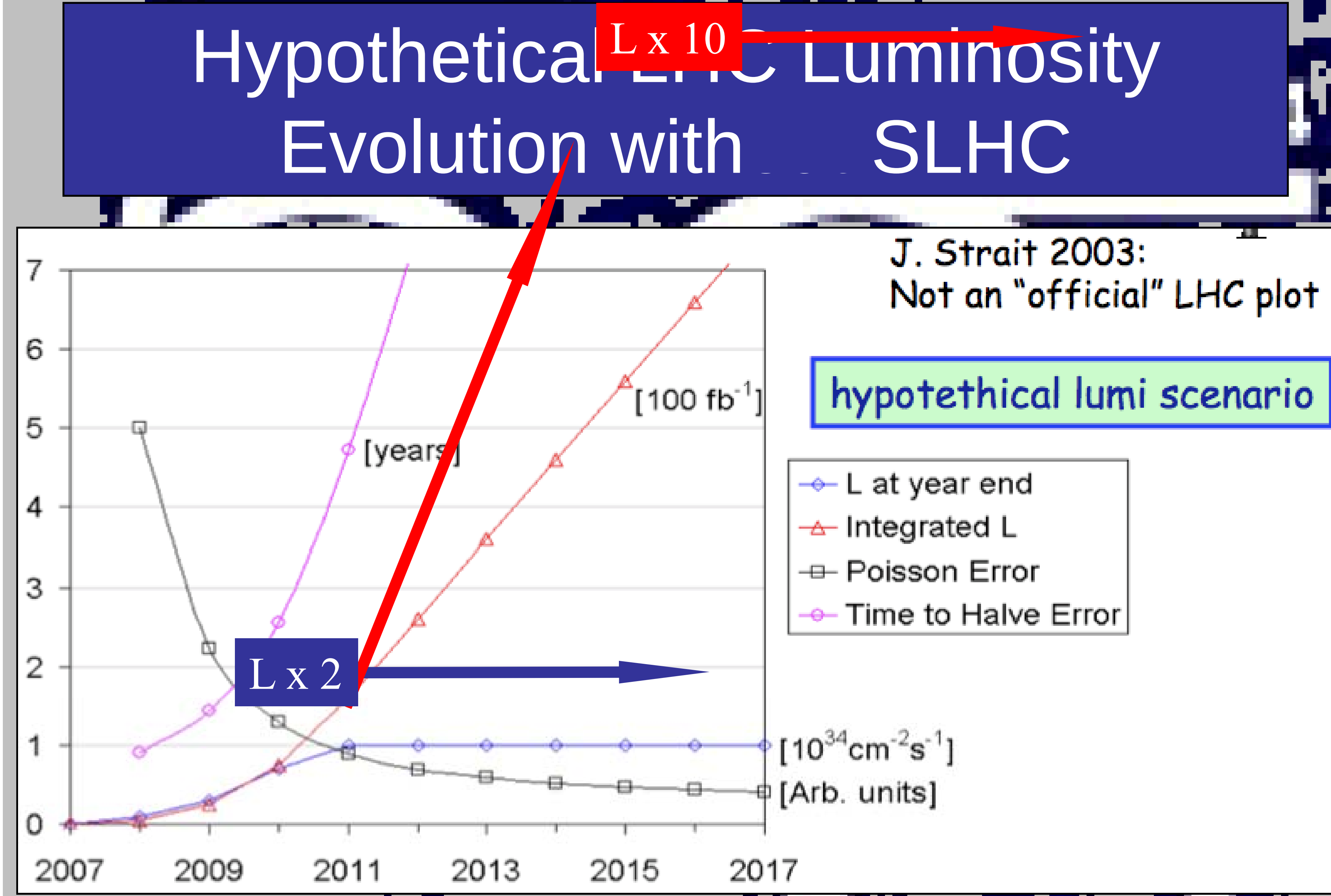
Physics Case for the Super-LHC

LHCC

John Ellis, May 7th, 2008

De Roeck, JE, Gianotti: hep-ph/0112004
Gianotti et al: hep-ph/0204087
POFPA: Blondel, Camilleri, Ceccucci, JE, Lindroos, Mangano, Rolandi: hep-ph/0609102
Presentations by De Roeck, Gianotti, Mangano

Hypothetical LHC Luminosity Evolution with SLHC



Physics Context in 2011 - 2015

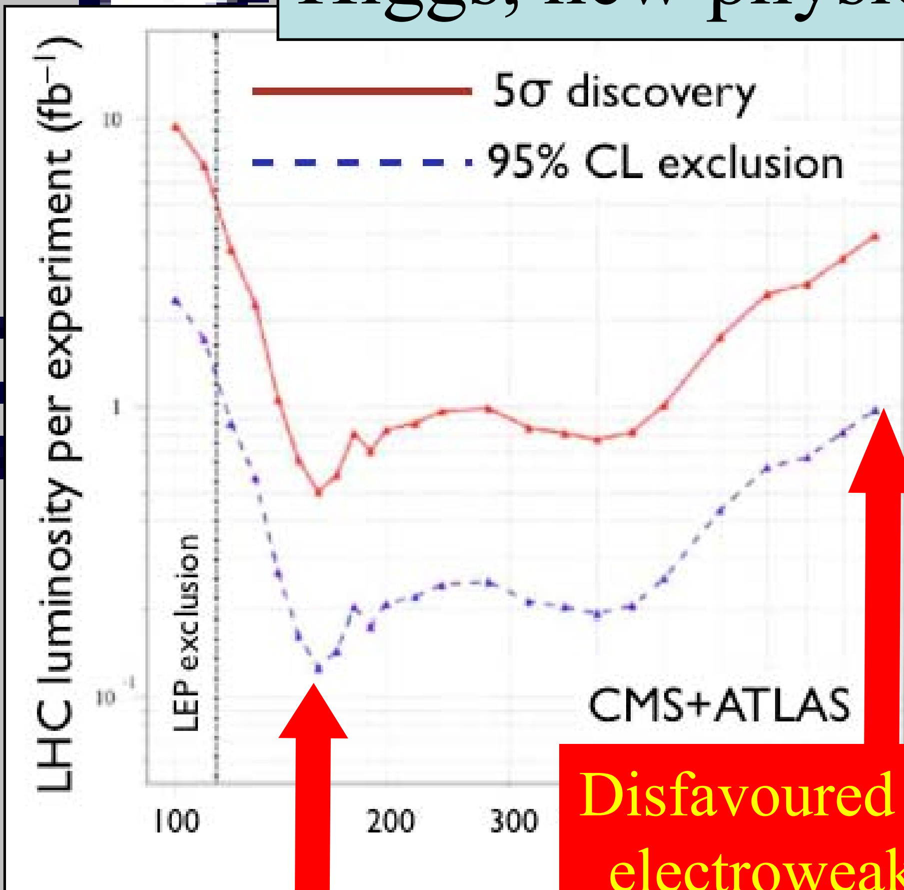
- New physics expected in TeV energy range
  - Higgs, supersymmetry, extra dimensions, …?
- Initial LHC data should indicate what physics, and at which energy scale
- Two possible scenarios:
  - New physics at a low energy scale
    - But perhaps more at higher energies (e.g., supersymmetry)

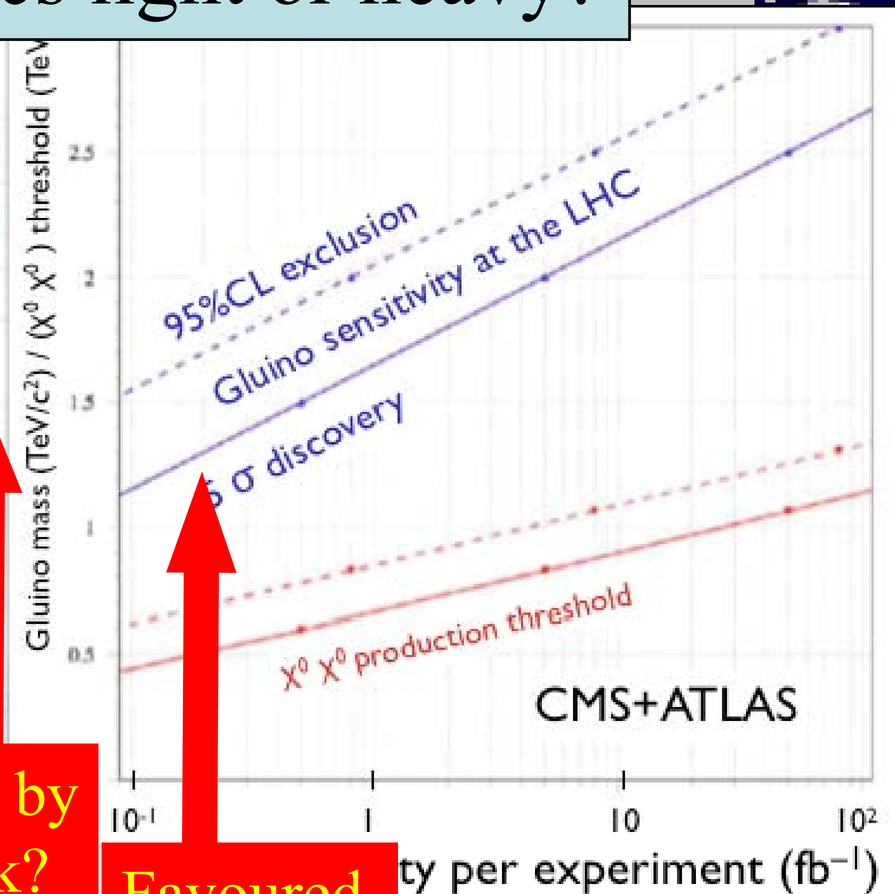
    SLHC will probe in more detail
  - New physics threshold at higher energy scale

    SLHC only available tool

Possible Physics Scenarios in 2011

Higgs, new physics light or heavy?





Tevatron almost here

Disfavoured by electroweak?

Favoured by g_μ-2?

Accelerator Context in 2011 - 2015

- ILC may be ready for approval, BUT:

From R. Orbach (DoE Undersecretary)
remarks to HEPAP, Febr 22 2007:

"Even assuming a positive decision to build an ILC, the schedules will almost certainly be lengthier than the optimistic projections. Completing the R&D and engineering design, negotiating an international structure, selecting a site, obtaining firm financial commitments, and building the machine could take us well into the **mid-2020s, if not later**."

- CLIC feasibility may be demonstrated, BUT
- Neither project may finished within another decade

SLHC may be the only game in town for a long time!

Possible LHC Upgrade Options

- Upgrade of Linac
  - More intense beam @ 160 MeV
- New LHC insertions:
  - **Luminosity → 2.10^{34} $cm^{-2}s^{-1}$**
- Superconducting Proton Linac
  - Low power or few MW @ few GeV?
- Replace PS
  - By PS2 @ 50 GeV?
- New LHC insertions:
  - **Luminosity → 10^{35} $cm^{-2}s^{-1}$**
- Replace SPS
  - By SC machine @ 1 TeV???

Planned within supplementary budget voted by Council

R&D within supplementary budget voted by Council

Upgrade Scenarios Currently Favoured

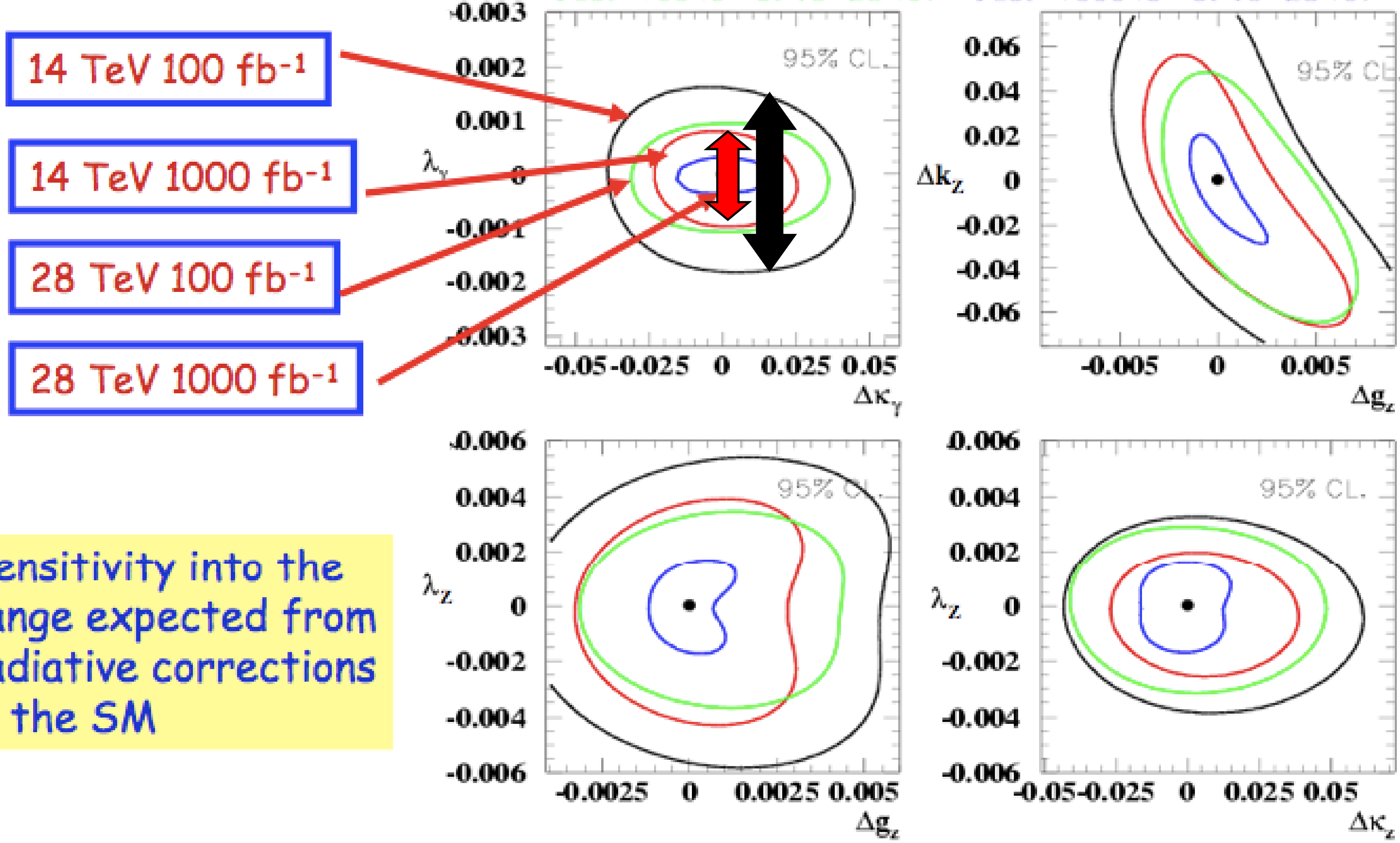
- Avoid problems with beam heating
- Peak luminosity ~ 10^{35} $cm^{-2}s^{-1}$

parameter	symbol	25 ns, small β*	50 ns, long
transverse emittance	ε [μm]	3.75	3.75
protons per bunch	N_b [10^{11}]	1.7	4.9
bunch spacing	Δt [ns]	25	50
beam current	I [A]	0.86	1.22
longitudinal profile		Gauss	Flat
rms bunch length	σ_z [cm]	7.55	11.8
beta* at IP1&5	β* [m]	0.08	0.25
full crossing angle	θ_c [μrad]	0	381
Piwinski parameter	$\phi=\theta_c\sigma_z/(2*\sigma_x*)$	0	2.0
hourglass reduction		0.86	0.99
peak luminosity	L [10^{34} $cm^{-2}s^{-1}$]	15.5	10.7
peak events per crossing		294	403
initial lumi lifetime	τ_L [h]	2.2	4.5
effective luminosity ($T_{turnaround}$=10 h)	L_{eff} [10^{34} $cm^{-2}s^{-1}$]	2.4	2.5
	$T_{run,opt}$ [h]	6.6	9.5
effective luminosity ($T_{turnaround}$=5 h)	L_{eff} [10^{34} $cm^{-2}s^{-1}$]	3.6	3.5
	$T_{run,opt}$ [h]	4.6	6.7
e-c heat SEY=1.4(1.3)	P [W/m]	1.04 (0.59)	0.36 (0.1)
SR heat load 4.6-20 K	P_{SR} [W/m]	0.25	0.36
image current heat	P_{IC} [W/m]	0.33	0.78
gas-s. 100 h (10 h) τ_b	P_{gas} [W/m]	0.06 (0.56)	0.09 (0.9)
extent luminous region	σ_l [cm]	3.7	5.3
comment		D0 + crab (+ Q0)	wire comp.

Outline of Physics Topics

- Standard Model:
  - Multi-W,Z couplings
  - Rare top decays
- Higgs physics:
  - Light Higgs: measure couplings, rare decays, self-coupling
  - Heavy Higgs: discover!
- New physics:
  - Supersymmetry: sensitivity to heavy sparticles
  - Z’
  - compositeness

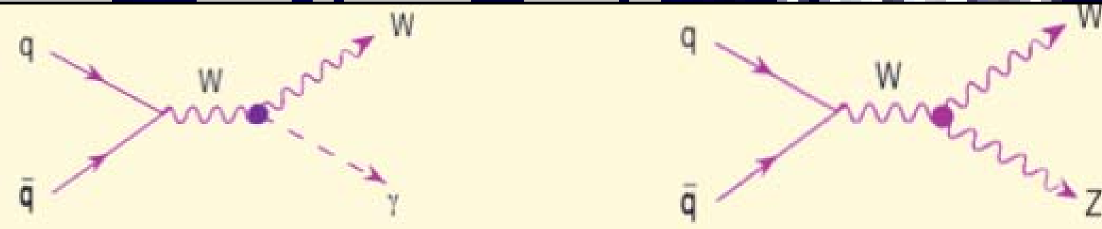
Gauge-Boson Couplings @ SLHC



Sensitivity into the range expected from radiative corrections in the SM

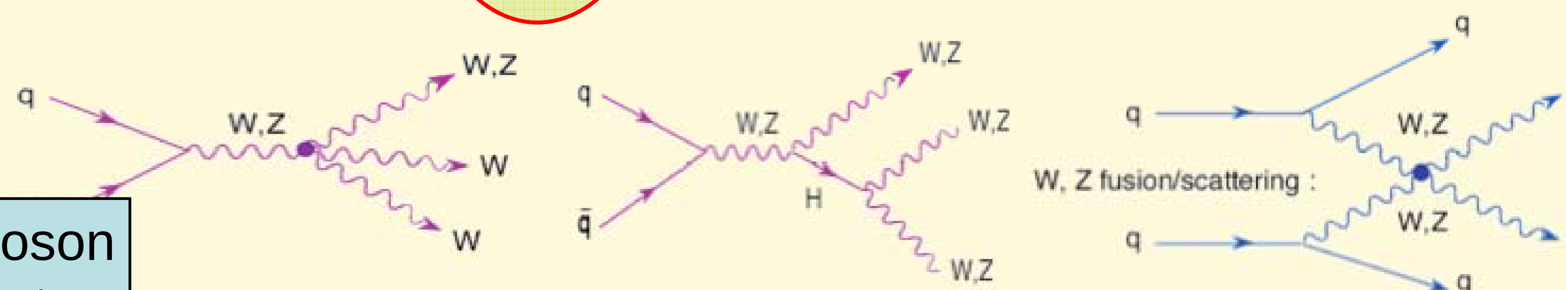
Multiple W/Z Boson Couplings

Accuracies for triple couplings



Coupling	14 TeV 100 fb^{-1}	14 TeV 1000 fb^{-1}	28 TeV 100 fb^{-1}	28 TeV 1000 fb^{-1}	LC 500 fb^{-1}, 500 GeV
λ_γ	0.0014	0.0006	0.0008	0.0002	0.0014
λ_Z	0.0028	0.0018	0.0023	0.009	0.0013
$\Delta\kappa_\gamma$	0.034	0.020	0.027	0.013	0.0010
$\Delta\kappa_Z$	0.040	0.034	0.036	0.013	0.0016
g^Z_1	0.0038	0.0024	0.0023	0.0007	0.0050

Multi-boson final states



(LO rates, CTEQ5M, k ~ 1.5 expected for these final states)

Process	*WWW*	*WWZ*	*ZZW*	*ZZZ*	*WWWW*	*WWWZ*
N(m_H = 120 GeV)	2600	1100	36	7	5	0.8
N(m_H = 200GeV)	7100	2000	130	33	20	1.6

Sensitivity to Rare Top decays

- Flavour-changing decays very suppressed in the Standard Model
- Window on physics beyond the Standard

t→qγ

b-tagging	ideal	real.	μ-tag
600 fb^{-1}	0.48	0.88	3.76
6000 fb^{-1}	0.14	0.26	0.97

t→qg

b-tagging	ideal	real.	μ-tag
600 fb^{-1}	22.3	60.8	210.
6000 fb^{-1}	7.04	19.2	66.2

t→qZ

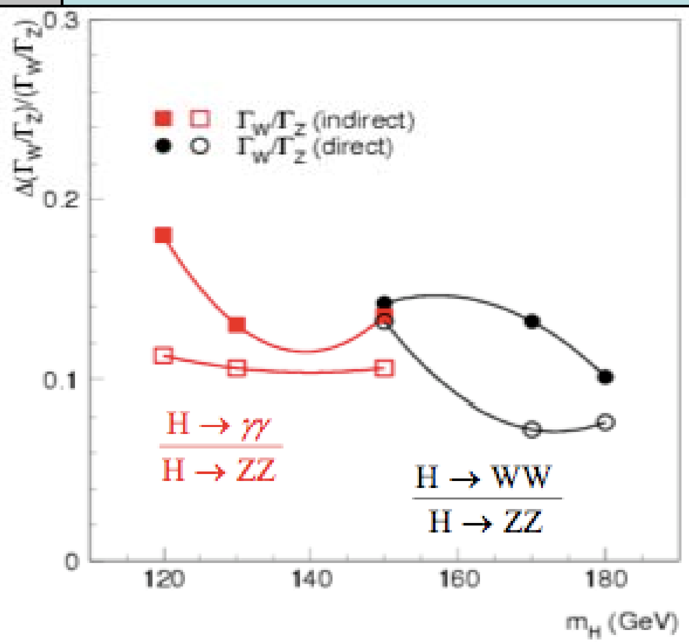
b-tagging	ideal	real.	μ-tag
600 fb^{-1}	0.46	1.1	83.3
6000 fb^{-1}	0.05	0.11	8.3

Results in units of 10^{-5}

Ideal = MC 4-vector
Real = B-tagging/cuts as for $10^{34} cm^{-2} s^{-1}$
μ-tag = assume only B-tag with muons works at $10^{35} cm^{-2} s^{-1}$

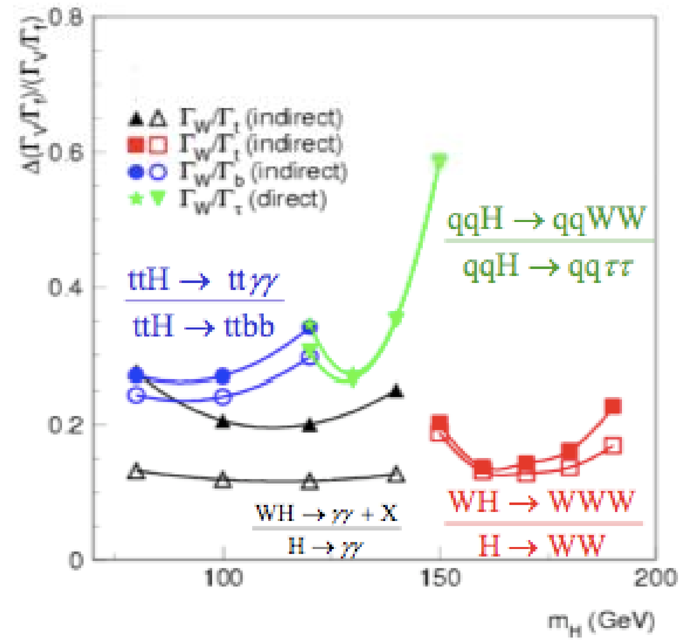
Measurements of Higgs Couplings

- Some decays limited by statistics
- Others limited by systematics



Closed symbols:
LHC 600 fb^{-1}

Open symbols:
SLHC 6000 fb^{-1}



Sensitivity to Rare Higgs Decays

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

Channels studied:
- $H \rightarrow Z\gamma \rightarrow \ell\ell\gamma$
- $H \rightarrow \mu\mu$

3000 fb^{-1}

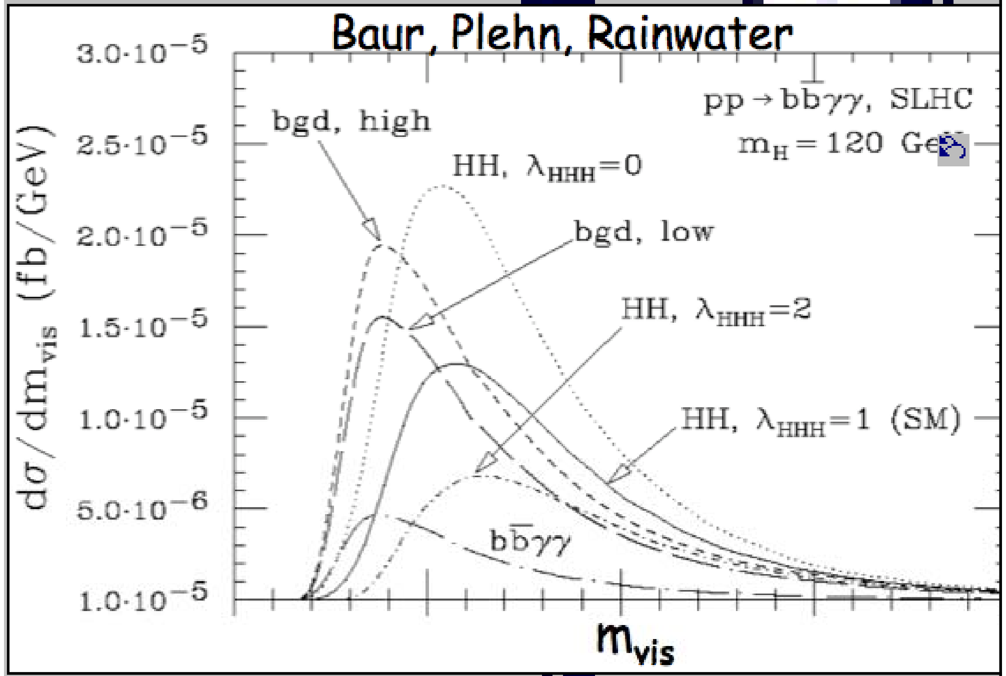
m_H (GeV)	$S/\sqrt{B}$	$\frac{\delta\sigma\times BR(H\to\mu\mu)}{\sigma\times BR}$
120 GeV	7.9	0.13
130 GeV	7.1	0.14
140 GeV	5.1	0.20
150 GeV	2.8	0.36

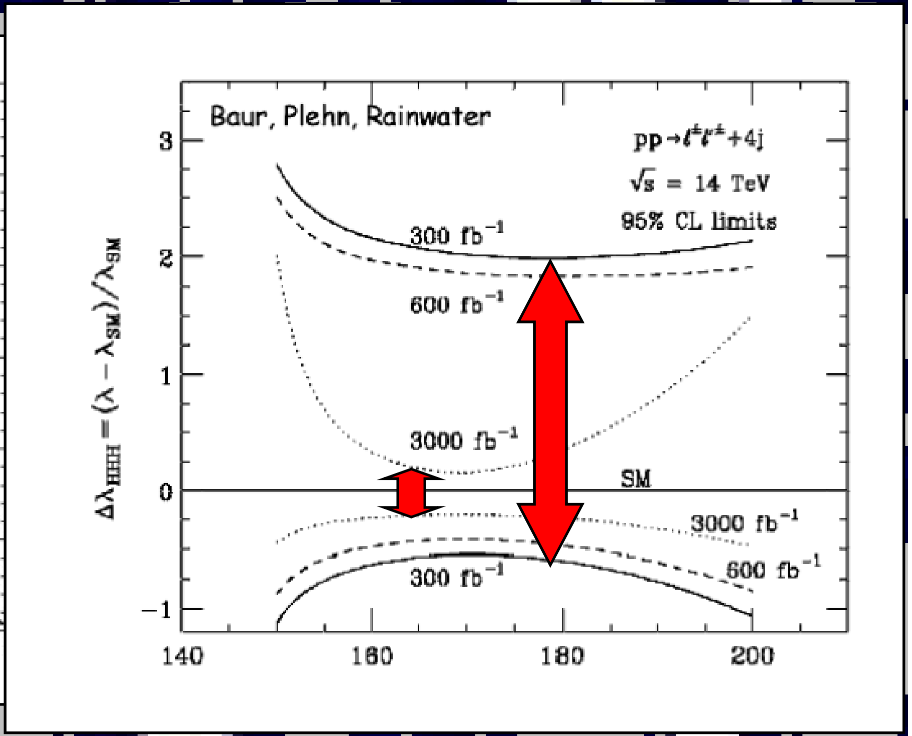
Channel	m_H	$S/\sqrt{B}$ LHC ($600\ fb^{-1}$)	$S/\sqrt{B}$ SLHC ($6000\ fb^{-1}$)
$H \rightarrow Z\gamma \rightarrow \ell\ell\gamma$	~ 140 GeV	~ 3.5	~ 11
$H \rightarrow \mu\mu$	130 GeV	~ 3.5 (gg+VBF)	~ 9.5 (gg)

Additional coupling measurements :
e.g. Γ_μ / Γ_W to ~ 20%

Higgs Self-Coupling @ SLHC?

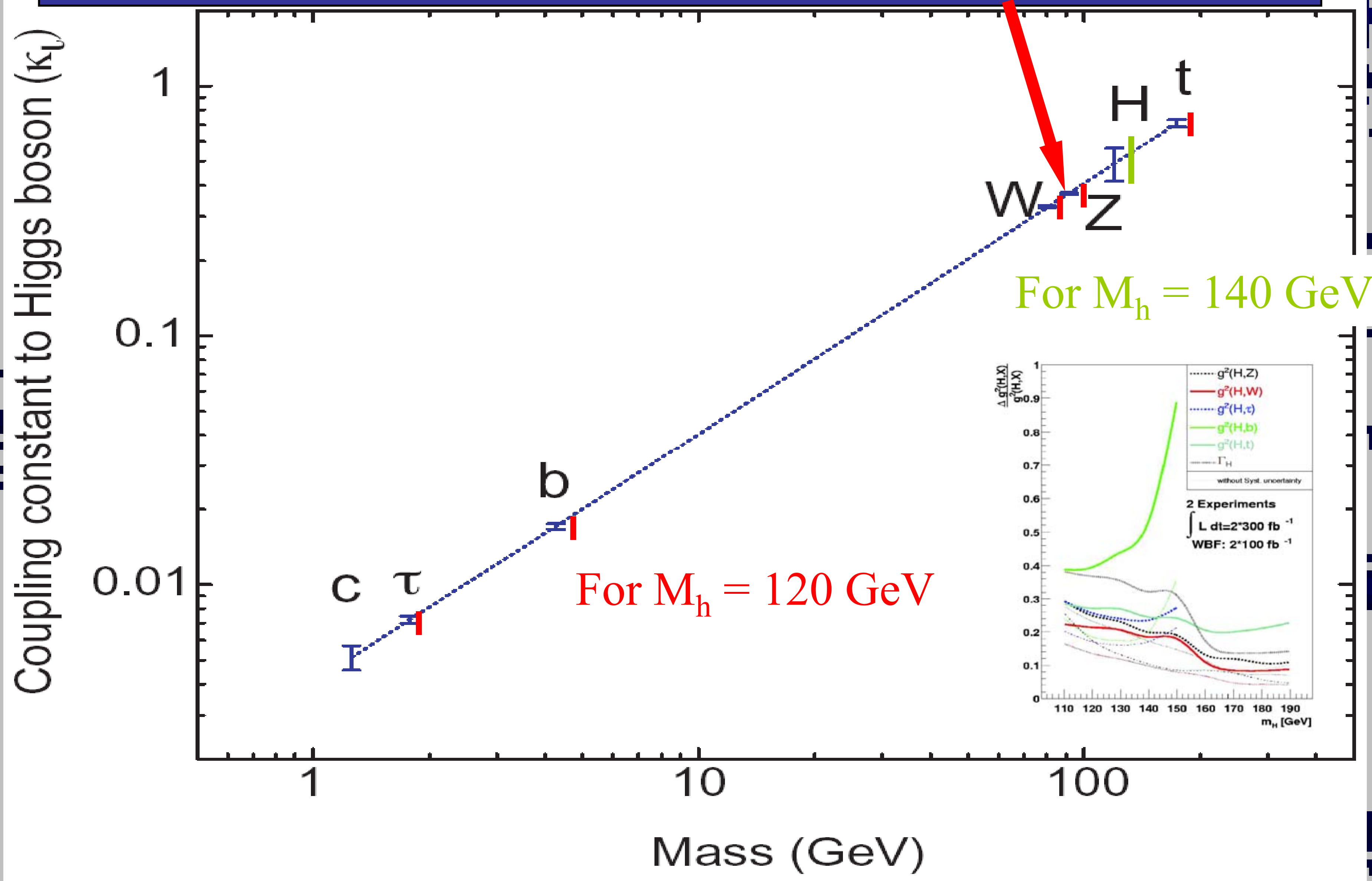
Measure triple-Higgs-boson coupling with accuracy comparable to 0.5 TeV ILC?



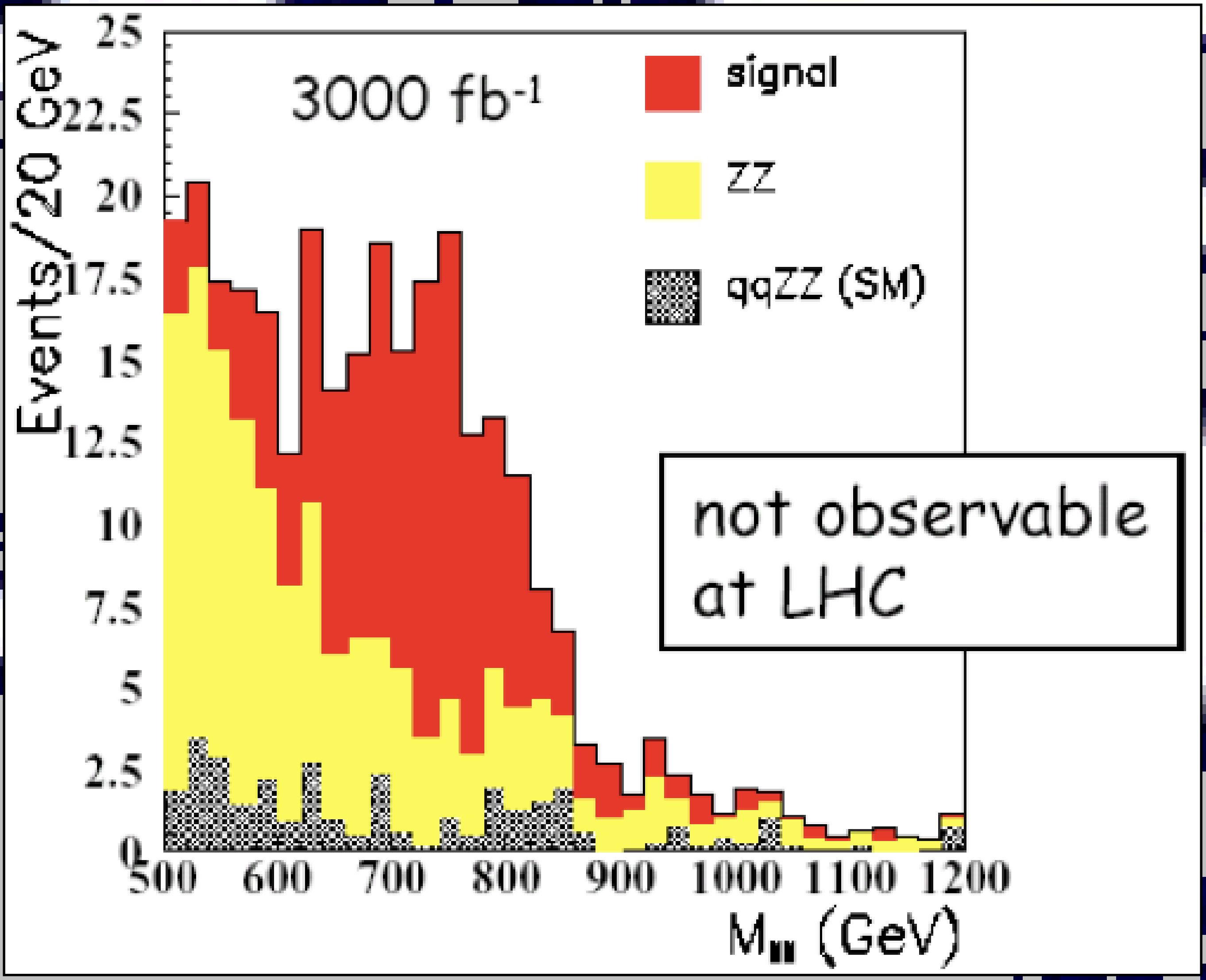


Awaits confirmation by detailed experimental simulation

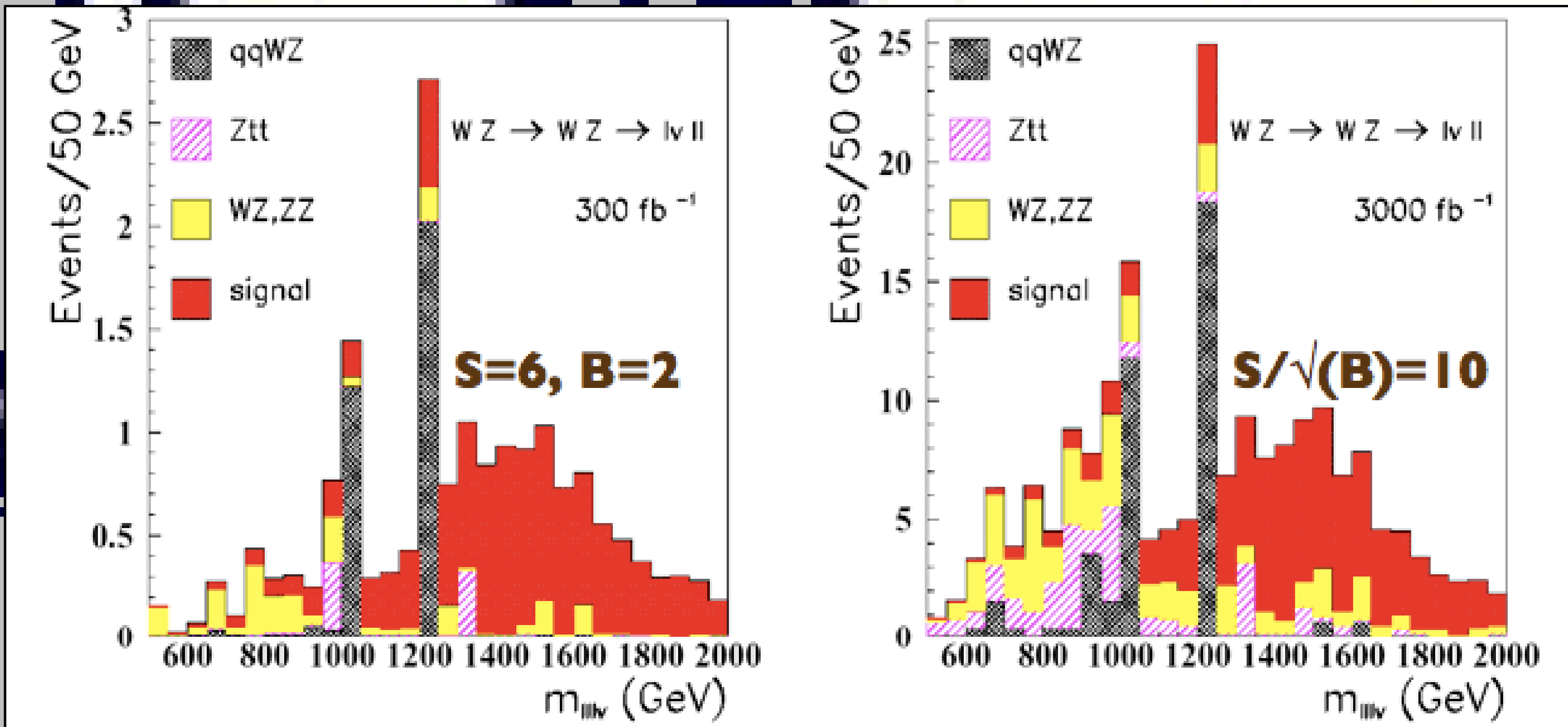
Higgs Measurements @ LHC & ILC



Heavy Higgs @ SLHC



Possible Resonance in WZ Channel



- ρ-like vector meson in chiral Lagrangian model
- Invisible with 300 fb^{-1}, clear with 3000 fb^{-1}

Longitudinal W^+W^+ Scattering

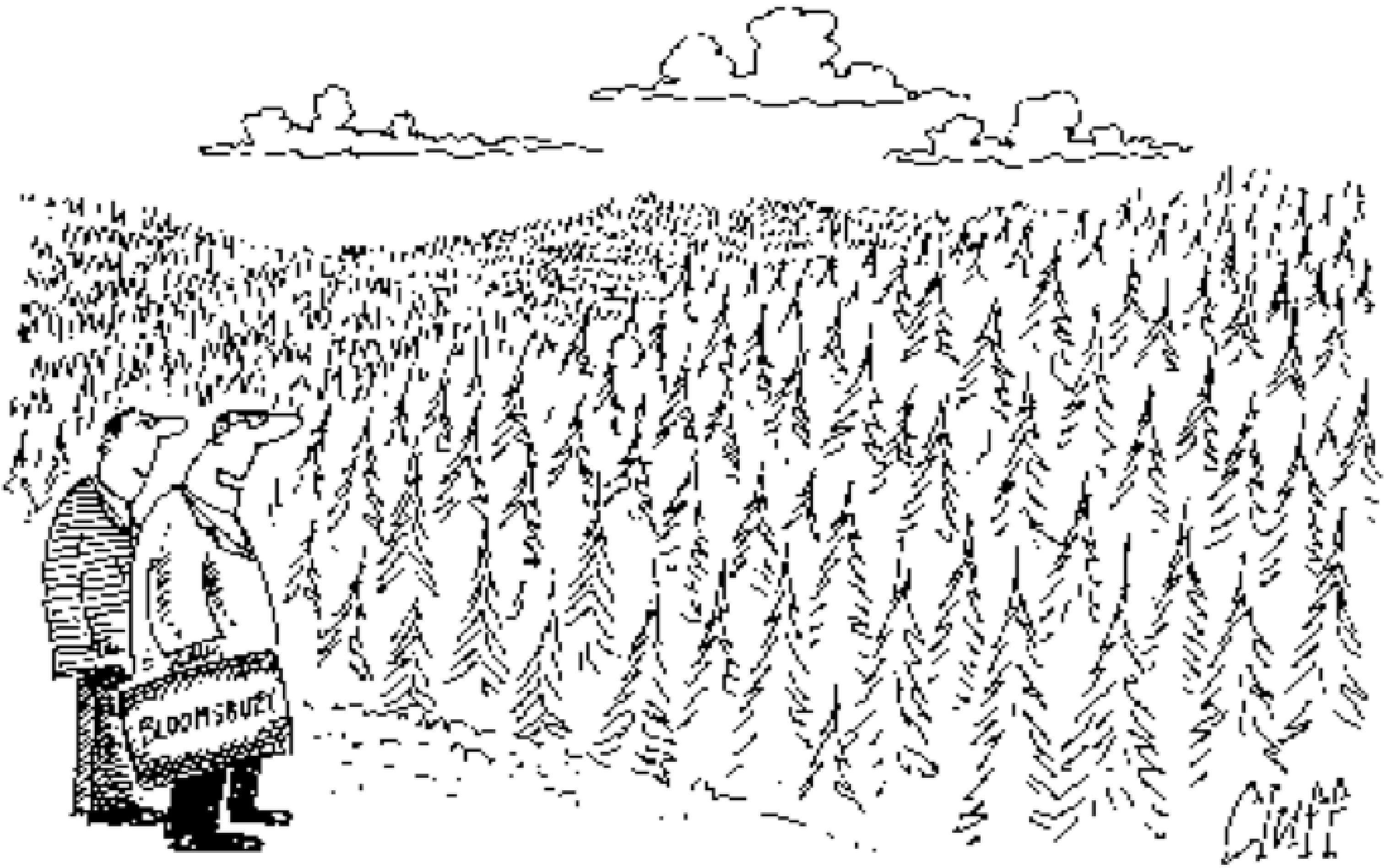
- Search for high-mass Higgs boson
- Or whatever replaces it

Table 10: Expected numbers of reconstructed events above an invariant mass of 600 GeV (for $\sqrt{s}$=14 TeV) and 800 GeV (for $\sqrt{s}$=28 TeV) for models with a strongly-coupled Higgs sector and for the background. The significance was computed as $S/\sqrt{S+B}$.

Model	300 fb^{-1} 14 TeV	3000 fb^{-1} 14 TeV	300 fb^{-1} 28 TeV	3000 fb^{-1} 28 TeV
Background	7.9	44	20	180
K-matrix Unitarization	14	87	57	490
Significance	3.0	7.6	6.5	18.9
Higgs, 1 TeV	7.2	42	18	147
Significance	1.8	4.5	2.9	8.1

How important are detectors in forward region?

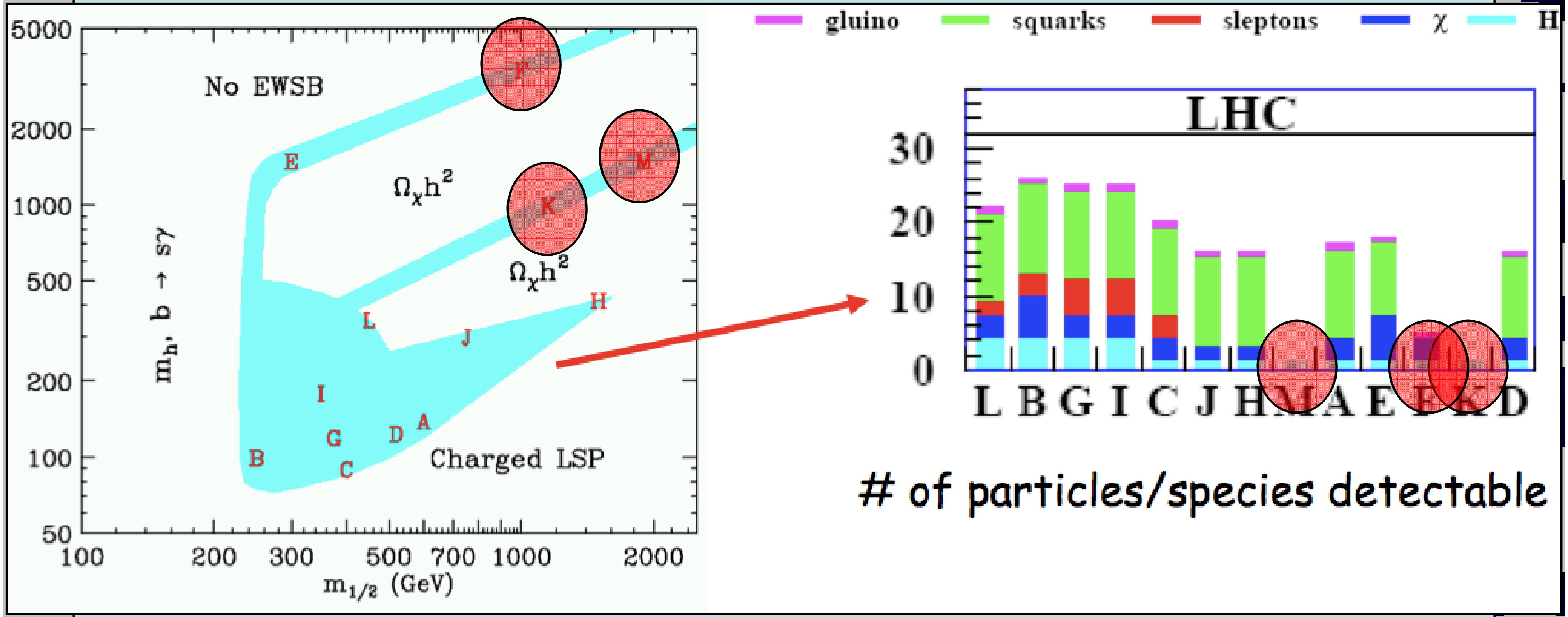
Search for Supersymmetry



"One day, all of these will be supersymmetric phenomenology papers."

Exploring the SUSY Parameter Space

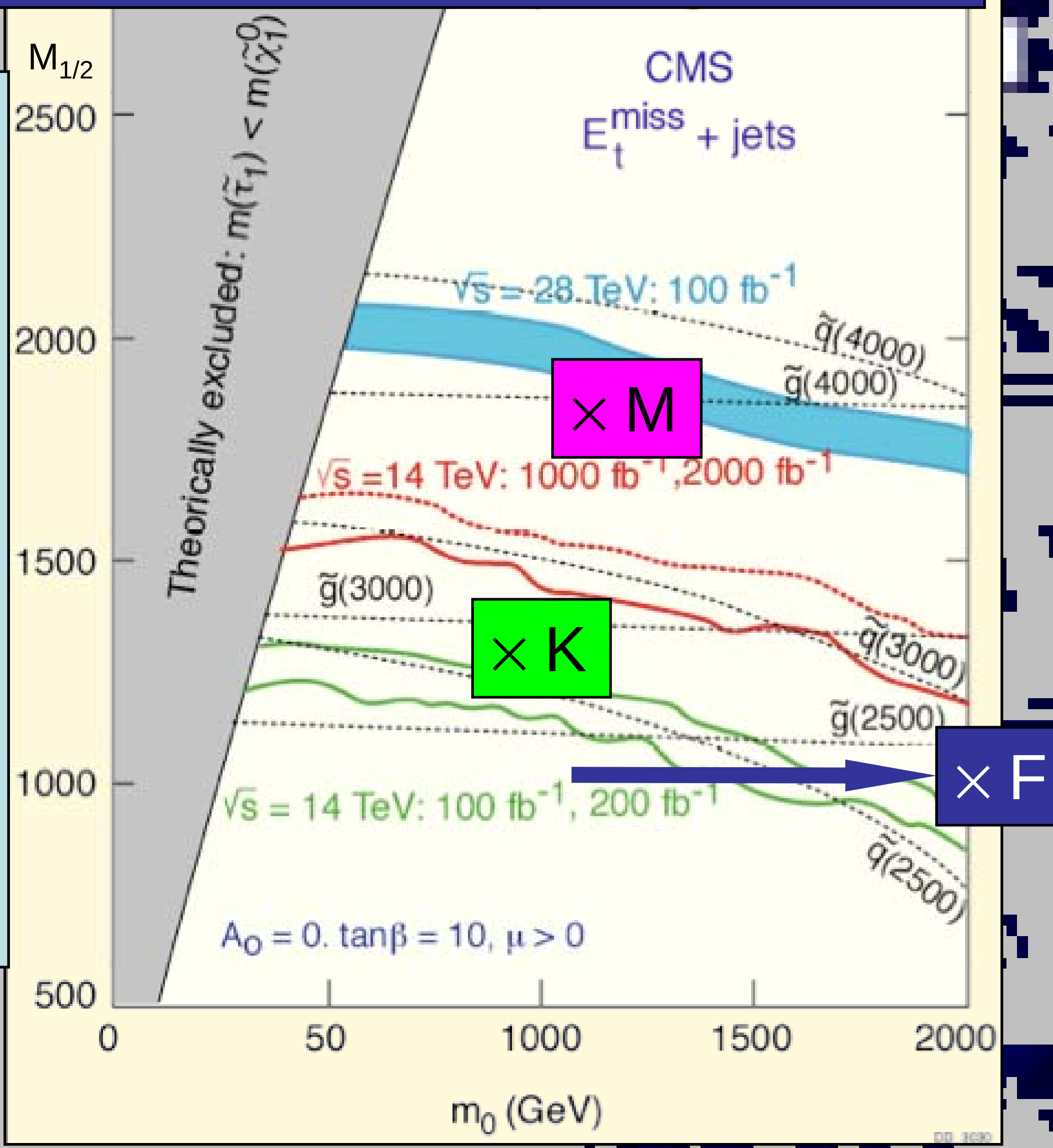
- Most of region allowed by accelerators, cold dark matter can be explored by LHC



- Some benchmark points difficult/impossible

Reach for Supersymmetry

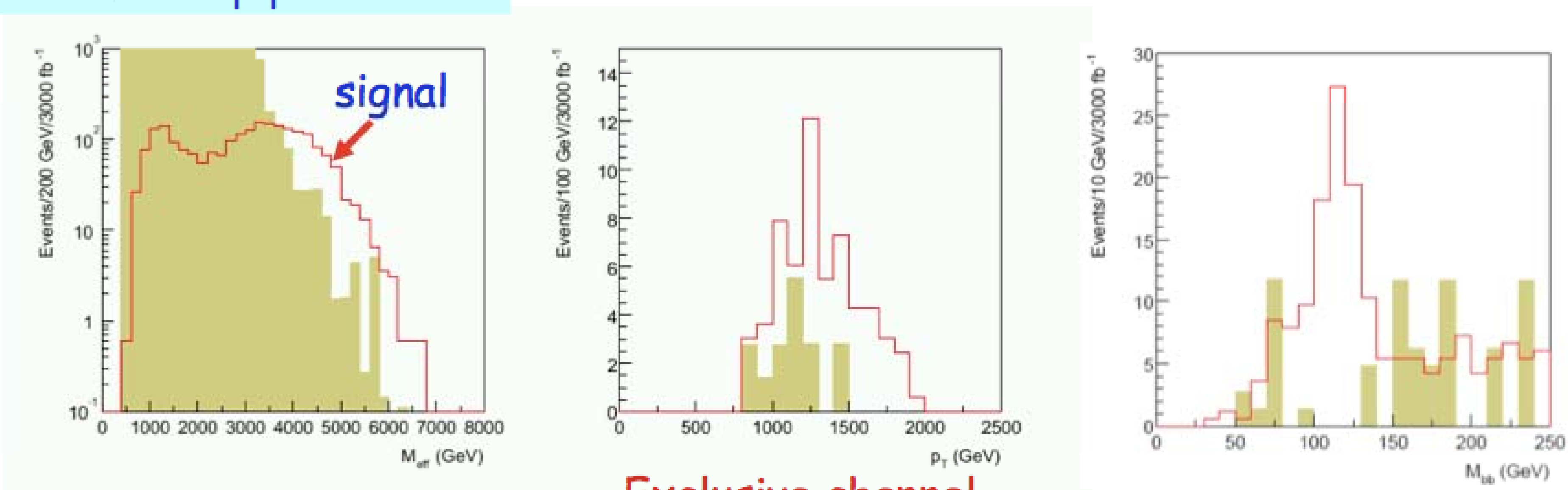
- LHC reaches squarks, gluinos ~ 2.5 TeV
- Does not cover all dark matter region
- SLHC could reach squarks, gluinos ~ 3.0 TeV



High-Mass SUSY @ SLHC

- Preliminary studies of LHC-unfriendly point

Point K in hep-ph/0306219



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

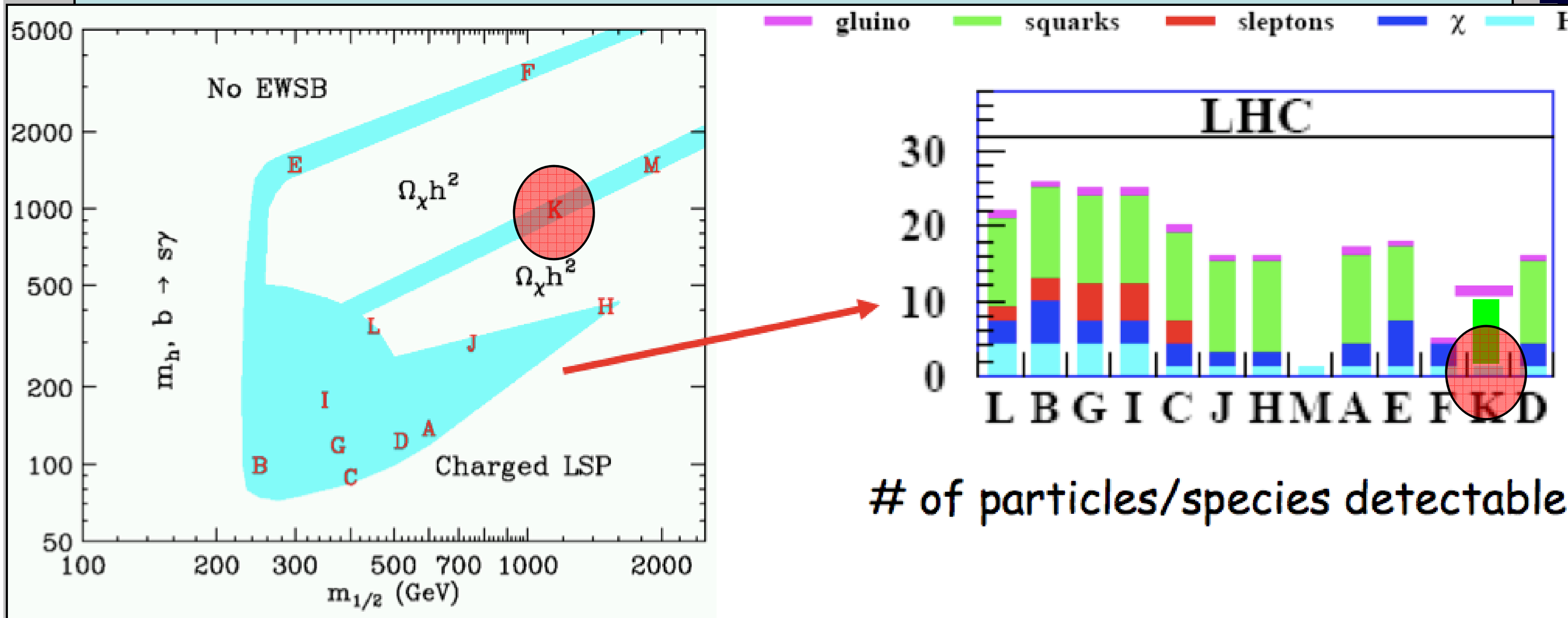
Exclusive channel
$\tilde{q}\tilde{q} \to \chi_1^0 \chi_1^0 qq$
S/B =120/30 (3000fb^{-1})

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

- Detectable @ SLHC

Exploring the SUSY Parameter Space

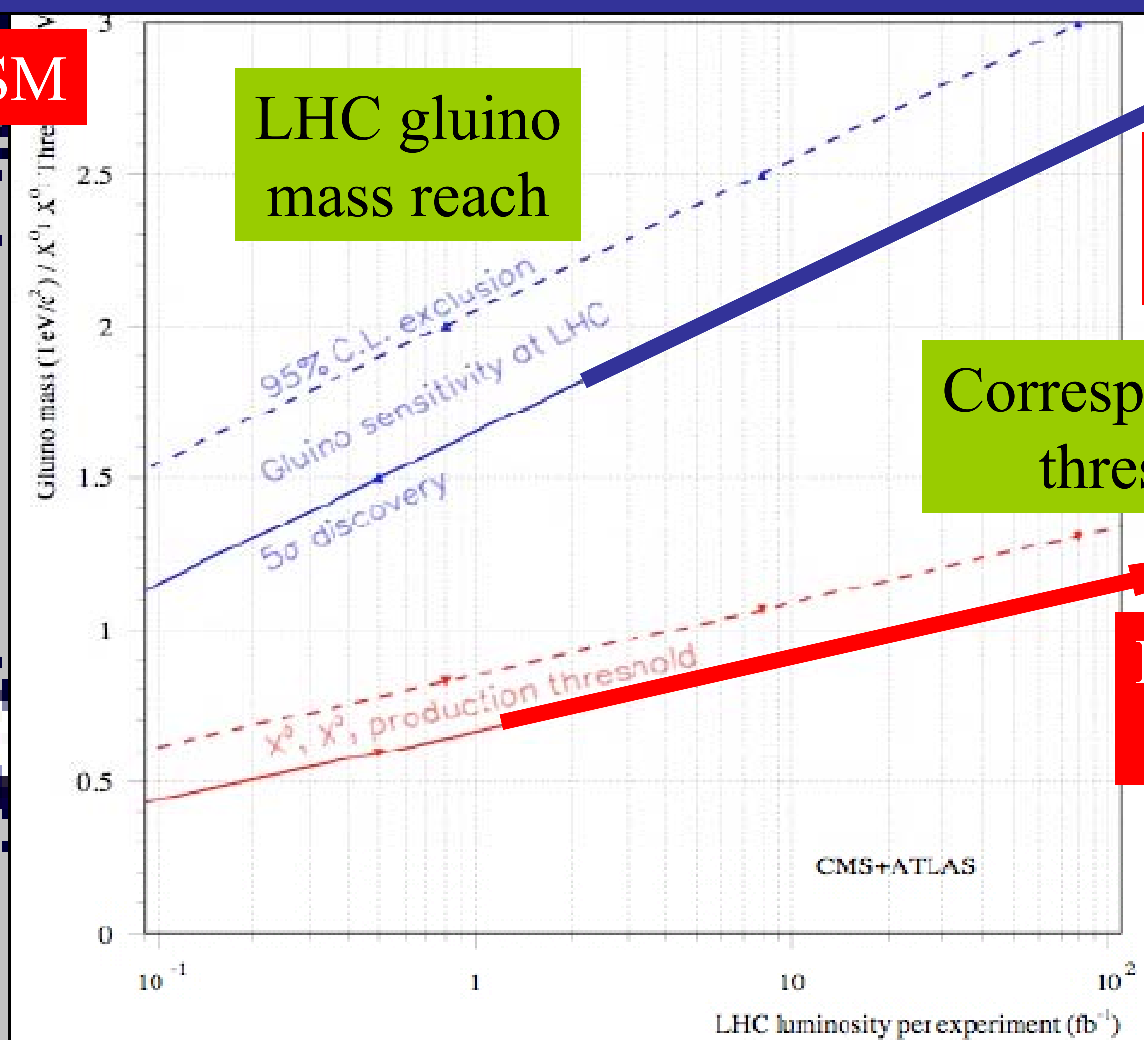
- Most of region allowed by accelerators, cold dark matter can be explored by LHC



- Some benchmark points detectable @SLHC

Implications of LHC Search for LCs

In CMSSM



LHC gluino mass reach

SLHC reach ~ CLIC

Corresponding sparticle thresholds @ LC

LHC will tell ILC where to look

'month' @ 10^{32}	'month' @ 10^{33}	1 'year' @ 10^{33}	1 'year' @ 10^{34}

Blaising, JE et al: 2006

Search for MSSM Higgses @ SLHC

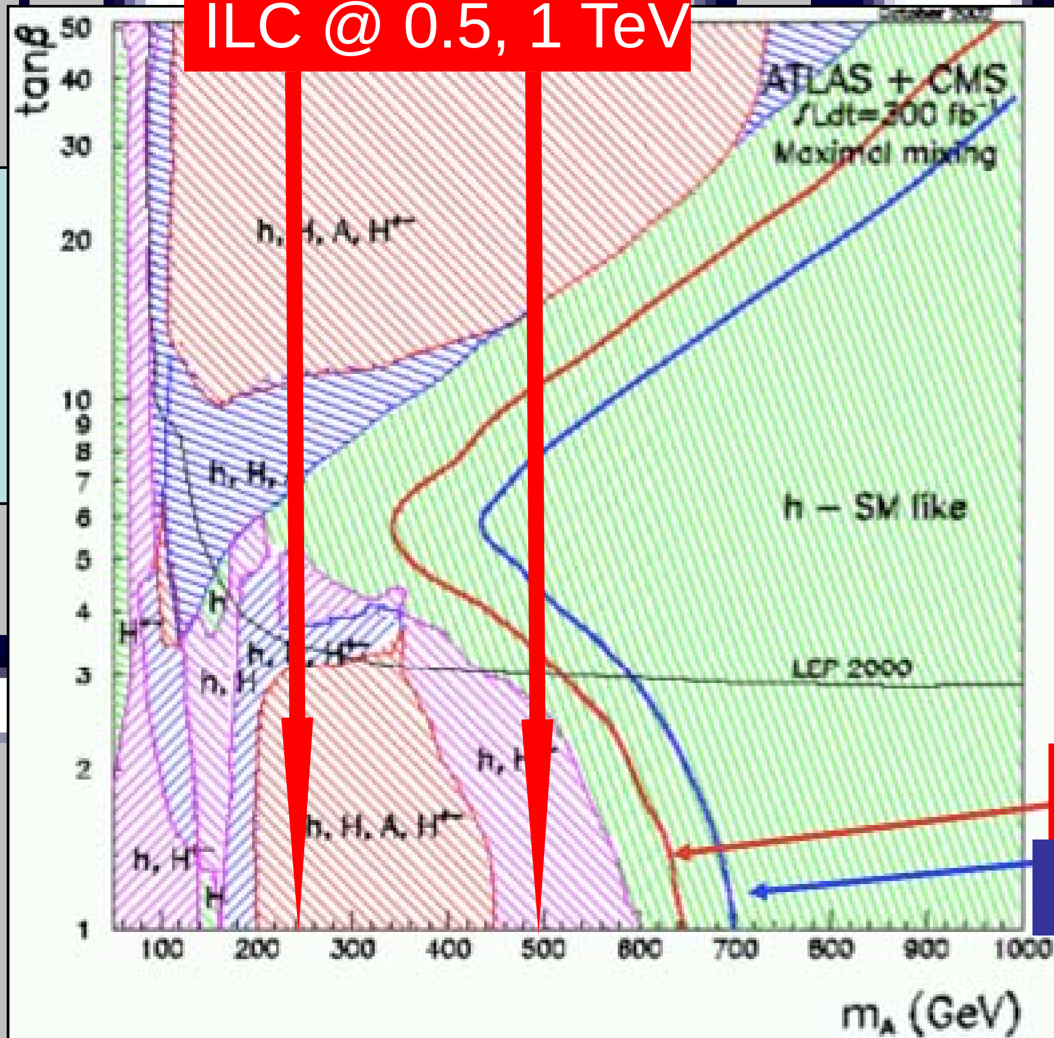
LHC

vs

vs

ILC 0.5

ILC @ 0.5, 1 TeV



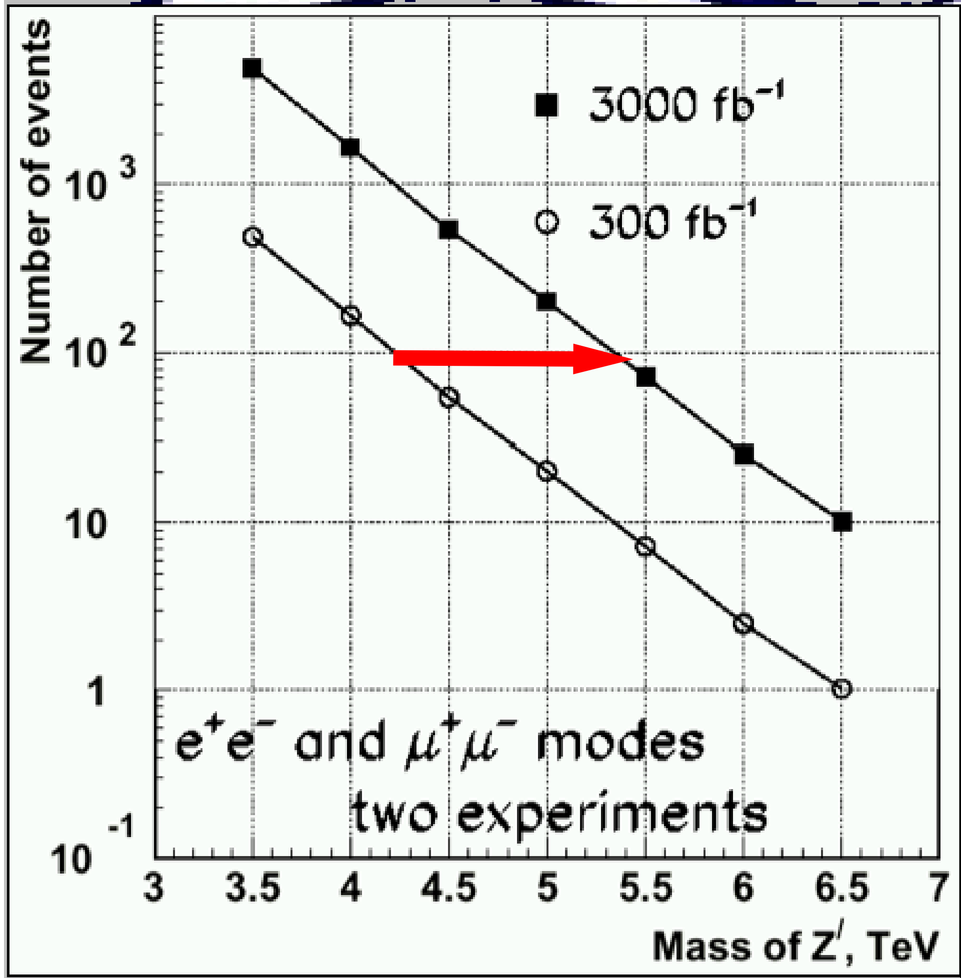
SLHC

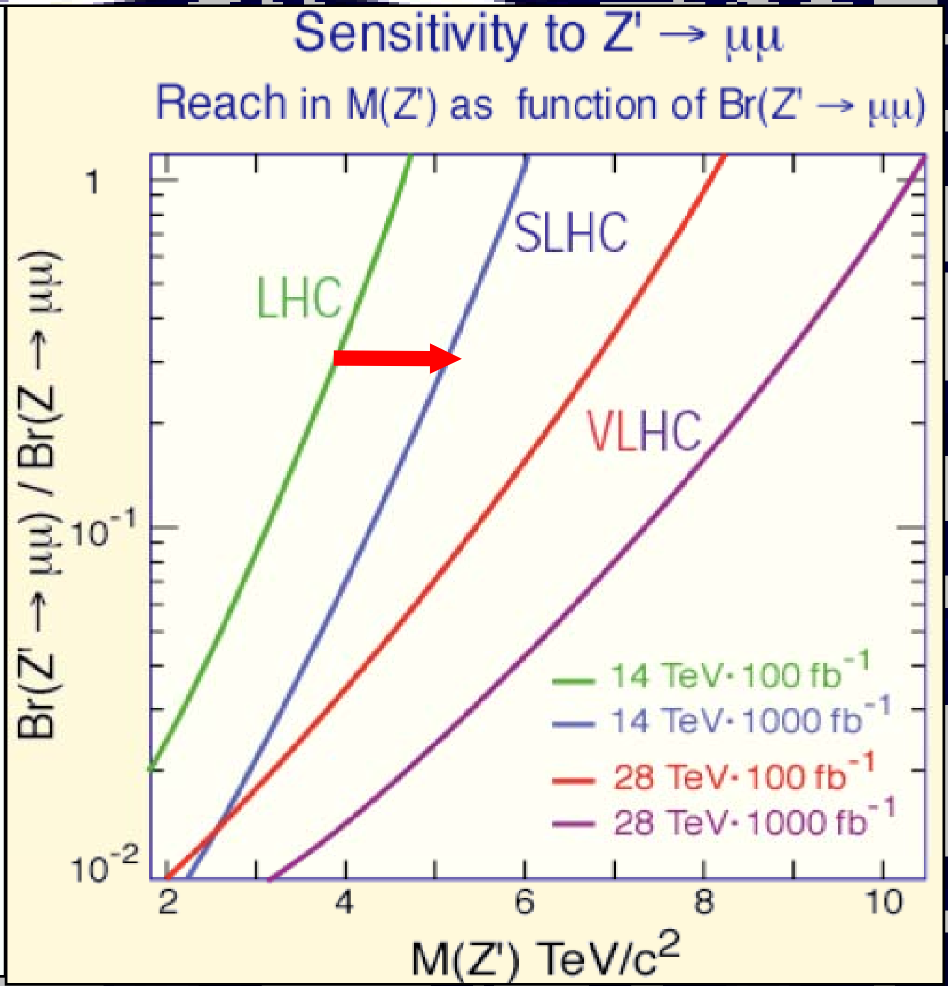
ILC 1.0

5-σ discovery

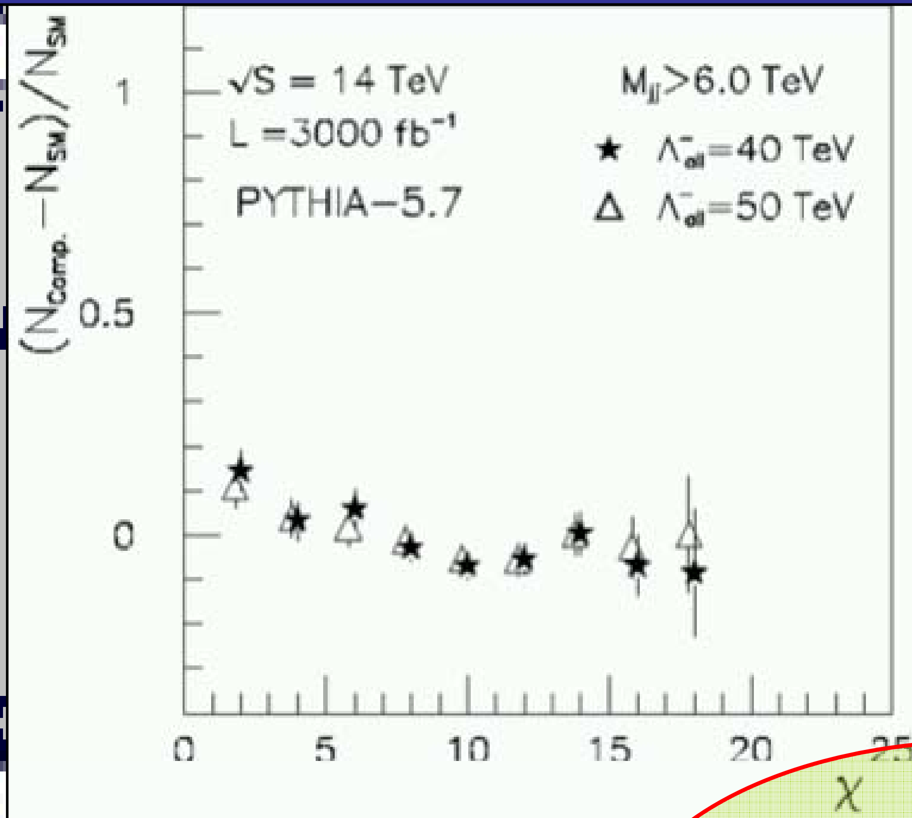
95% exclusion

Sensitivity to a Heavy Z’ Boson





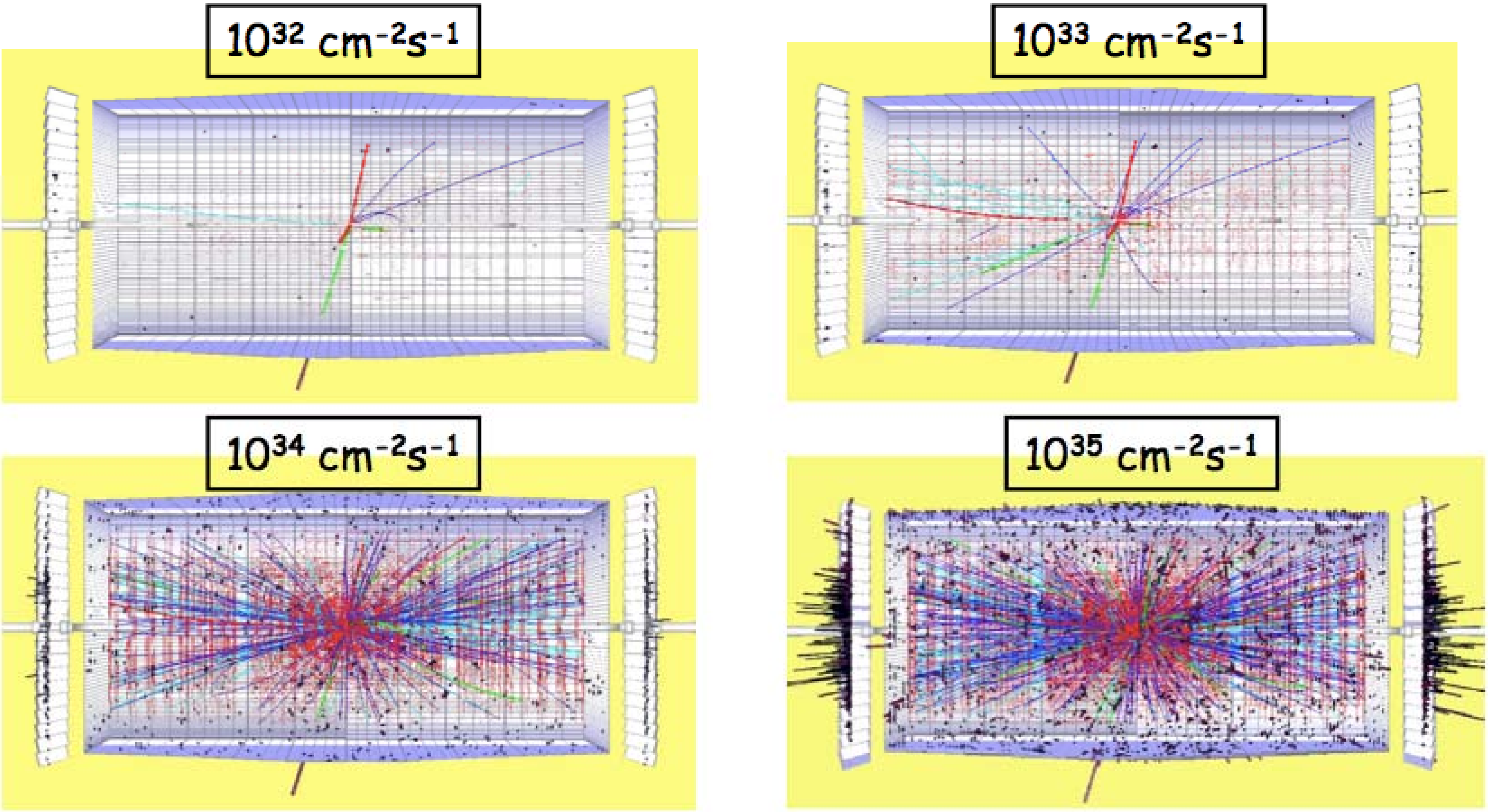
Sensitivity to Compositeness @ SLHC



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

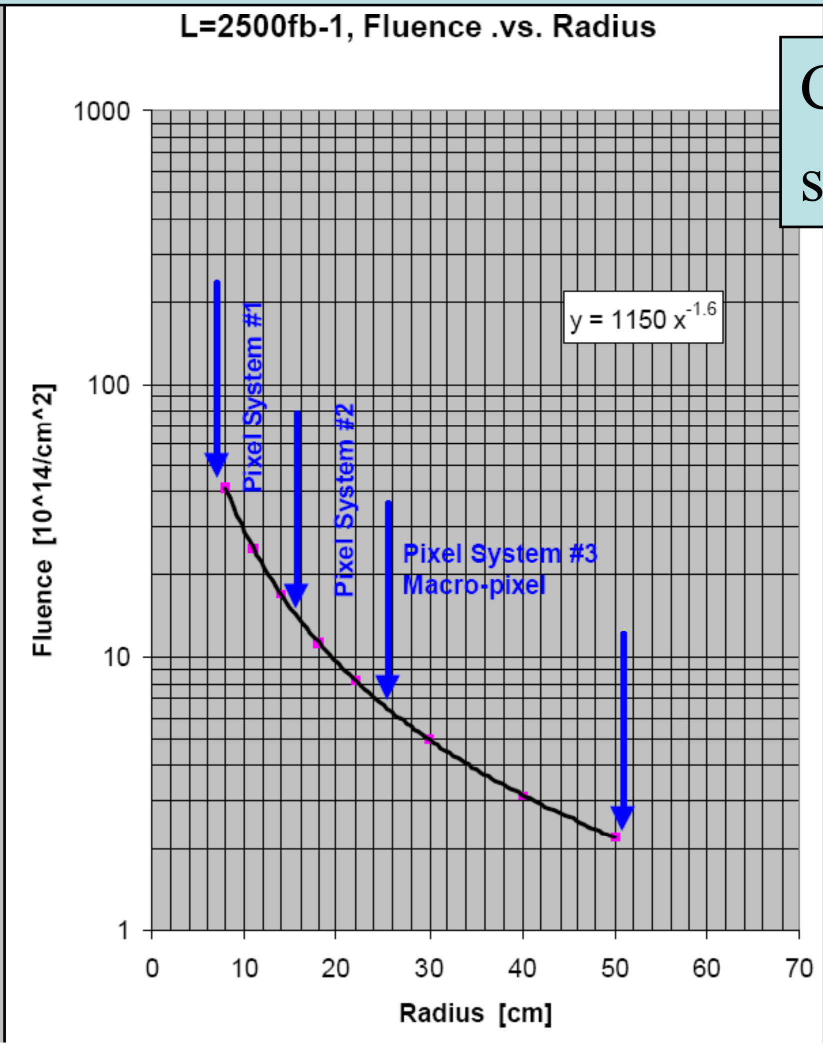
Pile-up at Different Luminosities

$H \rightarrow ZZ \rightarrow \mu\mu ee$ event with M_H= 300 GeV for different luminosities

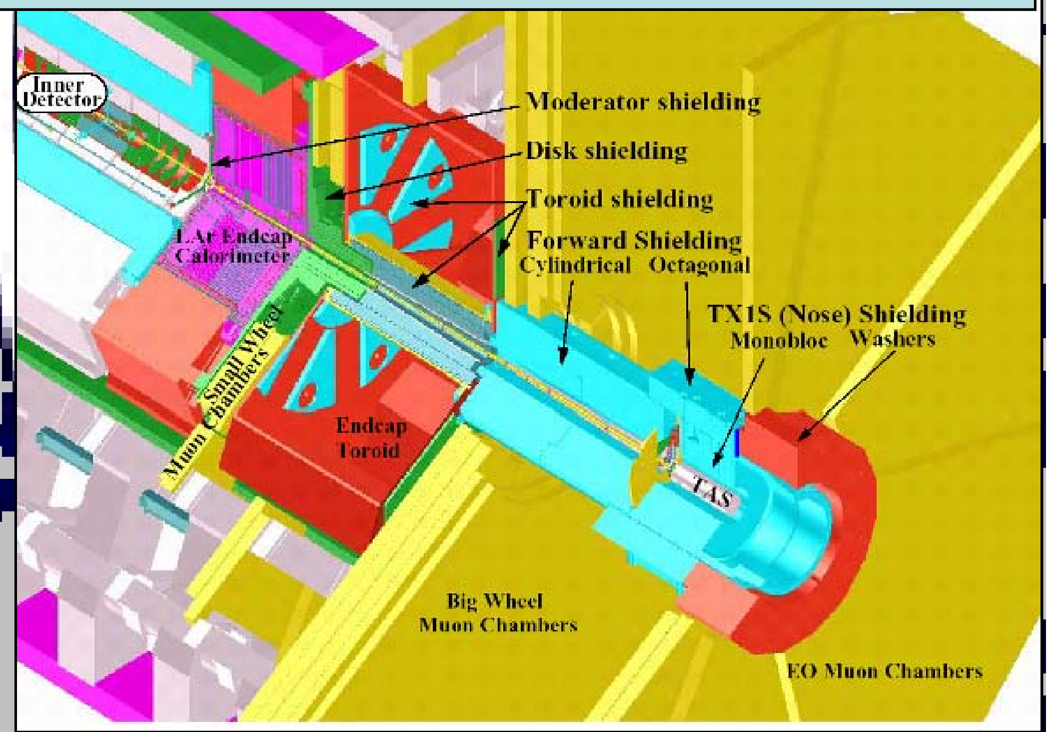


Detector Issues for the SLHC

High radiation in central tracker



Congested layout in forward direction: space for new low-β* machine elements?



General SLHC Detector Issues

Object	Physics benchmark	Performance benchmark	Detector issue
b jets & tau	Higgs identification, BR measurements	Tagging efficiency vs purity (statistics and bg suppression)	Tracking Pileup
b jets	Higgs mass determination, bg suppression	Mass resolution in the ~ 1-few x 100 GeV region	Pileup
fwd jets	Vector boson fusion: - measure H couplings - if no H, search strong WW phenomena	- jet tagging efficiency/fake rate vs jet E_T - jet E_T resolution	Final focus magnets: - acceptance - bg - resolution Pileup
cen jets	Jet vetoes for vector boson fusion	fake rate	Pileup
	Mass spectroscopy	mass resolution	Pileup
electrons	W/Z ID, SUSY decays, etc W'/Z' properties	ID efficiency vs fake rate	Pileup
muons	W/Z ID, SUSY and H decays, W'/Z' properties, etc.	Forward acceptance, fake rate	albedo forward efficiency final focus geometry

SLHC Physics Reach Compared

Only a few examples …. in many cases numbers are just indications ….

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

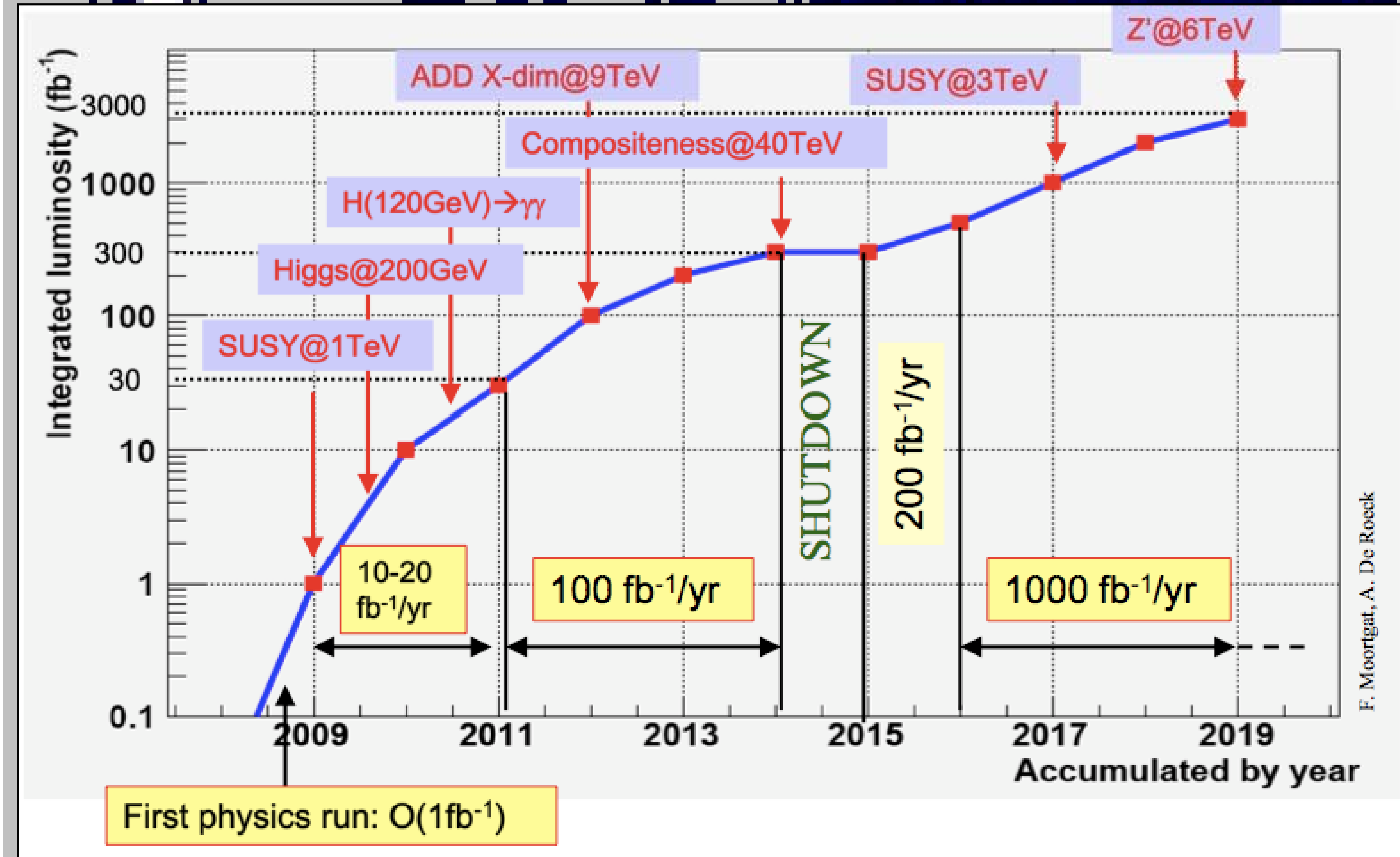
PROCESS	LHC 14 TeV 100 fb^{-1}	SLHC 14 TeV 1000 fb^{-1}	28 TeV 100 fb^{-1}	VLHC 40 TeV 100 fb^{-1}	VLHC 200 TeV 100 fb^{-1}	LC 0.8 TeV 500 fb^{-1}	CLIC 5 TeV 1000 fb^{-1}
Squarks	2.5	3	4	5	20	0.4	2.5
W_LW_L	2σ	4σ	4.5σ	7σ	18σ	6σ	90σ
Z'	5	6	8	11	35	8†	30†
Extra-dim (δ=2)	9	12	15	25	65	5-8.5†	30-55†
q*	6.5	7.5	9.5	13	75	0.8	5
Λ compositeness	30	40	40	50	100	100	400
TGC λ_γ (95%)	0.0014	0.0006	0.0008		0.0003	0.0004	0.00008

† indirect reach (from precision measurements)

Approximate direct mass reach :

$\sqrt{s}$ = 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
$\sqrt{s}$ = 28 TeV, L=10^{35} : up to ≈ 11 TeV

Dreaming is Compulsory



Conclusions

- The ‘expected’
  - Higgs - but where?
  - Study in detail for more clues
- The ‘expected unexpected’
  - Supersymmetry/extra dimensions
  - Unravelling it will need more data
- The ‘unexpected unexpected’
  - ?????
- Any new physics at the TeV scale will also motivate next step in B physics:
  - ‘Super-LHCb’