Introduction to ILC
- Physics & Detector

CCAST-Tsinghua School on Calorimetry for International Linear Collider, April 22-26

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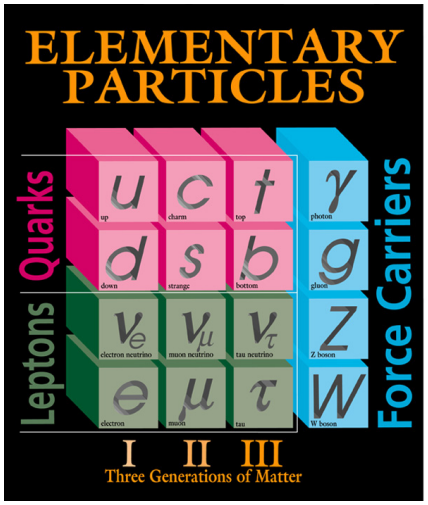
From Jae Yu's talk:

Preparation of a HEP Experiment

- Decide on physics topics and scientific goals to accomplish
- Explore accelerators, existing, upgraded or new
- Define the necessary detector performance requirements to accomplish the measurements of the topics
- Define the design parameters and look into available or new technologies to fit the performance parameters
- Perform Monte Carlo simulations to refine the requirements and test technical feasibilities
- Perform R&D for various detector technologies and construct and test prototypes
- Design an integrated detector and test them in the beam to understand, improve and calibrate its performance
- Construction, commissioning, data taking and analysis

The Standard Model



$$\mathcal{L} = -\frac{1}{4}F^{a}_{\mu\nu}F^{a\,\mu\nu} + i\bar{\psi}D\psi \qquad \textit{The gauge sector} \quad (1)$$

$$+\psi_i\lambda_{ij}\psi_j h + h.c. \qquad \textit{The flavor sector} \quad (2)$$

$$+|D_\mu h|^2 - V(h) \qquad \textit{The EWSB sector} \quad (3)$$

$$+N_i M_{ij} N_j \qquad \textit{The } \nu\textit{-mass sector (if Majorana)} \quad (4)$$

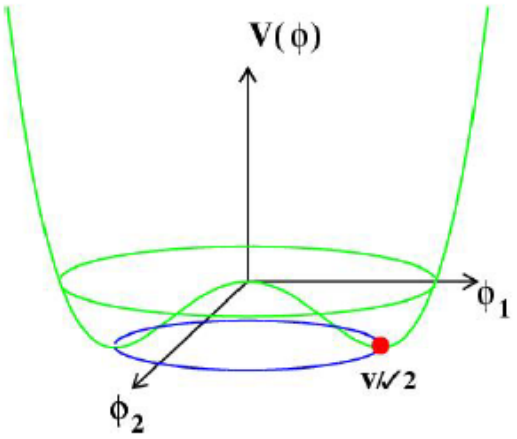
(1) : best tested, at least to per-mille accuracy

(2) + (4) : main developments of last ***10 years***
different in nature, both highly significant

(3): the most elusive, so far

The rule of Higgs field

$$V(\Phi) = -\mu^2|\Phi|^2 + \lambda|\Phi|^4$$



- **Symmetry breaking**

$$SU(2)_L \times U(1)_Y \rightarrow U(1)_{EM}$$

- **Give mass (and component) to W, Z**

$$\left(w^+, \phi^+\right) \rightarrow W^+$$

$$\left(w^-, \phi^-\right) \rightarrow W^-$$

$$\left(z^0, \phi^0\right) \rightarrow Z^0$$

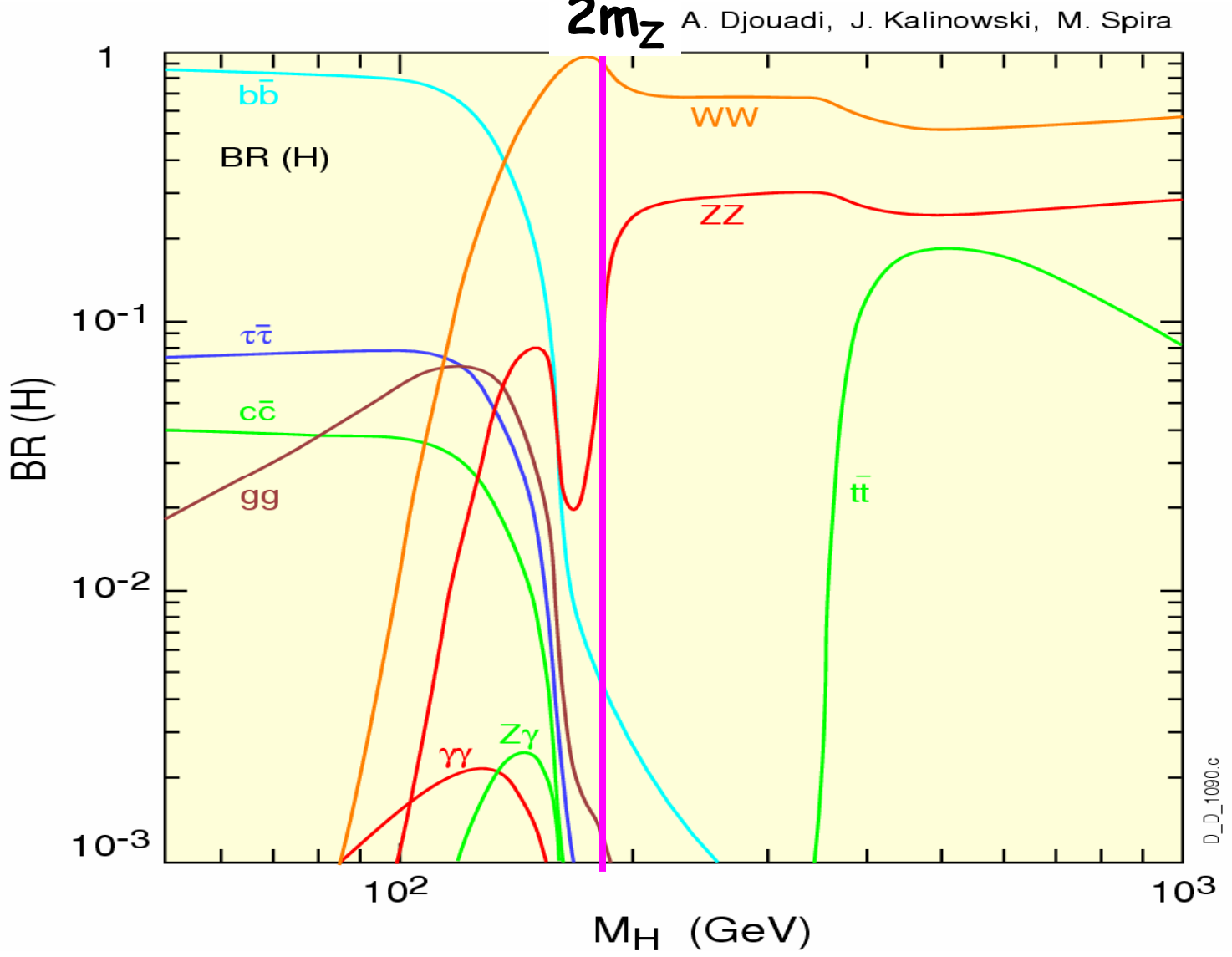
$$H \rightarrow$$ **Higgs boson !**

- **Give mass to fermions by Yukawa couplings**

$$m_f \bar{f} f + y_f H \bar{f} f, \qquad m_f = y_f \frac{v}{\sqrt{2}}$$

- SM Higgs decays

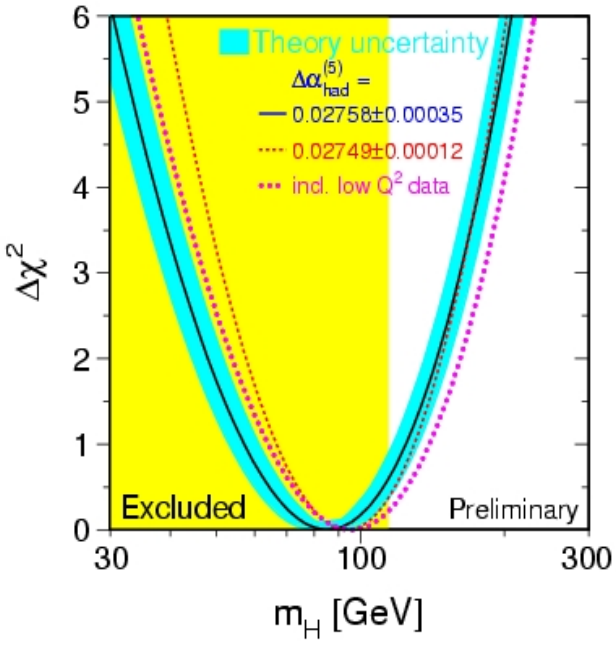
→ **Light higgs** ←



What we know about Higgs

- From precision measurements

$$M_H = 85^{+39}_{-28}\,\mathrm{GeV/c^2}$$

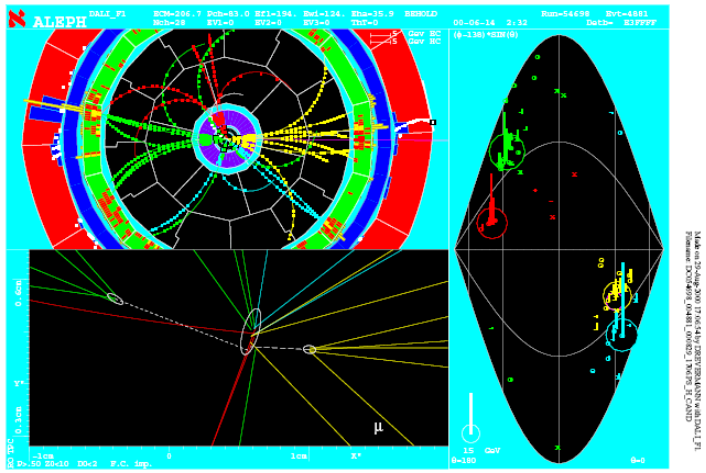


- From direct searches

$$M_H > 114.4\ \mathrm{GeV/c^2} \quad (95\%\ CL)$$

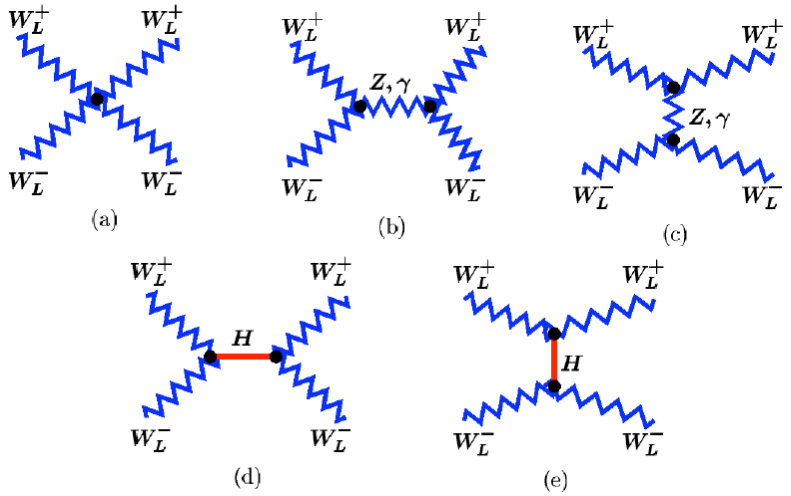
- Maybe even a hint!

4 jets from ALEPH



A Must: Higgs or something else!

- **Quantum field theory with massive exchange particles fails at high energies:**



Graphs	$g^2\frac{E^2}{m_w^2}$
(a)	$+2-6\cos\theta$
(b)	$-\cos\theta$
(c)	$-\frac{3}{2}+\frac{15}{2}\cos\theta$
(d + e)	$-\frac{1}{2}-\frac{1}{2}\cos\theta$
Sum including (d+e)	**0**

- $\mathcal{O}(E^0) \Rightarrow$ 4d m_H bound: $m_H < \sqrt{16\pi/3}\,v \simeq 1.0$ TeV
- If no Higgs $\Rightarrow \mathcal{O}(E^2) \Rightarrow$ $E < \sqrt{4\pi}\,v \simeq 0.9$ TeV

If nothing happens, something must happen!

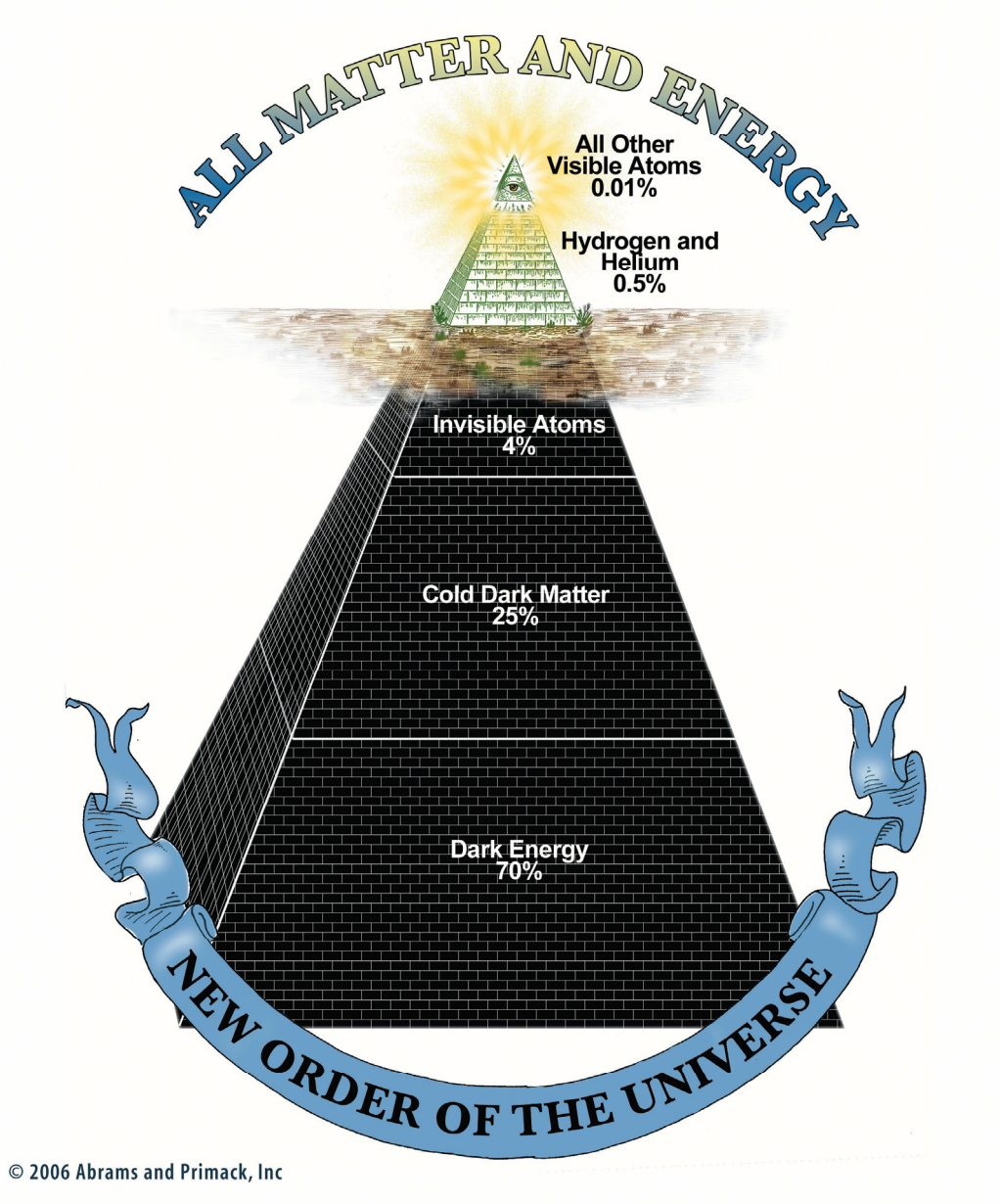
Also other things …

So the picture of the Universe is not this:

but

The "Top of Pyramid" picture of our understanding of universe.

Next step is to address this at accelerators and find the corresponding particles and understand what Dark Matter and Dark Energy are



What we expect from LHC

- Case I. A light Higgs discovered

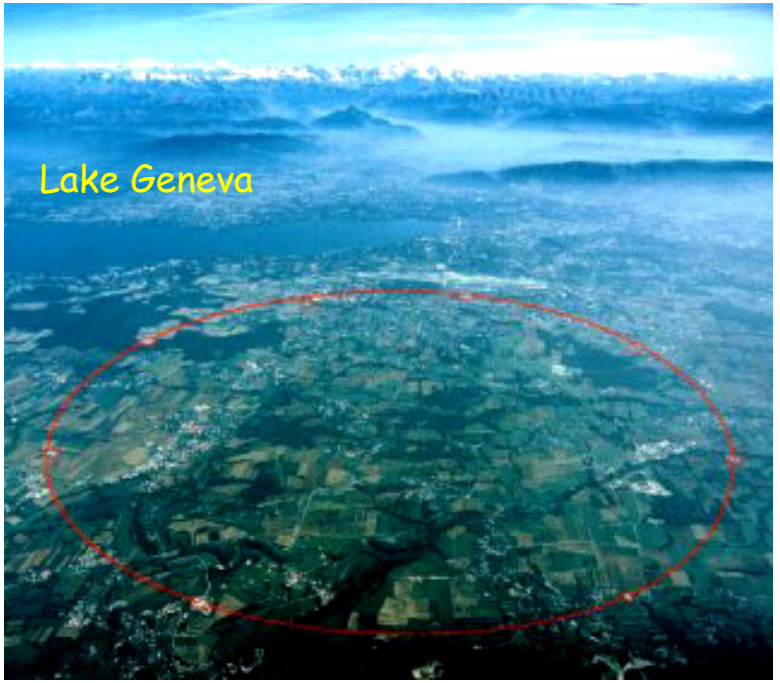
  - Nobel Prize!
  - Is the Higgs the Higgs ? Mass, width, spin, couplings …

- Case II. No light Higgs discovered

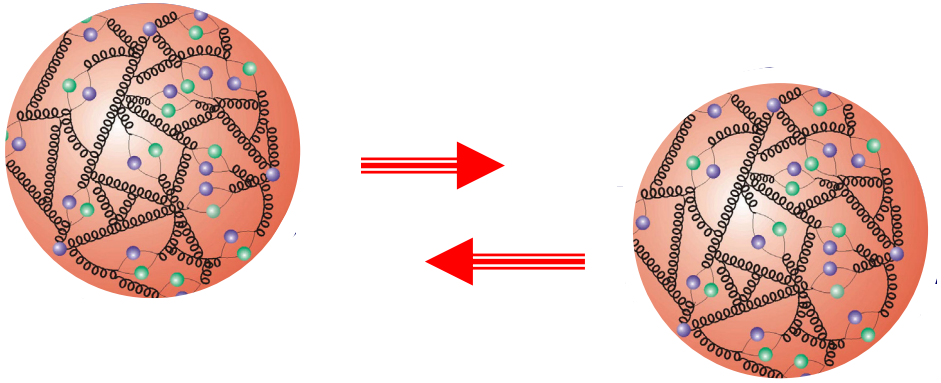
  - Even bigger discovery!
  - Nobel Prize?
  - Does it mean light Higgs not existed? Probably not…
  - We may have to re-consider the design, e.g. ILC or CLIC…

Some aspects of LHC

The 14 TeV (E_{CM}), 27 km circumference Large Hadron proton-proton Collider at CERN on the Swiss-French border – complete in 2008. The LHC will be the highest energy accelerator for many years.

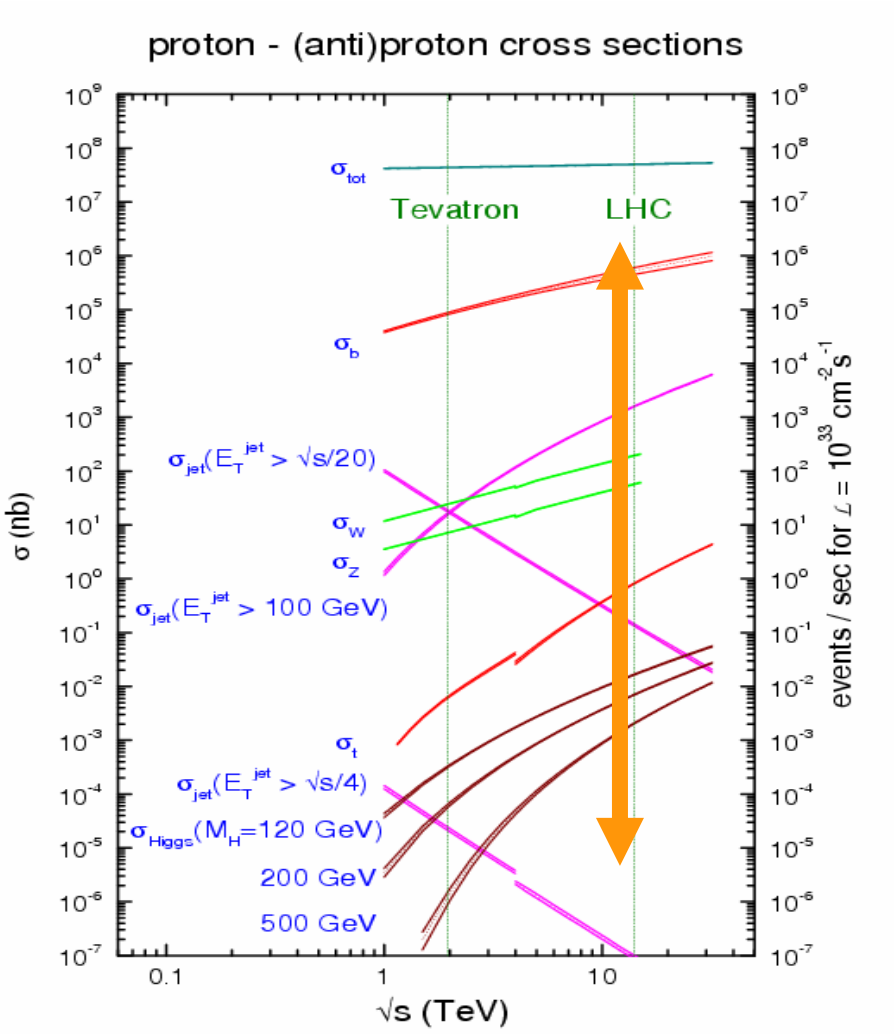


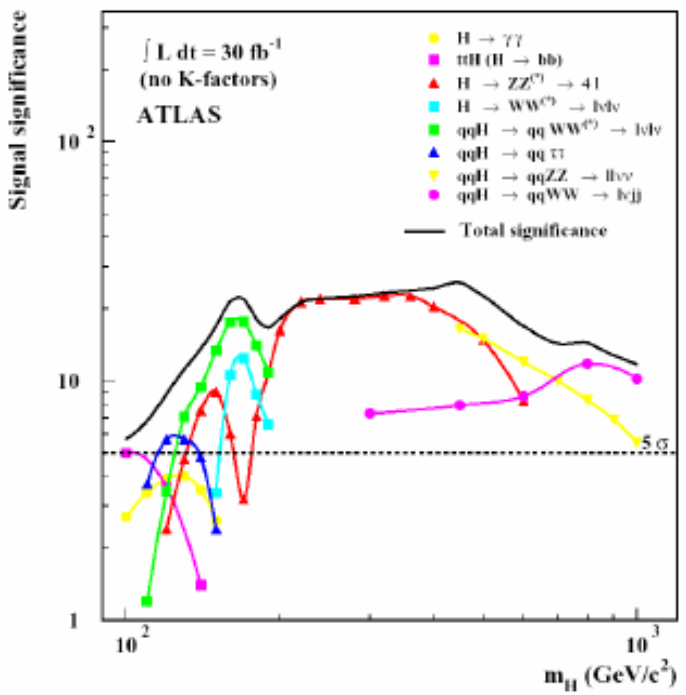
But …

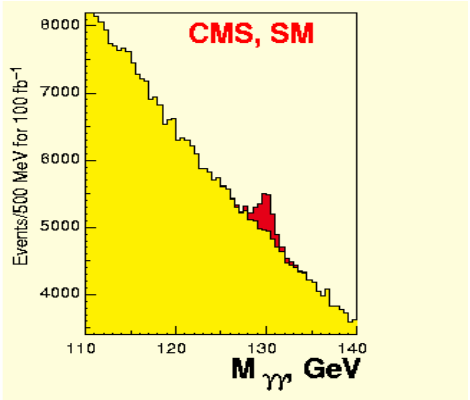


The protons are bags of many quarks and gluons (partons) which share the proton beam momentum. Parton collisions have a wide range of energies – up to ~2000 GeV. Initial angular momentum state is not fixed.

- **Find the light Higgs could be challenging at LHC**







H→γγ

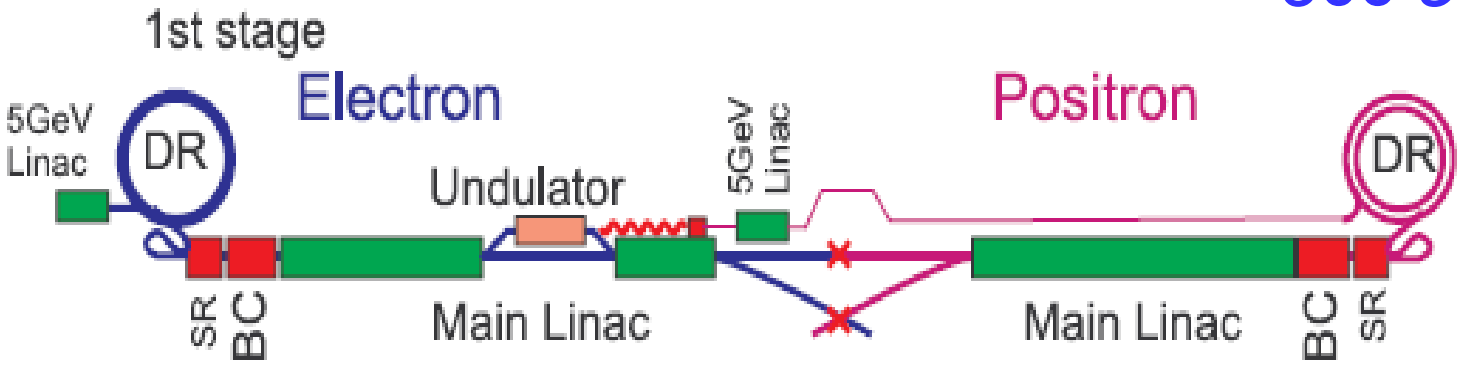
ILC basic parameters

- A machine colliding e^+e^-
- Parameter specification
  - Center of mass energy adjustable from 200 – 500 GeV
  - Luminosity → $\int L dt$ = 500 fb^{-1} in 4 years
  - Ability to scan between 200 and 500 GeV
  - Energy stability and precision below 0.1%
  - Electron polarization of at least 80%
  - Options for electron-electron and γ-γ collisions
  - The machine must be upgradeable to 1 TeV
- Three big challenges: energy, luminosity cost

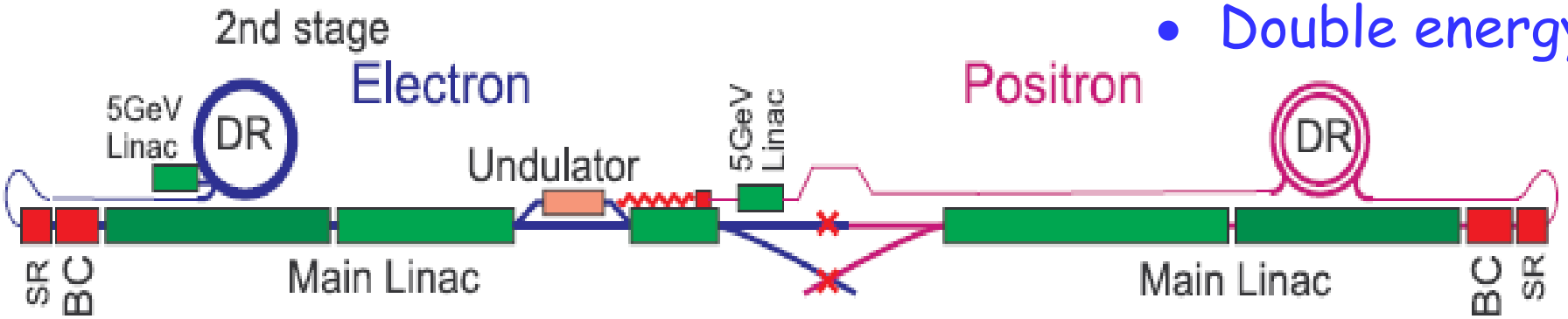
Baseline Configuration--Schematic

What is the ILC ?

- 500 GeV CM



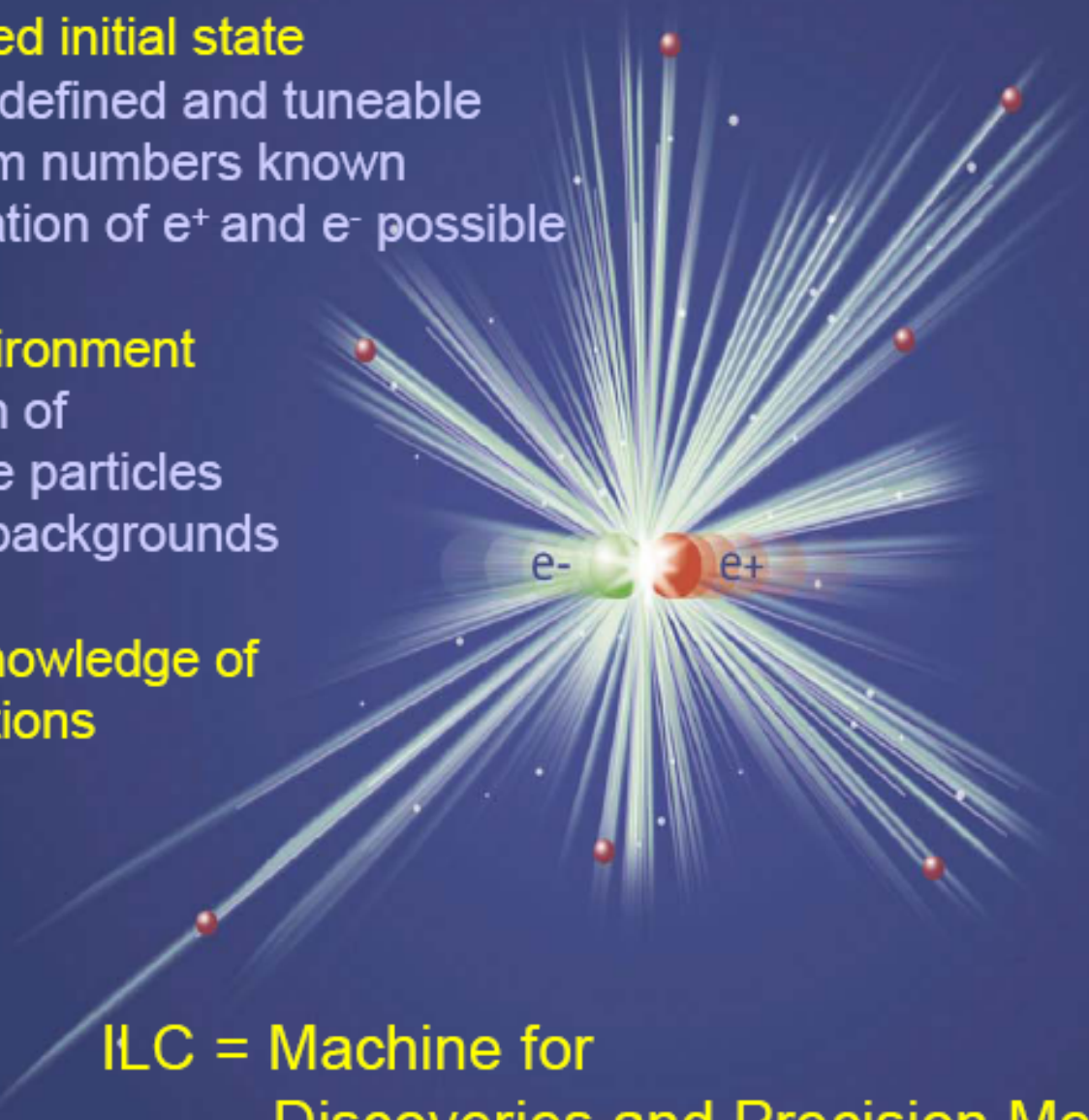
- Double energy



Given accel: ~35MV/m this implies large footprint (>30km)

The power of an Electron-Positron Linear Collider

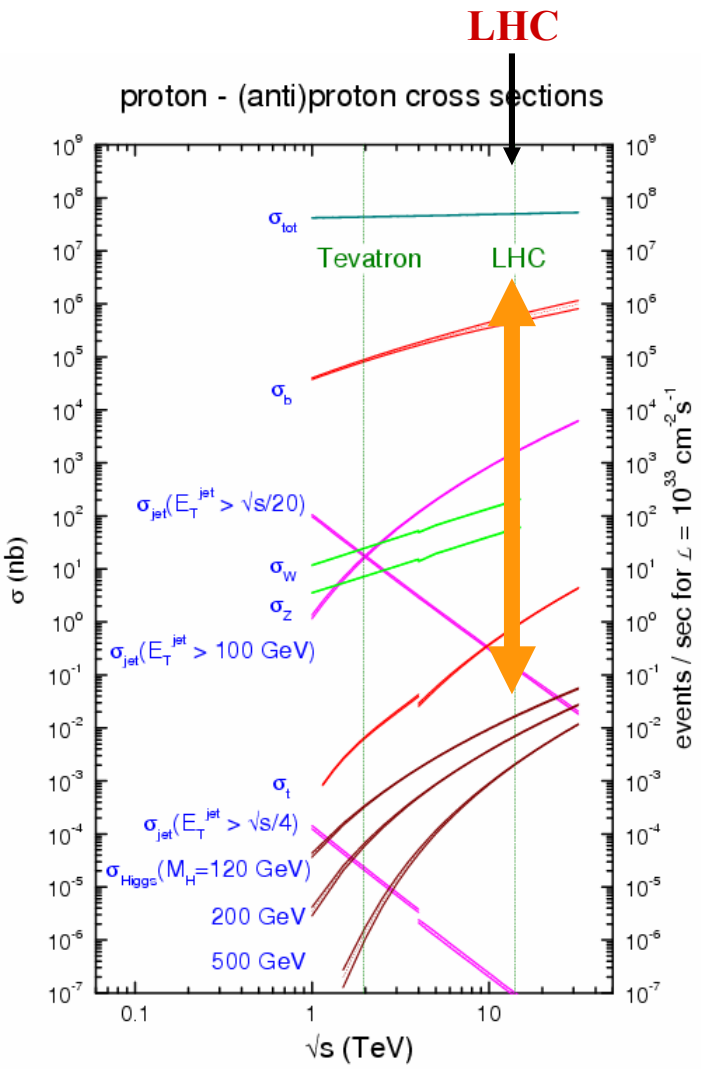
- well defined initial state
  - $\sqrt{s}$ well defined and tuneable
  - quantum numbers known
  - polarisation of e^+ and e^- possible
- clean environment
  - collision of pointlike particles
  - → low backgrounds
- precise knowledge of cross sections

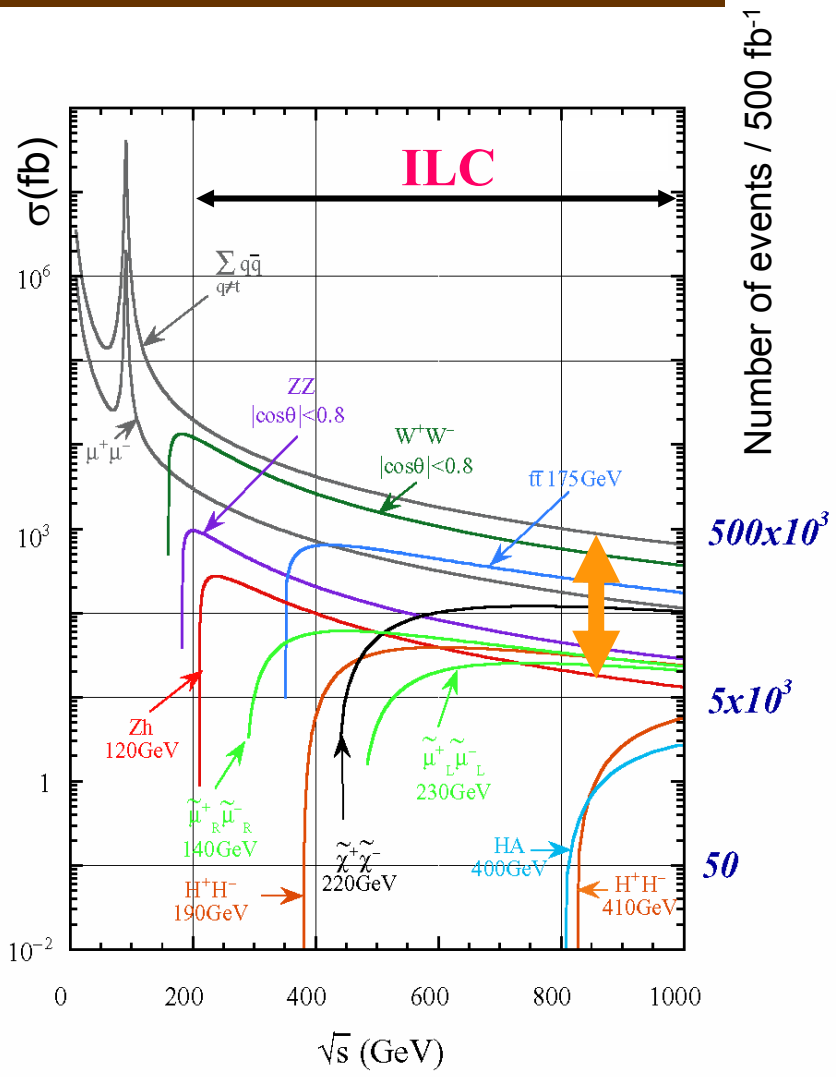


options:
e^-e^-, $e\gamma$, $\gamma\gamma$

ILC = Machine for
Discoveries and Precision Measurements

Signal and background Cross-section

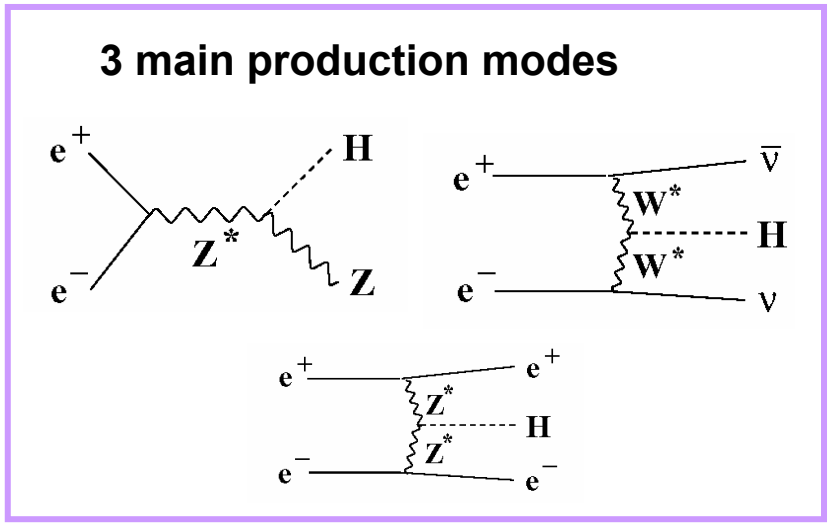


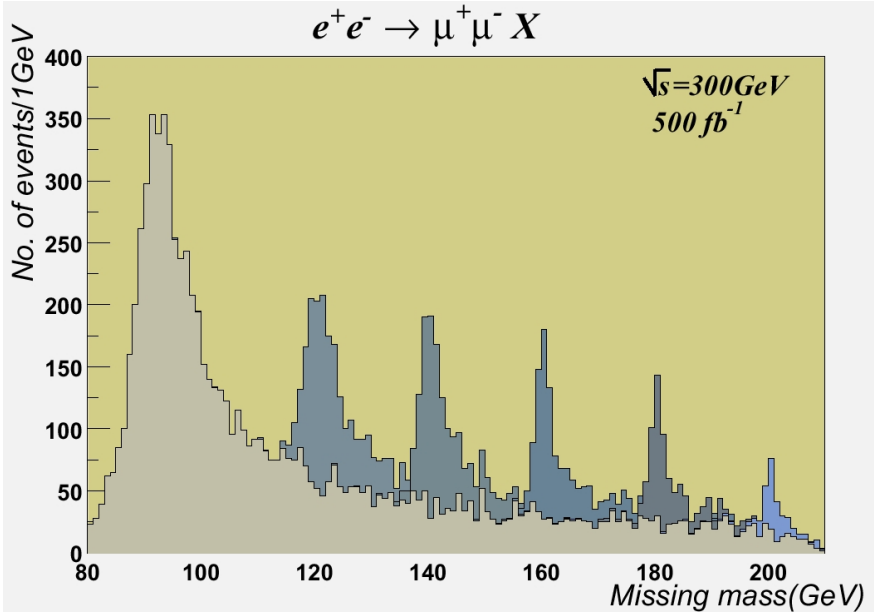


Physics at ILC

Discover the light Higgs if it exists

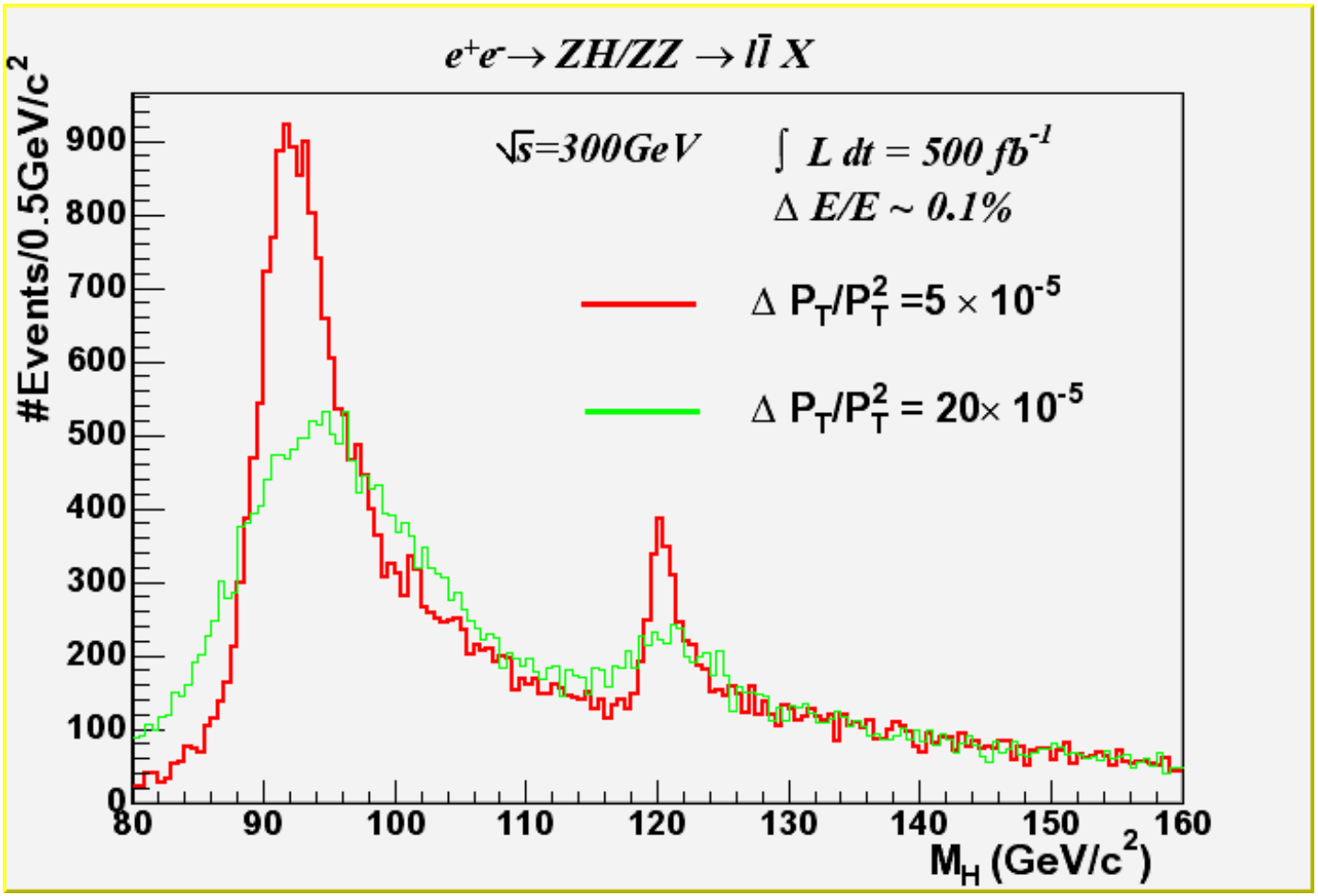
- Higgs mass measurement by Z recoil method
  - Model independent Higgs search
  - Δm_h~50MeV, $\Delta s/s$~3% possible in SM





- **A MUST: excellent tracker performance**

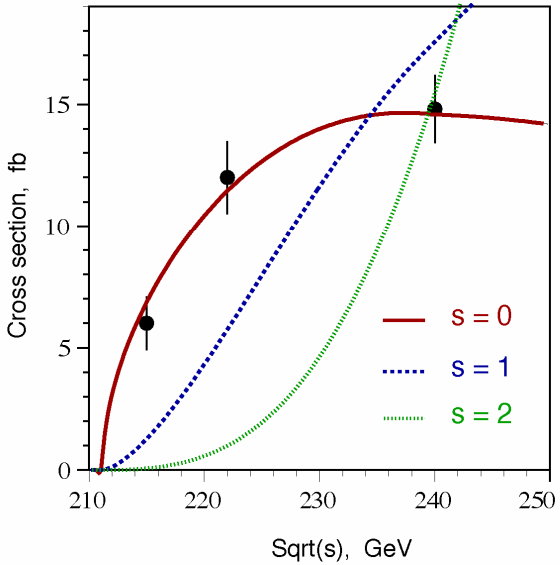
$$\sigma(1/p) = 5 \times 10^{-5}/\mathrm{GeV}$$

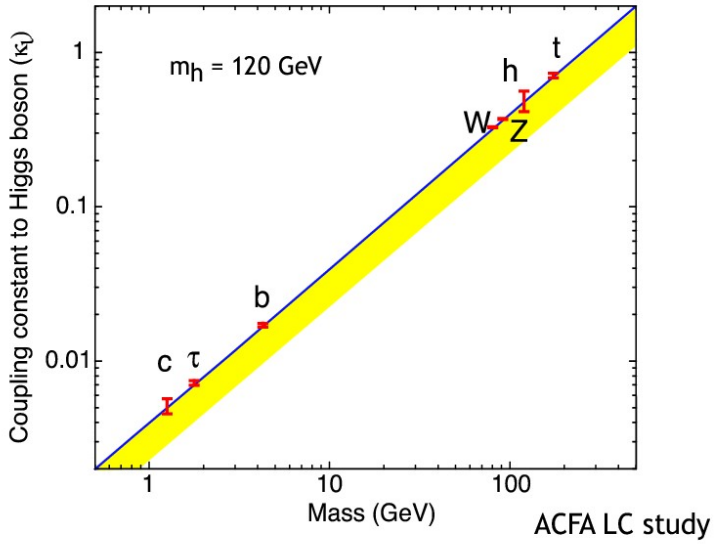


Physics at ILC

Measuring the properties of Higgs

- The linear collider will measure the spin of any Higgs it can produce by measuring the energy dependence from threshold



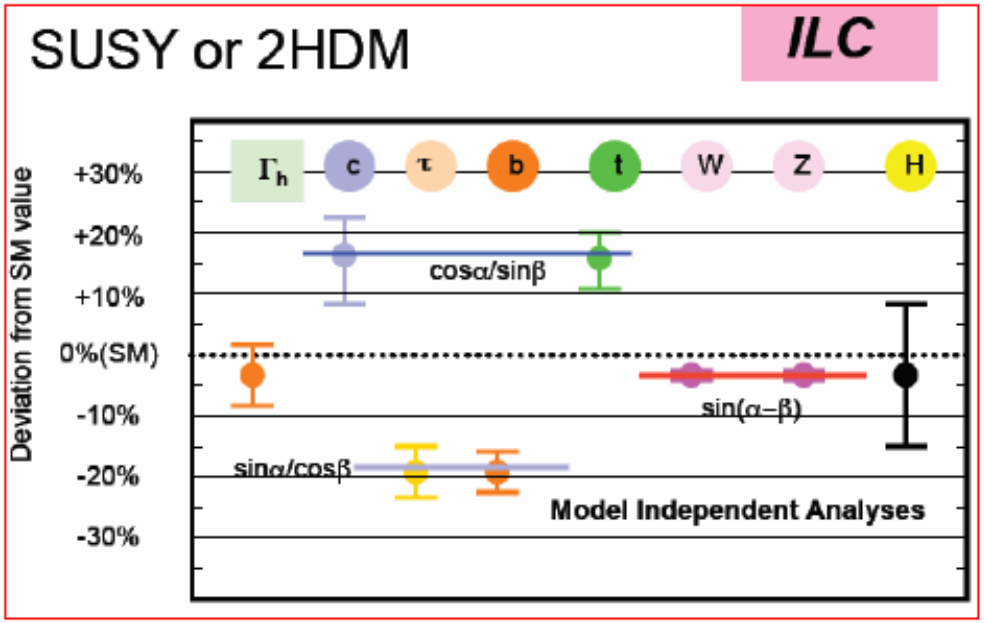


- Higgs couplings

- **A MUST: excellent vertex detection**

~1/5 rbeampipe,~1/30 pixel size (wrt LHC)

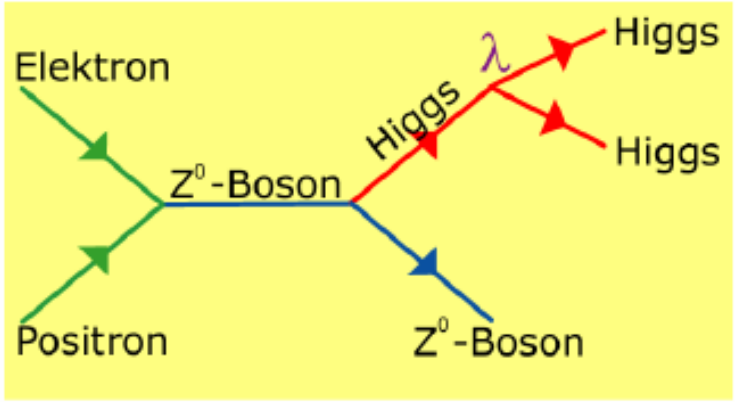
$$\sigma_{ip} = 5\mu m \oplus 10\mu m / p \sin^{3/2}\theta$$



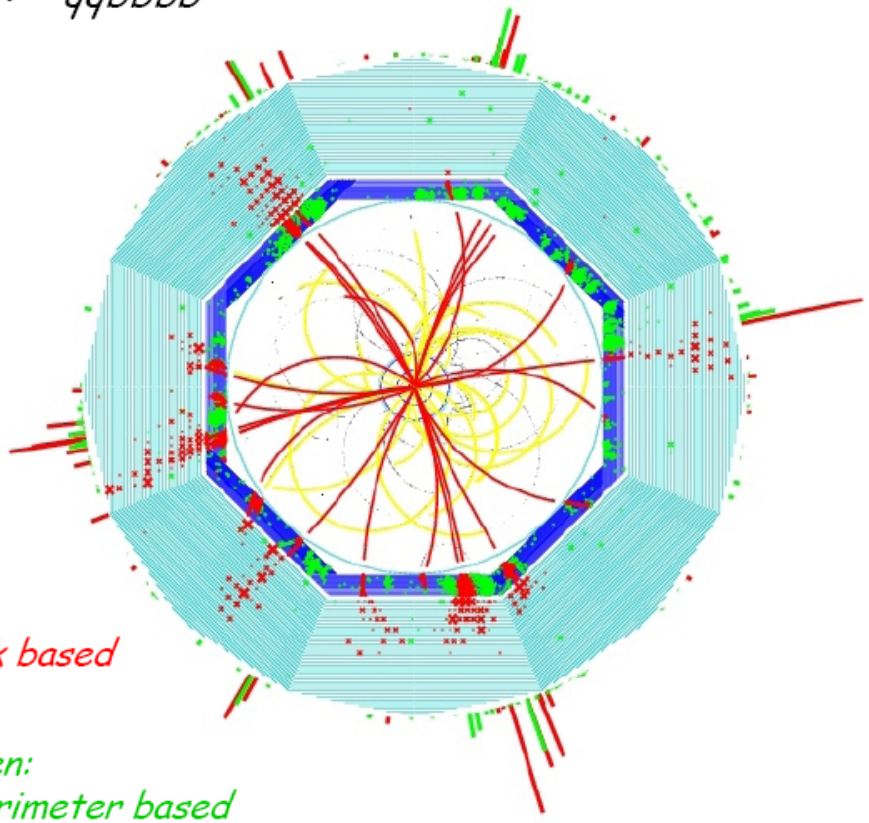
b-tag and also c-tag is essential

- **Higgs self coupling**

- **Is** the Higgs the Higgs?
- Check $\lambda = M^2_H/2v^2$



ZHH → qqbbbb



red:
track based

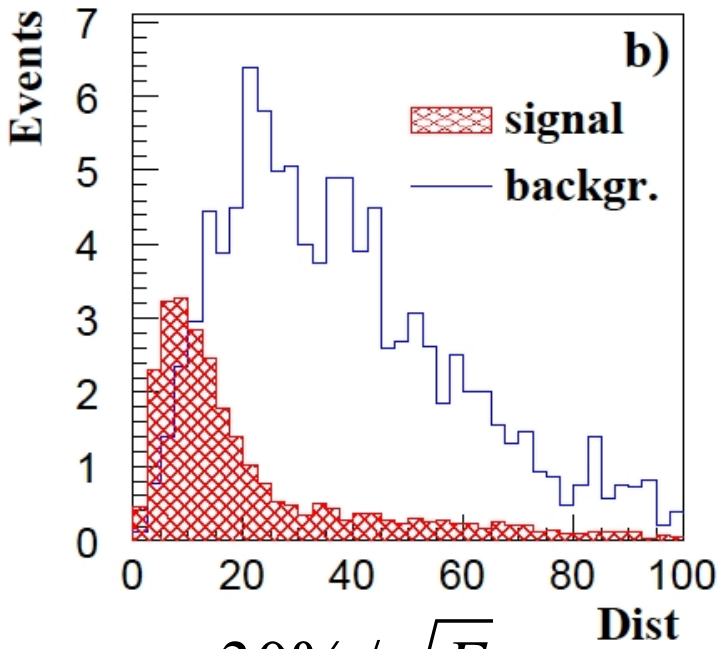
green:
calorimeter based

ee→ ZHH → 6 jets

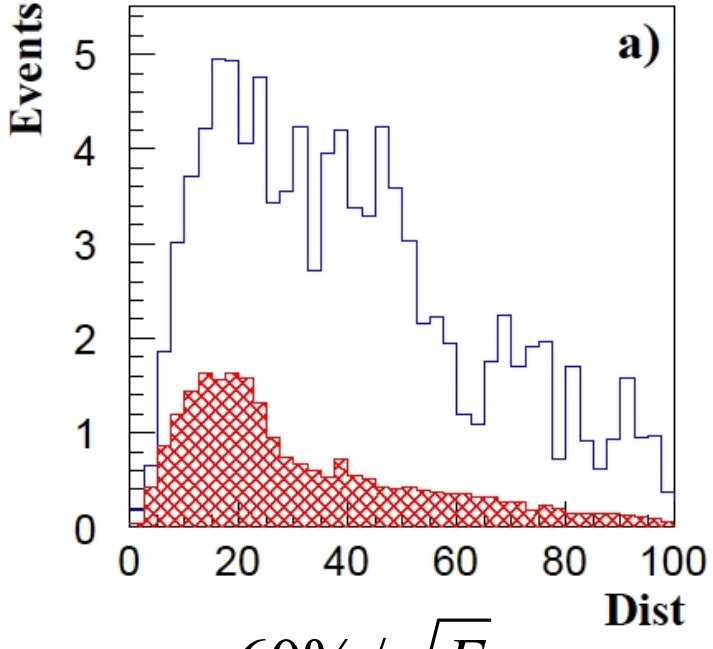
- few tens of events

- **A MUST: excellent jet energy resolution**

$$DIST = \sqrt{(M_{12} - M_h)^2 + (M_{34} - M_h)^2 + (M_{56} - M_Z)^2}$$



$30\%/\sqrt{E}$

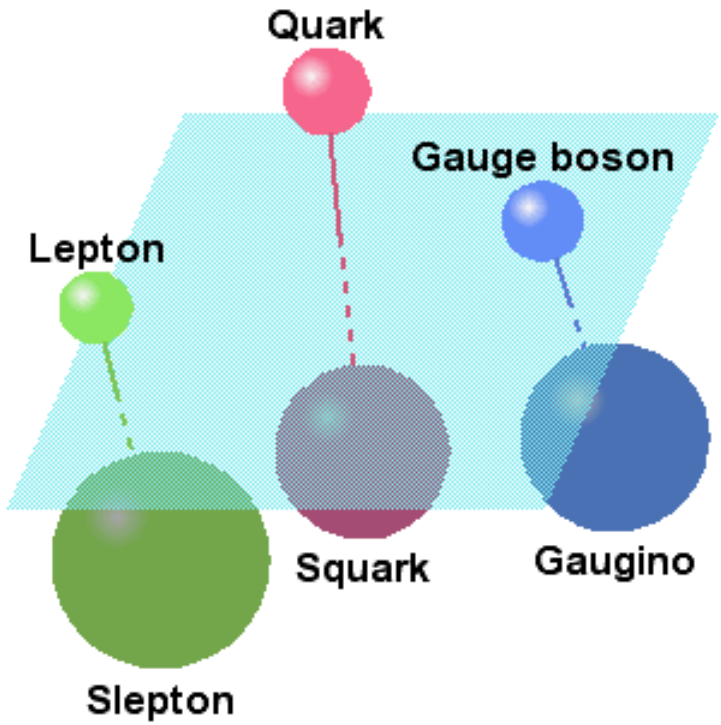


$60\%/\sqrt{E}$

Physics at ILC

Supersymmetry

Bosons ⟷ **Fermions**

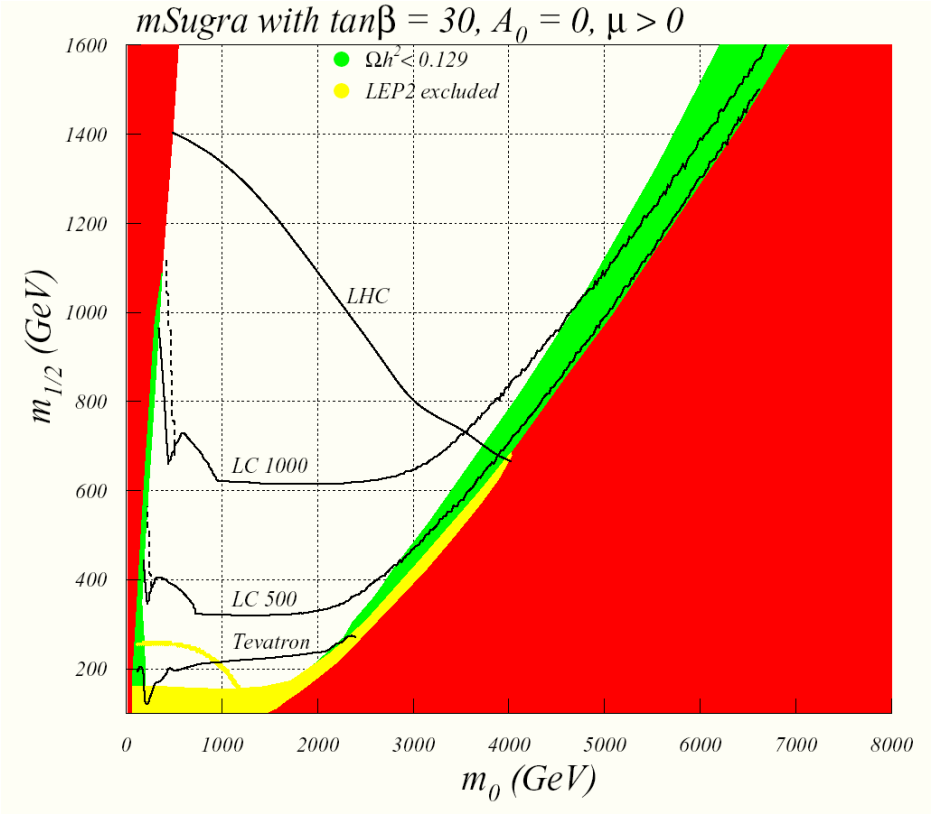


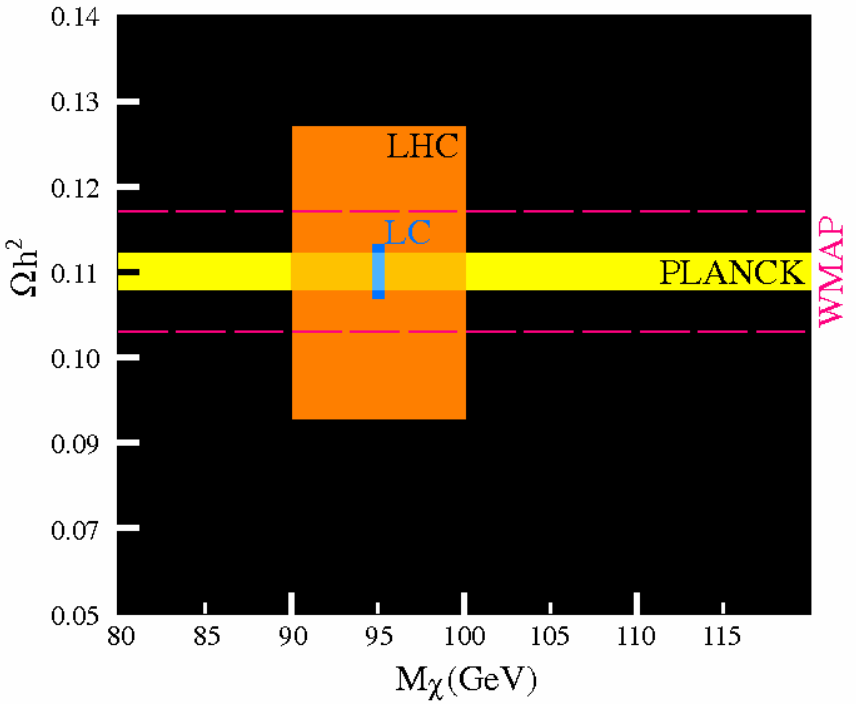
Virtues of Supersymmetry:

- Unification of Forces
- The Hierarchy Problem
- Dark Matter

...

Cosmology: Dark Matter = LSP?



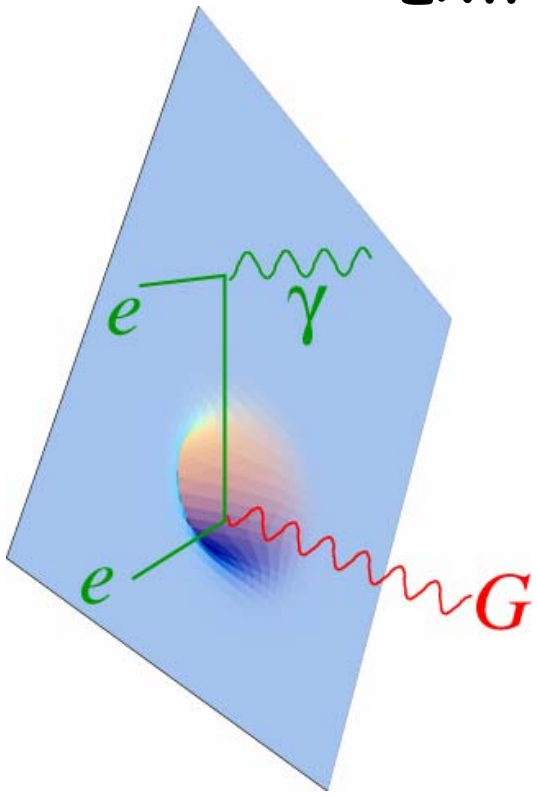


WMAP .094 < Ωh^2 < .128 (2 sigma)

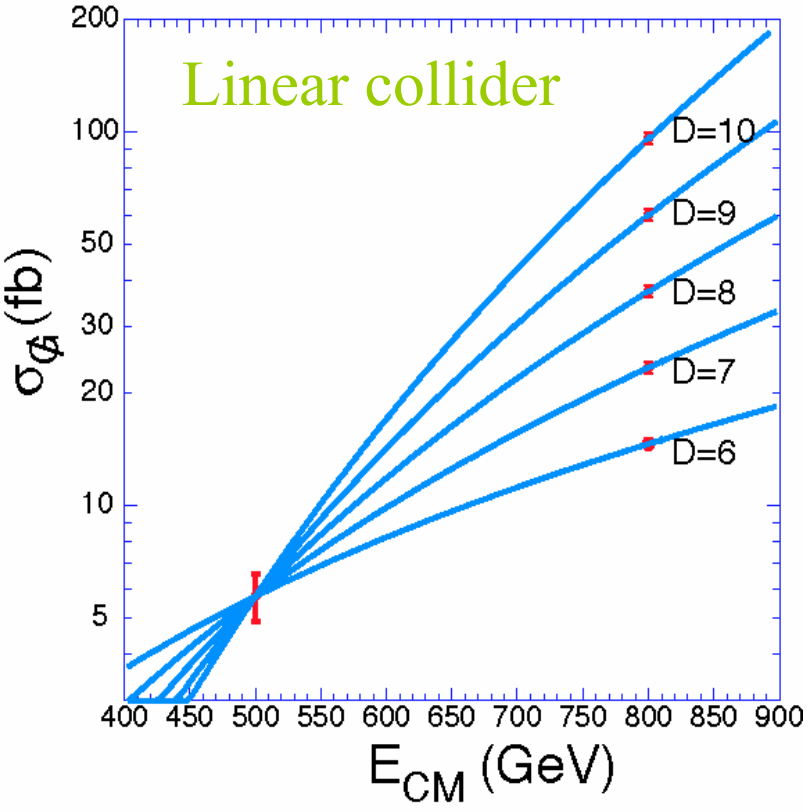
'WMAP'	7 %
LHC	~15 %
'Planck'	~2 %
ILC	~3 %

Physics at ILC

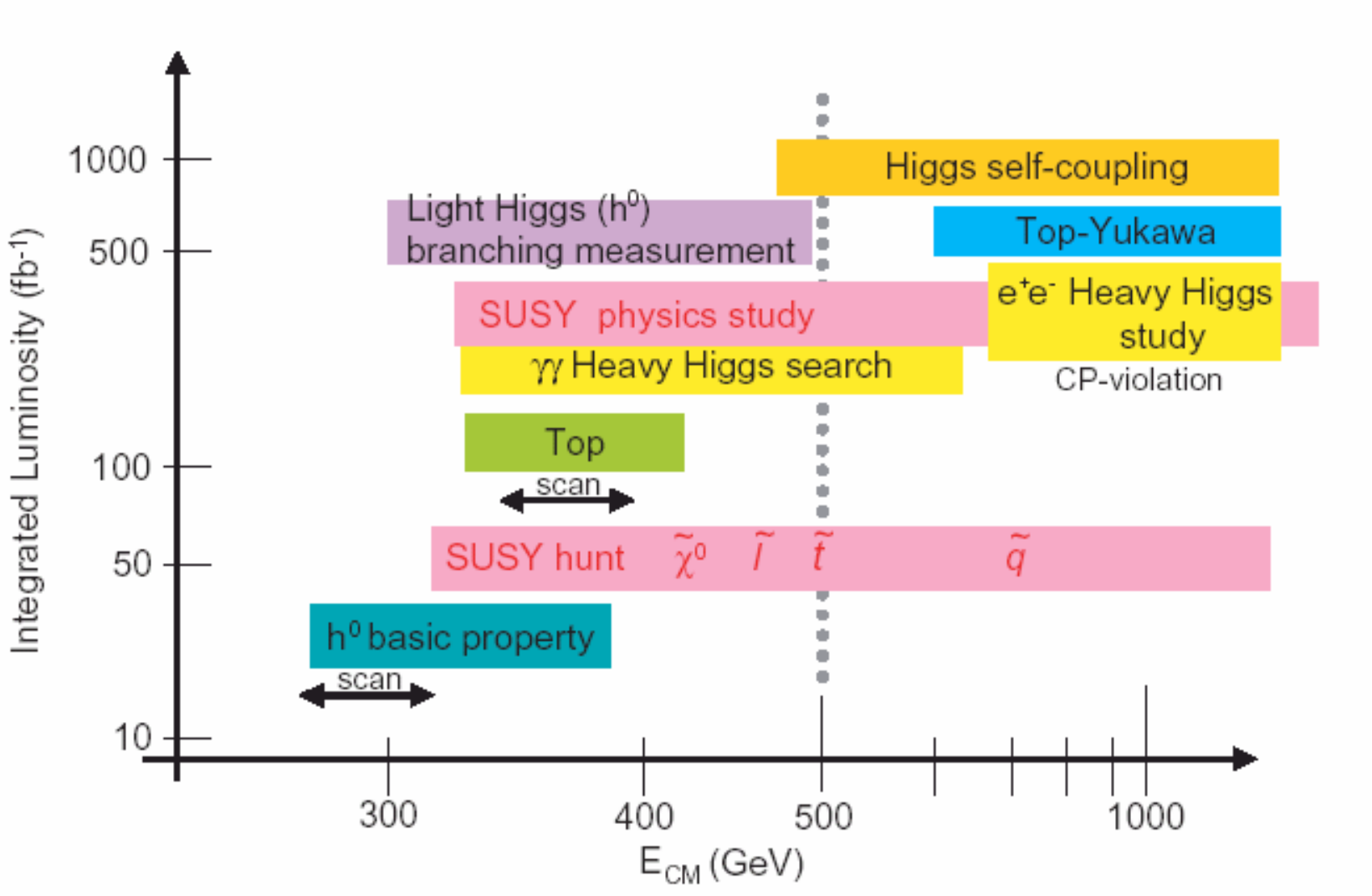
Extra Dimensions



New space-time dimensions can be mapped by studying the emission of gravitons into the extra dimensions, together with a photon or jets emitted into the normal dimensions.



Physics reach covered by ILC



Some basic parameters for detector design

(http://blueox.uoregon.edu/~lc/randd.pdf)

- Vertexing $(h \to b\bar{b}, c\bar{c}, \tau^+\tau^-)$
  - ~1/5 $r_{beampipe}$, ~1/30 pixel size (wrt LHC)

$$\sigma_{ip} = 5\mu m \oplus 10\mu m / p \sin^{3/2}\theta$$

- Tracking $(e^+e^- \to Zh \to \ell^+\ell^- X; \quad \text{incl. } h \to \text{nothing})$
  - ~1/6 material, ~1/10 resolution (wrt LHC)

$$\sigma(1/p) = 5 \times 10^{-5}/GeV \quad \text{or better}$$

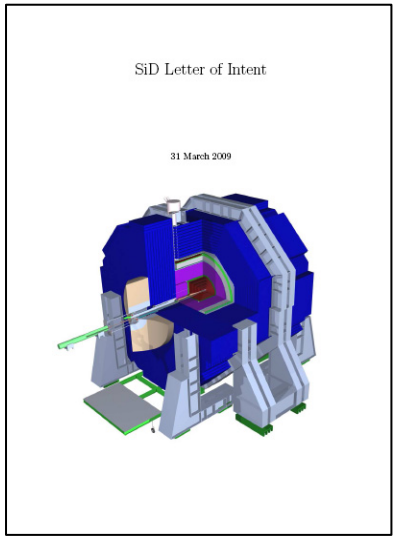
- Jet energy (Higgs self-coupling, W/Z sep. in SUSY study)
  - ~1/2 resolution (wrt LHC)

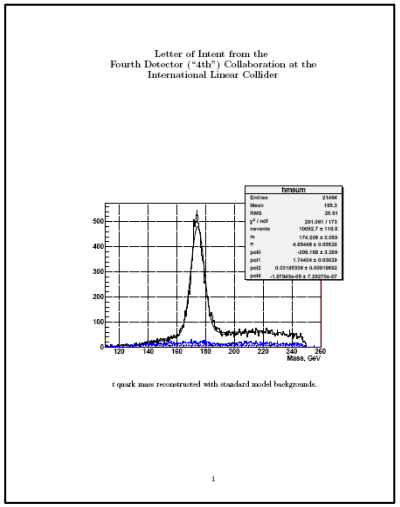
$$\sigma_E / E = 0.3 / \sqrt{E(GeV)}$$

Detector Concepts

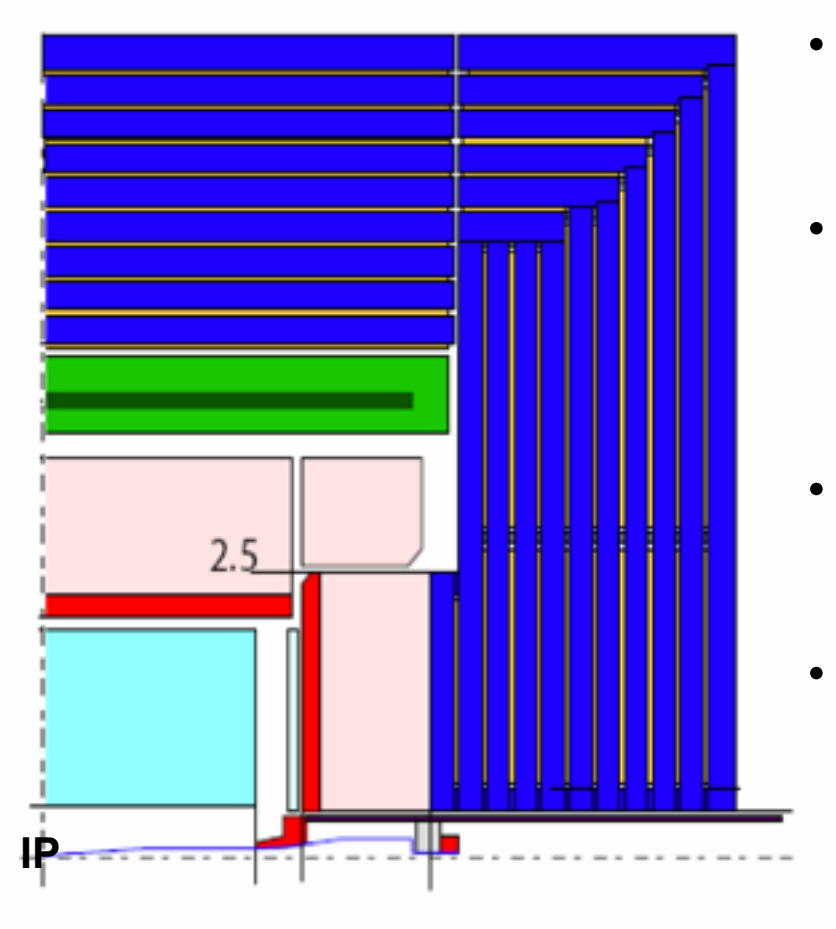
- Up to March 31,2009 , three "Letter of Intent (LOI)" submitted

  - ILD
  - SiD
  - 4th





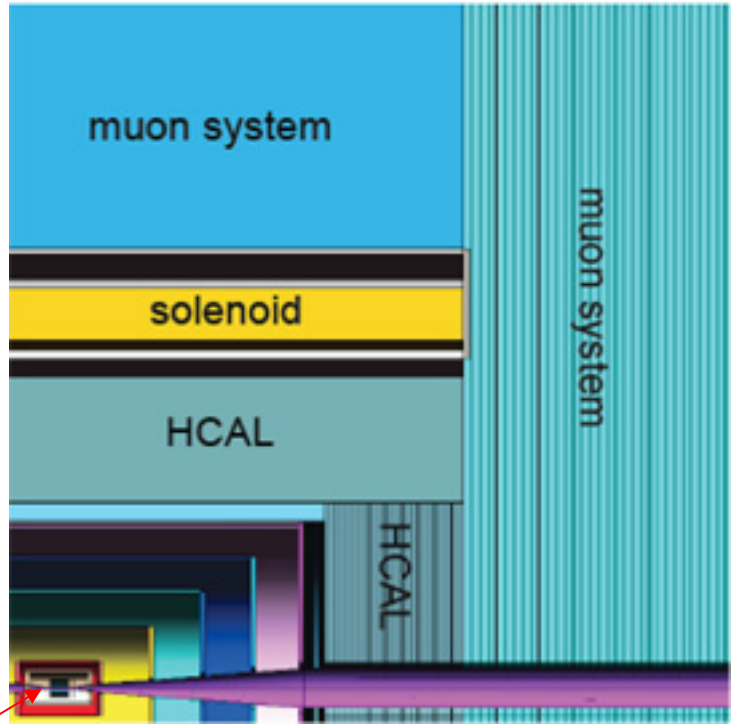
Detector Concepts - ILD



- LDC + GLD
- VTX + SI + TPC + CAL + SC Mag (3~4T) + Muon
- PFA
- Versatile detector with high precision, high reliability

OD ~ 14.4m, L ~ 15m total

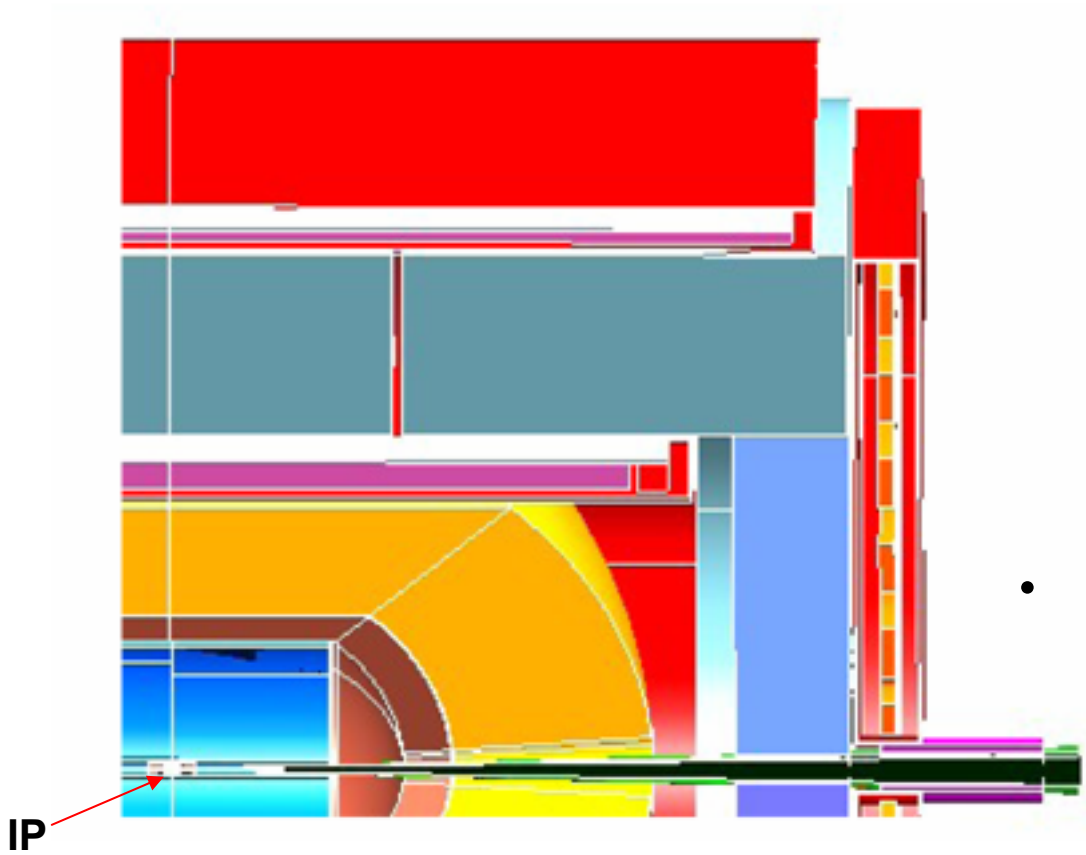
Detector Concepts - SiD



OD ~ 12 m, L ~ 12 m total

- VTX + Si-based tracker + Si/W ECAL + HCAL + SC Mag (~5T) + Muon
- Active use of Si technology
- PFA
- Versatile, compact detector with high precision, high reliability

Detector Concepts – 4th



OD ~ 12 .8 m, L ~ 15.4 m total

- VTX + Cluster-counting tracker (low-mass) + CAL with dual-readout + Iron-free dual-solenoid (~1.6T/3T) + CluCou muon tracker

- General-purpose detector with a very innovative approach to calorimetry, tracking and field configuration.

Jet Reconstruction Methods

Two approaches

- PFA (particle flow algorithm) - ILD & SiD
  - Measure charged particles with trackers
  - Measure neutrals with calorimeters
  - Remove over-counting (e.g. charged hadron showers)
  - Requires fine granularity and sophisticated logic

- Compensating calorimetry - 4th
  - Measure EM and hadronic shower components separately
  - Re-weight them to obtain jet energy

Jet reconstruction

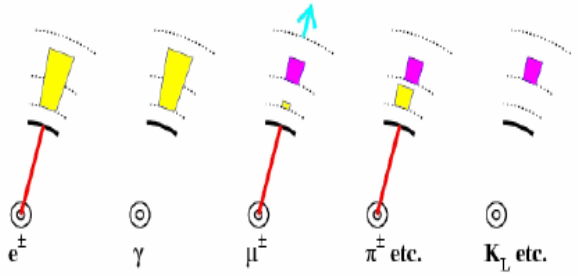
- **Particle Flow Algorithm (PFA)**

First measure charged particles (62%):

-momenta measured with tracking chambers

-merge track to calorimeter clusters

-substitute calorimeter energy with momentum

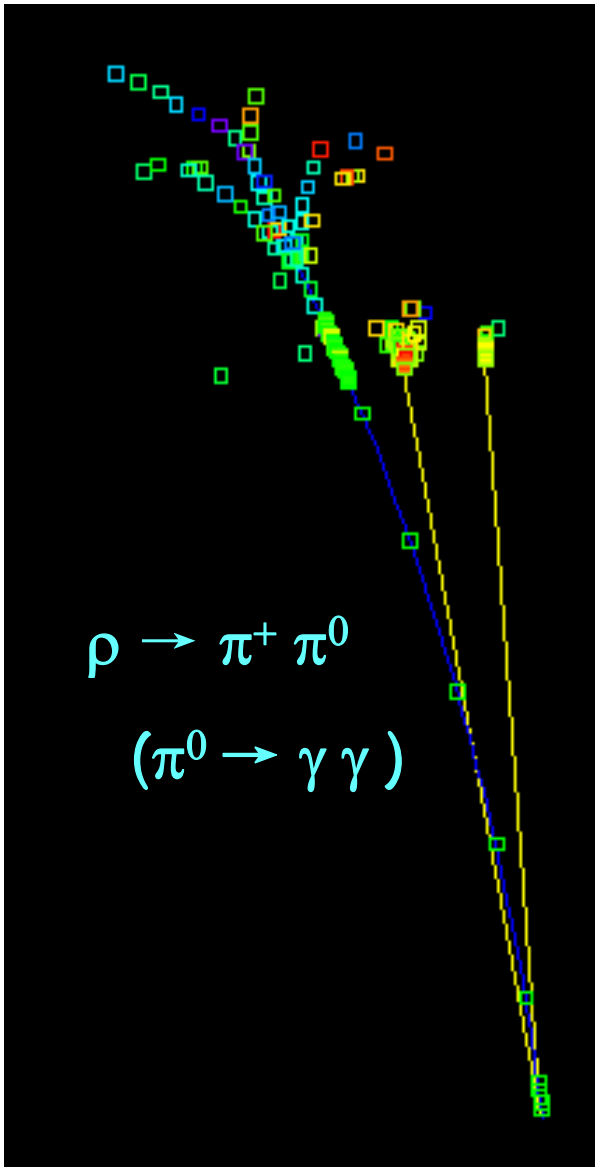


The rest of energy in the calorimeter is assigned to neutral clusters:

photons (26%):

neutral hadrons (10%)

➔ This method requires extremely high granularity



Summary

- Experimental tests of EWSB mechanism is curial : the origin of mass !
- Strong physics cases for a linear collider
- New detector technology needed to reach the physics goal
- World-wide studies are going on