東京大学
THE UNIVERSITY OF TOKYO

TODIAS
東京大学国際高等研究所
TODAI INSTITUTES FOR ADVANCED STUDY

KAVLI IPMU
INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

Physics at ILC and its status in Japan

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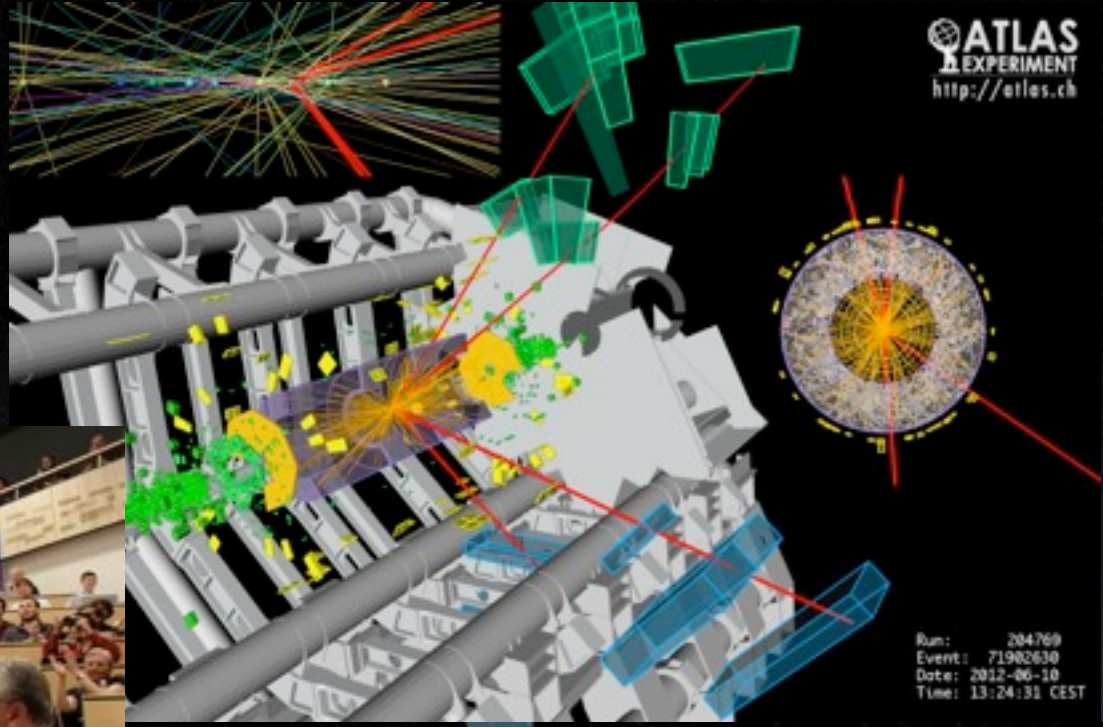
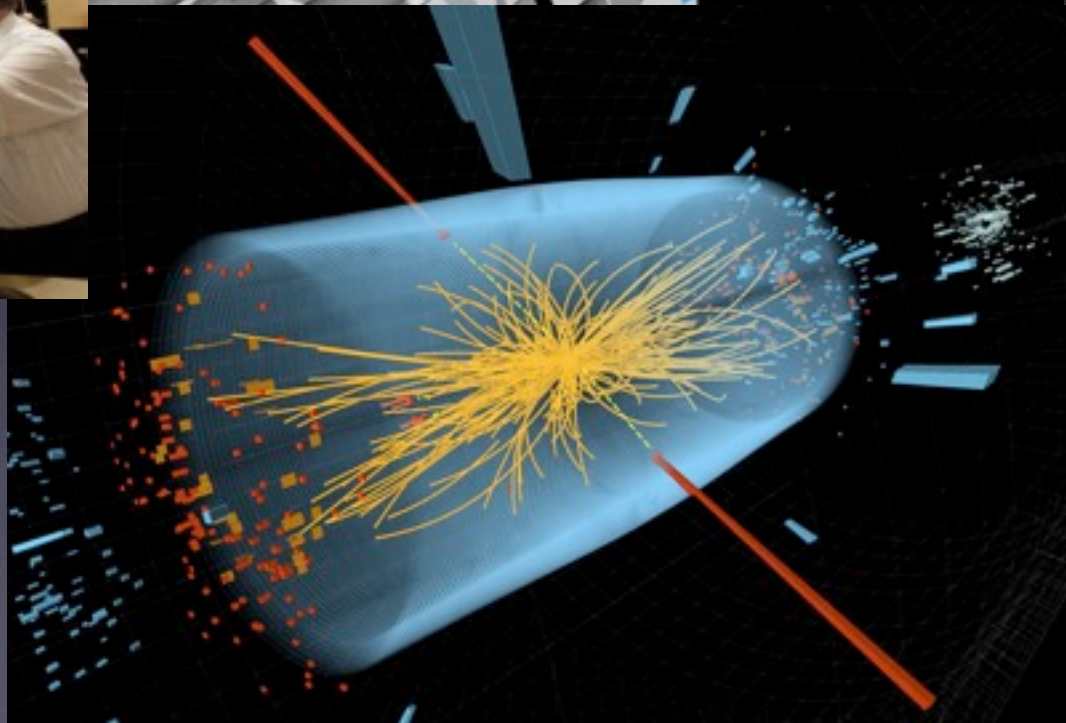
Séminaire du Laboratoire de l'Accélérateur Linéaire

19 Juin 2013

2012.7.4

discovery of
Higgs-like boson





theory：1964

concept：1984

construction：1998


Higgsdependence Day

A Higgs boson discovered!
decayed into two photons

Amazing!

pick up tens out of 10^{15}

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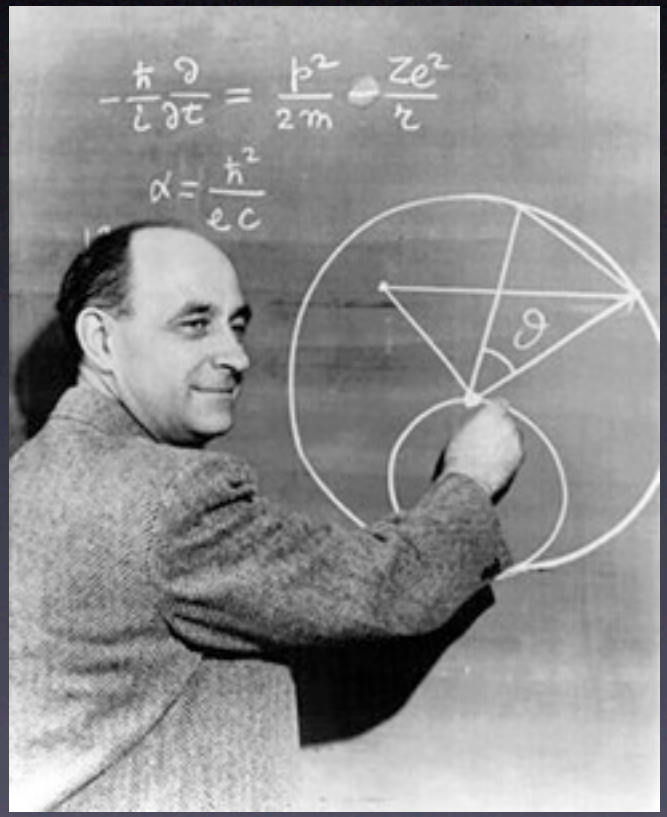
Fermi scale

- Fermi told us the energy scale to probe back in 1933
- $G_F^{-1/2}$ = 300 GeV
- We finally got there!



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New Era

- ~1900 reached atomic scale $10^{-8}\text{cm} \approx 1/(\alpha m_e)$
- ~1970 reached strong scale $10^{-13}\text{cm} \approx M e^{-2\pi/\alpha_s b0}$
- ~2010 reached weak scale $10^{-17}\text{cm} = \text{TeV}^{-1}$
- known since Fermi (1933), finally there!
- fundamental scale?
  - extra dimensions? TeV string theory?
- a derived scale?
  - from SUSY breaking? composite dynamics?
- rich spectrum of new particles?
- We'll start with Higgs boson(s)

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History of Colliders

1. precision measurements with e^- accelerator (*i.e.* polarized $e^- d$) predicted m_W, m_Z
2. UA1/UA2 (*ppbar*) discovered *W*/*Z* particles
3. LEP ($e^- e^+$) *nailed* the gauge sector
1. precision measurements of *W* and *Z* (*i.e.* LEP + Tevatron) predicted m_H
2. LHC (*pp*) discovered *H*-like particle
3. LC ($e^- e^+$) *nails* the Higgs sector?
1. precision measurements at LC predict ???

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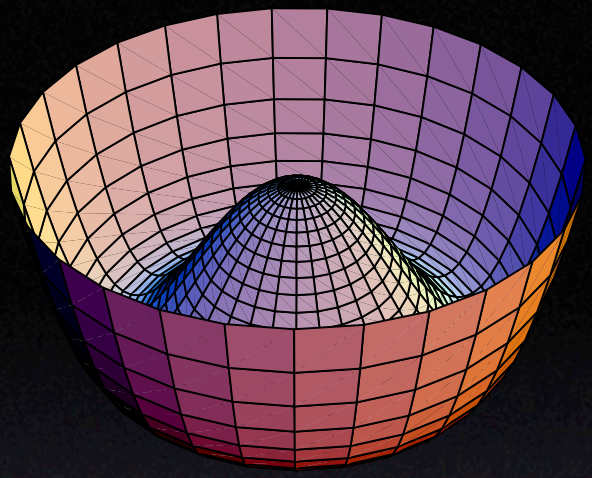
Physics at ILC

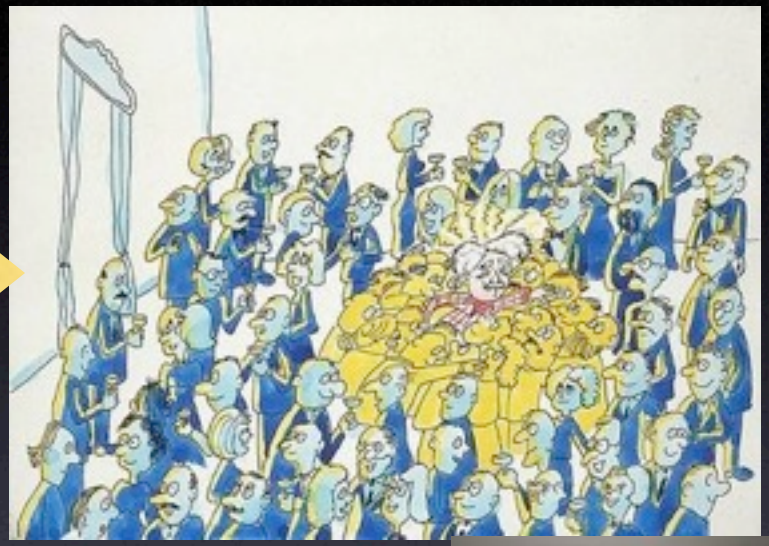
- now *guaranteed* at <500 GeV:
  - precision study of *a* Higgs particle
  - window to new physics?
  - top quark threshold
- also possible at higher energies:
  - Higgs self-coupling
  - discovery reach on electroweak particles
  - window to unification?

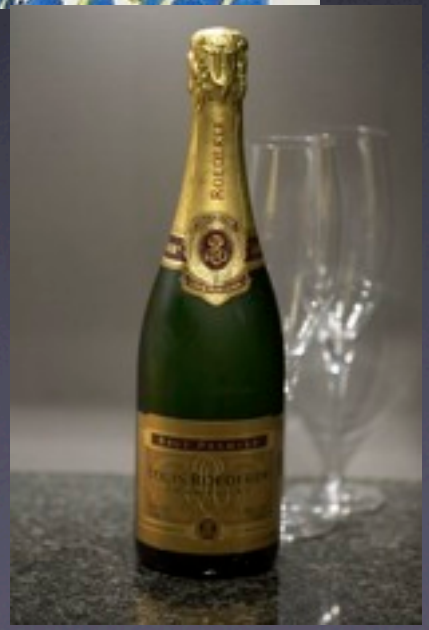


Why is "Higgs" so important?

Because it is a totally new kind of particle that creates order in the Universe.

1993 UK competition





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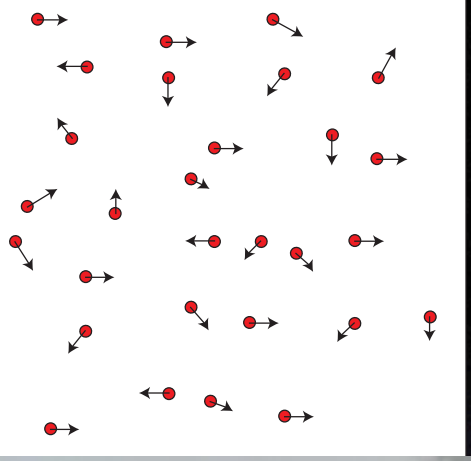
Cosmic Superconductor

- In a superconductor, magnetic field gets repelled (Meissner effect), and penetrates only over the "penetration length"

  ⇒ Magnetic field is short-ranged!

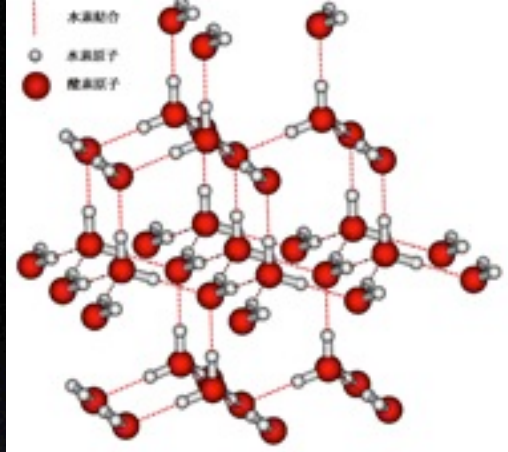
- Imagine a physicist living in a superconductor
- She finally figured:
  - magnetic field must be long-ranged
  - there must be a mysterious charge-two condensate in her "Universe"
  - But doesn't know what the condensate is, nor why it condenses
  - Doesn't have enough energy (gap) to break up Cooper pairs

That's the stage where we are!



Universe has been cooling

4 quadrillion degrees



symmetry breaks spontaneously

disorder ⇒ order

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atom

electron

nucleus

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uncomfortable

- Higgs boson is the *only spin 0 particle* in the standard model
  - one of its kind, no context
  - but does the most important job
- looks rather artificial
- also superficial, doesn't explain dynamics behind the condensate
- *Higgsless theories*: now dead

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Theory for Scalar Bosons?

Supersymmetry

- Higgs just one of *many* scalar bosons
- SUSY loops make m_h^2 negative

composite

- unitarity solved by KK states or form factors
- condensate by a strong attractive force, holography

Extra dimension

- Higgs spinning in extra dimensions
- new forces from particles running in extra D

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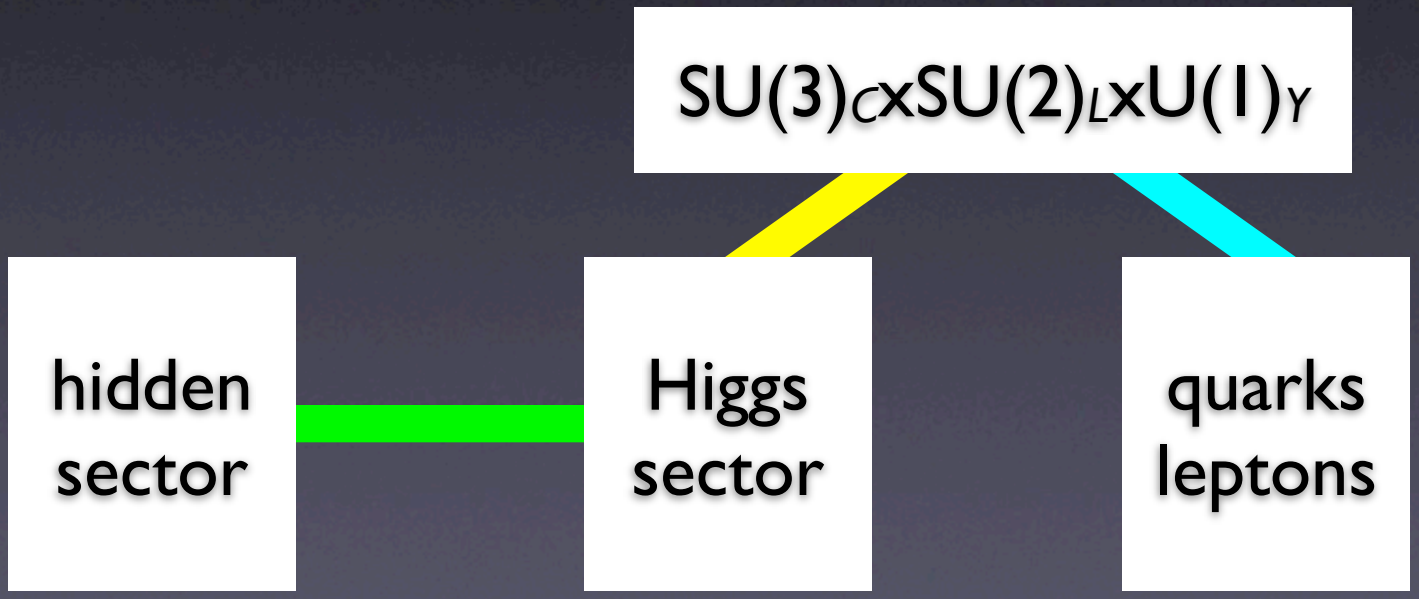
Higgs as a portal

- having discovered *a* Higgs boson
- Higgs boson may connect the Standard Model to other "sectors", i.e. dark matter



$$\mathcal{L} = \mathcal{O}_{hidden} H^\dagger H$$

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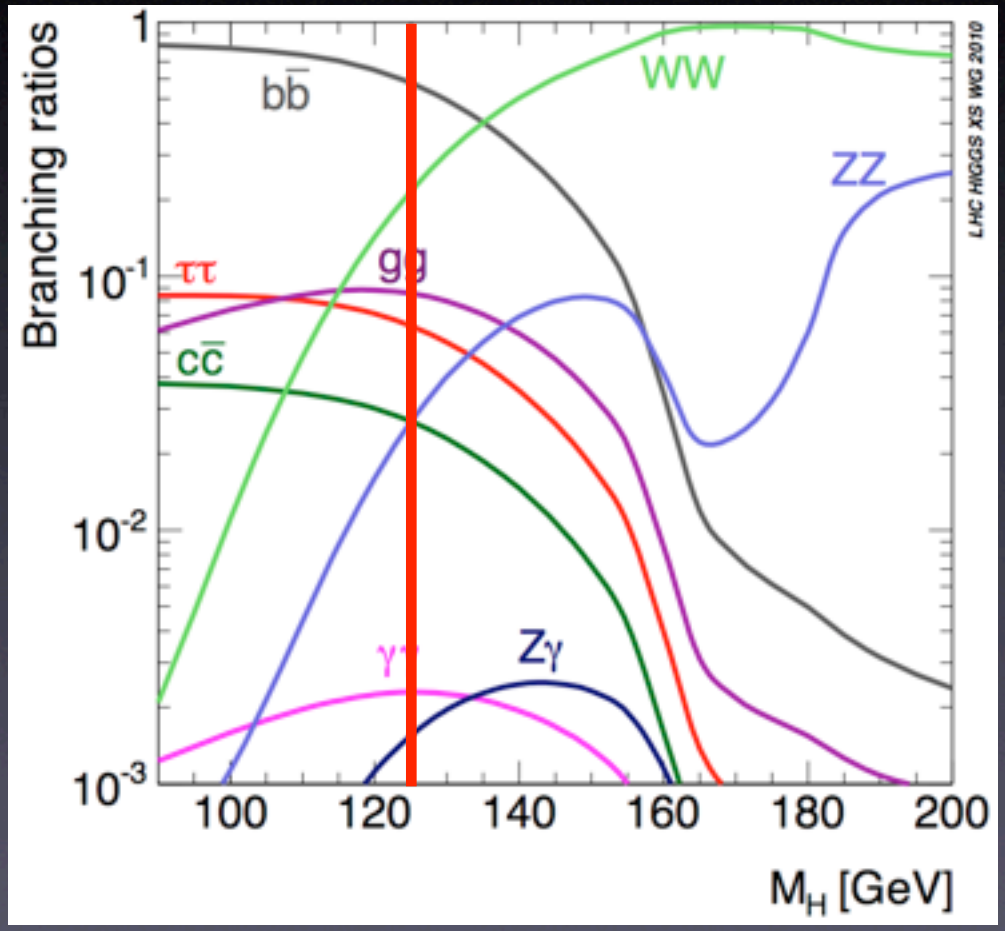
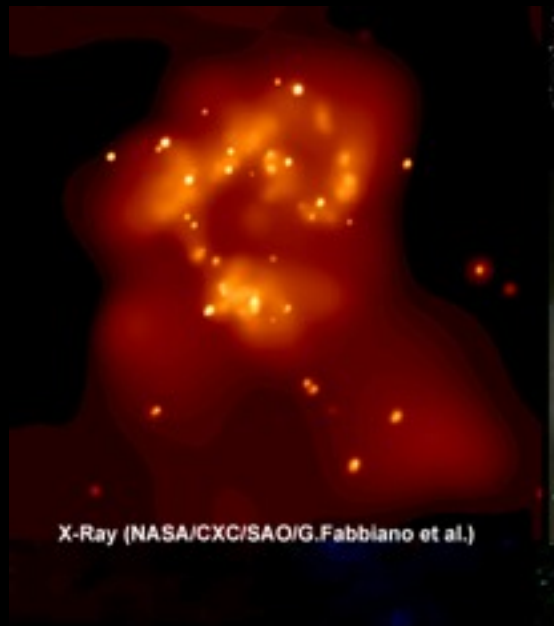
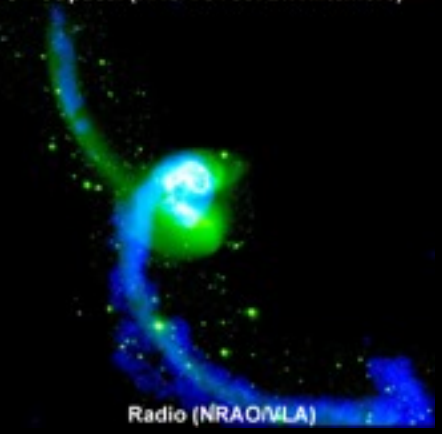
lucky for experiments



window to new world?

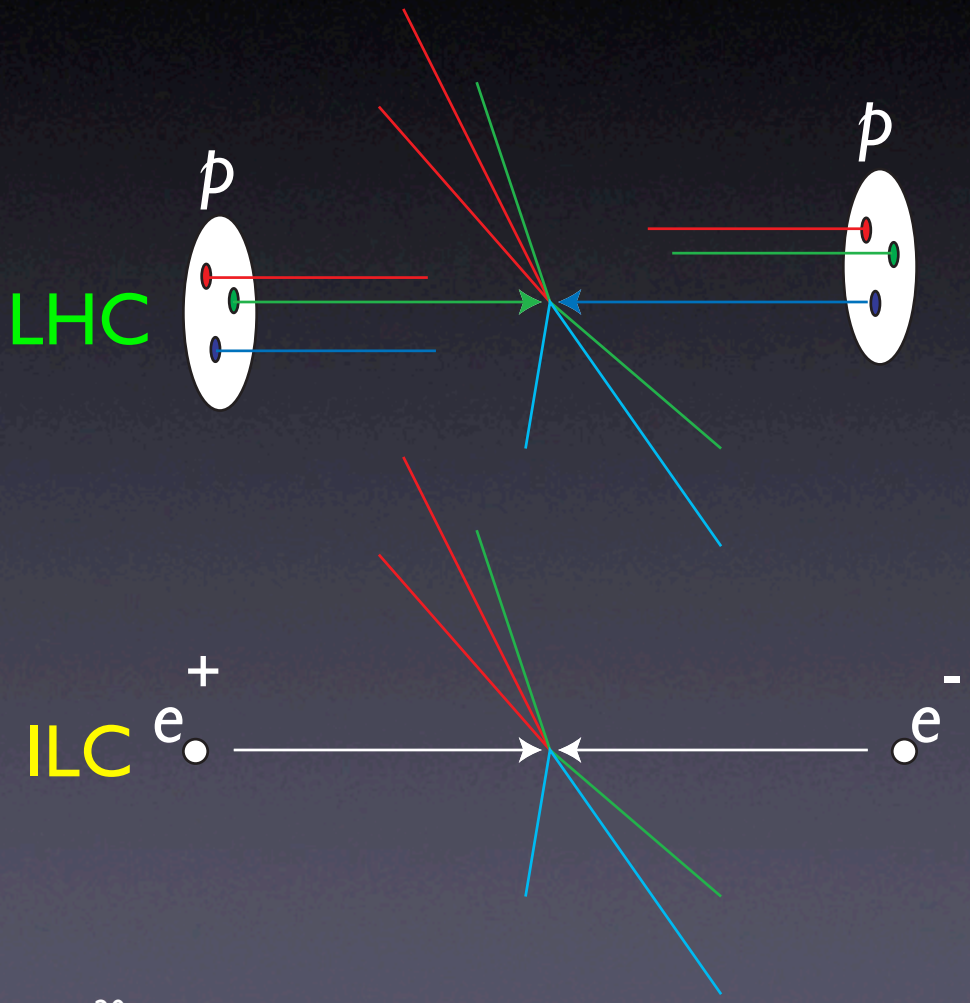
Need many probes for full understanding





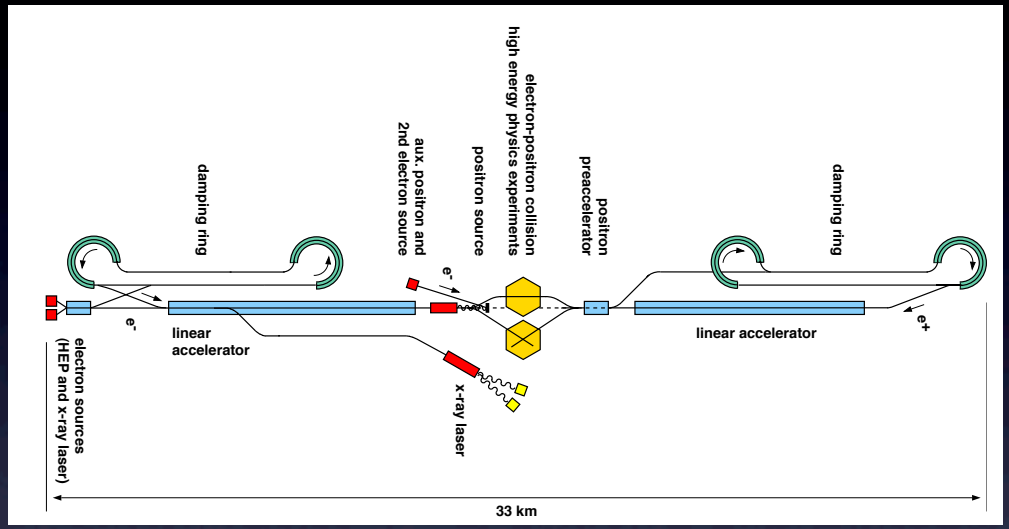
ILC

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



amazing high-tech

- collide electrons and positrons: "cherry pits"
- accelerate beams 15km
- focus beams down to a few nanometers and make sure they meet!
- extendable
- high beam polarization
- superconducting cavities with many possible industrial applications



International Linear Collider (ILC)

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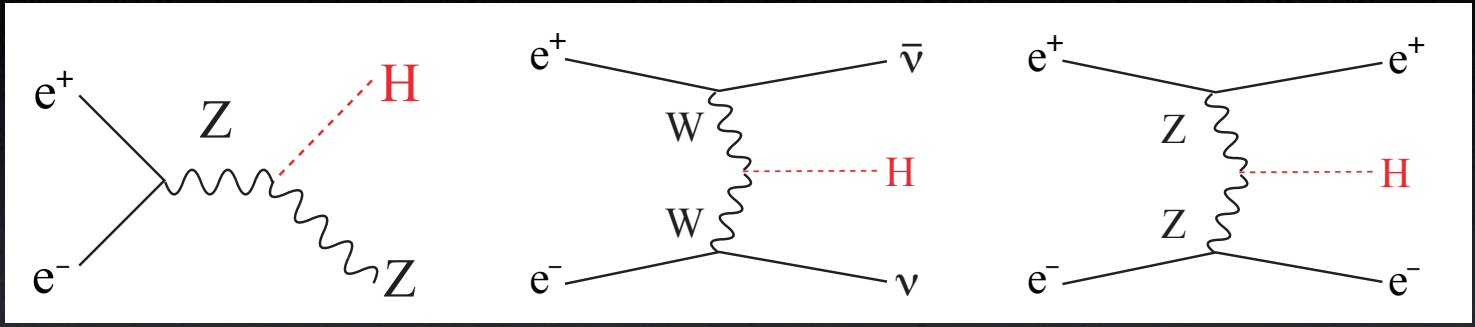
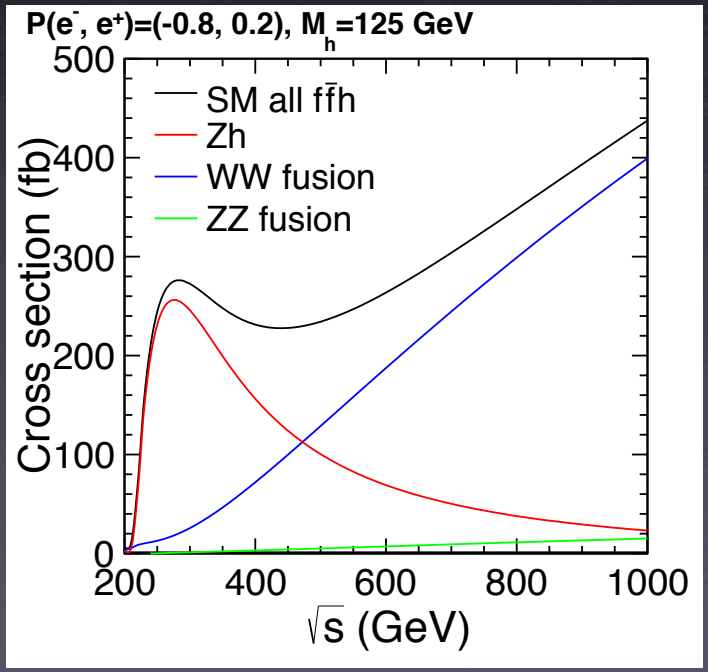
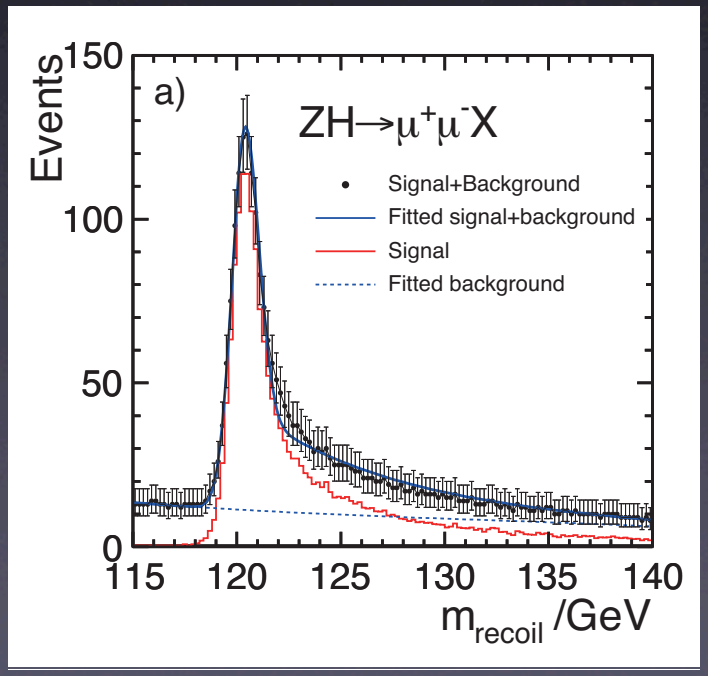
production mechanisms







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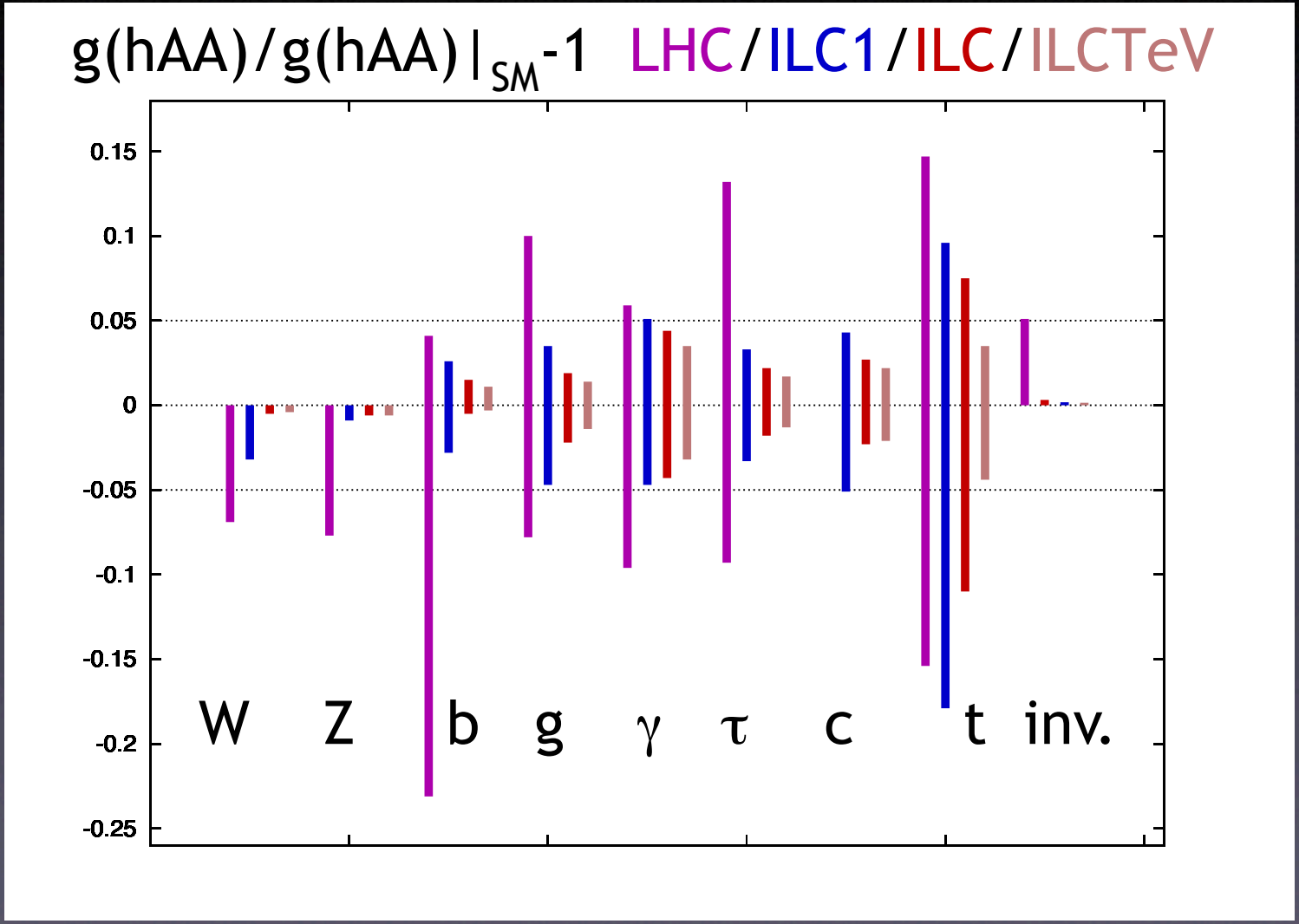
Coupling measurements



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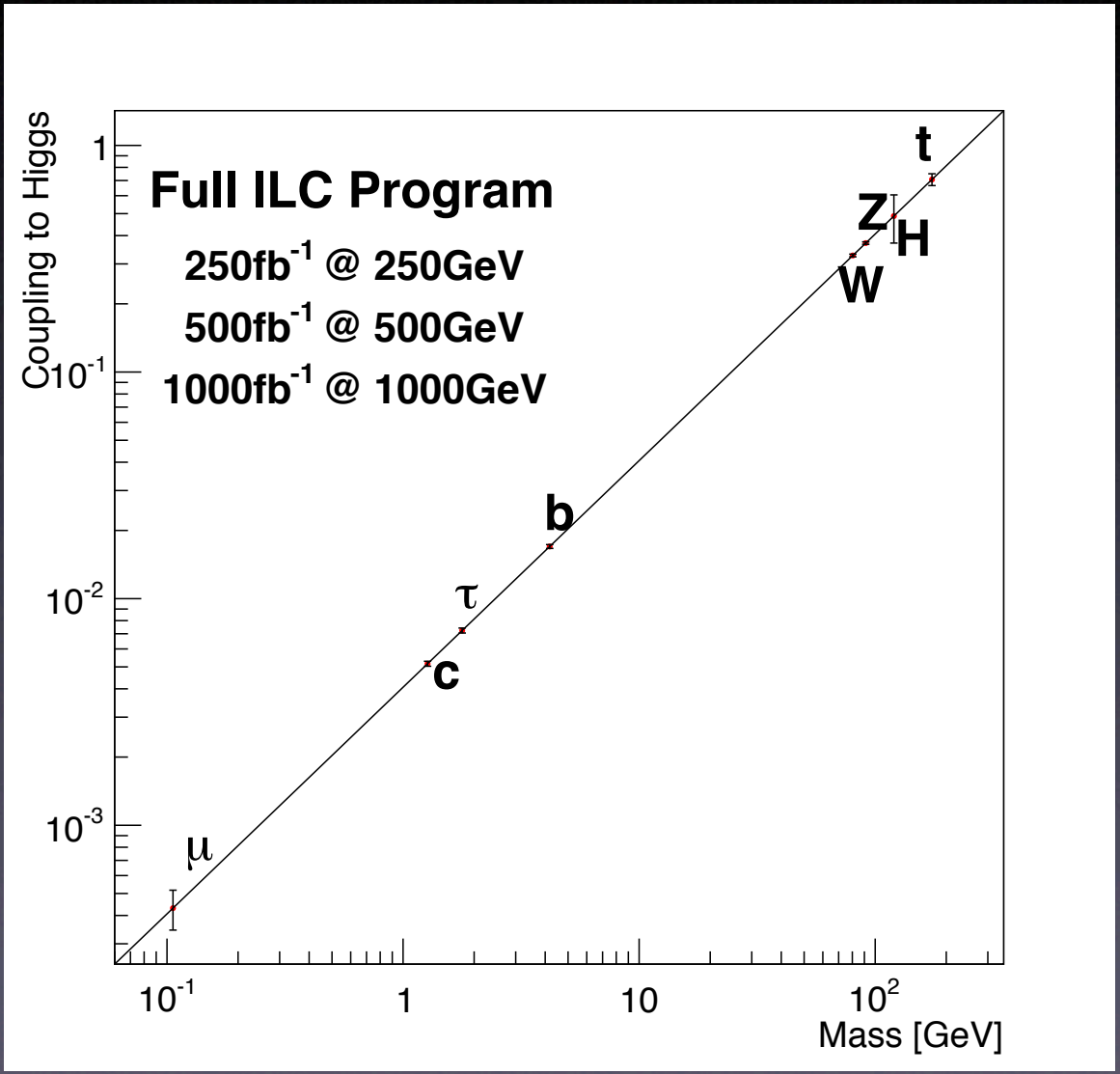

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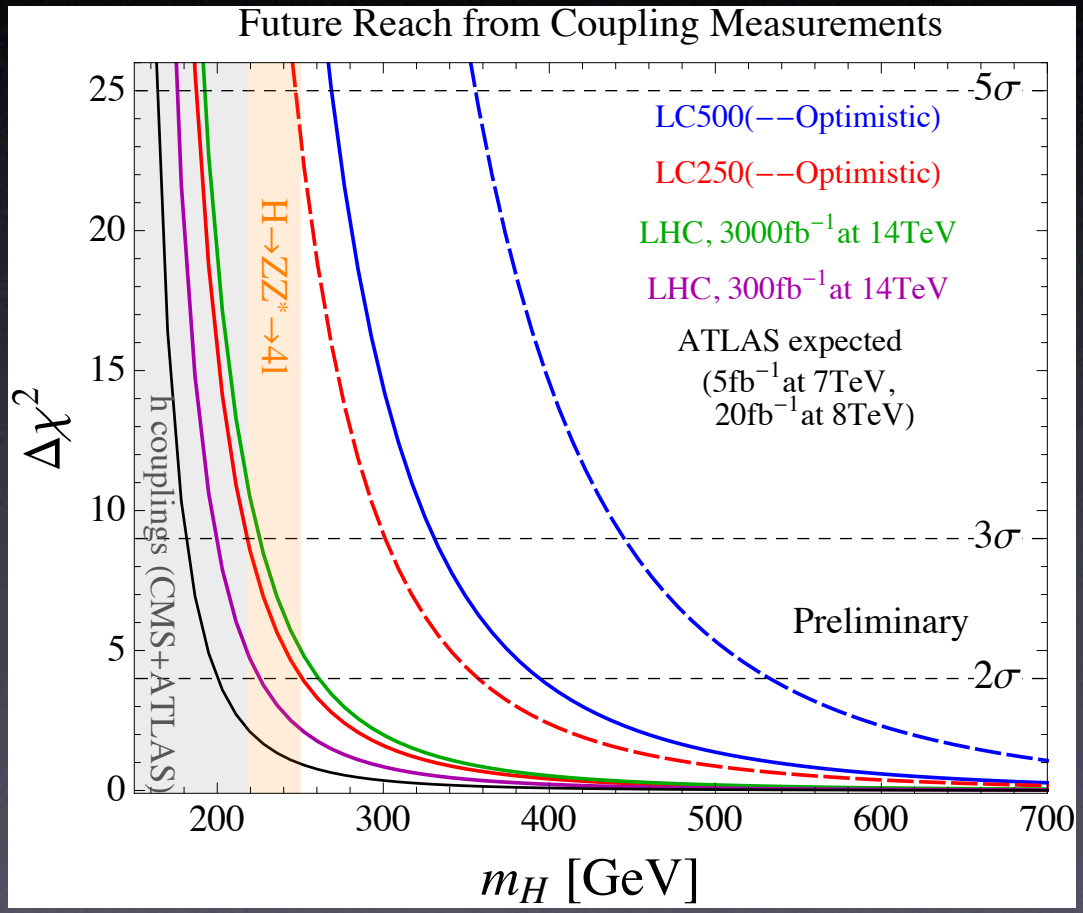
Is Higgs alone?

- Many models that try to explain m_h=125GeV require additional Higgs bosons
- precision measurements reveal their existence
- e.g. "Dirac NMSSM"



Lu, HM, Ruderman, Tobioka

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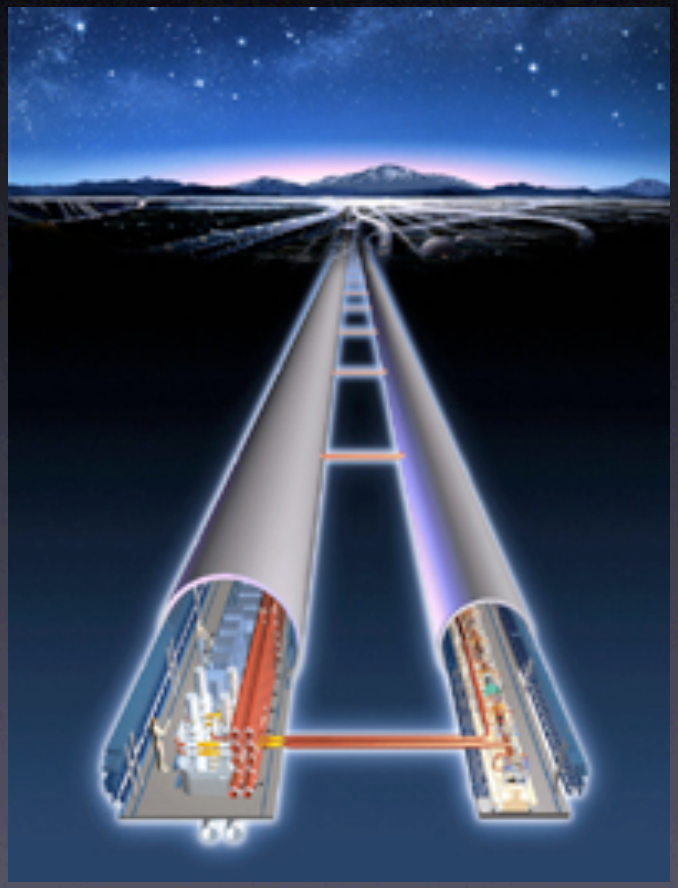
Power of ILC on new physics



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What did you find?

- Specify the fields
  - mass
  - spin ⇒ 0, 1/2, 1
  - SU(3)xSU(2)xU(1) quantum numbers
  - mixing of states
- Specify their interactions
  - SU(3)xSU(2)xU(1) quantum numbers determine gauge interactions
  - Yukawa couplings
  - trilinear and quartic scalar couplings

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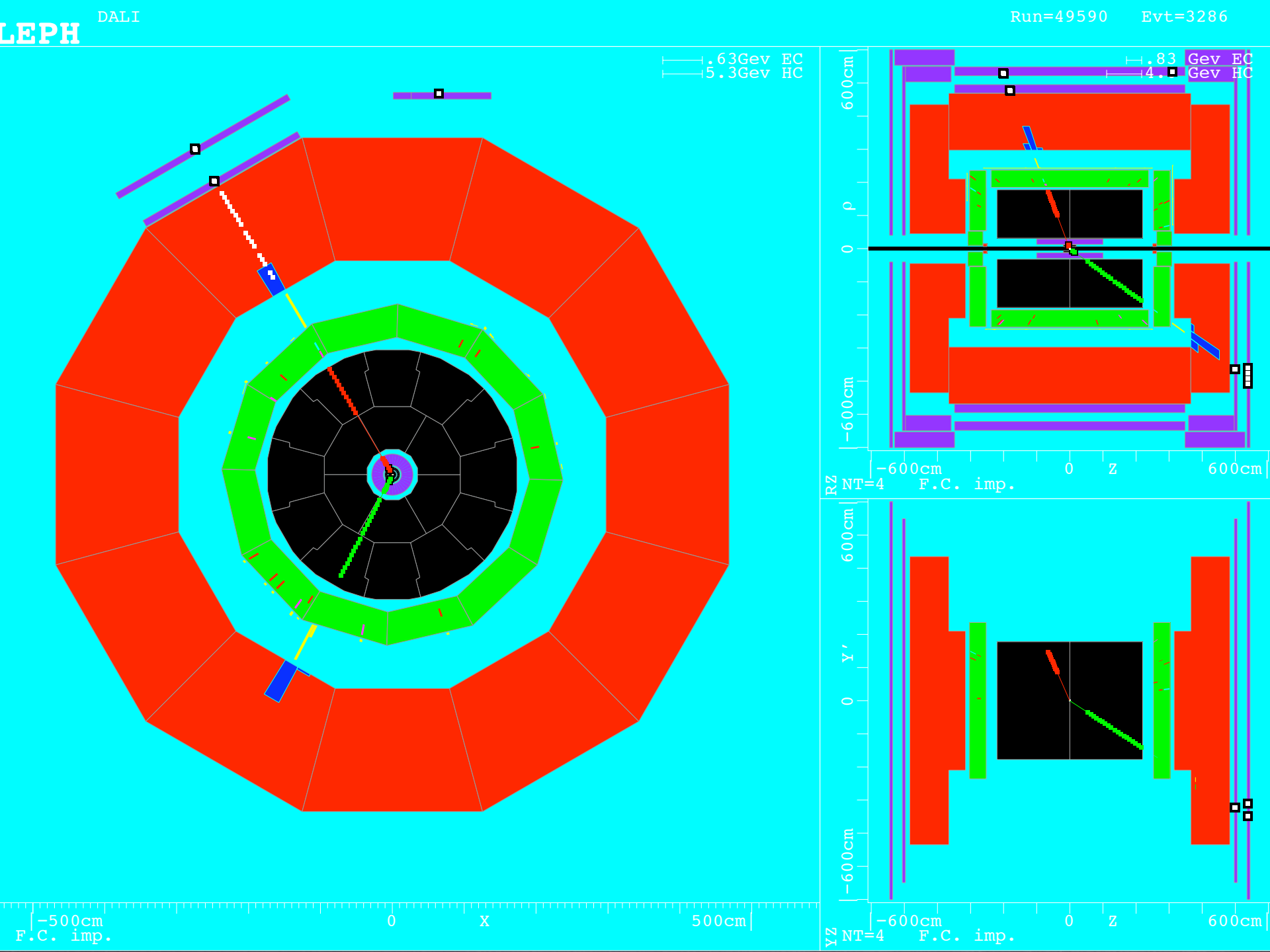
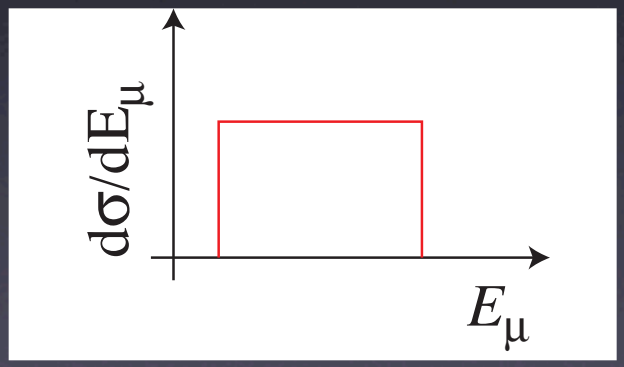

LEPH
DALI
Run=49590 Evt=3286
.63Gev EC
5.3Gev HC
-500cm
0
X
500cm
F.C. imp.
.83 Gev EC
4. Gev HC
600cm
ρ
0
-600cm
-600cm
0
Z
600cm
RZ
NT=4 F.C. imp.
600cm
Y'
0
-600cm
-600cm
0
Z
600cm
YZ
NT=4 F.C. imp.

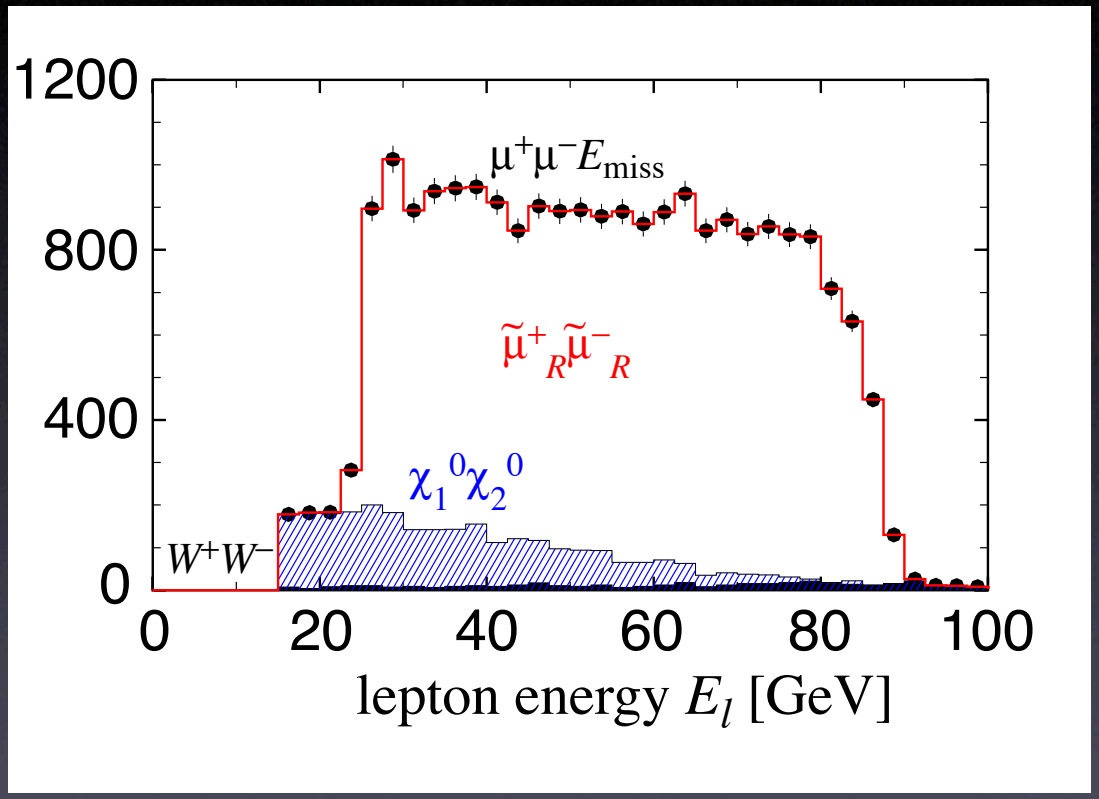
$\tilde{\mu} \to \mu \chi^0$

- fit to the kinetic distribution

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

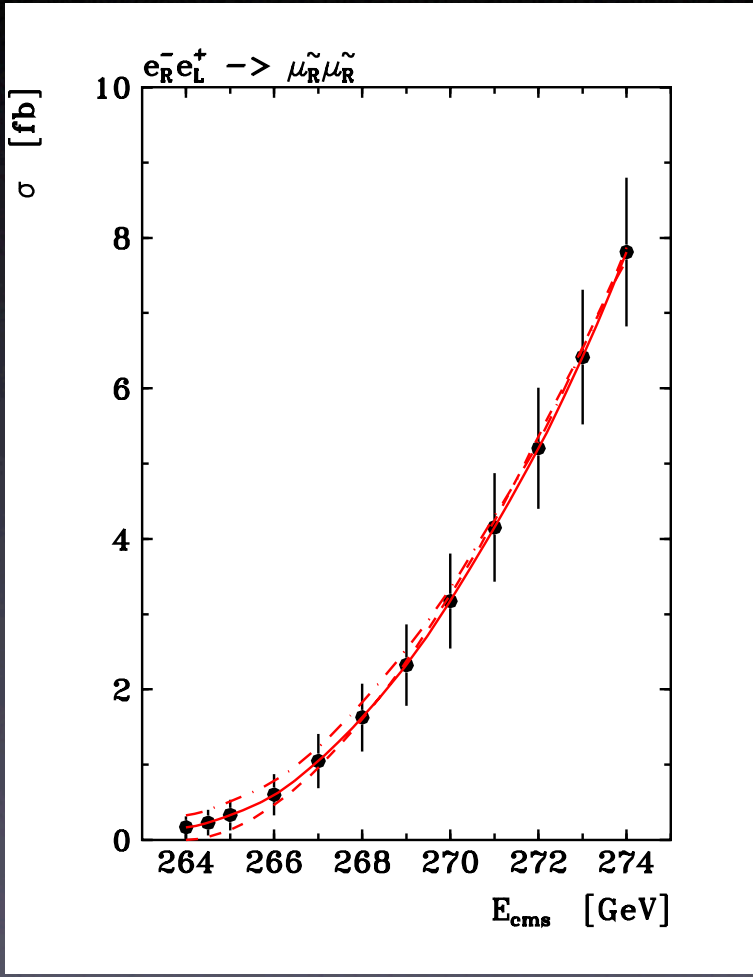
$m_{\tilde{\chi}^0} = 71.9 \pm 0.1$ GeV





$$\frac{\sqrt{s}}{4}\left(1-\frac{m_{\tilde{\chi}^0}^2}{m_{\tilde{\mu}}^0}\right)(1-\beta_{\tilde{\mu}}) < E_\mu < \frac{\sqrt{s}}{4}\left(1-\frac{m_{\tilde{\chi}^0}^2}{m_{\tilde{\mu}}^0}\right)(1+\beta_{\tilde{\mu}})$$

threshold scan



$$m_{\tilde{\mu}} = 132.0 \pm 0.09 \text{ GeV}$$
$$m_{\tilde{\chi}^0} = 71.9 \pm 0.05 \text{ GeV}$$

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What did you find?

- Specify the fields
  - mass
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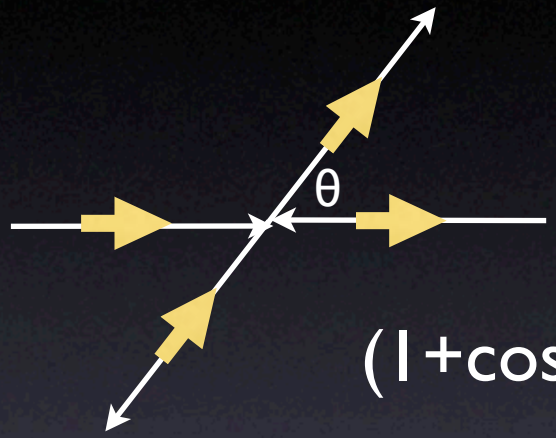
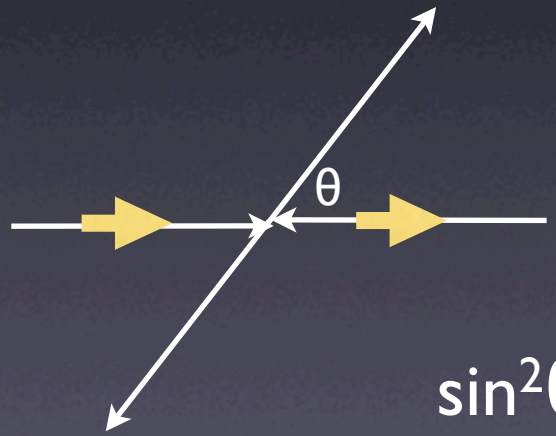
  - mixing of states
- Specify their interactions
  - SU(3)xSU(2)xU(1) quantum numbers determine gauge interactions
  - Yukawa couplings
  - trilinear and quartic scalar couplings

Spin

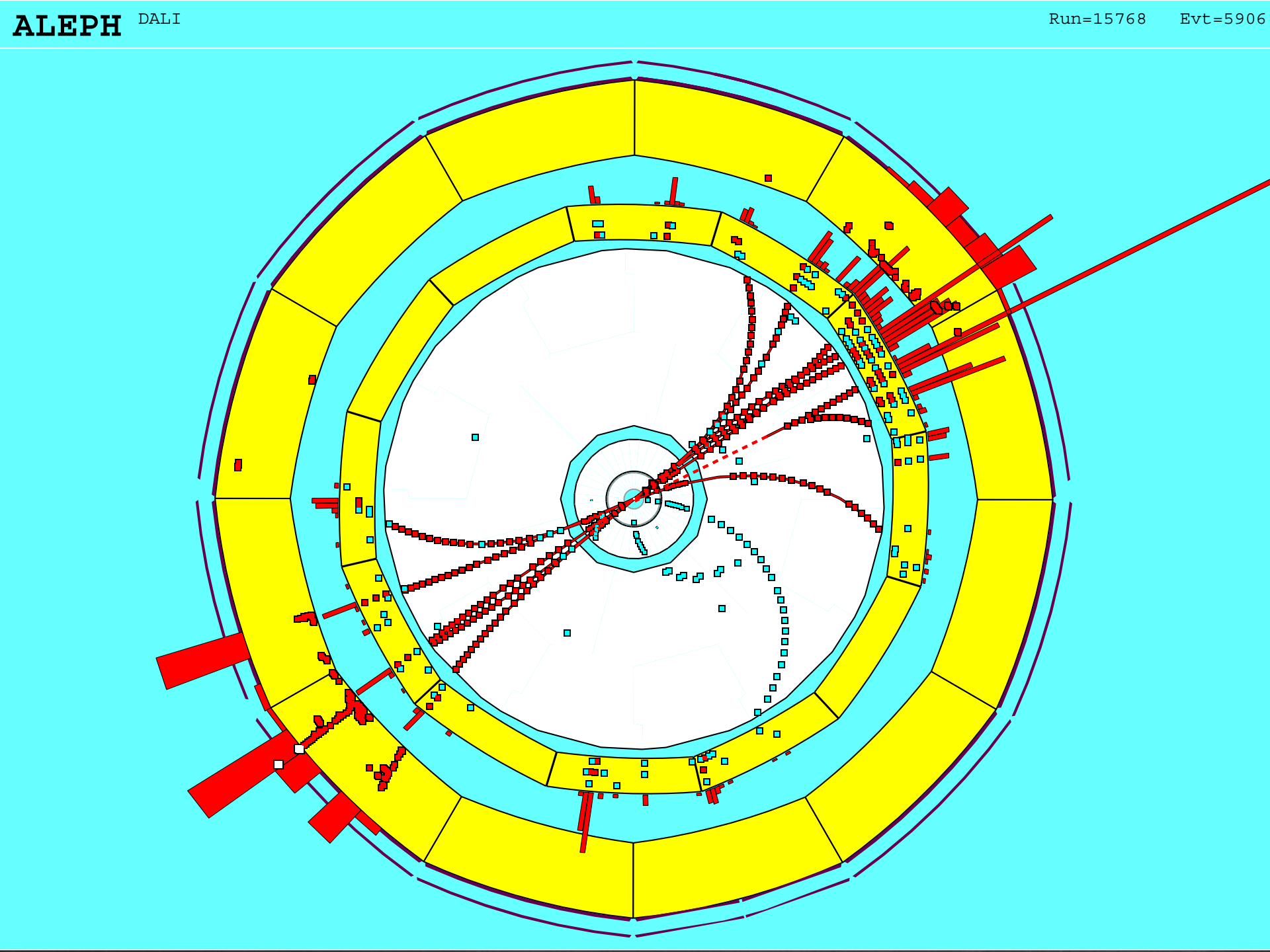
- production angle distribution well above the threshold:
- spin 1/2
- spin 0



$(1+\cos\theta)^2$

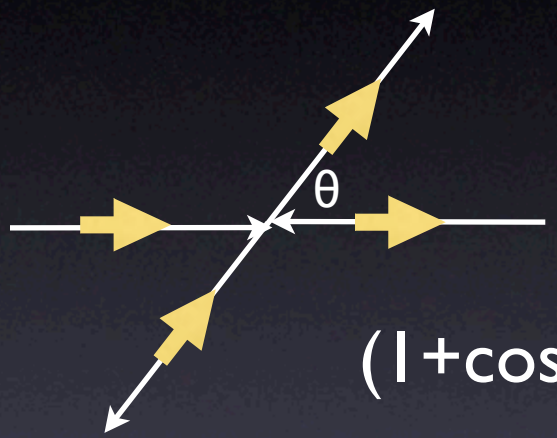


$\sin^2\theta$

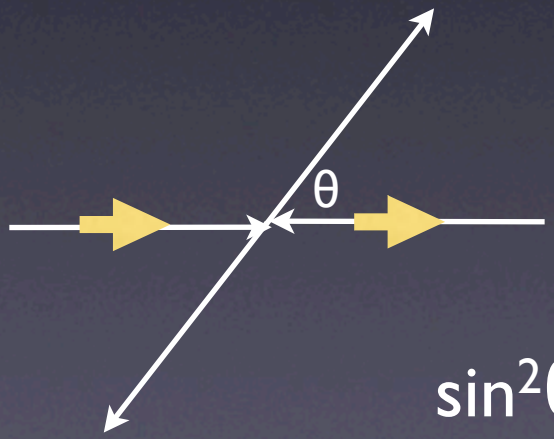

ALEPH
DALI
Run=15768
Evt=5906

"New particle" has spin 1/2

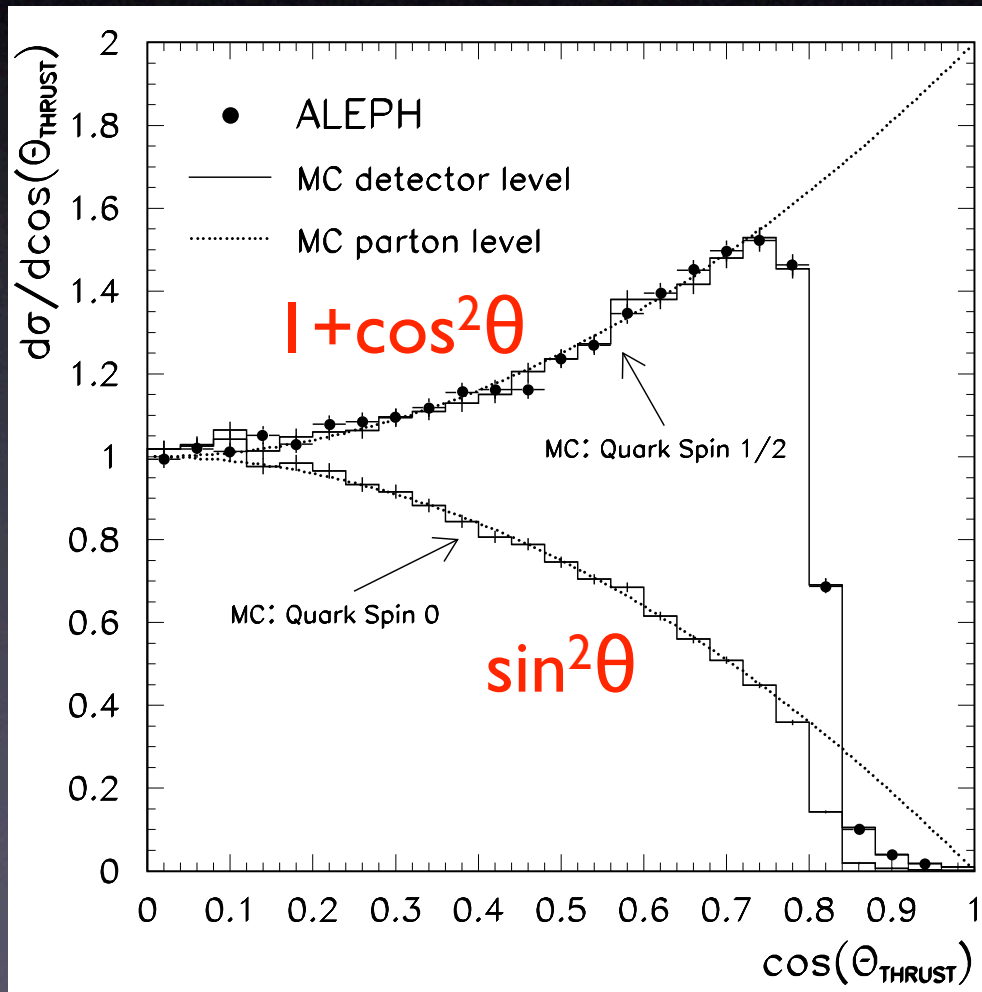
quark

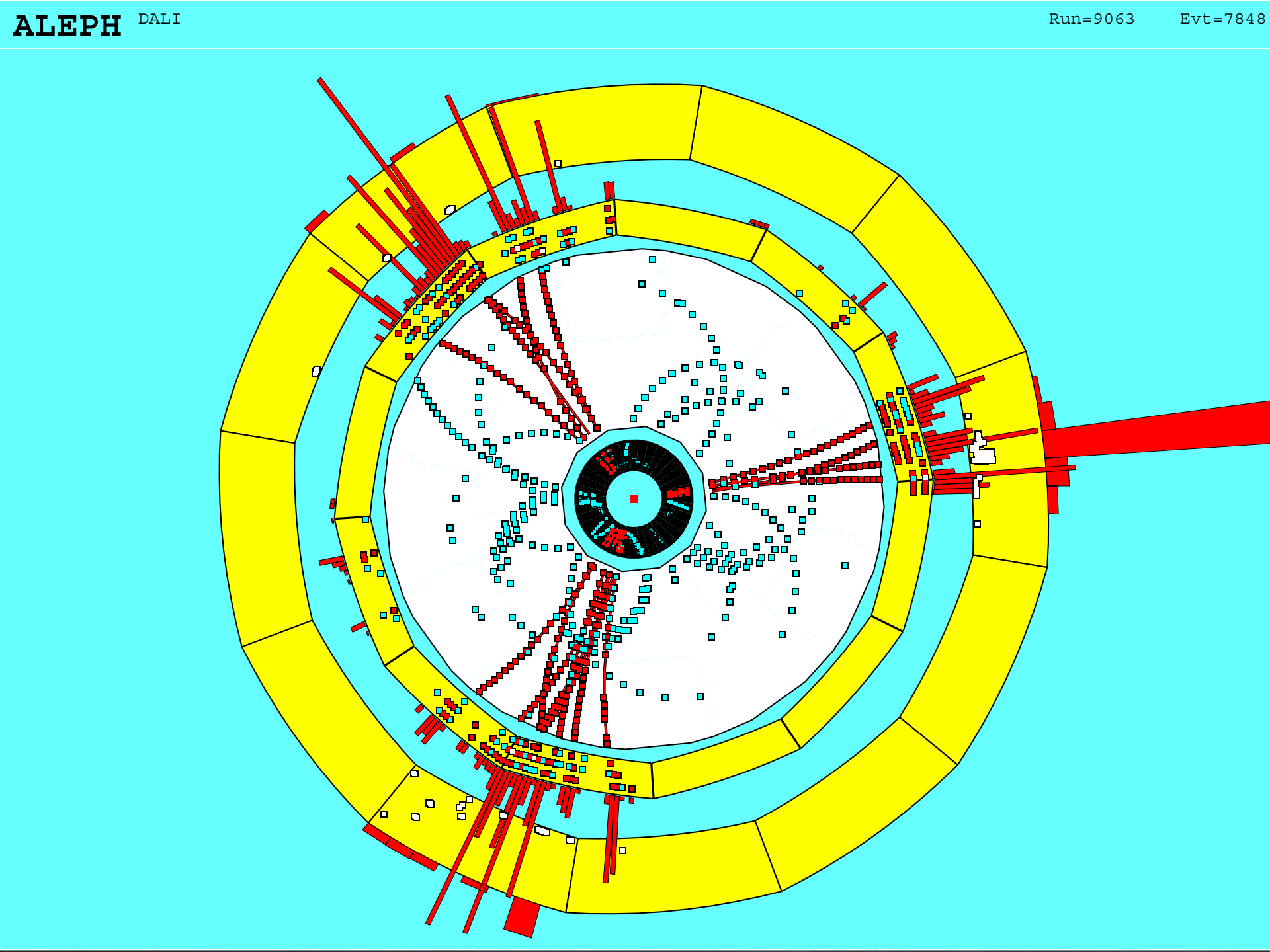


$(1+\cos\theta)^2$



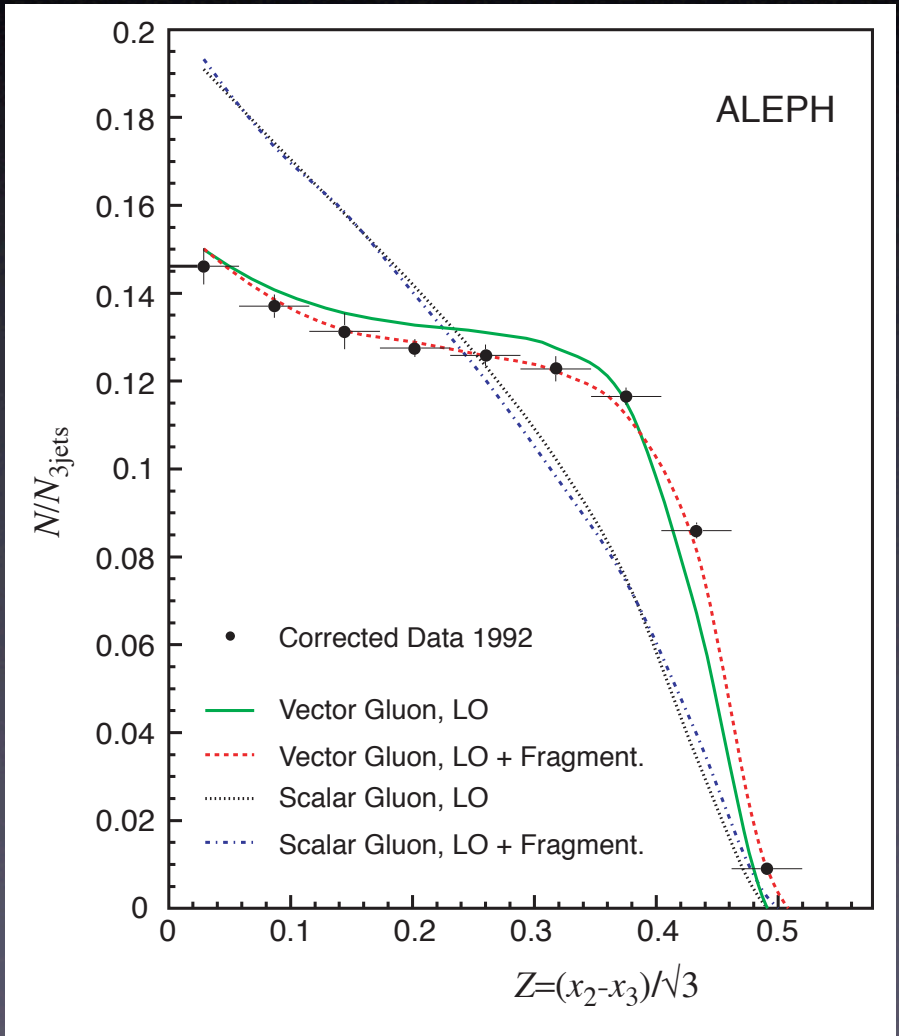
$\sin^2\theta$

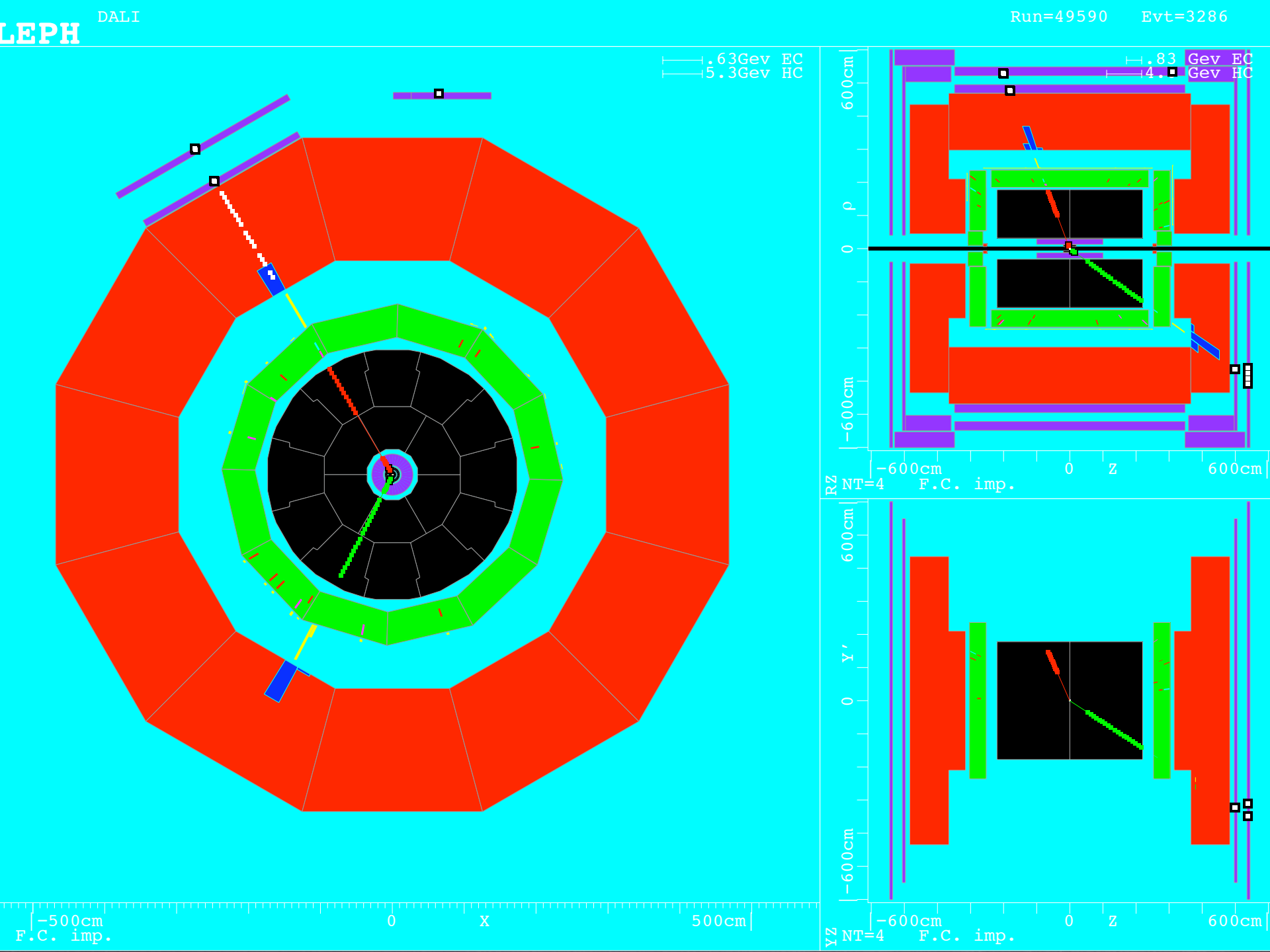



ALEPH
DALI
Run=9063
Evt=7848

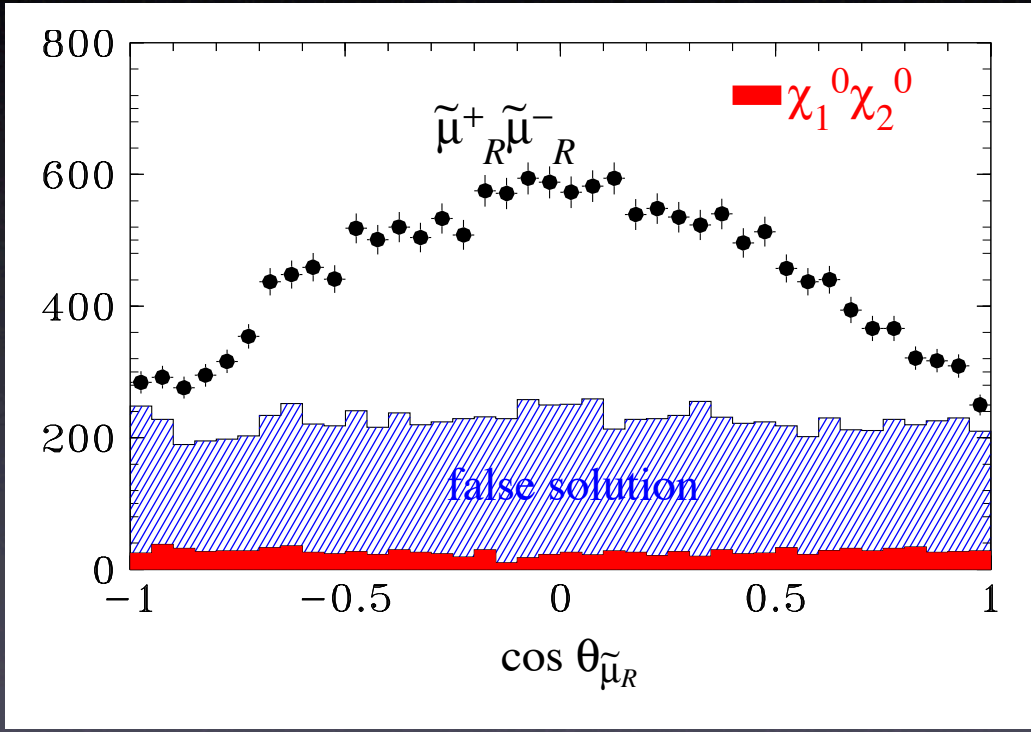
"New particle" has spin 1

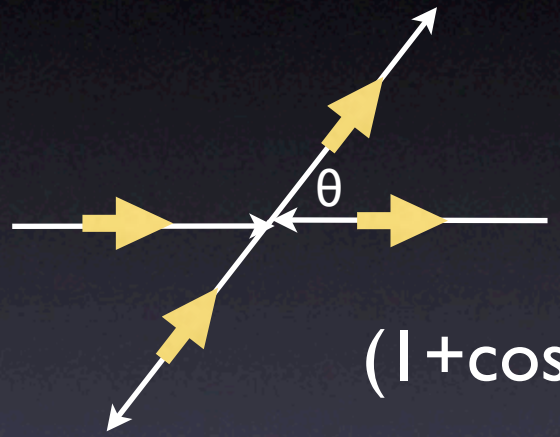
gluon

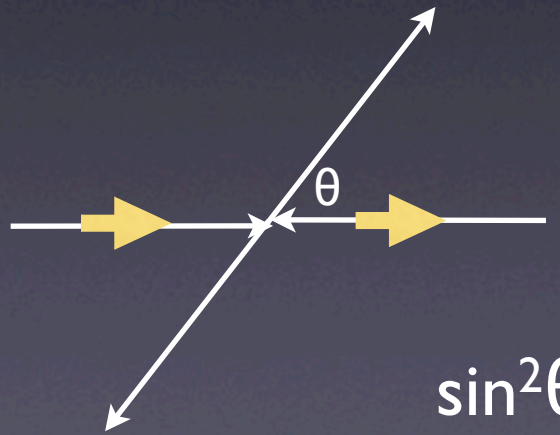



LEPH
DALI
Run=49590 Evt=3286
.63Gev EC
5.3Gev HC
-500cm
0
X
500cm
F.C. imp.
.83 Gev EC
4. Gev HC
600cm
ρ
0
-600cm
-600cm
0
Z
600cm
RZ
NT=4 F.C. imp.
600cm
Y'
0
-600cm
-600cm
0
Z
600cm
YZ
NT=4 F.C. imp.

Smuon has spin 0







can reconstruct with
a two-fold ambiguity

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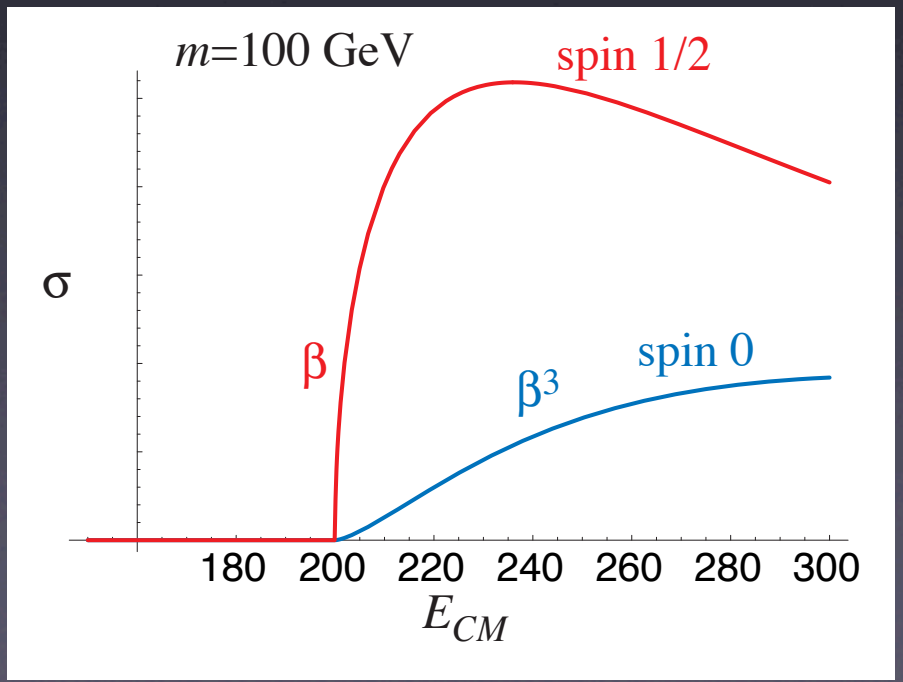
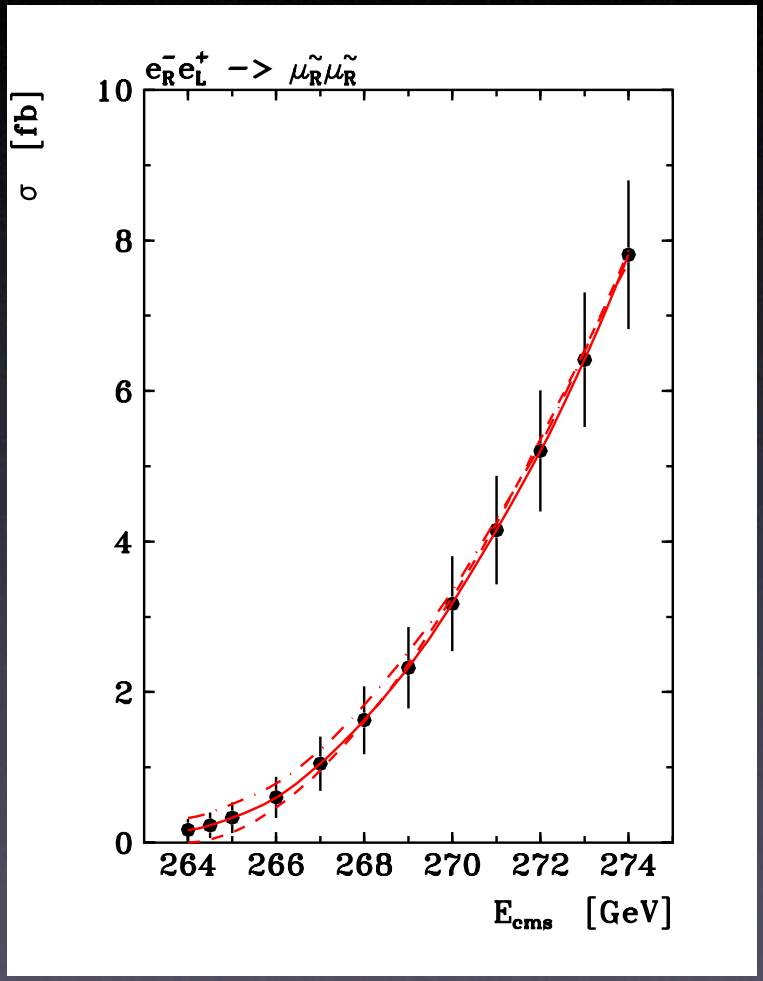
Spin

- threshold behavior non-relativistic limit: L, S separately conserved





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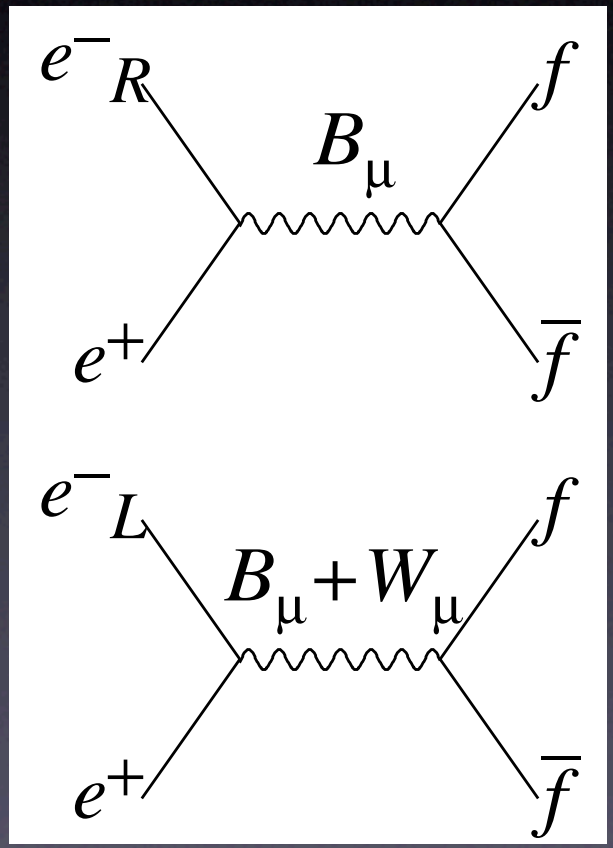
  - Yukawa couplings
  - trilinear and quartic scalar couplings

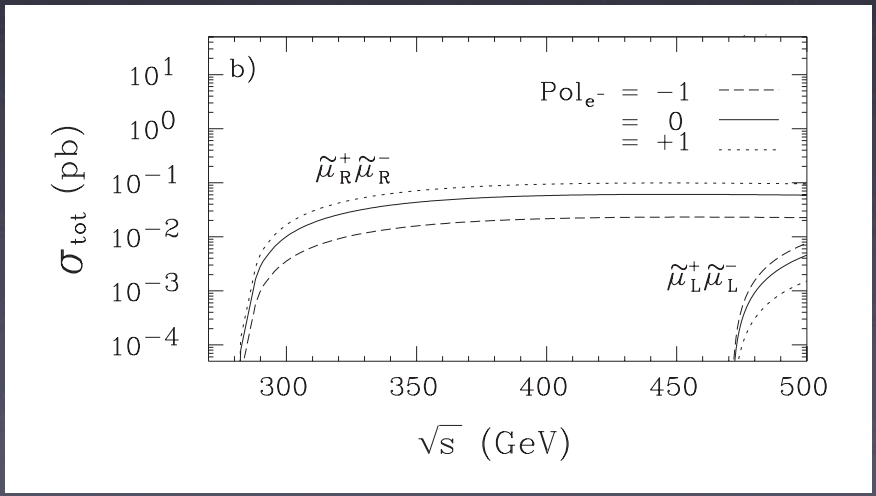
polarization

- Use polarized electron beam
- can ignore $m_Z^2 \ll s$
- e_R couples only to B_μ
- e_L couples to $B_\mu + W_\mu^0$



$\propto (g'^2 Y_f)^2$

$\propto (g'^2 Y_f + g^2 I_{3f})^2/4$



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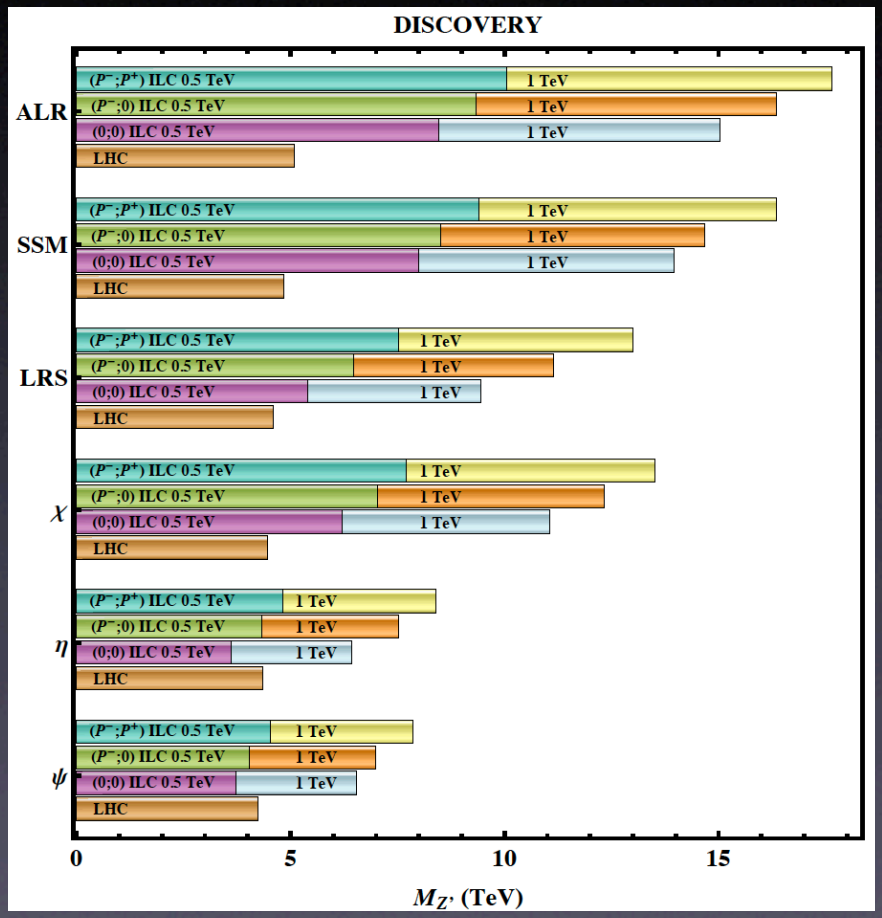
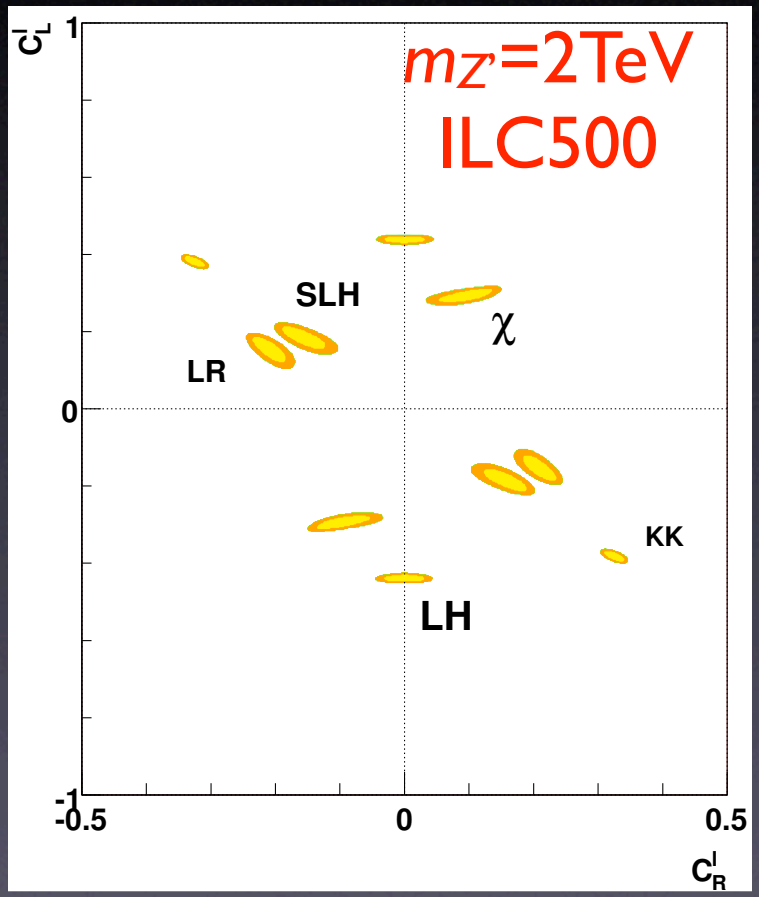
a new gauge boson





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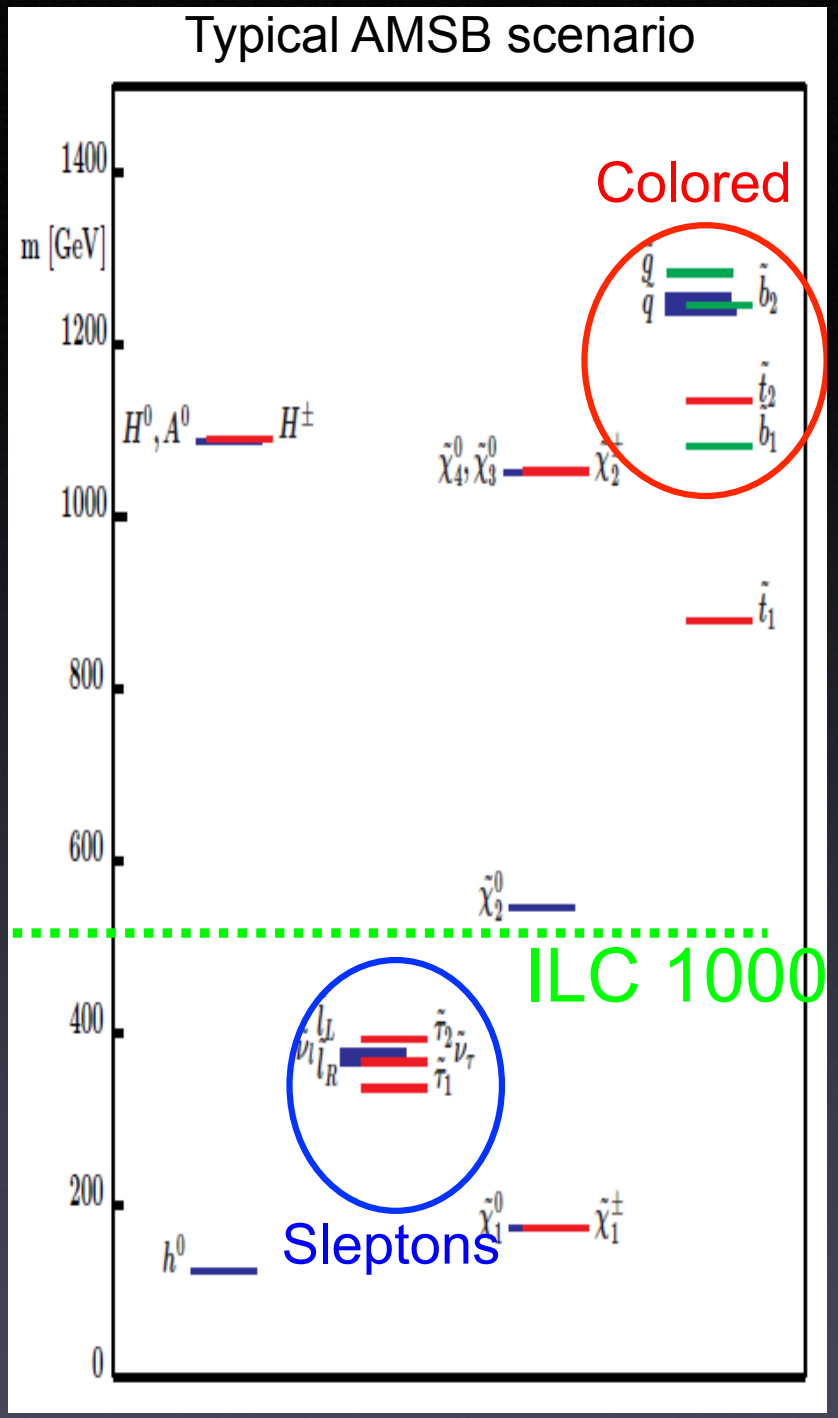
What did you find?

- Specify the fields
  - mass
  - spin ⇒ 0, 1/2, 1
  - SU(3)xSU(2)xU(1) quantum numbers
  - mixing of states
- Specify their interactions
  - SU(3)xSU(2)xU(1) quantum numbers determine gauge interactions
  - Yukawa couplings
  - trilinear and quartic scalar couplings

Supersymmetry

- access to color-neutral SUSY particles



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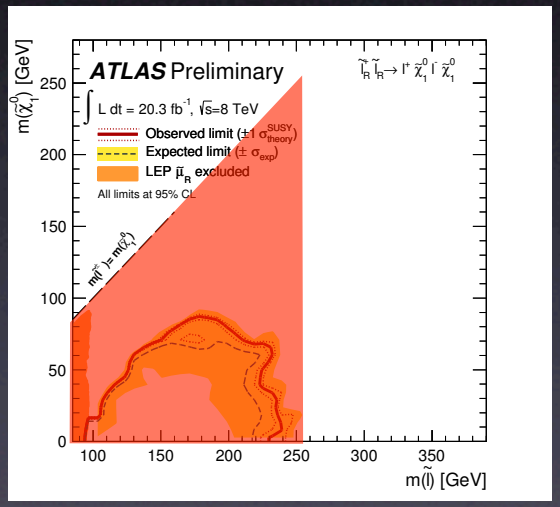
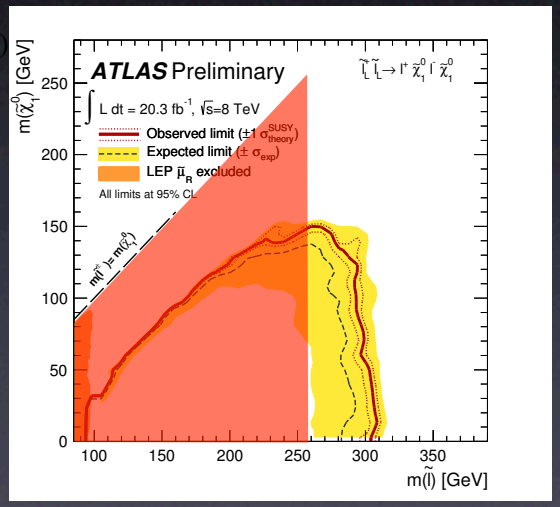
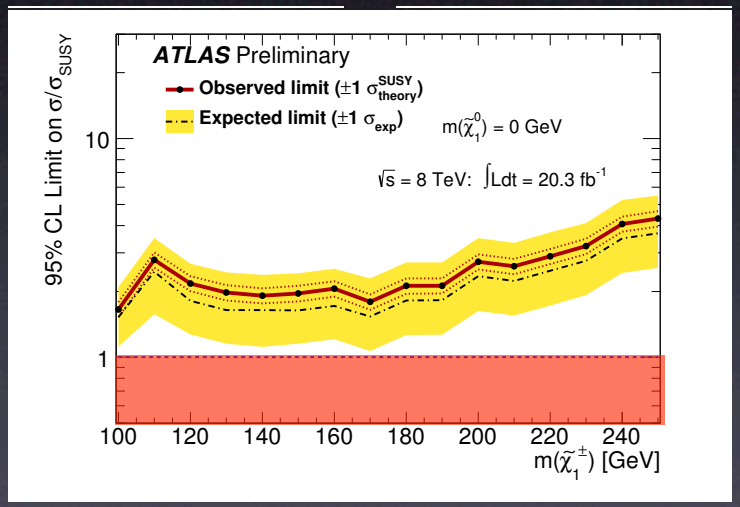
electroweak states

$\tilde{l}_R$ $\tilde{l}_L$ $\tilde{\chi}^{\pm}$







@ILC500

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Composite Higgs

- effect of compositeness appears as higher dimension operators
- precision Higgs measurements
- window to high-energy physics beyond TeV

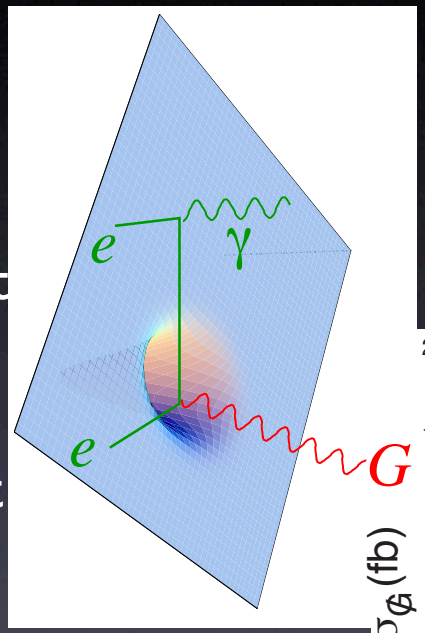
$$\mathcal{L}_{\rm SILH} = \frac{c_H}{2f^2}\partial^\mu \left(H^\dagger H\right)\partial_\mu \left(H^\dagger H\right) + \frac{c_T}{2f^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right)$$
$$-\frac{c_6\lambda}{f^2}\left(H^\dagger H\right)^3 + \left(\frac{c_y y_f}{f^2} H^\dagger H \bar{f}_L H f_R + \text{h.c.}\right)$$
$$+\frac{ic_W g}{2m_\rho^2}\left(H^\dagger \sigma^i \overleftrightarrow{D^\mu} H\right)\left(D^\nu W_{\mu\nu}\right)^i + \frac{ic_B g'}{2m_\rho^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)\left(\partial^\nu B_{\mu\nu}\right)$$
$$+\frac{ic_{HW} g}{16\pi^2 f^2}(D^\mu H)^\dagger \sigma^i (D^\nu H) W^i_{\mu\nu} + \frac{ic_{HB} g'}{16\pi^2 f^2}(D^\mu H)^\dagger (D^\nu H) B_{\mu\nu}$$
$$+\frac{c_\gamma g'^2}{16\pi^2 f^2}\frac{g^2}{g_\rho^2} H^\dagger H B_{\mu\nu} B^{\mu\nu} + \frac{c_g g_S^2}{16\pi^2 f^2}\frac{y_t^2}{g_\rho^2} H^\dagger H G^a_{\mu\nu} G^{a\mu\nu}.$$

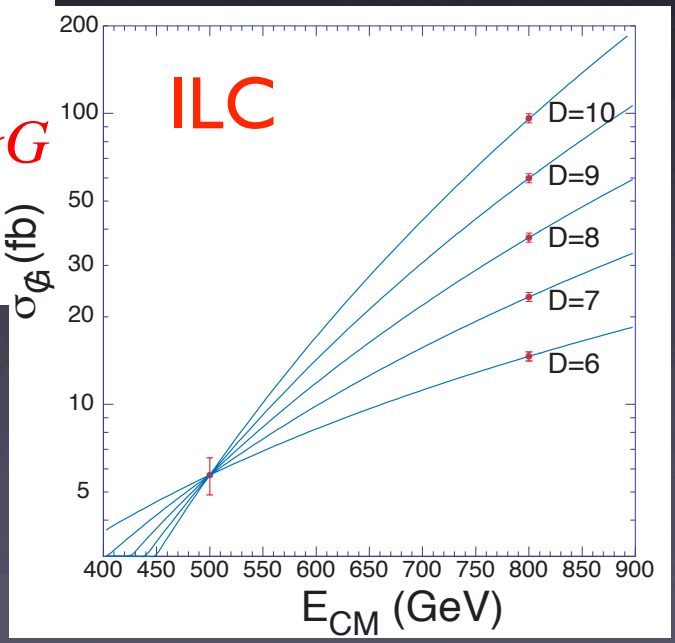
Giudice, Grojean, Pomarol, Rattazzi

Hidden Dimensions

- Hidden dimensions
- Can emit graviton int the bulk
- Events with apparent energy imbalance

⇒ How many extra dimensions are there?





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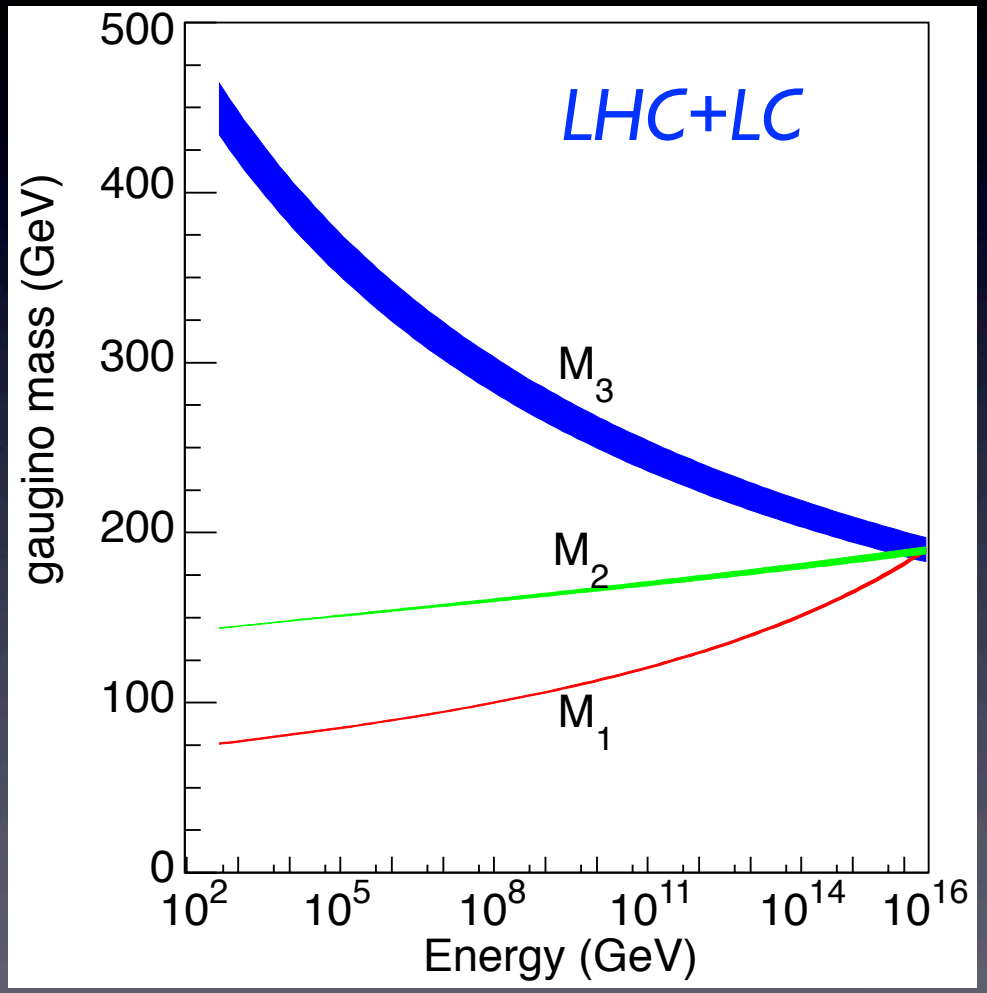
Superpartners as probe

- Most exciting thing about superpartners beyond existence:

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

"Are forces unified?"



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Physics at LCs

- now *guaranteed* at <500 GeV:
  - precision study of the Higgs-like particle
  - window to new physics?
  - top quark threshold
- also possible at higher energies:
  - Higgs self-coupling
  - discovery reach on electroweak particles
  - window to unification?

Sounds great,
but are we going
to have one?

JAHEP statement Oct 2012

In March 2012, the Japan Association of High Energy Physicists (JAHEP) accepted the recommendations of the Subcommittee on Future Projects of High Energy Physics[(1)] and adopted them as JAHEP's basic strategy for future projects. In July 2012, a new particle consistent with a Higgs Boson was discovered at LHC, while in December 2012 the Technical Design Report of the International Linear Collider (ILC) will be completed by a worldwide collaboration.

On the basis of these developments and following the subcommittee's recommendation on ILC, JAHEP proposes that ILC be constructed in Japan as a global project with the agreement of and participation by the international community in the following scenario:

(1) Physics studies shall start with a precision study of the "Higgs Boson", and then evolve into studies of the top quark, "dark matter" particles, and Higgs self-couplings, by upgrading the accelerator. A more specific scenario is as follows:

(A) A Higgs factory with a center-of-mass energy of approximately 250 GeV shall be constructed as a first phase.

(B) The machine shall be upgraded in stages up to a center-of-mass energy of ~500 GeV, which is the baseline energy of the overall project.

(C) Technical extendability to a 1 TeV region shall be secured.

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Is this a pipe dream?

- There is a lot of momentum in Japan:
  - Community
  - Industry & local regions
  - National Politics
- It crucially depends on international interest & support on its scientific case
- European Strategy supports the proposal for Japan to host an ILC, already helping

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European Strategy

There is a strong scientific case for an electron-positron collider, complementary to the LHC, that can study the properties of the Higgs boson and other particles with unprecedented precision and whose energy can be upgraded. The Technical Design Report of the International Linear Collider (ILC) has been completed, with large European participation. The initiative from the Japanese particle physics community to host the ILC in Japan is most welcome, and European groups are eager to participate. Europe looks forward to a proposal from Japan to discuss a possible participation.

HEPAP Facilities Subpanel: Report on Energy Frontier Facilities

S. Dawson, BNL

March 11, 2013

US Participation in Japanese Hosted ILC

S. Dav

- Science drives the need for e^+e^- collider
  - ILC addresses absolutely central physics questions and is complementary to the LHC
  - Japanese hosted ILC could be under construction before 2024
- Parameters of a potential US contribution are not known and depend on international agreements
  - The US has made substantial contributions to detector and accelerator development through the global effort
  - Should an agreement be reached, the US particle physics community would be eager to participate in both the accelerator and detector construction

Need discussions at the diplomatic levels

National Politics

Prime Minister Shinzo Abe

- Dec 2012 election
- LDP policy document for the election mentions ILC *twice*

LDP (Liberal Democratic Party) : New Ruling Party Policy Document

32 Rebuilding true command tower functions that strongly advance science and technology policies

- …We will actively promote the critical fields of energy creation, energy conservation, energy storage, etc. as knowledge-concentrated national strategies - for example, our country should be able to play a leading role in creation of international centers for scientific innovations such as the ILC (the international linear collider) project which is a grand project in the field of particle physics.

92 Creation of globally top-class centers for research and development

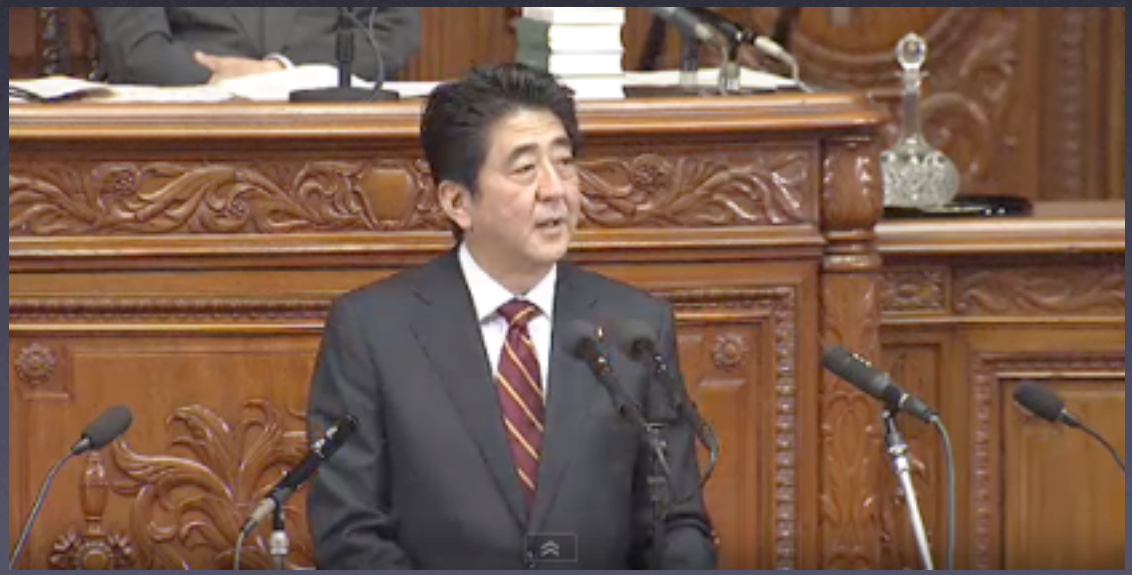
- …We will significantly strengthen supports for universities and public research facilities that perform studies at levels above the intentional standards, such as significant expansion of WPIs and playing a leading role in creation of international centers for scientific innovations such as the ILC (the international linear collider construction) project which is a grand project in the field of particle physics.

Inaugural Speech by PM Abe

(Japanese version of 'State of the Union')
Feb 28, 2013

- *'Japan is driving global innovation in cutting-edge areas, including among others the world's first production test of marine methane hydrate, a globally unparalleled rocket launch success rate, and our attempts to develop the most advanced accelerator technology in the world.'*

PM Abe at the 83rd session of Diet



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Press conference by the MEXT minister Shimomura

Jan 18, 2013

MEXT
Ministry of
Education
Culture
Sports
Science &
Technology

'(On ILC) We would like to consider the plan for the near future, while as the government actively negotiating with relevant countries in the first half of this year … we are now studying the legal framework.'

Federation of Diet Members for Promotion of ILC

- Established in 2008, expanded to a multi-partisan group
- Re-invigorated after the Higgs discovery: now >150 members!
- New chair: Mr. Kawamura (former MEXT minister)
- Meet *twice a month*

Lyn Evans meets Prime Minister
Mar 27, 2013

I understand ILC is a dream for humankind.
I need to monitor the developments carefully to see what role Japan can play.

Industry & regions & media

Science-Industry Alliance

- 'Advanced Accelerator Association for promoting science and technology (AAA)'
  - Established in 2008
  - Headed by a former CEO of Mitsubishi Heavy Industries: Mr. Nishioka
  - Hitachi, Toshiba, Mitsubishi, etc.
  - ~90 industries + ~30 universitie

Intensive activities:

- Lecture series, symposiums
- Civil engineering study
- Studies on large projects
- Science-industry cooperation
- …

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Apr 30 Symposium in Washington

Director DOE/HEP Siegrist

acting secretary of DOE Poneman

former MEXT Minister Kawamura

current MEXT Minister Shimomura

Japan Policy Council

- A private organization (an influential think tank)
  - Led by Hiroya Masuda
    - Professor of University of Tokyo
    - Former minister of internal affairs and communications
    - Former governor of Iwate prefecture

  - Issued a report:
    - Build a role model for the creation of a global city by reforming a local city through founding an international organization for the International Linear Collider (ILC).

Two Candidate Sites

- Kyushu
  - Sefuri mountains
- Tohoku
  - Kitakami mountains

In order to focus the design efforts:

one of them will be chosen by mid Aug based on:

1. Geology and other technical aspects
2. Infrastructure and economic ripple effects
3. Political aspects

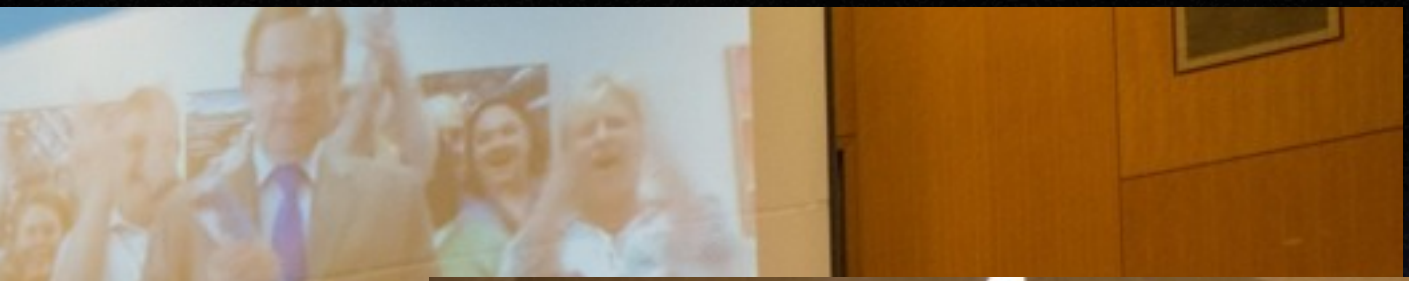
'ILC site evaluation council'

Co-chairs: Kawagoe, Yamamoto

Evaluates 1. and 2. (hopefully that is enough information for decision)


私たちは
国際リニアコライダー
計画を応援しています。
We support the International
Linear Collider Project.
一関商工会議所／岩手県ILC推進協議会

ILC TDR worldwide event June 12



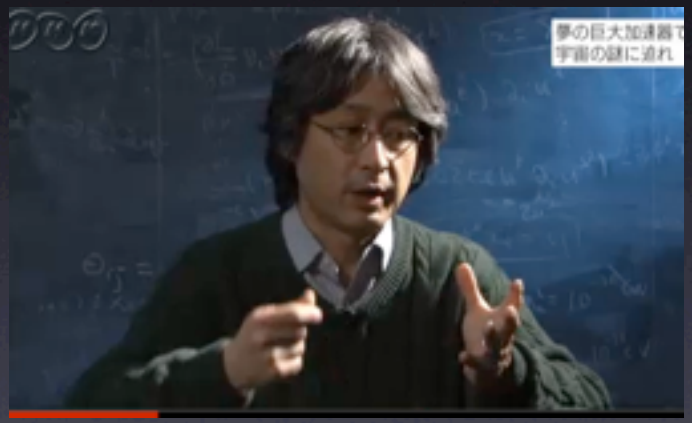
43 reporters

National Coverage of the ILC

- Many TV and newspaper coverages
  - 'Close-up Today' Feb 2013

NHK's flag-ship news program (30 min)

'Go beyond Higgs – Japan's Large Accelerator Project'



Anchor: Hirok

Near-term Timeline

end of July

- Science of Council was asked by MEXT to evaluate scientific merit of ILC *without* comparison to other projects
- report due end of July

mid-Aug

- site selection committee will select one site

end of Aug

- International committee to evaluate viability of the chosen site

Possible Timeline long-term

End 2013

- Japanese government announces its intent to bid

2013~2015

- Inter-governmental negotiations
- Completion of R&Ds, preparation for the ILC lab.

~2015

- Inputs from LHC@14TeV, decision to proceed

2015~16

- Construction begins (incl. bidding)

2026~27

- Commissioning

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Conclusion

- ILC has a very strong physics case
  - with upgradability, beam polarization
- concrete program with Higgs
  - starting at 250 GeV, up to 1 TeV
- keep our eyes on potential new physics on the way
- a lot of momentum building in Japan

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>50% non-Japanese