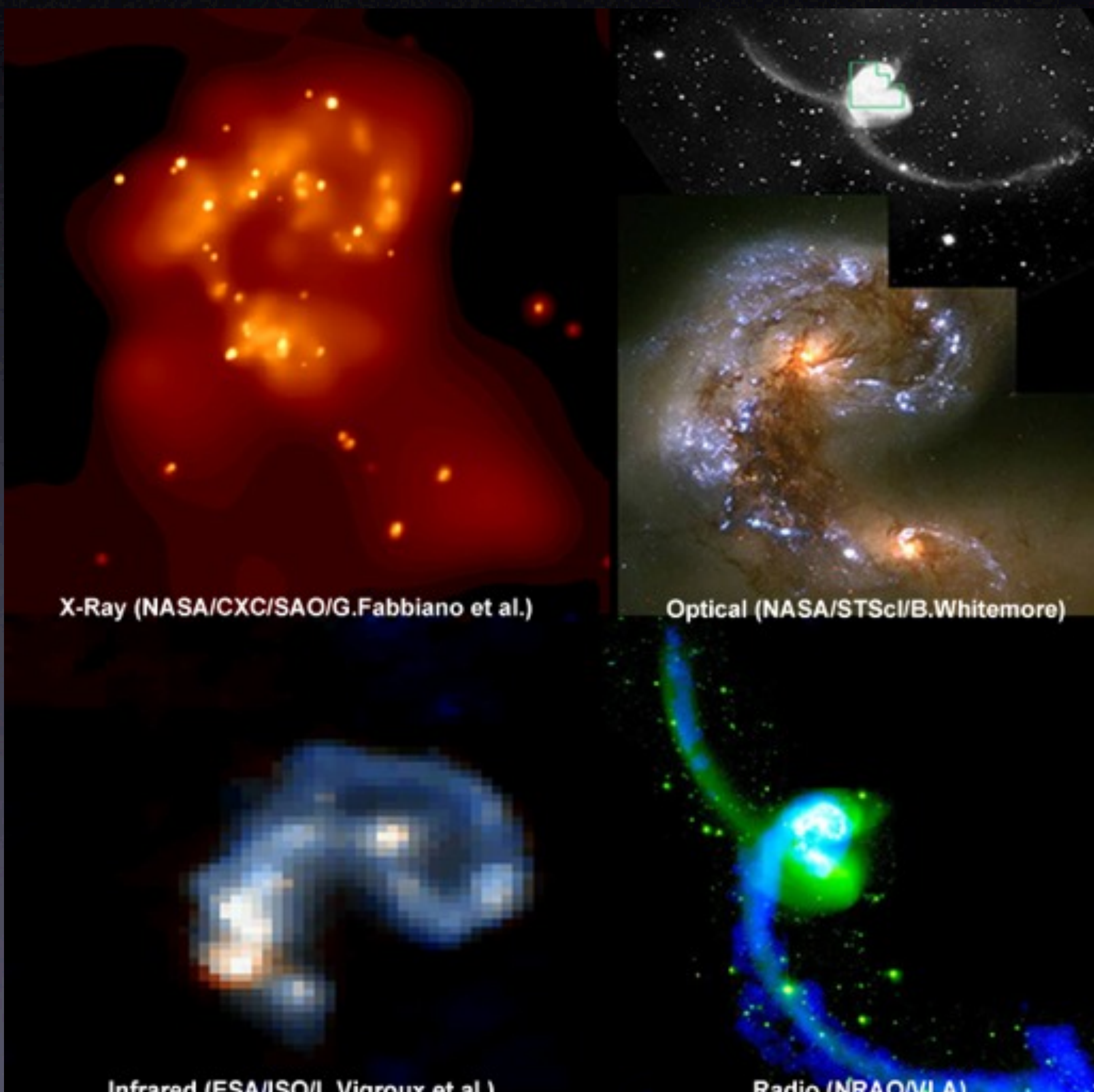
ILCへの期待と
米国の現状

Hitoshi Murayama (IPMU & Berkeley)
将来計画検討小委員会 Jan 23, 2010

Multiple Wavebands in Astronomy

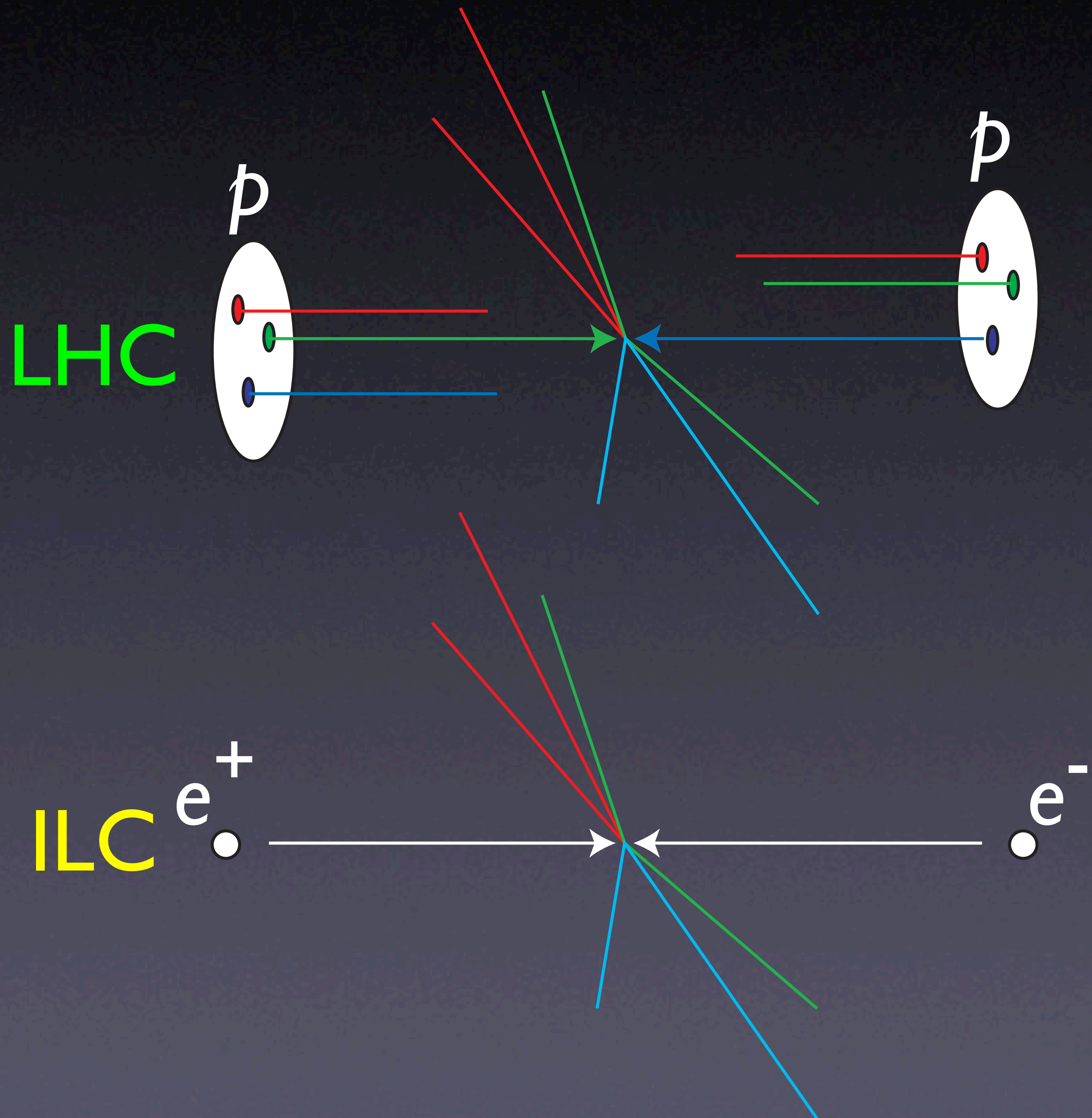


Telescopes vs Accelerators

aim	need	telescopes	accelerators
probe deeper	better resolution	better mirrors, CCD	higher energy
better image	better exposure	larger telescopes, more time	more powerful beams (luminosity)
full understanding	multiple probes	visible, radio, X-ray, infrared, UV, gamma	protons, electrons, neutrinos

ILC

- elementary particles
- well-defined energy, angular momentum
- uses its full energy
- can produce particles democratically
- can capture nearly full information



Obstruction to Cosmology

S. Weinberg "Gravitation and Cosmology" (1972)

15.11 The Very Early Universe

If we look back into the first 0.0001 sec of cosmic history, we encounter theoretical problems. At such temperatures copious number of strongly interacting particles will be in a state of continual mutual interaction and cannot reasonably be expected to obey any simple equation of state.

There are two extremely different simple models that reflect two divergent views of the nature of the strongly interacting particles. Neither model can be taken seriously.

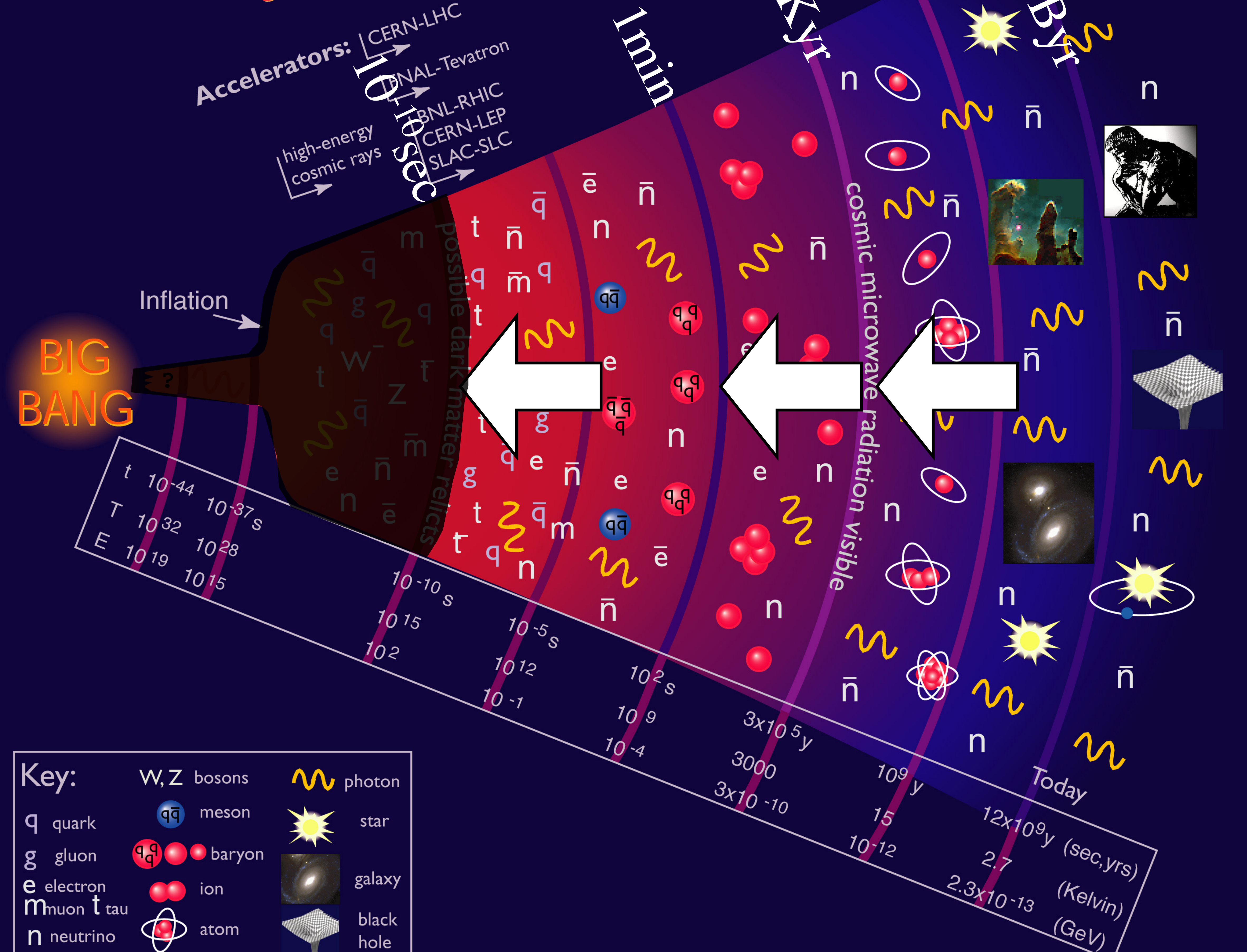
Why I look forward to ILC

My Ph.D. thesis 1991

“Study of the Symmetry Breaking Physics at JLC”

This thesis is not theory!

History of the Universe

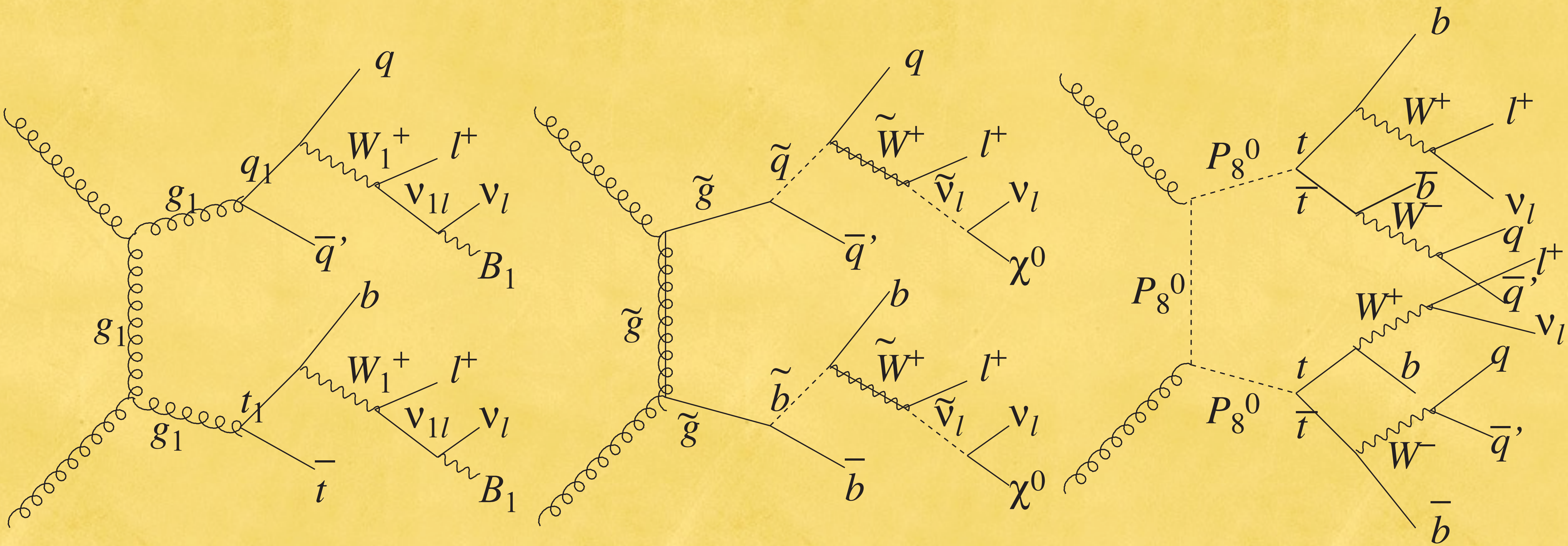


Particle Data Group, LBNL, © 2000. Supported by DOE and NSF

bosonic TC
composite Higgs
TC-TC
hypercolor
supercolor
techni-GIM
extended TC
pseudo NGB
NOT YET THOUGHT OF
NOT YET THOUGHT OF
NOT YET THOUGHT OF
effective SUSY
SUSY
NMSSM
NNMSSM
MSSM +νR
axigluon
sterile ν
heavy Majorana
6th gen
5th gen
4th gen
lepto quark
vector-like family
fractionally charged
milli-charged
mono-pole
X Y
S,T,U
shadow matter
mirror symmetry
triplet Higgs
doubly charged Higgs
Type I
Type II
general 2HDSM
spontaneous CP
superweak
milli-weak
Weinberg's 3HD
Majoron
axion
familon
NGB
saxion
axino
quintessence
k-essence
composite W,Z
contact int.
string
heterotic
matrix M
IIB
IIA
F
I
N=2
N=4
N=8
Extra dim
worm-hole

New physics looks alike

missing E_T, multiple jets, *b*-jets, (like-sign) di-leptons



UED
spin 1

SUSY
spin 1/2

technicolor
spin 0

+little Higgs with T-parity, warped ED with Z_3 baryon

The New York Times

July 23, 2011

The Other Half of the World Discovered

Geneva, Switzerland

As an example, supersymmetry

"New-York Times level" confidence

still a long way to

"Halliday-Resnick" level confidence

"We have learned that all particles we observe have unique partners of different spin and statistics, called superpartners, that make our theory of elementary particles valid to small distances."

Reconstruct Lagrangian from data

- Specify the fields
  - mass
  - spin:Klein-Gordon, Dirac, Majorana, gauge
  - SU(3)xSU(2)xU(1) quantum numbers
  - mixing of states
- Specify their interactions
  - gauge interactions
  - Yukawa couplings
  - trilinear and quartic scalar couplings

precision SUSY mea

- SUSY spectroscop
- kinematic fits, part wave analysis, Dali analysis, etc
- precision mass, BR measurements

Squarks $J=0?$ PDG 2012

The following data are averaged over all light flavors, presumably u, d, s, c with both chiralities. For flavor-tagged data, see listings for Stop and Sbottom. Most results assume minimal supergravity, an untested hypothesis with only five parameters. Alternative interpretation as extra dimensional particles is possible. See KK particle listing.

SQUARK MASS

VALUE (GeV)	DOCUMENT ID	TECN	COMMENT
538±10	**OUR FIT**		**mSUGRA assumptions**
532±11	[1]ABBIENDI 11D	CMS	Missing ET with mSUGRA assumptions
541±14	[2]ADLER 11O	ATLAS	Missing ET with mSUGRA assumptions
• • • We do not use the following data for averages, fits, limits, etc • • •			
652±105	[3]ABBIENDI 11K	CMS	extended mSUGRA with 5 more parameters

[1]ABBIENDI 11D assumes minimal supergravity in the fits to the data of jets and missing energies and set $A_0=0$ and $\tan\beta = 3$. See Fig. 5 of the paper for other choices of A_0 and $\tan\beta$. The result is correlated with the gluino mass M_3. See listing for gluino.

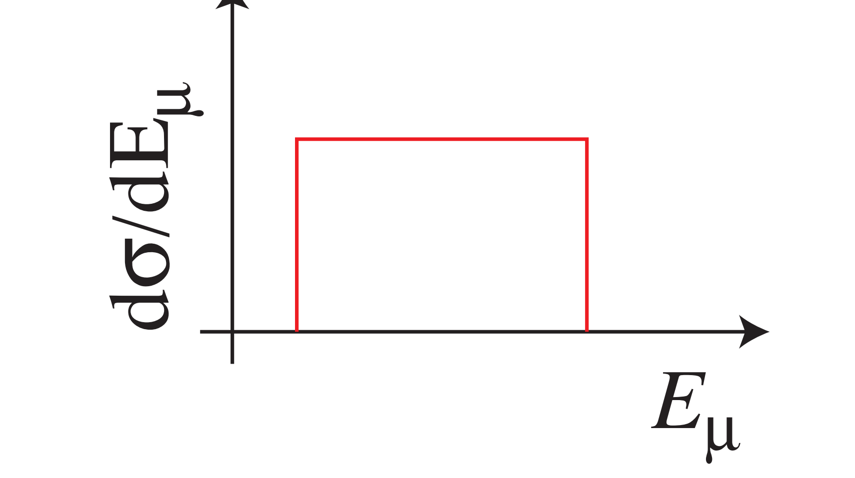
[2]ADLER 11O uses the same set of assumptions as ABBIENDI 11D, but with $\tan\beta = 5$.

[3]ABBIENDI 11K extends minimal supergravity by allowing for different scalar masses-squared for Hu, Hd, 5* and 10 scalars at the GUT scale.

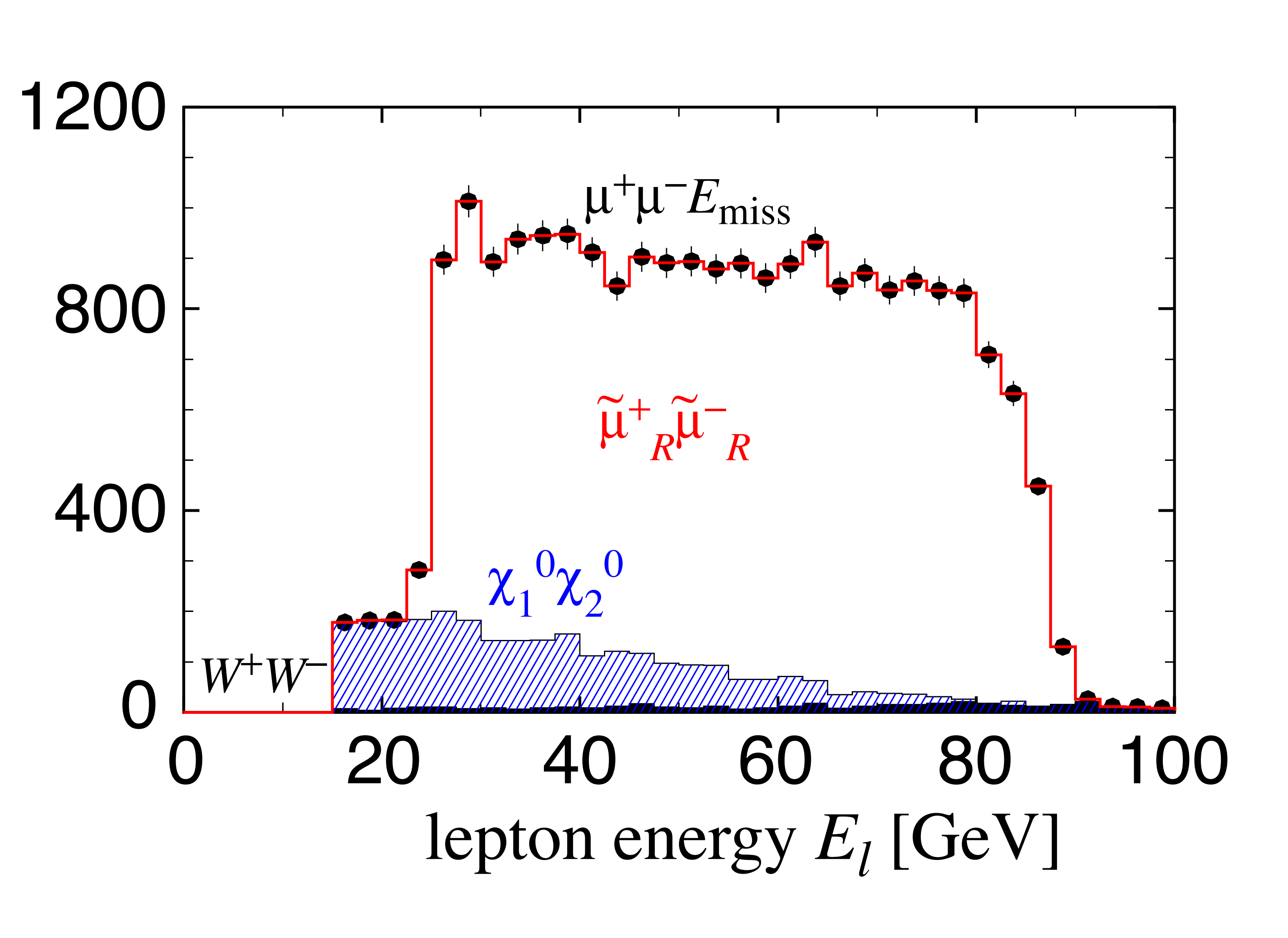
SQUARK DECAY MODES

MODE	BR(%)	DOCUMENT ID	TECN	COMMENT
j+miss	32±5	ABE 10U	ATLAS	
j l+miss	73±10	ABE 10U	ATLAS	lepton universality
j e+miss	22±8	ABE 10U	ATLAS	
j μ +miss	25±7	ABE 10U	ATLAS	
q χ^+	seen	ABE 10U	ATLAS	

$\tilde{\mu} \rightarrow \mu \chi^0$



$$E_\mu = \frac{m_{\tilde{\mu}}}{2}\left(1 - \frac{m^2_{\chi^0}}{m^2_{\tilde{\mu}}}\right)\gamma_{\tilde{\mu}}(1 + \beta_{\tilde{\mu}}\cos\hat{\theta})$$



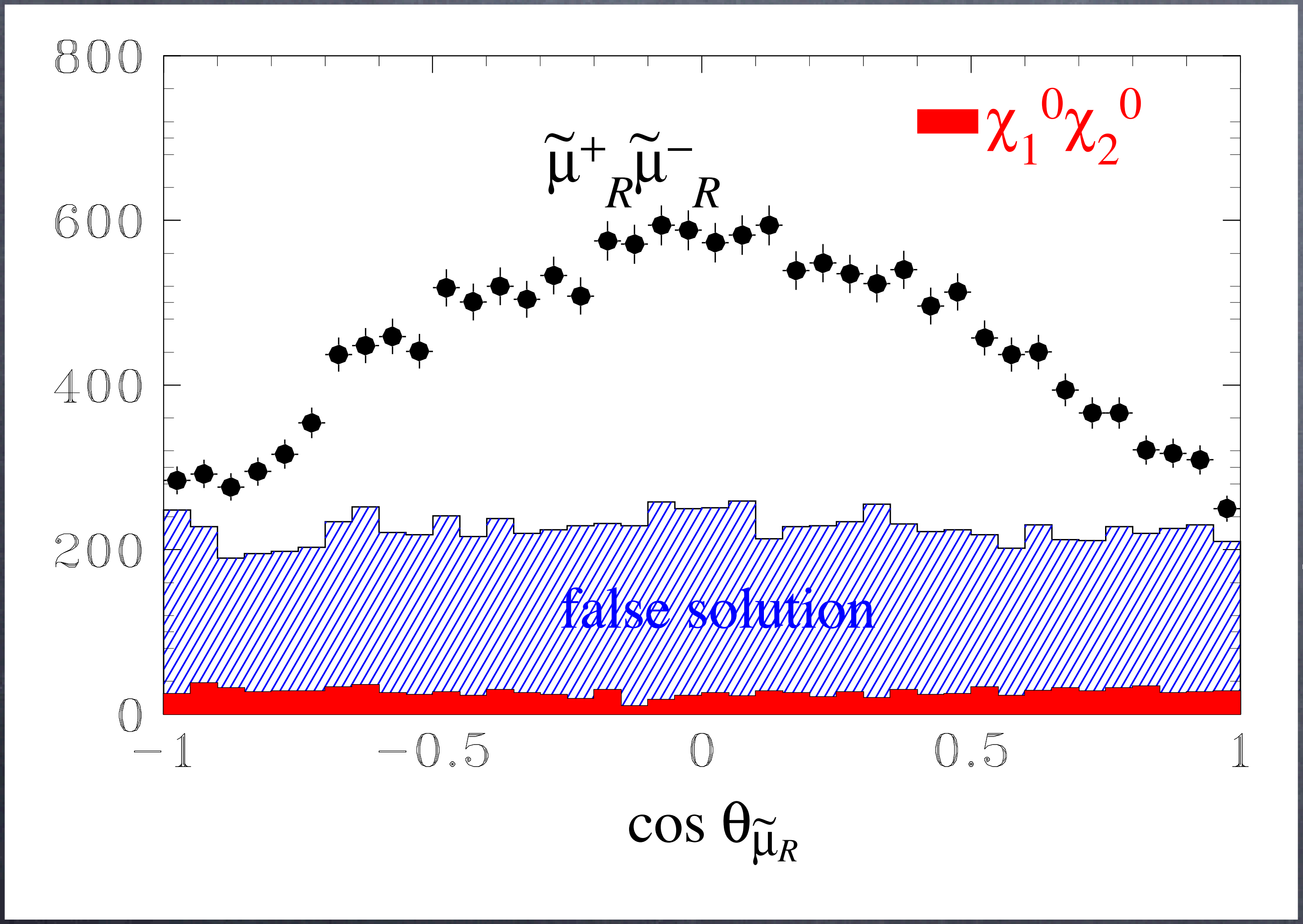
$$\frac{d\sigma}{dE_\mu} \propto \frac{d\sigma}{d\cos\hat{\theta}} = \text{constant}$$

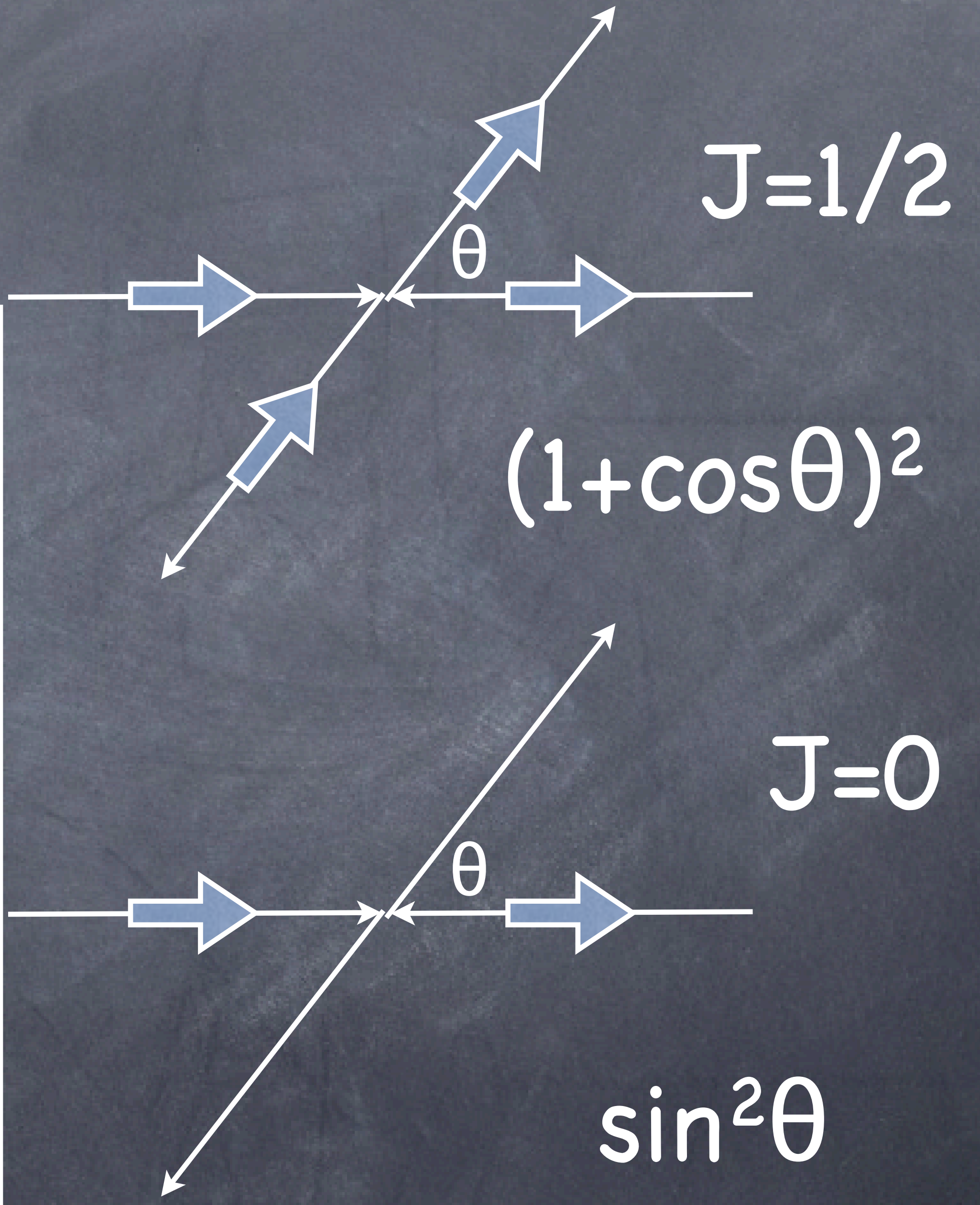
- fit to the kinetic distribution

$m_{\tilde{\mu}} = 132.0 \pm 0.3$ GeV

$m_{\tilde{\chi}^0} = 71.9 \pm 0.1$ GeV

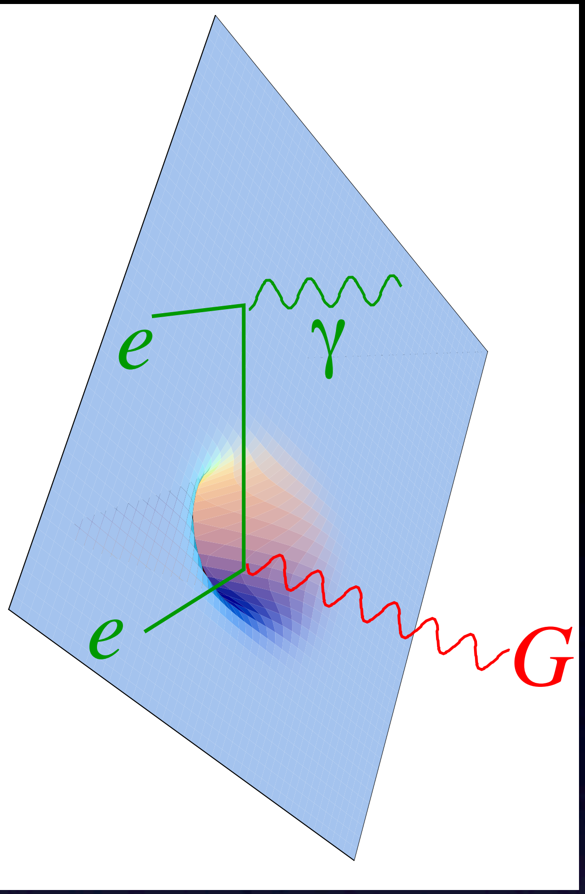
Smuon has spin 0

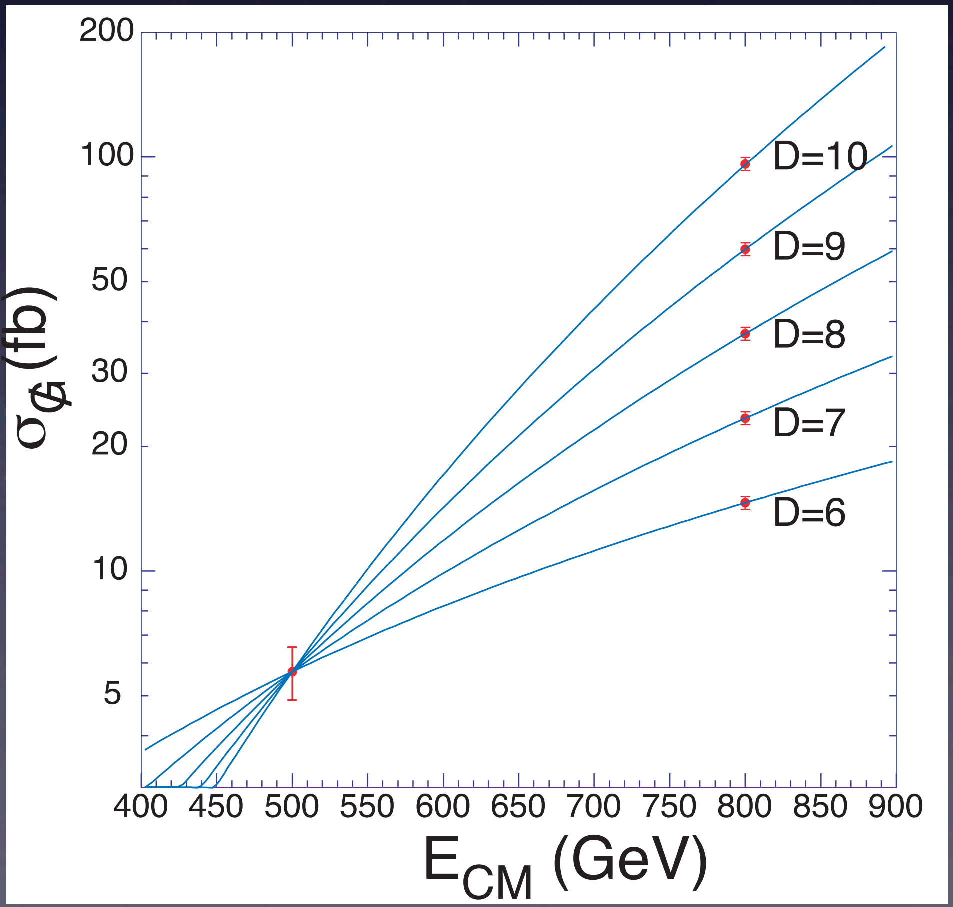


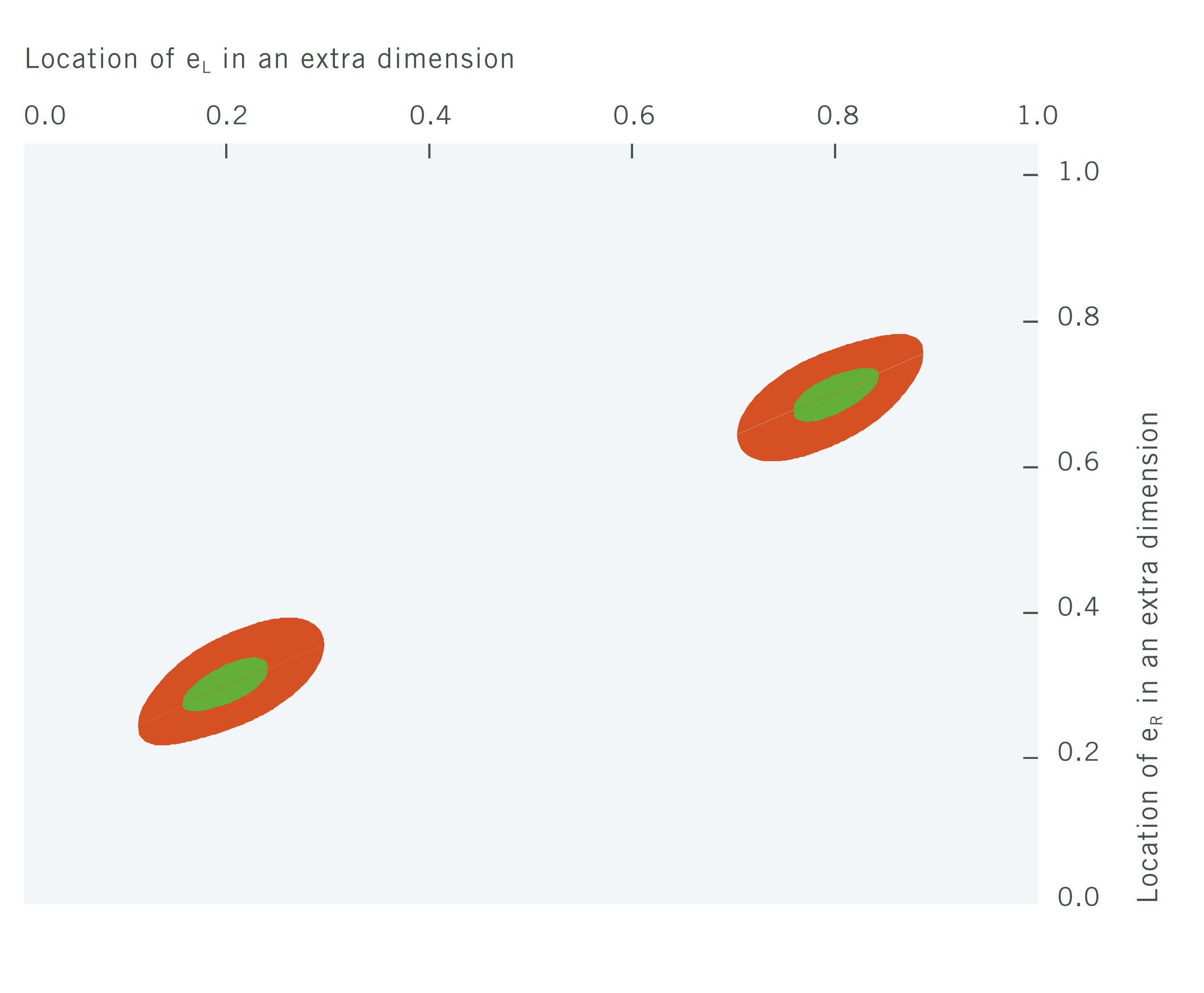


Extra D

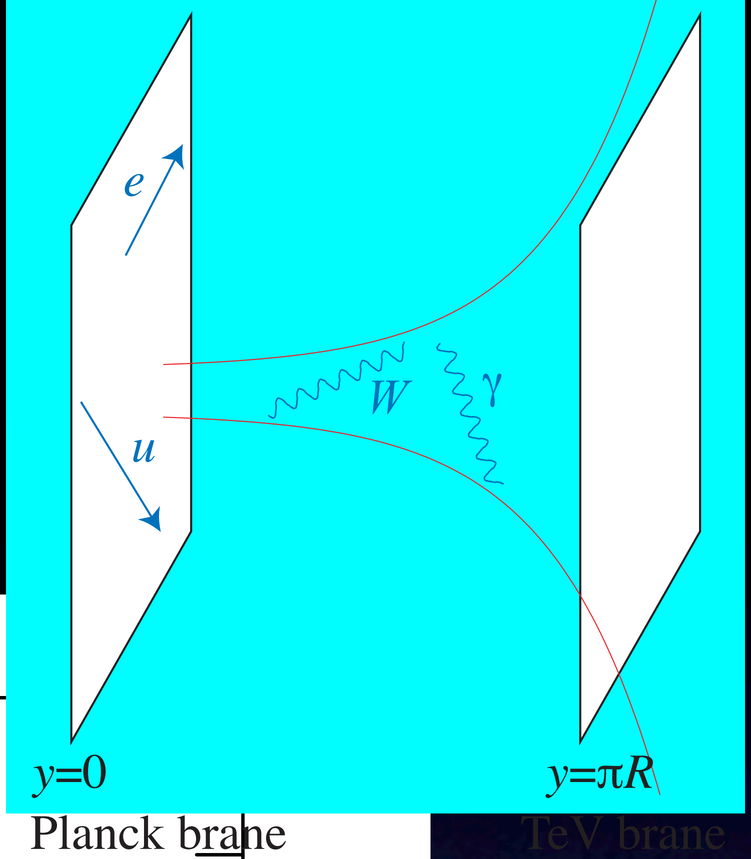
- measure the number of dimensions
- location of the wave functions

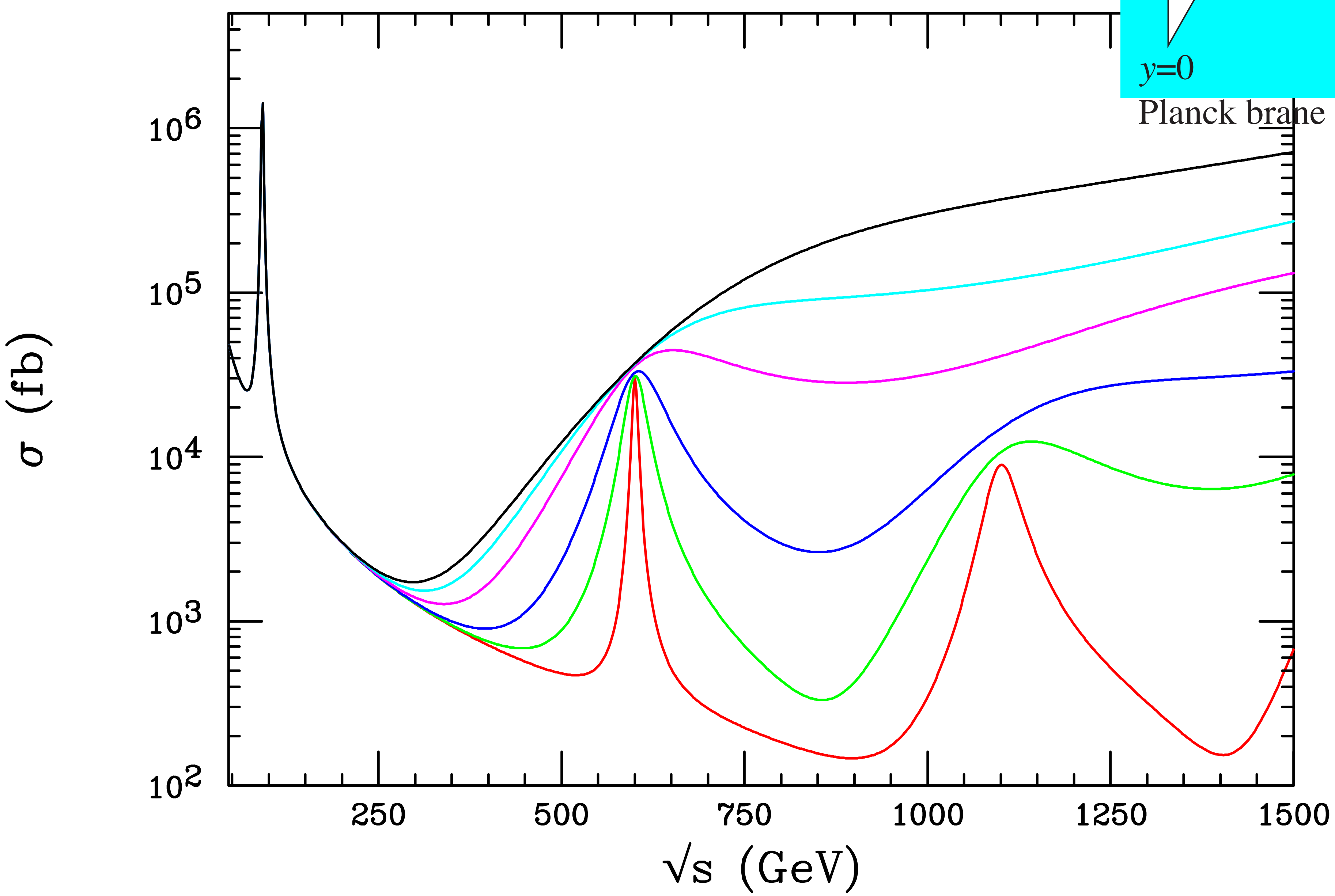






warped extra D
measure the "shape"



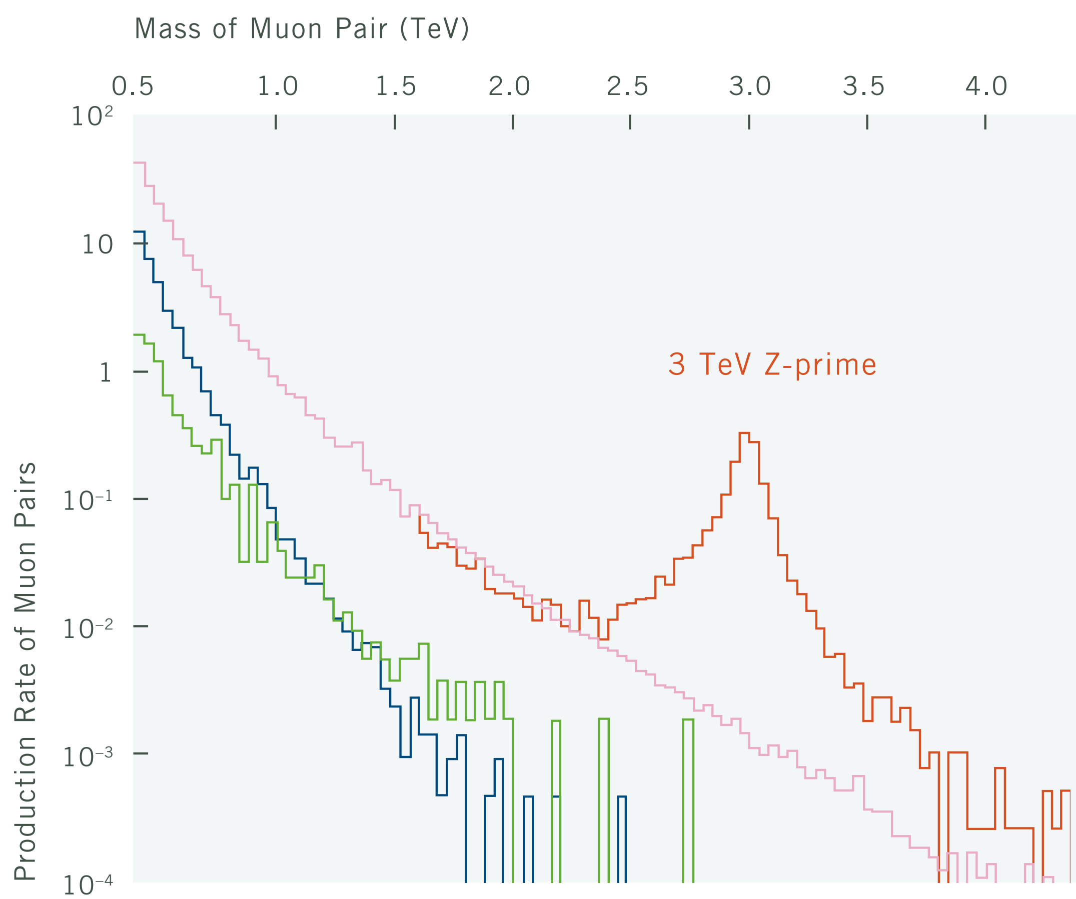


$e^+e^- \rightarrow \mu^+\mu^-$ for various curvatures of 5th D

Geometry

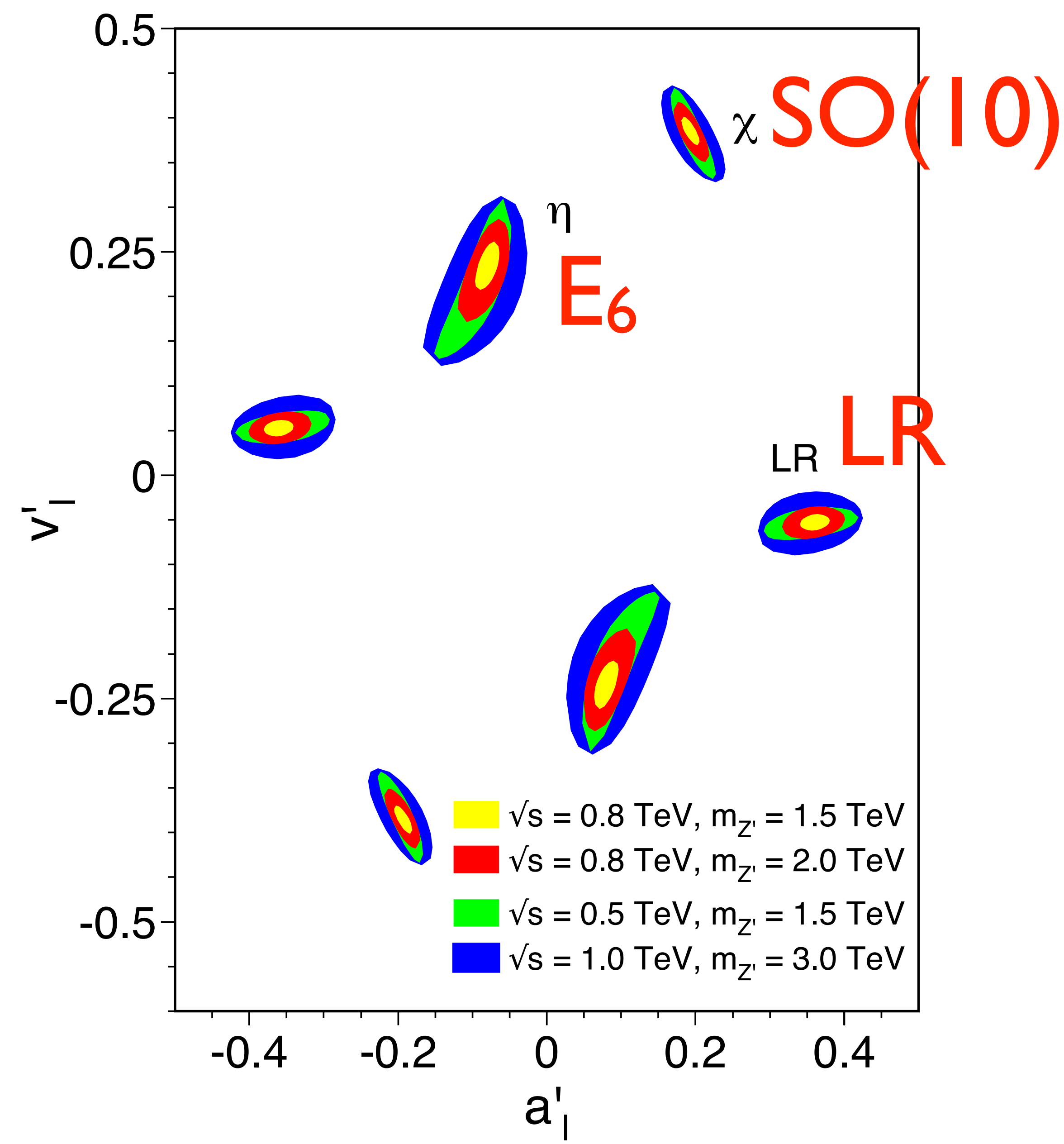
- Mathematics: the complete set of harmonic functions ⇔ geometry
- Physics: harmonic functions = KK modes
- especially low-lying modes more sensitive to topology and shape of space
- We can in principle reconstruct the geometry from KK spectroscopy

New force: Z′



~1/2 event/bin/fb^{-1}

What kind of force?



Einstein's Telescope

- With both LHC and ILC, we hope to see way beyond the energy scale we can probe directly, *i.e.* GUT and string scales

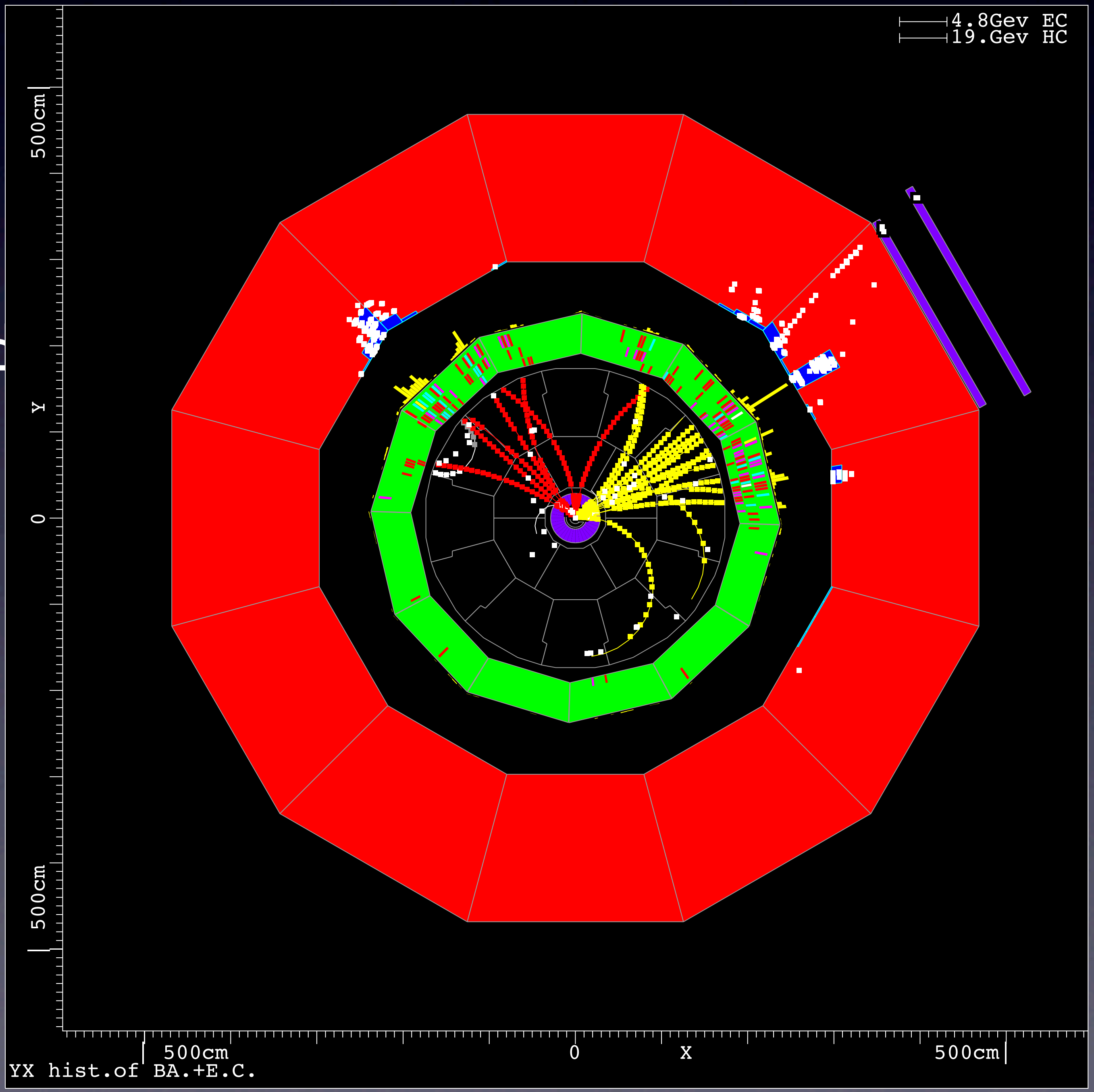
Producing Dark Matter in the laboratory

- Collision of high-energy particles mimic Big Bang
- We hope to create Dark Matter particles in the laboratory
- Look for events where energy and momenta are unbalanced

"missing energy" E_{miss}

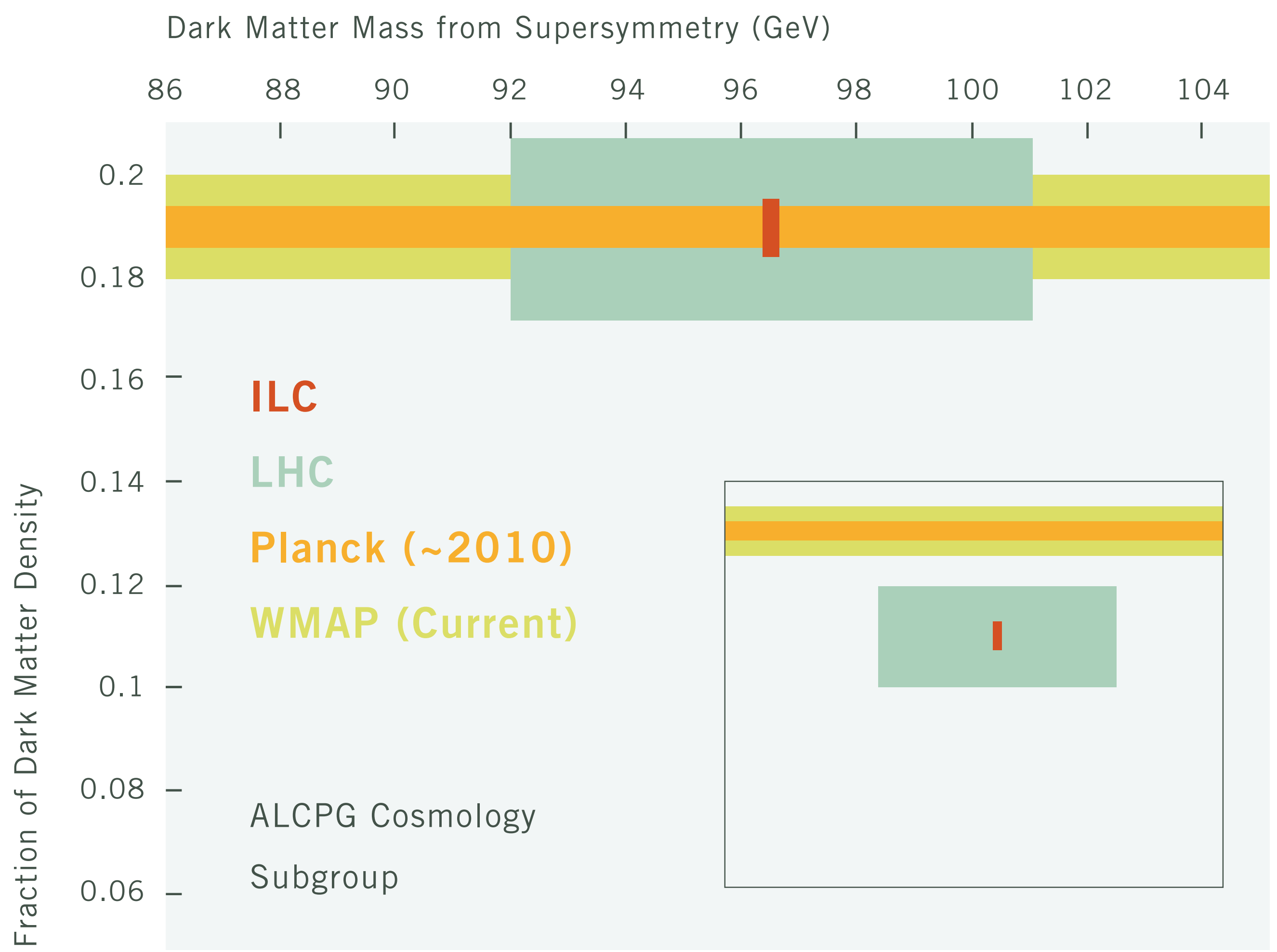
- Something is escaping the detector
- electrically neutral, weakly interacting

⇒Dark Matter!?

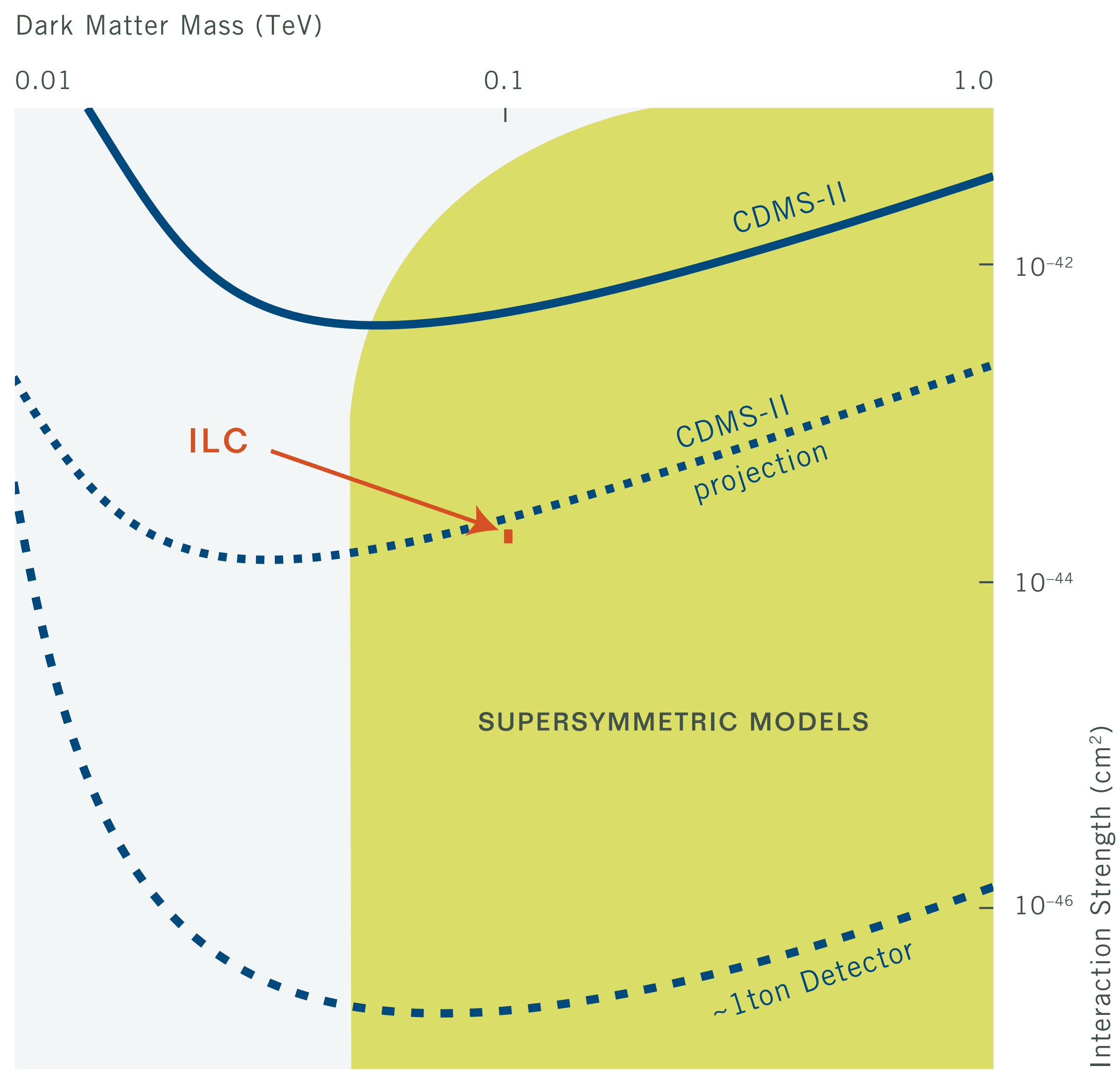


Dark Matter

abundance



direct cross section



Stau coanihillation

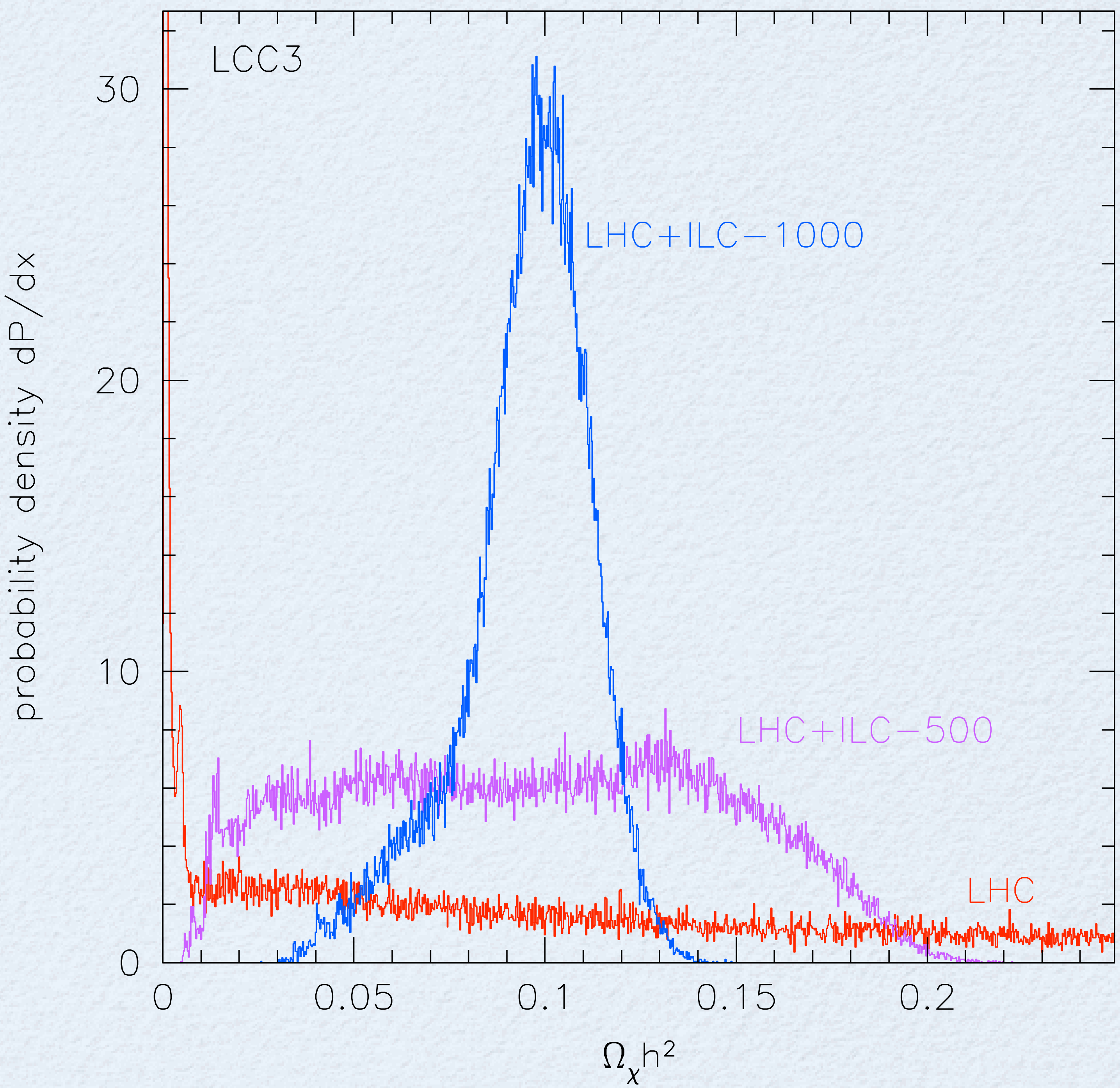
LHC data are not sensitve to mass difference betewnn LSP and stau

ILC@1TeV give important imformation

δΩ

167% (LHC@300fb^-1)

18% (ILC@500fb^-1)



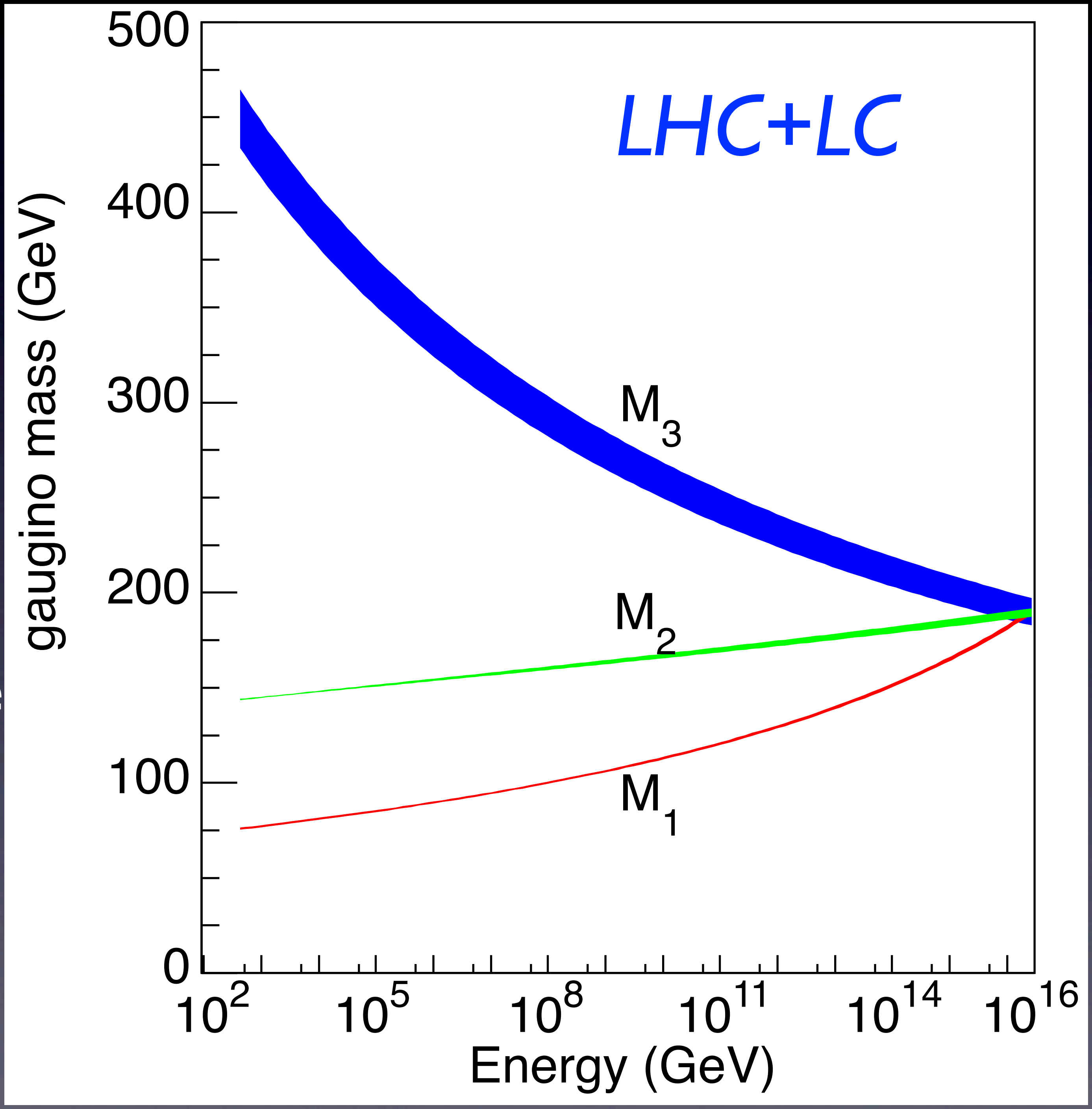
Shimizu, taken from E. Baltz et al

Superpartners as probe

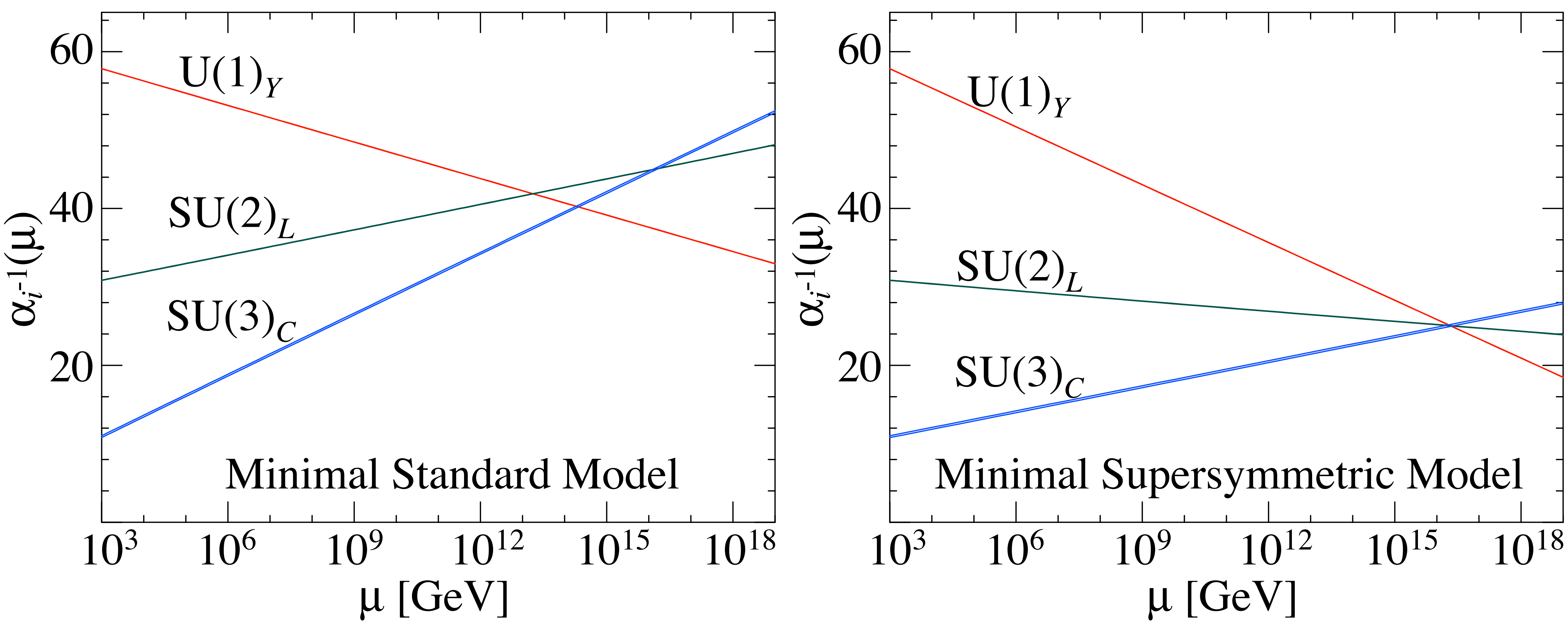
- Most exciting thing about superpartners beyond existence:

They carry information of small-distance physics to something we can measure

"Are forces unified?"



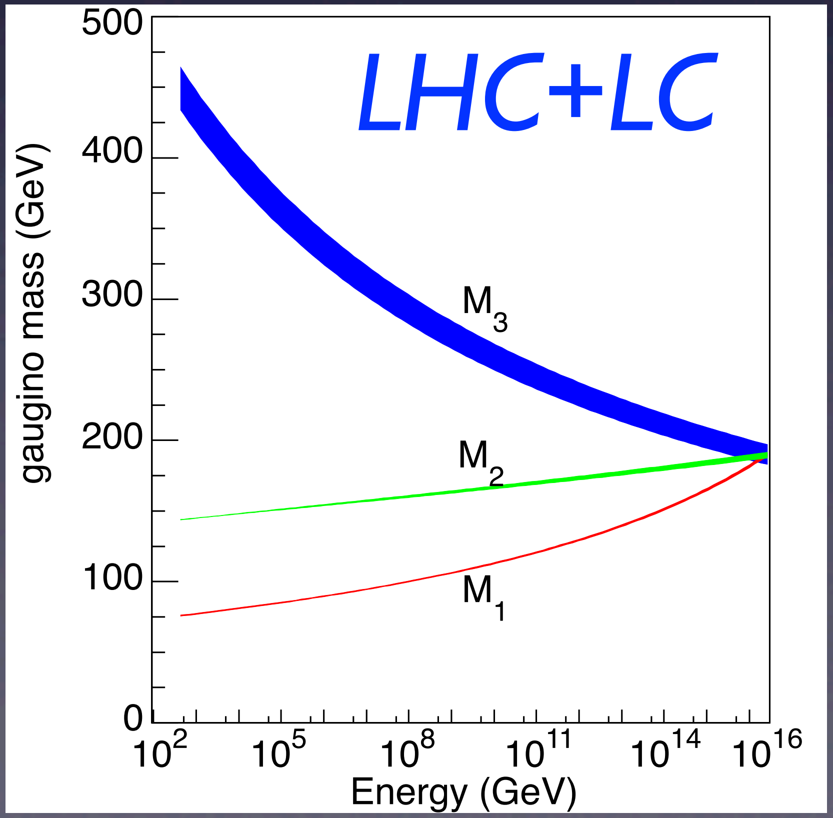
cf. gauge coupling unification

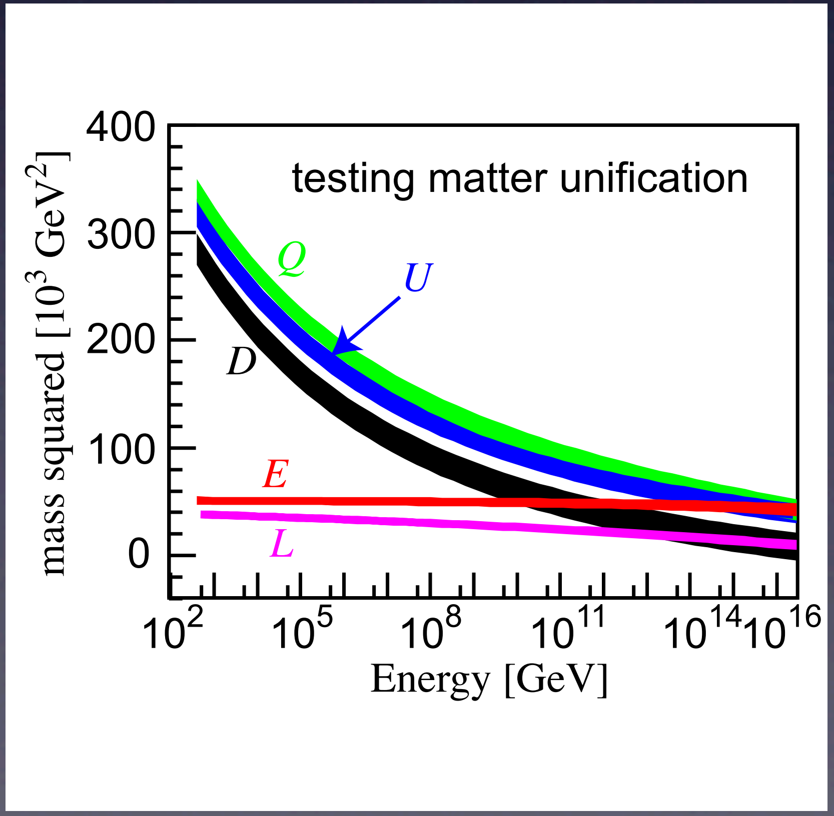


Gaugino and scalars

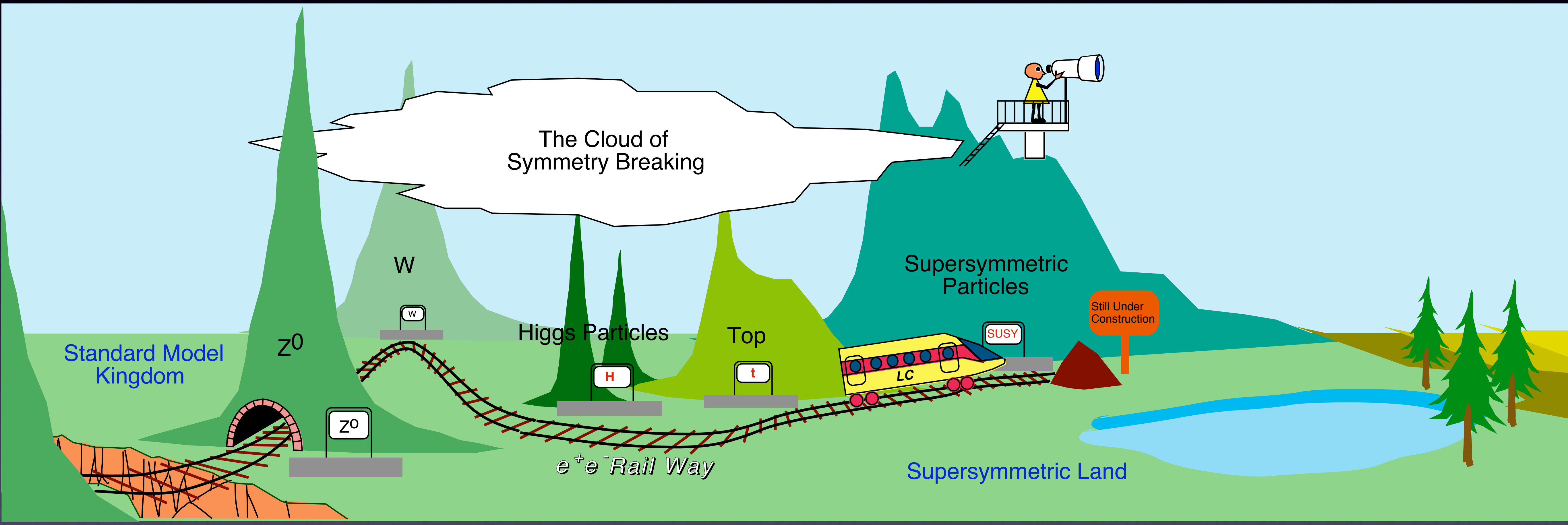
- Gaugino masses test unification itself independent of intermediate scales and extra complete SU(5) multiplets, also GMSB
- Scalar masses test beta functions at all scales, depend on the particle content

(Kawamura, HM, Yamaguchi)





X


The Cloud of
Symmetry Breaking
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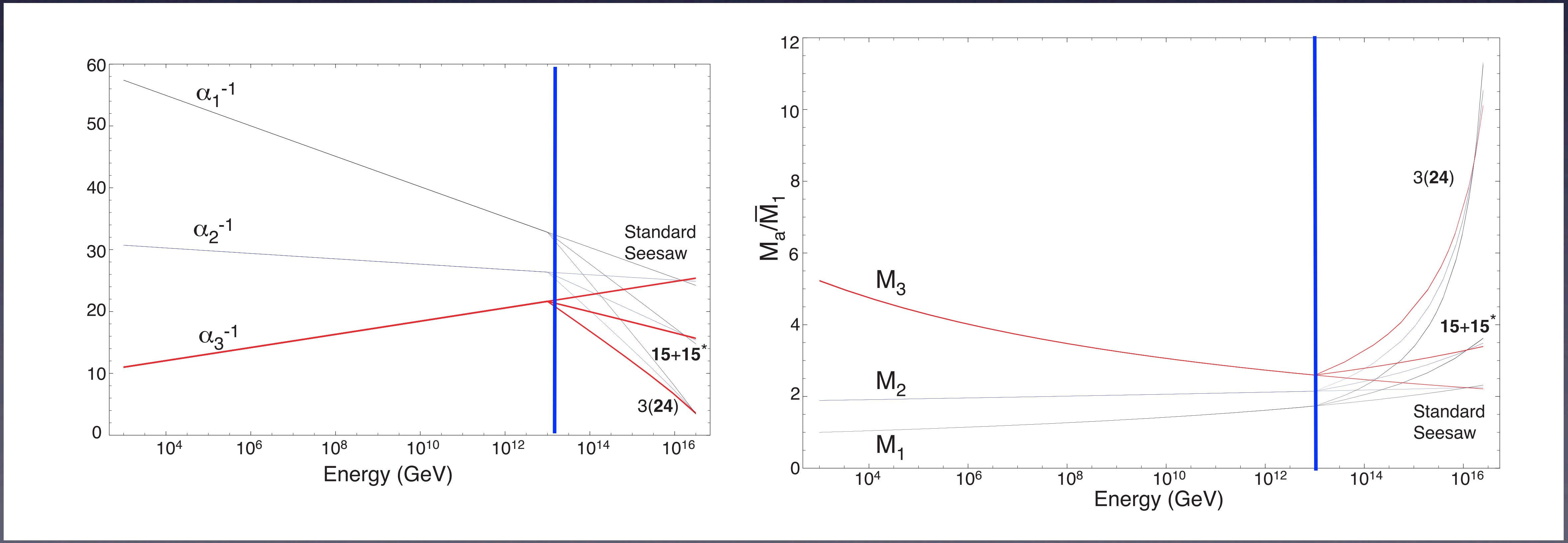
LC
Still Under
Construction
e+e- Rail Way
Supersymmetric Land

The Cloud of Symmetry Breaking
W
Z0
Standard Model Kingdom
Higgs Particles
Top
Supersymmetric Particles
Still Under Construction
SUSY
LC
e+e- Rail Way
Supersymmetric Land
Grand Desert
Big Bang
Grand Unified Land
Planck Kingdom

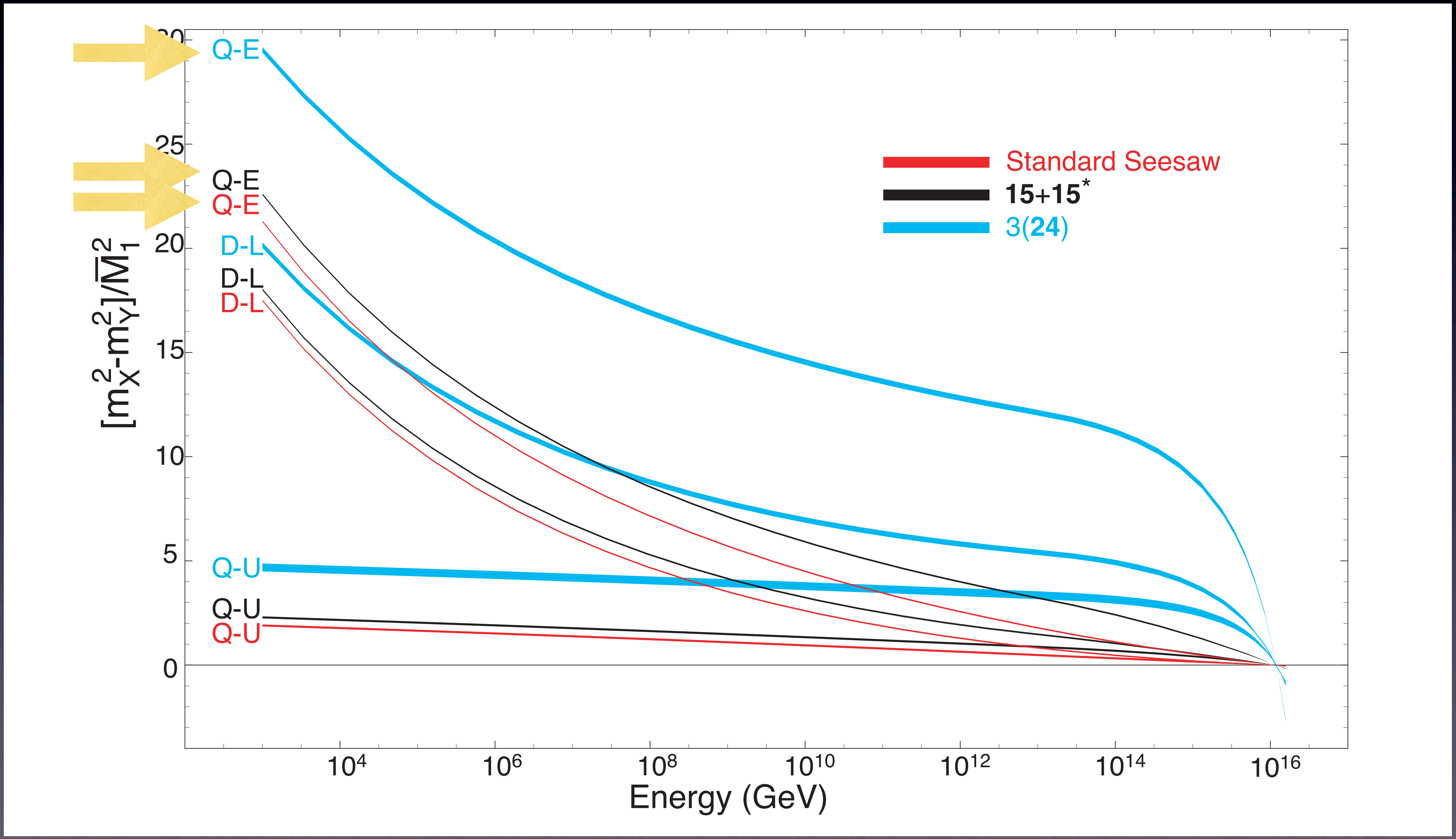
Need "New Physics" $\Lambda < 10^{14}$GeV

- Now that there must be Majorana operator at $\Lambda <$ a few $\times 10^{14}$GeV $< M_{GUT}$, we need new particles below M_{GUT}

$$\mathcal{L}_5 = (LH)(LH) \rightarrow \frac{1}{\Lambda}(L\langle H\rangle)(L\langle H\rangle) = m_\nu \nu\nu$$



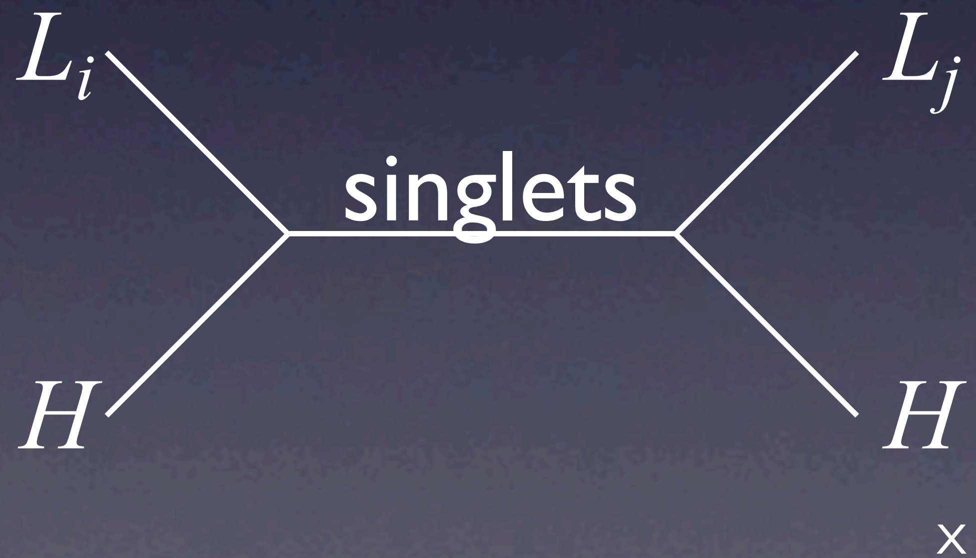
scalar masses tell them apart



No new gauge non-singlets below M_{GUT}

$$\mathcal{L}_5 = (LH)(LH) \rightarrow \frac{1}{\Lambda}(L\langle H\rangle)(L\langle H\rangle) = m_\nu \nu\nu$$

- If data come out this way, only possibility is gauge singlets if M<10^{14}GeV
- Nothing but the right-handed neutrinos



Scenarios

Can’t ignore LHC

- There is no way to make a case for ILC without results from LHC any more
- depending on what we see at LHC, different scenarios for ILC

Early ILC

- LHC turns on 2009
- find $Z' \to \mu^+\mu^-$ in 2010, $m_{Z'}$=800 GeV
- know energy need for ILC to hit Z′ resonance
- ILC decision ~2012
- ILC start ~2020

Normal ILC

- LHC finds new physics (missing E_T, multi-jet multi-leptons, etc) ~2011
- figures out the mass scale ~2013 with some uncertainty:

  e.g. new particle m=300±100 GeV
- find Higgs m_H=130 GeV ~2015
- ILC starts at 270 GeV ~ 2025
- eventually goes up in energy

Late ILC

- LHC discovers Higgs m_H=130 GeV ~2015
- some sign of new physics, not clear how to interpret, keeps running
- LHC luminosity upgrade ~2016
- ILC decision ~2017
- ILC start ~2025

No ILC?

- LHC finds m_H=210 GeV in $H \to ZZ$ ~ 2011, more-or-less consistent with precision EW
- spin parity determination, g_{HZZ}, g_{HWW} couplings measured ~10% by 2012
- keeps running, no sign of new physics 2020
- Anthropic???
- big debate in the community if ILC needed
- ILC decision >2020
- ILC start >2030

?????

- LHC doesn't find Higgs, nothing else till 2015
- luminosity upgrade ~2016
- still nothing ~2020, 3σ signal of strong WW scattering at high energies
- maybe scientifically most interesting!
- build GigaZ to redo precision EW?
- maybe missed Higgs: invisible? hadrophilic?
- partially Higgs, partially Higgsless?
- "Clear case" for ILC
- But would politicians buy into it?

Situation in the US

Bad!

HEP Community

- I buy the need for an e^+e^- machine *iff*
  - LHC finds new physics
  - it is within the reach of ILC
  - it is not too expensive
  - it doesn't compete with my pet project

Perception in the US

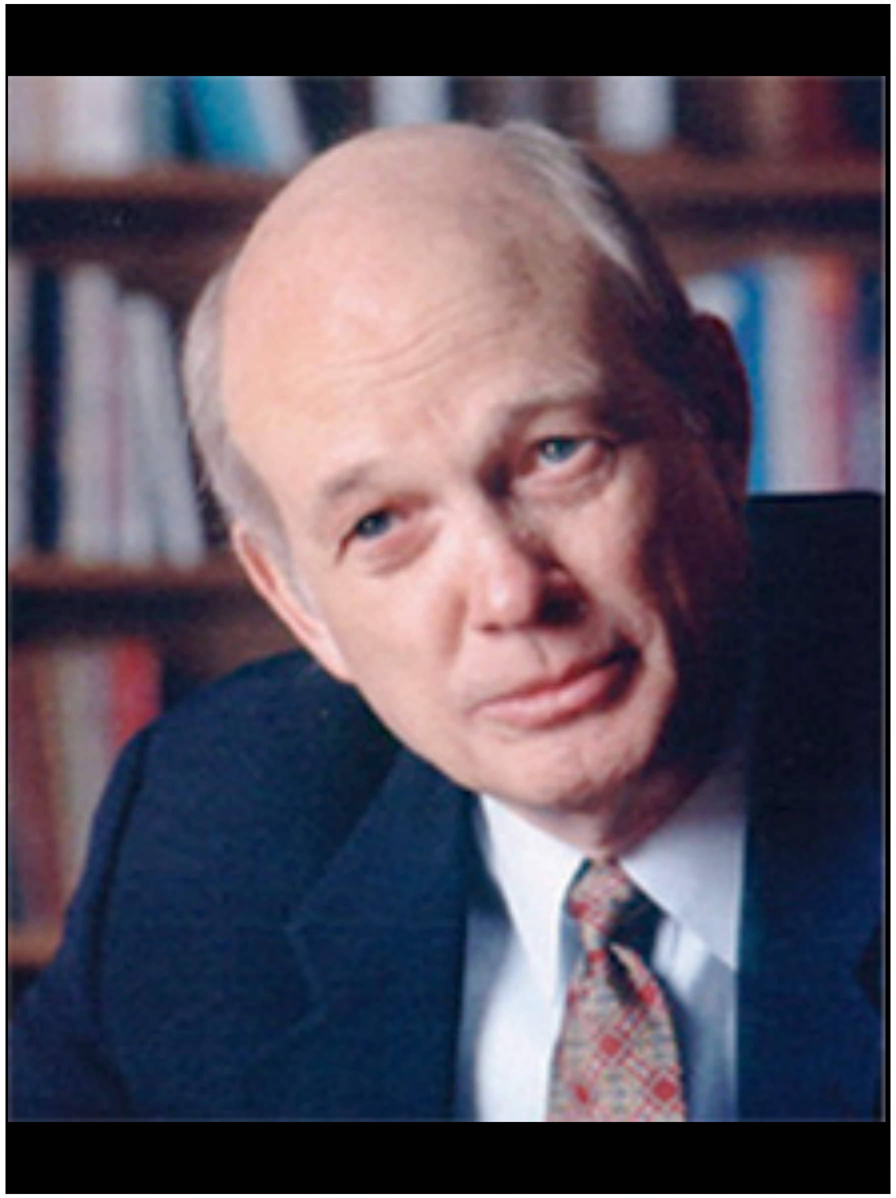
- LHC ~ 2010–2014
- LHC upgrade ~ 2016–2020
- ILC decision > 2020?
- ILC start > 2030?
- or ∞?

Steven Chu

Chu, a firm believer in the dangers of climate change, will try to fulfill Obama's promise to create millions of green collar jobs, develop alternative energy options and make the nation more energy independent. (Time)

High Energy Physics

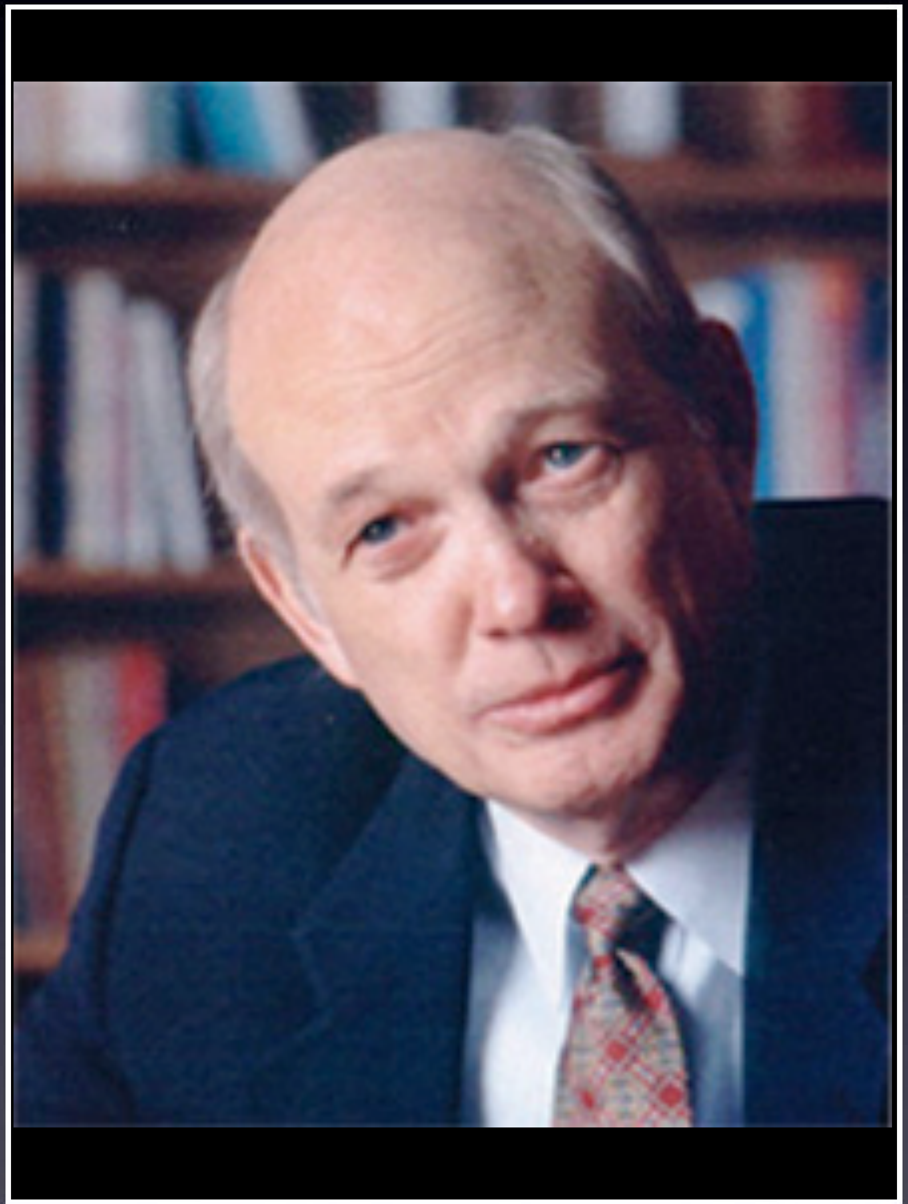
"*I like the idea of a little competition*" Brinkman told the panel, referring to Fermilab's Tevatron and the Large Hadron Collider. Approximately 1,000 U.S. scientists work at the LHC. About the LHC, he commented: "*hopefully it will be an exciting time.*" "*We want to keep alive high energy experimentation in the U.S., but need continued strong justification*" he said, adding the science case made to Congress



William Brinkman
Director, Office of Science

ILC

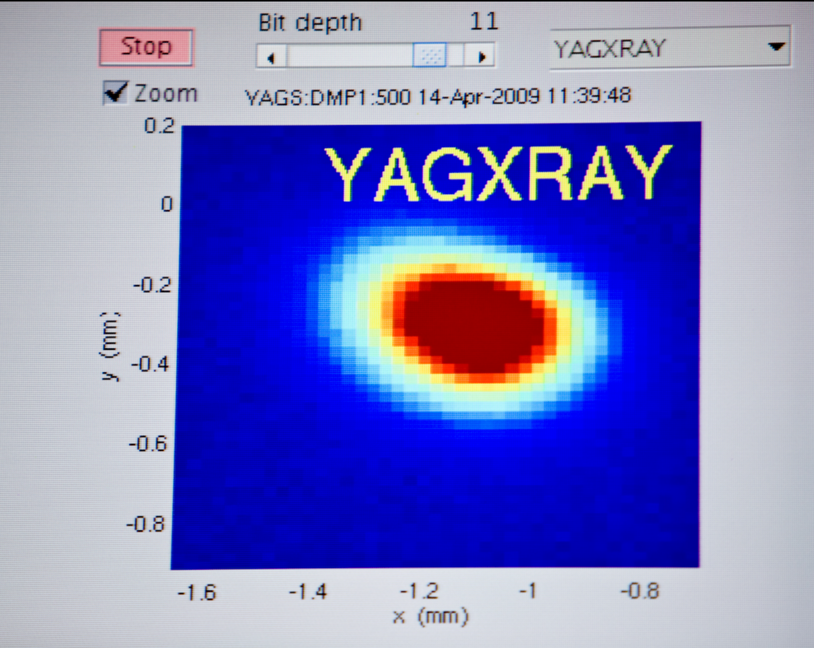
Responding to a question from a HEPAP member about the proposed International Linear Collider, now estimated to cost $20-$25 billion, Brinkman said "*In my opinion, the price pushes it way out . . . onto the back burner.*" Kovar said the decision that was to have been made in FY 2012 about the ILC will



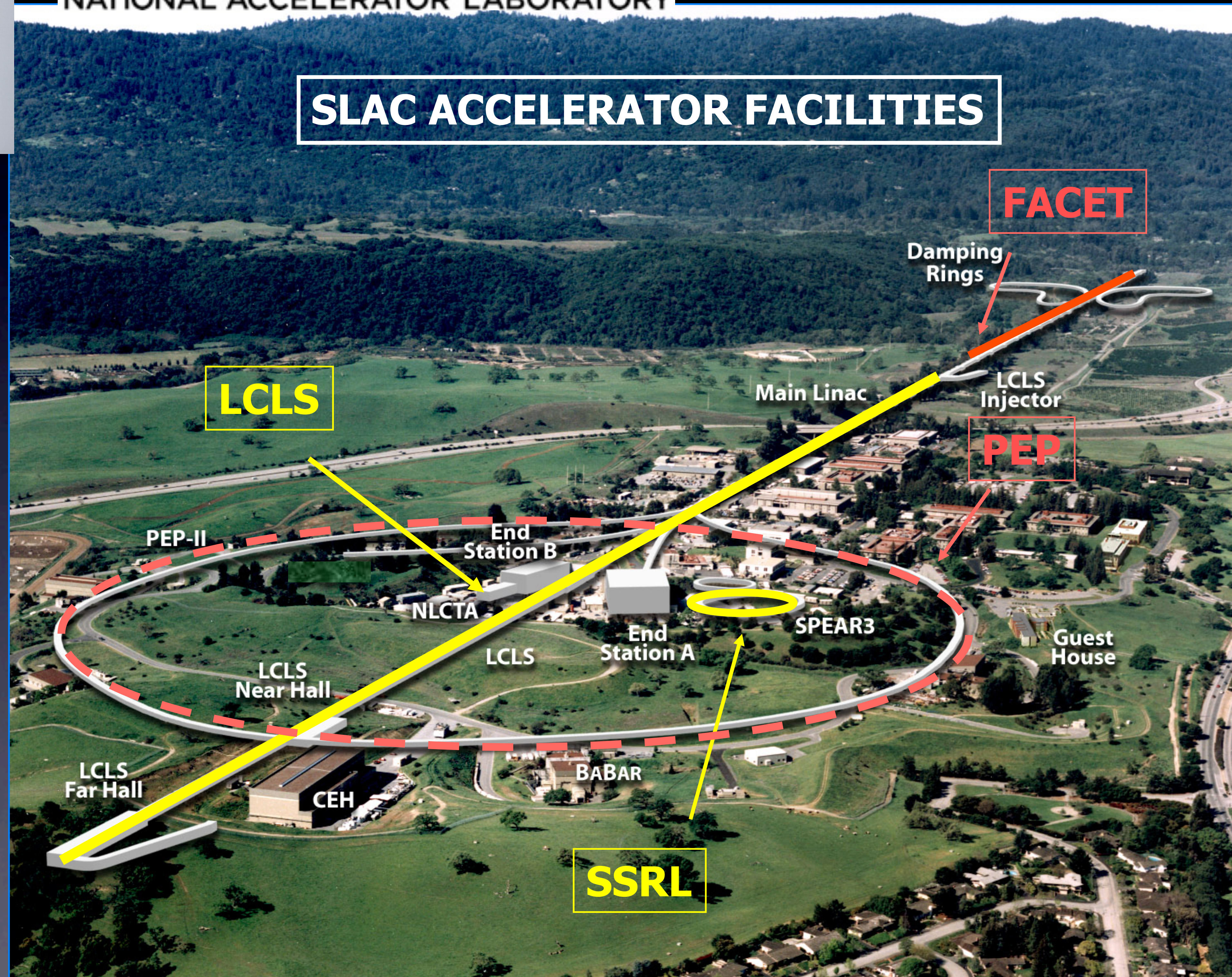
William Brinkman
Director, Office of Science

Why $20-25B?

- GDE: ~$6.7 billion ILCU
- Common understanding in the community: "escalation"
- US budget needs to include "escalation" to account for inflation 4-5%/year
- 5%: ×1.63 in 10 years, ×2.65 in 20 years
- without any change in actual cost, the number looks bigger



SLAC
NATIONAL ACCELERATOR LABORATORY



- HEP is dwindling down
- main focus: LCLS
- FACET received stimulus money

Fermilab

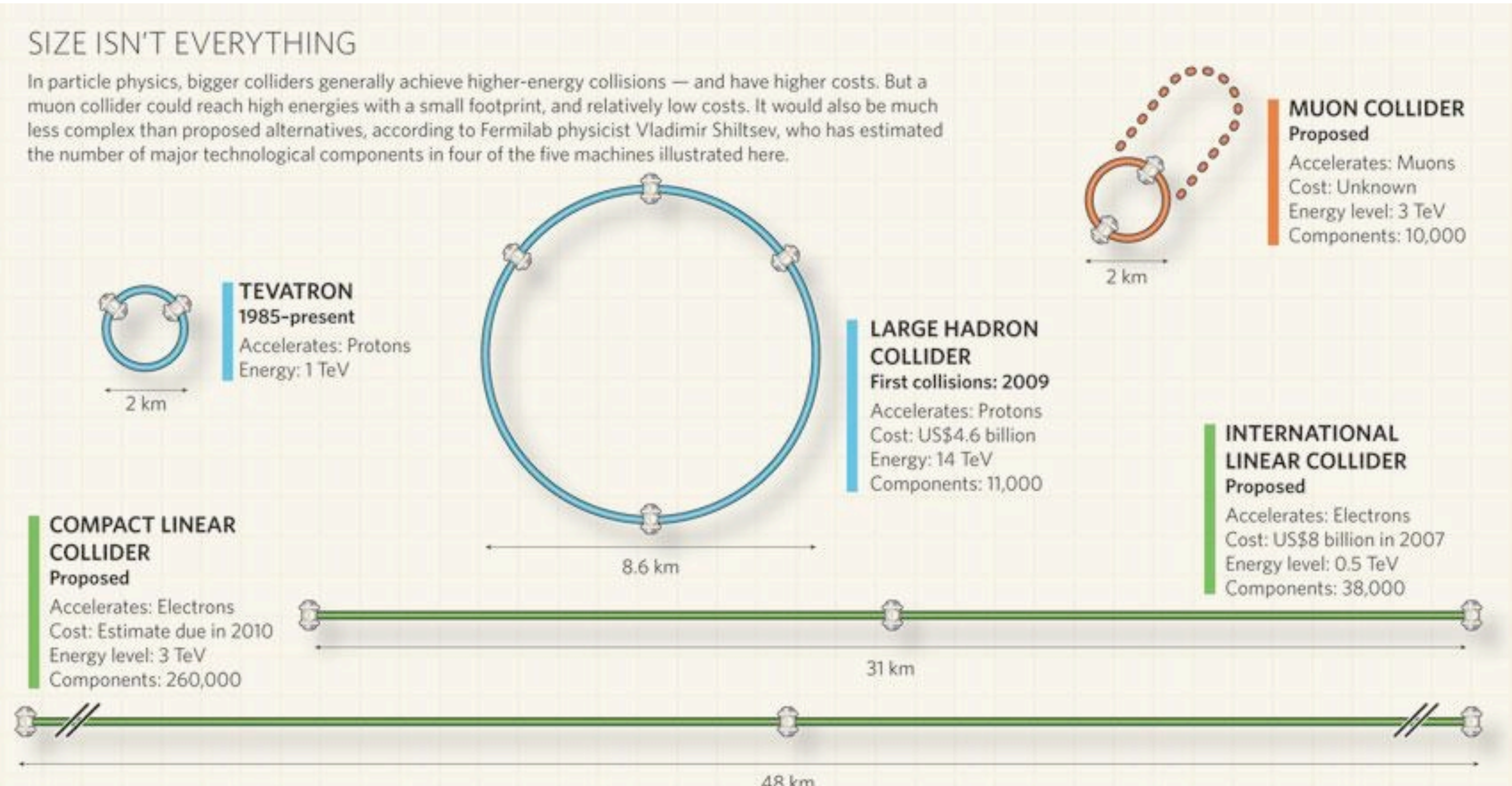
- *The only lab with HEP accelerator*
- Fermilab was once bidding to host ILC
- Now they are focused on
  - continuing Tevatron into FY2011
  - NOνA (stimulus money)
  - Project-X (à la J-PARC)
  - muon collider

naturenews

Published online 18 November 2009 | *Nature* **462**, 260-261 (2009) | doi:10.1038/462260a

News

Muon collider gains momentum



Conclusion

- I don’t have a conclusion