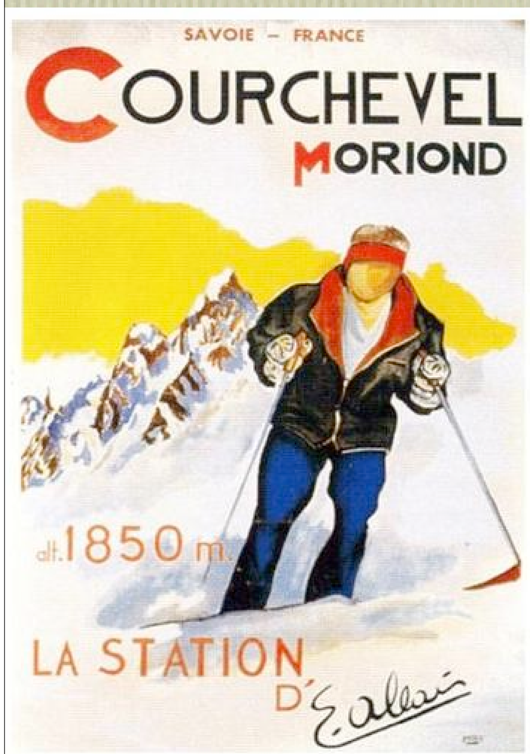
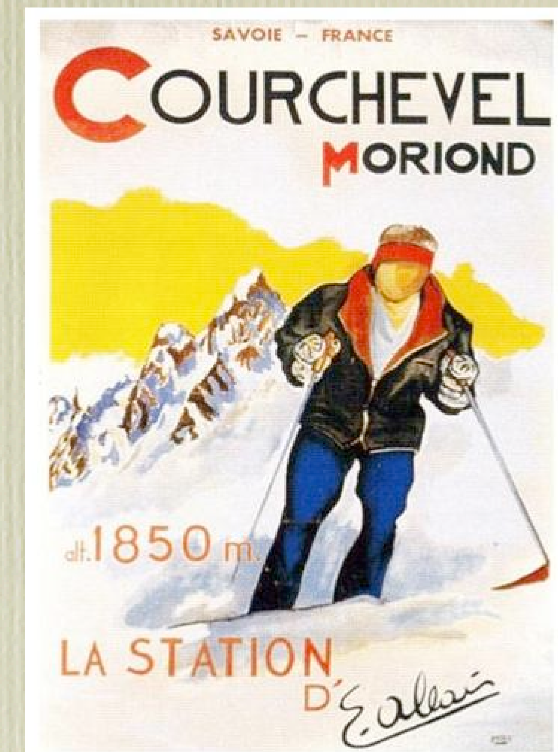
theory summary



Joseph Lykken
Fermilab



XLIst Rencontres de Moriond, La Thuile, 11-18 March 2006

innovations of the Rencontres de Moriond:

- first (only?) major international meetings that fully integrate junior physicists
- first major international meetings where theorists and experimentalists actually communicate with each other

the most significant achievement of the Rencontres de Moriond:

“it forces the theorists to change their predictions *twice* per year”

-M. Danilov

thanks and congratulations to all the organizers for yet another successful meeting

and special thanks and congatulations to Jean Tran Thanh Van for 40 years of Rencontres de Moriond!

outline

- are theorists necessary?
- a game of small discrepancies
- SciFi Channel framework for BSM
- the big picture
- neutrino origins
- cosmology 2006
- the future

are theorists necessary?

theorists engage in two types of activity:

- playing around with new/old/stolen ideas for going beyond the standard paradigm
  (easy, fun, richly rewarded, but potentially useless)

- calculating things within the standard paradigm
  (useful, but difficult, tedious, and poorly rewarded)

the importance of
Standard Model calculations

- the SM still rules (almost) all
- below the energy frontier, new physics means (mostly) rare processes, small discrepancies, small inconsistencies
- at the energy frontier, SM backgrounds are about to get 100-500 times worse (Steve Mrenna)

case in point: B physics

- lots and lots and lots of data
- need precise SM predictions for dozens of observables
- the opportunities for big obvious signals of new physics are dwindling...

Deviations still possible in:

(K)

$K^+ \to \pi^+ \nu \bar{\nu}$ — fact 2-3

$K^0 \to \pi^0 \nu \bar{\nu}$ — few orders of magn.

(B)

$B_s - \bar{B}_s$ — 30-40%

$B_s \to X_s \nu \bar{\nu}$ — 1 order of magn.

$B_{d,s} \to \ell^+ \ell^-$ — few orders of magn.

$B^- \to \tau \nu$ — fact 2

fully hadronic

$B \to \phi K_s$ — ...

$B \to \pi^0 K_s$

$\eta' K$

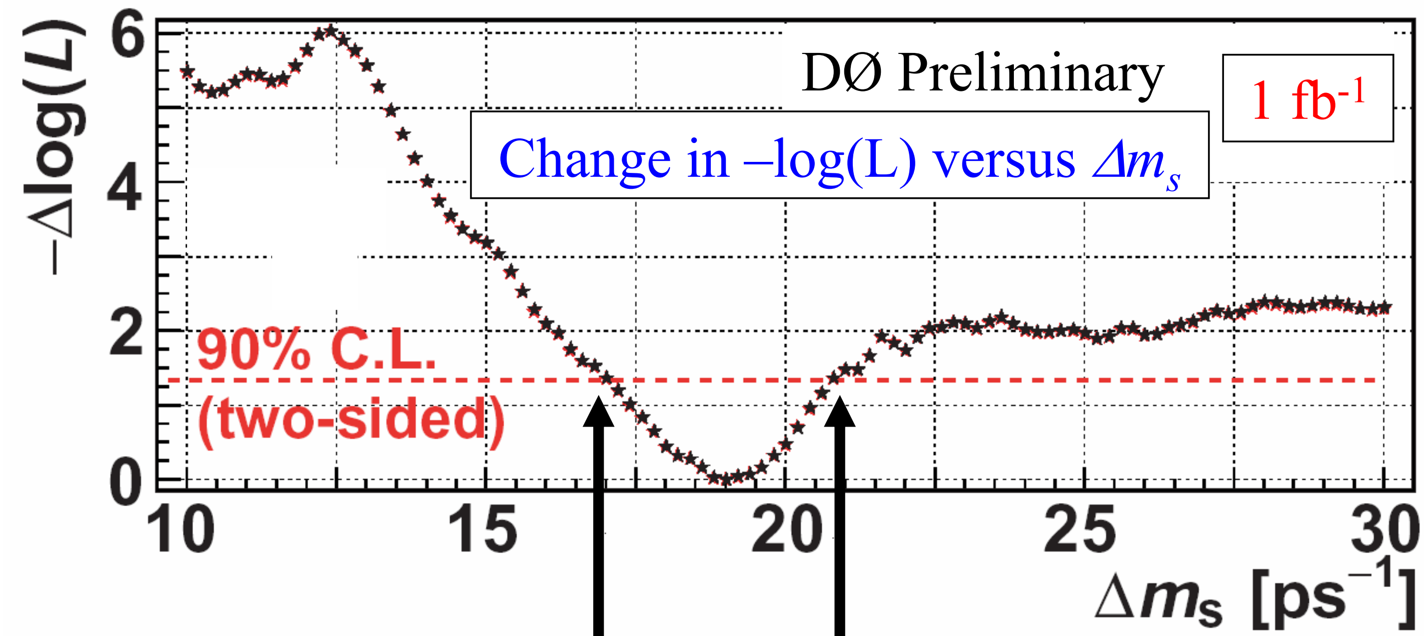
⋮

Francesca Borzumati

WITHOUT touching $B_d - \bar{B}_d$

moderately touching $B \to X_s \ell^+ \ell^-$, $B \to X_s \gamma$

Switch Back to Likelihood Fit



17 < Δm_s < **21 ps^{-1} @ 90% CL**

Maximum likelihood at Δm_s = 19 ps^{-1}

First time Δm_s bounded on both sides!!!!!

case in point: B physics

- the opportunities for big obvious signals of new physics are dwindling...
- ...so now the game is looking for small discrepancies and small inconsistencies

how do theorists compute B decays?

- combination of electroweak, perturbative QCD, and nonperturbative QCD, further complicated by multiple scales!
- computation of exclusive decays reduces to hadronic form factors, which can be computed from unquenched lattice QCD
- computation of inclusive decays is done using effective Hamiltonians and the Wilsonian operator product expansion

Concezio Bozzi

Exclusive $|V_{ub}|$

$$\frac{d\Gamma(B \to \pi l \nu)}{dq^2} = \frac{G_F^2}{24\pi^3} |V_{ub}|^2 \, p_\pi^3 \left| f_+(q^2) \right|^2$$

Calculations of $f_+(q^2)$:
- LQCD (q^2>16)
- Light-cone sum rules (q^2<14)
- Quark models (ISGW2)

- Theoretically:
  - Uncertainties complementary to inclusive approach
  - FF normalization dominates the error on $|V_{ub}|$ (~10% for all models)
- Experimentally:
  - Good S/B ratio, untagged analyses
  - Small branching fractions
  - Measure q^2 dependence, compare to theory

Babar untagged analysis:

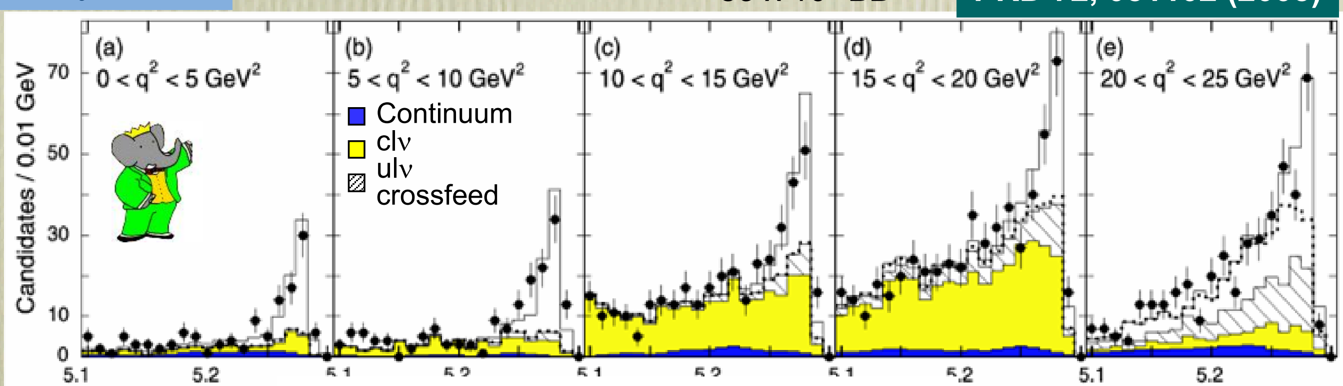
$B \to \pi l \nu$

83×10^6 $B\bar{B}$

PRD 72, 051102 (2005)

ν = missing $(E, \vec{p})$ of the event

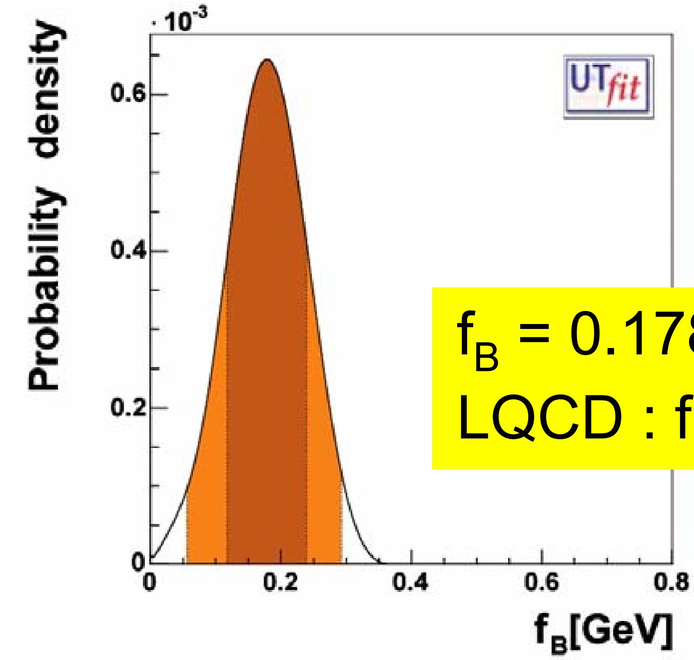
Fit of signal yield using B mass and ΔE in bins of q^2.



M_{ES} for $-0.15 < \Delta E < 0.25$ GeV

◆ B meson decay constant f_B ◆

$$\mathcal{B}(B^+ \to \tau\nu) = \frac{G_F^2 m_B}{8\pi} m_\tau^2 (1 - \frac{m_\tau^2}{m_B^2})^2 f_B^2 |V_{ub}^2| \tau_B$$



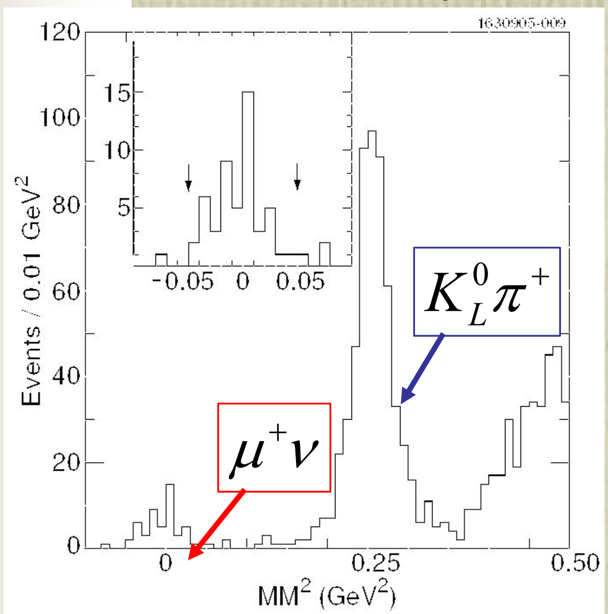
f_B = 0.178±0.062 GeV

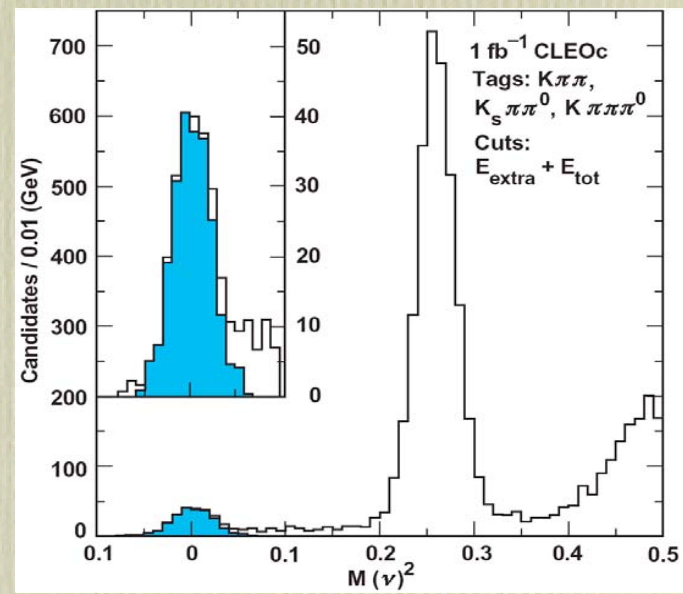
LQCD : f_B = 0.196±0.032 GeV

Koji Ikado

$D^+ \rightarrow \mu^+ \nu_\mu$

Data (281 pb^{-1}) **Monte Carlo (1 fb^{-1})**





Mode	Events
Data	50
$D^+ \rightarrow \pi^+ \pi^0$	1.4
$D^+ \rightarrow K_{long} \pi^+$	0.33
$D^+ \rightarrow \tau^+ \nu_\tau$	1.08
Total Bck:	2.81

$$B(D^+ \rightarrow \mu^+ \upsilon) = (4.40 \pm 0.66^{+0.09}_{-0.12}) \times 10^{-4}$$

CLEO-c

$$f_{D^+} = (222.6 \pm 16.7^{+2.8}_{-3.4}) MeV$$

PRL 95 251801 (2005)

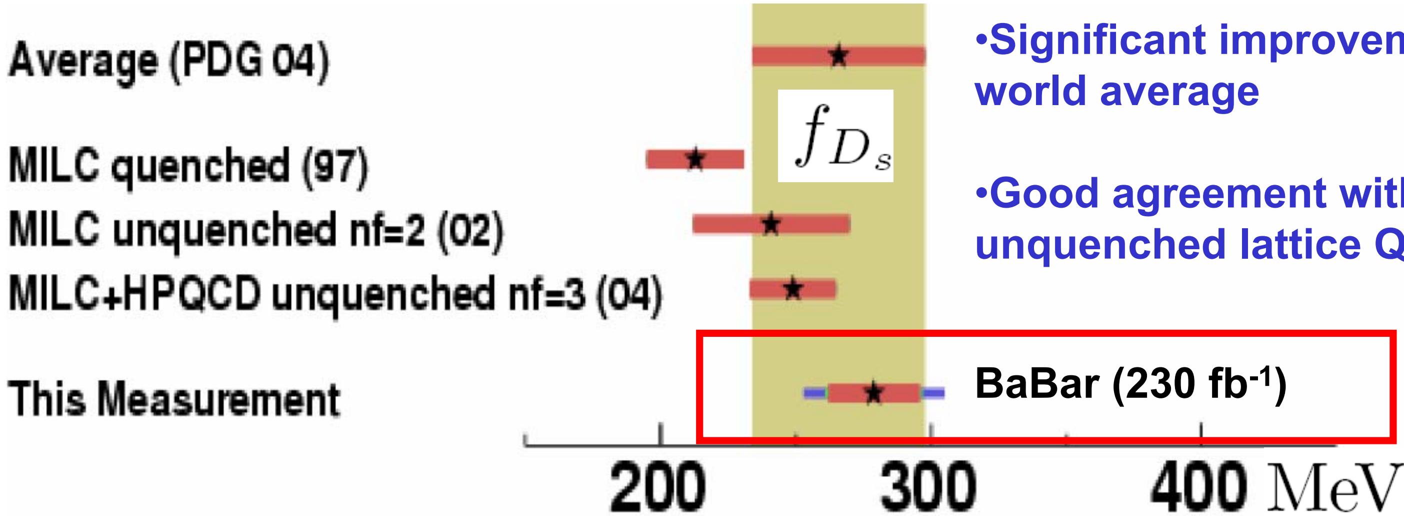
Lattice

$$f_{D^+} = (201 \pm 3 \pm 17) MeV$$

PRL 95 122002 (2005)

Daniel Cronin-Hennessy

$D_S \rightarrow \mu\nu$ Decay Constant f_{Ds}



- Significant improvement on world average
- Good agreement with unquenched lattice QCD

BF, D_S lifetime, and V_{cs} give D_s decay constant:

BaBar (230 fb^{-1}) $f_{D_s} = (279 \pm 17 \pm 6 \pm 19)$ MeV (stat, syst, $D_s \rightarrow \phi\pi$) *BABAR* Preliminary

Lattice QCD $f_{D_s} = (249 \pm 17)$ MeV Aubin et al. PRL 95 122002 (2005)

Validates recent QCD predictions at 10% level

will improve to <5% precision with 1 ab^{-1}

Summary of the main theoretical limitations.

P. Gambino hep-ph/0510085

process	quantity	Th error	needs	goal
$B \to D^* l\nu$	$\|V_{cb}\|$	$\sim 4\%$	unquenching, analytic work	1%
$B \to X_c l\nu$	$\|V_{cb}\|$	$\sim 1.5\%$	new pert calculations	<1%
$B \to \pi(\rho) l\nu$	$\|V_{ub}\|$	10-15%	2-loop lattice matching etc.	6%
$B \to X_u l\nu$	$\|V_{ub}\|$	$\sim 6-7\%$	more data/synergy with th	$< 5\%$
$B \to X_s \gamma$	BR	~10%	NNLO	<5%
$B \to \rho^0\gamma / B \to K^*\gamma$	$\|V_{td}/V_{ts}\|$	10-20%	lattice SU(3) breaking etc	?

- Note: in the K sector, unquenched lattice is already at percent level of accuracy
- e.g. 1% level MILC computation of $\mathbf{f_K}/\mathbf{f_\pi}$ is input for the KLOE test of CKM unitarity (Matteo Palutan)

inclusive B decays

effective Hamiltonian approach describes inclusive non-leptonic B decays:

$$\langle f|H_{\rm eff}|i\rangle = \frac{G_{\rm F}}{\sqrt{2}}\lambda_{\rm CKM}\sum_k C_k(\mu)\langle f|Q_k(\mu)|i\rangle$$

the Wilson coefs $\mathbf{C_k}(\mu, \alpha_\mathbf{s})$ are just the scale-dependent couplings of the interactions induced by the operators Q_k. Higher order operators are suppressed by powers of $\mathbf{\Lambda_{QCD}/m_b}$

$b \to s\gamma$ inclusive: BF results

fully inclusive | **semi-inclusive**

Thomas Schietinger

CLEO

- fully inclusive: $BF(b \to s\gamma) = 321 \pm 43 \pm 27^{+18}_{-10}$
  - $E(\gamma)>2.0$ GeV — PRL 87 (2001) 251807

Belle

- fully inclusive: $BF(b \to s\gamma) = 355 \pm 32\ ^{+30}_{-31}\ ^{+11}_{-7}$
  - $E(\gamma)>1.8$ GeV — PRL 93 (2004) 061803
- semi-inclusive: $BF(b \to s\gamma) = 336 \pm 53 \pm 42^{+50}_{-54}$
  - $E(\gamma)>2.24$ GeV — PLB 511 (2001) 151
  - 16 modes

BaBar

- fully inclusive: $BF(b \to s\gamma) = 367 \pm 29 \pm 34 \pm 29$
  - Lepton-tagged — hep-ex/0507001
  - $E(\gamma)>1.9$ GeV; BF not extrapolated below!
- semi-inclusive: $BF(b \to s\gamma) = 335 \pm 19\ ^{+56}_{-41}\ ^{+4}_{-9}$
  - $E(\gamma)>1.9$ GeV — PRD 72 (2005) 052004
  - 38 modes covering ~55%

errors are:
stat./syst./shap

New HFAG average of these measurements using a common shape function for the extrapolation to low photon energies and taking into account the correlated error from $b \to d\gamma$ contamination:

Calculation of extrapolation factors by
O. Buchmüller and H. Flächer, hep-ph/0507253

$$BF(b \to s\gamma) = 355 \pm 24\ ^{+9}_{-10} \pm 3$$

- $E(\gamma)>1.6$ GeV

stat./syst. combined — shape function — $b \to d\gamma$ contamination

(see http://www.slac.stanford.edu/xorg/hfag/rare for details)

Standard Model prediction (NLO):

$$BF(b \to s\gamma) = 357 \pm 30$$

- $E(\gamma)>1.6$ GeV

Gambino & Misiak, NPB 611 (2001) 338
Buras, Czarnecki, Misiak, Urban, NPB 631 (2002) 219

⇒ Depressing agreement between theory and experiment!

$\mathbf{B \to X_s}\,\gamma$ predictions

- impressive agreement between NLO theory and data
- but we need a NNLO calculation!
- NLO has too much renormalization scheme-dependence on the charm quark mass (Francesca Borzumati)
- + important effects from the scale $\mathbf{\Delta = m_b - 2E^{\gamma}_{min} \simeq 1}\ \mathrm{GeV}$

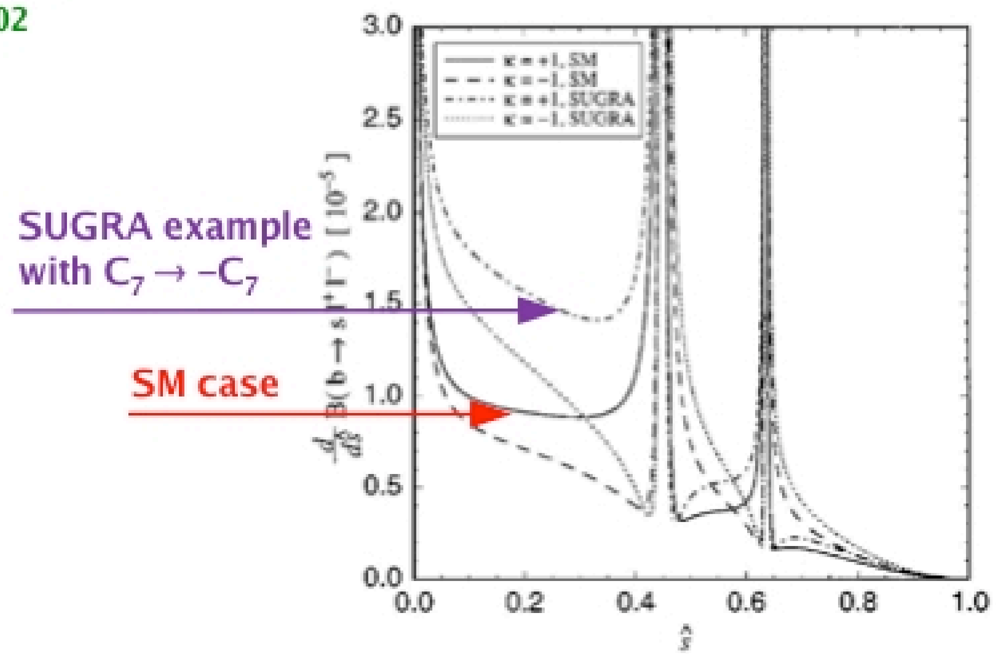
T. Becher and M. Neubert hep-ph/0512208

$b \to s\ell^+\ell^-$ inclusive: sign of C_7

Gambino, Haisch, Misiak, PRL 94 (2005) 061803

$BF(b \to s\ell^+\ell^-)$

q^2 range	Belle (152M $B\bar{B}$)	BaBar (89M $B\bar{B}$)	weighted average	SM	$C_7 \to -C_7$
$q^2 > (2m_\mu)^2$	4.1 ± 1.1	5.6 ± 2.0	4.5 ± 1.0	*4.4 ± 0.7*	*8.8 ± 1.0*
$1 < q^2 < 6$ GeV^2	1.5 ± 0.6	1.8 ± 0.9	1.6 ± 0.5	*1.57 ± 0.16*	*3.30 ± 0.25*
	PRD 72 (2005) 092005	PRL 93 (2004) 081802			



Goto et al., PRD 55 (1997) 4273

Experiments clearly favor SM-sign for C_7!

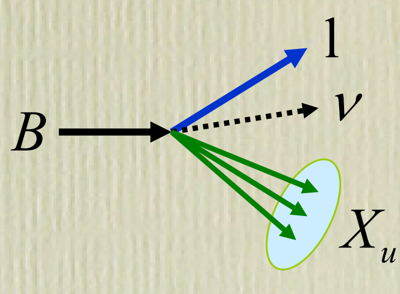
Thomas Schietinger

Concezio Bozzi

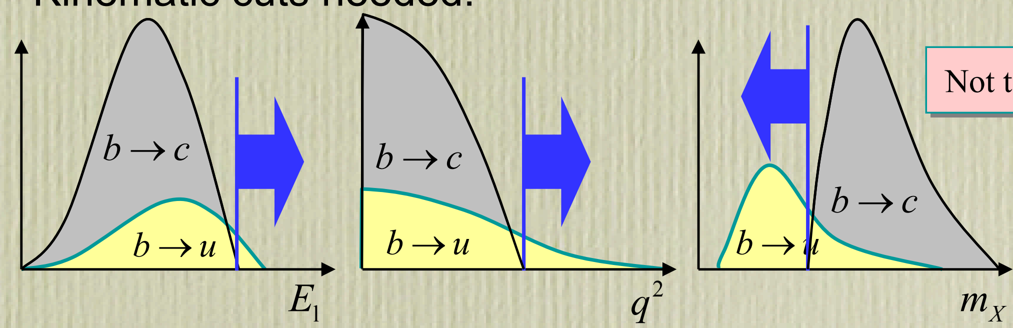
Inclusive decays: $|V_{ub}|$

$$\Gamma(B \to X_u l \nu) = \frac{G_F^2 |V_{ub}|^2 m_b^5}{192\pi^3}\left[1 - \mathcal{O}\left(\frac{\alpha_s}{\pi}\right) - \frac{9\lambda_2 - \lambda_1}{2m_b^2} + \ldots\right]$$

Close friends to the previous ones



- Unfortunately: $\frac{\Gamma(b \to u l \bar{\nu})}{\Gamma(b \to c l \bar{\nu})} \approx \frac{|V_{ub}|^2}{|V_{cb}|^2} \approx \frac{1}{50}$
- Kinematic cuts needed:



Not to scale!

E_l = lepton energy

q^2 = dilepton mass squared

m_X = hadron system mass

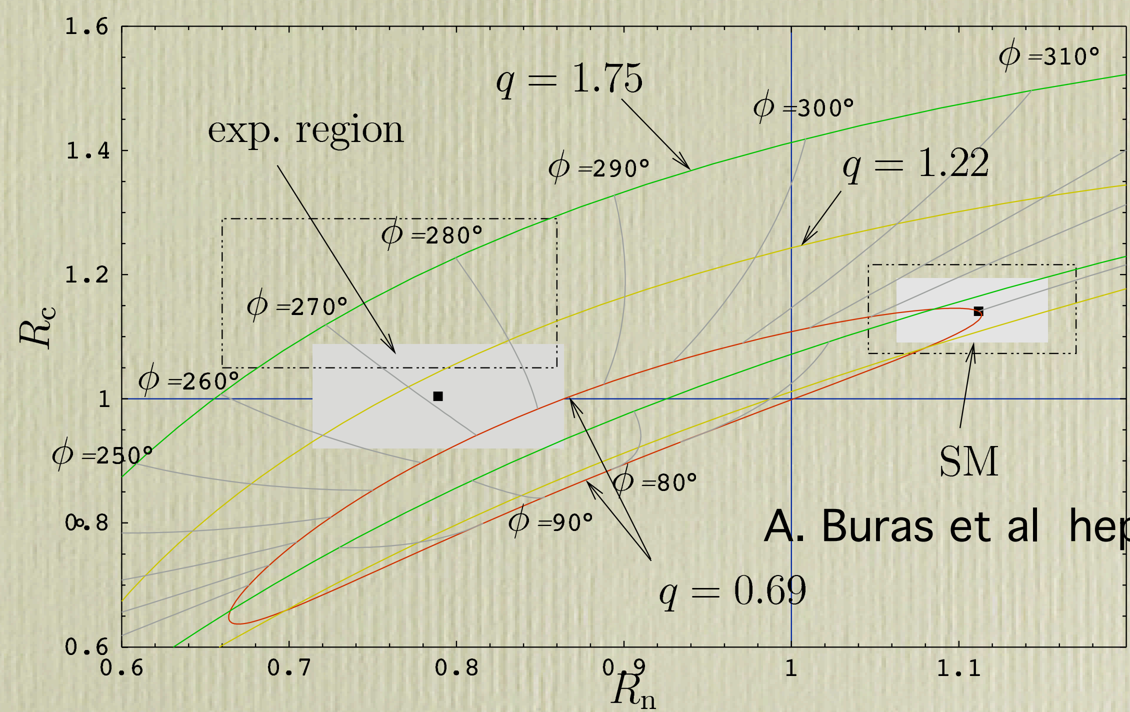
- Smaller acceptances, theory uncertainties increase
  - OPE breaks down
  - “shape function” to resum non-perturbative physics
- Strategy to minimize theory uncertainties:
  - maximize acceptance, or
  - choose “smart” regions/variables
- measure partial branching ratio $\Delta\mathcal{B}$
- get predicted partial rate $\zeta(\Delta p)$ from theory

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}}{\tau_b\, \zeta(\Delta p)}}$$

the $\mathbf{K}\,\pi$ puzzle

- difficult theory versus difficult experiment, with a possible inconsistency pointing to new physics
- step 1: isospin analysis of $\mathbf{B} \to \pi\,\pi$ data to extract hadronic parameters
- step 2: use SU(3) flavor, with known factorizable SU(3) breaking corrections, to apply this to $\mathbf{B} \to \mathbf{K}\,\pi$
- step 3: predict some ratios, check data:

theory vs data doesn't agree for ratios which are sensitive to EW penguins



A. Buras et al hep-ph/0512032

this analysis is being improved, but so far the problem is still there (Julie Malcles)

status of theories beyond the standard model

(an analogy based on the SciFi Channel)

status of theories beyond the standard model

- The BSM models were created by man
- They evolved
- They rebelled
- There are many copies
- And they have a plan

status of theories beyond the standard model

- The BSM models were created by man
- They evolved
- They rebelled
- There are many copies
- And they have a plan

Moriond circa 1983

- BSM theory was supersymmetry, grand unification, technicolor
- the models were primitive
- there was also a small strange community of “neutrino” people
- and a small strange community of “particle-astro” people

status of theories beyond the standard model

- The BSM models were created by man
- They evolved
- They rebelled
- There are many copies
- And they have a plan

Moriond circa 2006

- string theory took the BSM high ground
- supersymmetry models are much more sophisticated, detailed, and ambitious
- supersymmetry has become a framework to describe everything from Higgs to B physics, from inflation to baryogenesis, from unification to LFV, from dark matter to HyperCP
- technicolor mutated into AdS/CFT branes (Francesco Sannino)

status of theories
beyond the standard model

- The BSM models were created by man
- They evolved
- They rebelled
- There are many copies
- And they have a plan

they rebelled

- after 30 years, SUSY is still not discovered , despite golden opportunities with LEP, Tevatron, B physics, EDMs, etc (Carlos Munoz)
- mysteries of flavor and of vacuum energy, which SUSY already had trouble with, have gotten worse
- theorists got worried (and bored) and decided to try radically new things...

extra dimensions

- extra dimensions are the other generic prediction of string theory (Mariano Quiros) and anyway are generic new degs of freedom
- they could be infinite but hidden, very large (.1 mm to 10 fm), large (Tev-1), or tiny but warped.
- they could: break SUSY (Yael Shadmi), explain dark matter (Thomas Flacke), explain fermion masses (Gregory Moreau), explain a light Higgs (Mariano Quiros).

Higgs Shmiggs

- theorists are even questioning some of the holy assumptions:
  - models with no Higgs (Sekhar Chivukula)
  - landscape-inspired SUSY (Adam Falkowski), including split-SUSY
- and combining ideas, e.g. Little Higgs and SUSY (Piotr Chankowski)

status of theories beyond the standard model

- The BSM models were created by man
- They evolved
- They rebelled
- There are many copies
- And they have a plan

there are many copies

- despite different theoretical inputs, many BSM models end up looking the same phenomenologically
- this is because they are trying to do the same things
- while simultaneously getting around the bounds from existing data
  (Guido Mirandella)

there are many copies

- most BSM models have a WIMP dark matter, and thus missing energy signatures at colliders
-
- the EW precision data imply that the new heavy particles associated with EWSB are:
  - multi-TeV
  - conspiratorial
  - pair-produced (->DM) and minimal flavor-violating

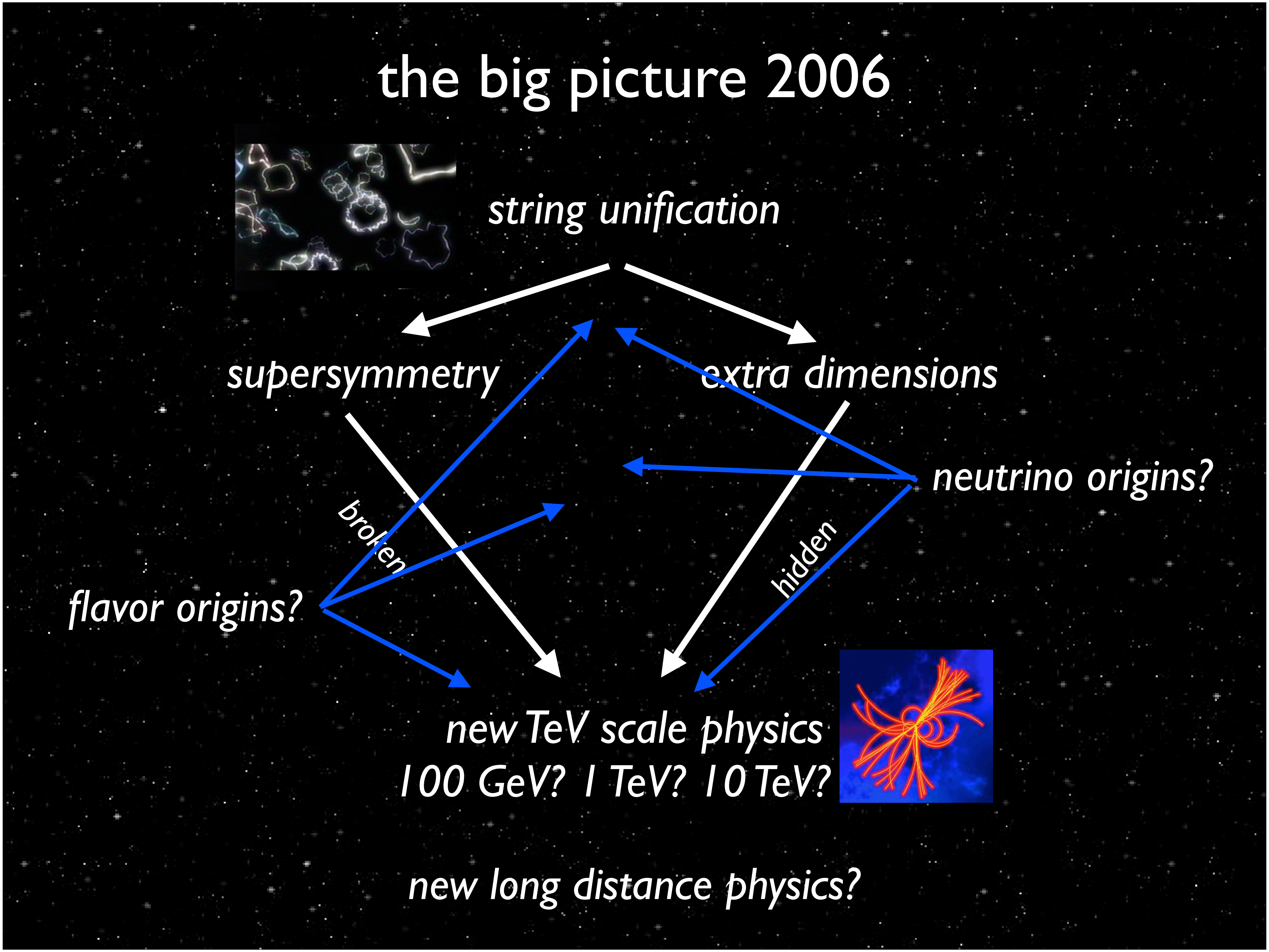
there are many copies

- so some new BSM models look like SUSY (Little Higgs with T-parity, UED,...)
- others resemble each other with new TeVish gauge bosons, top-partners, etc (Little Higgs, Randall-Sundrum, TeV extra dims, GUT-inspired,...)
- and it was already difficult to tell SUSY models apart (Martin White)

status of theories beyond the standard model

- The BSM models were created by man
- They evolved
- They rebelled
- There are many copies
- And they have a plan

replace the standard paradigm by ~2015


the big picture 2006
string unification
supersymmetry
extra dimensions
broken
hidden
neutrino origins?
flavor origins?
new TeV scale physics
100 GeV? 1 TeV? 10 TeV?
new long distance physics?

neutrino origins

$$|U_{\alpha i}| = \begin{pmatrix} |U_{e1}| & |U_{e2}| & |U_{e3}| \\ |U_{\mu 1}| & |U_{\mu 2}| & |U_{\mu 3}| \\ |U_{\tau 1}| & |U_{\tau 2}| & |U_{\tau 3}| \end{pmatrix} = \begin{pmatrix} 0.76-0.87 & 0.49-0.64 & 0.00-0.20 \\ 0.20-0.53 & 0.42-0.72 & 0.58-0.82 \\ 0.20-0.54 & 0.43-0.73 & 0.56-0.81 \end{pmatrix}$$

Gonzalez-Garcia et al (2005)

Different pattern for leptons and quarks

$$|U_{\alpha i}|_{CKM} = \begin{pmatrix} 0.9739-0.9751 & 0.221-0.227 & 0.0029-0.0045 \\ 0.221-0.227 & 0.9730-0.9744 & 0.039-0.044 \\ 0.0048-0.014 & 0.037-0.043 & 0.9990-0.9992 \end{pmatrix}$$

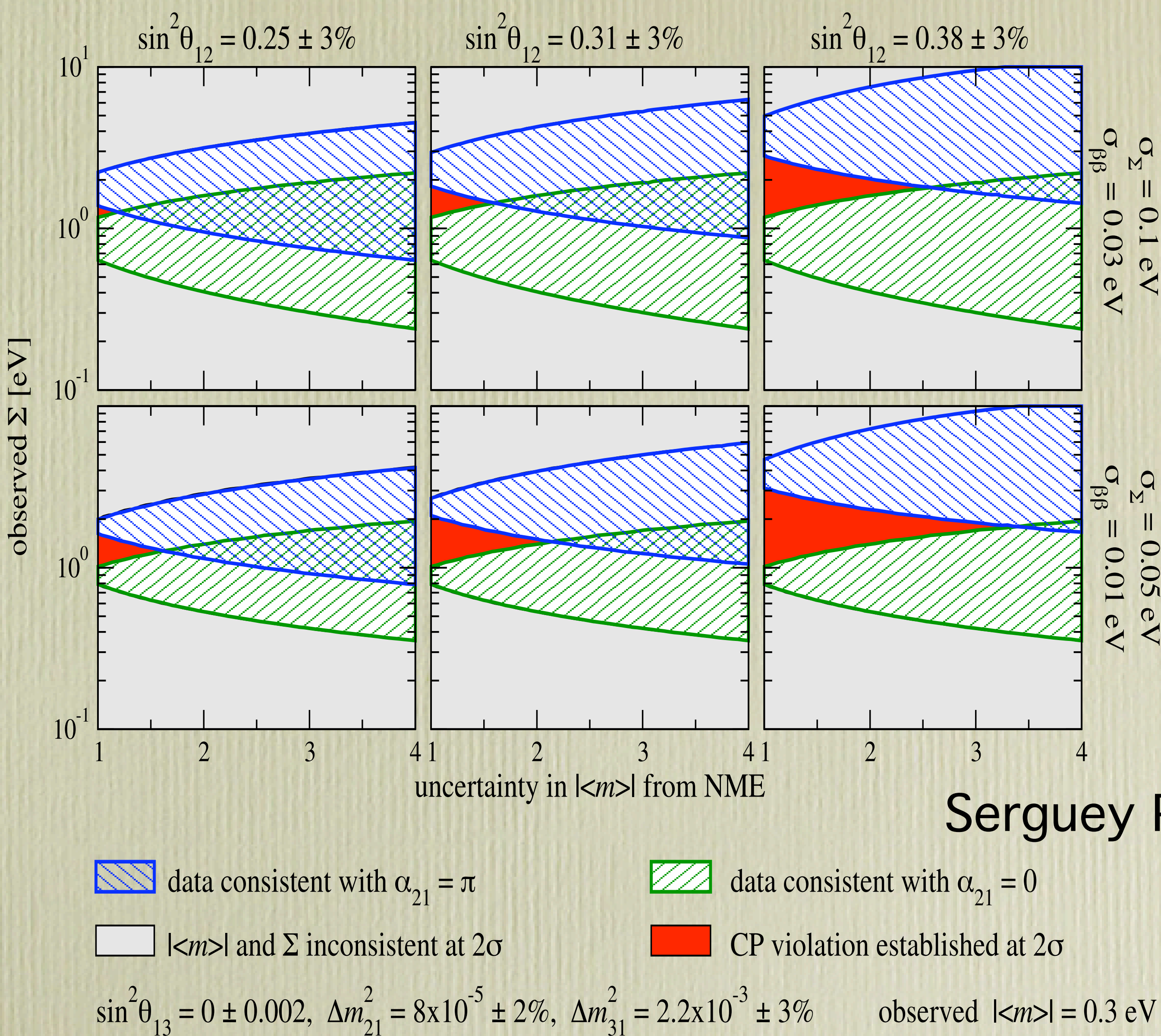
Carlos Pena Garay

- where did all this come from?
- what are the energy scales where this gets generated?
- is it related to our own genesis?

what we need to know about neutrinos

Serguey Petcov

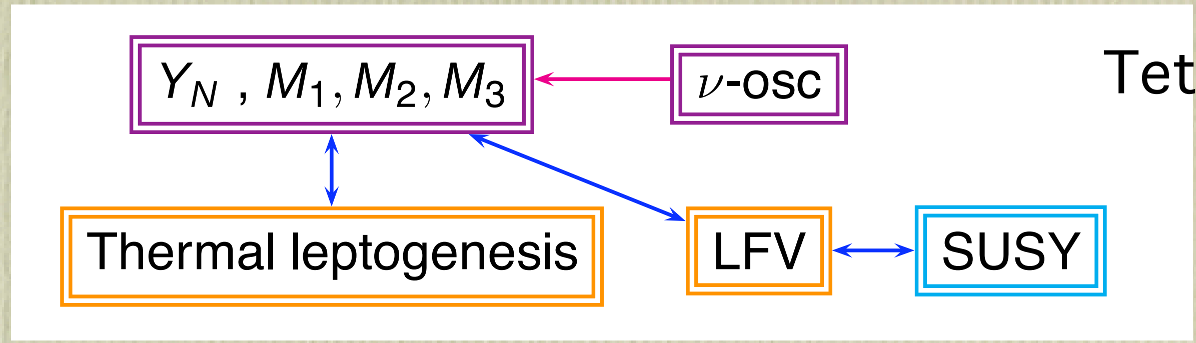
- Dirac or Majorana masses?
- Mass hierarchy: normal, inverted, quasi-degenerate?
- Absolute scale of masses?
- light steriles? eV, keV?
- relation to dark matter?
- theta_13?
- CP violation? Dirac or Majorana phases?
- lepton flavor violation apart from Majorana masses? related to TeV scale SUSY?
- relation to leptogenesis?
- origin of PMNS masses and mixings: what energy scales and symmetries are involved? relation to CKM?



Serguey Petcov

no no-go for discovering Majorana CPV

neutrino origins



Tetsuo Shindou

- we heard a story connecting SUSY@LHC to LFV data to discovery of IH and $0\nu\beta\beta$ to leptogenesis
- many such stories may be possible (Thomas Hambye, Fedor Bezrukov, Ernesto Arganda Carreras, Reinhold Rueckl, Pierre Hosteins, David Maybury, Lofti Boubekeur, Michel Tytgat, Thomas Underwood)
- huge long-term challenge to experiments, fertile ground for theorists

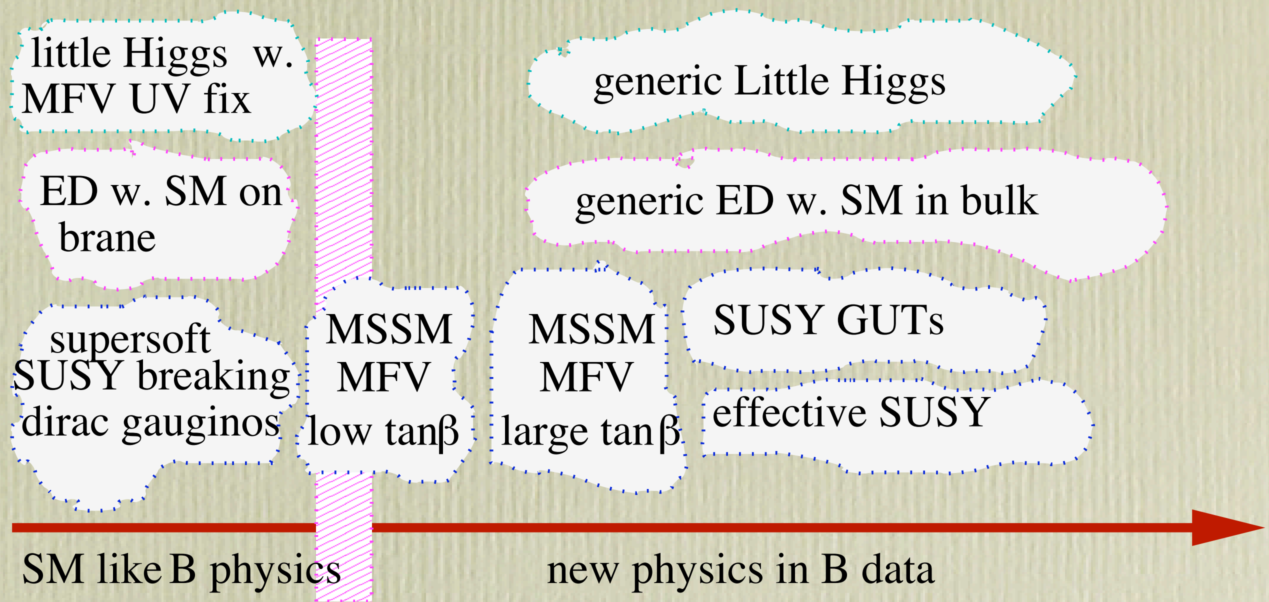
classify possible new flavor physics in the quark sector

(from Buras and Fleischer)

- Minimal Flavor Violation (MFV): new diagrams, but no new operators. Only source of flavor-changing effects (including CP violation) is the CKM matrix. Examples: THDM-II and CMSSM moderate tan beta
- New operators, but no new CP violation. Example: MSSM with large tan beta
- New CP violation, but no significant contributions from new operators. Example: MSSM with moderate tan beta and nondiagonal squark mass matrices
- General new flavor violation. Examples: generic SUSY, multi-Higgs, Little Higgs, extra dims

models of EWKSB with NP @ TeV

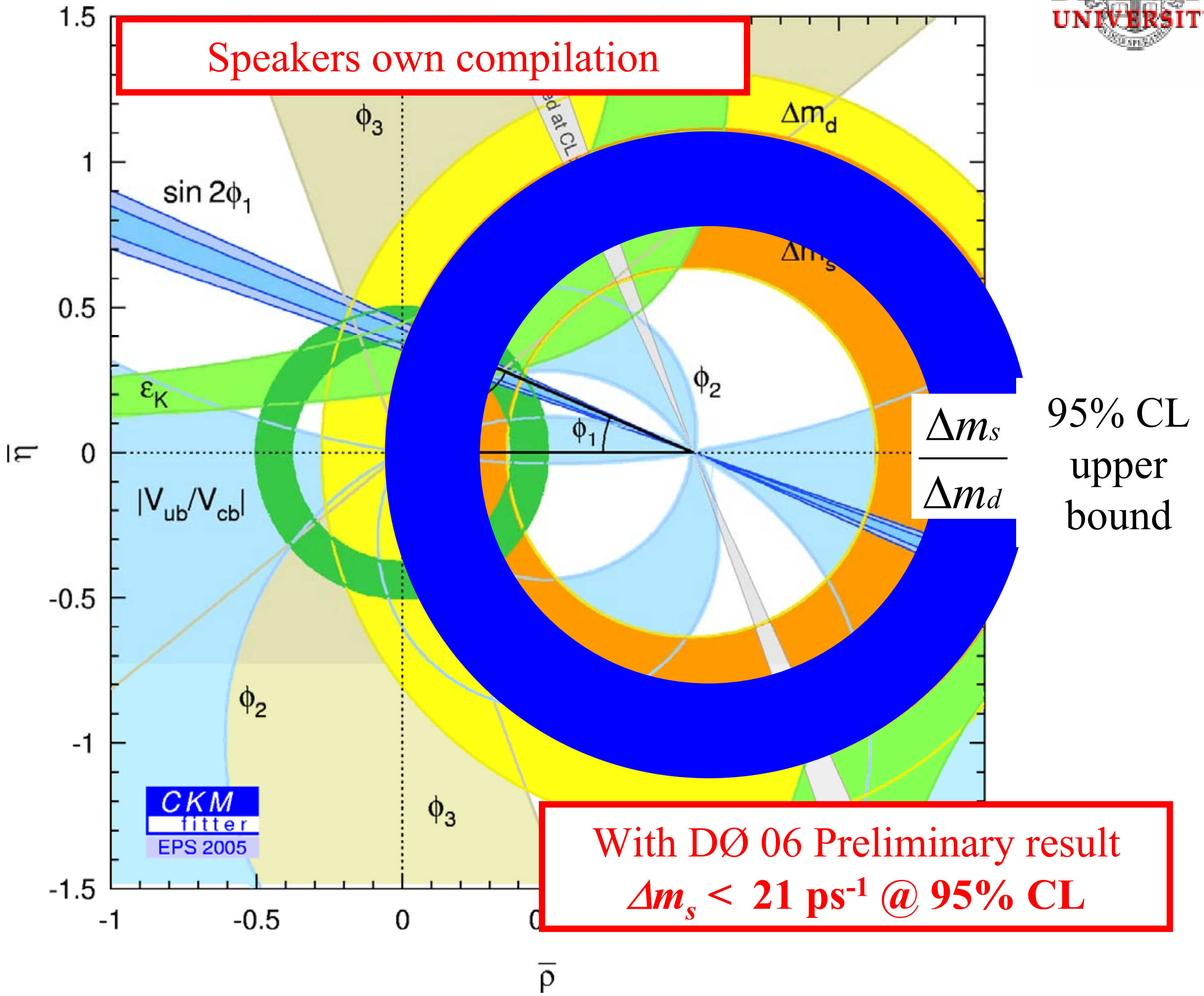
Fig from hep-ph/0207121



Gudrun Hiller, talk this week at CMS SUSY/BSM

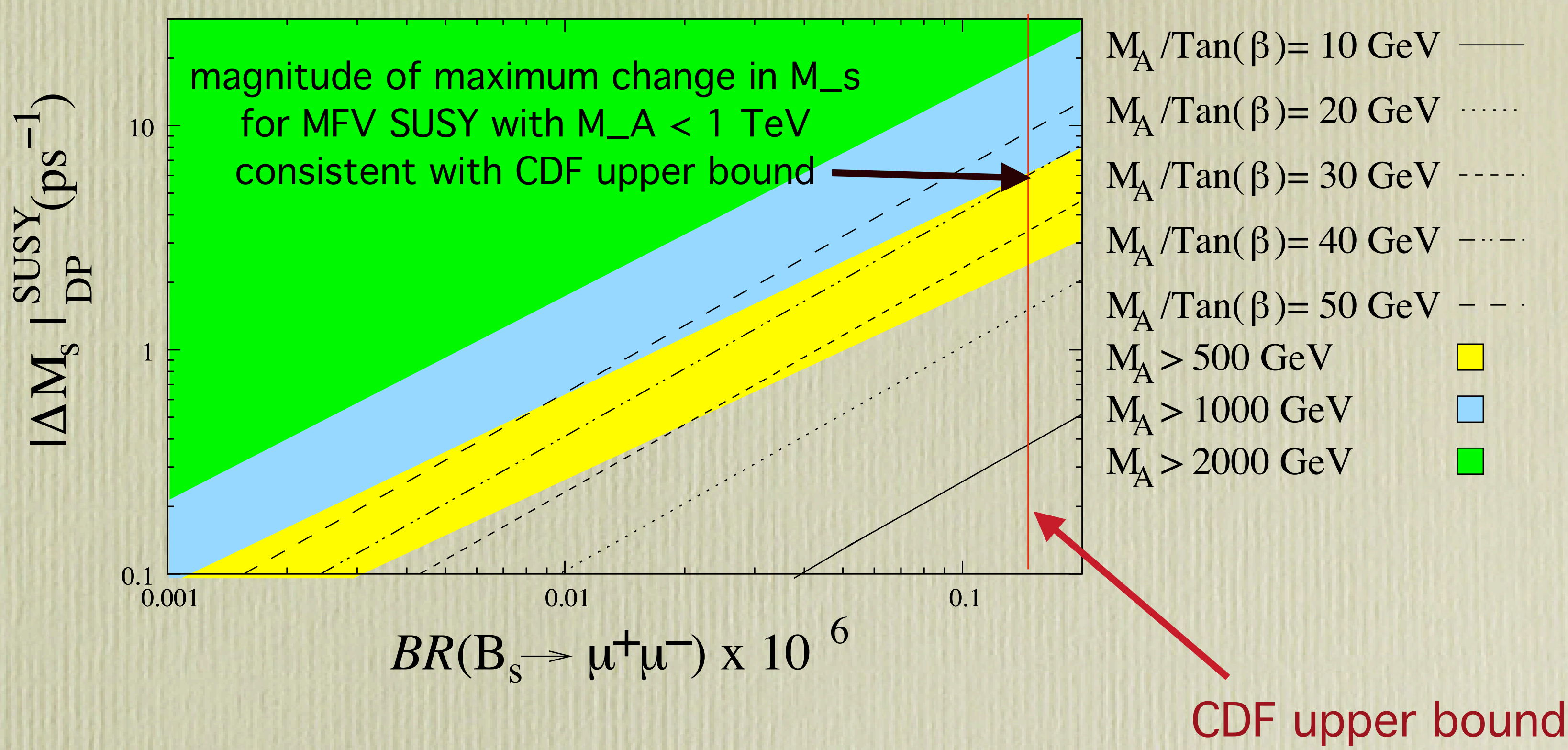
so what does the Dzero result on B_s mixing tell us?

New CKM Triangle

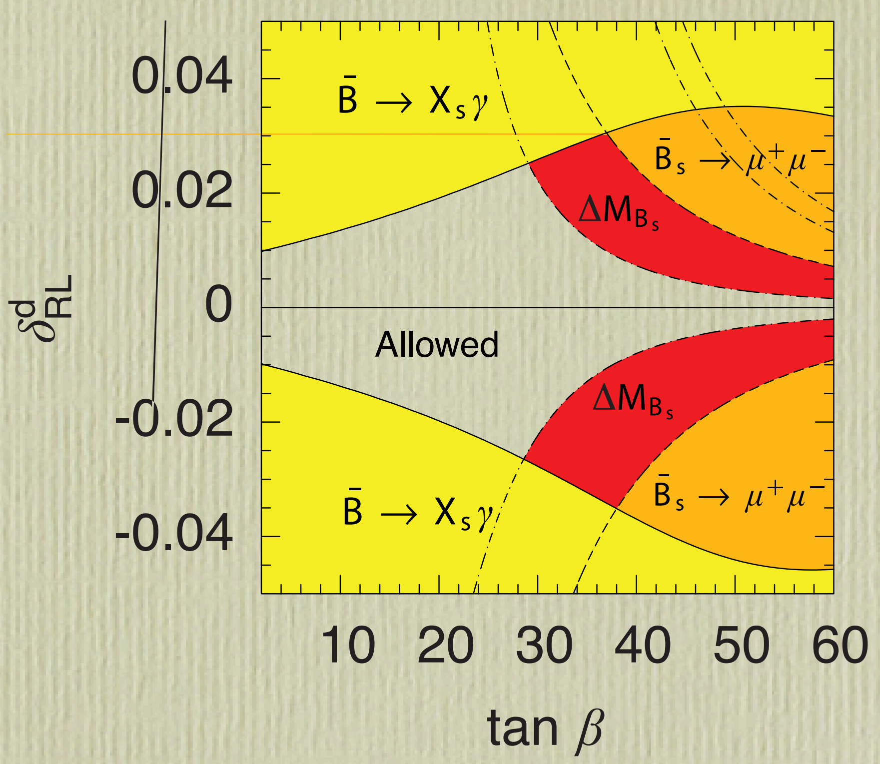


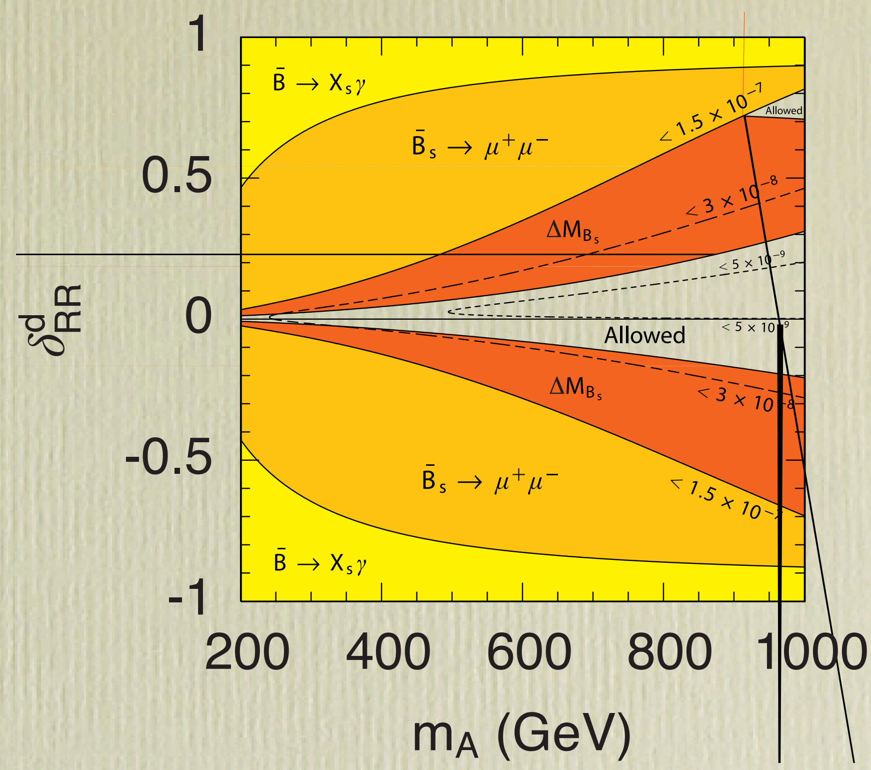
Brendan Casey

M. Carena et al hep-ph/0603106 this week



not much change for MFV SUSY





big constraints for generic SUSY

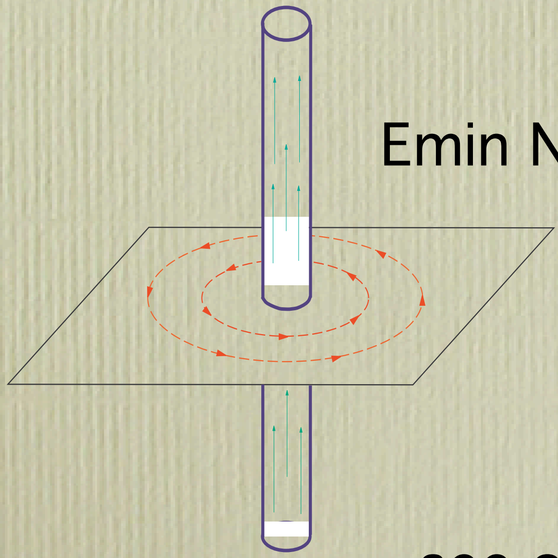
thanks to John Foster, Ken-ichi Okumura, and Leszek Roszkowski for these new plots!!

“I was hoping to see some enhancement in B_s mixing as a signal of large atmospheric neutrino mixing and SUSY-GUT, and I am definitely sad”

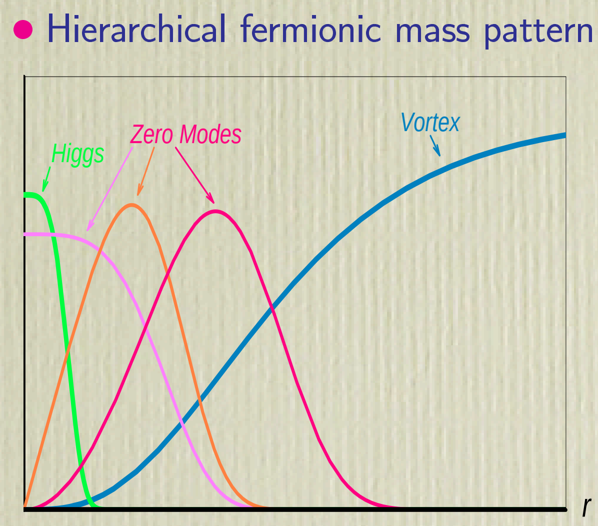
-Hitoshi Murayama

flavor 2006

- neutrino flavor is a mystery
- the origins of CKM + fermion mass hierarchies are a mystery
- increasingly appears that the new TeV scale physics is MFV, but we don't know why or how
- flavor is a big challenge - need new ideas!



Emin Nugaev



see also talk by Stefano Morisi on GUT flavor

cosmology 2006

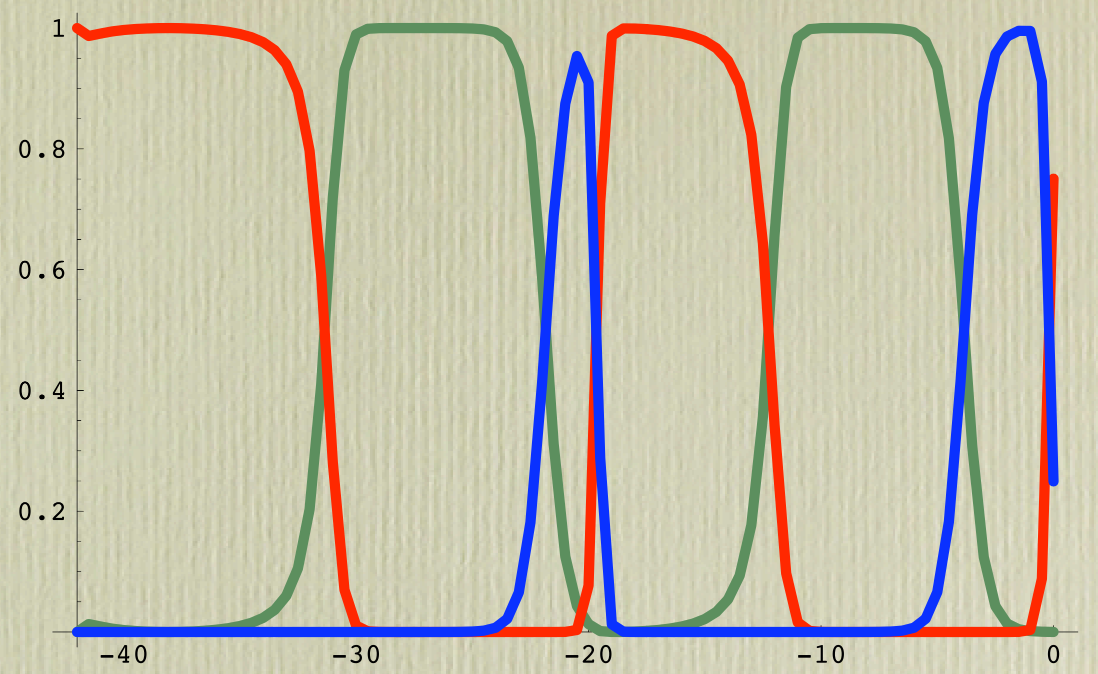
- the exciting WMAP 3-year results arrived during the conference and were reviewed by G. Barenboim and C. Pena Garay
- these results add yet more independent evidence for dark matter, while MOND is under attack from both ends (dwarf galaxies and clusters)
- WIMPs and axions are both well-motivated DM candidates, getting quite constrained by searches
- my guess is that DM will turn out to have several different components (like visible matter)

what we don’t know about WIMPS

- the neutralino relic density estimates are strongly dependent on the SUSY model (Martin White). Scanning just mSUGRA is not good enough (David Cerdeno).
- Kaluza-Klein DM estimates are based on baby models, could change.
- sneutrino DM was ruled out prematurely (Stephen West)
- don’t yet trust models for how WIMPS collect at the centers of galaxies (Malcolm Fairbairn)

the TeV frontier in cosmology

- WIMP relic density estimates assume a standard expansion rate and thermal history between BBN and T ~ 1 TeV
- but we have no independent knowledge of this!
- same is true of the EW phase transition at T~100 GeV, which in turn affects the prospects for EW baryogenesis (Stephan Huber)
- one of the great challenges for particle physicists is to help advance the cosmological frontier from T ~ 1 MeV to T ~1 TeV



Gabriela Barenboim

- Slinky has a thermal history which satisfies the usual requirements but looks very different before BBN
- we can get such nonstandard cosmologies from a single scalar inflaton, but it has to have a rather strange form:

$$\int \mathbf{d^4x}\,\frac{\mathbf{1}}{\mathbf{2}}\mathbf{F}(\phi)\partial^\mu\phi\partial_\mu\phi - \mathbf{V}(\phi)$$

$$\mathbf{F}(\phi) = \frac{\mathbf{3}}{\mathbf{8\pi G_N}}\,\frac{\mathbf{c_1}\mathrm{e}^{\mathbf{3}\phi} + \frac{\mathbf{4}}{\mathbf{3}}\mathbf{c_2}\mathrm{e}^{\mathbf{4}\phi}}{\mathbf{c_0} + \mathbf{c_1}\mathrm{e}^{\mathbf{3}\phi} + \mathbf{c_2}\mathrm{e}^{\mathbf{4}\phi}}$$

$$\mathbf{V}(\phi) = \mathbf{c_0} + \frac{\mathbf{1}}{\mathbf{2}}\mathbf{c_1}\mathrm{e}^{\mathbf{3}\phi} + \frac{\mathbf{1}}{\mathbf{3}}\mathbf{c_2}\mathrm{e}^{\mathbf{4}\phi}$$

actually this inflaton doesn't give the Slinky cosmology, in fact it mocks up standard $\Lambda\mathrm{CDM}$!

inflatons are phenomenological devices!

dark energy?

- all observational evidence for dark energy is indirect
- the current accelerating expansion could be explained in many ways:
  - the FRW approximation is breaking down (Rocky Kolb)
  - the Friedmann eqn is wrong due to modified gravity or extra dimensions (Ignacio Navarro)
  - a tiny cosmological constant
  - quintessence (whatever that is)

the future

“Never trust a theorist”

- S. Ting

The Compact Muon Solenoid Experiment

CMS Note

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

6 December 2008

Evidence for squark and gluino production in pp collisions at $\sqrt{s}$ = 1$\underline{4}$ TeV

CMS collaboration

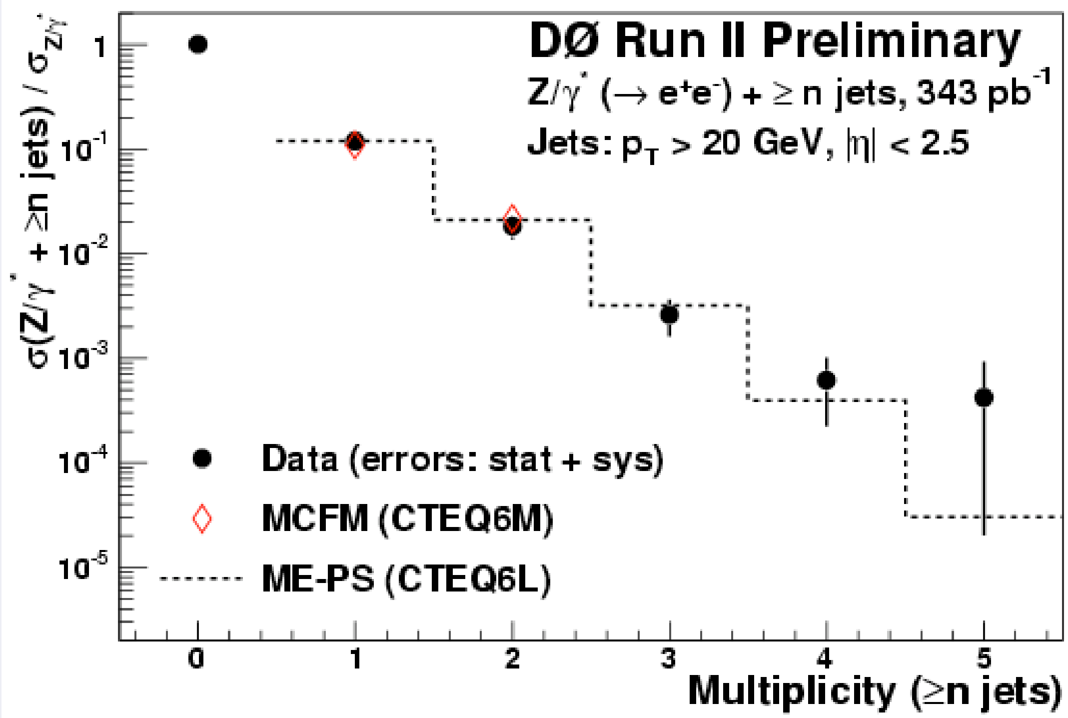
Abstract

Experimental evidence for squark and gluino production in pp collisions $\sqrt{s} = 14$ TeV with an integrated luminosity of 97 pb^{-1} at the Large Hadron Collider at CERN is reported. The CMS experiment has collected 320 events of events with several high E_T jets and large missing E_T, and the measured effective mass, i.e. the scalar sum of the four highest P_T jets and the event $\not{E}_T$, is consistent with squark and gluino masses of the order of 650 GeV/c^2. The probability that the measured yield is consistent with the background is 0.26%.

Submitted to *European Journal of Physics*

preview of Moriond 2009

Cross check on Run2 data



Includes up to $Zjjj$, $j = q, g$

Steve Mrenna

the future is now!