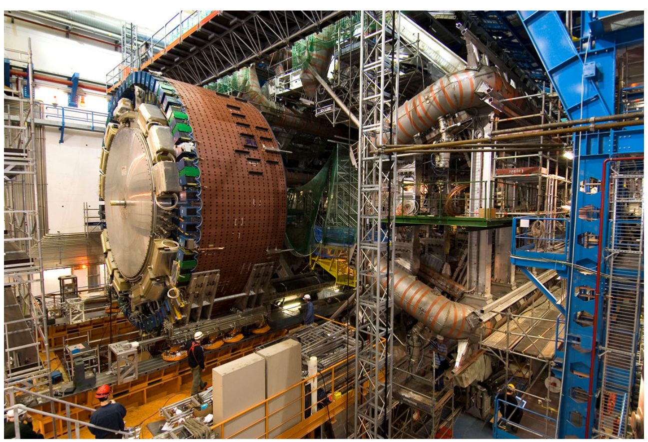
Early LHC Measurements and CLIC Energy

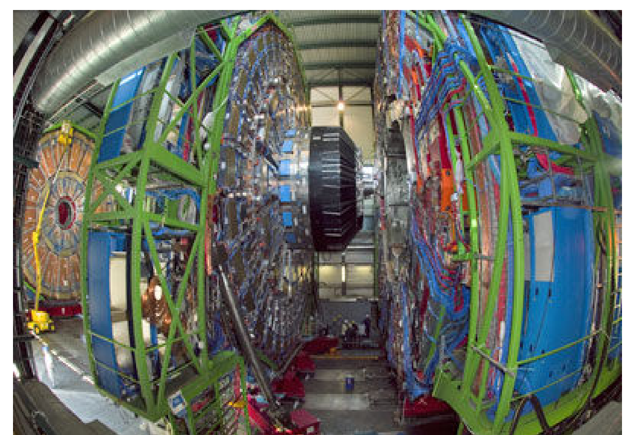
Albert De Roeck
CERN

CLIC09 Workshop

12-16 October 2009

CLIC



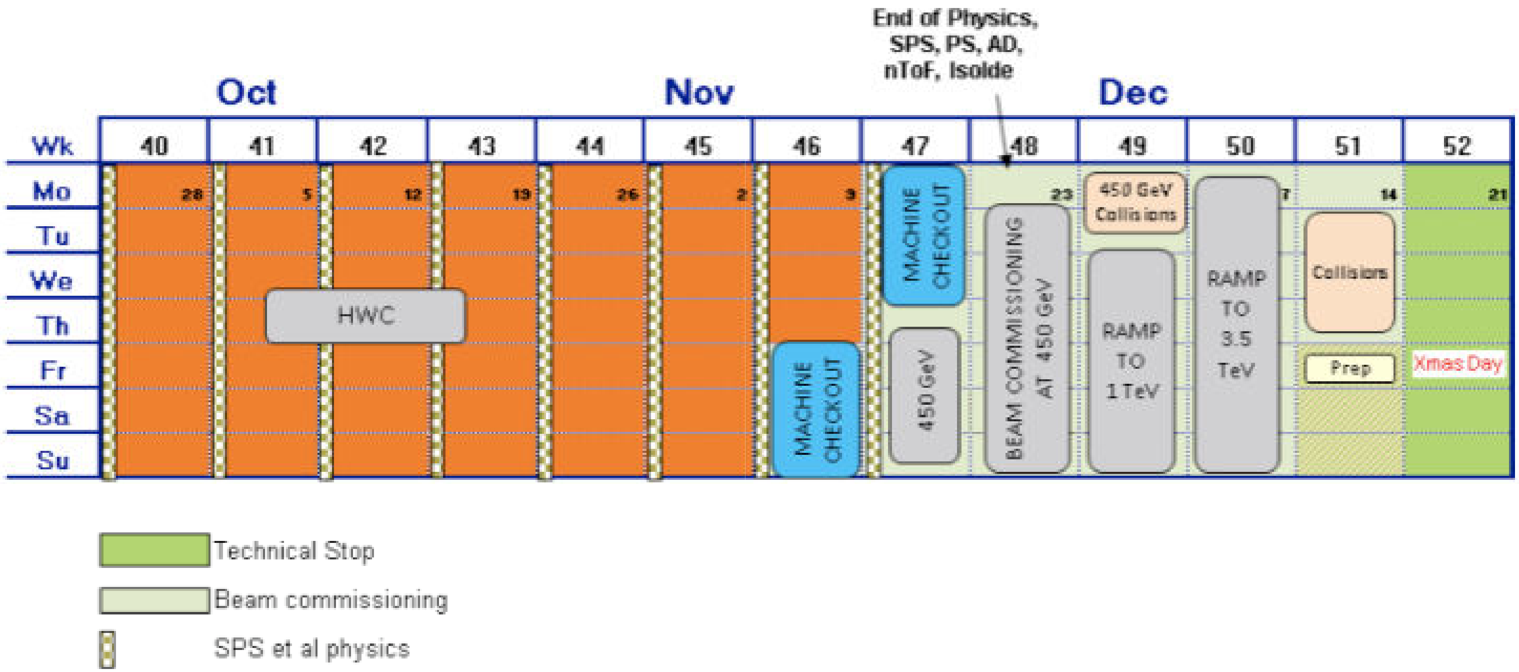


Contents

- LHC startup and profile
- LHC Evolution/sLHC
- First physics
  - Higgs
  - Supersymmetry
  - Other scenarios
- Conclusion

- Early data (first few years) ⇒ Energy scale of New Physics
- Full data samples (few 100 or few 1000 fb^{-1}) ⇒ precision

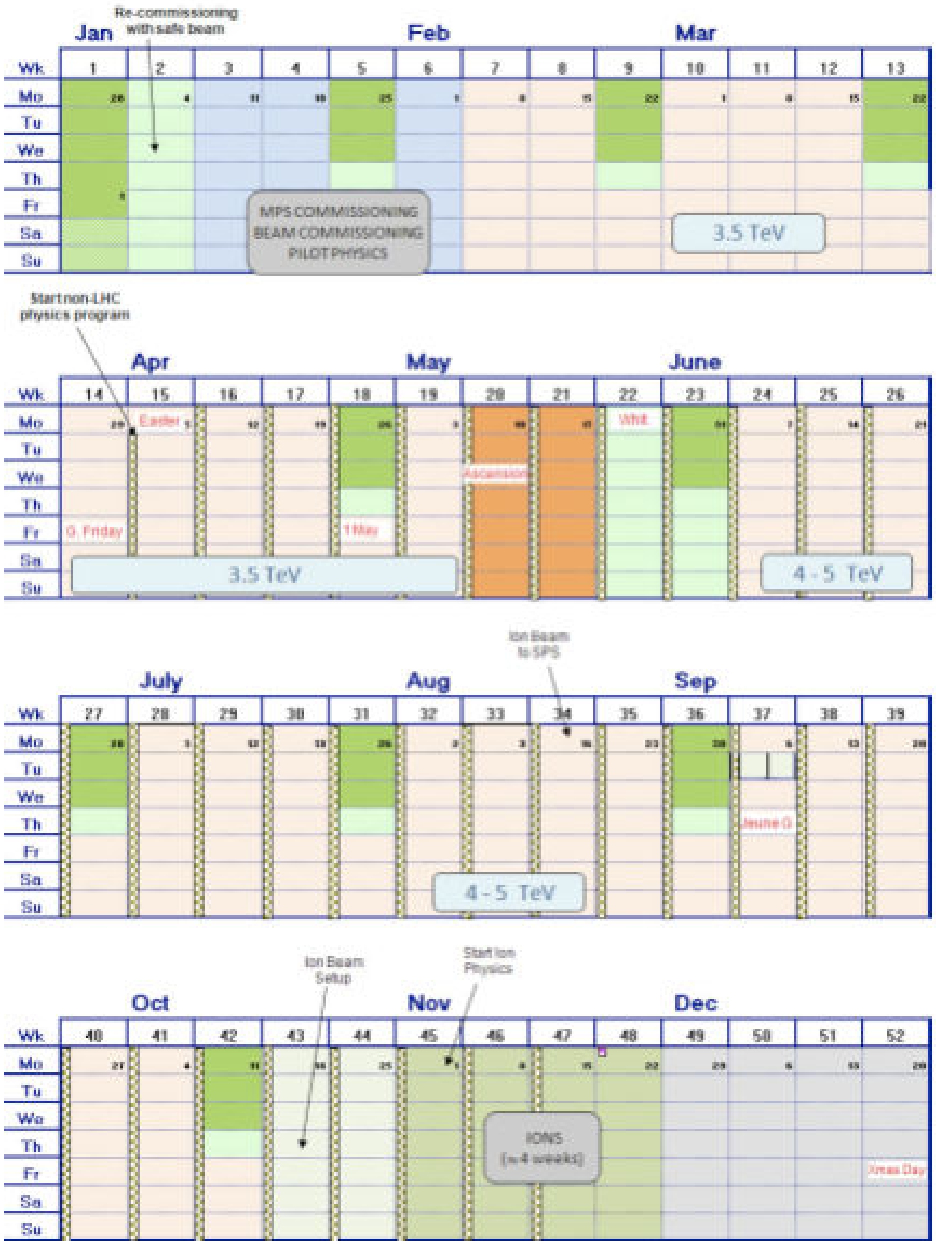
Plan: LHC 2009



- All dates approximate…
- Reasonable machine availability assumed
- Stop LHC with beam ~19th December 2009, restart ~ 4th January 2010

M. Lamont, CMS week September09

Plan 2010



O(30)pb^{-1} at 7 TeV
O(200) pb^{-1} at 10 TeV

- **2009:**
  - 1 month commissioning
- **2010:**
  - 1 month pilot & commissioning
  - 3 month 3.5 TeV
  - 1 month step-up
  - 5 month 4 - 5 TeV
  - 1 month ions

2011 ???

LHC Evolution?

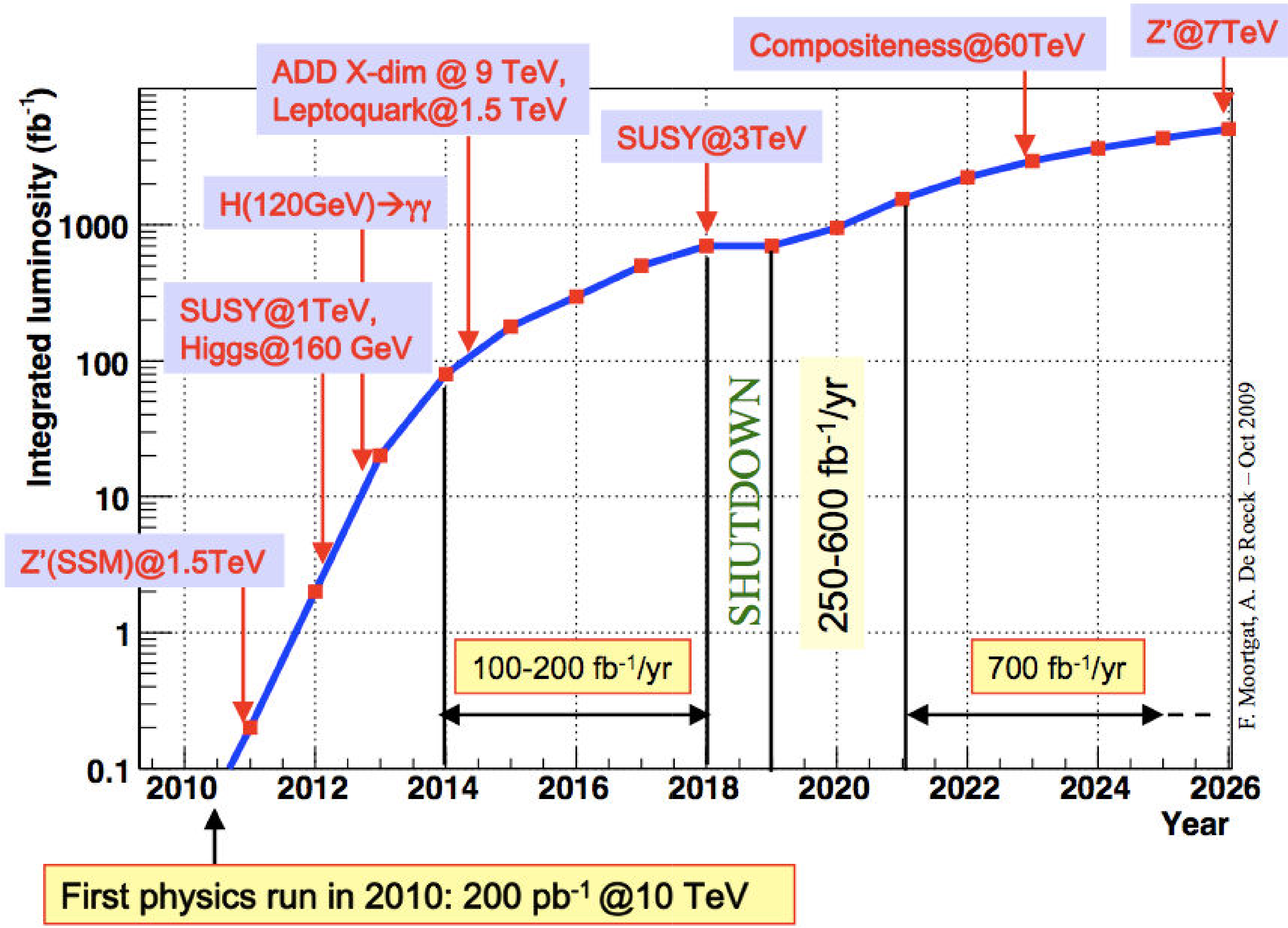
SLAC people seem to know more ☺
M. Peskin at the ALCPG09 Meeting

	July	LHC	
8 TeV	2010	3 pb^{-1}	min bias, QCD
	2011	300 pb^{-1}	$\tilde{q}$ at 600 GeV, MET at 2σ, l^+l^+ at 3σ Z’ at 1.5 TeV stable $\tilde{l}^-$ at 200 GeV
14 TeV	2012	1 fb^{-1}	$\tilde{q}$,$\tilde{g}$ at 1 TeV, MET, ll, lll at 5σ Higgs at 300 GeV in ZZ
	2013	10 fb^{-1}	Higgs at 140 GeV in ZZ*
	2014	30 fb^{-1}	Higgs at 120 GeV in $\gamma\gamma$ $t\bar{t}$ resonance at 3 TeV
	2015	100 fb^{-1}	strong WW scattering unexpected Q at 2 TeV
	2016	200 fb^{-1}	strong ZZ scattering unexpected Q at 3 TeV

Timeline to be taken as to guide the eye

This shows the events for a discovery…
What about measurements?

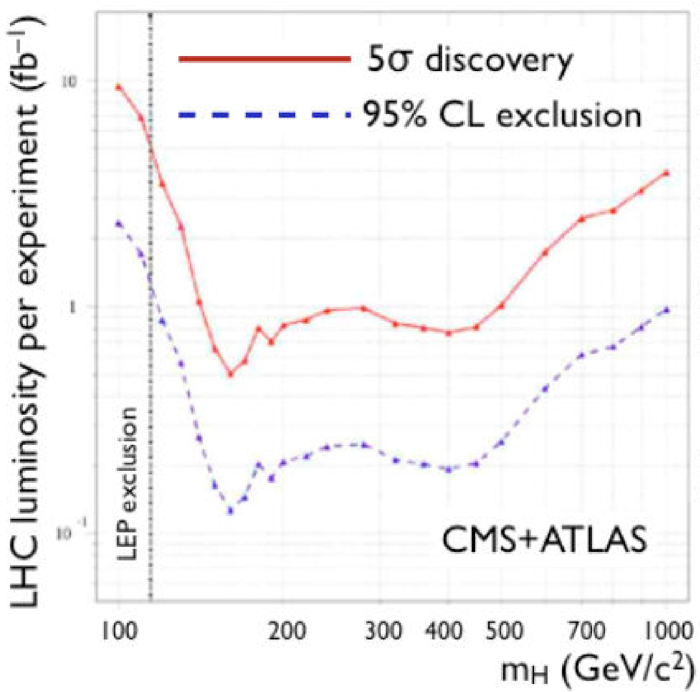
LHC Evolution?

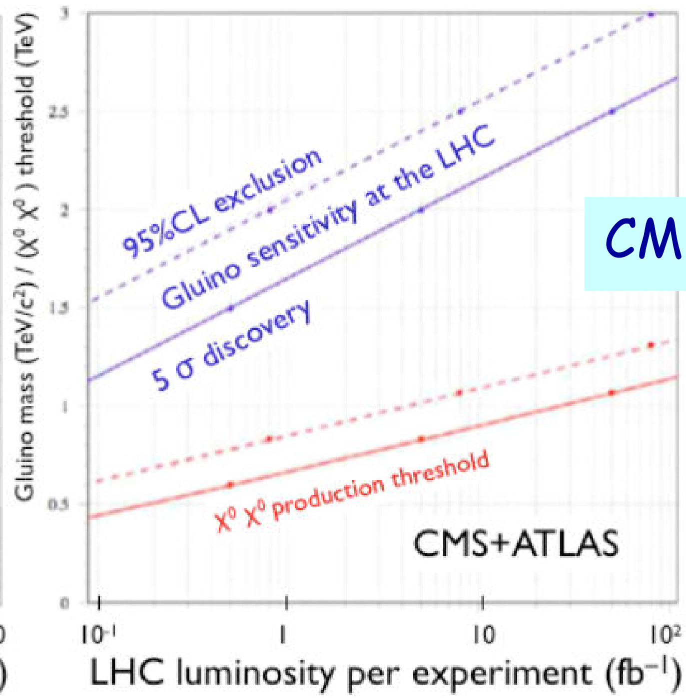


What do we expect from LHC?

Say for 10 fb^{-1} :a few good years of LHC running in the early phase

- A SM-like Higgs exists… or not??
- SUSY at the TeV scale?
- Extra Dimensions?
- Other new phenomena in the ~ TeV range? (Z', Leptoquarks,….)





CMSSM

LHC New Physics Reach Summary

2004

Measurements at LHC (14 TeV / 100 fb^{-1})

Higgs (SM)	$\rightarrow$ 1 TeV
Higgs (Heavy/MSSM)	Problems in medium $\tan\beta$ range
squarks	2.5 TeV
sleptons	0.3-0.35 TeV
Z' (direct)	5.4 TeV
q^*	6.5 TeV
l^*	3.4 TeV
TGC (λ 95%)	0.0014
Λ compos.	35-40 TeV
ED (ADD)	9 TeV
ED (RS)	2.6/4.7 TeV (c=0.01/0.1)
ED (TeV^{-1})	6.5-8 TeV
Black Holes	$\sim$ 6-10 TeV
Transplanckian effects	$\sim$ 10 TeV

Progress over the last years

- Full simulation/Closer to the real experimental set-up
- Improved signal & backgrounds (More complex MCs, NLO (QCD/EW) corrections)
- Studies for first luminosities (10-100 pb^{-1}- 1fb^{-1})
- Studies for detectors with start-up conditions (energy calibration, misalignment of the detectors)
- Special attention to the trigger
- Data driven methods to estimate backgrounds for discoveries.
- In a few cases, real in situ background estimates (cosmics, beam halo, noise…)

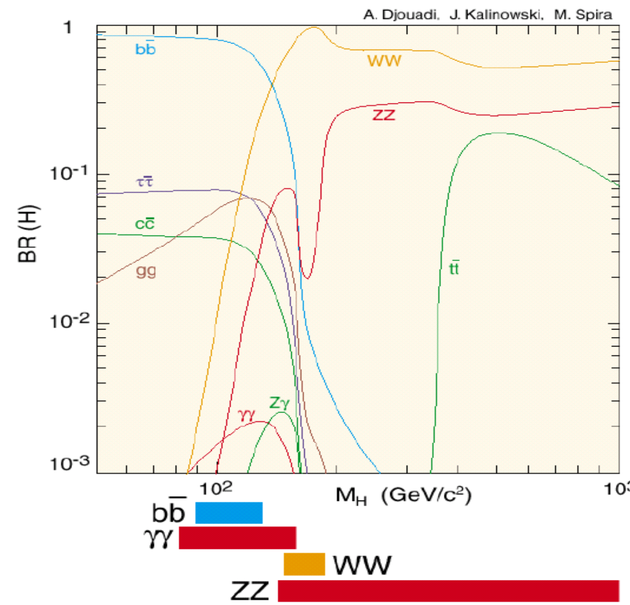
Sources: CMS Physics TDR Vol II, J. Phys. G34 (2007) 995
ATLAS CSC Notes: CERN-OPEN-2008-020
and recent updates

Higgs Studies

SM Higgs Search Channels

Low mass M_H ❐ 200 GeV

Production / DECAY	Inclusive	VBF	WH/ZH	ttH
$H \rightarrow \gamma\gamma$	YES	YES	YES	High lumi
$H \rightarrow bb$			YES?	High lumi
$H \rightarrow \tau\tau$		YES		
$H \rightarrow WW^*$	YES	YES	YES	
$H \rightarrow ZZ^*, Z \rightarrow \ell^+\ell^-, \ell$=e,μ	YES			
$H \rightarrow Z\gamma, Z \rightarrow \ell^+\ell^-, \ell$=e,μ	very low σ			



Intermediate mass
(200 GeV ❐ M_H ❐700 GeV)

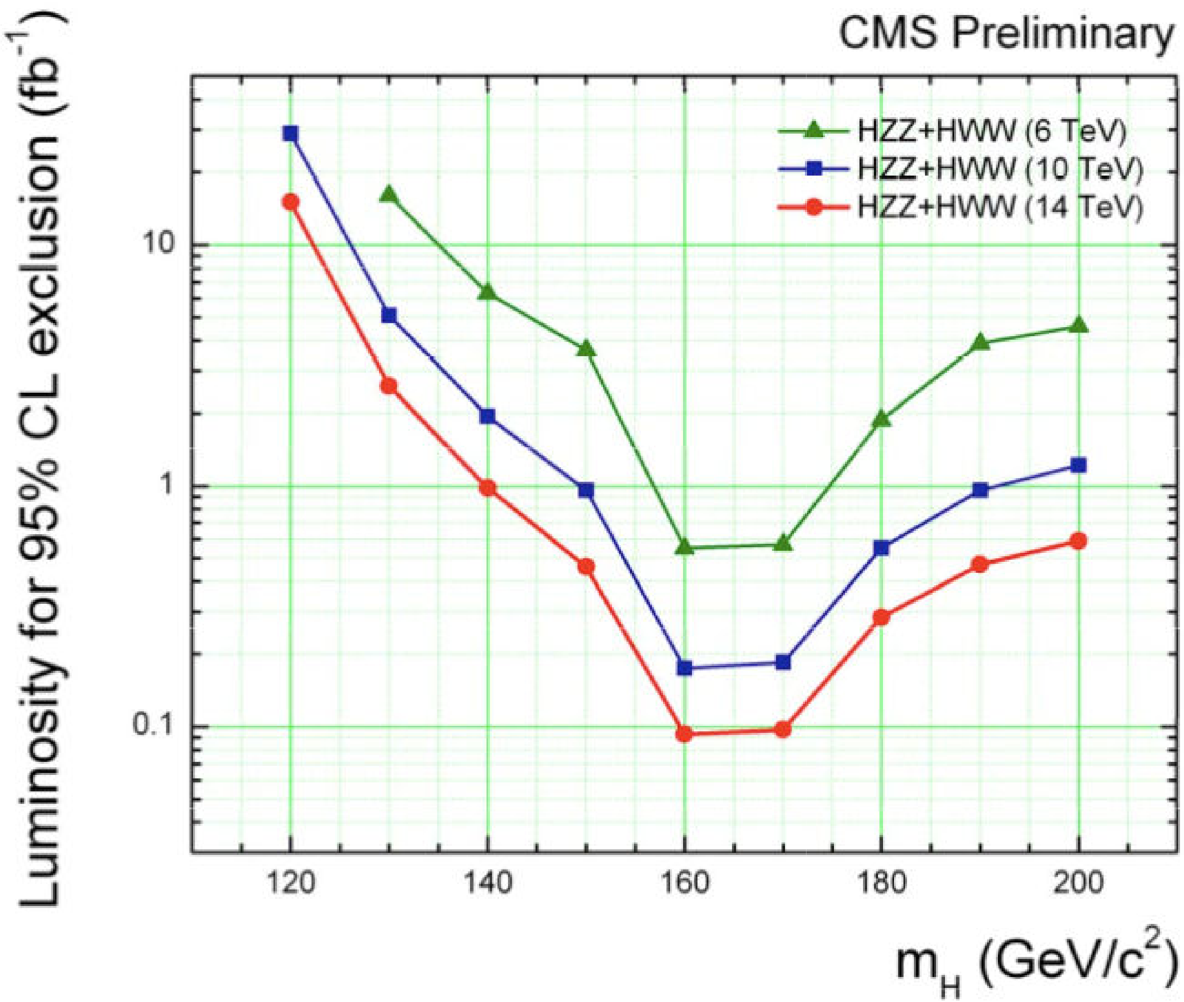
inclusive $H \rightarrow WW$
inclusive $H \rightarrow ZZ$

High mass (M_H ♦ 700 GeV)

VBF $qqH \rightarrow ZZ \rightarrow \ell\ell\nu\nu$
VBF $qqH \rightarrow WW \rightarrow \ell\nu jj$

$H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ^* \rightarrow 4\ell$ are the only channels with a very good mass resolution ~1%

Early Searches/Reduced Energy



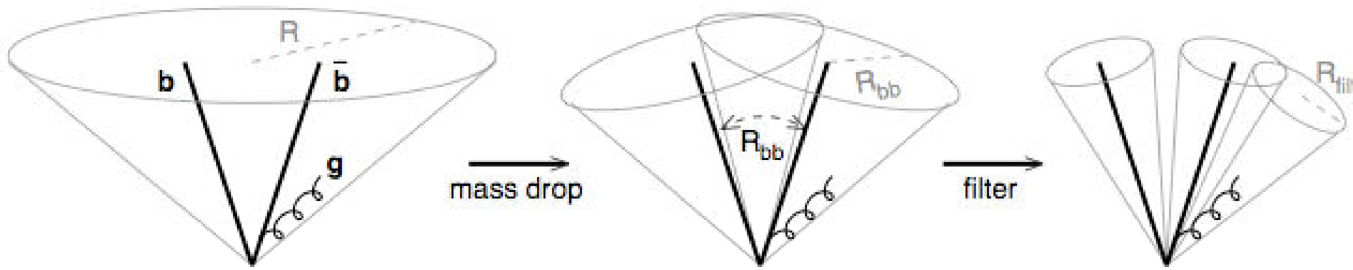
Luminosity needed for 95% CL exclusion

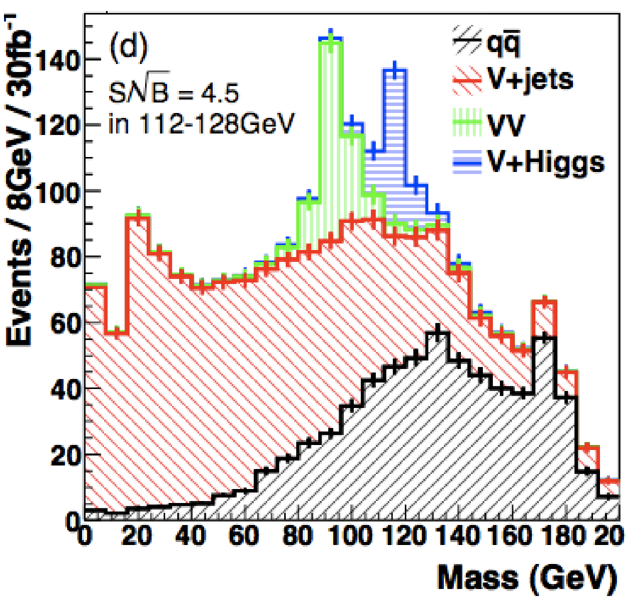
At 6 TeV you need 7 times more data than at 14 TeV

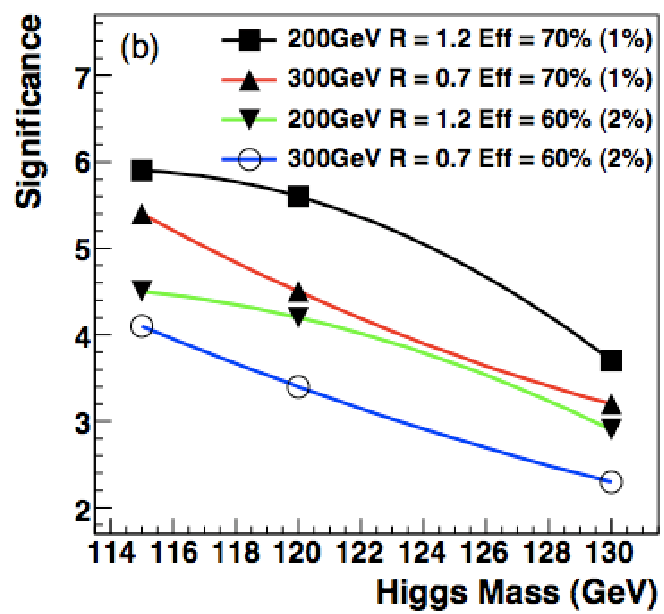
2010 will not be "the Year of the Higgs" for LHC…

So is H→bb Hopeless? Maybe not…

- New idea from Butterworth et al. arXiv:0802.2470
- Use high P_T associated WH production
- Use subjet analysis techniques & recover WH for O(30 fb^{-1})



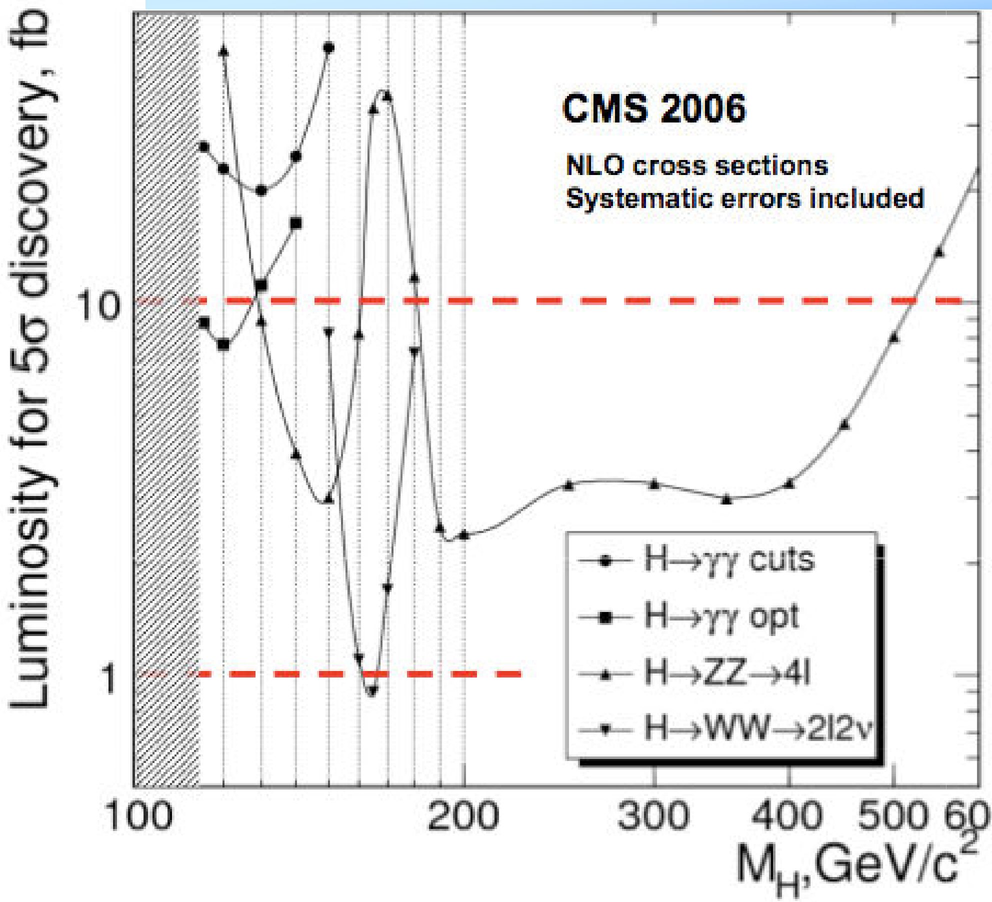


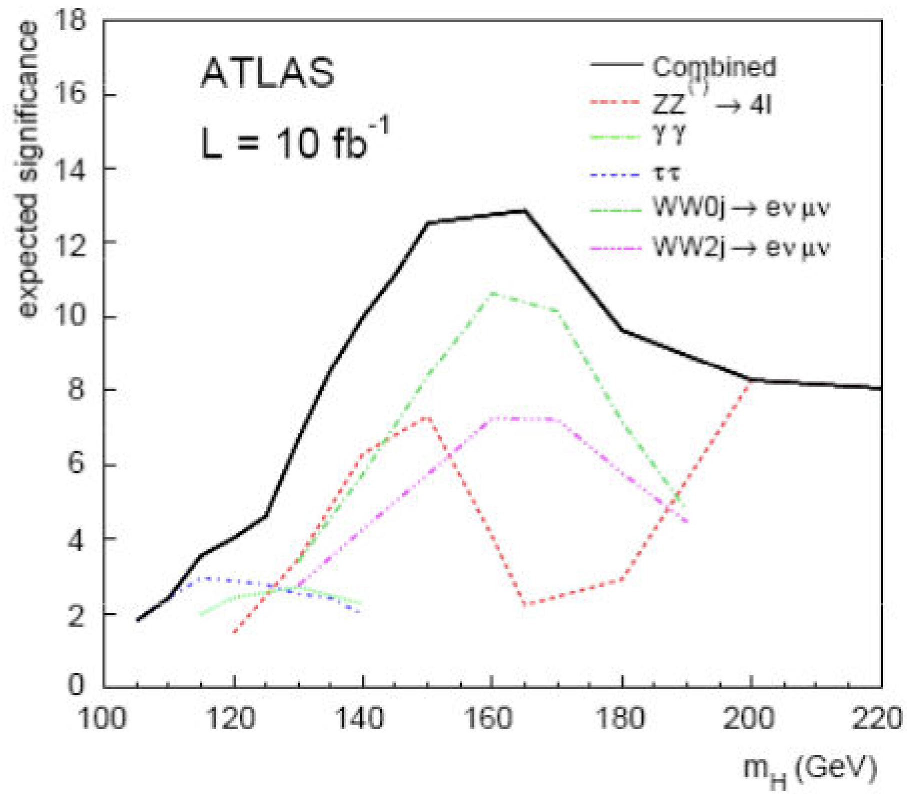


Detailed detector studies needed

+Exclusive production

SM Higgs Discovery





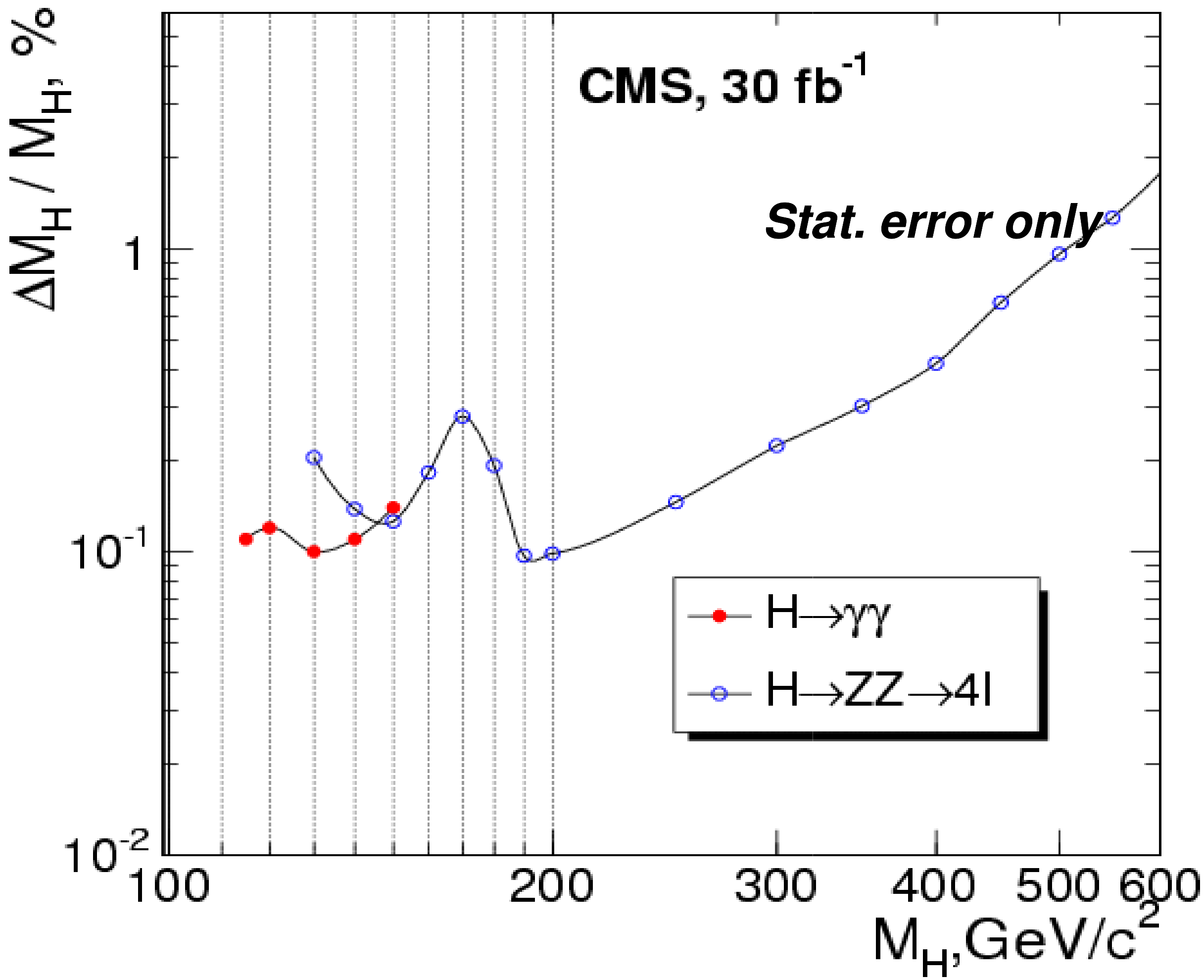
Benchmark luminosities:

- $0.1\ fb^{-1}$: exclusion limits will start carving into SM Higgs cross section
- $1\ fb^{-1}$: discoveries become possible if M_H~160-170 GeV
- $10\ fb^{-1}$: SM Higgs is discovered (or excluded) including low mass range (CMS)

Higgs Mass Measurements

Using the golden channels into $\gamma\gamma$ and ZZ

Statistical error only



Ratios of couplings

How to learn something on the
Couplings of the Higss to the
Bosons and fermions?

This is important to establish that
We are really looking at the Higgs

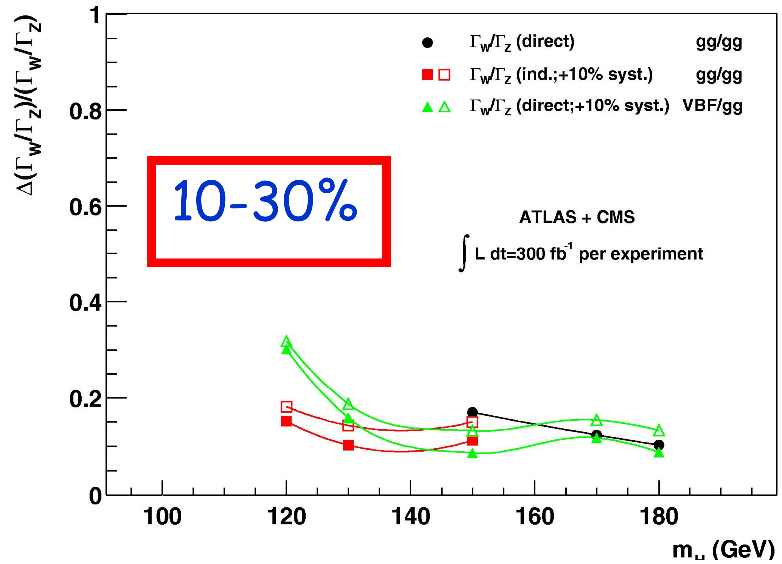
Coupling ~ mass of the particle!

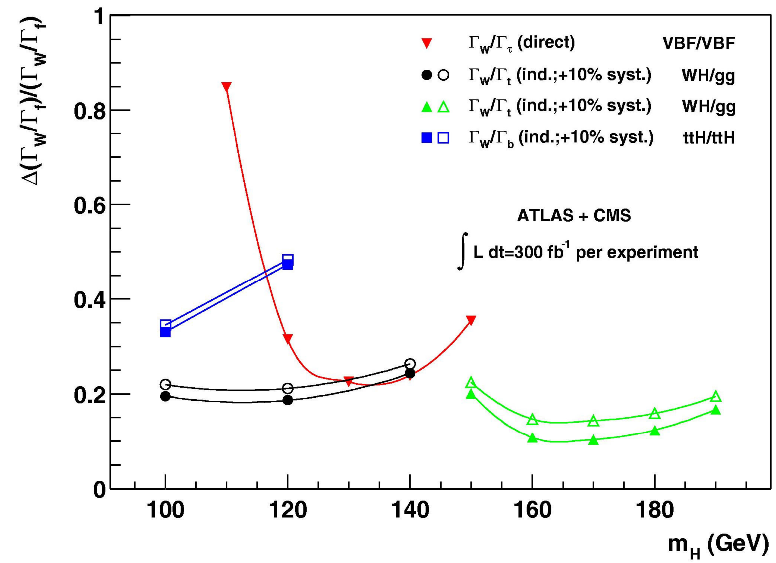
LHC solution: measure ratios

Example

– $$\frac{\sigma \times BR(H \rightarrow WW^*)}{\sigma \times BR(H \rightarrow ZZ^*)} = \frac{\Gamma_g \Gamma_W}{\Gamma_g \Gamma_Z} = \frac{\Gamma_W}{\Gamma_Z}$$

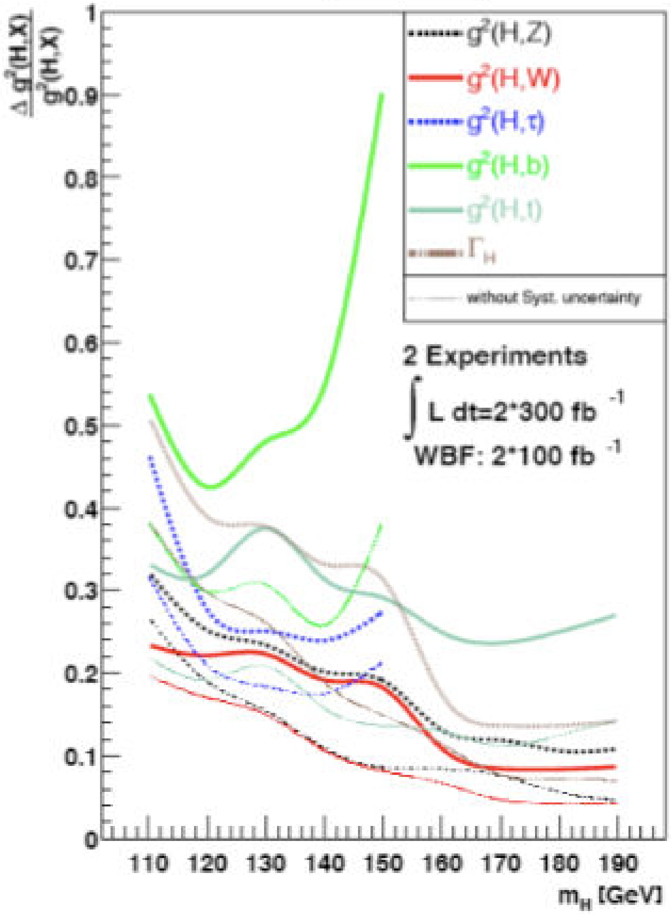
– $$\frac{\sigma \times BR(H \rightarrow \gamma\gamma)}{\sigma \times BR(H \rightarrow ZZ^*)} = \frac{\Gamma_g \Gamma_\gamma}{\Gamma_g \Gamma_Z} \sim \frac{\Gamma_W}{\Gamma_Z}$$



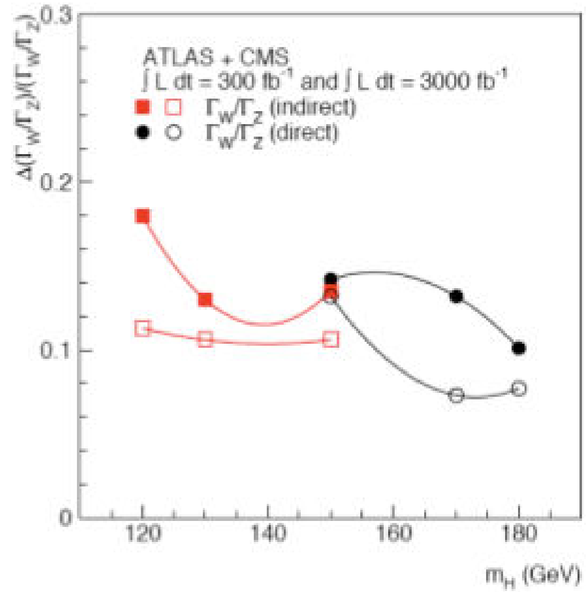


The measurement of the couplings

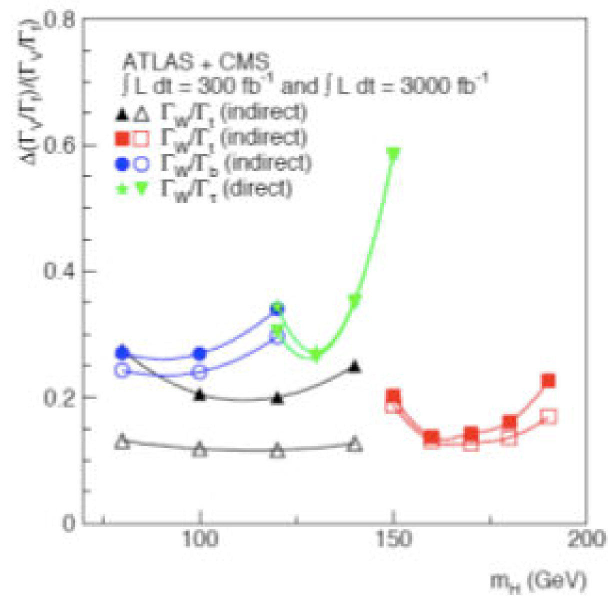
LHC



10-30%



SLHC



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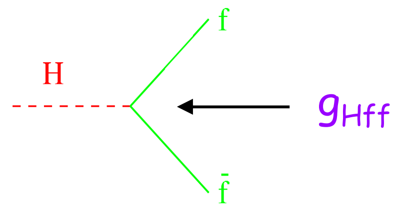
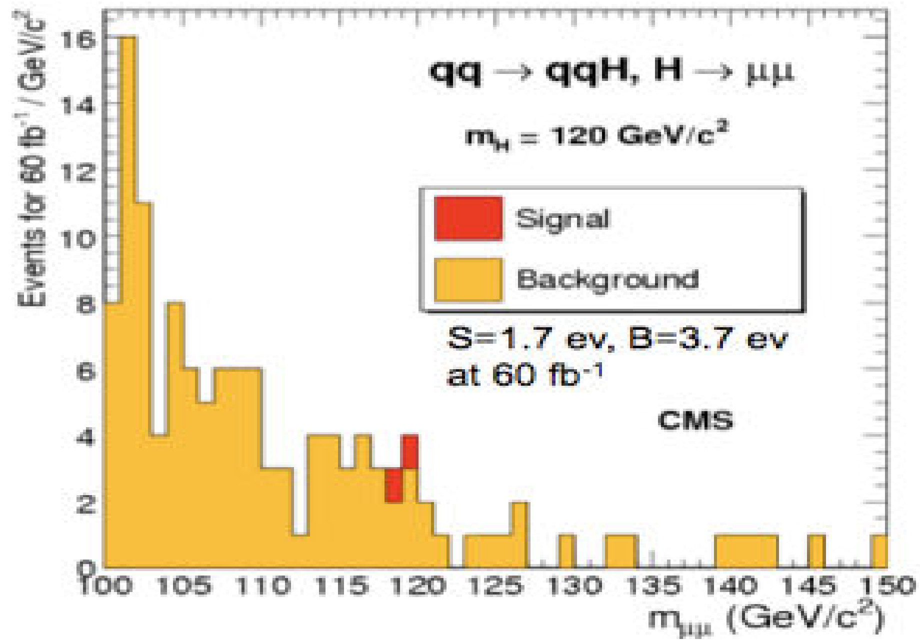
Higgs Decays Modes

Rare Higgs Decays

Channels studied:

- $H \rightarrow Z\gamma \rightarrow \ell\ell\gamma$
- $H \rightarrow \mu\mu$





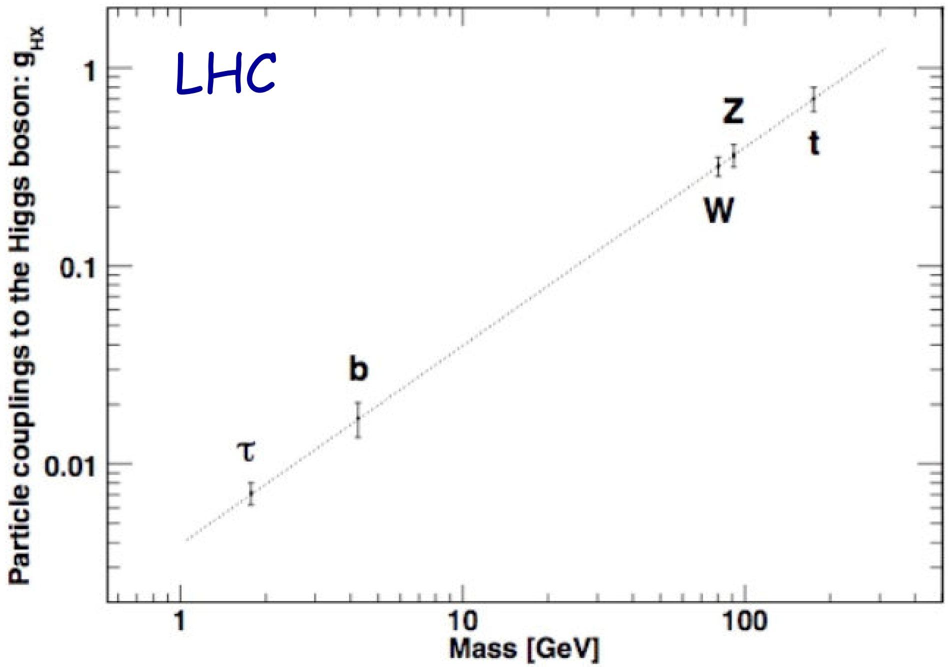
Branching ratio ~ 10^{-4} for these channels!
Cross section ~ few fb

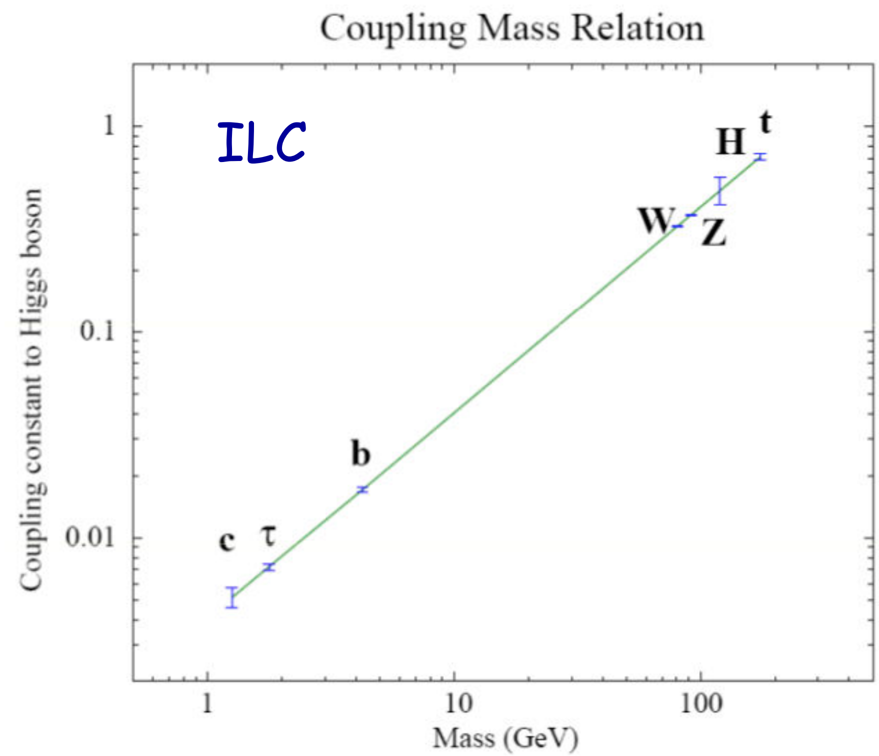
Channel	m_H	$S/\sqrt{B}$ LHC (600 fb^{-1})	$S/\sqrt{B}$ SLHC (6000 fb^{-1})
$H \rightarrow Z\gamma \rightarrow \ell\ell\gamma$	~ 140 GeV	~ 3.5	~ 11
$H \rightarrow \mu\mu$	130 GeV	~ 3.5 (gg+VBF)	~ 9.5 (gg)

Higgs Couplings (ratios)

Can be improved with a factor of 2: 20%→10% at SLHC

Coupling Mass Relation





Gianotti, Ellis, ADR et al.

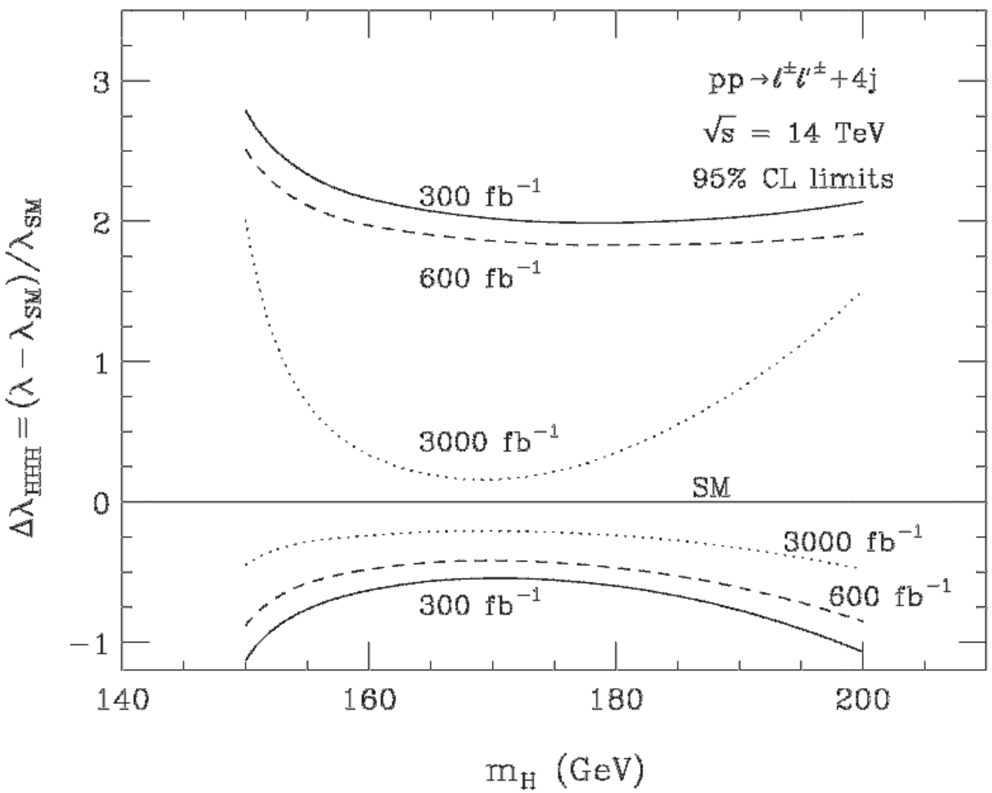
NB before the ttH "disappeared"

Higgs Self Coupling

Baur, Plehn, Rainwater

$HH \rightarrow W^+ W^- W^+ W^- \rightarrow \ell^\pm \nu jj \;\; \ell^\pm \nu jj$

Limits achievable at the 95% CL. for $\Delta\lambda=(\lambda-\lambda_{SM})/\lambda_{SM}$



LHC: λ= 0 can be excluded at 95% CL.

SLHC: λ can be determined to 20-30% (95% CL)

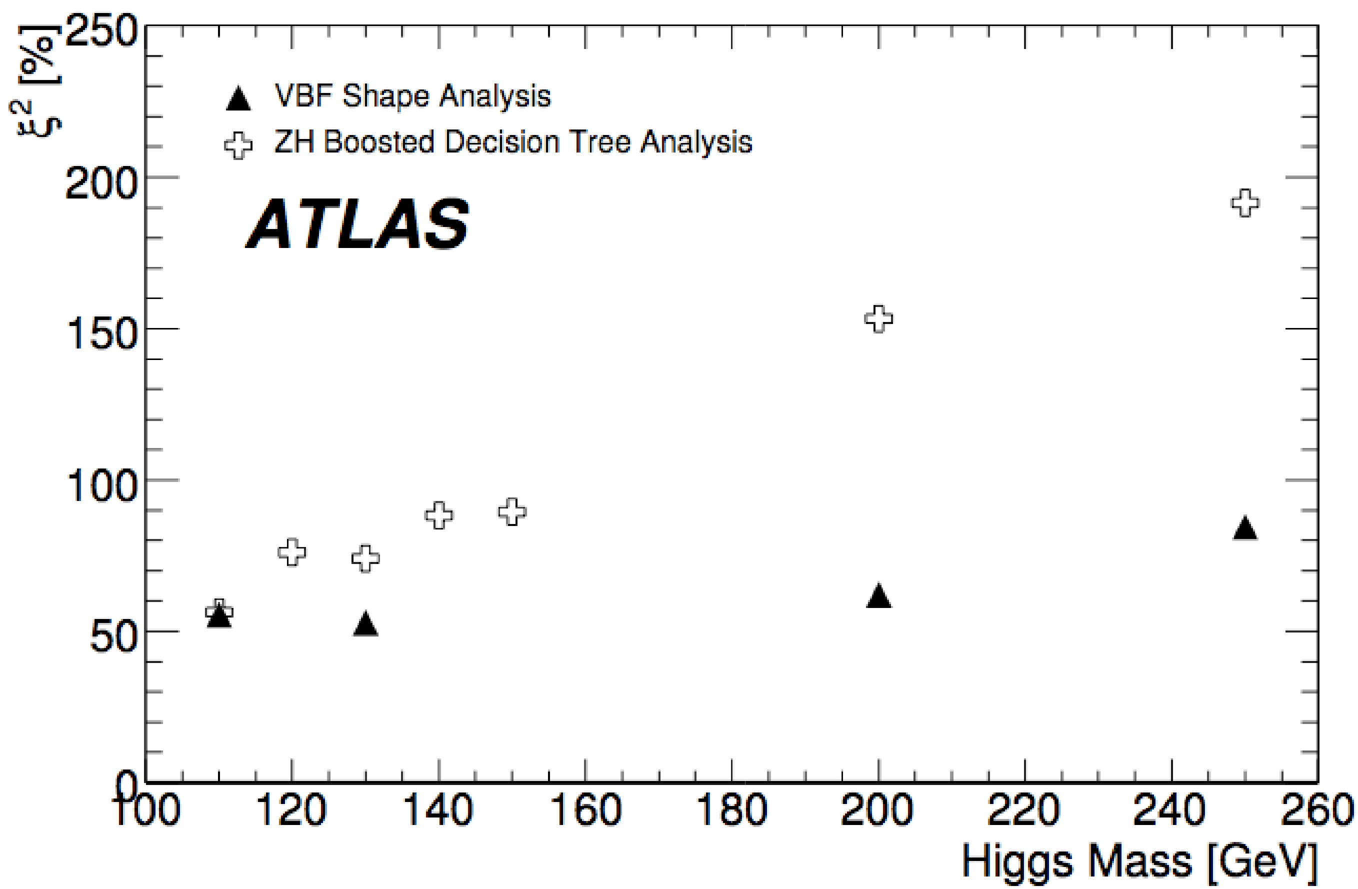
For M_H ~ 150 -180 GeV

Note: Different conclusion from ATLAS study Jury is still out

Invisible Higgs

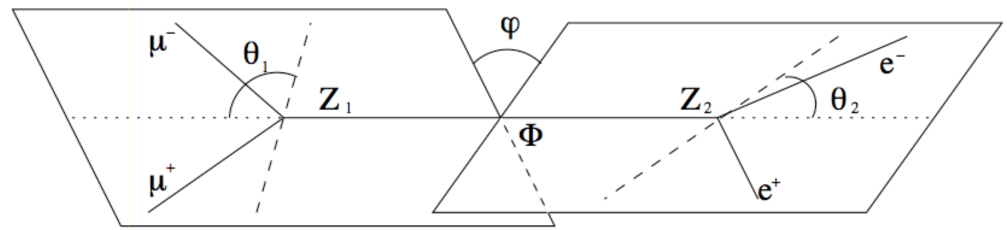
Sensitivity@ LHC

$$\xi^2 = BR(H \rightarrow inv.)\frac{\sigma_{BSM}}{\sigma_{SM}}$$

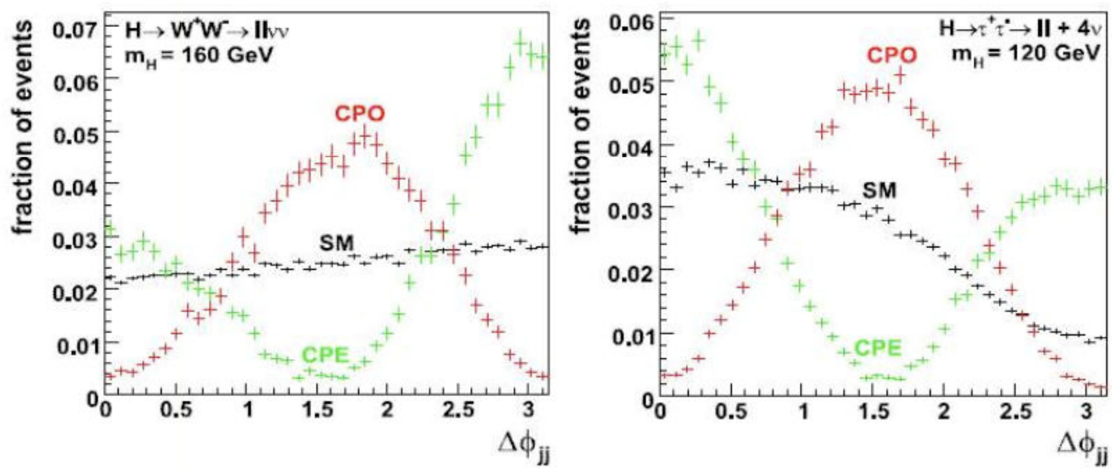


Spin/CP information on the Higgs

- In ZZ decays (if Higgs heavy ie > 200 GeV)



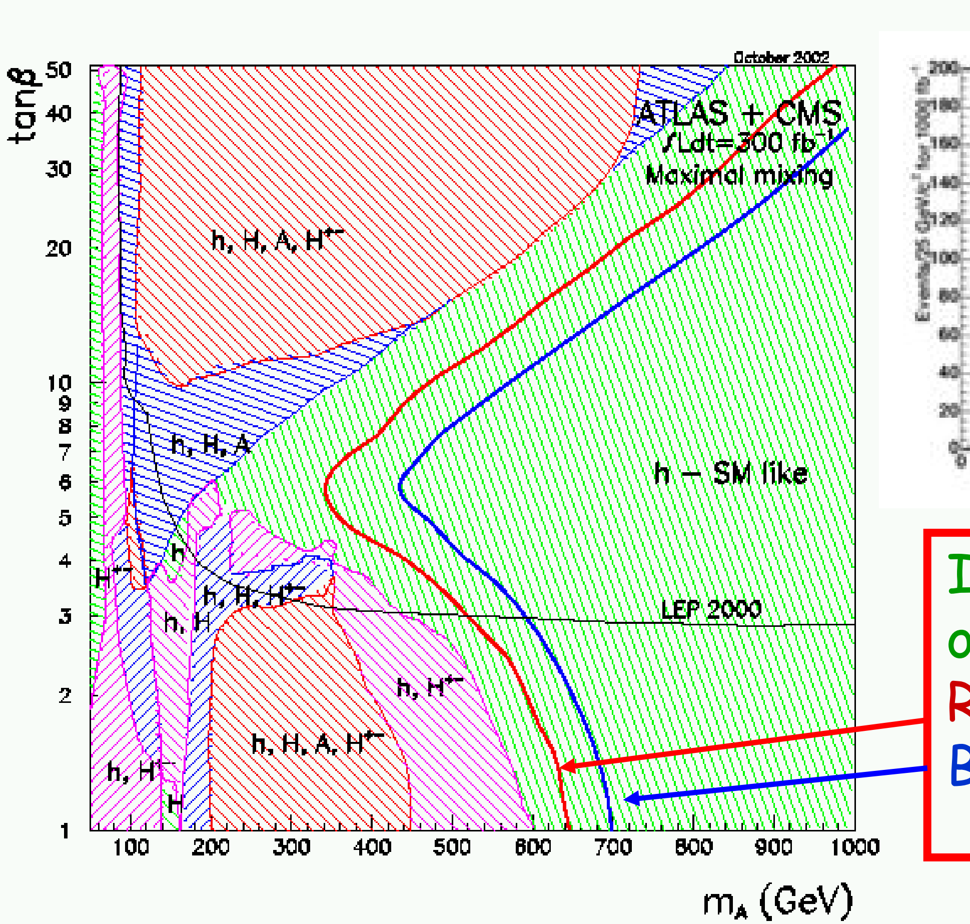
- In VBF ->WW decays

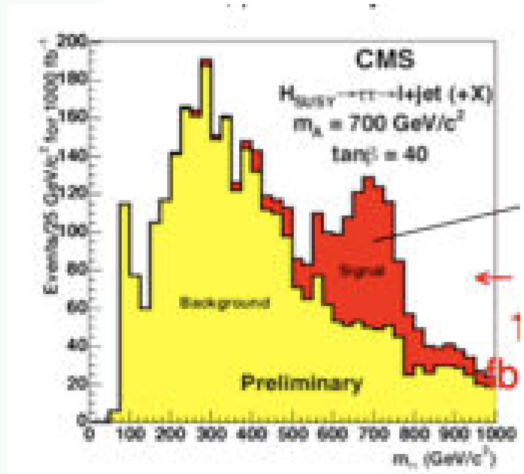


- In decays to taus?

- Exclusive production?

SUSY Higgs Particles: h,H,A,$H^{\pm}$





Dominated in the green wedge by signal/background.
⇒ Increase in statistics helps!!

In the green region only SM-like h observable with 300 fb^{-1}/exp
Red line: extension with 3000 fb^{-1}/exp
Blue line: 95% excl. with 3000 fb^{-1}/exp

Heavy Higgs reach increased by ~100 GeV at the SLHC.

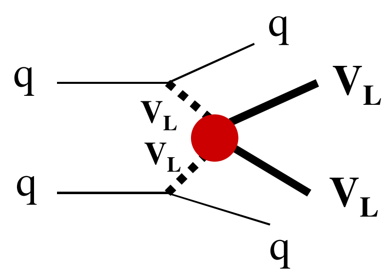
What can the LHC do?

- LHC will discover the SM Higgs in the full region up to 1 TeV or exclude its existence (1-10 fb^{-1}). If no Higgs, other new phenomena in VV $\rightarrow$VV should be observed around 1 TeV, but may need high luminosity
- The LHC will measure with full luminosity ($\geq$100 fb^{-1})
  - The Higgs mass with 0.1-1% precision
  - The Higgs width, for m_H> 200 GeV, with ~5-8% precision
  - Cross sections x branching ratios with 5-20% precision
  - Ratios of couplings with 10-30% precision
  - Absolute couplings only with additional assumptions
  - Spin information in the ZZ channel for m_H>200 GeV and VBF$\rightarrow$WW
  - CP information from exclusive central production: pp$\rightarrow$pHp
  - However: likely little information on the Higgs potential ($\rightarrow$sLHC)

..$\Rightarrow$will get a pretty good picture of the Higgs @ LHC
More detailed information from a Linear Collider

Strongly Coupled Vector Boson System

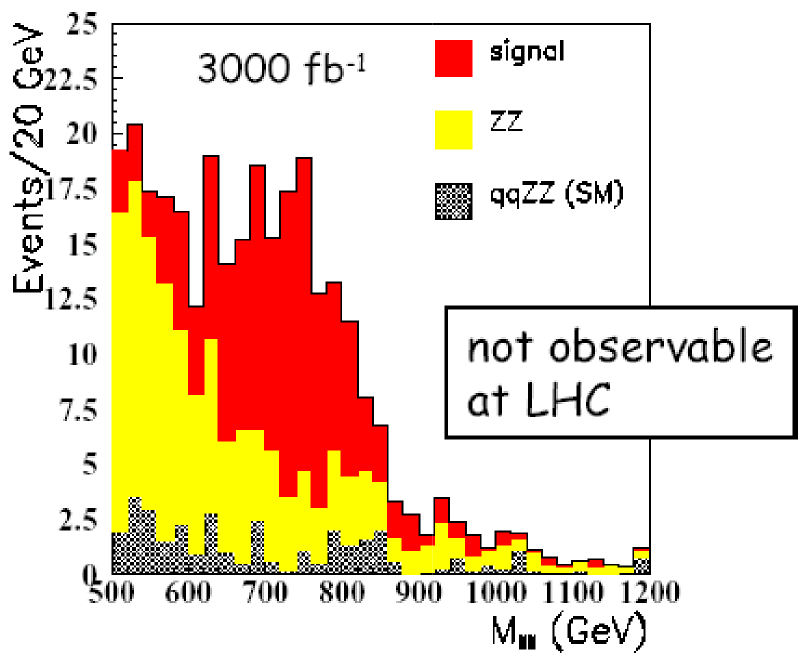
If no Higgs, expect strong $V_L V_L$ scattering (resonant or non-resonant) at ~ 1TeV



Could well 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

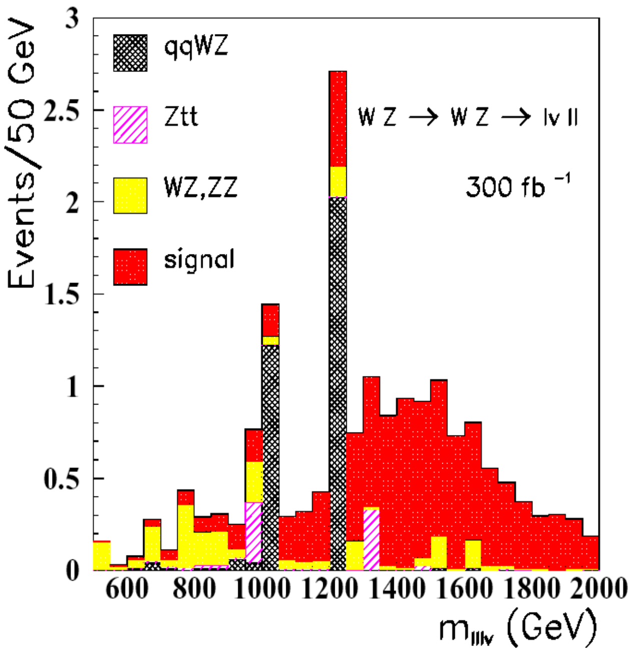
Scalar resonance $Z_L Z_L \to 4\ell$

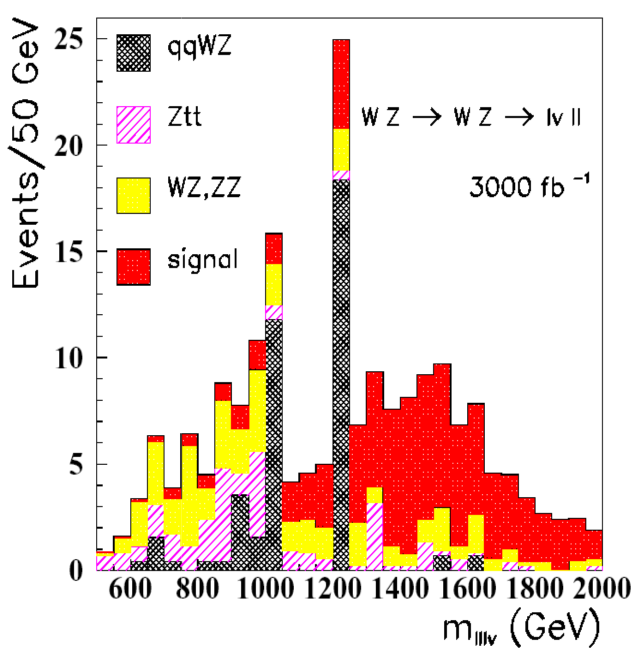


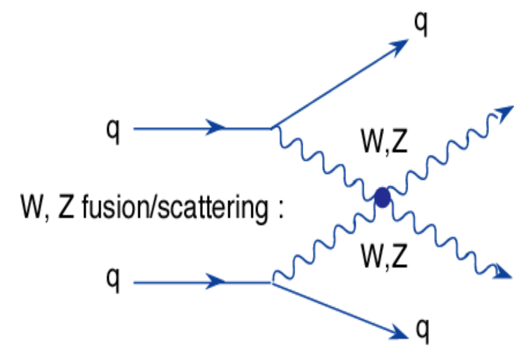
WZ resonances in Vector Boson Scattering

Vector resonance (ρ-like) in $W_L Z_L$ scattering from Chiral Lagrangian model
M = 1.5 TeV ⇒ 300 fb^{-1} (LHC) vs 3000 fb^{-1} (SLHC)

lepton cuts: $p_{t1} > 150$ GeV, $p_{t2} > 100$ GeV, $p_{t3} > 50$ GeV; $E_t^{miss} > 75$ GeV







These studies require both forward jet tagging and central jet vetoing! Expected (degraded) SLHC performance is included

At LHC: S = 6.6 events,
B = 2.2 events

At SLHC: $S/\sqrt{B} \sim 10$

Lower Mass WW, WZ, ZZ Resonances

Luminosity needed to observe the resonances

Process	Cross section (fb)		Luminosity (fb^{-1})		Significance
	signal	background	for 3σ	for 5σ	for 100 fb^{-1}
$WW/WZ \to \ell\nu\ jj$, $m = 500$ GeV	0.31 ± 0.05	0.79 ± 0.26	85	235	3.3 ± 0.7
$WW/WZ \to \ell\nu\ jj$, $m = 800$ GeV	0.65 ± 0.04	0.87 ± 0.28	20	60	6.3 ± 0.9
$WW/WZ \to \ell\nu\ jj$, $m = 1.1$ TeV	0.24 ± 0.03	0.46 ± 0.25	85	230	3.3 ± 0.8
$W_{jj}Z_{\ell\ell}$, $m = 500$ GeV	0.28 ± 0.04	0.20 ± 0.18	30	90	5.3 ± 1.9
$W_{\ell\nu}Z_{\ell\ell}$, $m = 500$ GeV	0.40 ± 0.03	0.25 ± 0.03	20	55	6.6 ± 0.5
$W_{jj}Z_{\ell\ell}$, $m = 800$ GeV	0.24 ± 0.02	0.30 ± 0.22	60	160	3.9 ± 1.2
$W_{j}Z_{\ell\ell}$, $m = 800$ GeV	$0.27 \pm 0.02 \pm 0.05$	$0.23 \pm 0.07 \pm 0.05$	38	105	4.9 ± 1.1
$W_{j}Z_{\ell\ell}$, $m = 1.1$ TeV	$0.19 \pm 0.01 \pm 0.04$	$0.22 \pm 0.07 \pm 0.05$	68	191	3.6 ± 1.0
$W_{\ell\nu}Z_{\ell\ell}$, $m = 1.1$ TeV	0.070 ± 0.004	0.020 ± 0.009	70	200	3.6 ± 0.5
$Z_{\nu\nu}Z_{\ell\ell}$, $m = 500$ GeV	0.32 ± 0.02	0.15 ± 0.03	20	60	6.6 ± 0.6

ATLAS

10's to 100's of fb^{-1}

SUSY

As a benchmark for new paticle production

Where do we expect SUSY?

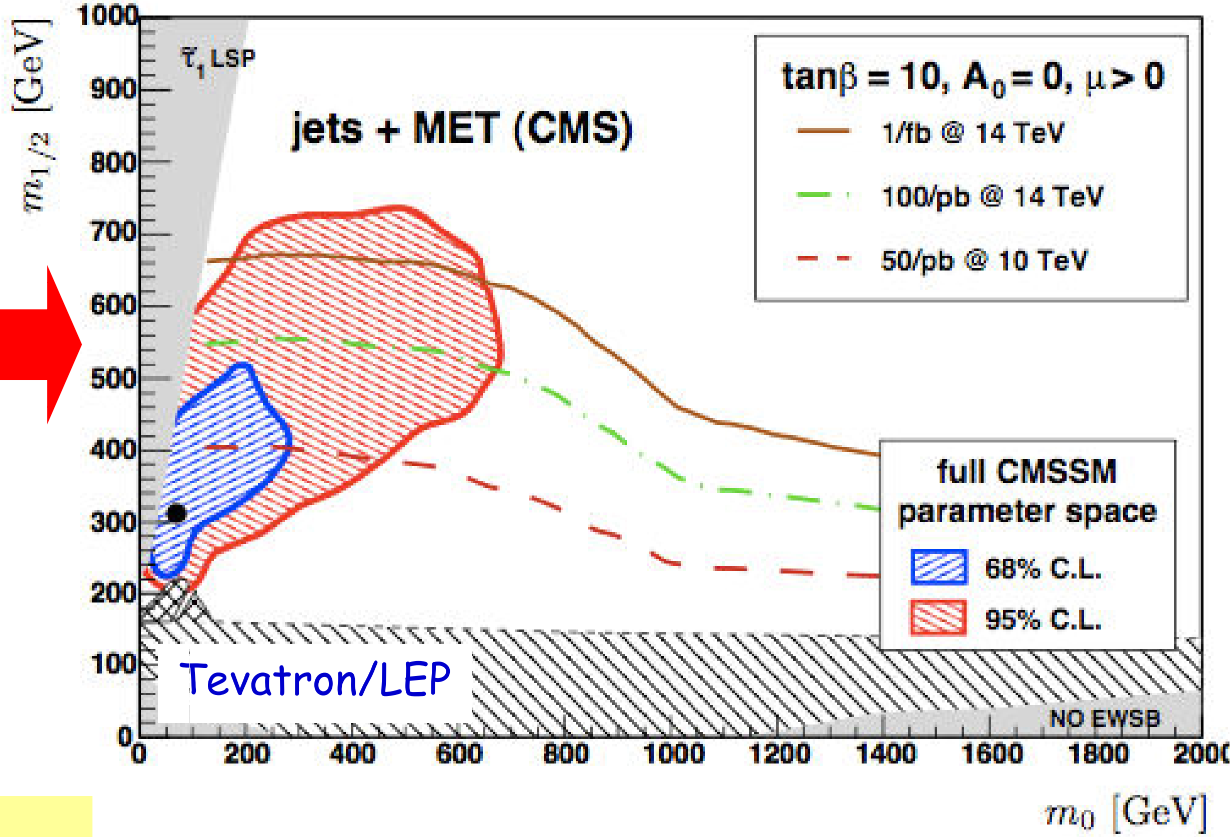
O. Buchmuller et al
arXiv:0808.4128

OB, R.Cavanaugh, A.De Roeck,
J.R.Ellis, H.~Flaecher, S.~Heineme
G.Isidor, K.A.Olive, P.Paradisi,
F.J.Ronga, G.Weiglein

Precision measurements
Heavy flavour observables

Simultaneous fit of CMSSM parameters m_0, $m_{1/2}$, A_0, tan (μ>0) to more than 30 collide and cosmology data (e.g. $M_{\rm}$, M_{top}, g-2, BR(B→Xγ), relic density)

"LHC Weather Forecast"



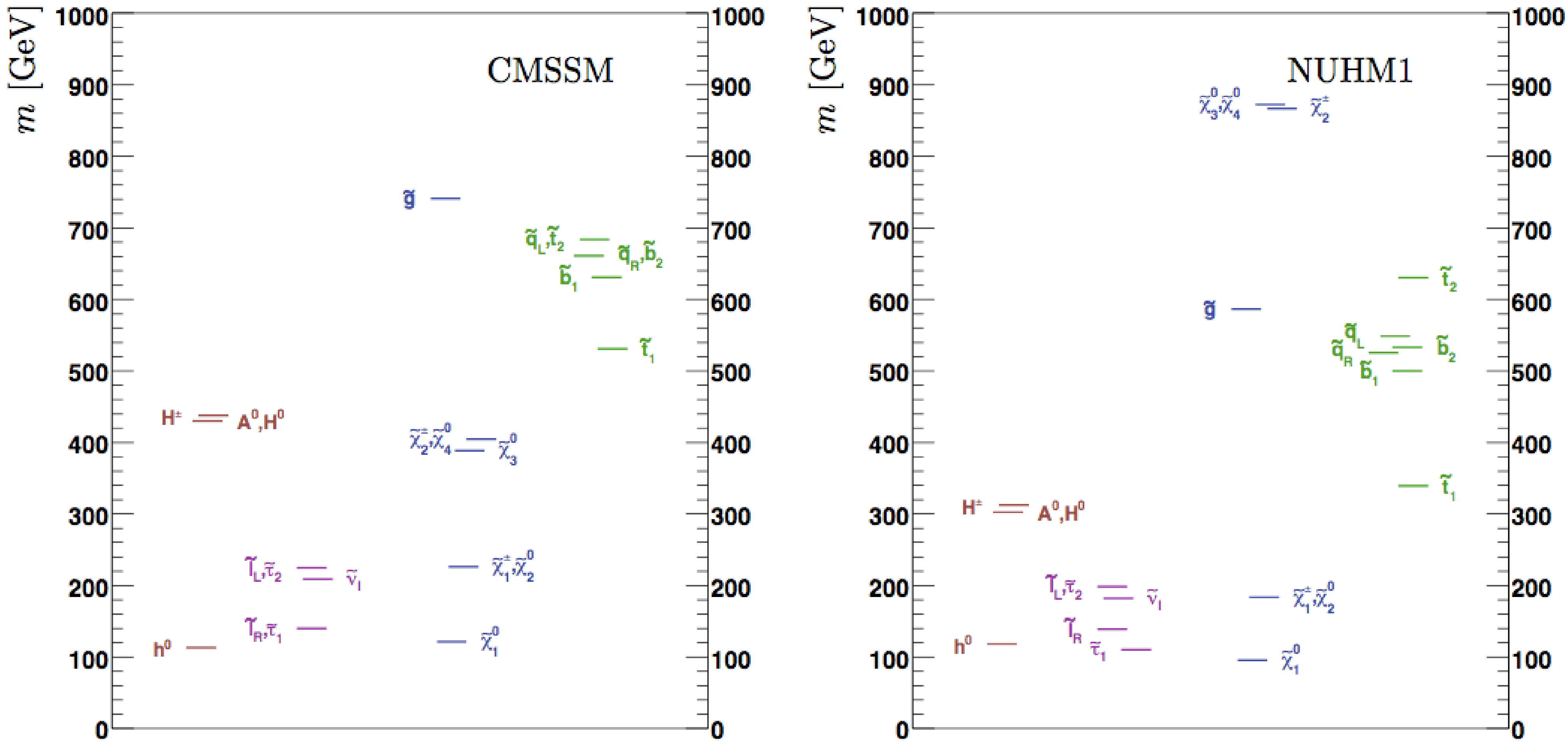
"Predict" on the basis of present data what the preferred region for SUSY is (in constrained MSSM SUSY)

"CMSSM fit clearly favors low-mass SUSY - Evidence that a signal might show up very early?!"

Many other groups attempt to make similar predictions
See eg R. Trotta tonight

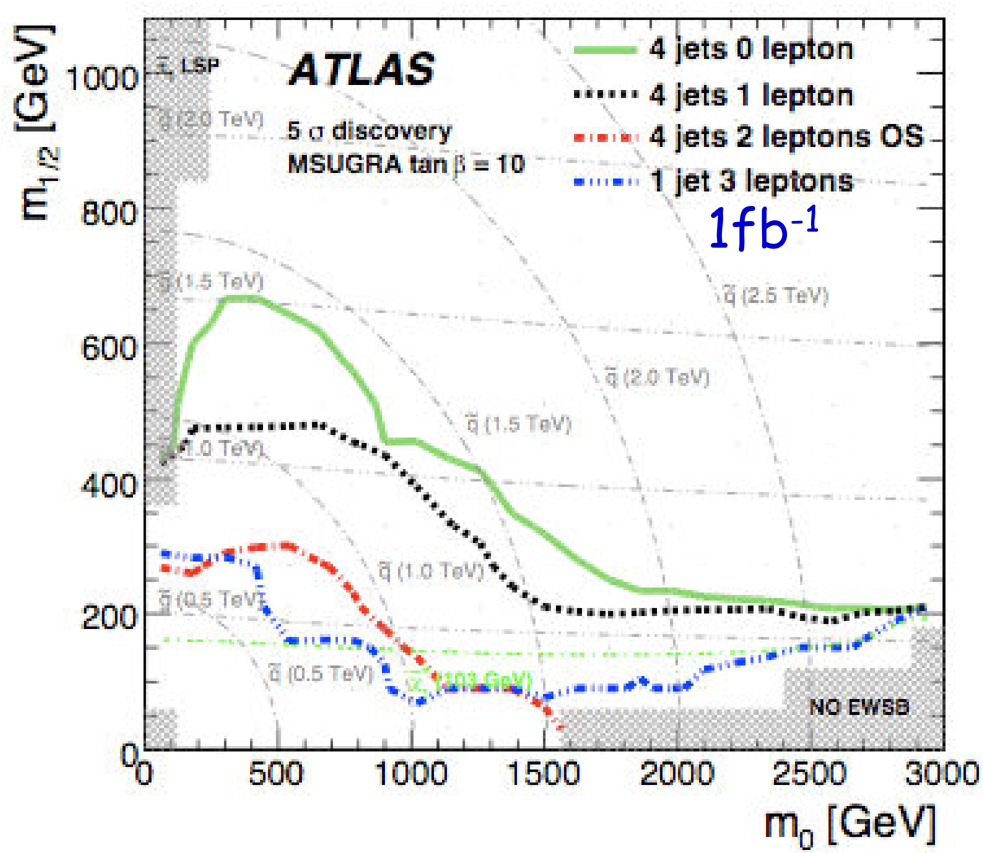
SUSY Particle Spectrum

"best" point: Mass spectrum



How well can we measure quark properties @ CLIC?
Can we distinguish squark species (charm, strangeness?)

Early SUSY Reach



minimal Supergravity (mSUGRA)

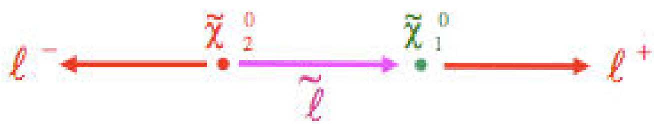
$m_{1/2}$: universal gaugino mass at GUT scale
m_0: universal scalar mass at GUT scale
tanβ: vev ratio for 2 Higgs doublets
sign(μ): sign of Higgs mixing parameter
A_0: trilinear coupling

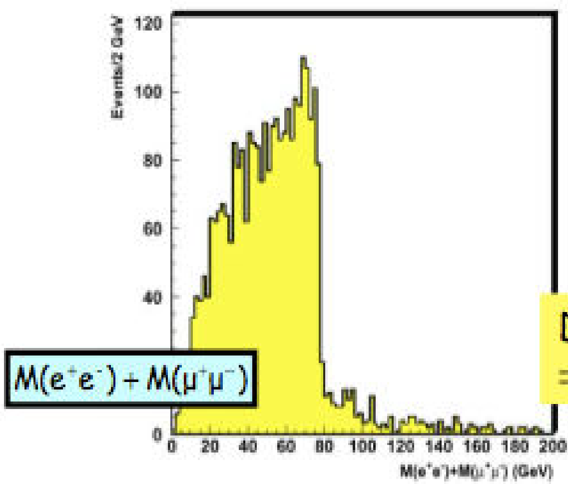
Low mass SUSY(m_{gluino}~500 GeV) will show an excess for O(100) pb^{-1}
⇒ Time for discovery will be determined by:
- Time needed to understand the detector performance, Etmiss tails,
- Time needed collect SM control samples such as W+jets, Z+jets, top..

Sparticle Detection & Reconstruction

Mass precision for a favorable benchmark point at the LHC
LCC1~ SPS1a~ point B′ with 100 fb^{-1}

m_0=100 GeV
$m_{1/2}$= 250 GeV
A_0=-100
$\tan\beta$ = 10
sign(μ)=+



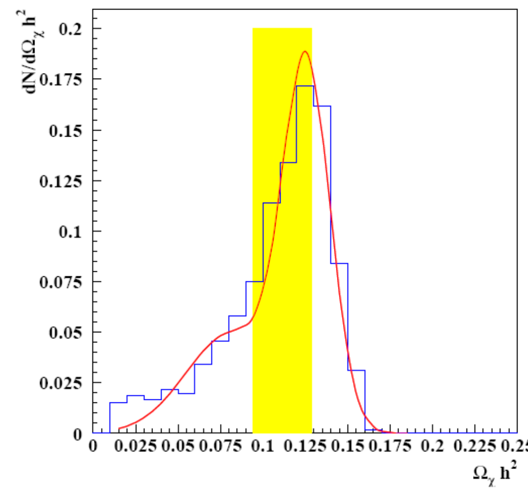


D. Miller et al
⇒Use shapes

hep-ph/0508198

GeV	LHC
$\Delta m_{\tilde\chi^0_1}$	4.8
$\Delta m_{\tilde\chi^0_2}$	4.7
$\Delta m_{\tilde\chi^0_4}$	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

Lightest neutralino → Dark Matter?
Fit SUSY model parameters to the measured SUSY particle masses to extract $\Omega\chi h^2$ ⇒ O(10%) for LCC1



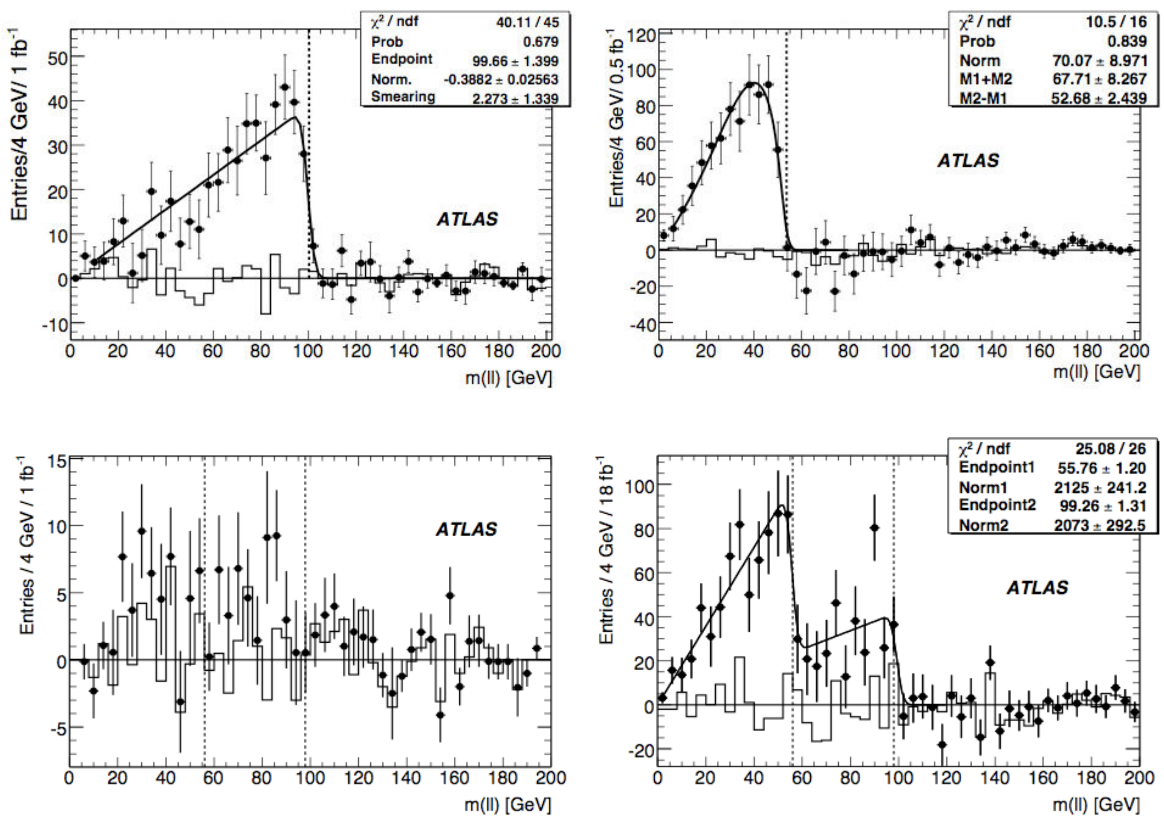
Endpoints: ATLAS Study

Mass Distribution	SU1 end point (GeV)	SU3 end point (GeV)	SU4 end point (GeV)
$m_{\ell\ell}^{\mathrm{edge}}$	56.1, 97.9	100.2	53.6
$m_{\tau\tau}^{\mathrm{edge}}$	77.7, 49.8	98.3	53.6
$m_{\ell\ell q}^{\mathrm{edge}}$	611, 611	501	340
$m_{\ell\ell q}^{\mathrm{thr}}$	133, 235	249	168
$m_{lq(\mathrm{low})}^{\mathrm{max}}$	180, 298	325	240
$m_{lq(\mathrm{high})}^{\mathrm{max}}$	604, 581	418	340

$$m_{\ell\ell}^{\mathrm{edge}} = m_{\tilde{\chi}_2^0}\sqrt{1-\left(\frac{m_{\tilde{\ell}}}{m_{\tilde{\chi}_2^0}}\right)^2}\sqrt{1-\left(\frac{m_{\tilde{\chi}_1^0}}{m_{\tilde{\ell}}}\right)^2}$$

Lepton endpoints

1 fb^{-1}



Endpoints: lepton + jets

Endpoint	SU3 truth	SU3 measured	SU4 truth	SU4 measured
$m_{\ell\ell q}^{\mathrm{edge}}$	501	$517 \pm 30 \pm 10 \pm 13$	340	$343 \pm 12 \pm 3 \pm 9$
$m_{\ell\ell q}^{\mathrm{thr}}$	249	$265 \pm 17 \pm 15 \pm 7$	168	$161 \pm 36 \pm 20 \pm 4$
$m_{lq(\mathrm{low})}^{\mathrm{max}}$	325	$333 \pm 6 \pm 6 \pm 8$	240	$201 \pm 9 \pm 3 \pm 5$
$m_{lq(\mathrm{high})}^{\mathrm{max}}$	418	$445 \pm 11 \pm 11 \pm 11$	340	$320 \pm 8 \pm 3 \pm 8$

1 fb^{-1}

Overall Result

Observable	SU3 m_{meas} [GeV]	SU3 m_{MC} [GeV]	SU4 m_{meas} [GeV]	SU4 m_{MC} [GeV]
$m_{\tilde{\chi}_1^0}$	$88 \pm 60 \mp 2$	118	$62 \pm 126 \mp 0.4$	60
$m_{\tilde{\chi}_2^0}$	$189 \pm 60 \mp 2$	219	$115 \pm 126 \mp 0.4$	114
$m_{\tilde{q}}$	$614 \pm 91 \pm 11$	634	$406 \pm 180 \pm 9$	416
$m_{\tilde{\ell}}$	$122 \pm 61 \mp 2$	155		
Observable	SU3 Δm_{meas} [GeV]	SU3 Δm_{MC} [GeV]	SU4 Δm_{meas} [GeV]	SU4 Δm_{MC} [GeV]
$m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$	$100.6 \pm 1.9 \mp 0.0$	100.7	$52.7 \pm 2.4 \mp 0.0$	53.6
$m_{\tilde{q}} - m_{\tilde{\chi}_1^0}$	$526 \pm 34 \pm 13$	516.0	$344 \pm 53 \pm 9$	356
$m_{\tilde{\ell}} - m_{\tilde{\chi}_1^0}$	$34.2 \pm 3.8 \mp 0.1$	37.6		

1 fb^{-1}

Parameter	SU3 value	fitted value	exp. unc.
	$\text{sign}(\mu) = +1$		
$\tan\beta$	6	7.4	4.6
M_0	100 GeV	98.5 GeV	$\pm$9.3 GeV
$M_{1/2}$	300 GeV	317.7 GeV	$\pm$6.9 GeV
A_0	$-$300 GeV	445 GeV	$\pm$408 GeV
	$\text{sign}(\mu) = -1$		
$\tan\beta$		13.9	$\pm$2.8
M_0		104 GeV	$\pm$18 GeV
$M_{1/2}$		309.6 GeV	$\pm$5.9 GeV
A_0		489 GeV	$\pm$189 GeV

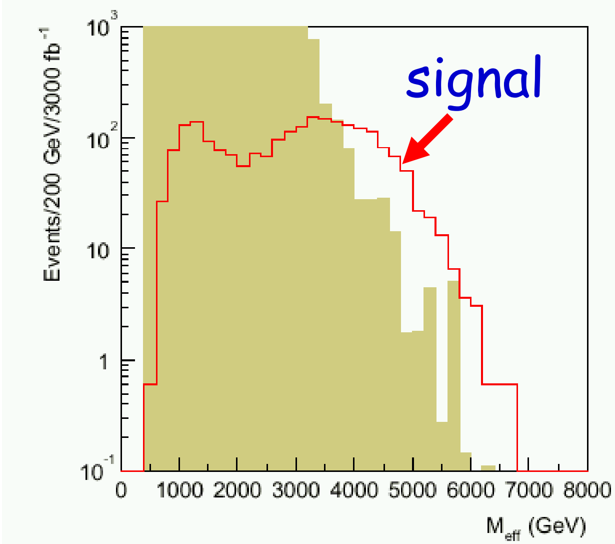
High Mass SUSY Particles

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

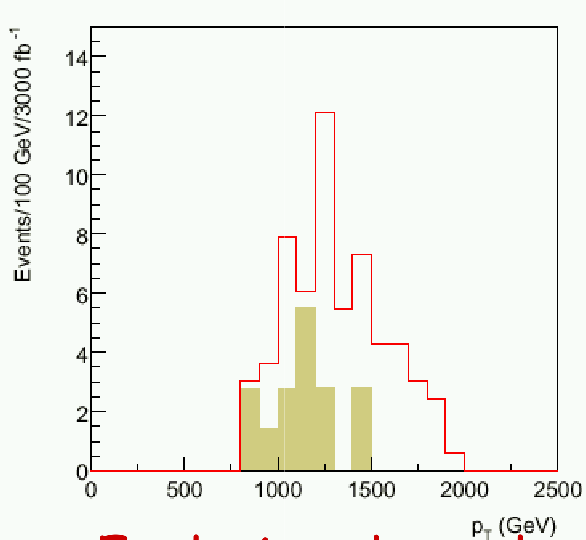
$$M_{eff} = E_T^{miss} + \sum_{jets} E_{T,jet} + \sum_{leptons} E_{T,lepton}$$

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

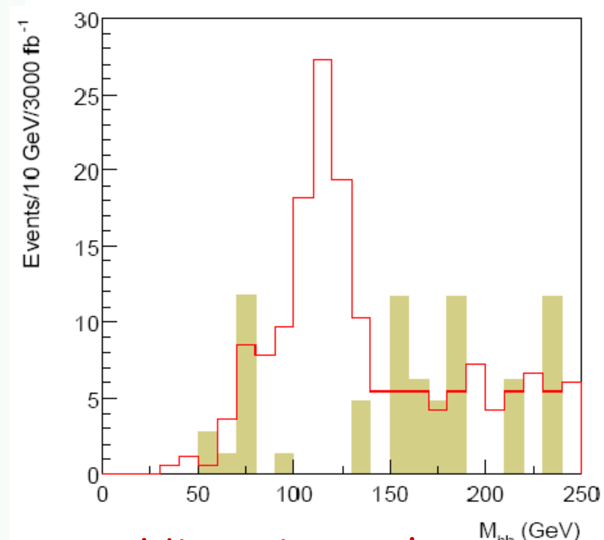
eg. Benchmark Point K in hep-ph/0306219



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



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

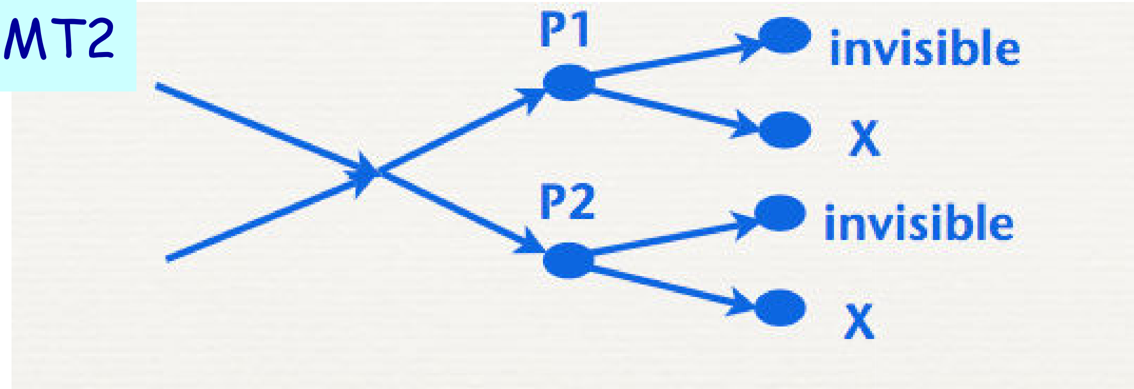


Higgs in χ_2 decay
$\chi_2 \rightarrow \chi_1 h$ becomes
Visible at 3000 fb^{-1}

SLHC will not be enough to measure masses precisely. CLIC?

New Mass Determination Methods

EG MT2

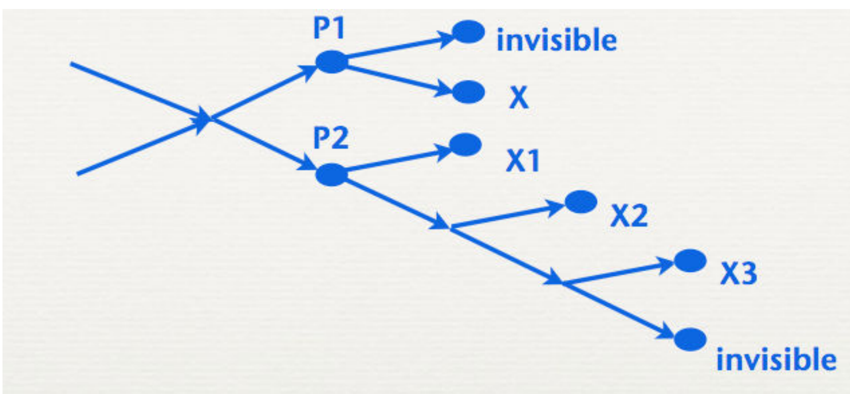


Get information on an ensemble of events when particles go undetected

$$m_{T2}^2 = \min_{p_T^{(1)} + p_T^{(2)} = p_T^{\text{miss}}} \left[\max \left[m_T^2(m_{\text{dm}}; p_T^{(1)}), m_T^2(m_{\text{dm}}; p_T^{(2)}) \right] \right]$$

so $\boxed{m_{T2} \leq m_{\text{P}}}$

Bar, Lester, Stephens



Can be extended
Still much to gain @LHC
by exploring kinematics

Mass Studies using Kinematics

- many improvements of mT2
- the mT2 upper endpoint as a function of m_dm has a "kink"at the true value of m_dm

W.S Cho, K. Choi, Y.G Kim, C.B. Park, arXiv:0709.0288

- can generalize mT2 to intermediate particles in sub-decay chains

M. Burns, KC Kong, K. Matchev, M. Park, arXiv:0810.5576

- can find new mT2-like observables, e.g. shat_min

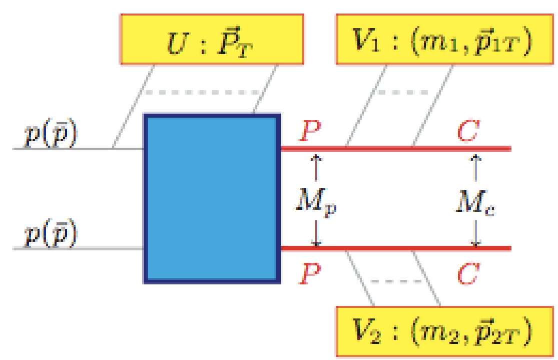
P. Konar, KC Kong, K. Matchev, arXiv:0812.1042

Gains of ~ factor 2 wrt ILC/LHC study reported…

Realism of these methods now being tested at the Tevatron

A general method for determining the masses of semi-invisibly decaying particles at hadron colliders

Konstantin T. Matchev and Myeonghun Park
Physics Department, University of Florida, Gainesville, FL 32611, USA
(Dated: 9 October, 2009)



How well can we measure masses at the LHC using all new techniques? Project?

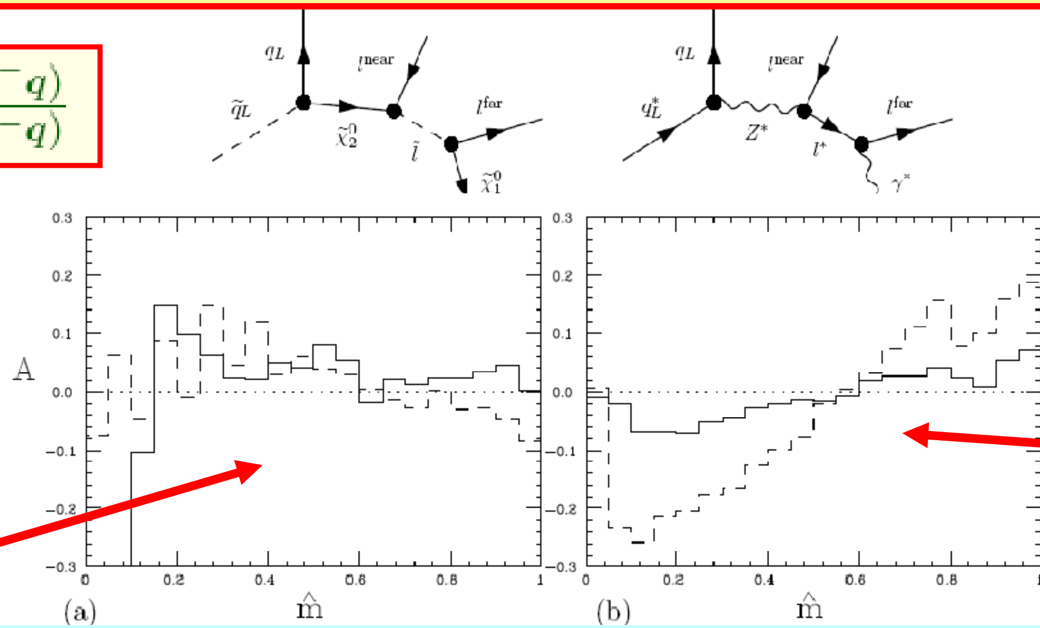
Is it SUSY?

Example: Universal Extra Dimensions
Phenomenology: a Kaluza Klein tower pattern like a SUSY mass spectrum:
Can the LHC distinguish?

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

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

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



Needs 10 fb^{-1} or more.

KK like spectrum (small mass splitting)

SPS1a benchmark type spectrum

Method works better or worse depending on (s)particles spectrum

More discriminating variables needed!!

Spin Measurements

Many new ideas being proposed
Most still need the detailed test of the 'experimental reality'

Kilic-Wang-Yavin:
Spin measurements in cascade decays
Angular correlations in decays...

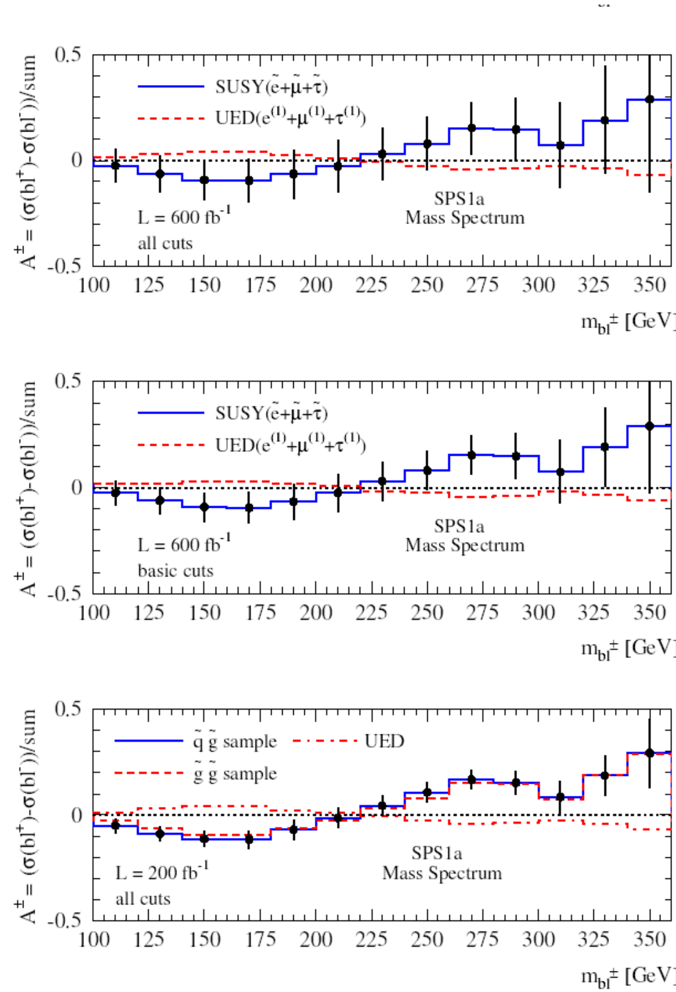
Alves-Eboli
Sbottom spin

Alves-Eboli-Plehn
Spins in Gluino Decays

Athanasiou-Lester-Smillie-Webber
Distinguishing spins in decay chains at the LHC

Choi-Hagiwara-Kim-Mawatari-Zerwas
Tau polarization in SUSY cascade decays

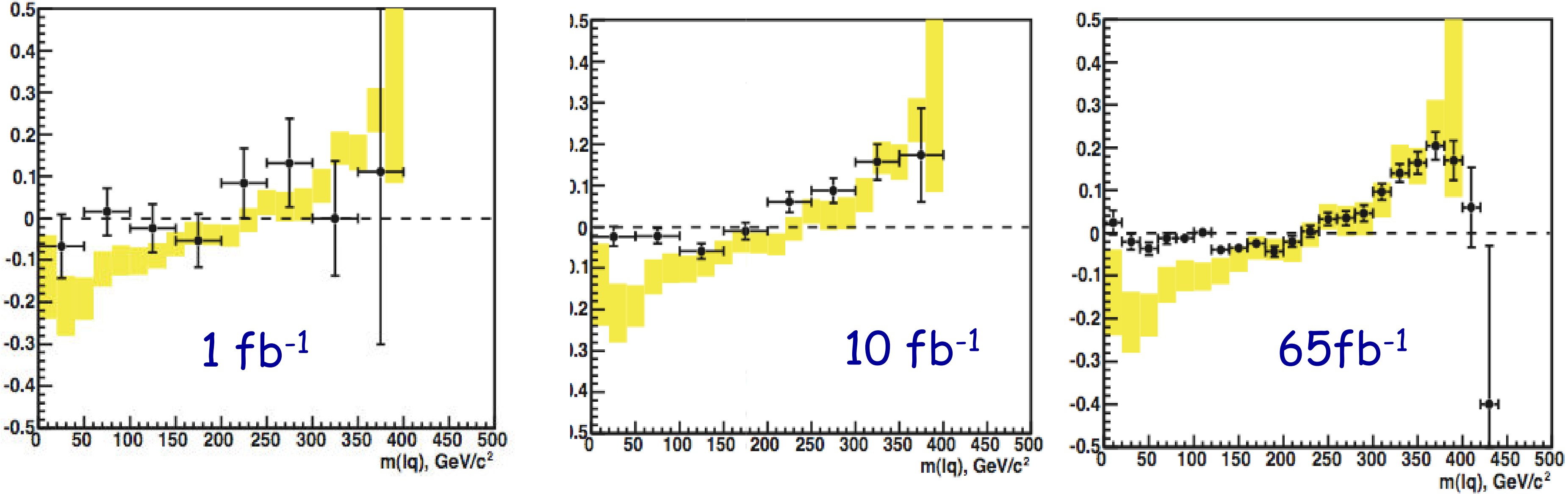
Further: Wang & Yavin, S. Thomas et al,



Spin Studies (LM1/SPS1)

$$\tilde{q} \to q\tilde{\chi}_2^0 \to q l^{\pm}_{near} \tilde{l}^{\mp} \to q l^{\pm}_{near} l^{\mp}_{far} \tilde{\chi}_1^0$$

Barr hep-ph/0405052; PL.B596 205 2004



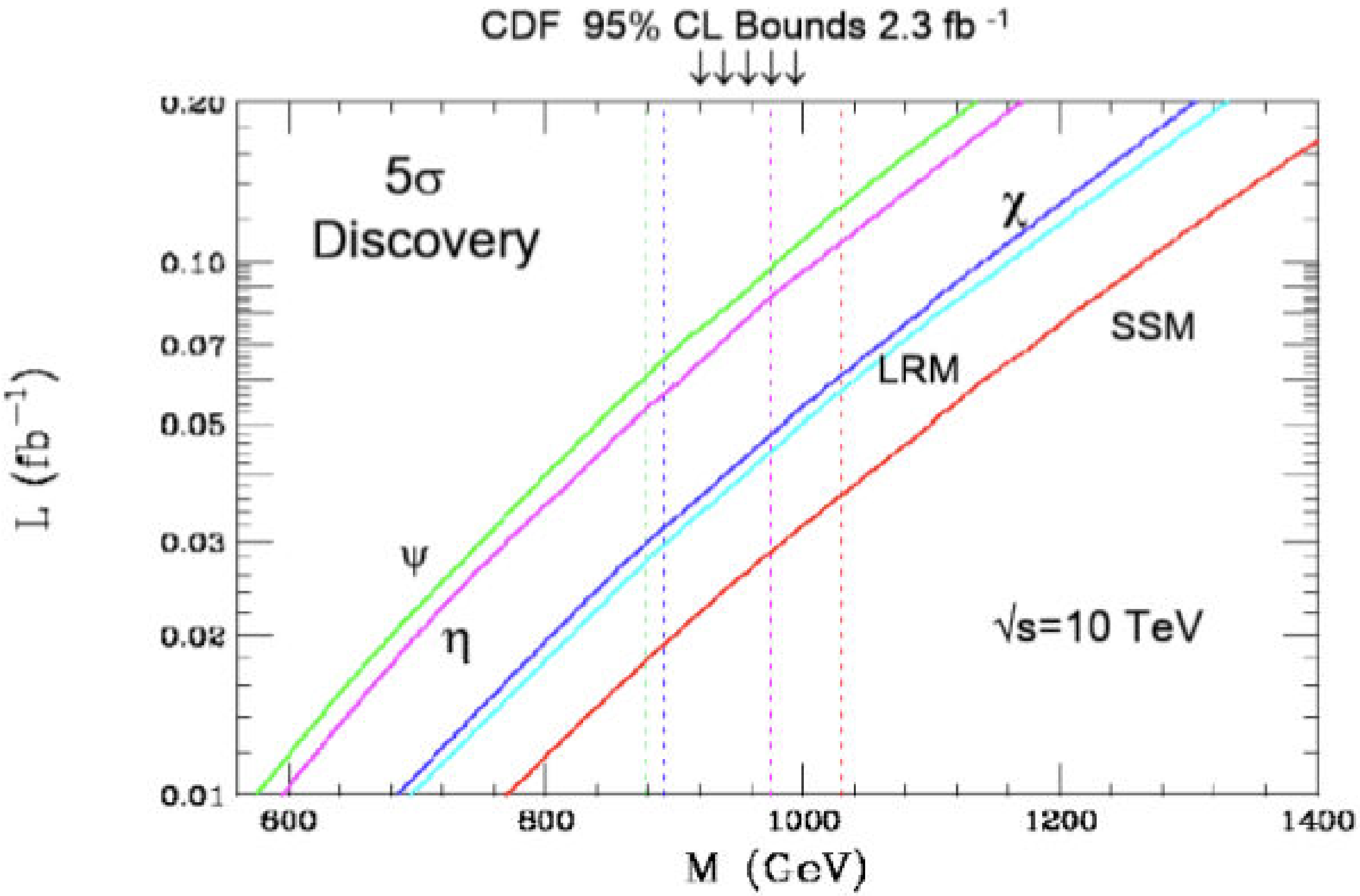
$$A = \frac{N(l^+q) - N(l^-q)}{N(l^+q) + N(l^-q)}$$

Signal + background

Preliminary study: work in progress (different LM points, other proposals)

A Few Other Models

Z' Reach

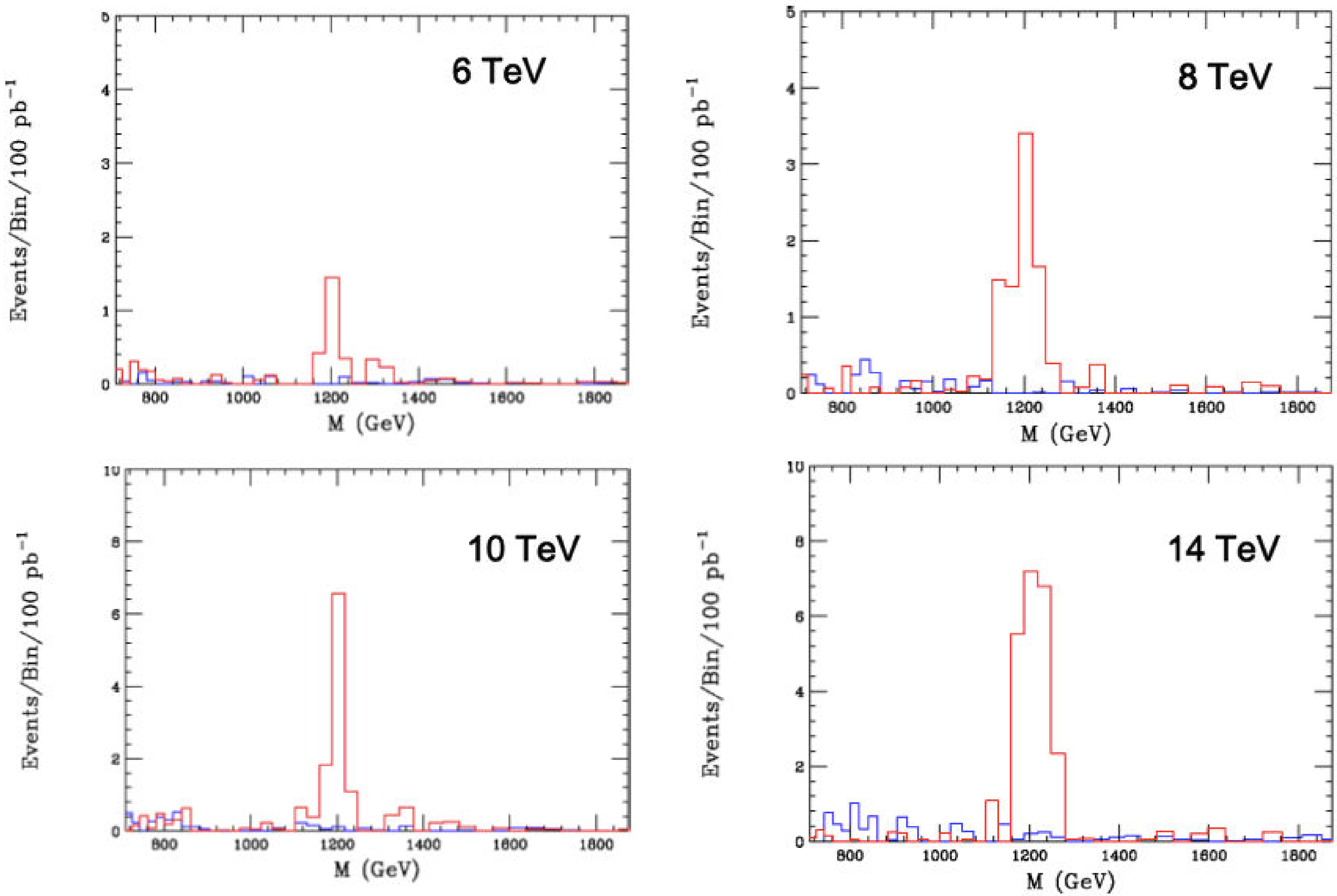


Rizzo

Enter new region even with 100 pb^{-1} and 10 TeV

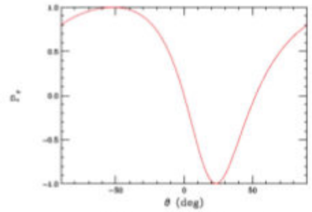
Zprime

Z'_{SSM} Signal at Different √s With Low Luminosity

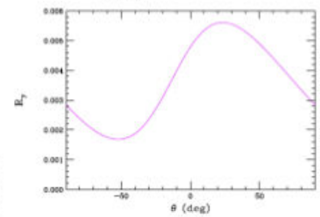


Z' Couplings

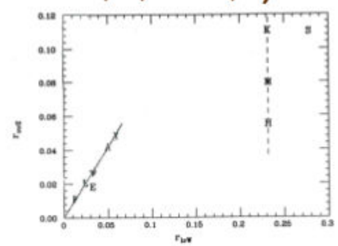
Other Possible Z' Observables For Coupling Determinations



- 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' $\rightarrow \bar{b}b$, $\bar{t}t$

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

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Options for LHC

Not yet fully worked out

LHeC?

- With CLIC it may be possible to sit on the resonance peak & extract **all** of the coupling information with high precision as was done by LEP/SLC. The discovery of a 2-3 TeV resonance at the LHC would be a **very strong motivation** to go as quickly as possible to this energy range.

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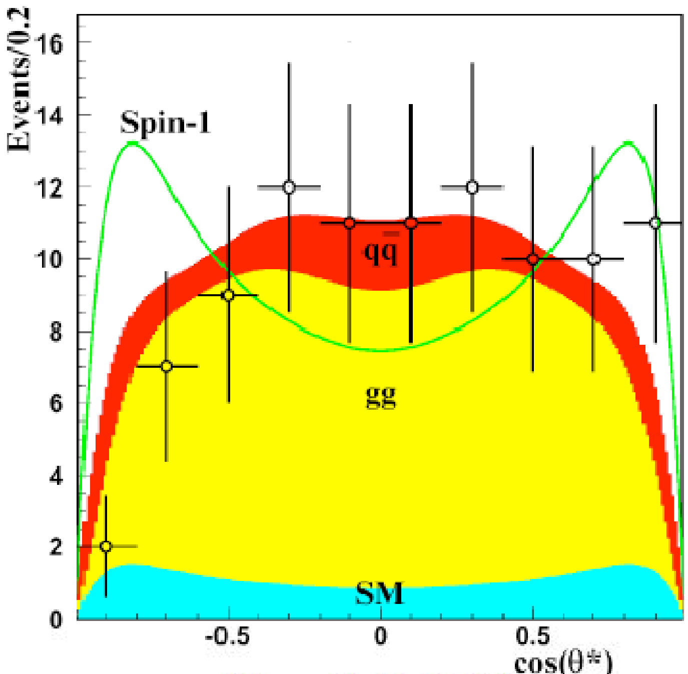
Spin Analysis (Z'⇔Randall Sundrum gravitons)

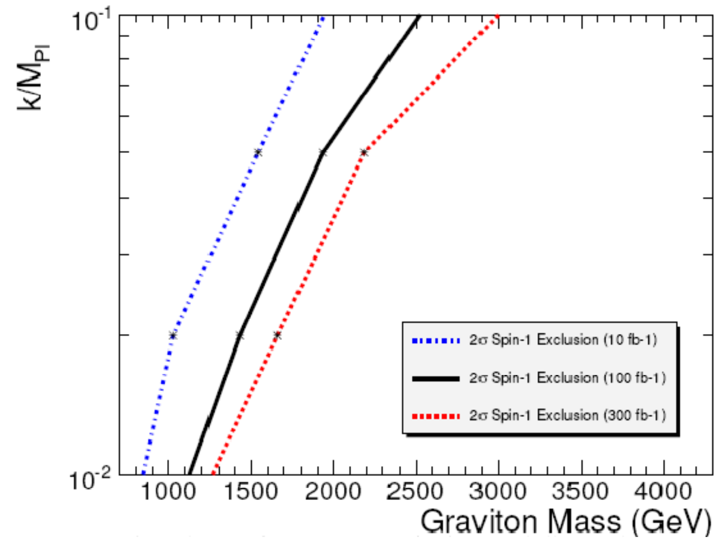
Luminosity required to discriminate a spin-1 from spin-2 hypothesis at the 2σ level

Needs statistics!



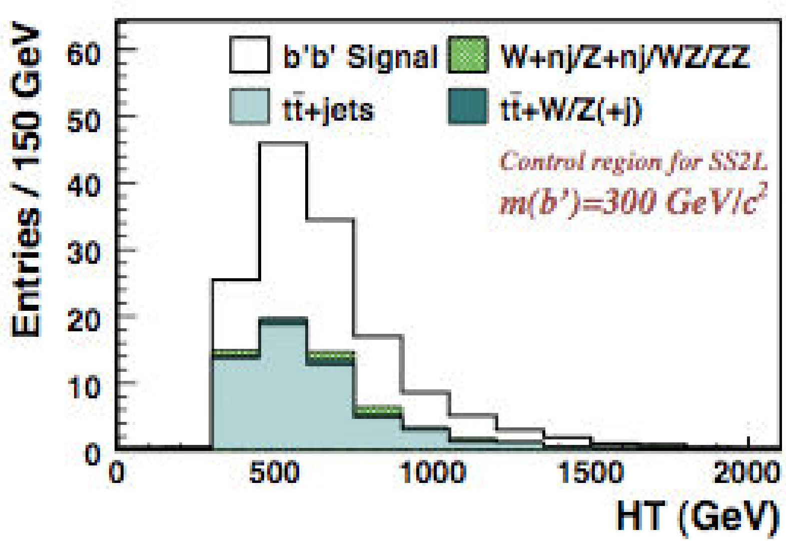
M_G = 1.5 TeV
$\int L$ = 100 fb^{-1}

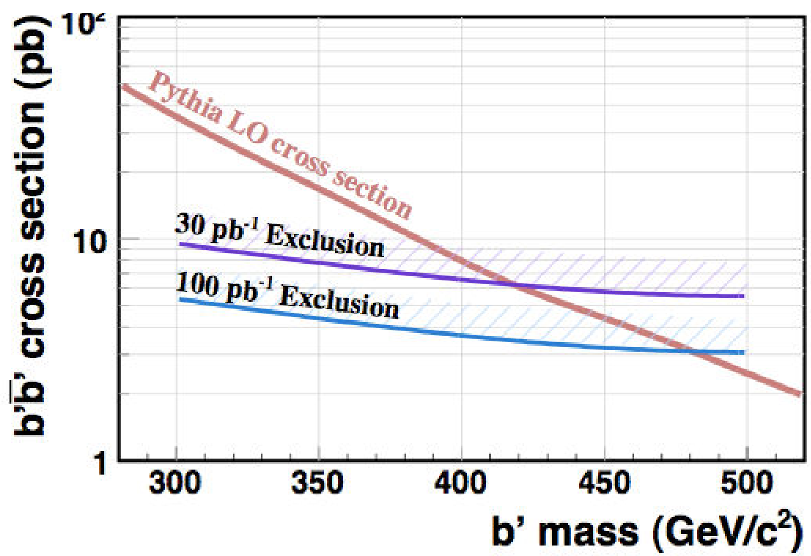
$\sqrt{s}$, TeV	c	$\int \mathcal{L}dt$, fb^{-1}	N_s	N_b
1.0	0.01	50	200	87
1.0	0.02	10	146	16
1.5	0.02	90	174	41
3.0	0.05	1200	154	22
3.0	0.10	290	148	6



- A case for the SLHC

b' production





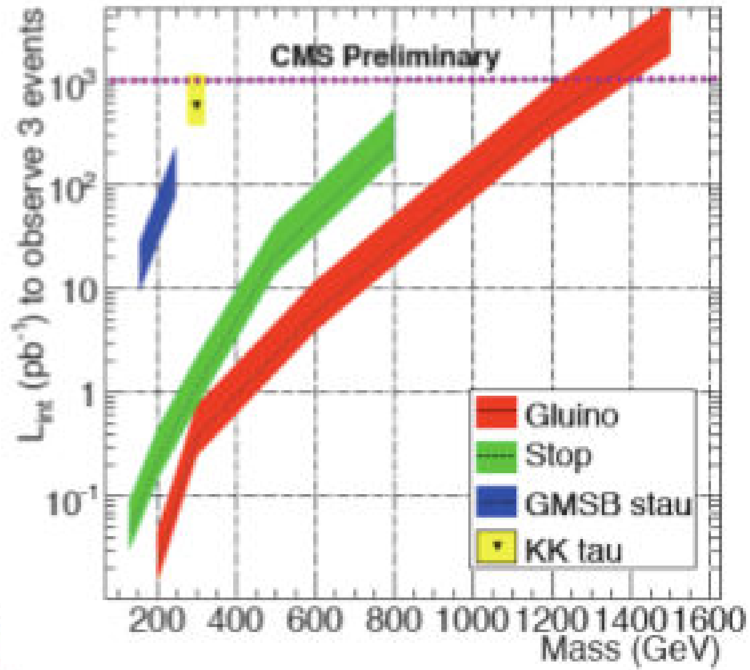
A 4th generation?

Look for b′ and t′ quarks

This channel
b′→ tW

Senstivity ~500 GeV with a few 100 pb^{-1}

New Stable Particles



Predicted by several models:

- *lepton like*
  - *GMSB staus*
  - *Kaluza-Klein tau's in UED*
- *R-Hadrons*
  - *long lived stop in SUSY*
  - *long lived gluino in split-susy*

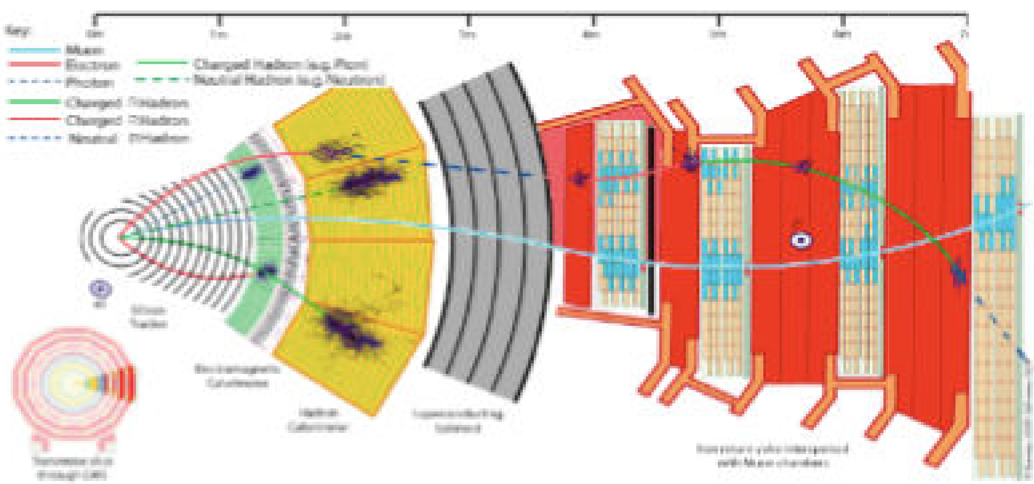
Properties:

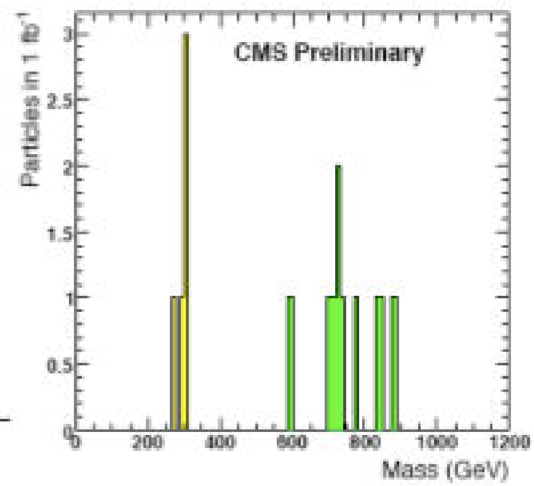
- *O(100 GeV), β<1*
- *$c\tau$ few meters*
- *electrical or colour charge*

Measurement

- *momentum in Tracker&Muon*
- *β TOF in Muon DT & dE/dx in Tracker*

ATLAS similar





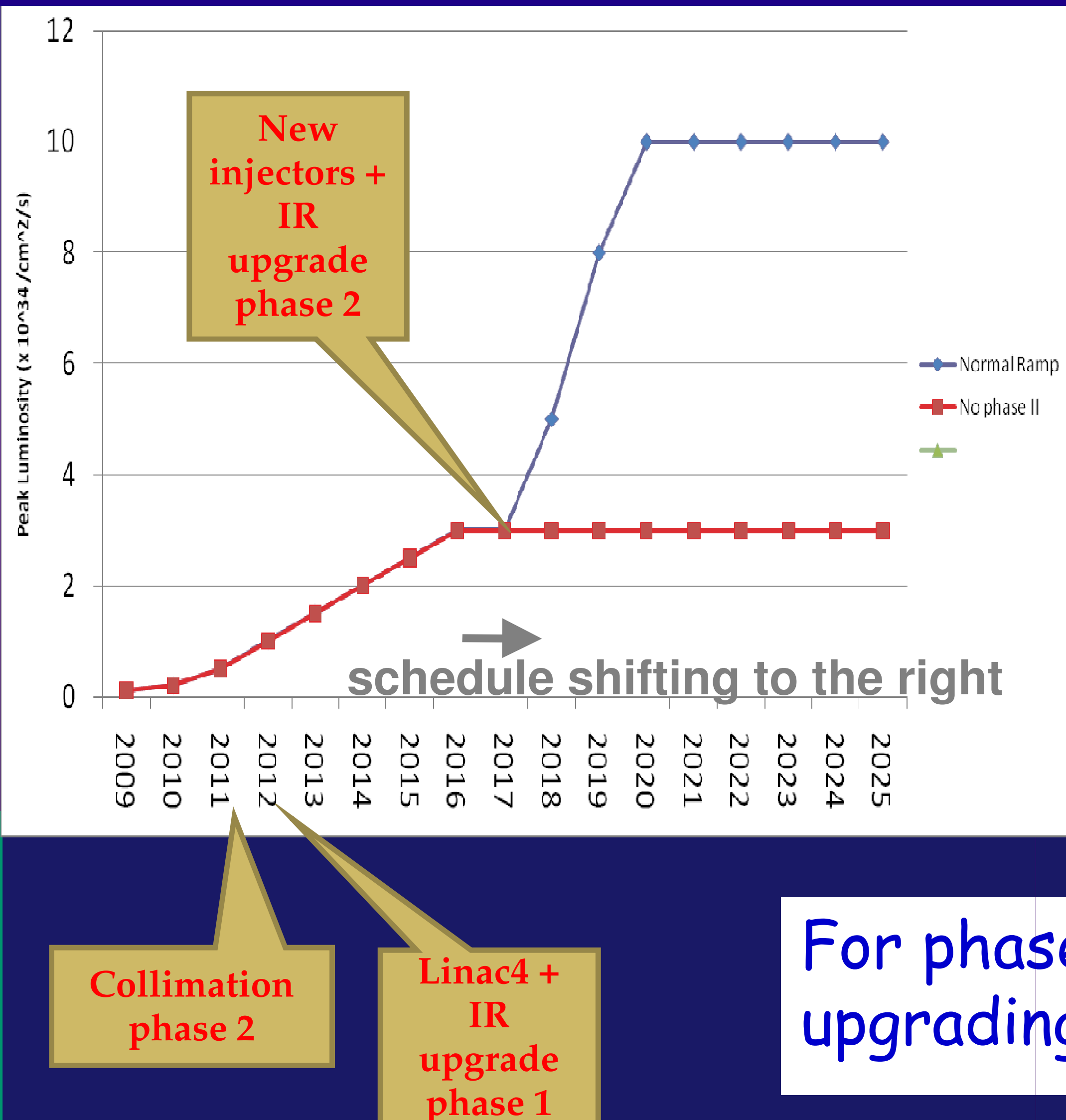
Strings 2008 O. Buchmüller

Summary

- New studies completed in ATLAS and CMS, with close to real detector conditions and for first luminosity
- LHC experiments will enter the TeV region very fast even with 10 (7) TeV, eg with 10 TeV/100 pb^{-1} they overtake the Tevatron reach
  - Coverage of the full region for the Higgs will take longer
  - Other EWSB signals like WW scattering expected take time as well
- However excluding masses/options will be also very important
- Measurements at the LHC prior to a new collider (LHC & sLHC):
  - New ideas being worked out (some of which still need reality tests)
    - Kinematics for particle properties (mass, spin)
    - Special processes for eg couplings
- CLIC: what precision/separation possibilities of high mass states?

Backup

Luminosity with Time



For phase II the detectors will need upgrading (tracker, trigger electronics…)

M. Nessi, R. Garoby, 2008