# The Higgs Factories & Beyond
## --- Views & News from Abroad

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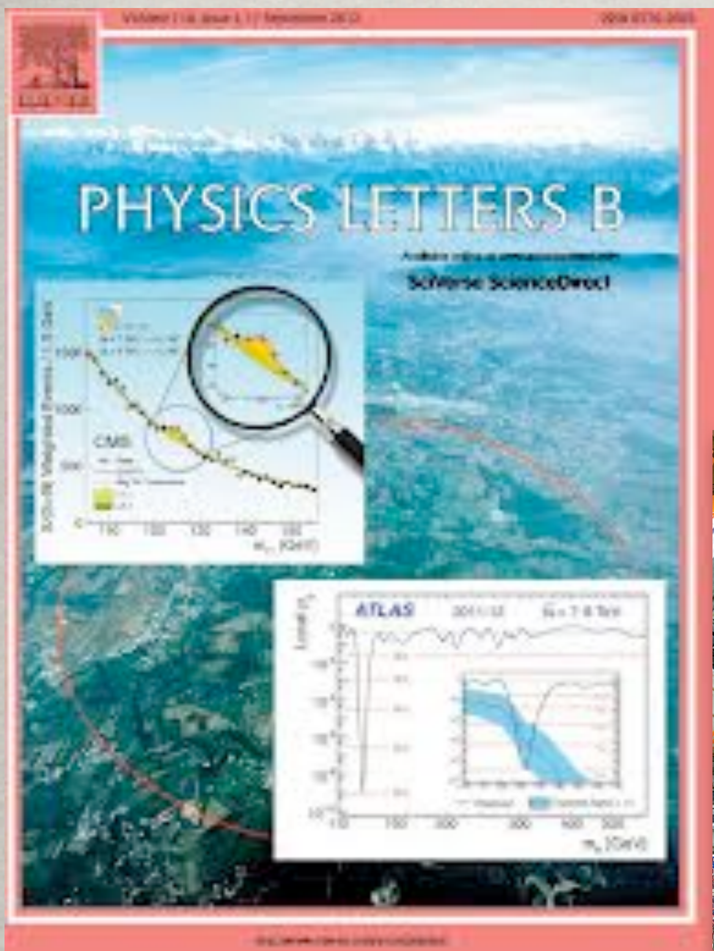
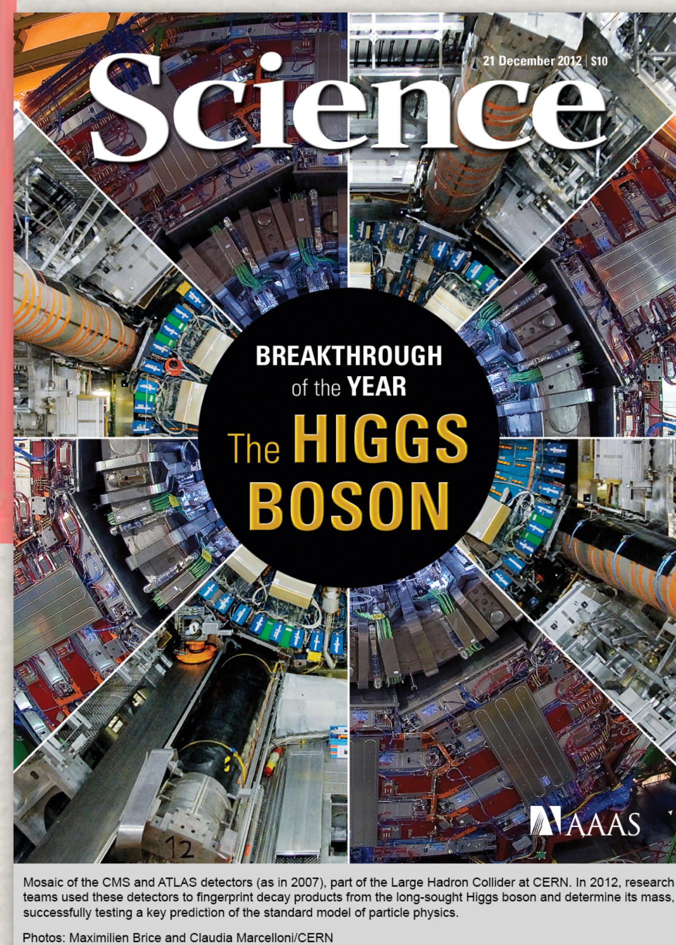
Kickoff Meeting for the CEPC/SppC Program
Sept. 13-14, 2013, Beijing


# The milestone Discovery:

July 4th, 2012:

$m_H \approx 126$ GeV
ATLAS: 5.9σ ; CMS: 5.0σ




# Half Century's Discoveries:

- Hadron spectroscopy: 1960 and on
- CP violation: 1964 (Nobel 1980)
- DIS for parton model: 1967 (Nobel 1990)
- Neutral currents: 1973
- charm quark: 1974 (Nobel 1976)
- tau lepton: 1975 (Nobel 1995)
- bottom quark: 1977
- gluon (jets): 1979
- $W^{\pm}, Z^0$: 1983 (Nobel 1984)
- top quark: 1995
- CKM in B system: 1999 and on (Nobel 2008)
- Neutrino oscillations: 1998 and on

**The Higgs discovery:**

**Most exciting since the charm in 1974!**

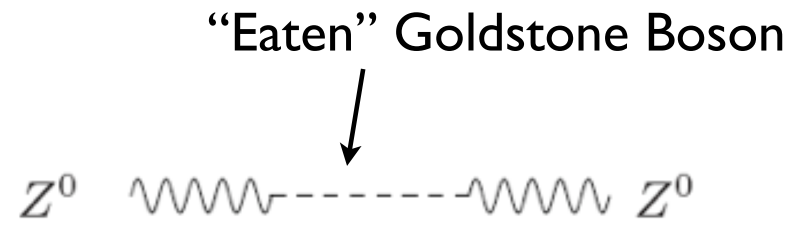
# Why Is It Exciting?

## (1) The Higgs boson does NOT have to exist!

**3 Nambu-Goldstone bosons were all we need**

The pole at $p^2 = 0$ is shifted to a non-zero value if:

$$\omega_1,\ \omega_2,\ \omega_3 \rightarrow W^+,\ W^-,\ Z^0 \qquad \Pi(p^2) \underset{p^2\to 0}{\simeq} \frac{-g^2v^2}{p^2}.$$




Then $p^2[1+\Pi(p^2)] = p^2 - g^2v^2$, yielding a gauge boson mass of $gv$.

**Non-linear realization of the gauge symmetry:**

$$U = \exp\{i\omega^i\tau^i/v\}, \quad D_\mu U = \partial_\mu U + igW^i_\mu \frac{\tau^i}{2} U - ig' U B_\mu \frac{\tau^3}{2}$$

$$\mathcal{L} = \frac{v^2}{2}[D^\mu U^\dagger D_\mu U] \rightarrow \frac{v^2}{4}(\sum_i g^2 W_i^2 + g'^2 B^2)$$

The theory is valid to a unitarity bound ~ 2 TeV

The fact that a Higgs boson shows up carries important information:

$$\phi = \frac{1}{\sqrt{2}} e^{i\sum \xi^i L^i} \begin{pmatrix} 0 \\ \nu + H \end{pmatrix}$$

Linearly realized by a doublet, unlike QCD.

# (2) The Higgs boson is a new class

It carries a ***vacuum quantum* #:** $J^{CP} = 0^{++}$
so that it couples to ANYTHING
(quantum mechanically)

Need to understand vacuum properties.

It is unlike a SM-singlet (not arbitrary)
Need to measure couplings to great precisions.

It is very narrow, $\Gamma/m \approx 3\times10^{-5}$, thus weakly coupled
(unlike hadrons in QCD, e.g. $\sigma$)

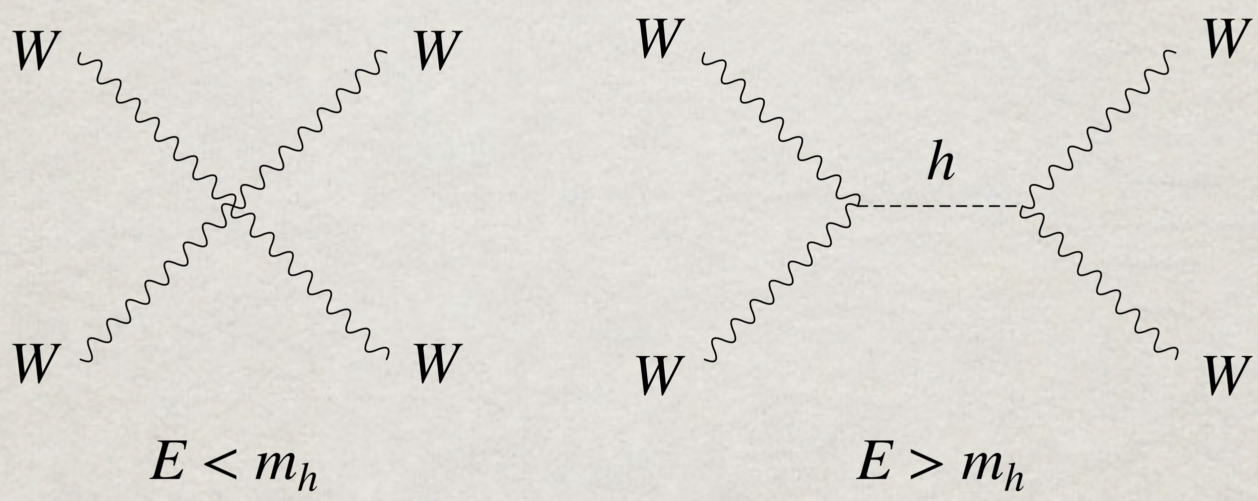
*Too heavy to be light (for SUSY);*
*too light to be heavy (Composite)!*

It must have a dynamical reason for that.

# (3) The Higgs boson couples to masses

## a. Electro-Weak Symmetry Breaking:

Consider the massive gauge boson scattering:



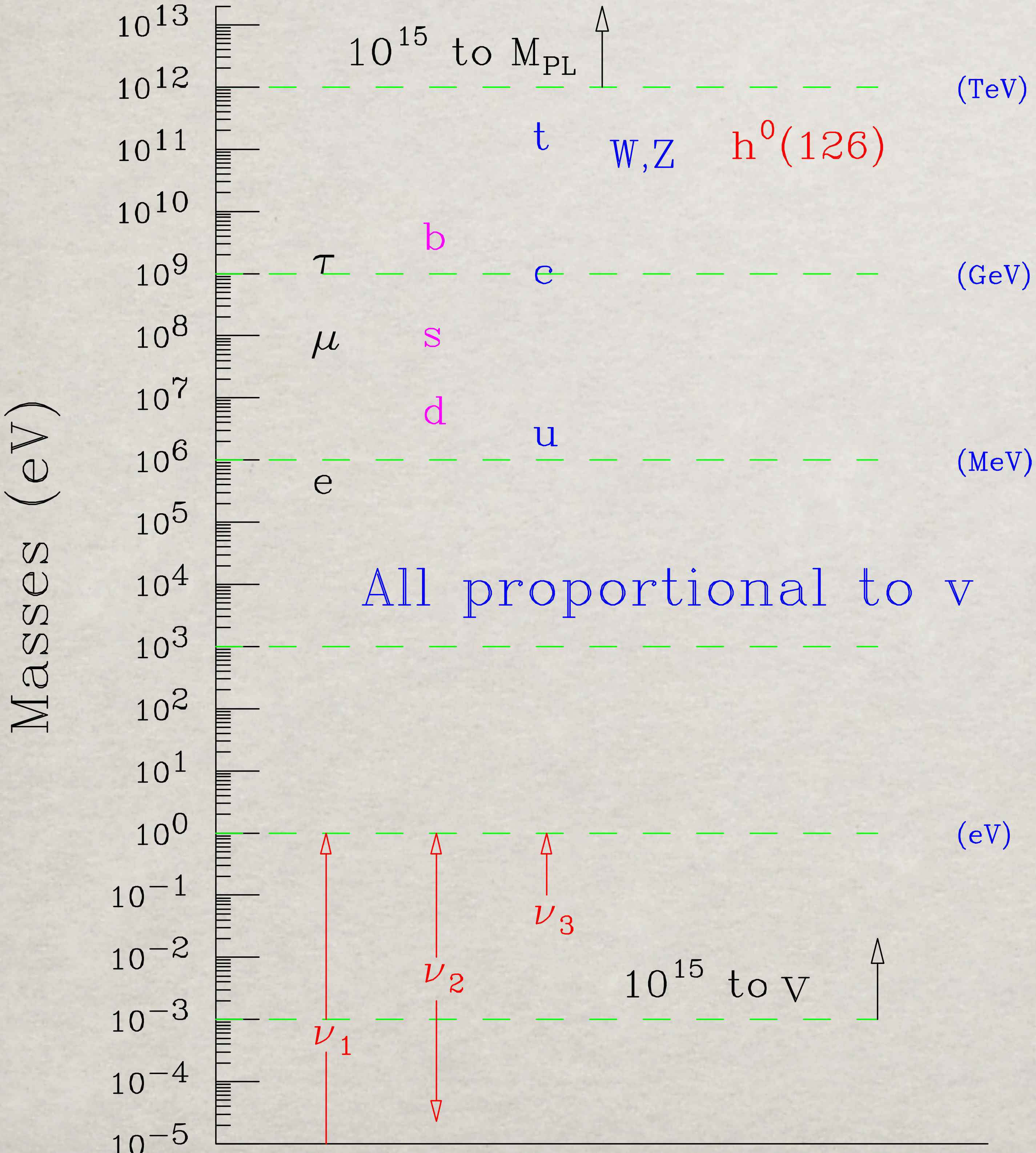

(a) (b)

$$\mathcal{M}(W_L W_L \to W_L W_L) \sim \begin{cases} E_{cm}^2/v^2 & \text{no light Higgs,} \\ m_h^2/v^2 & \text{with a SM Higgs.} \end{cases}$$

Need to continue on WW scattering

# Much$^n$ more difficult:

## b. Fermion masses & mixing: $y_f(\bar{f}_1, f_2)_L \begin{pmatrix} \phi_1 \\ \phi_2 \end{pmatrix}_L f_R$




All **elementary** particle masses.

Neutrino masses
$m_\nu \sim v^2/M$

Flavor physics
Will reveal!

# (4) The Higgs boson connects to high scale

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

the only dimensional parameter allowed by SM symmetry.

**The "large hierarchy":** $\mathrm{m}_h^2 - m_{h^0}^2 \sim -\frac{3}{8\pi^2} y_t^2 \Lambda^2$

ala, QED: $m_e \sim m^0_e\,[1 + 3\alpha/4\pi\ \ln(\Lambda/m_e)]$

Michael Dine's cancelation at Planck scale:

$m_H^2$ = 36,127,890,984,789,307,394,520,932,878,928,933,023

–36,127,890,984,789,307,394,520,932,878,928,917,398

= $(125\ \mathrm{GeV})^2$ ! ?

**"Naturalness" at $10^{-3}$ level?**

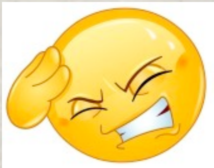
**→ TeV scale new physics.**

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

A weakly coupled new force (the 5th force):

- **In the SM, $\lambda$ is a free parameter,**
  **now measured $\lambda \approx 0.13$**
- **In SUSY, it is related to the gauge couplings**

**tree-level: $\lambda_{SUSY} = (g_L^2 + g_Y^2)/8 \approx 0.3/4$ ← a bit too small**



$\lambda$ is small ($m_H = \sqrt{2}\lambda\, v$)
→ Top-Yukawa drags the vacuum meta-stable,
or new physics below $10^{7-11}$ GeV.

# (5) The Higgs portals to Cosmos?

## (a). Dark Matter

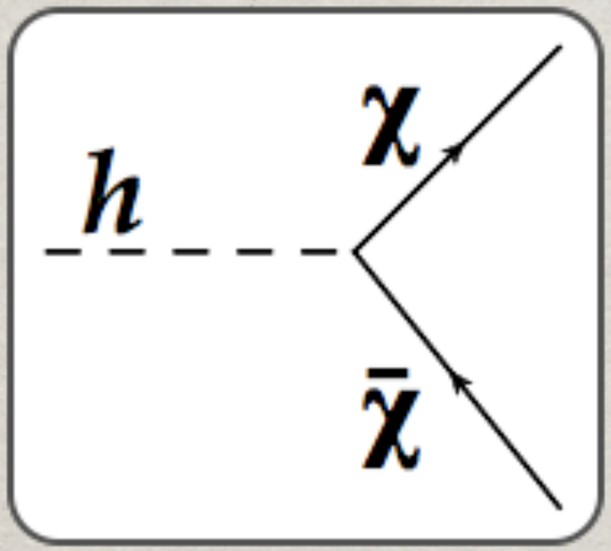
$H^\dagger H$ is the only bi-linear SM gauge singlet.

**Bad:** May lead to hierarchy problem with high-scale physics;

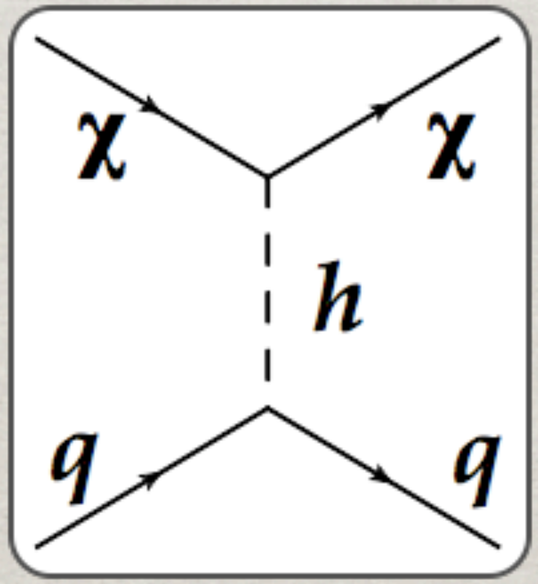
**Good:** May readily serve as a portal to the dark sector:

$$k_s H^\dagger H\ S^* S, \qquad \frac{k_\chi}{\Lambda} H^\dagger H\ \bar{\chi}\chi.$$

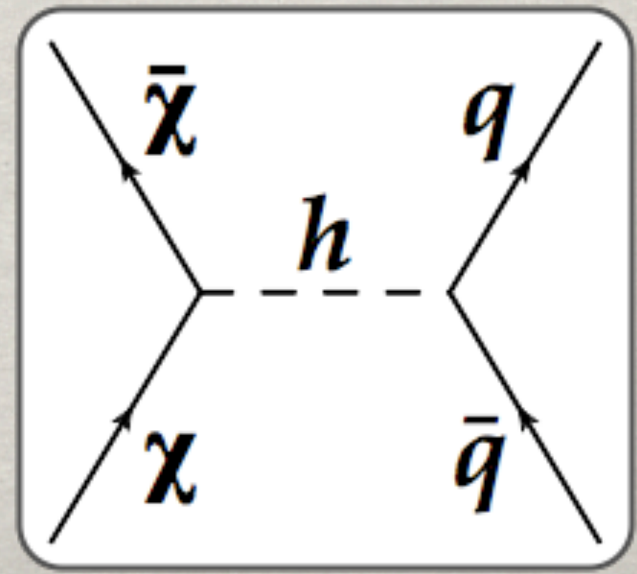
Missing energy at LHC




Direct detection




Indirect detection



# Other potential consequences

(b). Baryon – anti-baryon Asymmetry

For $M_H$ = 126 GeV,
EW baryogenesis needs light sparticles:

$m_{stop} \approx 150$ GeV,

plus a light neutralino, singlets …

(c). Higgs as an inflaton?
(d). Higgs field & Dark Energy?

**The existence of a fundamental scalar encourages the consideration of scalar fields in cosmological applications.**

*So, we want to know LOTS more about the Higgs.*

# The Need for a Higgs Factory

**For any discovery of a new elementary particle, we need a factory for it!**


The Z factories: LEP1, SLC:

Precision EW; neutrino counting …

The B factories: KEKB, PEP2, LHCb

CKM, rare decays

The tau-charm factories: CESR, BEPC

Properties, rare decays, QCD, spectroscopy …

Top quark factory: LHC Mass, couplings etc.

*The Higgs is NO exemption!*

*Especially when no sign for new physics yet …*

# (1) Current Status

## (A). HL-LHC **will be** a Higgs factory:

$pp \to H + X$ at $\sqrt{s} = 14$ TeV for $m_H = 125$ GeV

| | ggF | VBF | VH | $t\bar{t}H$ | Total |
|---|---|---|---|---|---|
| Cross section (pb) | 49.9 | 4.18 | 2.38 | 0.611 | 57.1 |
| | | | Numbers of events in 3000 fb$^{-1}$ | | |
| $H \to \gamma\gamma$ | 344,310 | 28,842 | 16,422 | 4,216 | 393,790 |
| $H \to ZZ^* \to 4\ell$ | 17,847 | 1,495 | 851 | 219 | 20,412 |
| $H \to WW^* \to \ell\nu\ell\nu$ | 1,501,647 | 125,789 | 71,622 | 18,387 | 1,717,445 |
| $H \to \tau\tau$ | 9,461,040 | 792,528 | 451,248 | 115,846 | 10,820,662 |
| $H \to b\bar{b}$ | 86,376,900 | 7,235,580 | 4,119,780 | 1,057,641 | 98,789,901 |
| $H \to \mu\mu$ | 32,934 | 2,759 | 1,570 | 403 | 37,667 |
| $H \to Z\gamma \to \ell\ell\gamma$ | 15,090 | 1,264 | 720 | 185 | 17,258 |
| $H \to$ all | 149,700,000 | 12,540,000 | 7,140,000 | 1,833,000 | 171,213,000 |

Coupling measurements with 2-10% precision. *Model-dependent!*

| L (fb$^{-1}$) | $\kappa_\gamma$ | $\kappa_W$ | $\kappa_Z$ | $\kappa_g$ | $\kappa_b$ | $\kappa_t$ | $\kappa_\tau$ | $\kappa_{Z\gamma}$ | BR$_{\text{inv}}$ |
|---|---|---|---|---|---|---|---|---|---|
| 300 | [5, 7] | [4, 6] | [4, 6] | [6, 8] | [10, 13] | [14, 15] | [6, 8] | [41, 41] | [14, 18] |
| 3000 | [2, 5] | [2, 5] | [2, 4] | [3, 5] | [4, 7] | [7, 10] | [2, 5] | [10, 12] | [7, 11] |

*"Europe's **top priority** should be the exploitation of the full potential of the LHC, including the **high-luminosity upgrade** of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030."*

# (B). ILC as a Higgs factory

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

Typically,

$$N_{\rm sig}^{pp} > N_{\rm sig}^{e^+e^-}$$

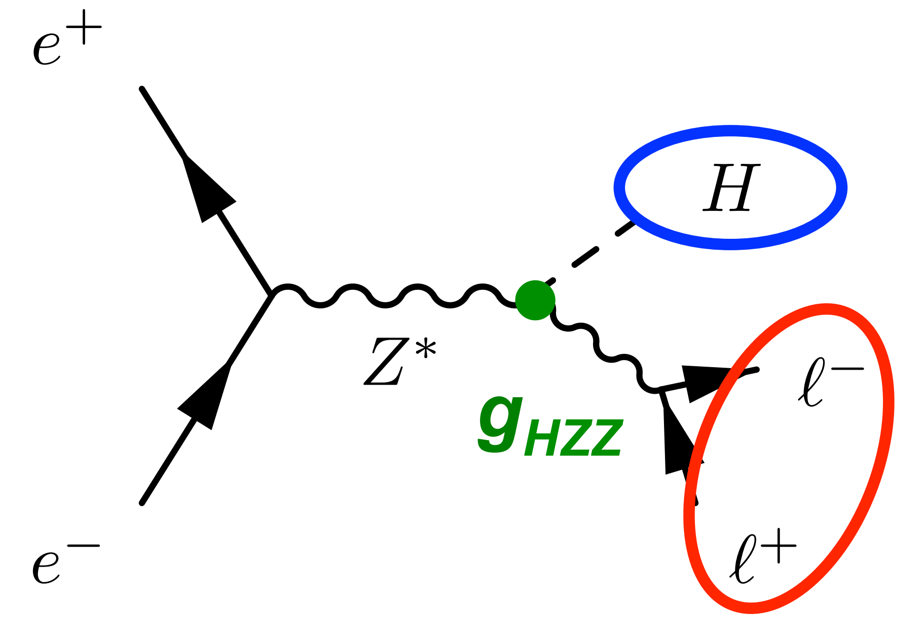
$$N_{\rm bkg}^{pp} \gg N_{\rm bkg}^{e^+e^-}$$

| | ILC500 | ILC500-up | ILC1000 | ILC1000-up |
|---|---|---|---|---|
| $\sqrt{s}$ (GeV) | 500 | 500 | 500/1000 | 500/1000 |
| $\int \mathcal{L}dt$ (fb$^{-1}$) | 500 | 1600$^\ddagger$ | 500+1000 | 1600+2500$^\ddagger$ |
| $P(e^-, e^+)$ | $(-0.8, 0.3)$ | $(-0.8, 0.3)$ | $(-0.8, 0.3/0.2)$ | $(-0.8, 0.3/0.2)$ |
| $\sigma\,(ZHH)$ | 42.7% | ? | 42.7% | 23.7% |
| $\sigma\,(\nu\bar{\nu}HH)$ | – | – | 26.3% | 16.7% |
| $\lambda$ | 83% | 46% | 21% | 13% |

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

independent of Higgs decay

*sensitive to invisible Higgs decays*




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

Model-independent, absolute measurements

($Z \to e^+e^-, \mu^+\mu^-$ combined):

**√s=250 GeV, L=250 fb-1**

**$\Delta m_H \lesssim 32$ MeV**

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

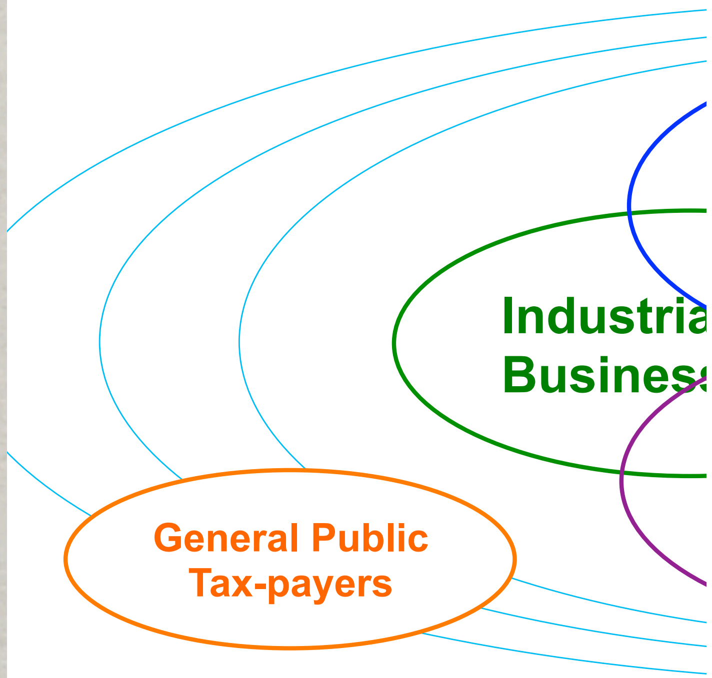
**$g_{HZZ} \lesssim 1.2\%$**

# ILC marching toward the reality

ILC is a genuine global project: most important key to its realization

- Global governance of the project
- Global cooperation
- Global design, construction, and operation

Realization of ILC requires t




**Require co**

**Kitakami** site in **Tohok**

- **Iwate** and **Miyagi** P
  - *Local governments*
    *the disaster recovery effort.*
- **Tohoku University**
- **Tohoku Economic Federation**

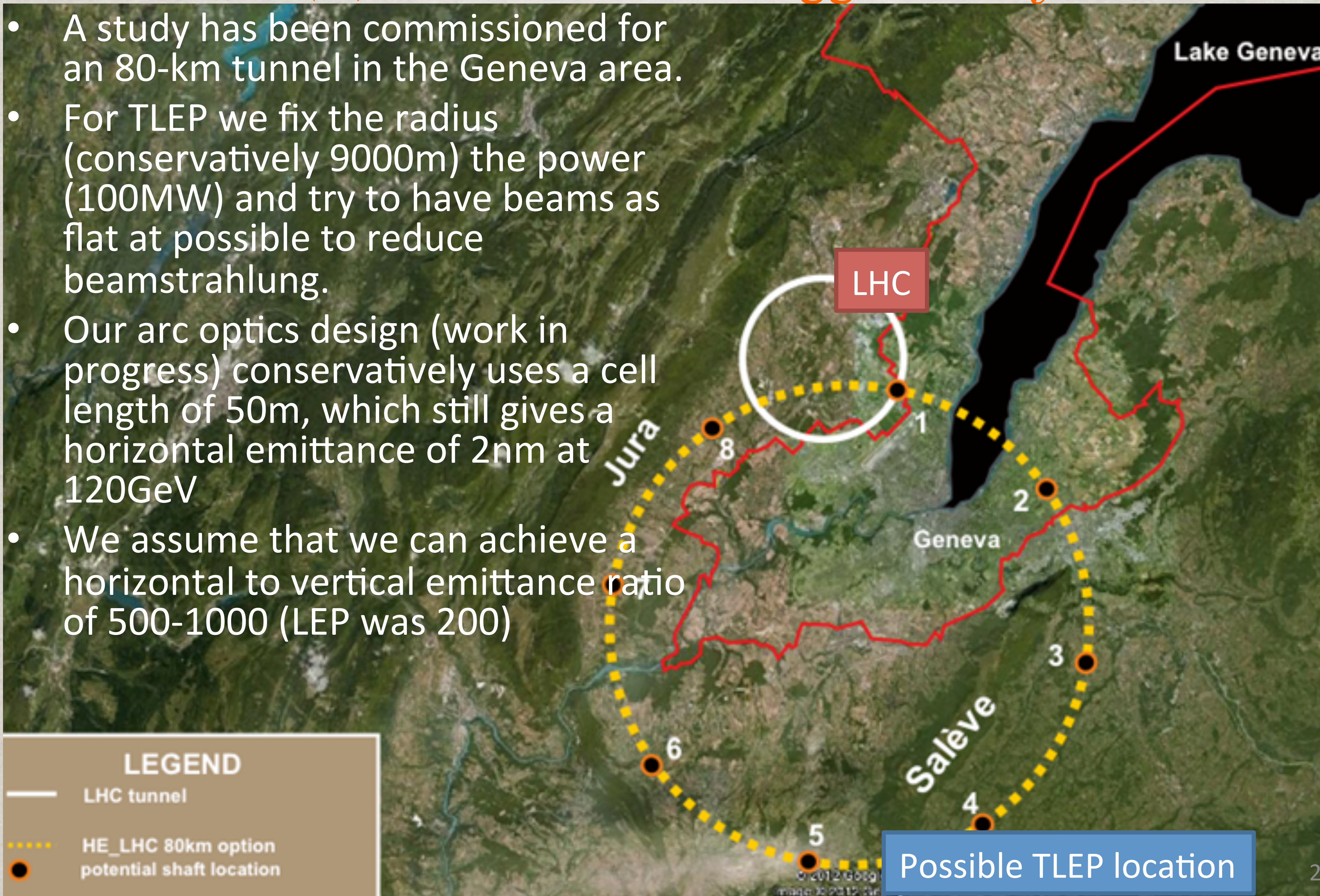

## Possible Timeline

| | |
|---|---|
| **End 2013** | Japanese government announces intent to bid |
| **2013-2015** | Inter-governmental negotiations<br>Engineering design for ILC<br>Preparation of ILC laboratory |
| **~2015** | Input from LHC 14 TeV, decision to proceed |
| **2015-201** | Begin construction (including bidding) |
| **2026-2027** | Commissioning |

# (2) Future Perspective

## (C). Circular e+e- Higgs factory

- A study has been commissioned for an 80-km tunnel in the Geneva area.
- For TLEP we fix the radius (conservatively 9000m) the power (100MW) and try to have beams as flat at possible to reduce beamstrahlung.
- Our arc optics design (work in progress) conservatively uses a cell length of 50m, which still gives a horizontal emittance of 2nm at 120GeV
- We assume that we can achieve a horizontal to vertical emittance ratio of 500-1000 (LEP was 200)



# TLEP : Possible Physics Programme

- **Higgs Factory mode at $\sqrt{s}$ = 240 GeV: 5+ years**
  - Higgs boson properties, WW and ZZ production. *Exciting!*
    - Periodic returns at the Z peak for detector and beam energy calibration
- **Top Threshold scan at $\sqrt{s}$ ~ 350 GeV: 5+ years**
  - Top quark mass, width, Yukawa coupling; top quark physics; more Higgs boson studies.
    - Periodic returns at the Z peak for detector and beam energy calibration
- **Z resonance scan at $\sqrt{s}$ ~ 91 GeV: 1-2 years** *Exciting!*
  - Get $10^{12}$ Z decays @ 15 kHz/IP. Repeat the LEP1 Physics Programme every 15 minutes.
    - Continuous transverse polarization of some bunches for precise $E_{beam}$ calibration
- **WW threshold scan at $\sqrt{s}$ ~ 161 GeV: 1-2 years**
  - Get $10^8$ W decays; Measure the W mass; Precise W studies.
    - Continuous transverse polarization of some bunches and returns to the Z peak.
- **Longitudinally polarized beams at $\sqrt{s}$ = $m_Z$: 1 year**
  - Get $10^{11}$ Z decays, and measure $A_{LR}$, $A_{FB}^{pol}$, etc.
    - Polarization wigglers, spin rotators
- **Luminosity, Energy, Polarization upgrades**
  - If justified by scientific arguments (with respect to the upgrade to VHE-LHC)

| | ILC-250 | TLEP-240 | ILC-350 | TLEP-350 |
|---|---|---|---|---|
| Lumi / 5 yrs | 250 $fb^{-1}$ | 10 $ab^{-1}$ | 350 $fb^{-1}$ | 2.6 $ab^{-1}$ |
| Beam Polarization | 80%, 30% | – | 80%,30% | – |
| # of HZ events | 70,000 | 2,000,000 | 65,000 | 325,000 |
| # of WW→H events | 3,000 | 50,000 | 20,000 | 65,000 |

TLEP: 10 times more luminosity/IP.

TLEP: 6 times better accuracy.

ILC TDR

From P. Azzi et al.
arXiV:1208.166

| | ILC-250 | TLEP-24 |
|---|---|---|
| $s_{HZ}$ | 2.5% | 0.4% |
| $s_{HZ}$ *BR(H→bb) | 1.1% | 0.2% |
| $s_{HZ}$ *BR(H→cc) | 7.4% | 1.2% |
| $s_{HZ}$ *BR(H→gg) | 9.1% | 1.4% |
| $s_{HZ}$ *BR(H→WW) | 6.4% | 0.9% |
| $s_{HZ}$ *BR(H→tt) | 4.2% | 0.8% |
| $s_{HZ}$ *BR(H→ZZ) | 19% | 3.1% |
| $s_{HZ}$ *BR(H→gg) | 35% | 3.0% |
| $s_{HZ}$ *BR(H→mm) | 100% | 13% |
| $G_{INV}$ / $G_H$ | < 1% | < 0.2% |
| $m_H$ | 40 MeV | 8 MeV |

- TLEP is a 3-in-1 package:
  - It is a powerful Higgs factory
  - It is a high-intensity EW parameter buster
  - It offers the path to a 100TeV pp collider
- TLEP is based on solid technology and offers little risk, has a price tag which is expensive but not out of reach, has reasonable consumption, offers multiple interaction points an d might even have an upgrade potential.

*Exciting!*

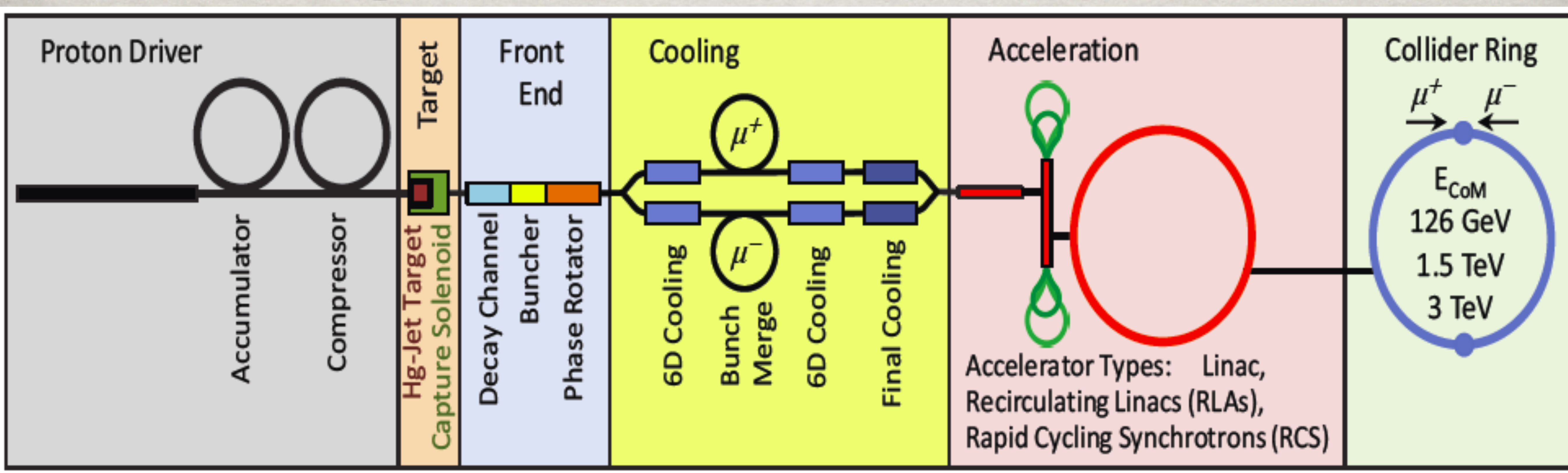
# (D). A Muon Collider

## Direct width measurement!

(0.5 – 1 $fb^{-1}$)

| $\Gamma_h = 4.21$ MeV | $L_{step}$ ($fb^{-1}$) | $\delta\Gamma_h$ (MeV) | $\delta B$ | $\delta m_h (MeV)$ |
|---|---|---|---|---|
| Case A | 0.005 | 1.5 | 13% | 0.51 |
| $R = 0.01\%$ | 0.025 | 0.85 | 6.1% | 0.32 |
| | 0.2 | 0.34 | 2.2% | 0.13 |
| Case B | 0.01 | 0.61 | 8.3% | 0.40 |
| $R = 0.003\%$ | 0.05 | 0.30 | 3.8% | 0.13 |
| | 0.2 | 0.17 | 2.0% | 0.10 |

TABLE II: Fitting accuracies for one standard deviation range of $\delta\Gamma_h$, $\delta B$ and $\delta m_h$ of the SM Higgs with the scanning scheme as specified in Eq. (7) for three representative luminosities per step.



# (3) Beyond the Higgs Factory

## (E). Compact Linear Collider (CLIC)

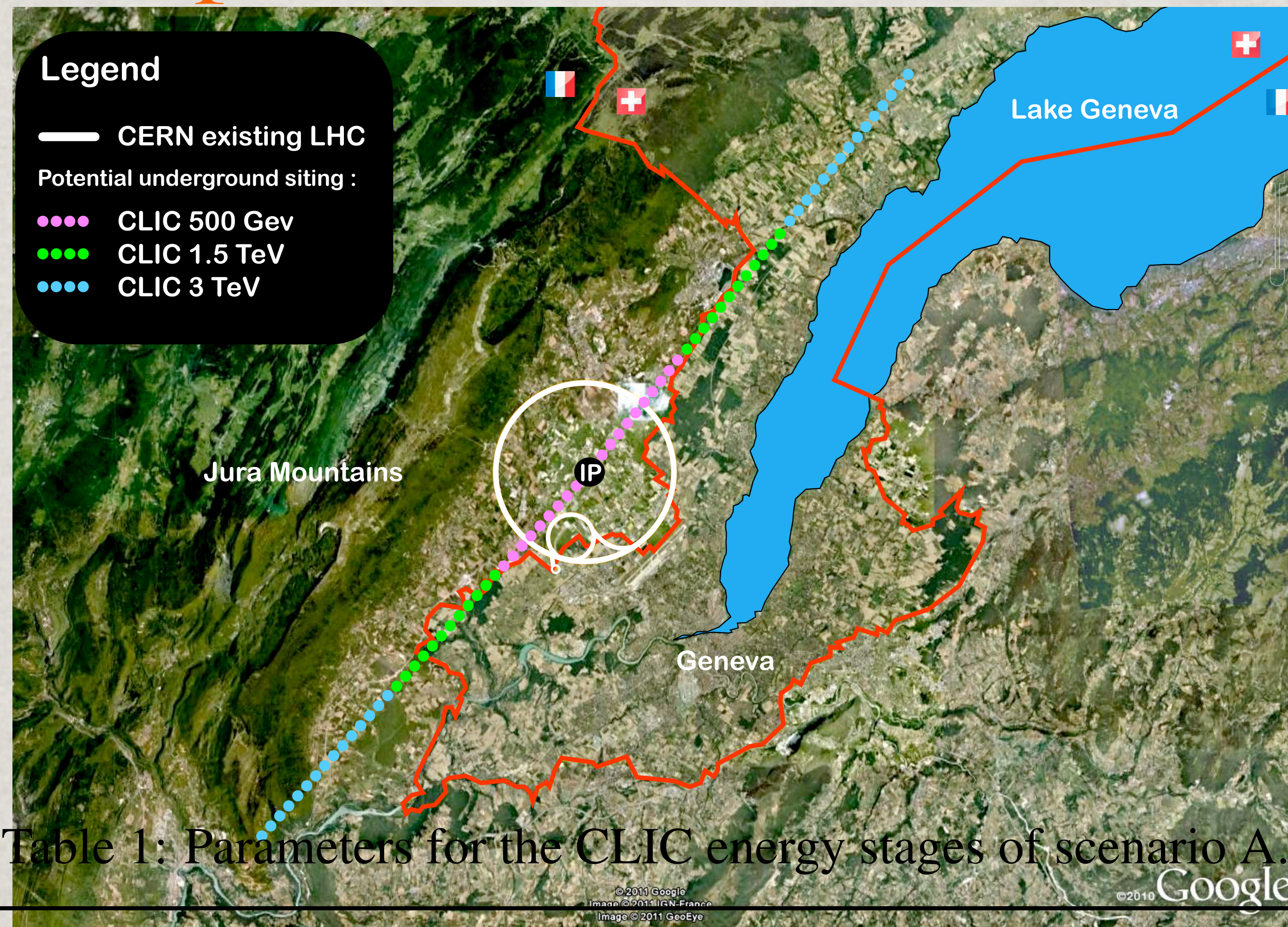



Table 1: Parameters for the CLIC energy stages of scenario A.

| Parameter | Symbol | Unit | | | |
|---|---|---|---|---|---|
| Centre-of-mass energy | $\sqrt{s}$ | GeV | 500 | 1400 | 3000 |
| Repetition frequency | $f_{rep}$ | Hz | 50 | 50 | 50 |
| Number of bunches per train | $n_b$ | | 354 | 312 | 312 |
| Bunch separation | $\Delta_t$ | ns | 0.5 | 0.5 | 0.5 |
| Accelerating gradient | $G$ | MV/m | 80 | 80/100 | 100 |
| Total luminosity | $\mathscr{L}$ | $10^{34}$ cm$^{-2}$s$^{-1}$ | 2.3 | 3.2 | 5.9 |
| Luminosity above 99% of $\sqrt{s}$ | $\mathscr{L}_{0.01}$ | $10^{34}$ cm$^{-2}$s$^{-1}$ | 1.4 | 1.3 | 2 |
| Main tunnel length | | km | 13.2 | 27.2 | 48.3 |

# (F). VHE-LHC (VLHC)

In TLEP ring: 80 – 100 km. Reach E(pp) = 80 – 100 TeV!

PHYSICS AT 100-200 TeV

Tao Han, Univ. of Wisconsin-Madison

(1999 VLHC Annual Meeting, June. 28)

Theory Overview

in the light of future hadron colliders

Tao Han

Univ. of Wisconsin - Madison

VLHC workshop, Fermilab, Oct. 16, 2003

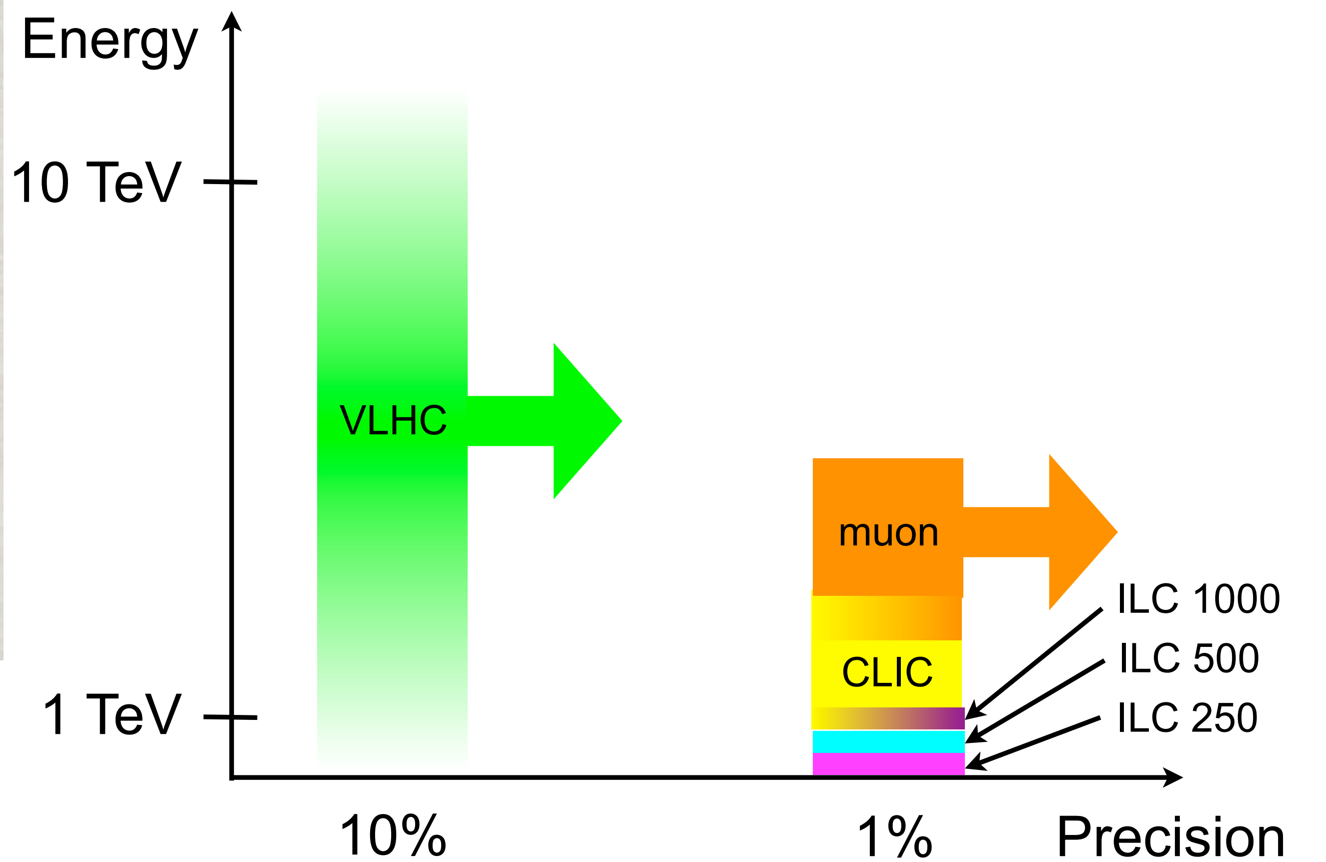
Top Reasons For The VLHC:

- There are important issues to learn after the LHC/LC. (in any scenarios, pretty much!)
- It is exciting to think about a physics program at a Very-Large machine.
- while the LHC is to study the "Large Hierarchy", VLHC is to explore the "Little Hierarchy".
- There must be things out there we have never thought about!

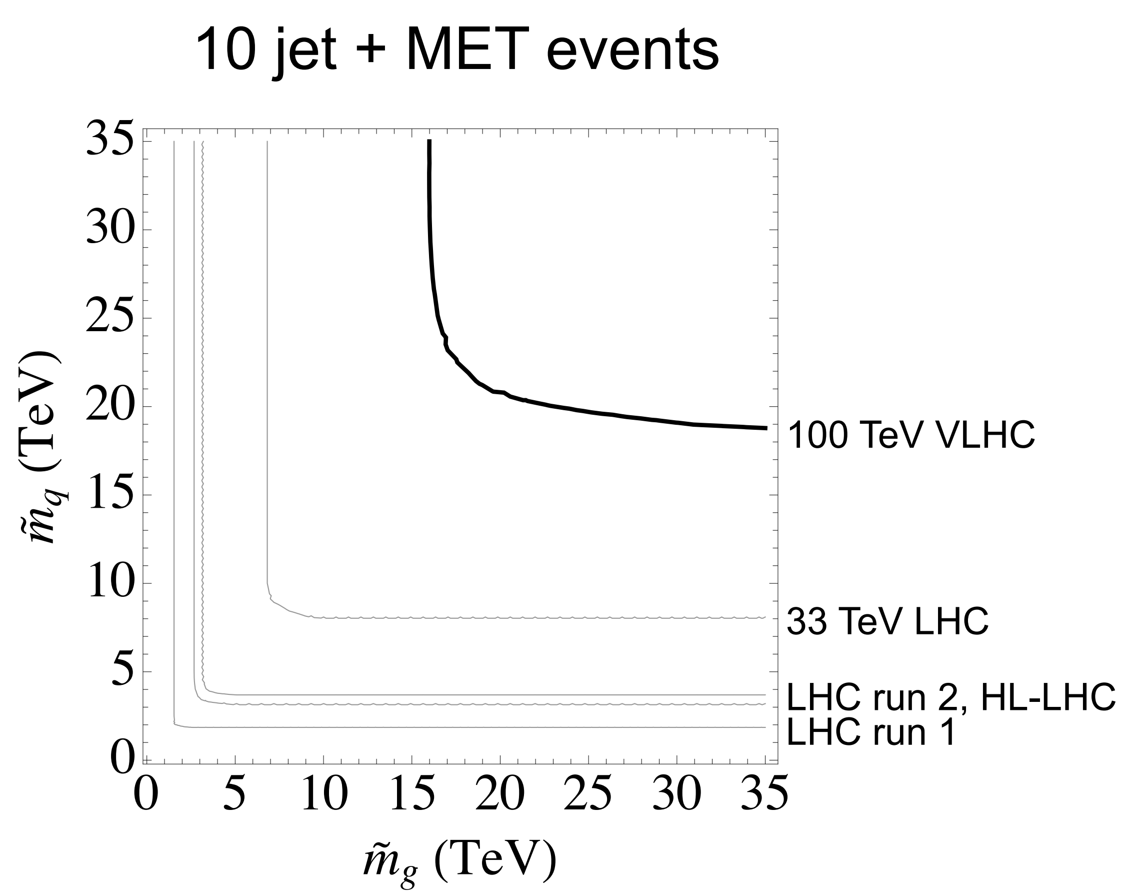
Go for the energy frontier!

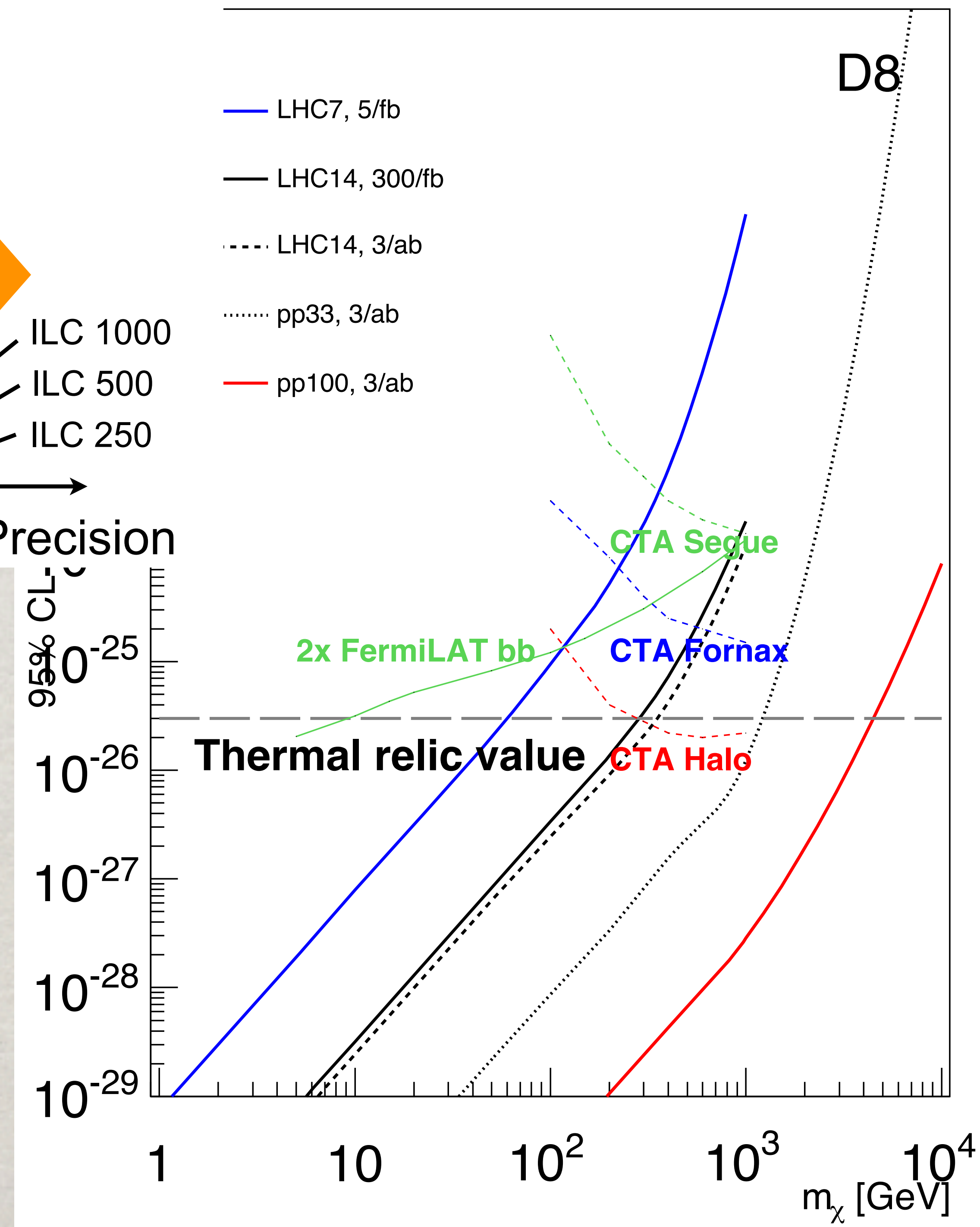
*(Bill Foster invited me for dinner, later quitted job at FNAL.)*

# Leptons vs. Hadrons




# SUSY

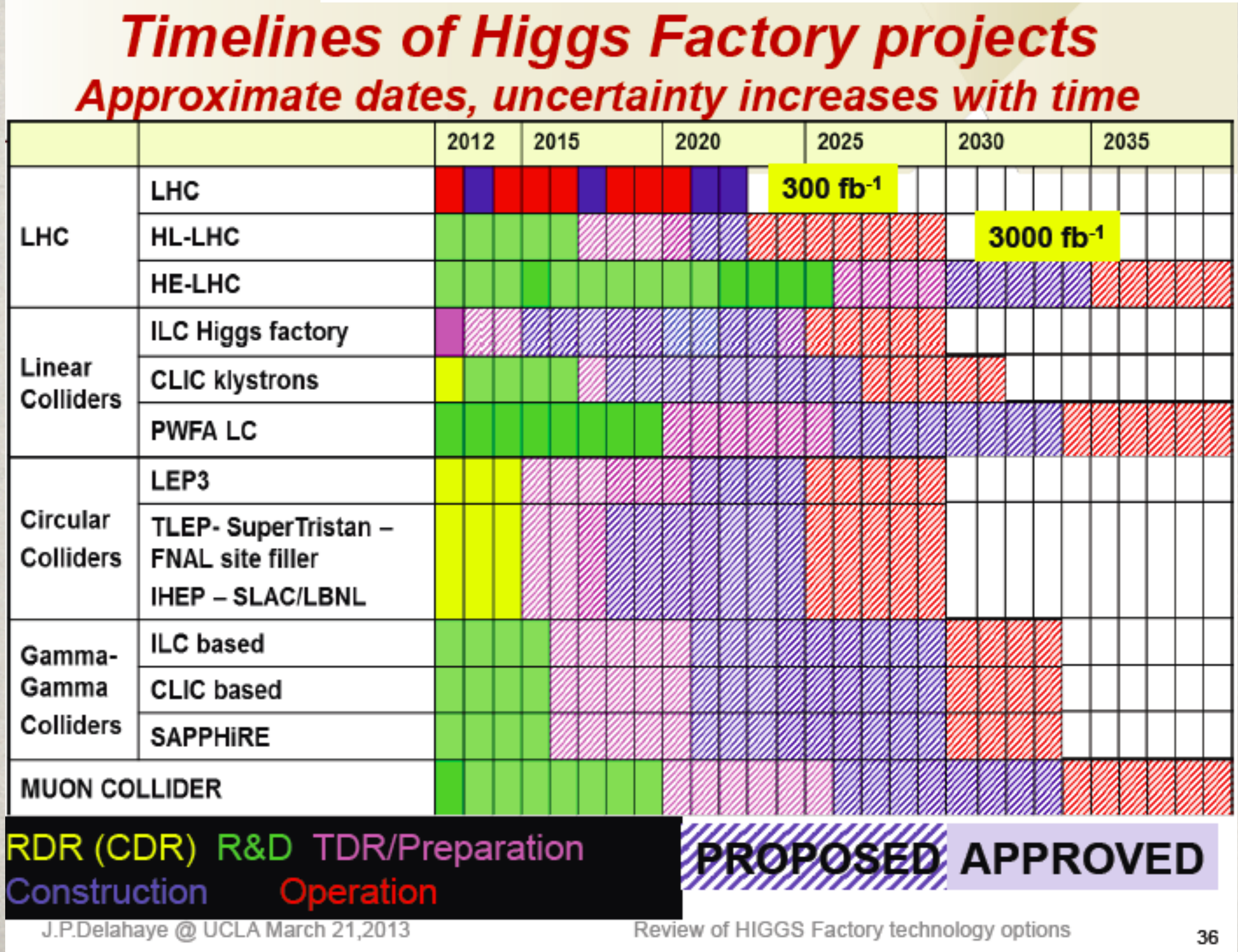



# Effective DM

# Timeline:

| LHC 100/fb | LHC 300/fb | LHC 3/ab | ILC 250-500GeV | ILC 1TeV | CLIC >1TeV | MC | TLEP | VLHC |
|---|---|---|---|---|---|---|---|---|
| years beyond TDR | TDR | LOI | TDR | TDR | CDR | | | |



# Activities, Mentality

## (1) International energy frontier

The discovery of the Higgs boson has tremendously inspired the field to consider future Higgs factories.

### CERN is in a strong position:

LHC, HL-LHC; CLIC, TLEP-VHE-LHC etc.

### Japan is in a good position:

ILC, etc. (SuerpKEKb/Belle2; Hyper-K)

### The US is in a difficult position:

Crucial participation in LHC, HL-LHC; ILC etc.

DOE: "We are the leaders, but not the drivers."

# The US exploration

## The Community Summer Study (Snowmass) just concluded:

**The Snowmass Report will be presented in such a way that it can be read at various levels. An Executive Summary lays out the broad topics treated in more detail in a summary chapter. Each Frontier (Intensity, Energy, Cosmic, Theory, Capabilities, Instrumentation, Computing, and Communication) has its own chapter containing further details. Reference is made to submissions by each Frontier's subgroups, and to contributed White Papers.**

- **Report to be ready November 1.**
- **Provides a detailed resource to P5.**

## The P5 has just announced:
## (Particle Physics Project Prioritization Panel)

- *"…develop an updated strategic plan for U.S. high energy physics that can be executed over a 10-year timescale, in the context of a 20-year global vision for the field."*
- *"…an assessment of the current and future scientific opportunities over the next 20 year period."*
- *"…a critical examination of the investments…to ensure the vitality, scientific productivity, and discovery potential of U.S. high energy physics research…"*

- **Preliminary comments by 1 March 2014**
- **Final report by 1 May 2014**

# Some theory activities:

Started organizing ourselves to explore, to motivate, to coordinate relevant physics issues.

Motivations For a 100 TeV pp-collider

Nima Arkani-Hamed

* It's the OBVIOUS FUTURE

* BIG physics ideas, BIG ambitions and BIG machines are the lifeblood of our field. It's how we've attracted the best minds on the planet to work on the hardest, most fundamental, most long-term problems in all of Science.

*This is a new initiative with Nima's drive: Please join hands and move!*

# (2) Personal Views

The Higgs factory is a Must, and will be done.

VHE-LHC is the obvious future, and will be carried out.

China is a strong record for international collaborations:
LEP-I,II, BES, SuperK, Belle, AMS, LHC, Daya Bay, …

Needs more and improvement/adjustment.

# Since many years ago …

## 雄心壮志远大：Dream Big!

我国高能物理的成就和地位，
仍与我们的经济实力，
国际政治地位不相匹配！

⇑

如果参与成功，地位稳固显赫，
为什么不竞争主导地位？
不是我们梦寐以求的吗？

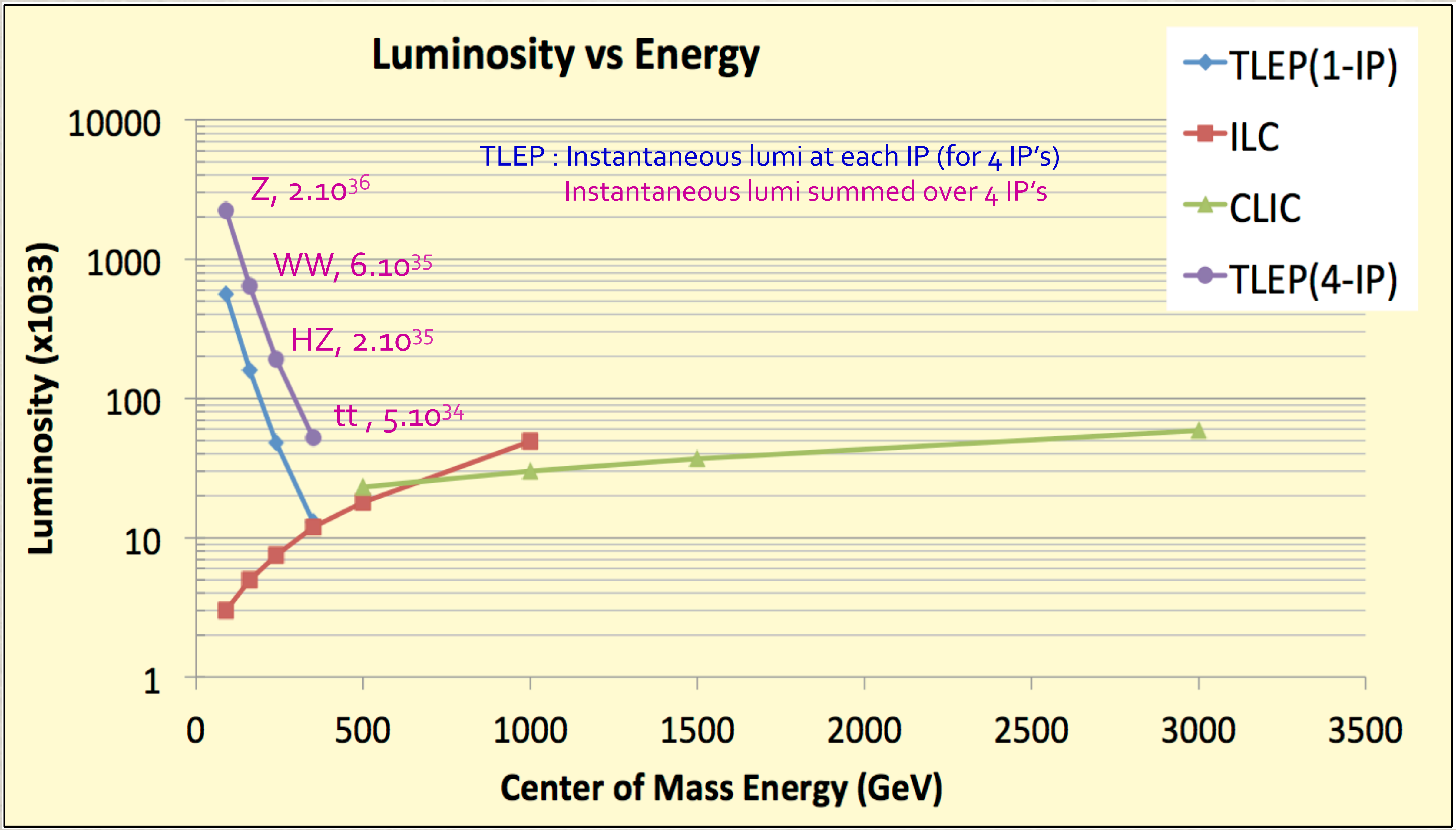
竞争 host country:
双赢方案 (win-win)！



Let's get together, and roll!

美国威斯康星大学
（清华大学；科学院理论物理所）
２００６年１２月５日，香山会议

# Backups:



Luminosity vs Energy
TLEP(1-IP)
ILC
CLIC
TLEP(4-IP)
TLEP : Instantaneous lumi at each IP (for 4 IP's)
Instantaneous lumi summed over 4 IP's
Z, 2.10^36
WW, 6.10^35
HZ, 2.10^35
tt , 5.10^34
10000
1000
100
10
1
0
500
1000
1500
2000
2500
3000
3500
Luminosity (x1033)
Center of Mass Energy (GeV)

In a pessimistic scenario, the LHC does not see a new particle associated with the Higgs sector, then the effects of a heavy state on $g_i$ at the scale $M$:

$$\Delta_i \equiv \frac{g_i}{g_{SM}} - 1 \sim \mathcal{O}(v^2/M^2) \approx \text{a few \% for } M \approx 1 \text{ TeV}$$

## Higgs coupling deviations:

| $\Delta$: | VVH | $b\bar{b}H + \tau\bar{\tau}H$ | ggH, $\gamma\gamma$H |
|---|---|---|---|
| Composite | (3-9)% (1 TeV/f )$^2$ | | |
| $H^0$, $A^0$ | | 6% (500 GeV/$M_A$)$^2$ | |
| T' | | | -10% (1 TeV/$M_T$)$^2$ |

Agashe et al.; Haber, Carena;
TH, Logan, Wang

1. LHC: $\sigma_{obs} \propto g_{in}^2 \frac{\Gamma_{final}}{\Gamma_{tot}}$

- $\sigma_{obs}/\sigma_{SM}$ measured at <10% level.
- $Br(h \to \bar{N}N,\ \chi\chi,\ ...)$ sensitive to <20% level.
- No model-independent measure for $\Gamma_i,\ \Gamma_{tot}$

2. $e^+e^-$ Higgs factory:

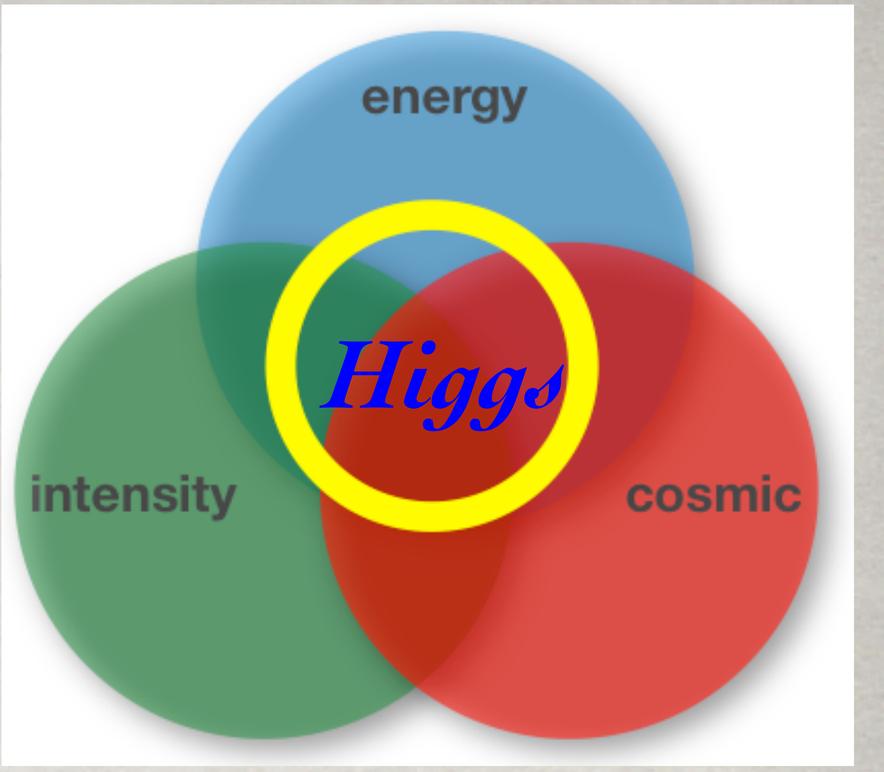
- model-independent for $g_{ZZh}$ at 1.5% level
- Extraction for $\Gamma_{tot} \equiv \Gamma_{ZZ}/BR_{ZZ}$

3. $\mu^+\mu^-$ Higgs factory:

- Direct measurement of $\Gamma_{tot}$ by scanning.

4. VHE-LHC: opens up the new energy territory!

# Summary:




- The Higgs boson is a new class, at a pivotal point of energy, intensity, cosmic frontiers.

## "Naturally speaking":

- It should not be a lonely solitary particle; has an "interactive friend circle": $t,\ W^{\pm},\ Z$
"relatives": $\tilde{H}^{0,\pm},\ \tilde{t},\ \tilde{b},\ (\tilde{g});\ S,\ \tilde{S}...$
"siblings": $H^0,\ A^0,\ H^{\pm},\ H^{\pm\pm},\ S...$
- LHC lights the way for the searches.
- Higgs factory may reveal their properties from Higgs coupling measurements at 1%-level.

**An exciting journey ahead!**