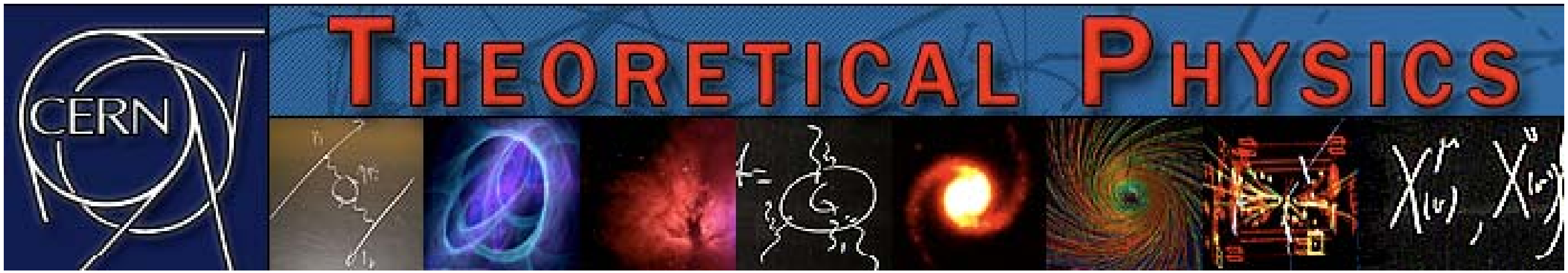
WG4 Summary

Albert De Roeck, for the conveners
ADR, T. Han, J. Hewett, S Riemann
+ all contributers

http://sites.google.com/site/lhc2fcwg4/



WG4

Other New Physics Signatures:

- Leptonic and other s-channel resonances
- multi-gauge-boson signals
- measurement of mass and spin, quantum numbers
- leptoquark-type signatures
- flavour physics
- fourth generation-type signatures, exotic quarks
- TeV scale gravity-type signatures
- other possible signatures of new physics

At this workshop

- New "classical" signatures
  - Extend discovery reach @ LHC
  - Measuring properties of the new particles/interactions
- New unusual "exotic" signatures
  - Impact on present and future detectors (eg at LC)
- Connection with flavor physics
- Discussion on data presentation and archiving
- Discussion of "What if" scenarios: which machines are optimal/useful for the next steps
  - Plenary discussions and discussion sessions on specific topics
  - General context: the charge of our WG for the physics classes allocated to us

Zprime studies

T. Rizzo

A Z'-like state at the TeV scale in the Drell-Yan channel is a very common prediction in *many* BSM scenarios:

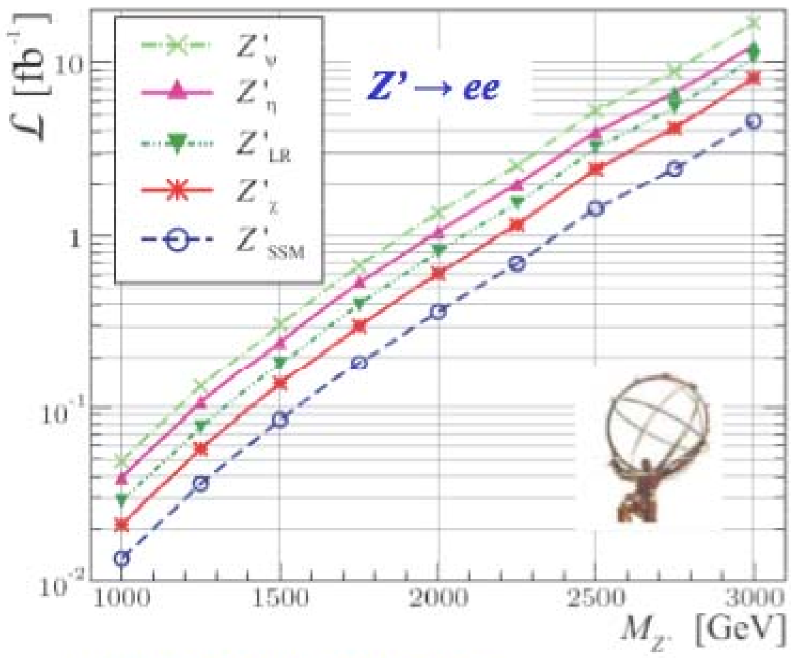
- Extended SUSY-GUT groups
- Sneutrinos in R-Parity violating SUSY
- String constructions/intersecting branes
- Little Higgs models
- Hidden Valley/Sector models
- Extra dimensions: gauge & graviton KK's
- String excitations
- Twin Higgs models
- Unparticles
- Wimponia
- ?????? = all the stuff we haven't though of yet

c/o Kevin Black

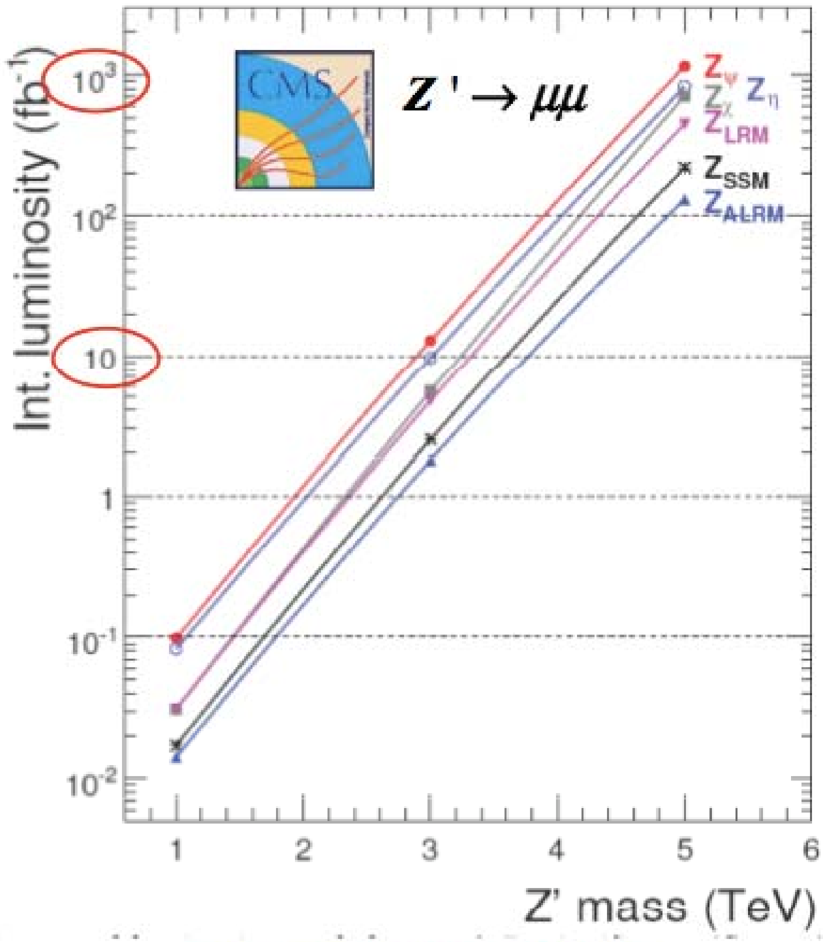
The LHC will open up a window to look for such states very soon… *but* how do we know what we've found??? 2

Zprime

Discovery reach at the LHC



Julien Morel, Thesis and
ATLAS CSC note, arXiv:0901.0512



CMS, CERN/LHCC 2006-021

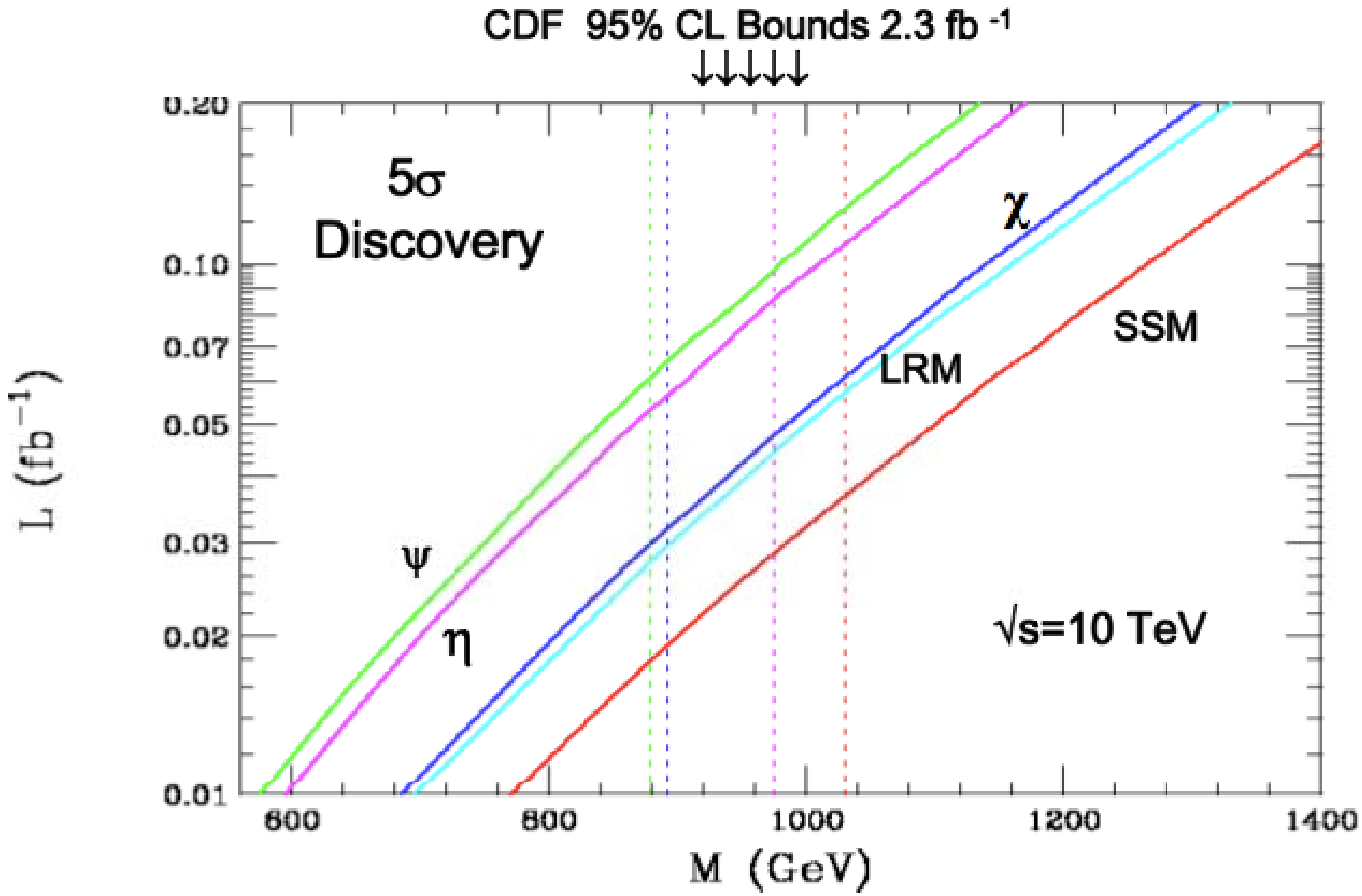
Present limits: 650-1000 GeV

G. Azuelos

Zprime

Z'→ leptons is a very clean mode and may provide the first signal of new physics to be observed at the LHC…*even* with √s=10 TeV and a relatively low integrated luminosity ~100-200 pb^{-1}

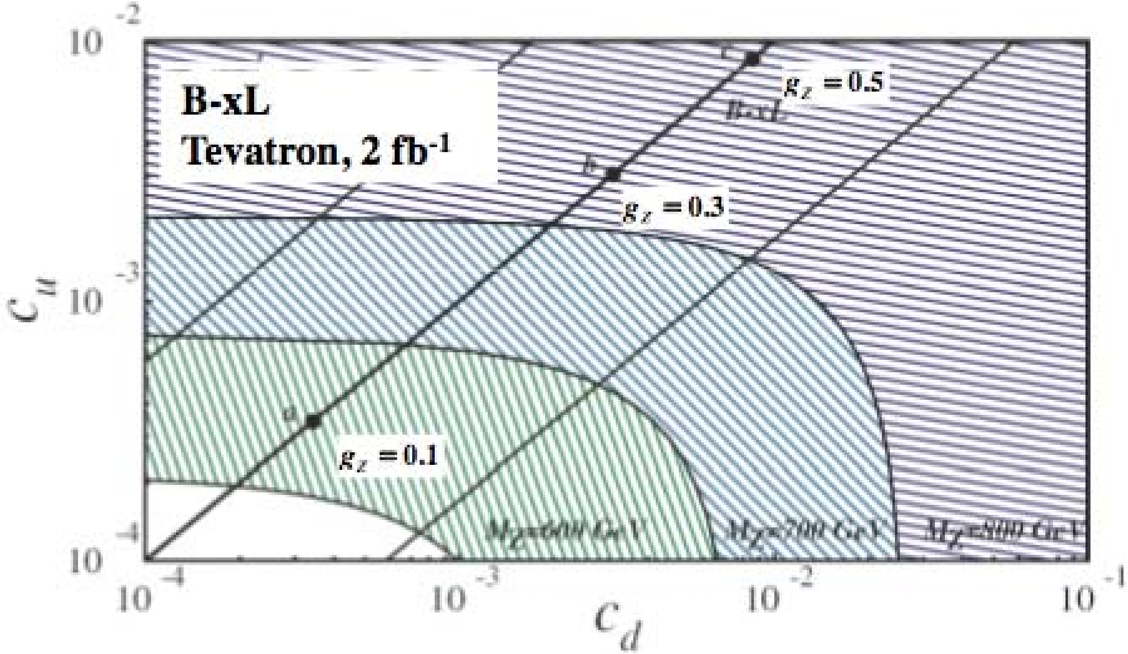
T. Rizzo



8

Zprime

Advocated presentation of the results/sensitivity (M. Carena et al)

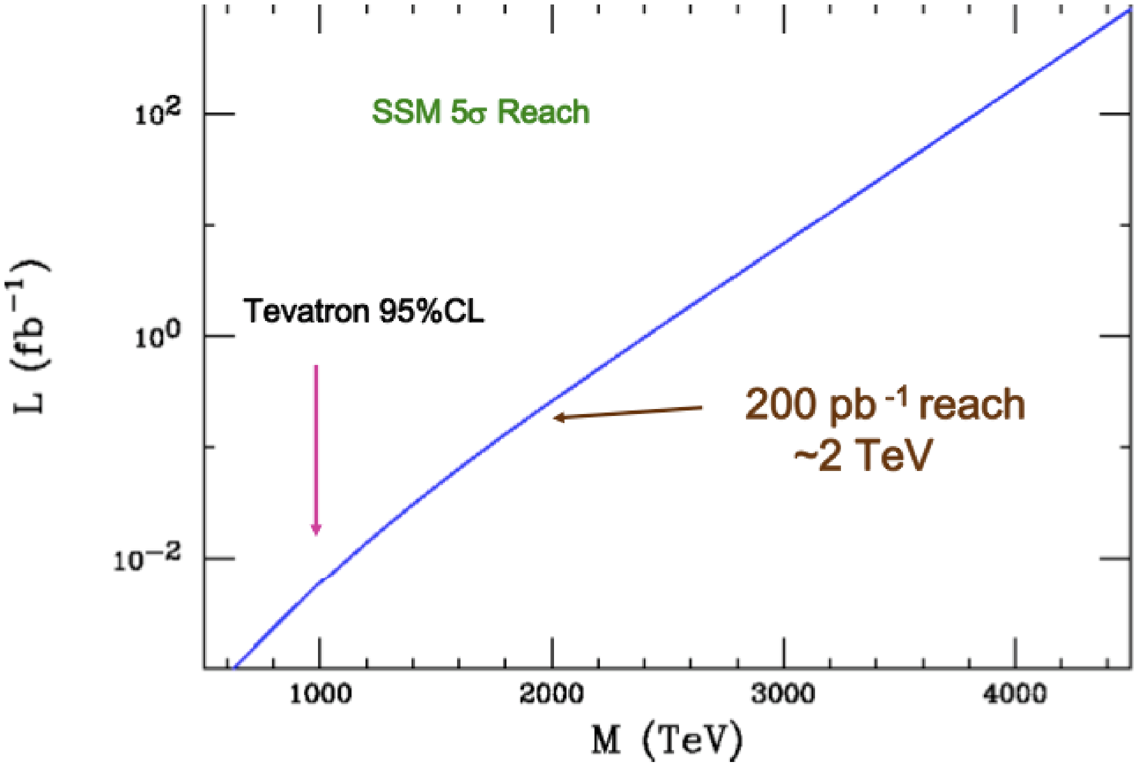


$$c_{u,d} = g_z^2(z_q^2 + z_{u,d}^2)\mathrm{Br}(Z' \rightarrow l^+ l^-)$$

http://arXiv.org/pdf/hep-ph/0408098

W' important too

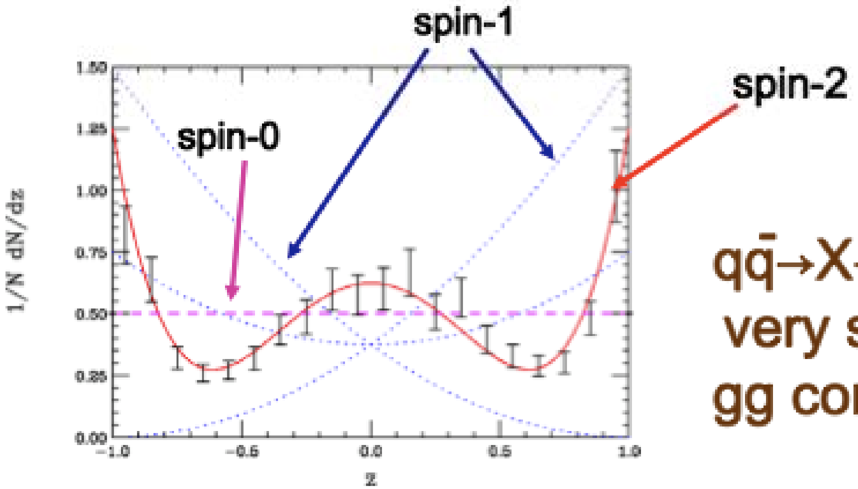
Sensitivity to W' often larger than to Z'
Less 'complete' to extract further information
Of course very meaningful for the interpreation if W' object is seen



W' Discovery at 10 TeV

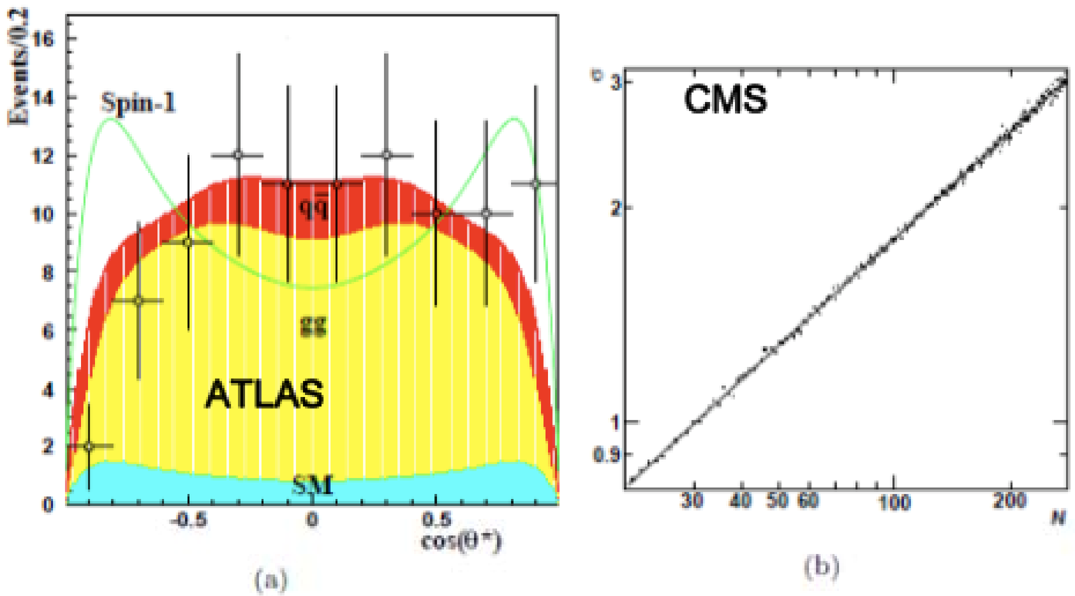
14

Zprime: Spin information



Resonance Spin

$q\bar{q} \rightarrow X \rightarrow l^+ l^-$ angular distributions are very sensitive to the spin of X, but gg contributions may be important too.

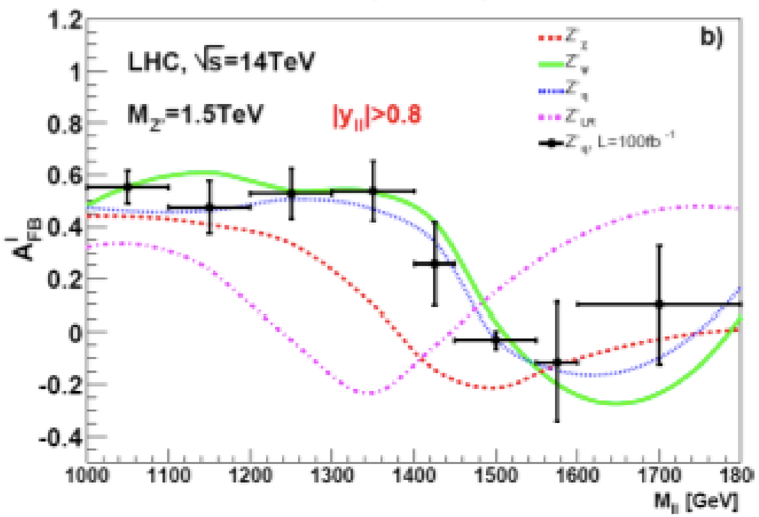


Differentiation of Z' vs KK-graviton at 1.5 TeV

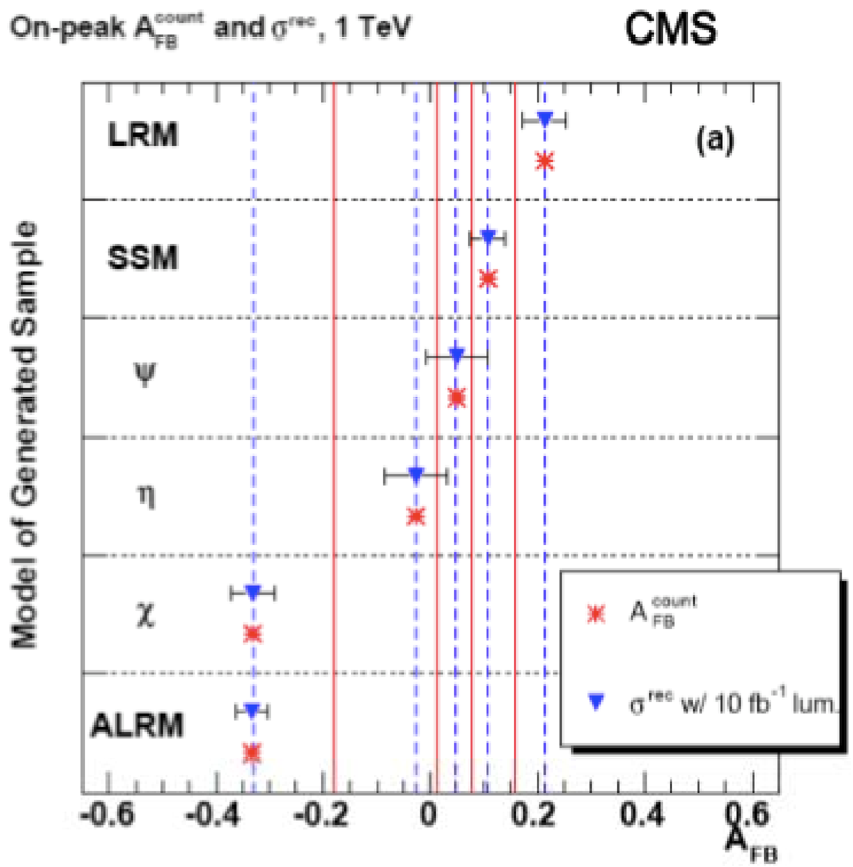
Clearly, this is just a matter of statistics once a resonance is actually found requiring ~ 300-500 signal events. This may be difficult to obtain for heavy states above ~3 TeV 19

Zprimes: getting more information

- A_{FB} both on- & off- resonance



M. Dittmar et al.



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

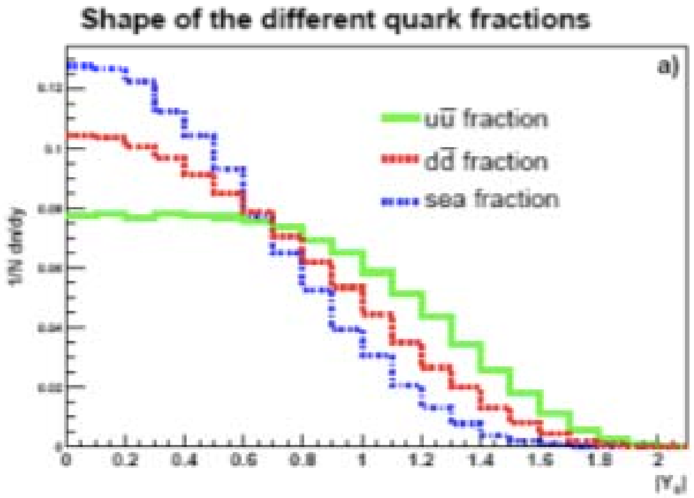
ATLAS/CMS simulations indicate these can be reasonably well measured at the LHC:

23

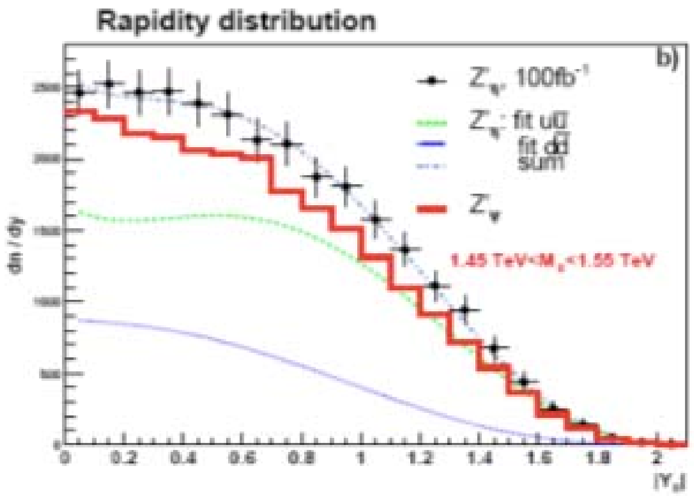
Zprimes: getting more information

- Rapidity distributions

M. Dittmar et al.



(a)



(b)

$$R = \frac{\int_{-y_1}^{y_1} \frac{d\sigma}{dy}\, dy}{\left[\int_{y_1}^{Y} + \int_{-Y}^{-y_1} \frac{d\sigma}{dy}\, dy\right]} .$$

or fit to R_{qq}, the event fraction from a given $q\bar{q}$ initial state…

ATLAS

	Generation level Fitted values (%)		Reconstruction level Fitted values (%)	
Model	Prop(Z'←dd)	Prop(Z'←uu)	Prop(Z'←dd)	Prop(Z'←uu)
SSM	41.±10.	52.±12.	22.±16.	60.±16.
χ	62.±12.	29.±14.	79.±17.	17.±19.
η	23.±13.	75.±14.	33.±6.	67.±8.
ψ	36.±12.	61.±13.	32.±15.	62.±17.
LR	57.±4.	43.±14.	53.±13.	46.±15.

Fig. 1.13. Comparison of R_{qq} values determined at the generator level and after detector simulation by ATLAS.

Zprime: couplings

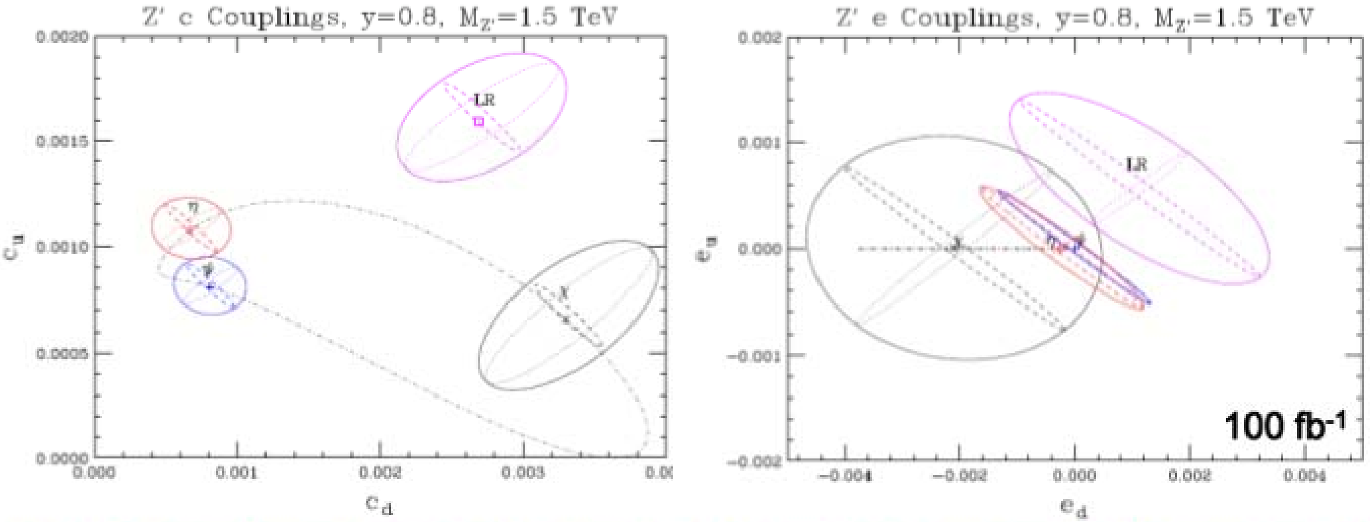
To first approximation these observables really *only* probe the 4 coupling combinations

Carena et al.

$$c_q = \frac{M_{Z'}}{24\pi\Gamma}(q_R^2 + q_L^2)(e_R^2 + e_L^2) \quad \text{for q=u,d}$$

$$e_q = \frac{M_{Z'}}{24\pi\Gamma}(q_R^2 - q_L^2)(e_R^2 - e_L^2)$$

Petriello & Quackenbush



which can be reasonably well determined in a simultaneous fit
...even including NLO QCD contributions

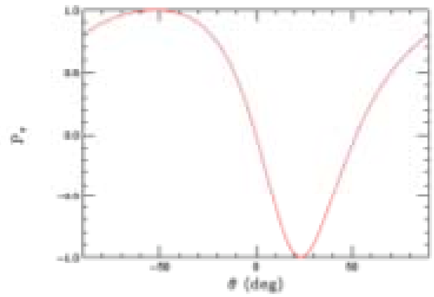
26

Will need more information

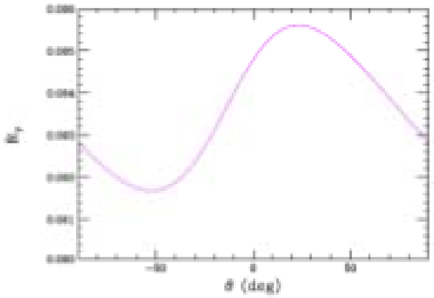
Zprime: couplings

T. Rizzo

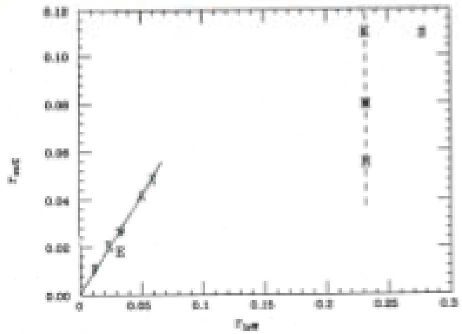
Other Possible Z' Observables For Coupling Determinations



- Z' $\rightarrow \tau\tau$ polarization measurement



- Associated on-shell Z' + (W,Z,γ) production
- Rare Decays: Z' $\rightarrow \bar{f} f' V$ (V = W,Z; f = l,ν)
- Z' → WW, Zh
- Z' $\rightarrow \bar{b}b$, $\bar{t}t$



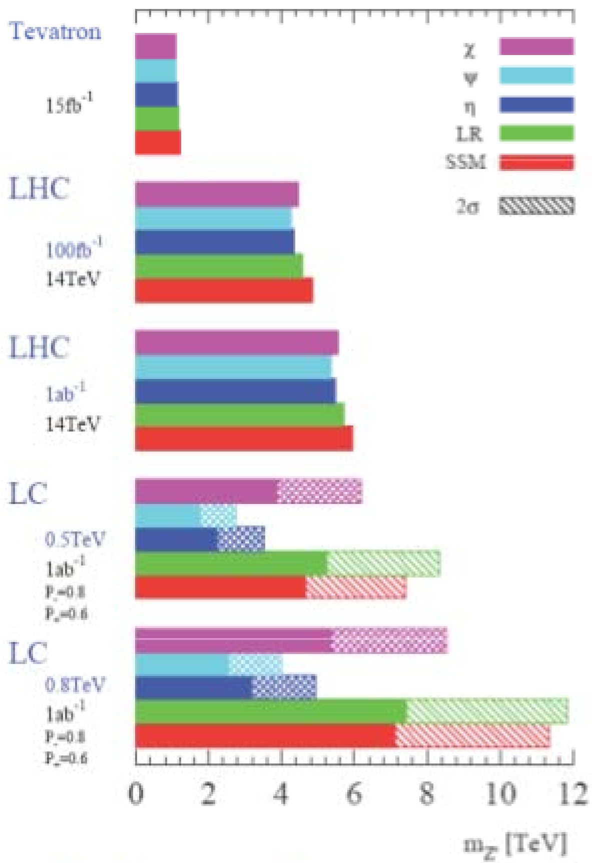
A case for SLHC

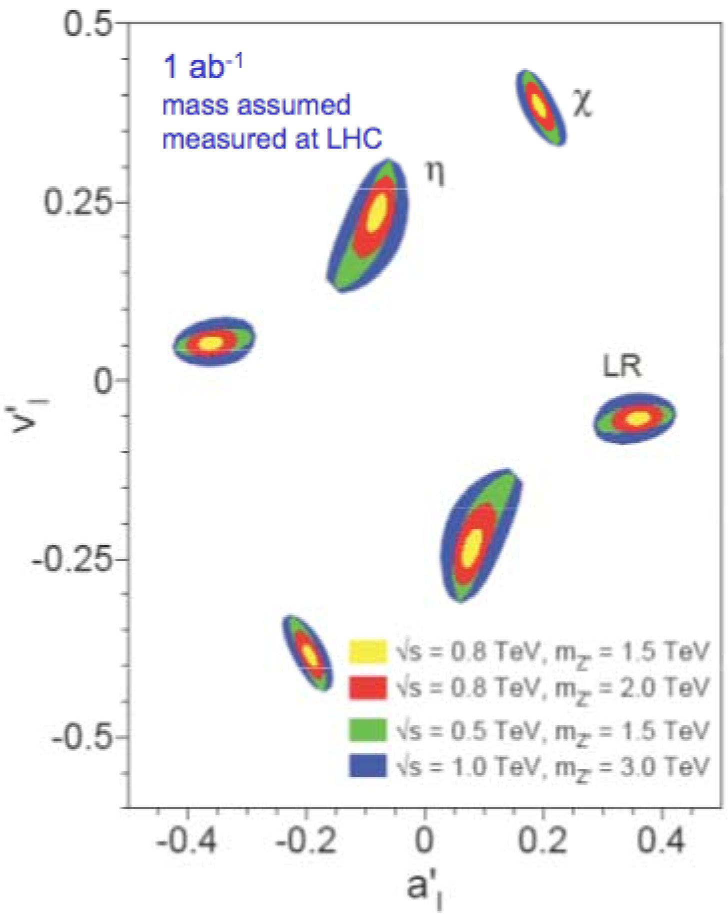
These have not been studied in any detail for the LHC but all will require quite high luminosity even for a light Z'

27

Zprime at an ILC

At the ILC, sensitivity s from Z'-Z interference
- can also be sensitive to high masses (contact-like interaction)



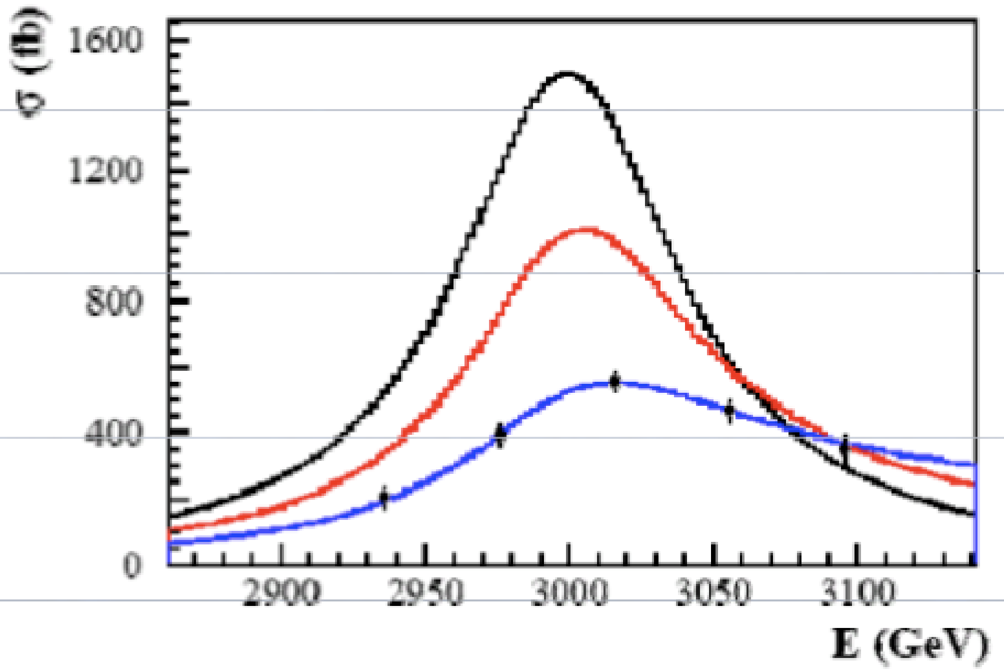


LHC/ILC Interplay, G. Weiglein et al, hep-ph/0410364

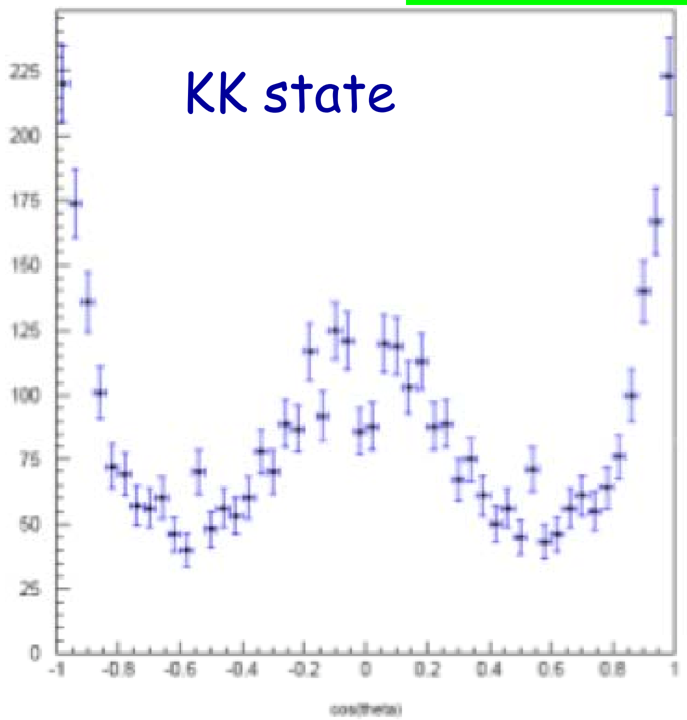
…But for $M_Z < 4.\sqrt{s}$…

Zprime at CLIC

M. Battaglia

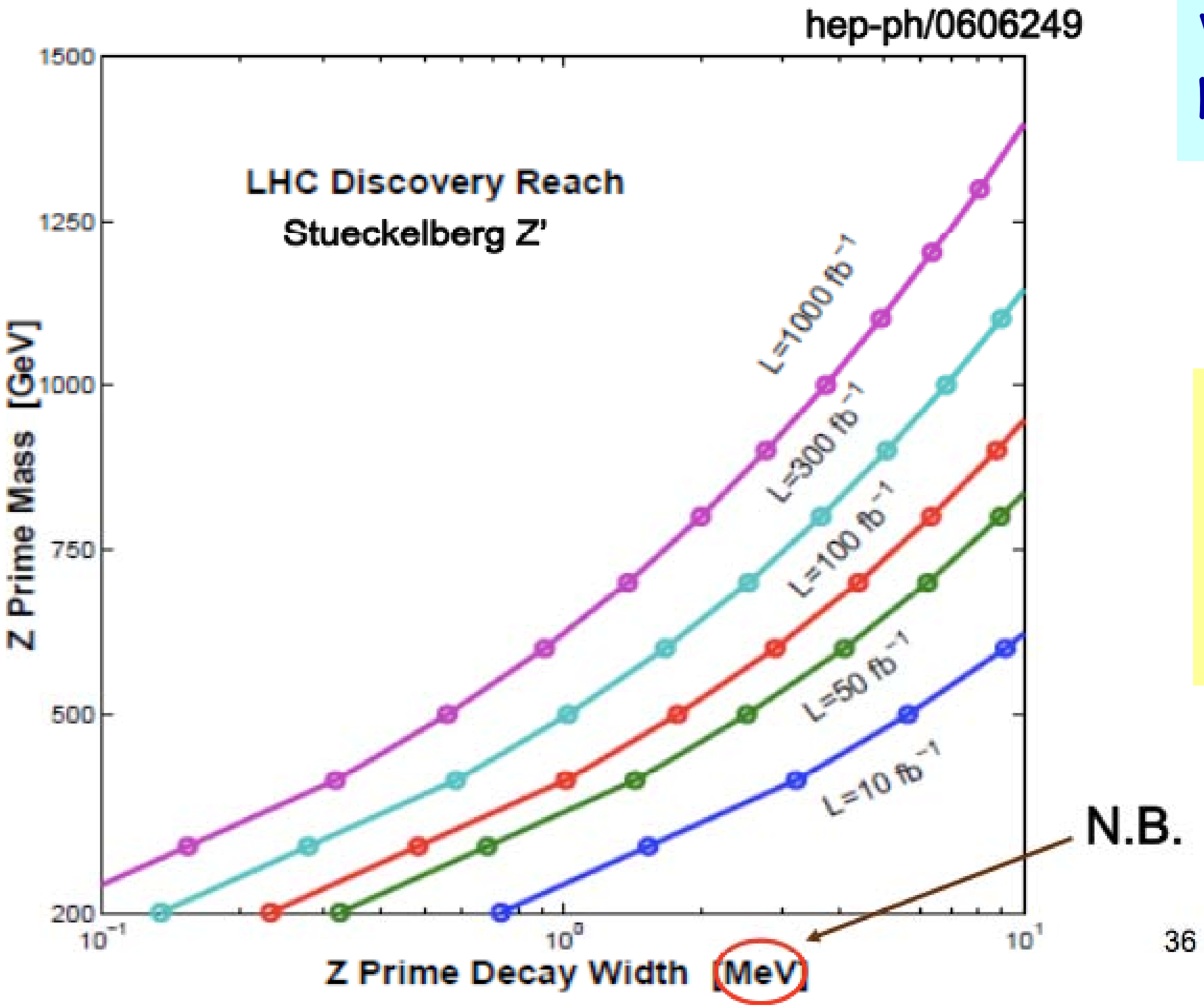


Observable	Breit Wigner	CLIC.01	CLIC.02
$M_{Z'}$ (GeV)	$3000 \pm .12$	$\pm .15$	$\pm .21$
$\Gamma(Z')/\Gamma_{SM}$	$1. \pm .001$	$\pm .003$	$\pm .004$
σ^{eff}_{peak} (fb)	1493 ± 2.0	564 ± 1.7	669 ± 2.9



Precision similar to LEP if the Z' is within the direct range

Zprimes finding not always easy



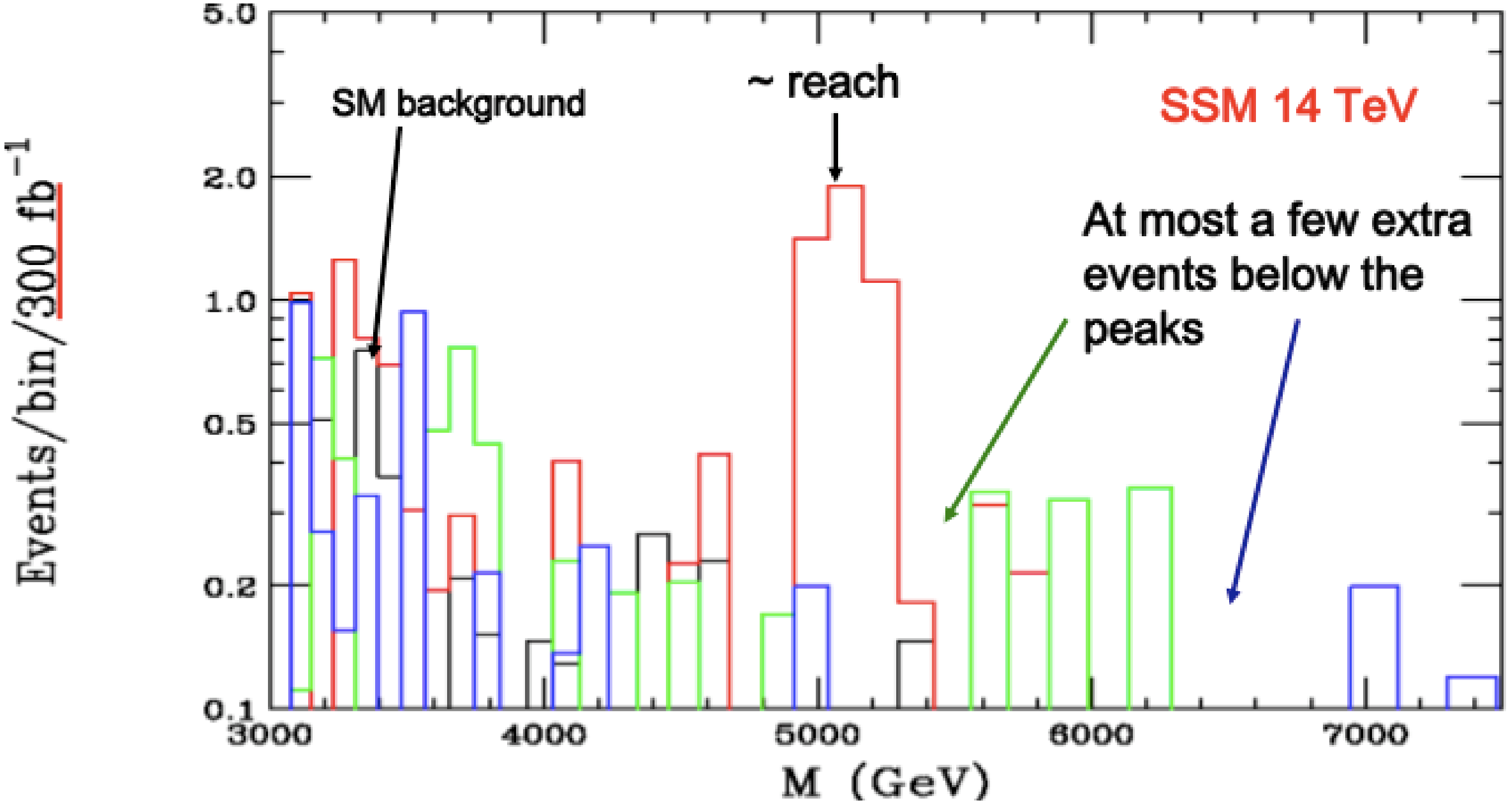
Weak Couplings
Narrow widths

Need a lot of lumi!
Bump seen at LHC
⇒SLHC needed to
Confirm & study

Indirect search

Indirect Z' Searches at LHC??

Can we observe a Z' below threshold at the LHC by 'contact-interaction-like' deviations in the cross section?? No statistics there to see any effect!



Zprime like objects: Summary

- If coupling not small and Z' not too heavy: discoveries with 10 fb^{-1} (200 pb^{-1}/10 TeV) possible!
- Detailed information on Z' needs more data: full LHC or even SLHC
- Weakly coupled Z' need full LHC luminosity to be detected and/or SLHC or can be missed all together…
- Full map of the couplings needs lots of luminosity or most likely another collider
  - E.g the LHeC (or a linear collider) can add/resolve the couplings
  - If few TeV Z' like object is found, then CLIC would be the most ideal machine (or muon collider, if feasible)
- Indirect Z' searches at LHC not likely to be useful

Dynamical EWSB in Warped Extra Dimensions

M. Carena

Warped ED inspired, strong dynamics models may offer elegant solutions to the hierarchy problem and the Dynamical Generation of EWSB

To provide such solutions at least some new particles are expected at the Tevatron/LHC reach, and a SM-like Higgs is expected to be there as well.

Gauge -Higgs Unification models may contain some TeV and lighter new quarks:

1st generation KK quark excitations which can be singly produced at the Tevatron/LHC

Top KK quark pair production, with possible new Higgs signatures for a SM like Higgs

Exotic charge KK quark excitations with mutiple W production

KK gauge boson excitations always at or above the few TeV range

Top condensation models in Warped ED may contain

A SM-like heavy (500 GeV) Higgs + a new vector-like, top-quark like singlet

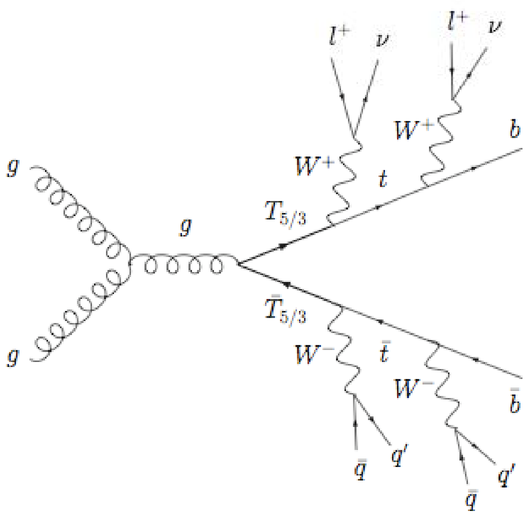
All KK excitations at the few tens of TeV range

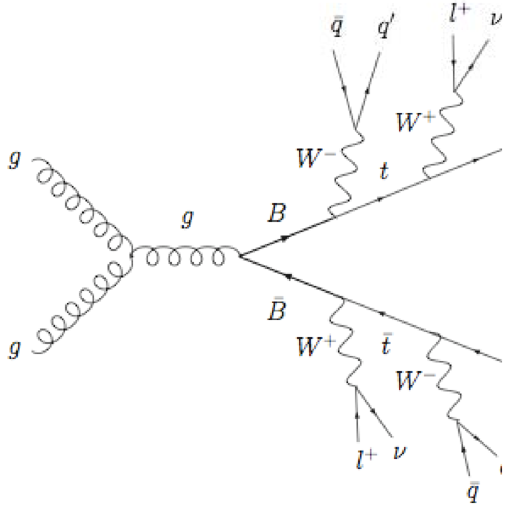
Exotic Quantum Numbers of the KK Fermions

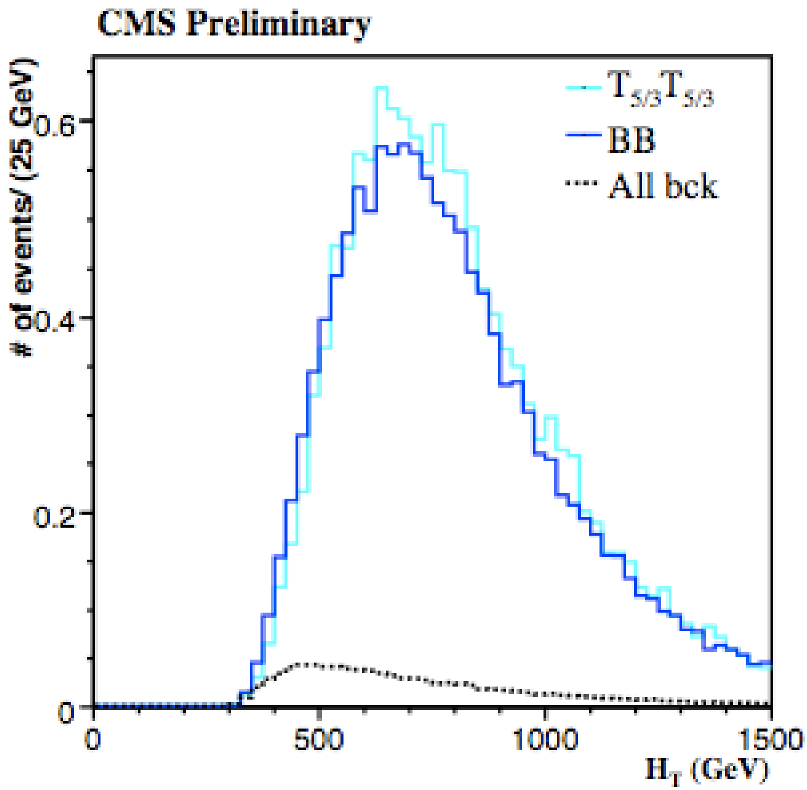
M. Carena

Top partners with Q = 5/3

CMS/Les Houches 07 contributuon







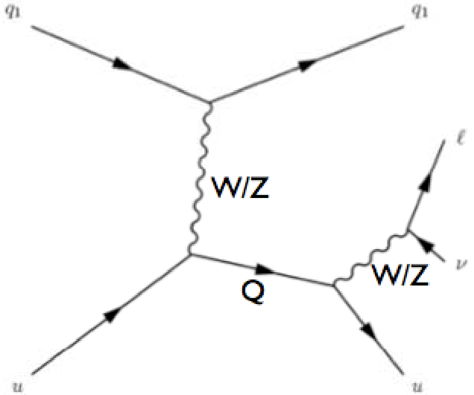
	$T_{5/3}T_{5/3}$ (M=500 GeV)	BB (M=500 GeV)	ttW	$ttWW$	WWW	WW
Efficiencies (ϵ_{main})	0.55	0.53	0.15	0.06	0.02	0.03
Expected number of events per fb^{-1}	57.2	55.1	2.76	0.30	0.374	0.46

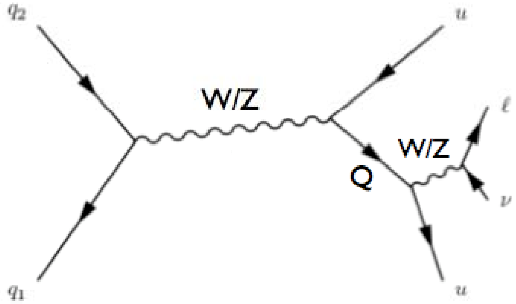
Single Heavy Quark Production

Heavy Quark Signals:

via Charged Current or Neutral Current Interactions

$$D \to W^- u,\ Zd,\ hd, \quad U \to W^+ d,\ Zu,\ hu.$$





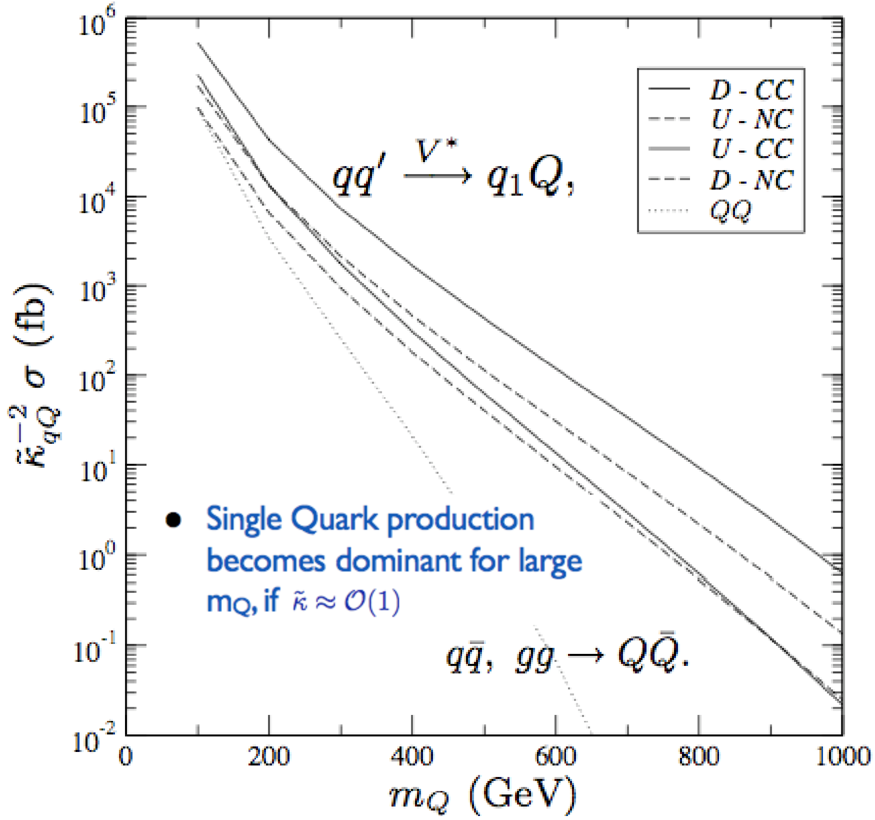
$pp(p\bar{p}) \to qQ \to quW \to qul\nu$ $\Rightarrow \mathrm{Signal}:\ 2j + l + \not{E}_T$

$pp(p\bar{p}) \to qQ \to quZ \to qul^+l^-$ $\Rightarrow \mathrm{Signal}:\ 2j + l^+l^-$

$pp(p\bar{p}) \to qQ \to quZ \to qu\nu\bar{\nu}$ $\Rightarrow \mathrm{Signal}:\ 2j + \not{E}_T$

Both D and $\bar{\mathrm{D}}$ or U and $\bar{\mathrm{U}}$ considered

Atre, M.C., Han, Santiago



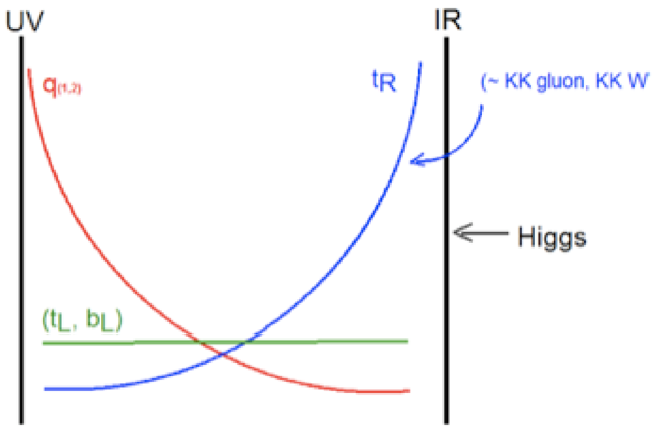
Tevatron. LHC?

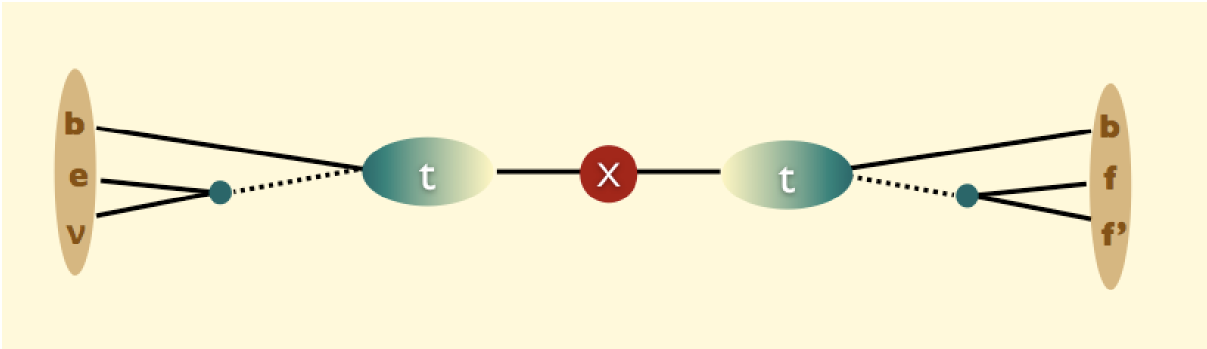
Highly Boosted Top

Recent developments in models: the prominent role of top production
Top co-anihilation SUSY, top resonances, RS→top top etc.
Often this leads to 'boosted top' ie the hadronic decay jets merge

T. Han et al.

- Eg RS → t tbar





The jets typically appear as 'fat' jets
with internal structure

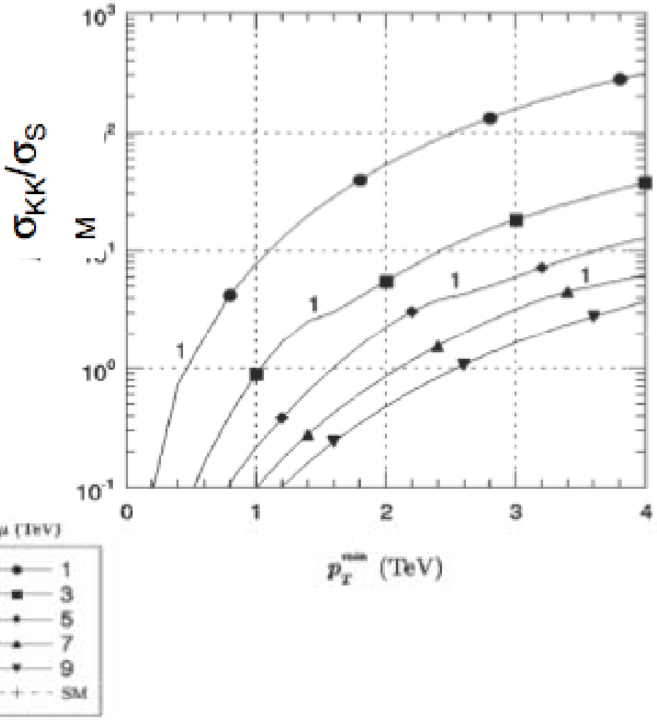
⇒High P_T tops

Re-emphasized as being a major tool for NP searches

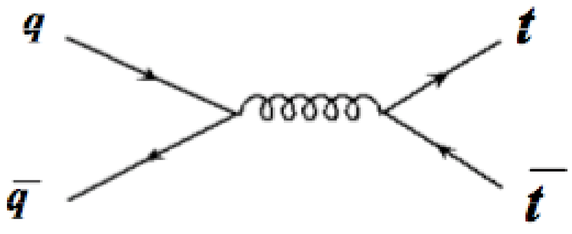
KK Excitations of the gluon

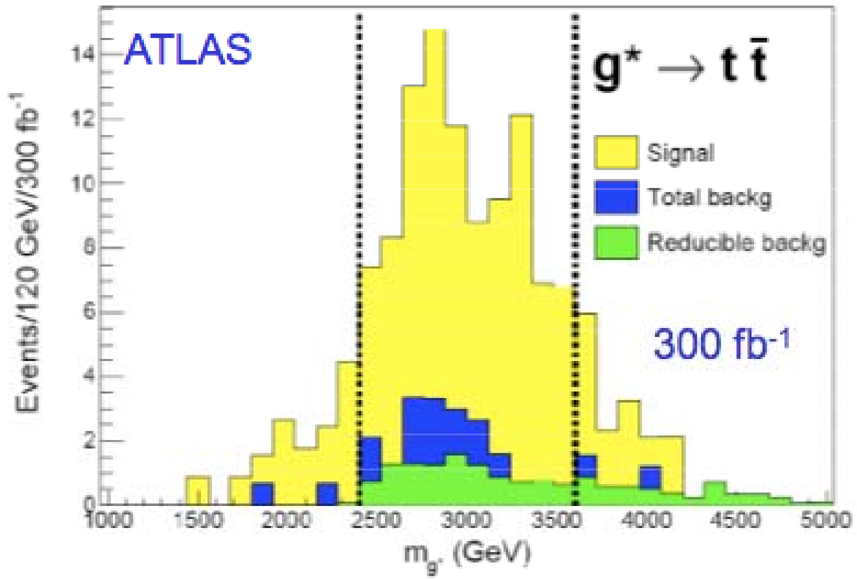
UED scenario

D.A. Dicus, C.D. McMullen and S. Nandi, PR D65 (2002) 076007



For heavy quark production, one diagram dominates:





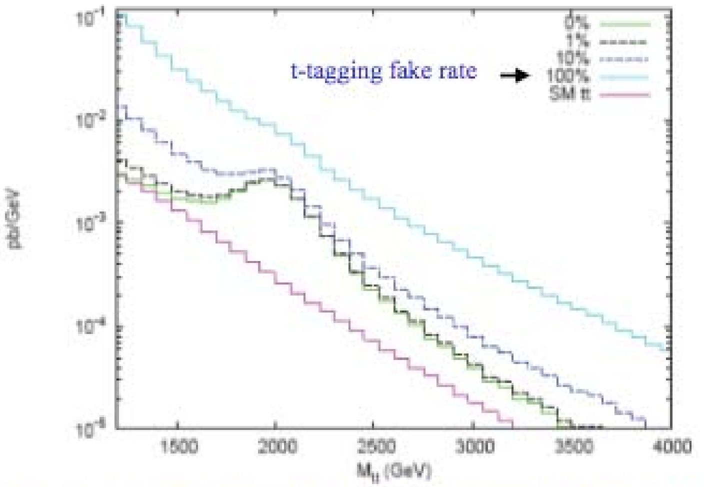
March, L; Ros, E; Salvachúa, B; ATL-PHYS-PUB-2006-002

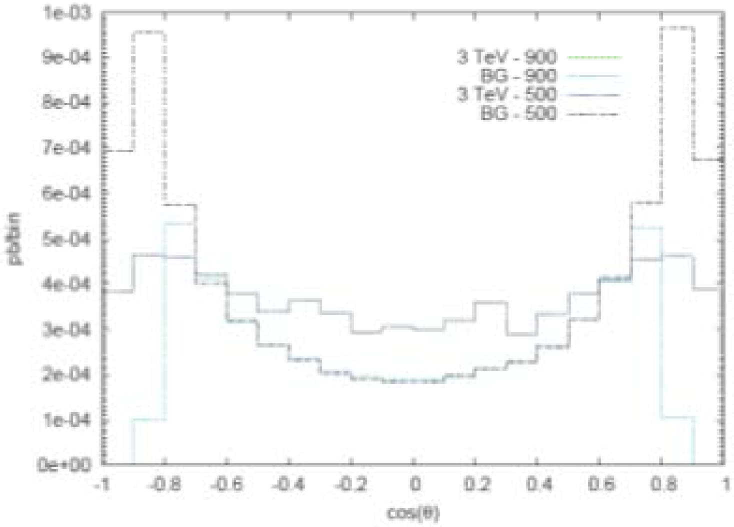
G. Azuelos

Top Resonances from bulk RS KK gluon

B. Lillie, L. Randall and L-T Wang, hep-ph/0701166

- large overlap of KK gluon and top quark wave functions because both are localized towards TeV brane





- can also measure spin correlations (t_R coupling?)
- experimental issues:
  - b-tagging
  - strong collimation of jets from top and from W's
    - jet mass can be used, as in:
      W. Skiba, D. Tucker-Smith hep-ph/0701247

- can also have graviton resonance to top pairs (or WW), but higher mass
  (Agashe et al., hep-ph/0701186)

Experimental studies are ongoing

Warped Space KK Gauge Bosons

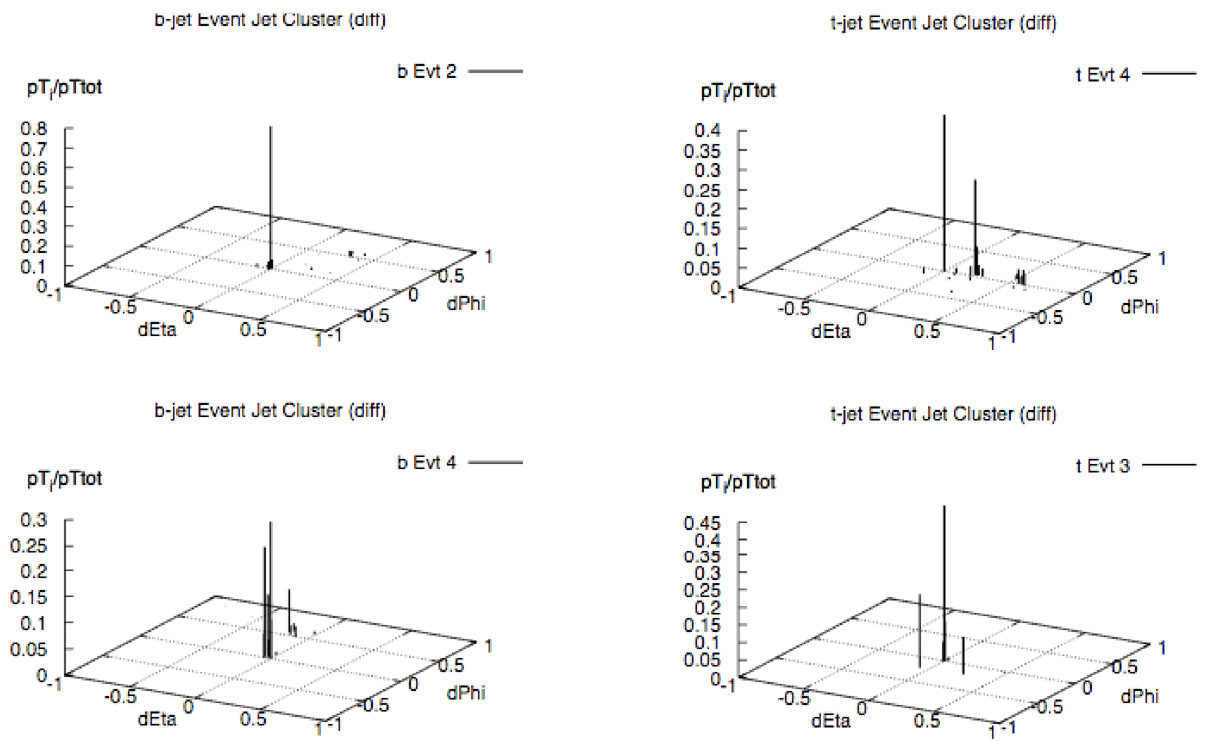
$W'^{\pm} \to t\, b \to \ell \nu b\, b$

S. Gopalakrishna

Signal c.s. $\sim 1 fb$

Bkgnd is single top + QCD W b b .... AND ...

$t\bar{t}$: hadronically decaying top can fake a b



Not easy with first data

RPV SUSY (e.g. Baryon Triality B_3)

H. Dreiner

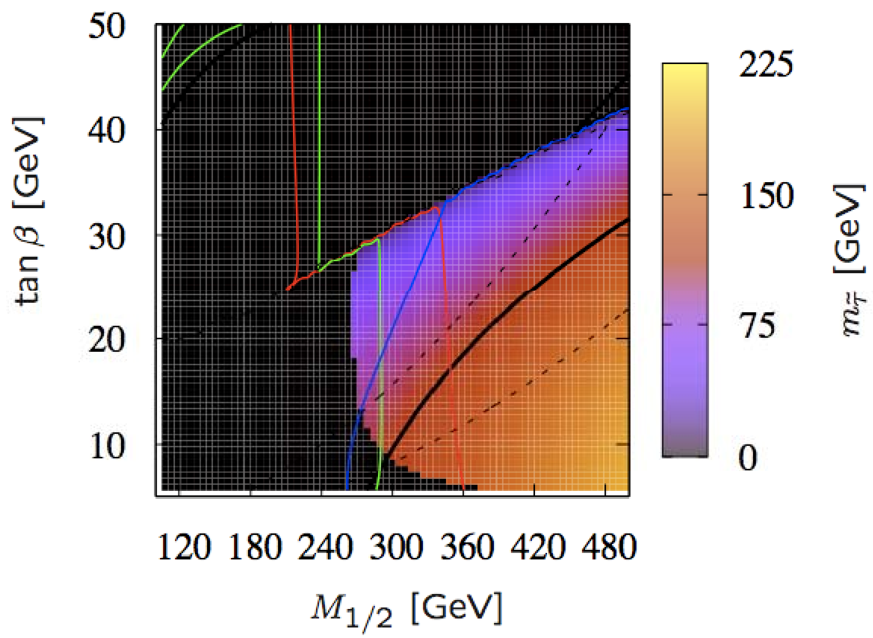
Proton protected as UDD terms are prohibited

Example Spectra

	SPS1a	$\lambda_{123} = 0.08$	$\lambda'_{331} = 0.122$	$\lambda''_{212} = 0.5$
$\tilde{\nu}_e$	189	187	189	189
$\tilde{\nu}_\mu$	189	187	189	189
$\tilde{\nu}_\tau$	188	188	**93**	188
$\tilde{e}^{\pm}_{R,L}$	146; 206	146; 205	146; 206	146; 206
$\tilde{\mu}^{\pm}_{R,L}$	146; 206	146; 205	146; 206	146; 206
$\tilde{\tau}^{\pm}_{1,2}$	137; 210	134; 210	**104**; **159**	137; 210
$\tilde{u}_1$	552	552	552	552
$\tilde{u}_2$	567	567	567	568
$\tilde{c}_1$	552	552	552	**394**
$\tilde{c}_2$	567	567	567	**562**
$\tilde{d}_1$	552	552	**536**	**393**
$\tilde{d}_2$	575	575	574	**570**
$\tilde{s}_1$	552	552	552	**393**
$\tilde{s}_2$	575	575	575	**570**
$\tilde{b}_{1,2}$	518; 550	518; 550	**511**; 549	519; 551
$\tilde{t}_{1,2}$	400; 591	400; 591	399; **586**	401; 592
$\tilde{\chi}^0_1$	97	97	97	97
$\tilde{\chi}^0_2$	181	181	181	181
$\tilde{\chi}^0_3$	362	362	360	362
$\tilde{\chi}^0_4$	380	380	379	380
$\tilde{\chi}^{\pm}_1$	182	182	181	182
$\tilde{\chi}^{\pm}_2$	378	378	377	378
$\tilde{g}$	610	610	610	**604**
h^0	110	110	110	110

$\tilde{\tau}$-LSP region largely unexplored

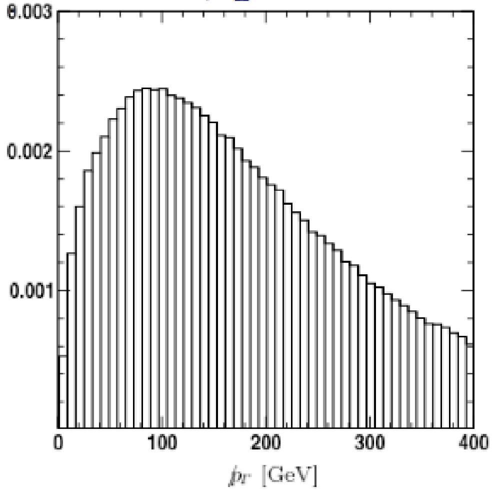
black contour: $m_h = m_{\tilde{\tau}_1}$. red: $m_{\chi^0_1} = m_{\tilde{e}_1}$. green: $m_h = m_{\chi^0_1}$. blue: $m_{\chi^0_2} = m_{\tilde{\tau}_2}$



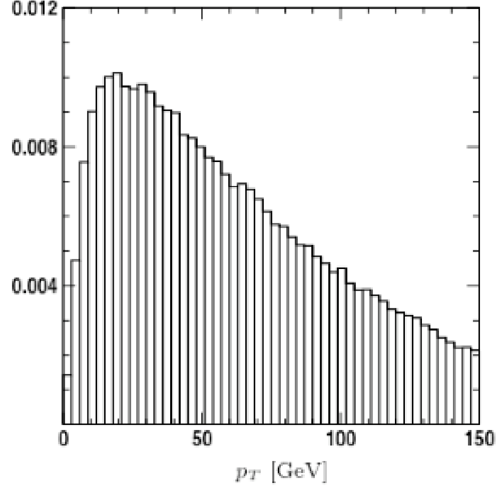
Missing E_T and high P_T muons in RPV SUSY

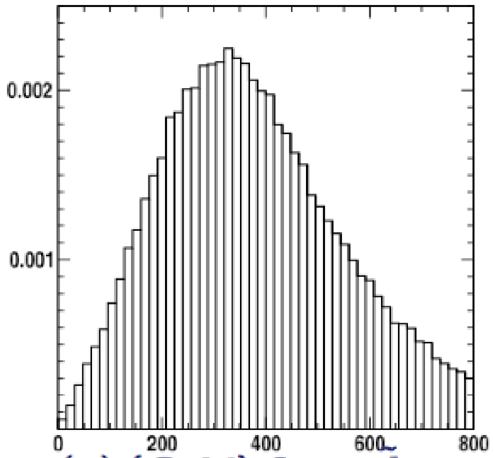
- High p_T muons arise from the direct decays: $\tilde{d}_R \to \mu^- t$; $\tilde{t}_1 \to \mu^+ d$.
  $\longrightarrow$ Plot

Neutrino $\not{p}_T$ (GeV)

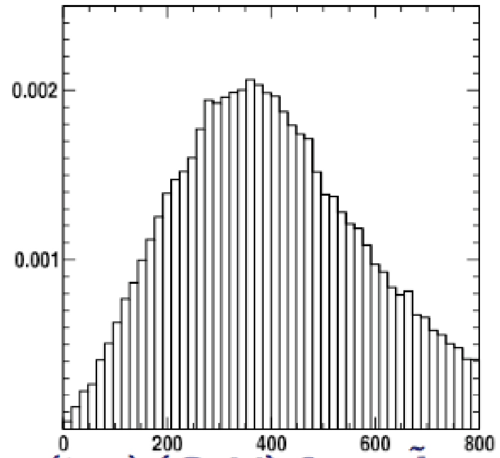


$p_T(\mu)$ (GeV) from $\tilde{\chi}_1^0 \to \tilde{\mu}\mu$





$p_T(\mu)$ (GeV) from $\tilde{d}_R \to \mu t$,



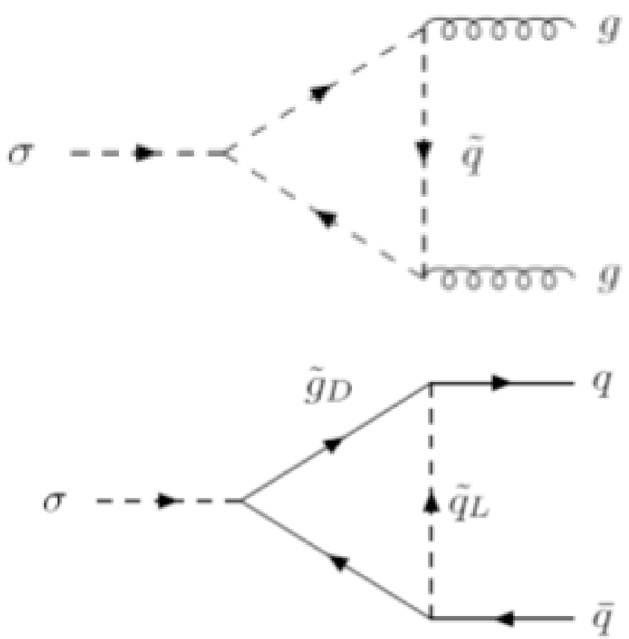
p_T(top) (GeV) from $\tilde{d}_R \to \mu t$

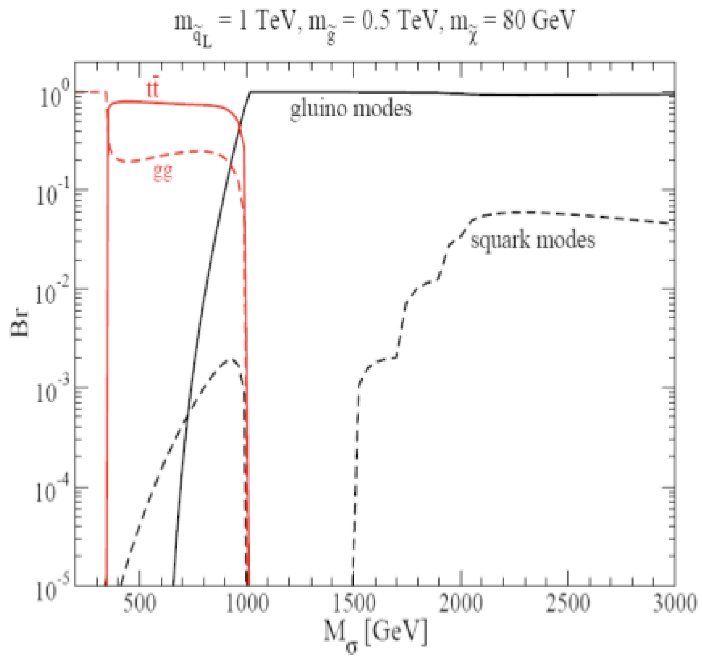
Color Octet Scalars at the LHC

Alternative N=1/N=2 realisation discussed

Dirac gluinos and color-octet scalars

J. Kalinowski





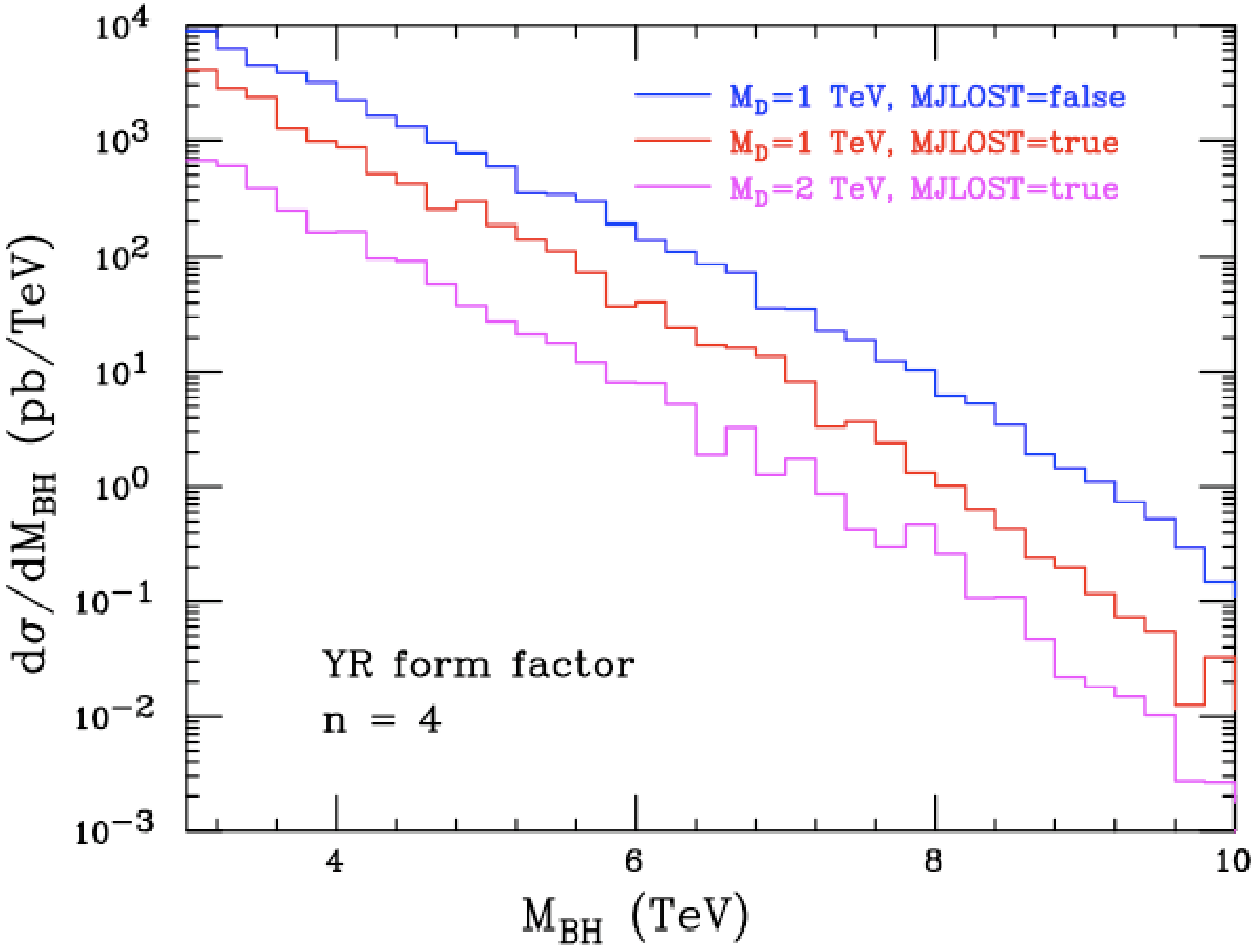
Cross section ~ 10-1000 fb

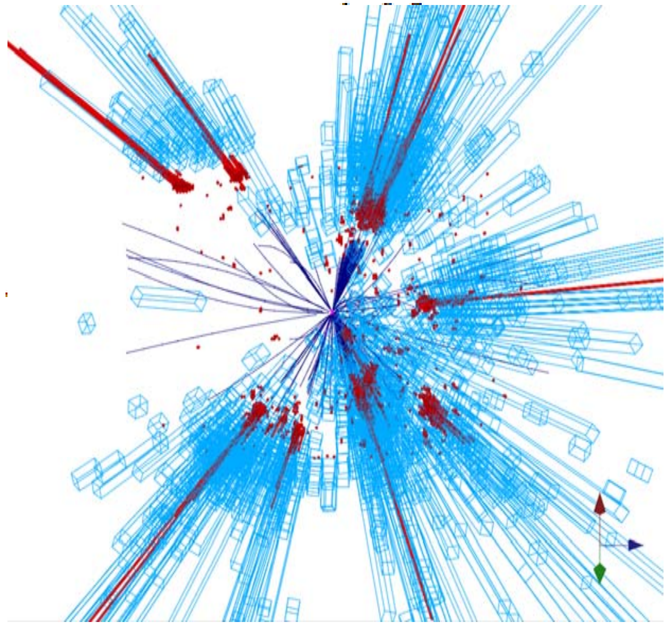
- $pp \to t\bar{t}t\bar{t}$ if $m_{\tilde{q}} \lesssim m_{\tilde{g}}$ and L/R mixing significant in stop sector
- $pp \to t\bar{t}c\bar{c}$ if flavor mixing in the up-type squark sector

Black Holes

BH cross section at LHC

B. Weber

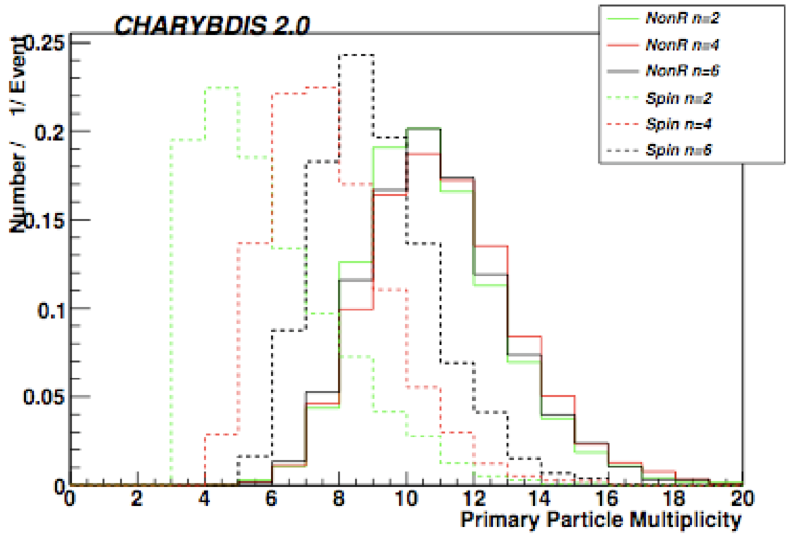


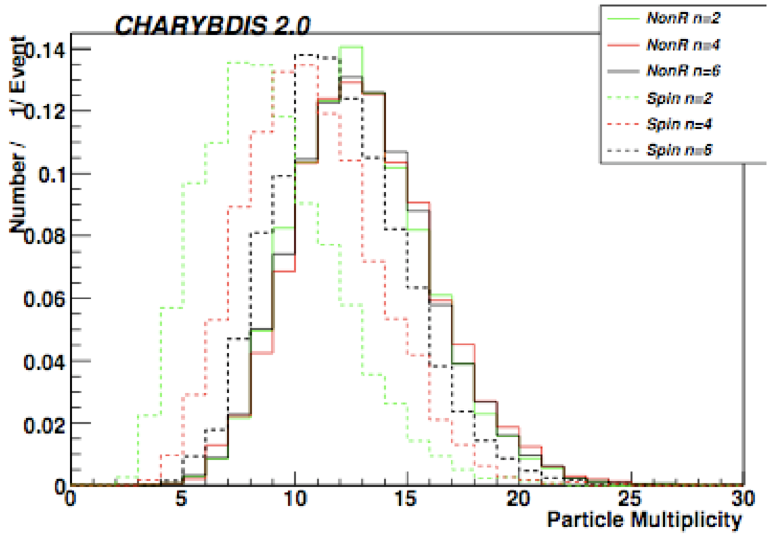


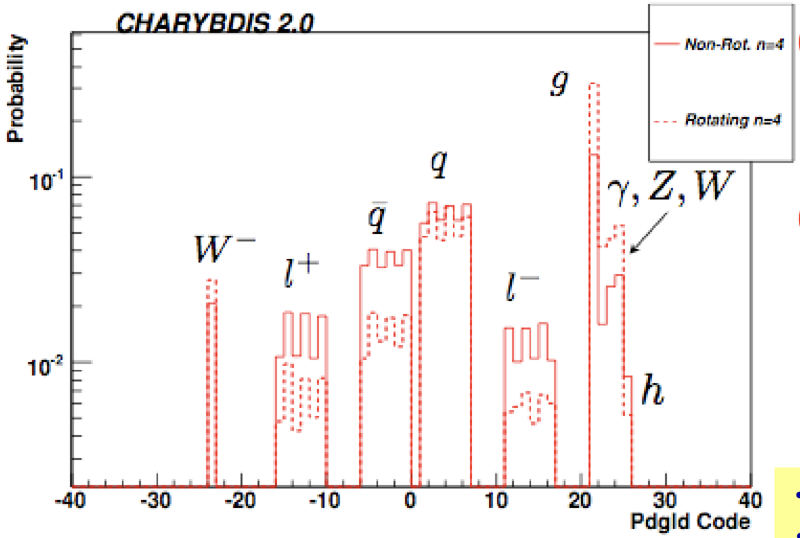
➡ A ~5 TeV BH per minute at LHC!

Rotating Black Holes

Observable effects of BH spin?



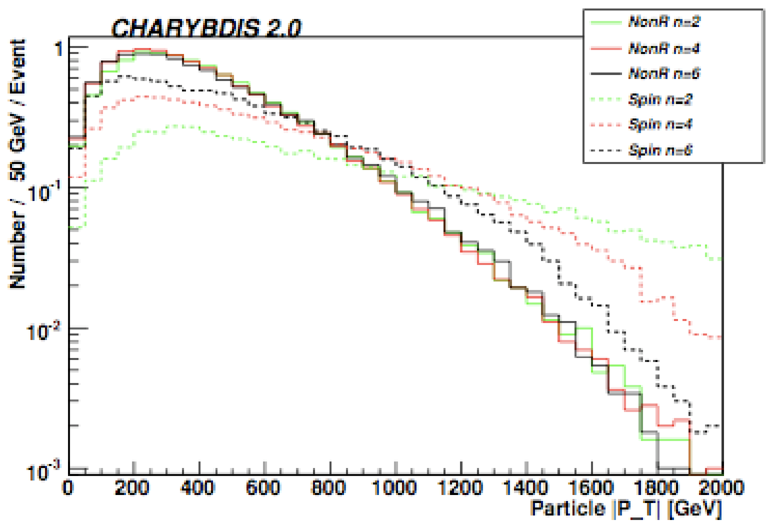


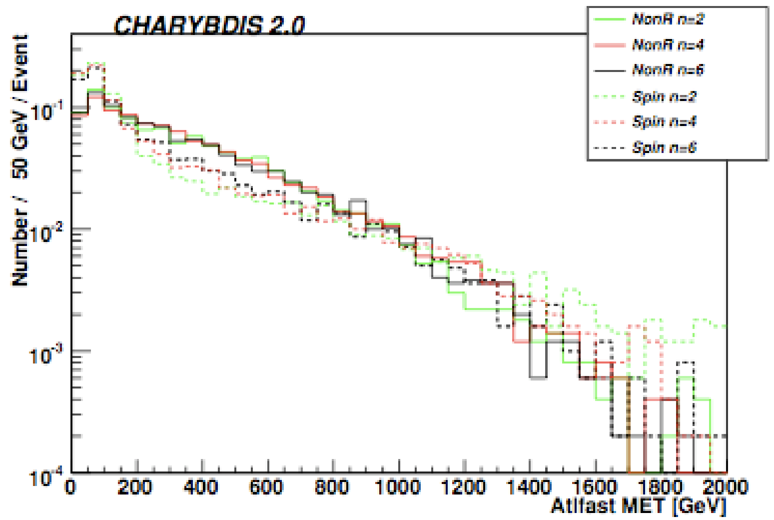


- Higher power flux
  - ➔ Fewer, more energetic particles
- Enhanced vector emission
  - ➔ More gluons, photons, W, Z
  - ➔ Aligned with BH axis, polarized

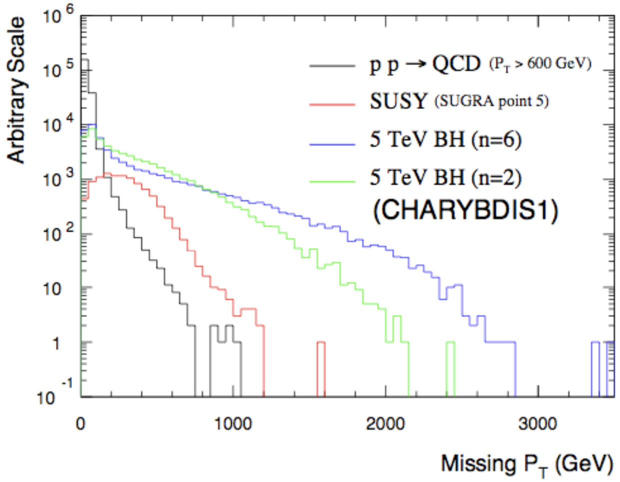
Included in BlackMax and CHARYBDIS2

Black Holes





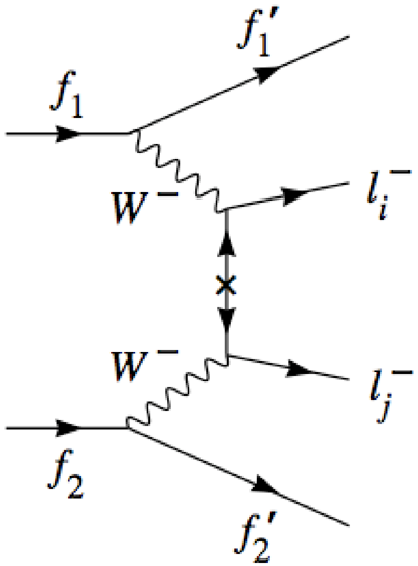
Missing transverse energy

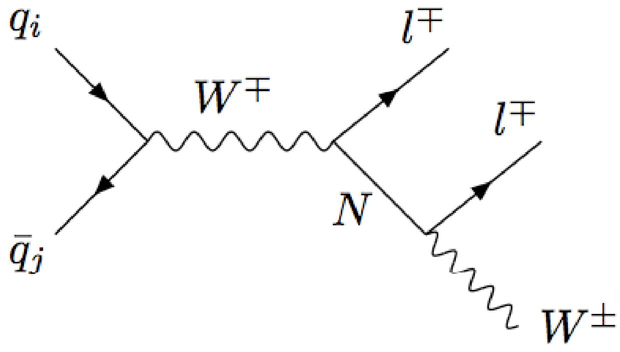


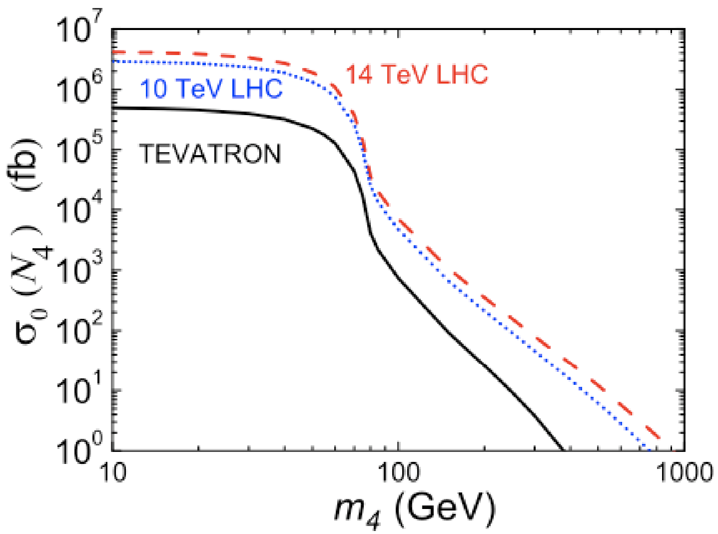
➡ Typically larger $\not{E}_T$ than SM or even MSSM

- Large cross section if Planck scale ~ TeV
- Clear signature, with large $\not{E}_T$
- But BH mass measurement needs small $\not{E}_T$
- Particle spectra, angular distributions and multiplicities strongly affected by BH spin
- Measuring n, M_D difficult but may be possible
- CHARYBDIS2 will be released soon!

Seesaw Mechanism: Majorana Neutrinos

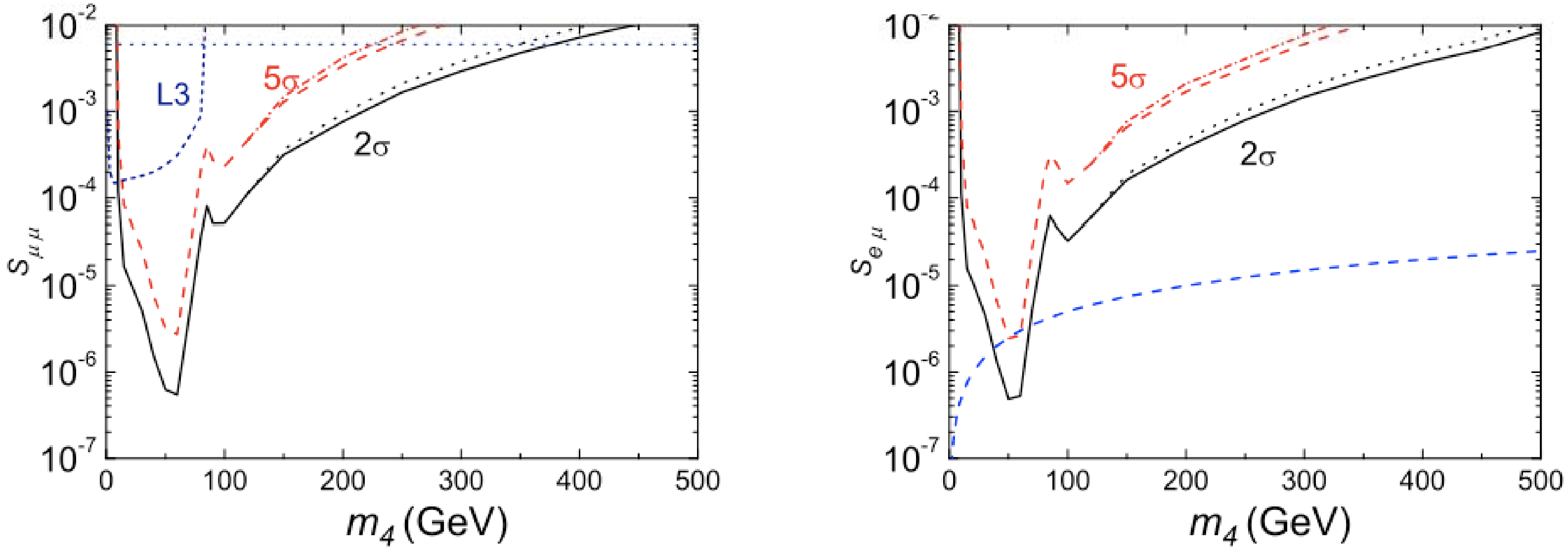




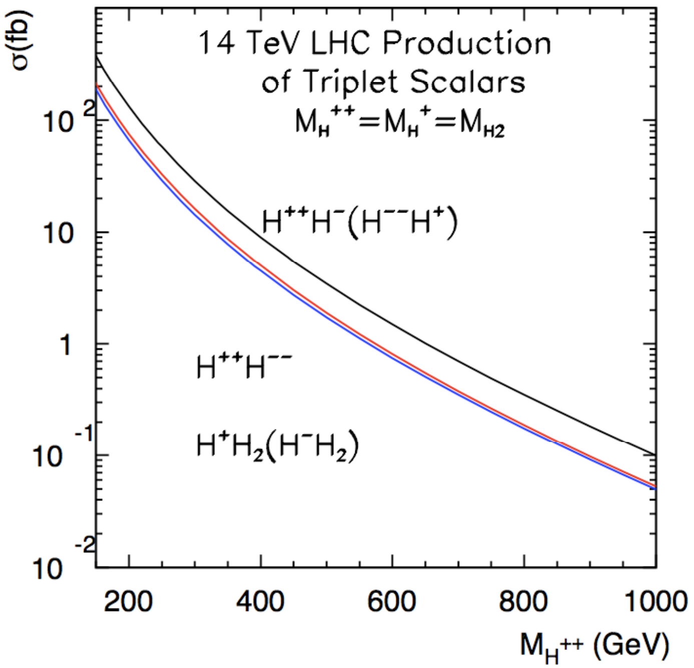


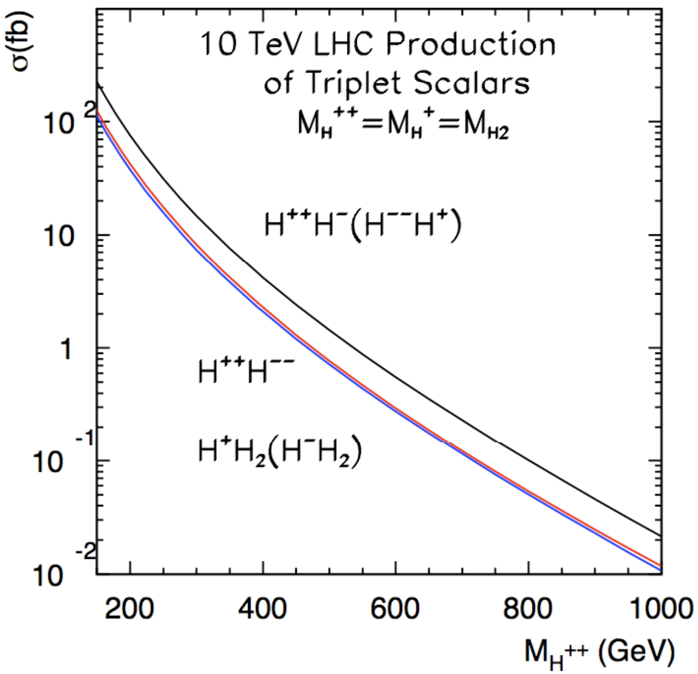
$\mu^\pm\mu^\pm\ jj$ and $\mu^\pm e^\pm\ jj$: 100 fb^{-1} reach

T. Han

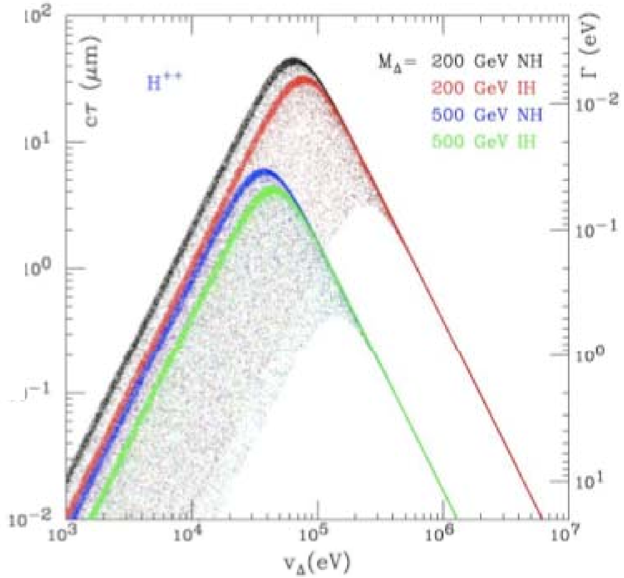


Seesaw Mechanism: H^{++} H^{--} production





Decay length:

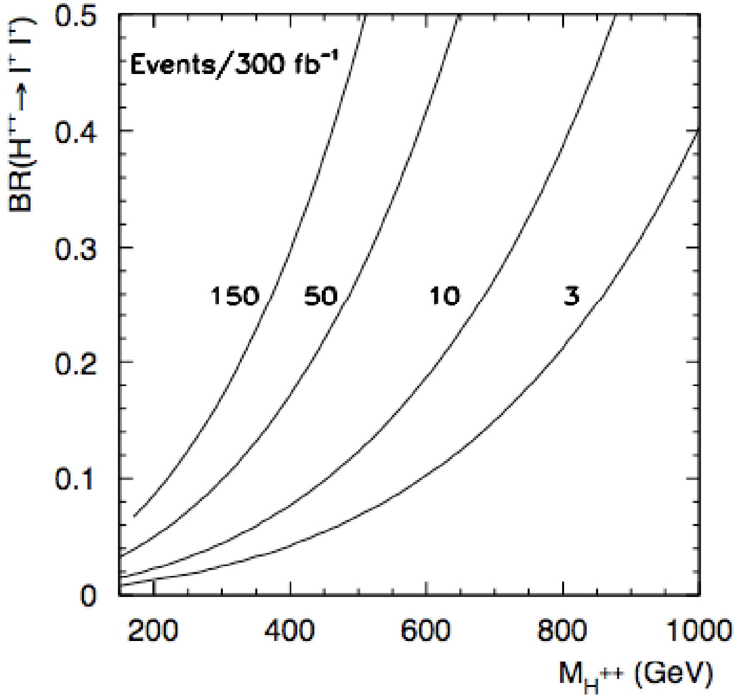


- $H^{\pm\pm}$, $H^{\pm}$ decay promptly: $H^{++} \to \ell^+\ell^+$, W^+W^+ complementary. May reach $20 - 80\ \mu$m, leading to displaced vertices.

Seesaw Mechanism: H^{++} H^{--} production

Sensitivity to $H^{++}H^{--} \to \ell^+\ell^+,\ \ell^-\ell^-$ Mode:

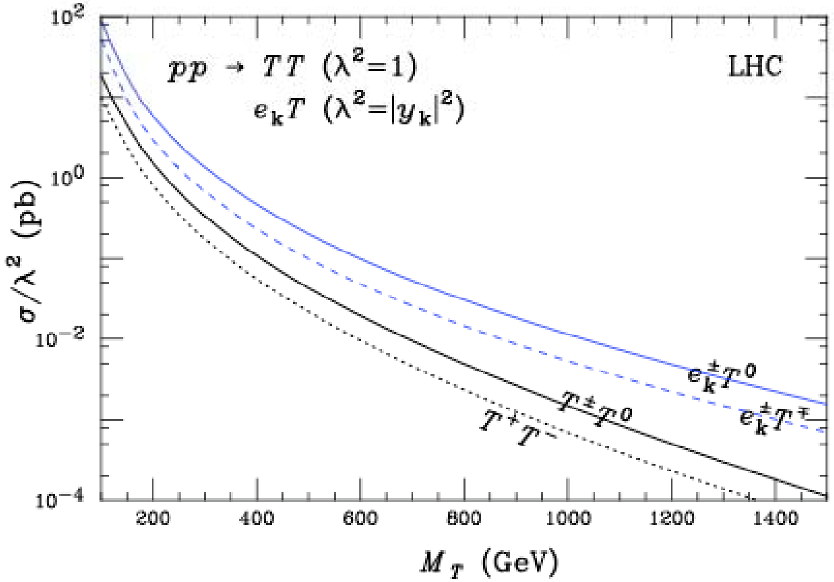
Nearly background-free.

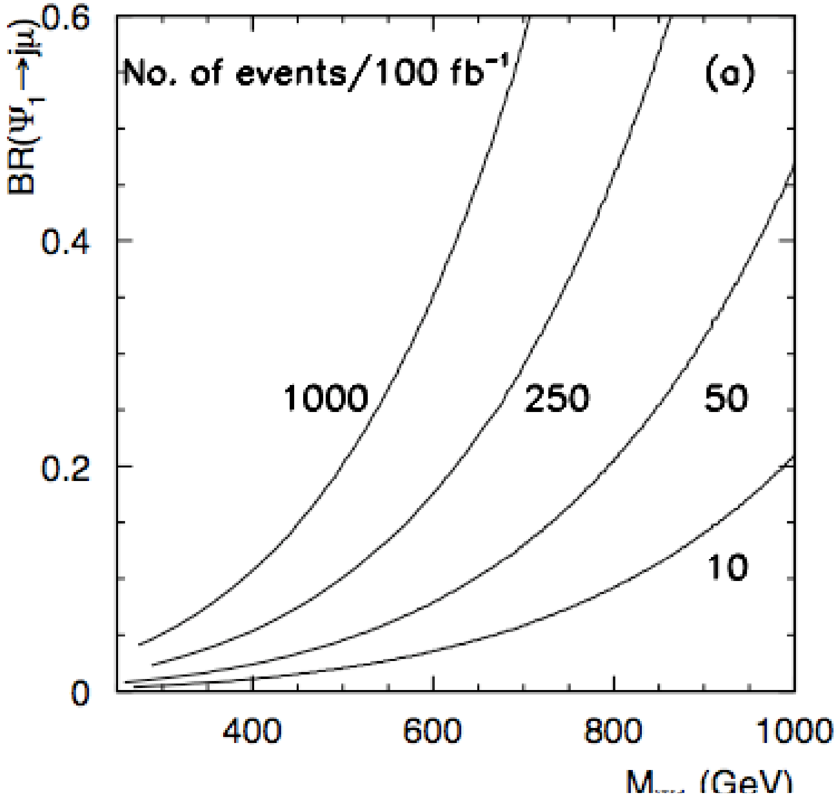


With 10 fb^{-1} integrated luminosity,
full coverage upto $M_{H^{++}} \sim 600 - 700$ GeV even with $BR \sim 40 - 50\%$.

Seesaw Mechanism: Heavy Leptons

Production rates at the LHC:





With 10 fb^{-1} integrated luminosity,
full coverage upto $M_{\Psi_1} \sim 800-1000$ GeV even with $BR \sim 20-30\%$.

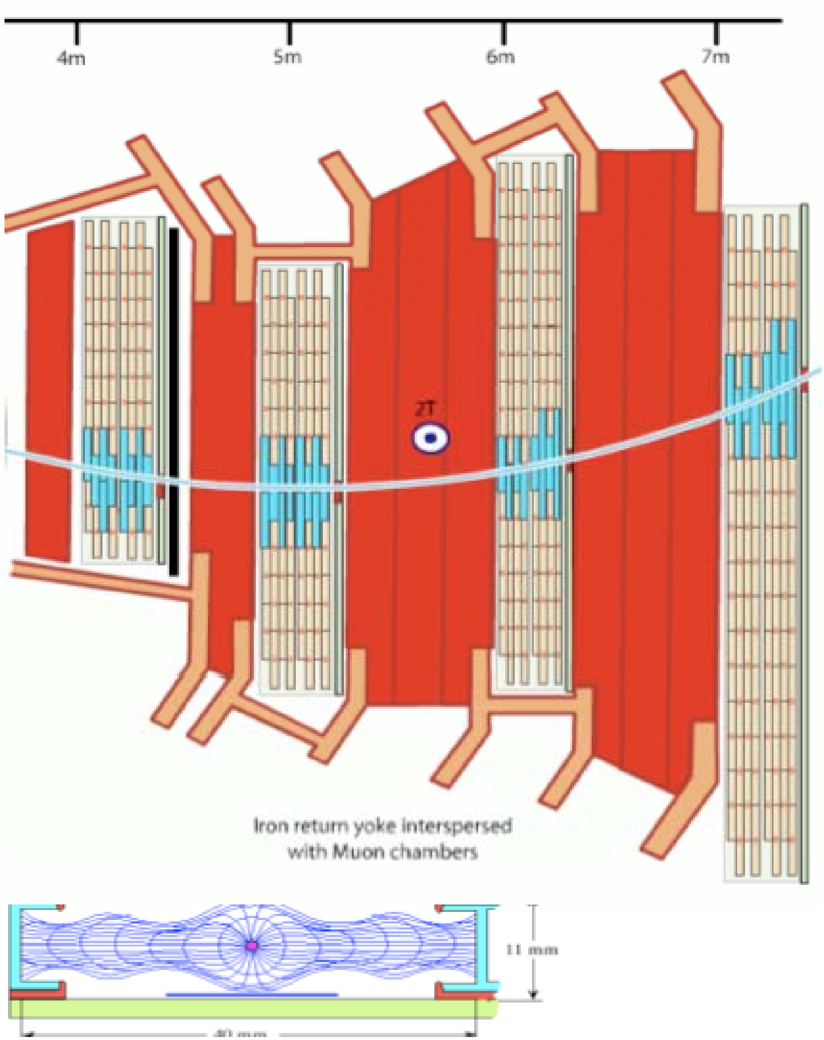
Seesaw Mechanism: Overview

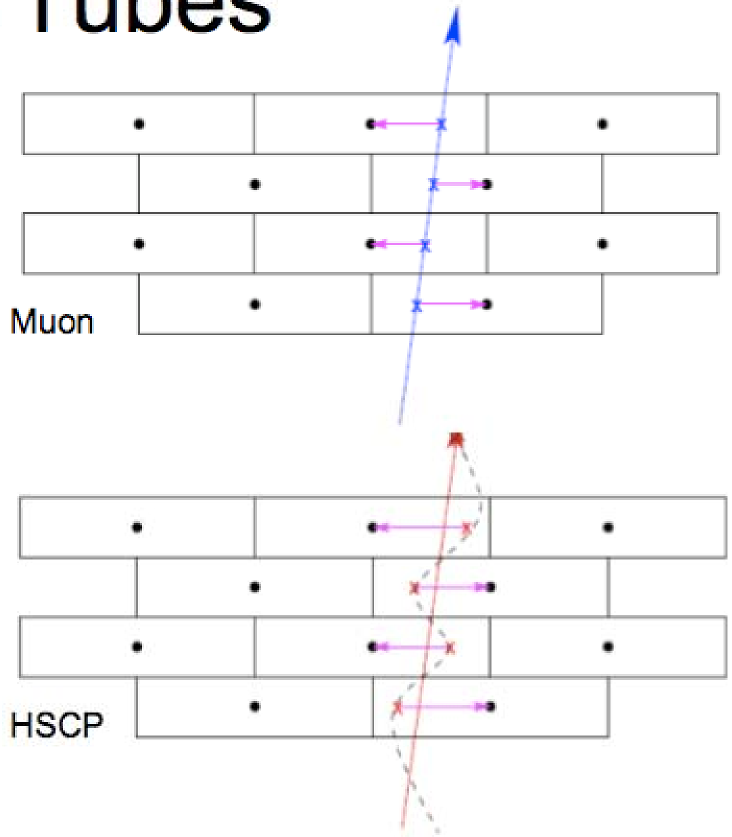
- It is of fundamental importance to test the Majorana nature of ν's,
  $\Delta L \neq 0$ in charged lepton sector is a necessity.
- For the three active ν's,
  $0\nu\beta\beta$ may be the only hope, IF $m_\nu \sim \sqrt{\Delta m_a^2} \sim 0.05$ eV.
- For a sterile neutrino N_4 in Type I Seesaw:
  - Tevatron sensitive: 10 GeV $< m_4 <$ 100 GeV, $10^{-4} < |V_{\mu 4}|^2 < 10^{-2}$;
  - LHC sensitive: 10 GeV $< m_4 <$ 400 GeV, $10^{-6} < |V_{\mu 4}|^2 < 10^{-2}$.
- For a scalar triplet $\Phi^{\pm\pm}$ in Type II Seesaw:
  - LHC sensitive: $M_\phi \sim 600 - 1000$ GeV ($\ell^\pm \ell^\pm$ *or* $W^\pm W^\pm$).
  - Distinguish Normal/Inverted Hierarchy; Probe Majorana phases.
- For a lepton triplet $T^\pm$, T^0 in Type III Seesaw:
  - LHC sensitive: $M_T \sim 800$ GeV.
  - Also distinguish Normal/Inverted Hierarchy.
- Certain GUTs can accommodate m_ν and LQ could be a window:
  - LHC sensitive: $M_{LQ} \sim 800 - 1000$ GeV.
  - Also distinguish Normal/Inverted Hierarchy.

Heavy stable charged particles

A. Giammanco
D. Milstead

TOF in Drift Tubes



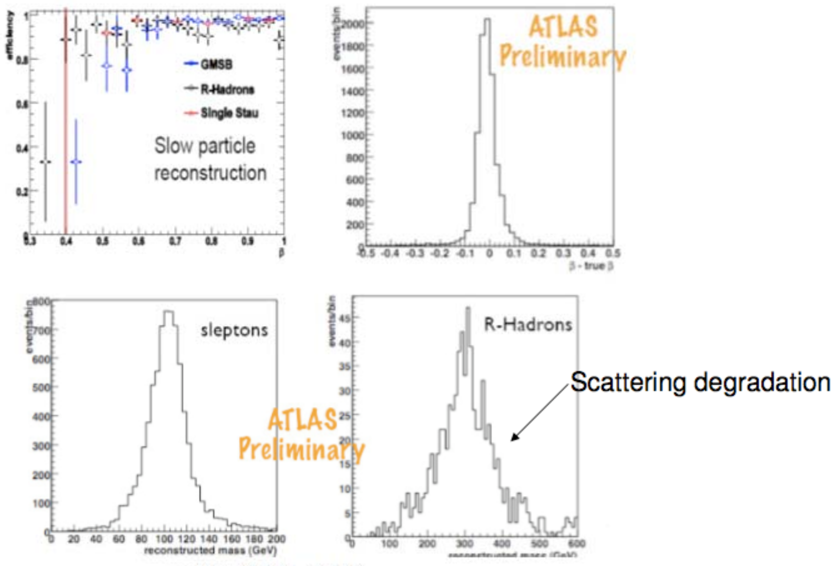


Normally the fit assumes β=1; here δt is left as a free parameter in the fit
=> TOF measurement
(see extra slides)

8

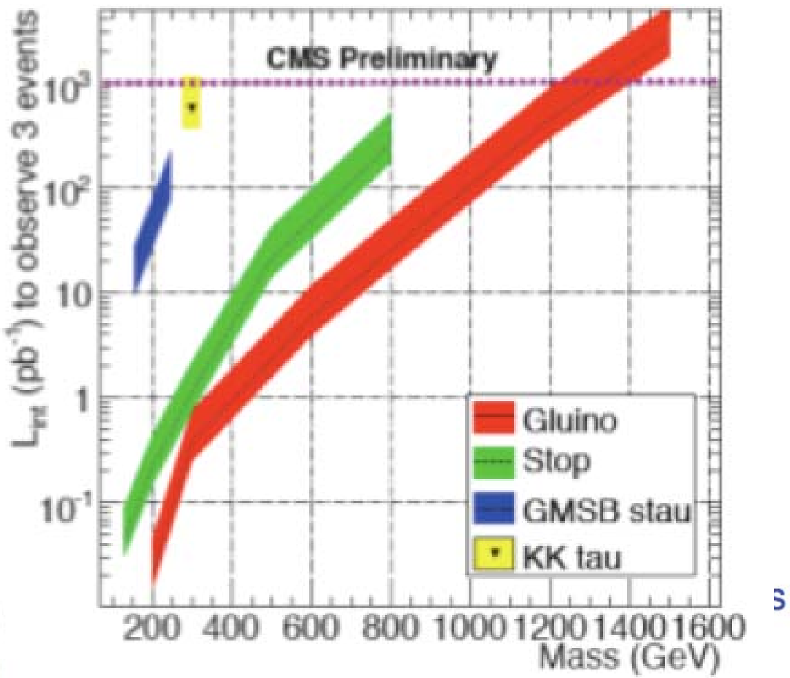
Heavy Charged Stable Particles

Reconstructing slow particles



arXiv:0901.0512

Stable Exotic particles

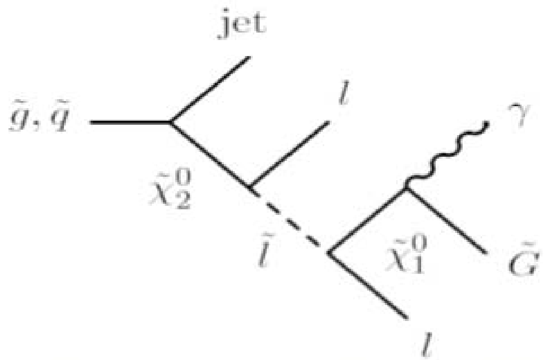


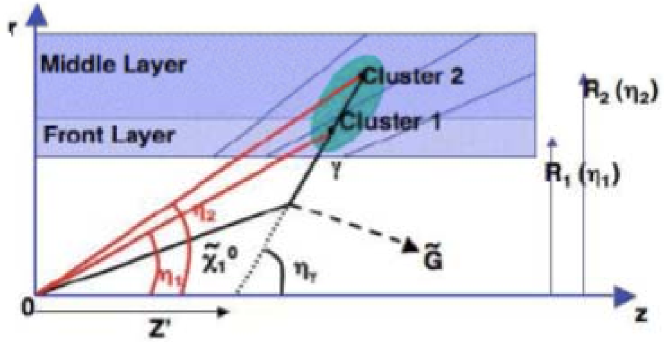
Impact on future detectors: TOF or multi-bunch information will become more important (SLHC?)
Mass scale determines the energy of the next machine

Non-pointing photons

GMSB scenarios - neutralino NLSP.

name	NLO (LO) σ [pb]	Λ [TeV]	M_m [TeV]	C_G	$c\tau$ [mm]	$M_{\tilde{\chi}_1^0}$ [GeV]
GMSB1	7.8 (5.1)	90	500	1.0	1.1	118.8
GMSB2	7.8 (5.1)	90	500	30.0	$9.5 \cdot 10^2$	118.8
GMSB3	7.8 (5.1)	90	500	55.0	$3.2 \cdot 10^3$	118.8



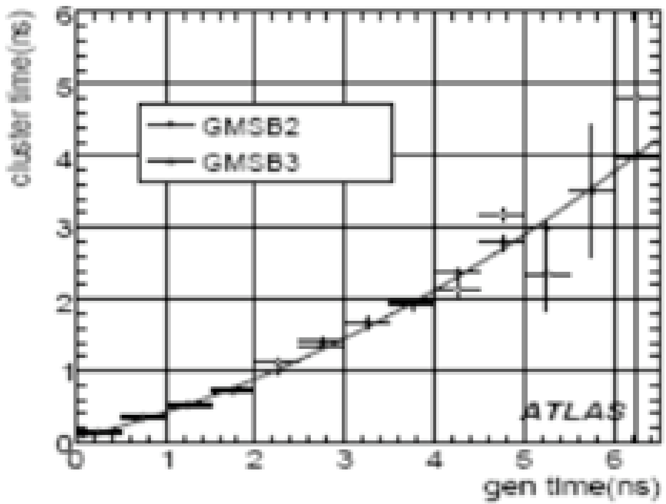


$C_{grav} > 1$

$\Rightarrow$ neutralino decays away from IP.

$\Rightarrow$ non-pointing high p_T photon.

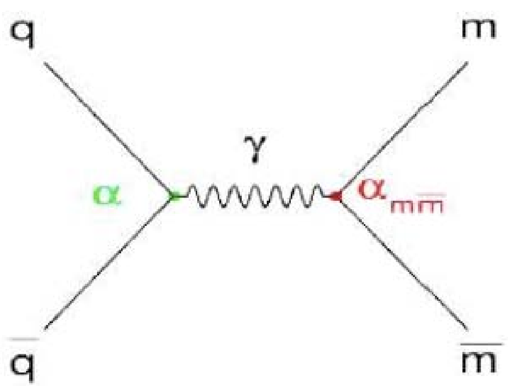
Δt reconstruction

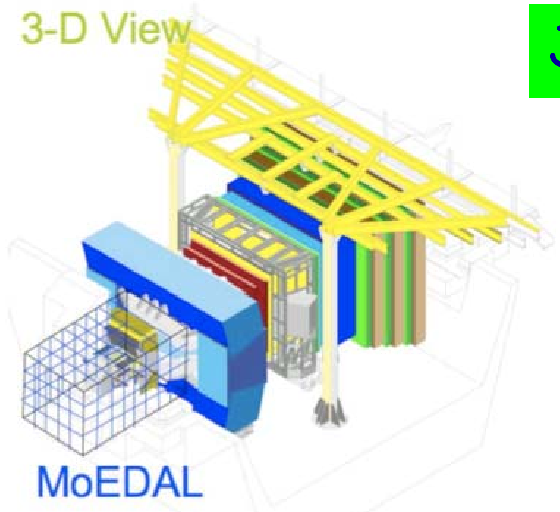


Impact on future detector

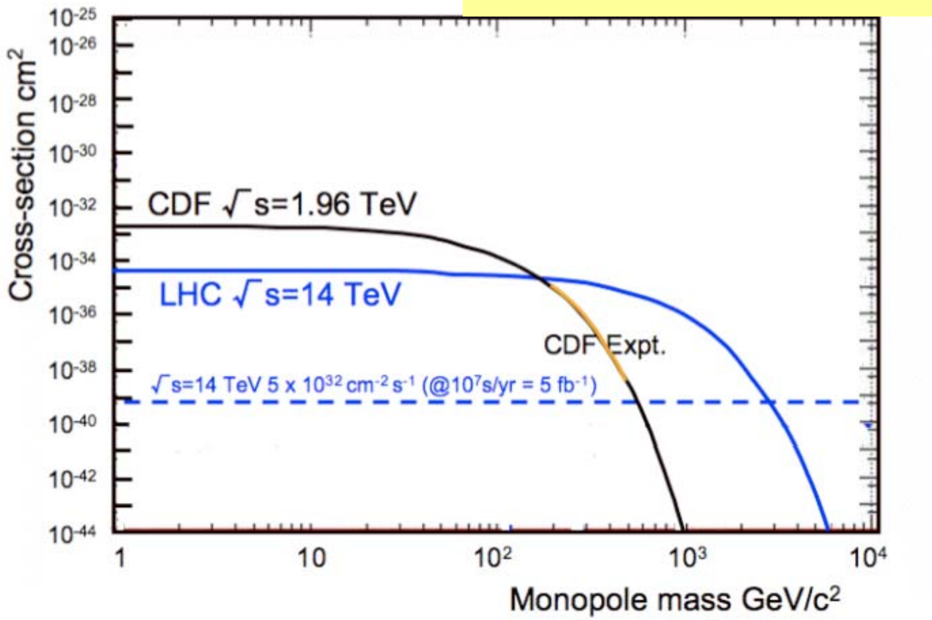
Moedal: MOnopole and Exotics Detector At the LHC

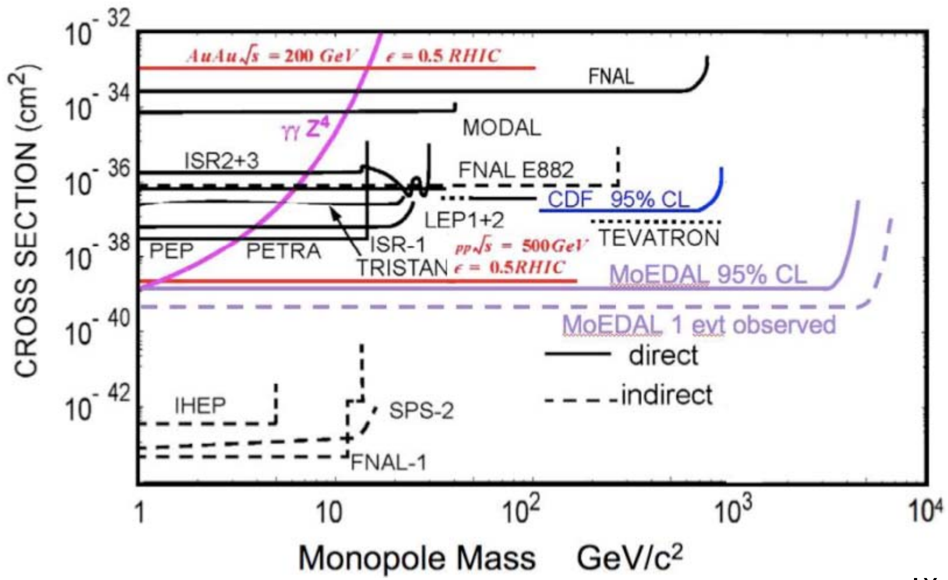
J. Pinfold





Figs are preliminary





The Heavy Flavor Physics connection

G. Isodori

Introduction

$$A = A_0 \left[c_{SM} \frac{1}{M_W^2} + c_{NP} \frac{1}{\Lambda^2} \right]$$

Λ = energy scale of the new particles

$c_{SM(NP)}$ = eff. couplings

- The sensitivity to the energy scale grows very slowly with the statistics or the luminosity of the experiment ($\sigma \sim 1/N^{1/4}$)
- The interest of a given observable depends on the magnitude of c_{SM} vs. c_{NP} (*loop-induced observables usually more interesting because of small c_{SM}, but other type of suppressions, such as the helicity suppression, can make specific tree-level processes particularly interesting*)
  and on the theoretical error of c_{SM}
  (*CKM + hadronic uncertainties → important role of auxiliary observables*)

Λ should not be too large for super-B factories!

Heavy Flavor ↔ High p_T Interplay

The most interesting observables in the MSSM with MFV:

$B(B_s \to \mu\mu)_{SM} \approx 3.5 \times 10^{-9}$

$B(B_d \to \mu\mu)_{SM} \approx 1.3 \times 10^{-10}$

e channels suppressed by $(m_e/m_\mu)^2$

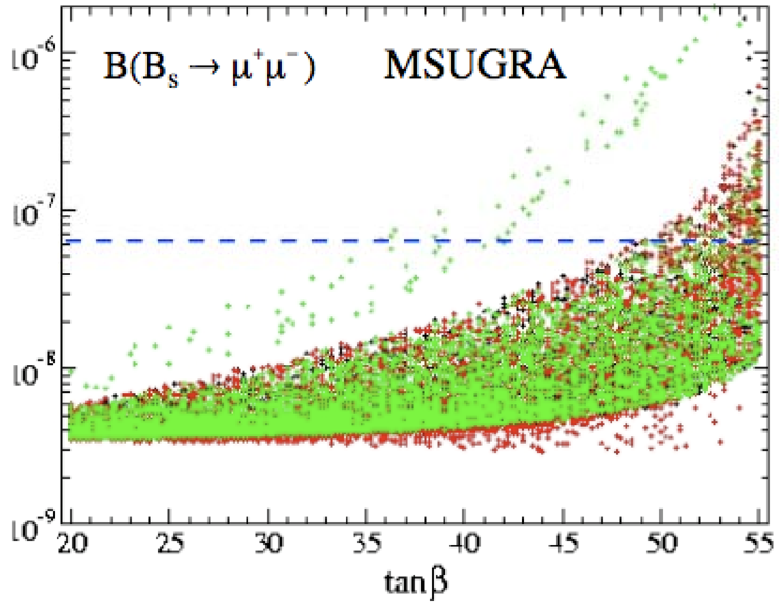
τ channles enhanced by $(m_\tau/m_\mu)^2$

Most interesting bound set by:

$B(B_s \to \mu\mu) < 5.8 \times 10^{-8}$ (95%CL)

CDF+D0 '07

Significant constraint, but a good fraction of the parameter space is still allowed



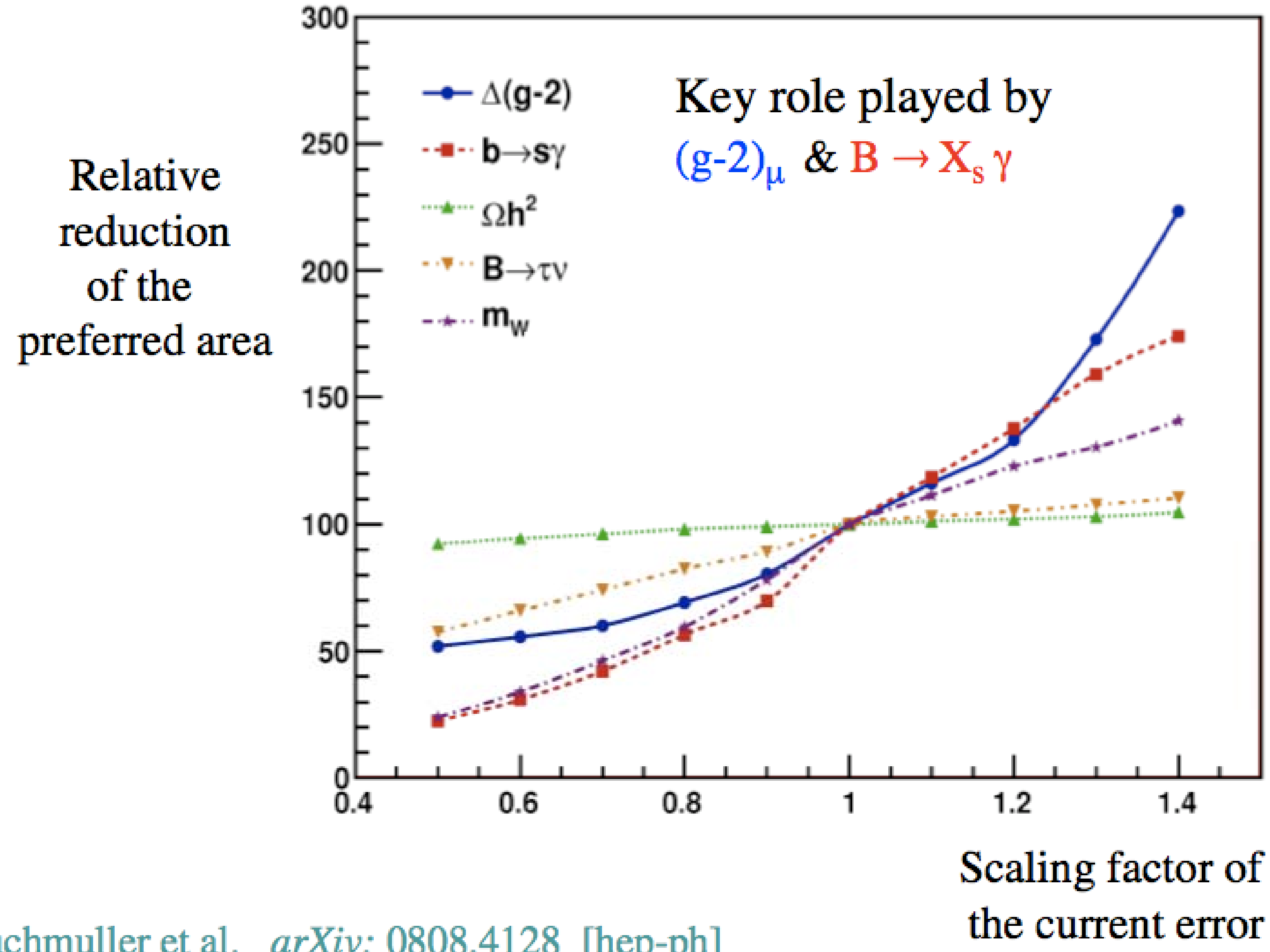
Kane *et al.* '03

N.B.: the $B(B_d \to \mu\mu)/B(B_s \to \mu\mu)$ ratio is a key observable to proof or falsify MFV

Unfortunately no systematic comparison between the LHCb and ATLAS/CMS New Physics reach yet…

Importance of precision measurements

E.g.: The role of indirect constraints in a global fit of the CMSSM:



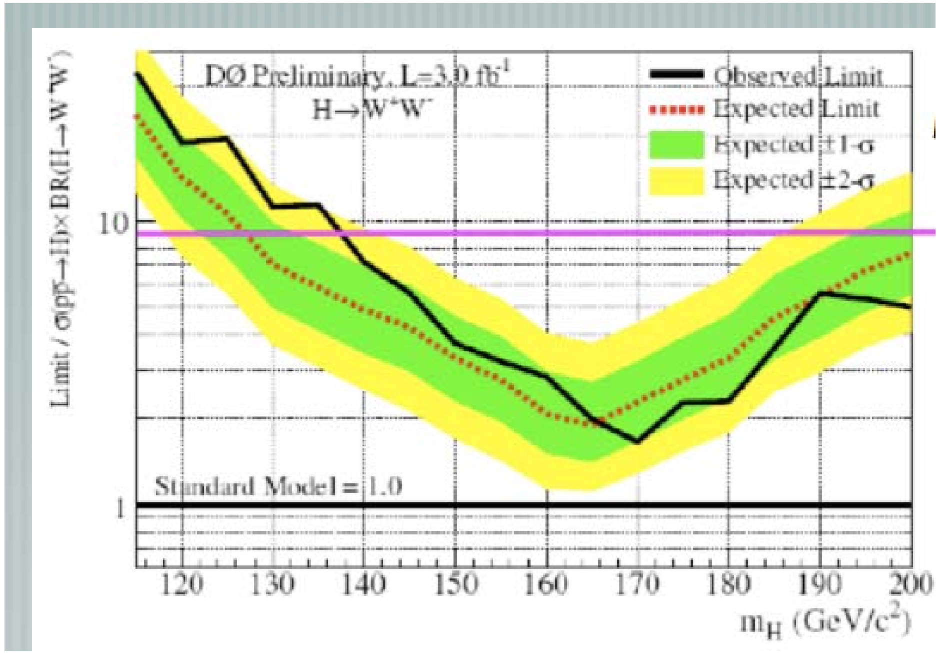
Buchmuller et al. *arXiv:* 0808.4128 [hep-ph]

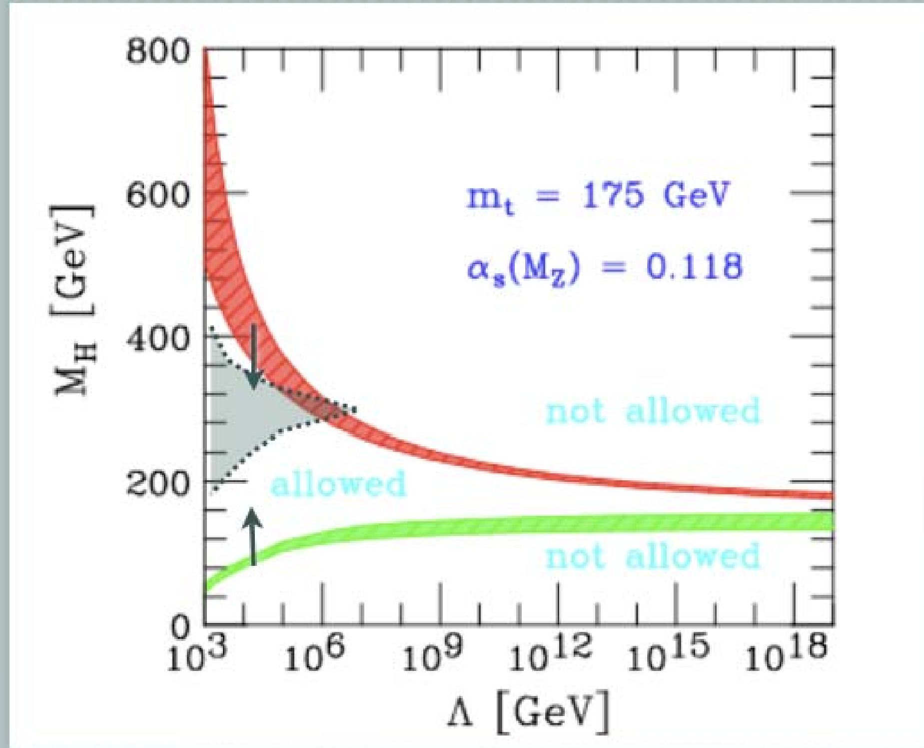
4th Generation

$m_{t'} > 311$ GeV ($t' \rightarrow bW$) $m_{b'} > 199$ GeV ($b' \rightarrow bZ$)

E. Kou, G. Hou
K.F. Chen, S. Sultansoy

Tevatron limits





Hambye et al 9610272
Djouadi 0503172
Kribs et al 0706.3718 (detailed study of Higgs physics for 4th generation)

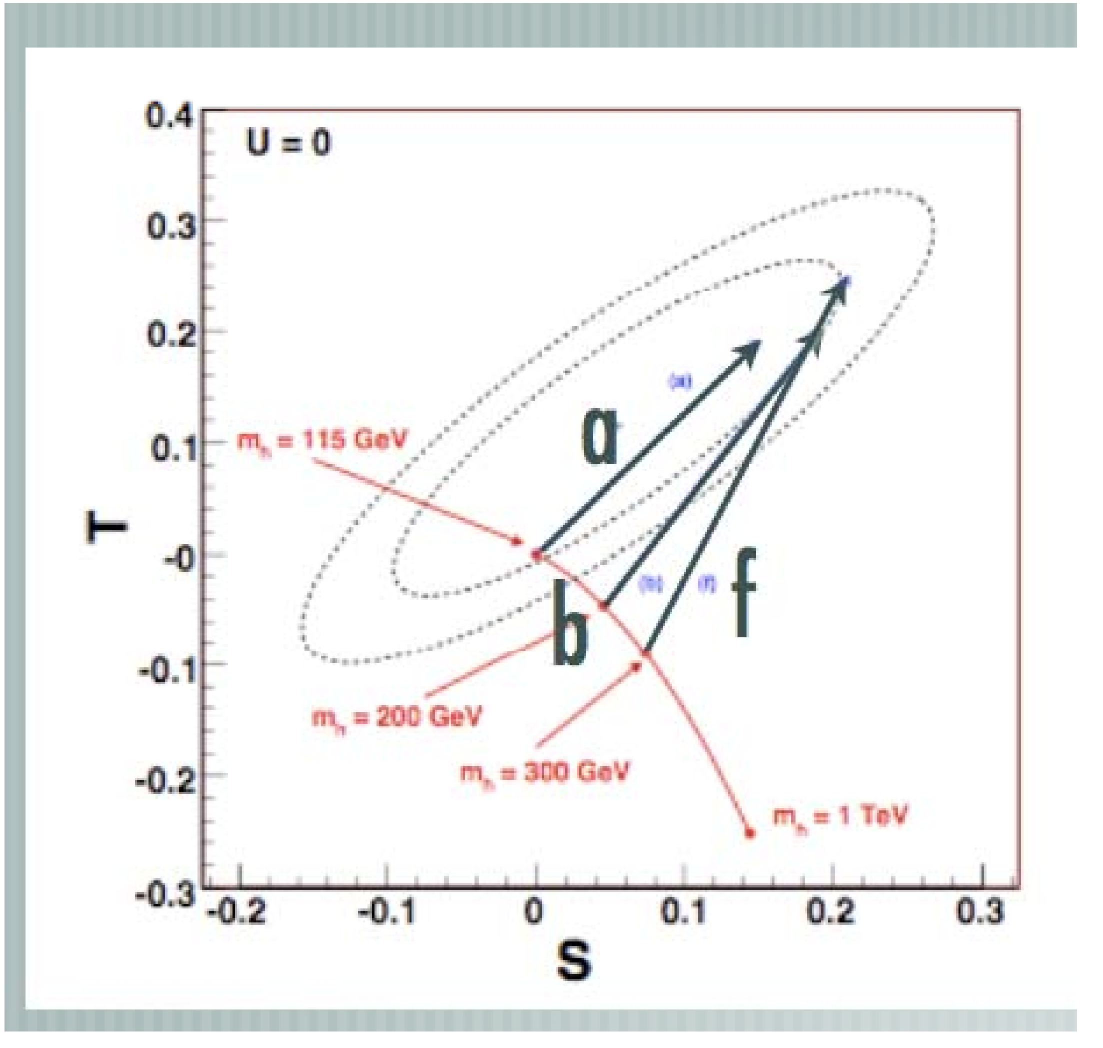
In this scenario the light Higgs is ruled out

New physics required < 1000 TeV

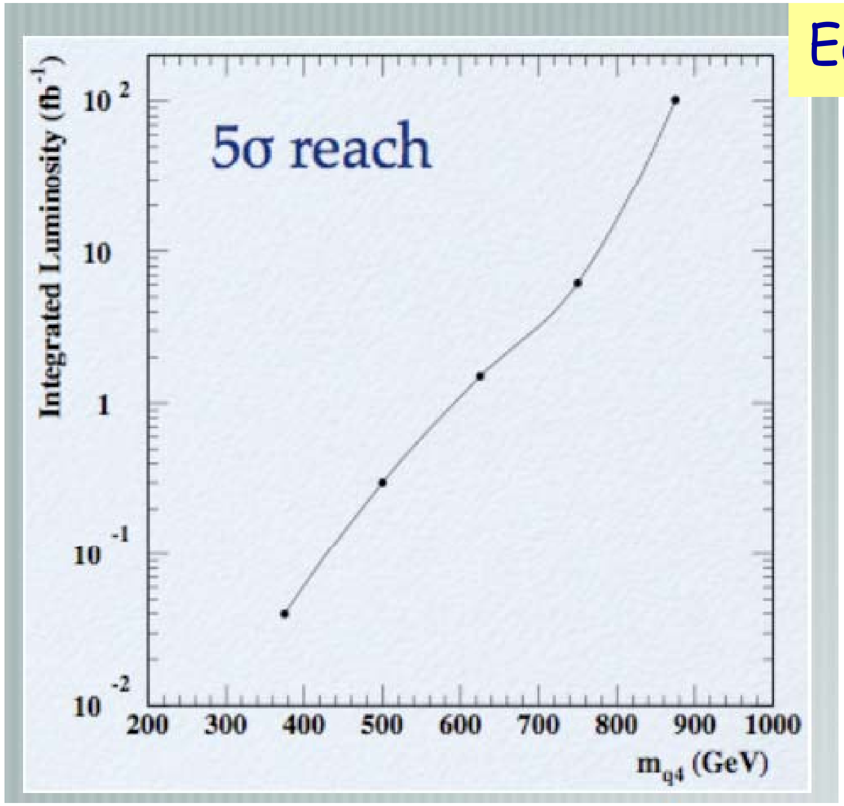
4th Generation

✓Not only the heavy fermions are allowed, but also a heavy Higgs becomes possible!

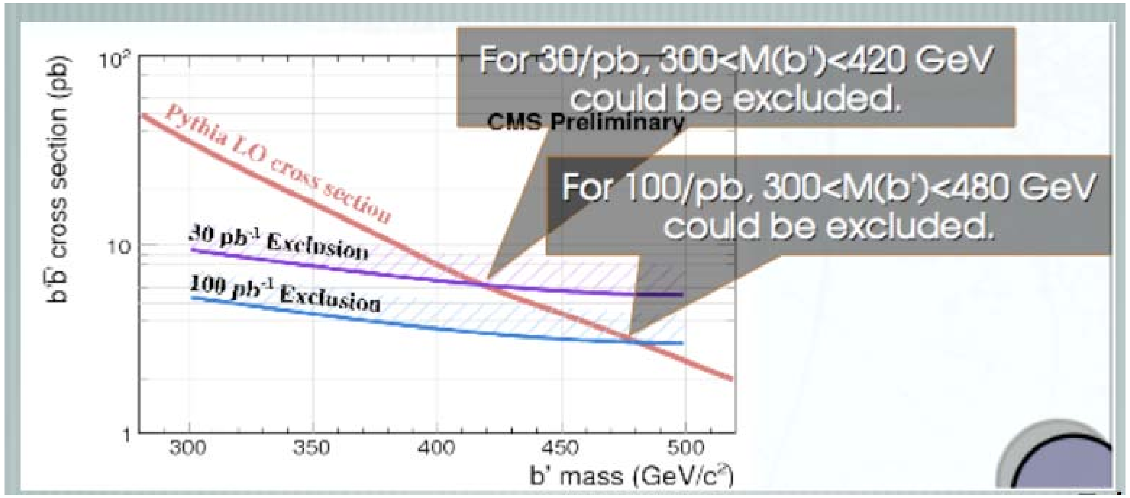
GeV	$M_{t'}$	$M_{b'}$	M_h
a	310	260	115
b	320	260	200
f	400	325	300

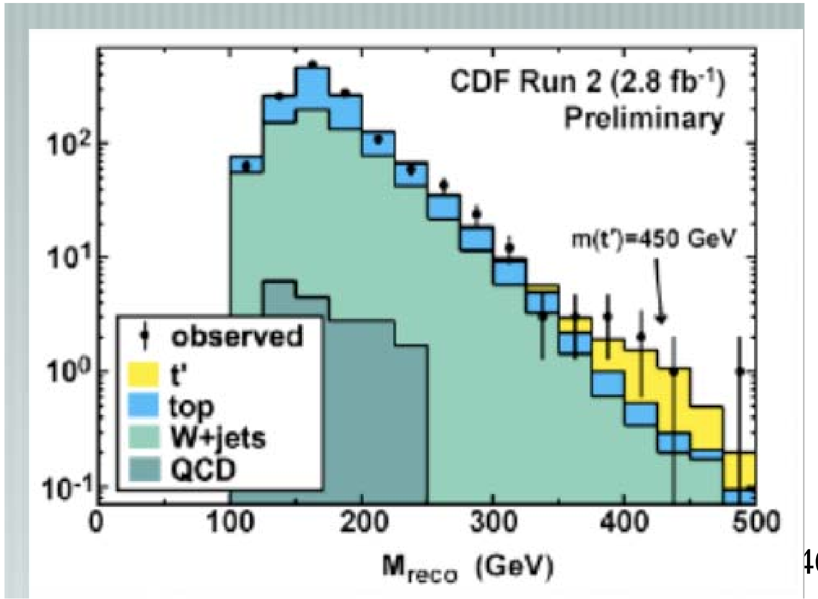


LHC Sensitivity



Early data will cover the region up to 500 GeV





Tantalizing 'hint' from CDF on t'
What does D0 say?
What is the MC 'tail' uncertainty?

4th generation

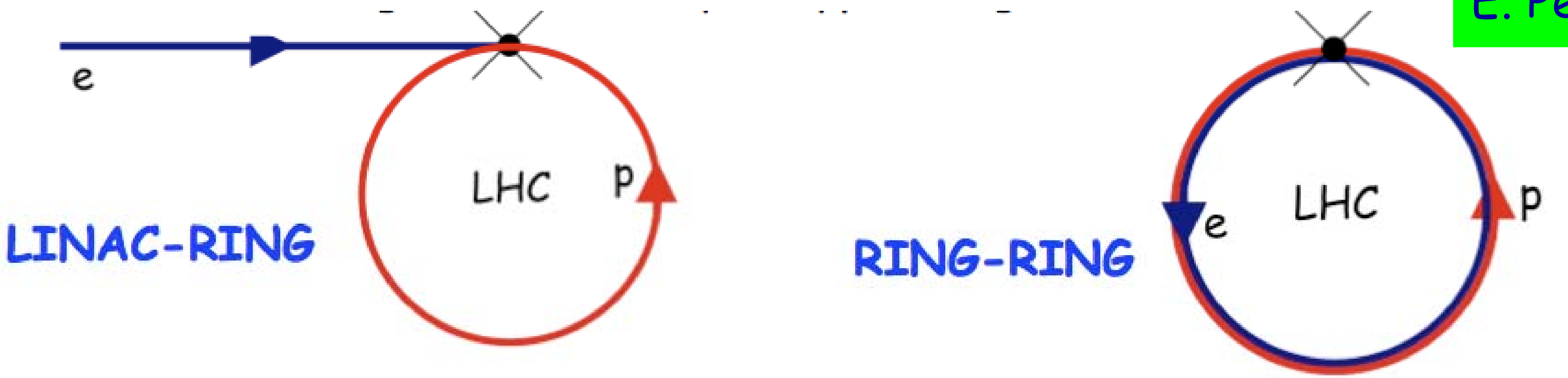
E. Kou, F. Richard

- Allowed by precision measurements provided that the quarks are semi-degenerate in mass mt'-mb'~50 GeV. This extra contribution to T allows to increase S and therefore allows to accommodate a heavy Higgs
- Suggested on the basis of TeV baryogenesis (provides increased CPV) and provides a mechanism for EWSB (through condensat of heavy quarks)
- Can explain various hints of experimental deviations in the B sector and a small excess observed in t' search at CDF
- LHC would cover this scenario with the luminosity foreseen in 2010 since unitarity sets an upper limit mt',b'<550 GeV (4th generation SM)
- The Higgs sector is deeply modified. One expects mH~mt' (stability limit) meaning that there is a heavy Higgs decaying into ZZ and therefore easy to discover at LHC. Moreover the gluon-gluon cross section is multiplied by ~9 allowing an early discovery at LHC
- 4MSSM is possible with tanβ~1 (to limit Yukawa couplings) and would allow to have a light Higgs. It would also provide the scalars needed for a 1^{st} order EW transition for baryogenesis if the squarks are quasi-degenerate in mass with the heavy quarks
- LC at ~1TeV would allow to reconstruct precisely the properties of the new fermions more particularly for what concerns the leptons not easy to produce at LHC. In 4MSSM where one predicts a complex scenario (quarks and quarks of the same mass) a LC would allow to disentangle the various hadronic states
- In a near future, Tevatron should allow to confirm the presence of CPV in Bs mixing which constitutes a important clue in favour of 4^{th}. Search for t' is ongoing at CDF and D0

Start of the WG4 write-up ☺

LHeC

E. Perez



LHeC: A Large Hadron electron Collider at the LHC
5-140 GeV $e^{\pm}$ on 1-7 TeV p,A

- Following a discovery at the LHC, LHeC may provide information about the underlying theory, examples :

  - electron-quark resonances
  - new Z' boson : couplings → underlying model
  - structure of a eeqq contact interaction
  - study of new leptons (sleptons, excited leptons)

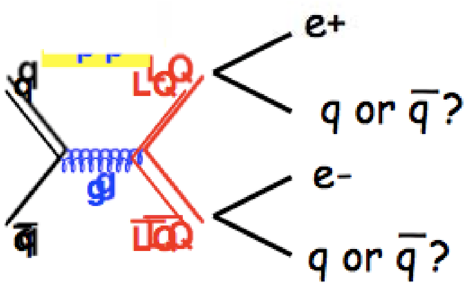
LHeC: Leptoquarks

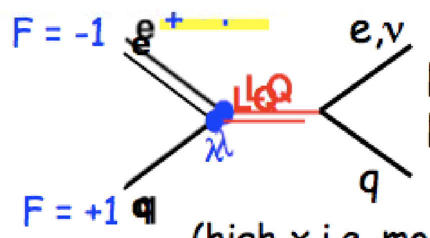
Determination of LQ properties

pp, pair production

ep, resonant production

- Fermion number



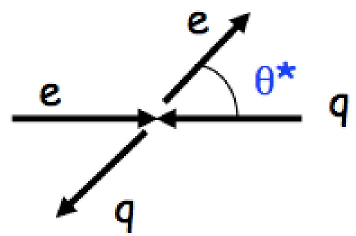


F=0 LQs : $\sigma(e^+)$ higher
F=2 LQs : $\sigma(e^-)$ higher

(high x i.e. mostly q in initial state)

- Scalar or Vector

$q\bar{q} \rightarrow g \rightarrow LQ\, \overline{LQ}$:
angular distributions depend on the structure of g-LQ-LQ. If coupling similar to γWW, vector LQs would be produced unpolarised...



cos(θ*) distribution gives the LQ spin.

- Chiral couplings

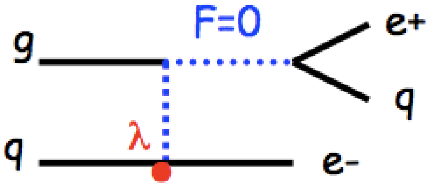
?

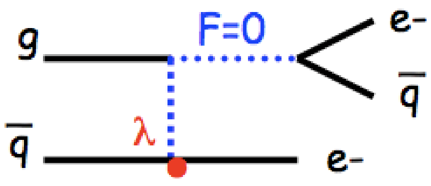
Play with lepton beam polarisation.

LHeC: Leptoquarks

Determination of LQ properties in single production: e.g. Fermion Number

In pp: look at signal separately when resonance is formed by (e^+ + jet) and (e^- + jet) :



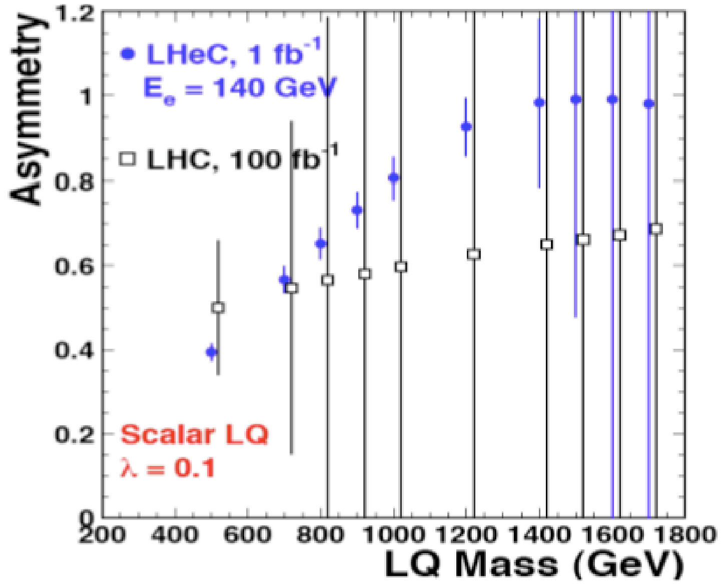


$\sigma(e^+_{out}) > \sigma(e^-_{out})$
for F=0

Sign of the asymmetry gives F, but could be statistically limited at LHC. (*)

Easier in ep ! Just look at the signal with incident e+ and incident e-, build the asymmetry between $\sigma(e^+_{in})$ and $\sigma(e^-_{in})$.

If LHC observes a LQ-like resonance, M < 1 - 1.5 TeV, with indications (single prod) that λ not too small, LHeC would solve the possibly remaining ambiguities.



(*) First rough study done for the 2006 paper.
Need to check / refine with a full analysis of signal and backgrounds.

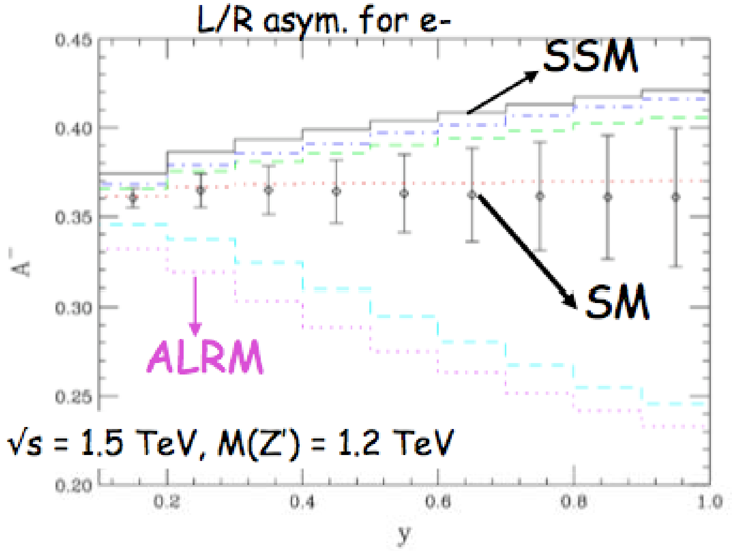
LHeC: Zprime & Contact Interactions

Other examples of new physics in eeqq amplitudes

- new Z' boson: pp measurements alone do not allow for a model-independent determination of all of the Z' couplings ($g_{L,R}^{e}$, $g_{L,R}^{u,d}$)

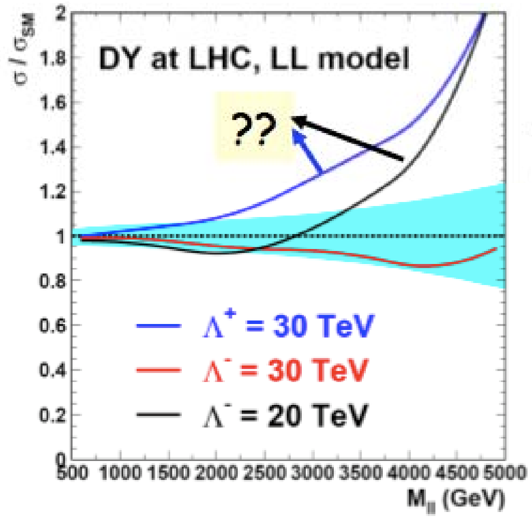
LHeC data may bring the necessary complementary information, before a LC.

T. Rizzo, PRD77 (2008) 115016

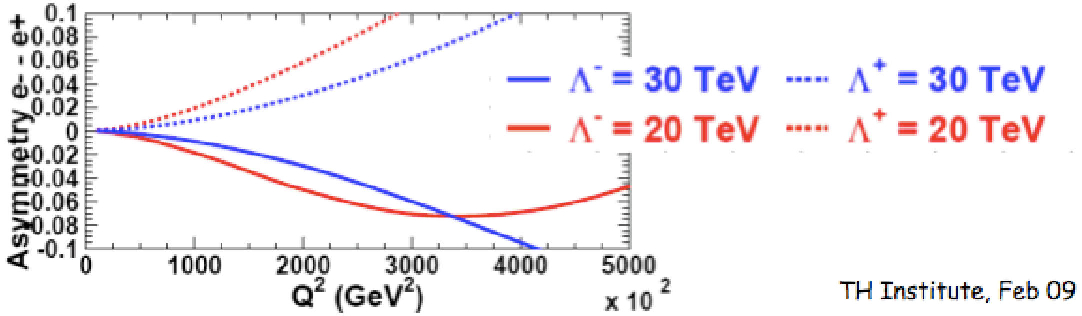


- Contact Interactions:

$$\mathcal{L}_{CI} = \sum_{i,j=L,R} \varepsilon_{ij}^{eq} \frac{4\pi}{\Lambda^2} (\bar{e}_i \gamma^\mu e_i)(\bar{q}_j \gamma_\mu q_j)$$

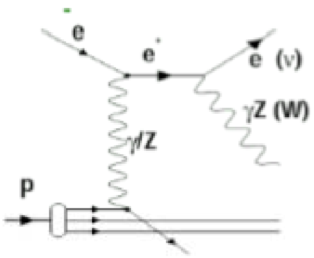


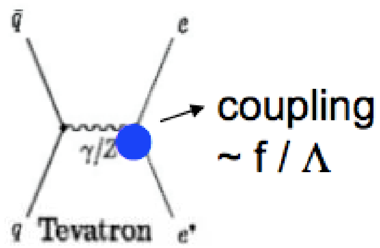
At LHeC, sign of the interference can be determined by looking at the asym. between σ/SM in e^- and e^+.



LHeC: Excited Electrons

Electron-boson resonances: excited electrons

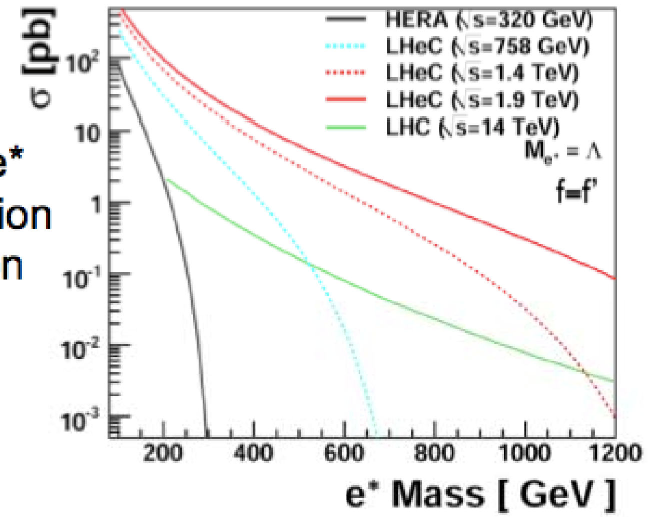




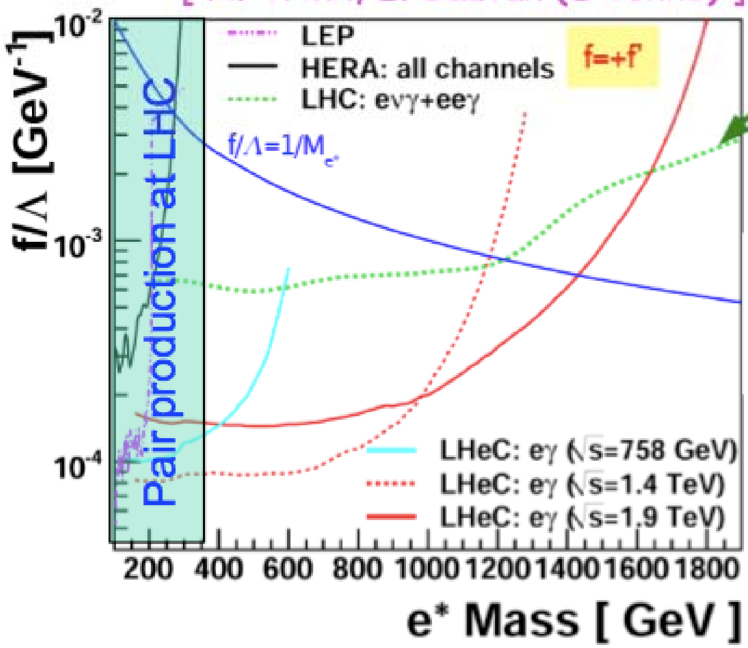
[Hagiwara et al. ZPC 29(1985)115]

[Boudjema et al. ZPC 57(1990)425]

Single e* production x-section



[N. Trinh, E. Sauvan (Divonne)]



[Phys. Rev D 65 (2002) 075003]

LHeC prelim. analysis, looking at $e^* \rightarrow e\gamma$

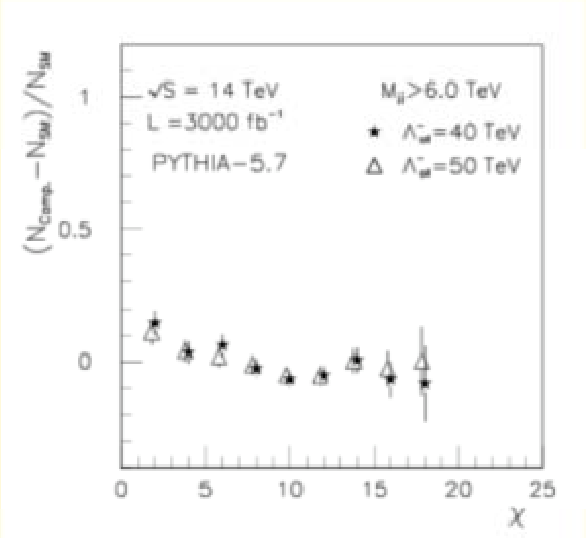
- If LHC discovers (pair prod) an e*: LHeC would be sensitive to much smaller f/Λ couplings.
  Possible determination of QNs [cf LQs]

- Discovery potential for higher masses

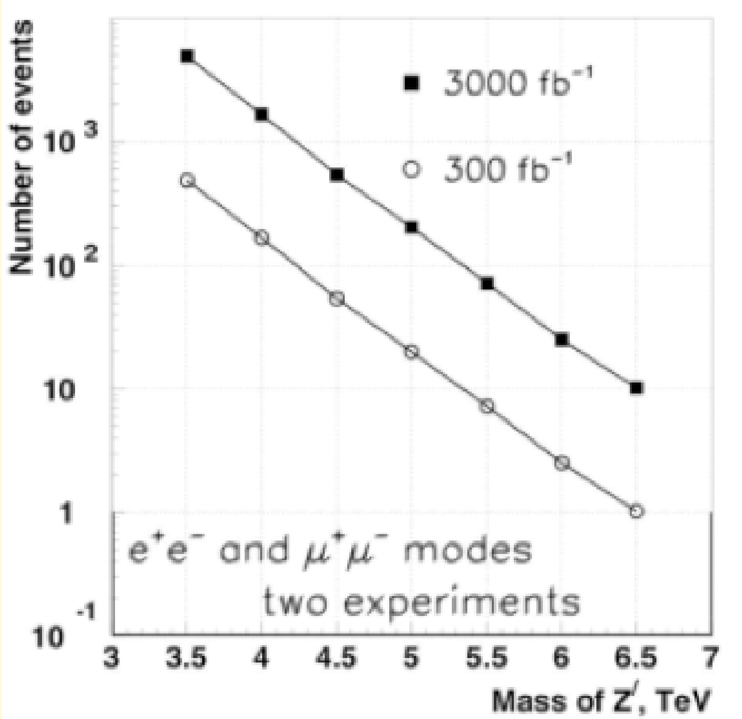
LHeC sensitivity,
with L=10 fb^{-1} for Ee=70/20 GeV
with L=1 fb^{-1} for Ee=140 GeV

SLHC…

Quark compositeness



Study large-E_T production and angular distributions at large M_{JJ}

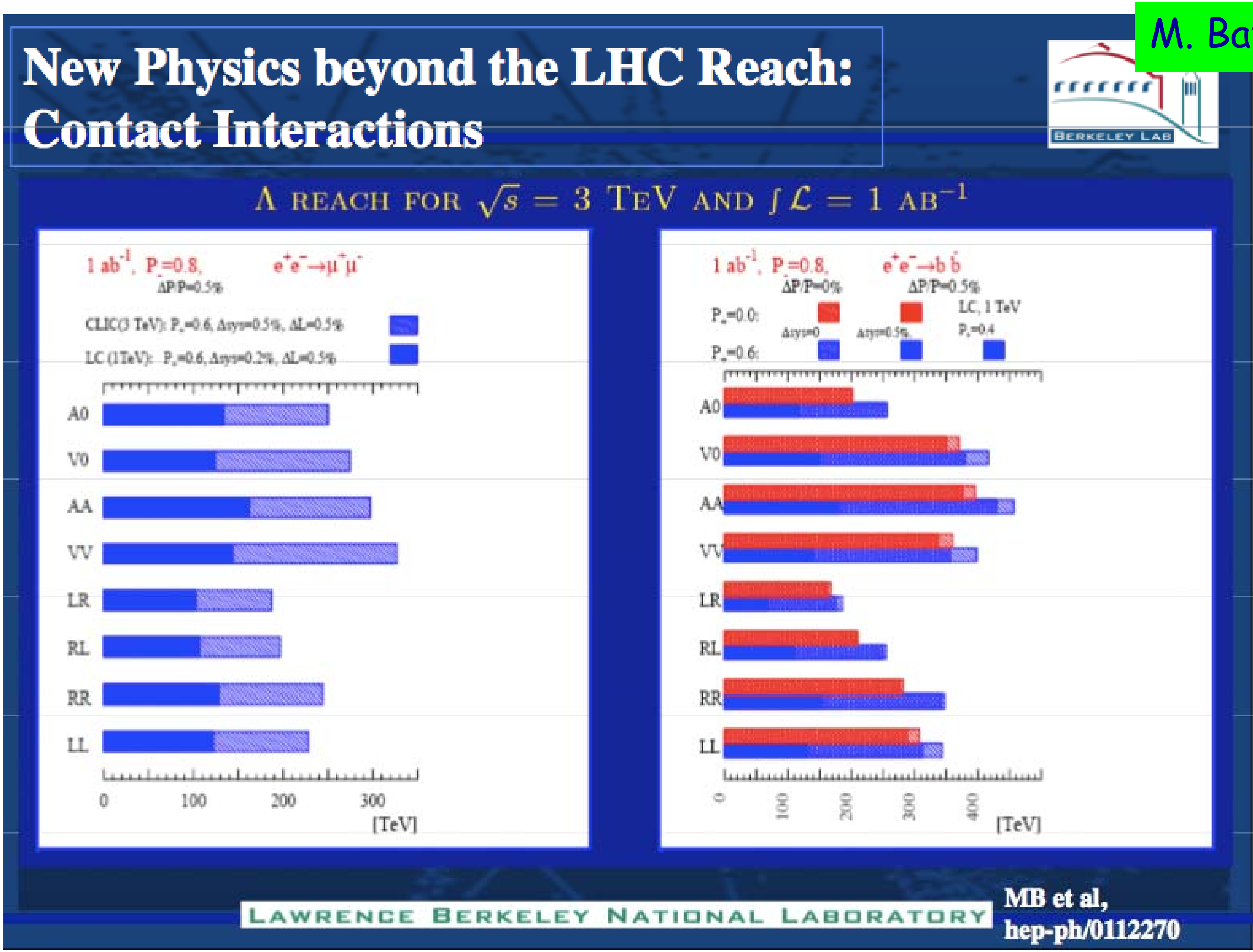


95% sensitivity

	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

CLIC: Example

M. Battaglia



Indicative Physics Reach

Ellis, Gianotti, ADR
hep-ex/0112004+ few updates

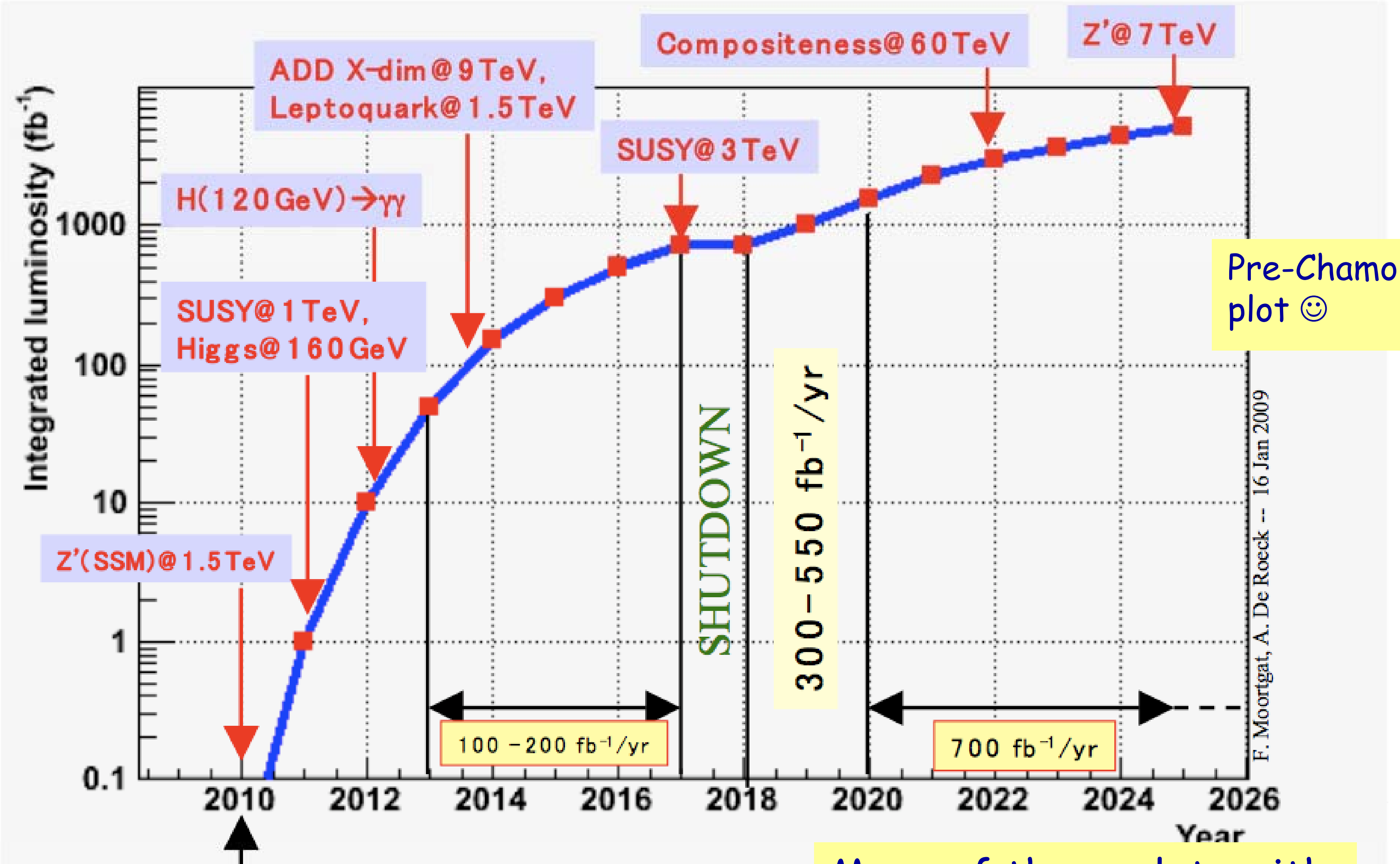
Units are TeV (except $W_L W_L$ reach)
$\int$Ldt correspond to 1 year of running at nominal luminosity for 1 experiment

PROCESS	LHC 14 TeV 100 fb^{-1}	SLHC 14 TeV 1000 fb^{-1}	DLHC 28 TeV 100 fb^{-1}	VLHC 40 TeV 100 fb^{-1}	VLHC 200 TeV 100 fb^{-1}	ILC 0.8 TeV 500 fb^{-1}	CLIC 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	6σ	90σ
Z'	5	6	8	11	35	8†	30†
Extra-dim (δ=2)	9	12	15	25	65	5-8.5†	30-55†
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

Example of the LHC Outlook



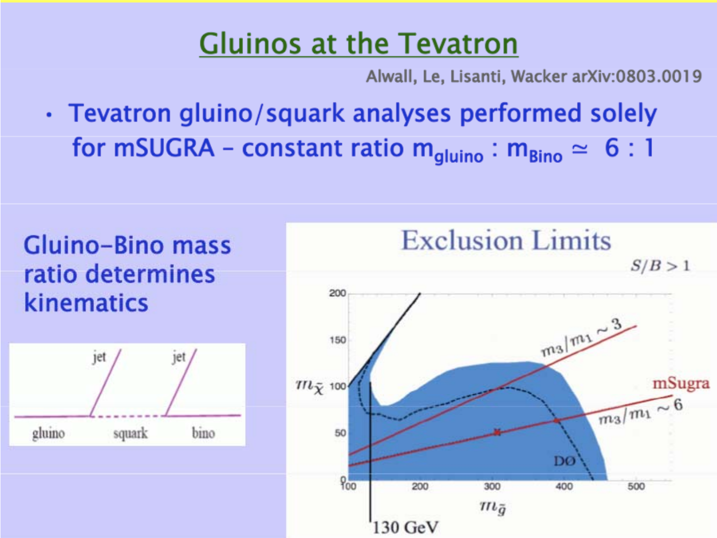
Pre-Chamonix plot ☺

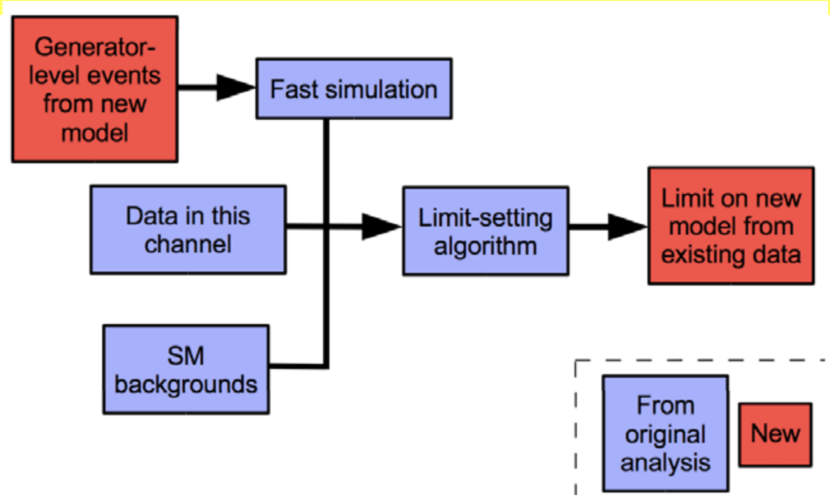
First physics run in 2009: 50 pb^{-1}

More of these plots with more details?

Data presentation/storage discussion

- Often released data are presented under model assumptions, thus making it difficult to interpret in a different context
- How to communicate/catalogue an excess best
- Time overlaps between running of big facilities (Eg LHC/SLC and the LC) could be small. How to bridge that gap so that (S)LHC data is still fully alive when the next machine comes online?





Lively discussion! To be continued

J. Hewett, C. Henderson
J. Incandela

Finally: Questions to Complete for Write-up

- Many of the exotica signals are accessible already with low luminosity. More lumi will extend the reach and allows to measure for characteristics. Some model tests will take more time (Eg. little Higgs)
  - Road-map of present knowledge on when we are sensitive to what mass 200 pb^{-1} (10 TeV) - 10 fb^{-1} (14 TeV) but also higher, up to SLHC (see example). What if NO signal? Interpretation of Signal
  - What characteristics can we determine with LHC alone and what would be needed as next machine… Energy/luminosity?
  - Detector design: unusual signatures. When can we get exp. feedback on stopped gluinos, Hidden Valley, Heavy stable charged particles?
- For our study: select a few benchmark processes like Z', leptoquarks? Contact interactions? Fourth generation…
- Some scenarios identified where good next options would be SLHC, LHeC, ILC or CLIC. No specific scenario for a muon collider, but should be similar to CLIC. DLHC/VLHC extend discovery reach, as shown