Theory Review

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IPPP Durham

Birmingham, 07/2009

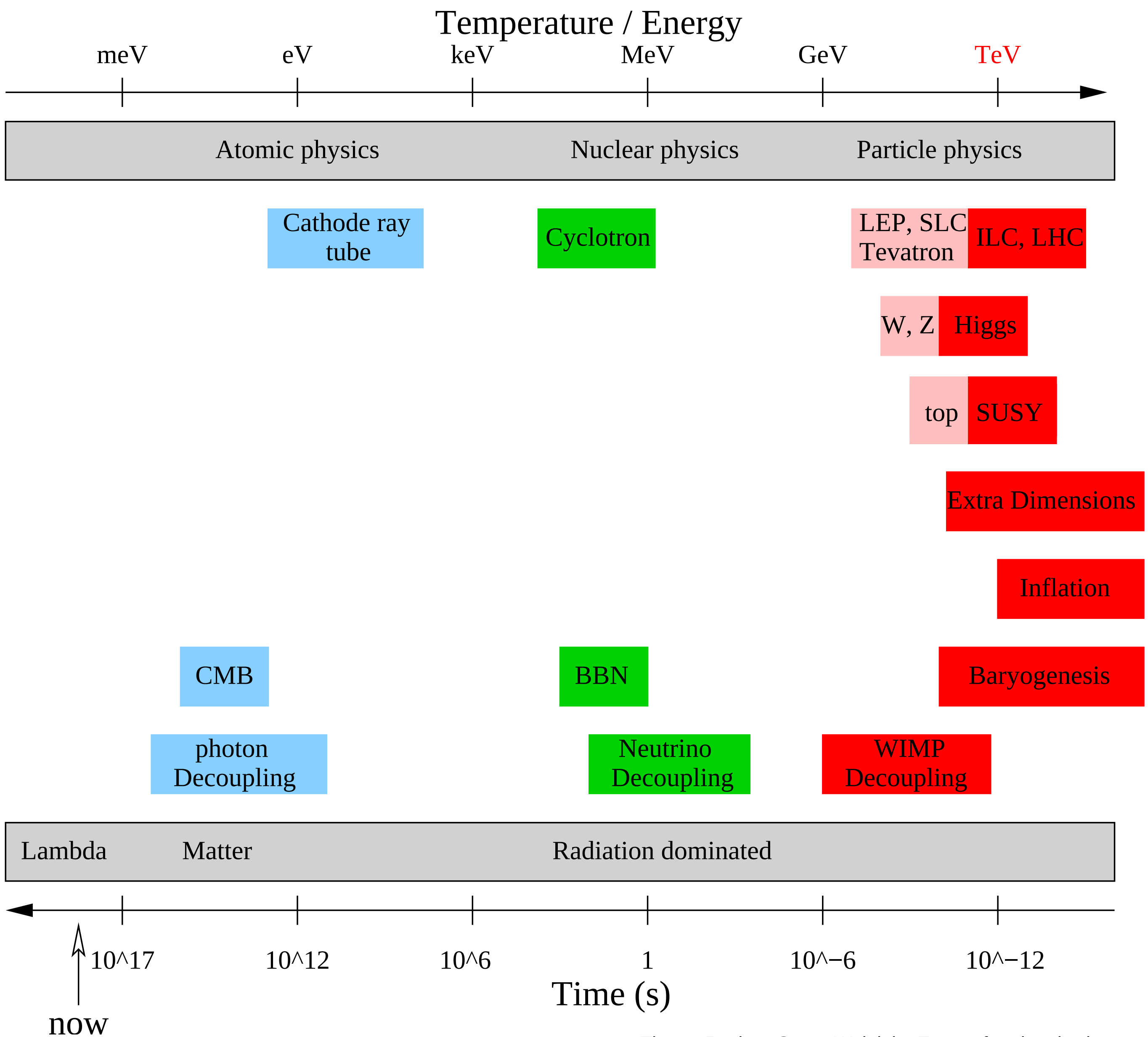
The charge for this talk

- Overview of phenomenology activities in UK
- Set scene for physics objectives over the next 20 years
  $\Rightarrow$ Introduction to the other talks today
- Review developments required in phenomenology to meet needs to enable interpretation of experimental results

Formal theory: [*see talks by Nick Dorey and Jerome Gauntlett*]

On the way to the TeV scale

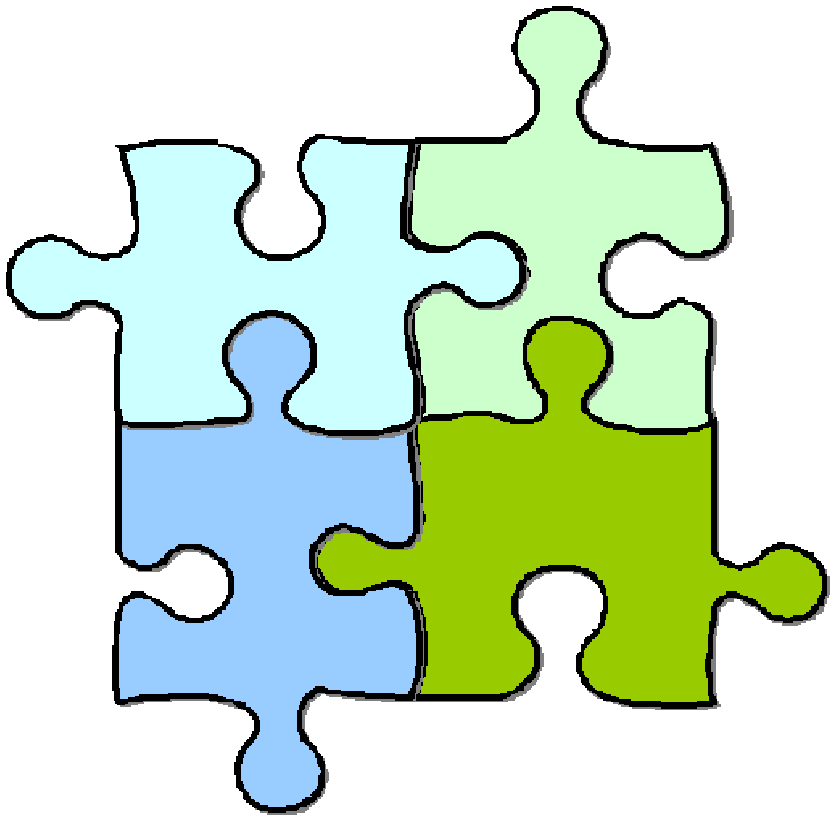
$$1\ \text{TeV} \approx 1000 \times m_{\text{proton}} \Leftrightarrow 2 \times 10^{-19}\ \text{m}$$



The Quantum Universe

Particle
Physics
Experiments
Accelerators
Underground

Quantum
Field
Theory
(Standard
Model)



Astronomy
Experiments
Telescopes
Satellites

Standard
Cosmology
Model

10^{-18} m

10^{26} m

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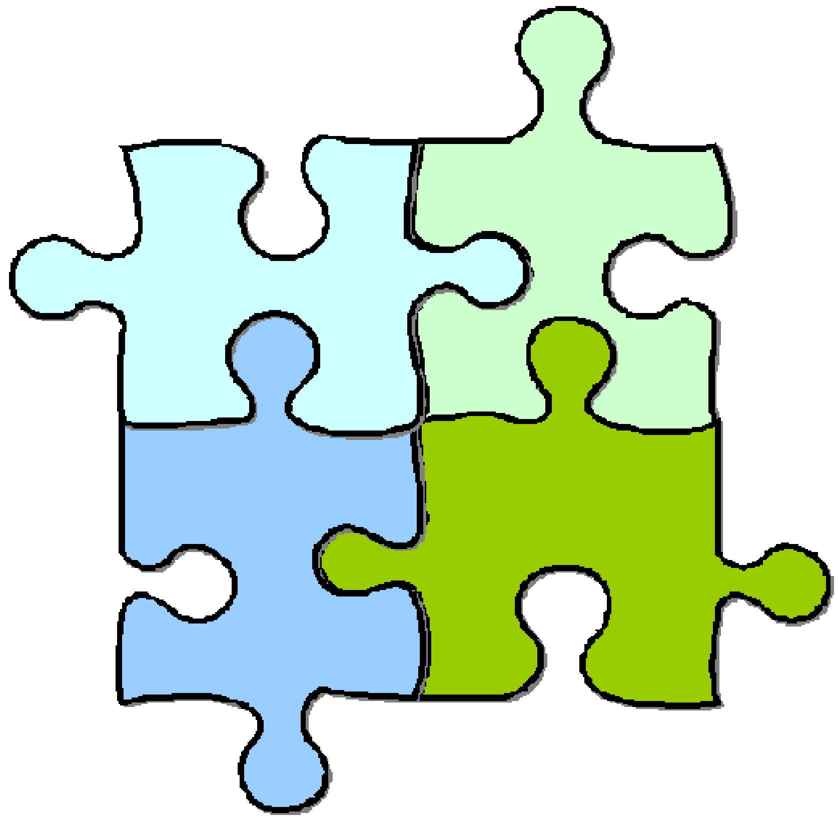

Astronomy Experiments Telescopes Satellites

Standard Cosmology Model

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[*John Womersley, Director of Science Programmes, STFC ’08*]

What can we learn from exploring the new territory of TeV-scale physics?

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- How do elementary particles obtain the property of mass: what is the mechanism of electroweak symmetry breaking?
- Do all the forces of nature arise from a single fundamental interaction?
- Are there more than three dimensions of space?
- Are space and time embedded into a “superspace”?
- What is dark matter? Can it be produced in the laboratory?
- ...

Probing the electroweak symmetry breaking mechanism at the TeV scale

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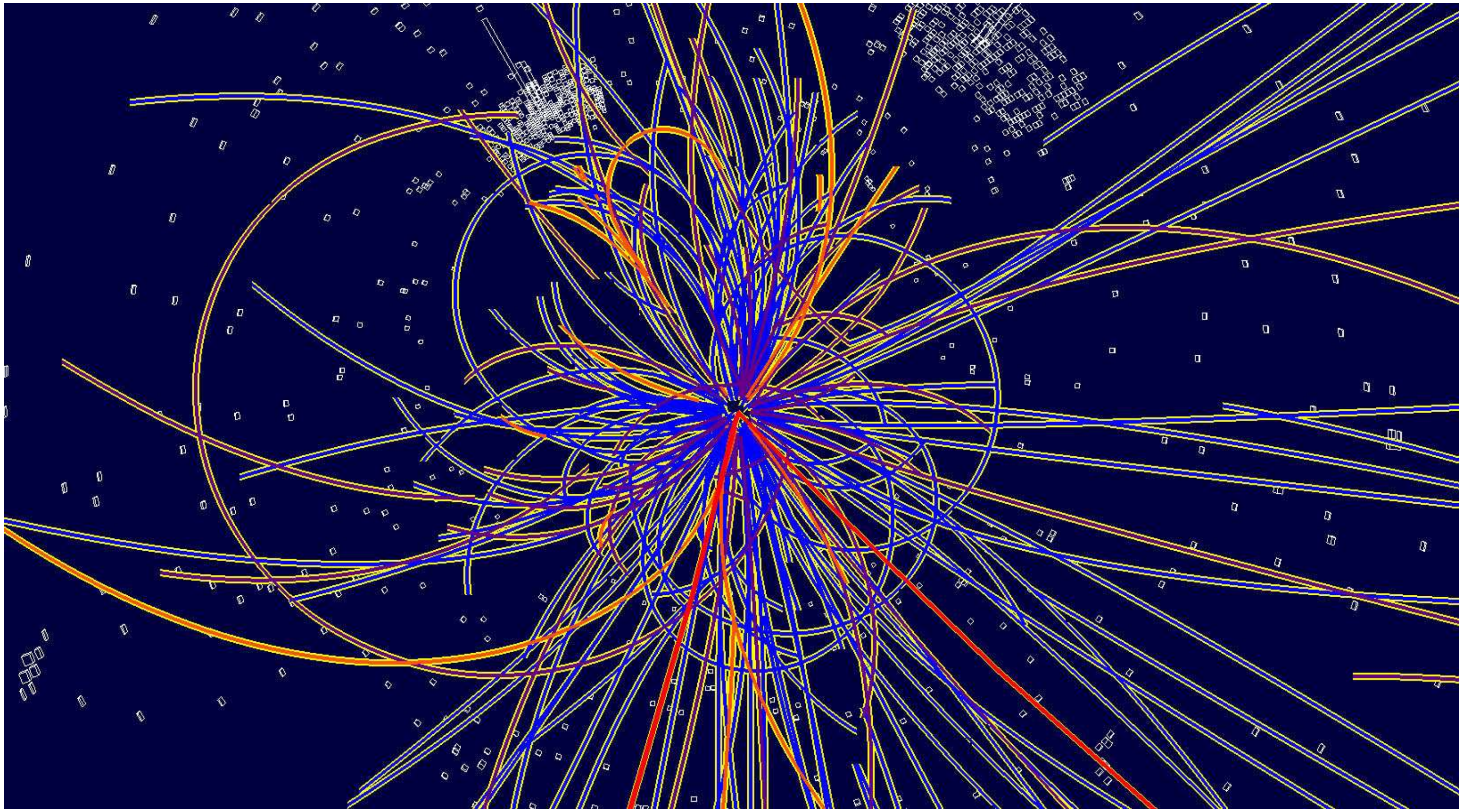
$\Rightarrow$ The mechanism of electroweak symmetry breaking will manifest itself at the TeV scale



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- Higgsless models in extra dimensions: boundary conditions for SM gauge bosons and fermions on Planck and TeV branes in higher-dimensional space

$\Rightarrow$ New phenomena required at the TeV scale

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  $\Rightarrow$ Would expect that all physics is driven up to the Planck scale

- Nature has found a way to prevent this
  The Standard Model provides no explanation

Hierarchy problem: how can the Planck scale be so much larger than the weak scale?

$\Rightarrow$ Expect new physics to stabilise the hierarchy

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Large corrections cancel out because of symmetry
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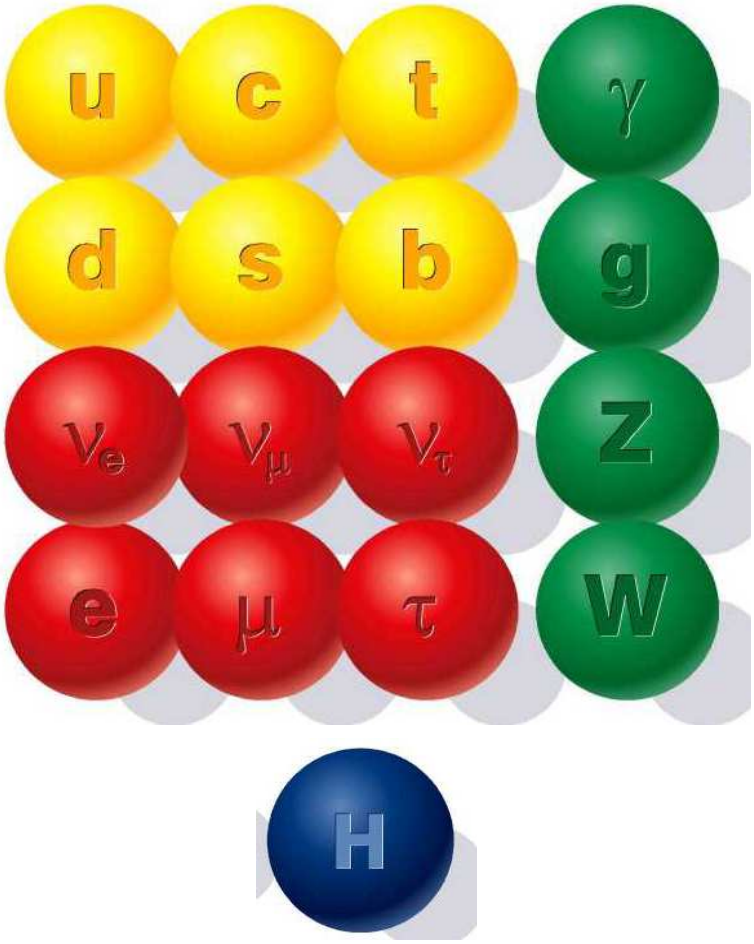
Extra dimensions of space:

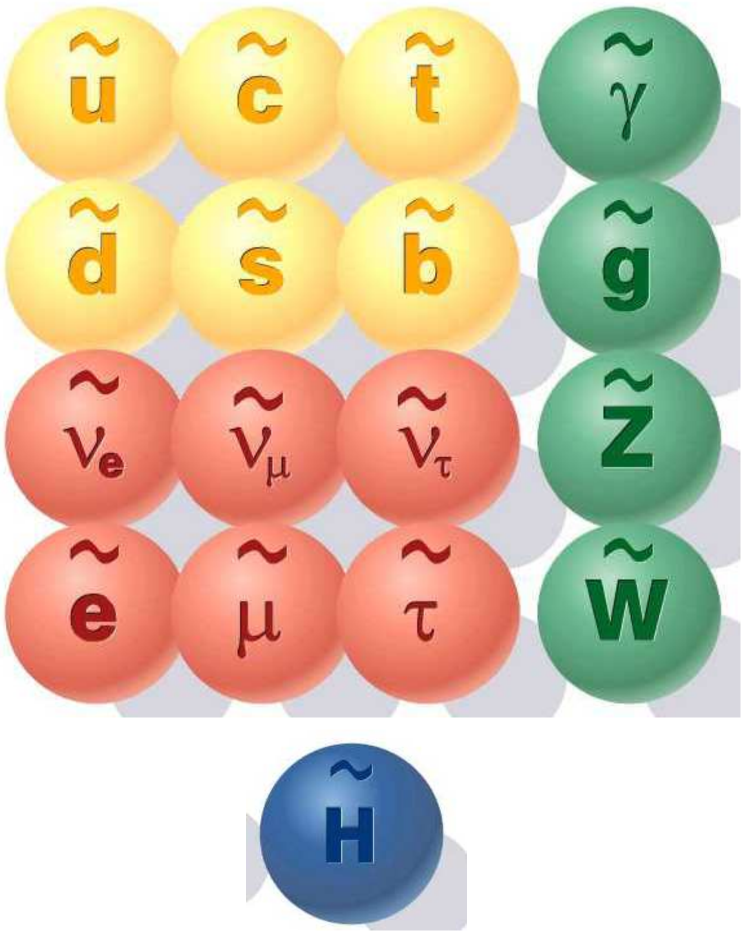
Fundamental Planck scale is $\sim \mathrm{TeV}$ (large extra dimensions),

hierarchy of scales is related to a “warp factor”
(“Randall–Sundrum” scenarios)

Supersymmetry (SUSY)

Supersymmetry: fermion $\longleftrightarrow$ boson symmetry,
leads to compensation of large quantum corrections





The Minimal Supersymmetric Standard Model (MSSM)

Superpartners for Standard Model particles:

$$\left[u, d, c, s, t, b\right]_{L,R} \quad \left[e, \mu, \tau\right]_{L,R} \quad \left[\nu_{e,\mu,\tau}\right]_L \qquad \text{Spin } \tfrac{1}{2}$$

$$\left[\tilde{u}, \tilde{d}, \tilde{c}, \tilde{s}, \tilde{t}, \tilde{b}\right]_{L,R} \quad \left[\tilde{e}, \tilde{\mu}, \tilde{\tau}\right]_{L,R} \quad \left[\tilde{\nu}_{e,\mu,\tau}\right]_L \qquad \text{Spin } 0$$

$$g \quad \underbrace{W^{\pm}, H^{\pm}} \quad \underbrace{\gamma, Z, H_1^0, H_2^0} \qquad \text{Spin } 1 \text{ / Spin } 0$$

$$\tilde{g} \qquad \tilde{\chi}^{\pm}_{1,2} \qquad \tilde{\chi}^{0}_{1,2,3,4} \qquad \text{Spin } \frac{1}{2}$$

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Two Higgs doublets, physical states: $h^0, H^0, A^0, H^{\pm}$

General parametrisation of possible SUSY-breaking terms
$\Rightarrow$ free parameters, no prediction for SUSY mass scale

Hierarchy problem $\Rightarrow$ expect observable effects at TeV scale

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Gauge coupling unification, $M_{\rm GUT} \sim 10^{16}$ GeV
neutrino masses: see-saw scale $\sim .01$–$.1\,M_{\rm GUT}$

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Strong phenomenological constraints on flavour off-diagonal and $\mathcal{CP}$-violating SUSY-breaking terms

$\Rightarrow$ Good phenomenological description for universal SUSY-breaking terms ($\approx$ diagonal in flavour space)

Simplest ansatz: the Constrained MSSM (CMSSM)

Assume universality at high energy scale ($M_{\rm GUT}$, $M_{\rm Pl}$, ...)
renormalisation group running down to weak scale
require correct value of $M_{\rm Z}$

$\Rightarrow$ CMSSM characterised by

$$m_0^2,\ m_{1/2},\ A_0,\ \tan\beta,\ \mathrm{sign}\,\mu$$

CMSSM is in agreement with all experimental constraints:
Electroweak precision observables (EWPO) $+$ flavour physics $+$ cold dark matter density $+$ ...

SUSY-breaking scenarios

“Hidden sector”: $\longrightarrow$ Visible sector:

SUSY breaking MSSM

“Gravity-mediated”: SUGRA

“Gauge-mediated”: GMSB

“Anomaly-mediated”: AMSB

...

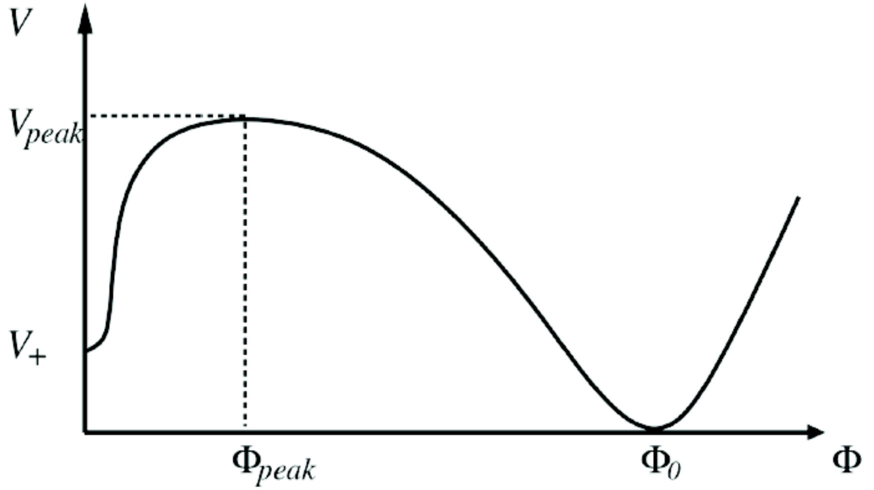
SUGRA: mediating interactions are gravitational

GMSB: mediating interactions are ordinary electroweak and QCD gauge interactions

AMSB: SUSY breaking happens on a different brane in a higher-dimensional theory

Do we live in a meta-stable vacuum?

Suppose we live in a SUSY-breaking meta-stable vacuum, while the global minimum has exact SUSY

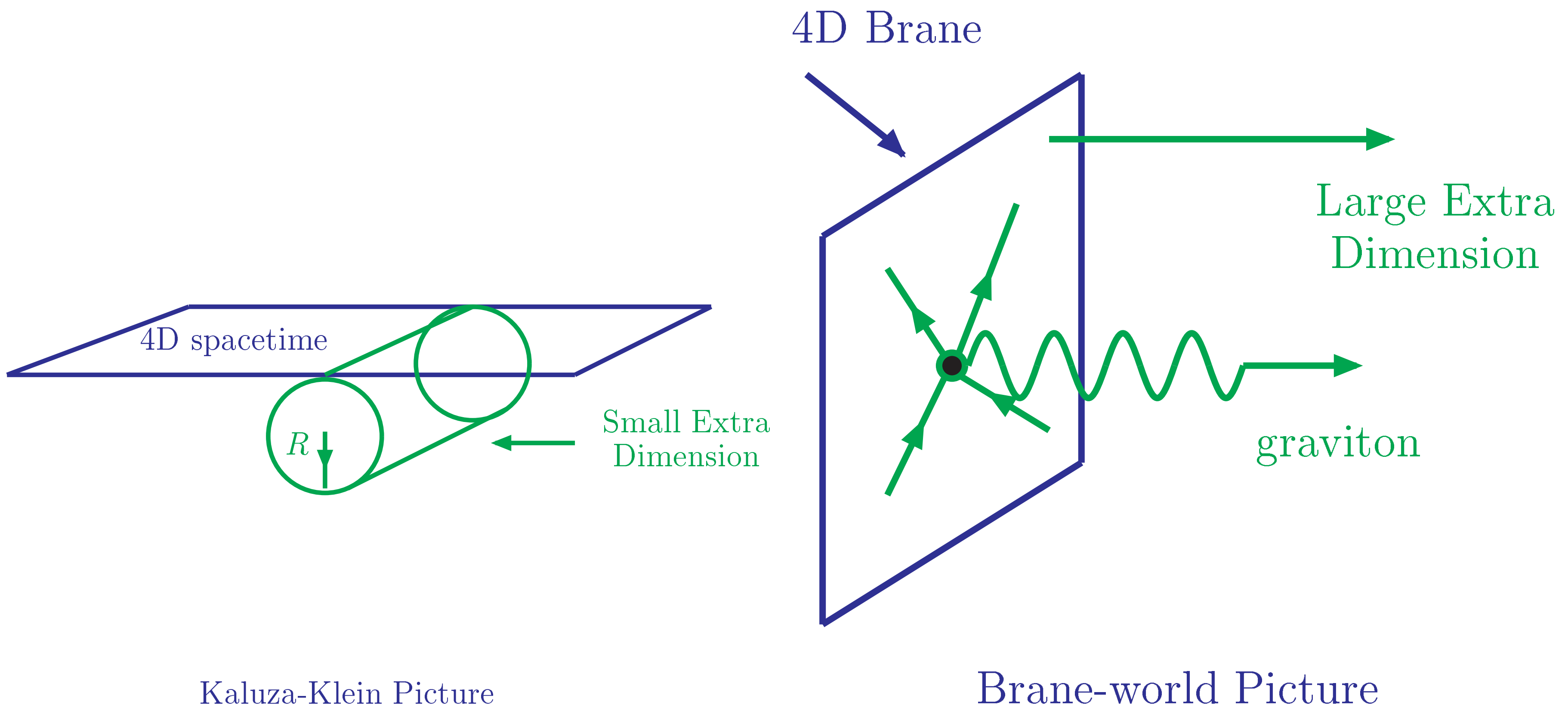


Recent developments: meta-stable vacua arise as generic feature of SUSY QCD with massive flavours

Meta-stable SUSY-breaking vacua are "generic" in local SUSY / string theory, can have cosmologically long life times [*K. Intriligator, N. Seiberg, D. Shih '06*], . . .

$\Rightarrow$ Large activity in model building, significant UK involvement

Models with extra dimensions of space

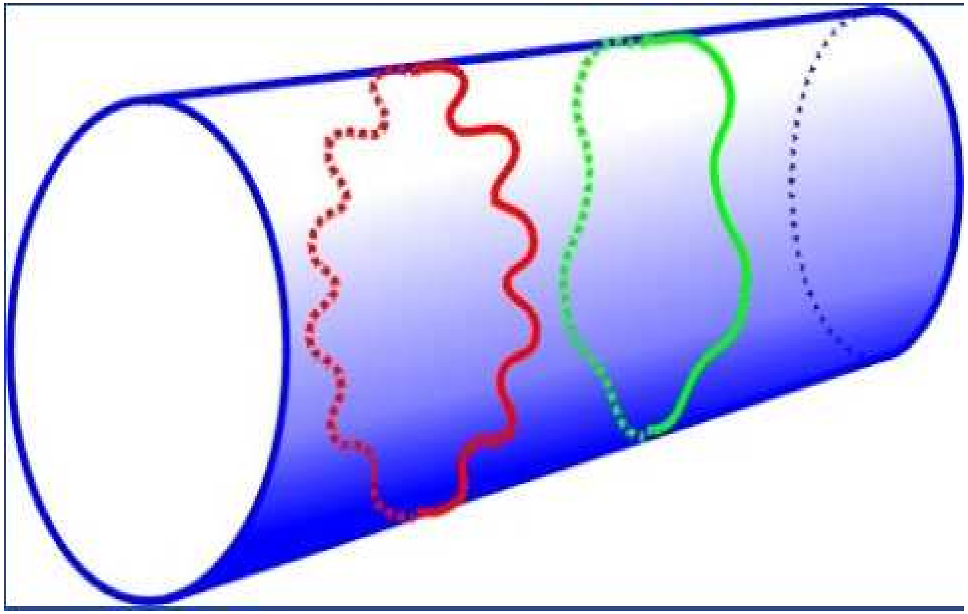


Hierarchy between M_{Planck} and M_{weak} is related to the volume or the geometrical structure of additional dimensions of space

$\Rightarrow$ observable effects at the TeV scale

Phenomenological consequences of extra dimensions

The wave function of a free particle must be $2\pi R$ periodic



$$e^{ip.x_5} = e^{ip.(x_5+2\pi R)}$$

$$p = \frac{n}{R}$$

$\Rightarrow$ momentum is quantised

$\Rightarrow$ Looks in 4-dim like a series of new, more massive partners associated with each known particle: “Kaluza–Klein tower”

Phenomenological consequences of extra dimensions

We may be trapped on a $(3+1)$-dimensional brane in a higher-dimensional space-time, while gravity can enter the extra dimensions

Extra dimensions could be large, even infinite

$\Rightarrow$ Could explain the apparent weakness of gravity in our 4-dimensional world

$\Rightarrow$ At the LHC, gravitons could be emitted into the extra dimensions

$\Rightarrow$ "missing energy" signals

If gravity is strong at the TeV scale, particle collisions at the LHC may form "mini black holes"

"Known unknowns" vs. "unknown unknowns"

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Maybe phenomenology at the TeV scale is completely different?

- Unparticles
- Hidden valley models
- Composite Higgs models
- Stable exotic (charged) particles
- . . .

Particle Physics – Cosmology connection

Is it possible to measure the properties of dark matter particles at TeV scale colliders and to predict the dark matter relic density in agreement with cosmological constraints and results from direct detection experiments?

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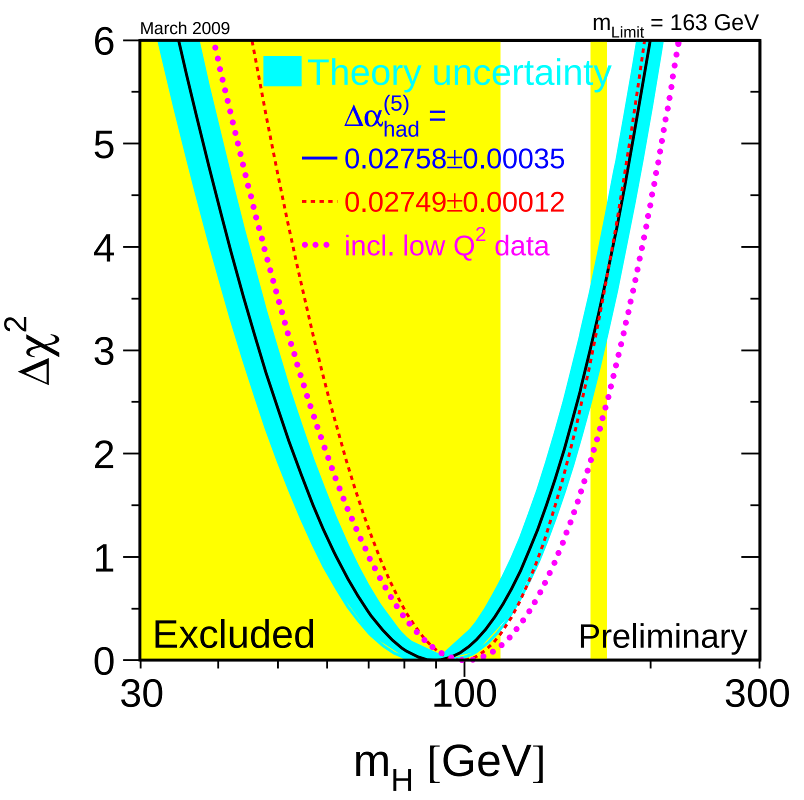
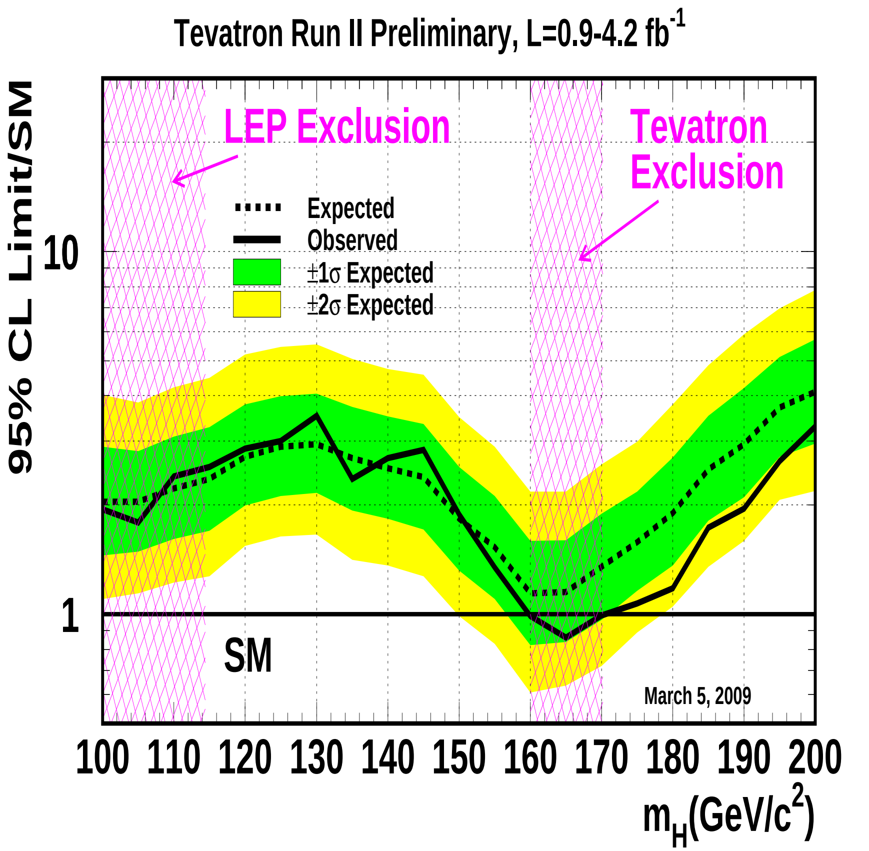
A prediction based on collider data with similar accuracy would enable a sensitive test of the dark matter hypothesis

Prospects for TeV-scale physics: Hints from electroweak precision data?

SM Higgs: ew. prec. data + direct search at LEP & Tevatron

[*LEPEWWG '09*] [*TEVNPH Working Group '09*]

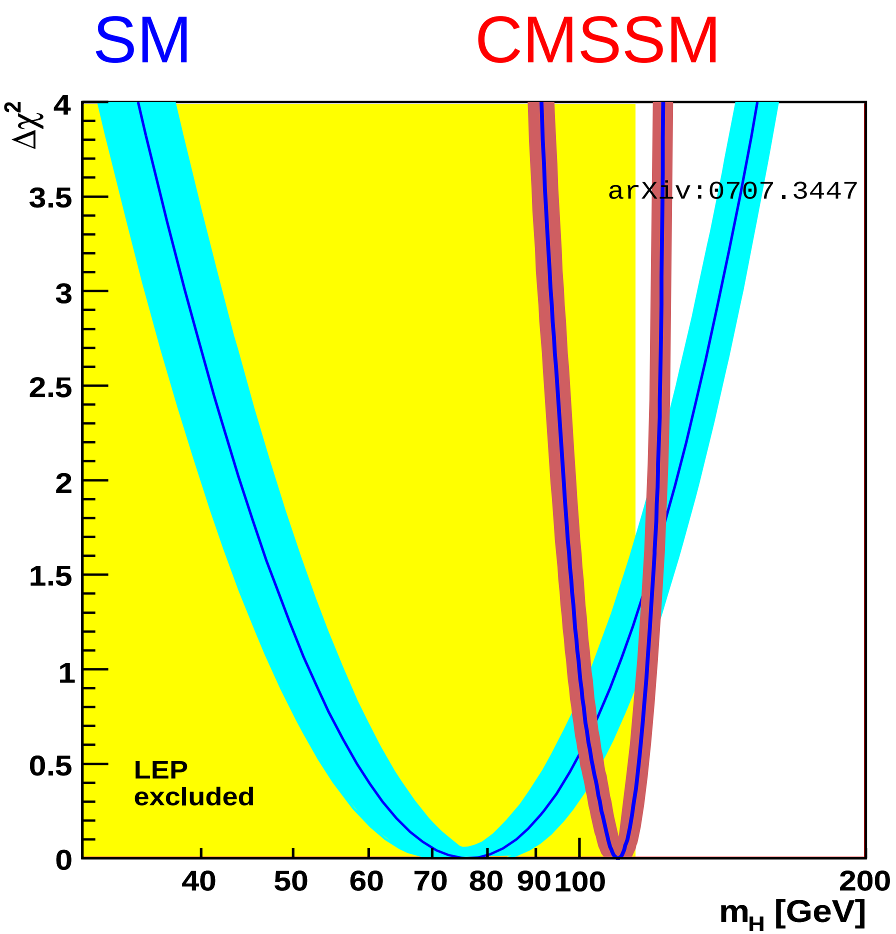




⇒ Preference for a light Higgs

Indirect prediction for the Higgs mass in the SM and the constrained MSSM (CMSSM) from precision data

χ^2 fit for $M_{\rm h}$, without imposing direct search limit [*O. Buchmueller, R. Cavanaugh, A. De Roeck, S. Heinemeyer, G. Isidori, P. Paradisi, F. Ronga, A. Weber, G. W. '07*]



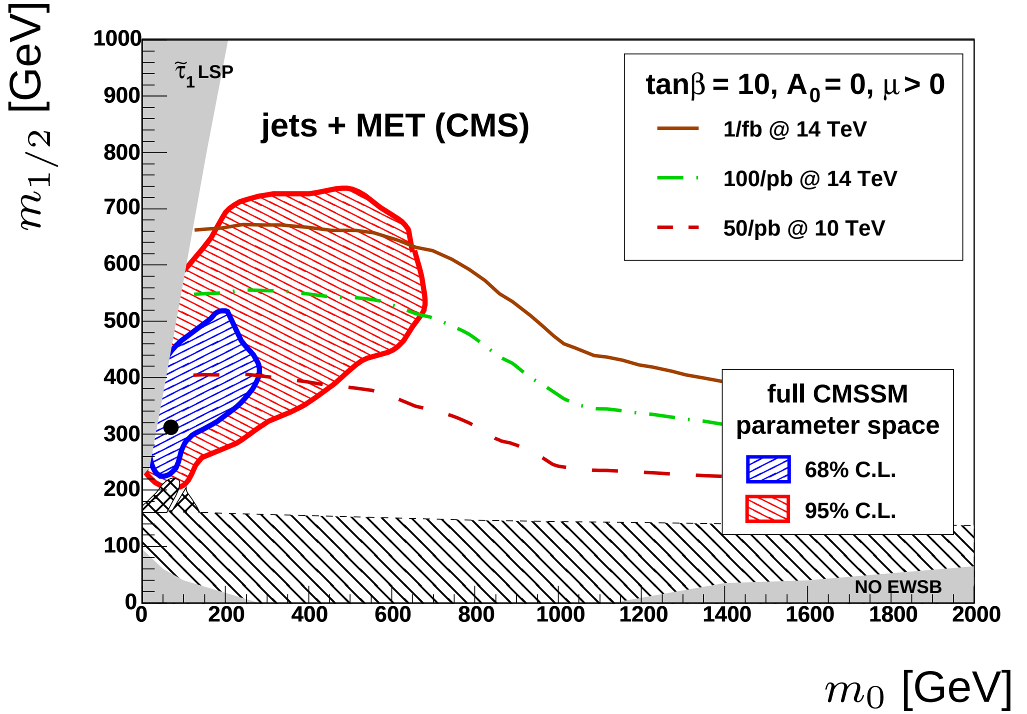
⇒ Accurate indirect prediction; Higgs "just around the corner"?

Predictions for the SUSY scale from precision data

Strong activity in the UK

Comparison: preferred region for the SUSY mass scale vs. LHC discovery reach for $1, 0.1, 0.05\ \mathrm{fb}^{-1}$ of understood data

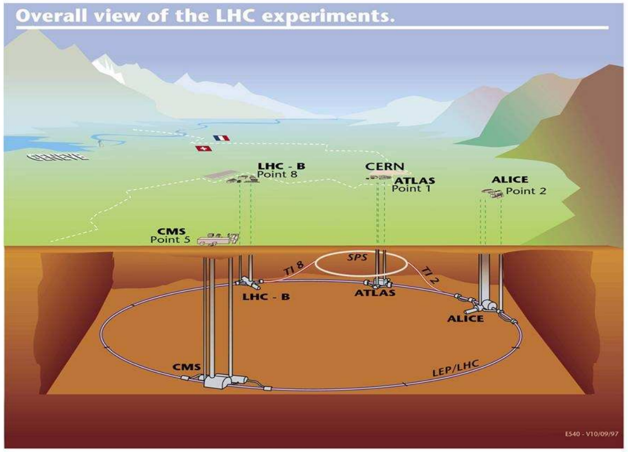
[*O. Buchmueller, R. Cavanaugh, A. De Roeck, J. Ellis, H. Flächer, S. Heinemeyer, G. Isidori, K. Olive, P. Paradisi, F. Ronga, G. W. '08*]

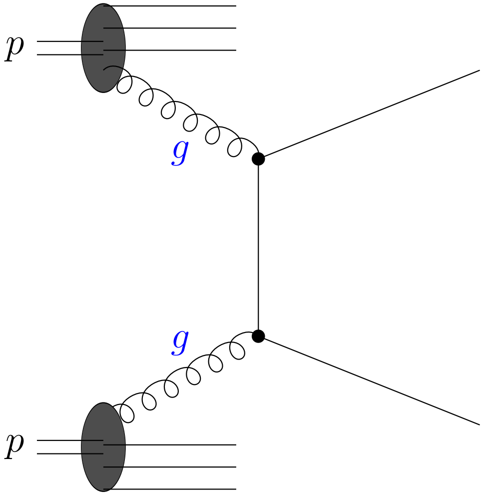


⇒ Preferred region would lead to early discovery

The Large Hadron Collider (LHC)

Proton–proton scattering at $14\,(10)\ \mathrm{TeV}$: composite objects of quarks and gluons, bound together by strong interaction





$\Rightarrow$ Opens up new energy domain

complicated scattering processes

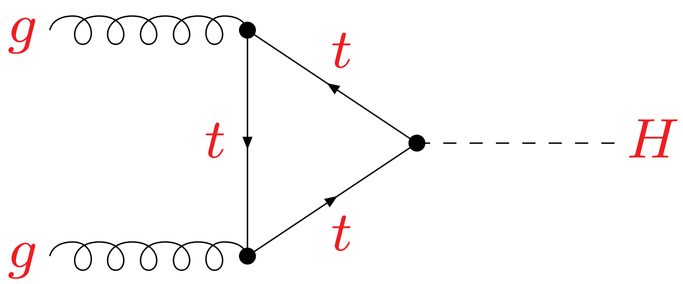
10^9 scattering events$/s$

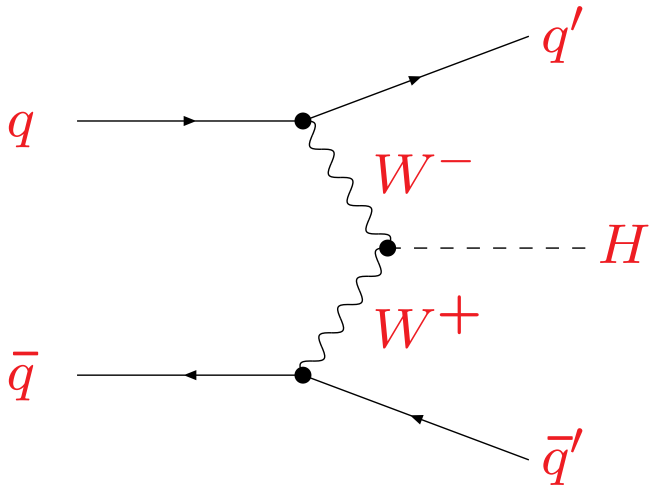
Production of a SM-like Higgs at the LHC

SM Higgs production at the LHC:

Dominant production processes:

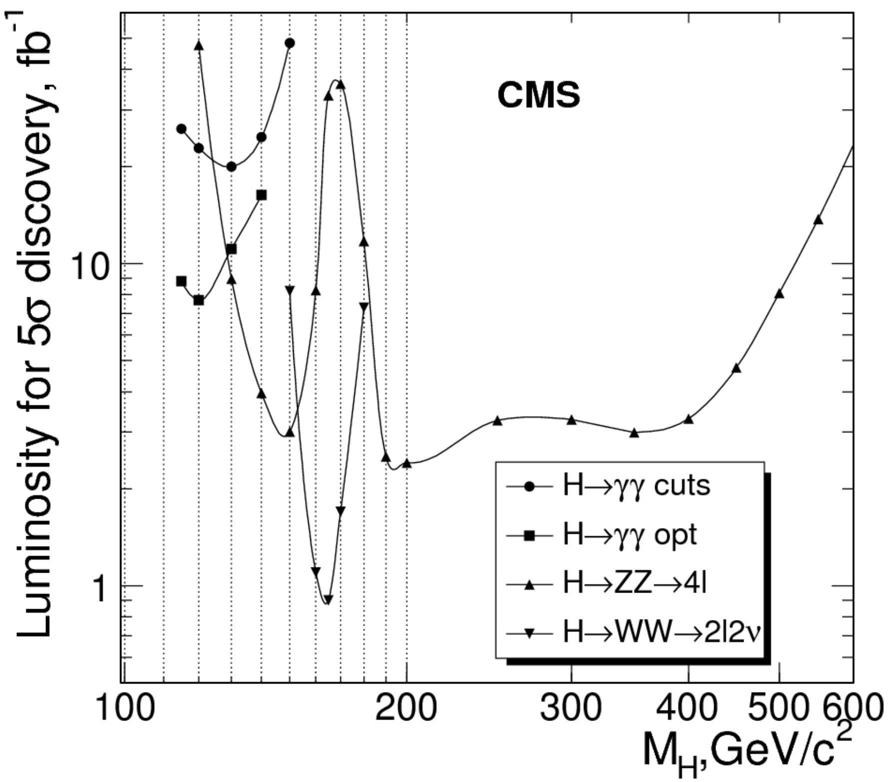
gluon fusion: $gg \to H$, weak boson fusion (WBF): $q\bar{q} \to q'\bar{q}'H$





Search for the SM Higgs at the LHC

[*CMS '06*]



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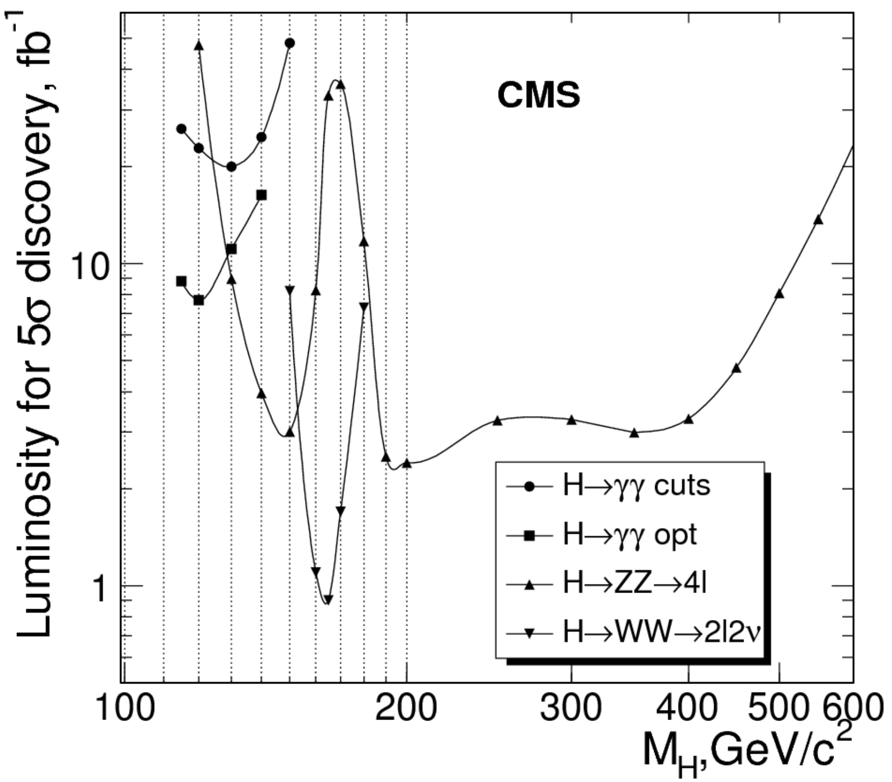

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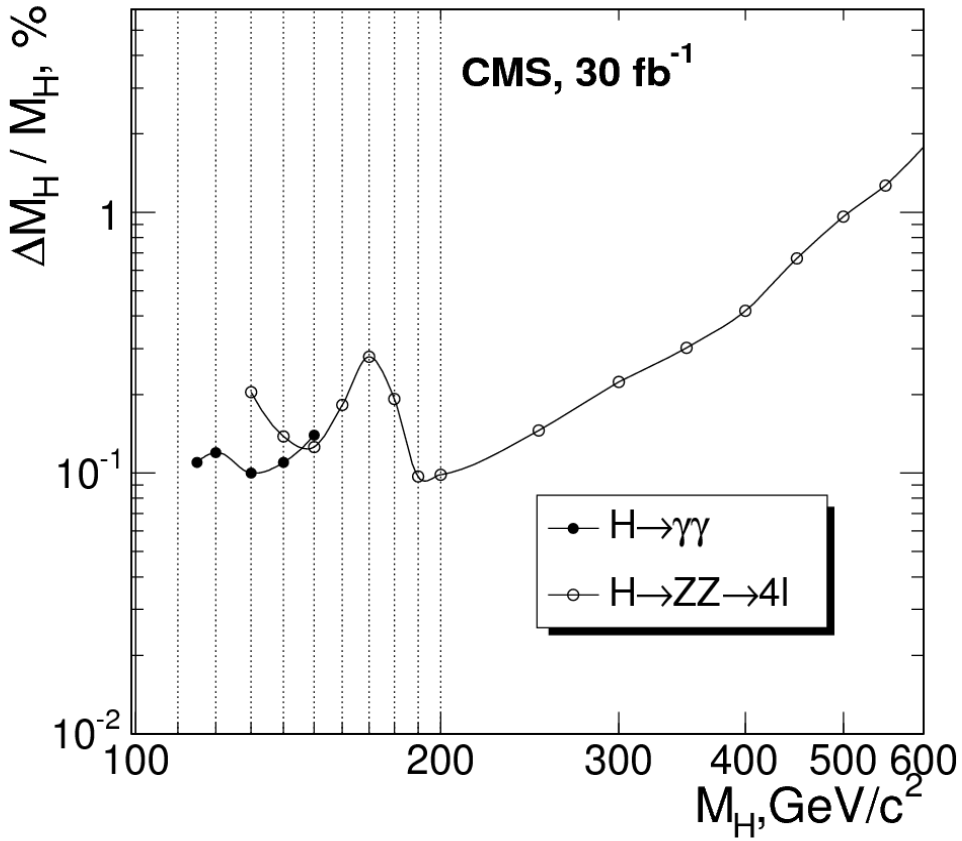
Low-mass region (just above LEP limit) is experimentally most challenging; $H \to b\bar{b}$ mode will be very difficult at the LHC

SM Higgs at the LHC: Higgs mass precision

[*CMS '06*]



For light SM-like Higgs, $H \to \gamma\gamma$ decay mode:

$\Rightarrow$ LHC can do first precision measurement in Higgs sector:

$$\delta M_{\rm H}^{\rm exp} \approx 0.2 \text{ GeV}$$

If a Higgs candidate has been detected: experimental questions

- Is it a Higgs boson?
- What are its mass, spin and $\mathcal{CP}$ properties?
- What are its couplings to fermions and gauge bosons? Are they really proportional to the masses of the particles?
- What are its self-couplings?
- Are its properties compatible with the SM, the MSSM, the NMSSM, . . . ?
- Are there indications that there are more than one Higgs bosons?
- Are there indications for other new states that influence Higgs physics?

Search for physics beyond the SM
example: SUSY

SUSY searches at the LHC:

Dominated by production of coloured particles:
gluino, squarks

Very large mass reach in the searches for
jets $+$ missing energy
$\Rightarrow$ gluino, squarks accessible up to 2–3 TeV

$\Rightarrow$ very good prospects for discovering SUSY particles if low-energy SUSY is realised in nature

SUSY signals at the LHC

LHC: good prospects for strongly interacting new particles

long decay chains possible $\Rightarrow$ complicated final states

e.g.: $\tilde{g} \to \bar{q}\tilde{q} \to \bar{q}q\tilde{\chi}_2^0 \to \bar{q}q\tilde{\tau}\tau \to \bar{q}q\tau\tau\tilde{\chi}_1^0$

Many states are produced at once, difficult to disentangle

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But ist it really SUSY? Which particles are actually produced?

Main background for determining SUSY properties at the LHC will be SUSY itself!

It quacks like SUSY, but . . .

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- does every SM particle really have a superpartner?
- do their spins differ by $1/2$?
- are their gauge quantum numbers the same?
- are their couplings identical?
- do the SUSY predictions for mass relations hold, . . . ?

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Even when we are sure that it is actually SUSY, we will still want to know:

- is the lightest SUSY particle really the neutralino, or the stau or the sneutrino, or the gravitino or . . . ?
- is it the MSSM, or the NMSSM, or the mNSSM, or the N^2MSSM, or . . . ?
- what are the experimental values of the 105 (or more) SUSY parameters?
- does SUSY give the right amount of dark matter?
- what is the mechanism of SUSY breaking?

We will ask similar questions for other kinds of new physics

Particle spins and $\mathcal{CP}$ properties

Determination of spin and $\mathcal{CP}$ prop. of observed new states will be crucial for establishing the SUSY nature of the signal

- Spin: establish fermion–boson symmetry, distinguish from universal extra dimensions (can have similar spectrum as in SUSY, but different spins), spin 2 excitations, ...

- $\mathcal{CP}$ properties: pseudo-scalar Higgs, mixed states, ...

- $\mathcal{CP}$ violation:

  Measure CPV effects in $\mathcal{CP}$-conserving observables?

  Access to $\mathcal{CP}$-violating observables: $\mathcal{CP}$ asymmetries, triple products, ...?

$\Rightarrow$ Very important information, but experimentally challenging at the LHC

SUSY parameter determination

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How well can we identify particles in different decay chains?

Theory uncertainties?

LHC luminosity upgrade: the SLHC

SuperLHC (SLHC): upgrade of LHC design luminosity by a factor of 10 to about $10^{35}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$

- Moderate extension of LHC mass reach
- More precise measurements of processes that are statistically limited
- Extended reach for rare processes

Difficult experimental environment: higher radiation levels in the detectors, increased pile-up background

Upgrades of ATLAS and CMS required

[*see talks by Marc Weber and Steve Myers*]

LHC physics: theory requirements

Hadron collider physics: need good understanding of quark and gluon content of the proton

$\Rightarrow$ determine parton distribution functions, using input from data at HERA, Tevatron, . . .

Long-term strength in the UK: MSTW (MRST), NNPDF, . . .

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Need to take into account also possible new physics backgrounds to other processes of new physics!

LHC physics: theory requirements

Signal processes: need precise predictions to assess prospects for the LHC (e.g. inclusive production of a SM Higgs, K-factor $\gtrsim 2$), to gain sensitivity to the properties of new physics (e.g. Higgs coupling determination) and to discriminate between different kinds of new physics (e.g. SM vs. MSSM vs. NMSSM . . . , SUSY vs. universal extra dimensions, models with heavy gauge bosons)

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Significant increase of UK activities over the last years

Monte Carlo event generators are a crucial tool for physics at the LHC; comparison: theory vs. experiment

Three major collaborations in the field

HERWIG and SHERPA are led from the UK

European network (MCnet) is UK-led

LHC physics: theory requirements

New theoretical developments:

Conceptual progress, improved techniques, model building, . . .

Identifying the underlying physics at the TeV scale:

Interpretation of the experimental results

Connection between experiment, collider phenomenology, flavour physics, cosmology, model building, formal theory, . . .

Early LHC data: shaping the future of particle physics

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- Exciting results from the early LHC data could open up a window of opportunity for securing a long-term future of the field: possibility to bring a new major facility on the way

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Early LHC results: a possible window of opportunity

- Exciting results from the early LHC data could open up a window of opportunity for securing a long-term future of the field: possibility to bring a new major facility on the way
- The particle physics community will have to act quickly and speak with a unanimous voice:

  We will need to come up with a convincing and scientifically solid conclusion on how to proceed

CERN Theory Institute: "From the LHC to Future Colliders", February 9–27, 2009, at CERN

Organisers: *Albert De Roeck, John Ellis, Christophe Grojean, Sven Heinemeyer, Karl Jakobs, G. W., James Wells*

Goals:

- Past: Discuss recent physics developments
- Present: Anticipate near-term capabilities of Tevatron, LHC and other experiments
- Future: Discuss most effective ways to be prepared for giving science input to plans of the post-LHC era

Considered future options for accelerator-based facilities at the TeV scale beyond the first phase of the LHC:
SLHC, ILC, CLIC, LHeC, Muon Collider, . . .

Working Group reports are in preparation

Possible scenarios of early LHC results

- Detection of a state in the first 10 fb^{-1} of LHC data with properties that are compatible with those of a Higgs boson (either SM-type or non SM-type) $+$ anything else
- No observation in the first 10 fb^{-1} of LHC data of a state with properties compatible with a Higgs boson ($+$ anything else)
- Detection of new states of physics beyond the Standard Model:
  - leptonic resonances
  - multi-gauge-boson signals
  - missing energy ($+$nothing, leptons, jets)
  - all other signatures of new states of BSM physics

DLHC: energy doubling of the LHC

Double beam energy to 14 TeV?

DLHC needs new magnets $\Rightarrow$ new machine

Significant increase of LHC search reach, but very good physics justification from future data needed

LHeC: electron–proton collisions in the LHC tunnel

Ring-Ring (RR) vs. Linac-Ring (LR) option

RR: energy limited, $\lesssim 70 \text{ GeV}$, better prospects for higher luminosity

LR: energy not physics limited, considered $\lesssim 150 \text{ GeV}$; lower luminosity

[*see talk by John Dainton*]

Potential for new physics searches at LHeC

- Electron-quark resonances, leptoquarks, SUSY with R-parity violation, . . .
- R-parity conserving SUSY: selectron $+$ squark production
- Higgs production in weak-boson fusion
- Excited leptons, anomalous top production, . . .
- . . .

CDR in preparation, to be completed in 2010

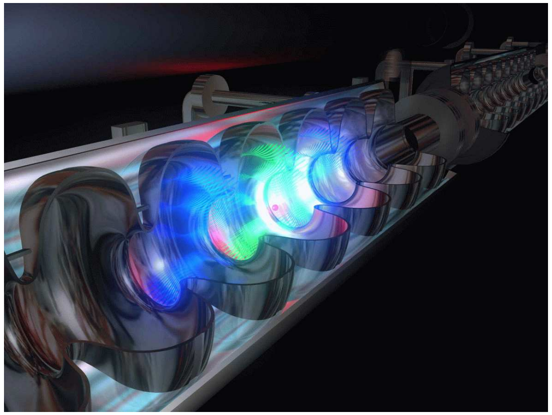
[*see talk by John Dainton*]

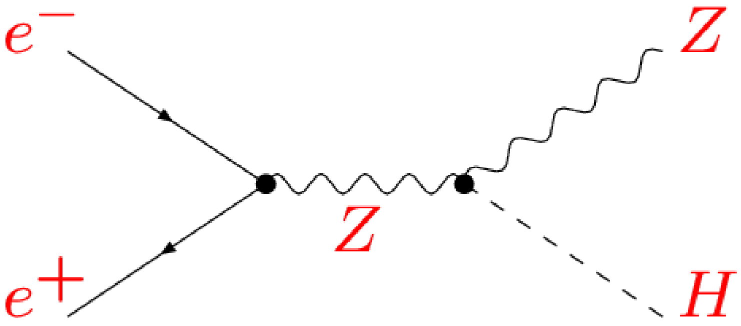
The ILC and CLIC

The International Linear Collider (ILC): RDR ($+$ costing) issued in 2007, Technical Design Phase is underway

The Compact Linear Collider (CLIC): Ongoing R&D on feasibility issues, preparation of Conceptual Design Report

e^+e^- scattering at $\lesssim$ 1 TeV (ILC), $\approx$0.5–3 TeV (CLIC)
fundamental particles, point-like, electroweak interaction
well-defined initial state, full collision energy usable, tunable

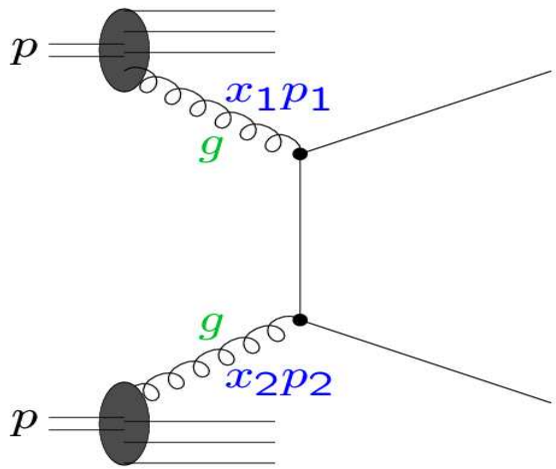




$\Rightarrow$ high-precision physics [*see talks by Andrei Nomerotski and Jim Clarke*]

Physics at LHC and LC in a nutshell

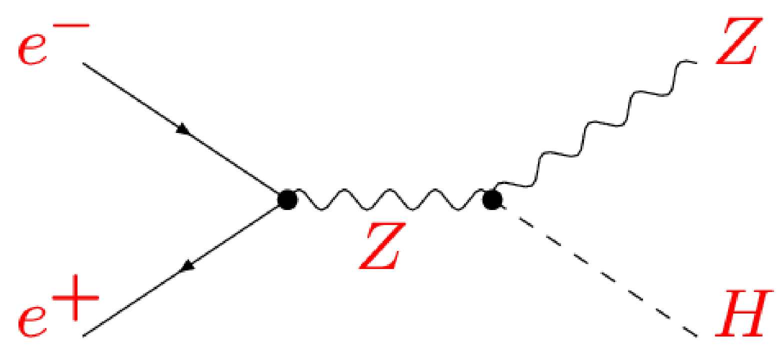
LHC: pp scattering at 14 TeV



Scattering process of proton constituents with energy up to several TeV,
strongly interacting

$\Rightarrow$ huge QCD backgrounds, low signal–to–background ratios

LC: e^+e^- scattering at $\lesssim$ 1 TeV (ILC), ≈0.5–3 TeV (CLIC)



Clean exp. environment:
well-defined initial state,
tunable energy,
beam polarization, GigaZ,
$\gamma\gamma$, $e\gamma$, e^-e^- options, . . .

$\Rightarrow$ rel. small backgrounds
high-precision physics

LHC / LC complementarity

The results of LHC and LC will be highly complementary

LHC: good prospects for producing new heavy states
(in particular strongly interacting new particles)

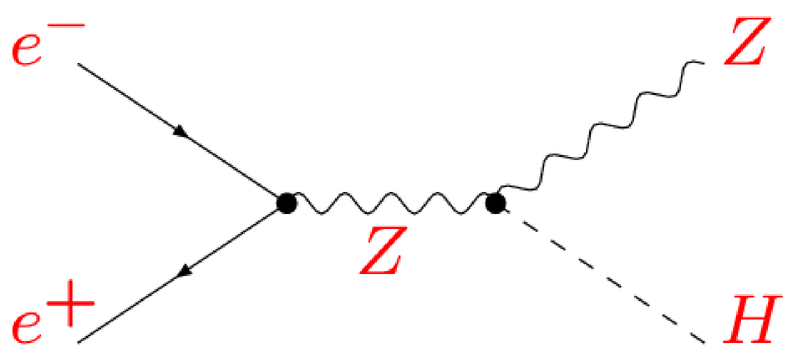
LC: direct production (in particular colour-neutral new particles)
$\oplus$ high sensitivity to effects of new physics via precision measurements

LHC / LC interplay
$\Rightarrow$ enhanced physics gain [*LHC / ILC Study Group Report '06*]
$\Rightarrow$ comprehensive picture of TeV scale physics

Higgs physics at the LC

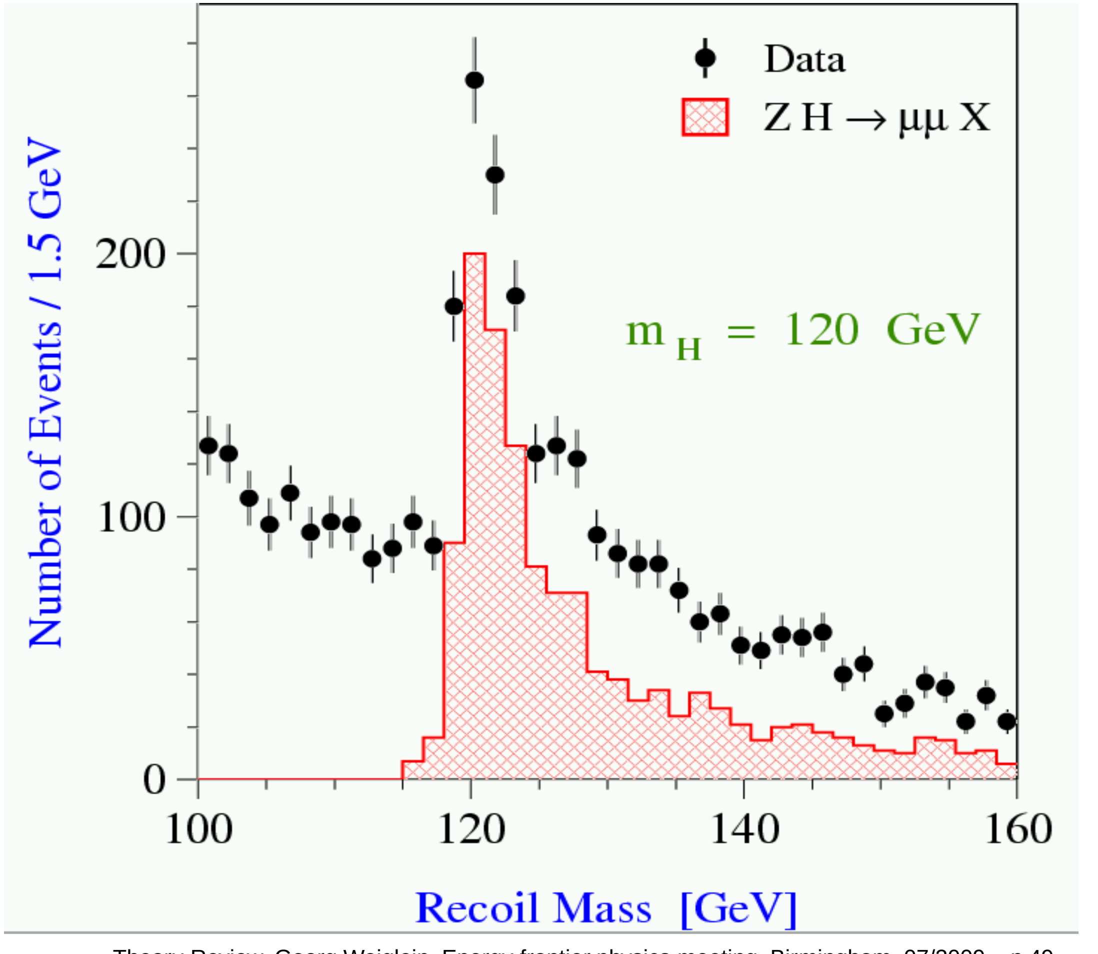
"Golden" production channel: $e^+e^- \to ZH$, $Z \to e^+e^-, \mu^+\mu^-$

Higgs discovery possible independently of decay modes (from recoil against Z boson)



$\Delta\sigma_{\rm HZ}/\sigma_{\rm HZ} \approx 2\%$
($E_{\rm CM} = 350$ GeV,
$\int \mathcal{L}dt = 500$ fb^{-1})

[*P. Garcia-Abia, W. Lohmann '00*]



The ILC will be a “Higgs factory”

Example: $E_{\rm CM} = 800$ GeV, 1000 fb^{-1}, $M_{\rm H} = 120$ GeV:

$\Rightarrow$ ≈ 160000 Higgs events in “clean” experimental environment

$\Rightarrow$ Precise measurement of Higgs mass and couplings, determination of Higgs spin and quantum numbers, . . .

Mass determination for a light Higgs:

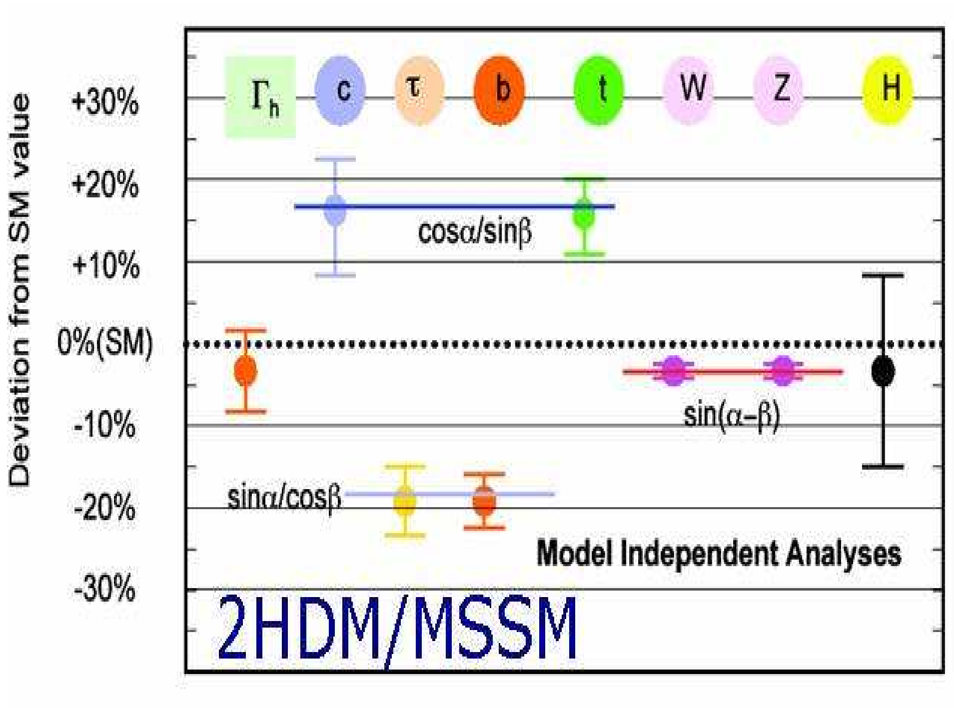
$$\delta M_{\rm H}^{\rm exp} \approx 0.05 \text{ GeV}$$

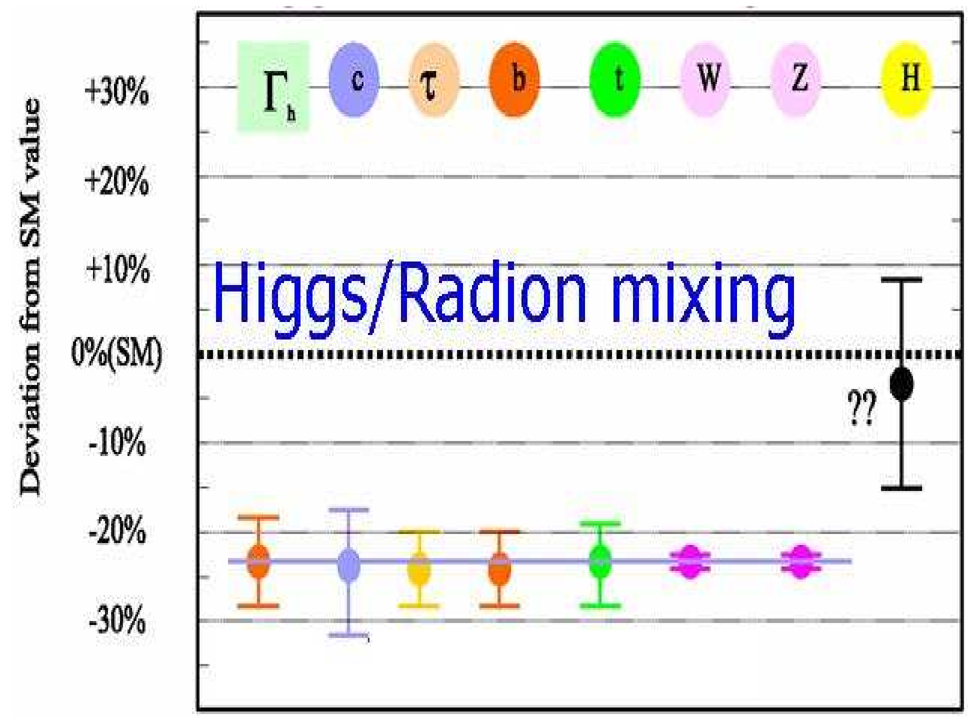
$\Rightarrow$ Verification of Higgs mechanism in model-independent way

distinction between different possible manifestations: extended Higgs sector, invisible decays, Higgs–radion mixing, . . .

Impact of ILC precision for the Higgs couplings

SM vs. BSM physics:





⇒ Precision measurement of Higgs couplings allows distinction between different models

The Higgs as a composite object

Renewed interest in composite Higgs models, mostly from extra dimensions

[*N. Arkani-Hamed, A. Cohen, H. Georgi '01*]

[*K. Agashe, R. Contino, A. Pomarol '05*], . . .

Composite Higgs: light remnant of a strong force

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Relation extra dimensions $\Leftrightarrow$ new strong forces?

Correspondence (AdS/CFT):

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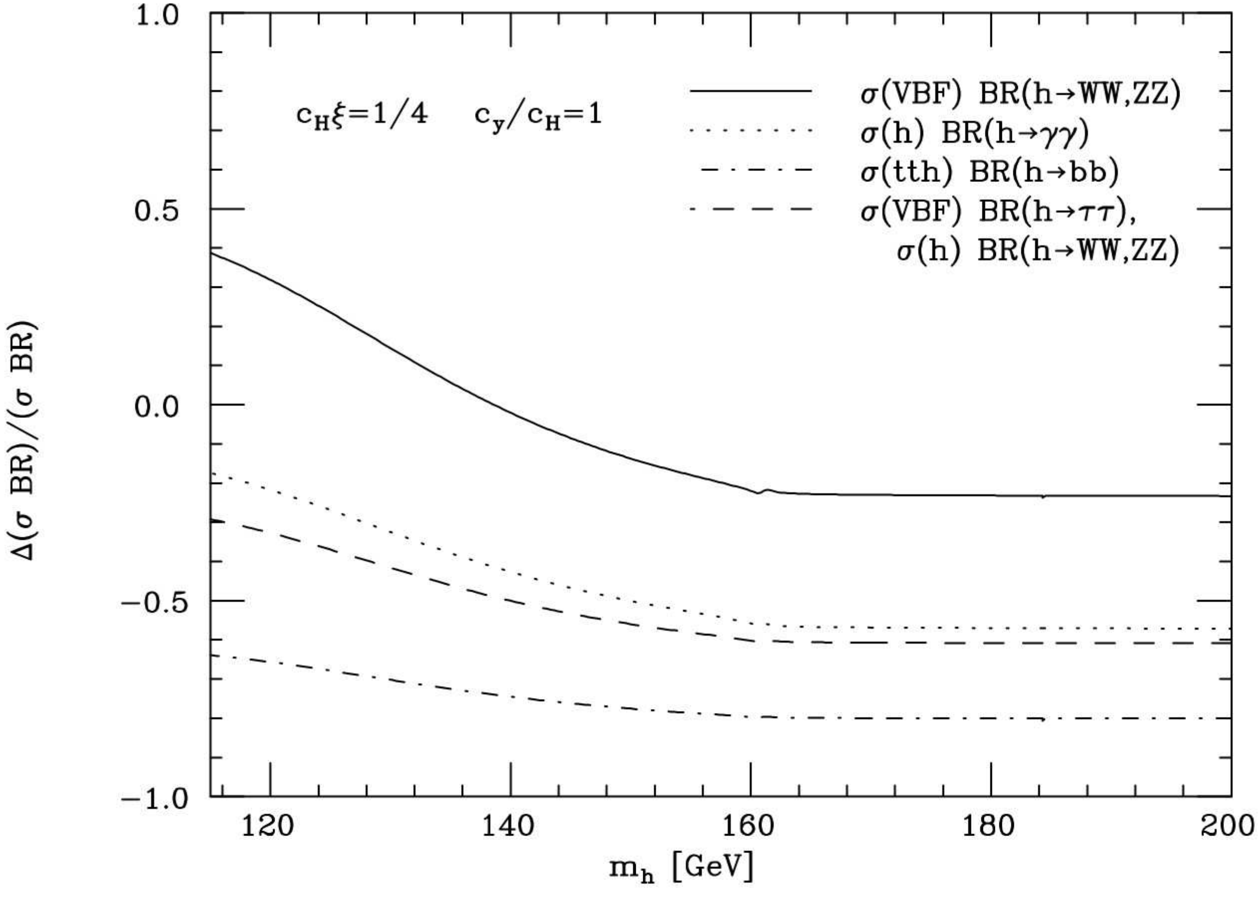
Signatures at LHC: new resonances, W', Z', t', KK excitations

Under pressure from electroweak precision tests

Strongly-Interacting Light Higgs: deviation of $\sigma \times \mathrm{BR}$ from the case of a SM Higgs

[*G. Giudice, C. Grojean, A. Pomarol, R. Ratazzi '07*]



Sensitivity at LHC: 20–40%, ILC: 1%

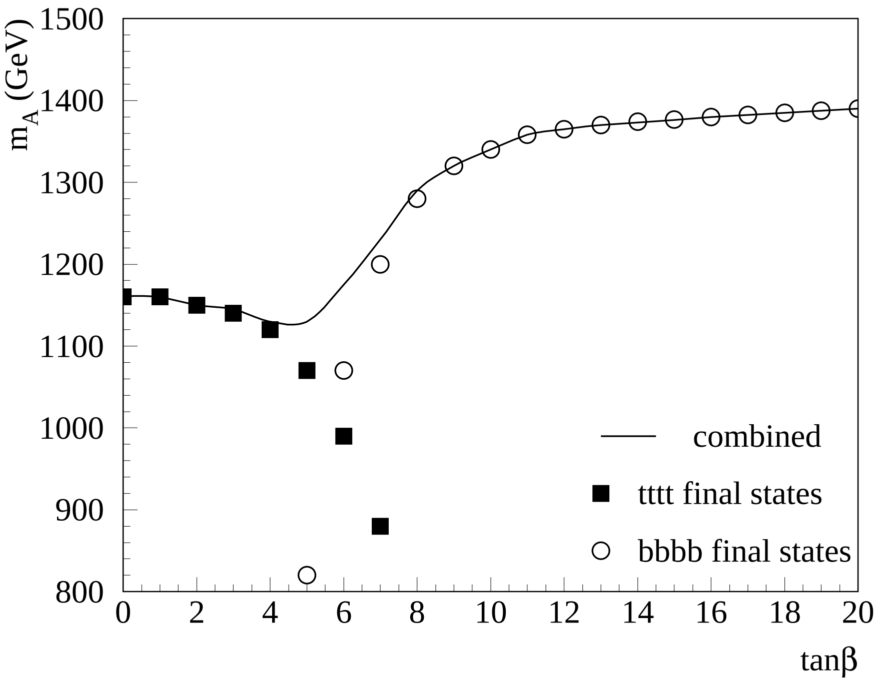
$\Rightarrow$ ILC can test scales up to $\sim 30\ \mathrm{TeV}$

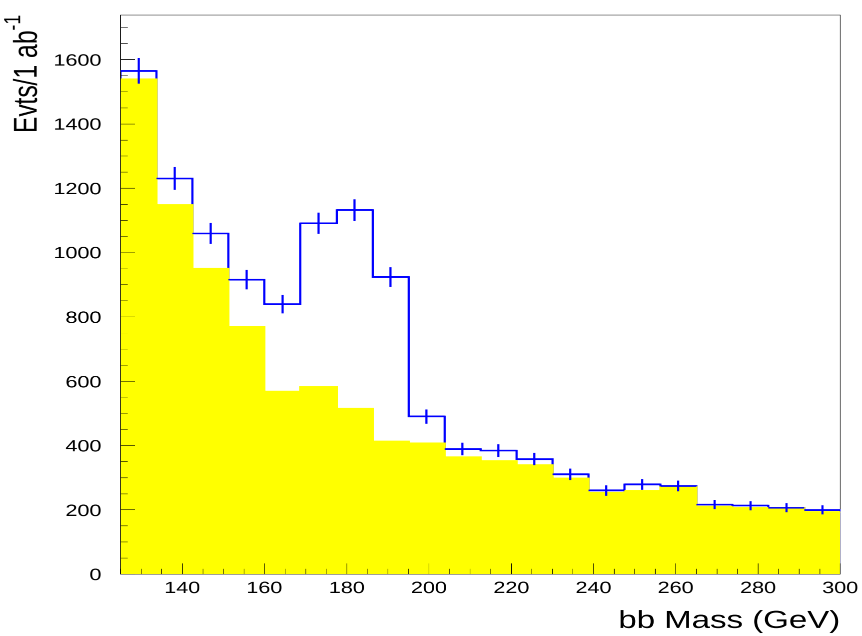
Higgs physics at CLIC

Large reach for heavy Higgs bosons (example HA, left)

Large cross section for weak-boson fusion Higgs production
$\Rightarrow$ access to rare Higgs decays (example $H \to b\bar{b}$ for heavy SM-like Higgs, right)
improved precision on Higgs self-coupling

[*CLIC Physics Working Group '04*]



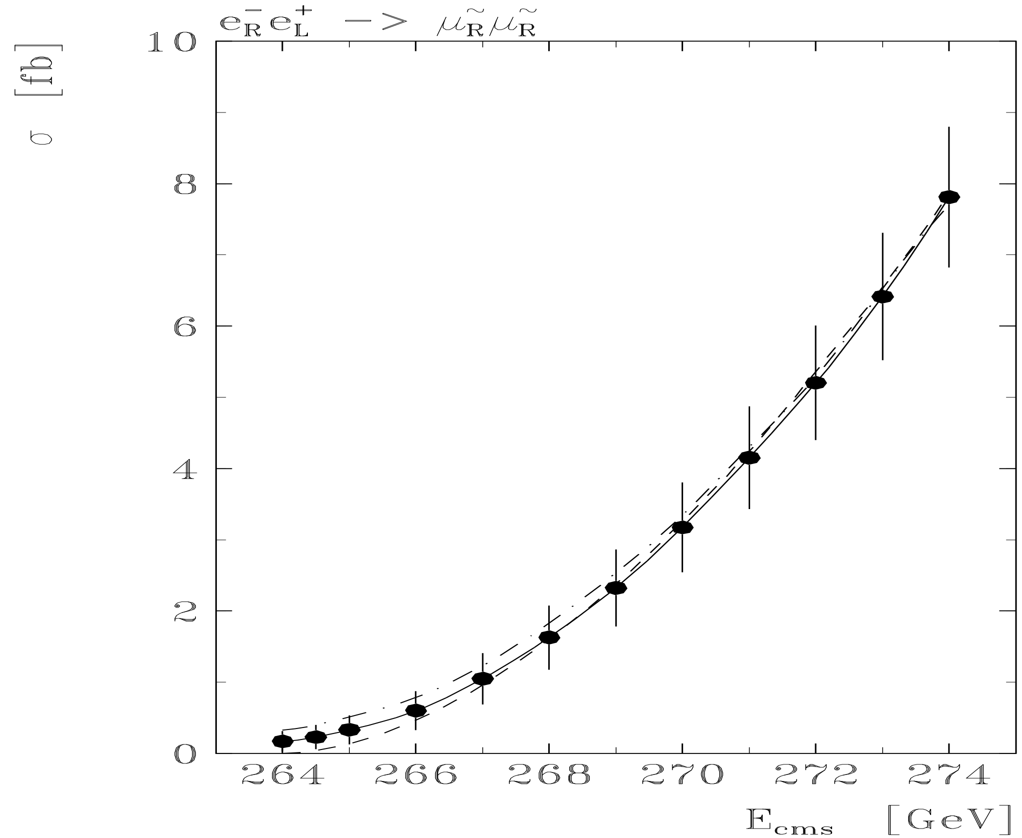


Production of SUSY particles at the ILC

Tunable energy $\Rightarrow$ can run directly at threshold

Example: Determination of mass and spin of SUSY particle $\tilde{\mu}_R$ from production at threshold:

[*TESLA TDR '01*]



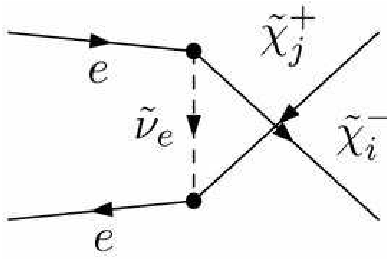
$$\Rightarrow \quad \frac{\Delta m_{\tilde{\mu}_R}}{m_{\tilde{\mu}_R}} < 1 \times 10^{-3}$$

$\Rightarrow$ test of $J = 0$ hypothesis

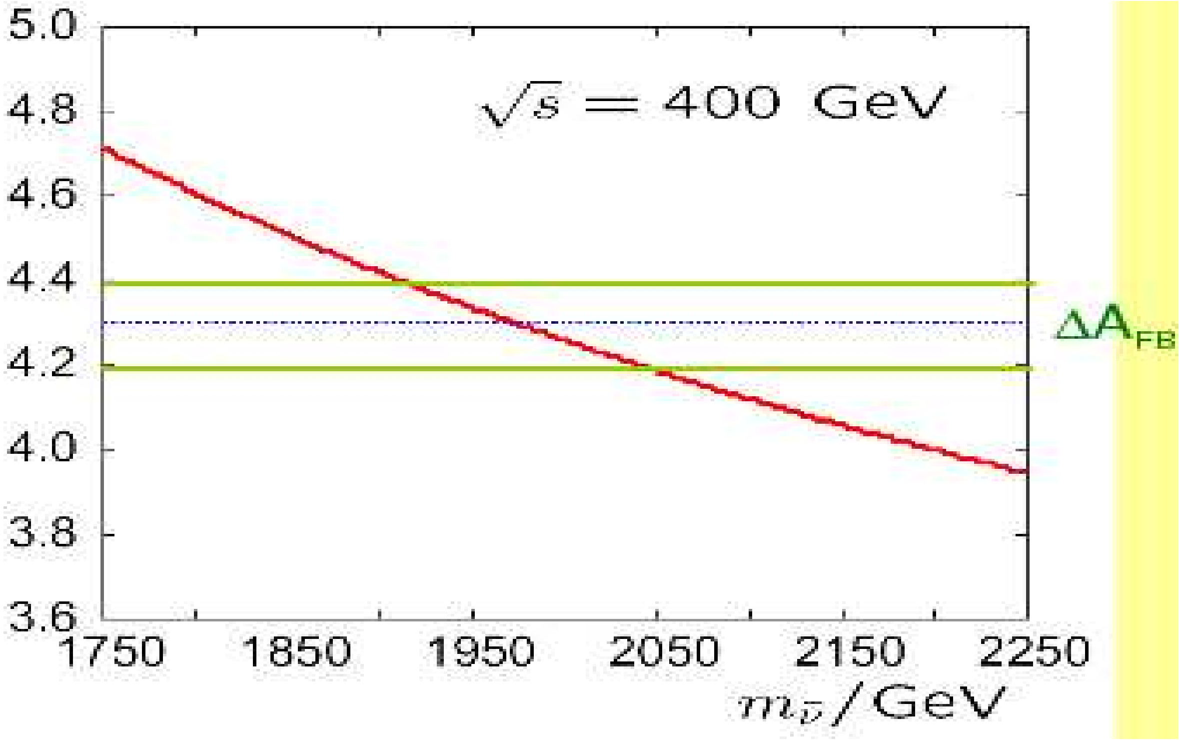
Furthermore: determination of quantum numbers, test of SUSY relations, information on SUSY breaking patterns, . . .

Prediction of heavier states from measurement of light SUSY particles at ILC(500)

Example: $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-$



[G. Moortgat-Pick '05]



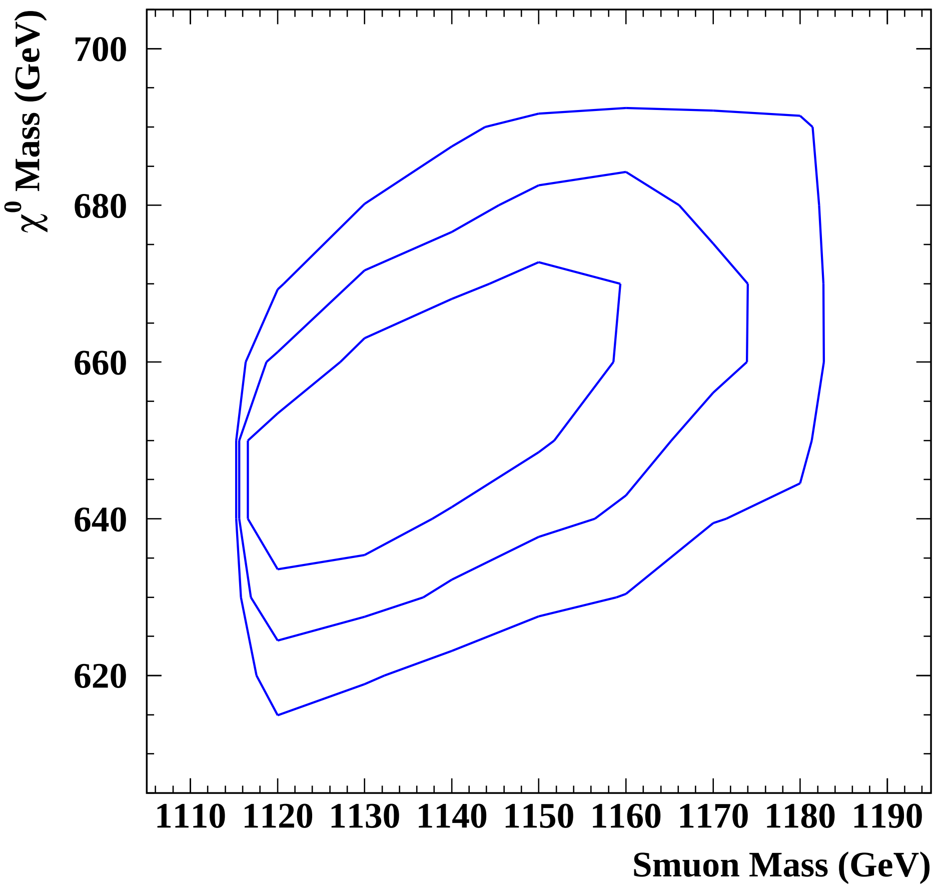
$\Rightarrow$ Indirect determination of sneutrino mass

distinction between models: focus point vs. split SUSY

Heavy SUSY particles at CLIC

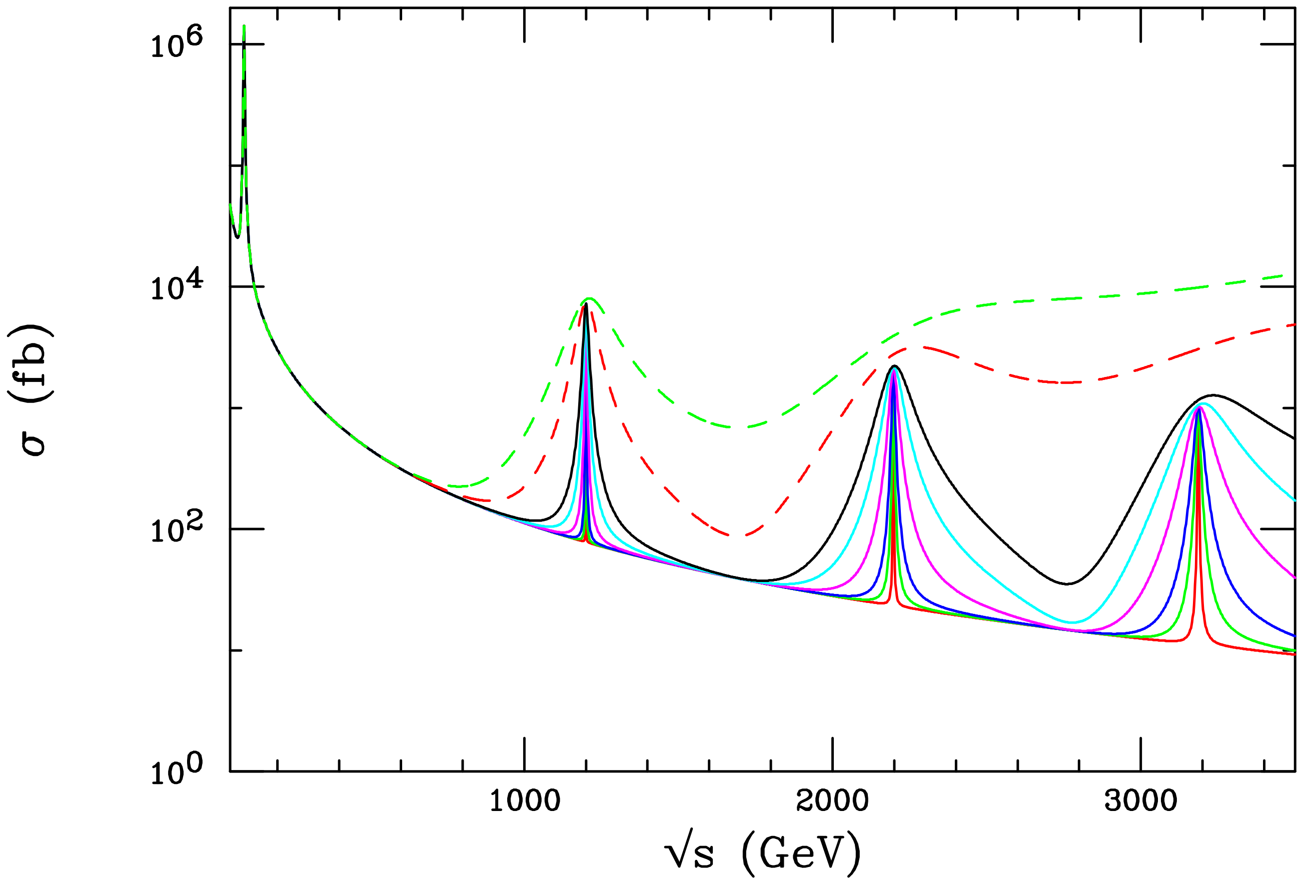
Example: production of heavy smuons, $\tilde{\mu} \to \tilde{\chi}^0 \mu$

[*CLIC Physics Working Group '04*]



Kaluza–Klein graviton excitations in $e^+e^- \to \mu^+\mu^-$ *at CLIC (RS model)*

[*CLIC Physics Working Group '04*]



$\Rightarrow$ Could possibly observe more than one excitation

[*see talks by Andrei Nomerotski and Jim Clarke*]

LC physics: theory requirements

In order to fully exploit the unprecedented level of accuracy of LC measurements a major effort will be required on the theory side

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$\Rightarrow$ Multi-loop and multi-leg high precision calculations will be required, taking into account effects of the strong and electroweak interactions from particles of known and new physics

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$\Rightarrow$ Multi-loop and multi-leg high precision calculations will be required, taking into account effects of the strong and electroweak interactions from particles of known and new physics

No showstoppers in principle, but very challenging in terms of the required manpower and the sophistication of the theoretical methods

Muon collider

A $\mu^+\mu^-$ collider in the energy range of 100 GeV to several TeV could emerge as a (major) upgrade of a neutrino factory

Higgs production in the s-channel

Physics potential of a multi-TeV muon collider is in principle similar to a multi-TeV e^+e^- collider
Can the same luminosity be achieved?

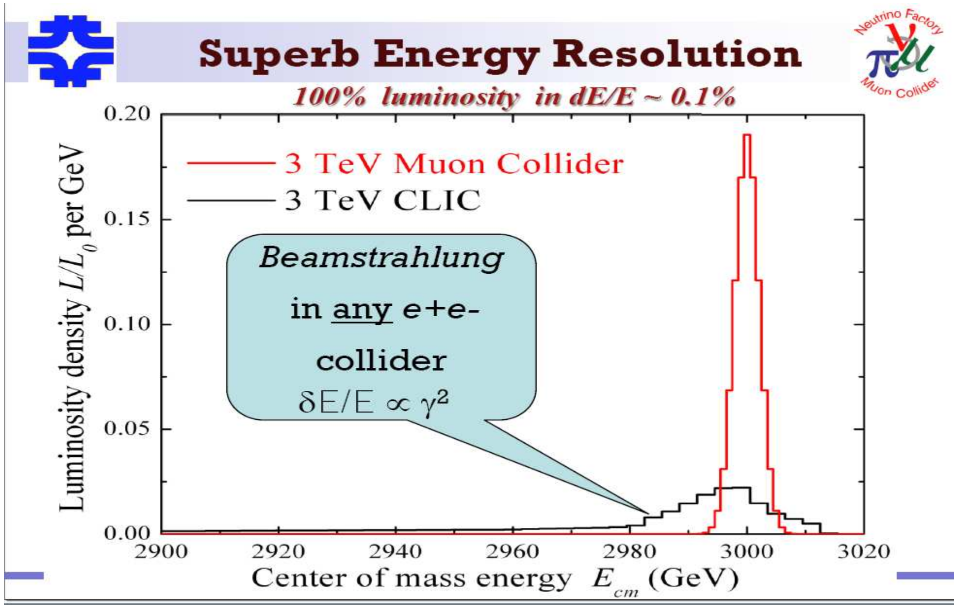
[*V. Shiltsev '08*]

Small ISR, beamstrahlung,

but huge backgrounds

from μ decay

[*see talk by Ken Long*]



Situation of particle theory in the UK: present and future

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The European Strategy for Particle Physics:
Approved by CERN Council, 07/2006

10. European theoretical physics has played a crucial role in shaping and consolidating the Standard Model and in formulating possible scenarios for future discoveries. Strong theoretical research and close collaboration with experimentalists are essential to the advancement of particle physics and to take full advantage of experimental progress; the forthcoming LHC results will open new opportunities for theoretical developments, and create new needs for theoretical calculations, which should be widely supported.

UK particle theory community

- 20 universities with theory groups
- Size:

  2008 STFC Rolling Grants round: 155 Investigators listed (tenured and non-tenured) $+$ IPPP $+$ EPSRC funded String/QFT posts in Maths $+$ Astro-Particle theorists
- Research topics:

  Cosmology, Lattice, Phenomenology, QFT, Strings

Strengths: current situation and recent developments

- Very noticeable strengthening of UK phenomenology and especially BSM physics: IPPP Durham (new 10 year grant awarded) $+$ significant expansion of several other groups
- Strong UK presence in perturbative QCD and collider physics
- Long history of excellence in string theory, gravity and formal QFT; recently became much more integrated with other UK particle theory
- Continuing excellence in astro-particle physics and cosmology; links with particle physics have been significantly strengthened
- UK is a major player in lattice QFT on both machine and theory issues

Second International Review of UK Research in Physics and Astronomy – Purpose and Scope

In November 2005, a Panel of international physicists and astronomers undertook a second Review of UK Physics and Astronomy Research, under the sponsorship of the Engineering and Physical Sciences Research Council (EPSRC), the Particle Physics and Astronomy Research Council (PPARC), the Royal Astronomical Society (RAS) and the Institute of Physics.

The Review, which followed on from an initial review of physics and astronomy research undertaken in April 2000, reported on the quality, distribution of effort and future potential of research in physics and astronomy in the UK. The Review aimed to indicate areas of strength, weakness, improvement, decline and growth with respect to the preceding review.

Second International Review of UK Research in Physics and Astronomy – Purpose and Scope

The Review was undertaken by an international Panel of eminent physicists and astronomers who visited the UK during the week beginning 31 October 2005. The Panel was chaired by Professor Jürgen Mlynek, President of the Helmholtz Association, Germany. The panel members visited several university physics and astronomy departments and the CCLRC Rutherford Appleton Laboratory. The Panel also had the opportunity to take evidence from relevant individuals involved in research, higher education and science policy.

The Review was organised by a Steering Group comprising: Professor Sir John Enderby (Chair; President, the Institute of Physics), Professor John O'Reilly (Chief Executive, EPSRC), Professor Keith Mason (Chief Executive, PPARC) and Professor Kathryn Whaler (President, the Royal Astronomical Society).

Second International Review of UK Research in Physics and Astronomy – Report

2.5 PARTICLE PHYSICS

2.5.2 THEORY

Particle theory in the UK is healthy, with a revitalised effort in particle phenomenology, a burgeoning contribution to the physics that might lie beyond the Standard Model, a strong and vital group of lattice theorists and continuing strength in string theory and general relativity.

With the founding of the IPPP, a joint venture of the University of Durham and PPARC, particle physics phenomenology in the UK has been substantially revived. The IPPP has had major successes: creating a critical mass of particle theorists in Durham. There have been very healthy interactions with formal and string theorists in the mathematics department, reviving particle phenomenology throughout the UK, and the organisation of many meetings and workshops. This development is very important, since it is essential that UK experimentalists and theorists be ready to exploit discoveries made at the LHC in the near future.

. . .

Formal Theory: [*see talk by Jerome Gauntlett*]

Second International Review of UK Research in Physics and Astronomy – Report

3. GENERAL FINDINGS ON PHYSICS AND ASTRONOMY
3.3 THEORY

It is the Panel's perception that there are fewer theorists in UK physics and astronomy departments than is the international norm, as was the case in 2000.

Mathematics departments take up some of the load, but it is not an ideal situation for both the theorists and their potential experimental colleagues. The situation is exacerbated by the observation that mathematics departments do not commonly participate in the mathematics teaching of physics students. Theoretical physics has not benefited substantially from the recent investments in infrastructure and the increases in funding. A noticeable exception is the strong revival of particle physics phenomenology with the founding of the IPPP.

Prospects for the future

Theoretical particle physics in the UK has been on an upward trajectory for several years

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However, the field has suffered from the funding situation within the last years: cuts to Advanced and Postdoctoral Fellowships, discontinuation of Senior Fellowship awards, . . .

The Rolling Grant round in 2008 has turned the situation into a major crisis with severe damage to the field:

- Several groups lost their Rolling Grant support
- fEC level of 20%
- Dramatic decline of PDRA numbers over the current Rolling Grant period

[*see talk by Jerome Gauntlett*]

Conclusions

- LHC will open up the new territory of TeV-scale physics
  $\Rightarrow$ expect manifestations of the mechanism(s) responsible for electroweak symmetry breaking and for stabilising the hierarchy $M_{\rm weak}$ / $M_{\rm Planck}$

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- How do we determine the underlying physics?
  ⇒ Very exciting and challenging time for experiment and theory; intense interaction will be crucial

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⇒ We need to be in a position to make use of them!