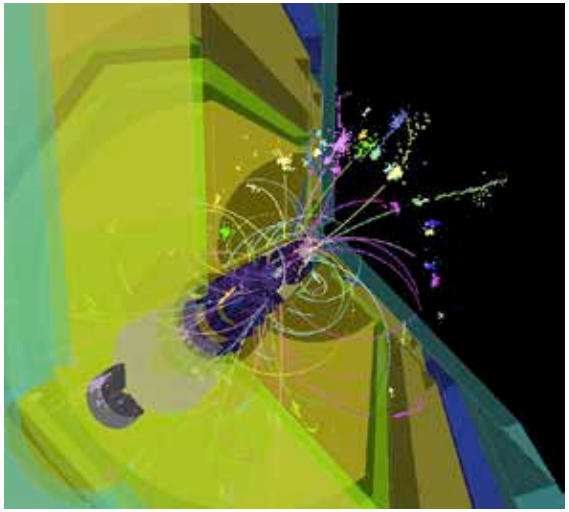
Physics at the ILC

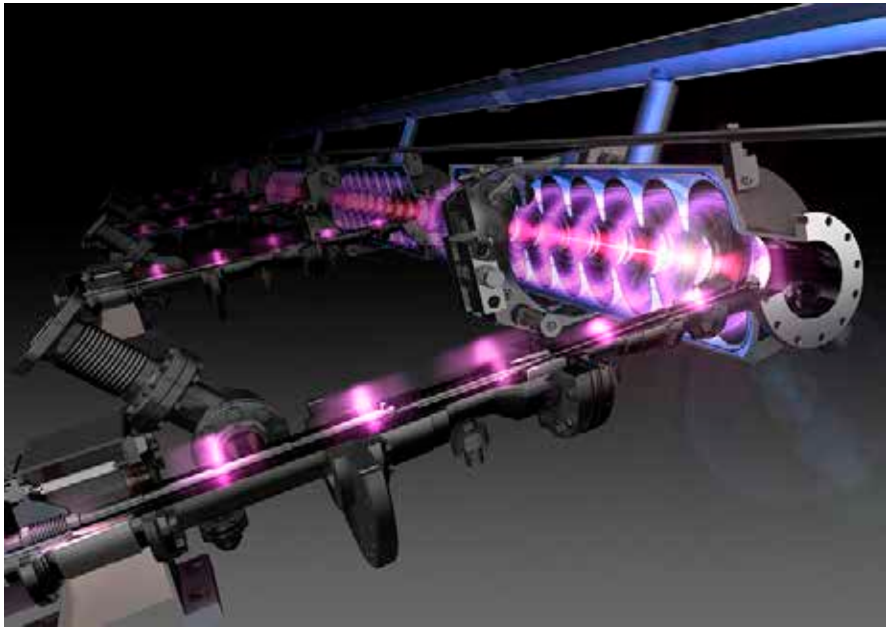
Tomohiko Tanabe
ICEPP, The University of Tokyo

July 17, 2013, Kavli IPMU
School on the Future of Collider Physics

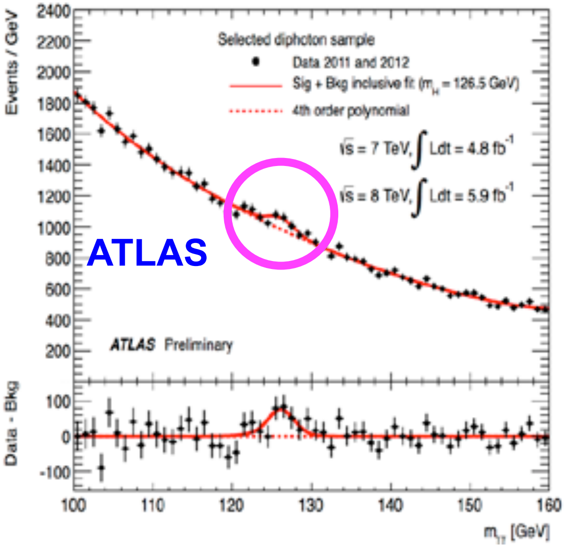
Outline

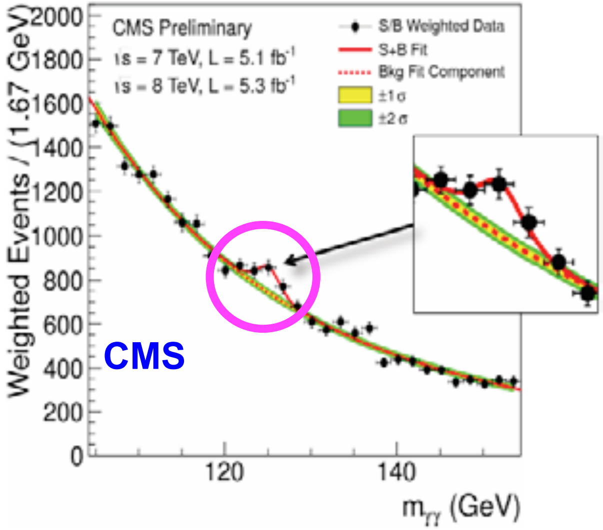


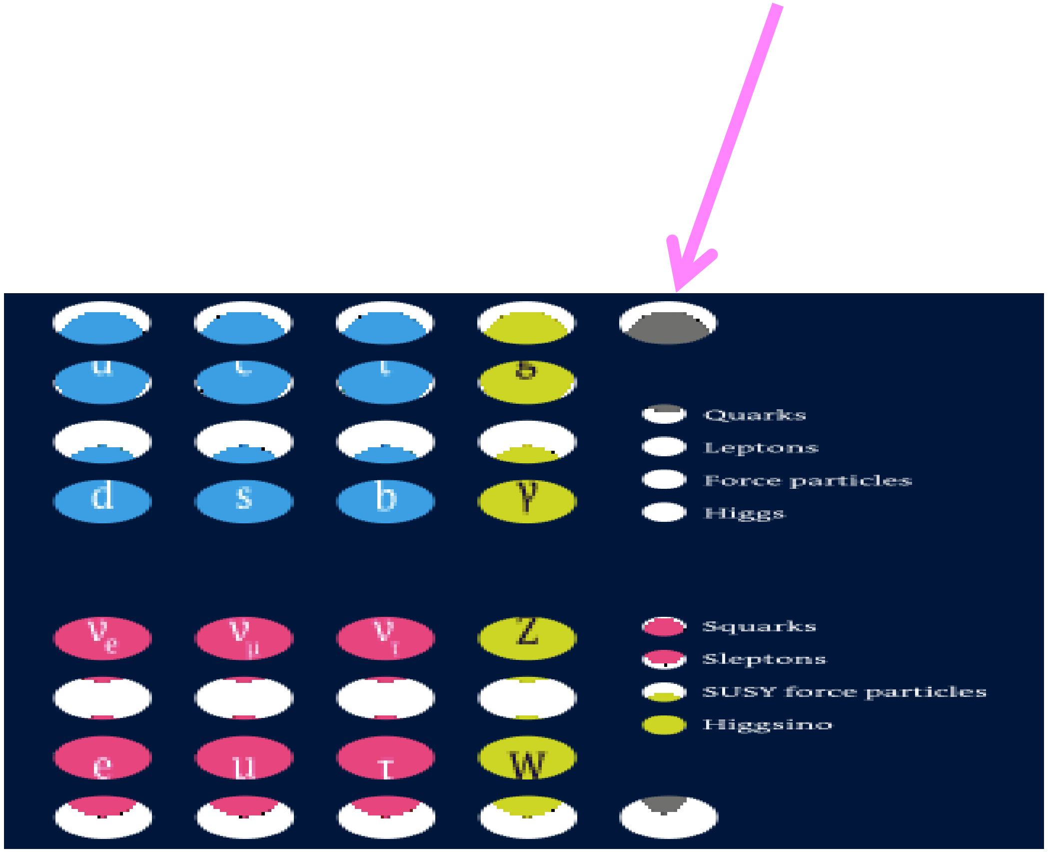
- Introduction
- Detectors & Event Reconstruction
- SUSY/DM at ILC
- Higgs Physics at ILC



July 4, 2012 – Discovery of new boson

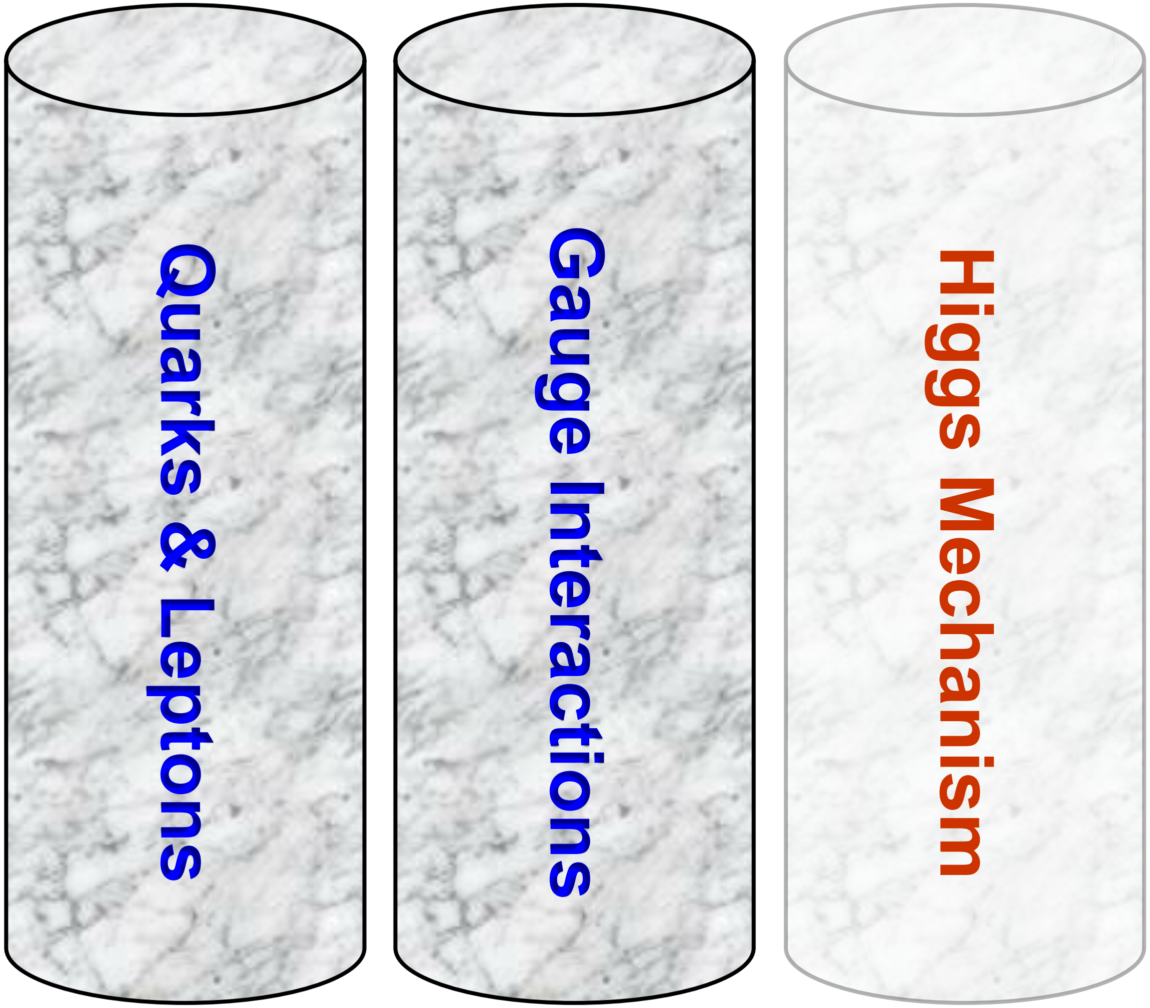






Now known as “a Higgs boson”

Pillars of Standard Model

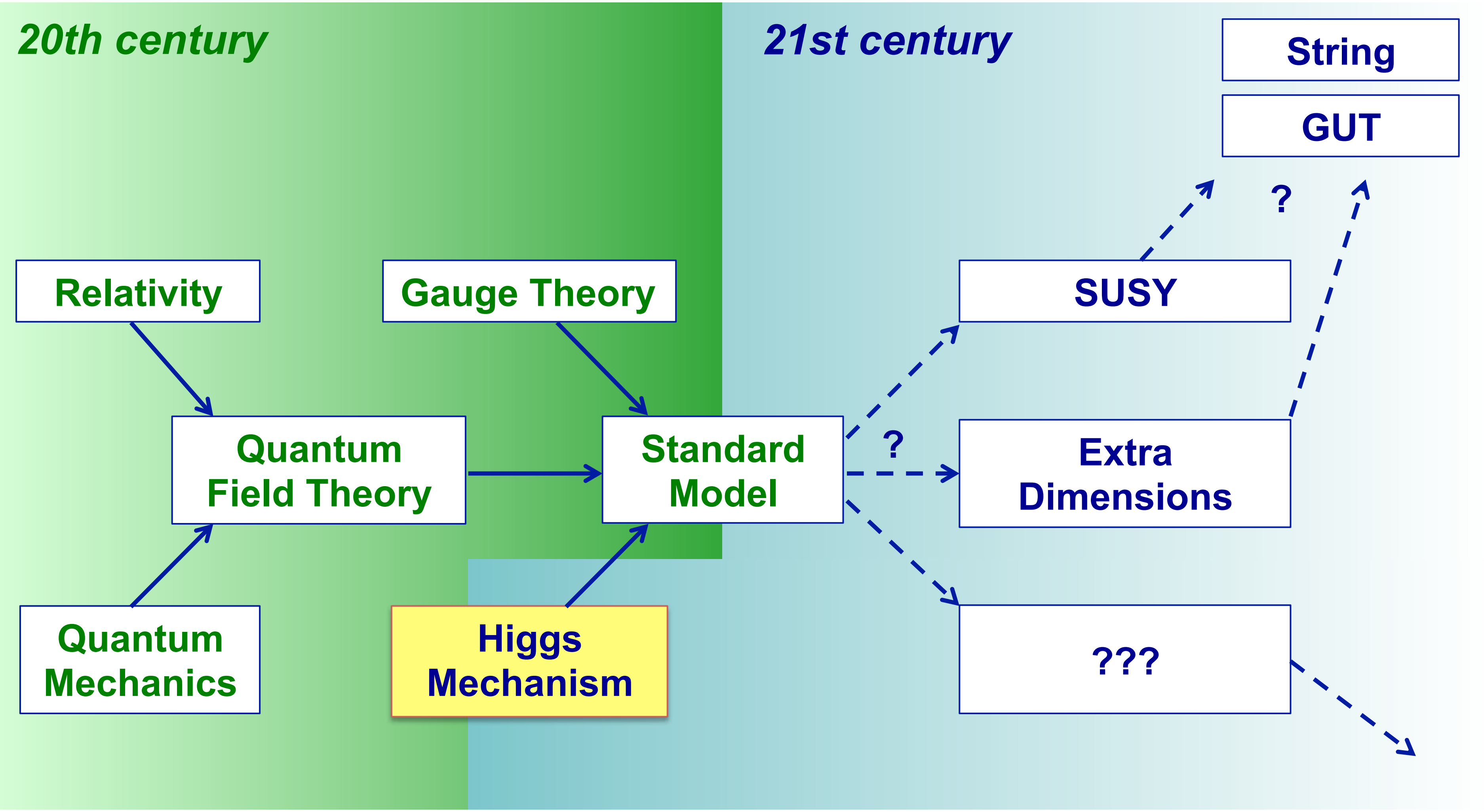


Quarks & Leptons

Gauge Interactions

Higgs Mechanism

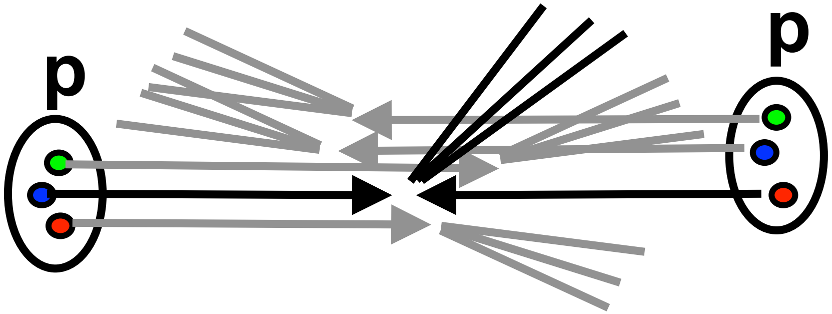
Brief History + Future of Particle Physics



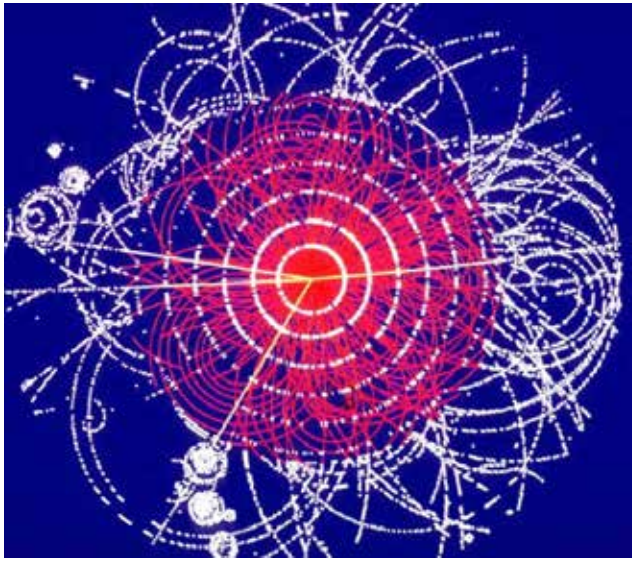
To be probed by
***colliders,** neutrino, dark matter search, astrophysics…*

Energy Frontier Colliders

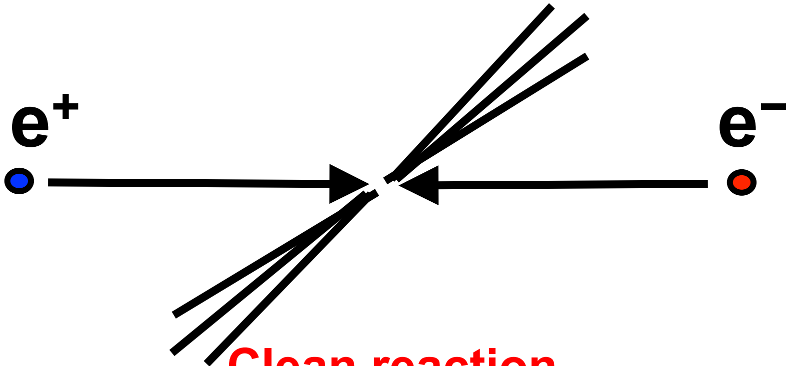
LHC: pp collider



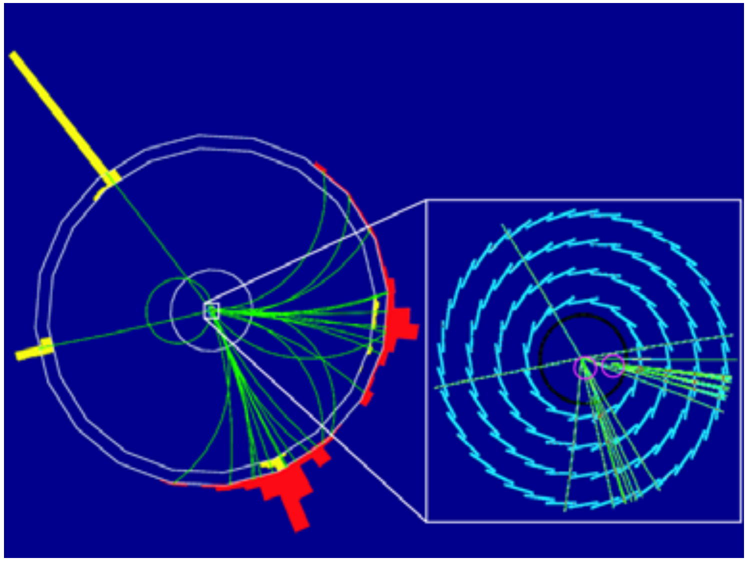
Multiple reactions
Initial energy unknown
CM energy: 7-14 TeV



ILC: e^+e^- collider

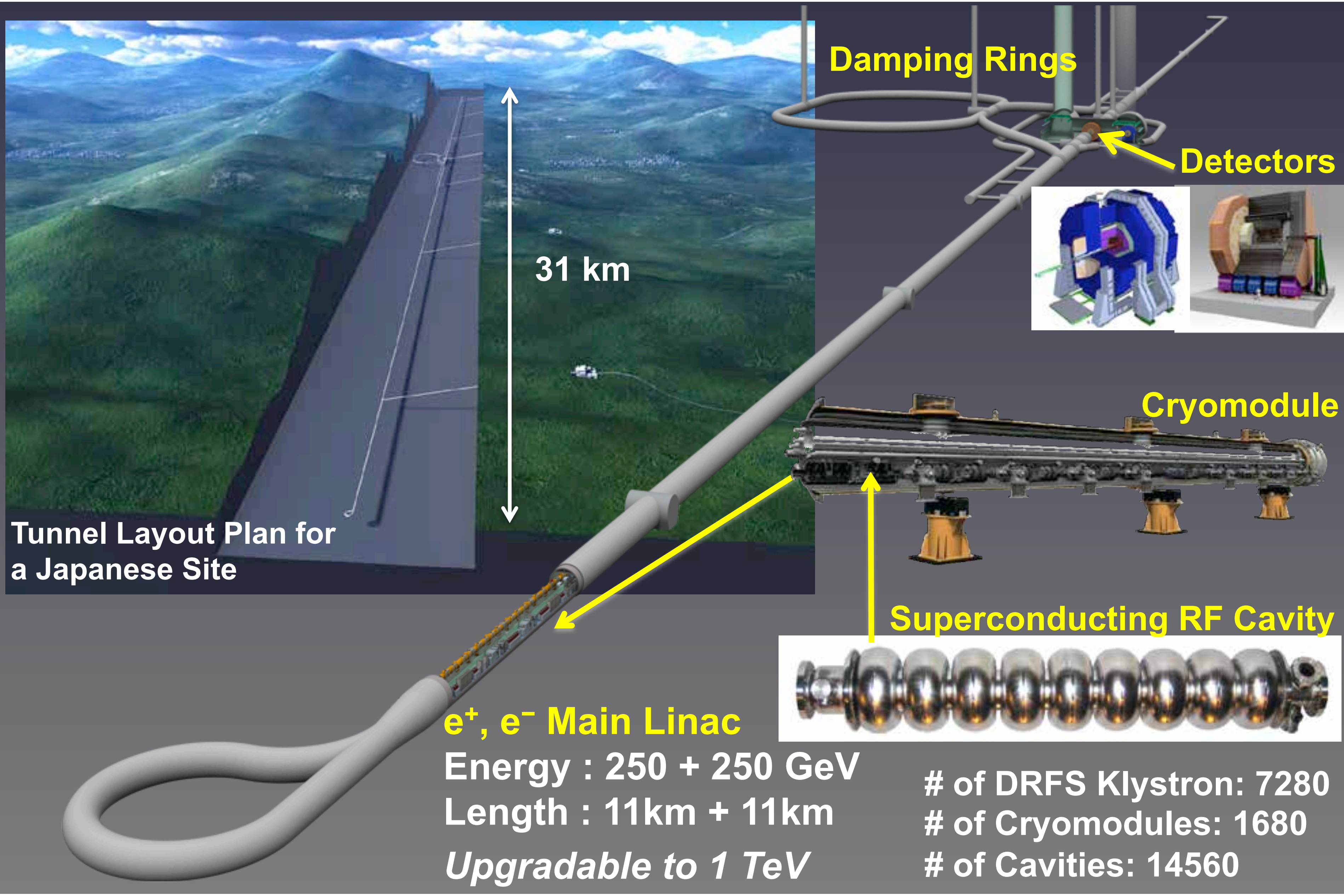


Clean reaction
Initial energy known
CM energy: **0.25-1 TeV**



Search for new physics with complementary machines

International Linear Collider



31 km

Tunnel Layout Plan for a Japanese Site

Damping Rings

Detectors

Cryomodule

Superconducting RF Cavity

e^+, e^- Main Linac

Energy : 250 + 250 GeV
Length : 11km + 11km

Upgradable to 1 TeV

# of DRFS Klystron: 7280
# of Cryomodules: 1680
# of Cavities: 14560

Technology-Driven Timeline

2005 2006 2007 2008 2009 2010 2011 2012 2013

LHC physics **Higgs**

1st Ecm range

S. Yamada (RD)

s Case and Research Strategy

or Design (**Research Directorate** process)

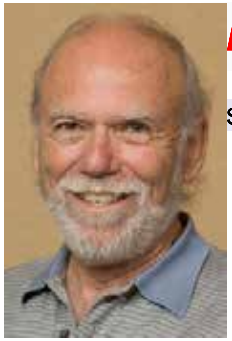
R&D

Ref. Design **Letter of Intent**

R&D / Design

TDR

near Collider
anization



B. Barish (GDE)

rator Design (**Global Design Effort** process)

seline

Ref. Design

TDP-1

Re-baseline

TDP-2

Technical Design Phase (TDP) 1&2

L. Evans

Linear Collider Collaboration

ICFA = International Committee for Future Accelerators

PAC = Project Advisory Committee

ICFA

PAC
Chair: Norbert Holtkamp

Linear Collider Board
Chair: Sachio Komamiya

Linear Collider Collaboration

Regional Directors
Harry Weerts, Brian Foster

Directorate
Lyn Evans

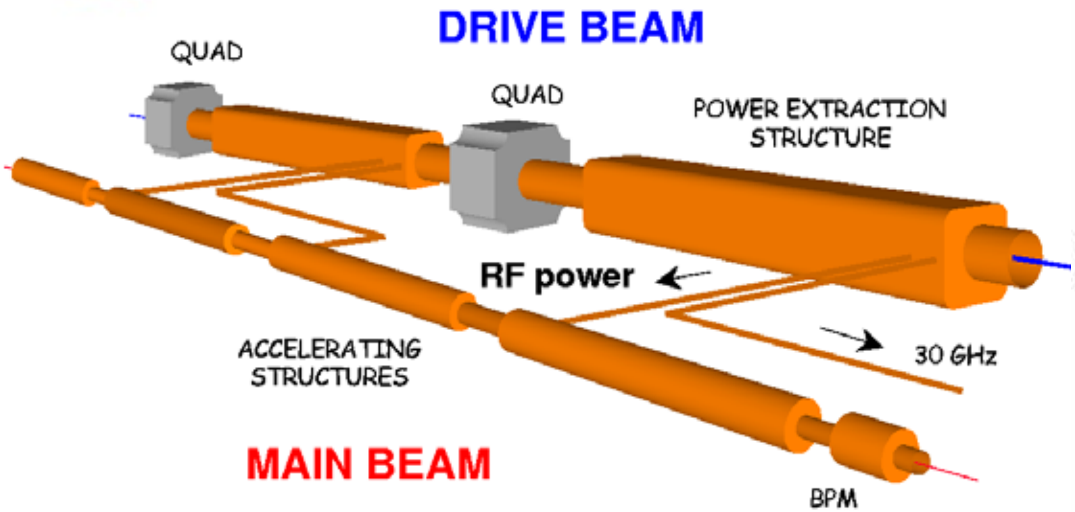
Deputy Direct
Hitoshi Murayama

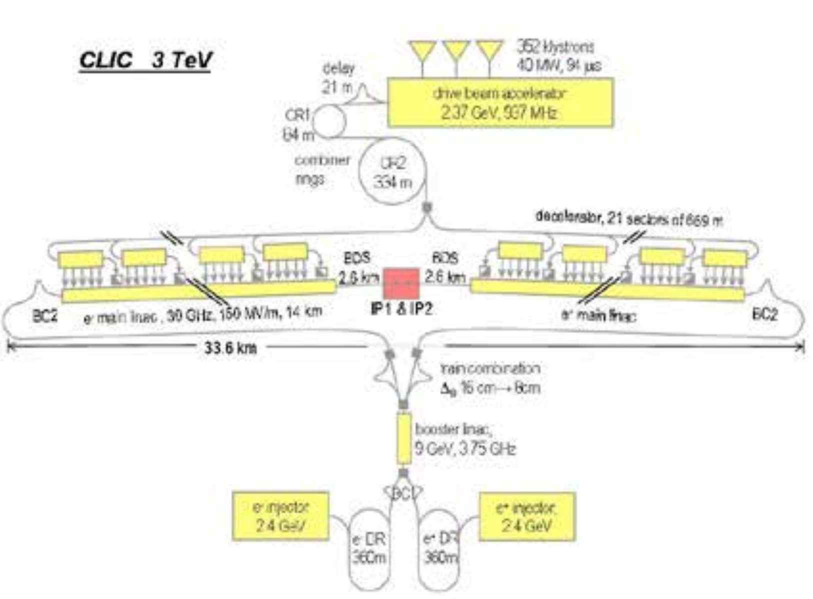
ILC Accelerator
Mike Harrison

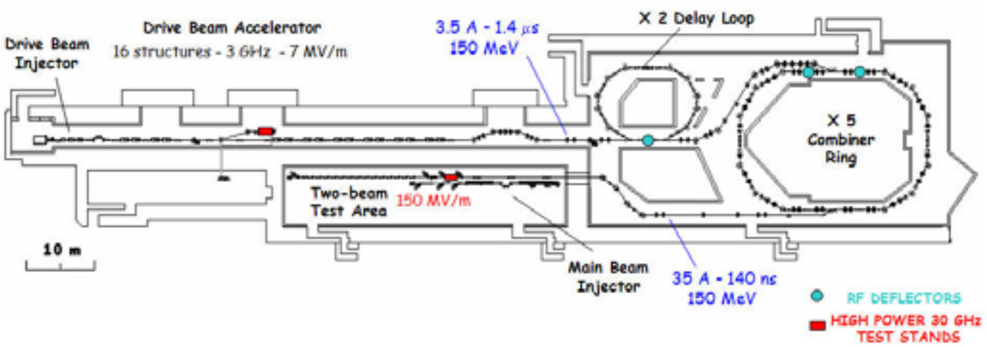
CLIC Accelerator
Steinar Stapnes

Physics & Detectors
Hitoshi Yamamoto

CLIC: Compact Linear Collider







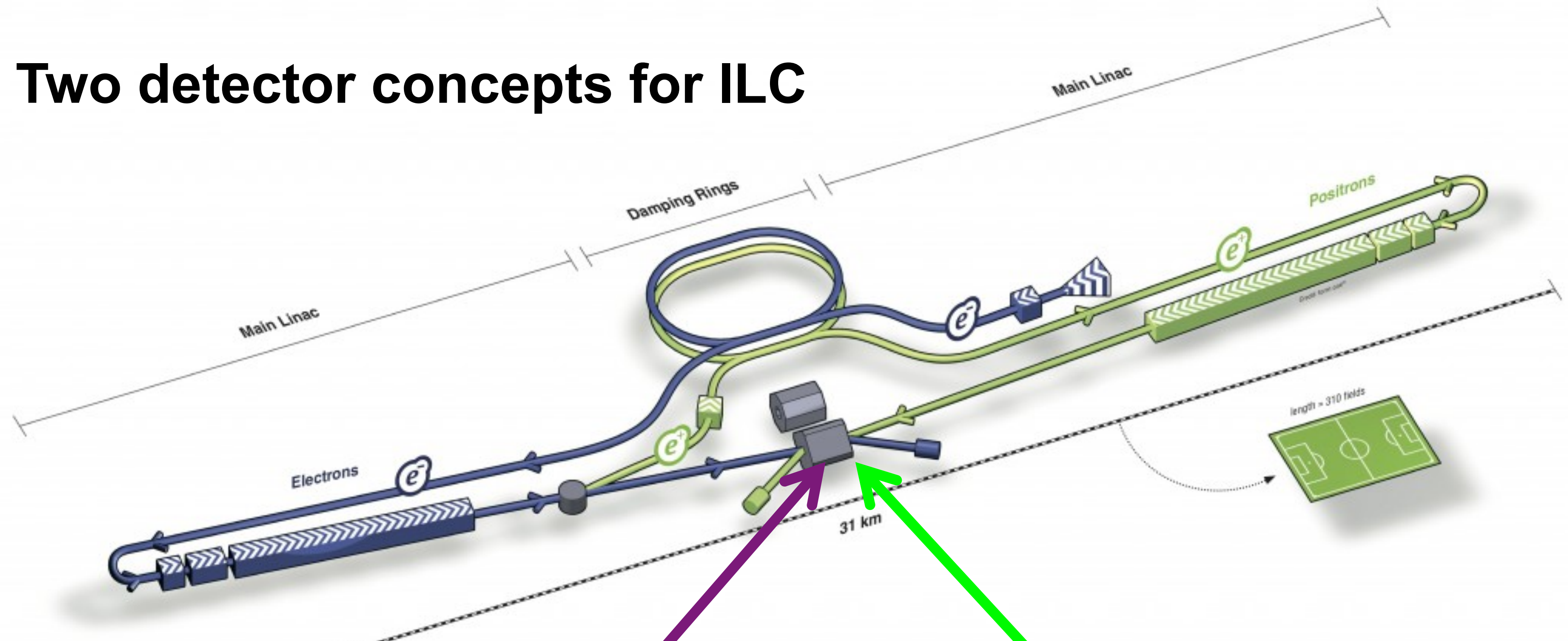
CDR published in 2012

→ Most mature technology for multi-TeV lepton collider

Detectors and reconstruction issues

ILC Detectors

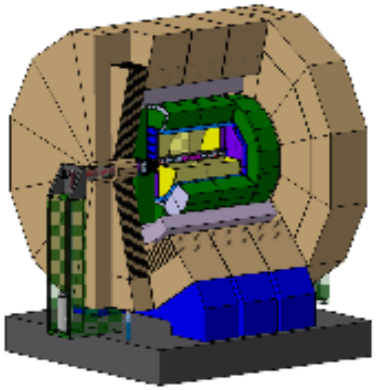
Two detector concepts for ILC

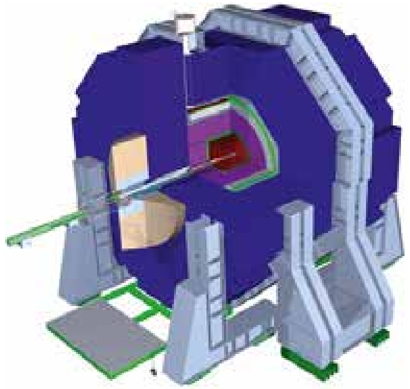


International Large Detector

ILD

http://ilcild.org





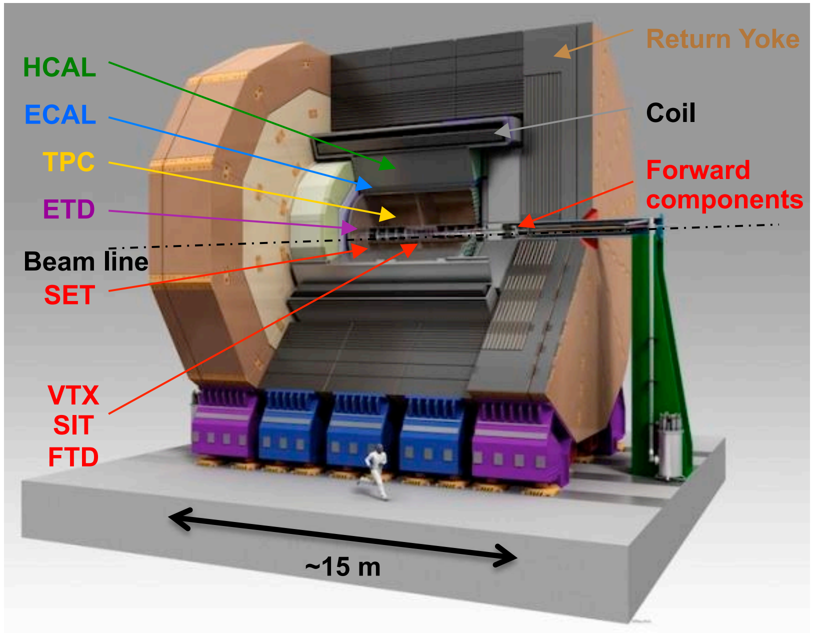
Silicon Detector

SiD

http://silicondetector.org

ILC Detector R&D

- **Vertex Detector:** low mass pixel sensors
- **Time Projection Chamber:** high resolution & low mass
- **Calorimeters:** high granularity sensors, 5x5mm^2 (ECAL), 3x3cm^2 (HCAL); absorbers for compact showers
- **Solenoid:** outside ECAL + HCAL



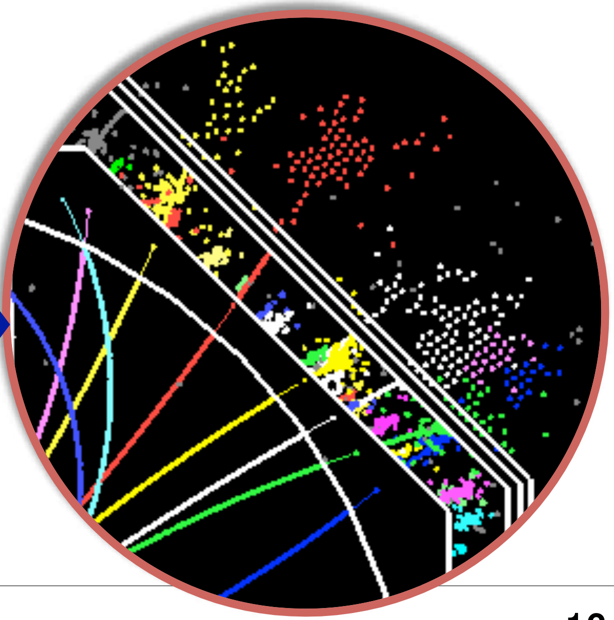
Sensor Size	ILC	ATLAS	Ratio
Vertex	**5×5 mm^2**	**400×50 mm^2**	**x800**
Tracker	**1×6 mm^2**	**13 mm^2**	**x2.2**
ECAL	**5×5 mm^2 (Si)**	**39×39 mm^2**	**x61**

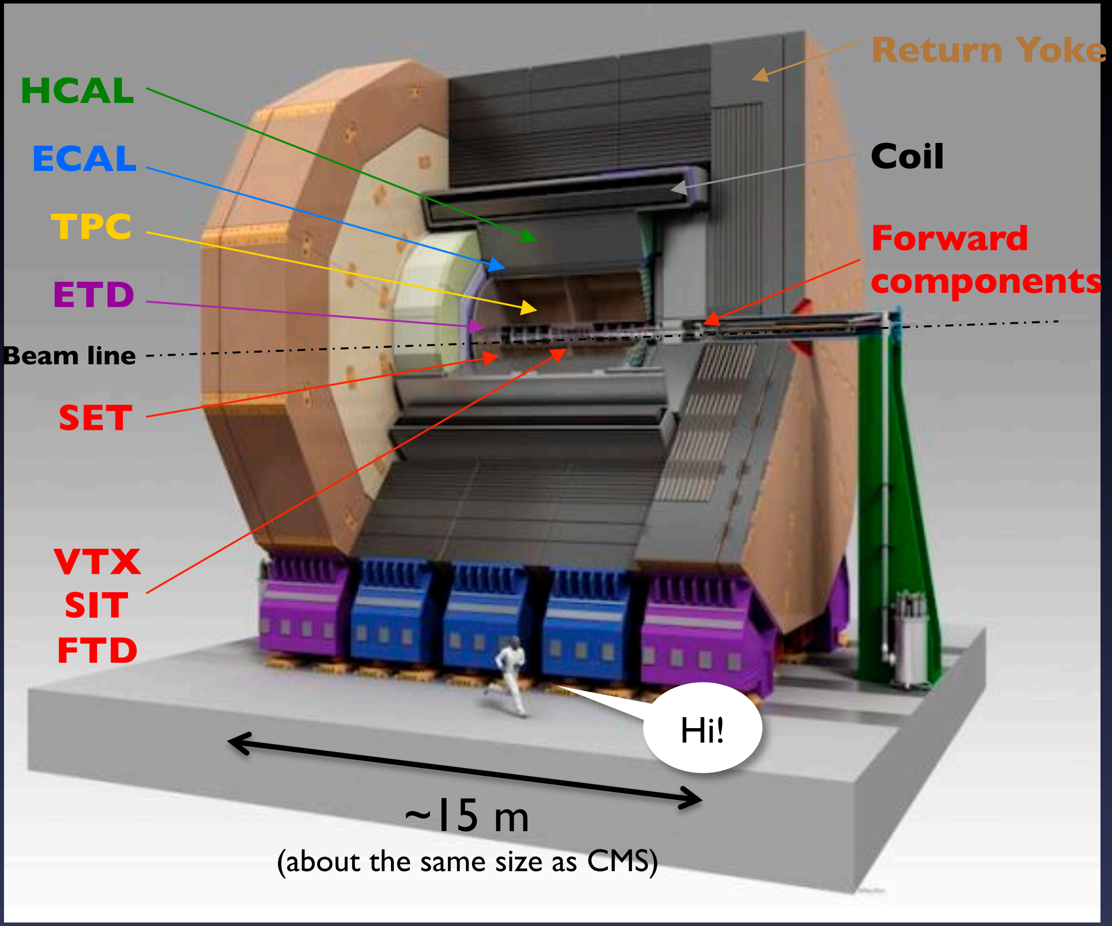
Optimized for Particle Flow Algorithm

Identify calorimeter hits for each particle

- use *best* energy measurement for *each* particle
- offers unprecedented **jet energy resolution**

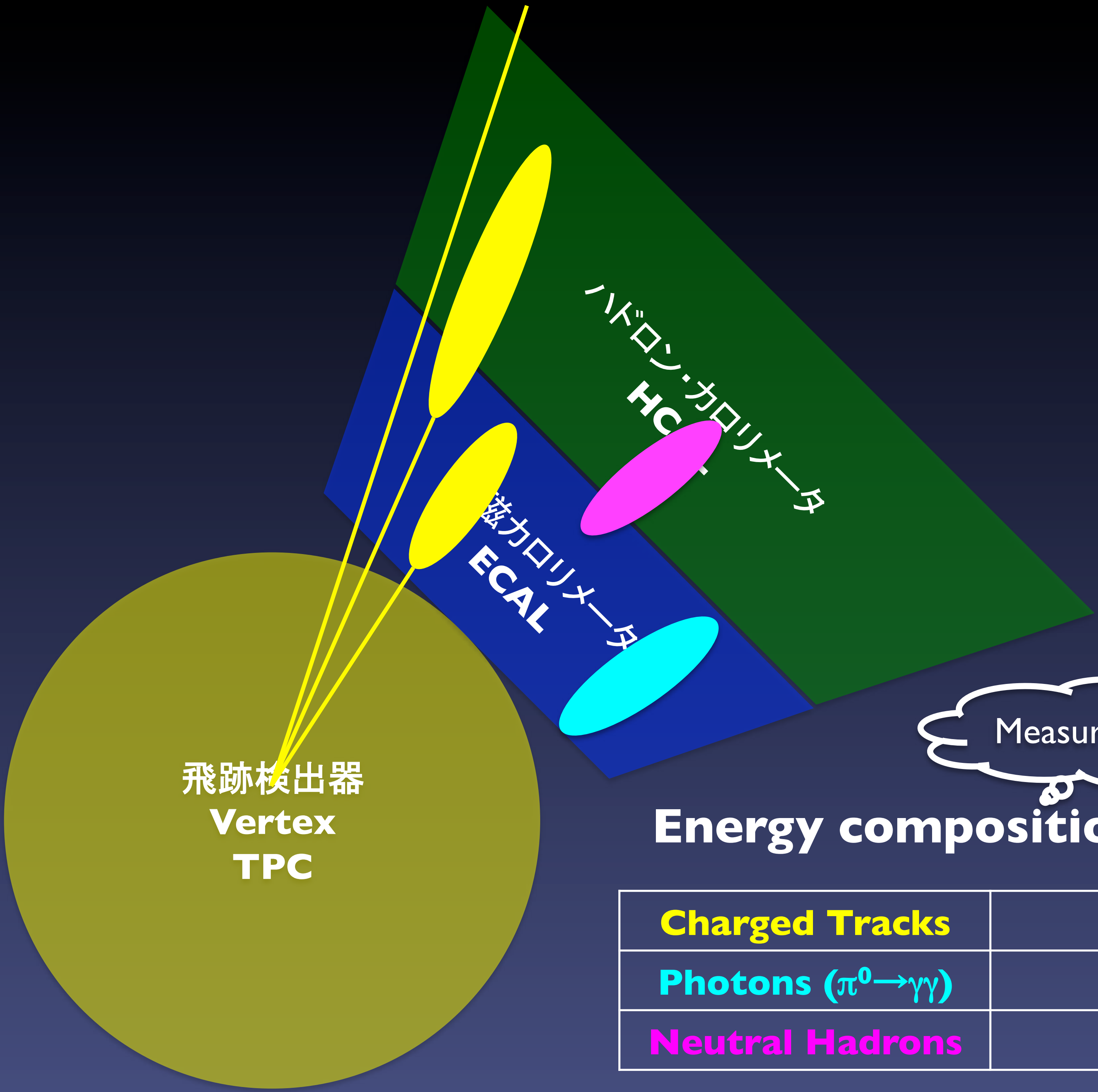
Charged Tracks → Tracker
Photons → ECAL
Neutral Hadrons → HCAL





Single particle energy resolution (ILC)

Detector	σ_E / E	@ 100 GeV
Tracker	**0.00002 × E**	**0.2%**
ECAL	**0.2 / $\sqrt{E}$**	**2%**
HCAL	**0.6 / $\sqrt{E}$**	**6%**

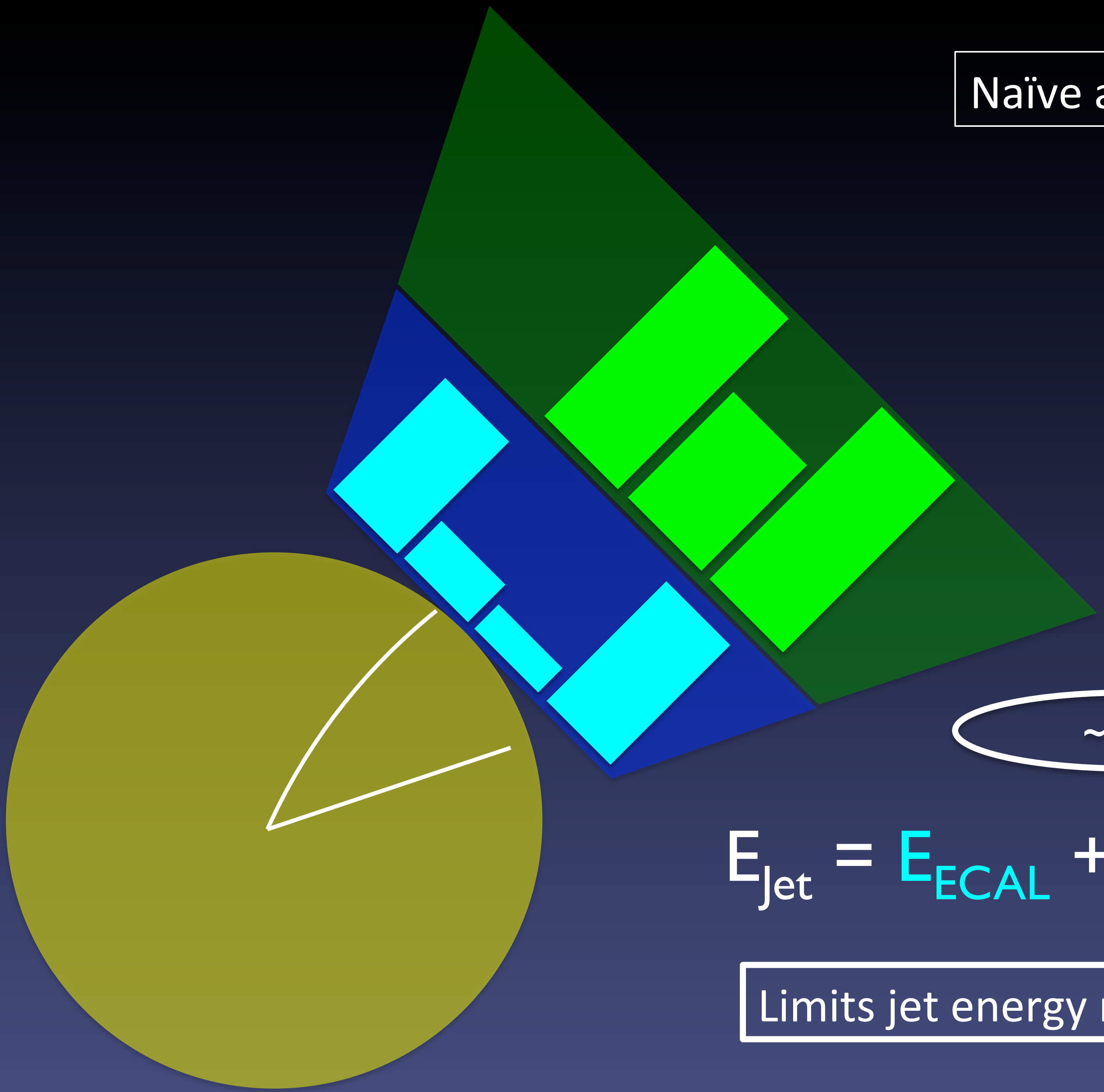


Measured at LEP

Energy composition in a jet

Charged Tracks	**~62%**
Photons ($\pi^0 \rightarrow \gamma\gamma$)	**~27%**
Neutral Hadrons	**~10%**

Naïve approach

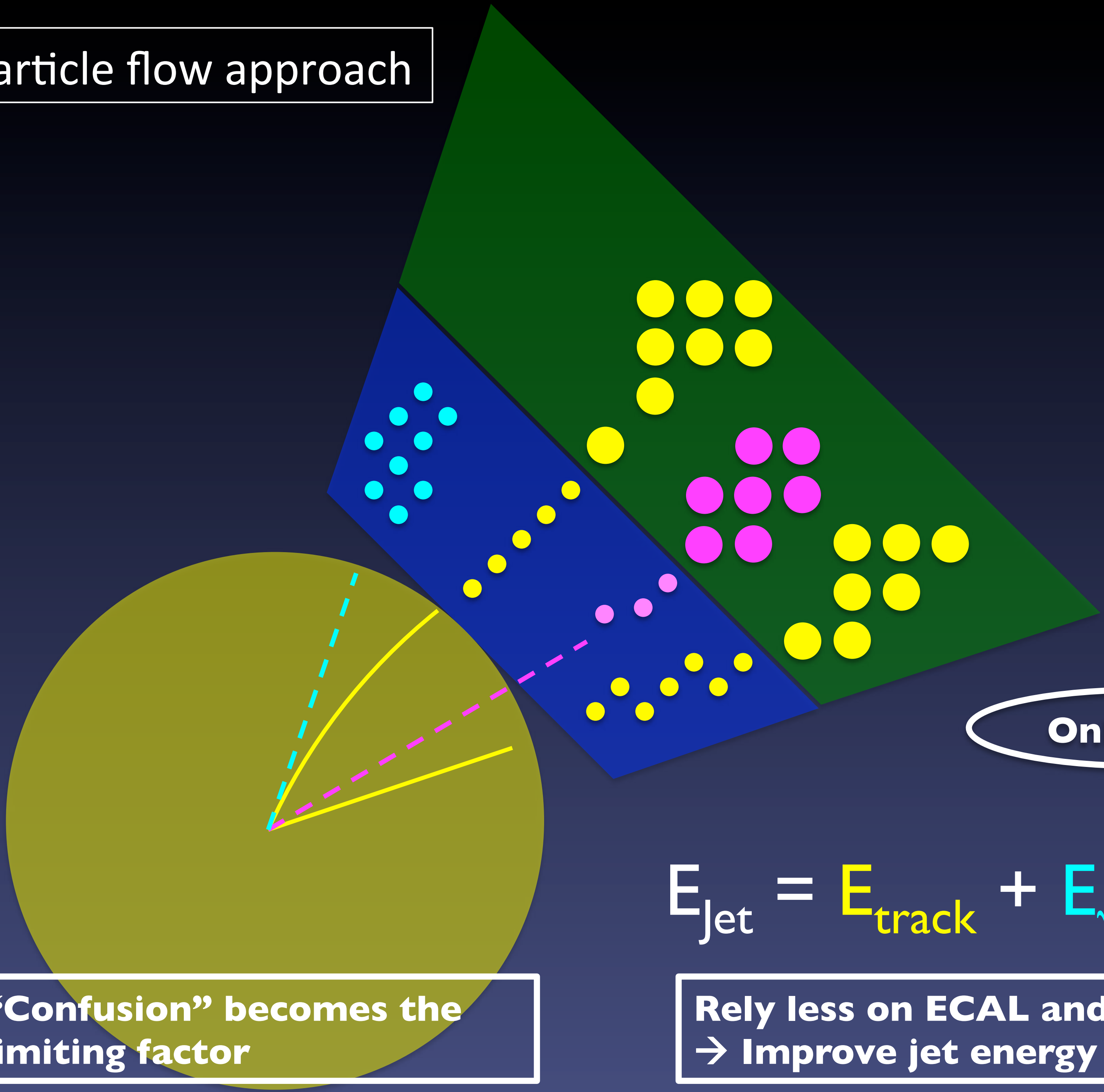


~72%

$$E_{Jet} = E_{ECAL} + E_{HCAL}$$

Limits jet energy resolution

Particle flow approach



Only ~10%

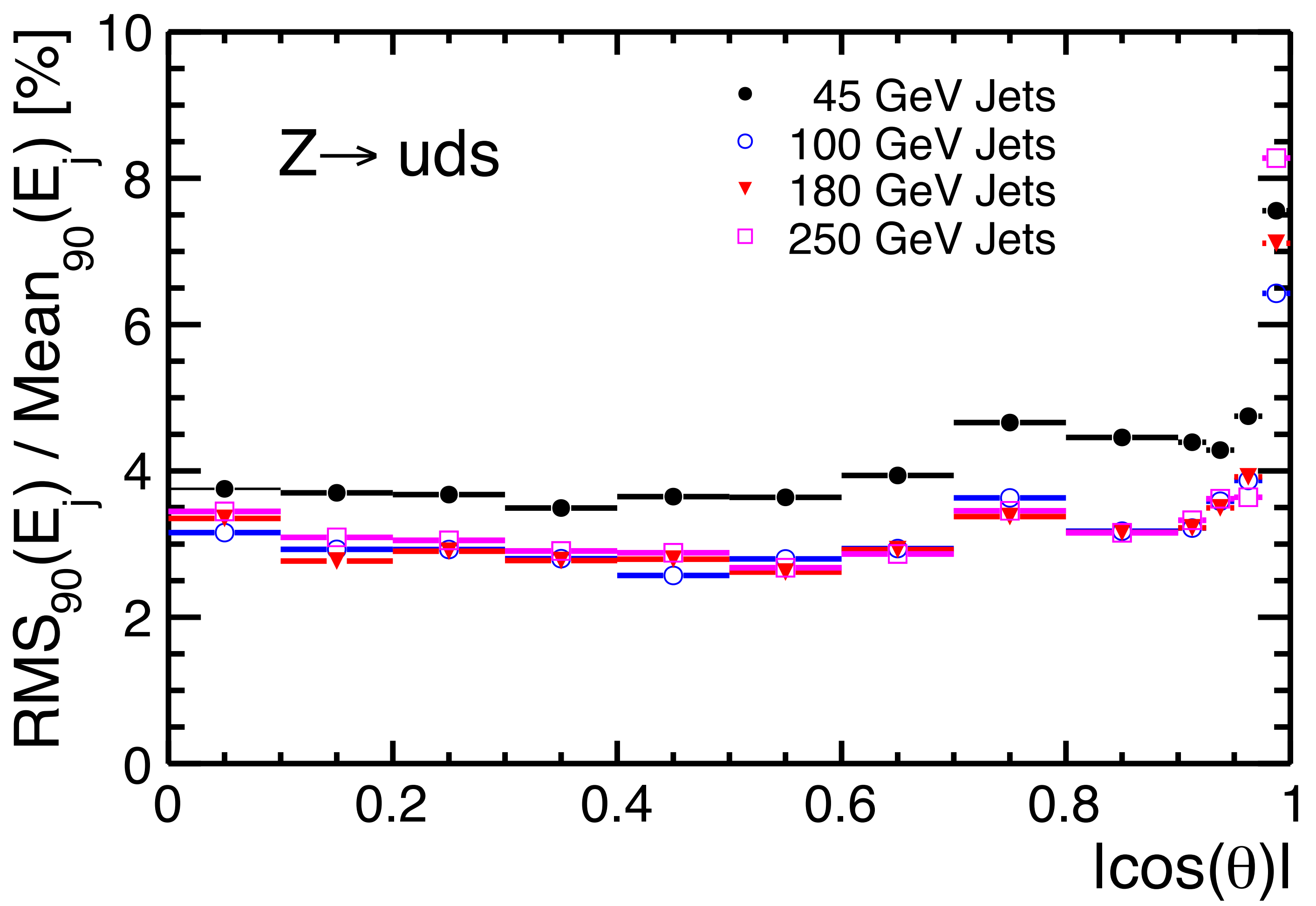
$$E_{Jet} = E_{track} + E_{\gamma} + E_{n}$$

"Confusion" becomes the limiting factor

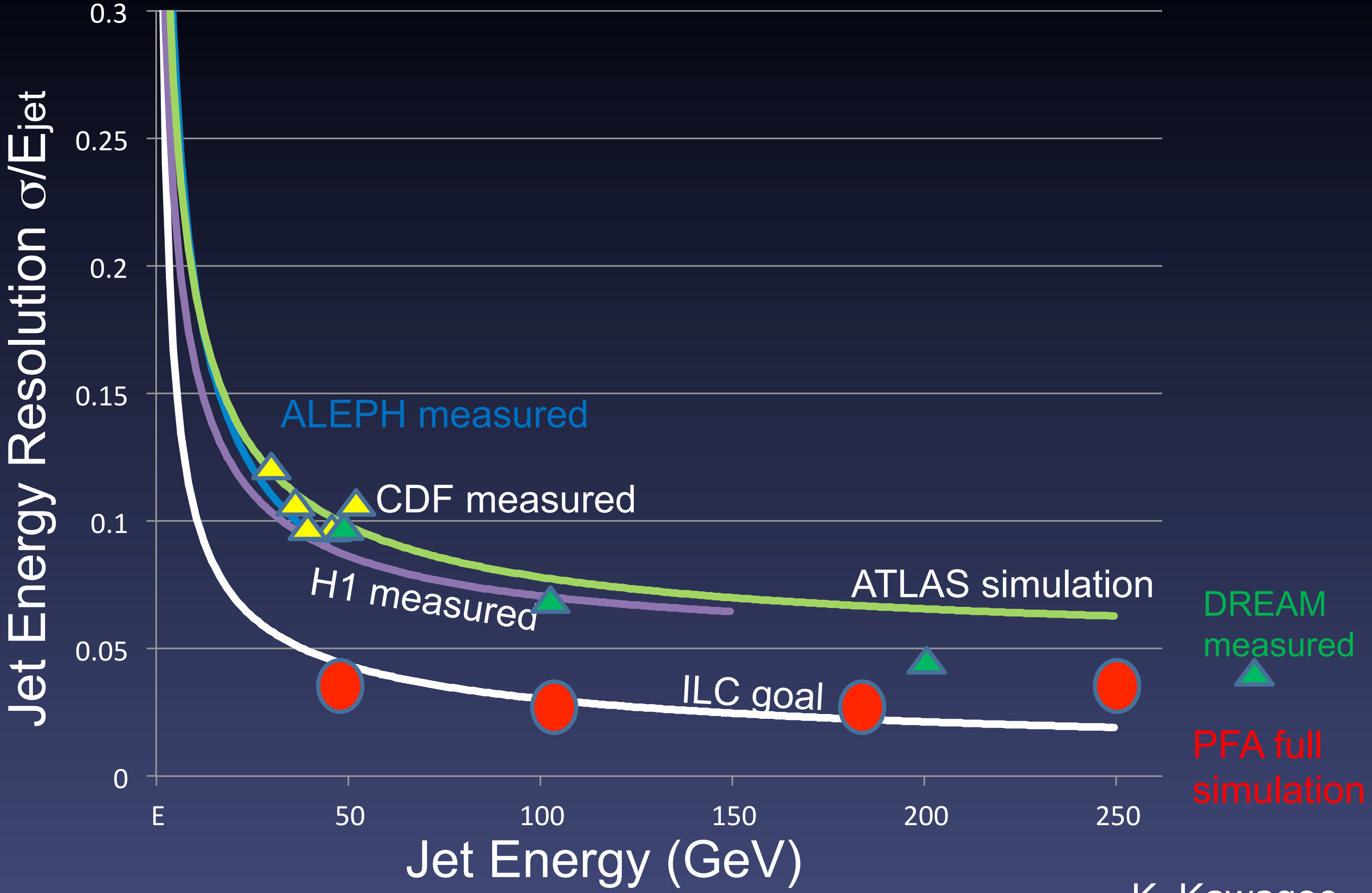
Rely less on ECAL and HCAL
→ Improve jet energy resolution

$e^- e^+ \rightarrow Zhh$

Jet energy resolution

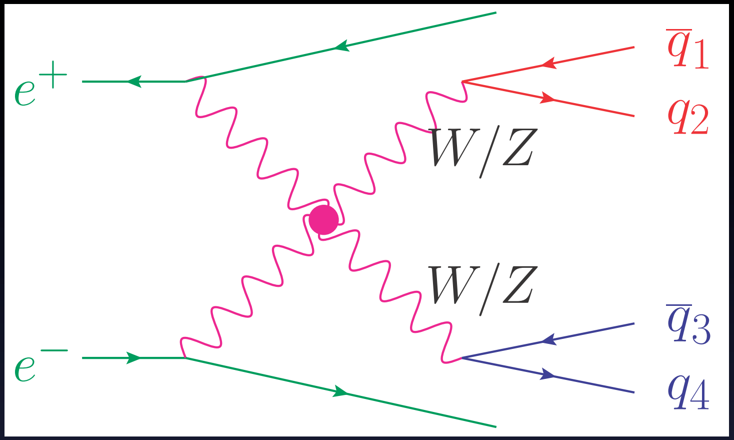


Jet energy resolution



K. Kawagoe

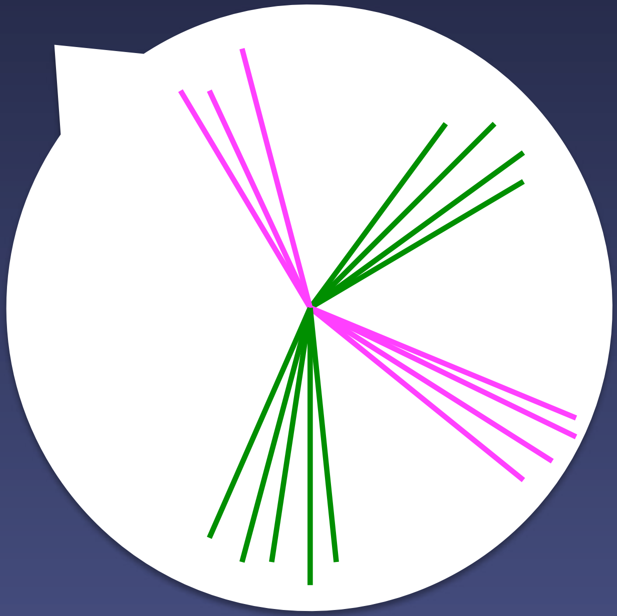
Jet energy resolution
$\sigma(E_{jet})/E_{jet} \approx$ 3~4%
can separate hadronic W and Z

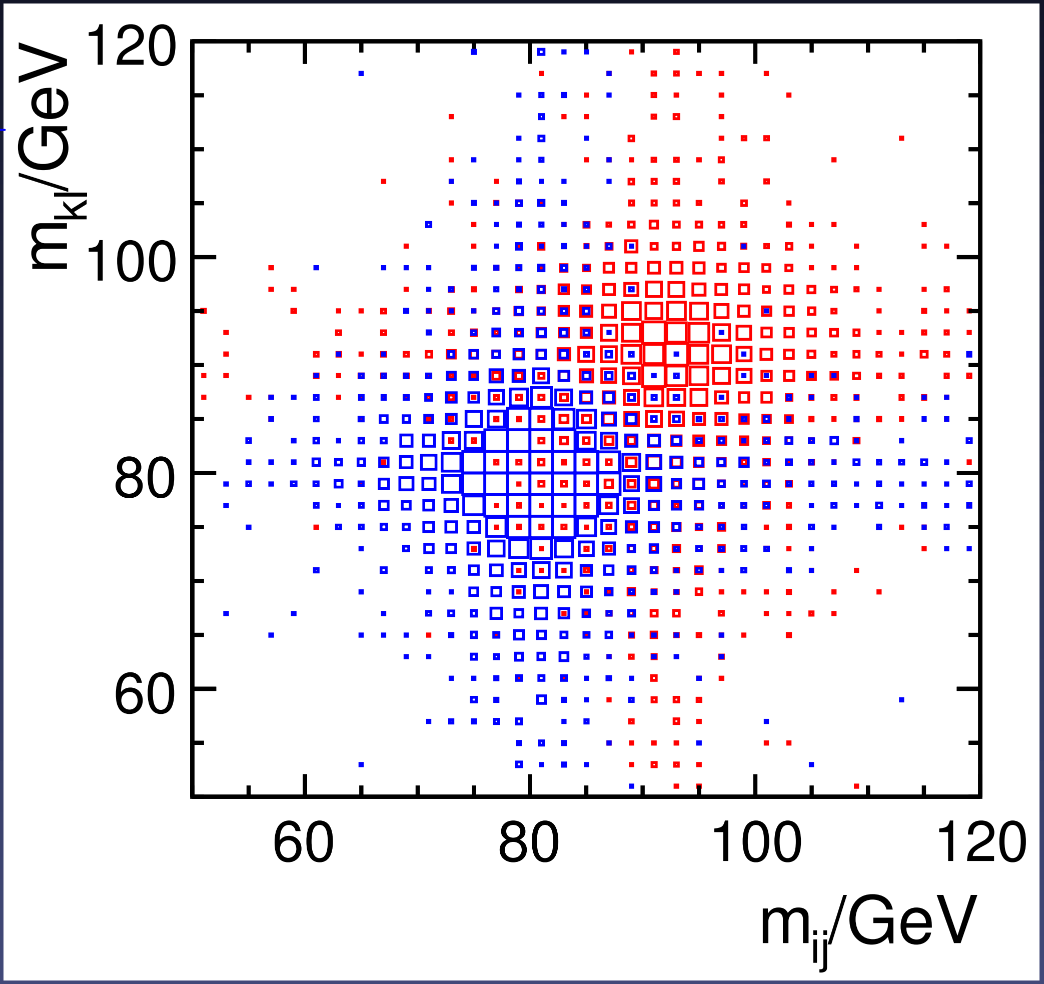


$$e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^-$$

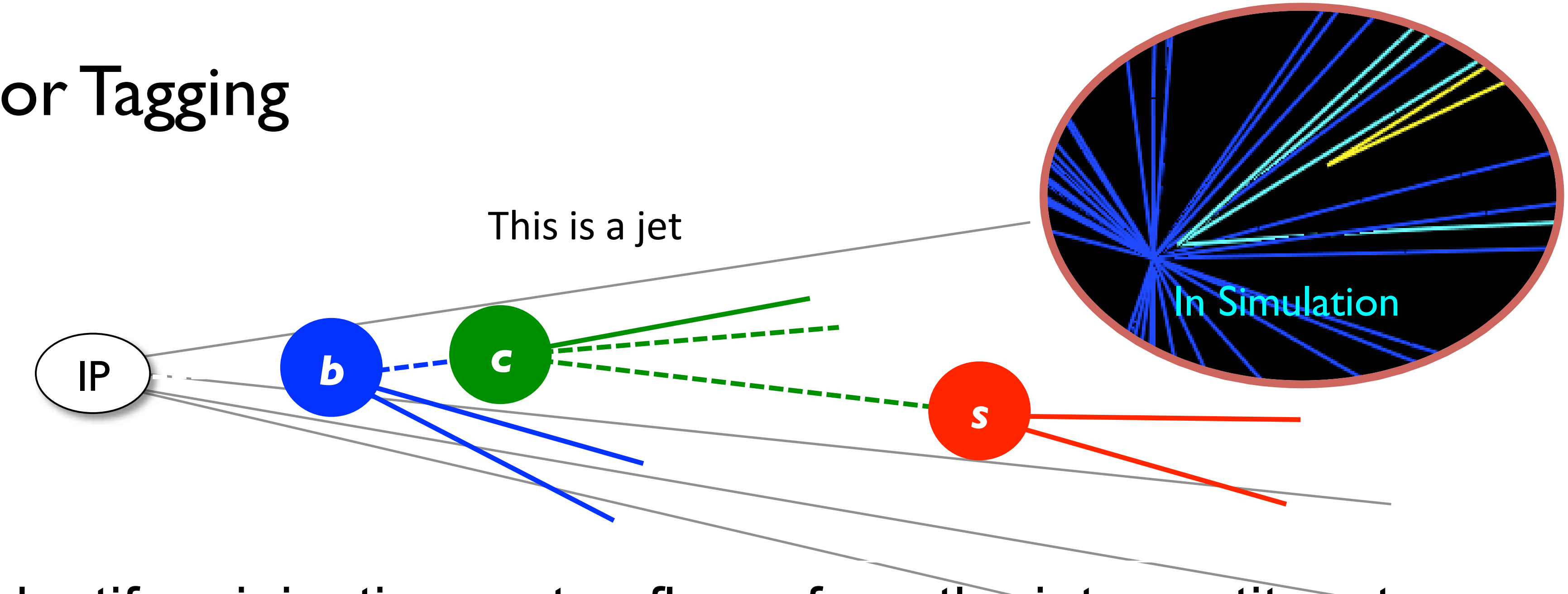
$$e^+e^- \rightarrow \tilde{\chi}_2^0\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 ZZ$$

Dark Matter





Flavor Tagging



Identify originating parton flavor from the jet constituents

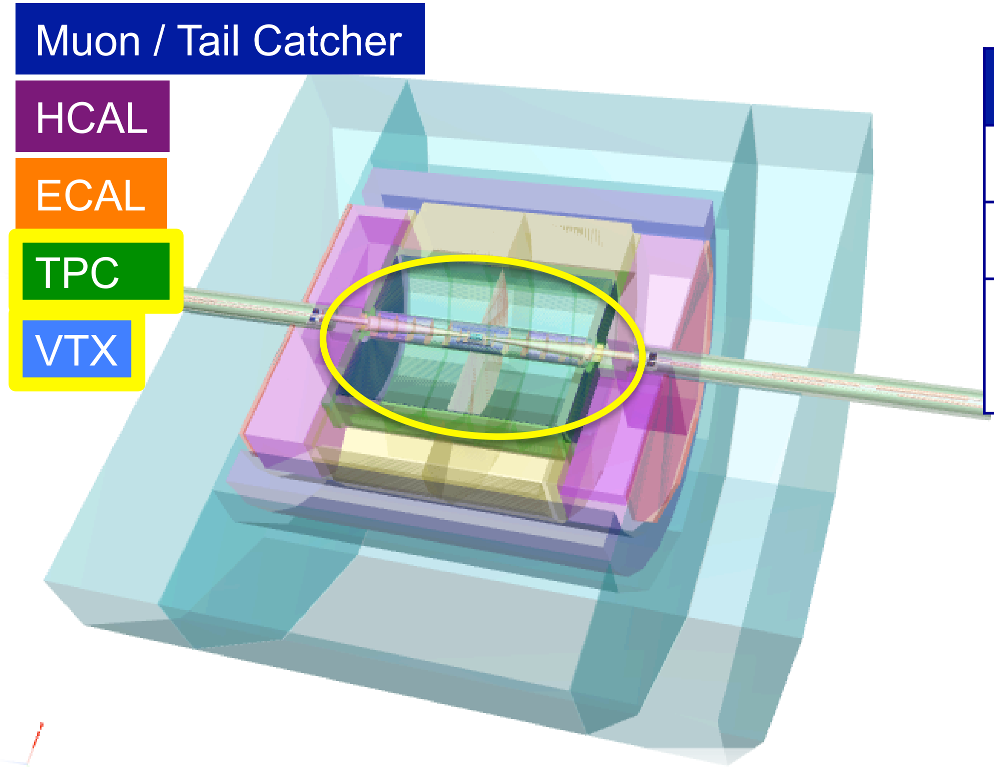
An example: discrimination by number of b jets

Signal $e^- e^+ \to Zhh \to q_5\bar{q}_6 b\bar{b}b\bar{b}$

Background $e^- e^+ \to t\bar{t} \to b q_1\bar{q}_2\bar{b}q_3\bar{q}_4$

Also crucial for Br(h→cc) measurement

Detector Requirements



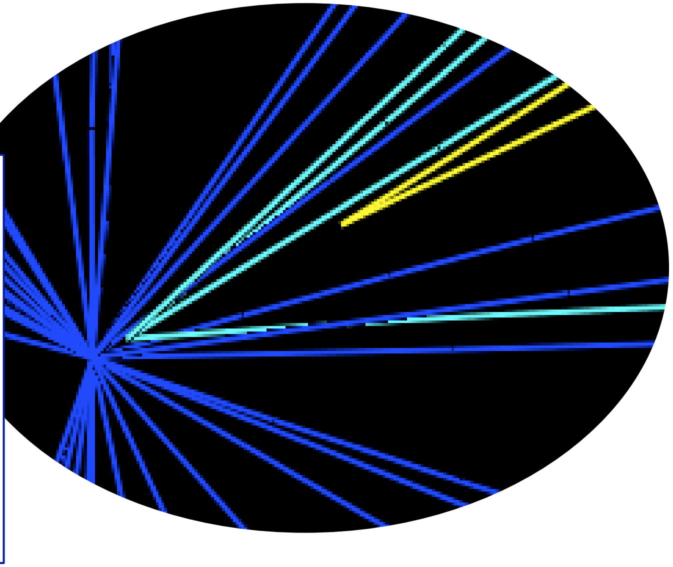
Vertex Detector (ILD / SiD)	
Inner radius	15 / 14 mm
Outer radius	60 mm
Impact parameter resolution	< 5 μm (high mom.)

Tracker: Track selection / V^0 rejection
Calorimeters: Lepton ID / PFA

Track impact parameter resolution goal at ILC:

$$\sigma_{r\phi} = 5\ \mu\mathrm{m} \oplus \frac{10}{p(\mathrm{GeV})\sin^{3/2}\theta}\ \mu\mathrm{m}.$$

Ensures good track measurement and flavor tagging.



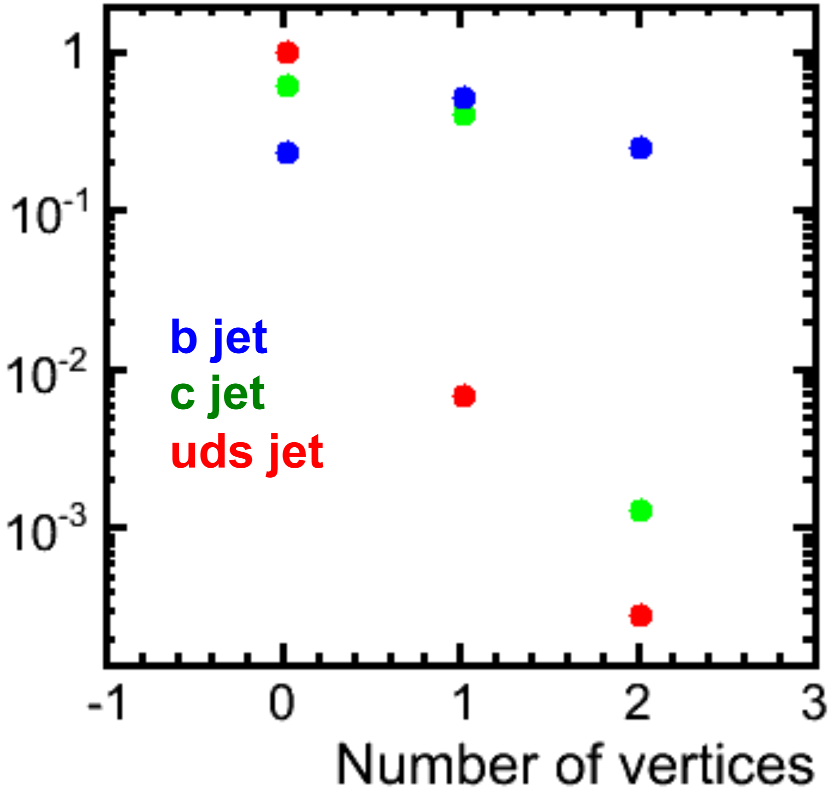
Input variables

Input variables use information from

- **jets:** tracks, neutrals
- **tracks:** impact parameters & covariance, lepton ID
- **vertex:** position, direction, momentum, mass

TMVA multiclass BDT with gradient boost in 3 classes (b, c, uds) and 4 categories

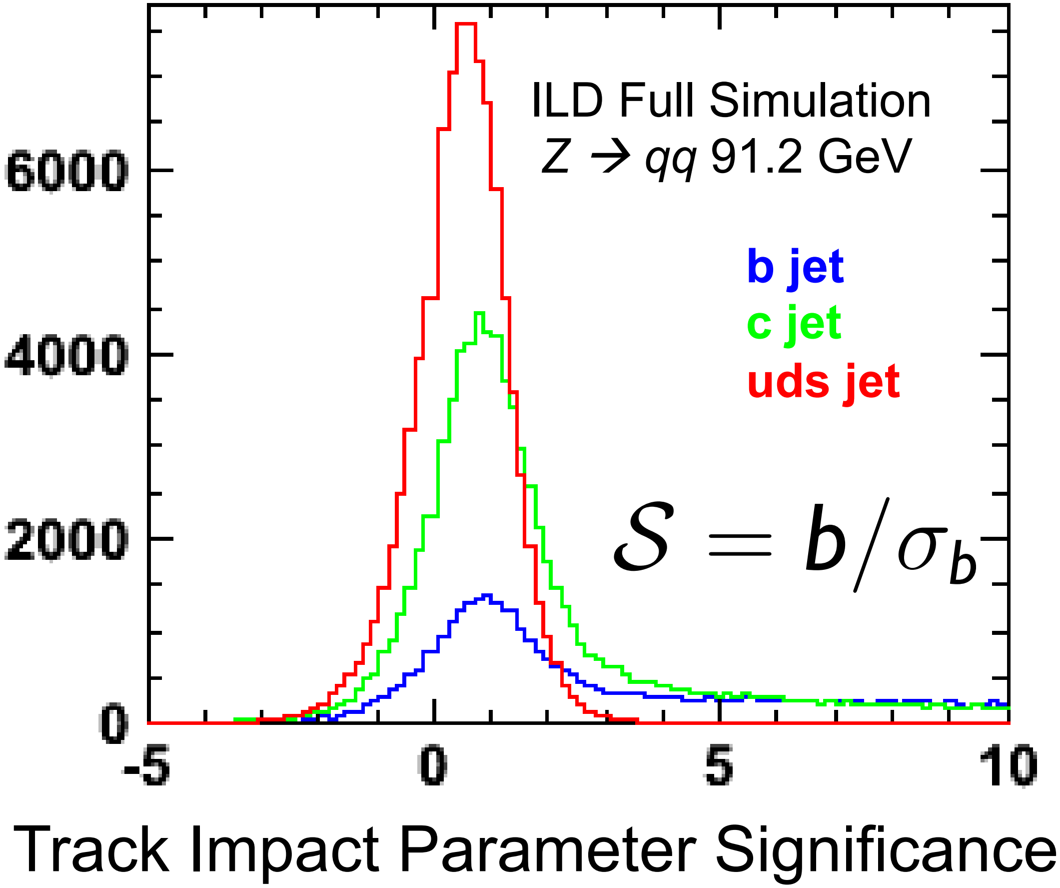
ILD Full Simulation, *Z* → *qq* 91.2 GeV



Vertex finder performance

Zhh → qqbbbb	Primary	b hadron	c hadron	other
# all reco. tracks	67575	12912	15246	4087
# tracks in vertex	617	8717	10529	358

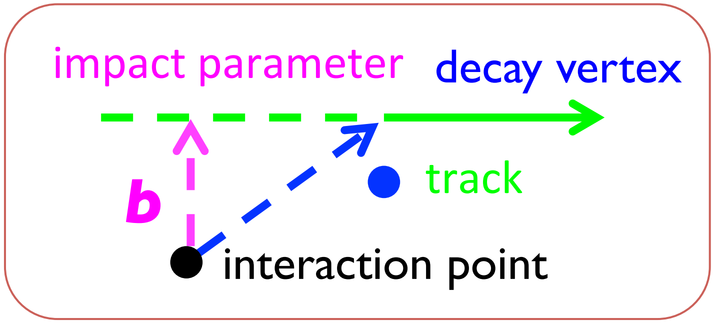
Flavor tag: by decay distance

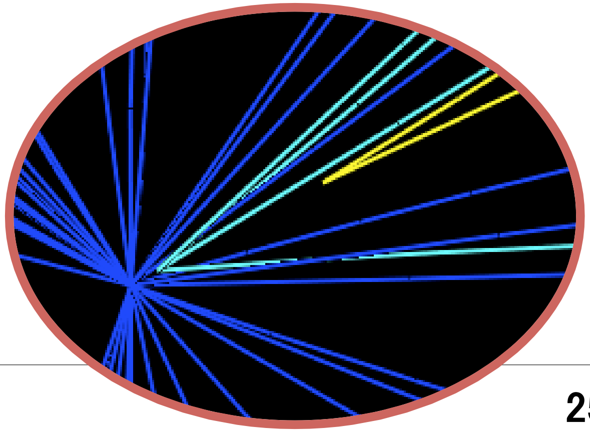


$c\tau_b \approx$ 450-500 mm

$c\tau_c \approx$ 100-300 mm

n.b. distribution is exponential decay
For boosted objects: mean decay distance = $\gamma\beta c\tau$

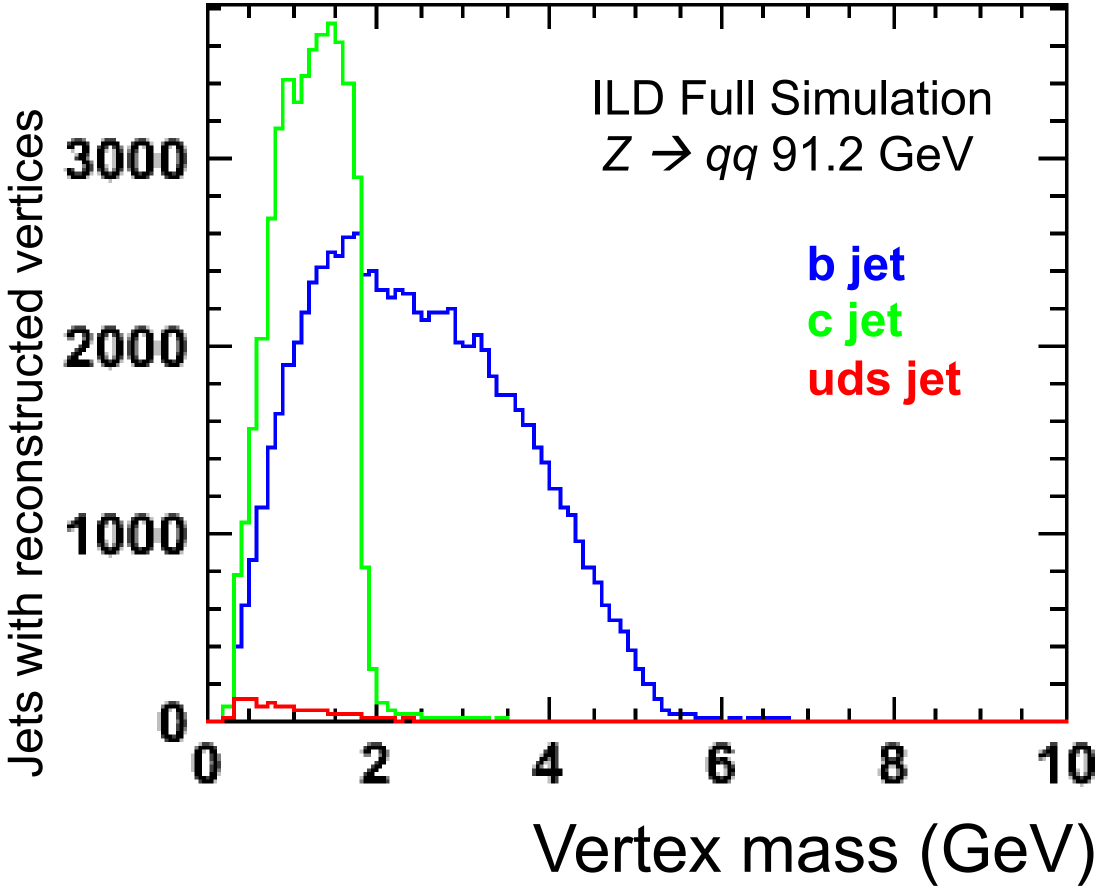




Significance = quantity divided by its uncertainty

Look at all the tracks in the jet

Flavor tag: by parton mass



with pT correction from neutral particles

$m_b \approx 5$ GeV
$m_c \approx 2$ GeV

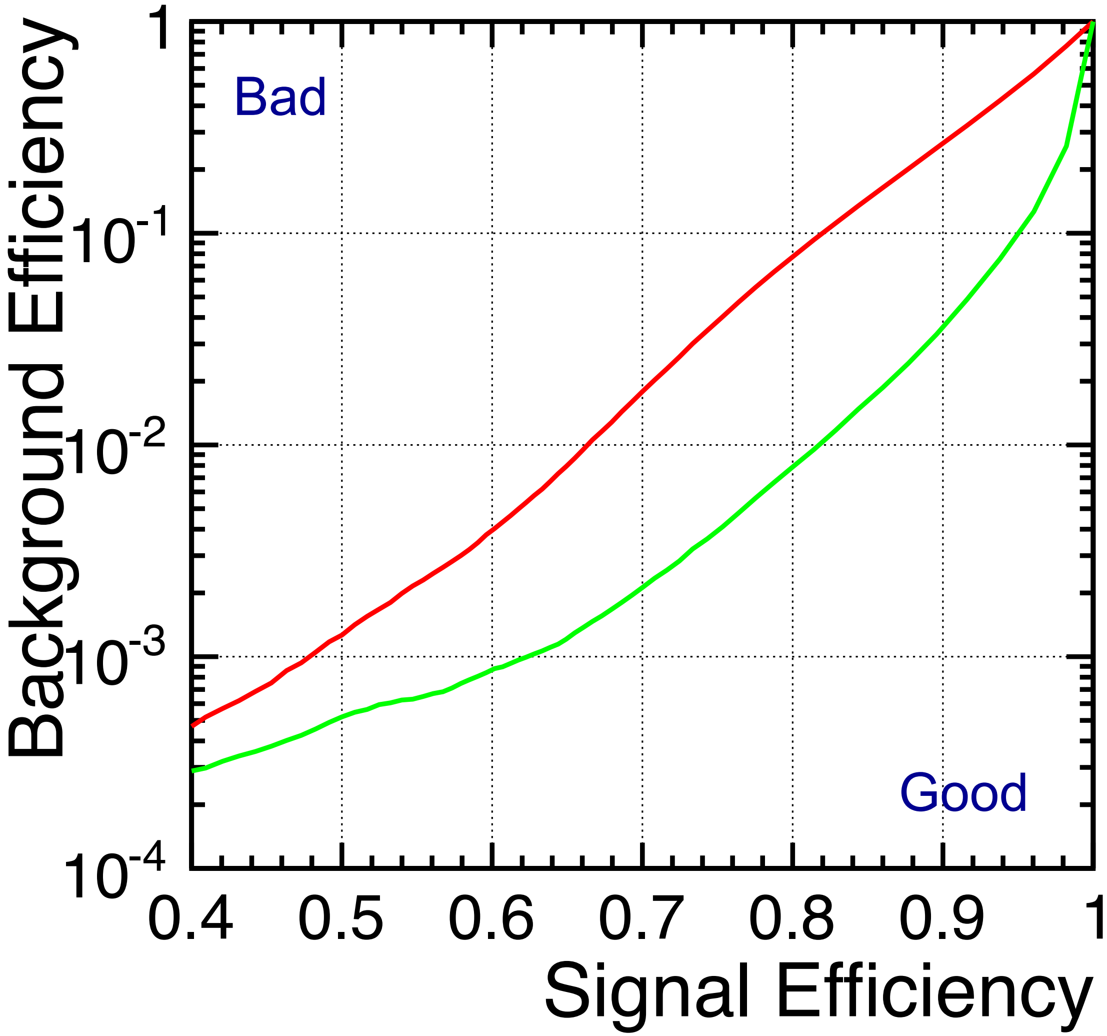
→ Final discriminant uses multivariate analysis

Flavor tag performance

ILD Full Simulation
LCFIPlus (Suehara, TT)

Z→qq, 91.2 GeV
c background
uds background

b eff	c fake	uds fake
80%	8%	0.8%
50%	0.1%	0.05%



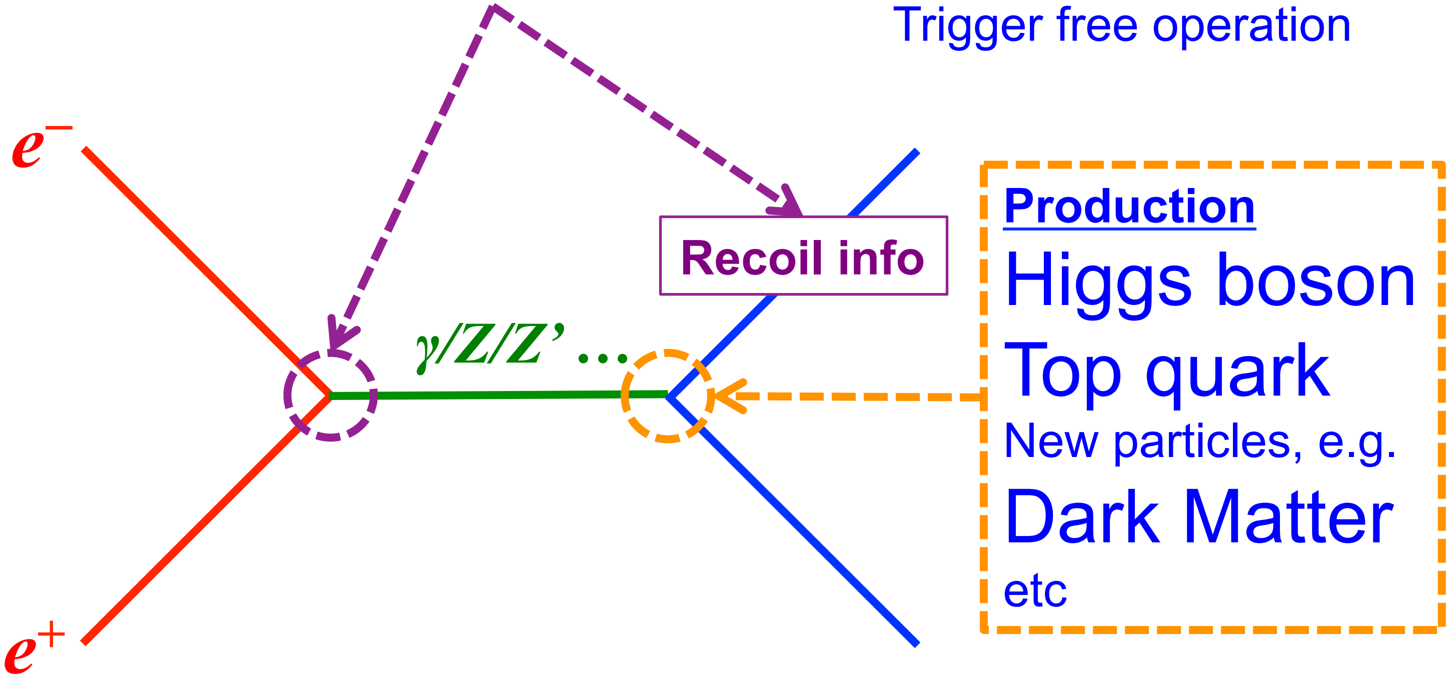
Physics at the ILC

Characteristics of ILC

Beam
Tunable energy
Polarization
$P_{\text{electron}} = \pm 80\%$
$P_{\text{positron}} = \pm 30\%$

Elementary process
Well-understood at LEP
Theoretical uncertainty <1%

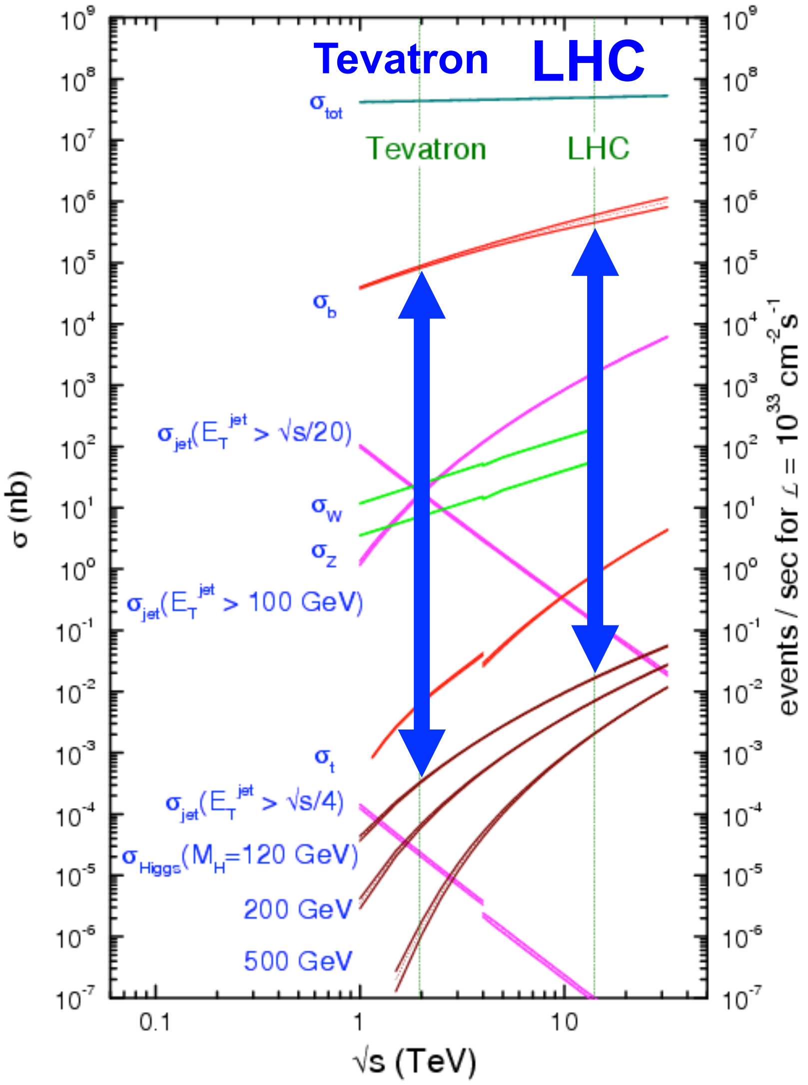
Detection
Low background
Highly granular sensors
Trigger free operation



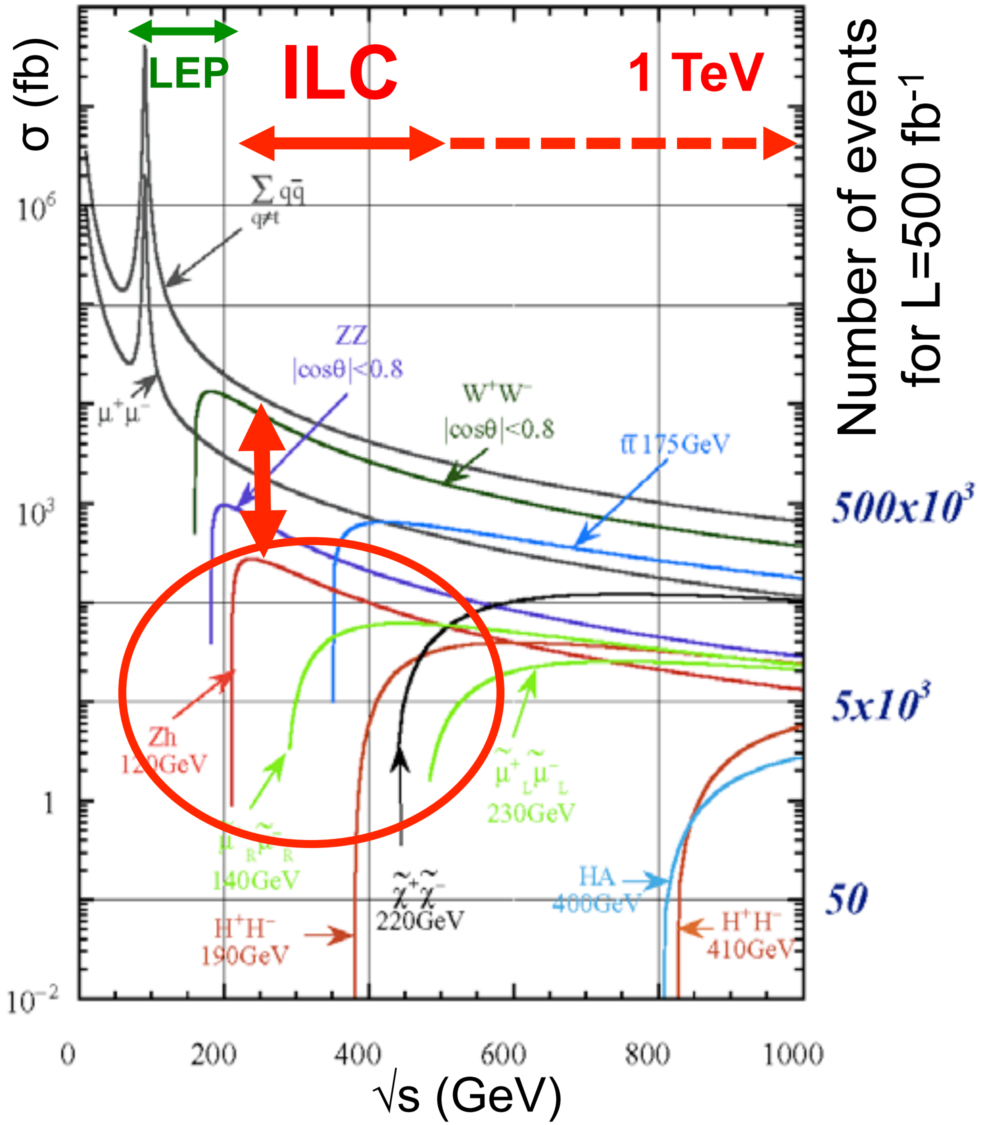
Production
Higgs boson
Top quark
New particles, e.g.
Dark Matter
etc

Cross Sections

proton - (anti)proton cross sections



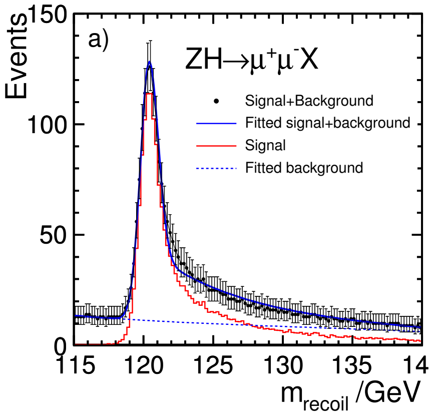
e⁺e⁻ cross sections

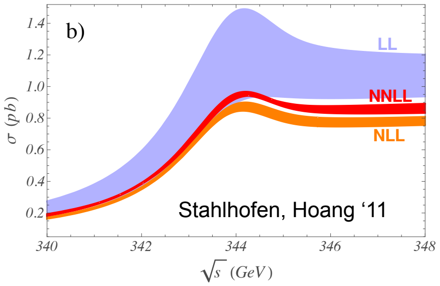


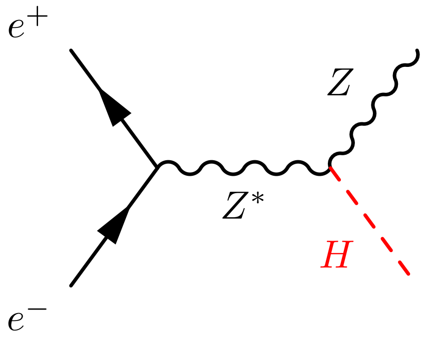
Physics at the ILC

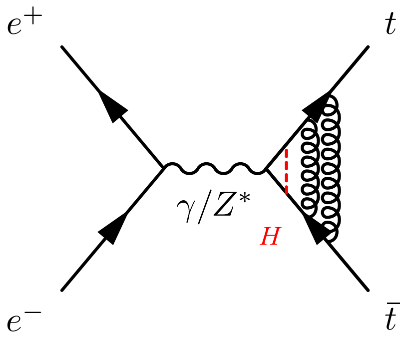
Main goals of the ILC physics program:

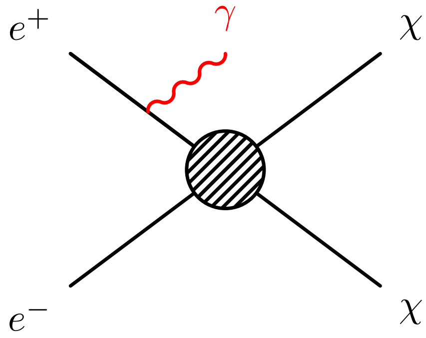
- **Precise measurements of:**
  - Properties of the **Higgs sector**
  - Interactions of **top, gauge bosons, and new particles**
- **Searches for new physics**
  - Discovery reach for **color-neutral states** (e.g. dark matter) can significantly exceed LHC
  - Sensitivity to new physics through **tree-level** and **quantum effects**

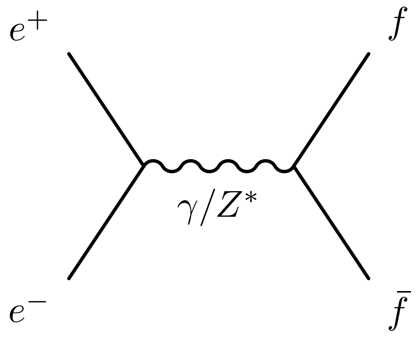












ILC Staging Strategy

- **ILC** can **gradually** increase the CM energy by **extending the Main Linac**
  - Cost does not scale linearly due to facilities such as Damping Rings

- **Physics** determines the target energy: **250, 350, 500 GeV → 1 TeV**
  - Perform energy scans in-between, focus if we find something new

TDR parameters

E_{CM} (GeV)	250	350	500	1000
Luminosity (10^{34} cm^{-2} s^{-1})	0.75	1.0	1.8	4.9
Integrated Luminosity (fb^{-1})	250	350	500	1000
Number of days *	385	405	322	233

*assuming continuous operation at **peak luminosity**

Luminosity can be increased by:
doubling the number of bunches per train (1300 → 2600)
doubling the collision rate (5 Hz → 10 Hz)

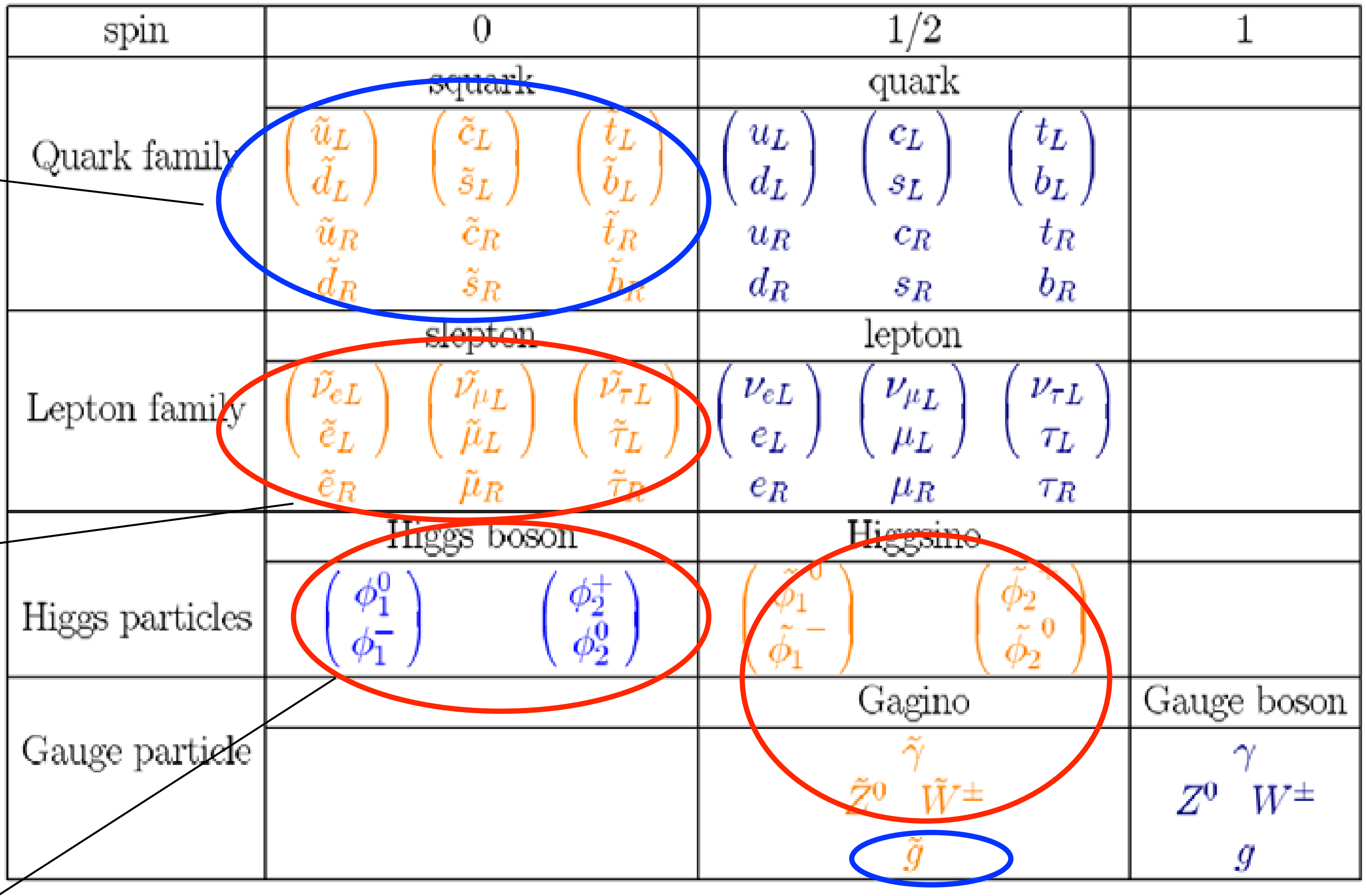
Discovering SUSY/DM at the ILC

New Physics at the TeV scale

Issues motivating the study of physics at **TeV scale**:

- **Naturalness**
  - Radiative correction to Higgs mass term has quadratic divergence
  - Require new physics / new particles in the TeV range to avoid excessive fine-tuning
    - e.g. Supersymmetry (SUSY), Composite Higgs, Extra Dimensions
- **Dark Matter (DM)**
  - WMAP relic density predicts O(100) GeV WIMP
  - New physics models predict natural DM candidates

SUSY Particles



spin	0	1/2	1
	squark	quark	
Quark family	$\begin{pmatrix}\tilde{u}_L\\ \tilde{d}_L\end{pmatrix}$ $\begin{pmatrix}\tilde{c}_L\\ \tilde{s}_L\end{pmatrix}$ $\begin{pmatrix}\tilde{t}_L\\ \tilde{b}_L\end{pmatrix}$ $\tilde{u}_R$ $\tilde{c}_R$ $\tilde{t}_R$ $\tilde{d}_R$ $\tilde{s}_R$ $\tilde{b}_R$	$\begin{pmatrix}u_L\\ d_L\end{pmatrix}$ $\begin{pmatrix}c_L\\ s_L\end{pmatrix}$ $\begin{pmatrix}t_L\\ b_L\end{pmatrix}$ u_R c_R t_R d_R s_R b_R	
	slepton	lepton	
Lepton family	$\begin{pmatrix}\tilde{\nu}_{eL}\\ \tilde{e}_L\end{pmatrix}$ $\begin{pmatrix}\tilde{\nu}_{\mu L}\\ \tilde{\mu}_L\end{pmatrix}$ $\begin{pmatrix}\tilde{\nu}_{\tau L}\\ \tilde{\tau}_L\end{pmatrix}$ $\tilde{e}_R$ $\tilde{\mu}_R$ $\tilde{\tau}_R$	$\begin{pmatrix}\nu_{eL}\\ e_L\end{pmatrix}$ $\begin{pmatrix}\nu_{\mu L}\\ \mu_L\end{pmatrix}$ $\begin{pmatrix}\nu_{\tau L}\\ \tau_L\end{pmatrix}$ e_R μ_R τ_R	
	Higgs boson	Higgsino	
Higgs particles	$\begin{pmatrix}\phi_1^0\\ \phi_1^-\end{pmatrix}$ $\begin{pmatrix}\phi_2^+\\ \phi_2^0\end{pmatrix}$	$\begin{pmatrix}\tilde{\phi}_1^0\\ \tilde{\phi}_1^-\end{pmatrix}$ $\begin{pmatrix}\tilde{\phi}_2^+\\ \tilde{\phi}_2^0\end{pmatrix}$	
		Gagino	Gauge boson
Gauge particle		$\tilde{\gamma}$ $\tilde{Z}^0$ $\tilde{W}^\pm$ $\tilde{g}$	γ Z^0 $W^\pm$ g

Colored

Color neutral

Extended Higgs
h, H, A, H^+, H^-

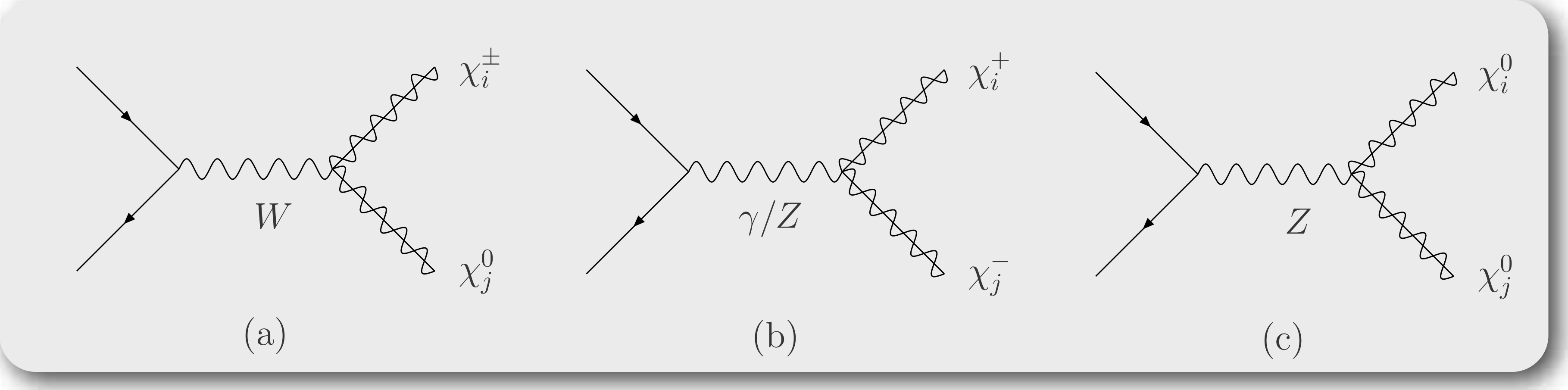
$$(\tilde{\gamma}, \tilde{Z}^0, \tilde{\phi}_1^0, \tilde{\phi}_2^0) \rightarrow (\tilde{\chi}_1^0,\ \tilde{\chi}_2^0,\ \tilde{\chi}_3^0,\ \tilde{\chi}_4^0)$$

$$(\tilde{W}^\pm,\ \tilde{\phi}^\pm) \rightarrow (\tilde{\chi}_1^\pm,\ \tilde{\chi}_2^\pm)$$

Lightest SUSY Particle (LSP) = Dark Matter candidate (if R-parity is conserved)

Electroweakino Direct Production

(Electroweakinos: collective name for gauginos and Higgsinos)



For LHC:

$$p\bar{p} \to \tilde{\chi}_1^\pm \tilde{\chi}_2^0 X,\ \tilde{\chi}_1^+ \tilde{\chi}_1^- X,\ \ldots$$

For ILC:

$$e^+e^- \to \tilde{\chi}_1^+ \tilde{\chi}_1^-,\ \tilde{\chi}_2^+ \tilde{\chi}_2^-,\ \tilde{\chi}_1^0 \tilde{\chi}_2^0,\ \ldots$$

Decays:

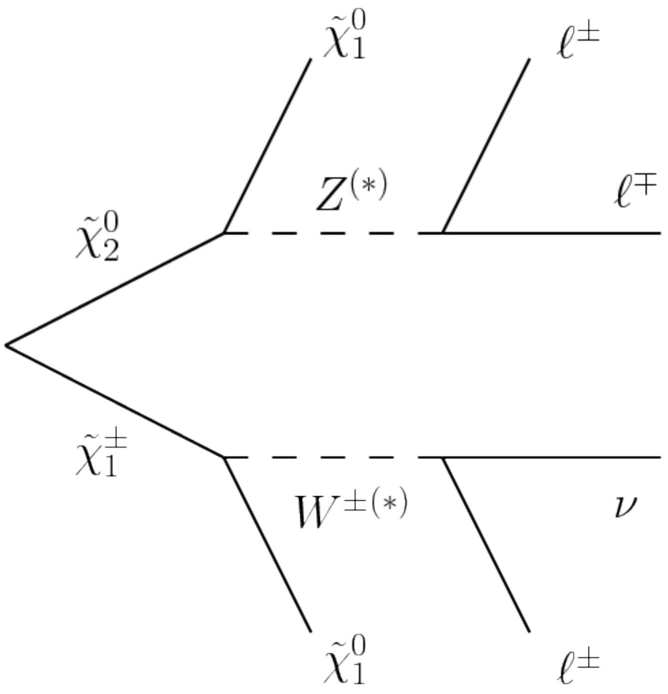
$$\tilde{\chi}_1^\pm \to W^\pm \tilde{\chi}_1^0$$

$$\tilde{\chi}_2^0 \to (Z/h)\tilde{\chi}_1^0$$

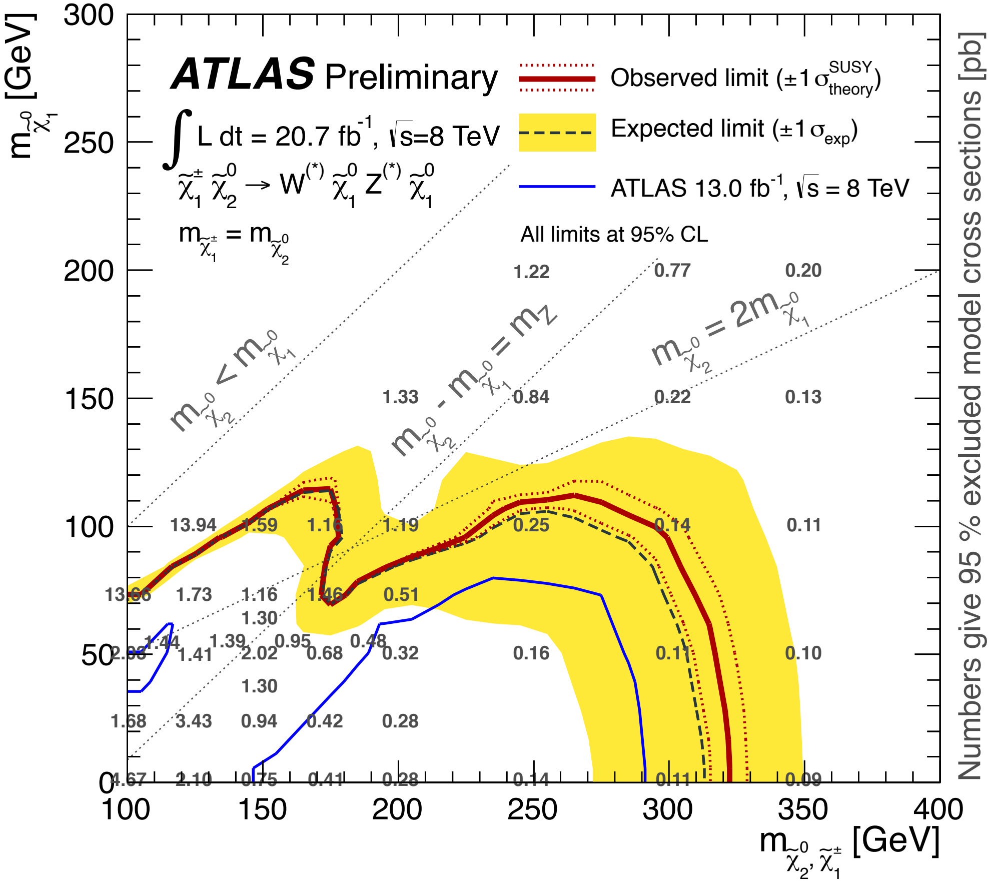
$$\cdots$$

From LHC

Simplified model:
$\tilde{\chi}_1^0$ is bino, $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$ are wino and degenerate



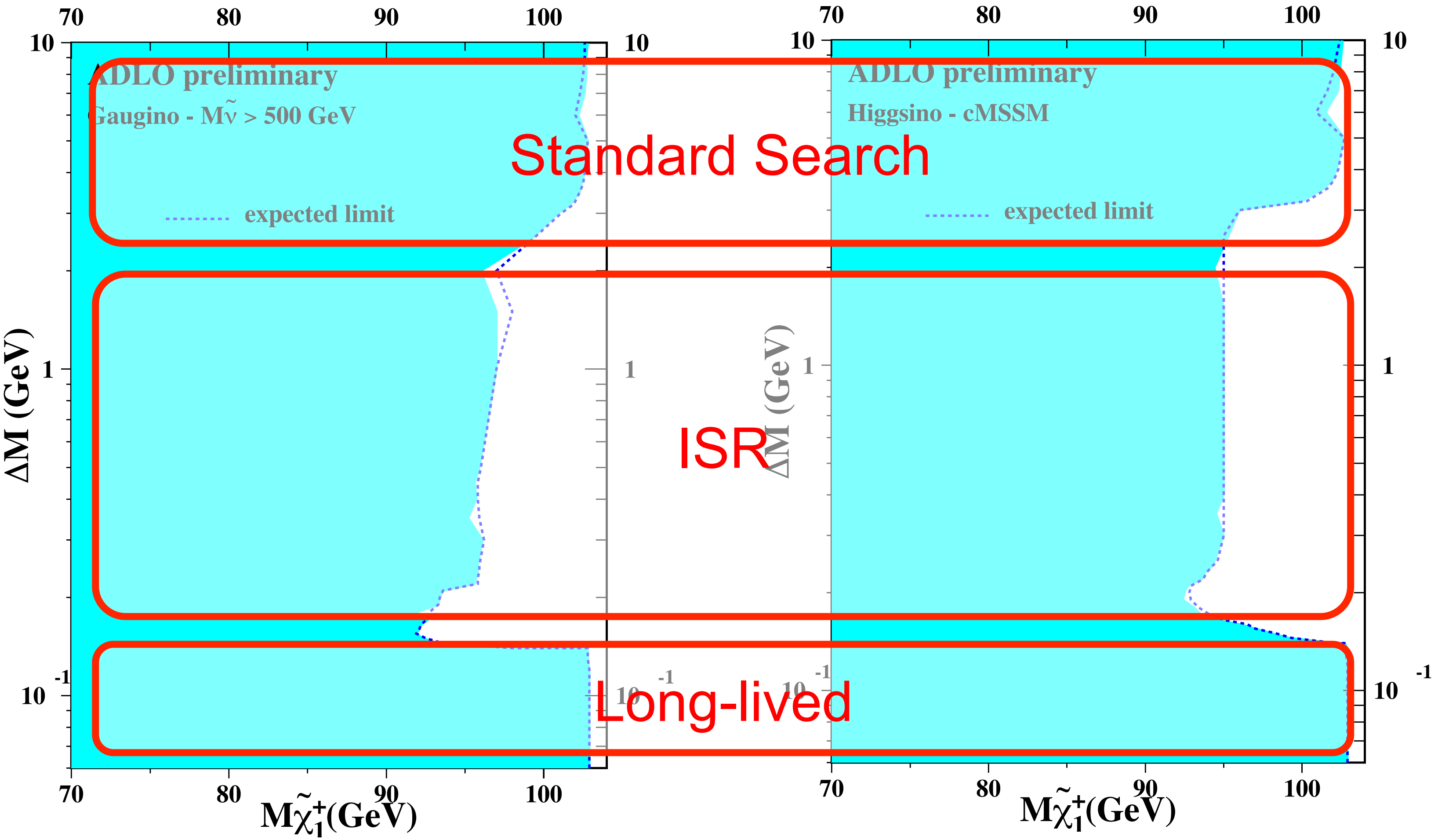
3 leptons + MET



100% BR into W/Z assumed

ATLAS-CONF-2013-035

From LEP



Chargino mass > 100 GeV

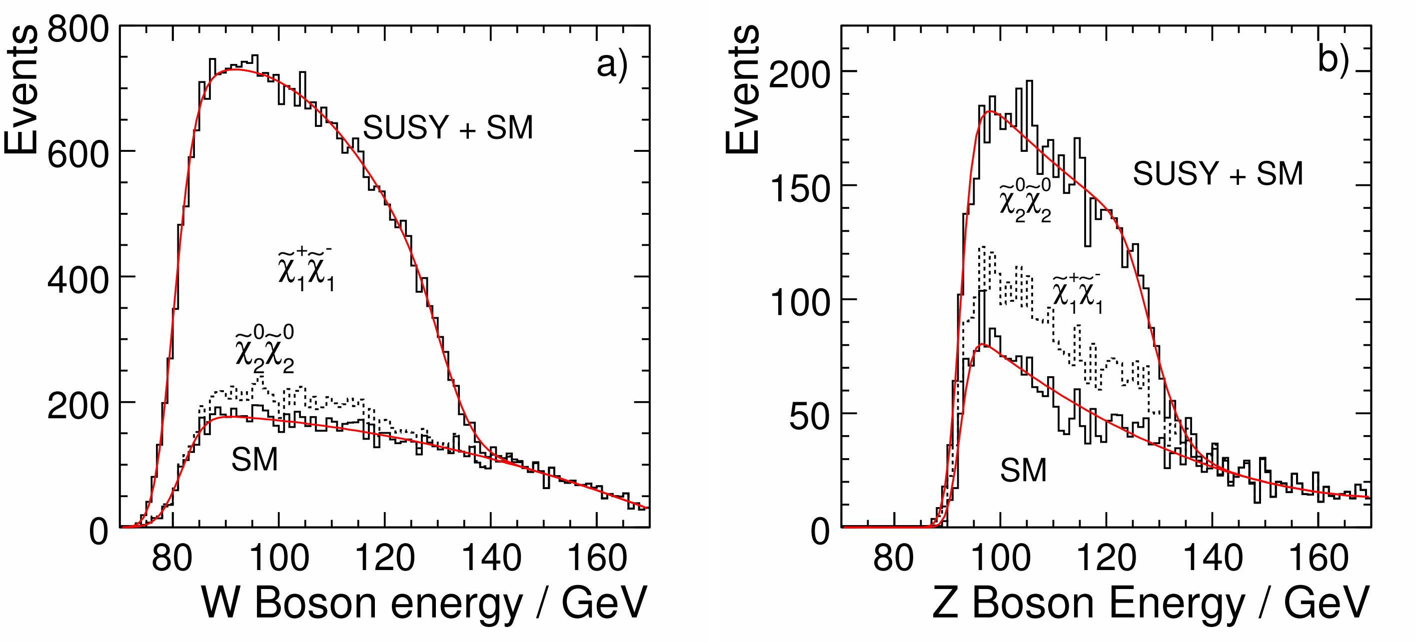
Gaugino pair production

- **ILC** can search for SUSY particles with **mass below √s/2**
- Consider pair production of chargino / neutralino whose masses are close
  - $e^+ e^- \rightarrow \chi_1^+ \chi_1^- \rightarrow \chi_1^0 \chi_1^0 W^+ W^-$
  - $e^+ e^- \rightarrow \chi_2^0 \chi_2^0 \rightarrow \chi_1^0 \chi_1^0 Z^0 Z^0$

If soft jets → challenging signature

- **Discovery** + mass measurement via detection of **kinematic edges**:

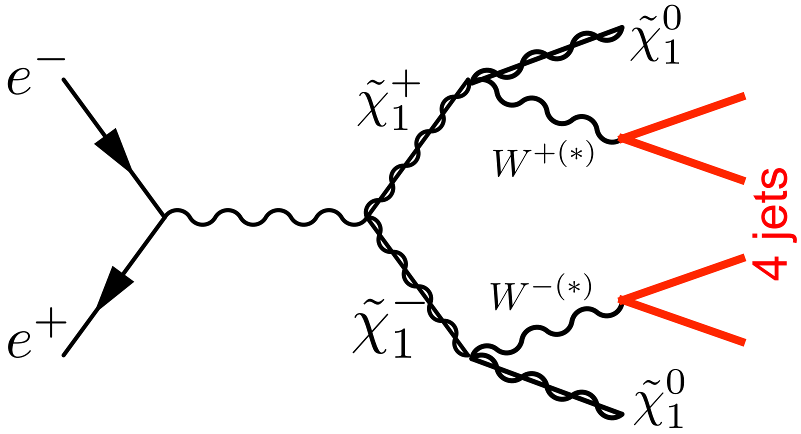
ILC 500 GeV



Suehara, List [arXiv: 0906.5508]

Chargino / Neutralino can be discovered
+ studied with mass resolution O(1)%

4 jets + missing 4-momentum

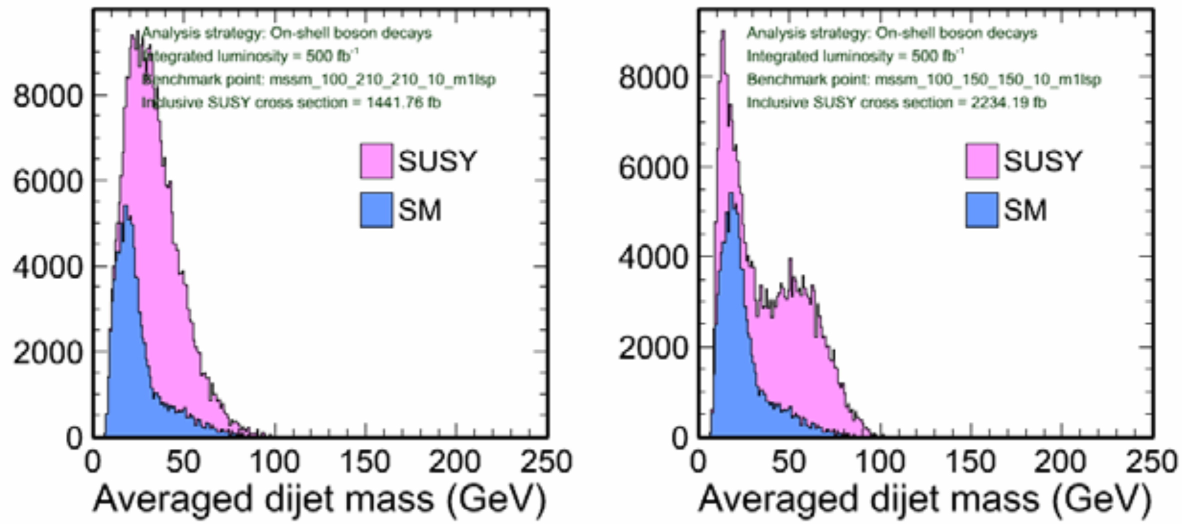


General strategy:
Reconstruct the hadronic decay of the chargino: **4 jets + missing 4-momentum** signature.

Choose jet combination most consistent with the same dijet mass.

Event selection based on:

- Number of particles
- Large missing energy
- Missing momentum ***not*** along the beam pipe
- Require minimum jet energy
- Jet finder transition values



$$M_{\tilde{\chi}_1^0} = 90.9 \text{ GeV}$$
$$M_{\tilde{\chi}_1^\pm} = 165.9 \text{ GeV}$$

$$M_{\tilde{\chi}_1^0} = 77.8 \text{ GeV}$$
$$M_{\tilde{\chi}_1^\pm} = 105.5 \text{ GeV}$$
$$M_{\tilde{\chi}_2^\pm} = 226.5 \text{ GeV}$$

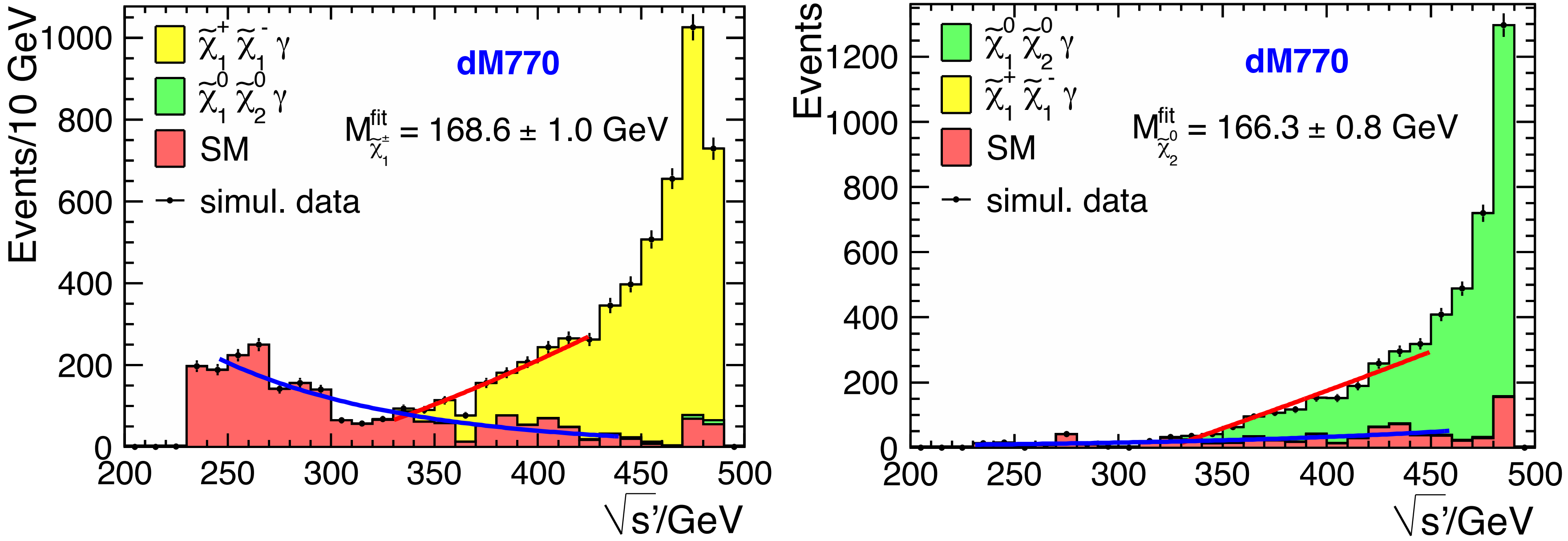
Inclusive SUSY signal is well reconstructed for mass differences > 25 GeV.

Higgsino pair production

Naturalness argument calls for light Higgsinos e.g. in the case of MSSM:

$$m_Z^2 = -2\left(m_{H_u}^2 + |\mu|^2\right) + \mathcal{O}(\cot^2\beta)$$

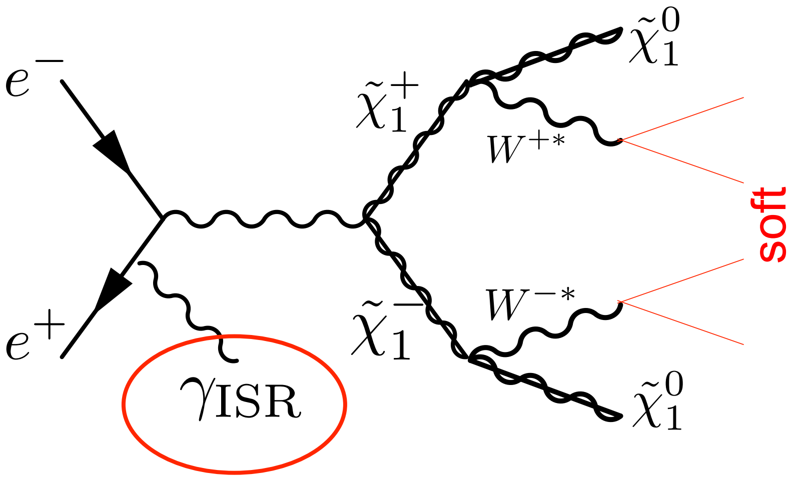
Higgsinos → small mass gaps



Berggren, Bruemmer, List, Moortgat-Pick,
Robens, Rolbiecki, Sert [arXiv:1307.3566]

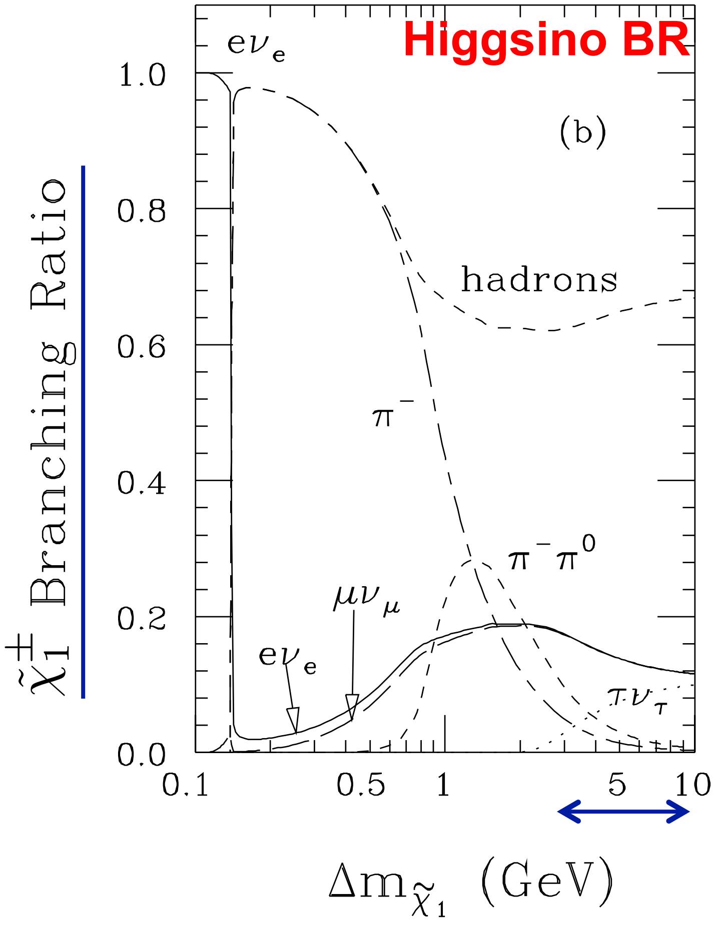
Even for sub-GeV mass differences, the charginos/neutralinos can be discovered / measured to O(1)% in mass.

ISR photon + soft particles



The **ISR tag** is critical in reducing γγ backgrounds by kicking the **hard forward electrons** into detector acceptance.

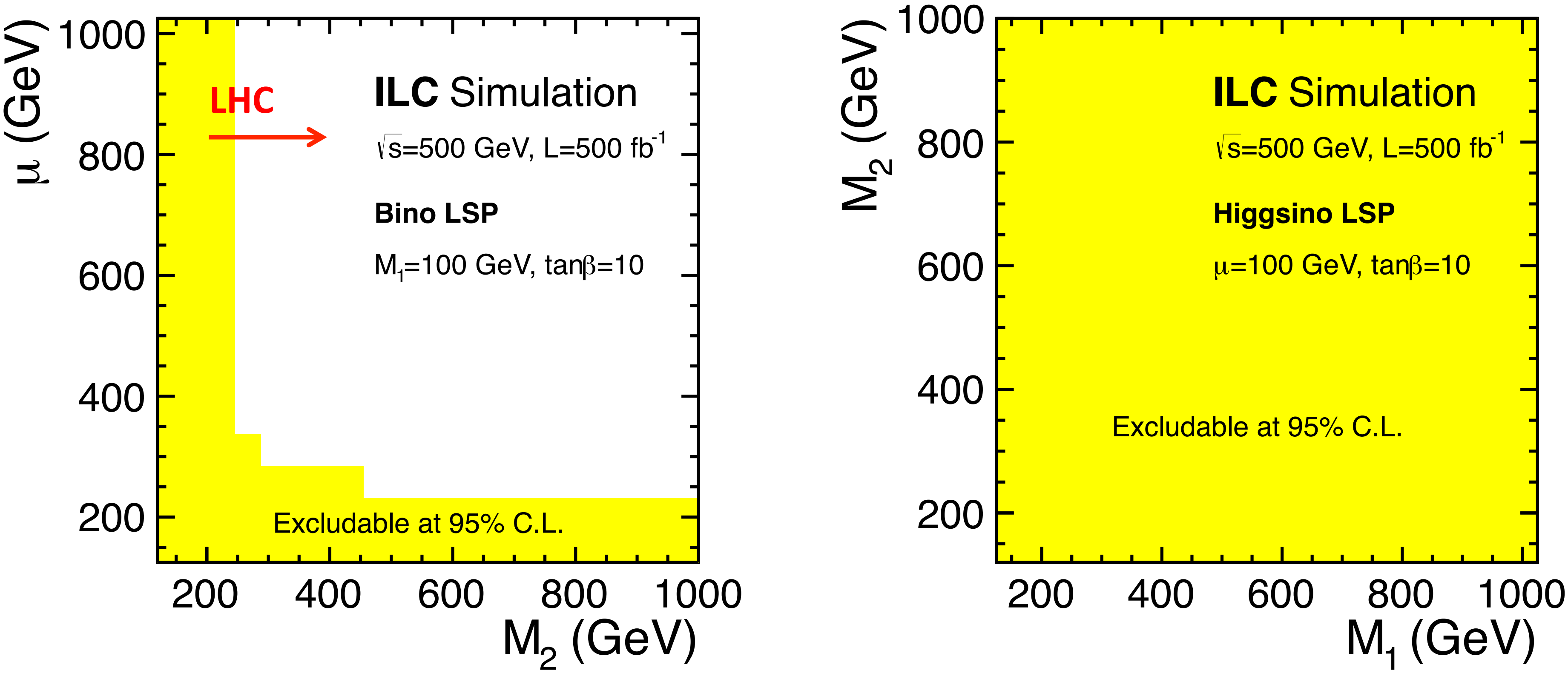
For the soft particles:
Choose characteristic signature, e.g.
lepton on one side + pions on the other side.



Chen, Drees, Gunion
[arXiv:hep-ph/9902309]

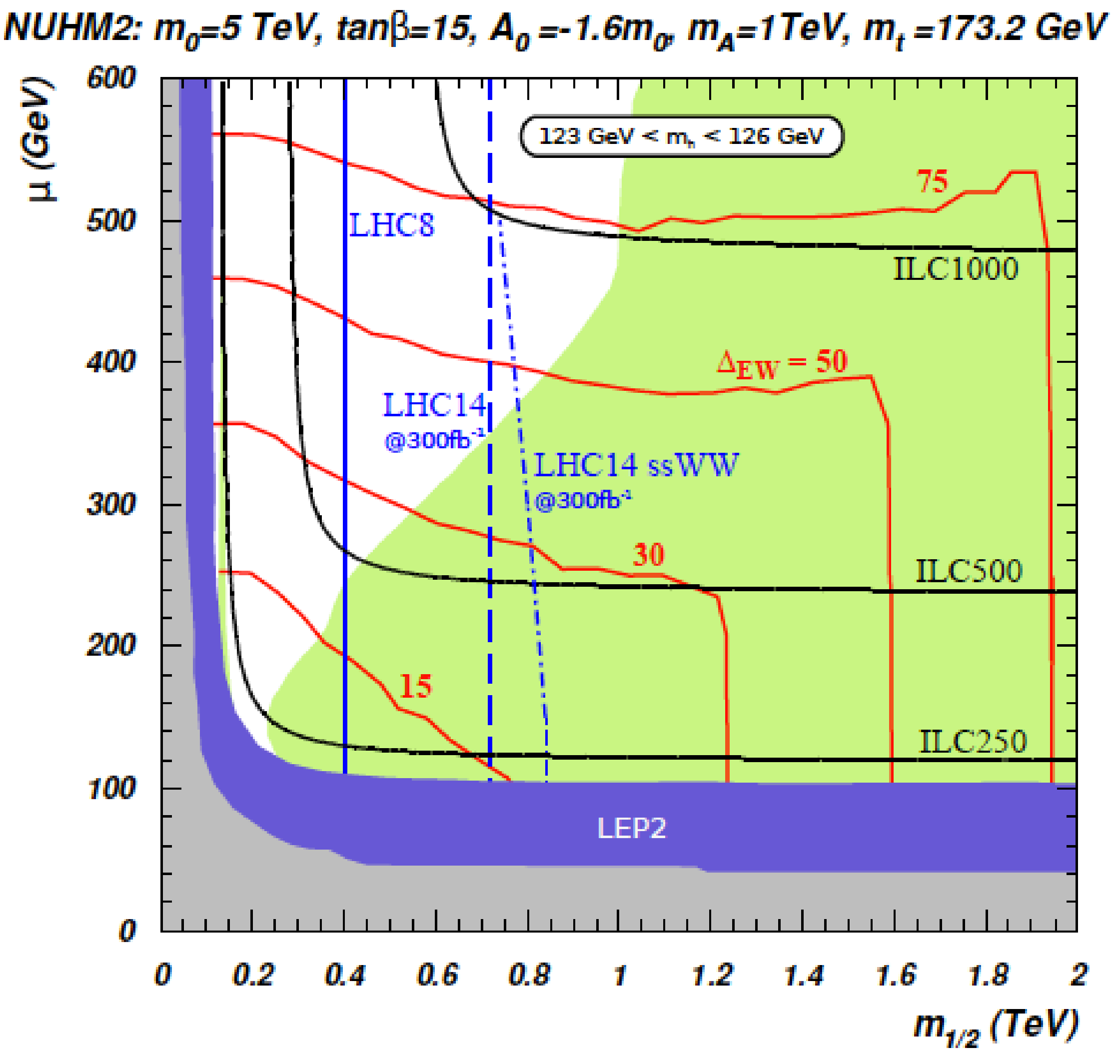
Electroweakino parameter scan

Scan over M1, M2, mu (fix 1 as LSP, scan over the two parameters)
The squark/slepton sectors are decoupled.



Berggren, Han, List, Padhi, Su, TT [to appear]

LHC/ILC Complementarity



Green region:
thermal higgsino relic abundance
$\Omega_h h^2 < 0.12$

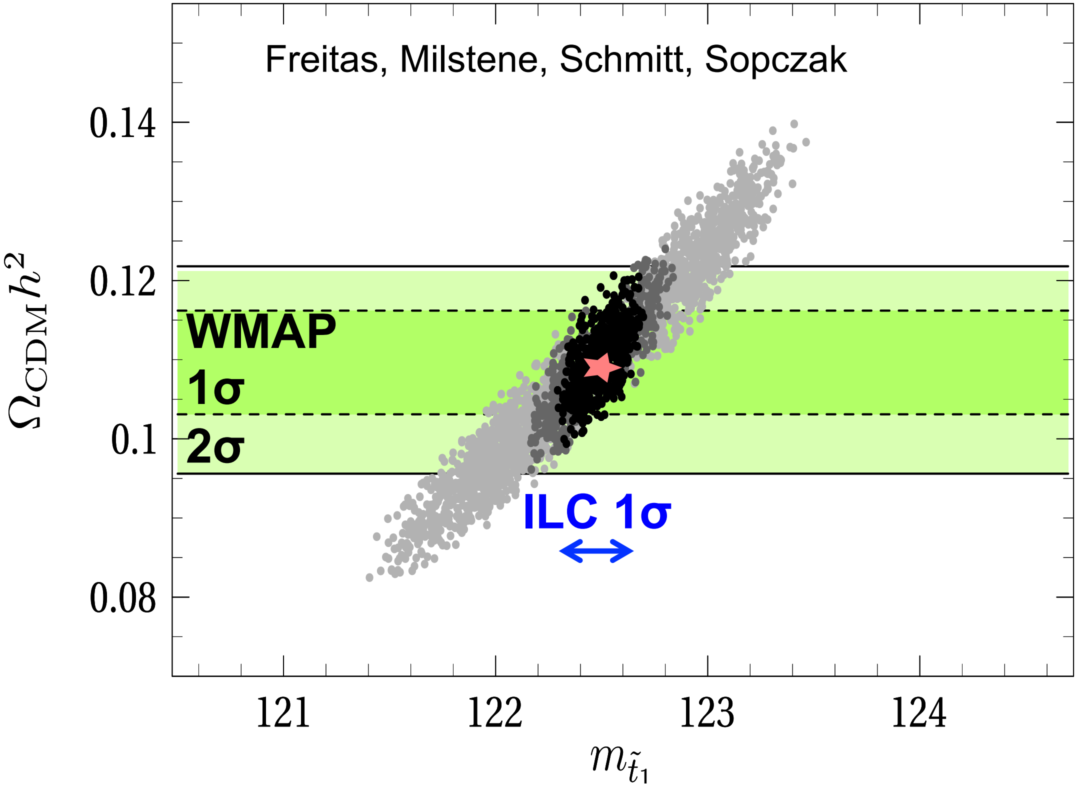
Baer, Barger, Huang, Mickelson, Mustafayev, Streehawong, Tata [arXiv:1306.3148]

SUSY / DM Connection

Neutralino LSP with light scalar top with small mass difference can provide cross sections consistent with WMAP data

$$m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} \lesssim 30 \text{ GeV}$$

Decay modes: $\tilde{t}_1 \to b\tilde{\chi}_1^+$ $\tilde{t}_1 \to c\tilde{\chi}_1^0$

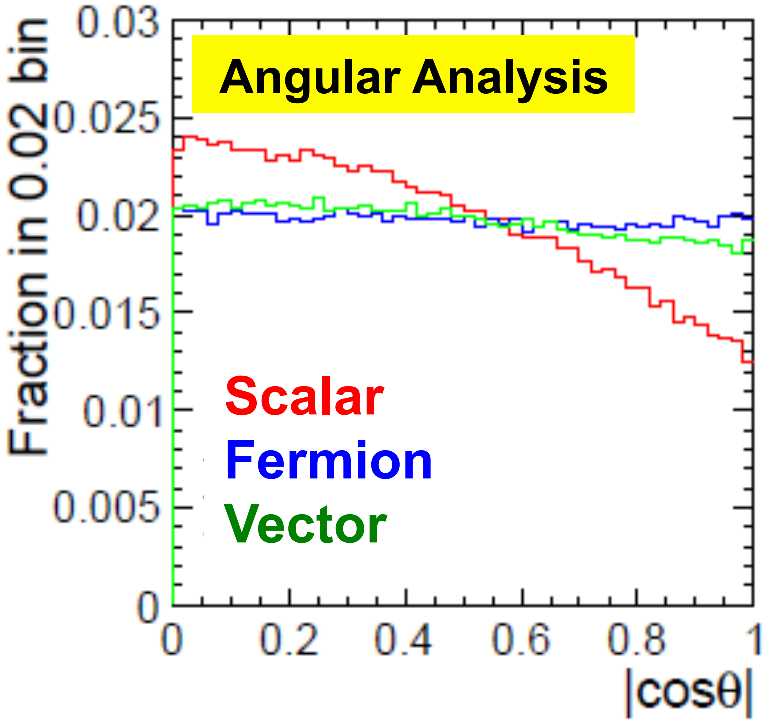


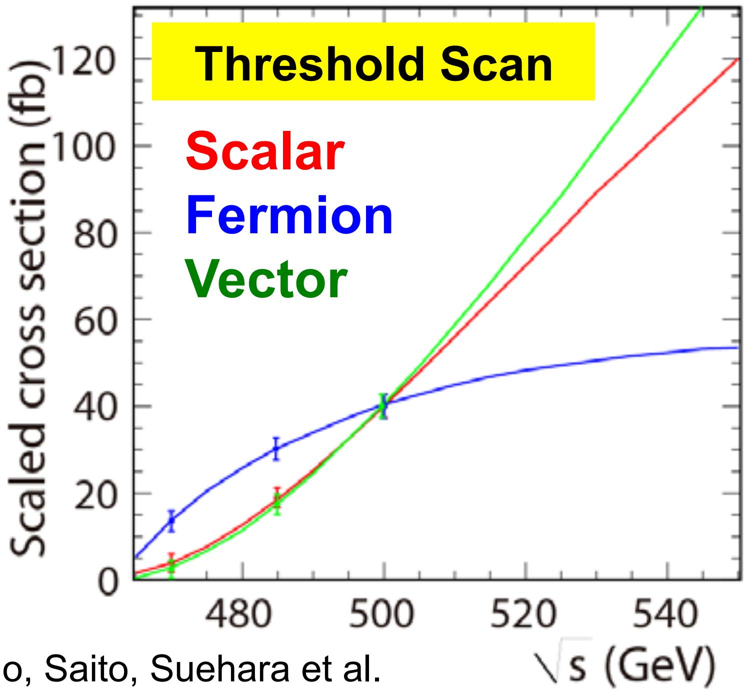
Scalar top discovery + Precision mass measurements

→ **Can establish neutralino as WIMP dark matter**

Model Discrimination

- Phenomenology: **X^+** + **X^-** → W^+ + **DM** + W^- + **DM**
- How to discriminate different physics models?
  - **Spin of X**: e.g. Inert Higgs (0), SUSY (1/2), Little Higgs (1)
- **Angular analysis** of **X production** + **Threshold Scan**



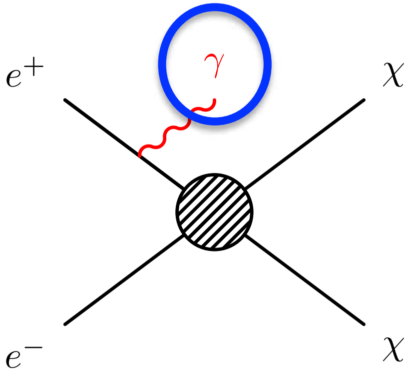


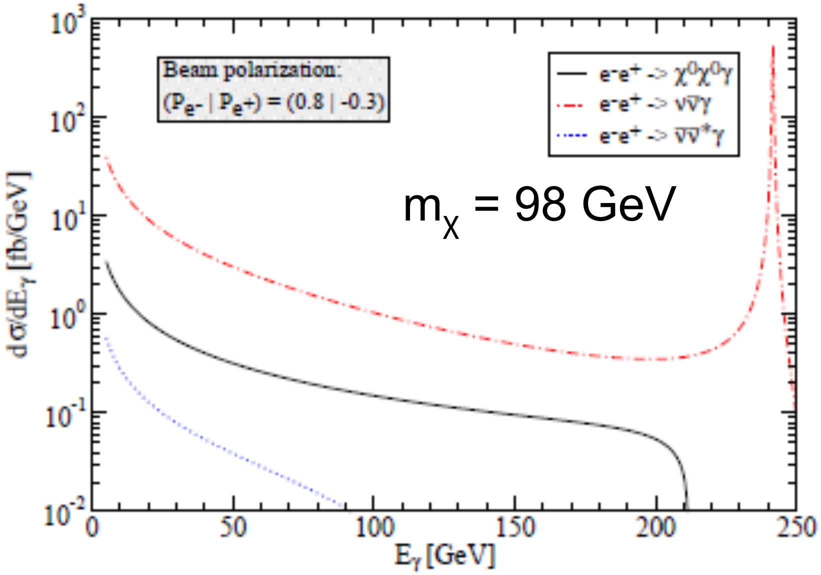
Asano, Saito, Suehara et al.

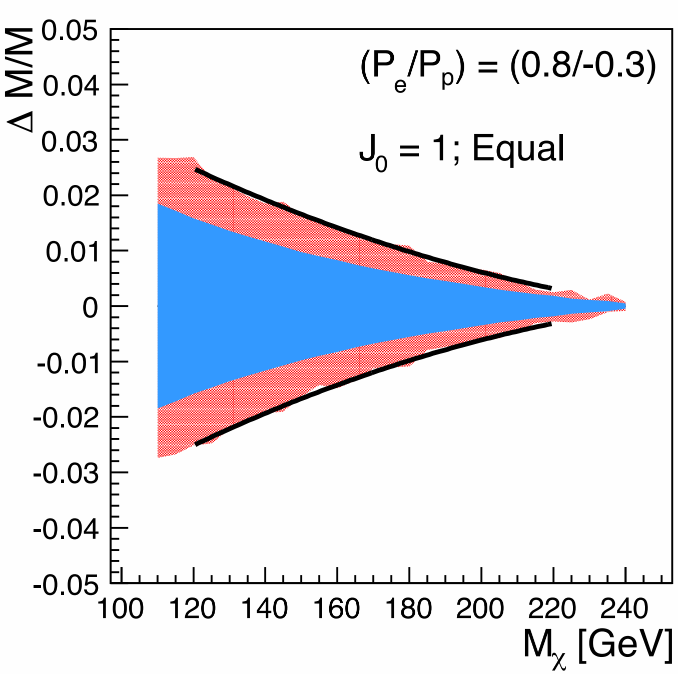
→ Model Discrimination with spin information

DM with Single Photons

Consider the case where only DM is accessible at ILC → Can still discover it with **single photons**







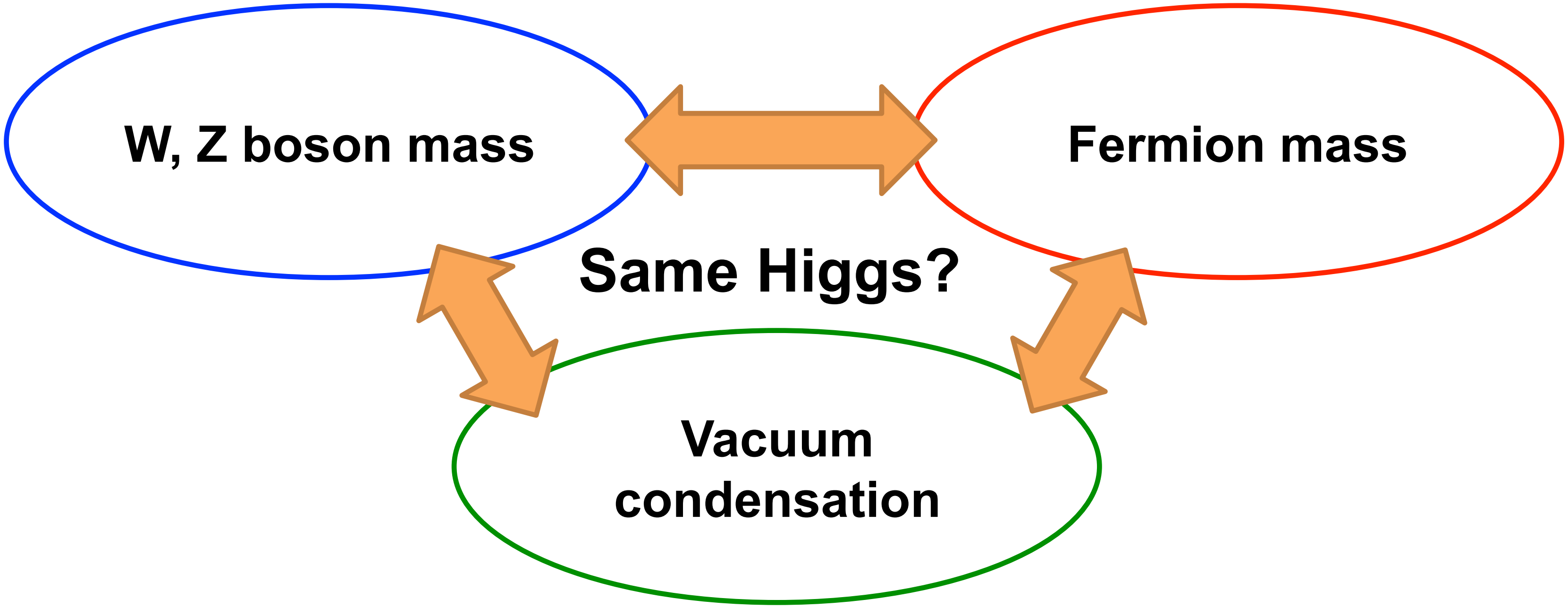
Bartels, List [arXiv:0901.4890]

Discovery of DM w/ mass precision $\Delta m(\chi^0_1)/\chi^0_1$ ~ 3% or better

Higgs Physics at the ILC

The Higgs Boson

The Higgs boson plays a unique role in the SM:

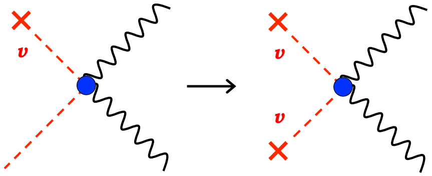


W, Z boson mass

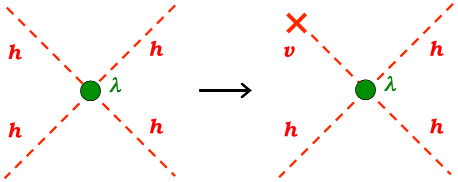
Fermion mass

Same Higgs?

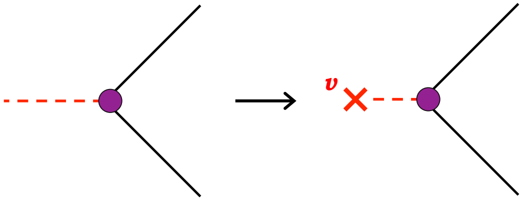
Vacuum condensation



HWW, HZZ coupling



Higgs self-coupling

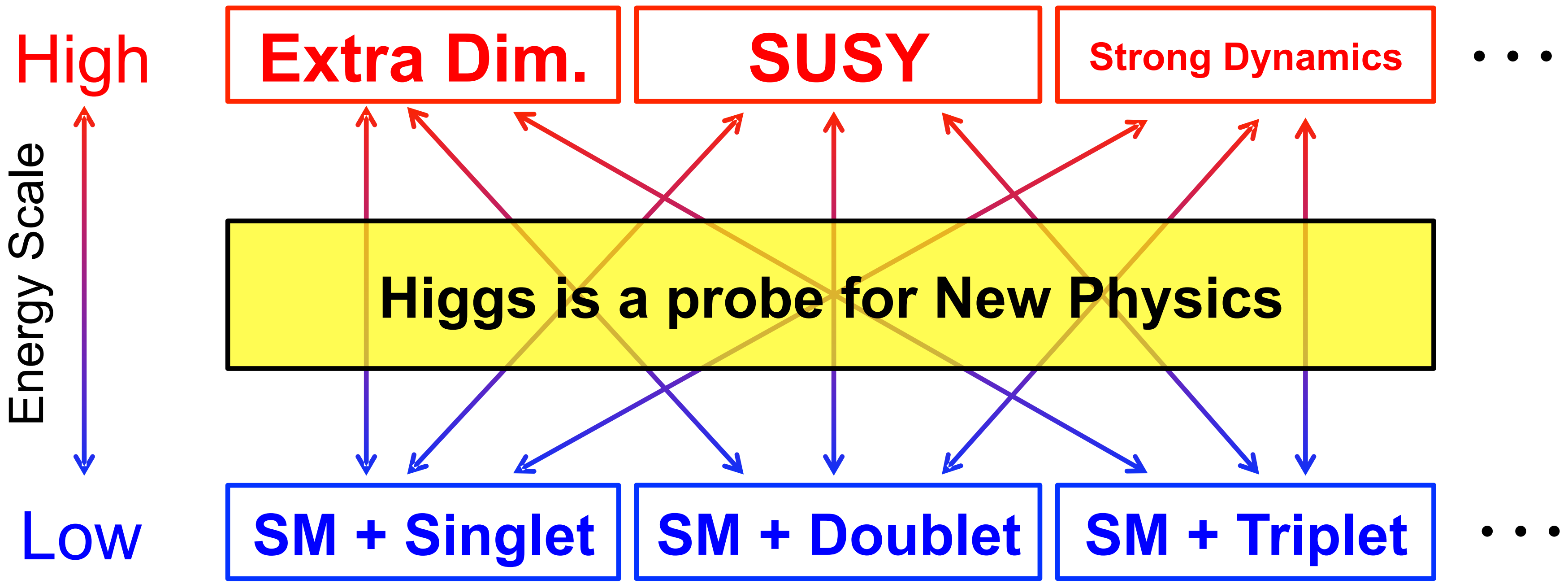


Yukawa coupling

SM contains the simplest possible Higgs sector.
There is no known principle for this simplicity.

Higgs Sector and New Physics

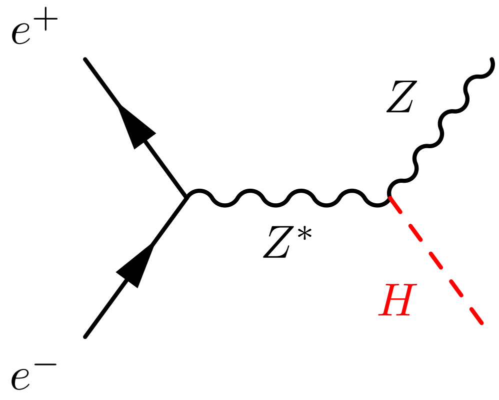
New physics can affect the **Higgs sector**



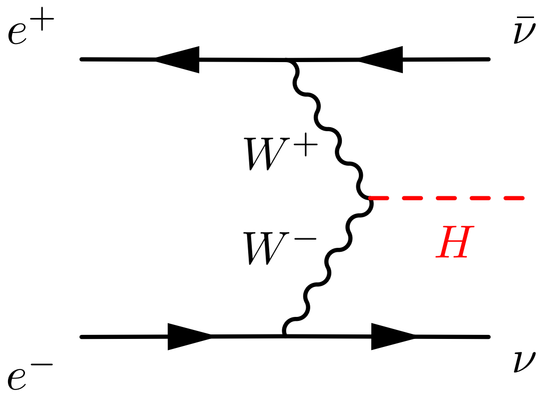
Extended Higgs Sector

May be able to explain well-established BSM phenomena: dark matter, neutrino oscillation, baryon asymmetry, etc.

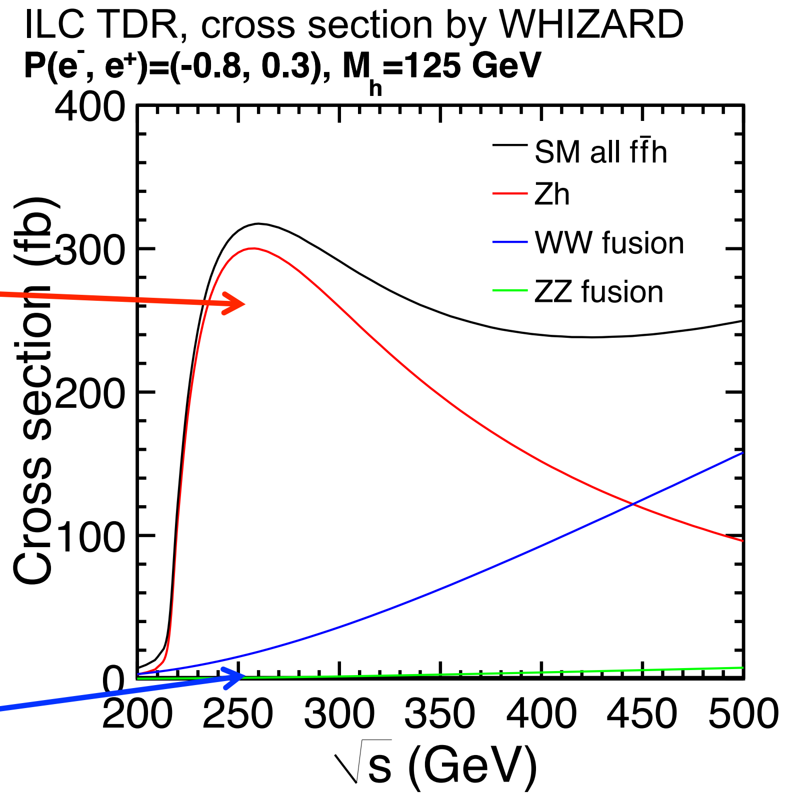
Higgs Production at ILC



Higgs-strahlung
peaks around 250 GeV



WW fusion
dominates at high energies



ILC TDR, cross section by WHIZARD

P(e⁻, e⁺)=(-0.8, 0.3), M_h=125 GeV

	250 GeV	**500 GeV**
$\sigma(e^+e^- \to ZH)$	303 fb	100 fb
$\sigma(e^+e^- \to vvH)$	16 fb	150 fb
Int. Luminosity	250 fb^{-1}	500 fb^{-1}
# ZH events	76,000	50,000
# vvH events	4,000	75,000

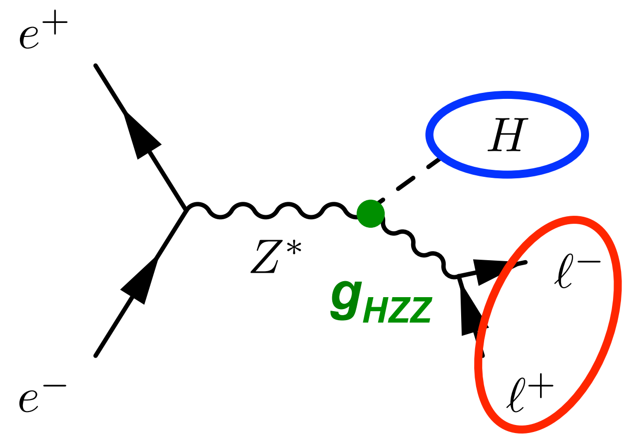
ILC is a Higgs Factory

Higgs recoil mass

Reconstruct $Z\to l^+l^-$

independent of Higgs decay

sensitive to invisible Higgs decays



$$m^2_{\mathrm{recoil}} = (\sqrt{s} - E_{\ell\ell})^2 - |\vec{p}_{\ell\ell}|^2$$

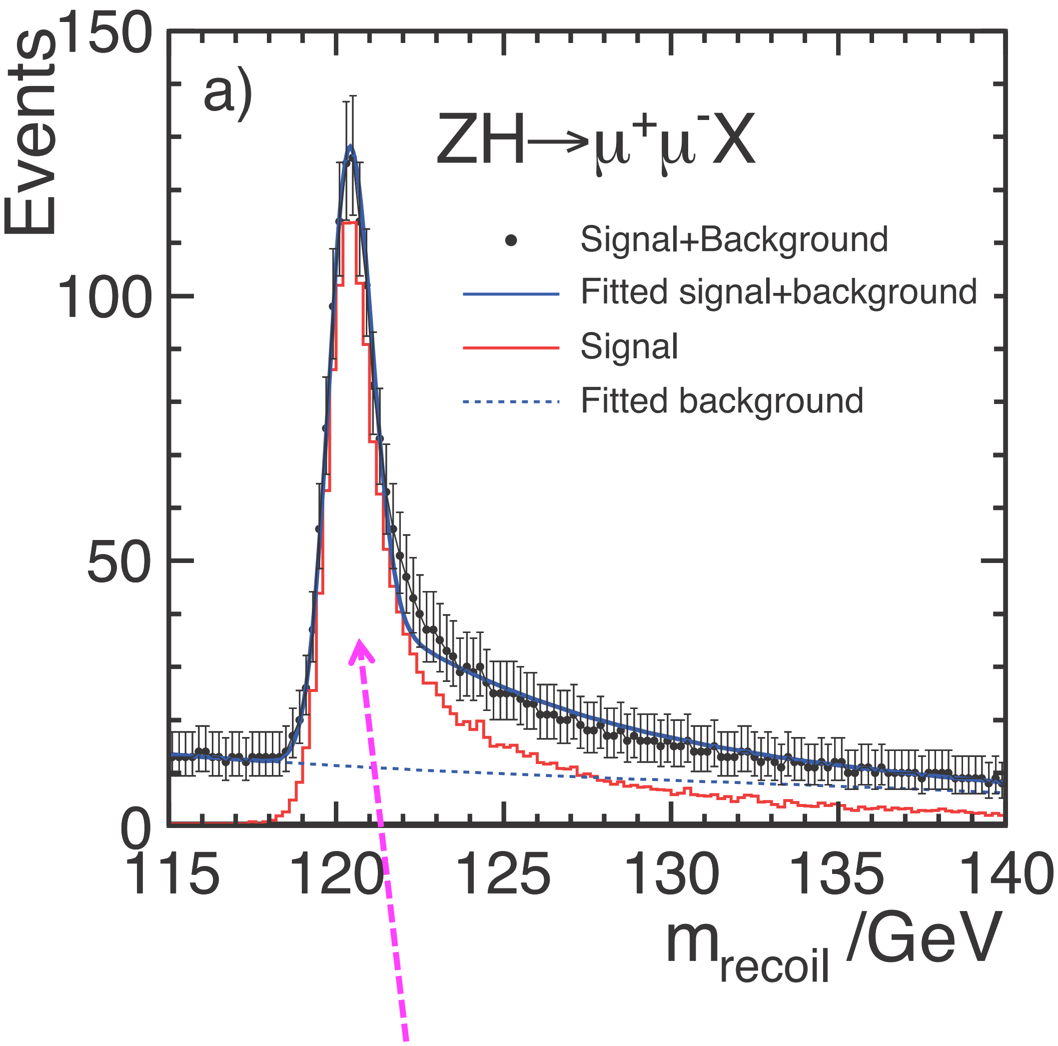
Model-independent, absolute measurements ($Z\to e^+e^-, \mu^+\mu^-$ combined):

$\Delta m_H \lesssim 32$ MeV

$\sigma_{ZH} \lesssim 2.5\%$

$g_{HZZ} \lesssim 1.2\%$

ILC TDR, $\sqrt{s}$=250 GeV, L=250 fb^{-1}

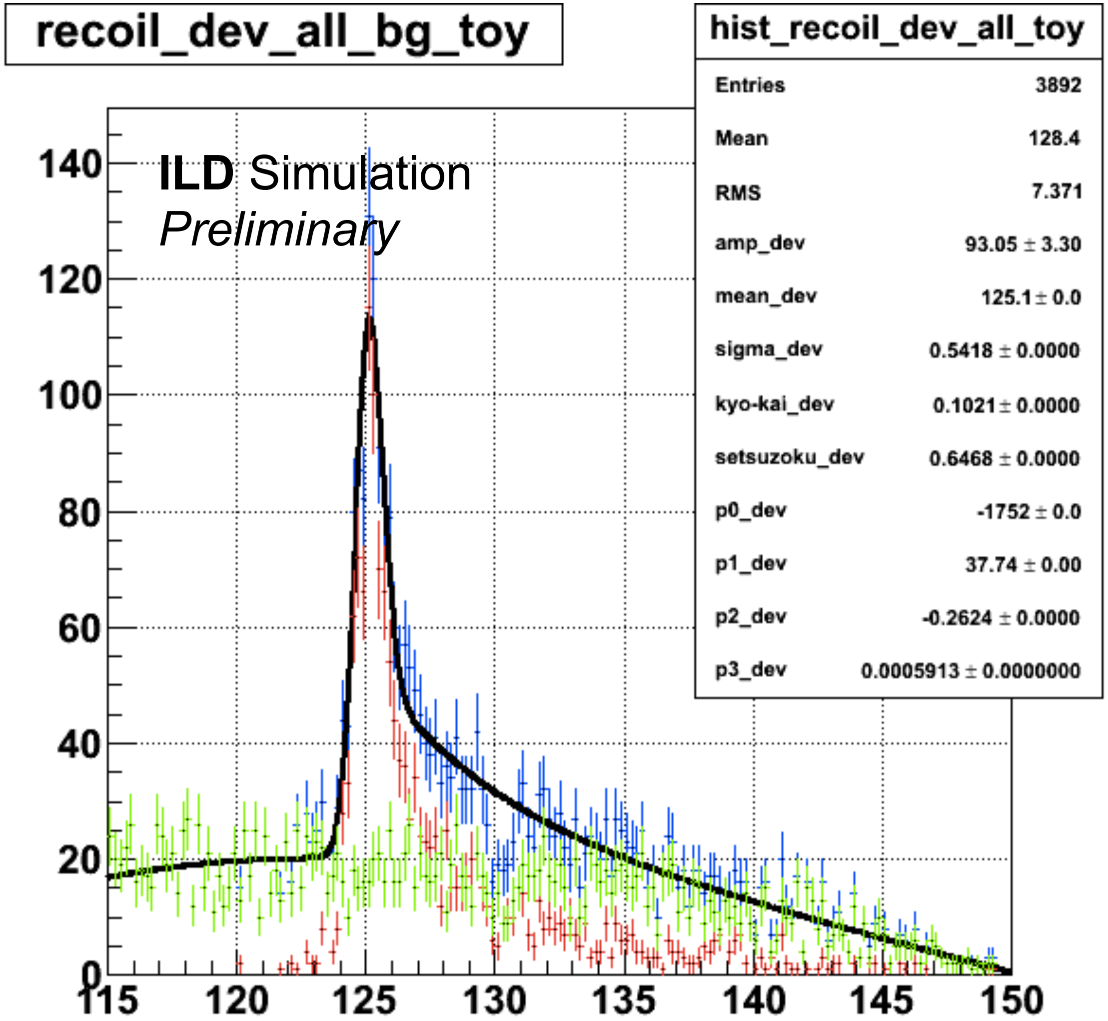


Gauss. width ≈ 650 MeV = 560 MeV ⊕ 330 MeV

beam energy spread

detector resolution

Higgs recoil mass



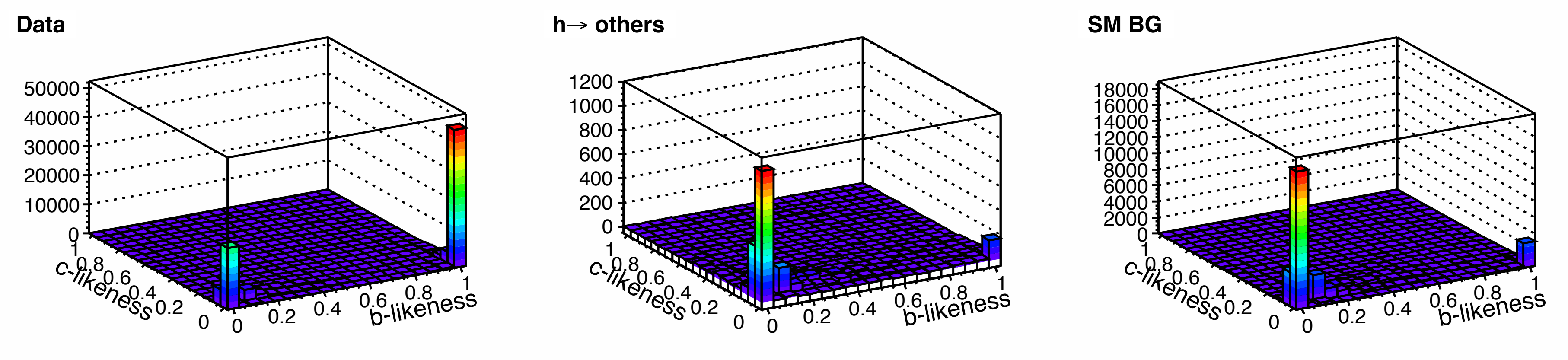
Watanuki, Ishikawa, Suehara [to appear]

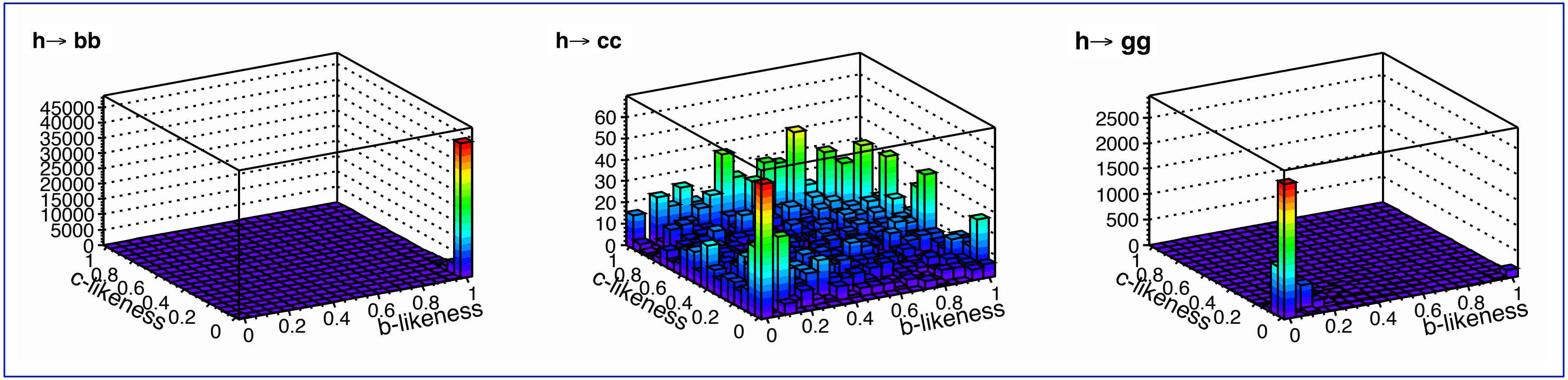
Update to m_H=125 GeV in progress…

Higgs: hadronic BRs

Measuring the Higgs BR into bb, cc, gg require flavor-tagging.
Apply flavor template fit to ZH sample:

[Hiroaki Ono]





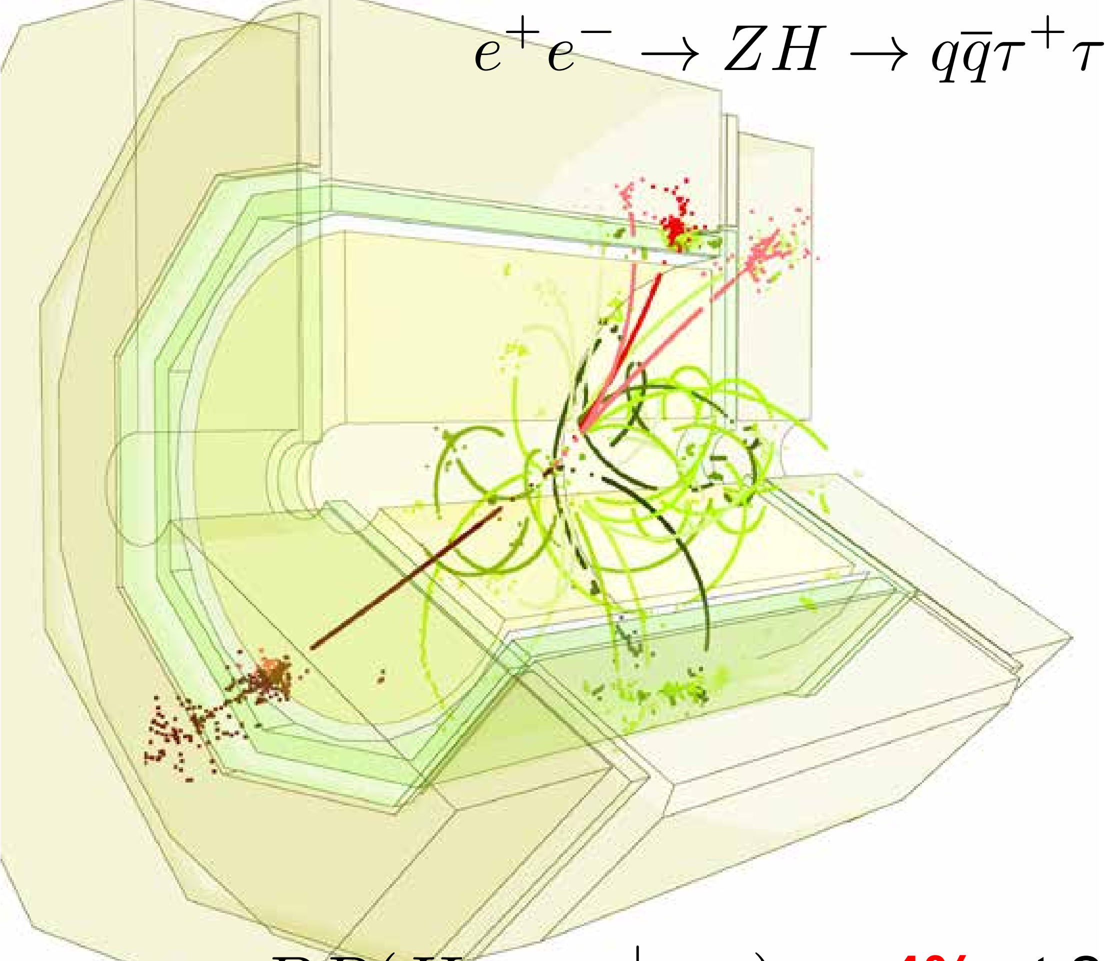
h→bb: ~1%, h→cc: ~7%, h→gg: ~9% at 250 GeV ILC with 250 fb-1
improves with more luminosity at higher energies

Higgs to tau pair decays

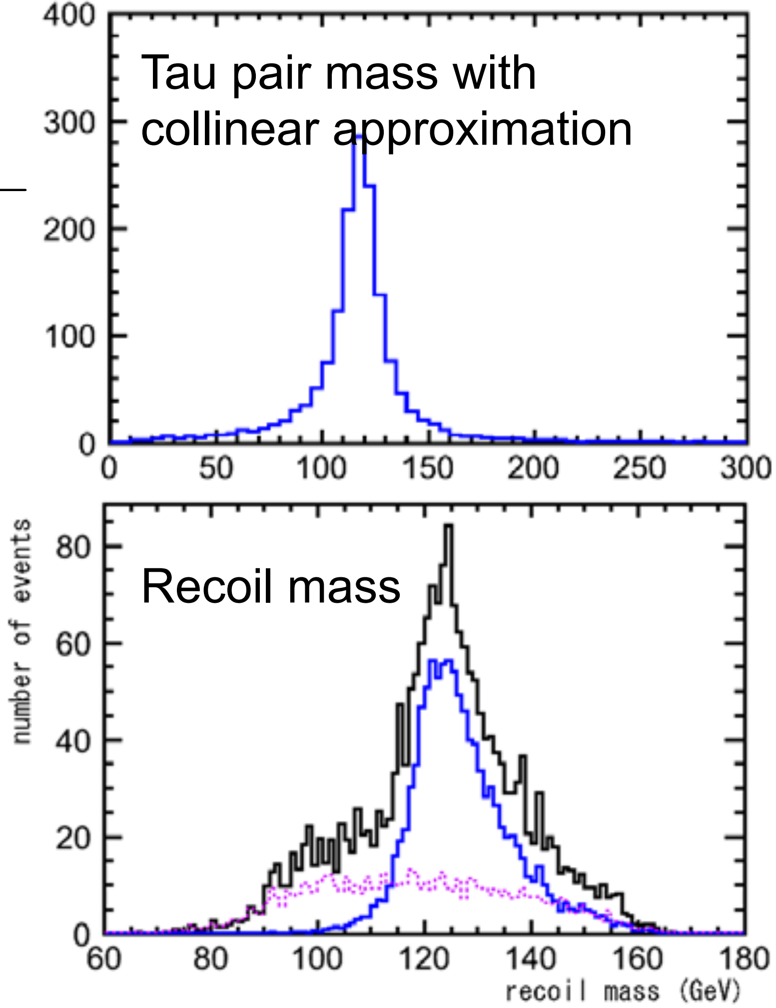
H→tautau good probe: small uncertainty in mass

Most sensitive channel at 250 GeV:

$$e^+e^- \to ZH \to q\bar{q}\tau^+\tau^-$$



[Kawada, Suehara, TT]

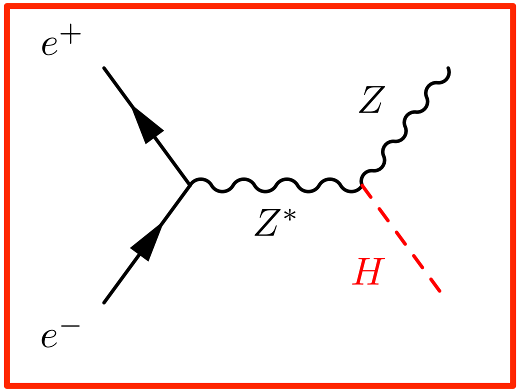


Tau pair mass with collinear approximation

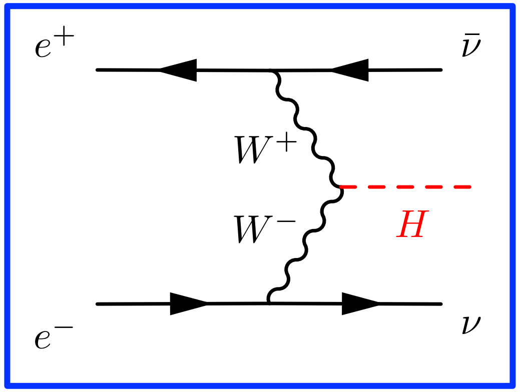
Recoil mass

$\sigma \cdot BR(H \to \tau^+\tau^-)$ **~4%** at 250 GeV ILC with 250 fb-1

Higgs Measurements at ILC (1)



250 GeV~
Higgs-strahlung

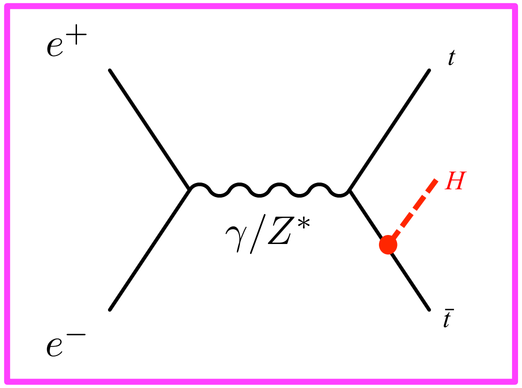


350 GeV~
WW fusion

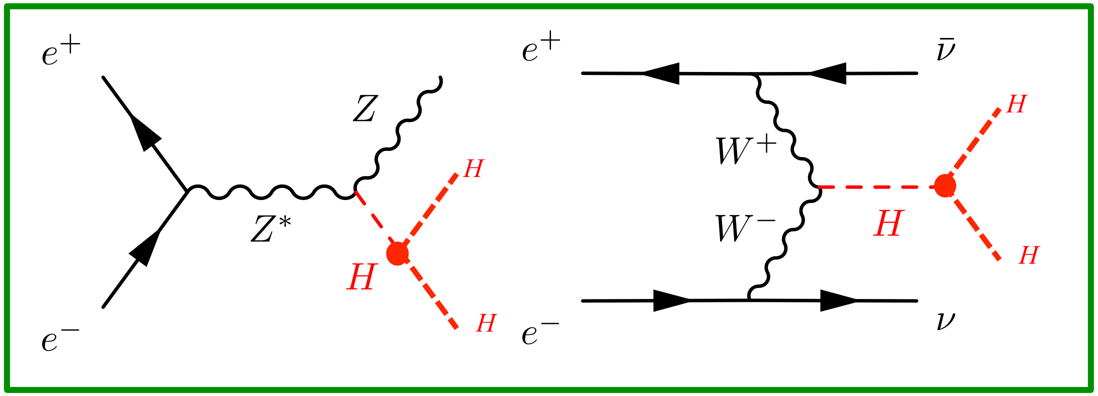
	$\Delta(\sigma \cdot BR)/(\sigma \cdot BR)$				
$\sqrt{s}$ and $\mathcal{L}$ (P_{e^-}, P_{e^+})	$250\,\mathrm{fb}^{-1}$ at $250\,\mathrm{GeV}$ (-0.8,+0.3)		$500\,\mathrm{fb}^{-1}$ at $500\,\mathrm{GeV}$ (-0.8,+0.3)		$1\,\mathrm{ab}^{-1}$ at $1\,\mathrm{TeV}$ (-0.8,+0.2)
mode	Zh	$\nu\bar{\nu}h$	Zh	$\nu\bar{\nu}h$	$\nu\bar{\nu}h$
$h \to b\bar{b}$	1.1%	10.5%	1.8%	0.66%	0.47%
$h \to c\bar{c}$	7.4%	-	12%	6.2%	7.6%
$h \to gg$	9.1%	-	14%	4.1%	3.1%
$h \to WW^*$	6.4%	-	9.2%	2.6%	3.3%
$h \to \tau^+\tau^-$	4.2%	-	5.4%	14%	3.5%
$h \to ZZ^*$	19%	-	25%	8.2%	4.4%
$h \to \gamma\gamma$	29-38%	-	29-38%	20-26%	7-10%
$h \to \mu^+\mu^-$	100%	-	-	-	32%

ILC TDR, m_H=125 GeV, BRs from LHC HXSWG assumed.

Higgs Measurements at ILC (2)



500 GeV~
Top Yukawa Coupling



500 GeV~
Higgs Self-Coupling

process	$\sqrt{s}$ [GeV]	$\mathcal{L}$ [ab^{-1}]	(P_{e^-}, P_{e^+})	$\Delta(\sigma \cdot BR)/(\sigma \cdot BR)$	$\Delta g/g$
$t\bar{t}h$	500	1	(-0.8,+0.3)	25%	13%
Zhh	500	2	(-0.8,+0.3)	32%	53%
$t\bar{t}h$	1000	1	(-0.8,+0.2)	8.7%	4.5%
$\nu\bar{\nu}hh$	1000	2	(-0.8,+0.2)	26%	21%

ILC TDR, m_H=125 GeV, BRs from LHC HXSWG assumed.
Higgs is reconstructed in the **h→bb mode only**.

Higgs coupling determination

[Junping Tian]

Absolute determination of couplings require knowledge of the total width:

$$Br(H \to XX) = \frac{\Gamma(H \to XX)}{\Gamma_0} \propto \frac{g^2_{HXX}}{\Gamma_0} \quad \longrightarrow \quad \Gamma_0 \propto \frac{g^2_{HXX}}{Br(H \to XX)}$$

An easy example:

$$\Gamma_0 \propto \frac{g^2_{HZZ}}{Br(H \to ZZ^*)} \propto \frac{\sigma(e^+e^- \to ZH)}{Br(H \to ZZ^*)}$$

~20% precision at 250 GeV

A more sophisticated example:

$$Y_1 = \sigma_{ZH} = g^2_{HZZ}$$

$$Y_2 = \sigma_{ZH} \cdot Br(H \to b\bar{b}) = \frac{g^2_{HZZ} \cdot g^2_{Hbb}}{\Gamma_0}$$

$$Y_3 = \sigma_{\nu\bar{\nu}H} \cdot Br(H \to b\bar{b}) = \frac{g^2_{HWW} \cdot g^2_{Hbb}}{\Gamma_0}$$

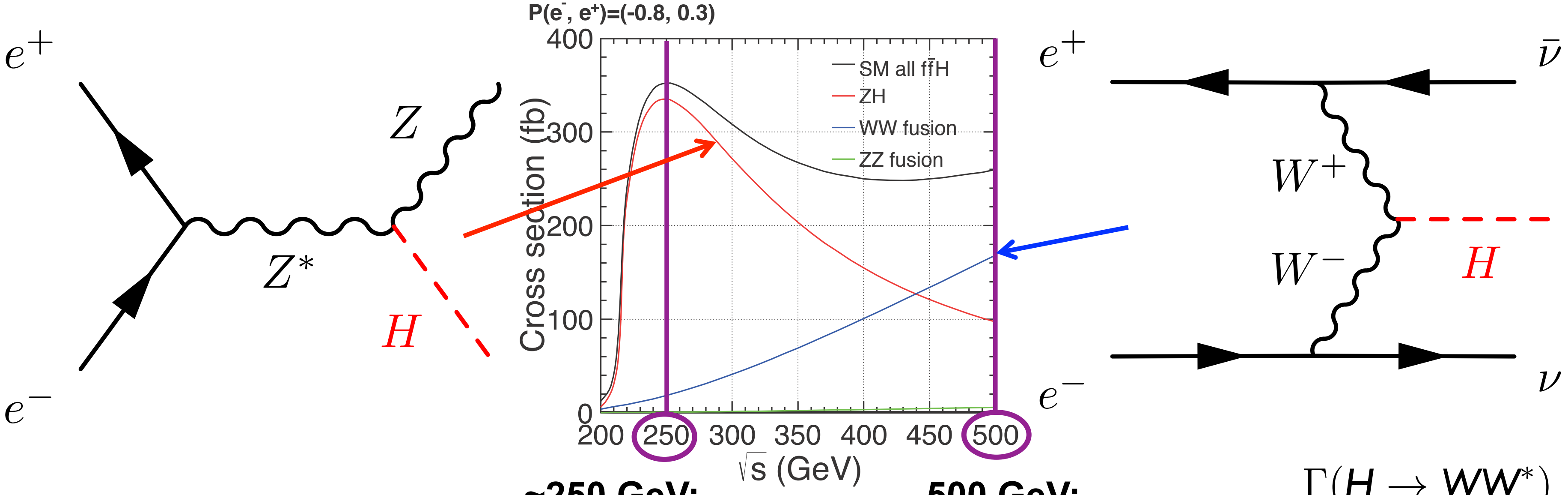
$$Y_4 = \sigma_{\nu\bar{\nu}H} \cdot Br(H \to WW^*) = \frac{g^4_{HWW}}{\Gamma_0}$$

$$\longrightarrow \quad \Gamma_0 = \frac{Y_1^2 \cdot Y_3^2}{Y_2^2 \cdot Y_4}$$

~6% precision combining
250 GeV + 500 GeV

Higgs Production at ILC

m_H=120 GeV



~250 GeV: ZH max.

500 GeV: vvH dominates

$$\Gamma_{\text{tot}} = \frac{\Gamma(H \to WW^*)}{BR(H \to WW^*)}$$

250 GeV

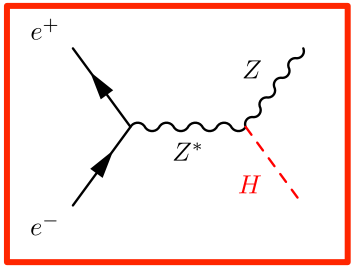
Precision	250 fb^{-1}	1000 fb^{-1}
σ_{ZH}	2.5%	1.2%
g_{HZZ}	1.2%	0.6%

500 GeV

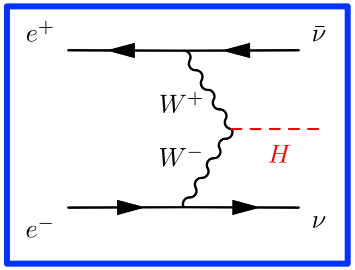
Precision	500 fb^{-1}	2000 fb^{-1}
g_{HWW}	1.3%	0.7%
Γ_{tot}	~6%	~3%

HZZ, HWW coupling precision: ~1% or better

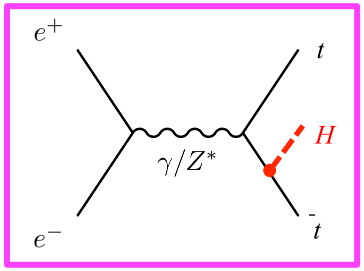
Higgs Couplings at ILC



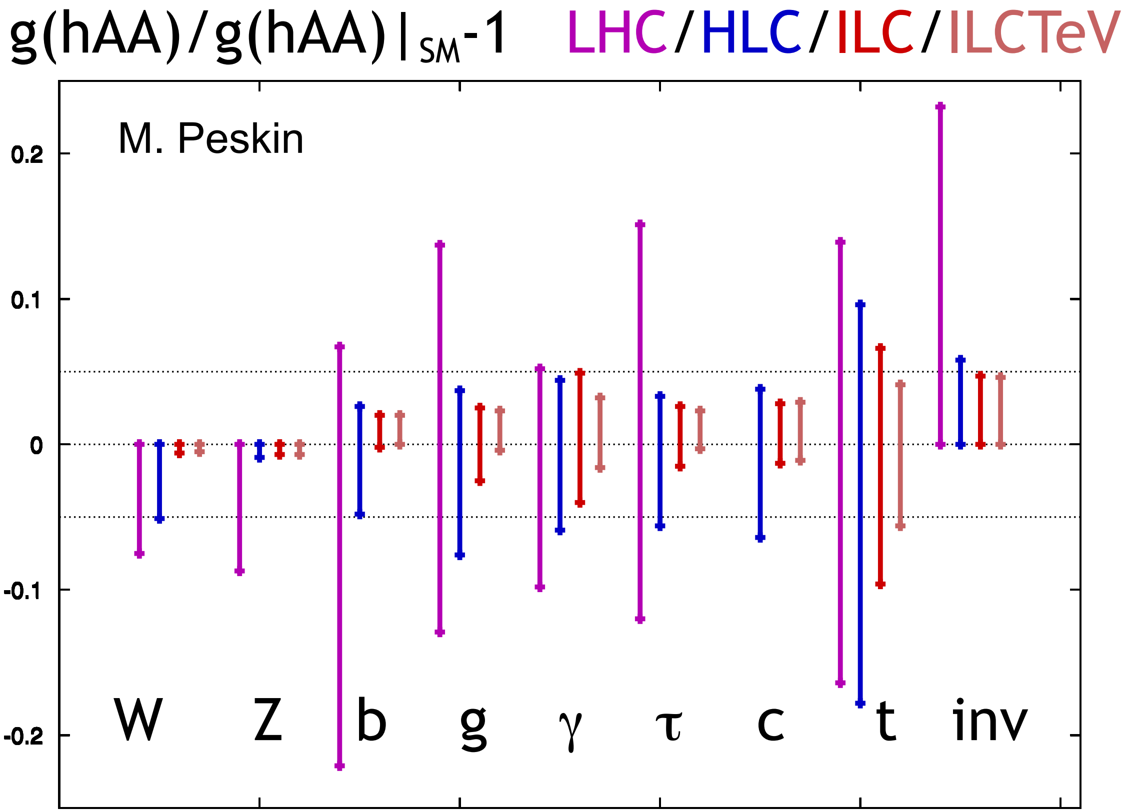
250 GeV~
Higgs BR via
Higgs-strahlung



350 GeV~
Higgs BR via
WW fusion

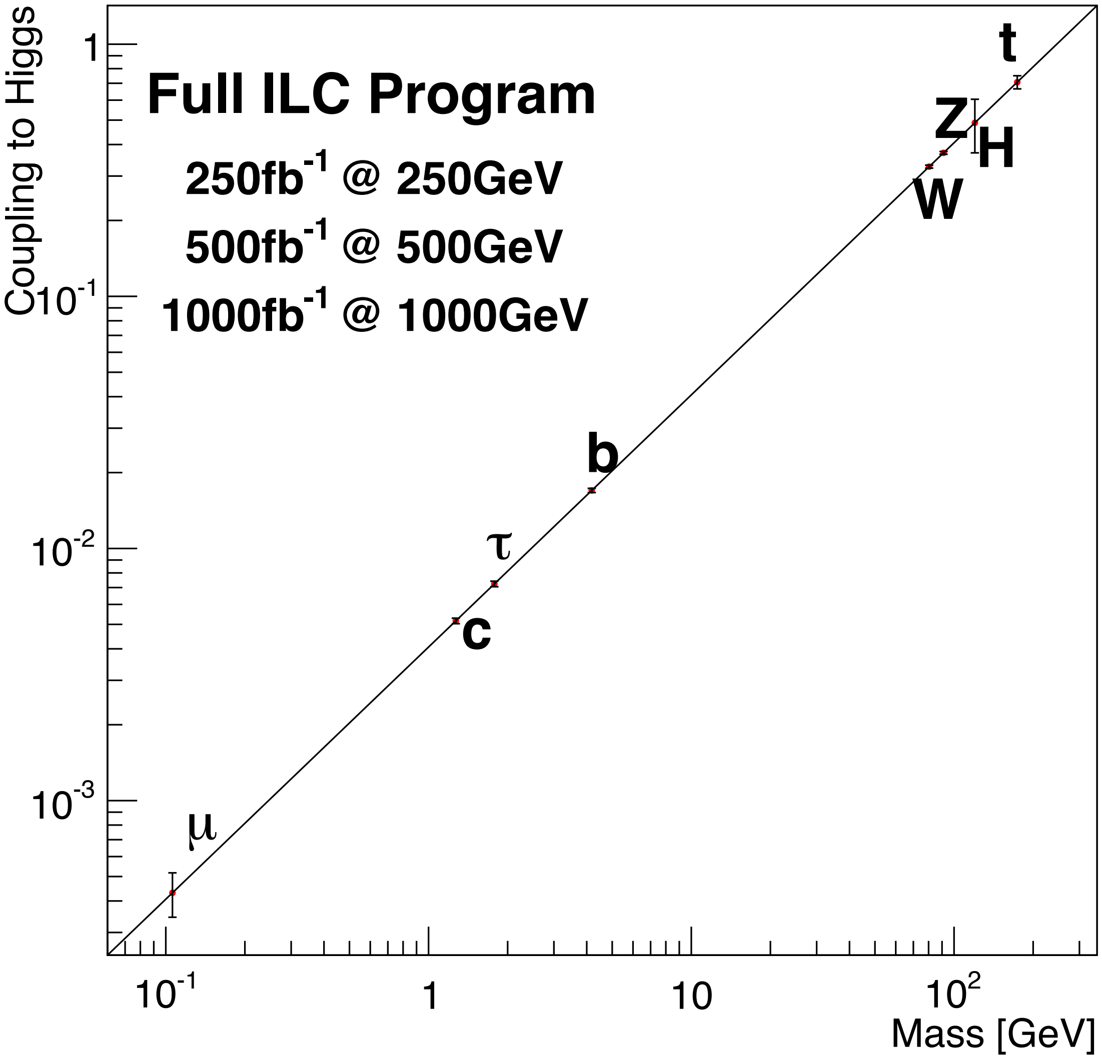


500 GeV~
Top Yukawa
Coupling



Measurement of σ×BR → Input to global fit → Extract Higgs couplings
Exploit LHC / ILC synergy.

LHC can measure $g_{H\gamma\gamma}$ / g_{HZZ} precisely (~5% at 3000 fb-1)
ILC measurement of g_{HZZ} → precise measurement of $g_{H\gamma\gamma}$



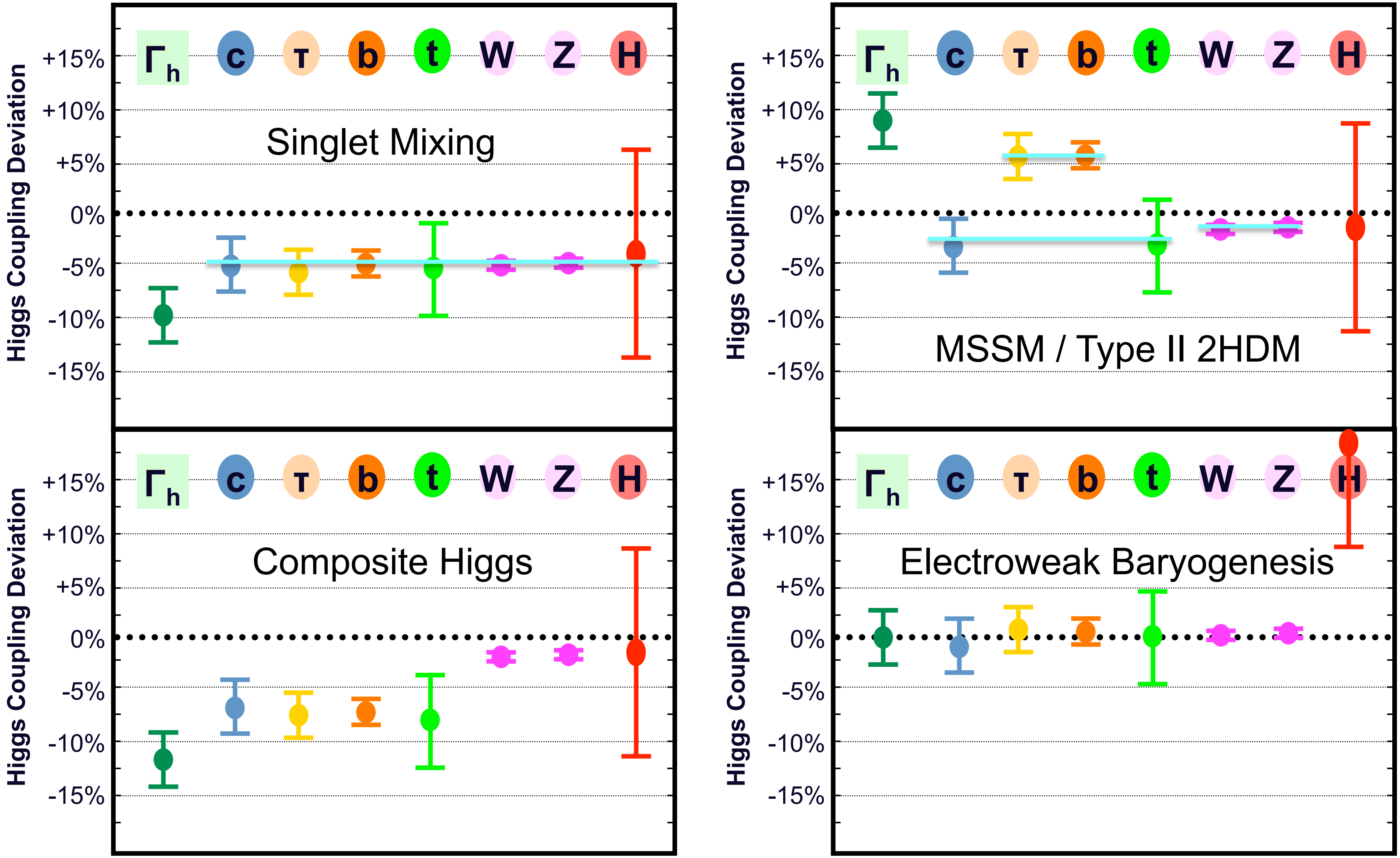
Verify relation between coupling and mass

→ confirmation of mass generation mechanism

Any deviation is a sign of new physics.

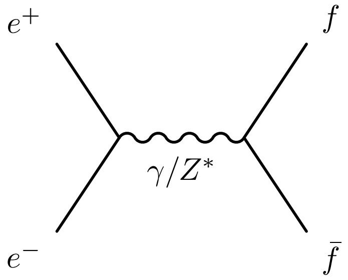
Model “Finger-printing”

Higgs Coupling Precision with “Full ILC Program” x2~3 (Model-Independent Analysis)



Identify new physics pattern via precision measurement of Higgs couplings

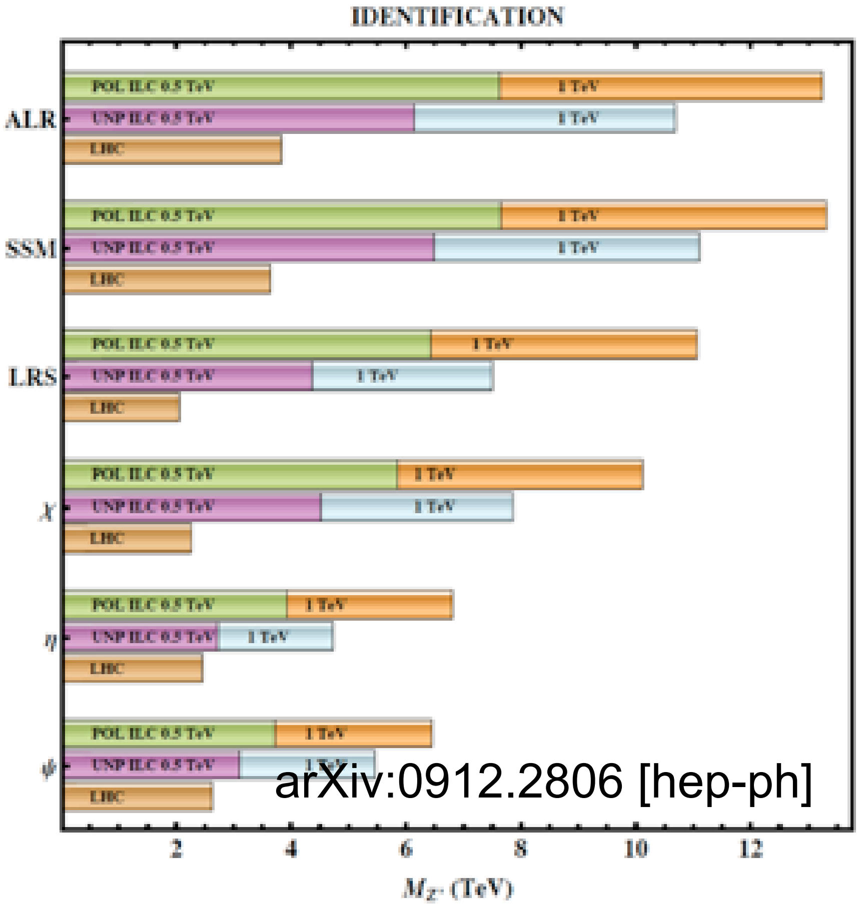
Two-Fermion Processes



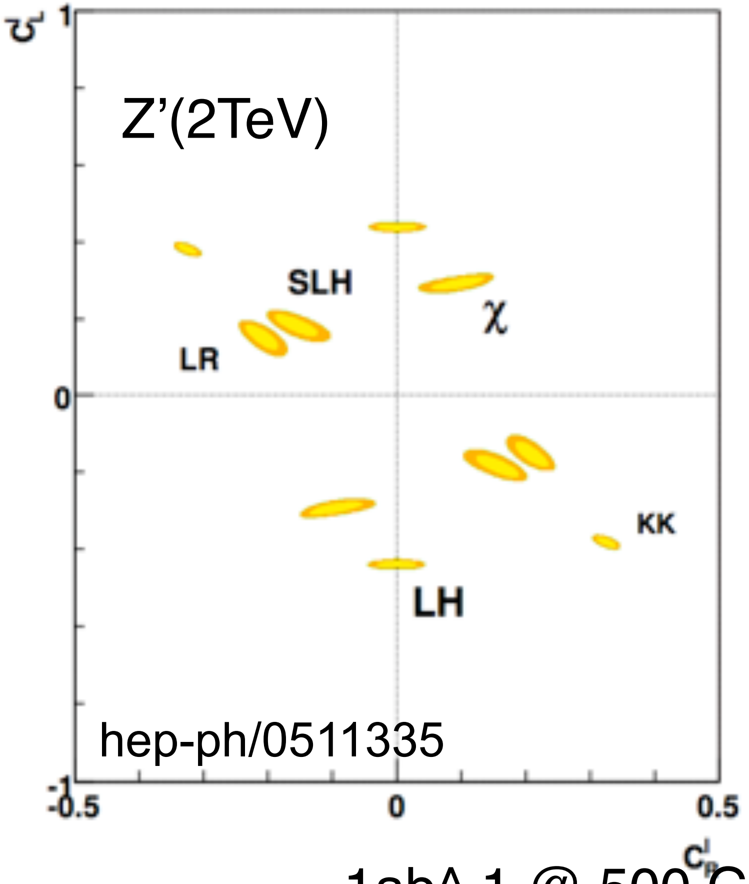
Search for Z' boson

Polarized differential cross sections: LL/RR/LR/RL

Forward-backward asymmetries



arXiv:0912.2806 [hep-ph]



Z'(2TeV)

hep-ph/0511335

1ab^-1 @ 500 GeV

Summary

The discovery of **“a Higgs boson”** at the **LHC** opened a new era in particle physics.

ILC is the ideal machine for the precise study of the **Higgs sector.**

Search for **new physics** at the **ILC** is in many ways complementary to that of the **LHC**. Unique opportunities available at **ILC**!

Again, from Hitoshi’s talk:

- There are efforts in Japan to promote the **ILC.**
- **Support from the international community** is vital to the success of **ILC** as a **truly global project**.