Computer-aided SUSY FCNC studies

Sebastian Jäger

Institut für Theoretische Physik E

RWTH Aachen

reporting on work done with A.J. Buras, T. Ewerth, and J. Rosiek

and a FORTRAN library by P. Chankowski, J. Rosiek, and others

presented at CPNSH subgroup meeting "Flavour and LHC", 31 Jan - 1 Feb 2005 at CERN

Overview

1. Library
   requirements – interface – implementation
2. Application
   example: $K \to \pi\nu\bar{\nu}$ – questions – technical issues – adaptive scan – program structure
3. Results
   size of effects – confirmed and unexpected parameter dependences – constraints on parameter space
4. Summary-Outlook

Goals and requirements

We want to compute flavour violating processes in the general MSSM.

$K \to \pi\nu\bar{\nu}$, $B_0 - \bar{B}_0$ mixing, $B \to X_s\gamma$, $B \to X_s l^+ l^-$, etc

Experimental (ranges, limits) and theoretical constraints (vacuum stability) must also be checked.

This fixes/suggests:

Inputs SUSY $\mathcal{L}$ – complete set of parameters !

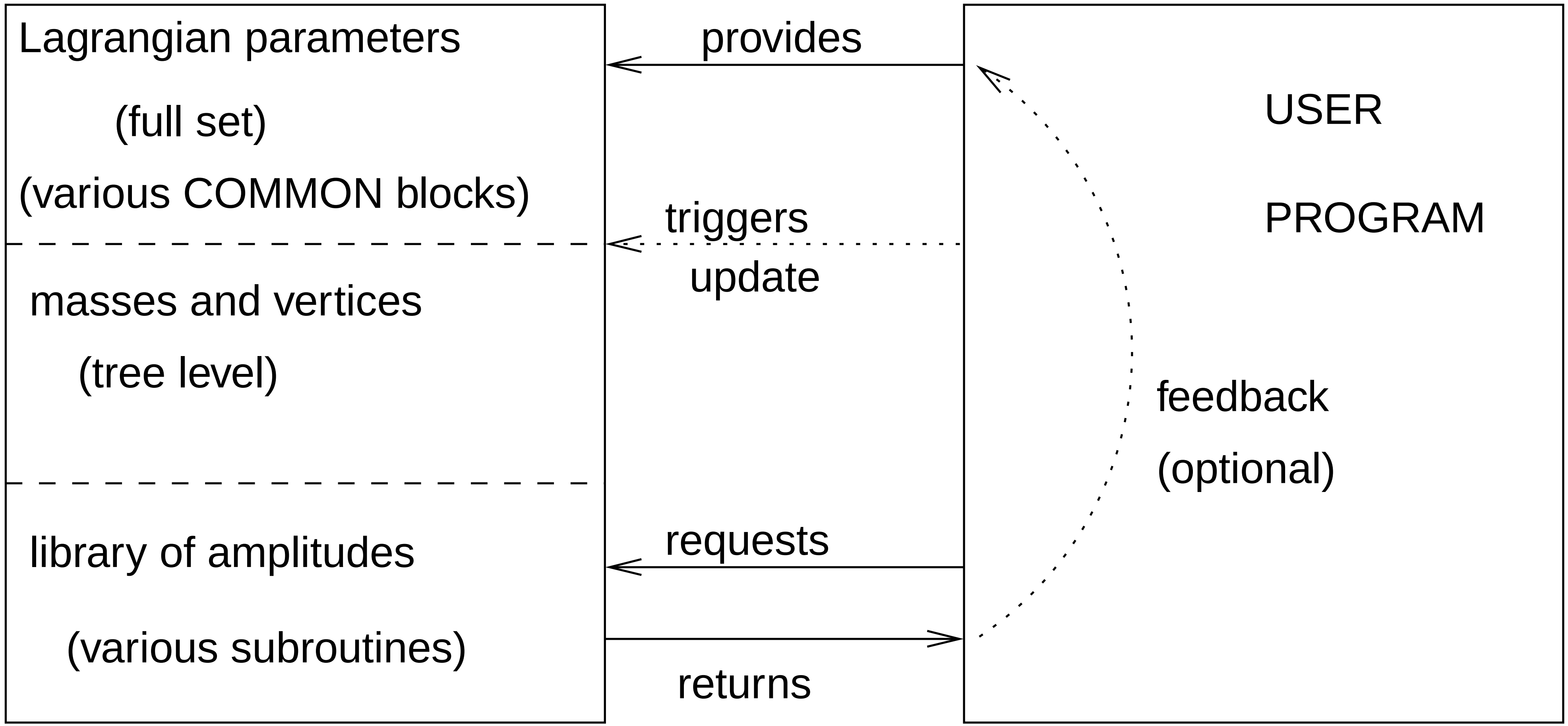
Outputs sparticle masses, vertices and (ideally) physical amplitudes

Library of FORTRAN common blocks and routines written by P. Chankowski and J. Rosiek, with numerous people using it so far.

Implementation

- Interface
  - common blocks storing SM and MSSM parameters
  - certain of these: inputs, to be set by calling program
  - initialization routines (mass diagonalization, consistency checks, finding remaining parameters, e.g. y_b)
  - MSSM tree vertices available through function calls
  - many amplitudes also available through function calls
- State
  - after initialization, state of library corresponds to Lagrangian parameters, tree-level masses, MSSM mixing angles
- Program code
  - FORTRAN77 – experimental C/C++ interface exists

Program-library interaction



Application: $K \to \pi\nu\bar{\nu}$ in the MSSM

- Motivation
  - small hadronic uncertainties, one Inami-Lim function X
  - range for $BR(K^+ \to \pi^+\nu\bar{\nu})$ from AGS E787 & E949: compatible with SM
  - bound on $BR(K_L \to \pi^0\nu\bar{\nu})$ from KTeV - $10^4\times$ SM rate. Factor 10 enhancement possible with new phase (Buras, Fleischer, Recksiegel, Schwab 2003-4). MSSM has lots of these!
  - bound on ratio of BRs from isospin (Grossman-Nir)
  - upcoming/future experiments – KEK E391a, CKM, NA48, KOPIO, JPARC: last could see $\mathcal{O}(100)$ SM $K_L \to \pi^0\nu\bar{\nu}$ events

$K \to \pi\nu\bar{\nu}$ in the MSSM (2)

- Physics questions
  - size of effect?
    Can $K^+ \to \pi^+\nu\bar{\nu}$ reach central exp value?
    Can $K_L \to \pi^0\nu\bar{\nu}$ receive order-of-magnitude enhancement in MSSM? (Each time satisfying all other bounds?)
    Can Grossman-Nir bound be saturated?
  - parameter dependence?
    expect: mainly charginos & up-type squarks, second-order up-type-squark LR mass insertions (Buras, Romanino, Silvestrini 1997; Colangelo, Isidori 1998; BRSCI 1999)
  - Conversely, what is constraining impact on MSSM parameter space (and on unitarity triangle)?
  - What is constraining impact of other constraints applied?

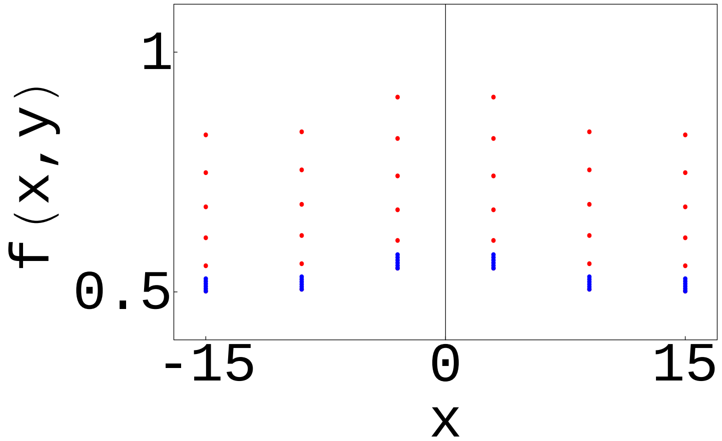
Technical issues

MSSM parameter space has $d = \mathcal{O}(100)$. Not all equally important!

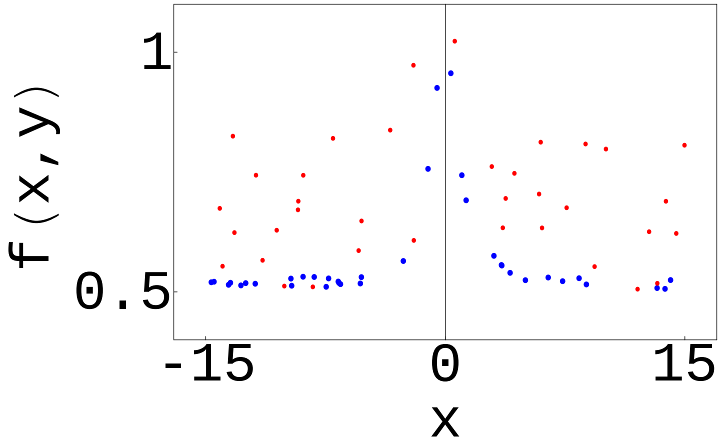
Consider $d = 2$. Two variables x, y, plus a fixed parameter a.

$$f(x,y) = \frac{1}{2}\, e^{ay} \left(1 + \frac{1}{1+x^2}\right)$$

$a = 1/2$ - strong, $a = 1/20$ - weak y-dependence



grid scan, 36 points



random scan, 36 points

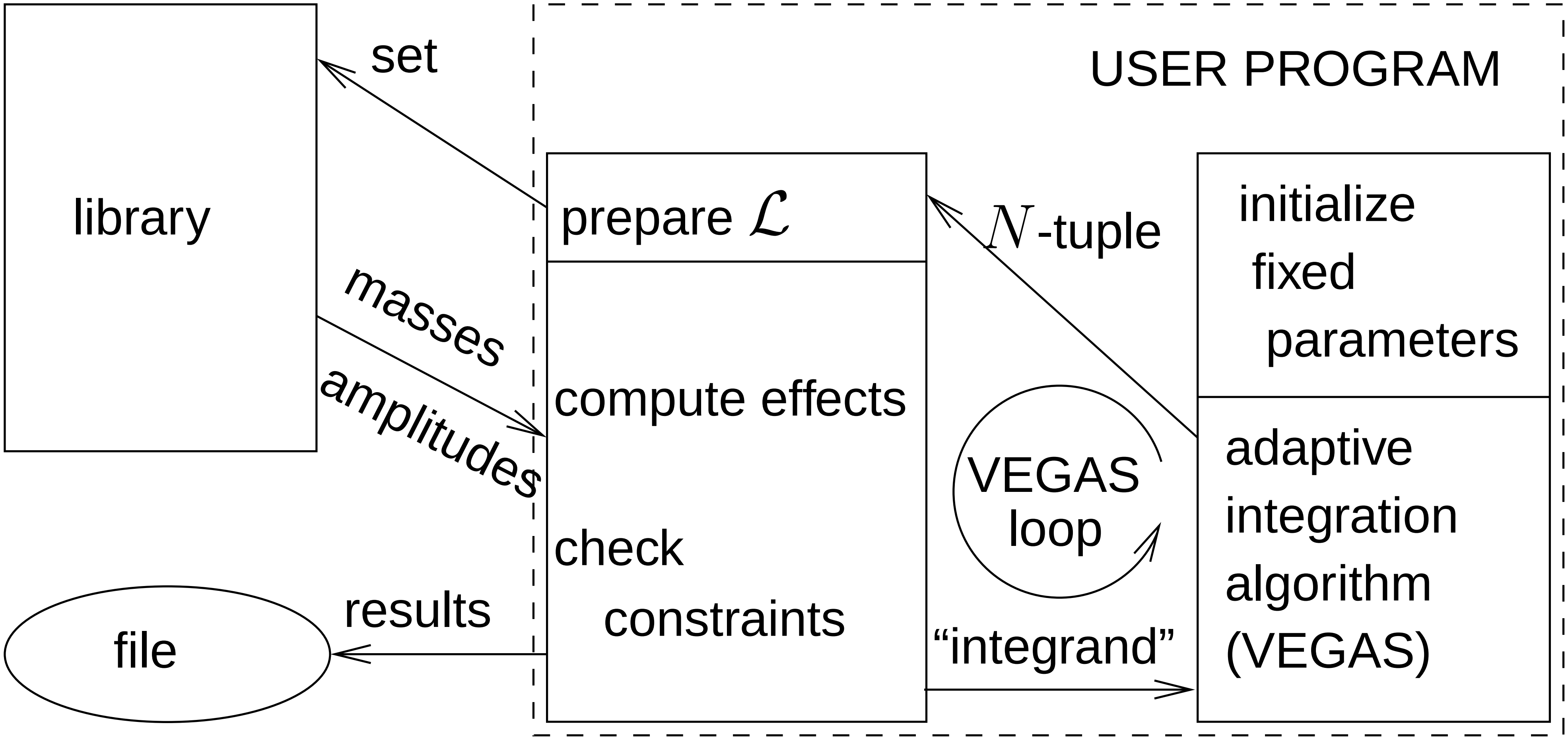
Grid scan: “wastes” points and misses peak.

Random scan: no redundant points, but still few in “interesting” (peak) region.

Adaptive random scan

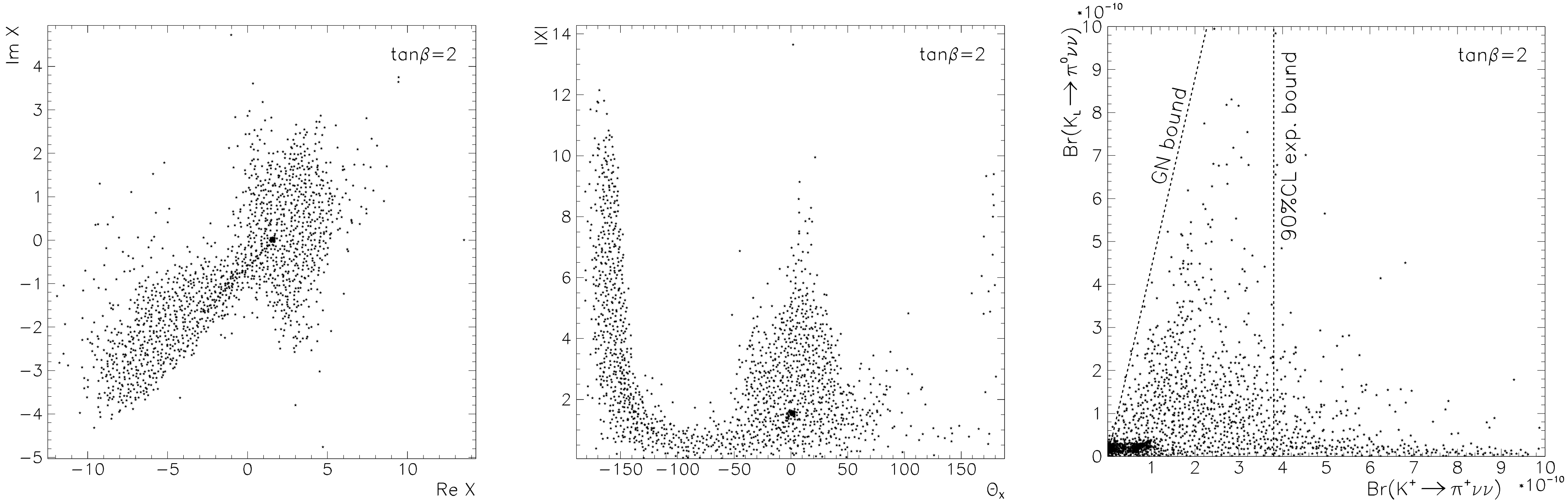
- Such a situation is typical - weak dependence on most parameters, interesting effects in small regions.
- Would like to focus on these, but not known beforehand
- Adaptive scan (Brein 2004): Use adaptive integration routine (VEGAS) and let it integrate a “pertinence function” f that is large where something interesting is found, small otherwise. During function evaluation: full physics analysis of parameter point generated by VEGAS.
- finding maxima of observable: $f = |X|^k$ (X = Inami-Lim function); VEGAS increases density of points where X is large
- detect boundaries of allowed parameter space: $f = 0$ if bounds violated. Boundaries are physical, probability densities aren’t!

Program layout



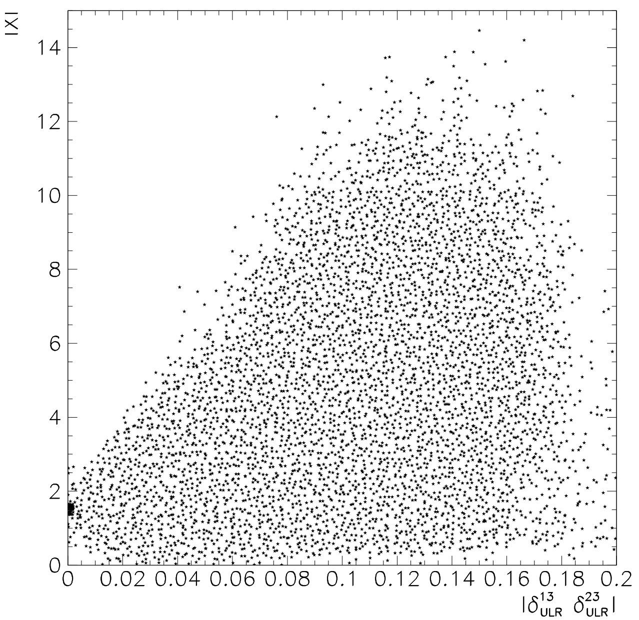
X function and branching ratios

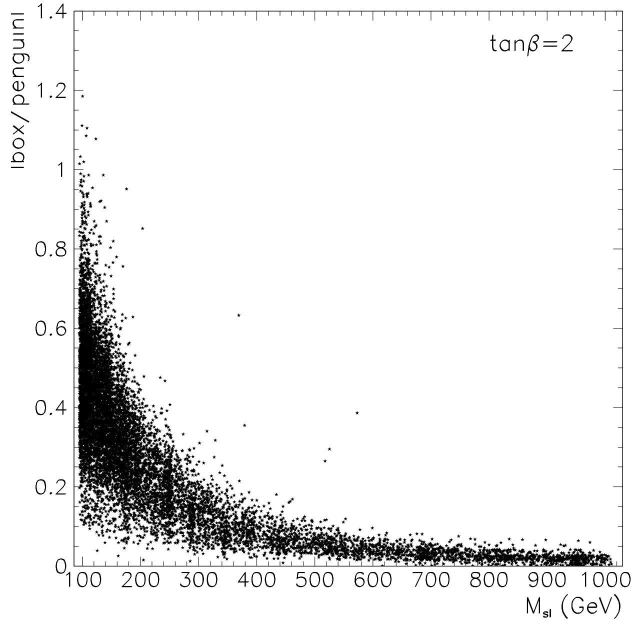
Adaptive scan, $N = 16$ parameters.



- $BR(K^+ \to \pi^+ \nu\bar{\nu})$ can easily reach exp. central value
- large phase of X possible. $BR(K_L \to \pi^0 \nu\bar{\nu})$ can be spectacular (visible to E391a). Grossmann-Nir bound can be saturated.
- observe sharp boundaries in complex X plane

Parameter dependences





- confirms importance of double LR mass insertion
  chargino contribution dominates when all contributions kept
- cannot neglect boxes, but same LR squark mass dependence.
  Slepton mass dependence autodetected by adaptive scan!
- Little change for $\tan\beta = 20$ or more parameters (63) scanned

Constraints on MSSM parameters

Byproducts of the analysis

- bounds on MSSM parameters, even allowing for cancellations – unlike usual MIA approach. For instance:

MI	$\tan\beta = 2$	$\tan\beta = 10$	$\tan\beta = 20$
$\mathrm{Re}\,\delta^{12}_{DLL}$	0.01	0.01	0.01
$\mathrm{Im}\,\delta^{12}_{DLL}$	0.01	0.01	$7.5 \cdot 10^{-3}$
$\mathrm{Re}\,\delta^{13}_{DLL}$	0.1	0.2	0.15
$\mathrm{Im}\,\delta^{13}_{DLL}$	0.1	0.2	0.15
$\mathrm{Re}\,\delta^{23}_{DLL}$	0.35	0.3	0.3
$\mathrm{Im}\,\delta^{23}_{DLL}$	0.35	0.28	0.25

- similarly for the CKM angle γ

$$20^\circ \le \gamma \le 110^\circ$$

Summary-Outlook

- FORTRAN library available for computing flavor-violating processes in the general MSSM
- abilities of libary together with adaptive parameter scan demonstrated for $K \to \pi\nu\bar{\nu}$
- parameter dependence essentially as expected (LR up-type-squark mixing)
- large BR's possible, $BR(K_L \to \pi^0\nu\bar{\nu})$ can be enhanced by factor of 20-30 – within the reach of KEK E391a
- nontrivial constraint on CKM angle γ even in the general MSSM
- robust bounds on MSSM parameters available without the need for technical assumptions
- Application to other processes?