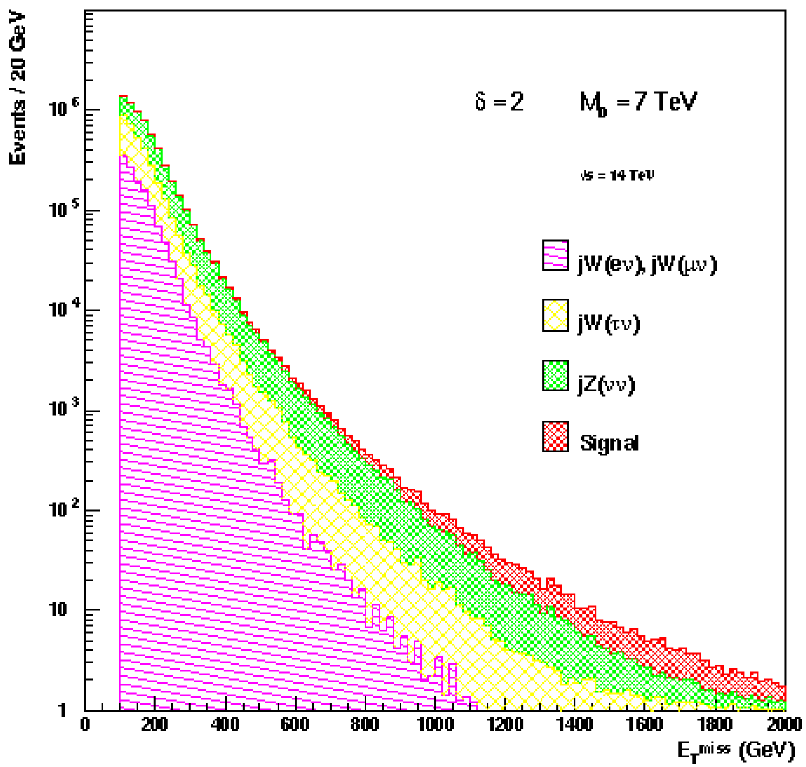
Background: single t, $t\bar{t}$

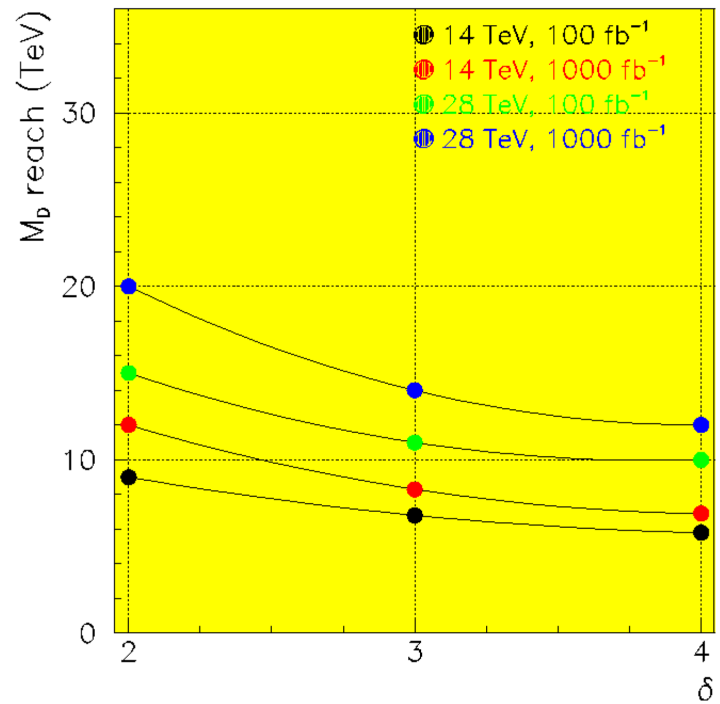
Extra Dimension signals at the LHC



Graviton production!
Graviton escapes detection

Signal: single jet + large missing ET





Test M_D to 7-9 TeV for 100 fb^{-1}
25% increase for lumi upgrade
50% increase for energy upgrade

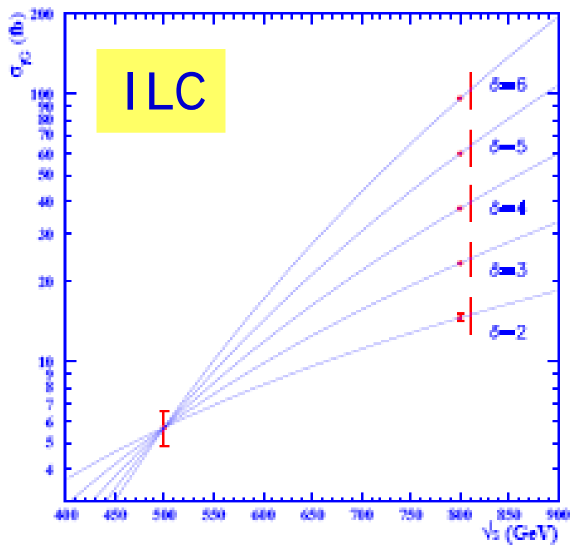
Number of Extra Dimensions and M_D

Can one disentangle δ and M_D at the LHC?

$$\text{Cross-section} \approx \frac{1}{M_D^{\;\delta+2}}$$

M_D = gravity scale

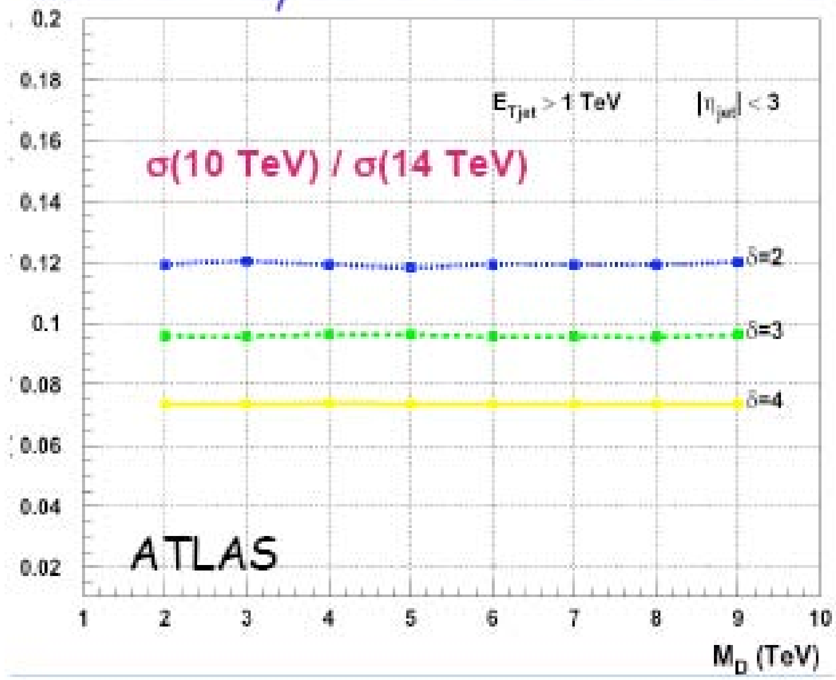
δ = number of extra-dimensions



To characterize the model need to measure M_D and δ

Measurement of cross-section gives ambiguous results: e.g. δ=2, M_D= 5 TeV very similar to δ=4, M_D= 4 TeV

Solution may be to run at different $\sqrt{s}$:

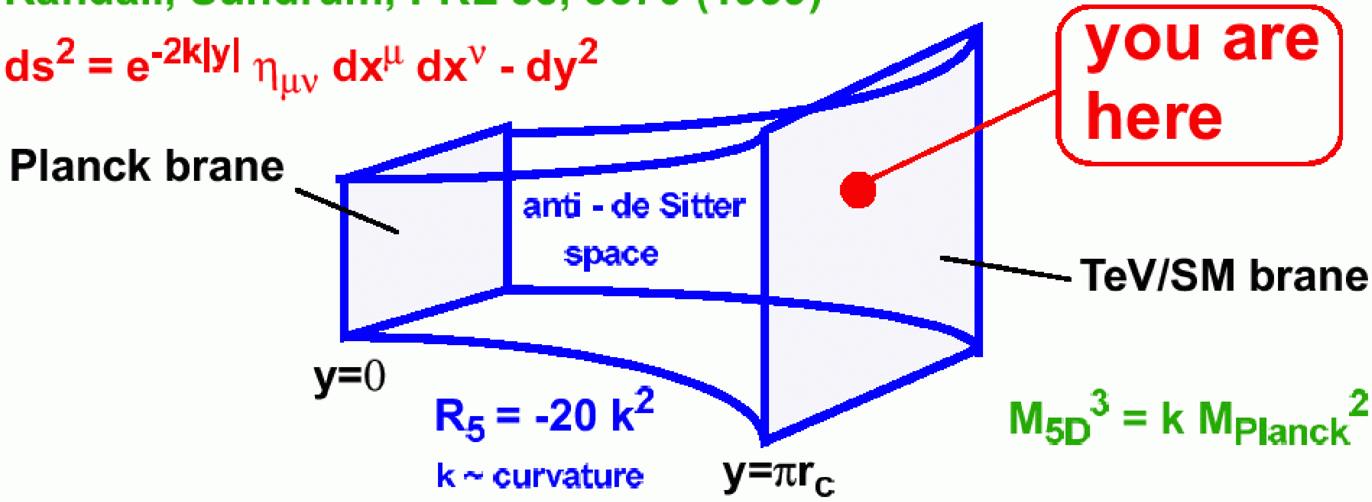


Further ideas: use topology (Spiropulu, Lykken, ADR)

Curved Space: RS Extra Dimensions

Randall, Sundrum, PRL 83, 3370 (1999)

$ds^2 = e^{-2k|y|} \eta_{\mu\nu} dx^\mu dx^\nu - dy^2$

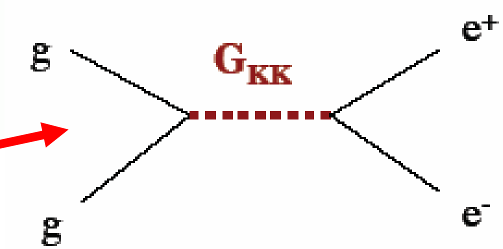


$R_5 = -20\ k^2$

k ~ curvature

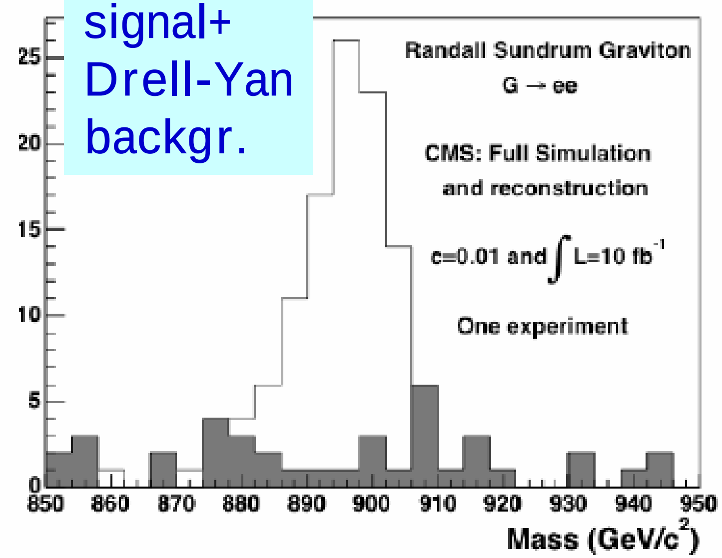
$M_{5D}^3 = k\ M_{Planck}^2$

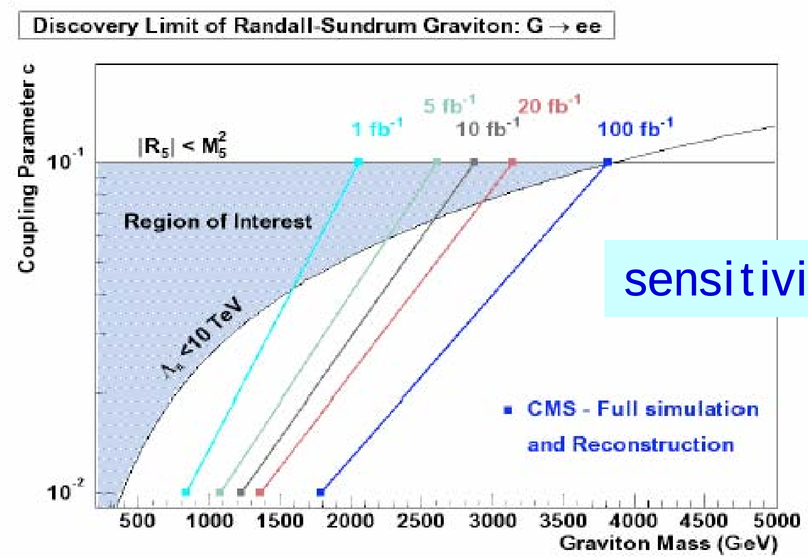
phenomenology



Study the channel pp→Graviton→ e+e-

signal+ Drell-Yan backgr.





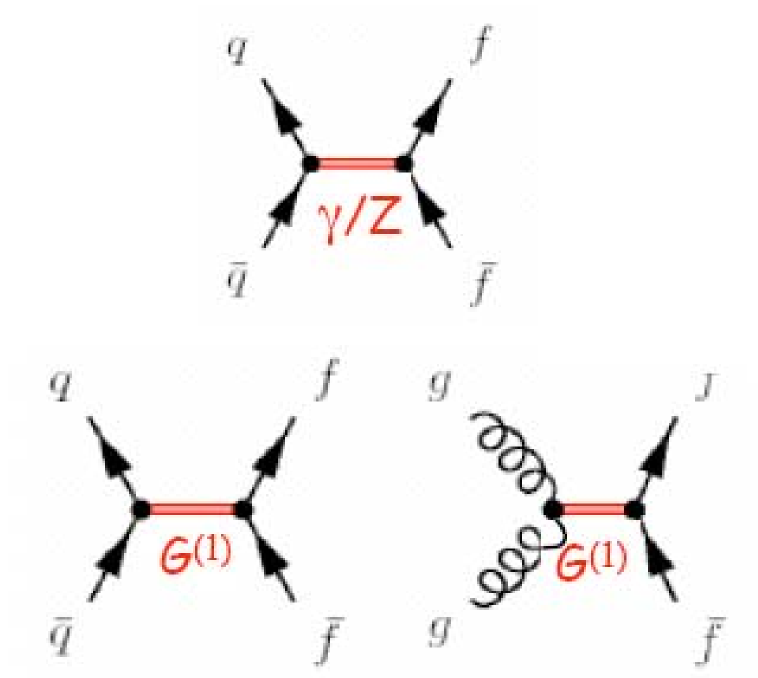
sensitivity

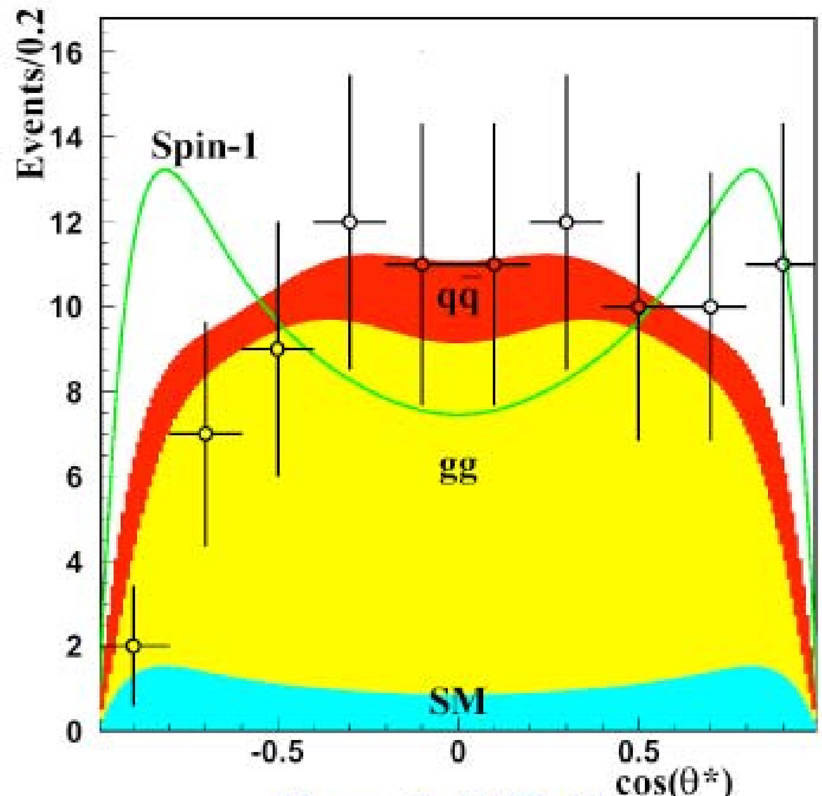
Randall - Sundrum EDs

We observe a peak in di-lepton spectrum

Is it a new gauge boson or a RS KK excitation

⇒ Study the spin of the object: spin 1 versus spin 2

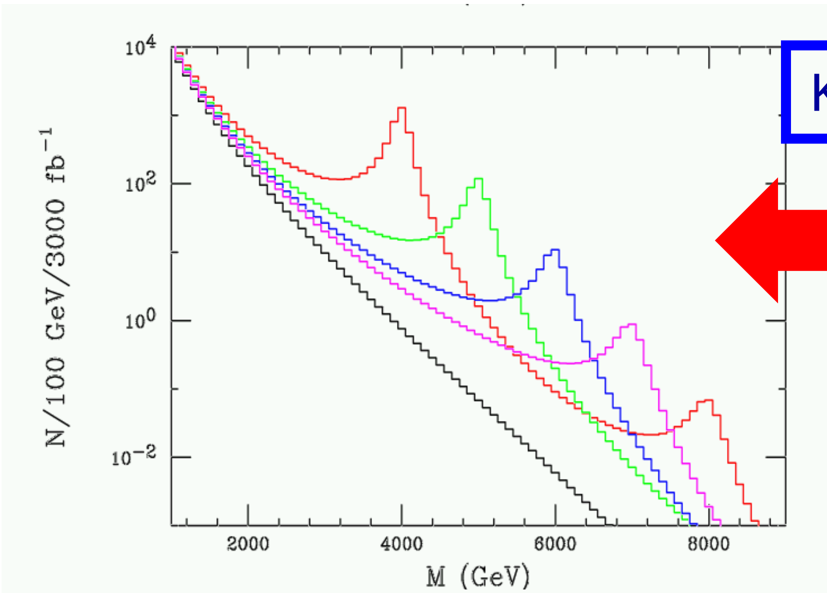




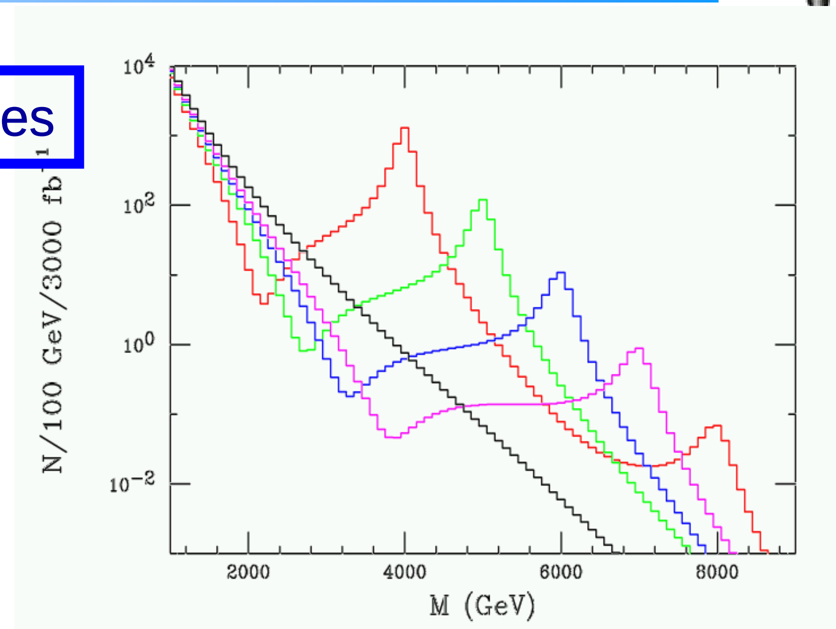
M_G = 1.5 TeV

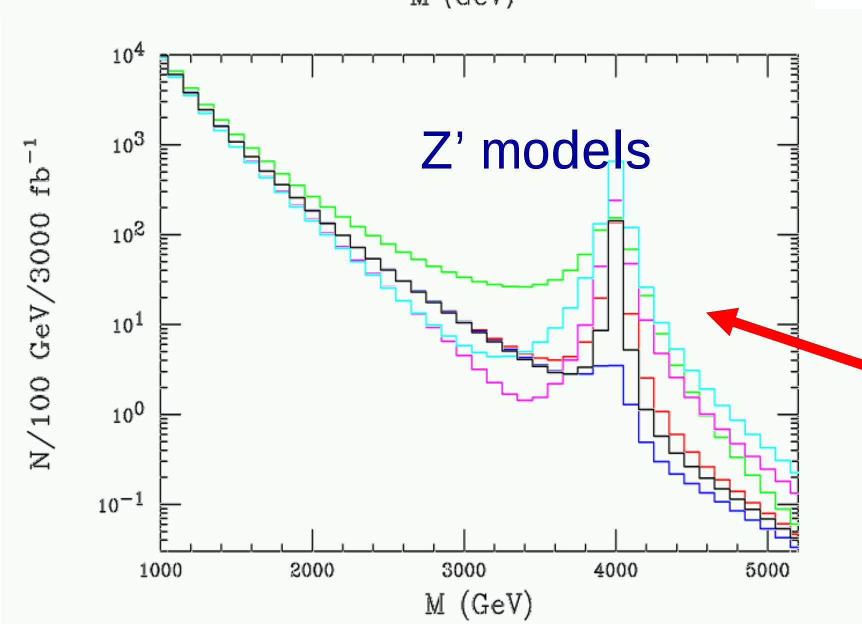
$\int L$ = 100 fb^{-1}

TeV scale Extra Dimensions



KK states





LEP: M > 4 TeV (indirect)

Sensitivity of the LHC

- Direct up to 5.8 TeV for 300 fb^{-1}
- Indirect up to 13 TeV for 300 fb^{-1}

How to distinguish from a Z'?

E.g. use Forw-Backw assymetries

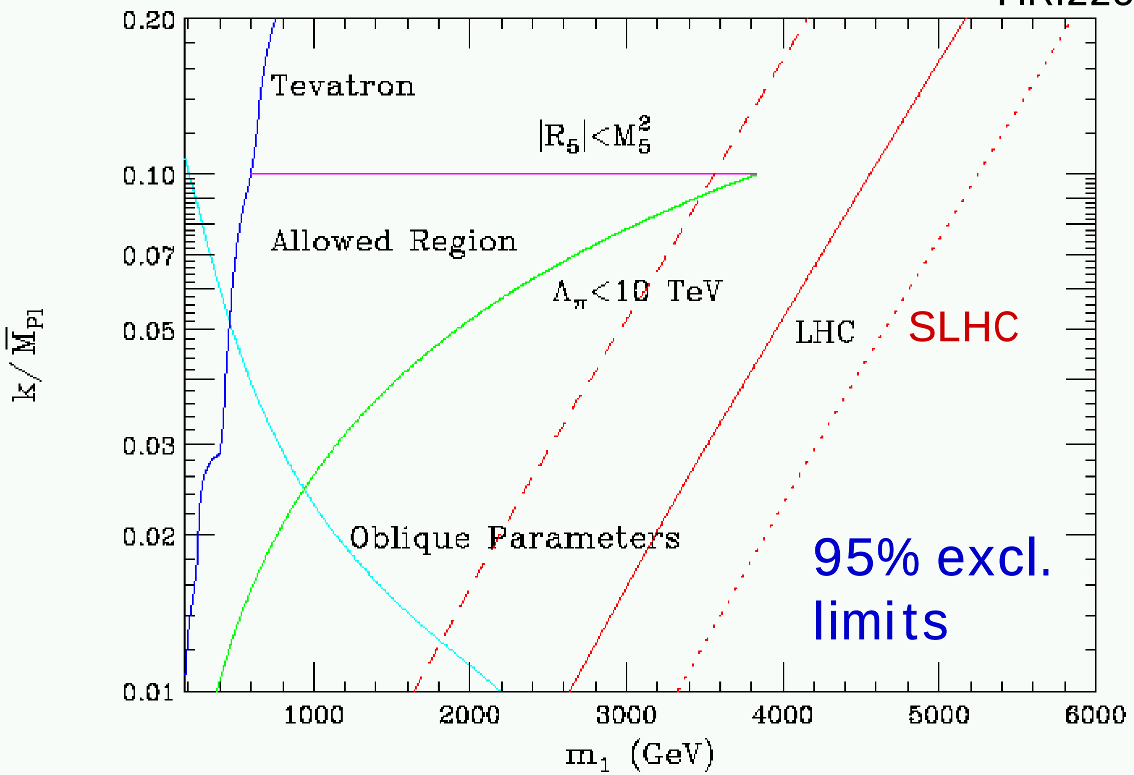
T. Rizzo (hep-ph/0305077)

SLHC: Extra Dimension Scenarios

Randall Sundrum model

- Predicts KK graviton resonances
- k= curvature of the 5-dim. Space
- m_1 = mass of the first KK state

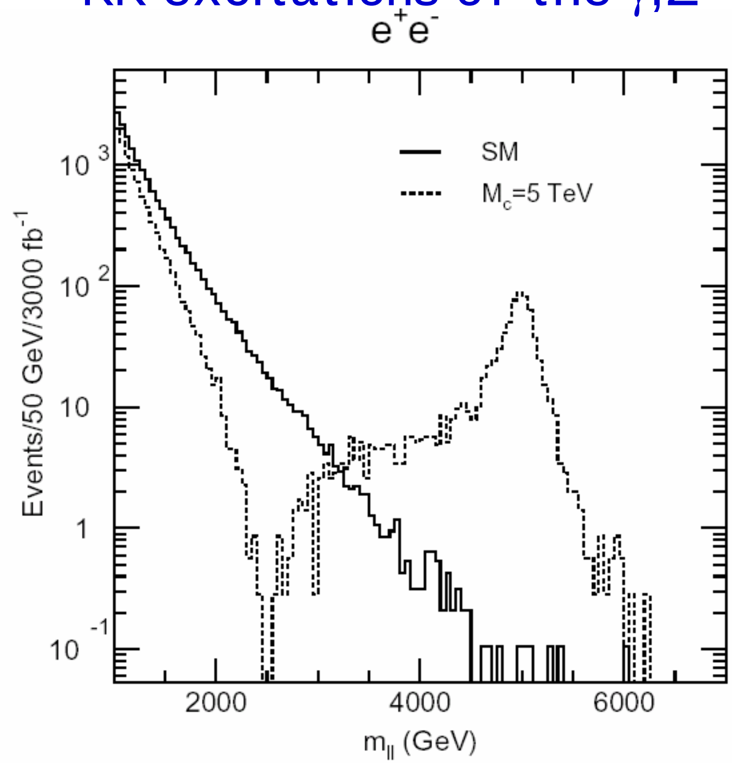
T.Rizzo



100→1000 fb^{-1}: Increase in reach by 25%

TeV scale ED's

- KK excitations of the γ,Z

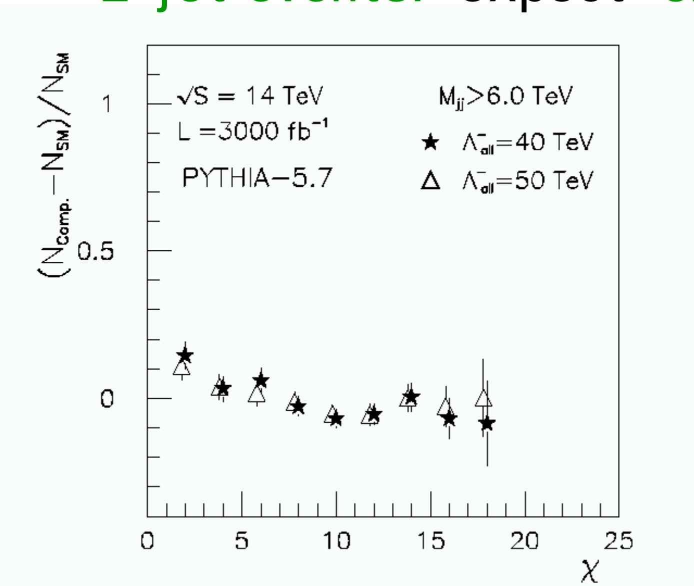


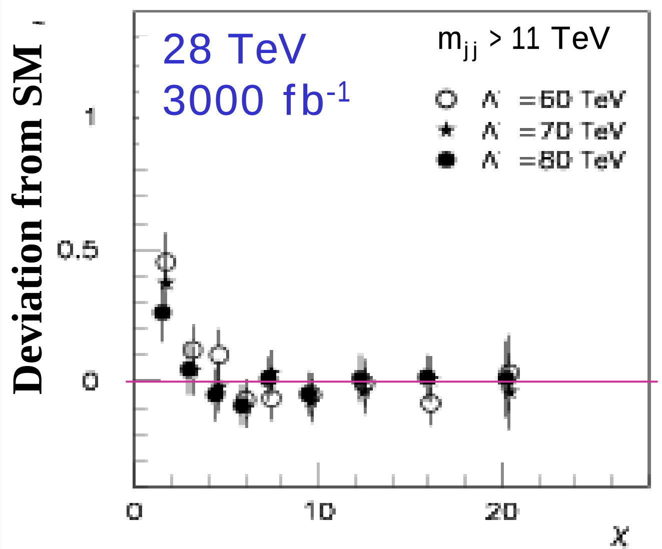
Direct:	LHC/600 fb^{-1}	6 TeV
	SLHC/6000 fb^{-1}	7.7 TeV
Interf:	SLHC/6000 fb^{-1}	20 TeV

Compositeness

$\sqrt{\hat{s}} << \Lambda$: contact interactions $qq \rightarrow qq$

2-jet events: expect excess of high-E_T centrally produced jets.





$$\chi = \frac{1+|\cos\theta^*|}{1-|\cos\theta^*|}$$

θ* angle btw jet & beam
If contact interactions
→ excess at low χ

95% CL	14 TeV 300 fb^{-1}	14 TeV 3000 fb^{-1}	28 TeV 300 fb^{-1}	28 TeV 3000 fb^{-1}
Λ (TeV)	40	60	60	≈ 85

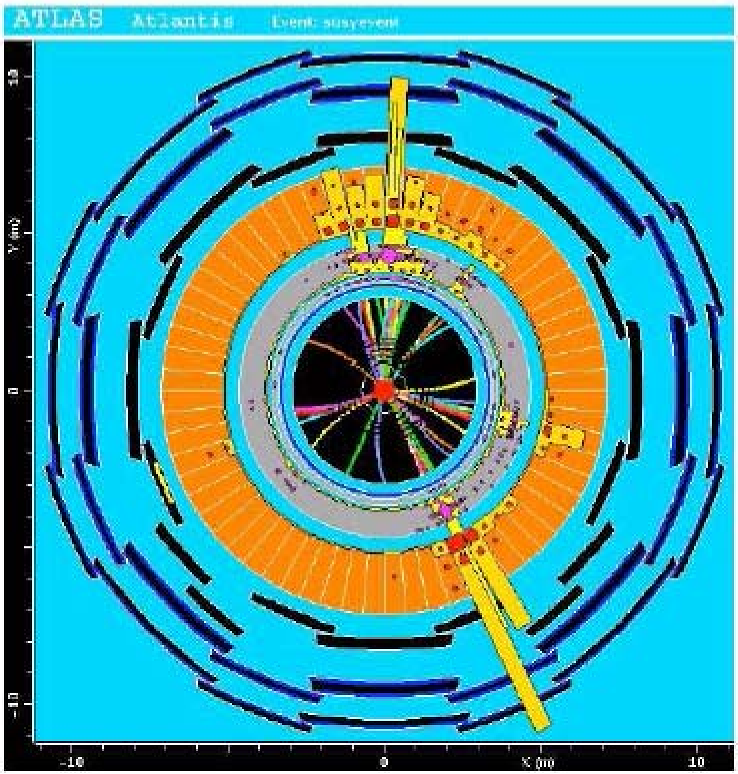
- For this study, no major detector upgrade needed at SLHC (but b-jet tag may be important)

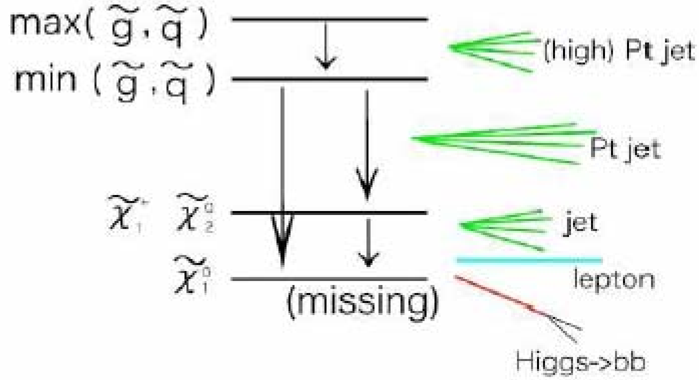
Supersymmetry:

SUSY could be at the rendez-vous very early on

M_{sp}(GeV)	σ (pb)	Evts/yr
500	100	10^6-10^7
1000	1	10^4-10^5
2000	0.01	10^2-10^3

$10\ fb^{-1}$





event topologies of SUSY

	multi	leptons
$\not{E}_T$ +	High P_T jets +	b-jets
		τ-jets

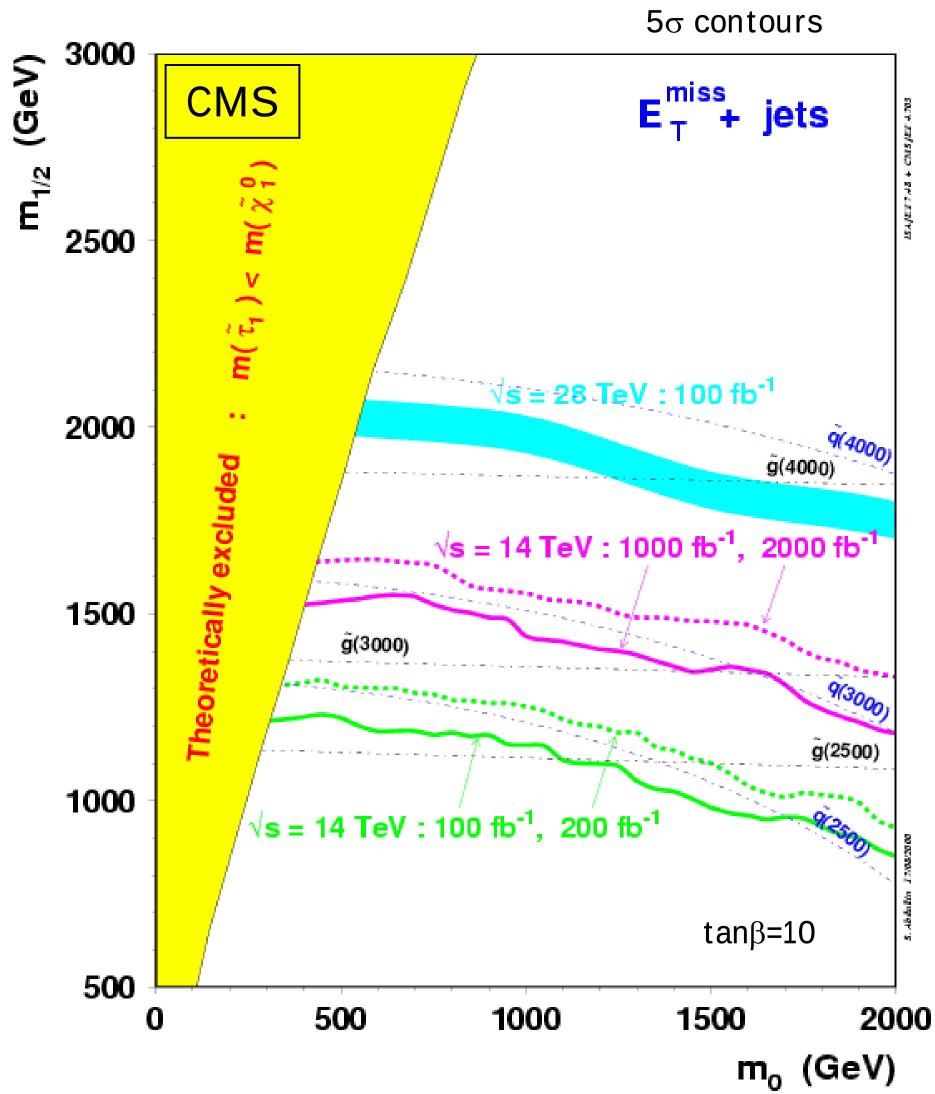
Main signal: lots of activity (jets, leptons, taus, missing E_T)

In many cases: evidence for new physics will be very prominent

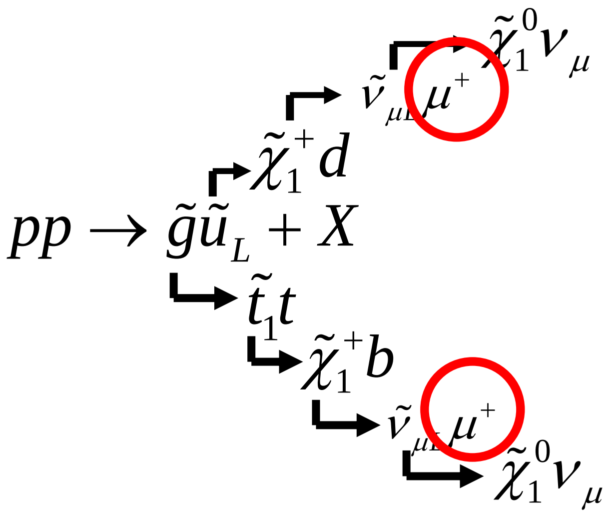
Supersymmetry Reach: LHC and SLHC

Impact of the SLHC
Extending the discovery region by roughly 0.5 TeV i.e. from
~2.5 TeV → 3 TeV

This extension involved high E_T jets/leptons and missing E_T
⇒ Not compromised by increased pile-up at SLHC



Supersymmetry: inclusive signatures

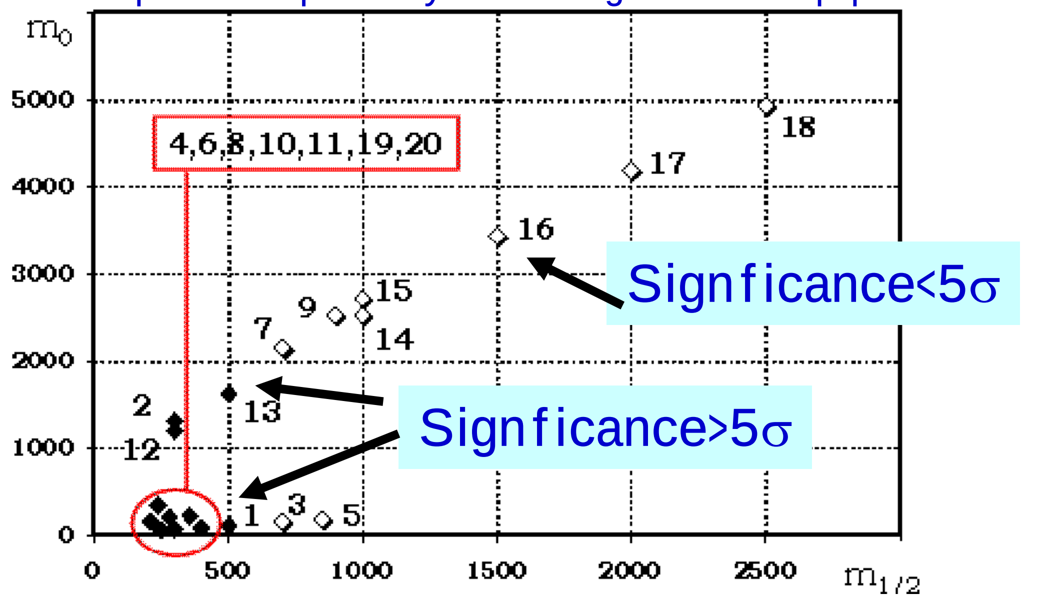


Cuts:
2 same sign isolated
muons, 1 or 2 jets and missing E_T

set	miss. E_T, GeV	E_{T,jet_1}, GeV	E_{T,jet_3}, GeV	P_{T,μ_1}, GeV	P_{T,μ_2}, GeV
1	> 200	> 0	> 170	> 20	> 10
2	> 100	> 300	> 100	> 10	> 10

Study signal excess expected over SM background

test points inspired by M. Battaglia et al. hep-ph/0306219



m_0 Universal scalar mass at GUT scale
$m_{1/2}$ Universal gaugino mass at GUT scale

A 5σ discovery is possible for $m_{1/2}$ < 650 GeV with 10 fb^{-1}

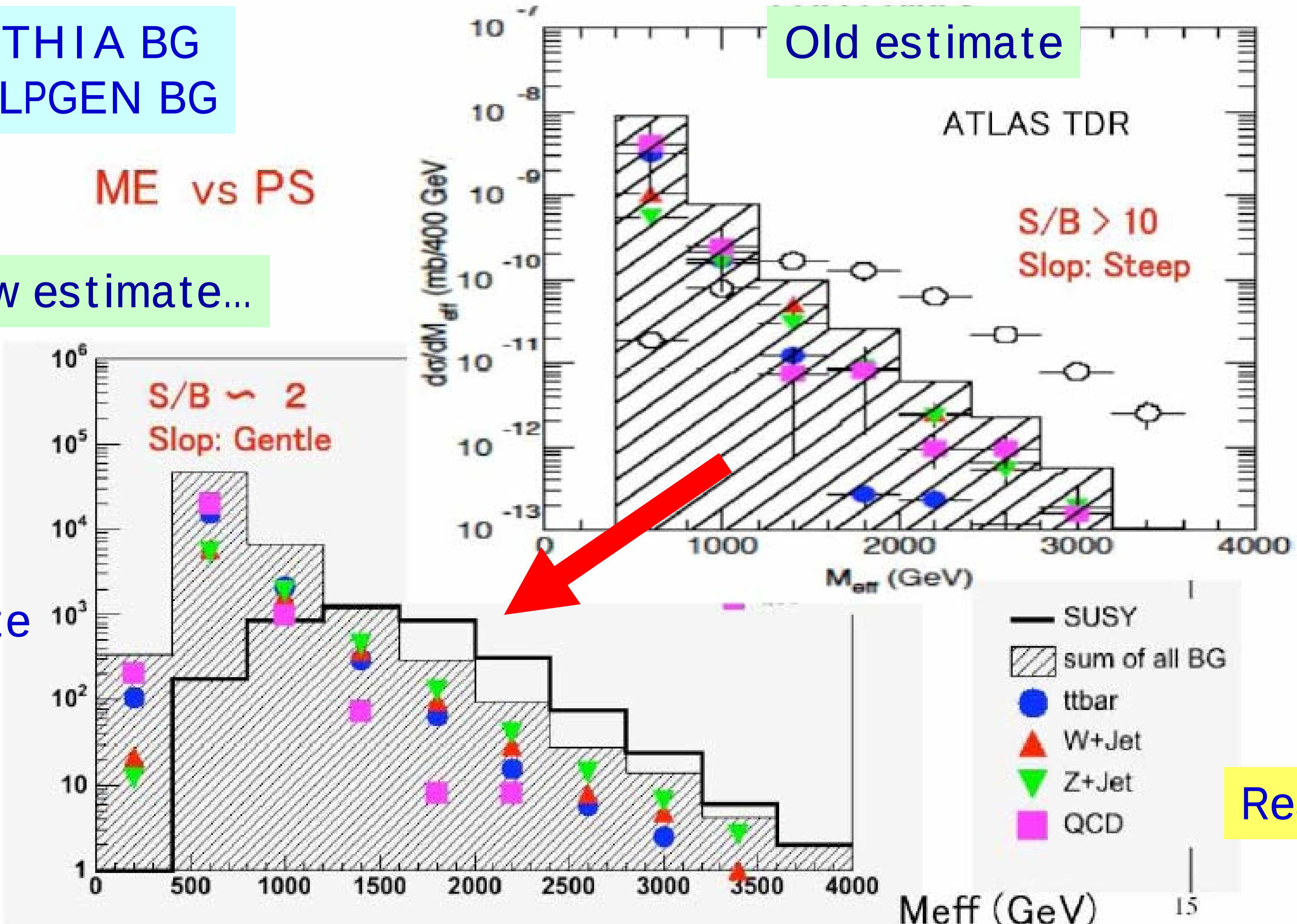
Warning: “Background effects”

Old PYTHIA BG
New ALPGEN BG

ME vs PS

New estimate...

All jets
Final state



Reach lower?

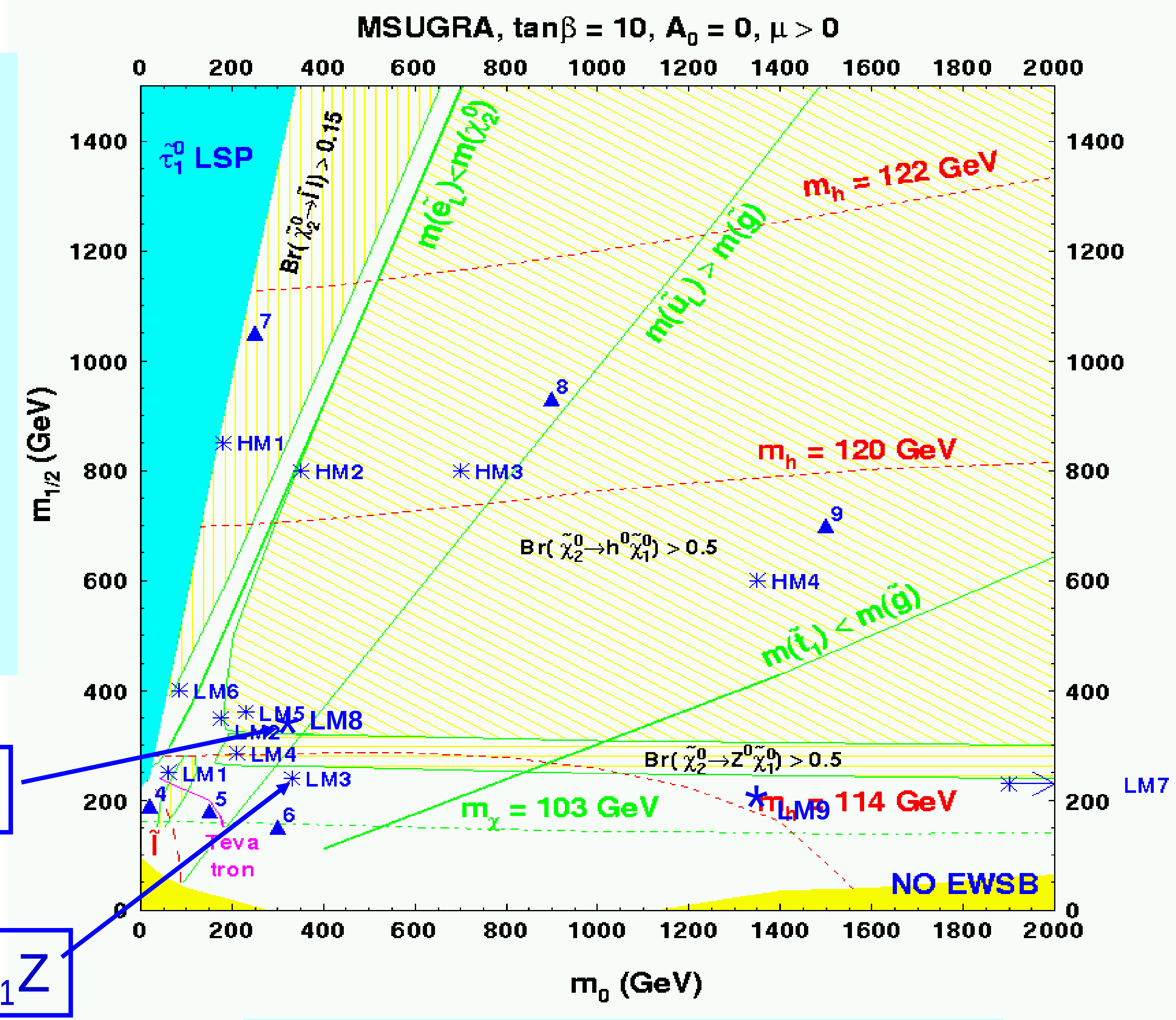
$$M_{\text{eff}} = \Sigma_i \left| p_{T(i)} \right| + \not{E}_T$$

SUSY Benchmark Points for PTDR Studies

CMS: preparation for Physics TDR (2006)

Important: different topologies/decay modes, i.e. on different signatures

Selection of 13 Points
Low mass LM1→LM9
High mass HM1→HM4



$\chi_2 \to \chi_1 h$

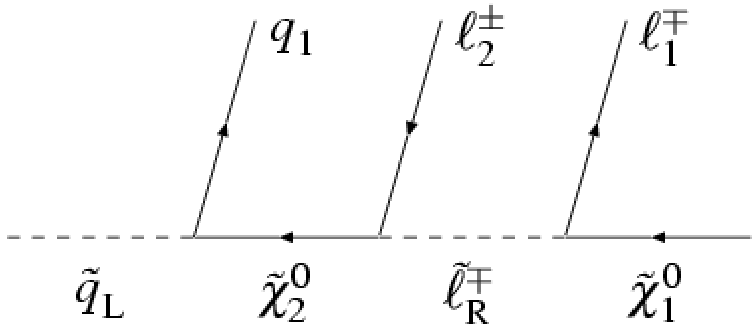
$\chi_2 \to \chi_1 Z$

Not on CMSSM WMAP lines!

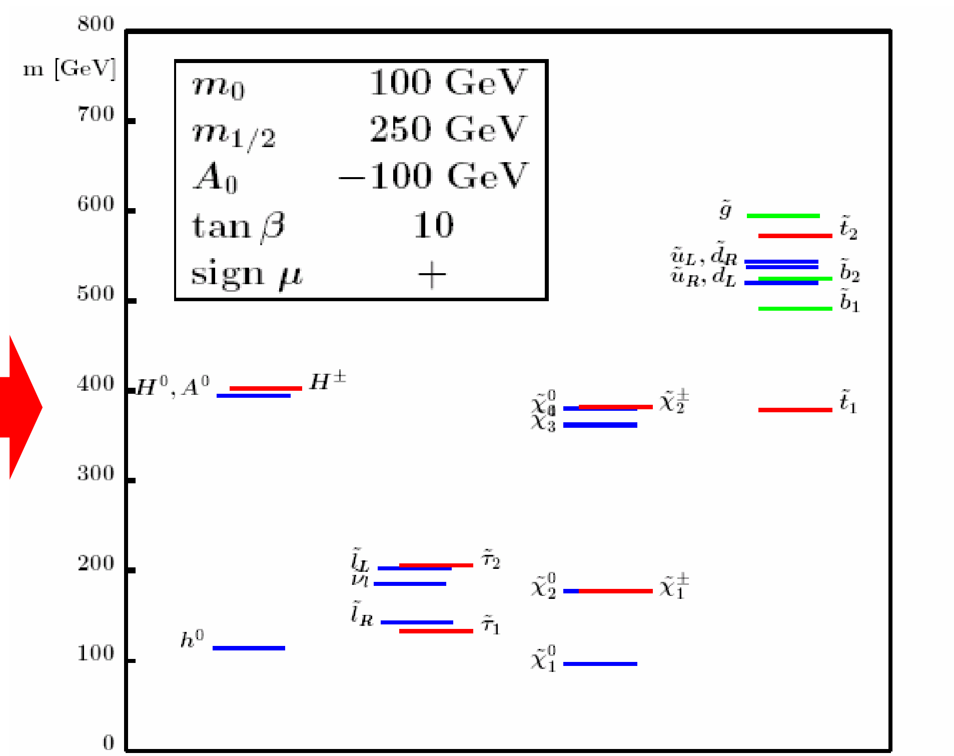
⇒Details in benchmark talk on Monday

SUSY studies: Benchmark points

LHC: complicated by decay chains for squarks and gluons



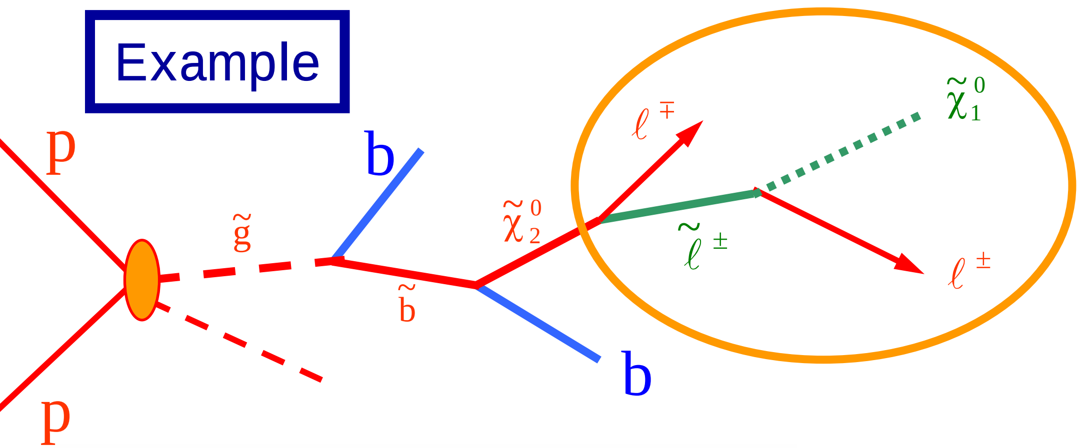
Examples worked out for SPS1a (point B) in ATLAS/CMS

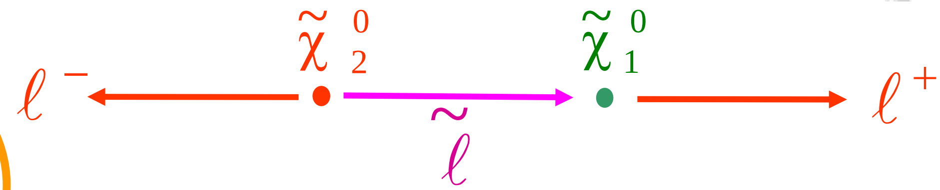


LHC will see all squarks, H,A and may see most gauginos

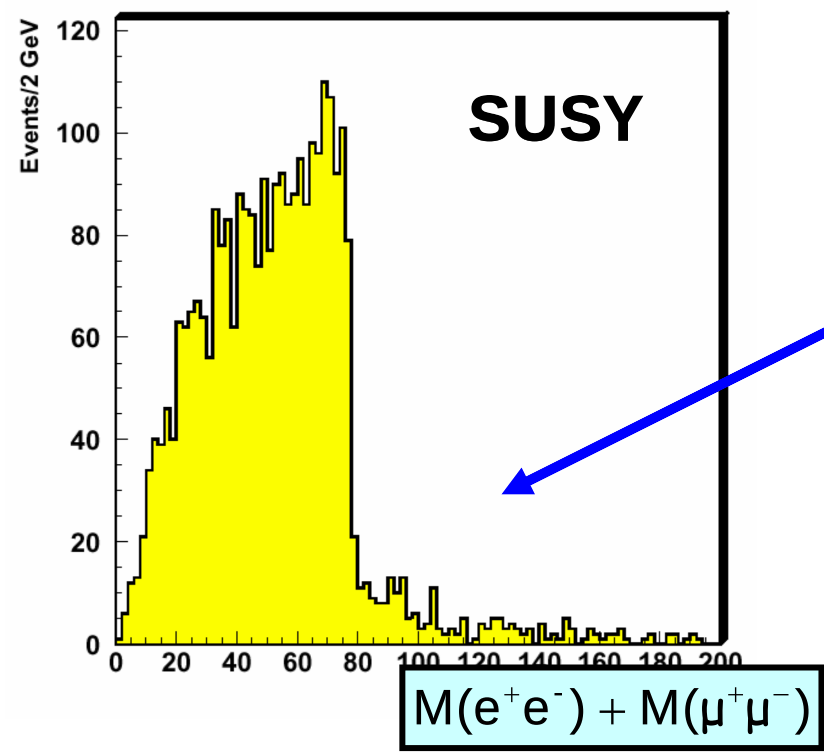
Sparticle Reconstruction

Example





Problem χ_1^0 measurement! It escapes detection like a neutrino!
Use kinematic formulae...



$$M_{\ell^+\ell^-}^{max} = \frac{\sqrt{(M_{\tilde{\chi}_2^0}^2 - M_{\tilde{\ell}}^2)(M_{\tilde{\ell}}^2 - M_{\tilde{\chi}_1^0}^2)}}{M_{\tilde{\ell}}}$$

Don't be afraid of endpoints (it's kinematics) !

General "Edge" Analysis

Analyse many edges of distributions:

$$(m_{ll}^2)^{\rm edge} = \frac{(m_{\tilde\chi_2^0}^2 - m_{\tilde l_R}^2)(m_{\tilde l_R}^2 - m_{\tilde\chi_1^0}^2)}{m_{\tilde l_R}^2}$$

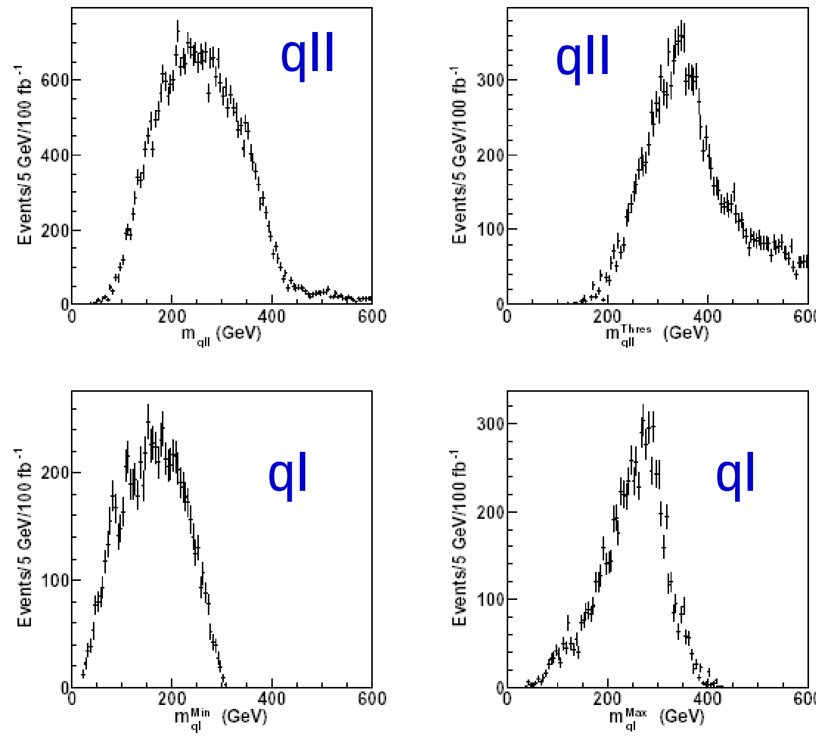
$$(m_{qll}^2)^{\rm edge} = \frac{(m_{\tilde q_L}^2 - m_{\tilde\chi_2^0}^2)(m_{\tilde\chi_2^0}^2 - m_{\tilde\chi_1^0}^2)}{m_{\tilde\chi_2^0}^2}$$

$$(m_{ql}^2)^{\rm edge}_{\rm min} = \frac{(m_{\tilde q_L}^2 - m_{\tilde\chi_2^0}^2)(m_{\tilde\chi_2^0}^2 - m_{\tilde l_R}^2)}{m_{\tilde\chi_2^0}^2}$$

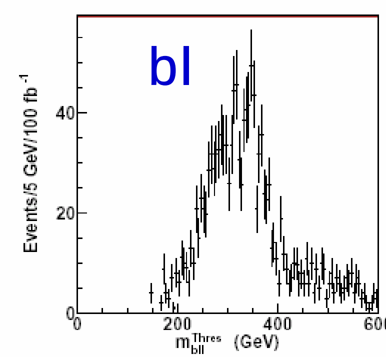
$$(m_{ql}^2)^{\rm edge}_{\rm max} = \frac{(m_{\tilde q_L}^2 - m_{\tilde\chi_2^0}^2)(m_{\tilde l_R}^2 - m_{\tilde\chi_1^0}^2)}{m_{\tilde l_R}^2}$$

$$(m_{qll}^2)^{\rm thres} = [(m_{\tilde q_L}^2 + m_{\tilde\chi_2^0}^2)(m_{\tilde\chi_2^0}^2 - m_{\tilde l_R}^2)(m_{\tilde l_R}^2 - m_{\tilde\chi_1^0}^2)$$
$$-(m_{\tilde q_L}^2 - m_{\tilde\chi_2^0}^2)\sqrt{(m_{\tilde\chi_2^0}^2 + m_{\tilde l_R}^2)^2(m_{\tilde l_R}^2 + m_{\tilde\chi_1^0}^2)^2 - 16 m_{\tilde\chi_2^0}^2 m_{\tilde l_R}^4 m_{\tilde\chi_1^0}^2}$$
$$+2m_{\tilde l_R}^2(m_{\tilde q_L}^2 - m_{\tilde\chi_2^0}^2)(m_{\tilde\chi_2^0}^2 - m_{\tilde\chi_1^0}^2)]/(4m_{\tilde l_R}^2 m_{\tilde\chi_2^0}^2)$$

SPS1a



Min,max refer to choice of lepton



Solve numerically equations ⇒ derive masses

Mass Measurements

LHC/ILC document: hep-ph/0410364

300 fb^{-1}@LHC

Takes into account 1% energy scale uncertainties

ΔM values in GeV

	LHC
$\Delta m_{\tilde{\chi}_1^0}$	4.8
$\Delta m_{\tilde{\chi}_2^0}$	4.7
$\Delta m_{\tilde{\chi}_4^0}$	5.1
$\Delta m_{\tilde{l}_R}$	4.8
$\Delta m_{\tilde{\ell}_L}$	5.0
Δm_{τ_1}	5-8
$\Delta m_{\tilde{q}L}$	8.7
$\Delta m_{\tilde{q}R}$	7-12
$\Delta m_{\tilde{b}_1}$	7.5
$\Delta m_{\tilde{b}_2}$	7.9
$\Delta m_{\tilde{g}}$	8.0

...but strongly depends on the chosen point

SFITTER →

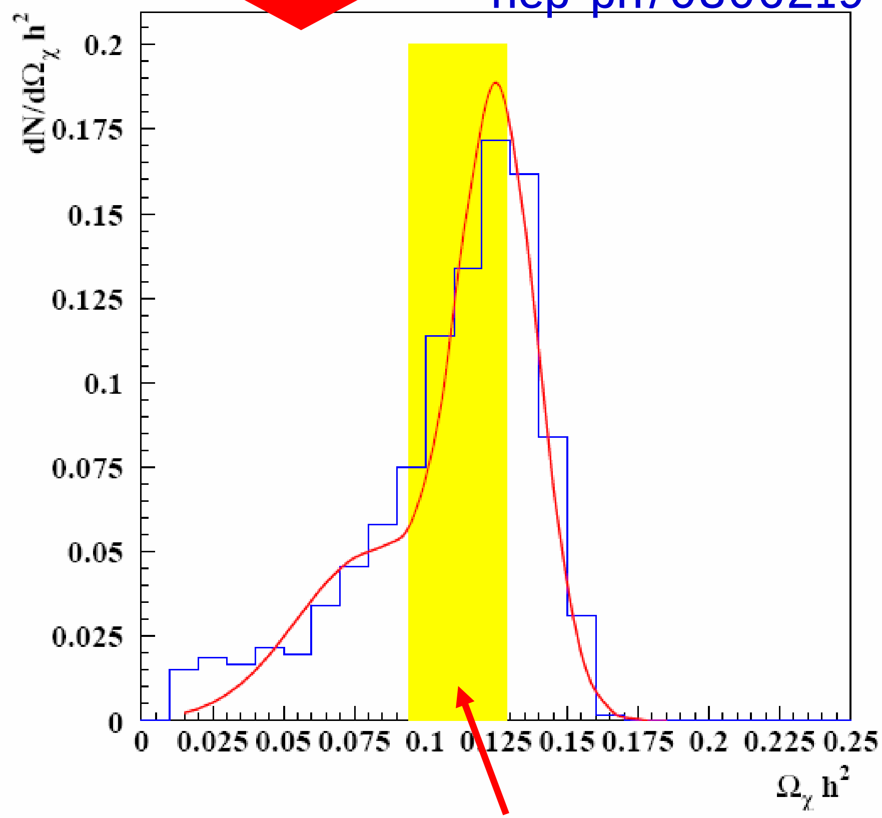
	SPS1a	StartFit	LHC	Δ_{LHC}
m_0	100	500	100.03	4.0
$m_{1/2}$	250	500	249.95	1.8
$\tan\beta$	10	50	9.87	1.3
A_0	-100	0	-99.29	31.8

	LHC	LC	LHC+LC	SPS1a
$\tan\beta$	10.22±9.1	10.26±0.3	10.06±0.2	10
M_1	102.45±5.3	102.32±0.1	102.23±0.1	102.2
M_2	191.8±7.3	192.52±0.7	191.79±0.2	191.8
M_3	578.67±15	fixed 500	588.05±11	589.4
$M_{\tilde{\tau}_L}$	fixed 500	197.68±1.2	199.25±1.1	197.8
$M_{\tilde{\tau}_R}$	129.03±6.9	135.66±0.3	133.35±0.6	135.5
$M_{\tilde{\mu}_L}$	198.7±5.1	198.7±0.5	198.7±0.5	198.7
$M_{\tilde{\mu}_R}$	138.2±5.0	138.2±0.2	138.2±0.2	138.2
$M_{\tilde{e}_L}$	198.7±5.1	198.7±0.2	198.7±0.2	198.7
$M_{\tilde{e}_R}$	138.2±5.0	138.2±0.05	138.2±0.05	138.2
$M_{\tilde{q}3_L}$	498.3±110	497.6±4.4	521.9±39	501.3
$M_{\tilde{t}_R}$	fixed 500	420±2.1	411.73±12	420.2
$M_{\tilde{b}_R}$	522.26±113	fixed 500	504.35±61	525.6
$M_{\tilde{q}2_L}$	550.72±13	fixed 500	553.31±5.5	553.7
$M_{\tilde{c}_R}$	529.02±20	fixed 500	531.70±15	532.1
$M_{\tilde{s}_R}$	526.21±20	fixed 500	528.90±15	529.3
$M_{\tilde{q}1_L}$	550.72±13	fixed 500	553.32±6.5	553.7
$M_{\tilde{u}_R}$	528.91±20	fixed 500	531.70±15	532.1
$M_{\tilde{d}_R}$	526.2±20	fixed 500	528.90±15	529.3
A_τ	fixed 0	-202.4±89.5	352.1±171	-253.5
A_t	-507.8±91	-501.95±2.7	-505.24±3.3	-504.9
A_b	-784.7±35603	fixed 0	-977±12467	-799.4
m_A	fixed 500	399.1±0.9	399.1±0.8	399.1
μ	345.21±7.3	344.34±2.3	344.36±1.0	344.3

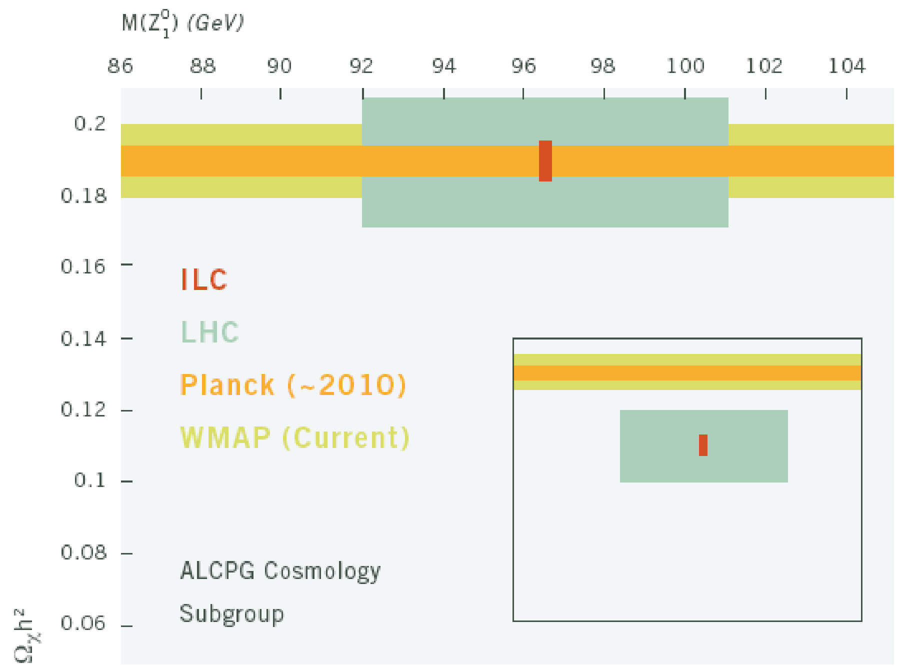
Dark Matter

- Fit the model parameters of the assumed SUSY breaking model to the measured SUSY particle masses $\rightarrow \Omega_\chi h^2$
- Typical precision:

hep-ph/0306219

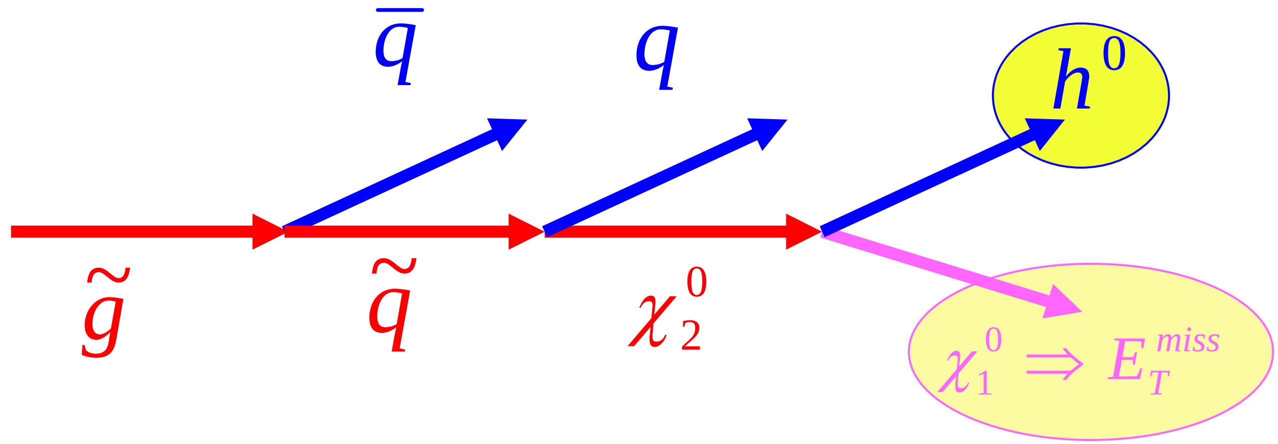


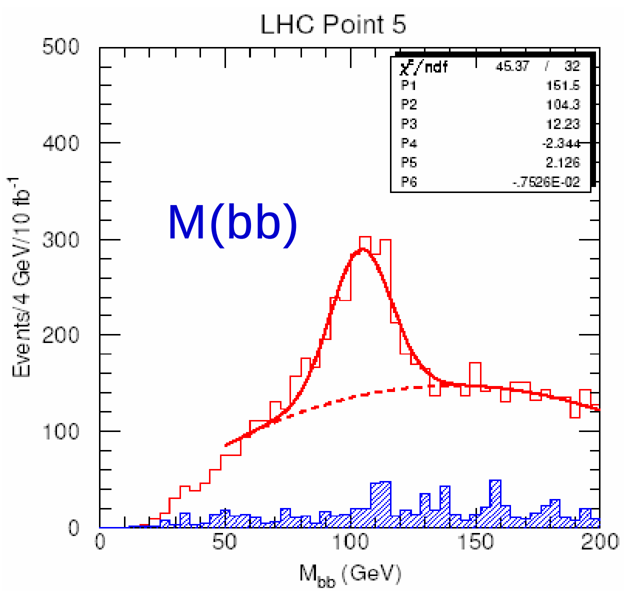
WMAP

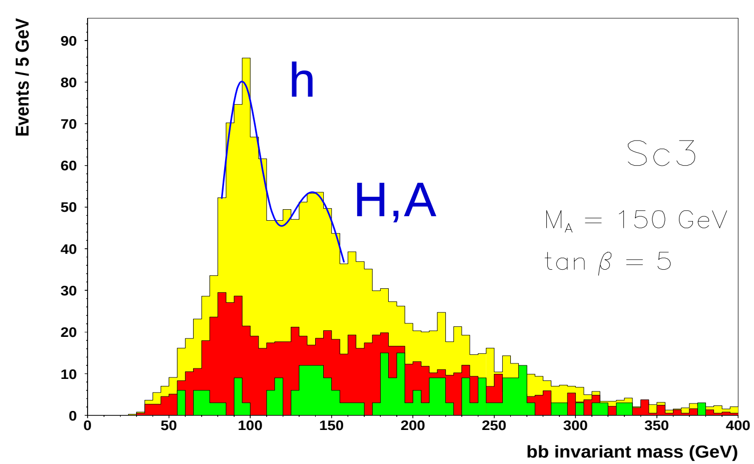


ILC: international linear collider
e+e- collider @ 0.5-1 TeV

Decay chain to h^0



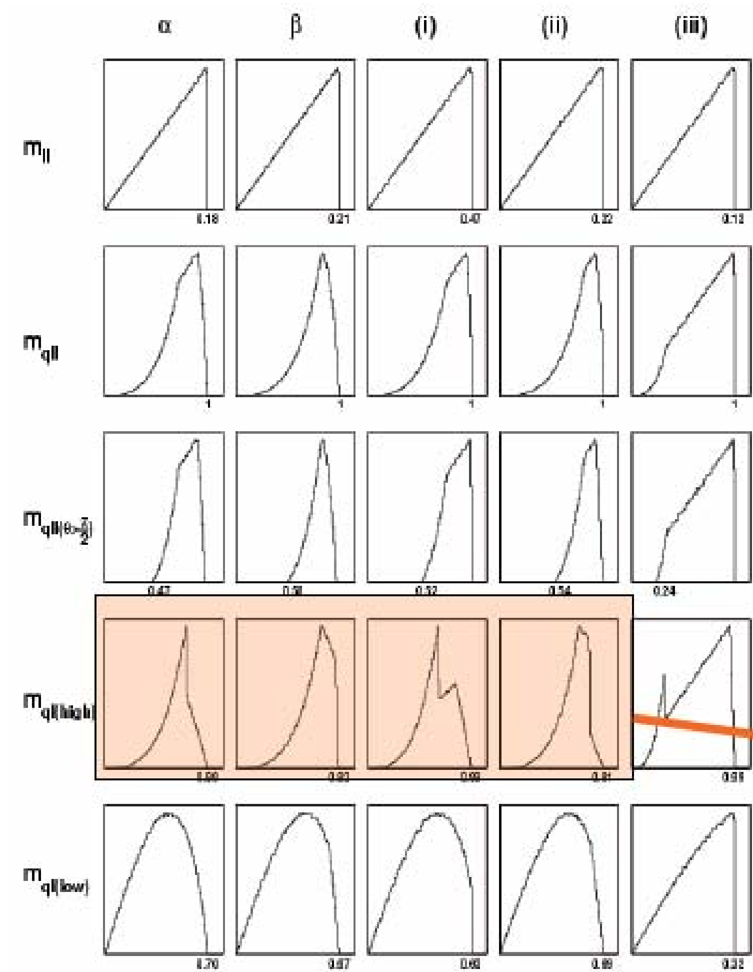




Could be a discovery channel for the higgs

Phenomenology Endpoints in Different models…

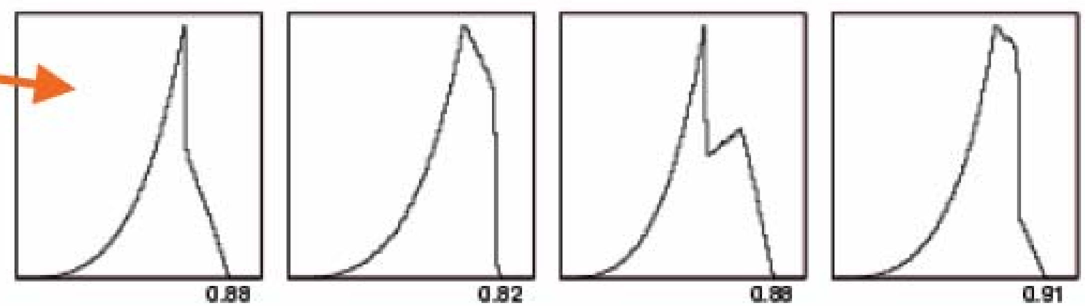
Ch. Lester/HCP05



What different invariant mass distributions look like for a selection of plausible supersymmetric models.

(hep-ph/0410303) D. Miller et al

Note that some edges are not simple!



New: use shapes, not just endpoints (D. Miller/SUSY05)

use edges+ inclusive cross sections, Markov Chain techniques

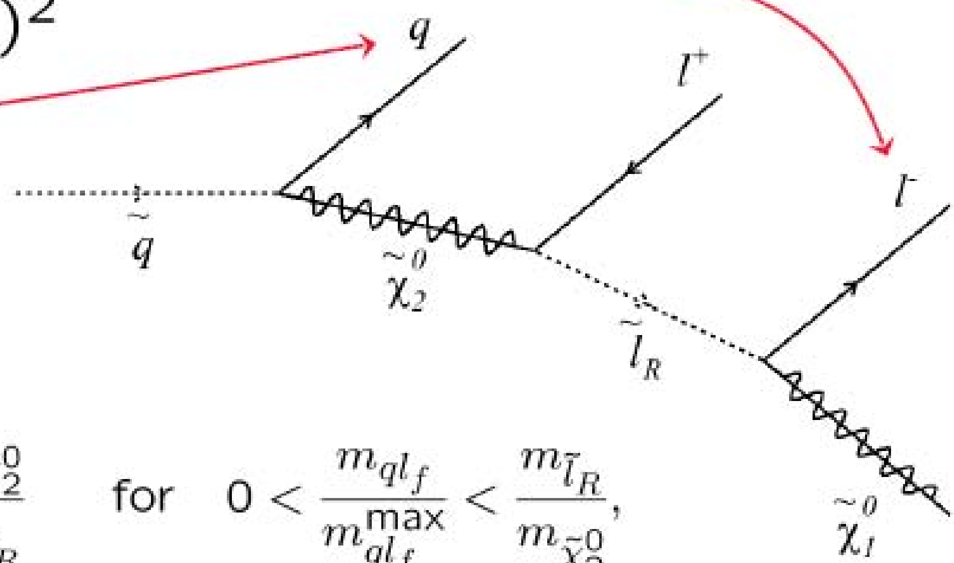
allow for end-point ambiguity (Lester, Parker, White hep-ph/0508143)

Getting information from the shapes

An example invariant mass distribution

D. Miller / SUSY05

Consider $m_{ql_f} = (p_q + p_{l_f})^2$



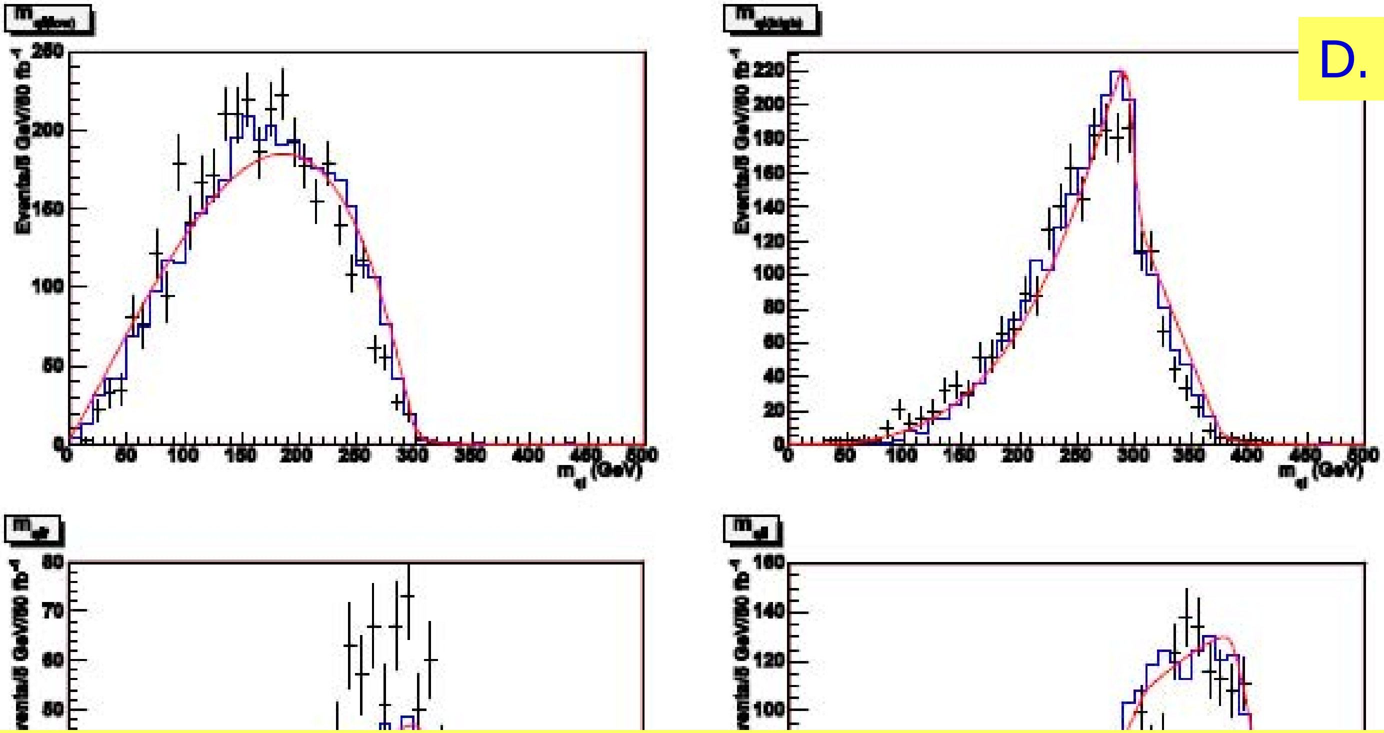
$$\frac{1}{\Gamma}\frac{\partial \Gamma}{\partial m_{ql_f}^2} = \begin{cases} \dfrac{2}{(m_{ql_f}^{\max})^2 a} \ln \dfrac{m_{\tilde{\chi}_2^0}}{m_{\tilde{l}_R}} & \text{for} \quad 0 < \dfrac{m_{ql_f}}{m_{ql_f}^{\max}} < \dfrac{m_{\tilde{l}_R}}{m_{\tilde{\chi}_2^0}}, \\ \dfrac{2}{(m_{ql_f}^{\max})^2 a} \ln \dfrac{m_{ql_f}^{\max}}{m_{ql_f}} & \text{for} \quad \dfrac{m_{\tilde{l}_R}}{m_{\tilde{\chi}_2^0}} < \dfrac{m_{ql_f}}{m_{ql_f}^{\max}} < 1, \end{cases}$$

$$\left[a \equiv 1 - \frac{m_{\tilde{l}_R}^2}{m_{\tilde{\chi}_2^0}^2} \right]$$

This invariant mass is not easily measurable (just a simple example) but shows the non-linear edge

ATLFAST detector level

D. Miller/SUSY05



Compare analytical calculations with MC

Use as
- A guide to the measurement of endpoints
- A fit function to be compared with the observed differential distributions and extract the masses directly… must understand backgrounds well

There will be more in the LHC data to exploit than used so far

Here we used extra cuts of lepton P_T to try and distinguish the two leptons.

Some combinotoric background remains because we were very conservative

SLHC: tackle difficult points

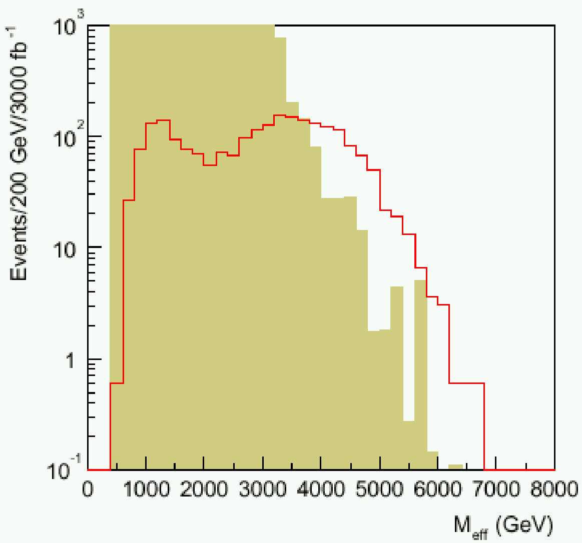
Squarks: 2.0-2.4 TeV Gluino: 2.5 TeV
Can discover the squarks at the LHC but cannot really study them

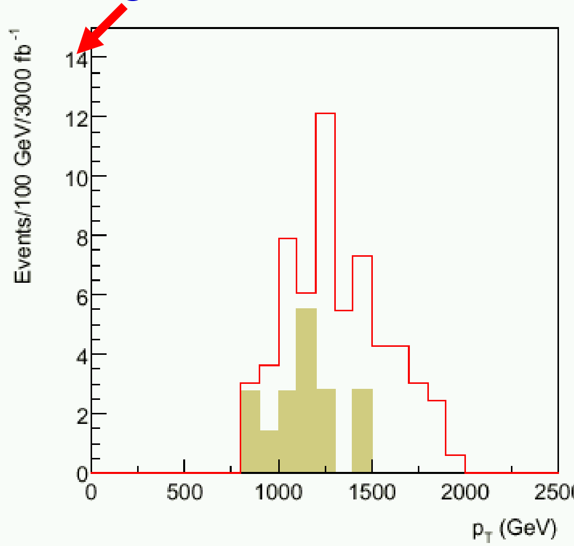
$$M_{eff} = E_T^{miss} + \sum_{jets} E_{T,jet} + \sum_{leptons} E_{T,lepton}$$

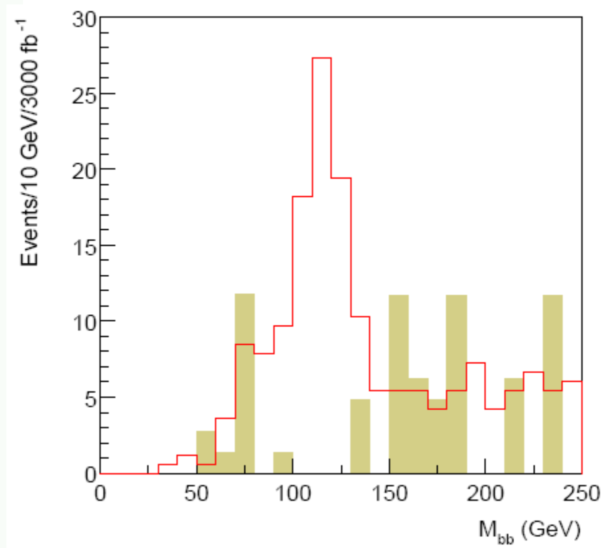
P_t >700 GeV & E_t^{miss}>600 GeV
P_t of the hardest jet

eg. Point K in hep-ph/0306219

signal







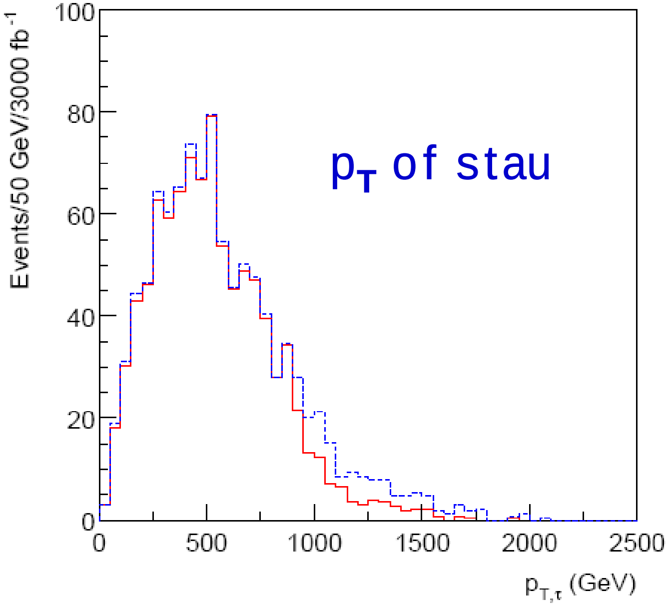
Inclusive: M_{eff} > 4000 GeV
S/B = 500/100 (3000 fb^{-1})

Exclusive channel
$\tilde{q}\tilde{q} \rightarrow \chi_1^0 \chi_1^0 qq$
S/B =120/30 (3000fb^{-1})

Higgs in χ_2 decay
$\chi_2 \rightarrow \chi_1 h$ becomes
Visible at 3000 fb^{-1}

Measurements become possible

SLHC: tackle difficult points

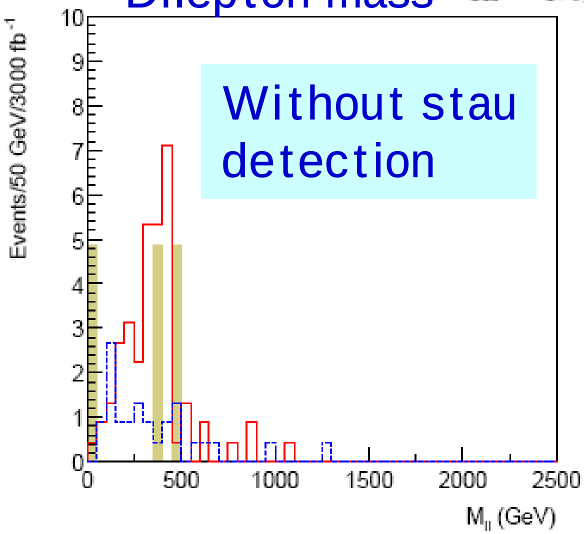


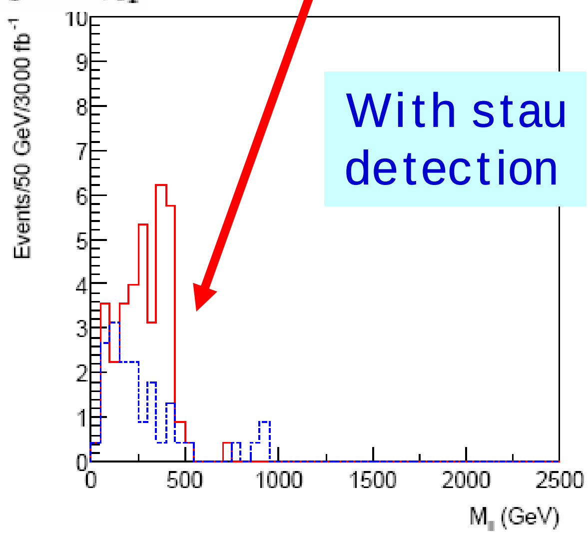
eg. Point H in hep-ph/0306219

Squarks, gluino mass > 2.5 TeV
χ-stau mass difference small < 1 GeV
$\Rightarrow$ Stau lives long

$$\sqrt{\frac{(M^2_{\tilde{\chi}^0_2} - M^2_{\tilde{\ell}_L})(M^2_{\tilde{\ell}_L} - M^2_{\tilde{\chi}^0_1})}{M^2_{\tilde{\ell}_L}}} = 447.3\,\mathrm{GeV}$$

Dilepton mass $\tilde{q}_L \to q\tilde{\chi}^0_2 \to q\ell^+\ell^-\tilde{\chi}^0_1$.





End point measurements are possible with large luminosity

Is it SUSY?

e.g. Cheng, Matchev, Schmaltz hep-ph/0205314

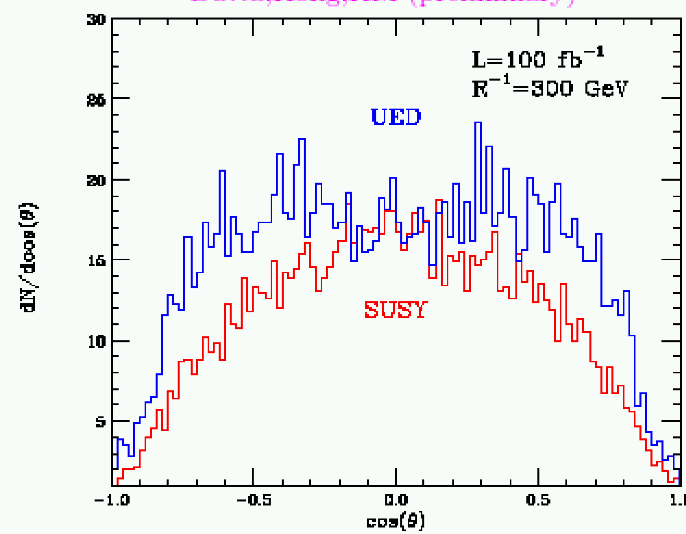
UED⇒ all particles in the bulk
Phenomenology: a KK tower pattern from ED's which looks like supersymmetry:
Can the LHC tell distinguish?

Tools: Cross sections factor 8 higher than SUSY/ spin of the "sparticles"/ No heavy higgses/ mass splitting small/pattern repeates at higher energies...

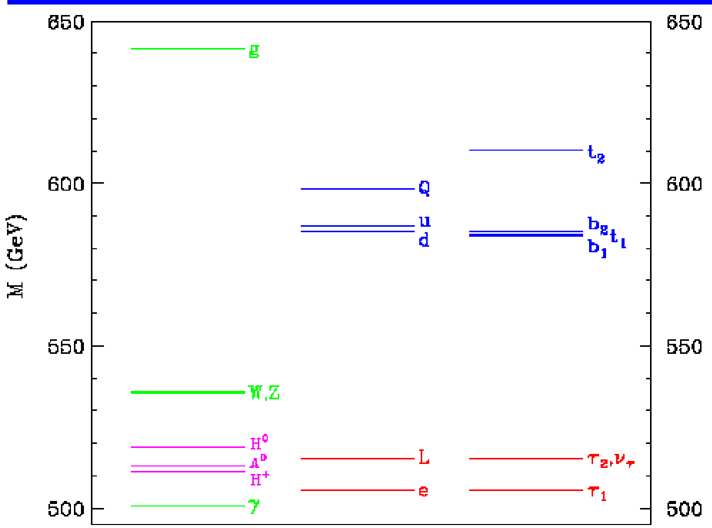
SUSY versus UED at the LHC

- Cuts:
  - $E_{\mu^+} + E_{\mu^-} > 40$ GeV (similar with 60 and 80 GeV).
  - $|\eta(\mu)| < 2.5$.
- We can recover to some extent the difference in shapes!

Datta,Kong,KM (preliminary)



Backgrounds? Other tricks? Strong KK production?



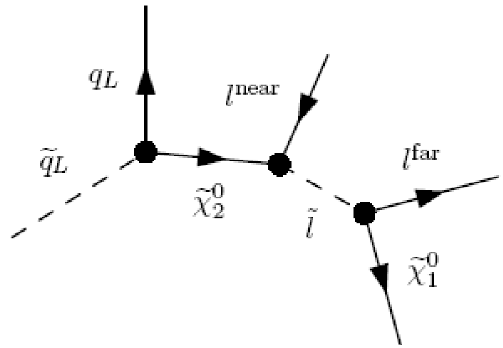
Study muon angular distribution in (approx.) smuon rest frame

First result looks encouraging
Also: A. Bar hep-ph/0405052 lepton charge asymmetry

Studies of spin sensitive variables needed!

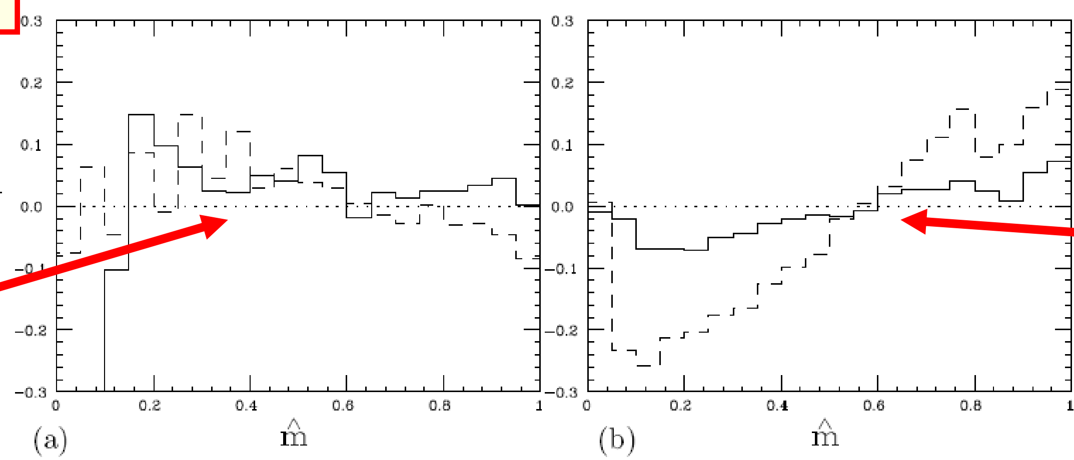
Spin

Look for variables sensitive to the particle spin eg. lepton charge asymmetries in squark/KKquark decay chains Barr hep-ph/0405052; Smillie & Webber hep-ph/0507170



$$A = \frac{(l^+q)-(l^-q)}{(l^+q)+(l^-q)}$$

KK like Spectrum (small mass Splitting)



SPS1a benchmark type spectrum

Method works better or worse depending mass differences between the particles

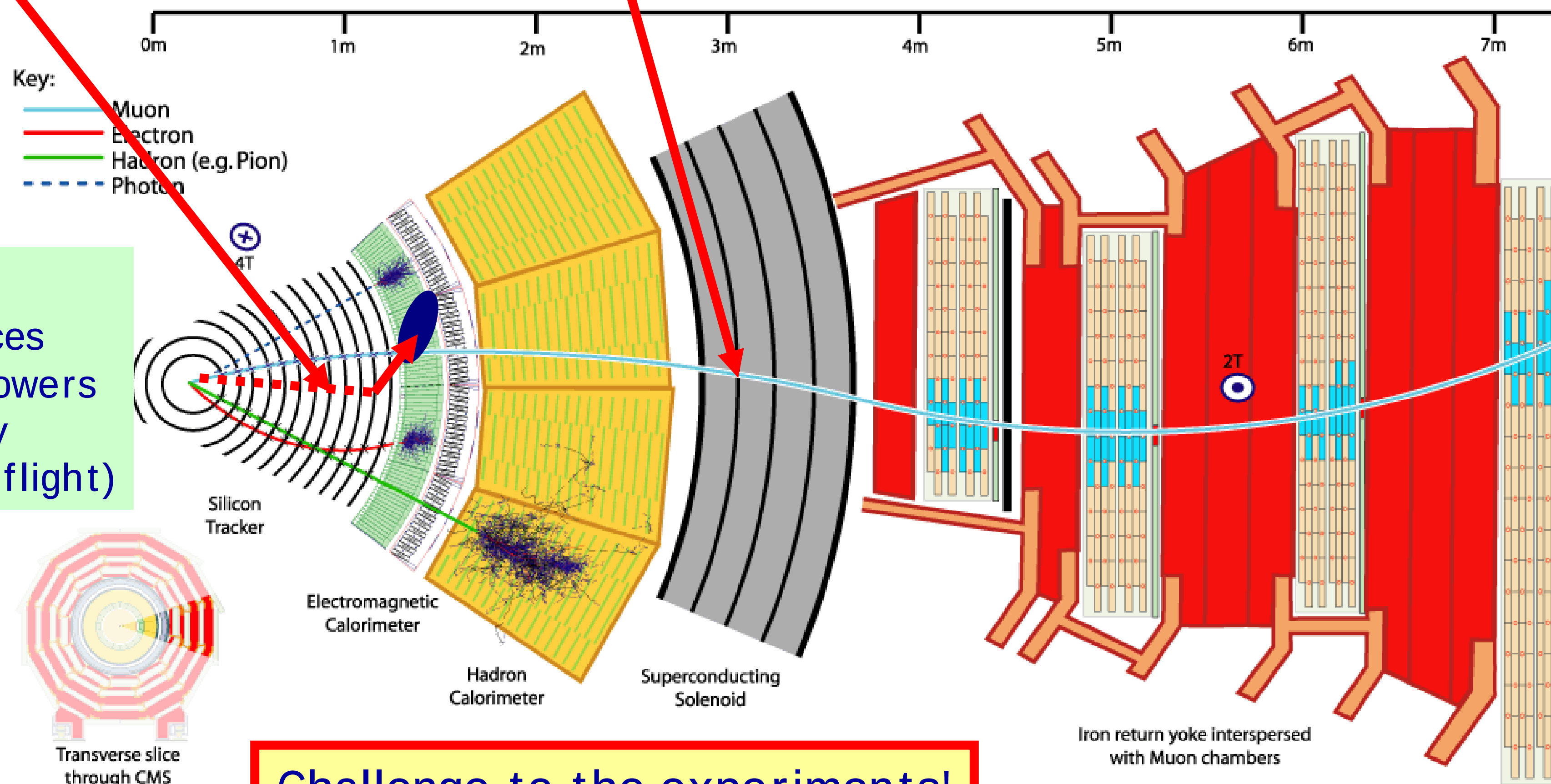
More ideas/variables for determining the spin @LHC welcome!

Recent Studies: Special signatures

In some models/phase space the gravitino is the LSP
Then the NLSP (neutralino, Stau lepton) can live 'long'
Eg. $\chi \rightarrow \gamma +$ gravitino or heavy (slow) stau slepton

GMSB or GDM models

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

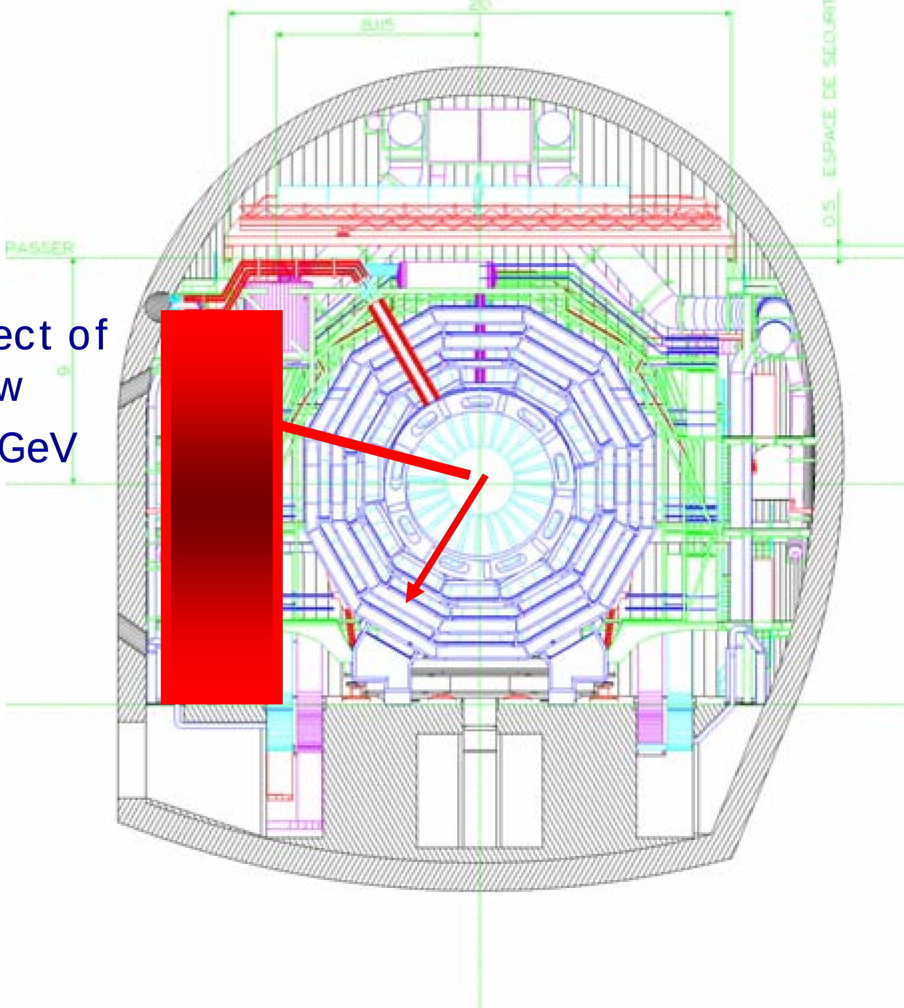


Challenge to the experiments!

Long lived sparticles

Some of these heavy long lived heavy sparticles will be stopped in the detector or walls around of the cavern. They will decay after some time: hours-days-weeks-months...

Object of a few 100 GeV



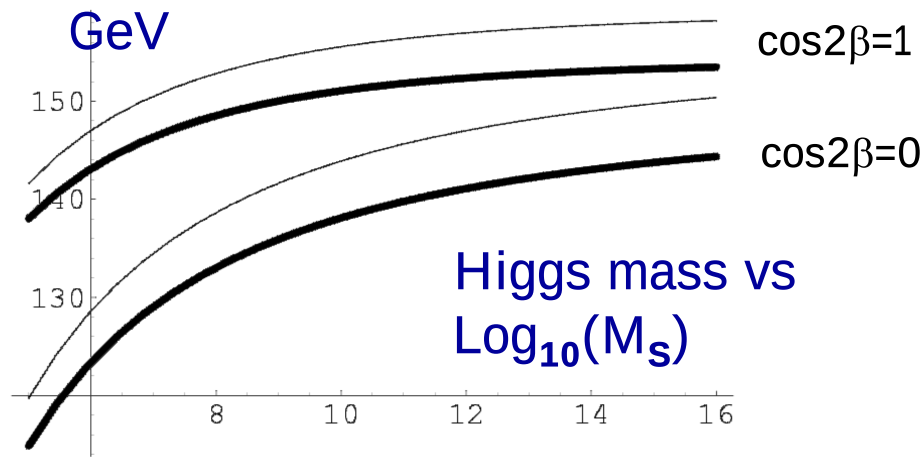
Some benchmark points with Lifetime of 10^4-10^6 sec are being studied:
M Nijori at al (to appear)
ADR, J. Ellis et al. hep-ph/0508198

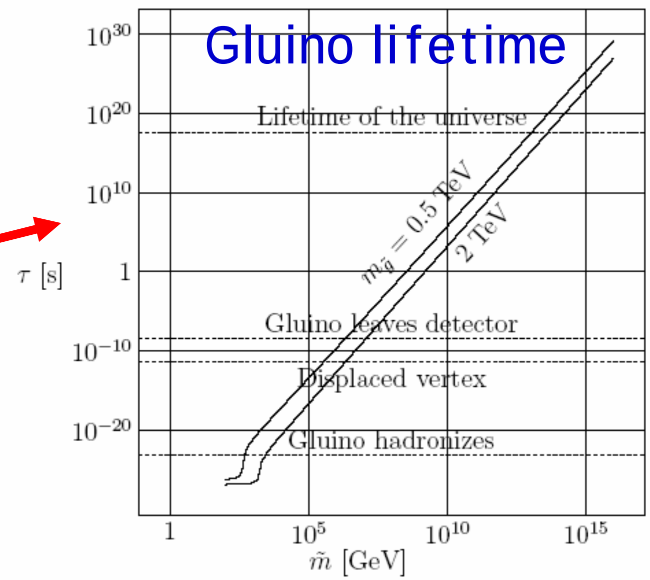
⇒ Ideas: Use the cavern wall or addition of slepton stoppers in the cavern (multi-kton object)

Split Supersymmetry

Arkani-Hamed et al., Giudice et al.

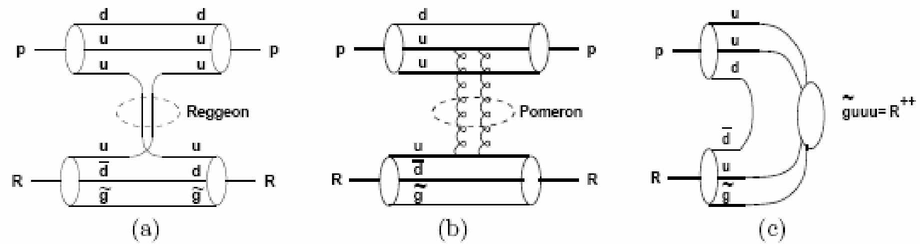
- Assumes nature is fine tuned and SUSY is broken at some high scale
- Motivated by cosmological constant problem and multitude of vacua in string theory (Landscape)
- The only light particles are the Higgs and the gauginos (several 100 GeV to several TeV)
- Interesting gluino phenomenology.
  - Gluino can live long: sec, min, years!
  - R-hadron formation: slow, heavy particles containing a heavy gluino –
  - special interactions with matter…





Can we detect these gluinos at LHC??…

How do these R-hadrons interact with matter?



R-Hadrons

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

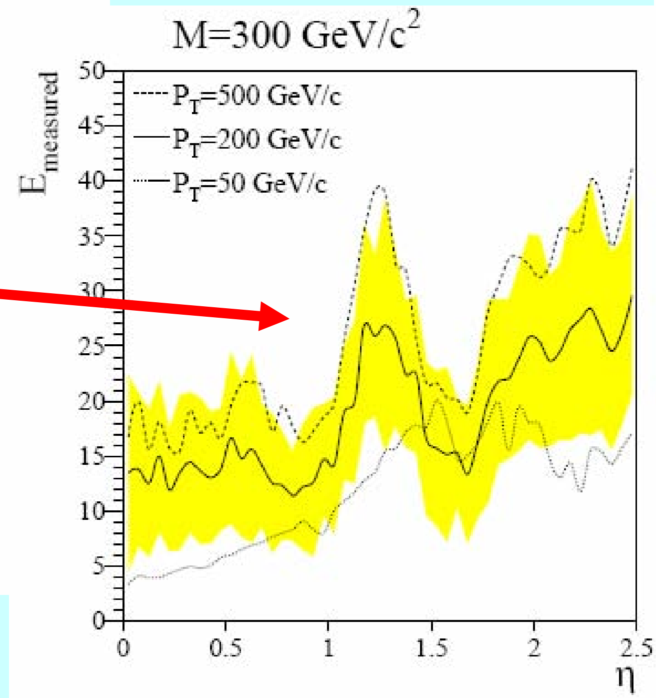
- Gluino interactions suppressed as $1/M^2$
- u,d quarks interact but with a kinetic energy of order 1 GeV

$\Rightarrow$ Hence energy loss reduced while passing through e.g the ATLAS calorimeter only about 10-15% is deposited.

This will be a remarkable signature

Also: charge flip while passing through matter

Need to modify the detector simulation toolkit (Geant4)



Do we understand the travel of heavy particles through matter well enough?

Indicative Physics Reach

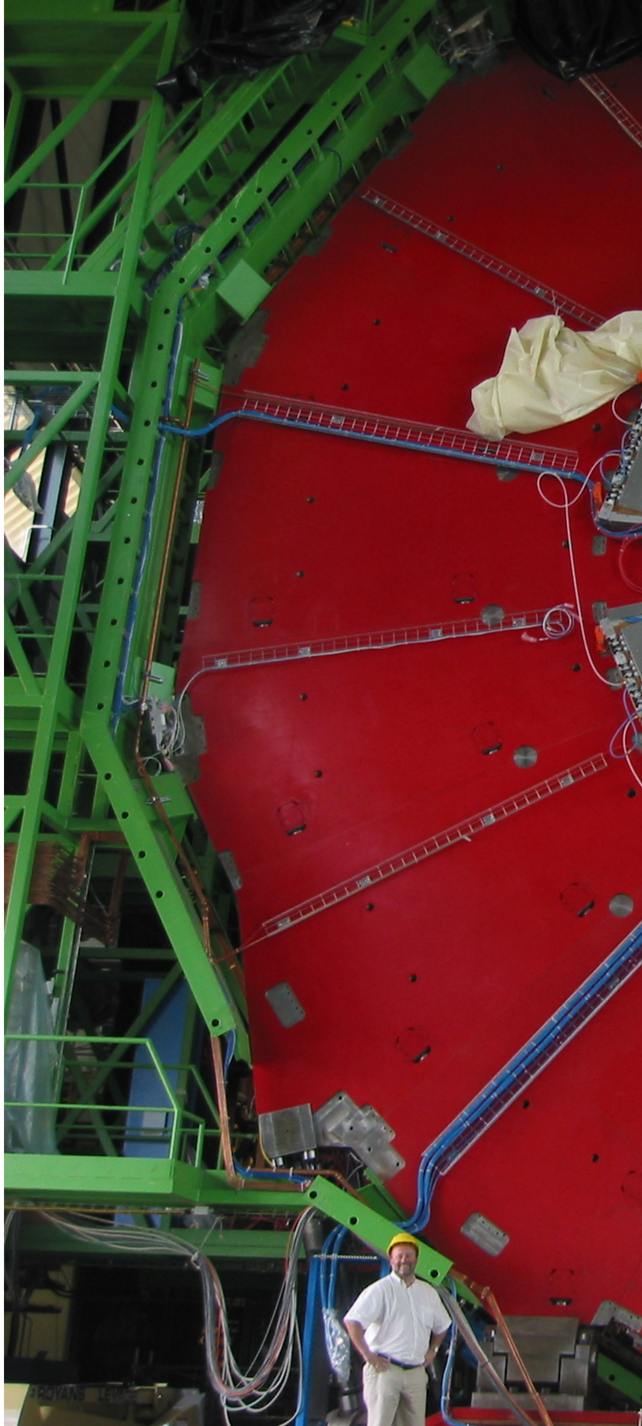
Ellis, Gianotti, ADR
hep-ex/0112004+ updates till 2003

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^{-1}	SLHC 14 TeV 1000 fb^{-1}	28 TeV 100 fb^{-1}	VLHC 40 TeV 100 fb^{-1}	VLHC 200 TeV 100 fb^{-1}	LC 0.8 TeV 500 fb^{-1}	LC 5 TeV 1000 fb^{-1}
Squarks	2.5	3	4	5	20	0.4	2.5
$W_L W_L$	2σ	4σ	4.5σ	7σ	18σ		90σ
Z'	5	6	8	11	35	$8^{\dagger}$	$30^{\dagger}$
Extra-dim (δ=2)	9	12	15	25	65	$5\text{-}8.5^{\dagger}$	$30\text{-}55^{\dagger}$
q*	6.5	7.5	9.5	13	75	0.8	5
Λcompositeness	30	40	40	50	100	100	400
TGC (λ_γ)	0.0014	0.0006	0.0008		0.0003	0.0004	0.00008

† indirect reach
(from precision measurements)

Approximate mass reach machines:
$\sqrt{s}$ = 14 TeV, $L=10^{34}$ (LHC) : up to ≈ 6.5 TeV
$\sqrt{s}$ = 14 TeV, $L=10^{35}$ (SLHC) : up to ≈ 8 TeV
$\sqrt{s}$ = 28 TeV, $L=10^{34}$: up to ≈ 10 TeV



LHC is coming! 2007 pilot run
2008 first physics run

Detector construction progressing well

⇒ BSM/SUSY search one of prime physics goals

What can the LHC do?

- Discover new phenomena in the multi-TeV range (6-7 TeV)
- Discover SUSY up to squark/gluino masses of 2.5 TeV
- Derive sparticle masses via kinematic measurments
- Constrain underlying theory by fitting a model to the data.
- Strongly reduce the "theory phase space"

What will be difficult or impossible at the LHC?

- Measure sleptons with mass larger than 350 GeV
- Disentangle quarks of the first two generations
- Measure the full gaugino spectrum
- Measure the spin parity of all sparticles and all couplings
- Constrain the underlying theory in a model independent way

SLHC will

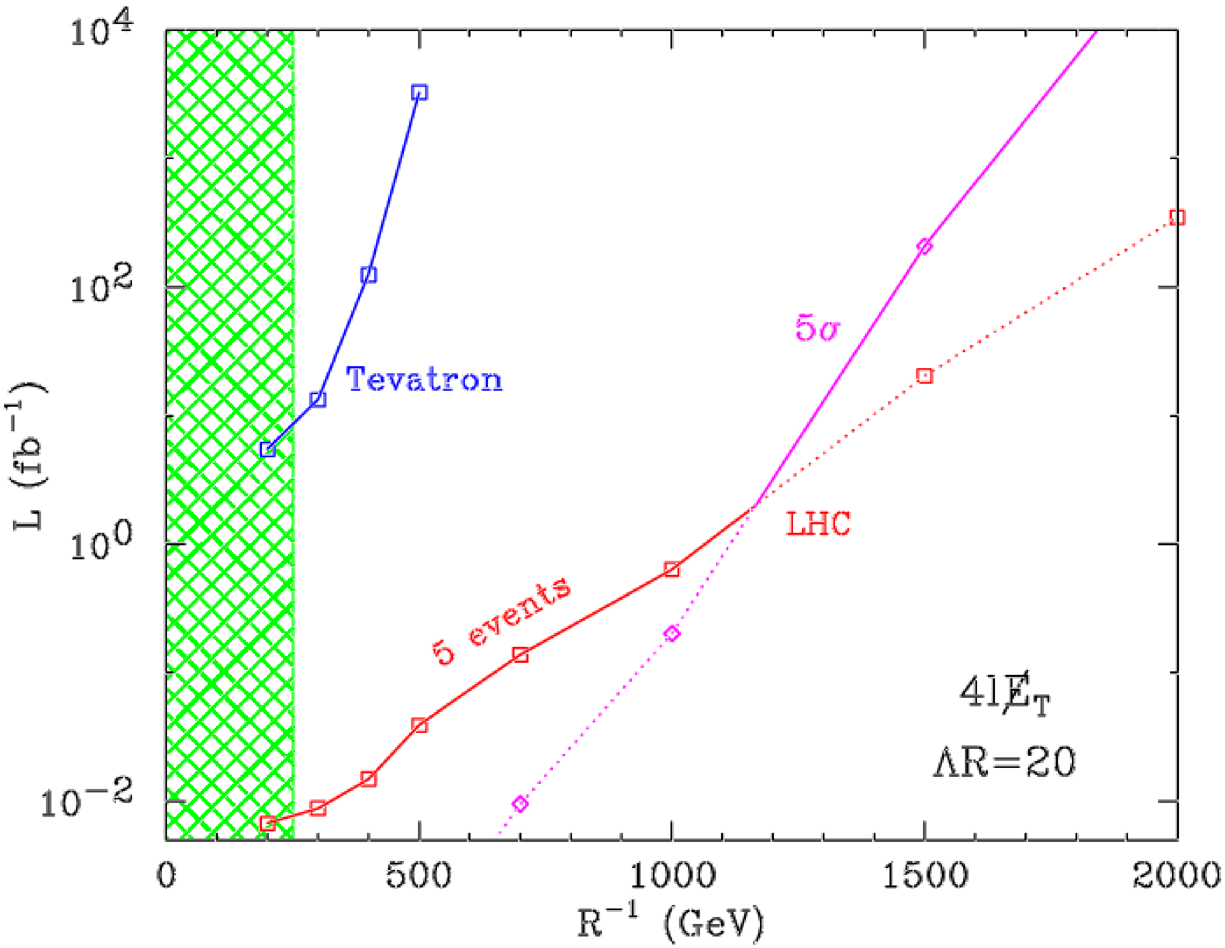
- Extend LHC reach by 30-50%
- Measurements for the "difficult points"

Backup Slides

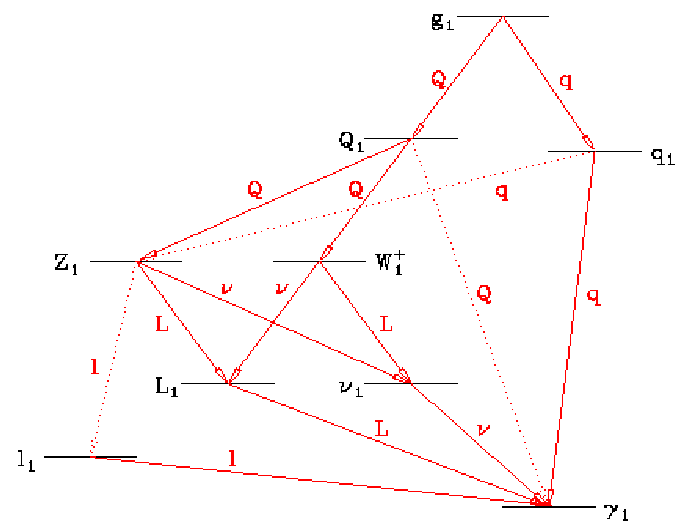
Universal Extra Dimensions

Everybody in the bulk!

e.g. Cheng, Matchev, Schmaltz hep-ph/0205314



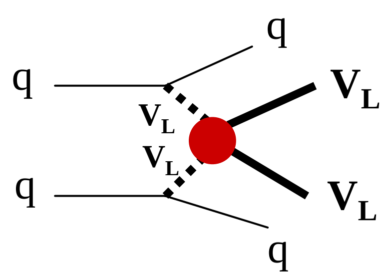
Search: e.g 4 leptons + E_T^{miss}



Increase of the sensitivity to R^{-1} from 1.5 TeV to 2 TeV

Strongly Coupled Vector Boson System

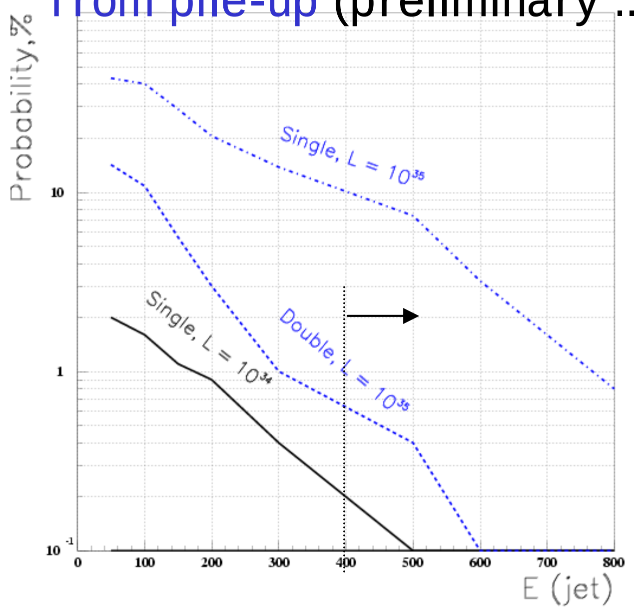
If no Higgs, expect strong $V_L V_L$ scattering (resonant or non-resonant) at $\sqrt{\hat{s}} \approx$ TeV



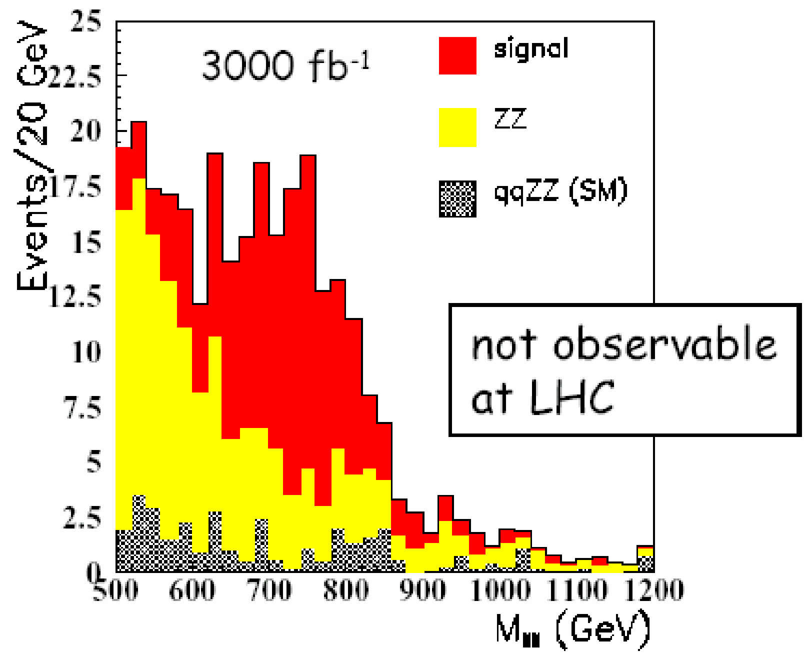
May be difficult at LHC. What about SLHC?

- degradation of fwd jet tag and central jet veto due to huge pile-up
- BUT : factor ~ 10 in statistics → 5-8σ excess in $W^+_L W^+_L$ scattering
  → other low-rate channels accessible

Fake fwd jet tag (|η| > 2) probability from pile-up (preliminary ...)



Scalar resonance $Z_L Z_L \to 4\ell$



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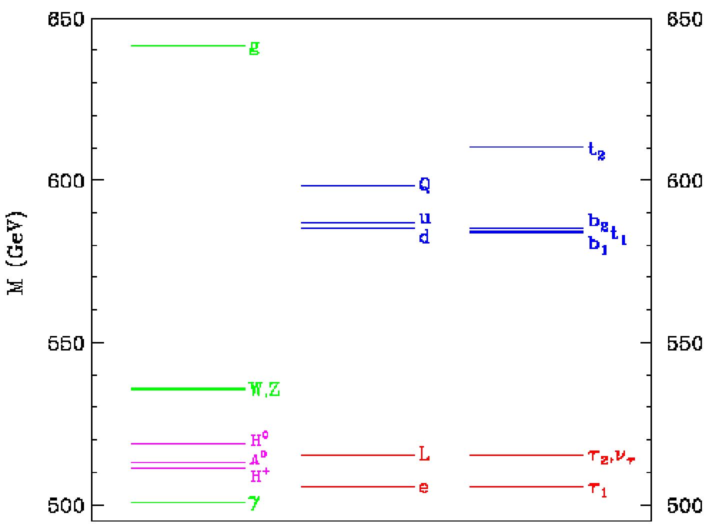

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Also: A. Bar hep-ph/0405052 lepton charge asymmetry

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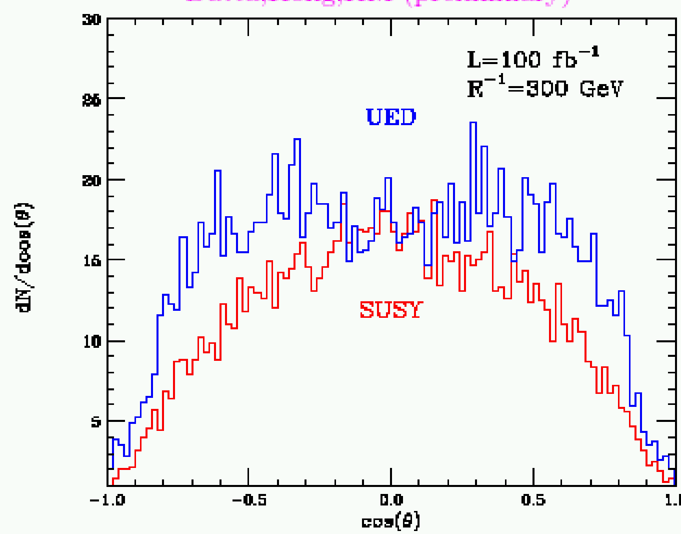
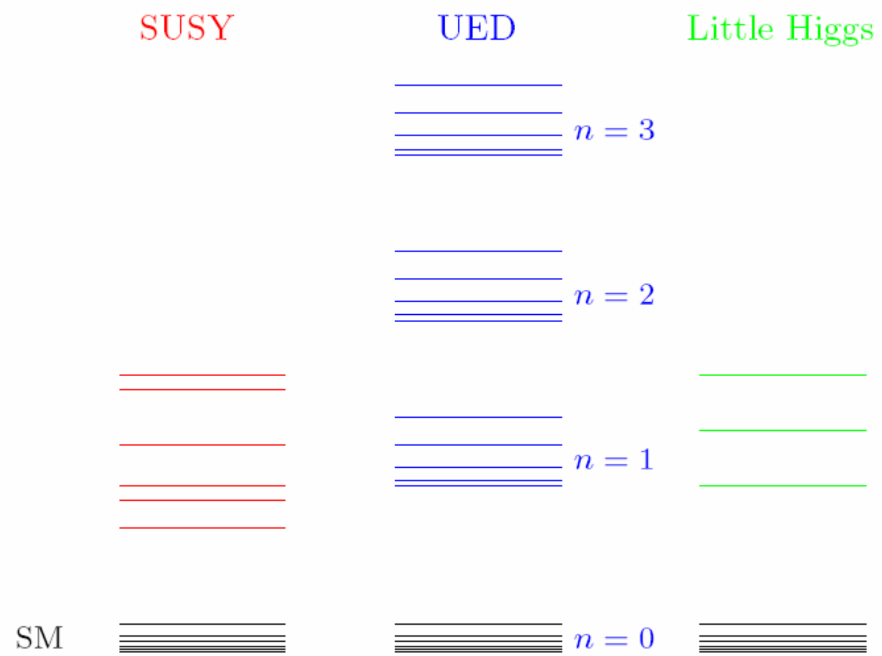


- Backgrounds? Other tricks? Strong KK production?

Studies of spin sensitive variables needed!

Benchmark points



	SUSY	UED	Little Higgs
DM particle	LSP	LKP	LTP
Spin	1/2	1	0
Symmetry	R-parity	KK-parity	T-parity
Mass range	50-200 GeV	600-800 GeV	400-800 GeV

Ok for SUSY

Common benchmarks for:
- UED?
- Little Higgs?
- Split SUSY?

Useful for ATLAS/CMS and LHC/ILC comparisons

General strategy toward understanding the underlying theory
(SUSY as an example ...)

Discovery phase: inclusive searches ... as model-independent as possible

First characterization of model: from general features: Large E_T^{miss} ? Many leptons ? Exotic signatures (heavy stable charged particles, many γ's, etc.) ? Excess of b-jets or τ's ? ...

Interpretation phase:

- reconstruct/look for semi-inclusive topologies, eg.:
  - -- $h \to bb$ peaks (can be abundantly produced in sparticle decays)
  - -- di-lepton edges
  - -- Higgs sector: e.g. $A/H \to \mu\mu, \tau\tau \Rightarrow$ indication about $\tan\beta$, measure masses
  - -- tt pairs and their spectra $\Rightarrow$ stop or sbottom production, gluino $\to$ stop-top
- determine (combinations of) masses from kinematic measurements (e.g. edges ...)
- measure observables sensitive to parameters of theory (e.g. mass hierarchy)

At each step narrow landscape of possible models and get guidance to go on:

- lot of information from LHC data (masses, cross-sections, topologies, etc.)
- consistency with other data (astrophysics, rare decays, etc.)
- joint effort theorists/experimentalists will be crucial

F. Gianotti
LP05

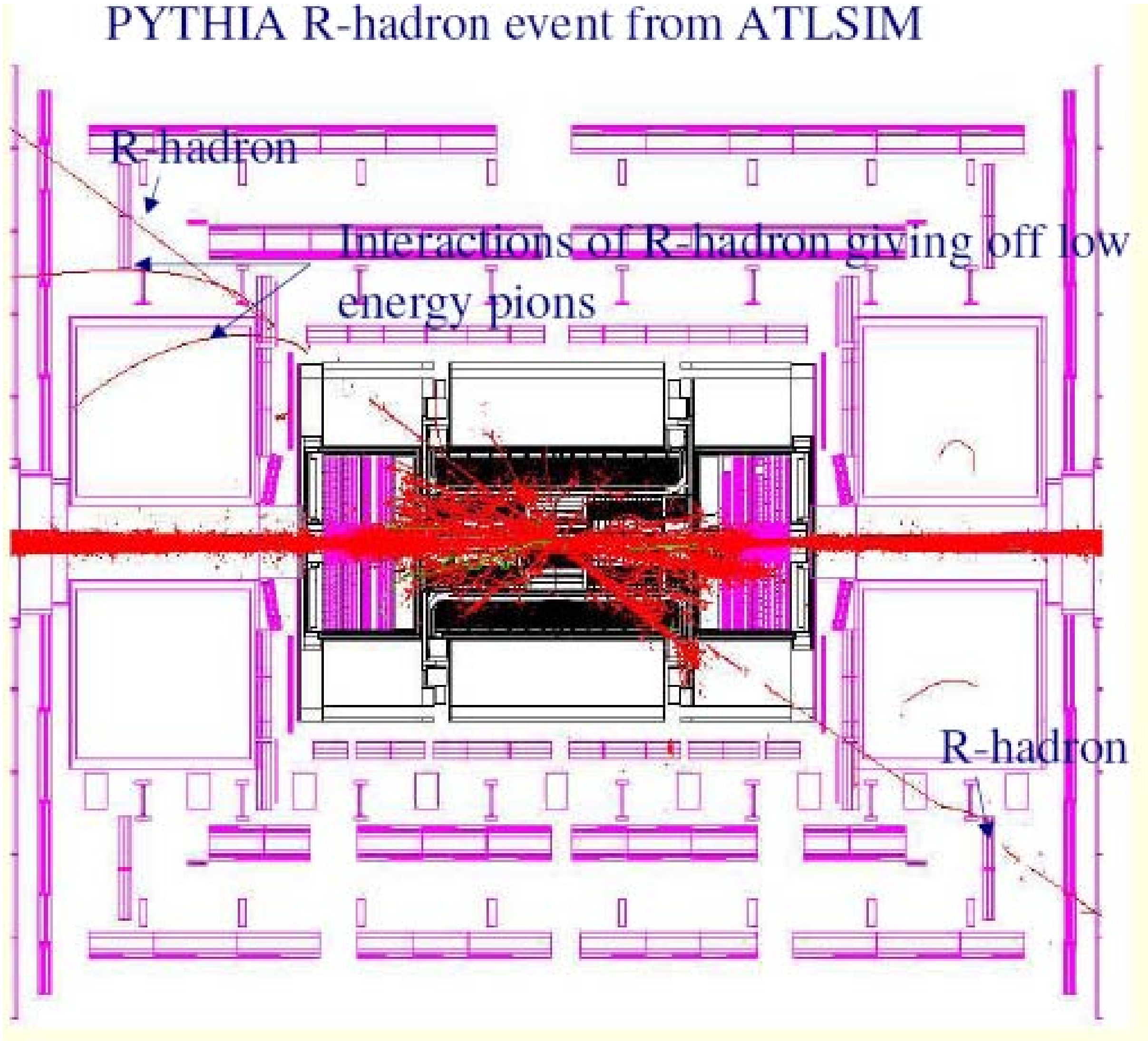
Towards the underlying theory

Next thoughts:

How can we go from the hadron collider data to the underlying theory?

- Can we map the measurements to theory phase space (e.g. SUSY)? Statistical techniques/Patterns?
  Interesting idea, encouraging result, but needs to go beyond inclusive variables. Endpoints etc. will be there early on and will be used to gain confidence that new particles have been produced.
- What variables/signals can be further looked at to reduce the degeneracy. Eg. to distinguish GDM & GMSB scenarios (both with semi-stable stau's) it appeared that the sparticle mass spectrum can help.
  Experimentalists will need guidance for this
- SUSY: measurements ⇔ parameters in the Langrangian
  Can we learn anything about underlying (string?) theory? Needs low scale predictions
- Are all the tools in place to do the exercise?
  Plethora of tools exist and almost all 'talk' via LHA-accord

R-Hadron in ATLAS

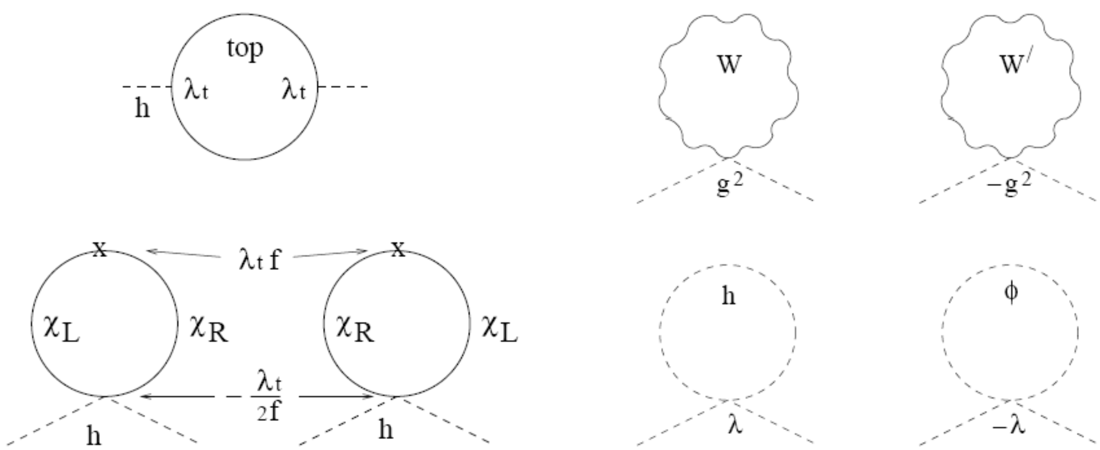


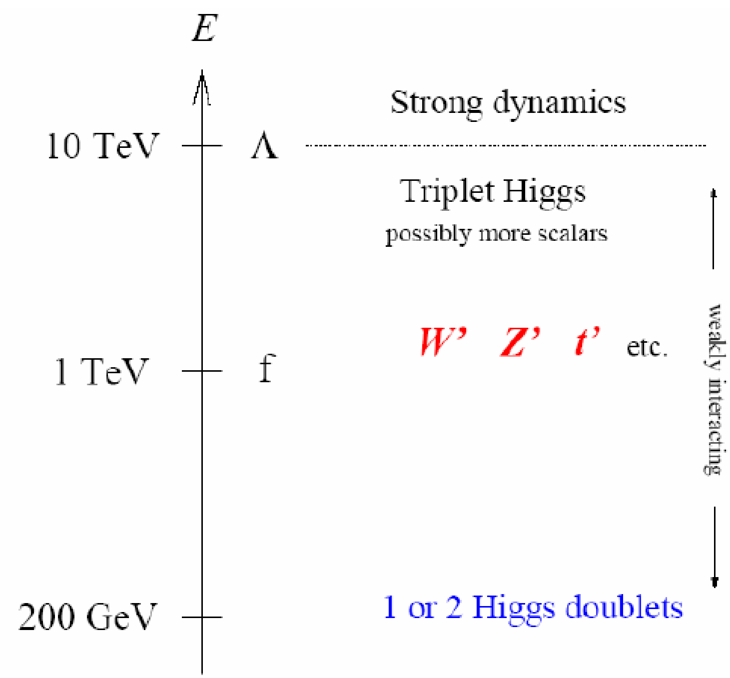
Little Higgs Models

Alternative to supersymmetry to protect the Higgs mass, via couplings of new particles

Arkani-Hamed et al.
Han et al.

$$W \leftrightarrow W_H \quad Z \leftrightarrow Z_H \quad B \leftrightarrow B_H \quad t \leftrightarrow T_H \quad H \leftrightarrow \Phi$$





$[SU(2)\otimes U(1)]_A \otimes [SU(2)\otimes U(1)]_B$

⇒ Expect new particles in the TeV range