Progress report on ISATOOLS

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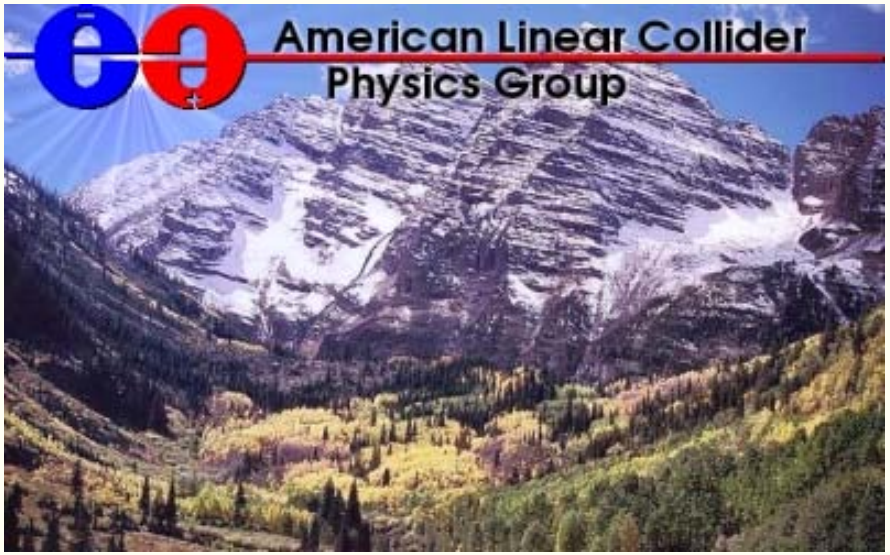

2005 International Linear Collider Physics and Detector Workshop
and Second ILC Accelerator Workshop
Snowmass, Colorado, August 14-27, 2005

OUTLINE

- *Motivation and history*
- *Structure*
- *How to install and use*
- *Conclusions and outlook*

Hunting for SUSY and SUSY constraints

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- **SUSY dark matter constraints:**

  neutralino relic density, Ωh^2

  (WMAP result)

  direct DM search, $\sigma_{\widetilde{Z}_{1p}}$

  (CDMS/EDELWEIS/ZEPLIN/DAMA/CRESST/GENIUS...)

  indirect DM search,

  ν_μ **(Antares/ICECUBE),** γ**'s (EGRET/GLASS),**

  e^+**'s (PAMELA/Ams02/HEAT),** $\bar{p}$**(BESS)**

- **low energy/rare processes constraints**

  $b \to s\gamma$

  (BELLE, CLEO, ALEPH),

  $B_s \to \mu^+\mu^-$

  (CDF),

  δa_μ

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- **collider search at LEP2,Tevatron, LHC,ILC**

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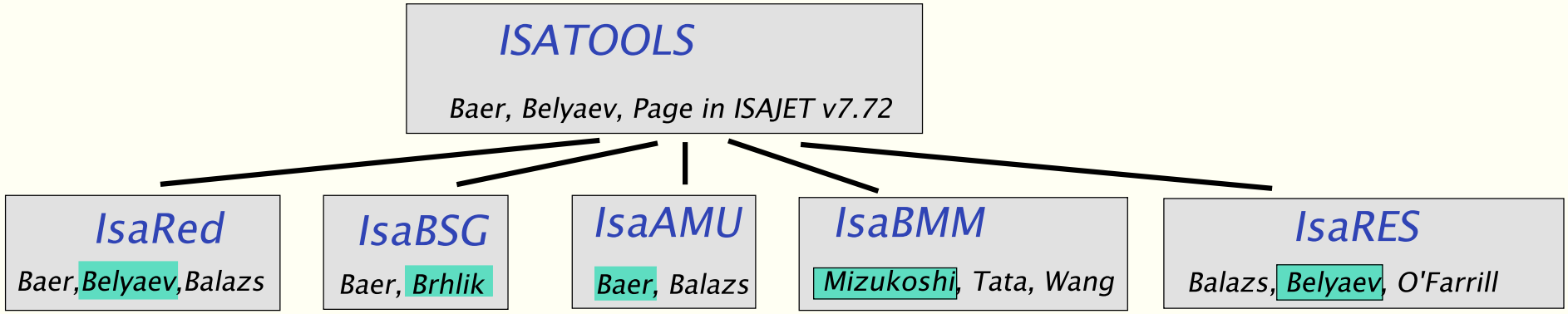
The structure of ISATOOLS package

IsaTools is a package of subroutines for the evaluation of various supersymmetric constraints using the Isajet supersymmetry code.

by Baer,Belyaev,Paige



- **IsaRED** – to evaluate the relic density of neutralino dark matter
- **IsaBSG** – to evaluate the branching fraction $BF(b \to s\gamma)$,
- **IsaAMU** – to evaluate SUSY contributions to $\Delta a_\mu \equiv (g-2)_\mu/2$,
- **IsaBMM** – to evaluate MSSM $BF(B_s \to \mu^+\mu^-)$ and $BF(B_d \to \tau^+\tau^-)$
- **IsaRES** – to evaluate the spin-independent and spin-dependent neutralino-proton/neutron scattering CS

A little bit history and details on ISATOOLS components

IsaTools is an optional set of subroutines that runs with Isajet v. 7.72 or greater. Details on the application of IsaTools and on the structure of IsaRED, IsaBSG, IsaBMM and IsaRES could be found at
http://hep.pa.msu.edu/belyaev/proj/dark_matter/isatools_publi

IsaRed (H. Baer, C.Balazs, A. Belyaev)

- *Was created in 2001, first publication is by* **Baer,Balazs,Belyaev; hep-ph/0202076**
  "NEUTRALINO RELIC DENSITY IN MINIMAL SUPERGRAVITY WITH COANNIHILATIONS"
- *The idea was to have our own independent program for evaluating of CDM relic density*
  neutdriver had no stau CA (only public) and Olive-Ellis private code were on the market
- *Christmas 2001 present – MicrOMEGAs by*
  Belanger,Boudjema,Pukhov,Semenov;hep-ph/0112278

IsaRED (H. Baer, C.Balazs, A. Belyaev)

- Evaluates the neutralino relic density in the MSSM, the complete set of tree-level $\widetilde{Z}_1\widetilde{Z}_1$ annihilation and co-annihilation processes is evaluated.
- Calculations are based on the matrix element library created using the CompHEP program and interfaced to Isajet.
- SUSY the initial state are taken into account:
  $\widetilde{Z}_1, \widetilde{Z}_2, \widetilde{W}_1, \tilde{e}_1, \tilde{\mu}_1, \tilde{\tau}_1, \tilde{\nu}_e, \tilde{\nu}_\mu, \tilde{\nu}_\tau, \tilde{u}_1, \tilde{d}_1, \tilde{c}_1, \tilde{s}_1, \tilde{t}_1, \tilde{b}_1, \tilde{g}$
- The fully relativistic thermally averaged cross section times velocity is computed using the Gondolo-Gelmini and Gondolo-Edsjo formalism.
- The freeze out temperature is solved for iteratively
- Three-dimensional integral over *i.)* the final state subprocess scattering angle, *ii.)* the subprocess energy parameter, and *iii.)* the temperature from freeze-out to the present day temperature of the universe
- satisfactory agreement with MicroMEGAs and DarkSUSY packages

IsaBSG (H. Baer and M. Brhlik)

- evaluates the $BF(b \to s\gamma)$ using the effective field theory approach of Anlauf: the Wilson co-efficients (WC) of various operators are calculated at the relevant scales where various sparticles are integrated out of the theory.
  This method is used to handle the tW, tH^- and $\tilde{t}_{1,2}\widetilde{W}_{1,2}$ loops.
- The WC are evolved to scale $Q = M_W$, wherein the eff theory is taken to be the SM. The SM WC are evolved to $Q = m_b$ using NLO anomalous dimension matrices.
- The scale dependence of the final result is of order 10%.
- In the high scale calculation, the weak scale value of $m_b(M_{SUSY})$ is calculated using two loop RG evolution with full 1-loop corrections to m_b.
- Also, $\tilde{g}\tilde{q}$ and $\widetilde{Z}_i\tilde{q}$ loops are included directly at scale $Q = M_W$
  (Masiero et al.) This necessitates an RG computation of well over 100 soft terms and couplings in order to generate the proper off diagonal soft terms at scale $Q = M_W$.

IsaAMU (H. Baer and C. Balazs)

- Supersymmetric contributions to $a_\mu \equiv (g-2)_\mu/2$ come from $\widetilde{W}_i\tilde{\nu}_\mu$ and $\widetilde{Z}_i\tilde{\mu}_{1,2}$ loops.
- Complete formula for these contributions in the MSSM can be found in the article by T. Morroi

IsaBMM (J. K. Mizukoshi, X. Tata and Y. Wang)

This subroutine evaluates the branching ratio of the decays $B_s \to \mu^+\mu^-$ *and* $B_d \to \tau^+\tau^-$

$$B(B_{d'} \to \ell^+\ell^-) = \frac{G_F^2\alpha^2 m_{B_{d'}}^3 \tau_{B_{d'}} f_{B_{d'}}^2}{64\pi^3}|V_{tb}^* V_{td'}|^2 \sqrt{1-\frac{4m_\ell^2}{m_{B_{d'}}^2}}$$

$$\times\left[\left(1-\frac{4m_\ell^2}{m_{B_{d'}}^2}\right)\left|\frac{m_{B_{d'}}}{m_b+m_{d'}} C_{Q_1}\right|^2 + \left|\frac{2m_\ell}{m_{B_{d'}}} C_{10} - \frac{m_{B_{d'}}}{m_b+m_{d'}} C_{Q_2}\right|^2\right],$$ *where* $d' = s, d$ *and* $\ell = \mu, \tau$.

The coefficients of the effective Hamiltonian of the above processes,

$$C_{Q_1} = \frac{2\pi}{\alpha}\chi_{FC}\frac{m_b m_\ell}{\cos^2\beta \sin^2\beta}\left(\frac{\cos(\beta+\alpha)\sin\alpha}{m_h^2} - \frac{\sin(\beta+\alpha)\cos\alpha}{m_H^2}\right)$$

$$C_{Q_2} = \frac{2\pi}{\alpha}\chi_{FC}\frac{m_b m_\ell}{\cos^2\beta}\frac{1}{m_A^2}$$

contain the Higgs-mediated FCNC that arise as a consequence of coupling of Higgs superfield $\hat{h}_u$ *with down type fermions at one-loop level.*

IsaRES (Balazs, A. Belyaev, O'Farrill)

- *Evaluates the spin-independent and spin-dependent neutralino-proton and neutralino-neutron scattering cross sections.*
- *The interactions for elastic scattering of neutralinos on nuclei can be described by the sum of spin-independent ($\mathcal{L}^{eff}_{scalar}$) and spin-dependent ($\mathcal{L}^{eff}_{spin}$) Lagrangian terms:* $\mathcal{L}^{eff}_{elastic} = \mathcal{L}^{eff}_{scalar} + \mathcal{L}^{eff}_{spin}$
- *σ_{SI} for neutralino scattering off of nuclei is the main experimental observable – σ_{SI} contributions from individual nucleons in the nucleus add coherently and can be expressed via SI nuclear form-factors* **(Drees-Nojiri)** .
- *The cross section σ_{SI} receives contributions from neutralino-quark interactions via squark, Z and Higgs boson exchanges, and from neutralino-gluon interactions involving quarks, squarks and Higgs bosons at the 1-loop level.*

- The differential σ_{SI} off a nucleus X^A_Z with mass m_A takes the form

$$\frac{d\sigma^{SI}}{d|\vec{q}|^2} = \frac{1}{\pi v^2}[Zf_p + (A-Z)f_n]^2 F^2(Q_r),$$

where $\vec{q} = \frac{m_A m_{\tilde{Z}_1}}{m_A + m_{\tilde{Z}_1}}\vec{v}$ is the three-momentum transfer, $Q_r = \frac{|\vec{q}|^2}{2m_A}$

$$\frac{f_N}{m_N} = \sum_{q=u,d,s} \frac{f^{(N)}_{Tq}}{m_q}\left[f^{(\tilde{q})}_q + f^{(H)}_q - \frac{1}{2}m_q m_{\tilde{Z}_1} g_q\right] + \frac{2}{27} f^{(N)}_{TG} \sum_{c,b,t} \frac{f^{(H)}_q}{m_q} + \cdots$$

where $N = p,\ n$ for neutron, proton respectively, and $f^{(N)}_{TG} = 1 - \sum_{q=u,d,s} f^{(N)}_{Tq}$.

The parameters $f^{(p)}_{Tq}$, defined by $< N|m_q\bar{q}q|N >= m_N f^{(N)}_{Tq}$

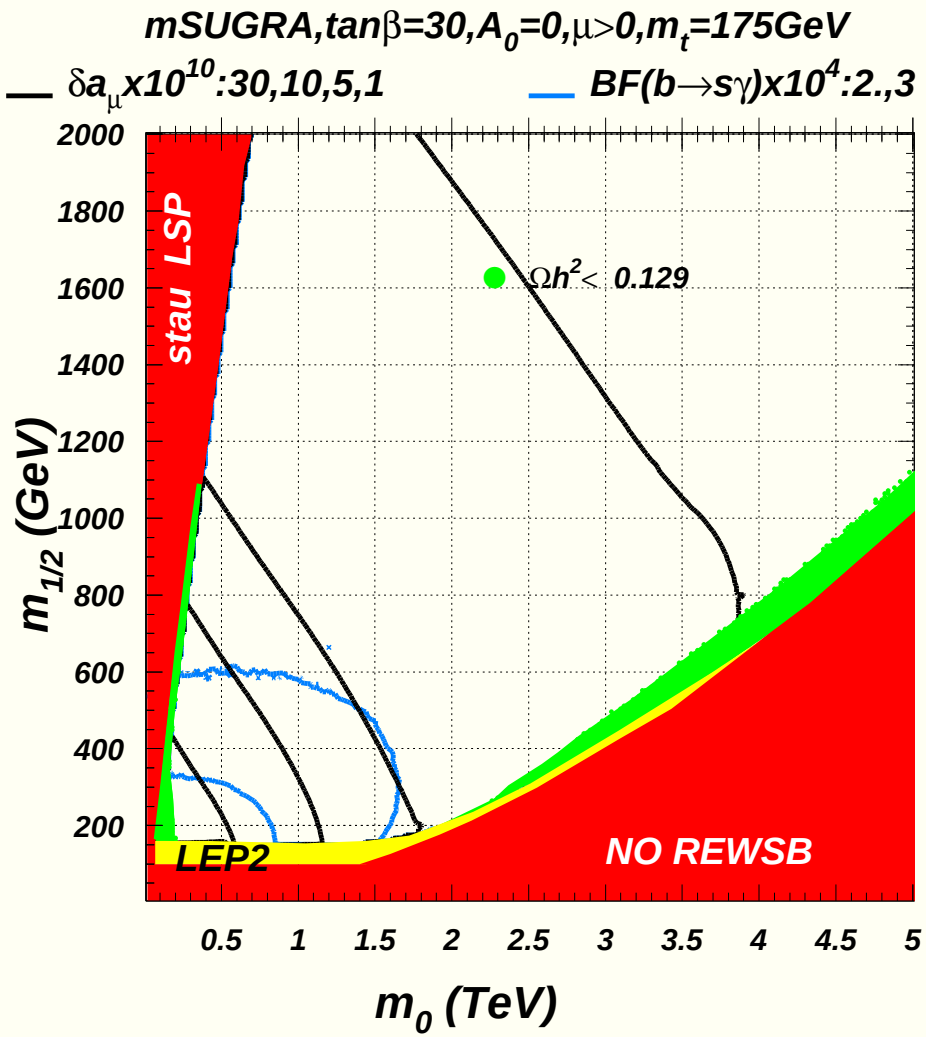
$f^{(p)}_{Tu} = 0.020 \pm 0.004, \qquad f^{(p)}_{Td} = 0.026 \pm 0.005, \qquad f^{(p)}_{Ts} = 0.118 \pm 0.062$

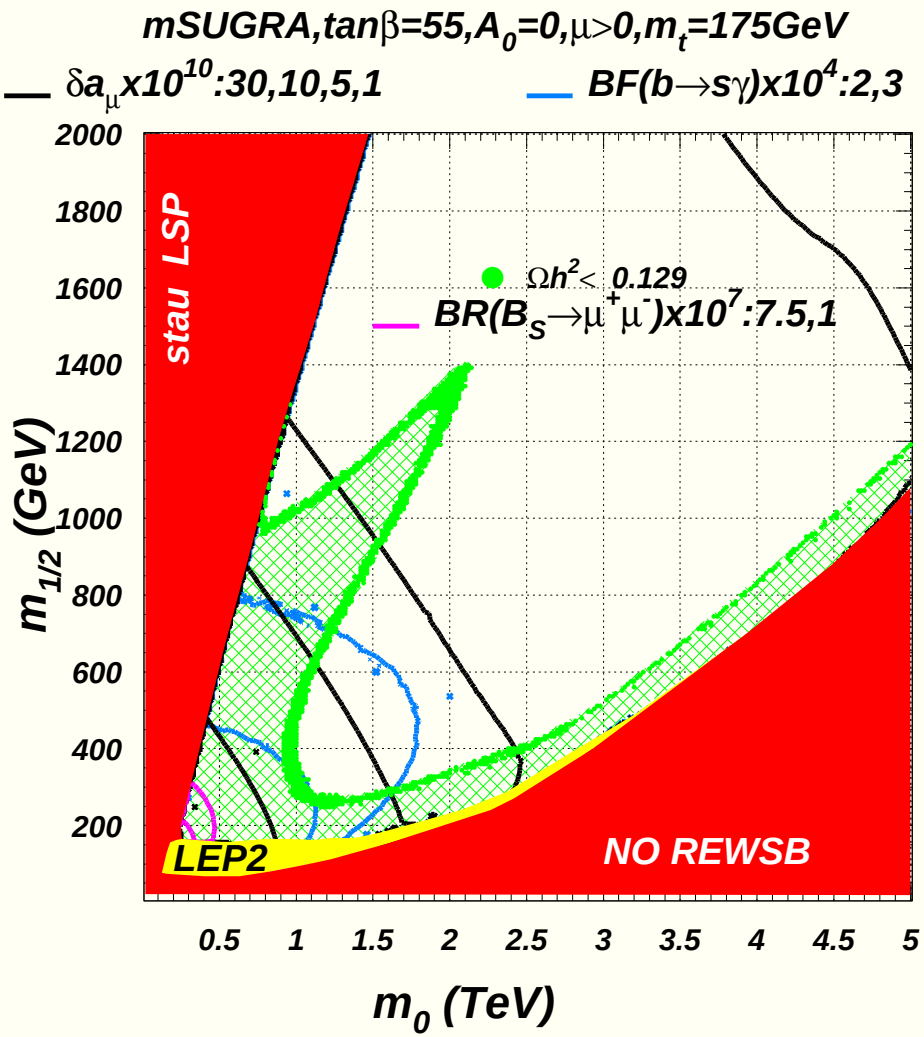
- The cross section σ^{SI}_p for neutralino scattering off the proton is calculated in the limit of zero momentum transfer $\sigma^{SI} = \frac{4}{\pi} {m_r^N}^2 f_N^2$,

$m^N_r = m_N m_{\tilde{Z}_1}/(m_N + m_{\tilde{Z}_1})$ CTEQ5L PDF, $Q = \sqrt{M^2_{SUSY} - m^2_{\tilde{Z}_1}}$ scale

mSUGRA constraints

Baer,Belyaev,Krupovnickas,Mustafayev, hep-ph/0403214





$BF(b \to s\gamma) = (3.25 \pm 0.37) \times 10^{-4}$ *(BELLE,CLEO and ALEPH)*

$(g-2)_\mu/2 =$ *116591 208(6) (g-2 collaboration)* $\Leftarrow$ *Experiment*

$\Delta a_\mu = (27.1 \pm 9.4) \times 10^{-10}$ *Davier,Eidelman,Höcker,Zhang* $\Leftarrow$ *TH* ($e^+e^- \to had$ *data)*

ISATOOLS: how to install and use

- *Finally public! Nothing to learn – just use it!*
- *Installation and usage:*
  1. *comes with ISAJET v7.72, go to ISAJET page and take*

  `http://www.phy.bnl.gov/~isajet/isajet.car`

  `http://www.phy.bnl.gov/~isajet/isared.tar.gz`
  2. ***make isatools***
  3. ***make***
  4. ***isasugra.x***

ISATOOLS output

```
 Minimal supergravity (mSUGRA) model:
 M_0,  M_(1/2),  A_0,  tan(beta),  sgn(mu),  M_t =
    90.000   400.000     0.000    10.000      1.0   175.000
ISASUGRA unification:
 M_GUT       = 0.194E+17   g_GUT           =0.709      alpha_GUT =0.040
 FT_GUT      = 0.514       FB_GUT          = 0.050     FL_GUT = 0.069
.................................................
 Output from ISATOOLS:
 Delta a_mu          =  0.14694E-08    BF(b->s gamma)    =  0.34392E-03
 Omega h^2           =  0.16816E+00
 BF(Bs -> mu mu)     =  0.39204E-08    BF(B -> tau tau) =  0.30862E-07
 LSP-nucleon spin independent (SI) and dependent (SD) sigmas:
 sigma(p,SI)[pb]     =  0.82726E-09    sigma(n,SI)[pb]   =  0.83425E-09
 sigma(p,SD)[pb]     =  0.50058E-05    sigma(n,SD)[pb]   =  0.25809E-05
```

ISATOOLS: how to install and use

- ***Non-interactive usage:***

  `http://hep.pa.msu.edu/belyaev/proj/dark_matter/isatools_public/`

  1. `READ_ME_FIRST!`
  2. ***isatools.zip***
  3. `READ_ME_FIRST!` ***include/*** ***isaamu/*** ***isabsg/*** ***isabmm/*** ***isared/*** ***isares/*** ***isatools.dat*** ***isatools.out*** `isatools_sample.f` `link_isatools`
  4. ***isatools.dat:*** `link_isatools` $\longrightarrow$ ***isatools.x*** $\longrightarrow$ ***isatools.out***

Conclusions and outlook

- *You are welcome to use ISATOOLS*
- *Any comments/suggestions are appreciated*
- *Isatools for Isasusy (EW input) – near future project*
- *Subroutines for Indirect DM search observables to be implemented*