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The path to new physics at the LHC and beyond

XV Christmas Workshop

Windows on the Unknown

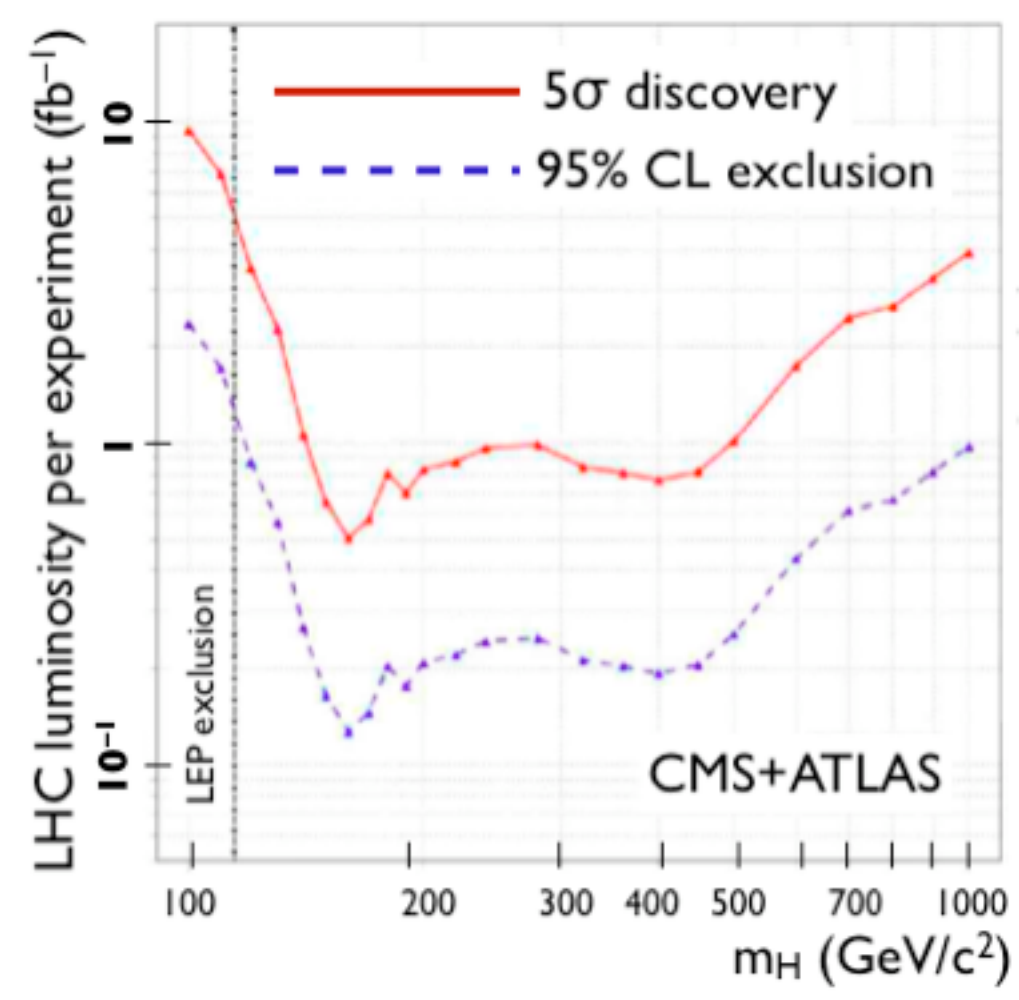
Madrid, 16-18 Dec 2009

The LHC was designed to answer one question:

is electroweak symmetry broken as postulated in the SM Higgs mechanism?

- SM production and decay rates well known
- Detector performance for SM channels well understood
- $115 < m_H < 200$ from LEP and EW fits in the SM

Summary of SM Higgs discovery potential



Within ~3 yrs from startup we should have an answer

IF Higgs seen with SM production/decay rates, but outside SM mass range:

- new physics to explain EW fits, or
- problems with LEP/SLD data

In either case,

- easy prey with low luminosity up to ~ 800 GeV, but more lum is needed to understand why it does not fit in the SM mass range!

IF NOT SEEN UP TO m_H ~ 0.8-1 TeV GEV:

$\sigma < \sigma_{SM}$: $\Rightarrow$ new physics

or

BR(H→visible) < BR_{SM}: $\Rightarrow$ new physics

or

m_H>800 GeV: expect WW/ZZ resonances at $\sqrt{s}$ ~ TeV $\Rightarrow$ **new physics**

- **Sorting out non-SM scenarios may take longer than the SM H observation, and may well require LHC luminosity upgrades and/or a lepton collider, but the conclusion about the existence of a BSM origin of EWSB will come early and unequivocal**

- **Exposing the mechanism of EW symmetry breaking (EWSB) and identifying the Higgs boson or its alternatives is necessary to set the scene for what’s next**

We would also like the LHC to help us address the three key experimental shortcomings of the Standard Model:

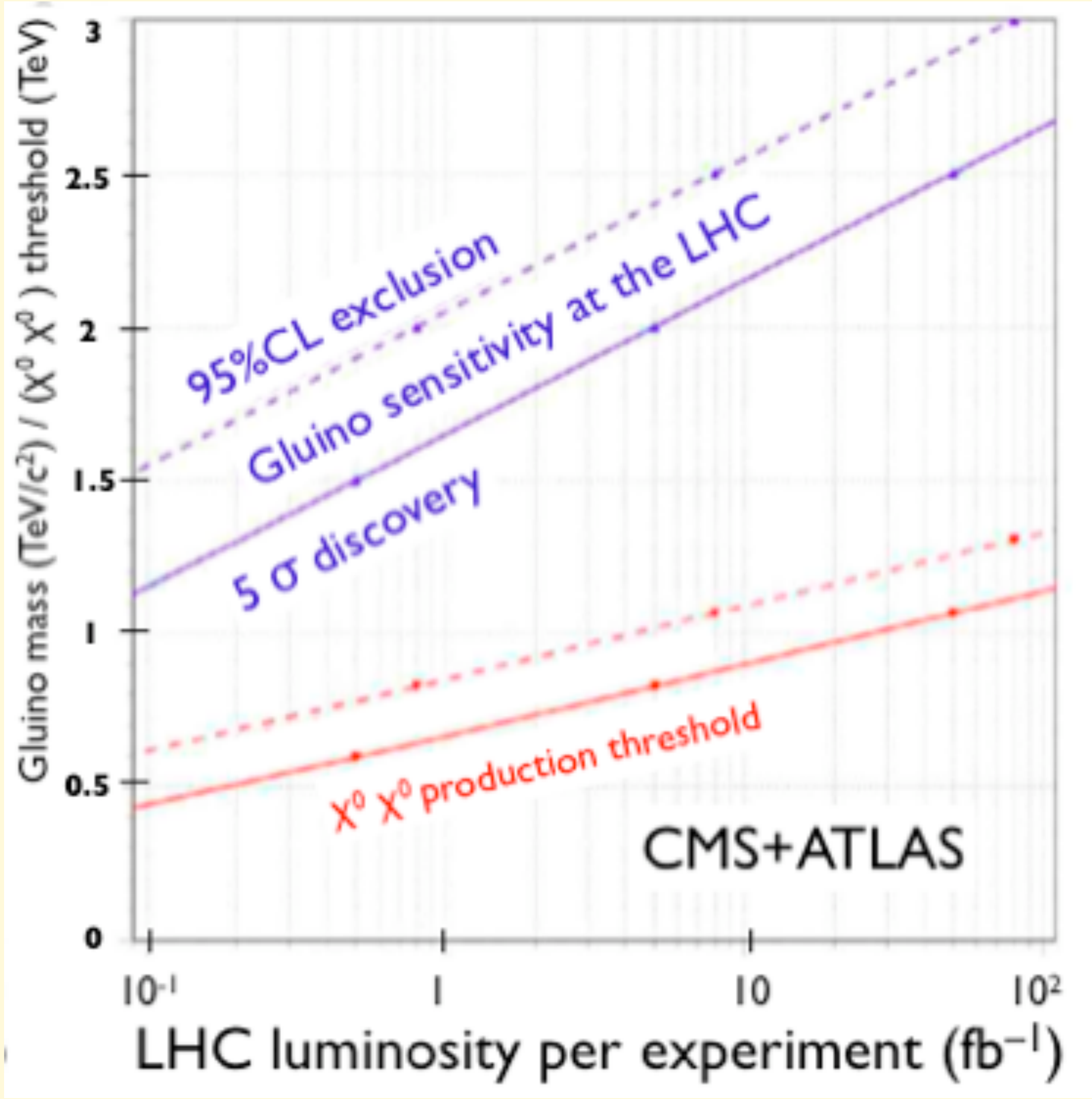
- **Neutrino masses**
- **Dark matter**
- **Baryon asymmetry of the universe**

as well as its theoretical weakness, the hierarchy problem

Will the answers to these questions be related to each other?

Which experimental programme, at the LHC and beyond, will allow us to address them?

Example: timeline for SUSY (MSSM) discovery/exclusion



The discovery of SUSY (or whatever else) will only the beginning of a new era of exploration, dominated by questions like

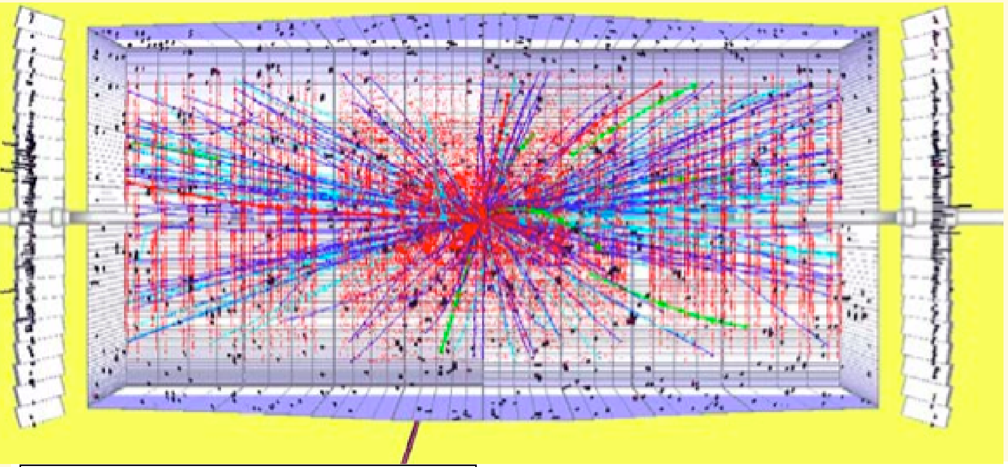
what is the mechanism of SUSY breaking?

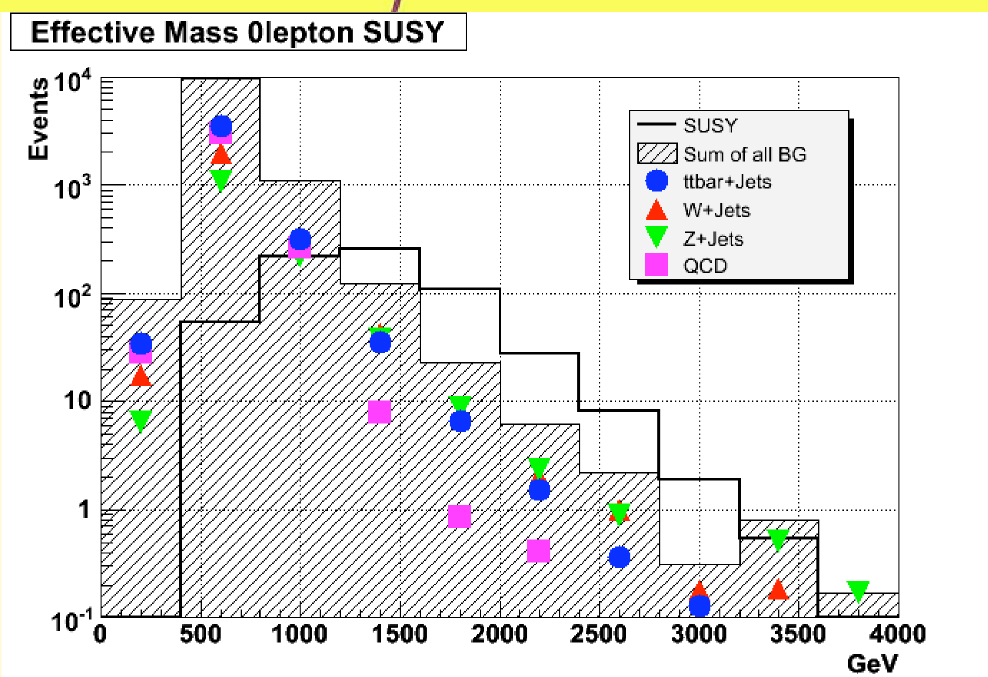
New expt'l input will be needed to start addressing such issues. E.g.:

- Chargino/gluino mass spectrum
- Squarks and sleptons masses and mixings
- CP structure of SUSY couplings
- .....

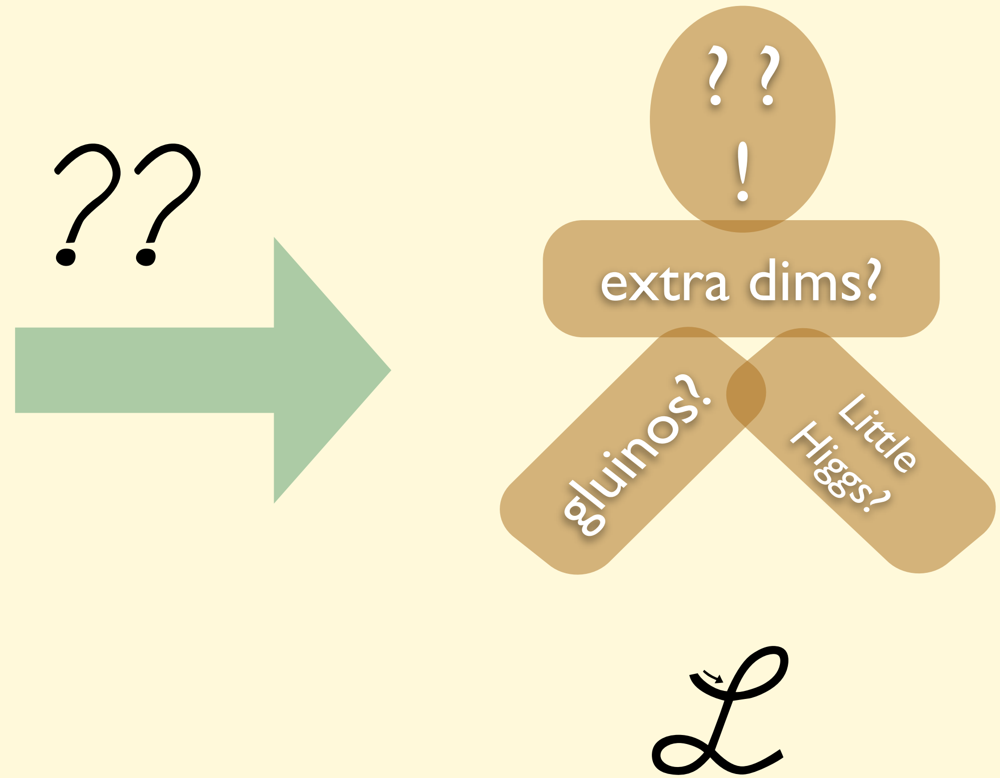
The LHC inverse problem

Reconstruct the Lagrangian of new physics from the LHC data





$$M_{eff}\,(\text{GeV}) = \sum_{i=1,4} E_T\,(i) + E_T^{\,miss}$$



- Very likely, the understanding of the new physics will emerge from a step-by-step consolidation of prominent features of the data, restricting more and more the class of models first, and their parameters later.
- Single key inputs, even if only partially accurate, can provide more valuable information than dozens of vaguely suggestive hints. For example, if SUSY:
  - the relation between gluino and chargino mass,
  - evidence for GMSB in the final states (prompt photons and MET),
  - the determination of the stop parameters and mH, etc.

NB

- **< 1973: theoretical foundations of the SM**
    - renormalizability of SU(2)xU(1) with Higgs mechanism for EWSB
    - asymptotic freedom, QCD as gauge theory of strong interactions
    - KM description of CP violation
- **Followed by 30 years of consolidation:**
    - **technical theoretical advances** (higher-order calculations, lattice QCD, ...)
    - **experimental** verification, via **discovery** of
        - **Fermions**: charm, 3rd family (USA)
        - **Bosons**: gluon, W and Z (Europe; .... waiting to add the Higgs ....)
    - **experimental** consolidation, via **measurement** of
        - EW radiative corrections
        - running of α_S
        - CKM parameters

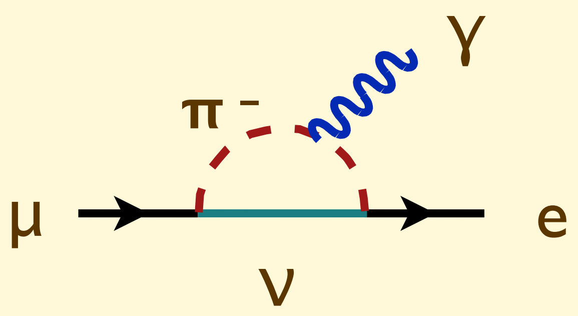
It's unlikely it will take less than 30 yrs to clarify and consolidate the understanding of new phenomena to be unveiled by the LHC!

Notice that of the 3 empirical proofs that the SM in incomplete:

- **Neutrino masses**
- **Dark matter**
- **Baryon asymmetry of the universe**

at least **two** are directly related to flavour .....

Flavour phenomena have contributed shaping modern HEP as much as the gauge principle



$\mu \not\to e\,\gamma \;\Rightarrow\; \nu_\mu \neq \nu_e$

$K^0 \to \mu^+ \mu^-$
K-$\bar{K}$ mixing → **GIM, charm**

ε_K , $\not{C}\!P$ → **KM**

B_d-$\bar{B}_d$ mixing → **large m_{top}, well before EW tests**

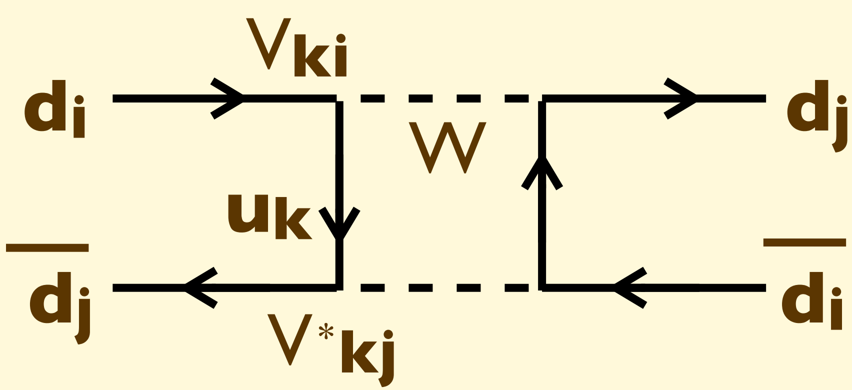
ν masses → **see-saw, SO(10) GUT, ... ?**

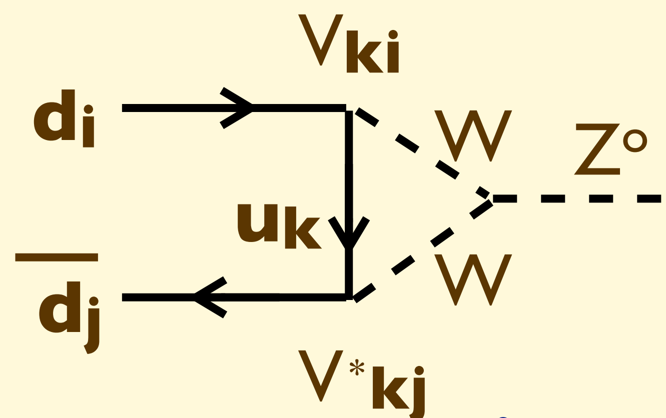
What is “flavour physics” ?

- In the SM, flavour is what deals with the fermion sector (family replicas, spectra and mixings):
  - all flavour phenomena are encoded in the fermion Yukawa matrices.

FCNC and CPV in the SM

- Suppression of FCNC and CPV are guaranteed in the SM by the following facts:
  - Quark sector:
    - unitarity of CKM (GIM mechanism)
    - small mixings between heavy and light generations





$$\Delta_{ij} \sim \sum_{k=u,c,t} V_{ki} V^*_{kj}\, f(m_k/m_W) \sim \sum_{k=c,t} V_{ki} V^*_{kj}\, m_k^2/m_W^2 \;\sim V_{ci} V^*_{cj} \frac{m_c^2}{m_W^2} + V_{ti} V^*_{tj}$$

  - Lepton sector:
    - mν=0 ⇒ all phases and angles absorbed by field redefinitions, no mixings/CPV at all

What is “flavour physics” ?

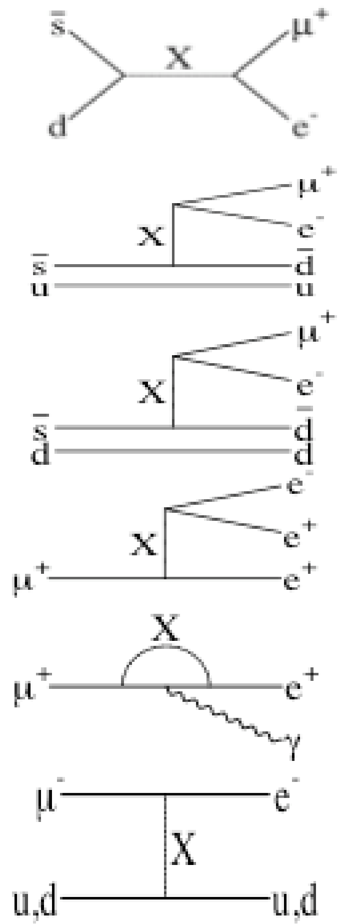
- In the SM, flavour is what deals with the fermion sector (family replicas, spectra and mixings):
    - all flavour phenomena are encoded in the fermion Yukawa matrices.
- Beyond the SM, “flavour” phenomena cover a wider landscape. E.g.
    - FCNC can be mediated by
        - gauge-sector particles, like charged higgses, gauginos, new gauge bosons, or by
        - SUSY scalar partners
    - New flavours in the form of new generations, exotic partners of standard quarks (e.g. Kaluza Klein excitations, T’ in LH), etc.
    - CP violation can reside in gauge/Higgs couplings

FCNC beyond the SM

S.Geer

- There is absolutely no guarantee that the suppression of FCNC and CPV is present in extensions of the SM
- As soon as these are released, effects are devastating!

Compare the to O(10 TeV) sensitivity w.r.t. modifications of the gauge/EW sector



$B(K_L \to \mu e) < 4.7 \times 10^{-12}$	$M_X > 150$ TeV/c²
$B(K^+ \to \pi^+\mu^+e^-) < 4 \times 10^{-11}$	$M_X > 31$ TeV/c²
$B(K_L \to \pi^0\mu^+e^-) < 3.2 \times 10^{-10}$	$M_X > 37$ TeV/c²
$B(\mu^+ \to eee) < 1 \times 10^{-12}$	$M_X > 86$ TeV/c²
$B(\mu^+ \to e^+\gamma) < 1.2 \times 10^{-11}$	$M_X > 21$ TeV/c²
Normalized Rate $< 6.1 \times 10^{-13}$	$M_X > 365$ TeV/c²

N.B. Once coupling constants – say of EW size – and $O(\theta_c)$ mixings, are included, these scales are not much bigger than the TeV scale accessible at the LHC ⇨

great potential synergy between LHC and flavour observables

EWSB and flavour

- EWSB is intimately related to flavour:
  - No EWSB ⇒ fermions degenerate ⇒ no visible flavour effect
- In most EWSB models flavour plays a key role. E.g.:
  - Technicolor: tightly constrained by large FCNC
  - Supersymmetry: large value of top mass drives radiative EWSB
  - In several extra-dim models the structure of extra dimensions -- driven by the need to explain the hierarchy problem of EWSB -- determines the fermionic mass spectrum
  - Little Higgs theories ⇒ top quark partners
- Why $m_{top} = g/\sqrt{2}\, m_W$ ($\Leftrightarrow y_{top} = 1$) ?

What will be the main driving theme of the exploration of the new physics revealed by the LHC?

the gauge sector (Higgs, EWSB)

↓

The High Energy Frontier

- LHC
- SLHC
- VLHC
- ILC
- CLIC
- ....

the flavour sector (ν mixings, CPV, FCNC, EDM, LFV)

↓

The High Intensity Frontier

Neutrinos:	**Quarks:**	**Charged leptons:**
super beams	B factories	stopped μ
beta-beams	K factories	$\ell \rightarrow \ell'$ conversion
ν factory	n EDM	e/μ EDM

+ Astrophysics and cosmology

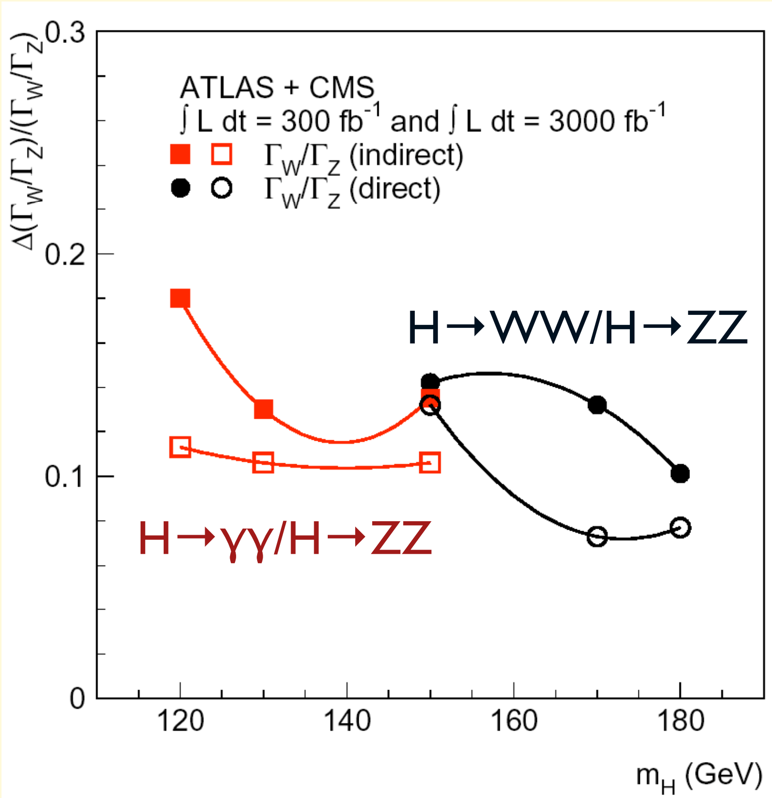
What can we get from more integrated luminosity after LHC's first phase?

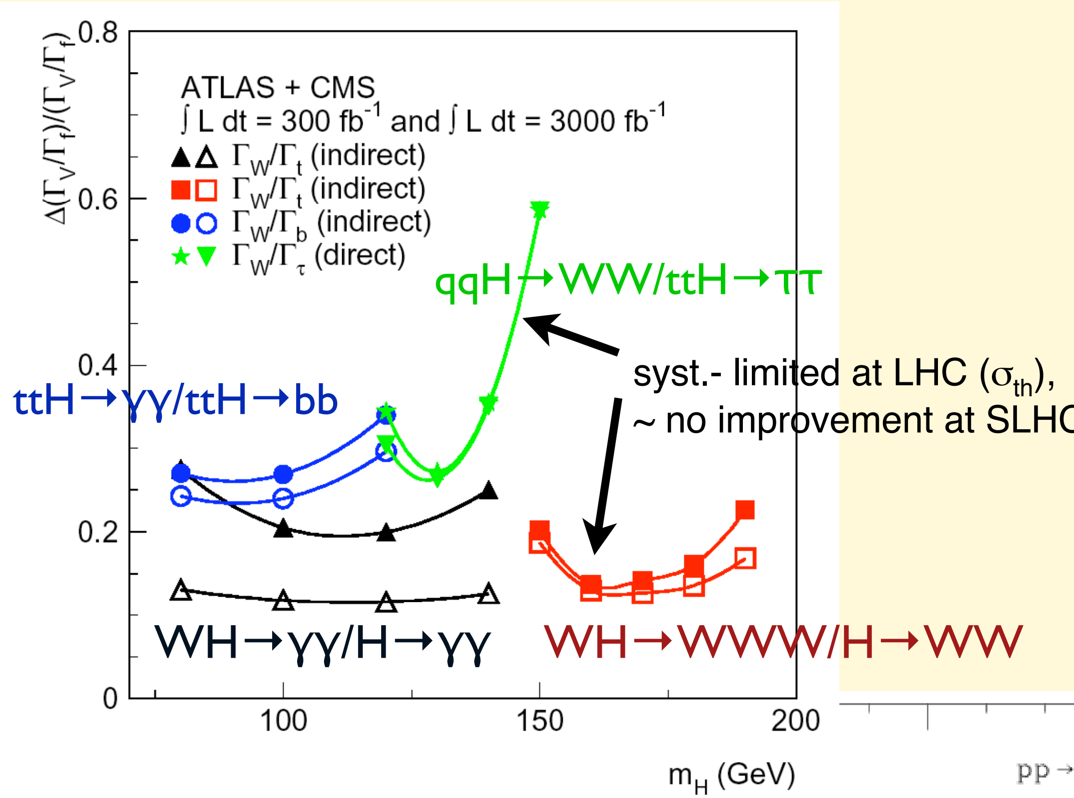
1. Improve measurements of new phenomena seen at the LHC. E.g.
   - Higgs couplings and self-couplings
   - Properties of SUSY particles (mass, decay BR's, etc)
   - Couplings of new Z' or W' gauge bosons (e.g. L-R symmetry restoration?)
2. Detect/search low-rate phenomena inaccessible at the LHC. E.g.:
   - $H \to \mu^+\mu^-$, $H \to Z\gamma$
   - top quark FCNCs
3. Push sensitivity to new high-mass scales. E.g.
   - New forces (Z', W_R)
   - Quark substructure
   - ....

Energies/masses in the few-100 GeV range. Detector performance at SLHC should equal (or improve) in absolute terms the one at LHC

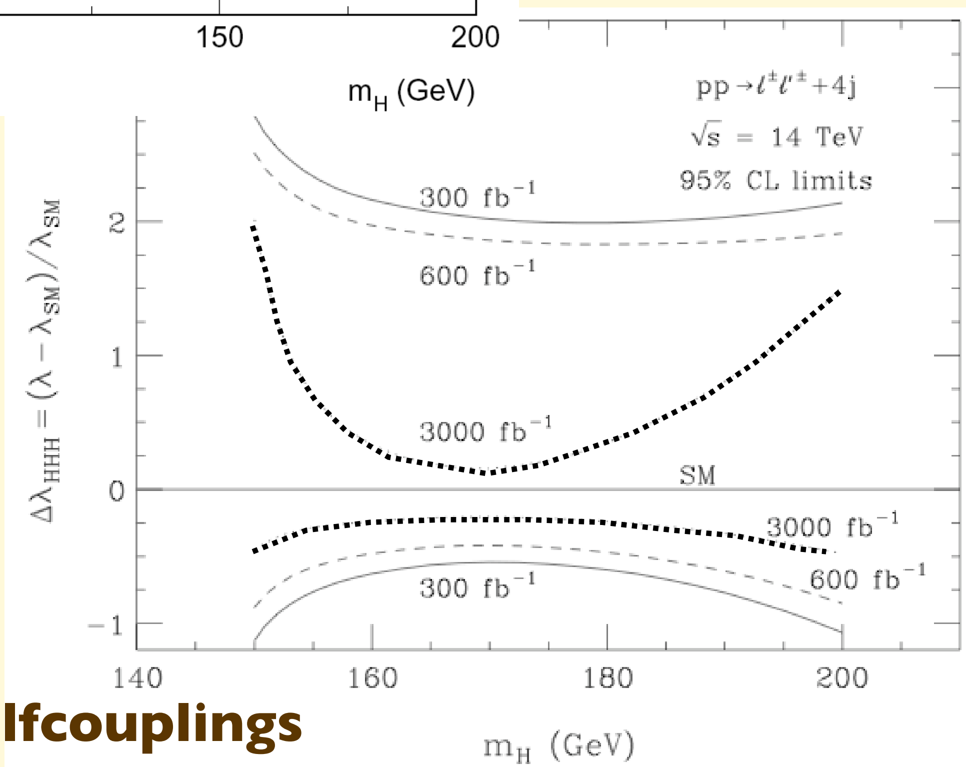
Very high masses, energies, rather insensititive to high-lum environment.
Not very demanding on detector performance
Slightly degraded detector performance tolerable

Measurement of Higgs couplings - Accuracy goal: 10-20%



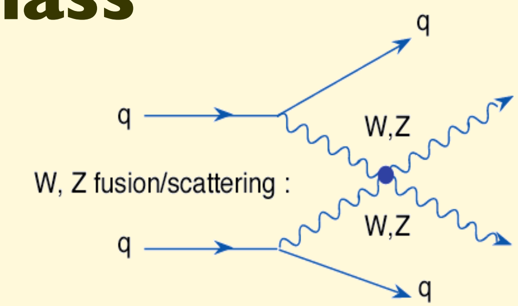


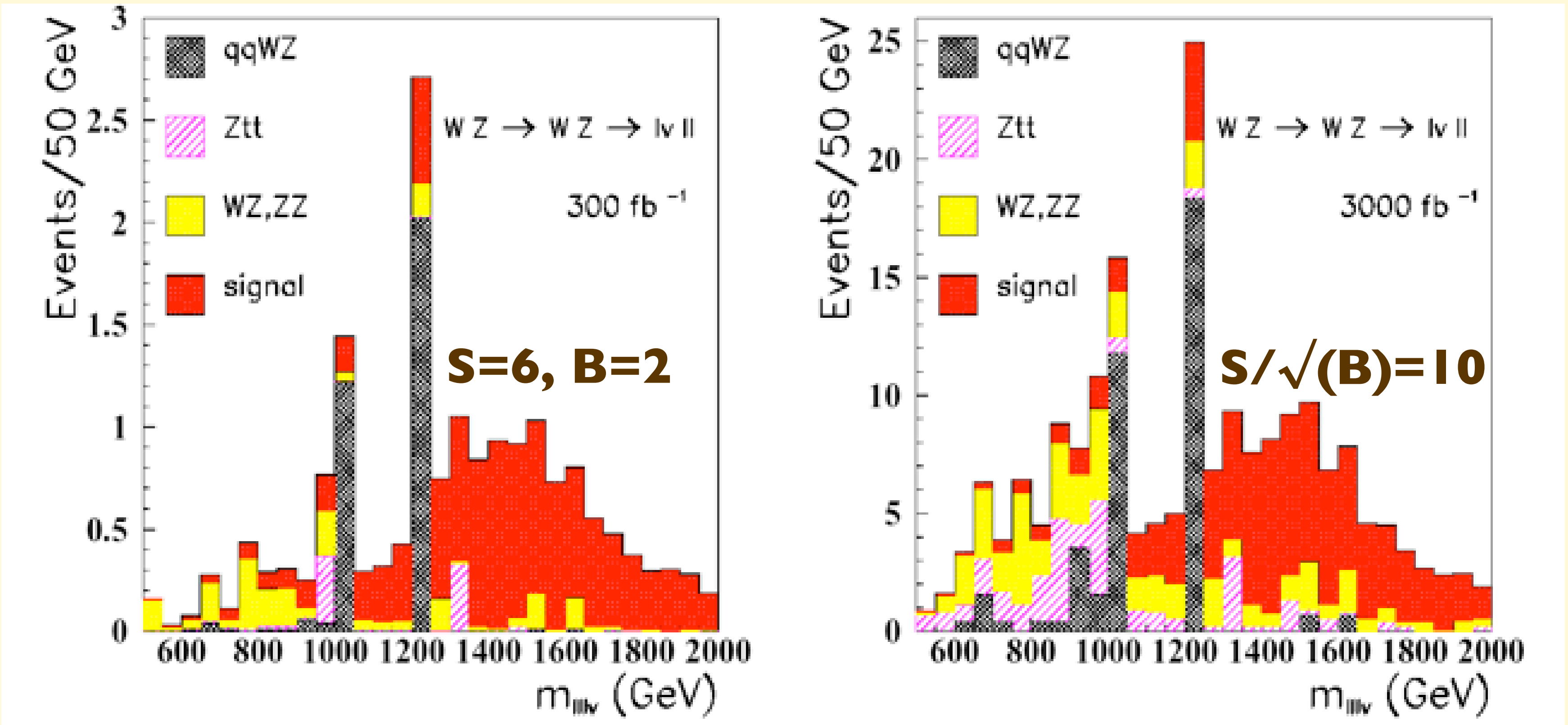
Higgs boson couplings to fermions and gauge bosons



Higgs boson selfcouplings

Strong resonances in high-mass WW or WZ scattering

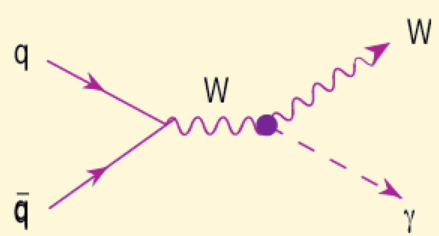


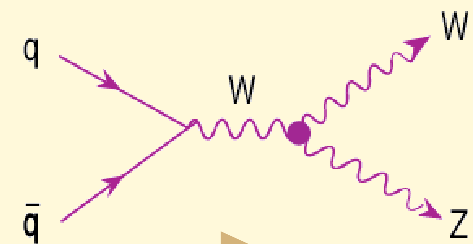


Vector resonance (ρ-like) in $W_L Z_L$ scattering from Chiral Lagrangian model
M = 1.5 TeV, leptonic final states, 300 fb^{-1} (LHC) vs 3000 fb^{-1} (SLHC)

Ex: Precise determinations of the self-couplings of EW gauge bosons

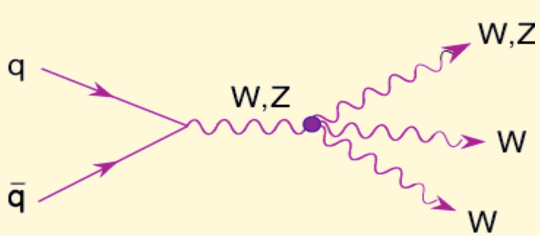
5 parameters describing weak and EM dipole and quadrupole moments of gauge bosons. The SM predicts their value with accuracies at the level of **10^{-3}**, which is therefore the goal of the required experimental precision

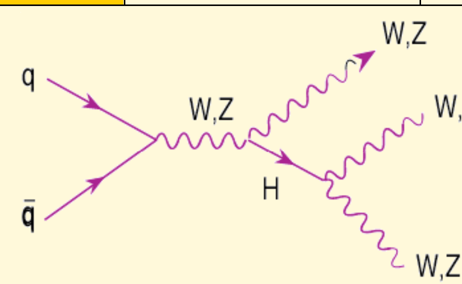




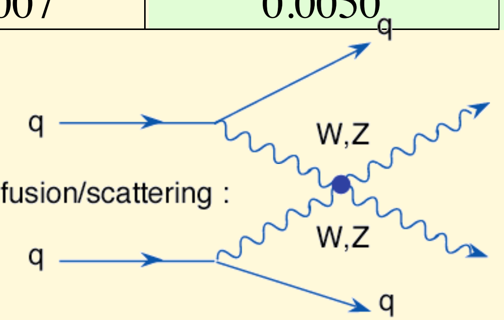
LHC options

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



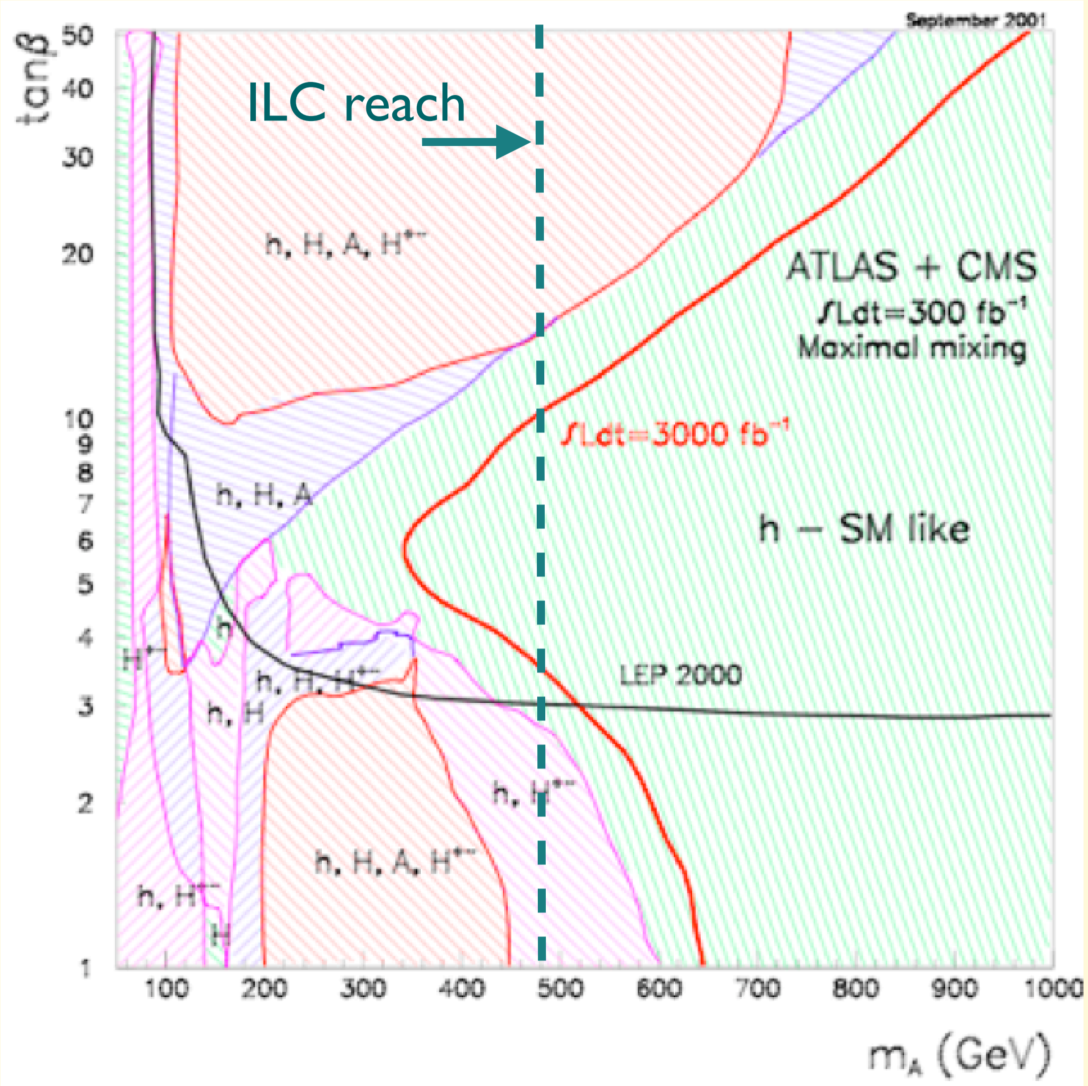


W, Z fusion/scattering :

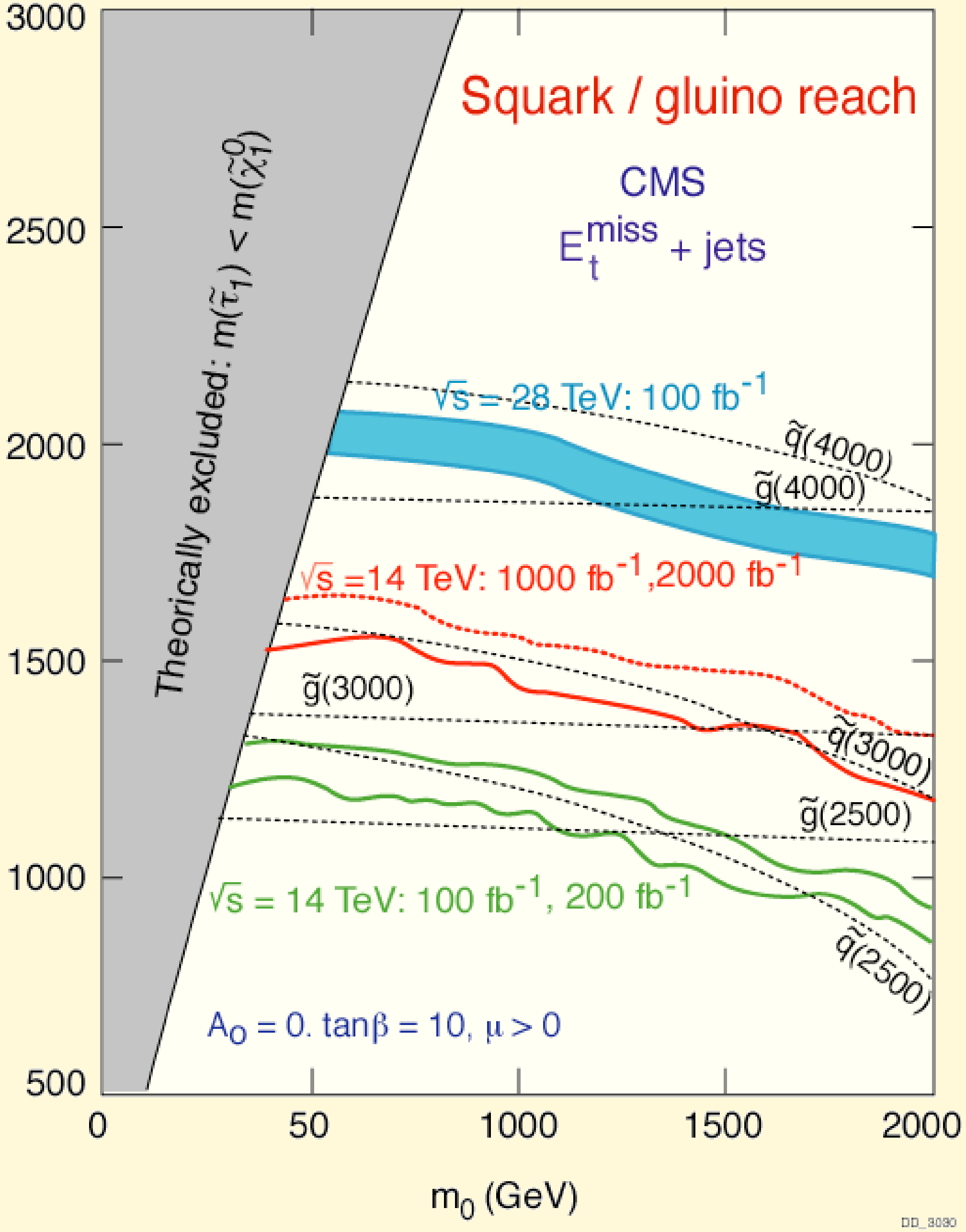


(LO rates, CTEQ5M, k ~ 1.5 expected for these final states)						
Process	*WWW*	*WWZ*	*ZZW*	*ZZZ*	*WWWW*	*WWWZ*
N(m_H = 120 GeV)	2600	1100	36	7	5	0.8
N(m_H = 200GeV)	7100	2000	130	33	20	1.6

Detecting the presence of extra H particles (as expected in SUSY)

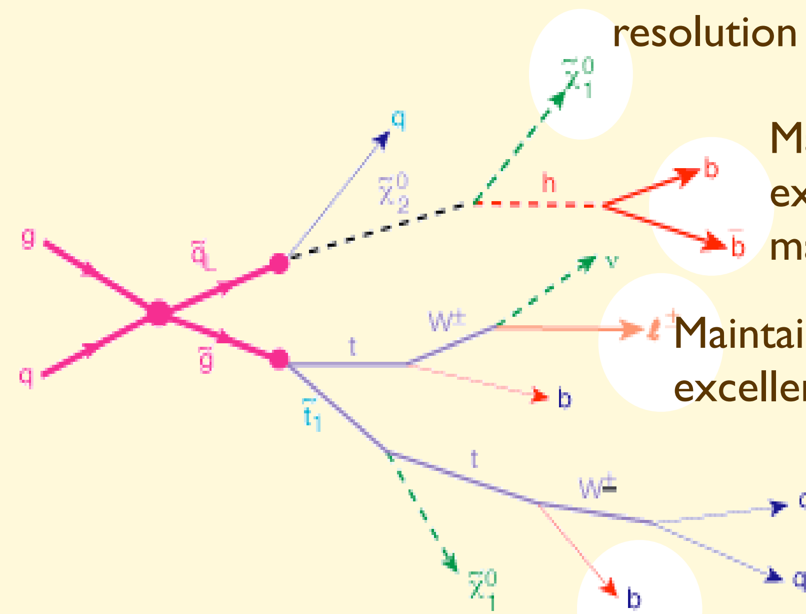


SUSY reach and studies



SLHC

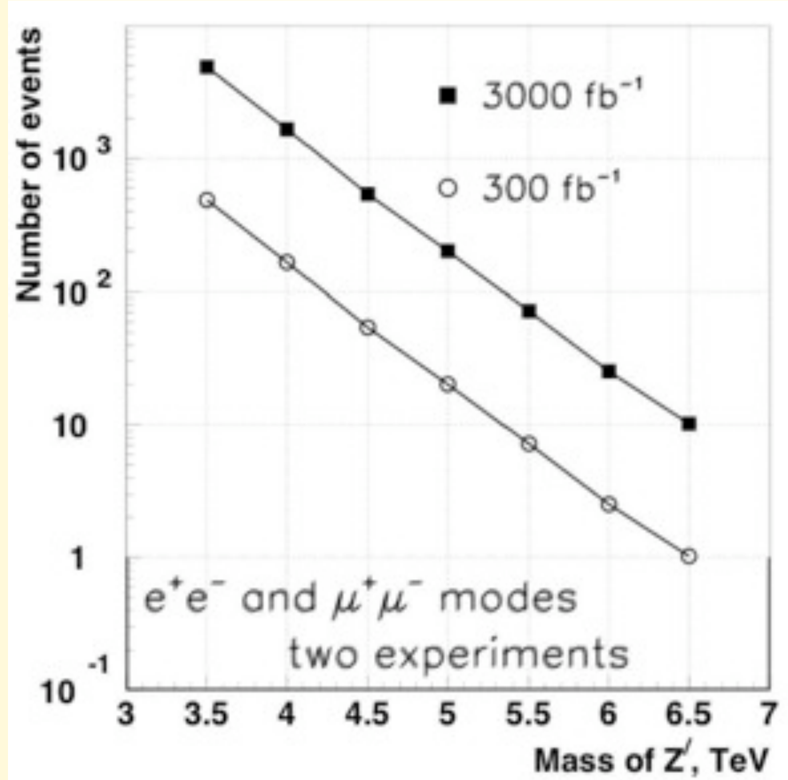
LHC



Mass reach: squarks and gluinos up to 2.5-3 TeV

Searching new forces: W’, Z’

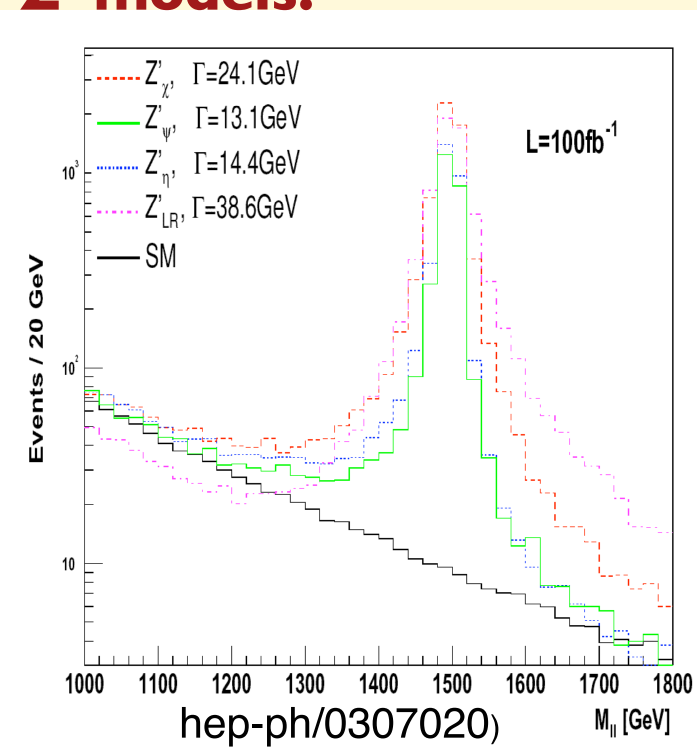
E.g. a W’ coupling to R-handed fermions, to reestablish at high energy the R/L symmetry

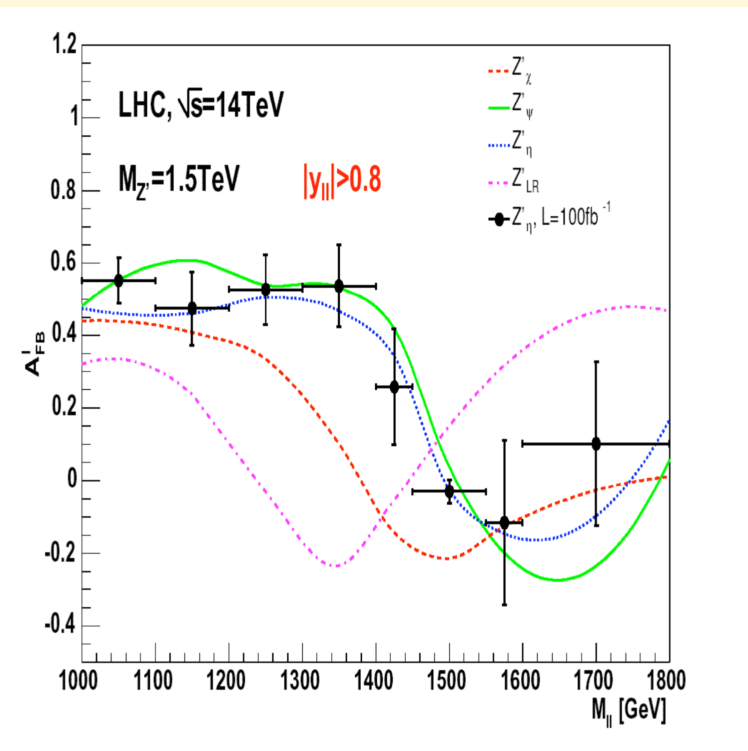


100 fb^{-1} discovery reach up to ~ 5.5 TeV

but ….

Differentiating among different Z’ models:

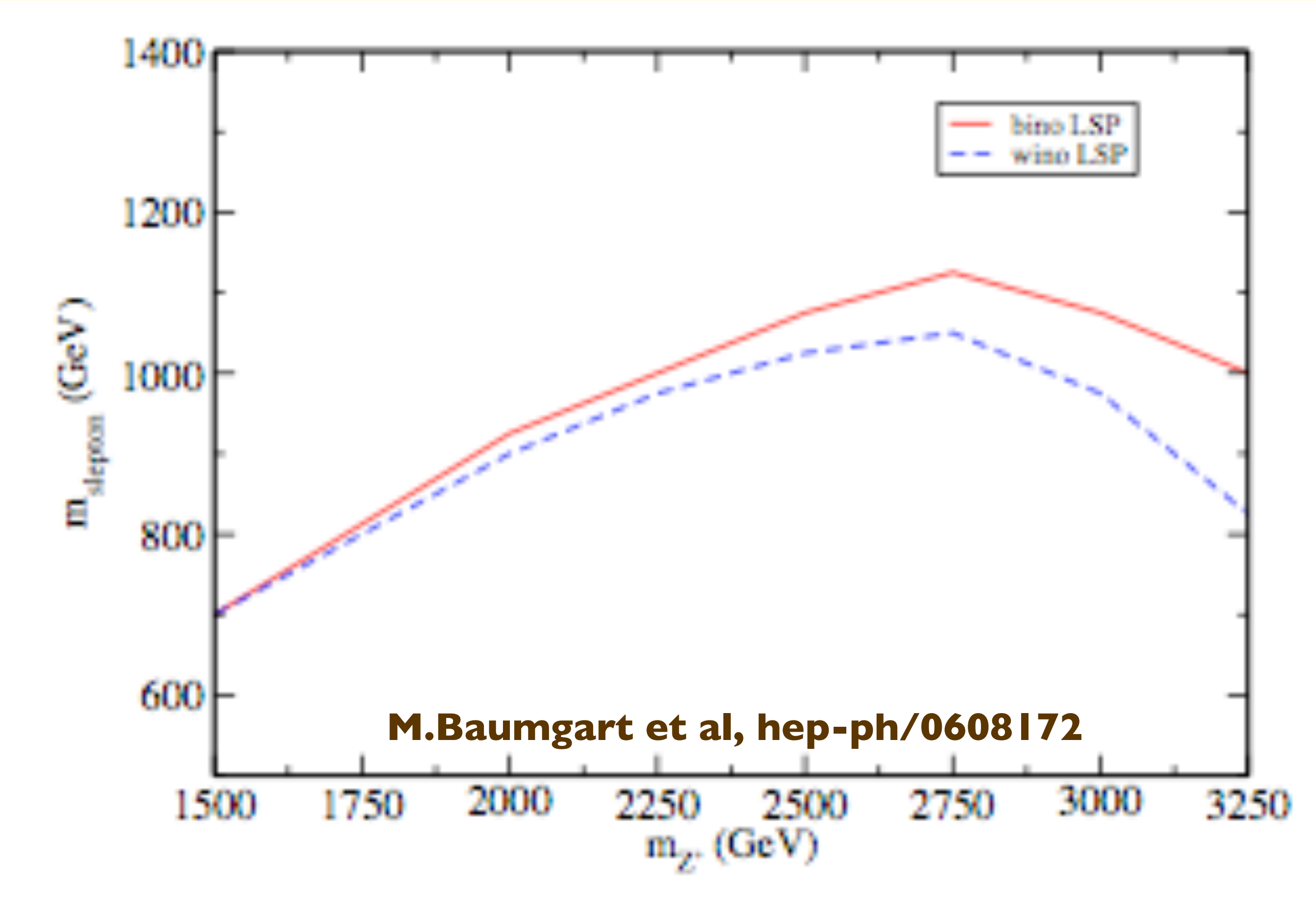




100 fb^{-1} model discrimination up to 2.5 TeV

Z’ and SUSY

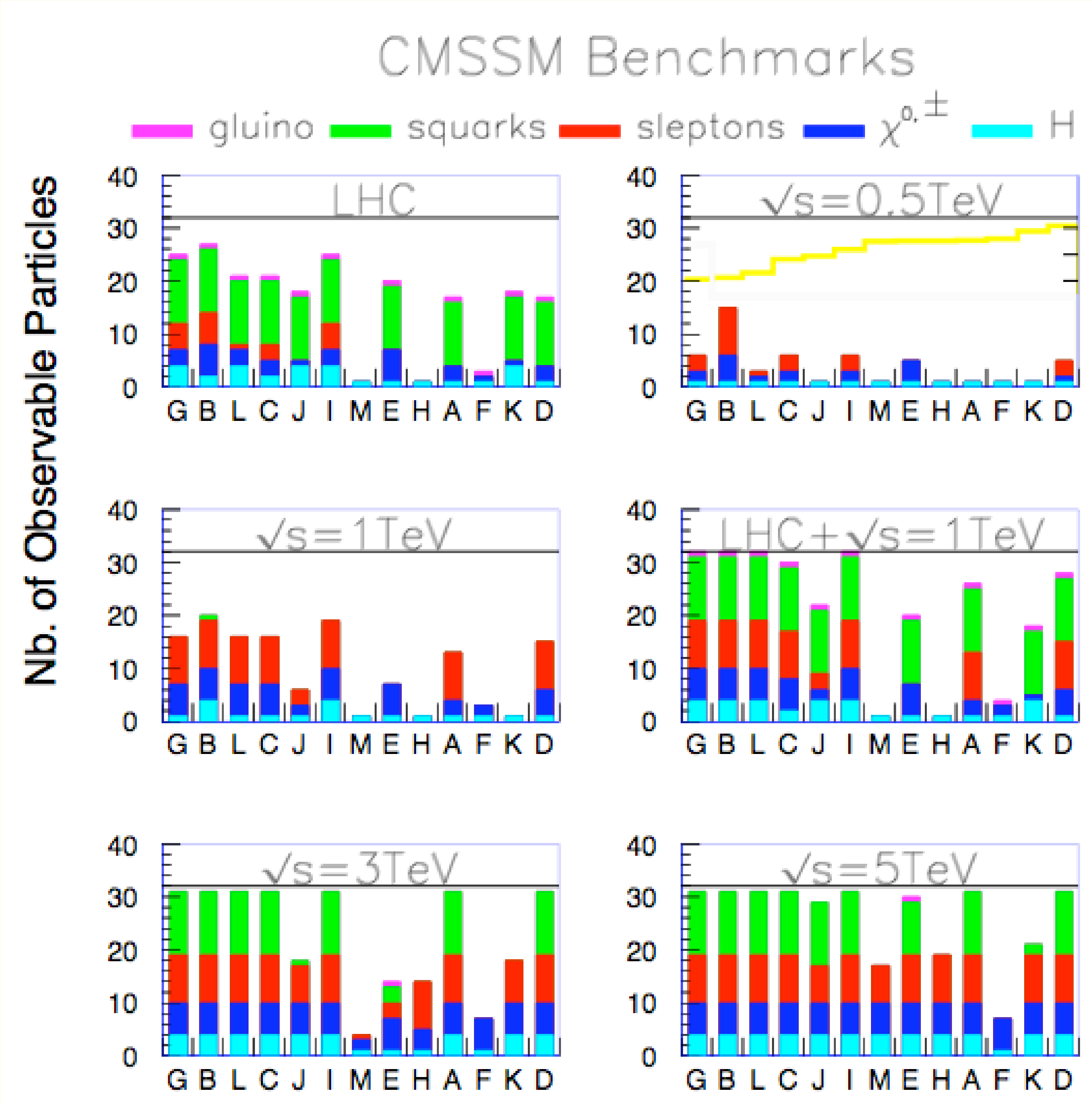
Discovery potential (100fb^{-1}) for sleptons, in presence of a Z’



(without Z’, can only access masses up to 2-300 GeV)

SUSY Beyond the LHC: ILC/CLIC

Example:
Exploration of the Supersymmetric particle spectrum, for 10 different SUSY models



Reference: Physics at CLIC, Battaglia, De Roeck, Ellis, Schulte eds., hep-ph/0412251

Neutrinos

- LEP: 3 weakly interacting neutrinos with $m<M_Z/2$
- 2 relative masses, one absolute mass scale, 3 mixing angles, 1 CKM phase δ, 2 extra relative phases if Majorana

$\|\Delta m^2_{23}\|$	Δm^2_{12}	m_1	$\sin^2\theta_{12}$	$\sin^2\theta_{23}$	$\sin^2\theta_{13}$	δ_i
$\sim 2.6\times10^{-3}$	$\sim 7\times10^{-5}$	?	0.2-0.4	0.3-0.7	<0.05	?

- Iff all $\theta_{ij}\neq 0$ and at least one phase $\delta\neq 0$, then CPV
  - Leptogenesis (lepton-driven B asymmetry of the Universe)
- Dark Matter: WMAP $\Rightarrow$ $\Omega_\nu<0.015$, $m_\nu<0.23$ eV

The completion of the neutrino programme, with the full determination of

mass hierarchy

majorana vs dirac nature

full spectrum of masses and mixing angles

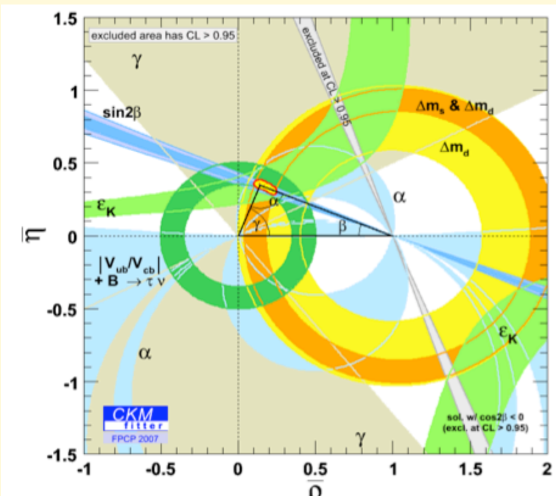
CPV phase(s)

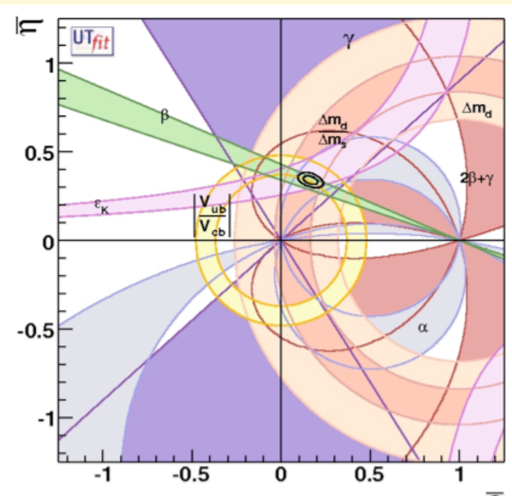
will "just" put us in the position we are today in the quark sector: we know masses and mixings, but have no idea where they come from.

This is not enough.

- To interpret these parameters we need to establish a **connection with the other sectors of the theory**

- We need a **redundancy of inputs** to expose deviations from the simple mixing picture. The equivalent of all redundant measurements of CKM offered by the many channels where we measure CKM angles and phases





Neutrinos and SUSY

For details and refs, see: Masiero, Profumo, Vempati, Yaguna, hep-ph/0401138

The merging of neutrino masses, SUSY and GUT leads to very interesting constraints and consequences:

SUSY ⇒ Higgs field giving Dirac υ mass = Higgs field giving up-quark masses

$$L_m \propto y_\ell H_d L_i L_i^c + y_\nu^{ij} H_u L_i N_j + M_N^{ij} N_i N_j$$

GUT (e.g. SO(10)) ⇒ Yukawa ν-mass matrix = Up-quark Yukawa matrix

$$L_m \propto y_{i,j}^{d,\ell} \mathbf{16}_i \mathbf{16}_j H_d + y_{i,j}^{u,\nu} \mathbf{16}_i \mathbf{16}_j H_u + y_{i,j}^{R} \mathbf{16}_i \mathbf{16}_j H_R^{126}$$

where $\mathbf{16} = (u_L, d_L, u^c, e^c)_{10} + (d^c, L)_5 + N^c$

⇒ one entry in the neutrino Yukawa matrix is of order of the top Yukawa coupling!

⇒ $m(N_R) = f(m_{up}, m_\nu) \approx (m_t^2 / m_\nu,\ m_c^2 / m_\nu, m_u^2 / m_\nu)$

⇒ $m_\nu > m_t^2 / M_{GUT}$ to ensure that $m(N_R) < M_{GUT}$

Even more interestingly, quark mixings induce charged **slepton** mixing via RG evolution from M_{GUT} to $m(N_R)$:

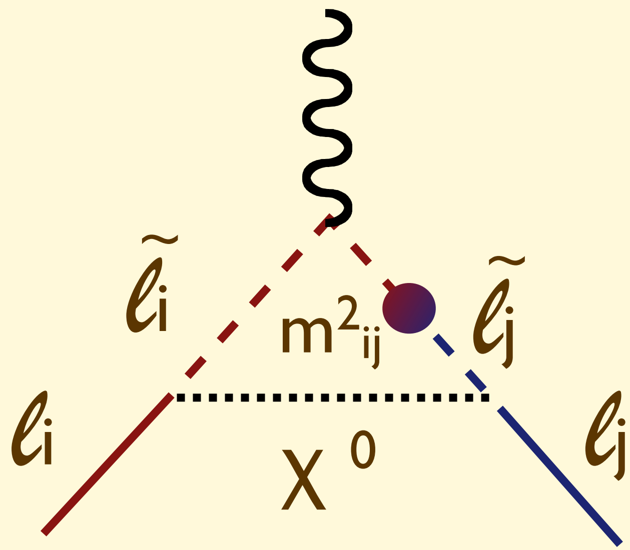
$$(m^2_{\tilde{L}})_{ij} \sim -\frac{3m_0^2 + A_0^2}{8\pi^2}\, y_t^2\, O_{ij} \log\frac{M_{GUT}}{M_{N_R}}$$

SUSY breaking param's

nu mixing param's

$y_t^2\, O_{ij} = \sum_k\; y^\nu_{ik}\, y^{\nu *}_{jk}$

$\ell_i \to \ell_j\, \gamma$ transitions:

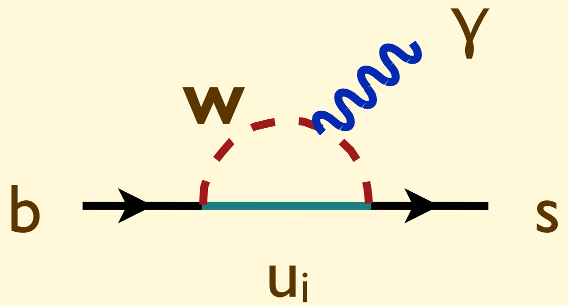


Possible scenarios:

$O_{\mu e} = V_{td} V_{ts}$ "CKM
$O_{\tau\mu} = V_{tb} V_{ts}$ scenario"

$O_{\mu e} = U_{e3} U_{\mu 3}$ "MNS
$O_{\tau\mu} = U_{\tau 3} U_{\mu 3}$ scenario"

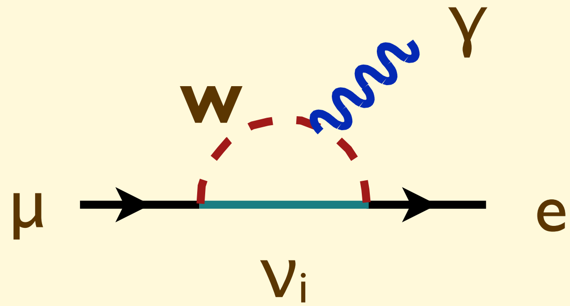
In the SM



GIM

O(1)

$$\propto \left| \frac{m_c^2 - m_u^2}{m_W^2} V_{cb} V_{cs}^* + \frac{m_t^2 - m_u^2}{m_W^2} V_{tb} V_{ts}^* \right|^2 \sim \frac{m_t^4}{m_W^4} |V_{tb} V_{ts}^*|^2$$



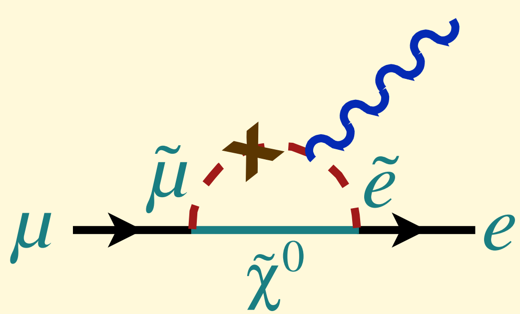
$O(10^{-49})$

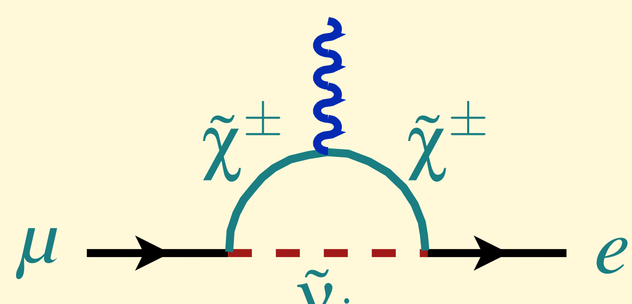
$$\propto \left| \frac{m_1^2 - m_2^2}{m_W^2} M_{12} M_{11}^* + \frac{m_3^2 - m_2^2}{m_W^2} M_{32} M_{31}^* \right|^2 \sim \frac{\Delta m_{23}^4}{m_W^4} s_{23}^2\, c_{31}^2\, s_{31}^2$$

The smallness of B(μ→eγ) is entirely due to the smallness of ν masses (and splittings)

The moment we have new states in the loop, the rates goes up!

Example: SUSY



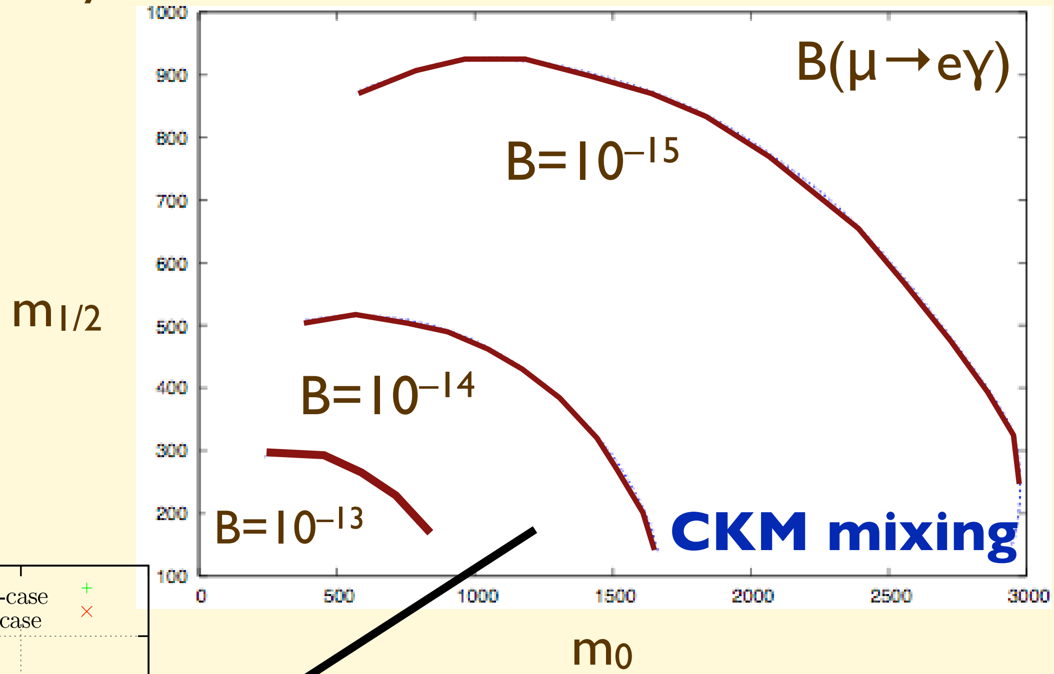


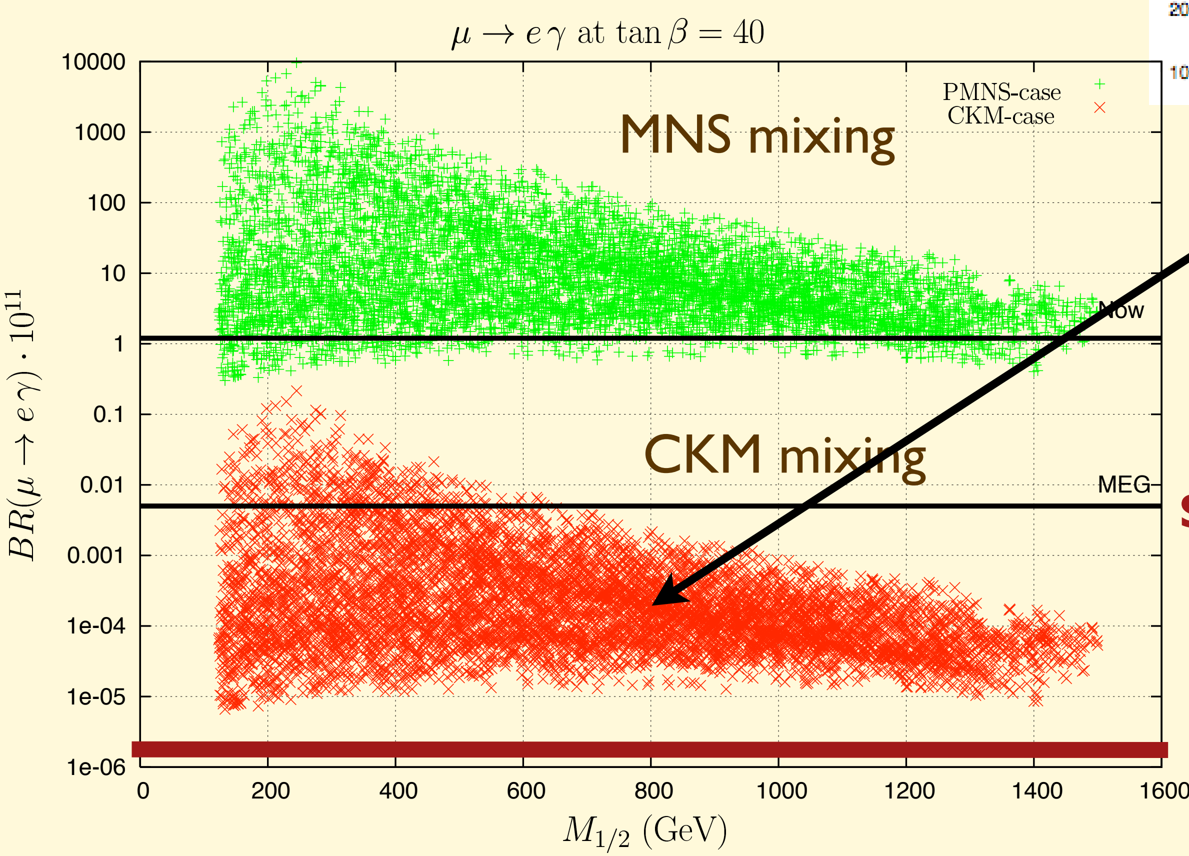
$$B \propto \left| \frac{\Delta m^2(\tilde{\nu})}{m_{\tilde{\chi}}^2} \times \varepsilon_{12}^2 \right|^2$$

Examples of LHC-(μ→eγ) sinergy:

SO(10) GUT scenario, slepton mixign induced by RG evolution

To push to the ultimate LHC squark reach (m~2.5–3 TeV) may require sensitivity to B(μ→eγ) ~ 10^{-15}



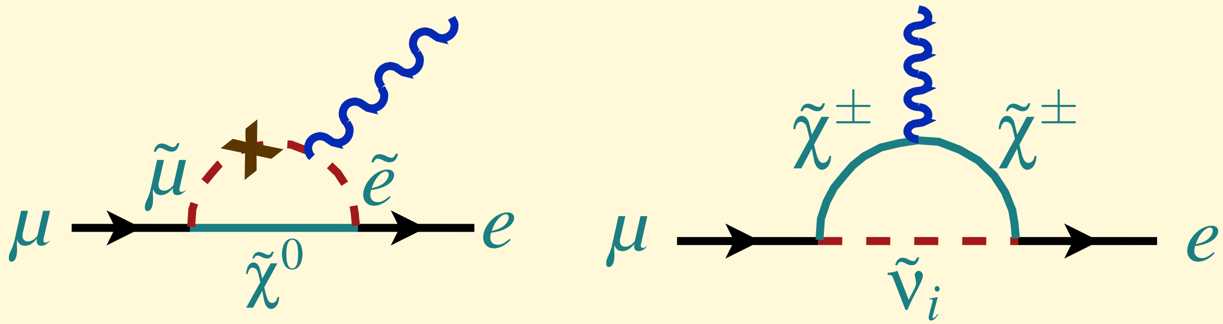


SO(10) mSUGRA scan with m(squark)<2.5 TeV

Calibbi et al, hep-ph/0605139

Sensitivity of MEG experiment

Sensitivity of Project-X mu2e conversion



Neglecting mixing, these diagrams are also responsible for $(g\text{-}2)_\mu$

Assuming that the BNL data are explained by SUSY,

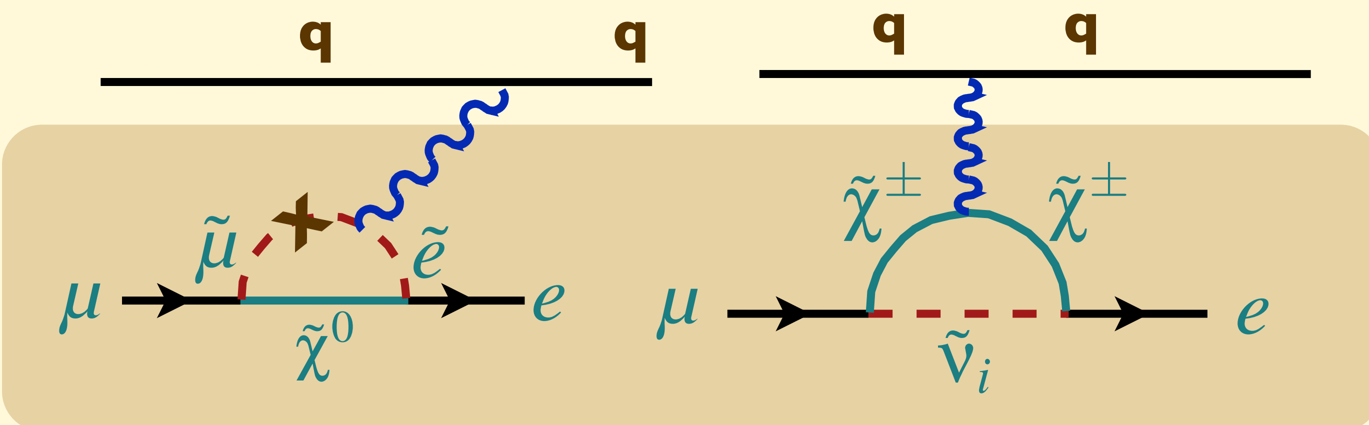
$$(g\text{-}2)_\mu^{data} - (g\text{-}2)_\mu^{SM} = (g\text{-}2)_\mu^{SUSY}$$

sets a scale for m(SUSY) ~ 100 GeV

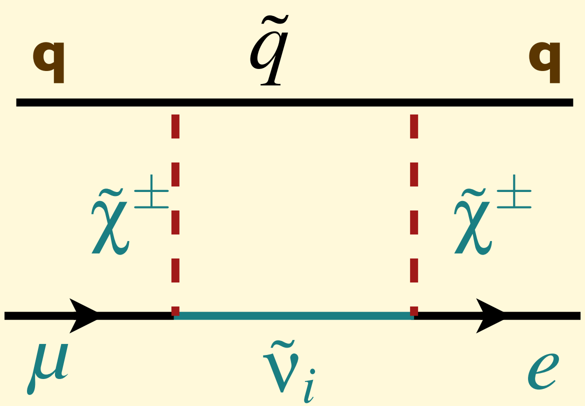
Current B($\mu \to e\gamma$) limits then indicate mass splittings in the slepton sector of few 10s MeV !!

Sensitive to natural mass splittings $m(\tilde{\mu})-m(\tilde{e}) \sim O(m_\mu)$

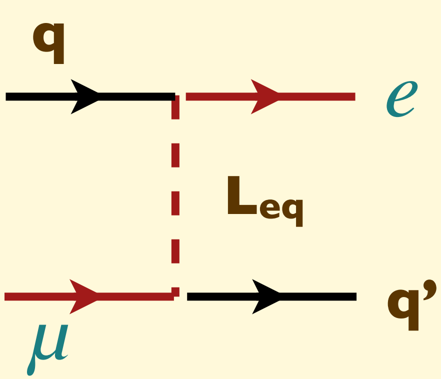
$\mu \to e\gamma$ vs $\mu N \to eN$ complementarity

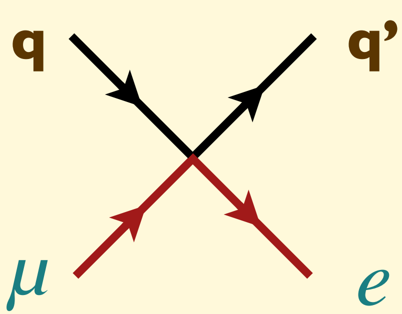


$\mu \to e\gamma$ diagrams



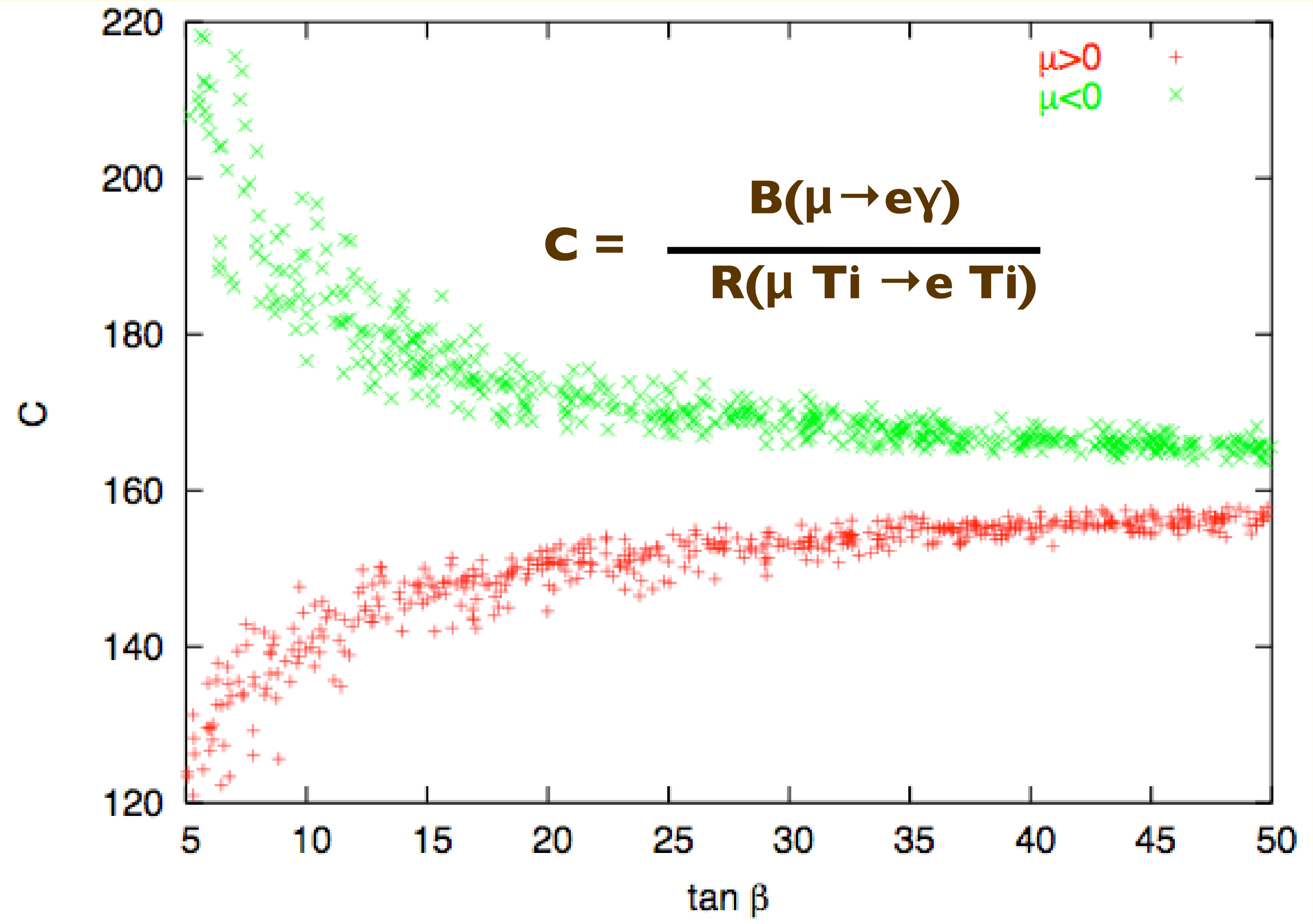
extra contributions, sensitive to additional model parameters





extra contributions, sensitive to other underlying dynamics

$K \to e\mu$?



C Yagouna, hep-ph/0502014

$\mu \to e\gamma$

Current limits on $B(\mu \to e\gamma)$

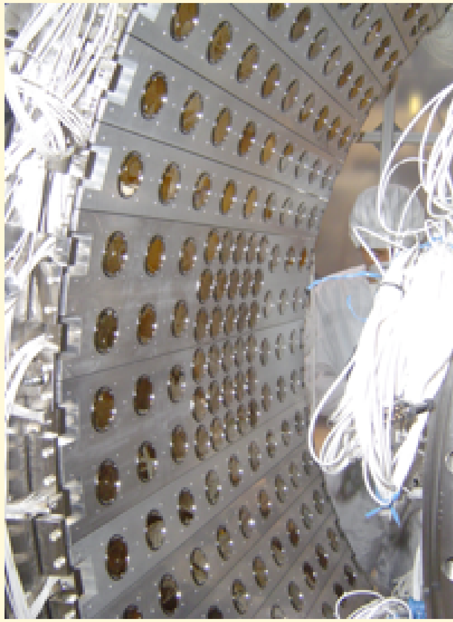
mode	upper limit (90% C.L.)	year	Exp./Lab.
$\mu^+ \to e^+\gamma$	1.2×10^{-11}	2002	MEGA / LAMPF
$\mu^+ \to e^+e^+e^-$	1.0×10^{-12}	1988	SINDRUM I/ PSI
$\mu^+e^- \leftrightarrow \mu^-e^+$	8.3×10^{-11}	1999	PSI
μ^- Ti $\to e^-$Ti	6.1×10^{-13}	1998	SINDRUM II / PSI
μ^- Ti $\to e^+$Ca*	3.6×10^{-11}	1998	SINDRUM II / PSI
μ^- Pb $\to e^-$Pb	4.6×10^{-11}	1996	SINDRUM II / PSI
μ^- Au $\to e^-$Au	7×10^{-13}	2006	SINDRUM II / PSI

Future:

near: $\mu \to e\gamma$

MEG at PSI http://meg.web.psi.ch/

- o First data taking 2008, single-event sensitivity at BR<$\mathbf{5x10^{-12}}$
- o Run Fall 2009 underway, full detector => match current limits
- o New 2-yr run to start April 2010
- o ultimate sensitivity: BR<$\mathbf{1x10^{-14}}$ at 90%CL by 2011



far: $\mu \to e$ conv

MU2e at Fermilab

- o 1st stage DoE approval achieved Fall 09. Could be taking data by 2016
- o sensitivity: $R(\mu \to e) < \mathbf{6x10^{-17}}$ @90%CL $\to \mathbf{10^{-18}}$ with Project-X

↙

(i.e. BR< $\mathbf{\sim 10^{-14}}$ if only ($\mu \to e\gamma$) diagrams contribute)

More physics with charged leptons

- $\mu \to eee$ (typically $O(\alpha)$, but $O(1)$ in LH models)
- $\tau \to \mu\,\gamma$ $\tau \to e\,\gamma$: model-dependent correlations with $\mu \to e\gamma$
- $\tau \to \mu\mu\mu$ (LHCb ?)
- CP violation in SM-allowed τ decays?
  - $O(10^{-3})$ CP asymmetry in $\tau \to \nu K\pi$ ⇨ $B(\tau \to \mu\,\gamma) \sim O(10^{-9})$
- .....

Example of correlations between ν and quark-sector observables

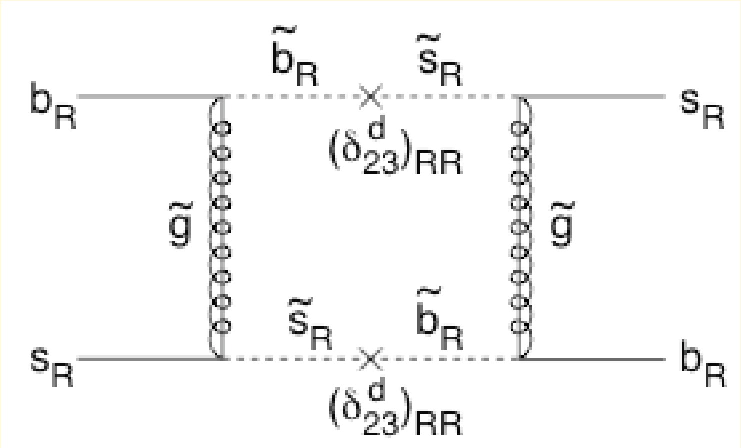
$$L_m \propto y^{d,\ell}_{i,j}\,\mathbf{16}_i\mathbf{16}_j H_d + y^{u,\nu}_{i,j}\,\mathbf{16}_i\mathbf{16}_j H_u + y^{R}_{i,j}\,\mathbf{16}_i\mathbf{16}_j H_R^{126}$$

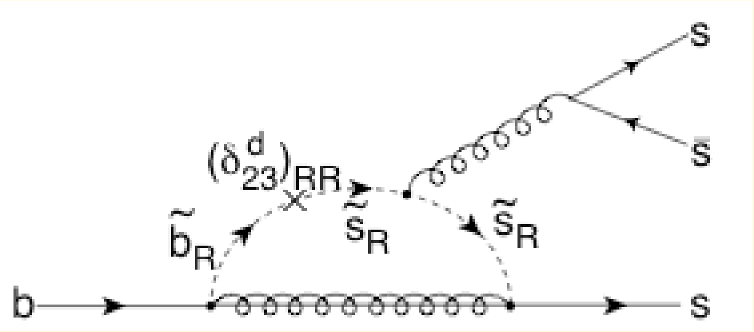
$$\mathbf{16} = (u_L, d_L, u^c, e^c)_{10} + (d^c, L)_5 + N^c$$

A large mixing between ν_μ and ν_τ implies a large mixing between

$$(b_R, \bar{\nu}_\tau, \tau^+) \qquad (s_R, \bar{\nu}_\mu, \mu^+)$$

This has no direct impact on phenomenology, since right-handed quarks do not couple to weak interactions. However it leads to a large mixing between the scalar partners of R-handed squarks, and to interactions like





with potentially large contributions to:

Bs mixing, CP violation in Bs→φψ (~0 in the SM)

sin2β(B→φKs) ≠sin2β(B→ψKs)

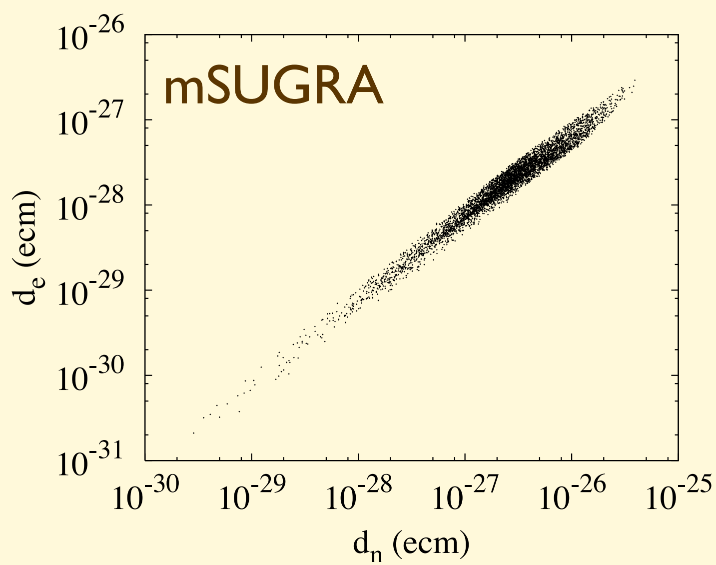
EDMs

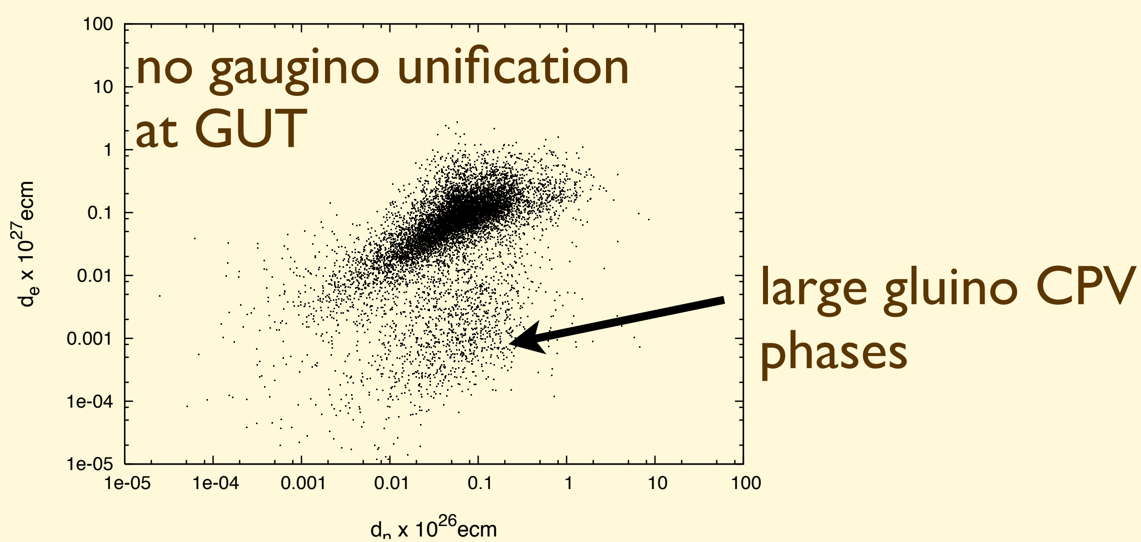
- **Flavour-conserving CPV**
- **Sensitive probes of CPV in extended gauge sectors (e.g. SUSY gluinos, gauginos, higgsinos)**

Probes of mechanisms to generate the antimatter asymmetry of the universe

d_e / d_n correlations:

SUSY: $d_e / d_n \sim m_e/m_q \sim 0.1$





Extra-dim, 2HDM: $d_e / d_n << 1$

Atoms:

paramagnetic (Tl): – fundamental electron EDM

– CPV eeqq interactions

diamagnetic (Hg): – fundamental electron EDM

– fundamental quark EDM and θ_{QCD}

– CPV eeqq interactions

heavy molecules with unpaired electrons (YbF): – fundamental electron EDM

Neutron:

– fundamental quark EDM and θ_{QCD}

– higher-dim CPV qq operators (int^{ns} with gluinos, etc)

Neutron EDM

Current limit: $d_{neutron}$ = **3×10^{-26}** e cm

C.A. Baker et al, (RAL, Sussex, ILL Grenoble)
http://arxiv.org/pdf/hep-ex/0602020

Forthcoming experiments with ultracold neutrons:

ILL (Grenoble) and **PSI**

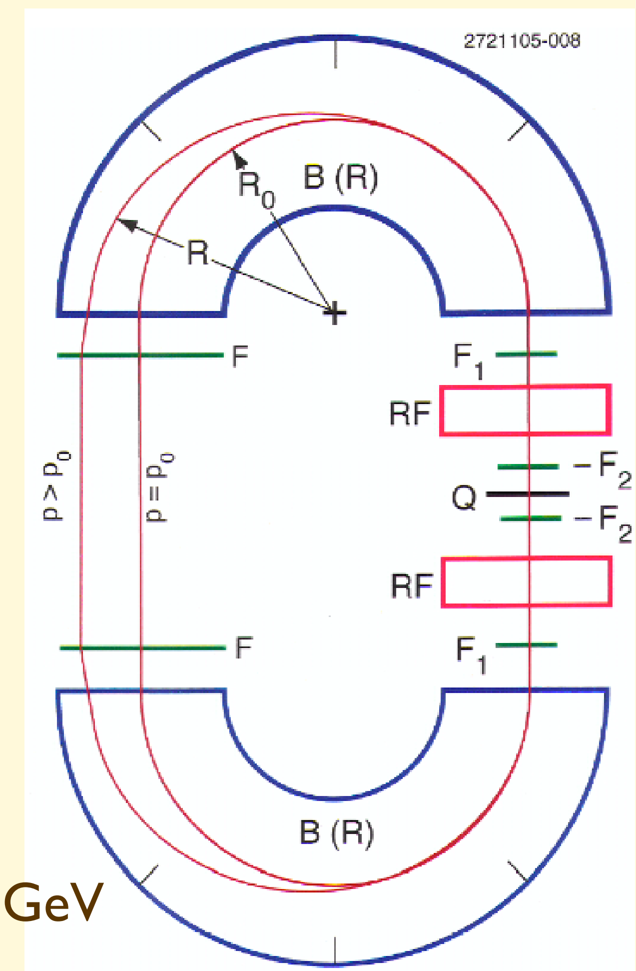
- R&D and construction of new detectors/beamline
- new runs 2009-2011 (ILL) and 2011-2014 (PSI)
- Goal: $d_{neutron}$ < **$\sim 2 \times 10^{-28}$** e cm/yr

⇨ **probe SUSY CPV phase of $O(10^{-4})$**

Deuteron EDM in a storage ring

Orlov, Morse, Semertzidis,
http://arxiv.org/pdf/hep-ex/0605022

- Inject deuterons from LEIR, CERN's low-energy ion ring used to prepare heavy ion beams for the LHC
- Sensitivity: σ_d = **2.5×10^{-29}** e cm/yr



1.5 GeV

Rare K decays

$K_L^0 \to \pi^0 \nu \nu$ $B(K_L^0 \to \pi^0 \nu \nu)_{SM}$ = **$2.8 \pm 0.4 \times 10^{-11}$**

E391 at KEK, final result:
$B(K_L^0 \to \pi^0 \nu \nu) < 2600 \times 10^{-11}$ @ 90% CL
arXiv:0911.4789

K0T0 (E14) at JPARC
http://www-ps.kek.jp/jhf-np/NuclPart/0701/Day2_AM/E14.ppt.pdf

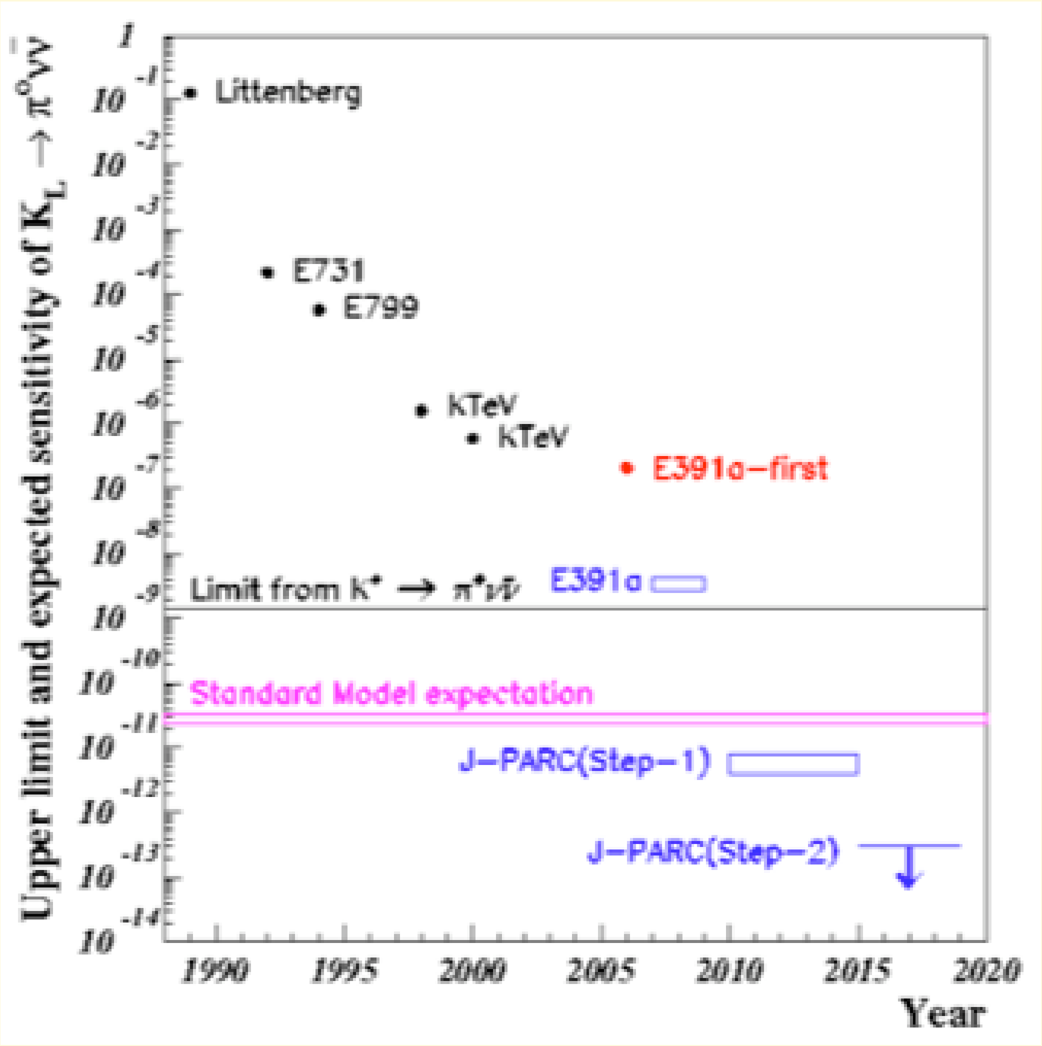
o Aim to 3000 x rate[E391]

o Detector completion: 2010

o Beam construction/survey: 2009. Status: K_L observed, Dec 7

o Data: 2012-20

o Goal: $O(10^{-13})$, ΔBR~10%



Rare K decays, CERN

$K^+ \to \pi^+ \nu \nu$ $B(K^+ \to \pi^+ \nu \nu)_{E787/949\ BNL}$ = **$1.73 \pm 1 \times 10^{-10}$** (3 events, arXiv:0808.2459)

$B(K^+ \to \pi^+ \nu \nu)_{SM}$ = **$0.85 \pm 0.07 \times 10^{-10}$**

Expected reduction to 4% error via NNLO +better input parameters (m_{top}, etc)

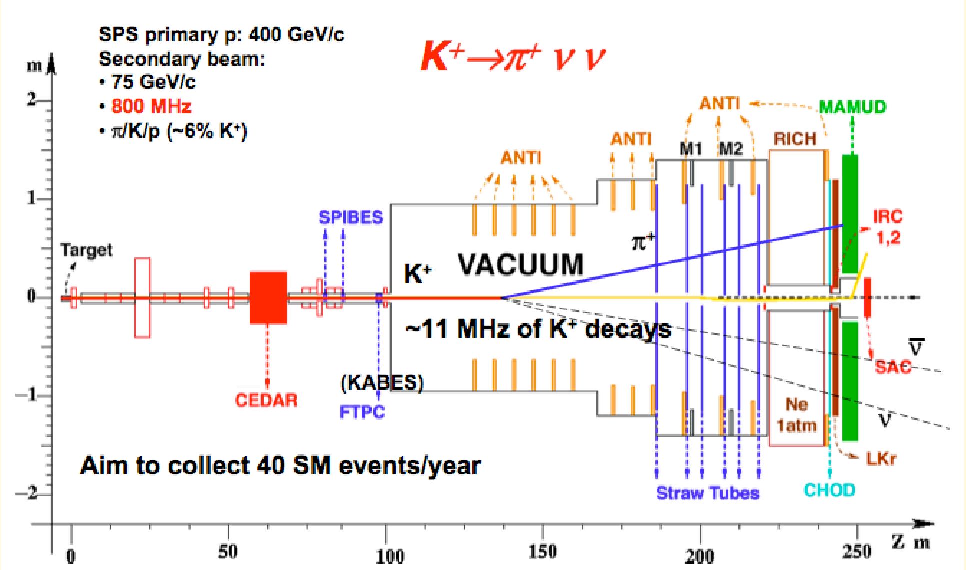
NA62

http://na48.web.cern.ch/NA48/NA48-3/

o R&D ongoing, with 2007 run for $R_{e/\mu} = \Gamma(K \to e\,\nu) / \Gamma(K \to \mu\,\nu)$ to 0.3%

o Ready for beam: Fall 2012

o Goal: 80 events (@SM rate) in 2 yrs of run, S/B=10/1 $\Rightarrow \delta|V_{td}|$=10%



$K_L^0 \to \pi^0 e^+e^-$ $K_L^0 \to \pi^0 \mu^+\mu^-$ **NA48/4**

$K_L^0 \to \pi^0 \nu \nu$ **NA48/5**

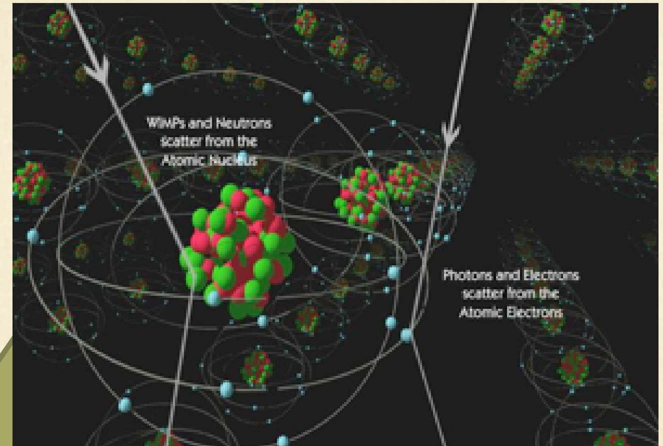
Require more protons than available from the SPS today

2015, a dream scenario

- SUSY is seen at LHC, with squarks/gluinos at ~ 1 TeV, weak sparticles at ~0.1 TeV
- Observe in parallel:
  - LHC: $B_S \to \mu^+\mu^-$ at rates > SM, and NA62: $K^+ \to \pi+ \nu\nu$ at rates > SM
  - MEG: $\mu \to e\gamma$
  - ILL/PSI: neutron EDM
  - large θ_{13} → measurable CP violation in nu mixing
- Z' at 2–2.5 TeV seen at LHC:
  - open decays to all SUSY sparticles => very accurate studies
  - the LHC turns into a Z' factory
  - CLIC is above threshold to further study it in the future
- Direct DM detection underground fits well neutralino properties
- .....

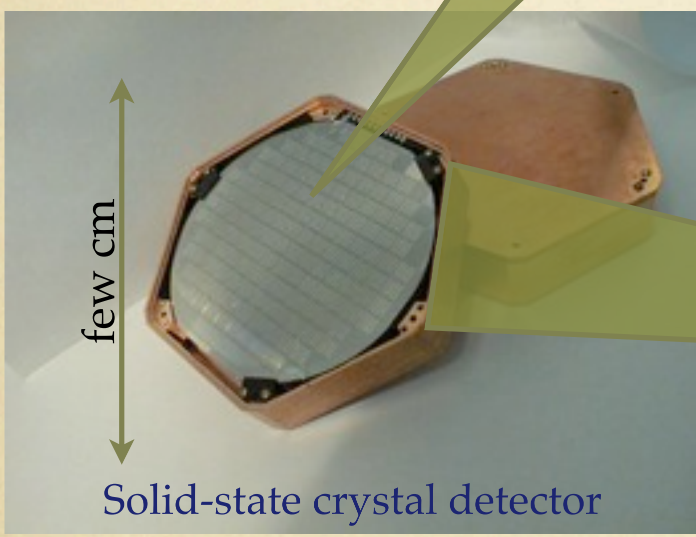
It's a dream, but not an impossible one !

Search for Direct <u>detection</u> of Dark Matter particles flying through the galaxy



CDMS experiment,
Stanford and Soudan mine

See http://cdms.berkeley.edu/



Solid-state crystal detector

Cryogenic box

Dec 17 2009:

- reported results of 2007-08 exposure (2xprevious results)
- **2 events ~ → 25% probability of being bg**
- will have 3 x the current detector volume available by Summer 2010

Conclusions

- **Progress in the field will be 100% driven by new and better experimental data.** We are running out of ideas and tools to make progress based on first principles only.
- Nevertheless, we created scenarios for BSM physics which, in addition to addressing the most outstanding **theoretical puzzles** and the **established deviations** from the SM (DM, BAU, nu mixing), predict galore of new phenomena at energy and accuracy scales just behind the corner
- Maintaining **diversity** in the exp'l programme is our best investment for HEP.