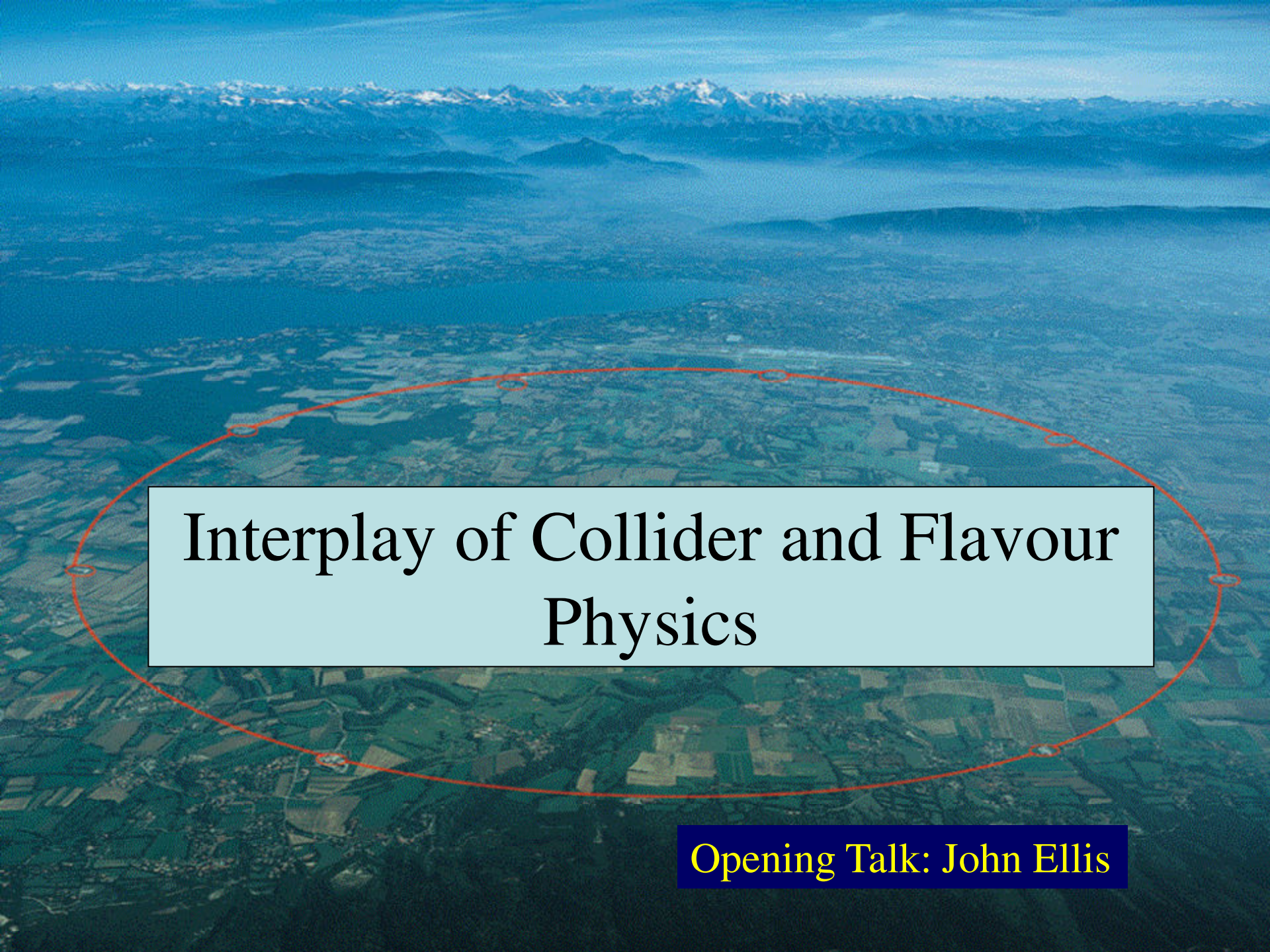


Interplay of Collider and Flavour Physics

Opening Talk: John Ellis

Open Questions beyond the Standard Model

- What is the origin of particle masses?
  due to a Higgs boson? + other physics?
  solution at energy < 1 TeV (1000 GeV)
- Why so many flavours of matter particles?
  mixing and CP violation?
- Unification of the fundamental forces?
  at very high energy ~ 10^{16} GeV?
  probe directly via neutrino physics, indirectly via masses, couplings
- Quantum theory of gravity?
  (super)string theory: extra space-time dimensions?

LHC

LHC

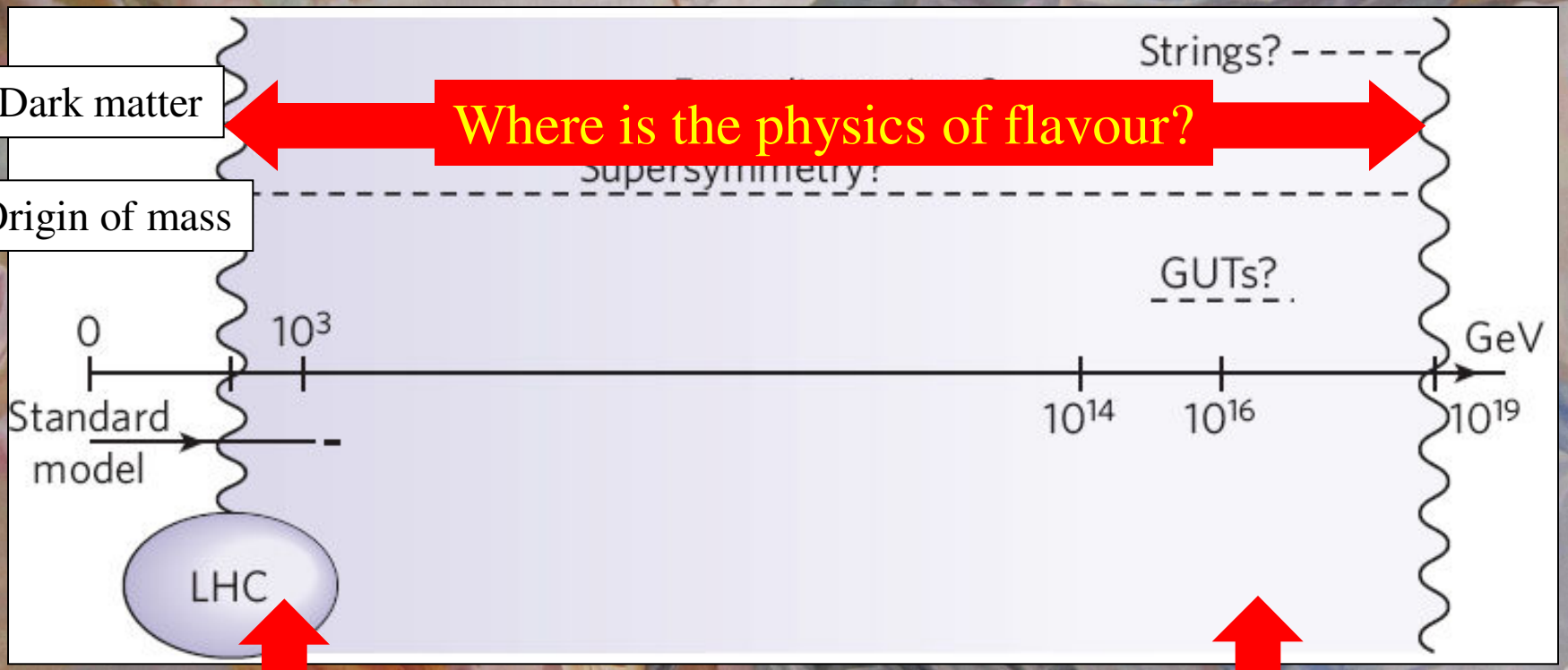
LHC

LHC

High-p_T Physics Meets Flavour

- The major particle physics objectives of the LHC
  - ATLAS, CMS, LHCb
- Good reasons to expect new physics at the TeV scale:
  - Higgs, naturalness, dark matter
- No clue where flavour physics originates
- What is flavour structure of TeV physics?
- How to reveal it?
  - Combine direct and indirect approaches

At what Energy is the New Physics?



A lot accessible to the LHC

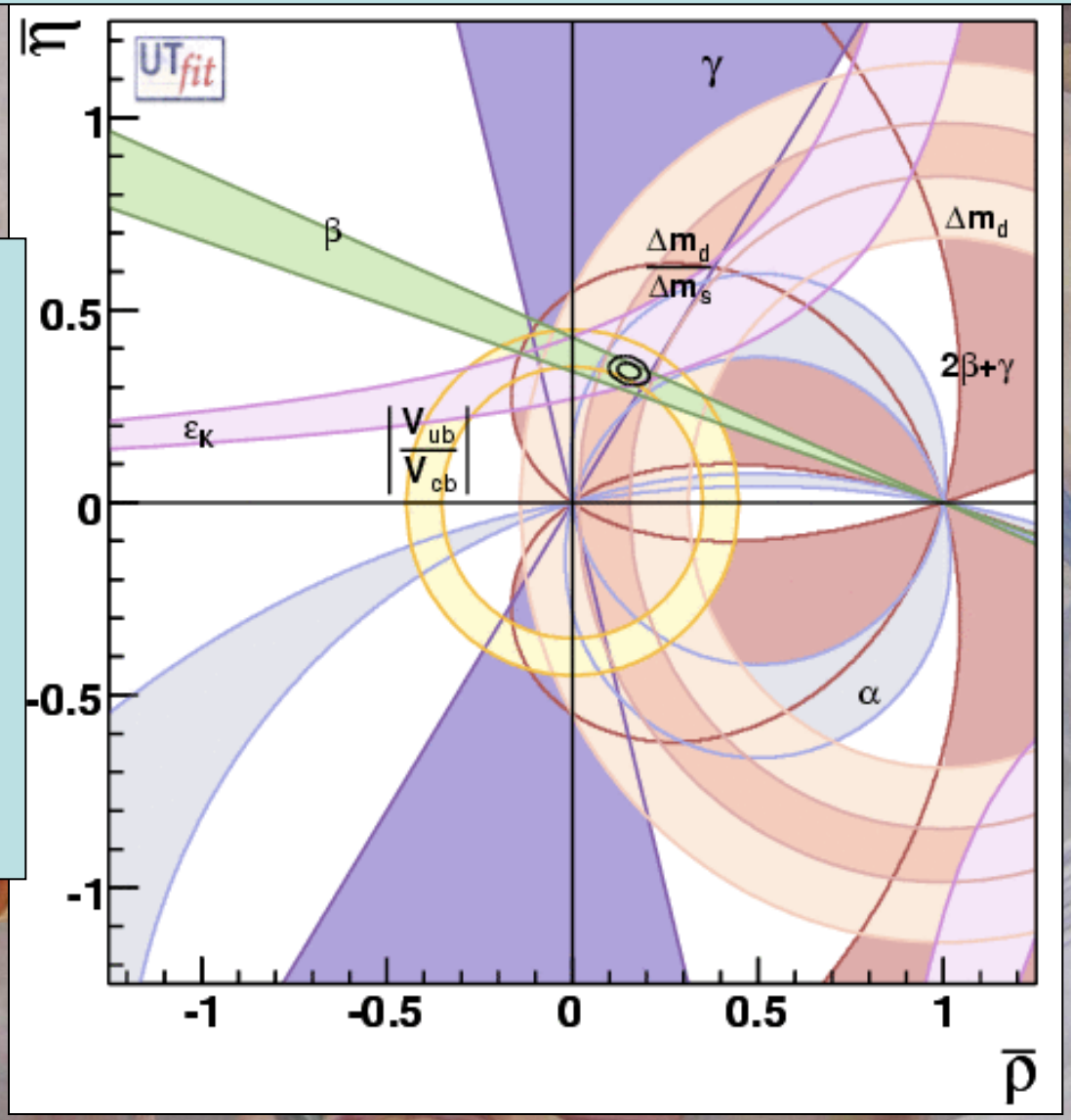
Some accessible only indirectly

The Dogs that did (not) Bark

- In the quark sector:
  - CKM model describes perfectly the available data on quark mixing and CP violation
  - Passes consistency tests
- In the lepton sector:
  - MNS model describes neutrino mixing
  - No consistency tests
  - Muon anomalous magnetic moment may suggest new physics at the TeV scale

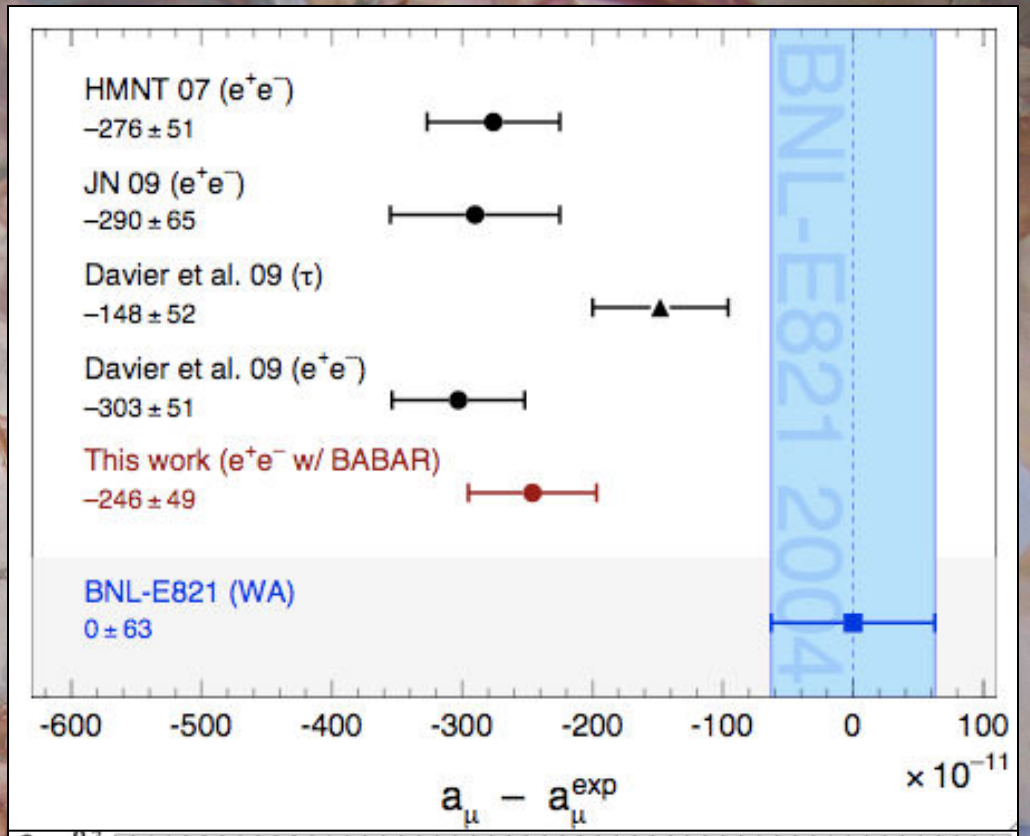
Flavour and CP Violation

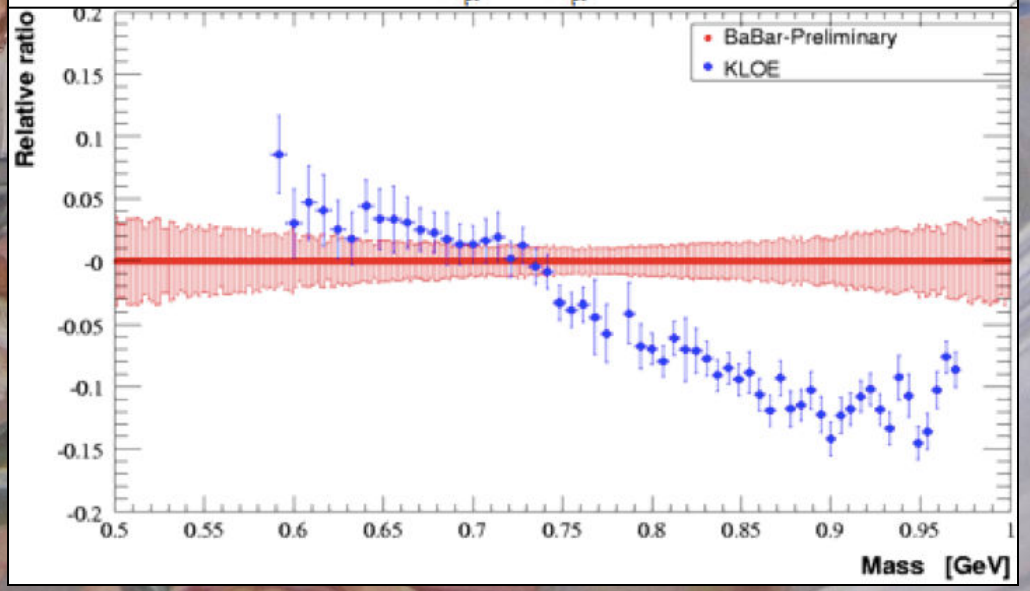
- CKM model successful at present
- A pillar of the Standard Model
- What lies beyond it?



Quo Vadis $g_\mu - 2$?

- Older e^+e^- data show discrepancy
  - now 3.4 σ
- Disagreement with τ decay data
  - Discrepancy ~ 2 σ
- New BABAR e^+e^- data agree poorly with previous e^+e^- data
  - Intermediate between e^+e^- and τ decay data
- Combination with previous e^+e^- data yield discrepancy ~ 3.1 σ





Dark Matter in the Universe

Astronomers say that most of the matter in the Universe is invisible
Dark Matter

LSP ? LKP ? LTP ?

We shall look for them with the LHC

Relics leaving thermal equilibrium in early Universe provide cold dark matter if mass ~ $(2.7\ \mathrm{K} \times M_{planck})^{1/2}$ ~ TeV

Minimal Supersymmetric Extension of Standard Model (MSSM)

- Particles + spartners

$$\begin{pmatrix} \frac{1}{2} \\ 0 \end{pmatrix} \; e.g., \; \begin{pmatrix} \ell \; (lepton) \\ \tilde{\ell} \; (slepton) \end{pmatrix} \; or \; \begin{pmatrix} q \; (quark) \\ \tilde{q} \; (squark) \end{pmatrix} \quad \begin{pmatrix} 1 \\ \frac{1}{2} \end{pmatrix} \; e.g., \; \begin{pmatrix} \gamma \; (photon) \\ \tilde{\gamma} \; (photino) \end{pmatrix} \; or \; \begin{pmatrix} g \; (gluon) \\ \tilde{g} \; (gluino) \end{pmatrix}$$

- 2 Higgs doublets, coupling μ, ratio of v.e.v.'s = $\tan \beta$
- Unknown supersymmetry-breaking parameters:
  Scalar masses m_0, gaugino masses $m_{1/2}$,
  trilinear soft couplings A_λ, bilinear soft coupling B_μ
- Assume universality? constrained MSSM = CMSSM
  Single m_0, single $m_{1/2}$, single A_λ, B_μ: not string?
- Not the same as minimal supergravity (mSUGRA)
- Gravitino mass, additional relations

$$m_{3/2} = m_0, \; B_\mu = A_\lambda - m_0$$

Minimal Flavour Violation (MFV)

- All squark mixing due to CKM matrix
- Universal scalar masses at high scale for sparticles with same quantum numbers
- Parametrization:

$$M_{1,2,3}\,, \quad M^2_{H_{u,d}}\,, \qquad \widetilde{\mathbf{M}}^2_{Q,L,U,D,E} = \widetilde{M}^2_{Q,L,U,D,E}\,\mathbf{1}_3\,, \qquad \mathbf{A}_{u,d,e} = A_{u,d,e}\,\mathbf{1}_3$$

- Maximally CP-violating MFV (MCPMFV) model has 19 parameters, of which 6 violate CP:

$$\mathrm{Im}\, M_{1,2,3} \text{ and } \mathrm{Im}\, A_{u,d,e}$$

- Often assume universal ImM_a, ImA_f, but non-universality compatible with MFV: **MCPMFV**

JE + Lee + Pilaftsis: arXiv 0708.2079

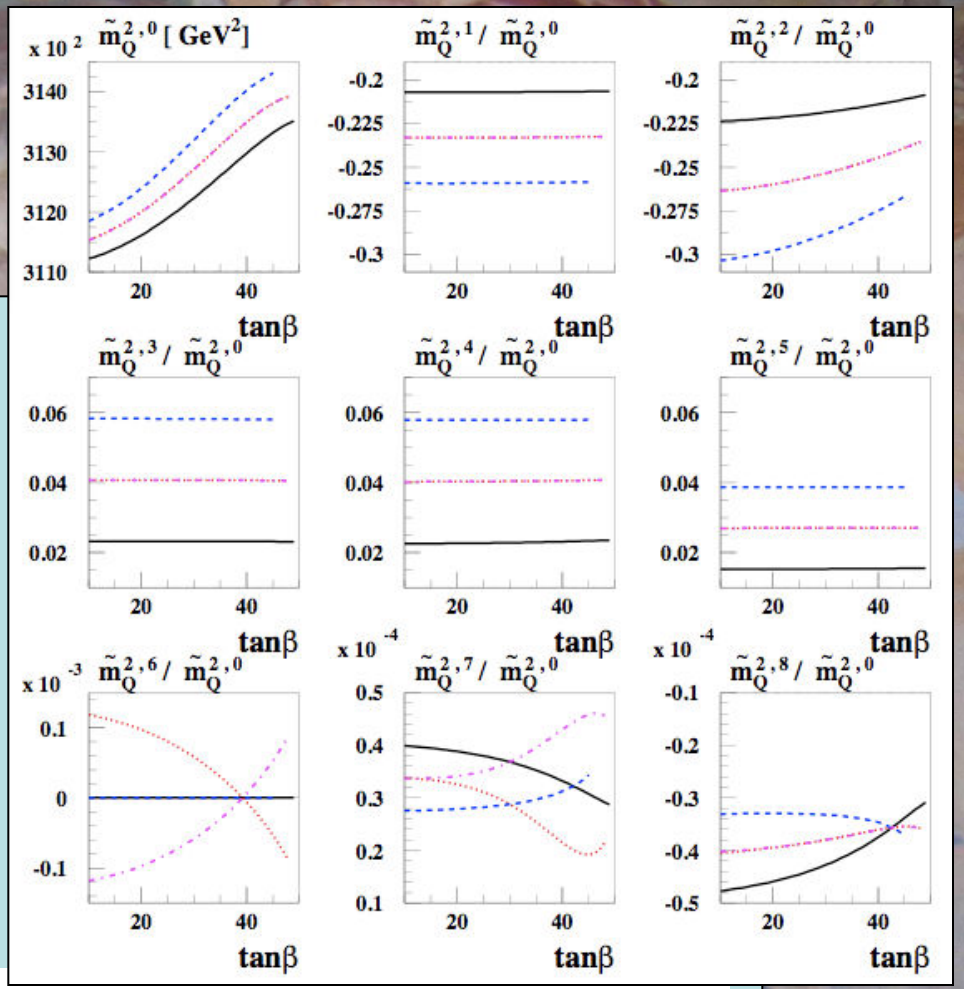
Flavour Geometry

- Expand scalar mass^2 matrices in complete basis derived from Yukawa couplings:

$$\widetilde{\mathbf{M}}_Q^2(M_X) \;=\; \sum_{I=0}^{8} \widetilde{m}_Q^{2,I}(M_X)\, \mathbf{H}_I^Q(M_X)$$

where:

$$\left\{ \mathbf{H}_I^Q \right\} = \Big\{ \mathbf{1}_3\,,\; \mathbf{h}_u^\dagger \mathbf{h}_u\,,\; \mathbf{h}_d^\dagger \mathbf{h}_d\,,\; (\mathbf{h}_u^\dagger \mathbf{h}_u)^2\,,\; (\mathbf{h}_d^\dagger \mathbf{h}_d)^2\,,\; [\mathbf{h}_u^\dagger \mathbf{h}_u\,,\mathbf{h}_d^\dagger \mathbf{h}_d]_+\,,\; i[\mathbf{h}_u^\dagger \mathbf{h}_u\,,\mathbf{h}_d^\dagger \mathbf{h}_d]_-$$
$$\mathbf{h}_u^\dagger \mathbf{h}_u \mathbf{h}_d^\dagger \mathbf{h}_d \mathbf{h}_u^\dagger \mathbf{h}_u\,,\; \mathbf{h}_d^\dagger \mathbf{h}_d \mathbf{h}_u^\dagger \mathbf{h}_u \mathbf{h}_d^\dagger \mathbf{h}_d \Big\}\,.$$



- Use RGEs to study magnitudes in MCPMFV
- **Use data to constrain coefficients**

JE + Hodgkinson +Lee + Pilaftsis: arXiv 0911.3611

Current Constraints on CMSSM

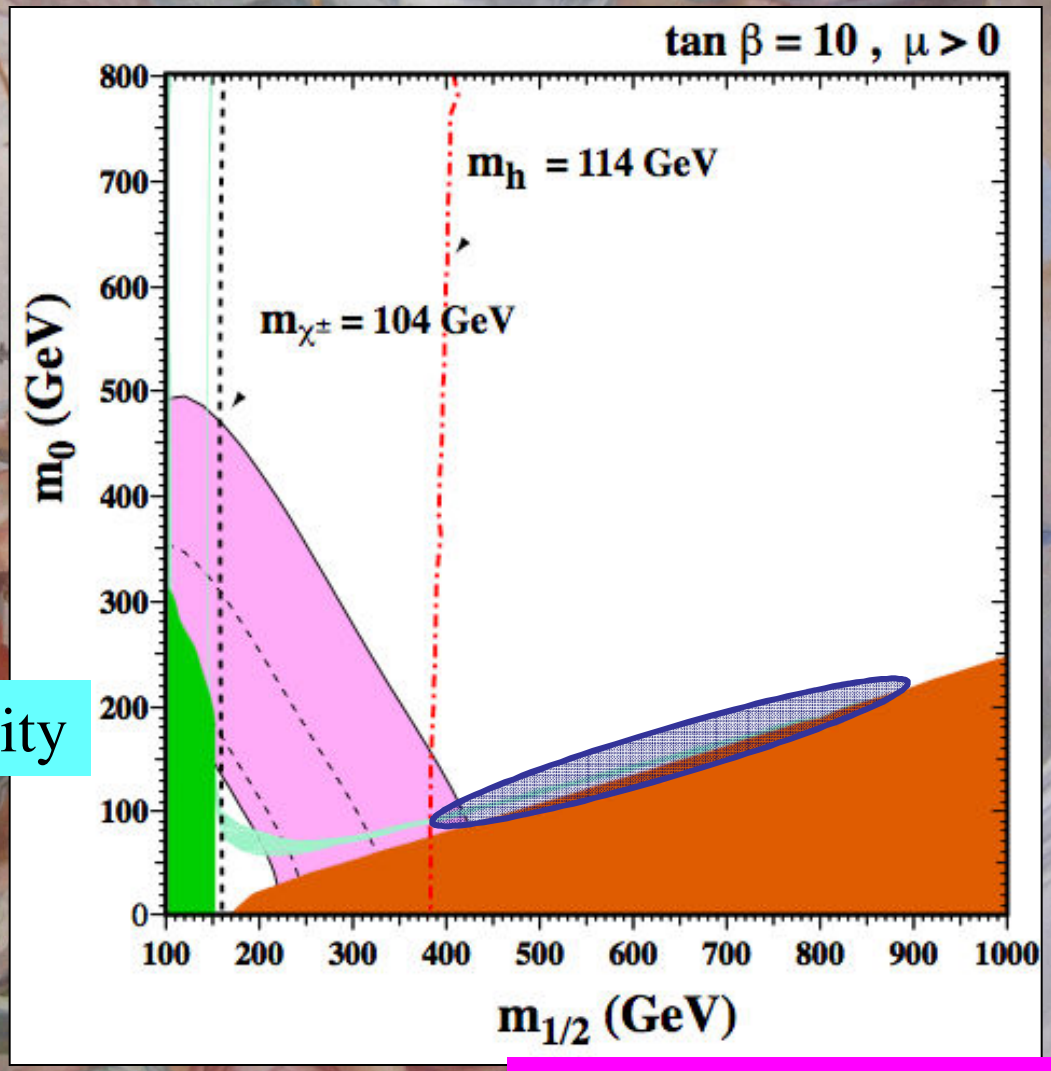
Assuming the lightest sparticle is a neutralino

Excluded because stau LSP

Excluded by b → s gamma

WMAP constraint on relic density

Preferred (?) by latest g - 2



JE + Olive + Santoso + Spanos

Non-Universal Scalar Masses

- Different sfermions with same quantum #s?

  e.g., d, s squarks?

  disfavoured by upper limits on flavour-changing neutral interactions

- Squarks with different #s, squarks and sleptons?

  disfavoured in various GUT models

  e.g., $d_R = e_R$, $d_L = u_L = u_R = e_R$ in SU(5), all in SO(10)

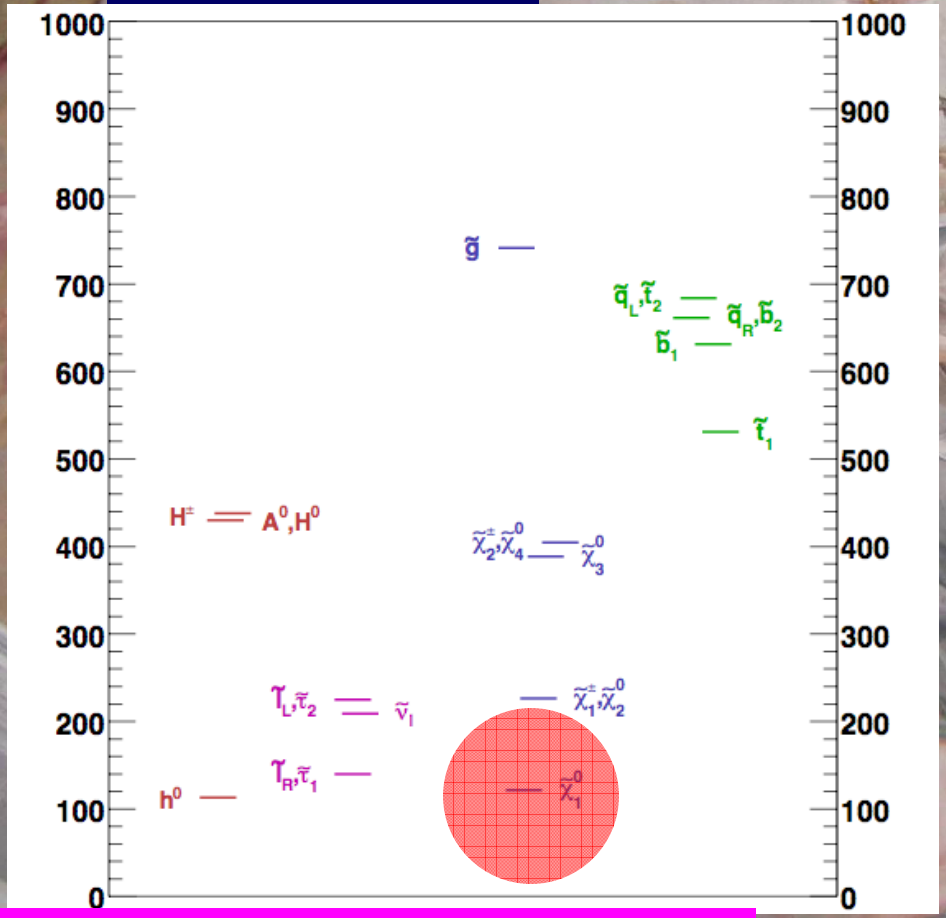
- Non-universal susy-breaking masses for Higgses?

  No reason why not!

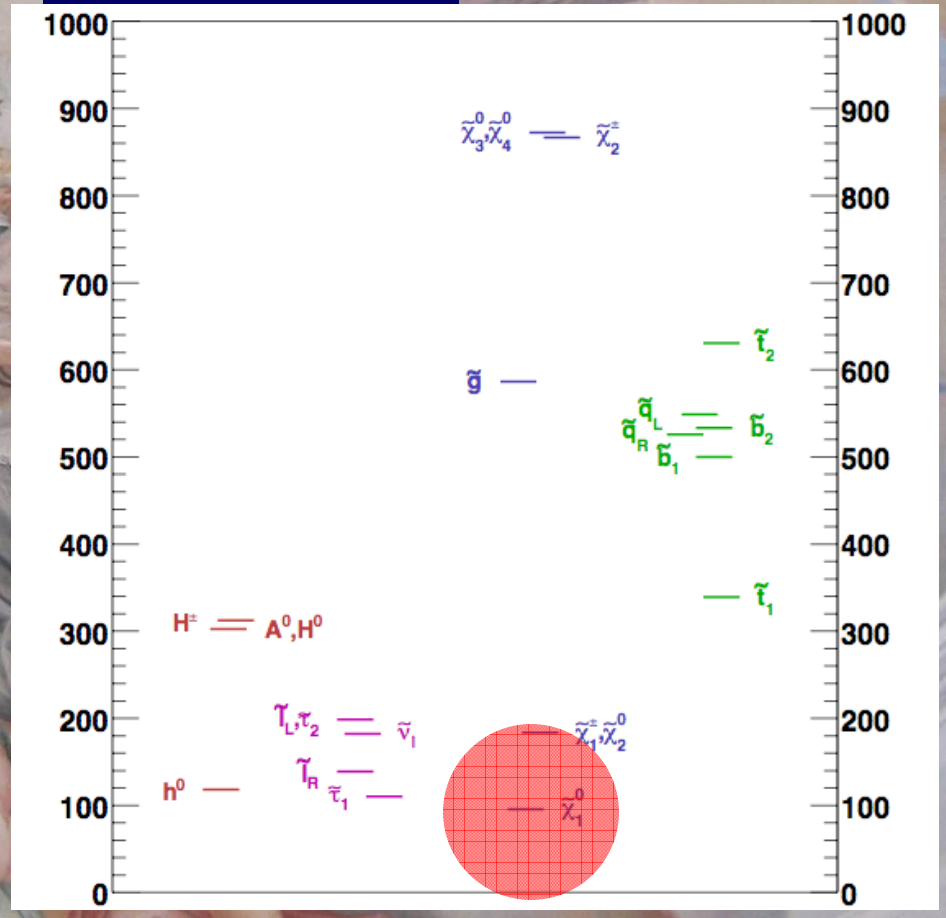
NUHM

Best-Fit Spectra

CMSSM

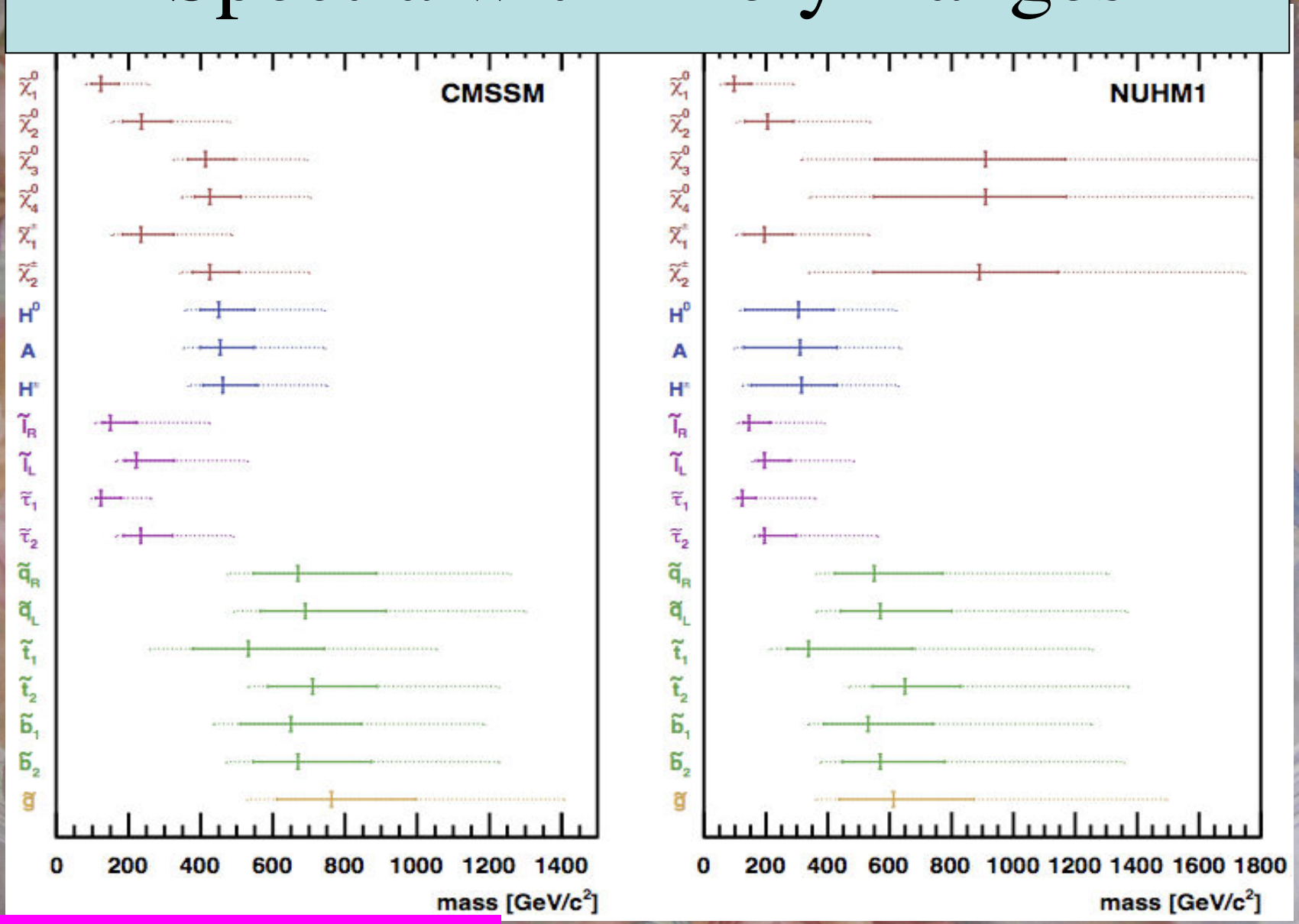


NUHM1



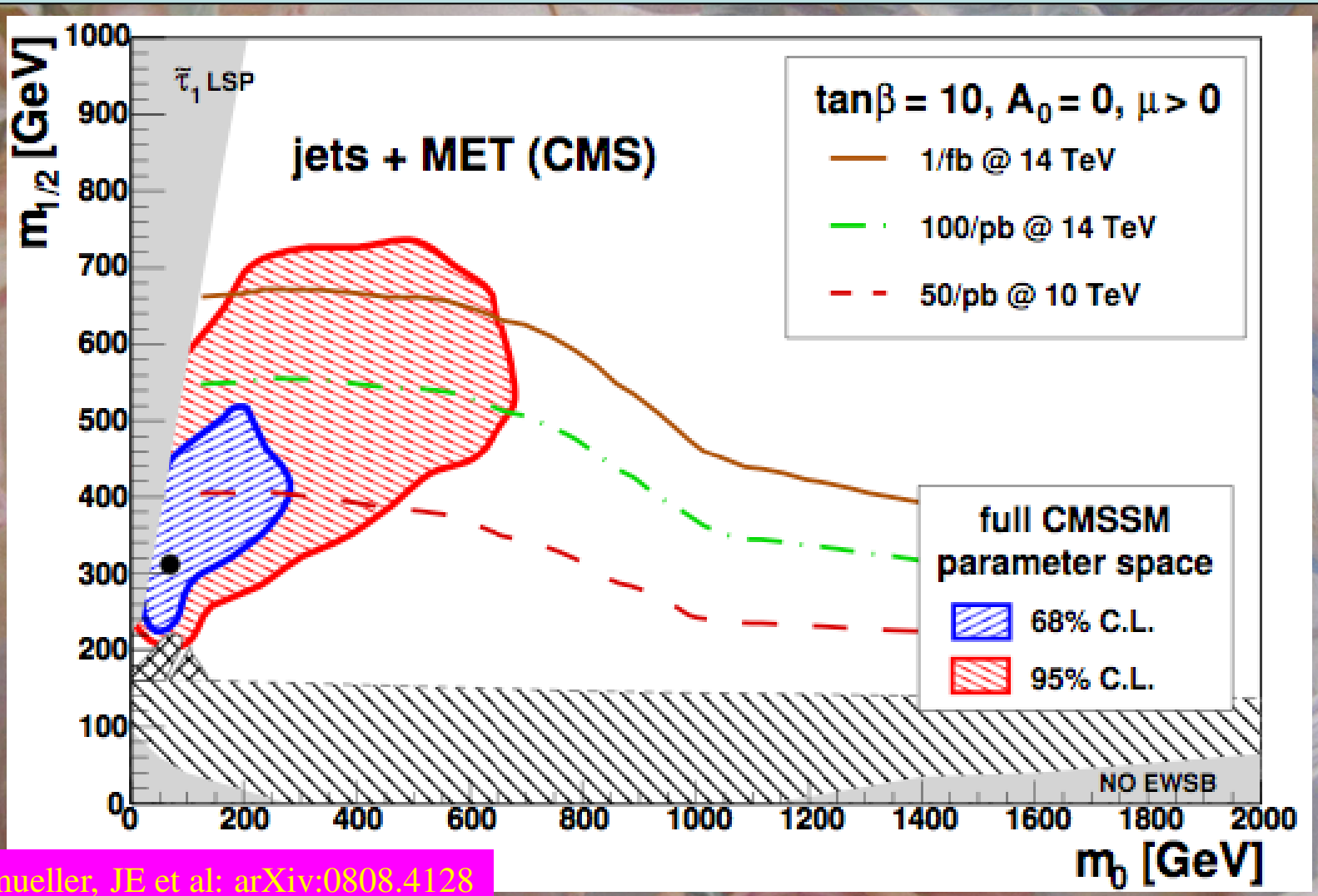
O.Buchmueller, JE et al: arXiv:0808.4128

Spectra with likely Ranges



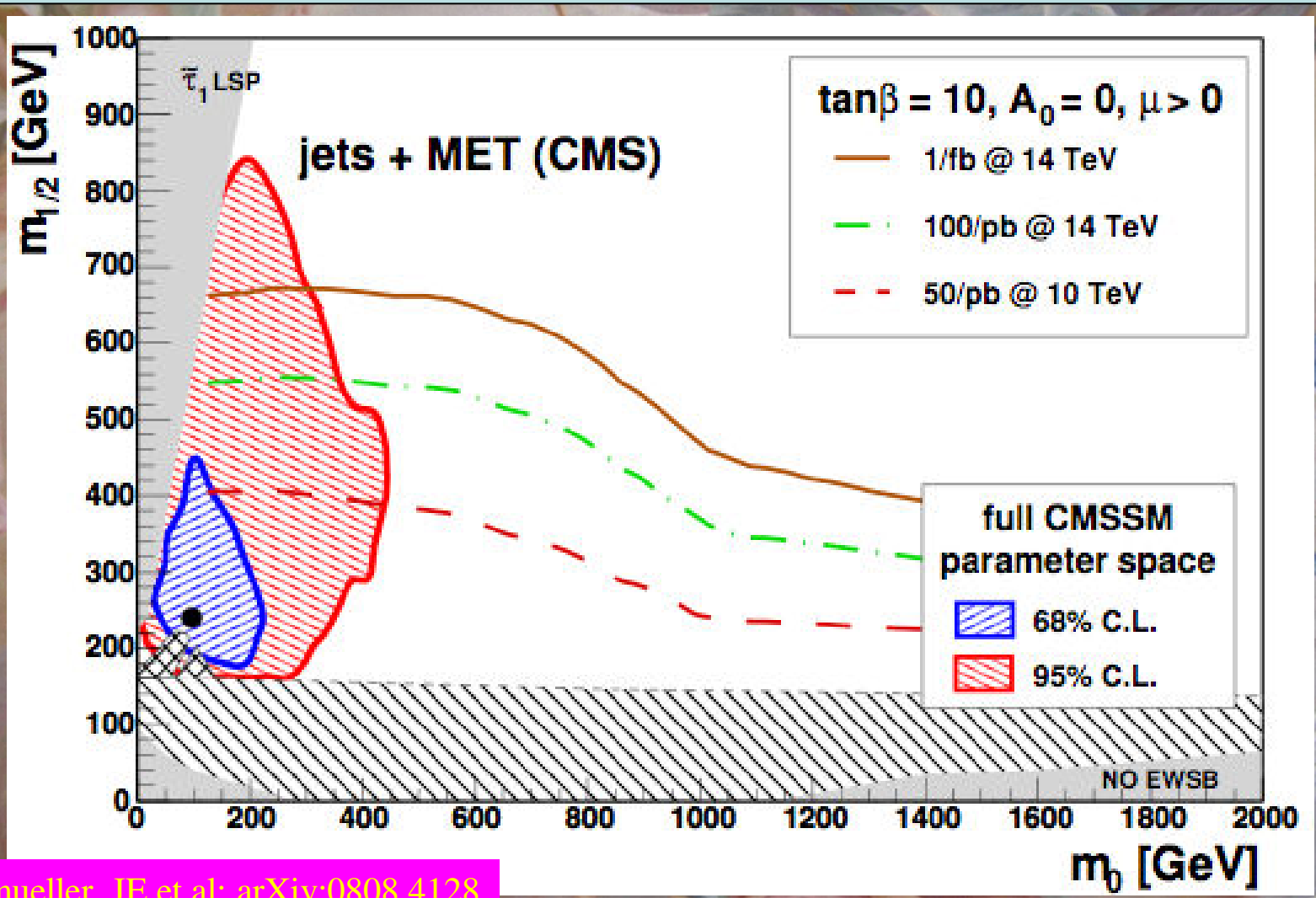
O.Buchmueller, JE et al: arXiv:0907.5568

How Soon Might the CMSSM be Detected?



O.Buchmueller, JE et al: arXiv:0808.4128

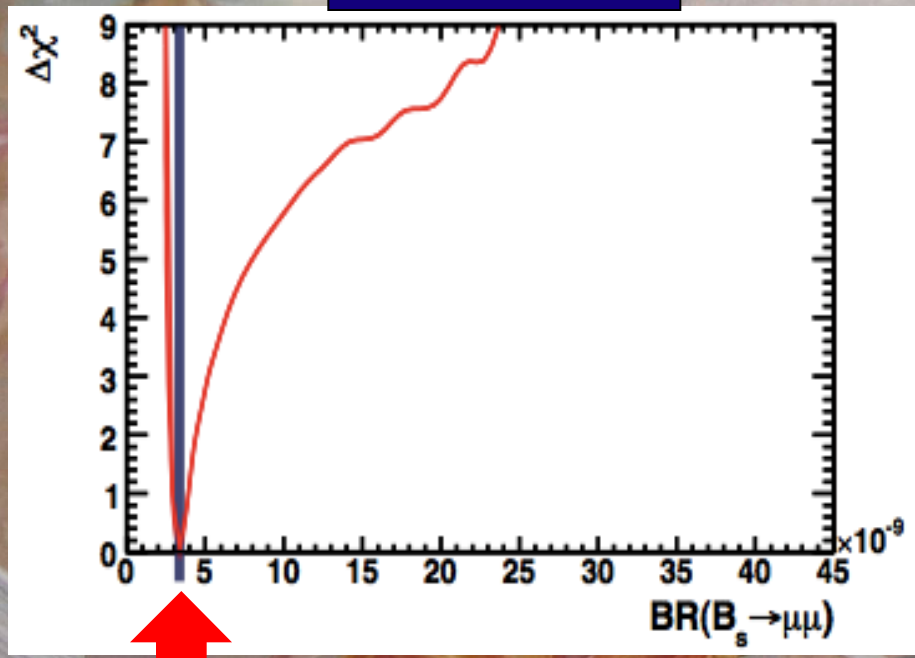
How Soon Might the NUHM1 be Detected?



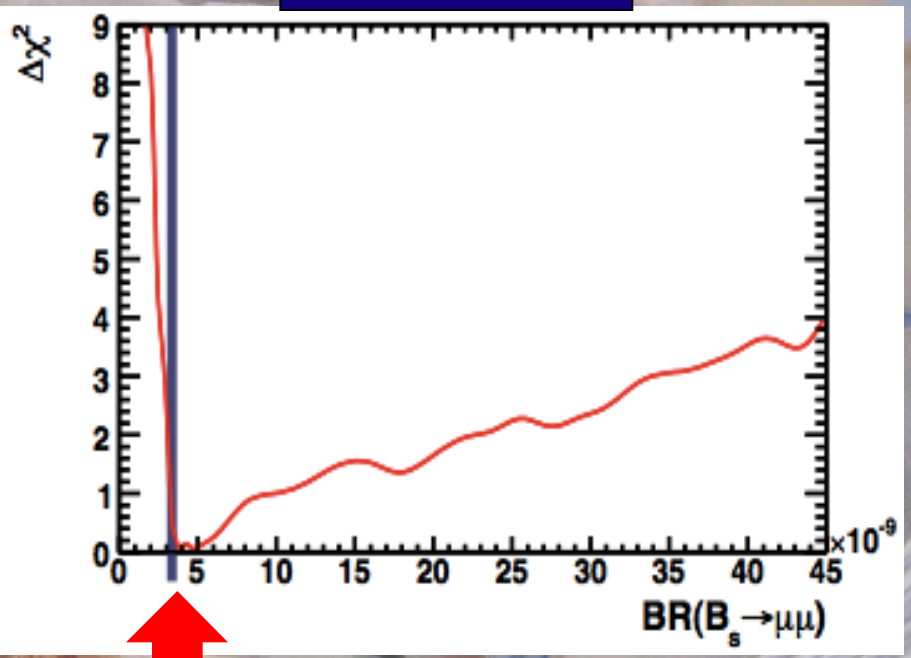
O.Buchmueller, JE et al: arXiv:0808.4128

Likelihood Function for $B_s \rightarrow \mu^+\mu^-$

CMSSM



NUHM1

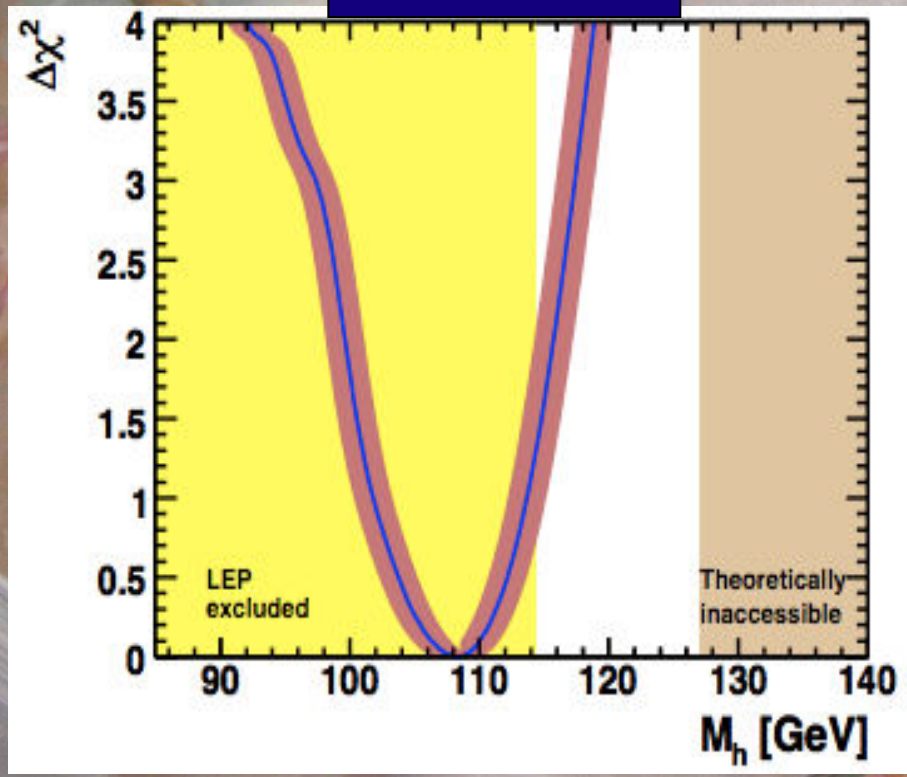


Standard Model prediction

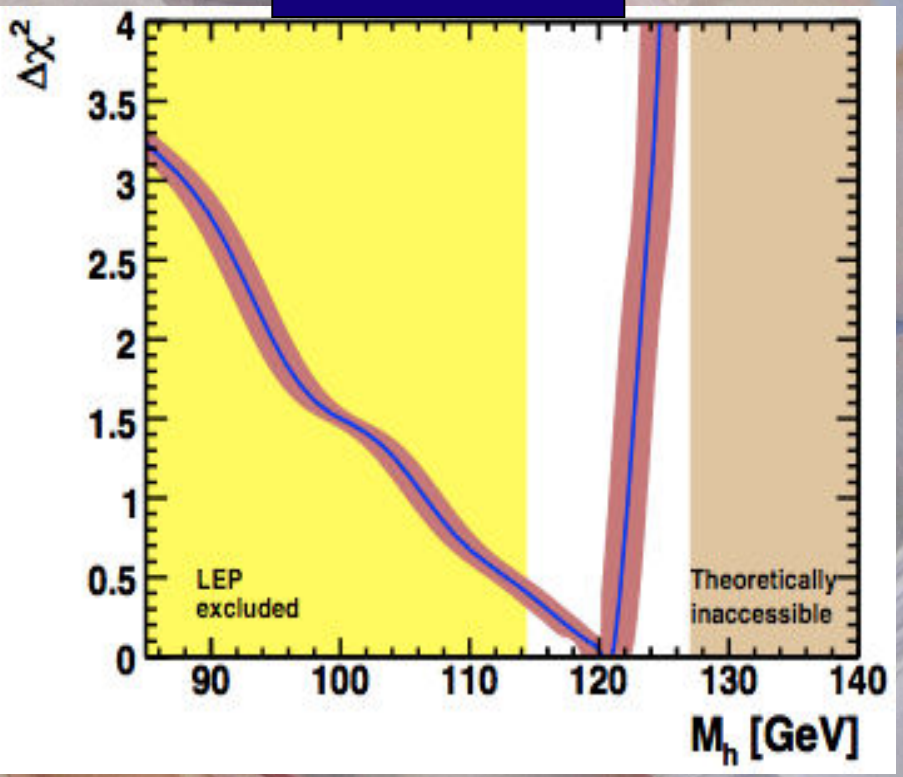
O.Buchmueller, JE et al: arXiv:0907.5568

Likelihood Function for Higgs Mass

CMSSM



NUHM1

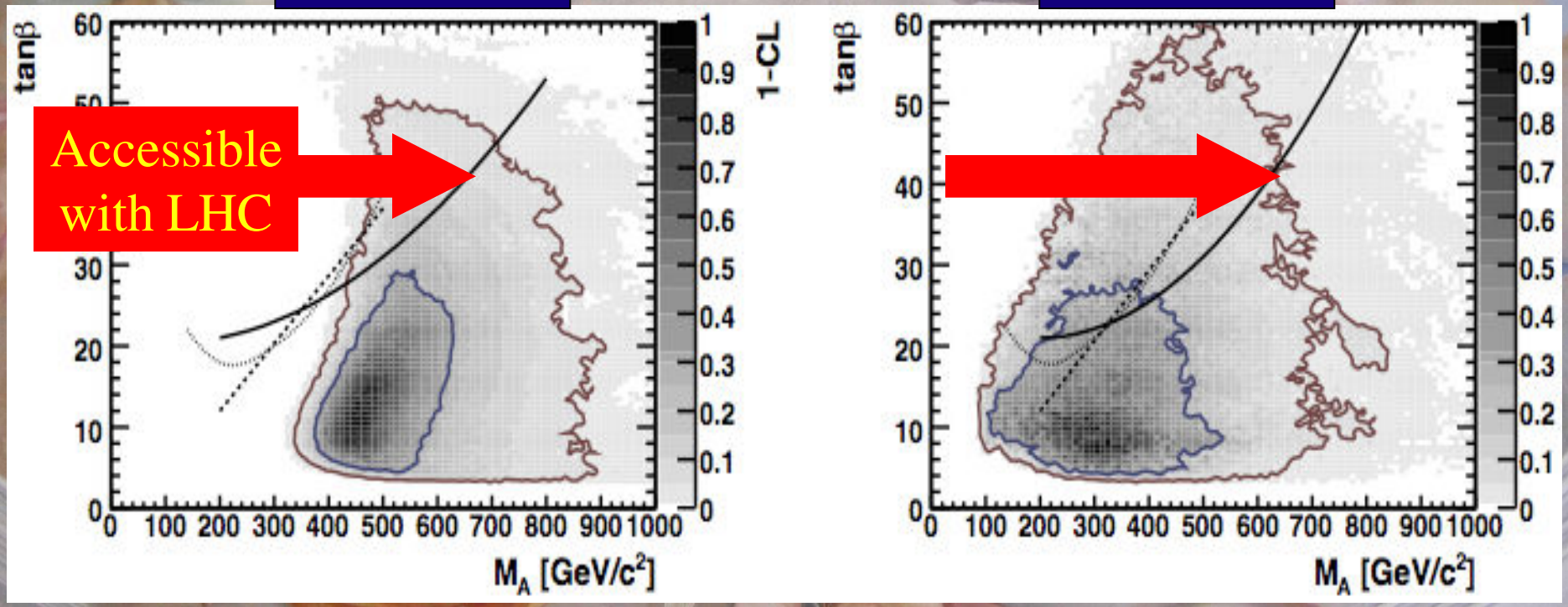


O.Buchmueller, JE et al: arXiv:0907.5568

Can the LHC find heavier Higgs Bosons?

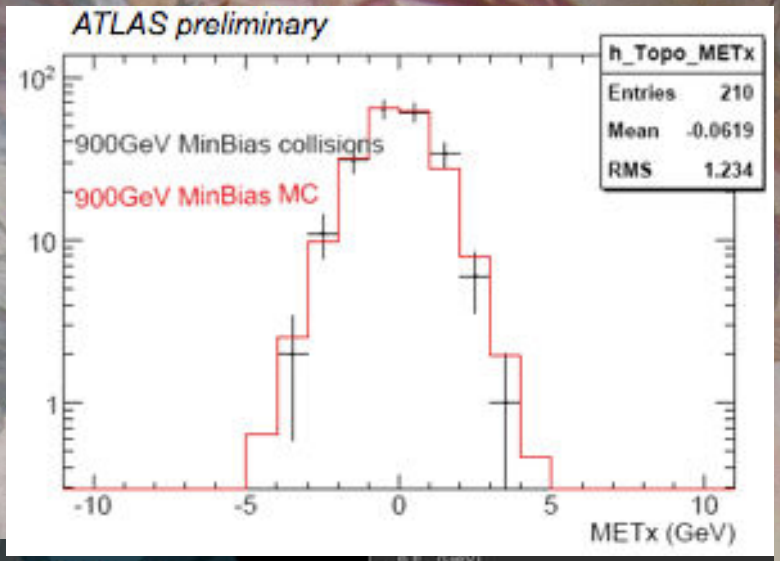
CMSSM

NUHM1



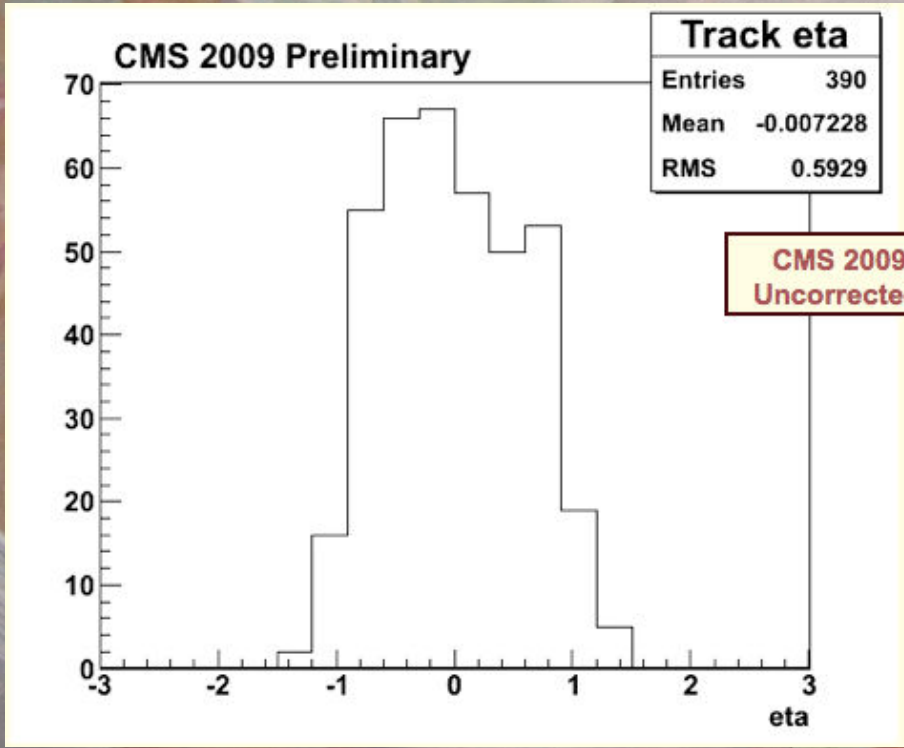
O.Buchmueller, JE et al: arXiv:0907.5568

No Supersymmetry yet!

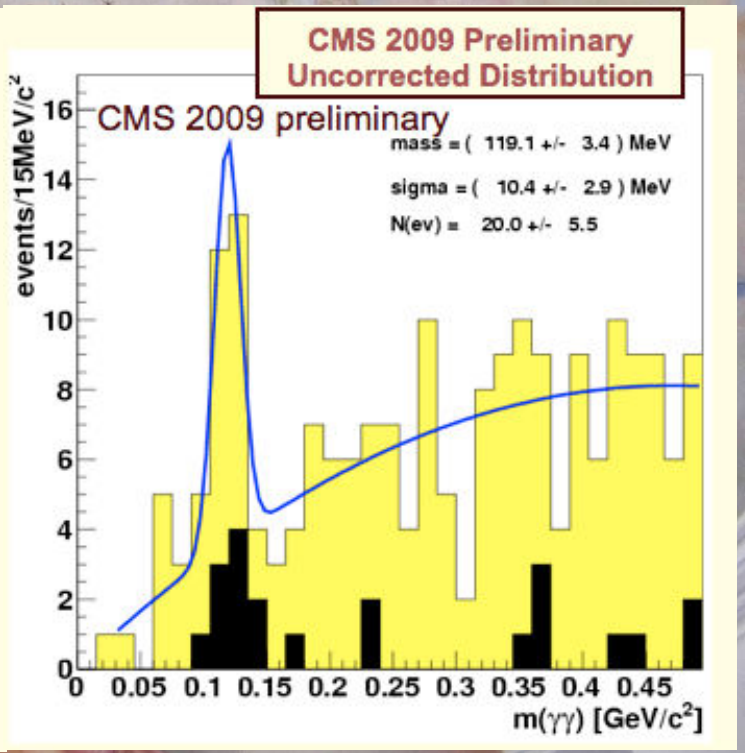


No Higgs yet!

Pseudo-rapidity distribution



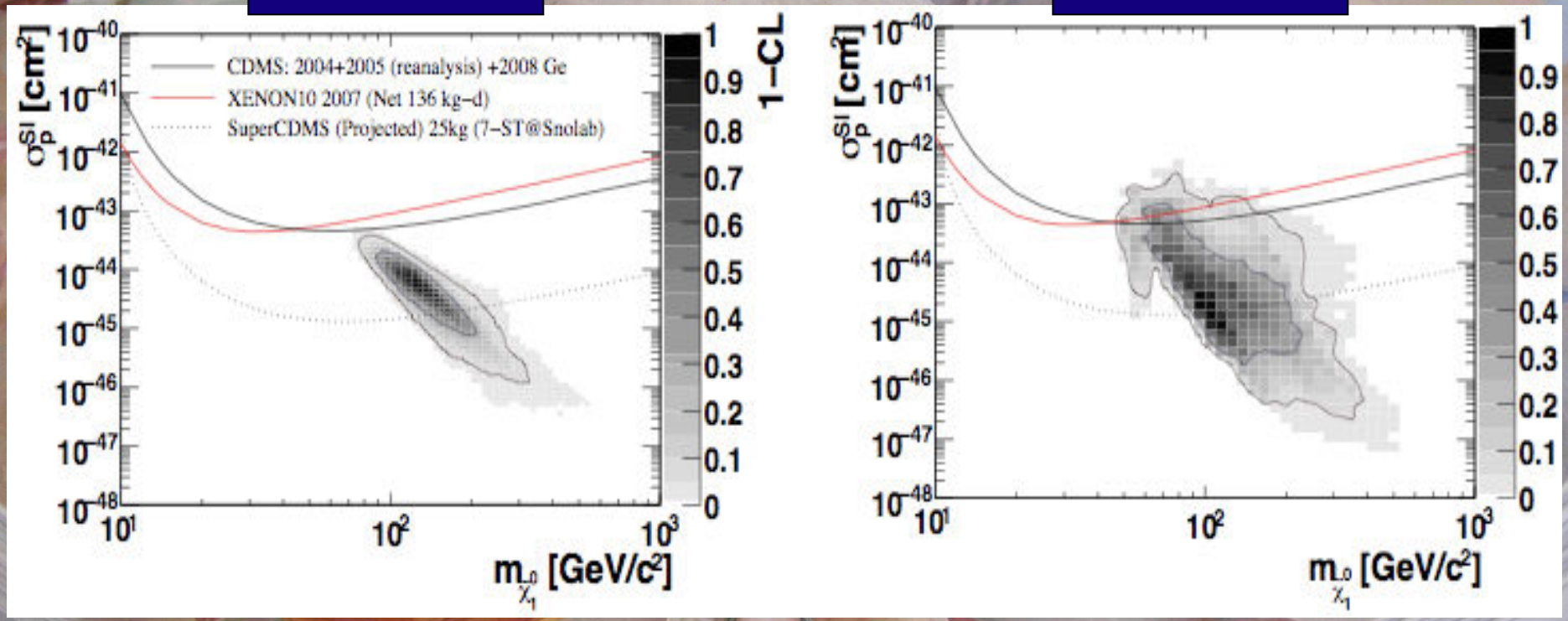
$\gamma\gamma$ invariant mass distribution



Elastic Scattering Cross Sections

CMSSM

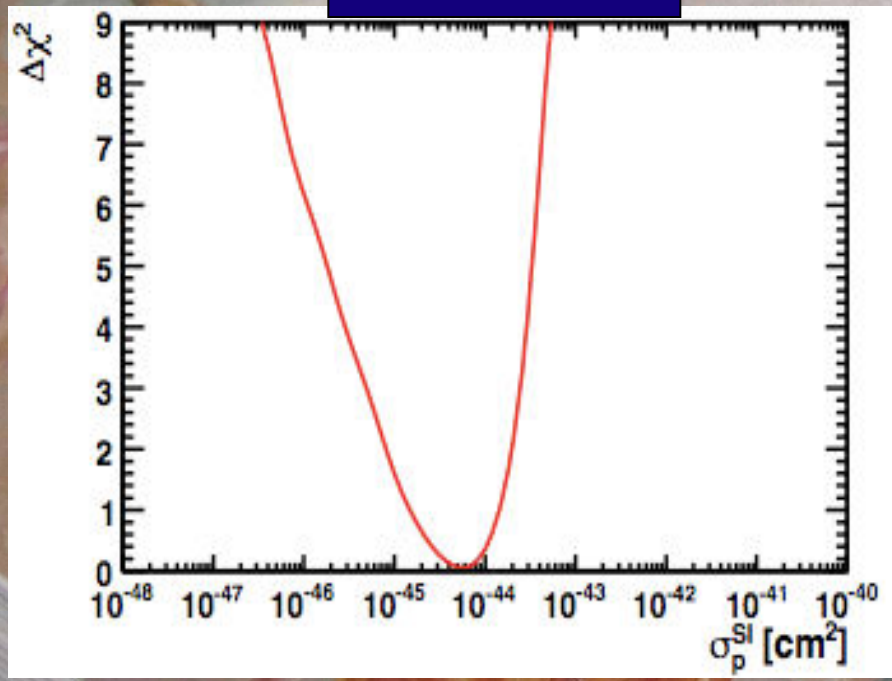
NUHM1



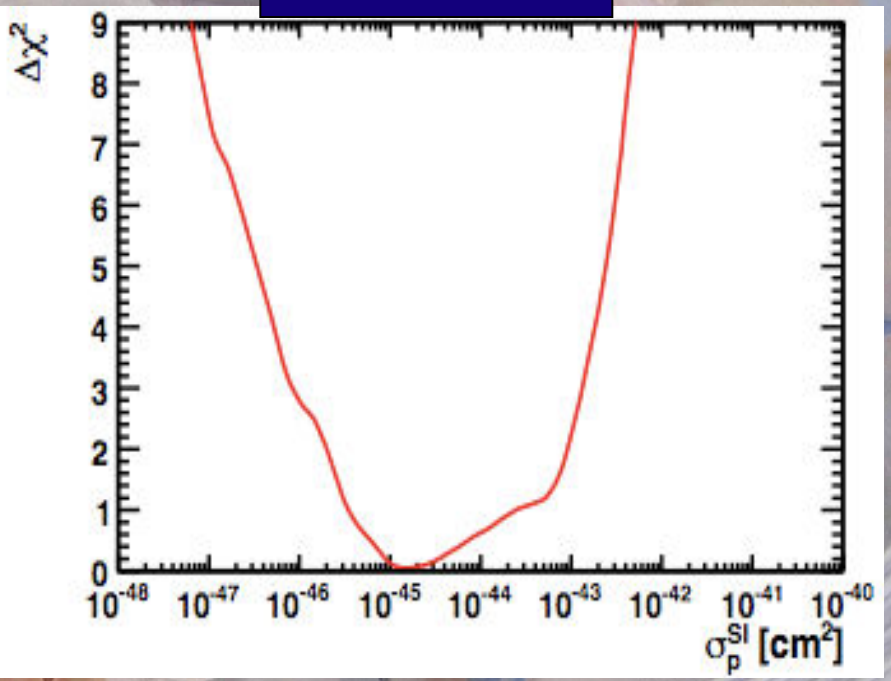
O.Buchmueller, JE et al: arXiv:0907.5568

Likelihood Function for Spin-Independent Dark Matter Scattering

CMSSM

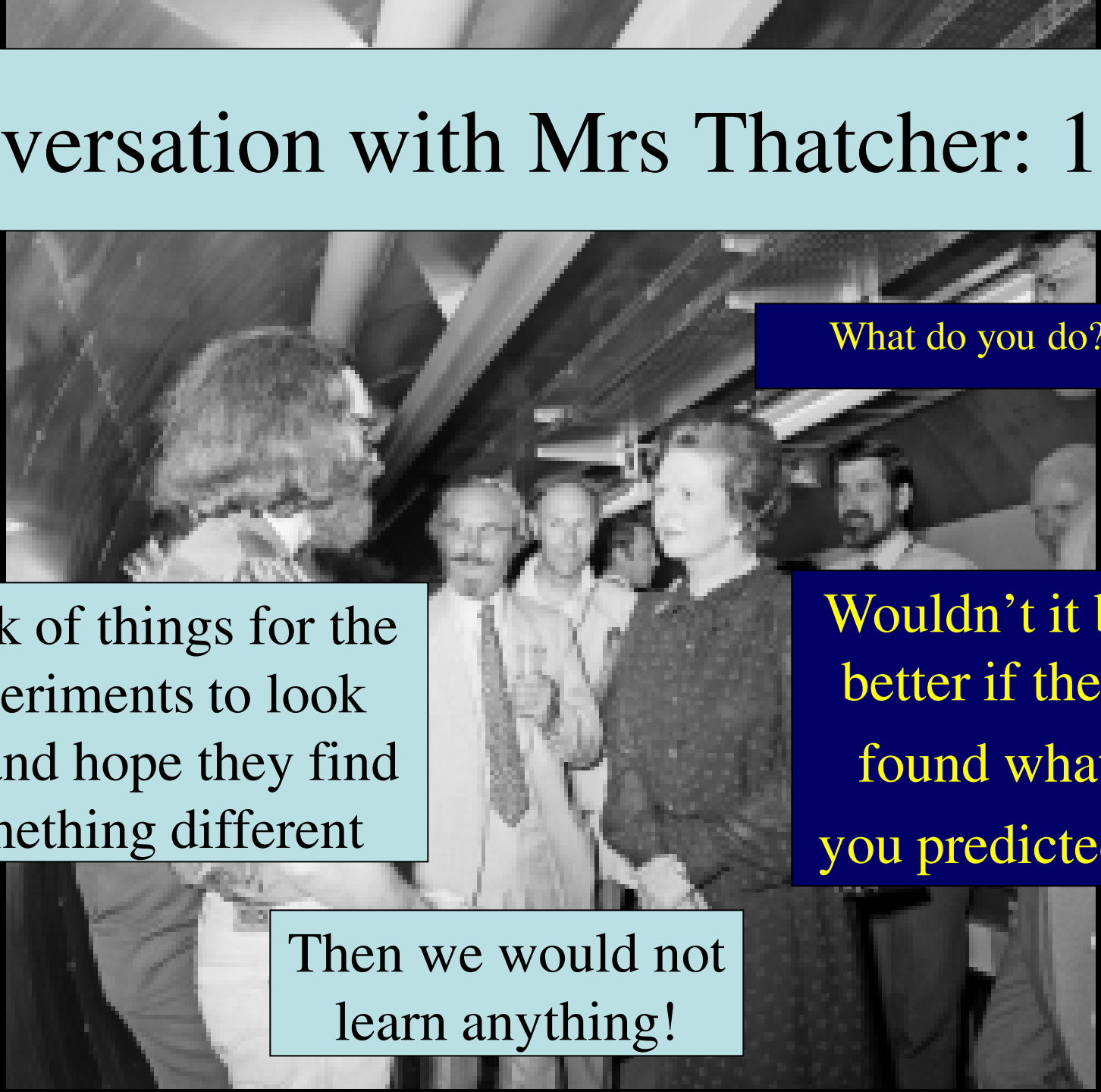


NUHM1



O.Buchmueller, JE et al: arXiv:0907.5568

Conversation with Mrs Thatcher: 1982

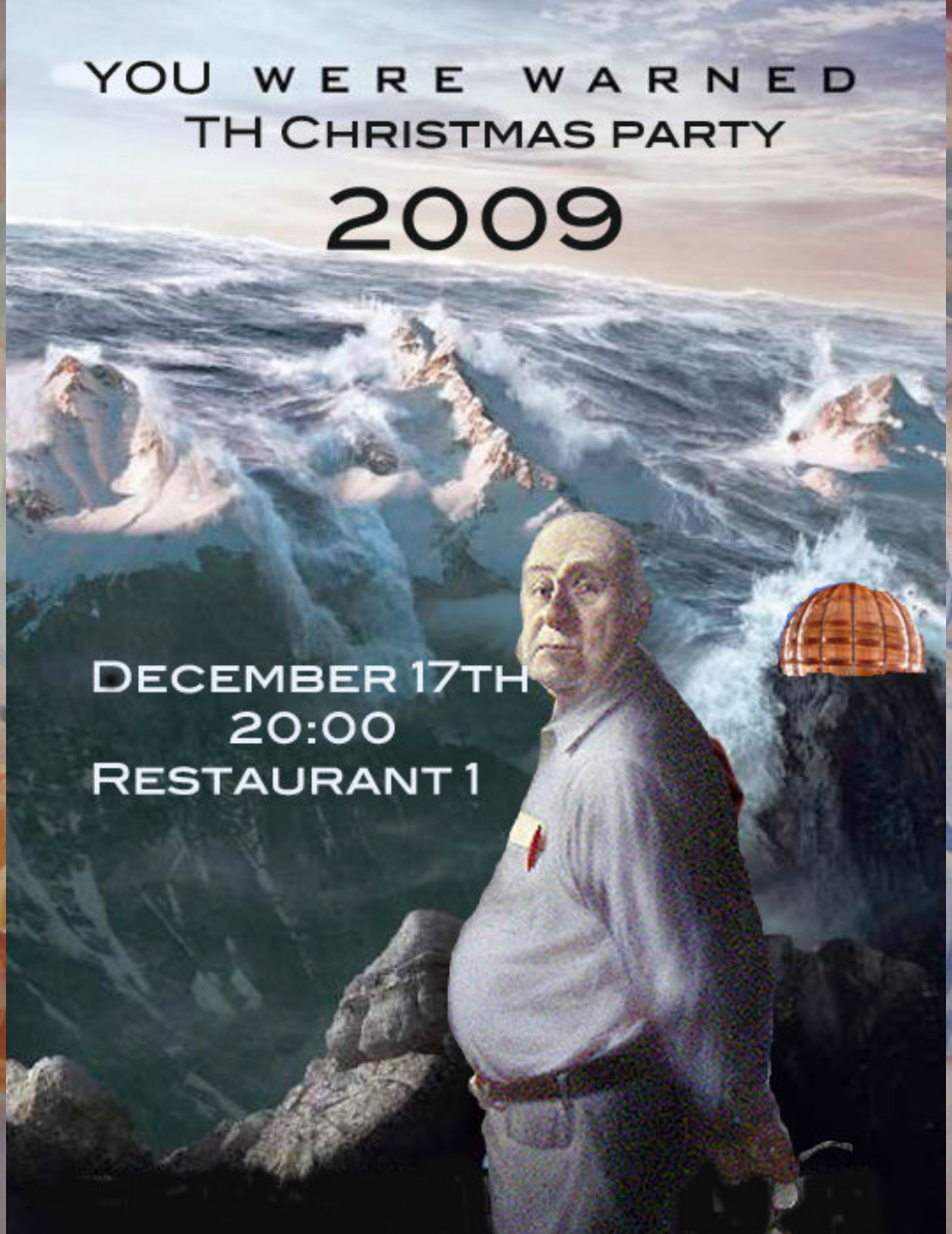


What do you do?

Think of things for the experiments to look for, and hope they find something different

Wouldn't it be better if they found what you predicted?

Then we would not learn anything!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2009
DECEMBER 17TH
20:00
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