Frank Paige: The SUSY Phenomenologist

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XERXES TATA
University of Hawaii

A personal (and perhaps warped) perspective

My overlap with Frank is limited to meetings at conferences and many email exchanges. But I looked at Frank's tree-rings on INSPIRE.

- Frank in the dark-ages.
- Frank embraces gauge theories.
- Frank and Isabelle....Isajet......SSC and LHC physics.

⋆ Frank, the SUSY phenomenologist.

- Frank, the card-carrying experimentalist.

Frank in the dark ages

- Veneziano model for nucleon-nucleon scattering (1970).
- Two-pomeranchukon cut and its relation to diffractive inclusive processes (1972).
- Regge-cut discontinuities and elastic unitarity (1972).
- Pomeron cuts and inclusive reactions (1974).
- Regge Cuts and Charge-Exchange Reactions in the Triple-Regge Region (1976).
- Normalization of the Triple-Pomeron Coupling (1976).
- Cut Reggeon Field Theory in the Triple-Regge Region (1977).

Frank embraces gauge theories

- Constraints on Gauge Theories with Diagonal Neutral Currents (1977).
- Symmetry Breaking and Naturalness of Parity Conservation in Weak Neutral Currents in Left-Right Symmetric Gauge Theories (1978).
- Gluon Corrections to the Drell-Yan Model (1979).
- Updated Estimates of W Production in pp and $p\bar{p}$ Interactions (1979).
- Justification of the OZI Rule in Quantum Chromodynamics (1980).
- Snowmass 1982 contributions to heavy Higgs production and detection, W, Z^0 Production at a pp Collider, and heavy quark jets.
- Pioneered many SSC studies.
- Associated production of Higgs bosons with $t\bar{t}$ pairs (1991).
- Neutral and Charged Higgs Detection: Heavy Quark Fusion, Top Quark Mass Dependence and Rare Decays (1987).

Frank, the SUSY phenomenologist

Frank's earliest work that I found was: Detecting Supersymmetric Hadrons, S.H. Aronson, L.S. Littenberg, F.E. Paige, I. Stumer, D.P. Weygand, Snowmass (1982), eConf C8206282 (1982) 505-509.

- Searching for Supersymmetry at the SSC Sally Dawson et al. (Snowmass 1984).
- Testing The Viability Of The $\not{E}_T$ Signature In Gluino Production At The SSC R.Michael Barnett, J. Freeman, R. Raja, J.F. Gunion, H.E. Haber, R. Hollebeek, F.E. Paige, A.P. White (Snowmass 1988).

Sparticles directly decayed to LSP......no multi-jet + multi-lepton signatures.

1993: SUSY in ISAJET with ISAJET7.0/ISASUSY1.0 (Howie)

SUSYing with Frank

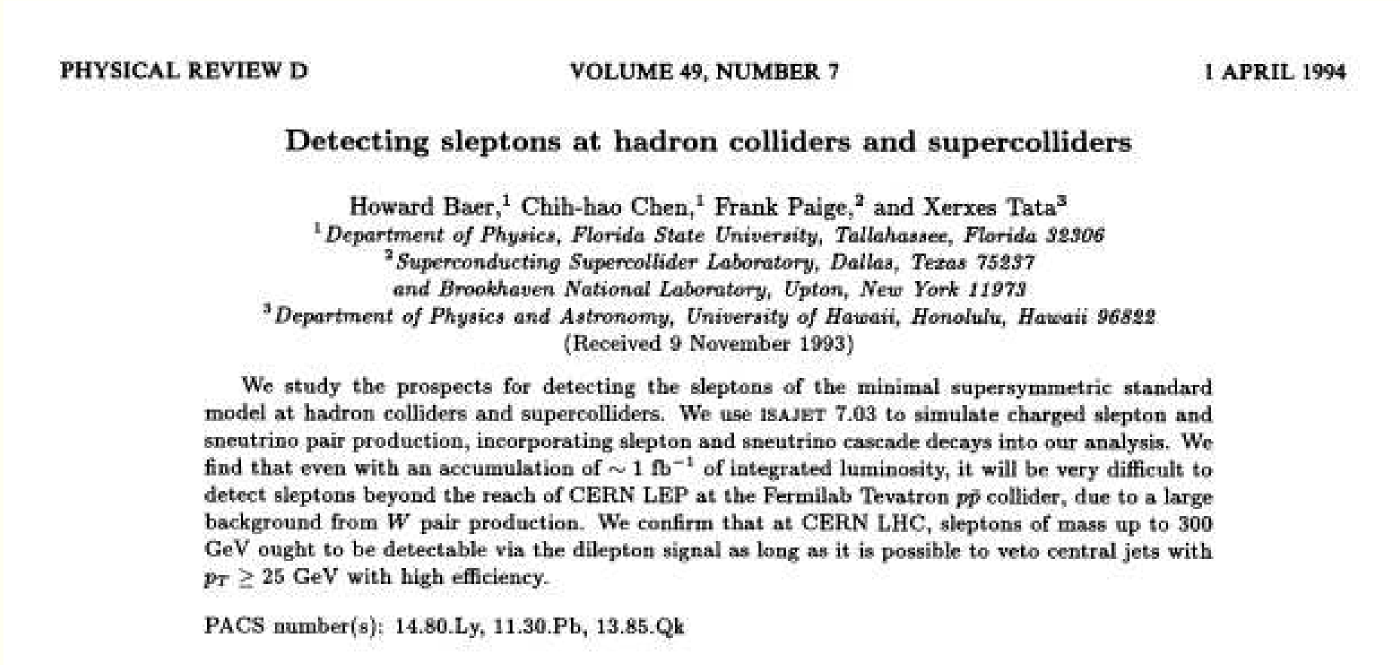
Howie already described how SUSY got incorporated into ISAJET. This gave us a new tool with which together the three of us (along with others) had fun exploring the SUSY arena.

I will try and give you a flavour of some of the work that we did together, and describe some results that we obtained.

Most of the "nitty-gritty physics discussions" on the papers we did together with Frank were via email. Indeed this is my first trip to Brookhaven!

Mostly, we worked on strategies for extracting the SUSY signal, and on possible techniques for extracting information about how superpartners acquire masses.

With Ian Hinchliffe, Frank also pioneered a number of mass measurements, and together they introduced the iconic $M_{\rm eff}$ used today in many SUSY analyses.


PHYSICAL REVIEW D VOLUME 49, NUMBER 7 1 APRIL 1994

Detecting sleptons at hadron colliders and supercolliders

Howard Baer,[1] Chih-hao Chen,[1] Frank Paige,[2] and Xerxes Tata[3]
[1] *Department of Physics, Florida State University, Tallahassee, Florida 32306*
[2] *Superconducting Supercollider Laboratory, Dallas, Texas 75237 and Brookhaven National Laboratory, Upton, New York 11973*
[3] *Department of Physics and Astronomy, University of Hawaii, Honolulu, Hawaii 96822*
(Received 9 November 1993)

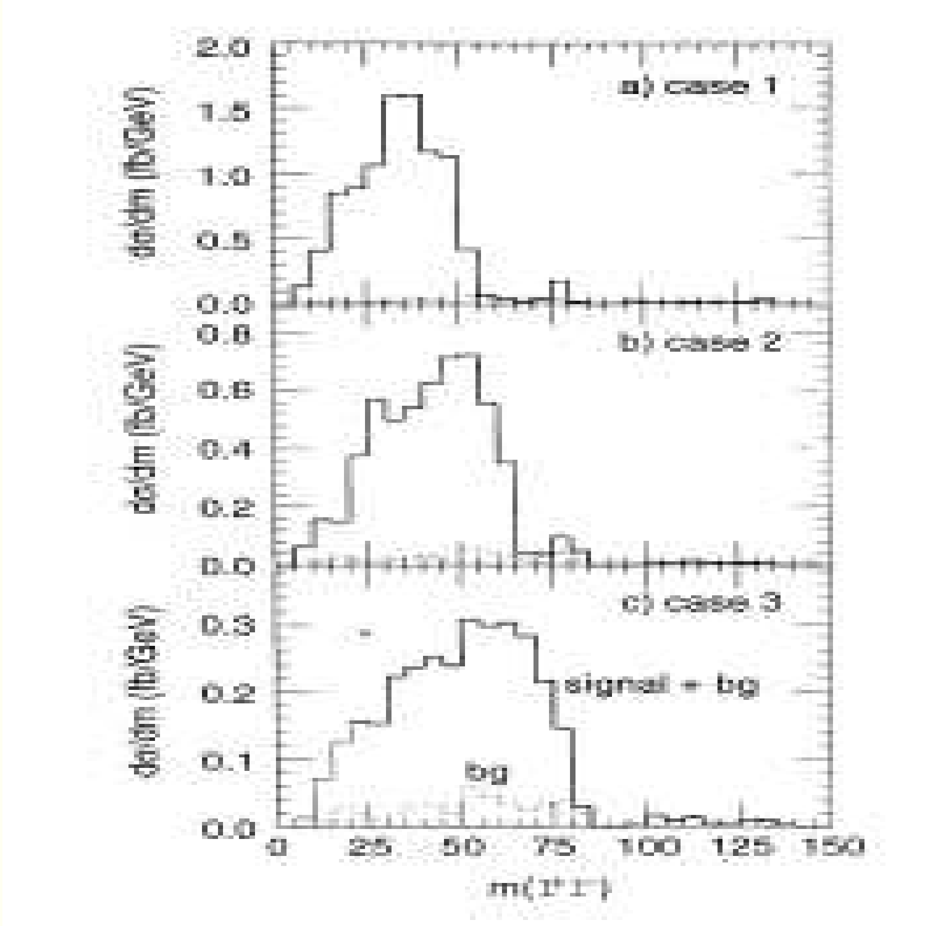
We study the prospects for detecting the sleptons of the minimal supersymmetric standard model at hadron colliders and supercolliders. We use ISAJET 7.03 to simulate charged slepton and sneutrino pair production, incorporating slepton and sneutrino cascade decays into our analysis. We find that even with an accumulation of ~ 1 fb^{-1} of integrated luminosity, it will be very difficult to detect sleptons beyond the reach of CERN LEP at the Fermilab Tevatron $p\bar{p}$ collider, due to a large background from W pair production. We confirm that at CERN LHC, sleptons of mass up to 300 GeV ought to be detectable via the dilepton signal as long as it is possible to veto central jets with $p_T \geq 25$ GeV with high efficiency.

PACS number(s): 14.80.Ly, 11.30.Pb, 13.85.Qk

We confirm that at the CERN LHC, sleptons of mass up to 300 GeV ought to be detectable via the dilepton signal as long as it is possible to veto central jets with $p_T \geq 25$ GeV with high efficiency.

Earliest journal application of Isajet The qualifier in the last sentence was the sort of thing we learned from Frank in our early days of working together.

Trileptons from chargino-neutralino production at the CERN LHC



Baer, Chen, Paige, XT, PRD50 (1994) 4508

Early LHC study of neutralino dilepton mass edge

Since SUSY phenomenology is largely determined by sparticle masses, the $m_0 - m_{1/2}$ plane provides a broad panorama of the phenomenology of this model.

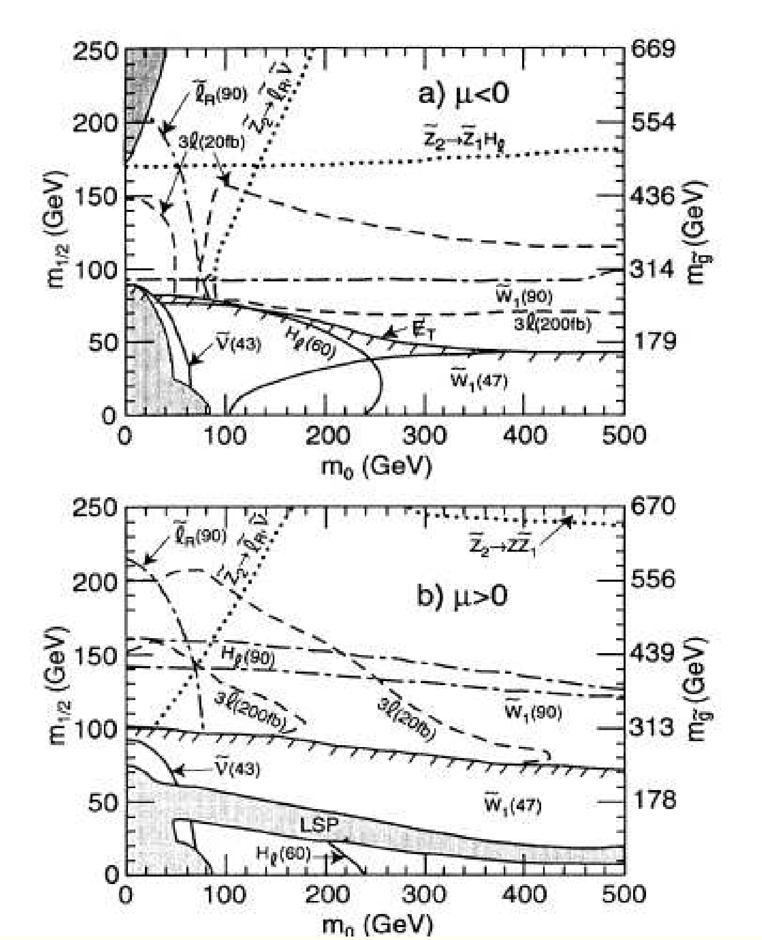
PHYSICAL REVIEW D VOLUME 51, NUMBER 3 1 FEBRUARY 1995

Multichannel search for minimal supergravity at $p\bar{p}$ and e^+e^- colliders

Howard Baer,[1] Chih-hao Chen,[1] Ray Munroe,[1] Frank E. Paige,[2] and Xerxes Tata[3]
[1] *Department of Physics, Florida State University, Tallahassee, Florida 32306*
[2] *Brookhaven National Laboratory, Upton, New York, 11973*
[3] *Department of Physics and Astronomy, University of Hawaii, Honolulu, Hawaii 96822*
(Received 10 August 1994)

We examine the phenomenology of minimal supergravity models, assuming only that the low energy theory has the minimal particle content, that electroweak symmetry is radiatively broken, and that R parity is essentially conserved. After delineating regions of supergravity parameter space currently excluded by direct particle searches at CERN LEP and the Fermilab Tevatron we quantify how this search region will be expanded when LEP II and the Tevatron main injector upgrades become operational. We describe how various experimental analyses can be consistently combined within a single framework, resulting in a multichannel search for supersymmetry, but note that this analysis is sensitive to specific assumptions about physics at the unification scale.

Of course, phenomena which explicitly depend on details of mixing will be sensitive to other parameters.



Theory constraint exclusions, Tevatron and LEP phenomenology

PHYSICAL REVIEW D VOLUME 52, NUMBER 5 1 SEPTEMBER 1995

Signals for minimal supergravity at the CERN Large Hadron Collider: Multijet plus missing energy channel

Howard Baer,[1] Chih-hao Chen,[1] Frank Paige,[2] and Xerxes Tata[3]
[1] *Department of Physics, Florida State University, Tallahassee, Florida 32306*
[2] *Brookhaven National Laboratory, Upton, New York 11973*
[3] *Department of Physics and Astronomy, University of Hawaii, Honolulu, Hawaii 96822*
(Received 8 March 1995)

PHYSICAL REVIEW D VOLUME 53, NUMBER 11 1 JUNE 1996

Signals for minimal supergravity at the CERN Large Hadron Collider. II. Multilepton channels

Howard Baer,[1] Chih-hao Chen,[2] Frank Paige,[3] and Xerxes Tata[4,1]
[1] *Department of Physics, Florida State University, Tallahassee, Florida 32306*
[2] *Department of Physics, University of California, Davis, California 95616*
[3] *Brookhaven National Laboratory, Upton, New York 11973*
[4] *Department of Physics and Astronomy, University of Hawaii, Honolulu, Hawaii 96822*
(Received 21 December 1995)

My two favourite LHC papers with Frank, where we explored various aspects of how to extract the SUSY signal, and also to obtain info about what the underlying physics was.

Plot reach results in many channels in the $m_0 - m_{1/2}$ plane.

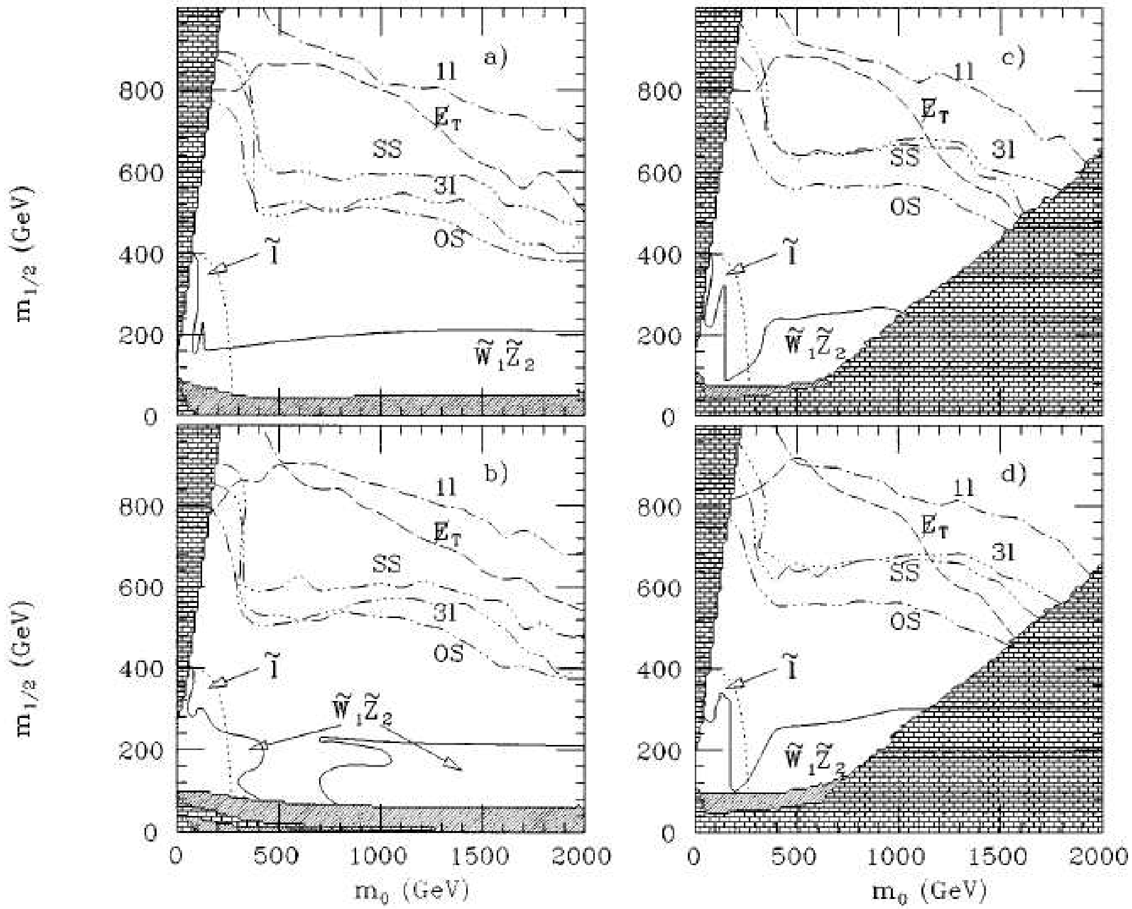


FIG. 18. A summary of the LHC reach (assuming 10 fb^{-1} of integrated luminosity) in the m_0 vs $m_{1/2}$ plane for the four cases of Fig. 1 via the various multilepton channels discussed in this paper. The dashed-dotted curves show the maximal LHC reach (obtained for some choice of E_T^c) for the 1ℓ, SS, OS, and 3ℓ+jets+E_T signals. Also shown is the reach via the complementary clean dilepton (marked $\tilde{\ell}$) and clean trilepton (marked $\widetilde{W}_1\widetilde{Z}_2$) channels. The boundary of the parameter plane that can be probed via multijet+E_T events (with no isolated lepton, denoted by E_T) as obtained in Ref. [11] shown for comparison as the dashed curve.

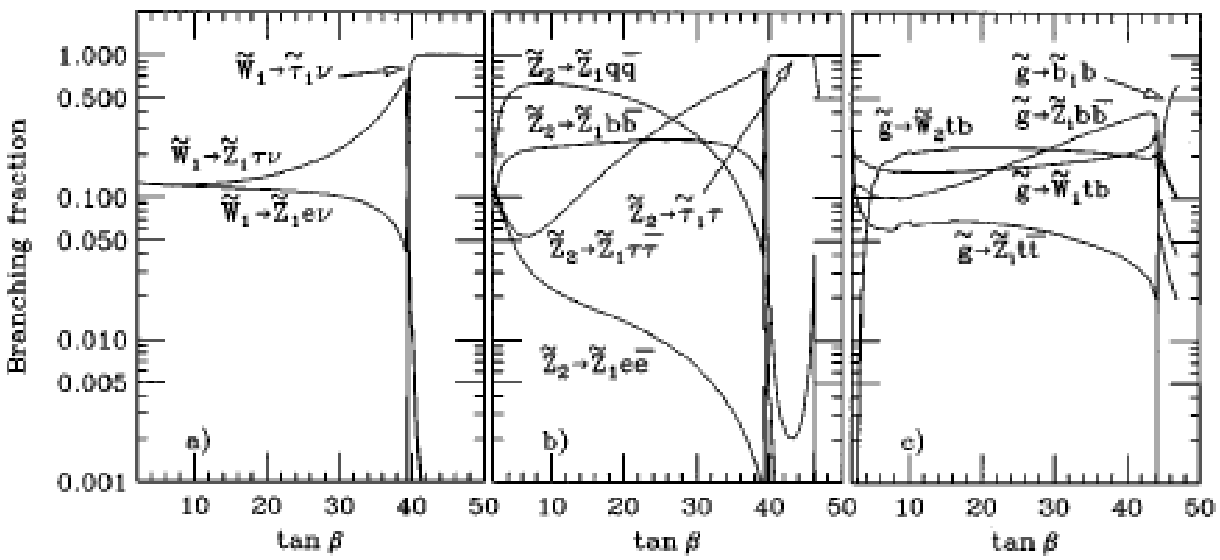
These papers introduced:

- ⋆ A sliding E_{Tc} cut variable and required $E_T(j_1), E_T(j_2)$ and $\not{E}_T > E_{Tc}$ to roughly optimize the signal depending on the SUSY mass. A pre-cursor of $M_{\rm eff}$ for SUSY analyses.
- ⋆ Preliminary attempts to extract gluino mass, taken up and done much better for several superpartner masses by Frank, Ian and collaborators.
- ⋆ Lepton charge asymmetries to distinguish squark and gluino pair production at a pp collider.
- ⋆ Lepton flavour asymmetries as an indicator of neutralino production.
- ⋆ $\langle n_j \rangle$ and $\langle n_b \rangle$ as diagnostics for SUSY events.

VOLUME 79, NUMBER 6 PHYSICAL REVIEW LETTERS 11 AUGUST 1997

Collider Phenomenology for Supersymmetry with Large tan β

Howard Baer,[1] Chih-hao Chen,[2] Manuel Drees,[3] Frank Paige,[4] and Xerxes Tata[5]



Large down-type Yukawa couplings affect SUSY Phenomenology.

Down type Yukawa couplings to h can become large for large $\tan\beta$ values, and can have an impact on collider phenomenology, both because of coupling value, but also because of accompanying reduced third generation sfermion mass.

Modifications incorporated into Isajet, and their implications for Tevatron and LHC phenomenology were subsequently examined in:

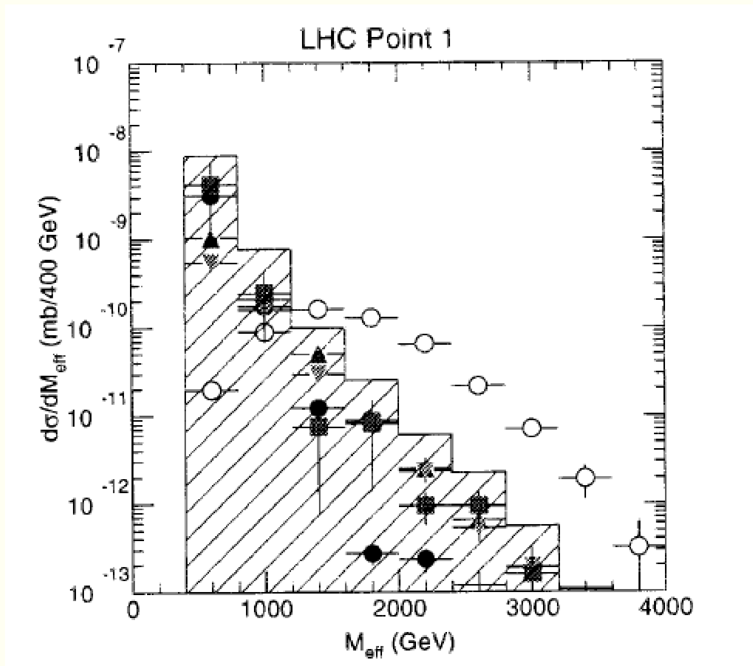
Supersymmetry reach of Tevatron upgrades: The Large $\tan\beta$ case, Howard Baer, Chih-hao Chen, Manuel Drees, Frank Paige, XT, Phys.Rev. D58 (1998) 075008.

Probing minimal supergravity at the CERN LHC for large $\tan\beta$,Howard Baer, Chih-hao Chen, Manuel Drees, Frank Paige, XT, Phys.Rev. D59 (1999) 055014.

Frank, Ian and collaborators used ISAJET for some pioneering studies on superparticle mass measurements from long SUSY decay chains.

Precision SUSY measurements at CERN LHC

I. Hinchliffe,[1] F. E. Paige,[2] M. D. Shapiro,[1] J. Söderqvist,[3] and W. Yao[1]
[1]*Lawrence Berkeley National Laboratory, Berkeley, California 94720*
[2]*Brookhaven National Laboratory, Upton, New York 11973*
[3]*Royal Institute of Technology (KTH), Stockholm, Sweden S-10044*
(Received 7 November 1996)



This paper (which arose from Snowmass) introduced $M_{\rm eff}$ commonly used today.

In a pioneering study of what one might have been able to do at the LHC, Bachacou, Paige and Hinchliffe examined an mSUGRA model with the decay chain, $\tilde{q}_L \to q\widetilde{Z}_2 \to \tilde{\ell}lq \to \ell\ell q\widetilde{Z}_1$ and teased out mSUGRA parameters from various experimentally constructable distributions.

PHYSICAL REVIEW D, VOLUME 62, 015009

Measurements of masses in supergravity models at CERN LHC

Henri Bachacou
Lawrence Berkeley National Laboratory, Berkeley, California 94720
and Kungliga Tekniska Högskolan, Stockholm, Sweden

Ian Hinchliffe
Lawrence Berkeley National Laboratory, Berkeley, California 94720

Frank E. Paige
Brookhaven National Laboratory, Upton, New York 11973
(Received 27 July 1999; published 31 May 2000)

They showed that a fit to the mSUGRA model (assuming a series of two body decays) yielded, $m_0 = (100 \pm 3.6)$ GeV, $m_{1/2} = (300 \pm 4.9)$ GeV, $\tan\beta = 2.11 \pm 0.18$, and $\mu > 0$. [It was assumed the Higgs mass would be known from LEP.]

Of course, the scenario they considered has long since excluded, but the key thing is these authors showed that hadron colliders (at least in some favourable – and at the time not crazy – circumstances) could make precision measurements despite two missing particles.

Please recognize these as pioneering efforts on which more will some day be built, but first we need a new discovery.

I have just touched on just one aspect of Frank's work.

Many of his significant contributions are in conference reports, starting from Isabelle days, and going on through various real as well as imaginary colliders, including an early study of the high luminosity LHC upgrade.

Eur. Phys. J. C 39, 293–333 (2005)
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THE EUROPEAN PHYSICAL JOURNAL C

Physics potential and experimental challenges of the LHC luminosity upgrade

Conveners: F. Gianotti[1], M.L. Mangano[2], T. Virdee[1,3]
Contributors: S. Abdullin[4], G. Azuelos[5], A. Ball[1], D. Barberis[6], A. Belyaev[7], P. Bloch[1], M. Bosman[8], L. Casagrande[1], D. Cavalli[9], P. Chumney[10], S. Cittolin[1], S.Dasu[10], A. De Roeck[1], N. Ellis[1], P. Farthouat[1], D. Fournier[11], J.-B. Hansen[1], I. Hinchliffe[12], M. Hohlfeld[13], M. Huhtinen[1], K. Jakobs[13], C. Joram[1], F. Mazzucato[14], G.Mikenberg[15], A. Miagkov[16], M. Moretti[17], S. Moretti[2,18], T. Niinikoski[1], A. Nikitenko[3,†], A. Nisati[19], F. Paige[20], S. Palestini[1], C.G. Papadopoulos[21], F. Piccinini[2,‡], R. Pittau[22], G. Polesello[23], E. Richter-Was[24], P. Sharp[1], S.R. Slabospitsky[16], W.H. Smith[10], S. Stapnes[25], G. Tonelli[26], E. Tsesmelis[1], Z. Usubov[27,28], L. Vacavant[12], J. van der Bij[29], A. Watson[30], M. Wielers[31]

Frank, the card-carrying experimentalist (Peter)

- ⋆ Howie and I (Howie, much more directly) continued to work with Frank on Isajet until 2017 when Isajet 7.87 was released. Our last journal article with Frank was almost 20 years ago, Phys. Rev. D61 (2000) 095007. Since then, a sense of negativity about SUSY has emerged, largely because LHC experiments have not yet discovered anything beyond the SM.

- ⋆ Dismay at the non-appearance of SUSY seems premature. The LHC run has a long way to go.

- ⋆ Fine-tuning arguments which suggest LHC data imply that SUSY is already tuned at per mille level <u>assume</u> SUSY breaking parameters are uncorrelated. Viable natural spectra exist without a need for superpartners beyond MSSM.

- ⋆ Light higgsinos seem necessary for naturalness, and <u>will likely</u> yield the novel LHC signals: $W^{\pm}W^{\pm} + \not{E}_T$ events, monojet + soft dilepton events (already being searched for by Atlas and CMS).

- ⋆ The high energy LHC, or a 600 GeV e^+e^- collider would definitively probe SUSY models with no worse than a part in thirty electroweak fine-tuning.

★ In my opinion, weak scale SUSY still offers the best resolution of the big hierarchy problem, and there may well be viable models with just the MSSM spectrum where the fine-tuning is no worse than a few percent.

Although Frank, and perhaps also some of us, will not be there to see it, I hope that Frank's pioneering efforts will one day bear fruit that would have brought a big smile on his face.

★ A small story