Title: What Counts as String Phenomenology?

Date: Mar 28, 2005 10:00 AM

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Abstract:

WHAT COUNTS AS STRING PHENOMENOLOGY?

-- INCREASINGLY MORE

COLLIDER PHYSICS DOES – HOW CAN WE LEARN ABOUT THE UNDERLYING THEORY, ABOUT SUPERSYMMETYRY BREAKING, FROM DATA – NOT SO EASY

LHC STRETCHING EXERCISE – REPORT OF FIRST DISCOVERIES

Gordy Kane, Perimeter, March 2005

What counts as string phenomenology?

- Cosmology—inflaton, CC
- 3 families
- 3-2-1 Standard Model gauge group
- Supersymmetry

- Unification of forces? E.g. in D-brane models?
- Fermion yukawas
- Exotics (beyond superpartners) – in particular, Z′?
- Electroweak symmetry breaking?
- Supersymmetry breaking
- Superpartner masses
- Neutrino masses, FC interactions, CP physics?
- Proton decay?
- Cosmic strings?

String phenomenology attempts to <u>**explain**</u> at least:
(definition of string phenomenology)

No other subfield focuses on these

- No large cosmological constant
- Dark energy—what, how much
- What is the dark matter
- Baryon asymmetry – amount, origin
- Inflation, big bang
- Standard model (why quarks and leptons, their charges, gauge group)
- Electroweak symmetry breaking – calculate M_Z
- Unification of forces
- Supersymmetry
- Supersymmetry breaking
- Superpartner masses
- Number of families – why not 1?
- Quark and lepton and neutrino masses
- Origin and pattern of CP violation

Why are many of us excited about string theory?

--quantum theory of gravity?

--OK, but more important, because string theory can address all (?) basic questions

QUESTION	Standard Model(s)	Supersymmetric SM(s), light superpartners	String Theory
What is matter?	√		√
What is light?	√√		
What interactions give our world?	√		√
Gravity			√√
Stabilize weak scale hierarchy?		√√	
Explain weak scale hierarchy?			√
Unify gauge couplings?		√√	
Higgs mechanism?		√	
What is dark matter?		√	√
Baryon asymmetry?		√	
Low scale superpartners?			√
How is supersymmetry broken?			√
More than one family? 3?			√
Values of quark, lepton masses?			√
Values of neutrino masses?			√
Origin of CP violation?		√	√
Inflaton?		√	√
Cosmological constant not large?			√
Dark energy?			√
What is electric charge?			√
Space-time?			√
Quantum theory?			√
Origin of universe?			√

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Origin of universe?			√

see talk of Joel Giedt

Electroweak symmetry breaking

--why are relevant superpartner masses ~ TeV?

--why is μ ~ TeV?

--calculate $\tan\beta$ top-down

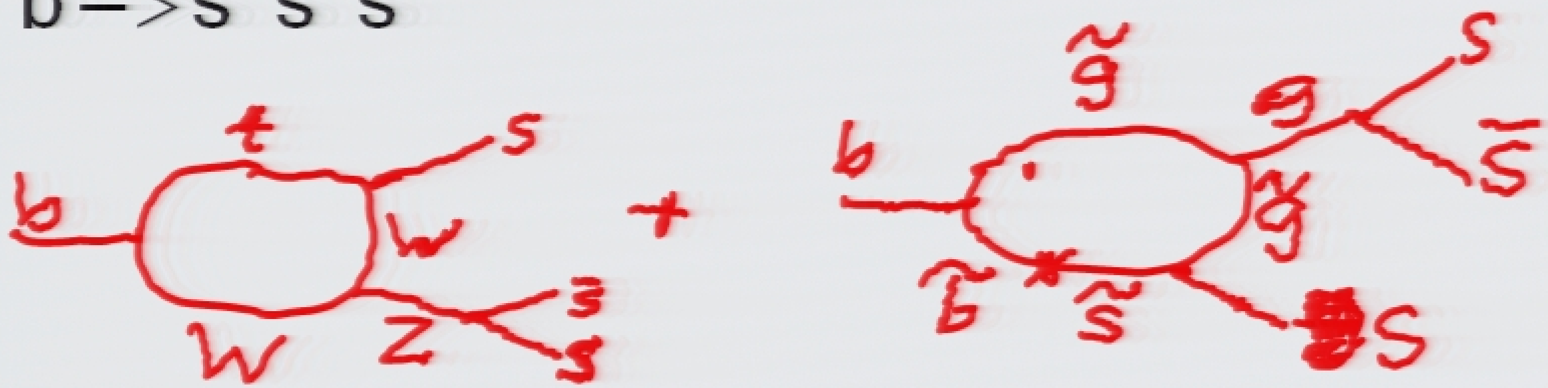
- $\tan\beta$ not in high scale theory!

--deduce EWSB!

--calculate M(Z)

FC physics – no tree level

$b \rightarrow s\ \bar{s}\ s$



so sensitive to light superpartners – currently ~3 σ effect CP asymmetry in several channels, combining Belle and Babar

- If this persists it corresponds to a fairly large high scale effect GK, L-T. Wang, H. Wang, T. Wang, ph/0407351
- Cannot get it with diagonal, universal trilinears and Kahler potential, but it could arise from either diagonal non-universal, or off-diagonal terms ~ 10%
- Probes stringy physics
- If no such effects, why not?

CPV origins, pattern??

- From projection of 10D to 4D? From F-term vevs that break susy?
- Presumably enters 4D world via superpotential, Kahler potential
- Must enter W in yukawas to give CKM phase—only there? Presumably also in soft breaking Lagrangian
- At least 2 independent phases in 4D effective theory, CKM and baryogenesis – conceivably could come from one phase in underlying theory or susy breaking
- CP asymmetry in b→sss would require another phase in the soft breaking Lagrangian

Discovery of superpartners at Tevatron, LHC could be especially productive

--L_{soft} is determined by W, K, f, which in turn are generated as go to 4D world

-- so if we can measure L_{soft} maybe we can go the other way and learn about the 10D theory

-- also need to learn about phases since most masses in L_{soft} are complex

Further – Lagrangian masses mostly complex

- No known symmetry implies phases small – if the phases *are* small it tells us something basic
- Some phases constrained by EDMs, most not
- Phases affect superpartner masses, σxBR, higgs sector, dark matter, etc
- If set phases to zero when analyzing data can be very misleading (e.g higgs mass limit from LEP) – L. Wang, GK
- Need to develop techniques to search for existence of phases by consistency checks, looking for CPV effects in hadron collider data

So see signal

- String theorists: so what, we knew that, keep studying theory
- Just look at data and think a little?
- Not so simple!
  - Particularly at hadron collider, many obstacles
  - Usual methods cannot work!
    - Experiments measure masses of mass-eigenstates (usually mass differences), σ x BR, but those not in Lagrangian (e.g. rate for events with same sign dileptons with energies above 20 GeV and missing transverse energy above 100 GeV is 53fb)
    - At hadron colliders there are always more Lagrangian parameters than observables, so cannot in general solve for Lagrangian parameters such as soft-breaking masses (*actually best reason to want a linear collider)*
    - No general method known to measure tanβ (certain lucky situations may occur …), test gaugino mass degeneracy, etc

What was learned from LEP? Basically 3 things:

- Gauge coupling unification
- Global fit implies light fundamental higgs boson
- No deviations from SM numbers implies weakly coupled extension

-- *All required major interaction of experiment and theory – none could be learned from data alone*

--*All suggest supersymmetric SM*

What will happen at LHC?

- First, a susy signal of some sort
- Then, like LEP – without big role of theory no clue to implications

Is it susy??

- Same sign dileptons, or …

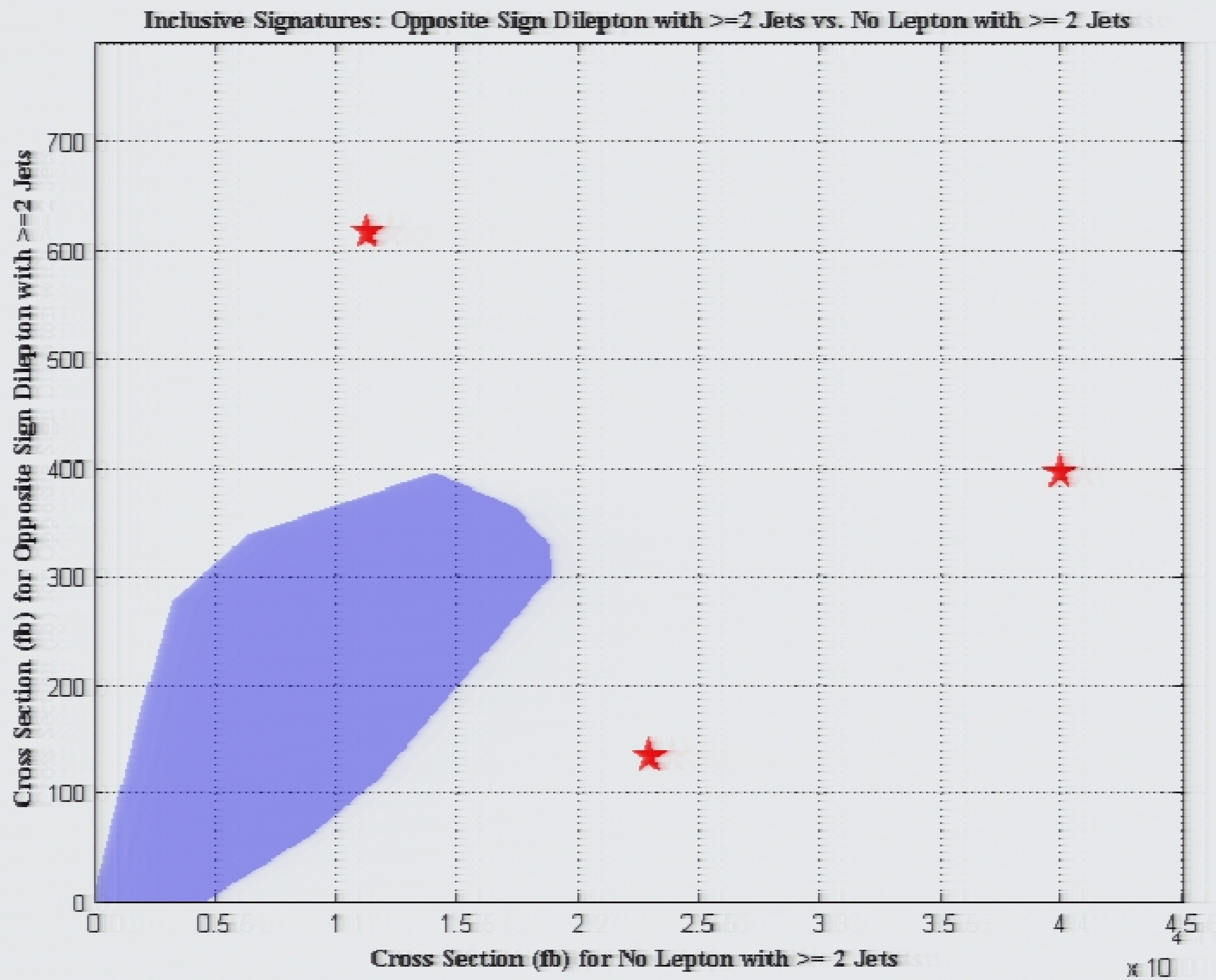
Datta, GK, Toharia

What kind of information will experimenters report? How can we learn to interpret it?

- Show "inclusive signature" plots

  main paper: Pierre Binetruy, GK, Brent Nelson, LianTao Wang, hep-ph/0312248, see for references

- Their pattern contains much information that usual approaches do not
- Collaborators also Jake Bourjaily, Piyush Kumar, Ting Wang
- All signatures have missing transverse energy > 100 GeV, so assume this removes all SM "background"

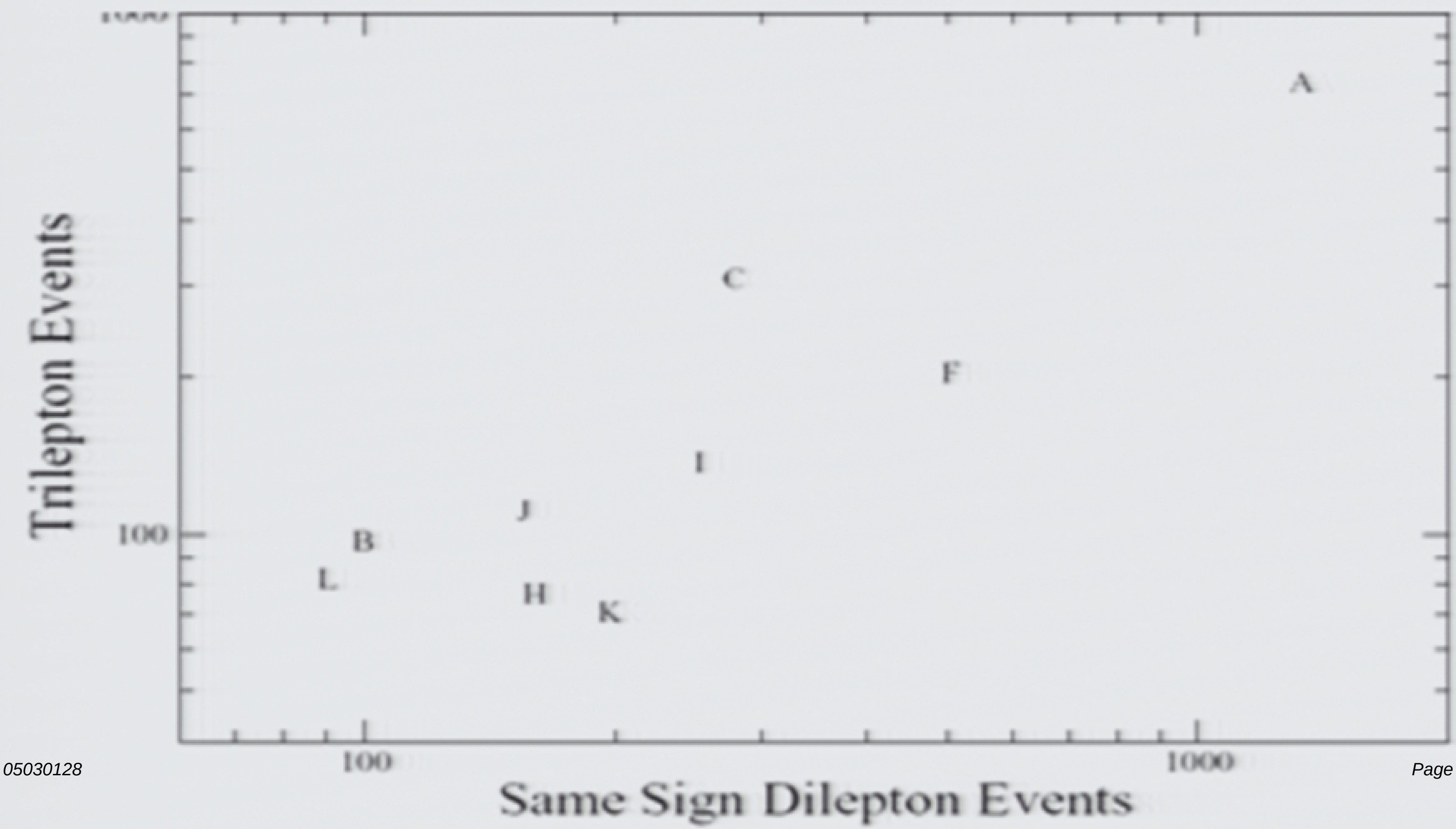

Inclusive Signatures: Opposite Sign Dilepton with >=2 Jets vs. No Lepton with >= 2 Jets
Cross Section (fb) for Opposite Sign Dilepton with >=2 Jets
Cross Section (fb) for No Lepton with >= 2 Jets
700
600
500
400
300
200
100
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
x 10^4

- mSUGRA must lie in blue region, for any parameter values

- Easy to lie outside that region – red stars are string constructions

- Make such plots for many observables – every hypothesis covers some region that does not cover area

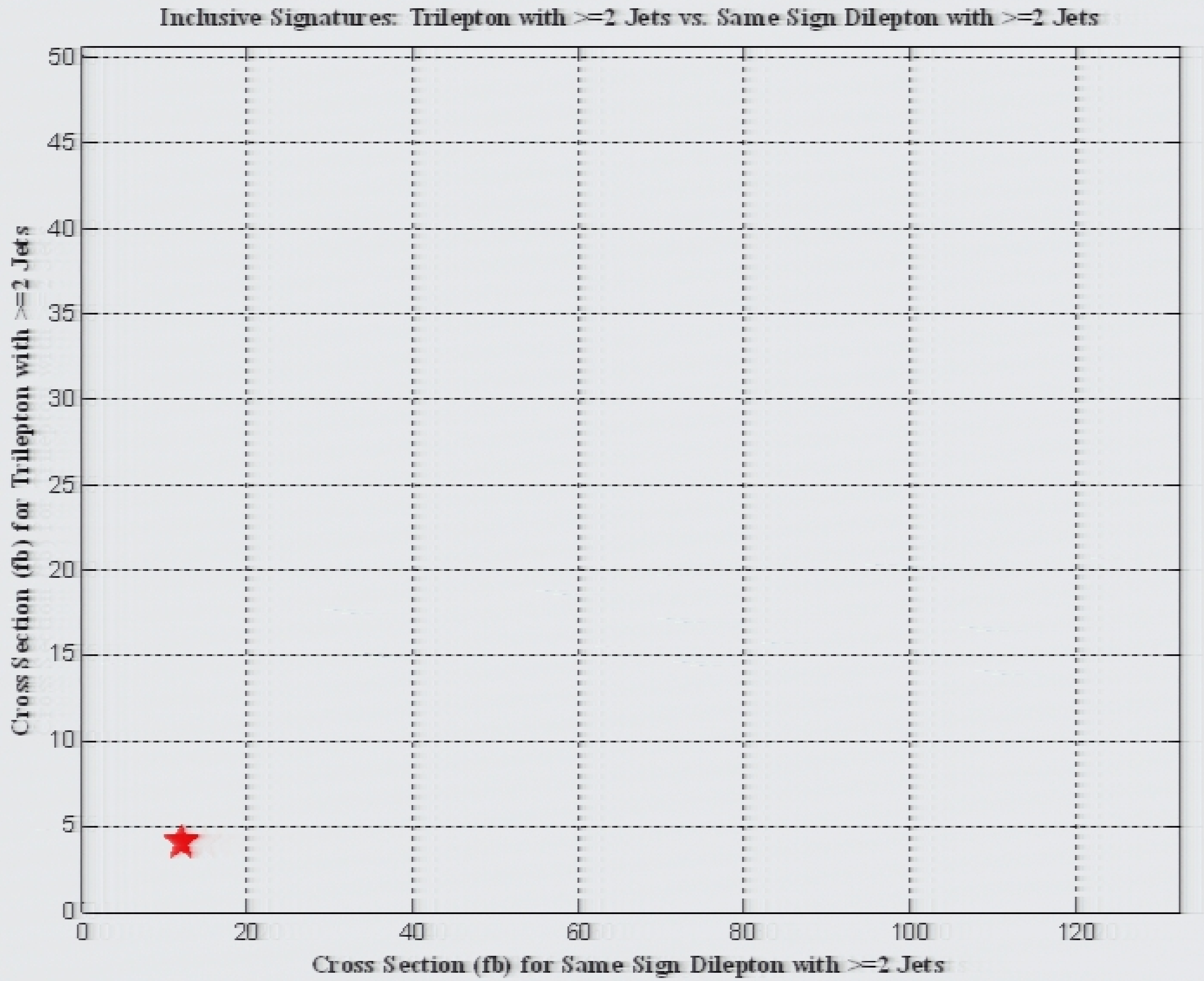
Can get more systematic, study underlying theories (letters are string constructions)

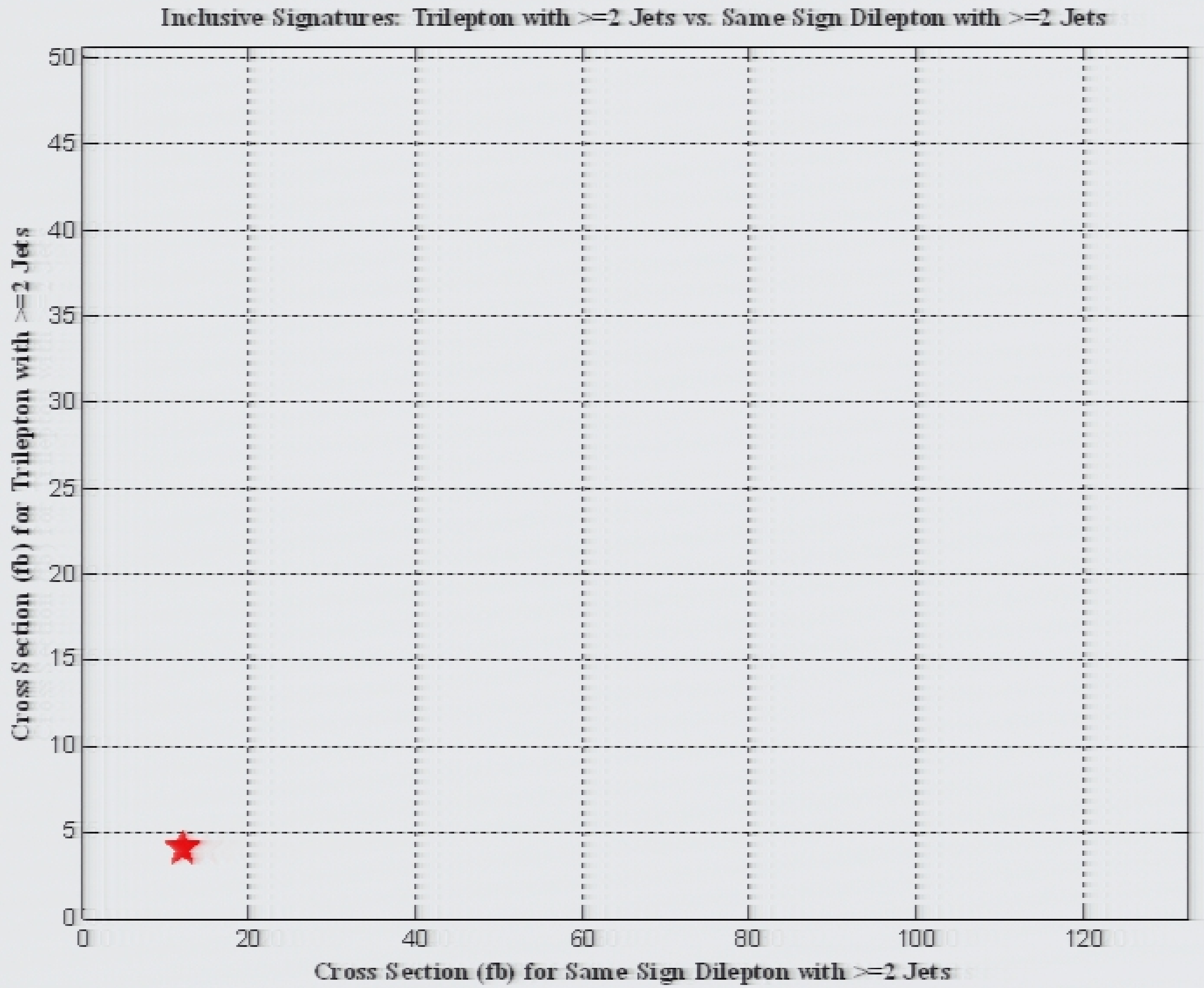


- High scale theory
- RGEs to get low scale, calculate spectrum, e.g. SUSPECT2 (Djouadi, Kneur, Moultaka)
- PYTHIA to produce events, impose cuts, etc
- With data, hope to reverse direction

LHC STRETCHING EXERCISE

LHC HAS RUN FOR A WHILE, NEXT WE SUMMARIZE THE INITIAL RESULTS FOR OBSERVED SIGNALS BEYOND THE STANDARD MODEL


Inclusive Signatures: Trilepton with >=2 Jets vs. Same Sign Dilepton with >=2 Jets
Cross Section (fb) for Trilepton with >=2 Jets
Cross Section (fb) for Same Sign Dilepton with >=2 Jets
0
5
10
15
20
25
30
35
40
45
50
0
20
40
60
80
100
120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50
0
20
40
60
80
100
120

Inclusive Signatures: Opposite Sign Dilepton with >=2 Jets vs. Single Lepton with >=2 Jets
Cross Section (fb) for Opposite Sign Dilepton with >=2 Jets
0
50
100
150
200
250
300
350
0
500
1000
1500
2000
2500
3000
3500
4000
Cross Section (fb) for Single Lepton with >=2 Jets

Inclusive signatures

($10\ fb^{-1} = 1yr,\ 10^{33}\ cm^{-2} sec^{-1}$)

CROSS SECTION fb	2 jets	3 jets	>3 jets
0 leptons	33036	5874	373
1 lepton	2292	393	20
OS dileptons	89	16	0
SS dileptons	4	8	0
trileptons	0	4	0

- For opposite sign dilepton channels, the dilepton invariant mass distribution has its end point at 20 GeV

- For channels without leptons, the sum of missing E_T and P_T of all jets has its peak at 715 GeV

CUTS

- η<3 for jets
- R>0.7
- Jets have E_T>100 GeV
- Leptons =e,μ with η<5 and p_T>20 GeV
- Lepton isolation, E_T within a cone of R=0.3<5 GeV
- Missing E_T>100 GeV
- Transverse plane angle between missing E_T and closest jet > 15°

REMEMBER

- String phenomenology is here to stay – domain should be expanded

- Learning implications of LHC data will take serious effort and thinking – start learning and thinking now