AFTER THE CHAMPAGNE ....

* FIRST, DISCOVER NEW PHYSICS SIGNALS

* THEN, IN PARALLEL
  - TEST INDEED SUSY
  - GO FROM DATA TO INSIGHT INTO UNDERLYING THEORY

* DISCUSS IN SUSY CONTEXT -- IF SOMETHING ELSE SIMILAR ISSUES ARISE

* ASSUME NO LINEAR COLLIDER ON RELEVANT TIME SCALES

BRENT NELSON, LIANTAO WANG, TING WANG,
PIERRE BINETRUY, JOE LYKKEN

HEP-PH/0312248

(RECENT REVIEW HEP-PH/0312378
Chung, Everett, Kane, King, Lykken, Wang)

GORDY KANE, LHC, VIENNA

*DEFAULT CONTINUES TO BE SUSY

- AS THE LOW-SCALE PREDICTION OF A HIGH-SCALE THEORY, SUSY

ALL SIMULTANEOUSLY

  -- CAN STABALIZE HIERARCHY
  -- CAN EXPLAIN EWSB
  -- CAN PROVIDE DARK MATTER CANDIDATE
  -- PREDICTS GAUGE COUPLING UNIFICATION, LARGE M_{top}, $\sin^2\theta_W$ IF GUT
  -- ALLOWS UNDERSTANDING BARYON ASYMMETRY
  -- JUSTIFIES HIGH SCALE NEEDED FOR SMALL ν MASSES
  -- EXPLAINS (PREDICTED) NO BTSM PRECISION DATA

- AND, PROBABLY NEEDED FOR STABLE STRING VACUA

- AND, PROVIDES A WINDOW ON PLANCK SCALE PHYSICS

* CENTRAL PROBLEM STILL TO UNDERSTAND EWSB

-- FIND, STUDY HIGGS SPECTRUM -- POINTS TO HOW SM EXTENDED

-- FIND, STUDY SUSY -- POINTS TO HOW ~~SUSY~~, TO UNDERLYING THEORY

* THEN ~~SUSY~~ BECOMES CENTRAL PROBLEM

* HOW GO FROM DATA TO IMPROVED UNDERSTANDING, INSIGHT INTO UNDERLYING THEORY ?

-- FROM HADRON COLLIDER (+ LOW ENERGY DATA)

OBSTACLES

* EXPERIMENTS MEASURE MASSES OF MASS-EIGENSTATES, $\sigma \times BR$ -- BUT THESE ARE NOT IN THEORIST'S LAGRANGIAN

* AT HADRON COLLIDERS, ALWAYS MORE LAGRANGIAN PARAMETERS THAN OBSERVABLES -- SO CANNOT IN GENERAL SOLVE FOR LAGRANGIAN PARAMETERS

* AS IF HAD ONLY HADRON COLLIDERS TO MEASURE V_{CKM} -- NEEDED b-FACTORIES

* SO UNLIKELY TO MEASURE $\tan\beta$, μ, $M_1, M_2, M_3, M_0, A_i \dots$

  $\Longrightarrow$ STUDIES BASED ON THESE MAY NOT BE HELPFUL

ALSO

* TOP-DOWN CALCULATIONS PREDICTING OBSERVABLES ?
  -- $\tan\beta$ NOT IN HIGH-SCALE UNDERLYING THEORY
  -- μ GENERATED DIFFERENTLY

  BUT PREDICTIONS DEPEND STRONGLY ON THESE ....

* RGE RUNNING MODEL-DEPENDENT
  -- INTERMEDIATE SCALE MATTER ?
  -- INITIAL, FINAL SCALES
  -- INFRARED FIXED POINTS

* LAGRANGIAN PARAMETERS COMPLEX
  -- PHASES AFFECT SUPERPARTNER MASSES, $\sigma \times BR$, HIGGS SECTOR, DARK MATTER ......
  -- NO KNOWN SYMMETRY IMPLIES PHASES SMALL

ETC

ALL OBSTACLES SOLVABLE WITH SUFFICIENT PRECISION DATA -- NEED NEW TECHNIQUES TO MAKE MAJOR PROGRESS FROM HADRON COLLIDERS

* WHAT DO EXPERIMENTERS MEASURE?

* MASSES OF MASS EIGENSTATES
* $\sigma \times BR$ " " "

CONSIDER CHARGINOS

IN LAGRANGIAN

$$M_{\tilde{C}} = \begin{array}{cc} \left(\begin{array}{cc} M_2 e^{i\varphi_2} & \sqrt{2} m_W \sin\beta \\ \sqrt{2} m_W \cos\beta & \mu e^{i\varphi_\mu} \end{array}\right) & \begin{array}{c} \tilde{W} \\ \tilde{h} \end{array} \\ \begin{array}{cc} \tilde{W} & \tilde{h} \end{array} & \end{array}$$

OBSERVABLE

$$m^2_{\tilde{C}_1} + m^2_{\tilde{C}_2} = \mathrm{Tr}\, M^\dagger_{\tilde{C}} M_{\tilde{C}} = M_2^2 + \mu^2 + 2m_W^2$$

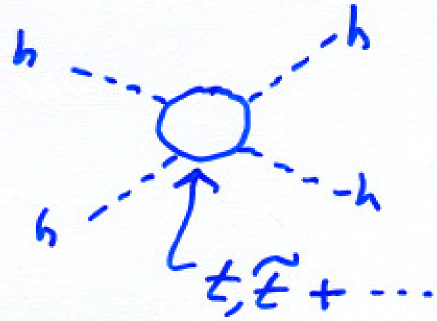
$$m^2_{\tilde{C}_1} m^2_{\tilde{C}_2} = \mathrm{Det}\, M^\dagger_{\tilde{C}} M_{\tilde{C}} = M_2^2\mu^2 + 2m_W^4 \sin^2 2\beta - 2m_W^2 M_2 \mu \sin 2\beta \cos(\varphi_2 + \varphi_\mu)$$

* HAVE TO INVERT -- NEED MORE EQ THAN UNKNOWNS -- m_{LSP} WILL ENTER KINEMATICS

$\longrightarrow$ CAN'T INVERT!

* ADD $\sigma \times BR$? BUT THEN

* HIGGS SECTOR

V = TREE LEVEL + 

$\Rightarrow$ AT LEAST 7 PARAMETERS IMPORTANT,

$\tan\beta, \mu, m^2_{H_U}, m^2_{H_D}, M_{\tilde{t}}, A_t, \varphi_\mu - \varphi_{A_t}$

SO AT LEAST 7 OBSERVABLES NEEDED TO INVERT

* SOME PARAMETERS COMMON SO COMBINED ANALYSIS CAN HELP

* HOW CAN WE SOLVE/EVADE THESE PROBLEMS?

* EXPERIMENTAL SIDE

-- FOCUS ON "INCLUSIVE SIGNATURES", ANY OBSERVABLE BTSM RATE

-- DON'T MAKE TOO MANY CUTS TO BRING OUT SIGNALS, ADD ALL WAYS SIGNATURE CAN ARISE

* THEORY SIDE

-- BEGIN WITH CANDIDATE UNDERLYING THEORIES, MAKE MOTIVATED ASSUMPTIONS AS NEEDED

-- CALCULATE INCLUSIVE SIGNATURES

-- VARY ASSUMPTIONS

* MAYBE NOT QUITE SO BAD, BECAUSE SUSY IS A REAL THEORY

-- VERY CONSTRAINED

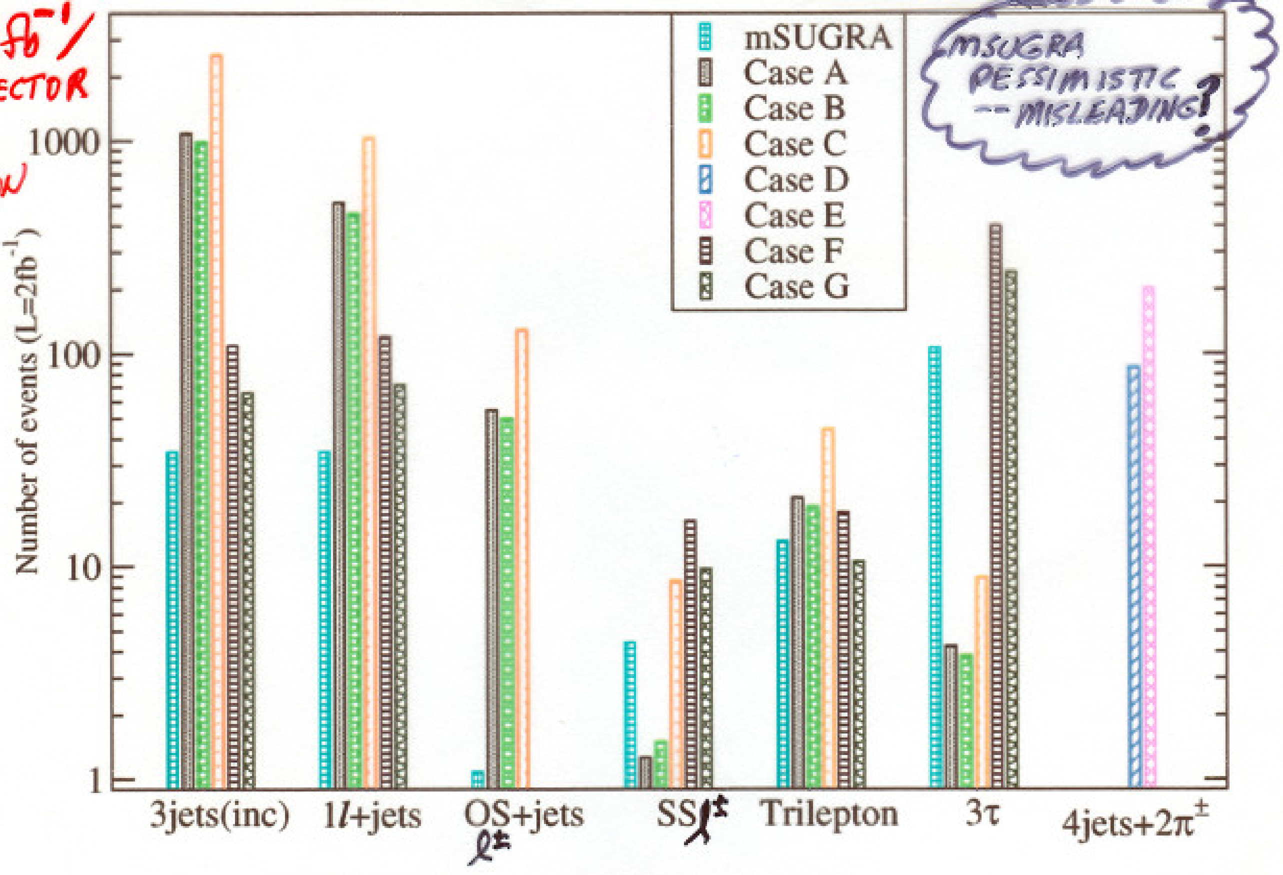
-- CAN DO A LOT WITH INCOMPLETE INFO

GRAVITY

INCLUSIVE SIGNATURES	$\tilde{G}$MSB LARGE μ	$\tilde{G}$MSB SMALL μ	GMSB	....
LARGE $\not{E}_T$	YES	YES	YES	
PROMPT γ's	NO	SOMETIMES	YES (BUT...)	....
TRILEPTONS	YES	NO	NO	
SAME SIGN DILEPTONS		⋮		
b-RICH				
⋮				

BENCHMARK MODELS

INCLUSIVE SIGNATURES



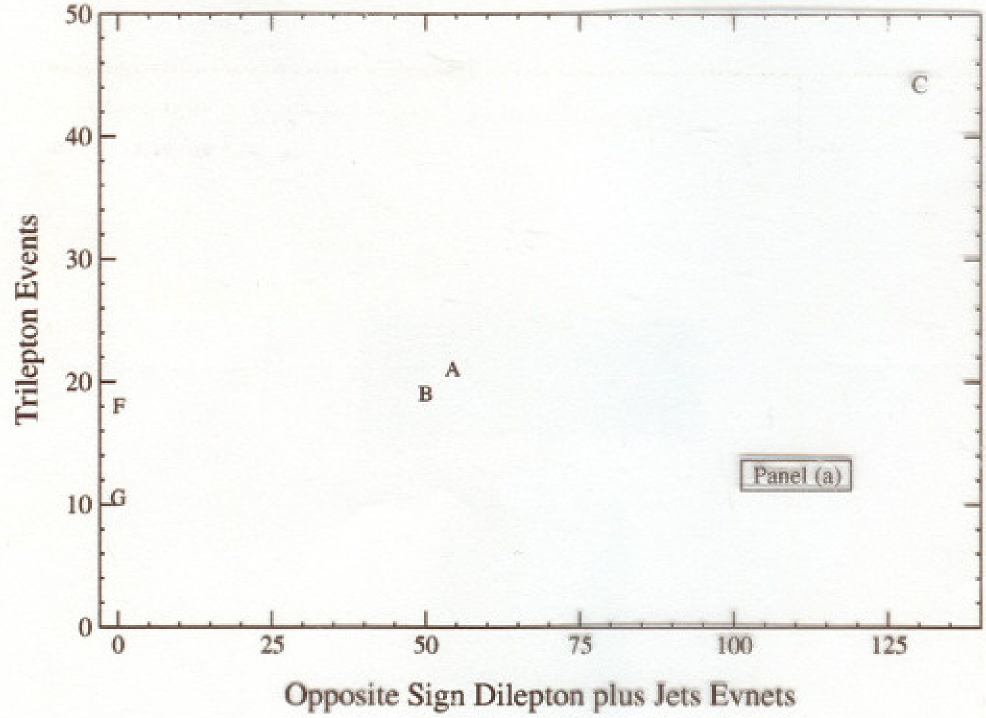
ALL HAVE LARGE $\not{E}_T$

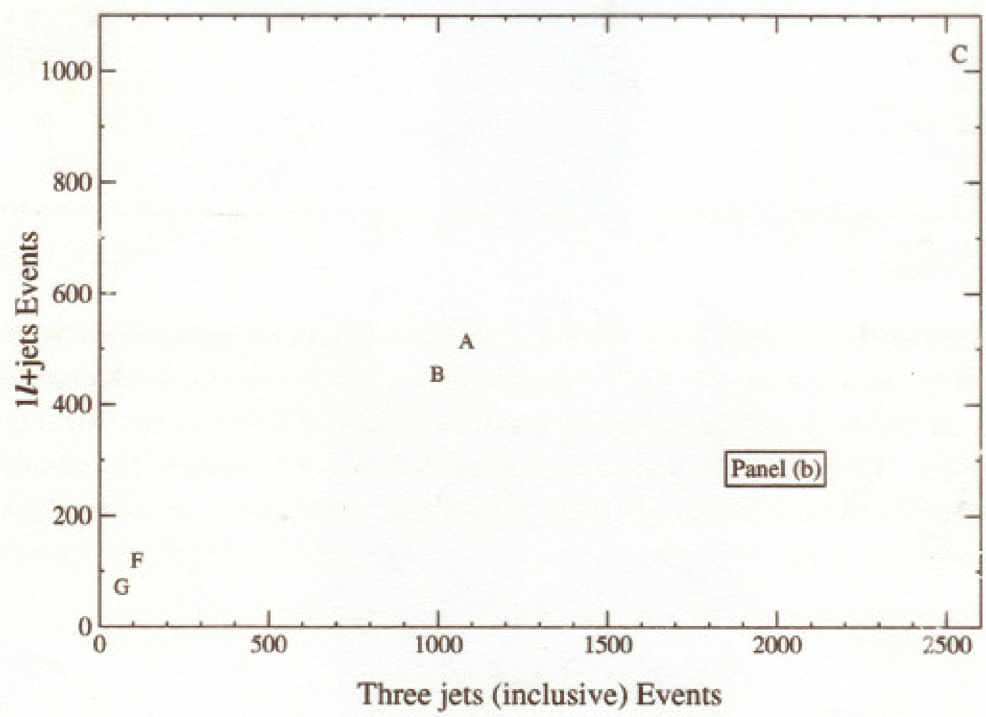
Figure 3: Number of BTSM events of different signatures for different models at Tevatron with 2fb^{-1}. Every signature has missing energy. The first one is inclusive multi-jets signauture with $n_{jets} \geq 3$. This signature is used by CDF to search for gluino and squark. The second one is one lepton plus $n_{jets} \geq 2$. The third one is opposite sign dilepton plus $n_{jets} \geq 2$. The forth one is same-sign dilepton signature. The fifth one is trilepton signature. The sixth one has 3 tau. For these three, no requirement on number of jets. The last one is 4 jets plus 2 charged pions.

* TO CONSTRUCT INCLUSIVE SIGNATURE TABLE, DON'T MAKE CUTS -- INCLUDE SM CONTRIBUTIONS TO EACH SIGNATURE

* NOTE SIGNIFICANT MODEL DEPENDENCE -- GOOD!

* DON'T NEED FULL LHC LUMINOSITY INITIALLY, OR ENERGY


Trilepton Events
0
10
20
30
40
50
0
25
50
75
100
125
Opposite Sign Dilepton plus Jets Evnets
A
B
C
F
G
Panel (a)


1ℓ+jets Events
0
200
400
600
800
1000
0
500
1000
1500
2000
2500
Three jets (inclusive) Events
A
B
C
F
G
Panel (b)

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ANOTHER TECHNIQUE -- GLOBAL THEORY χ^2

* NEED TO COMBINE MEASUREMENTS -- DIFFERENT COLLIDER OBSERVABLES, AND EVEN NON-COLLIDER ONES

* NEED SYSTEMATIC WAY(S) TO SEE WHERE DATA POINTS IN THEORY SPACE

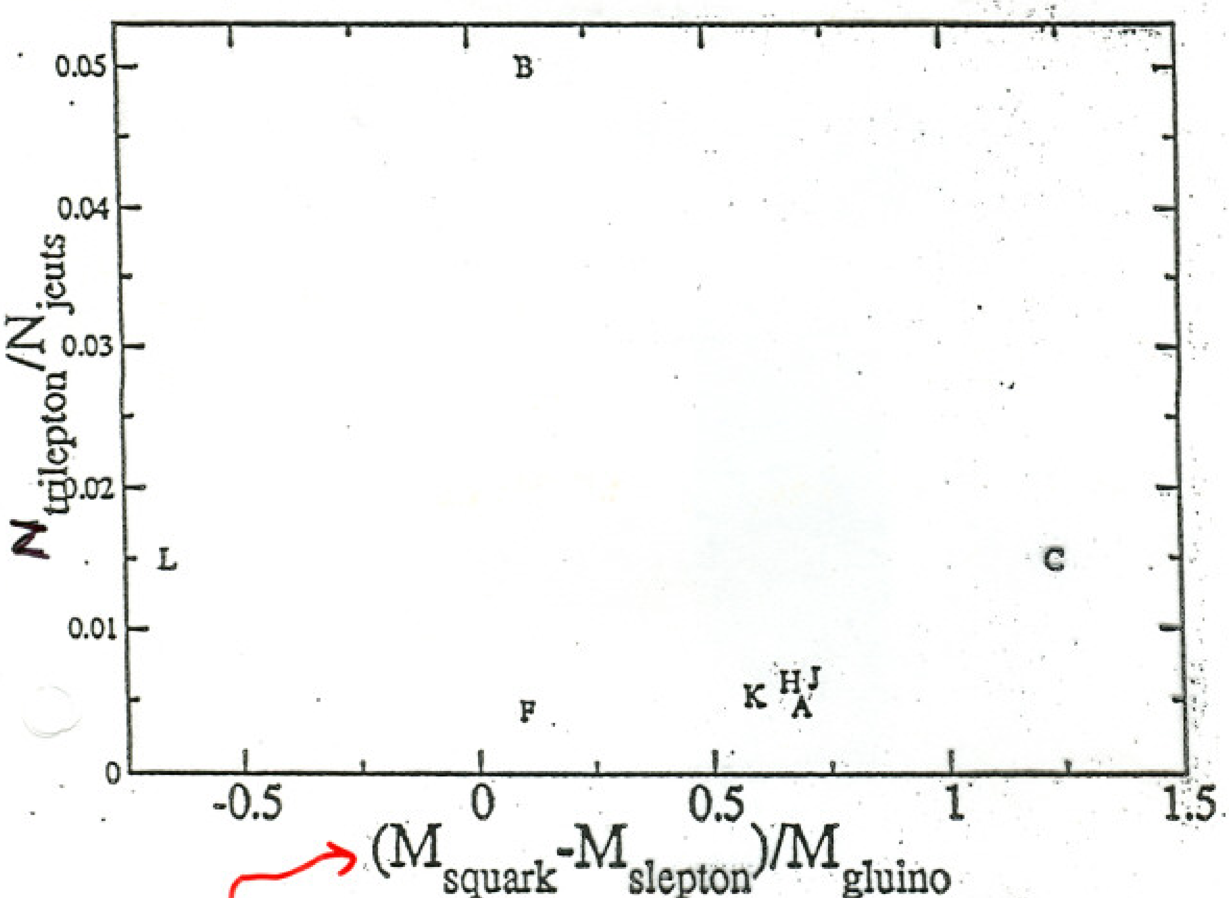
* GOOD AREA FOR THEORY-EXPERIMENTER COLLABORATIONS

-- USE "χ^2" TO "MEASURE" PARAMETERS THAT CANNOT BE UNIQUELY MEASURED
(LIKE m_h AT LEP)

-- GO FURTHER -- FIND FAVORED CLASS OF MODELS IN MODEL SPACE

- SEE ALSO ALLANACH, GRELLSCHEID, QUEVEDO HEP-PH/0406277, "GENETIC ALGORITHMS AND EXPERIMENTAL DISCRIMINATION OF SUSY MODELS"

CAN FIND USEFUL OBSERVABLES



SENSITIVE TO LENGTH OF RGE RUNNING

APPROPRIATE MEASURES

BENCHMARK MODELS

* VERY USEFUL
  -- DETECTOR DESIGN, TRIGGERS, BACKGROUNDS, PRIORITIES

  -- FOR THEORISTS, LEARNING HOW TO CONSTRUCT FULL MODELS, HOW PIECES INTERACT

* BUT GIGO, LAMPPOST ...

* CURRENTLY VERY FINE TUNED --
  LAMPPOST CONSTRAINTS SUCH AS DM IN THERMAL EQUILBRIUM -- MANY ASSUMPTIONS (GAUGINO MASS DEGENERACY, NO PHASES ...) → MISLEADING?
  (e.g. TRILINEAR σ's AT FNAL?)

→ BETTER MODELS NEEDED

* CP VIOLATION AT HADRON COLLIDERS?

GK, HAN, L-T WANG

* COULD BE LARGE -- CONSTRAINTS FROM EDMS, RARE DECAYS INCOMPLETE -- NO SYMMETRY IMPLIES PHASES SMALL

* LEARN TO STUDY ~~CP~~ AT HADRON COLLIDERS
  - -- USE INCLUSIVE SIGNATURES TO GET STATISTICS
  - -- SM "BACKGROUND" SHOULD BE SMALL
  - -- DEVELOP TECHNIQUES FOR MEASURING JET CHARGES

• Im, GK, Malde hep-ph/9302255

• GK, Mrenna, L-T Wang hep-ph/9910477

-- EXAMPLES OF DISTRIBUTIONS THAT DEPEND ON CPV PHASES, TRIPLE SCALAR PRODUCTS

(• EXTENSIVE STUDIES AT LINEAR COLLIDERS -- BARTL, FRAAS, KITTEL, MAJEROTTO, POROD, HIDAKA, BARGER, HAN ......)

* TOO MUCH THEORY?

* SM AN EFFECTIVE THEORY -- HOW EXTEND IT?

  • LEP + THEORY POINTS TO ANSWER:

THEORY + DATA ⇒ { GAUGE COUPLING UNIFICATION, LIGHT FUNDAMENTAL HIGGS, WEAKLY COUPLED EXTENSION } ⇒ SUSY SM

* SUSY AN EFFECTIVE THEORY -- HOW EXTEND IT?

  • LHC DATA (+ LOW SCALE DATA) + THEORY WILL POINT TOWARD SUSY BREAKING, UNDERLYING THEORY

PH/0312248
PH/0312378

* THEORY HAS TO COMPENSATE FOR NO LINEAR COLLIDER IN LHC ERA

* CAN/SHOULD DEVELOP TECHNIQUES BEFORE DATA -- MAY AFFECT ANALYSES

* WITHOUT EXTENSIVE COOPERATION/COLLABORATION OF EXPERIMENTERS AND THEORISTS, IT WILL BE HARD TO GO BEYOND BASIC DISCOVERY

* EVEN WITH LIMITED DATA, INCOMPLETE UNDERSTANDING OF THEORY, GOOD PHYSICISTS CAN FIGURE OUT THE NEXT STAGE(S)