Status of CompHEP

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- Where CompHEP is used
- How it works
- New features and plans
- Summary

Beyond the SM with CompHEP:
main fields of interest (theory).

- Effective operators of higher dimensions (ndim>4)
  - anomalous triple W+W-, Z W+W- couplings
  - anomalous quartic Z,W± couplings
  - anomalous t-quark (Wtb) couplings
  - anomalous Higgs self-couplings ndim=6
  - contact 4-fermion interactions
- SUSY models
  - chargino, neutralino and sfermion production
  - h, H, A and H± production
  - intense coupling regime in the Higgs sector
  - explicit CP violation in the Higgs sector
- Extensions of SM (other than SUSY) and exotica
  - Leptoquarks, scalar and vector
  - excited quarks and leptons
  - extra generations and heavy neutrino
  - SU(2)LxSU(2)RxU(1) model, W' and Z'
  - SU(3)LxU(1) model, W' and Z', Higgs bosons
  - lepton flavor violation, FCNC

BSM with CompHEP (cont'd)

The list of topics is based on the analysis of about 1000 papers quoting CompHEP.

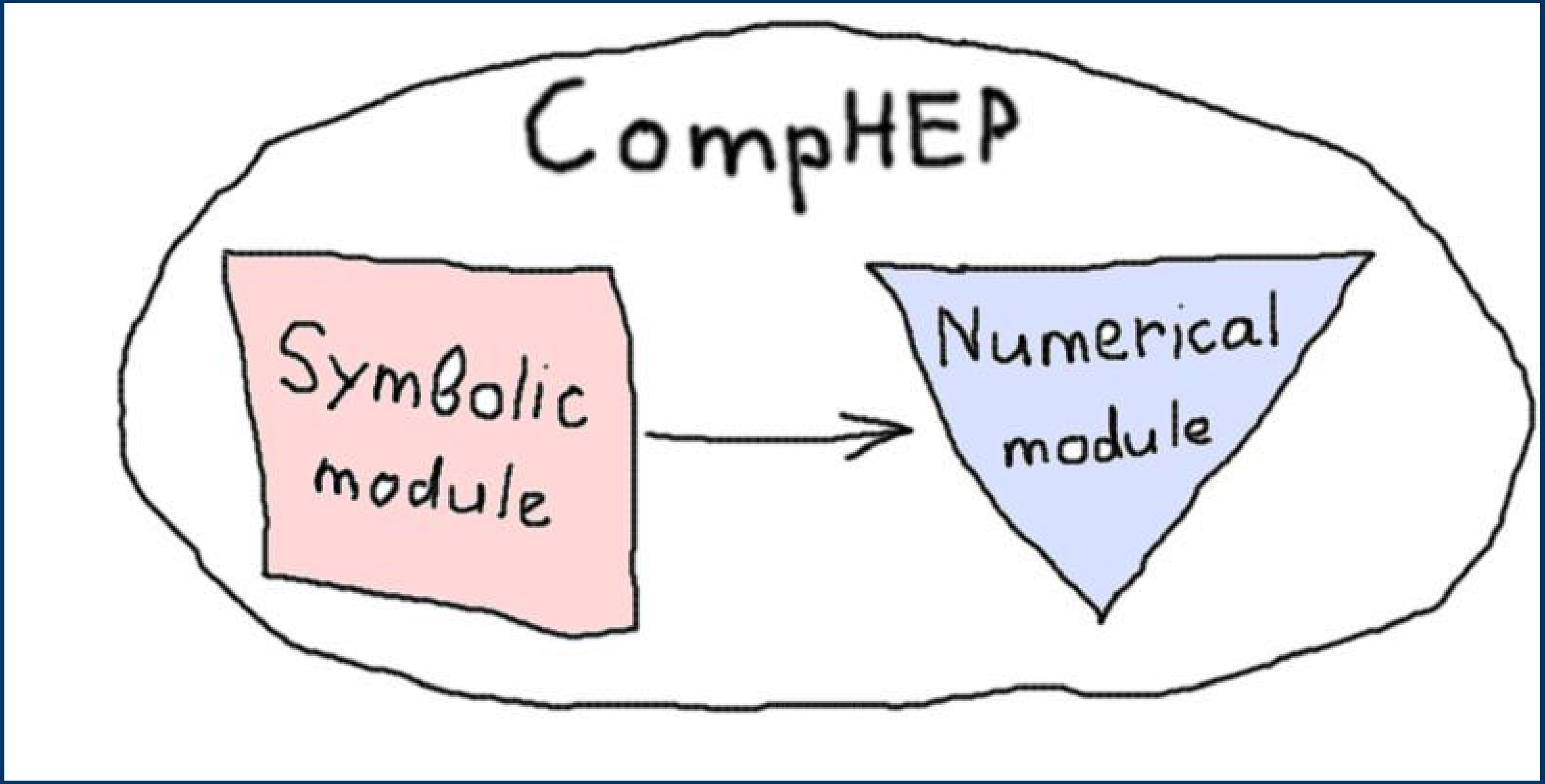
- Quantum gravity and extra dimensions
  - universal extra dimensions; constraining SUSY
  - neutral gauge boson from extra dimensions
  - Higgs signals in large extra dimensions
  - graviton production in KK with large extra dimensions
  - relic density of KK dark matter
- Dark matter and relic density
  - little Higgs models
  - doubly charged Higgs bosons
  - KARMEN time anomaly
  - EGRET excess

Published experimental analyses quoting CompHEP

DELPHI	'98	chargino, neutralino, gravitino at	LEP2
ALEPH	'98	SUSY in +miss ET,	LEP2
DELPHI	'99	H in events with isolated	LEP2
D0	'01	leptoquark pairs	Tevatron
H1	'02	excited	HERA
H1	'03	e and μ with miss PT	HERA
ZEUS	'03	single top production	HERA
D0,CDF	'03	single top production	Tevatron
OPAL	'03	single production of H++, H--	LEP2
D0	'04	three and four body stop decays	Tevatron
CDF	'05	excited and exotic lepton –› e	Tevatron
CMS	'05	discovery of SUSY with μμ	LHC
H1	'05	doubly charged Higgs bosons	HERA
H1	'05	search for monopole	HERA

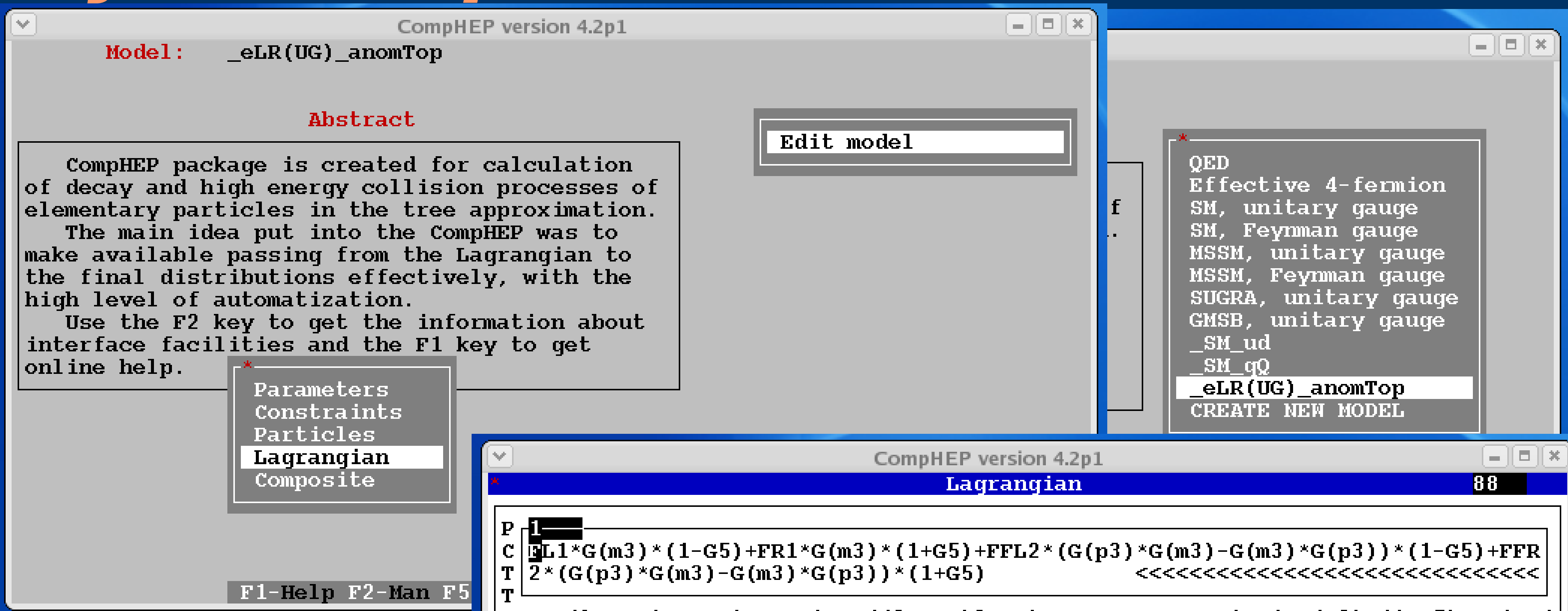
List is not full. A number of CMS and Tevatron studies '05-'06 are in progress or not yet appeared.

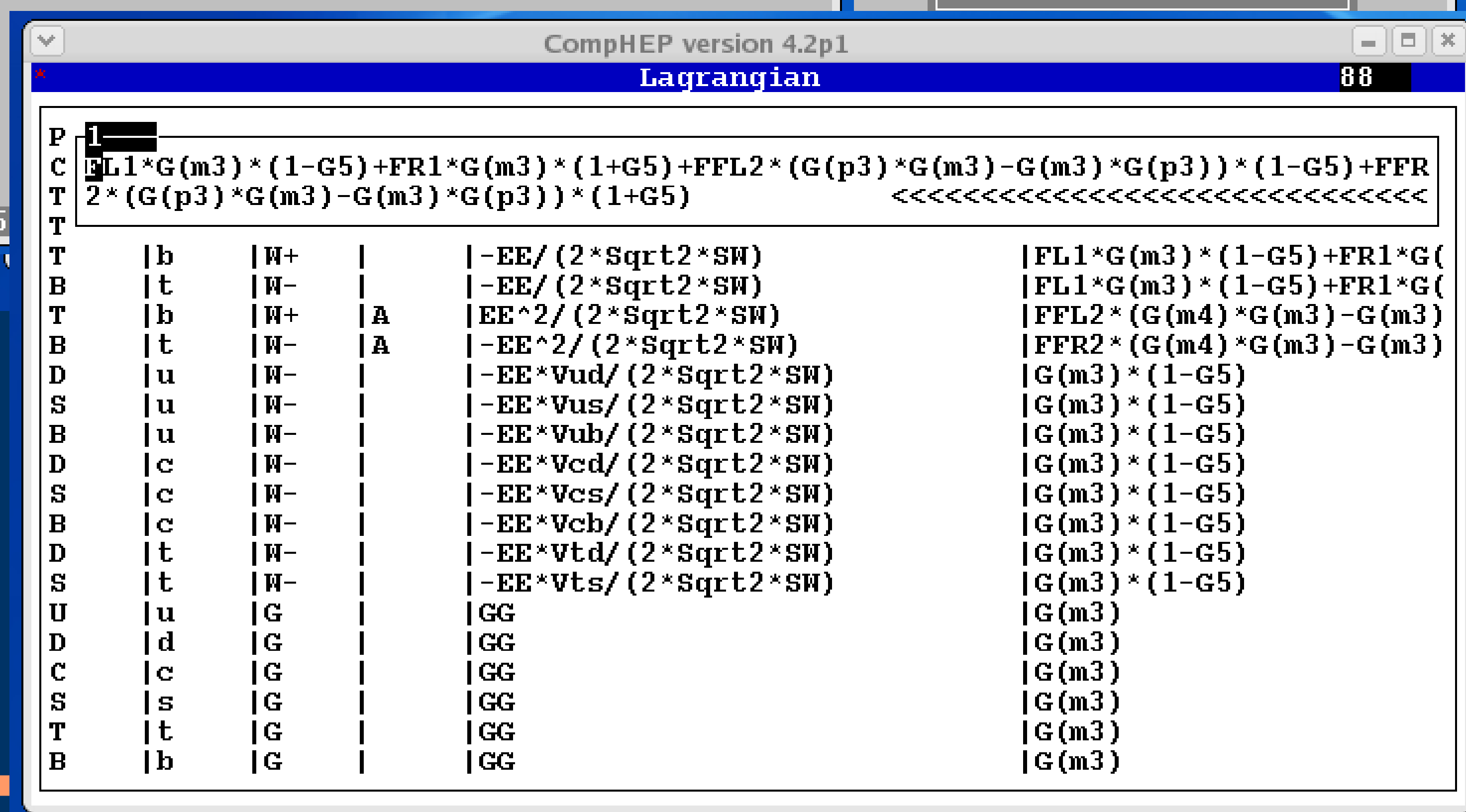
Structure of CompHEP



In additional, LanHEP package can generate Feynman rules in CompHEP format from the Lagrangian in coordinate space

Symbolic part

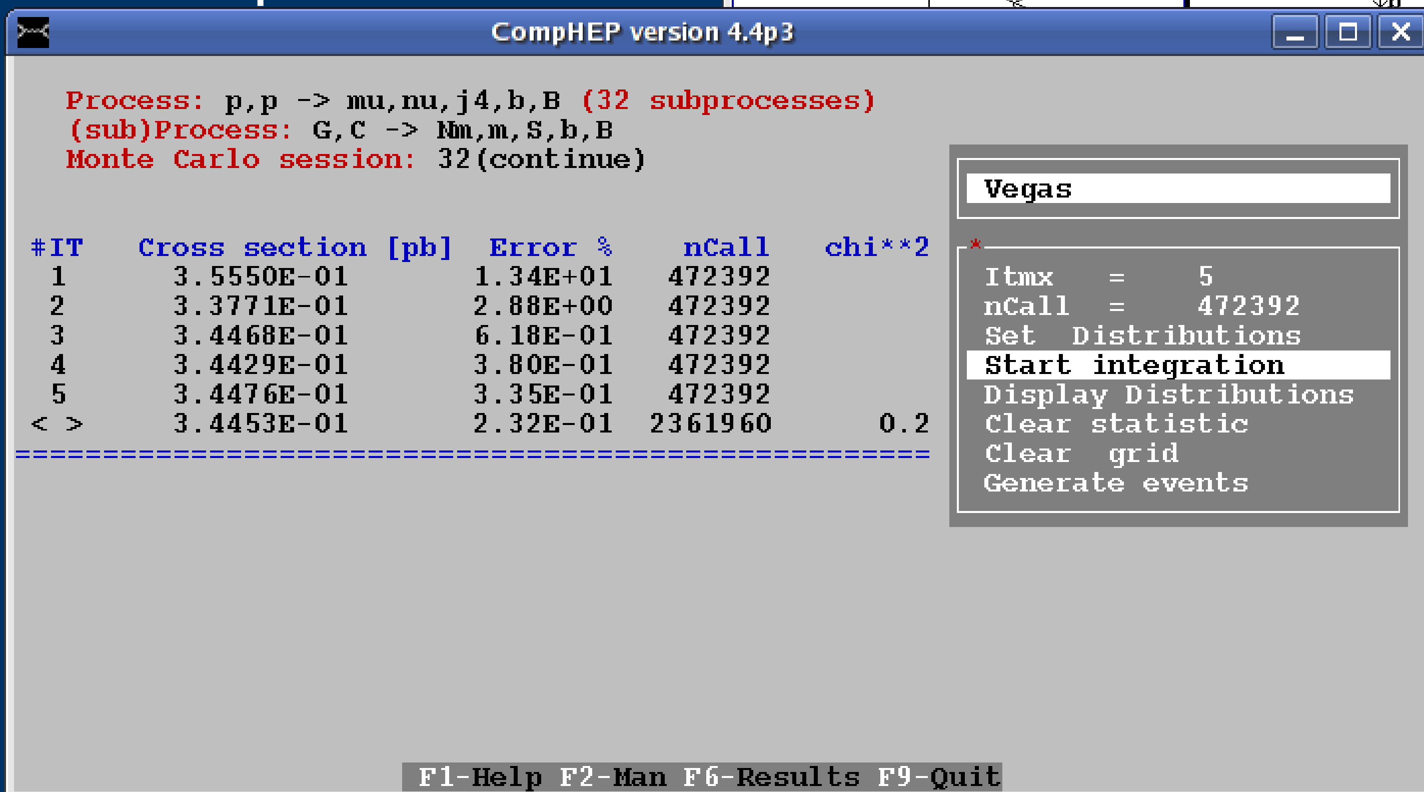


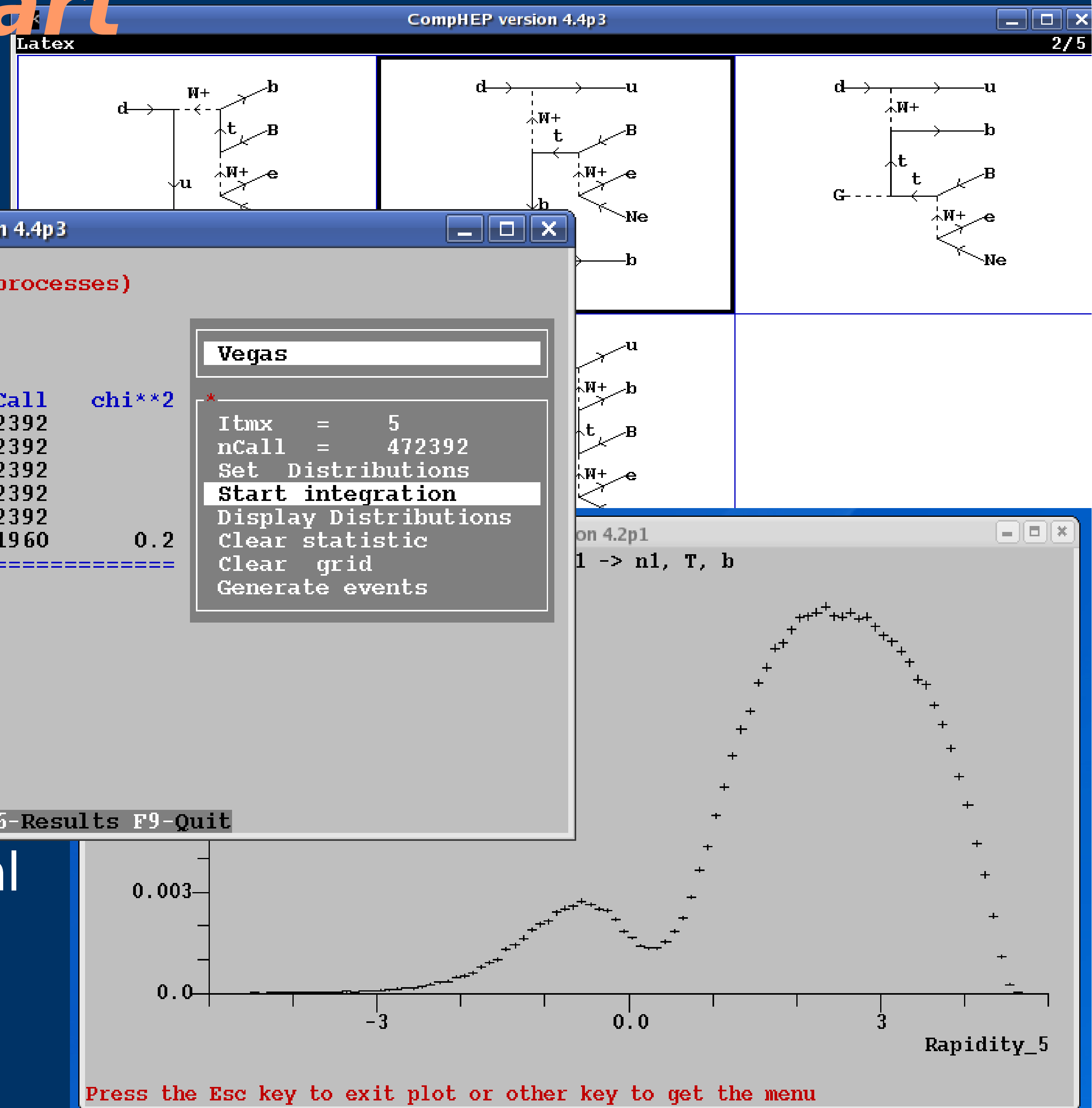


1. TH model
2. Phys. Process
3. Feynman diag.
4. Symbolic Calc's
5. Matrix element in analytical form

Numerical Part

1. Integration over Phase Space





2. Total and differential cross sections

3. Event generation

New Features in CompHEP 4.4 (Beams)

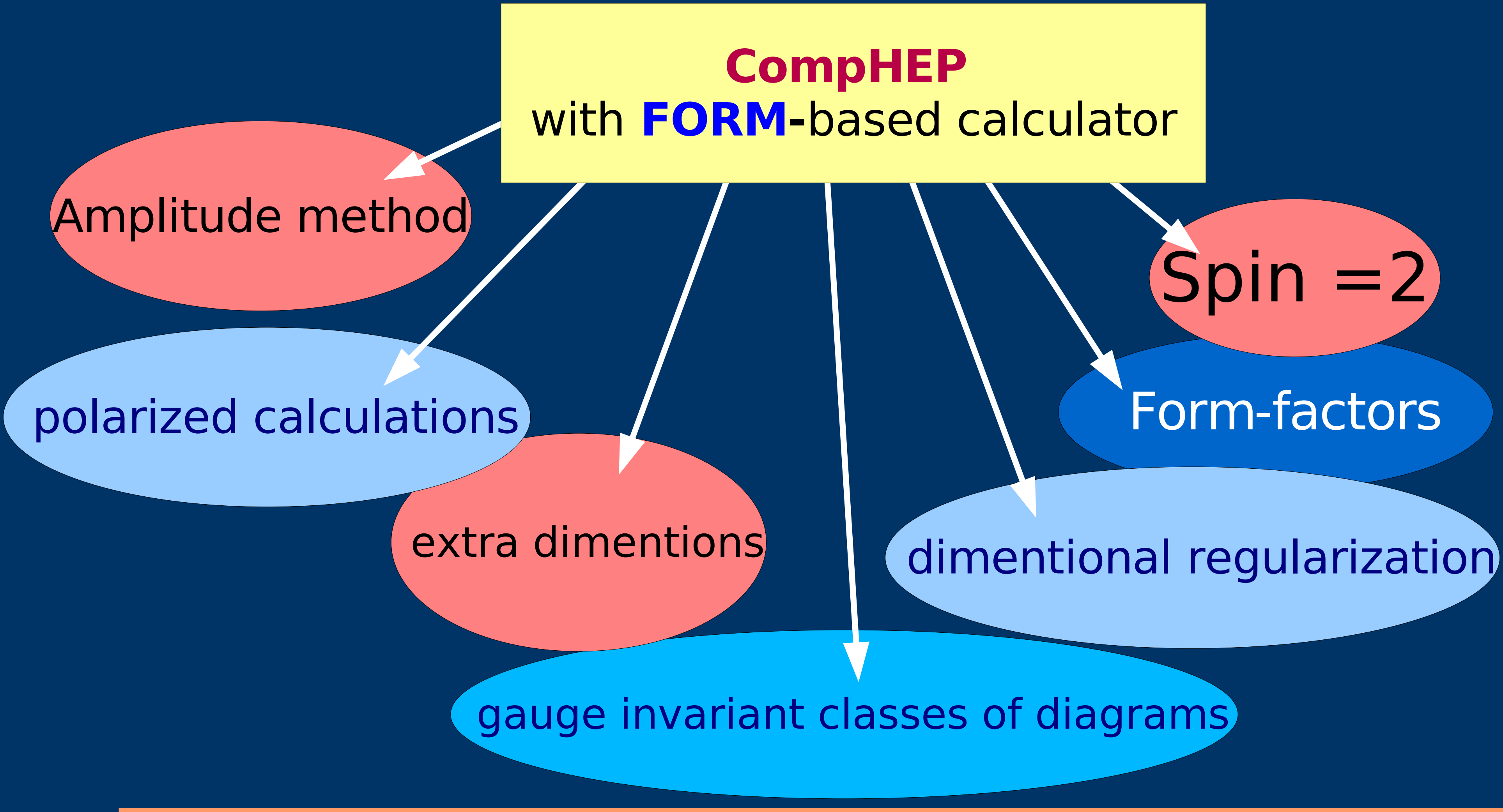
- "Colliding beams option" - a possibility to introduce arbitrary initial states with the following assignment of parton distribution functions to them. Beam is a set of partons: quark, electron or photon could be beams (e.g. effective W, photon etc approximations)

New Features in CompHEP 4.4 (TH Models)

- Developments in the built-in SUSY models: effective potential in the Higgs sector (by FeynHiggsFast), SUGRA and GMSB models (linked to ISAJET), R-parity violation, model with gravitino and sgoldstino
- Effective field theory for MSSM with explicit CP-violation in the Higgs sector
- Reduction of a number of partonic subprocesses (“hash models” _SM _ud, _SM _qQ with u#, d#)

New Features in CompHEP 4.4 (FORM)

- New features of parallel version of CompHEP, based on FORM language



New Features in CompHEP 4.4 (Batch modes)

- Symbolical batch script (the non-GUI mode) - large symbolic calculation tasks.
- Numerical batch mode - large numerical computations, computer farms (PBS, LSF compatible), parallel calculations .

New Features in CompHEP 4.4 (Algorithms)

- New algorithm for amplitude computations based on functional integral for S-matrix
(not for Green functions)

  - gauge invariance for all structures
  - effective recursive procedure
  - advantages in speed of computations

First publication soon...

New Features in CompHEP 4.4 (Interfaces)

- CompHEP->PYTHIA (CPYTH) (ready)
- CompHEP->PYTHIA-TAUOLA (ready)
- CompHEP->HERWIG (ready)
- CompHEP->HERWIG++ (in progress)
- Interfaced to Exp. Collaboration SW:

  SIMDET(ILC), CMKIN(CMS), ATHENA(ATLAS) and D0 (Tevatron) Run II software.
- Macros of interface to ROOT graphics (in progress)
- Output Events are ready for LCG MCDB Data Base

Future Plans

- Implement FORM symbolic calculations as a standard option
- New Tree Amplitude calculations
- 1-loop corrections and NLO
- Parallel computations and implementation of GRID technology
- XML format of Input/Output information (HepML)

Summary

- CompHEP is a powerful tool for the SM and BSM physics
- CompHEP with the interfaces to PYTHIA, HERWIG, TAUOLA is a powerful tool for phenomenological and experimental analysis of different physics processes at hadron and lepton colliders
- CompHEP has been used already in many analyses and experimentalists are familiar with this package

BackUp Slides

Steps of Symbolic Calculations

- Select theoretical model and process
- Generate Feynman diagrams (FD), display, etc.
- Exclude some diagrams (if necessary)
- Generate, display, exclude squared FD
- Calculate analytical expression of FD
- Save symbolic results in Mathematica, Reduce, FORM and C code
- Launch built-in numerical calculations

Numerical Calculations

- Convolute FD with PDF, beam spectra, laser photons, Beamstrahlung spectra of electrons, etc.
- Modify physical parameters (masses, scale, ...)
- Introduce kinematic cuts and kinematic scheme
- Introduce a phase space mapping
- Perform a Monte-Carlo phase space integration
- Generate parton level events
- Display distributions of kinematic variables
- Use CPYTH to pass events to the next level of simulation

(I) Anomalous interactions of top-quark

$$L_{eff} = L_{SM} + \frac{1}{\Lambda^2}\sum_i C_i O_i + O(\frac{1}{\Lambda^4})$$

Seven SU(2)⊗U(1) invariant effective operators of dimension six contributing to the Wtb vertex

$$\begin{aligned}
O_{tW\Phi} &= [(\bar{q}_L\sigma^{\mu\nu}\tau^I t_R)\Phi + \Phi^+(\bar{t}_R\sigma^{\mu\nu}\tau^I q_L)]W^I_{\mu\nu} \\
O_{bW\Phi} &= [(\bar{q}_L\sigma^{\mu\nu}\tau^I b_R)\Phi + \Phi^+(\bar{b}_R\sigma^{\mu\nu}\tau^I q_L)]W^I_{\mu\nu} \\
O_{t3} &= i[(\Phi^+ D_\mu\Phi)(\bar{t}_R\gamma_\mu b_R) - (D_\mu\Phi)^+\Phi(\bar{b}_R\gamma_\mu t_R)] \\
O_{Dt} &= (q_L D_\mu t_R)D^\mu\Phi + (D^\mu\Phi)^+(\overline{D_\mu t_R} q_L) \\
O_{qW} &= [\bar{q}_L\gamma^\mu\tau^I D^\nu q_L + \overline{D^\nu q_L}\gamma^\mu\tau^I q_L]W^I_{\mu\nu} \\
O^3_{\Phi q} &= i[\Phi^+\tau^I D_\mu\Phi - (D_\mu\Phi)^+\tau^I\Phi]\bar{q}_L\gamma_\mu\tau^I q_L \\
O_{Db} &= (q_L D_\mu b_R)D^\mu\Phi + (D_\mu\Phi)^+(\overline{D_\mu b_R} q_L)
\end{aligned}$$

$$q_L = \begin{pmatrix} t_L \\ b_L \end{pmatrix}, \qquad W^I_{\mu\nu} = \partial_\mu W^I_\nu - \partial_\nu W^I_\mu + g\epsilon_{IJK}W^J_\mu W^K_\nu$$

O_tWΦ and O_bWΦ give the effective Lagrangian

$$\mathcal{L} = \frac{g}{\sqrt{2}} \frac{1}{2m_W} W_{\mu\nu} \bar{t} \sigma^{\mu\nu} (f_{2R} P_L + f_{2L} P_R) b + \mathrm{h.c.}$$

where f_2L and f_2R are the Wtb anomalous couplings

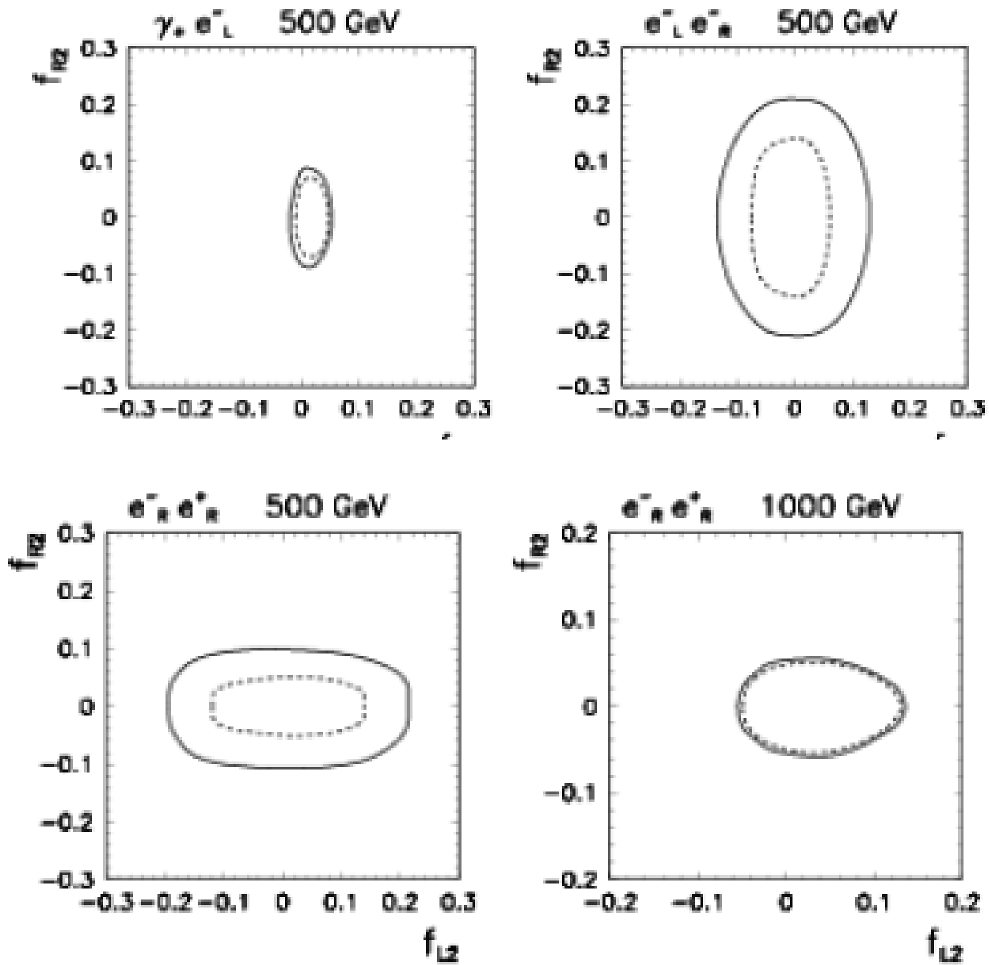
$$f_{2L} = \frac{C_{tW\Phi}}{\Lambda^2} \frac{v\sqrt{2}\, m_W}{g}, \quad f_{2R} = \frac{C_{bW\Phi}}{\Lambda^2} \frac{v\sqrt{2}\, m_W}{g}$$

$$W_{\mu\nu} = D_\mu W_\nu - D_\nu W_\mu, \qquad D_\mu = \partial_\mu - ieA_\mu$$

$$P_{R,L} = \frac{1}{2}(1 \pm \gamma_5), \qquad \sigma_{\mu\nu} = \frac{i}{2}(\gamma_\mu \gamma_\nu - \gamma_\nu \gamma_\mu)$$

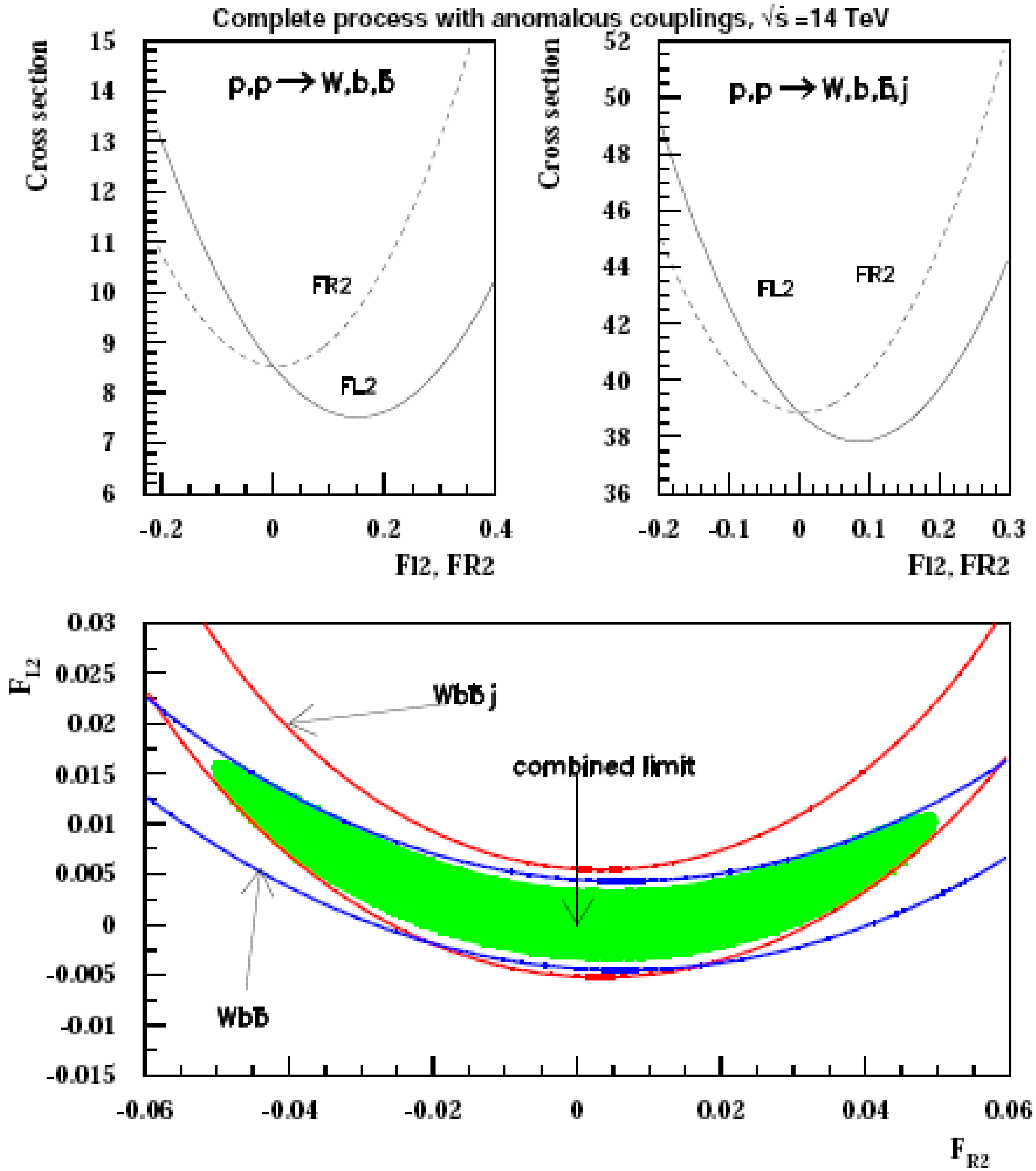
E.Boos, L.Dudko, M.D., T.Ohl, A.Pukhov, M.Sachwitz, H.Schreiber
EPJC 21(2001) 81, EPJC C16(2000)269, EPJC C11(1999)473

Anomalous top couplings: tt and single t production, NLC



2σ bounds on the anomalous couplings f_{2L} and f_{2R} from the reactions $\gamma_+ e^-_L \to \nu_e \bar{t} b$, $e^-_L e^-_R \to e^- \nu_e \bar{t} b$ and $e^-_R e^+_R \to e^- \bar{\nu}_e t \bar{b}$ at $\sqrt{s}$ =0.5 TeV and 1.0 TeV, for integrated luminosities of 100 fb^{-1} (solid lines) and 500 fb^{-1} (dashed lines).

Anomalous top couplings: single top production, LHC



(II) MSSM. Determination of tan β and trilinear couplings A_ τ,b,t in the sfermion pair production with polarization measurement in stau decays to τ-lepton, stop/sbottom → top

E.Boos, H.Martyn, G.Moortgat-Pick, M.Sachwitz, A.Sherstnev, P.Zerwas, EPJC 30(2003)395

Exact decay distributions of the 5-body final state

$$e^+e^- \to \tilde{b}_1 + t\,\tilde{\chi}_1^\pm \to \tilde{b}_1 + bc\bar{s}\,\tilde{\chi}_1^\pm .$$

calculated by CompHEP

Polarisation in sfermion ⇨ fermion + neutralino/chargino

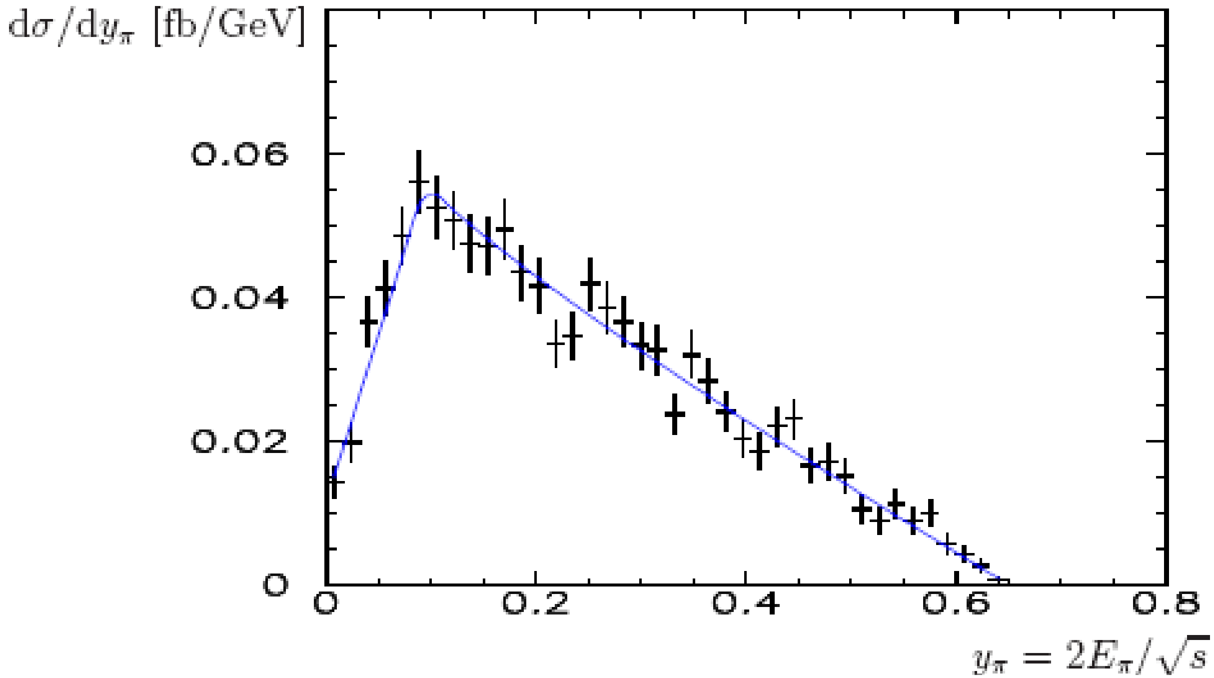


Figure 3: *Pion energy spectrum* $y_\pi = 2E_\pi/\sqrt{s}$ *from* $\tau \to \pi\nu$ *decays of* $e_L^+ e_R^- \to \tilde{\tau}_1^+ \tilde{\tau}_1^- \to \tau^+ \tilde{\chi}_1^0 + \tau^- \tilde{\chi}_1^0$ *production with* $P_{e^-} = +0.8$, $P_{e^+} = -0.6$ *at* $\sqrt{s} = 500$ GeV, *corresponding to* $\mathcal{L} = 500$ fb^{-1}; *reference scenario RP. The curve represents a fit to a* τ *polarisation of* $P_\tau = 0.82 \pm 0.03$.

$$\frac{1}{\sigma}\frac{d\sigma}{dy_\pi} = \frac{1}{x_+ - x_-}\begin{cases}(1-P_\tau)\log\frac{x_+}{x_-} + 2P_\tau\, y_\pi\left(\frac{1}{x_-}-\frac{1}{x_+}\right) & 0 < y_\pi < x_- \\ (1-P_\tau)\log\frac{x_+}{y_\pi} + 2P_\tau\left(1-\frac{y_\pi}{x_+}\right) & x_- < y_\pi < x_+\end{cases}$$

where

$$x_{+/-} = \frac{m_{\tilde{\tau}}}{\sqrt{s}}\left(1-\frac{m_{\tilde{\chi}}^2}{m_{\tilde{\tau}}^2}\right)\frac{1\pm\beta}{\sqrt{1-\beta^2}} \quad \text{with} \quad \beta = \sqrt{1-4m_{\tilde{\tau}}^2/s}\,.$$

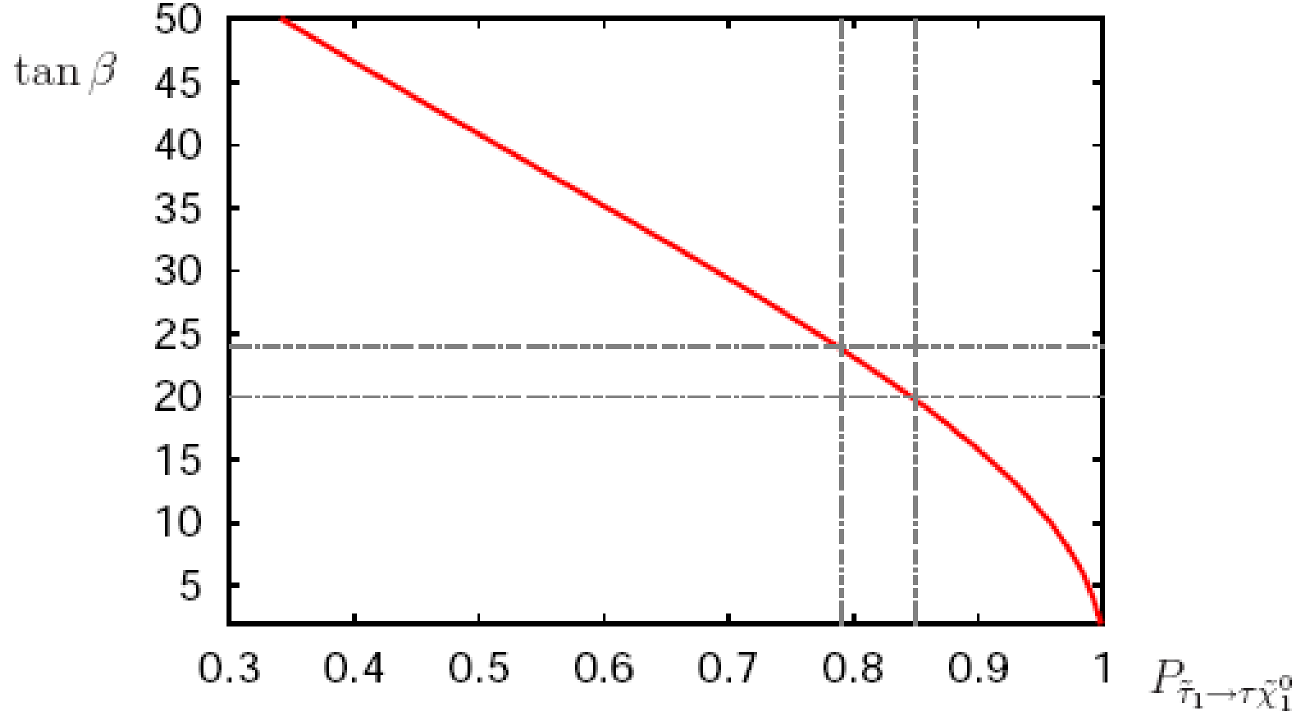
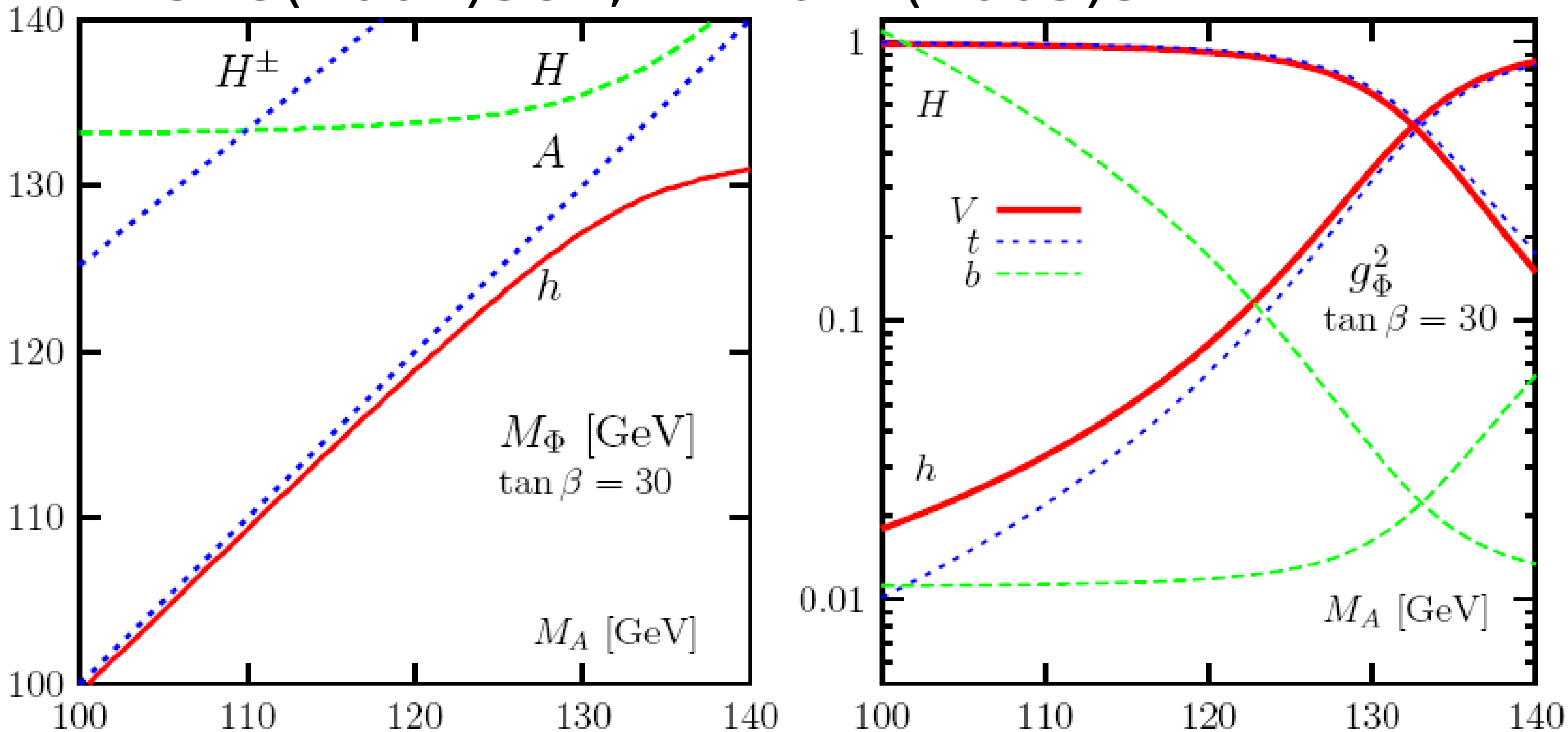


Figure 4: $\tan\beta$ *versus* τ *polarisation* $P_{\tilde{\tau}_1 \to \tau \tilde{\chi}_1^0}$ *for the reference scenario RP. The bands illustrate a measurement of* $P_\tau = 0.82 \pm 0.03$ *leading to* $\tan\beta = 22 \pm 2$.

(III) Intense coupling regime for the MSSM Higgs bosons

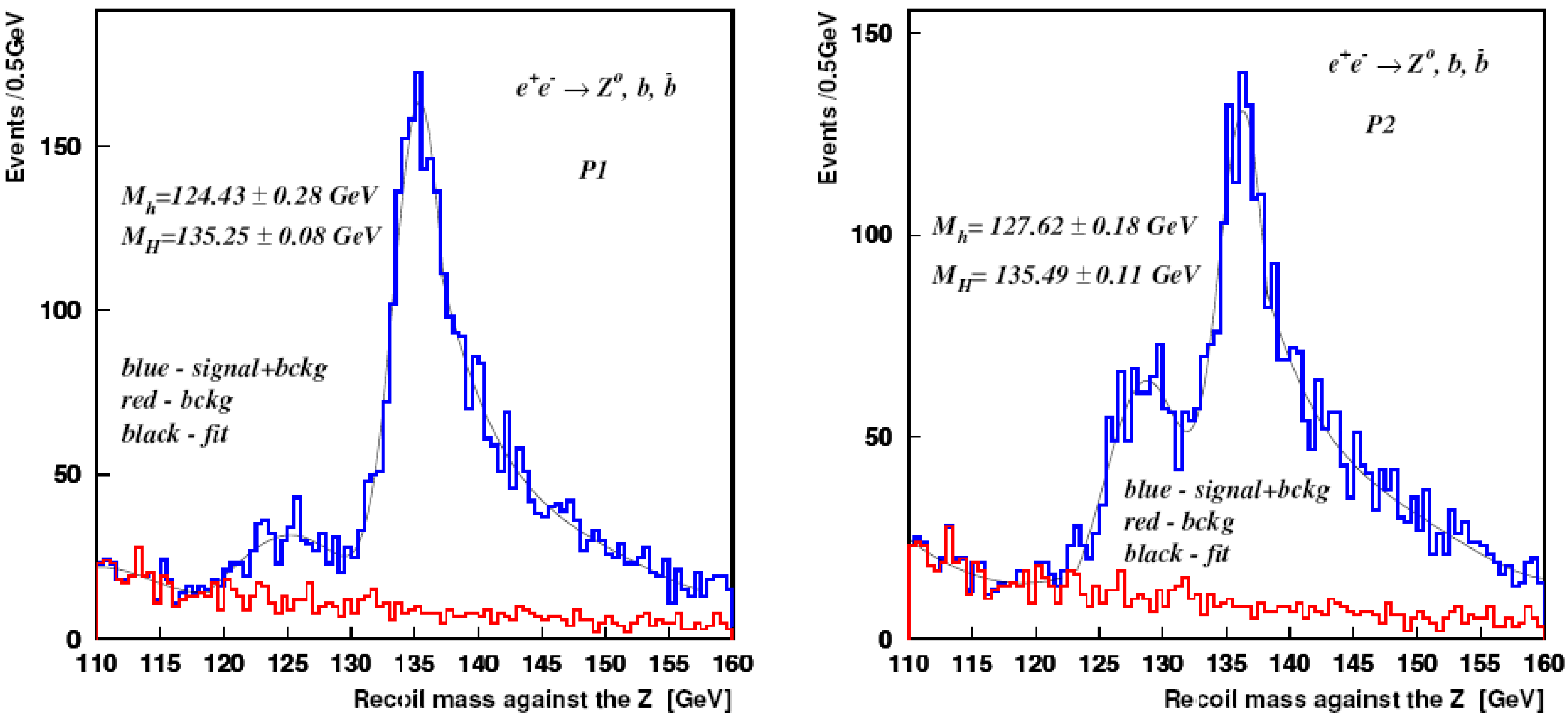
Masses of CP-even/CP-odd states are very close, widhts are large, at large tan β couplings and Br are different from the decoupling regime.

E.Boos, V.Bunichev, A.Djouadi, M.Muhlleitner, A.Nikitenko, H.Schreiber, PRD 66(2002)055004, PLB 578(2004)384, PLB 622(2005)311



H and h reconstruction in the llbb final state using the invariant mass recoiling against the Z, intense coupling regime, NLC

Recoil mass in the Zbb sample at 300 GeV LC



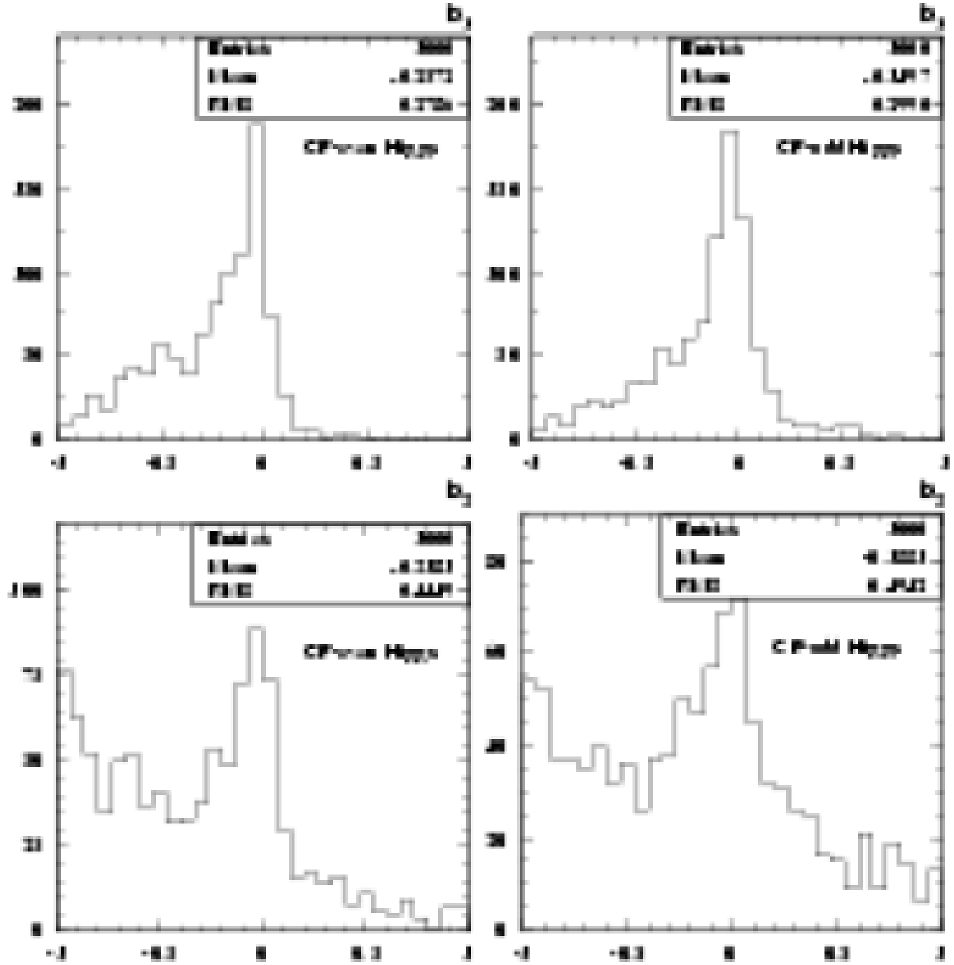
(IV) MSSM with explicit CP violation in the Higgs sector. Strong mixing of CP-even/CP-odd states (the CPX scenario)

$$
\begin{aligned}
U(\Phi_1,\Phi_2) = \quad & -\mu_1^2(\Phi_1^+\Phi_1) - \mu_2^2(\Phi_2^+\Phi_2) \\
& -\mu_{12}^2(\Phi_1^+\Phi_2) - \mu_{12}^{*2}(\Phi_2^+\Phi_1) \\
& +\lambda_1(\Phi_1^+\Phi_1)^2 + \lambda_2(\Phi_2^+\Phi_2)^2 + \lambda_3(\Phi_1^+\Phi_1)(\Phi_2^+\Phi_2) + \lambda_4(\Phi_1^+\Phi_2)(\Phi_2^+\Phi_1) \\
& +\frac{\lambda_5}{2}(\Phi_1^+\Phi_2)(\Phi_1^+\Phi_2) + \frac{\lambda_5^*}{2}(\Phi_2^+\Phi_1)(\Phi_2^+\Phi_1) \\
& +\lambda_6(\Phi_1^+\Phi_1)(\Phi_1^+\Phi_2) + \lambda_6^*(\Phi_1^+\Phi_1)(\Phi_2^+\Phi_1) \\
& +\lambda_7(\Phi_2^+\Phi_2)(\Phi_1^+\Phi_2) + \lambda_7^*(\Phi_2^+\Phi_2)(\Phi_2^+\Phi_1)
\end{aligned}
$$

$\lambda_5,\ \lambda_6\ \lambda_7$ are complex variables,

$$
(h,H,A)\ M^2 \begin{pmatrix} h \\ H \\ A \end{pmatrix} = (h_1,h_2,h_3)\ a_{ik}^T\ M_{kl}^2\ a_{lj} \begin{pmatrix} h_1 \\ h_2 \\ h_3 \end{pmatrix}
$$

Reconstruction of Gunion-Xe variables in the tth channel with full CMS detector simulation



$$a_1 = \frac{(\vec{p}_+ \times \hat{n}) \cdot (\vec{p}_- \times \hat{n})}{|(\vec{p}_+ \times \hat{n}) \cdot (\vec{p}_- \times \hat{n})|}, \quad a_2 = \frac{p_+^z p_-^z}{|p_+^z p_-^z|}$$

$$b_1 = \frac{(\vec{p}_+ \times \hat{n}) \cdot (\vec{p}_- \times \hat{n})}{p_+^T p_-^T}, \quad b_2 = \frac{(\vec{p}_+ \times \hat{n}) \cdot (\vec{p}_- \times \hat{n})}{|\vec{p}_+||\vec{p}_-|}$$

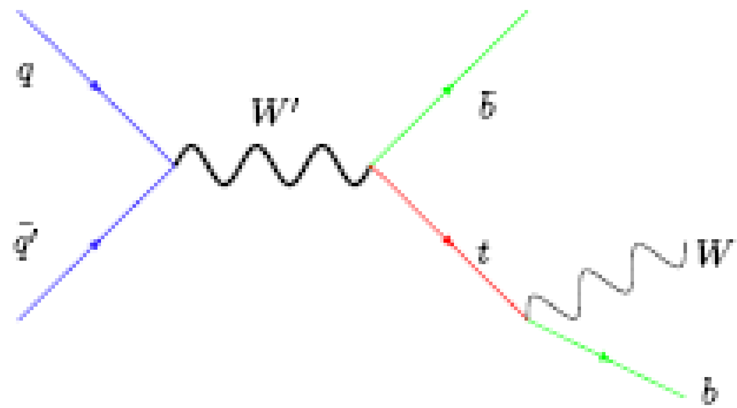
$$b_3 = \frac{p_+^x p_-^x}{p_+^T p_-^T}, \qquad b_4 = \frac{p_+^z p_-^z}{|\vec{p}_+||\vec{p}_-|},$$

J.Albert, M.D., V.Litvin, H.Newmar
Proc.of the Workshop on CP-violation and Nonstandard Higgs Physics (CPNSH), CERN Yellow report, to appear.

CPNSH survey in the talk by Sabine Kraml.

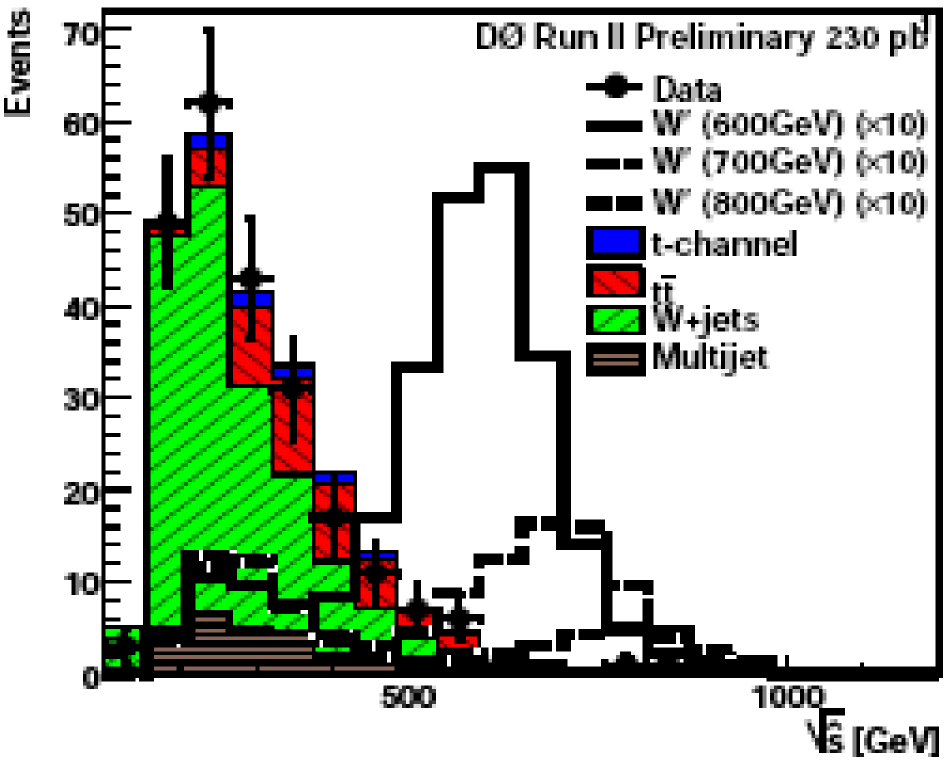
E.Akhmetzyanova, M.Dolgopolov, M.D., A.Semenov, EPJC 28(2003)223 , PRD 71(2005)075008

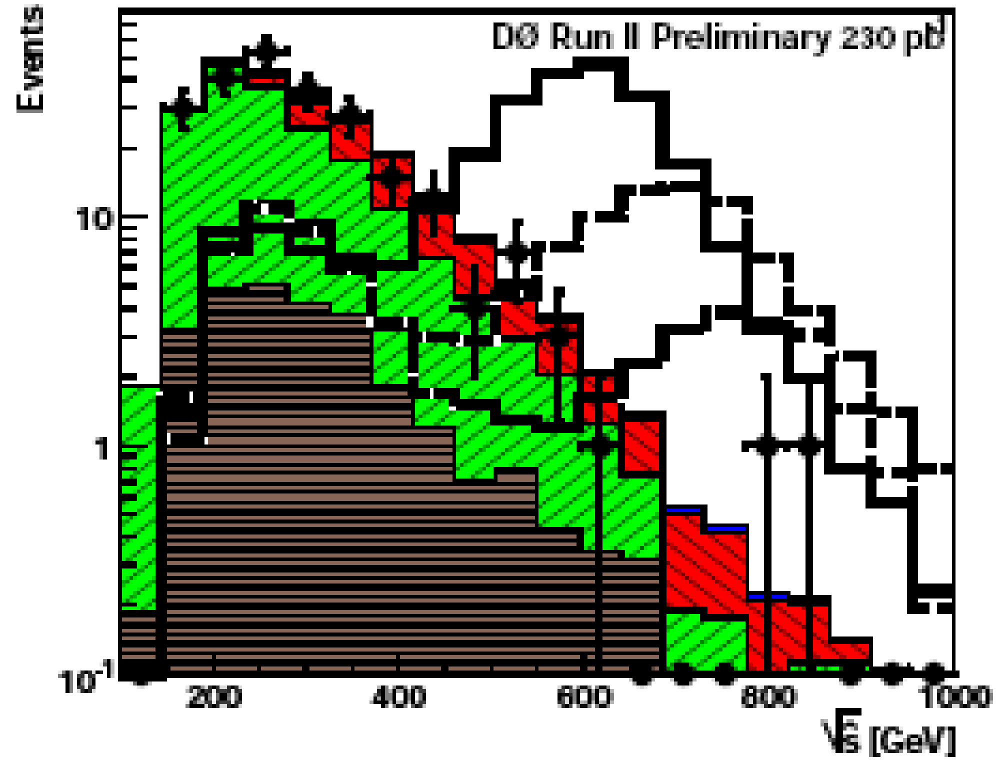
(V) W' reconstruction in the single top quark production
D0, Tevatron Run II



The W' coupling to fermions is SM-like. The CKM mixing matrix for the W' is one. Complete set of the the 4-body final state (lepton, missing E_T, b,b) diagrams calculated by CompHEP.

W' boson invariant mass reconstructed in the M(tb) distribution, Tevatron





Cross section limits at the 95% CL vs W' mass. Also shown are the W' cross sections with SM-like couplings.The shaded region is excluded.