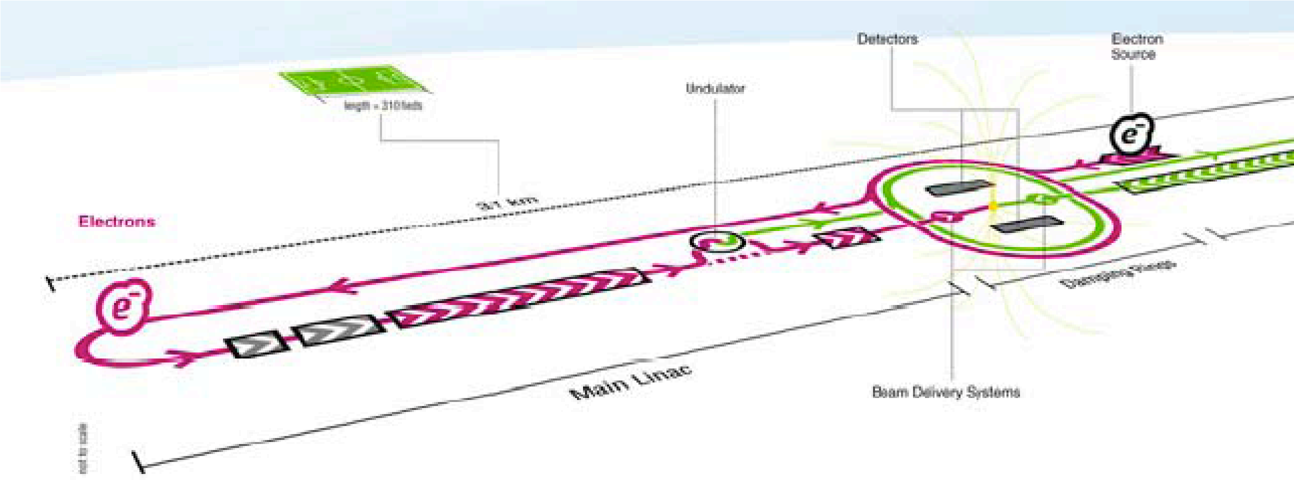
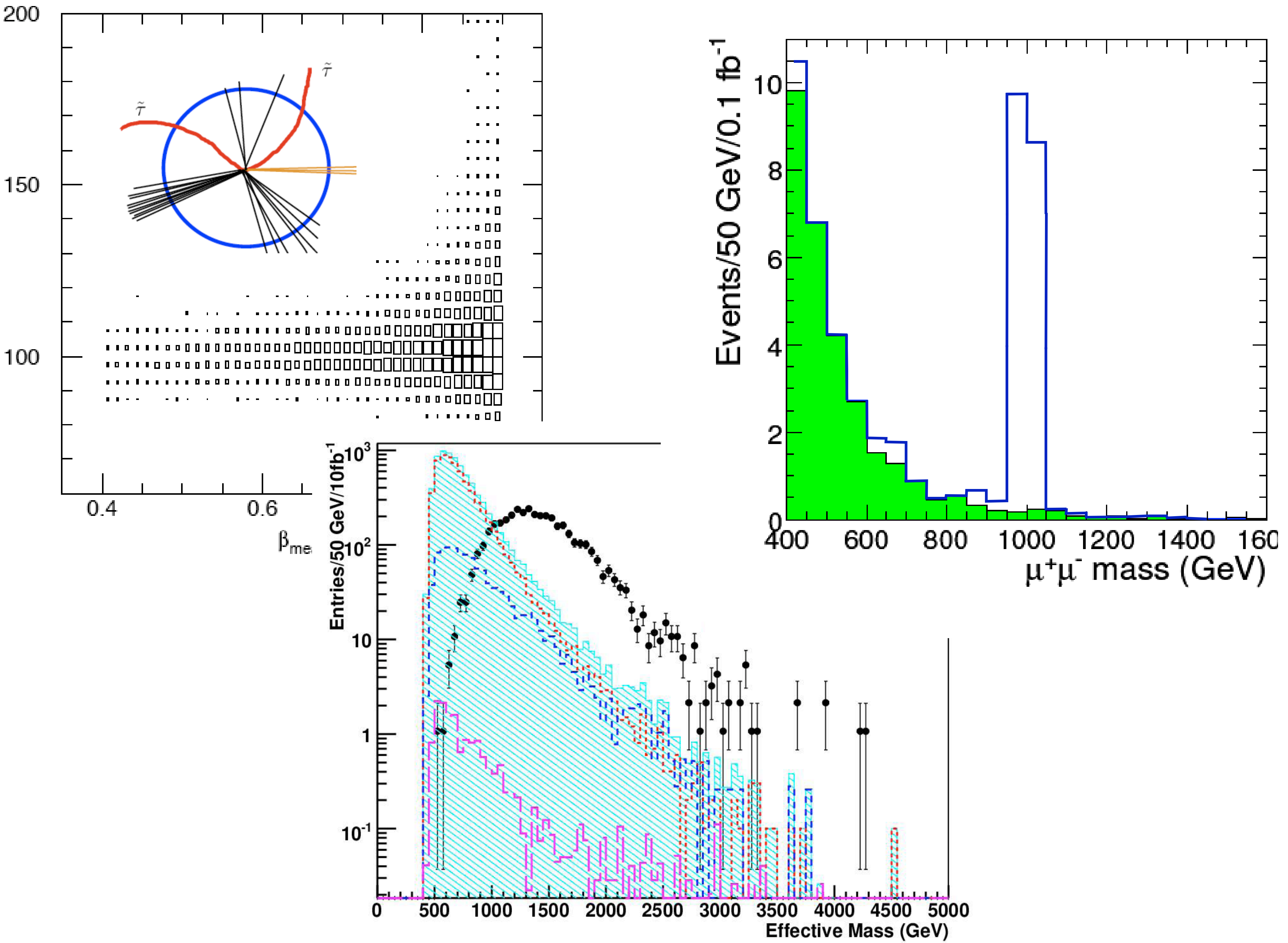
The Physics Landscape: Now and Tomorrow



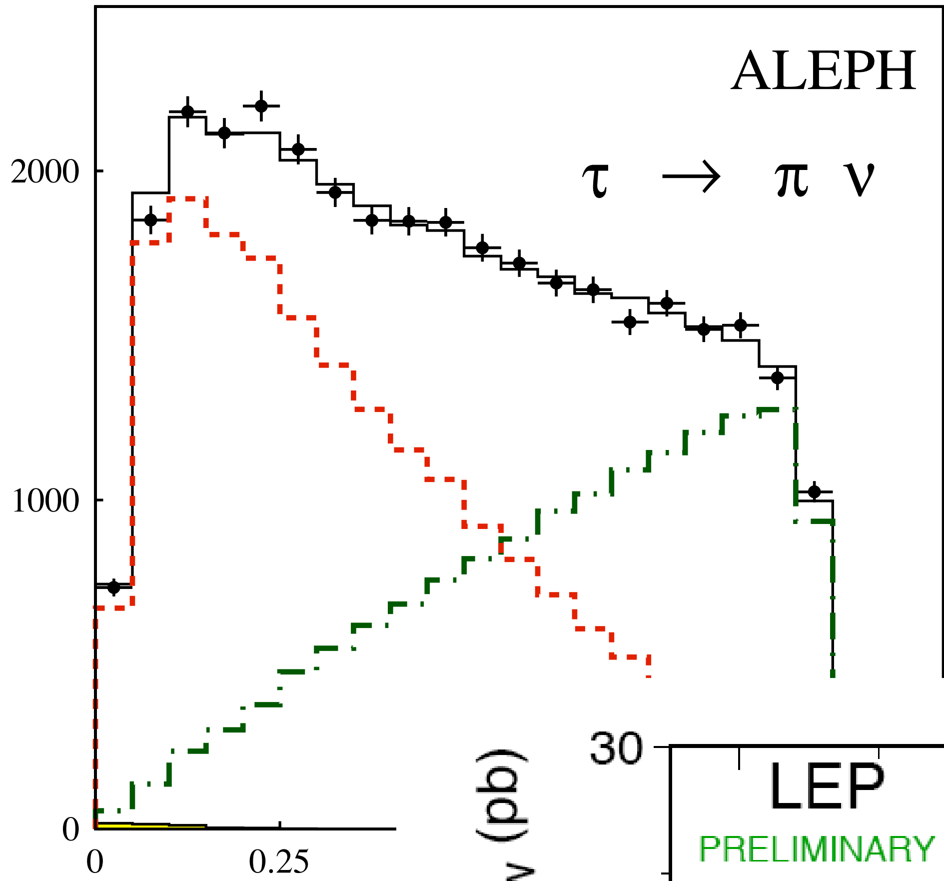
M. E. Peskin
ALCPG 2007 @ Fermilab

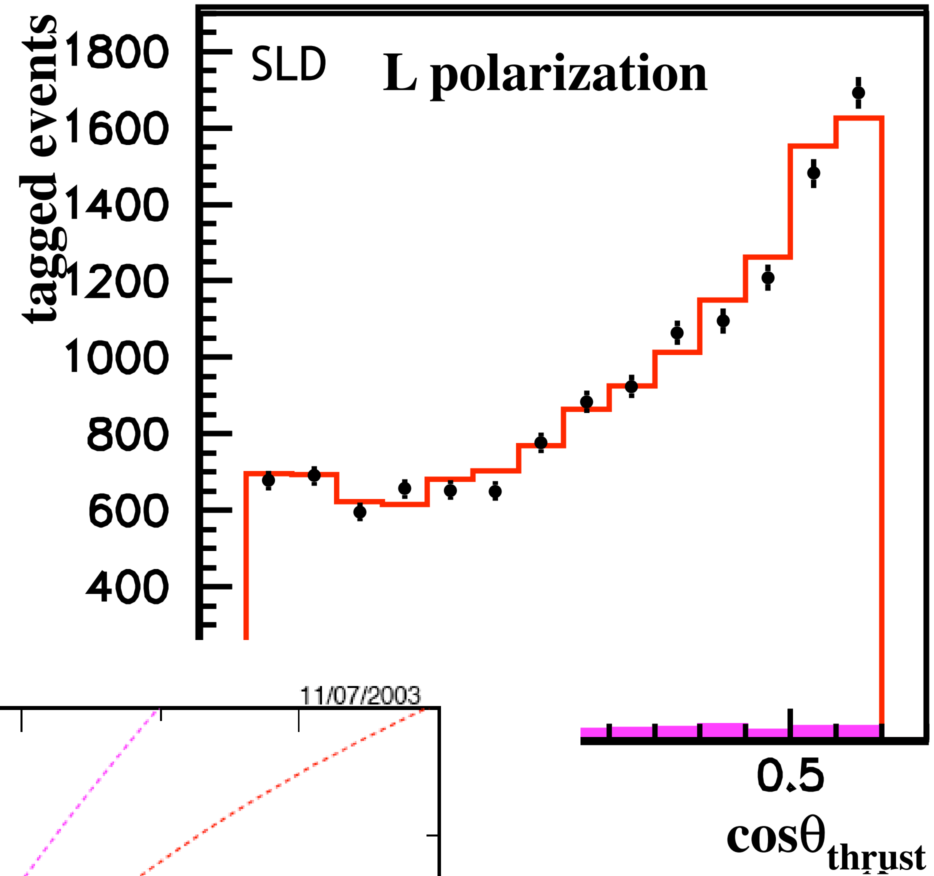
How will we see the world of physics two years after the first data from the LHC ?

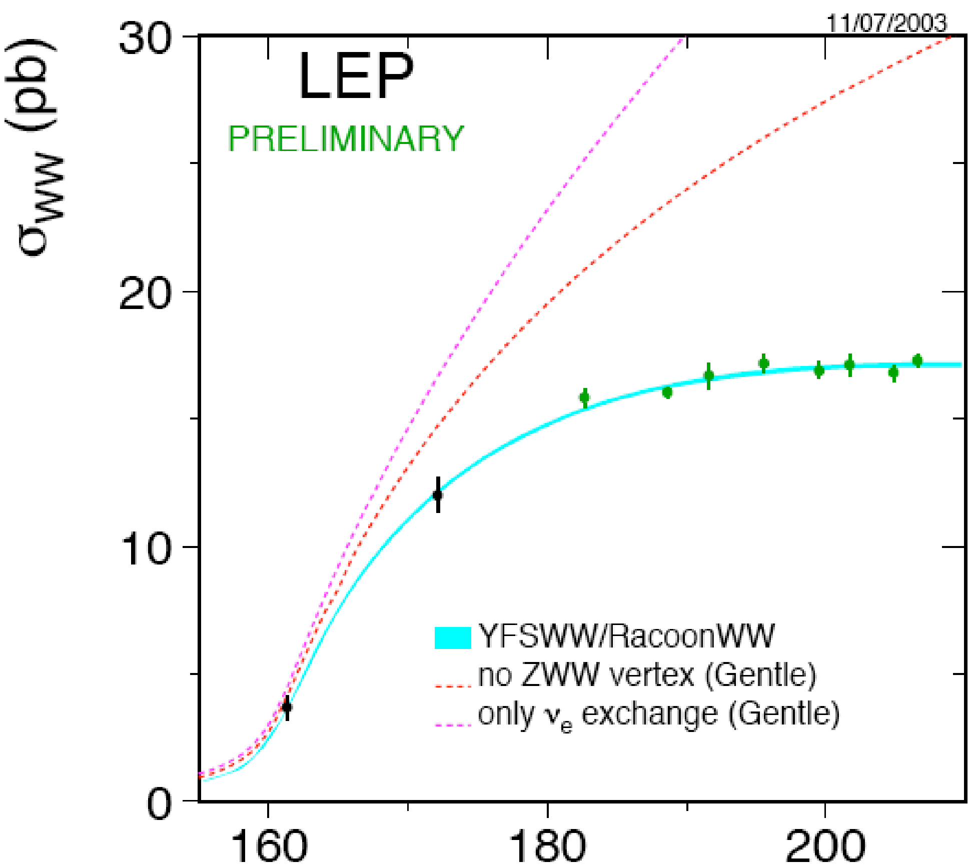

200
150
100
0.4
0.6
β_{me}
$\tilde{\tau}$
$\tilde{\tau}$
Events/50 GeV/0.1 fb^{-1}
10
8
6
4
2
0
400
600
800
1000
1200
1400
160
$\mu^+\mu^-$ mass (GeV)
Entries/50 GeV/10fb^{-1}
10^3
10^2
10
1
10^{-1}
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Effective Mass (GeV)

Why new physics at the LHC ?

1. What breaks the symmetry of the weak interactions ?


ALEPH
τ → π ν
2000
1000
0
0
0.25


SLD
L polarization
tagged events
1800
1600
1400
1200
1000
800
600
400
0.5
cosθ_thrust


LEP
PRELIMINARY
11/07/2003
σ_WW (pb)
30
20
10
0
160
180
200
YFSWW/RacoonWW
no ZWW vertex (Gentle)
only ν_e exchange (Gentle)

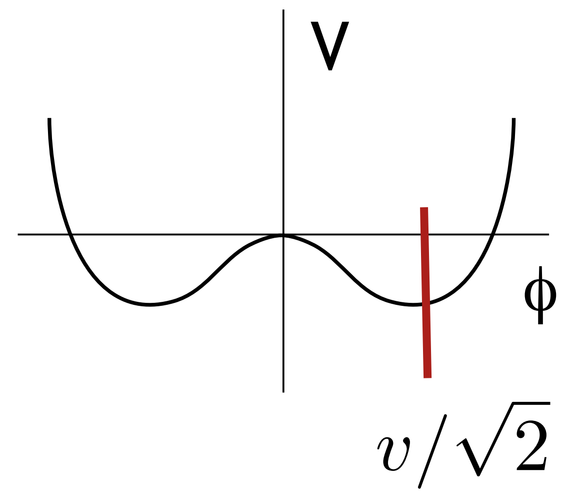
The Standard Model of weak interactions runs on formulae such as

$$m_W = \frac{g}{2} v \quad m_t = \frac{\lambda}{\sqrt{2}} v$$

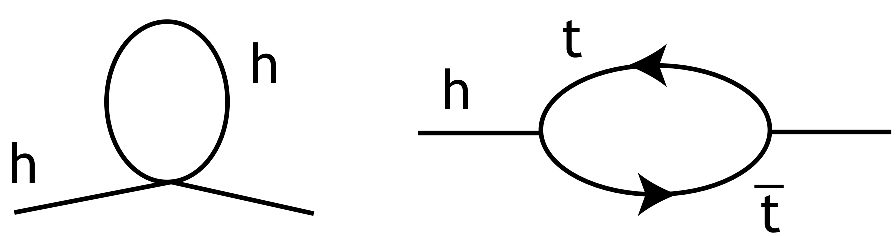
but where does the parameter v come from ?

In the minimal model, we postulate a Higgs field ϕ and the potential energy function

$$V = -\mu^2 |\phi|^2 + \lambda |\phi|^4$$



But, this is not a physics explanation !

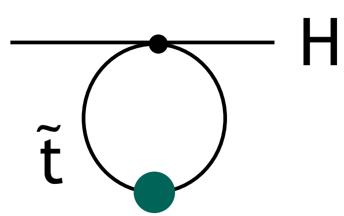


To explain this, there is one good idea out there:

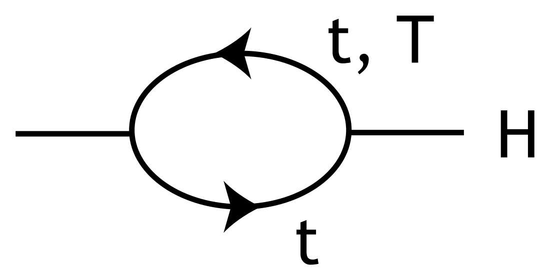
Build a theory that contains a weakly-coupled Higgs field in which the $\mu^2|\phi|^2$ term is forbidden by symmetry.

Break the symmetry; then the zero is filled in.

Diagrams using the heavy top quark create radiative corrections with a definite negative sign:



supersymmetry

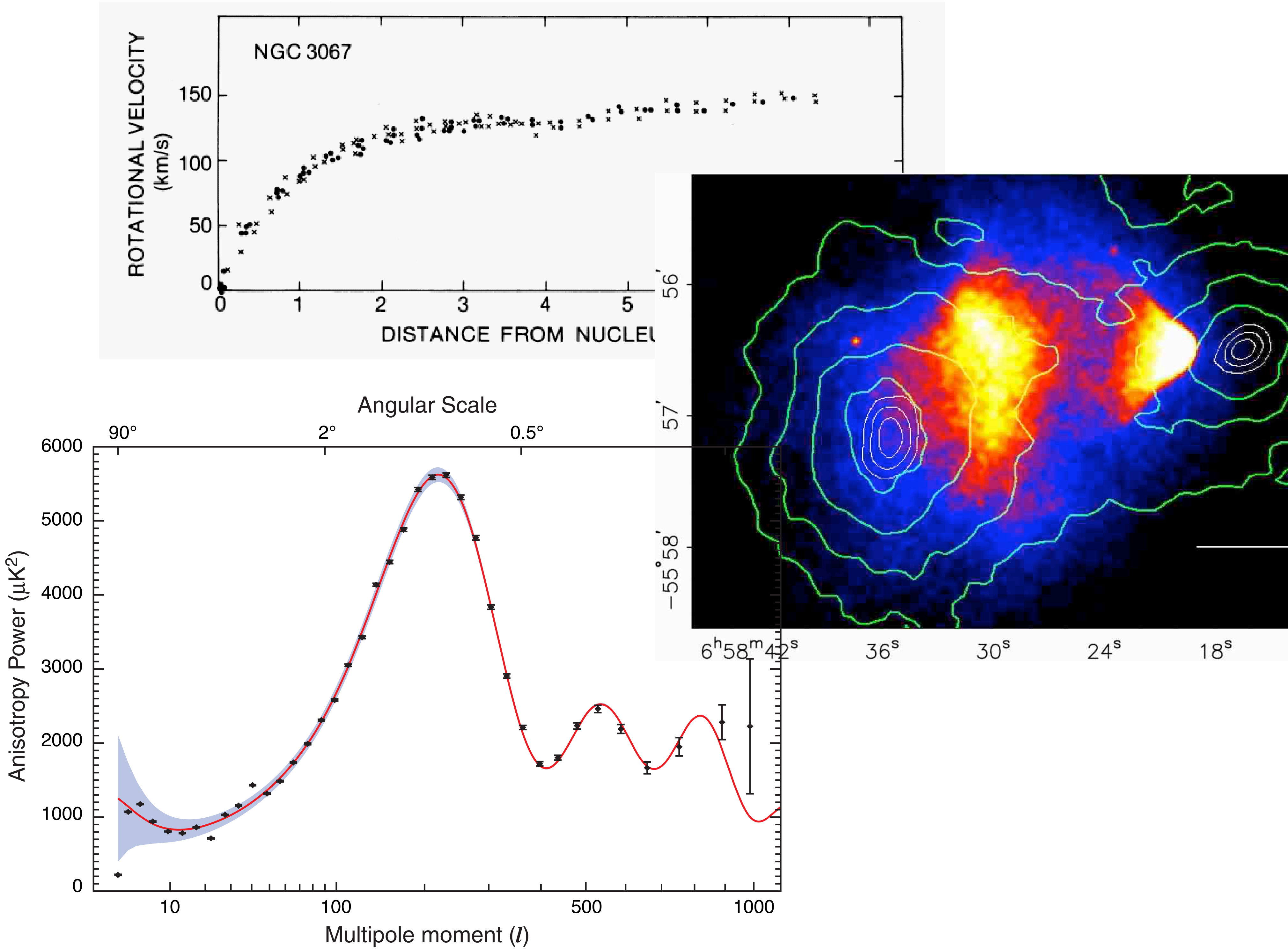


Little Higgs

This requires more than a particle, it requires a spectrum.

Why new physics at the LHC ?

2. What particle makes up cosmic dark matter ?


NGC 3067
ROTATIONAL VELOCITY (km/s)
150
100
50
0
0
1
2
3
4
5
DISTANCE FROM NUCLEU
56′
57′
−55°58′
6h58m42s
36s
30s
24s
18s
Angular Scale
90°
2°
0.5°
6000
5000
4000
3000
2000
1000
0
Anisotropy Power (μK2)
10
100
500
1000
Multipole moment (l)

Dark matter cannot be composed of a particle in the Standard Model.

Postulate a new particle, the WIMP, that is

heavy, neutral, stable, and weakly-interacting

Assume that WIMPs have some interaction, and a thermal abundance in the very early universe. Then one can show

$$\Omega_W = \frac{s_0}{\rho_c} \left(\frac{45}{\pi g_*} \right)^{1/2} \frac{x_f}{m_{\rm Pl} \, \langle \sigma v \rangle}$$

Put in the numbers:

$$\langle \sigma v \rangle = 1 \ \mathrm{pb} \qquad M \sim 100 \ \mathrm{GeV}$$

To explain this, there is one good idea out there:

The new sector of particles responsible for electroweak symmetry breaking must have a discrete symmetry that keeps that lightest new particle stable.

supersymmetry: R parity
extra dimensions: geometrical parity or Z_3

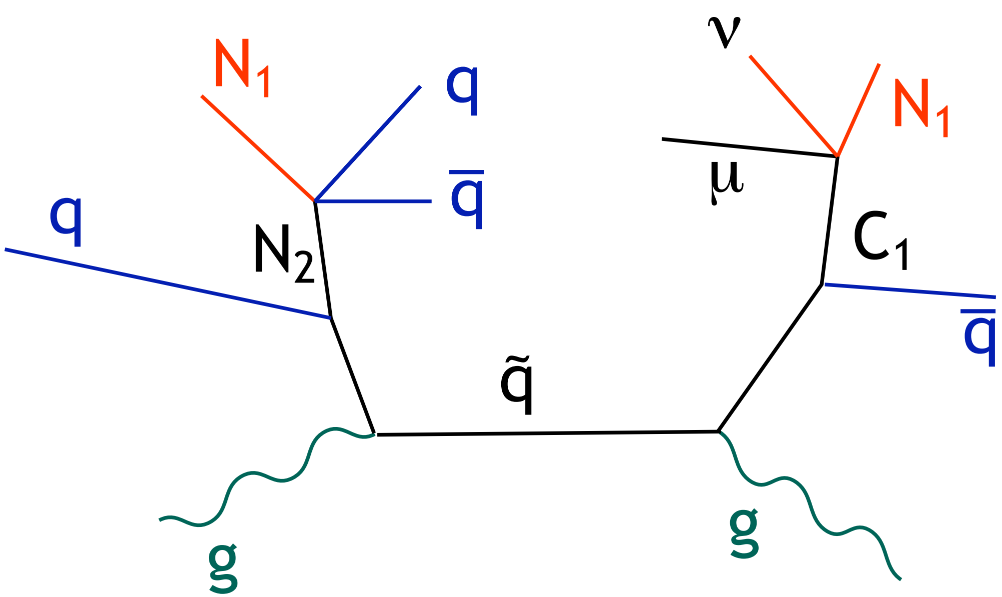
This seems ad hoc if we are adding one particle, but it is natural if we have a spectrum of particles.

The lightest new particle with electroweak interactions might be the invisible WIMP, or it might be a quasi-stable charged particle that decays to a super-WIMP.

The arguments for new physics at the LHC are very strong.

They call for a spectrum of particles, with

- a weakly coupled Higgs boson similar to the MSM h^0
- partners of the top quark at the hundred GeV mass scale
- stable or quasi-stable decay products associated with the WIMP



These arguments are not a guarantee.

But,

they present an opportunity that we must be prepared to take up.

the next step …

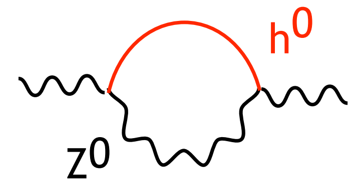
Higgs boson(s)

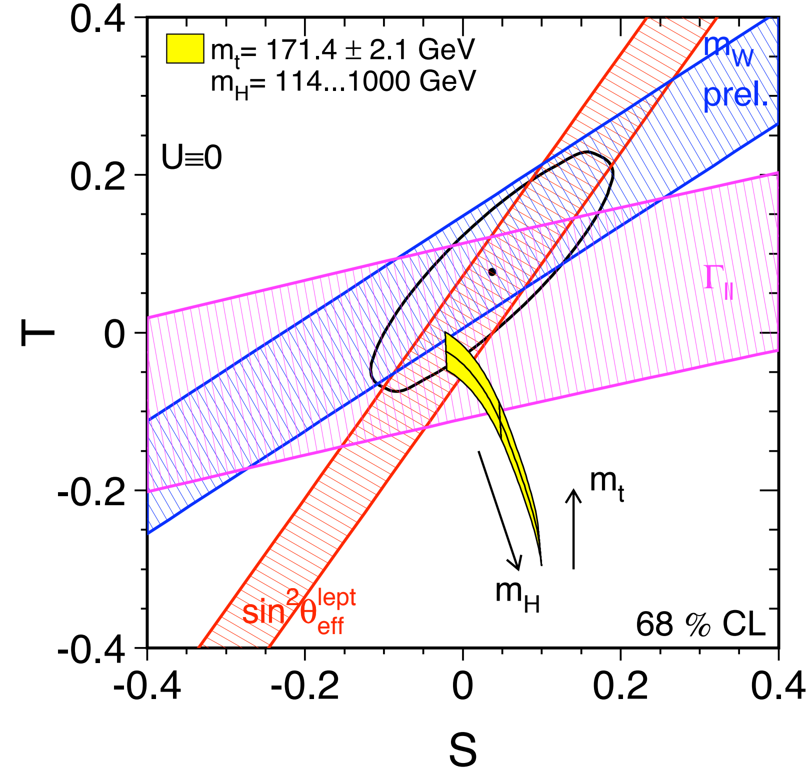
The Higgs boson is a central part of the structure, and we must understand it well. Precision electroweak fits in the MSM give

$$\sum_i \frac{v_i^2}{v^2} \log \frac{m_{hi}}{m_Z} < \log \frac{182 \text{ GeV}}{m_Z}$$

(LEP EWWG 95% CL)

This bound can be violated outside the MSM, but only if there is new physics of certain specific types*.





We should discover the Higgs at the Tevatron or the LHC.

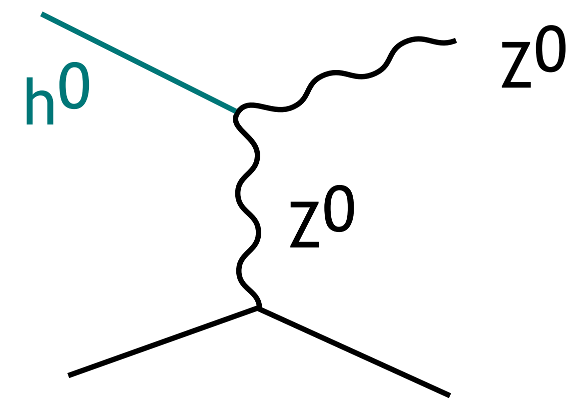
The ILC is an ideal machine for learning its detailed properties.

* MEP + J. Wells, 2001

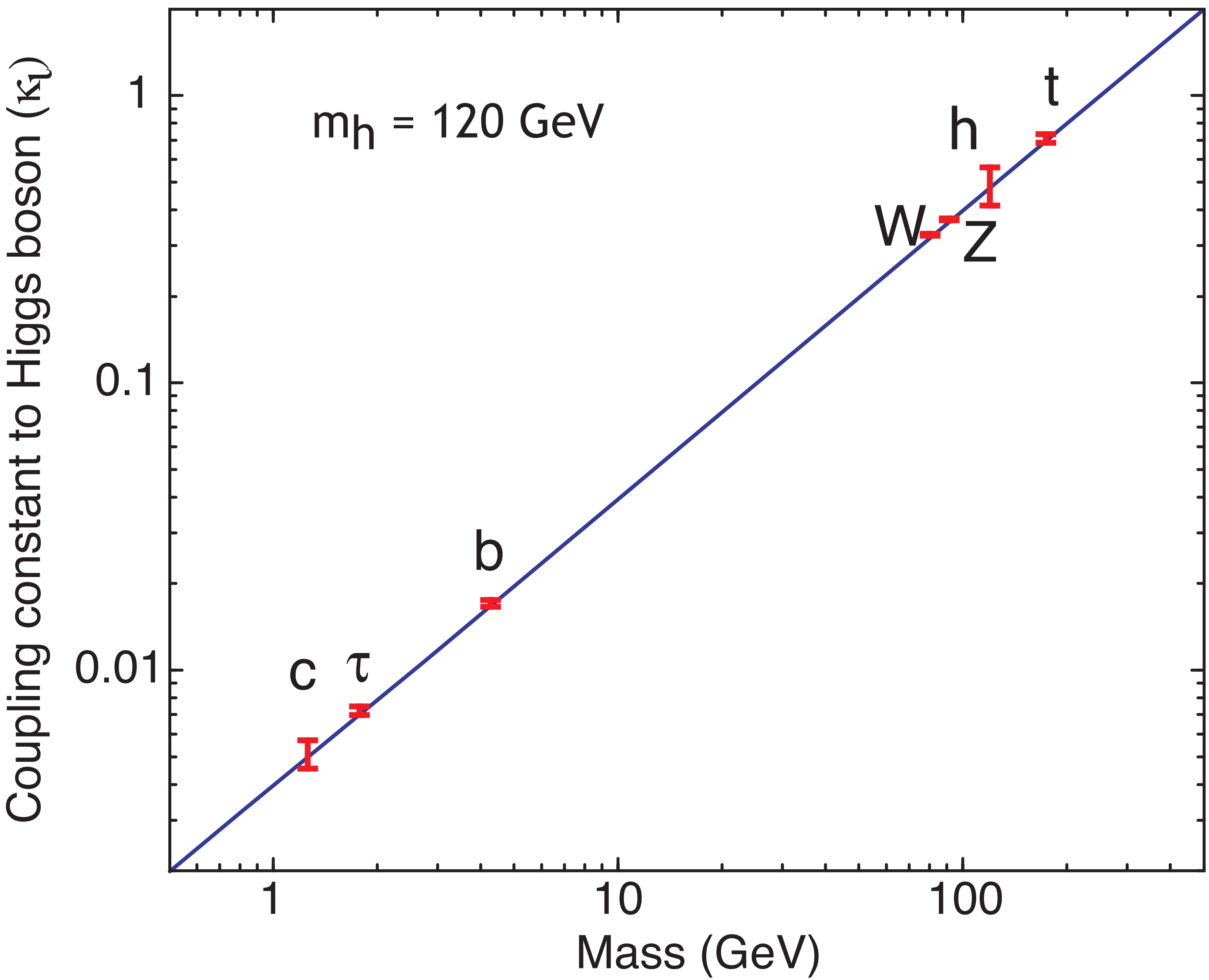
Focus on the analysis of the Higgs boson (or bosons) in $e^+e^- \to Z^0 h^0$.

The total cross section involves the coupling that gives mass to the Z^0 :

$$g_{h_i ZZ} = 2\frac{m_Z^2}{v} \cdot \frac{v_i}{v}$$



The observation of the Higgs in recoil allows the measurement of any branching ratio.

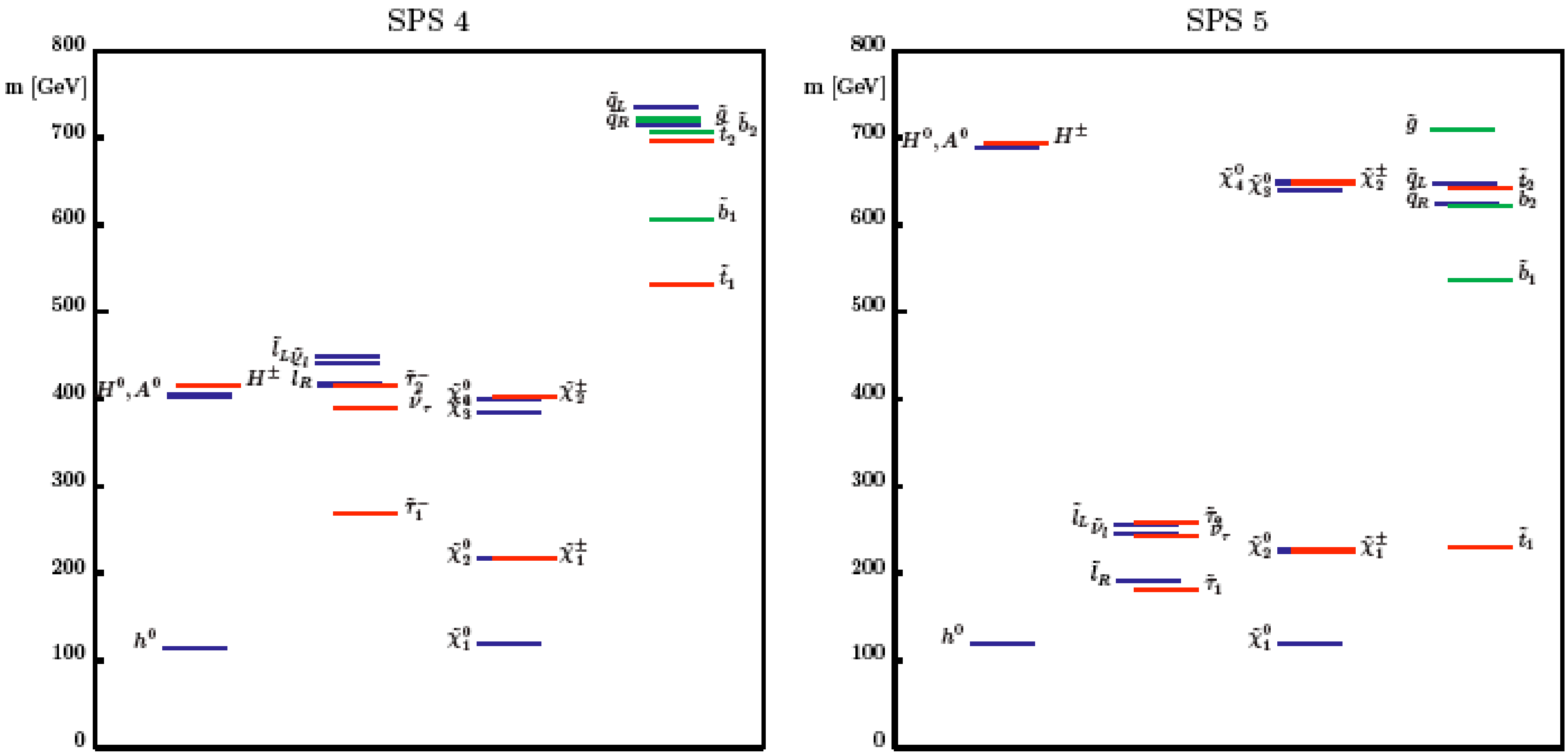


ACFA LC study

the next step …

WIMPs

The WIMP should be a part of a complex spectrum, much of which may not be accessible at the 500 GeV ILC.



SUSY spectra from the Snowmass 2001 Points and Slopes

We will start measuring this spectrum at the LHC.

The ILC brings new strengths to this problem:
precision measurements, polarization observables.

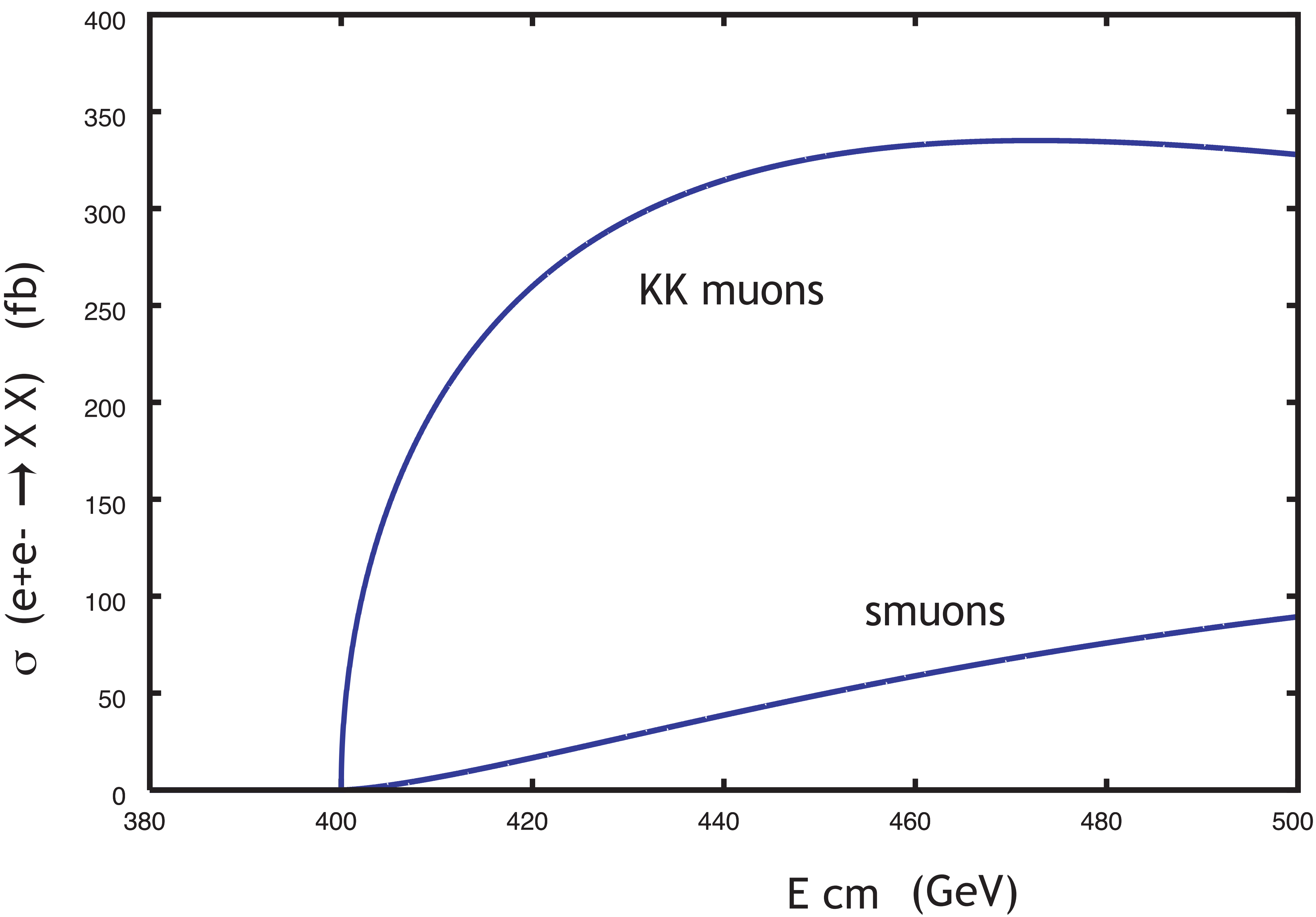
Applied to the lighest new particles, these give

unambiguous qualitative identification
of spins and quantum numbers

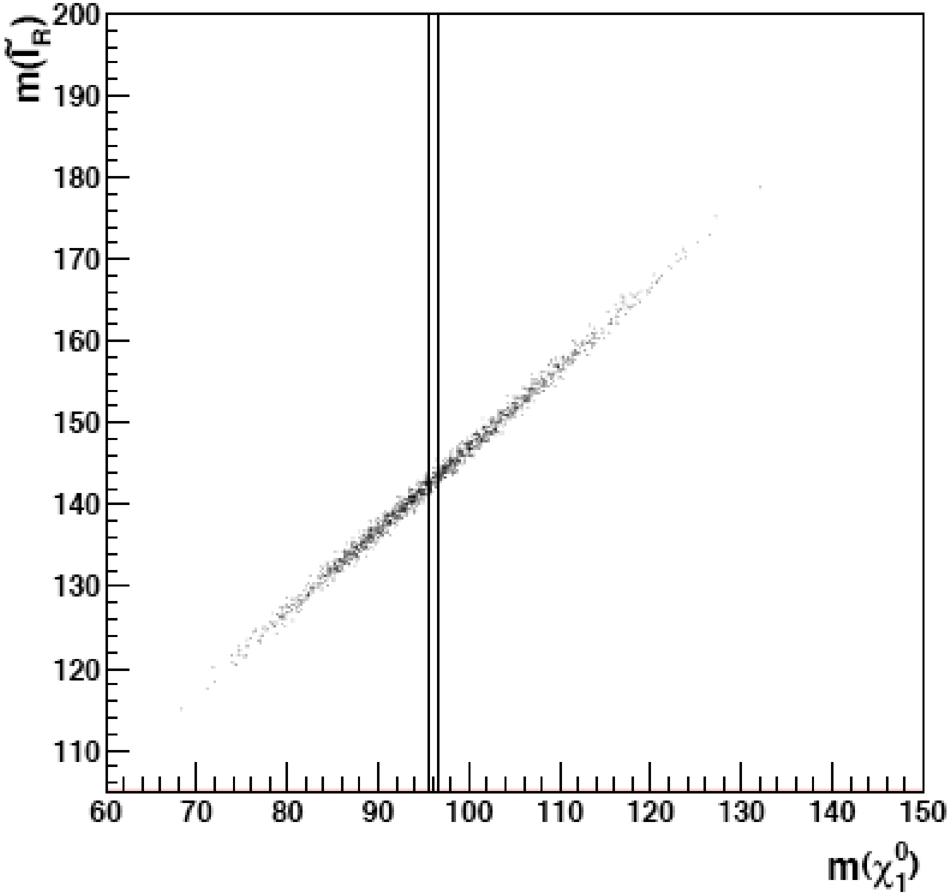
sharpening of kinematic analyses from hadron colliders

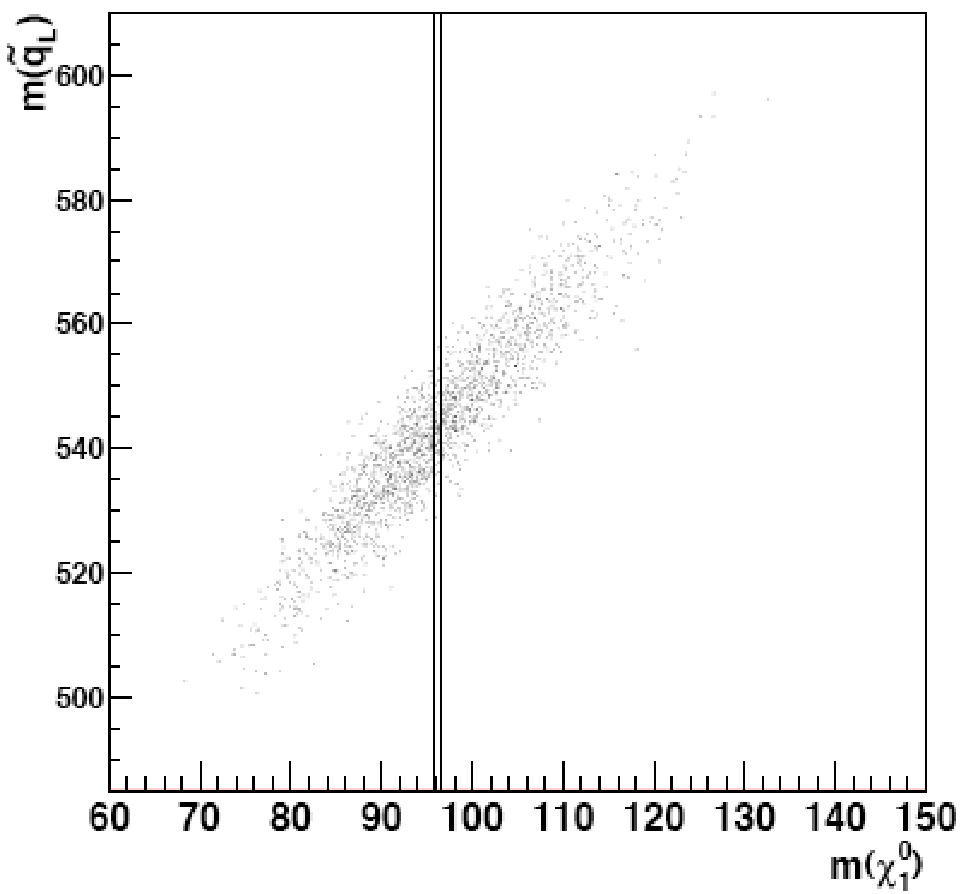
measurement of mixing angles and couplings

measurement of critical parameters $(\tan\beta,\ m(\widetilde{l}_L)/m(\widetilde{l}_R))$

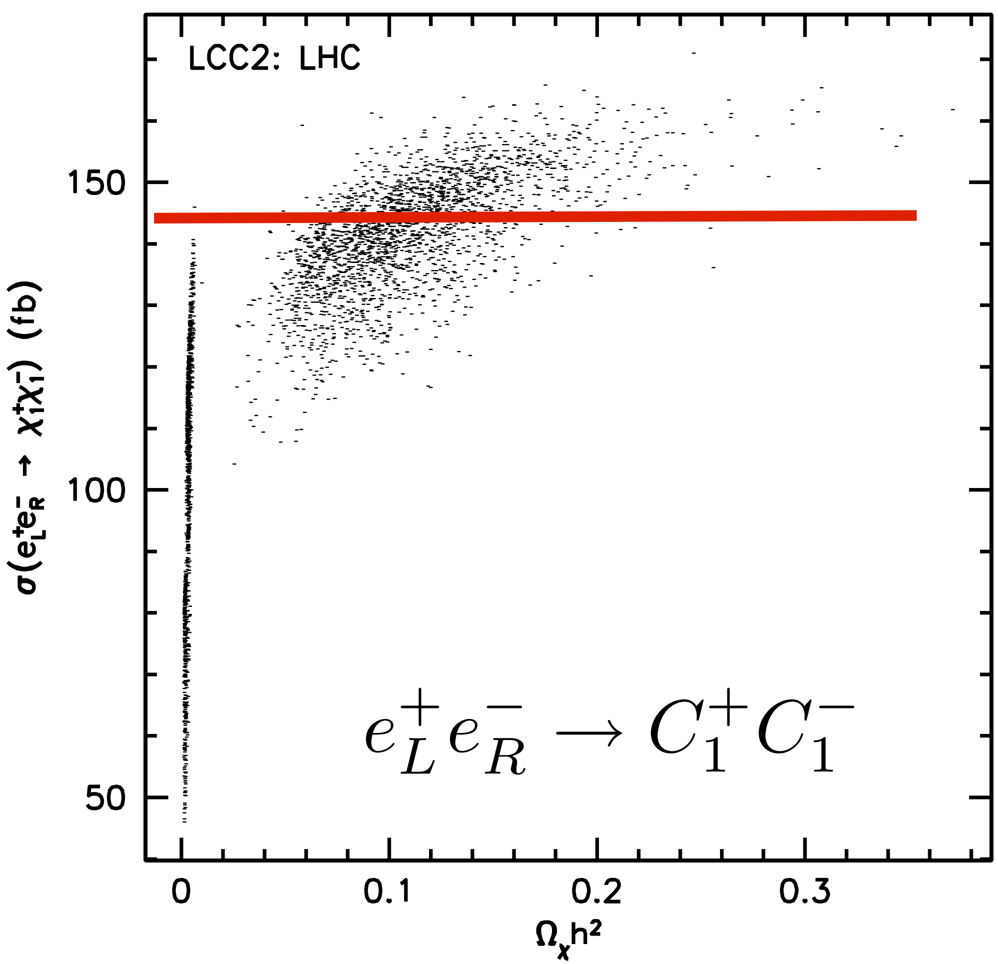


400
350
300
250
200
150
100
50
0
380
400
420
440
460
480
500
KK muons
smuons
σ (e+e- → X X̄) (fb)
E cm (GeV)

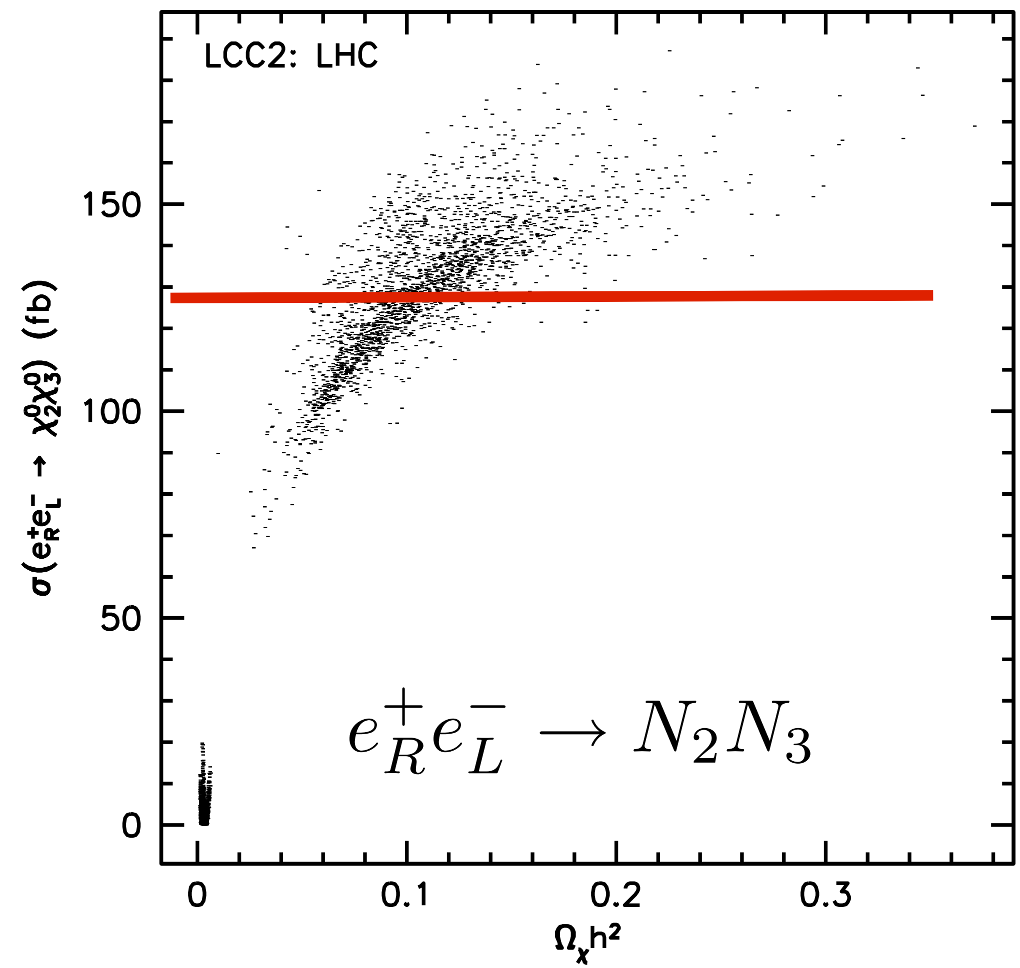




SPS1a, LHC/ILC study

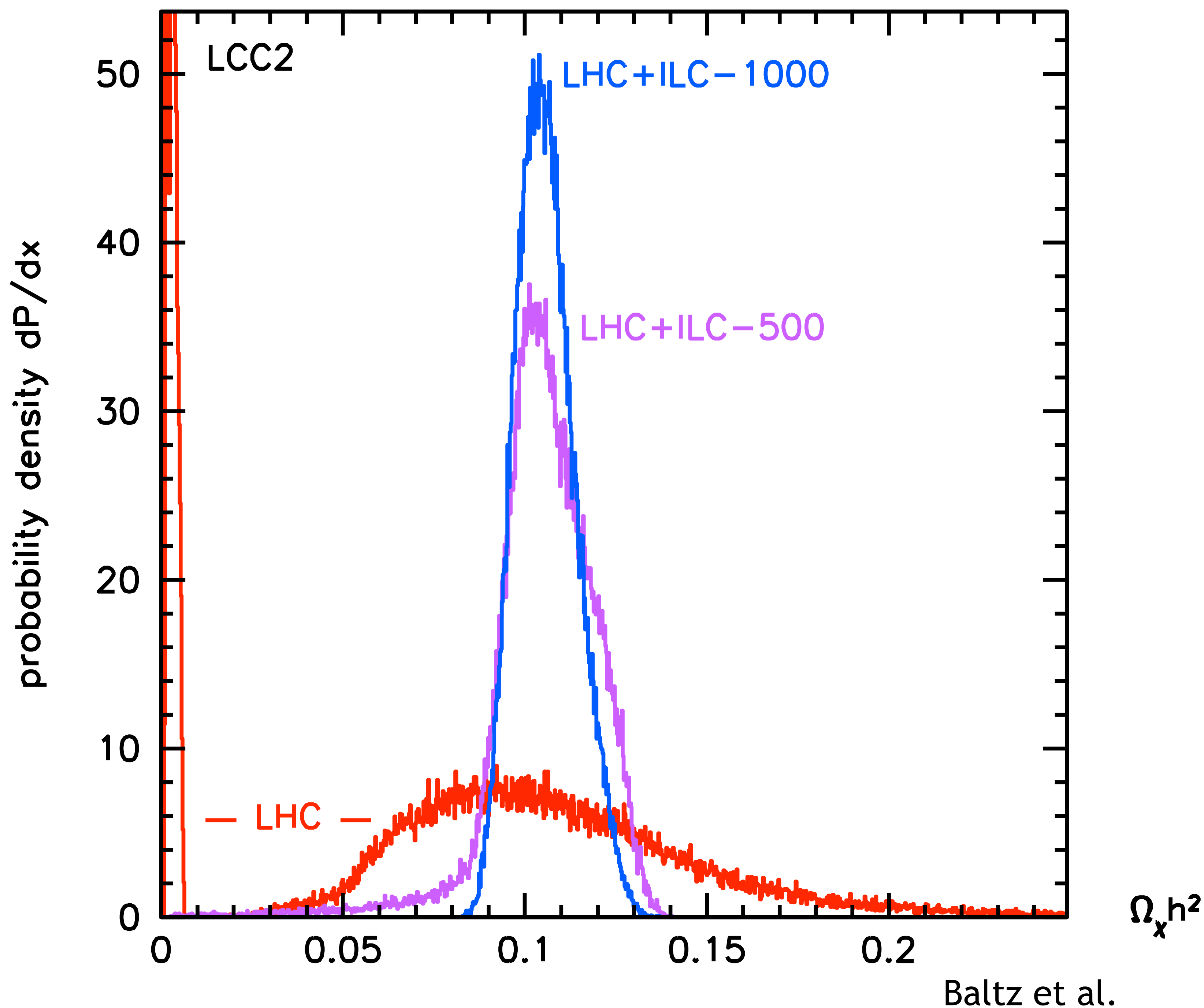


LCC2: LHC
150
100
50
0
0.1
0.2
0.3
$\sigma(e^+_L e^-_R \to \chi^+_1 \chi^-_1)$ (fb)
$\Omega_\chi h^2$
$e^+_L e^-_R \longrightarrow C^+_1 C^-_1$



LCC2: LHC
150
100
50
0
0.1
0.2
0.3
$\sigma(e^+_R e^-_L \to \chi^0_2 \chi^0_3)$ (fb)
$\Omega_\chi h^2$
$e^+_R e^-_L \longrightarrow N_2 N_3$

Baltz et al.


LCC2
LHC+ILC−1000
LHC+ILC−500
— LHC —
probability density dP/dx
50
40
30
20
10
0
0
0.05
0.1
0.15
0.2
$\Omega_\chi h^2$
Baltz et al.

the next step …

resonances

Many models of new physics require new resonances or interactions in the annihilation channel:

extended gauge group (Z' , moose)

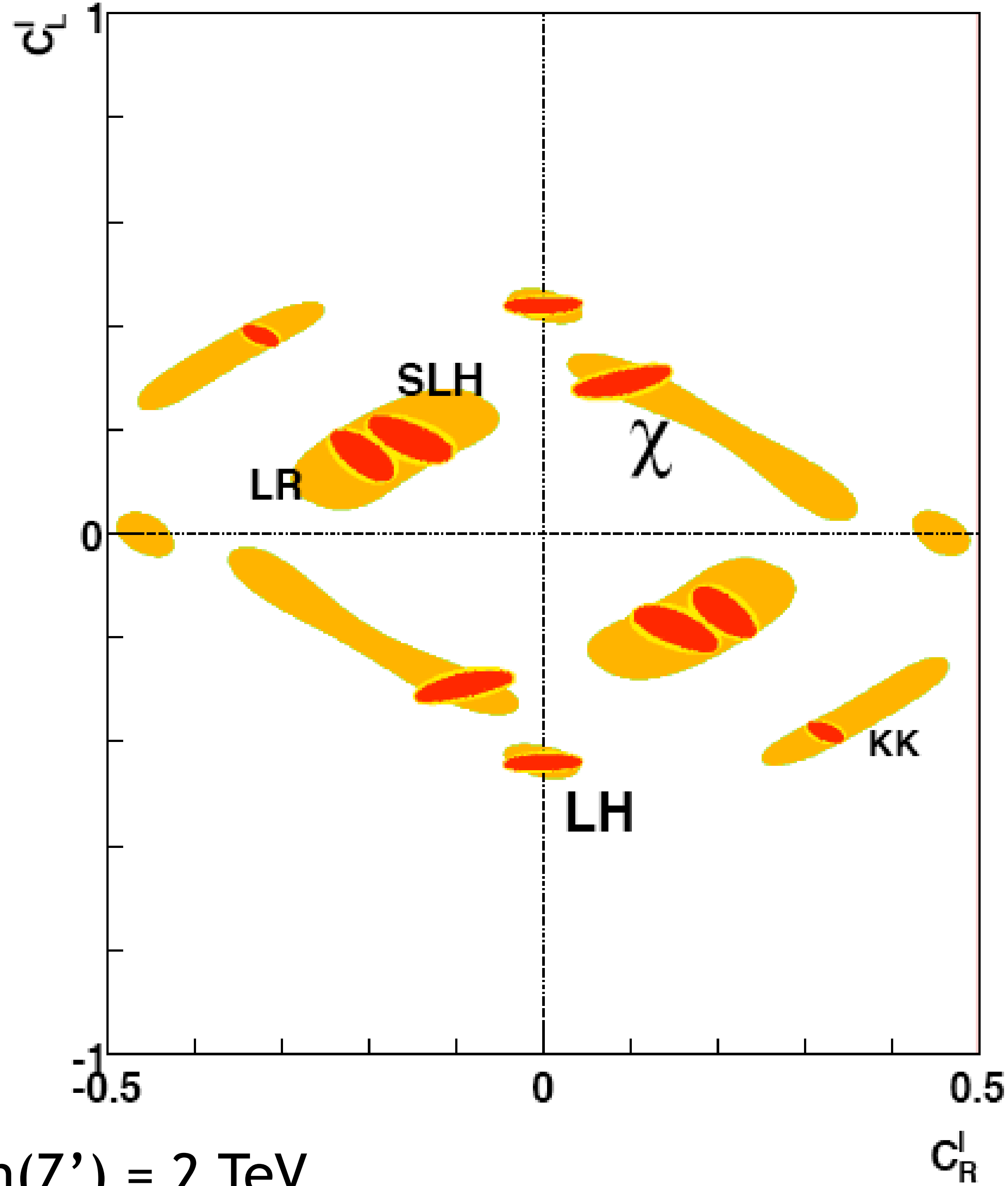
extra dimensions

compositeness

LHC will discover resonances up to 3 - 5 TeV.

Then we will need to identify what particles these are.

The ILC provides a suite of tools, even at 500 GeV.



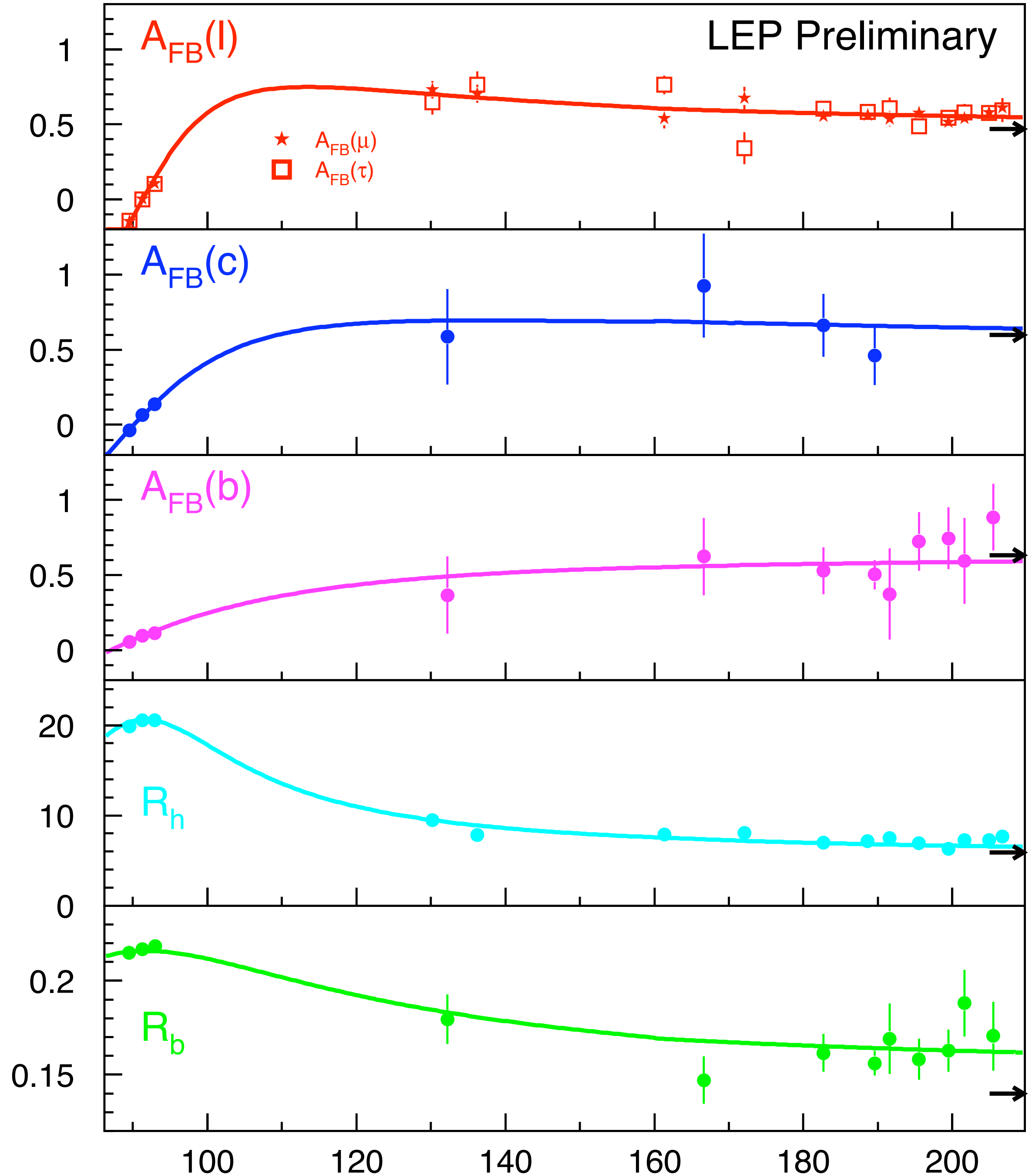
500 GeV, m(Z') = 2 TeV
1 ab-1, $e^+e^- \to \mu^+\mu^-$

Godfrey, Kalyniak, Tomkins

LEP 2 tests of SU(2)xU(1)

for ILC, add

initial-state polarization
efficient b,c tagging
polarization
per mil level of accuracy



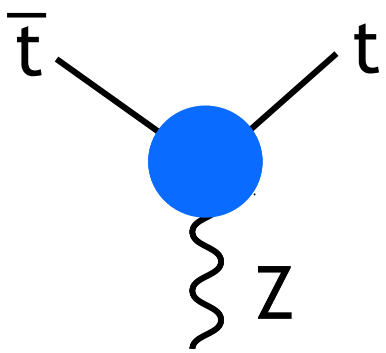
data compilation
by Hildreth

the next step …

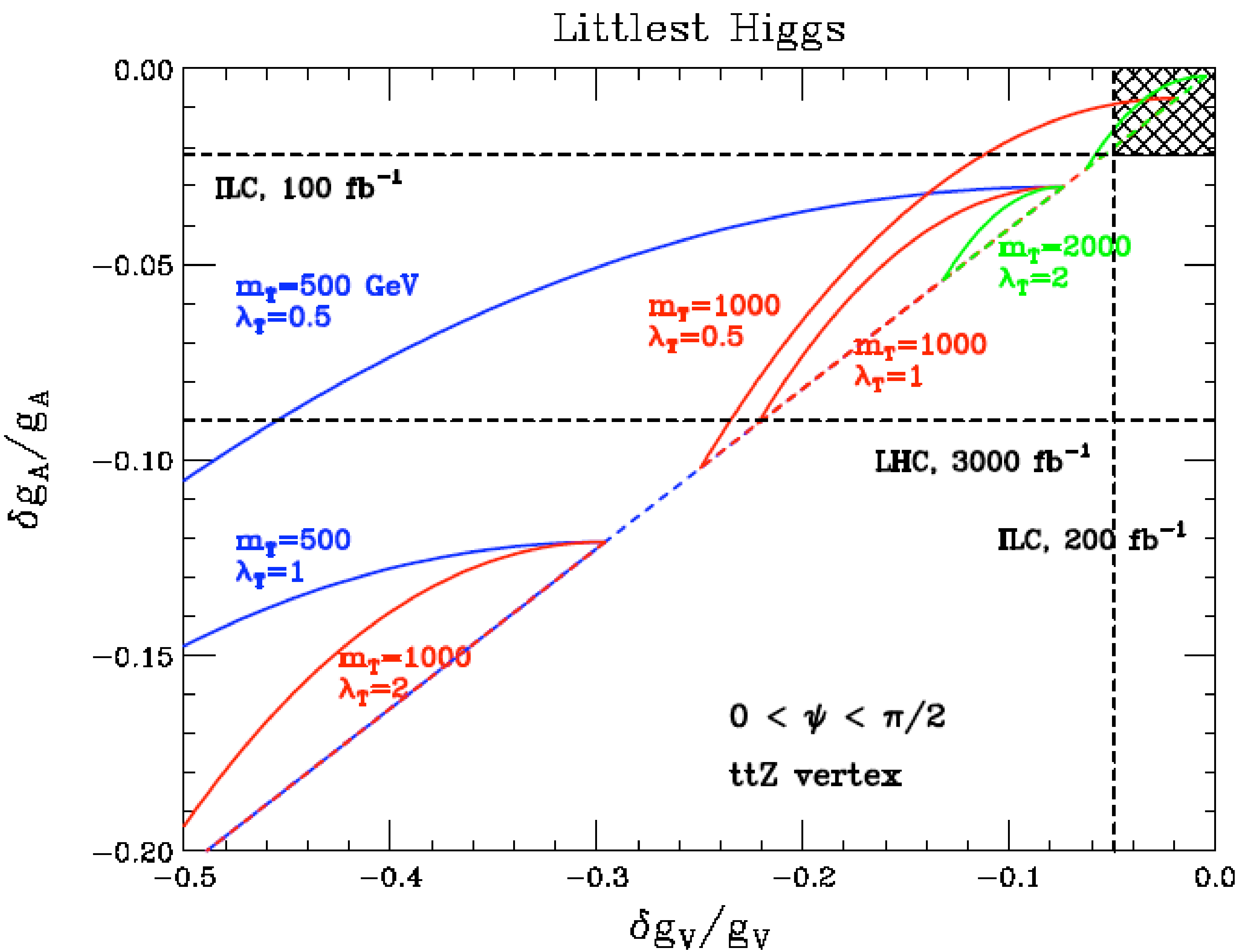
top quark

The LHC will produce 10^8 top quark pairs per year, allowing detailed study for of the top quark kinematics and strong interactions.

But ILC polarized cross section measurements give access to the electroweak couplings, in particular



for which large corrections are expected in, e.g. Little Higgs and Randall-Sundrum extra dimensions.



Berger, Petriello, Perelstein

We expect to find new particles at the LHC. The problems of the SM require a new spectrum for their solution.

The discovery will raise new questions. We will need the ILC to find the answers.

Think about this as an opportunity. We must be ready for it when it comes.