ILC Project

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ILC Basic Parameters

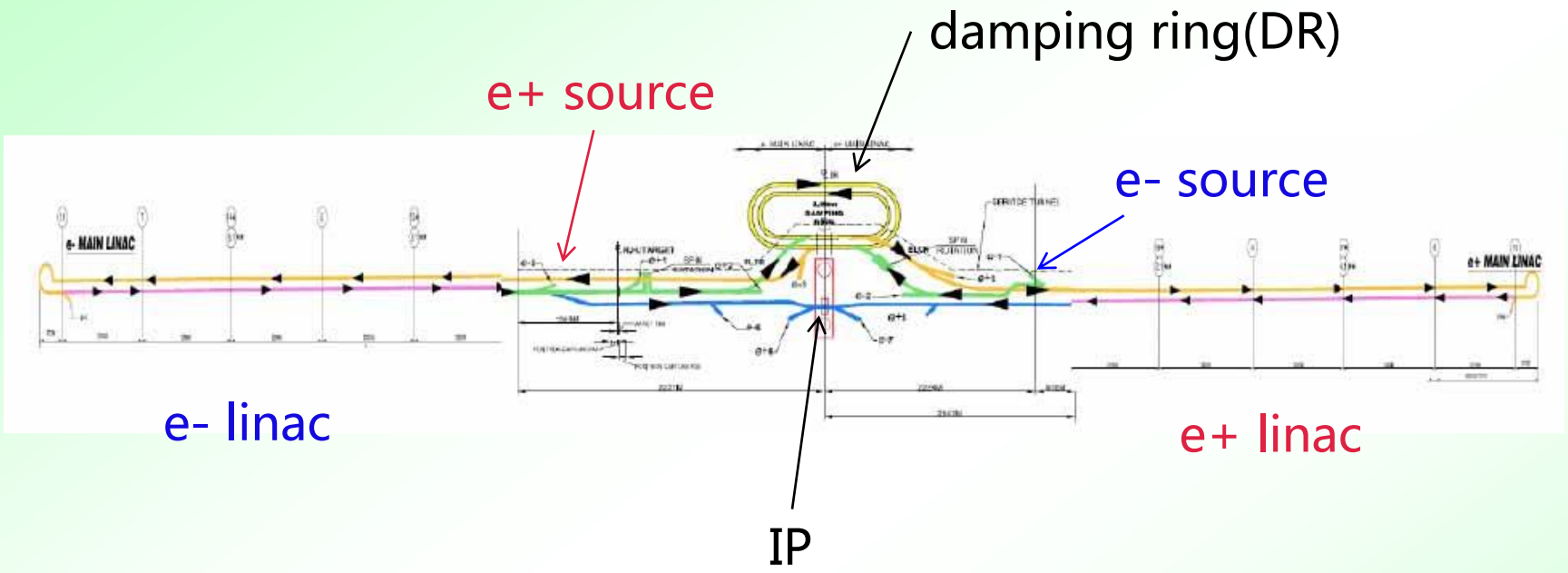
(http://www.fnal.gov/directorate/icfa/para-Nov20-final.pdf)

- Phase 1
  - E_{CM} 200-500 GeV scannable
  - e– polarization > 80%, helicity ±
  - 500 fb^{-1} in 4 years
- Phase 2
  - Energy upgrade to ~1TeV
  - 1000 fb^{-1} in 2~3 years
- Physics run: 7 years after start of construction

ILC Options

- e^+ polarization > 50%
  - ~30% polarization is included in the baseline
- $\gamma\gamma$, $\gamma e-$, $e-e-$ colliders
  - γ generated by inverse Compton scattering
- Giga-Z
  - ~10^9 Z on Z pole

ILC (500 GeV_{CM})



- Length 31 km
- Beam bunch at IP ：height 4nm、width 500nm、length 300μm
- 1300 bunches/train、 5 trains/s
- One IP、 14 mrad crossing angle
- L = $2x10^{34}/cm^2 \cdot s$

Key Technologies

- Acceleration
  - Main Linacs
    250 Gev in ~ 8000 m → ~ 31.5 MV/m accelerating gradient
    1 m RF cavity: ~8000x2 = ~16000 RF cavities needed

- Focusing
  - Dumping ring : reduce emittance
    Emittance ~ (spread in space) x （spread in direction）
    Parallel direction → can be focused to a point
  - Final focus system
    Focus to 4nm height、stable position → collision

Main Linacs

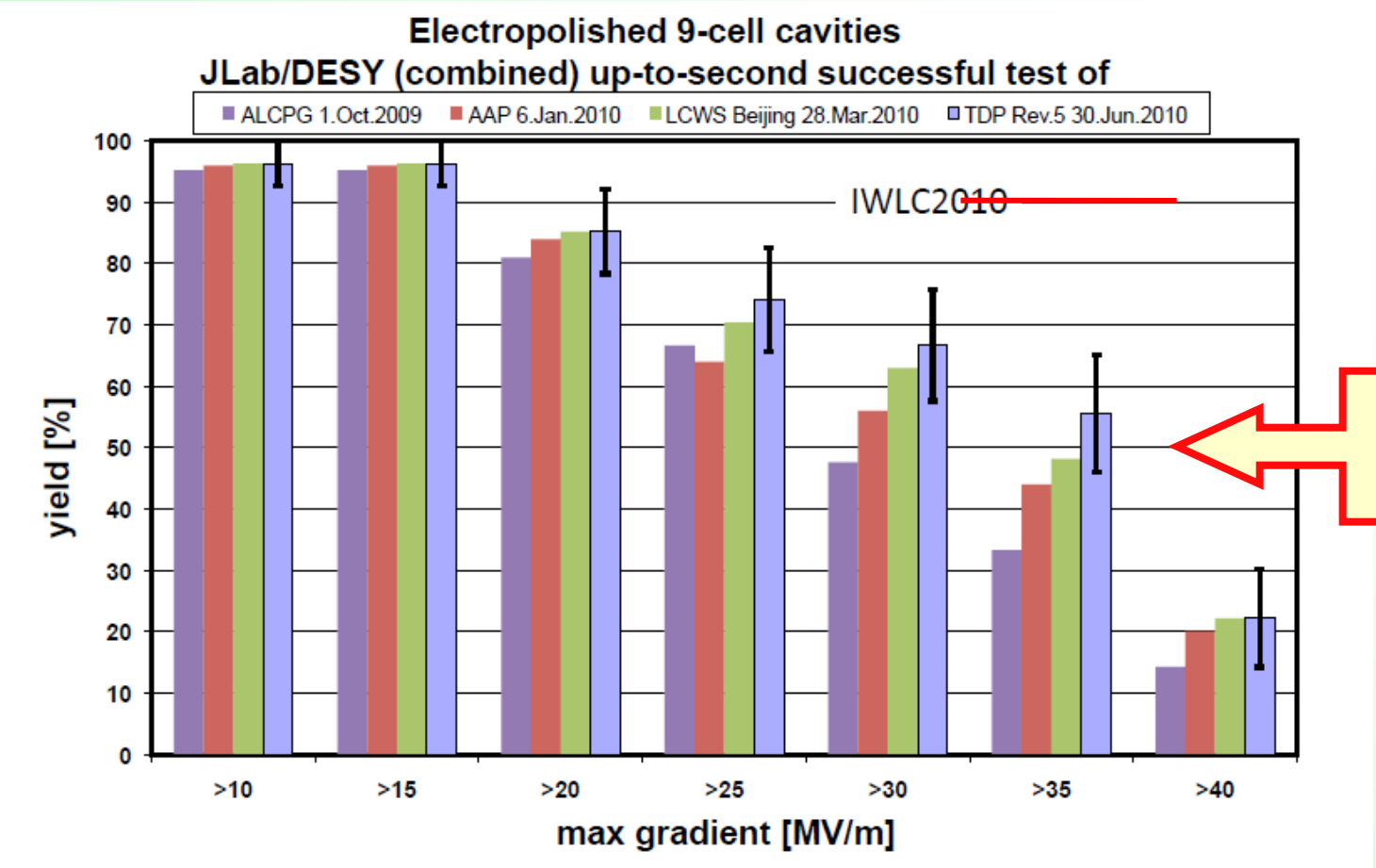
- Accelerating unit
  - One 10 MW krystron serving 3 cryomodules with 8-9 super-conducting 9-cell cavities each
  - Accelerating gradient : 31.5 MV/m (35 MV/m vertical test)
  - Default cavity design: Tesla design
  - Alternatives: Improved types are under study

    Cornell re-entrant type, DESY/KEK low-loss type.

9-cell cavity

Cryomodule test at KEK

Accelerating Gradient
- 2010 milestone achieved -



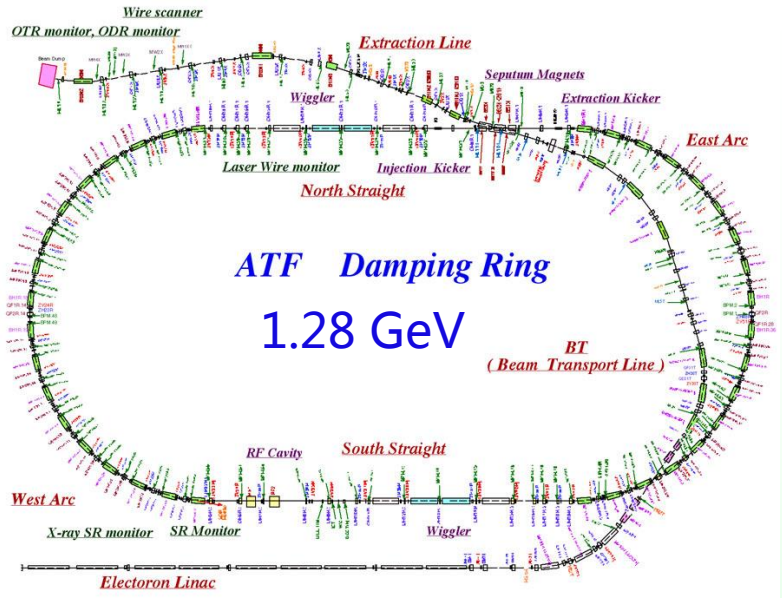
2010 milestone: 50% yield @ 35 MV/m

Final goal (2012): 90% yield @ 35 MV/m

Dumping Rings

- Dumping Rings for e+ and e- located centrally near IP
  - Housed in a single tunnel (~3 km circumference: 10μs)
  - 5 GeV, entire 1ms train is stored compressed

    → fast injection/ extraction kicker
  - $\gamma\varepsilon_y$ reduced to 1.2 10^{-8} m in 200 ms



ATF (@KEK)

(Accelerator Test Facility)

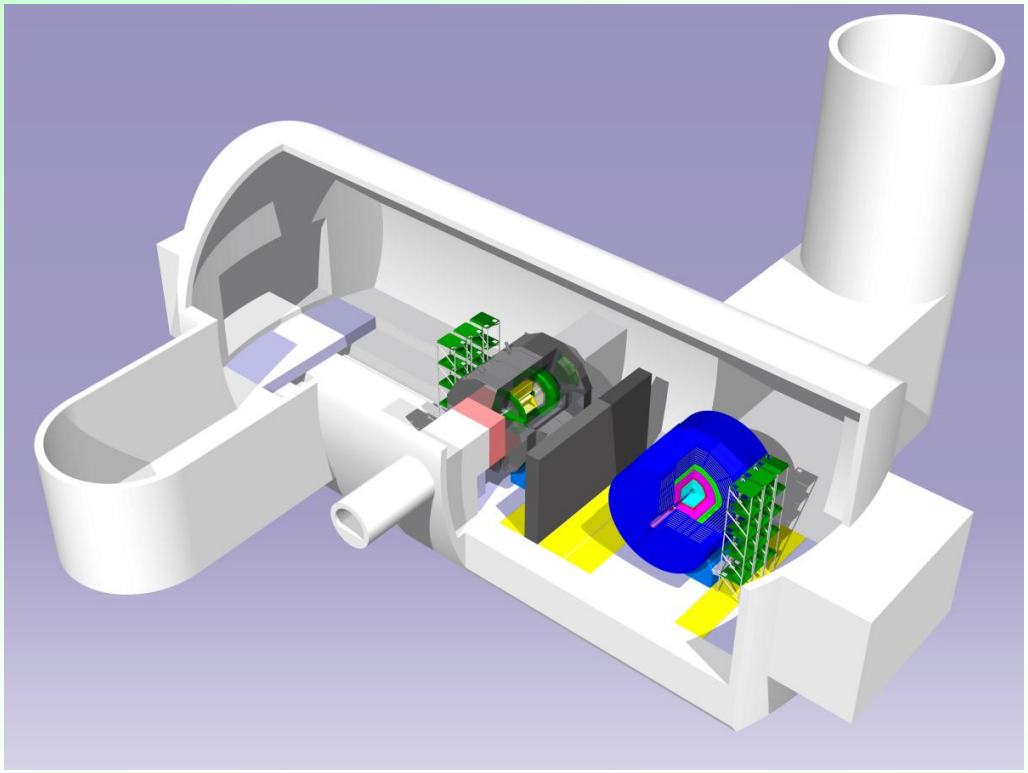
achieved $\gamma\varepsilon_y$ = 1.2 10^{-8} m goal

→ ATF2 on its way to the goals

Goal: Focus to 37nm σ_y

Beam stabilization

Experimental Hall



Two detectors

- Scientific complementarity
- Competition
- No loss of luminosity while one detector is in repair
- More physicists can participate

One collision point

→ Push-pull

ILC Detector Performances

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

- Vertexing : b,c tag etc.
  - 1/5 $r_{beampipe}$, 1/(40-1000) pixel area (wrt LHC)

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

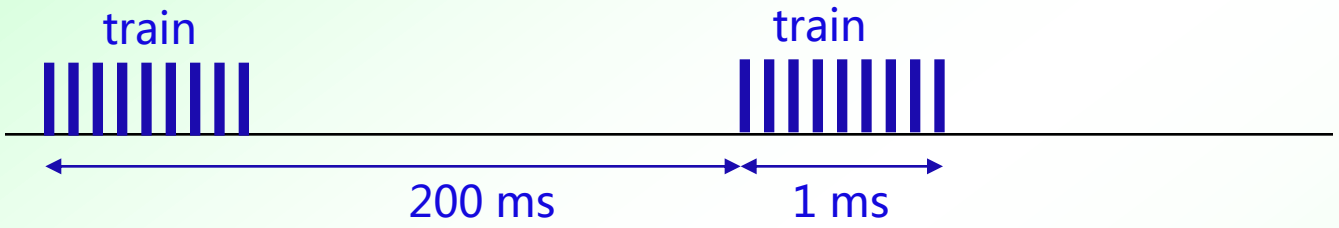
  - Tracking : tagged Higgs etc.
  - 1/6 material, 1/10 resolution

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

- Jet energy : quark reconstruction
  - 1/2 resolution

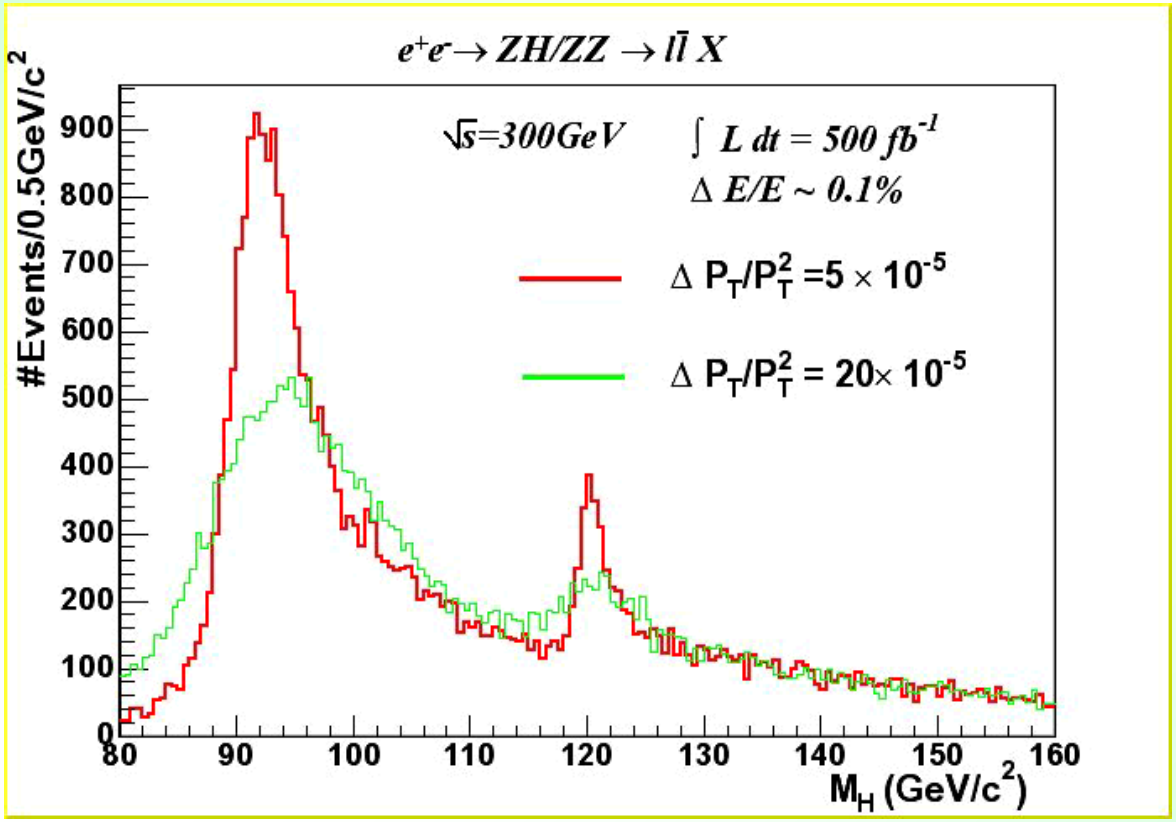
$$\sigma_E / E = 0.3/\sqrt{E(\mathrm{GeV})}$$

Beam Bunch Pattern



- 5 trains/s, 1 train = 1300 bunches in 1 ms
- Readout during the 200 ms gap for some sub-detectors
- Turn off powers during the gap
  - 'Power pulsing'
  - Save power and minimize heat generation

Recoil mass resolution

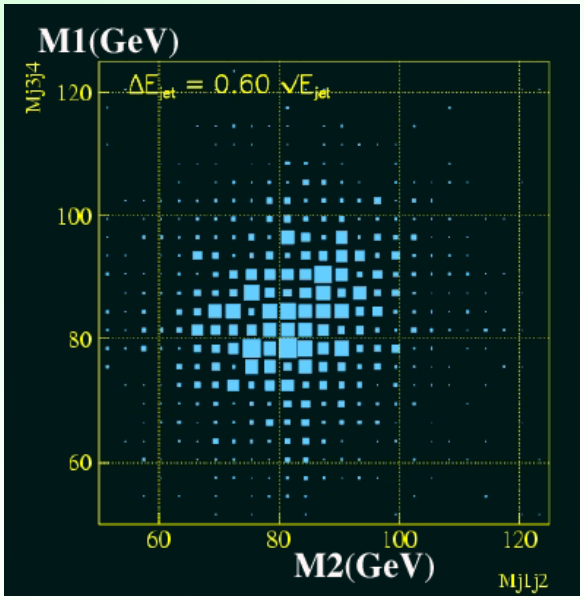


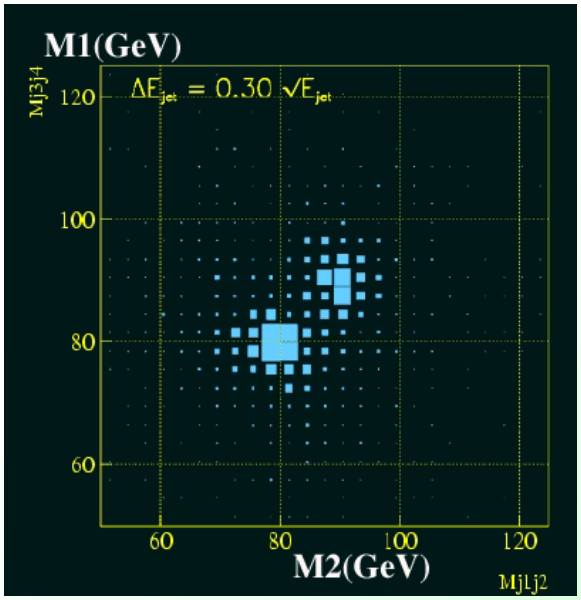
- Good momentum resolution of tracking is <u>required.</u>

Jet(quark) reconstruction

$e^+e^- \to \nu\bar{\nu}WW, \nu\bar{\nu}ZZ \qquad W/Z \to jj$

(Important mode if no Higgs is found)





$\sigma_E/E = 0.6/\sqrt{E(\mathrm{GeV})}$

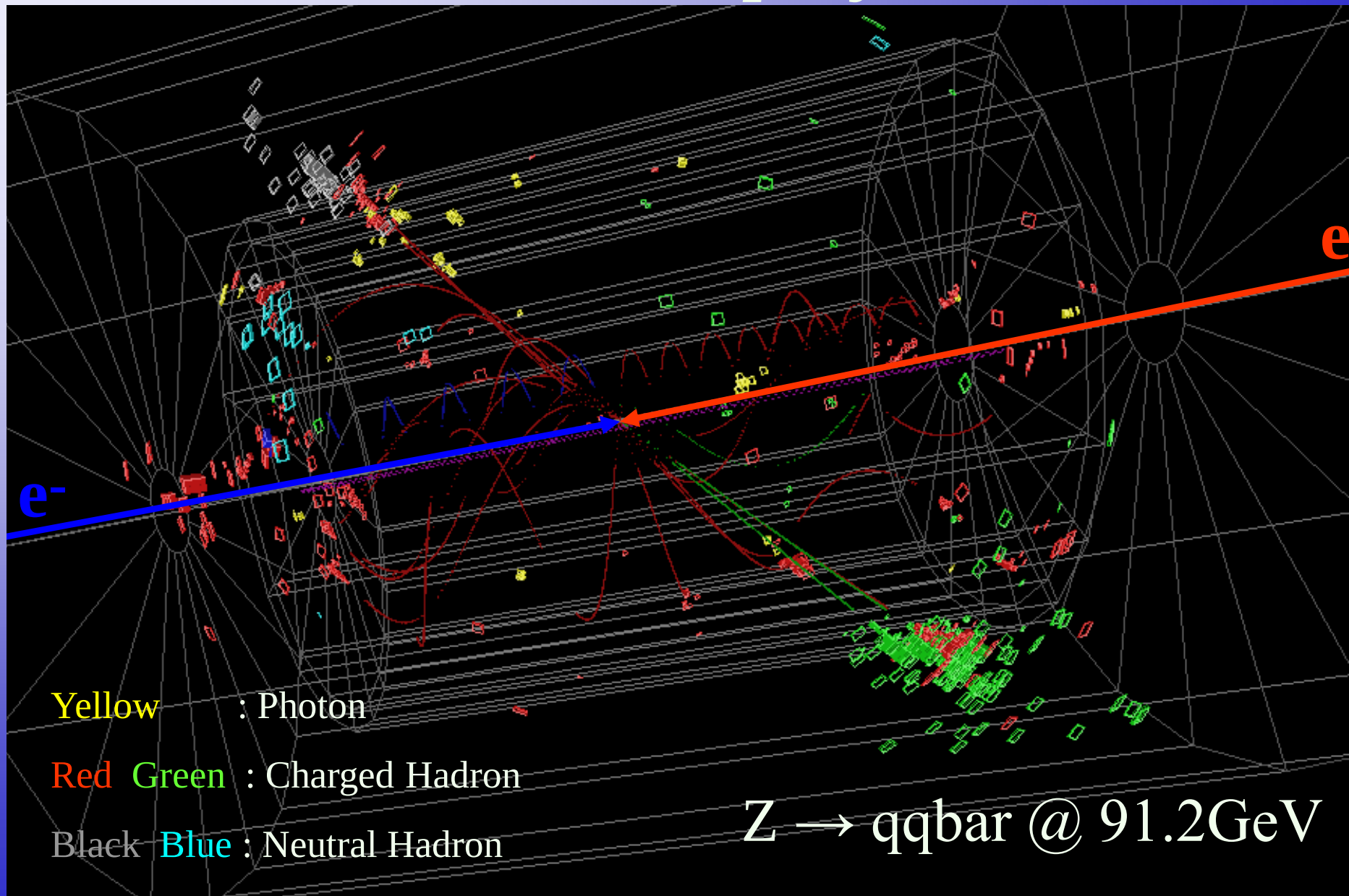
$\sigma_E/E = 0.3/\sqrt{E(\mathrm{GeV})}$

- With $\sigma_E/E = 0.3/\sqrt{E}$, Z/W→jj can be reconstructed and separated : Technique = PFA (Particle Flow Algorithm)

PFA

Event Display

T. Yoshioka



Yellow : Photon

Red Green : Charged Hadron

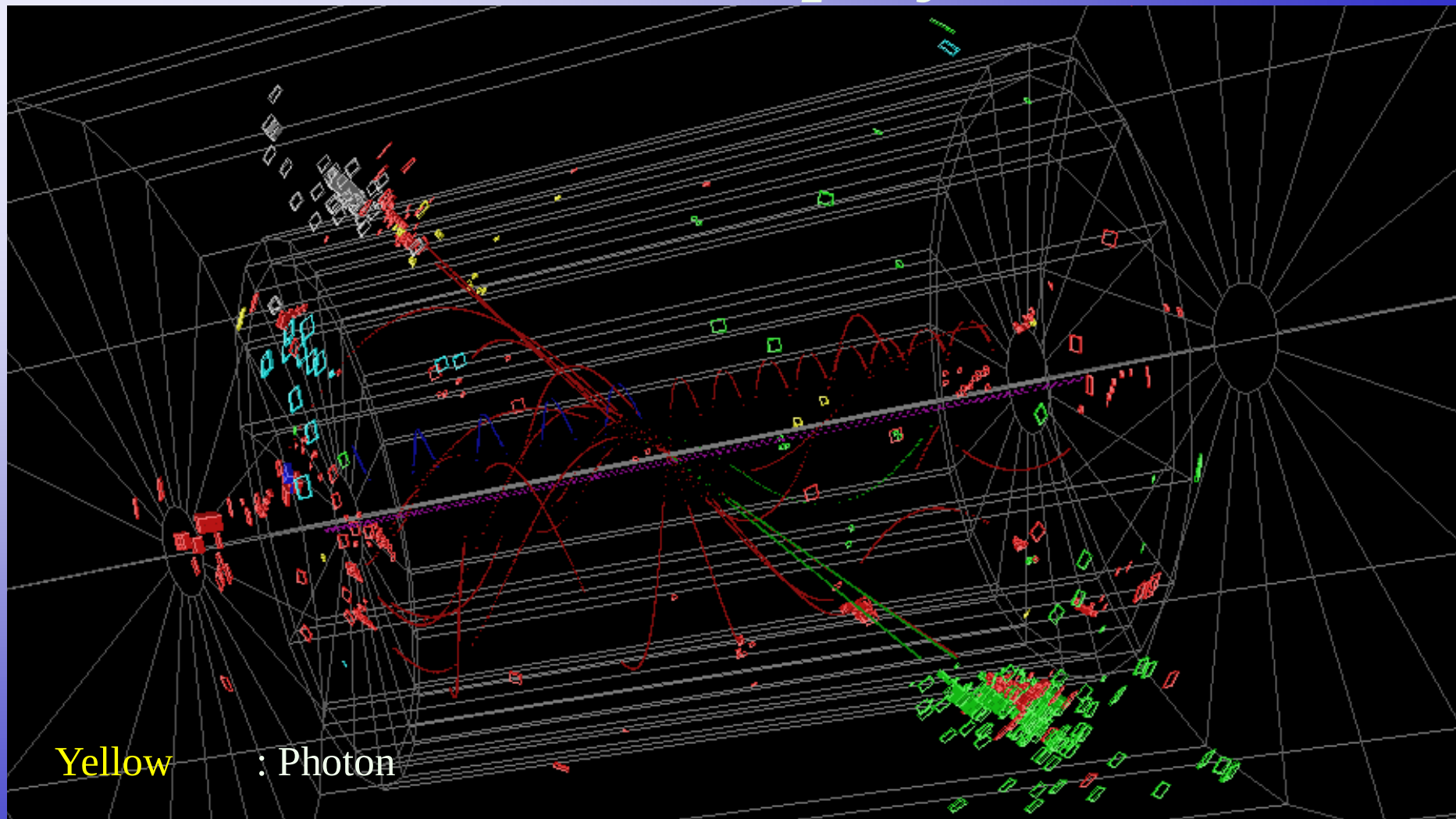
Black Blue : Neutral Hadron

$Z \rightarrow q\bar{q}$ @ 91.2GeV

PFA

Event Display

T. Yoshioka



Yellow : Photon

Red Green : Charged Hadron

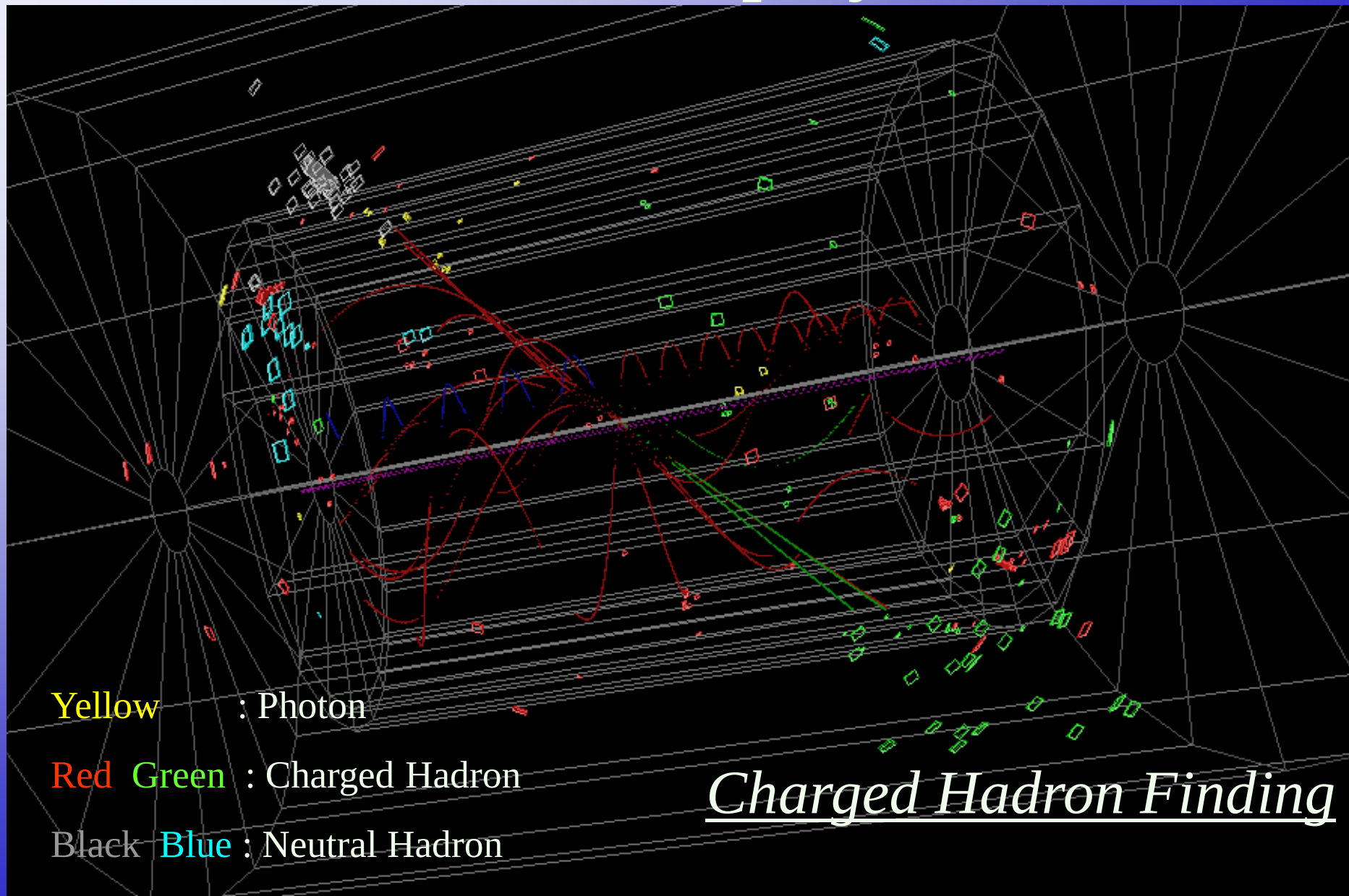
Black Blue : Neutral Hadron

Gamma Finding

PFA

Event Display

T. Yoshioka



Yellow : Photon

Red Green : Charged Hadron

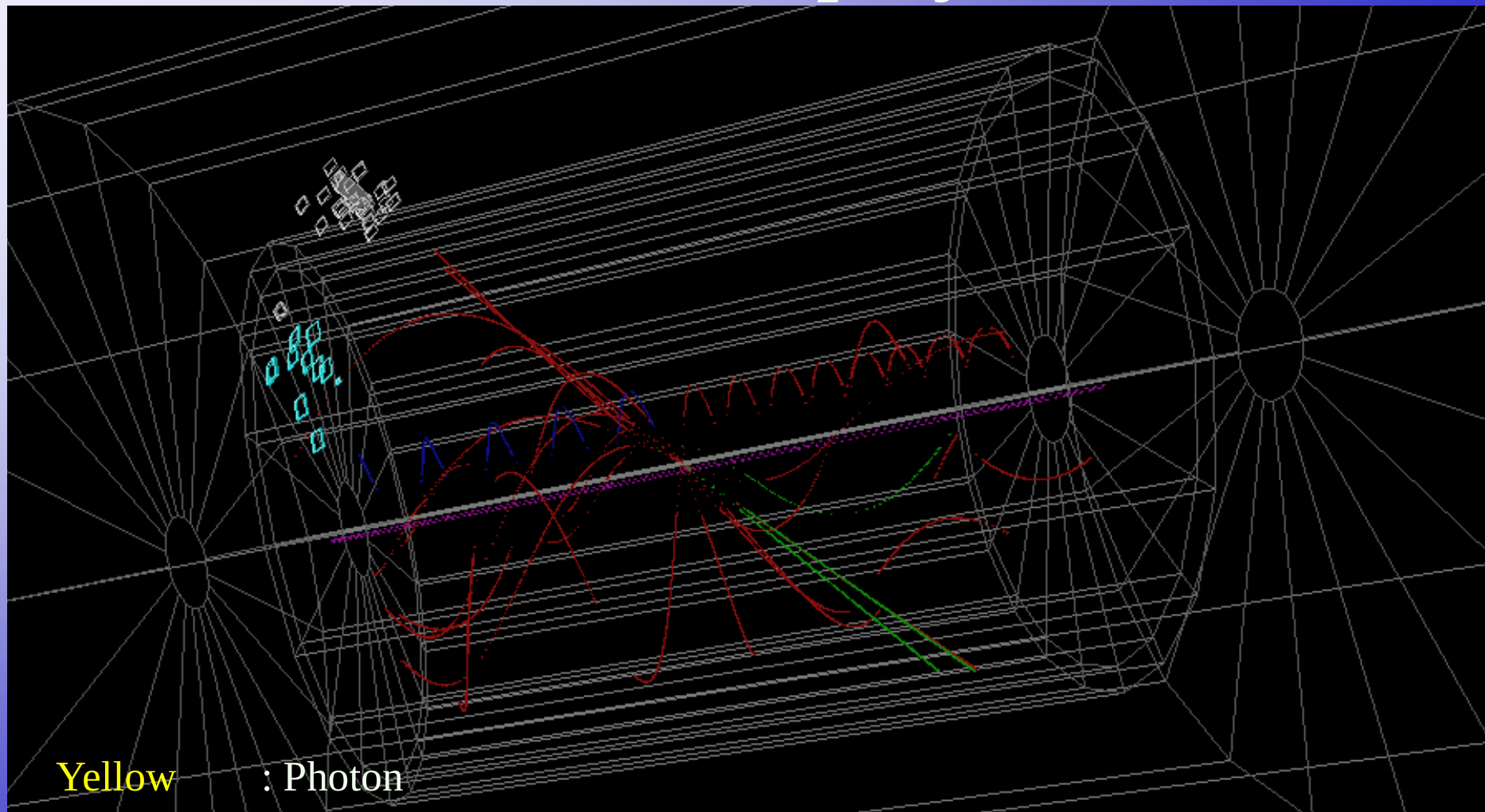
Black Blue : Neutral Hadron

Charged Hadron Finding

PFA

Event Display

T. Yoshioka



Yellow : Photon

Red Green : Charged Hadron

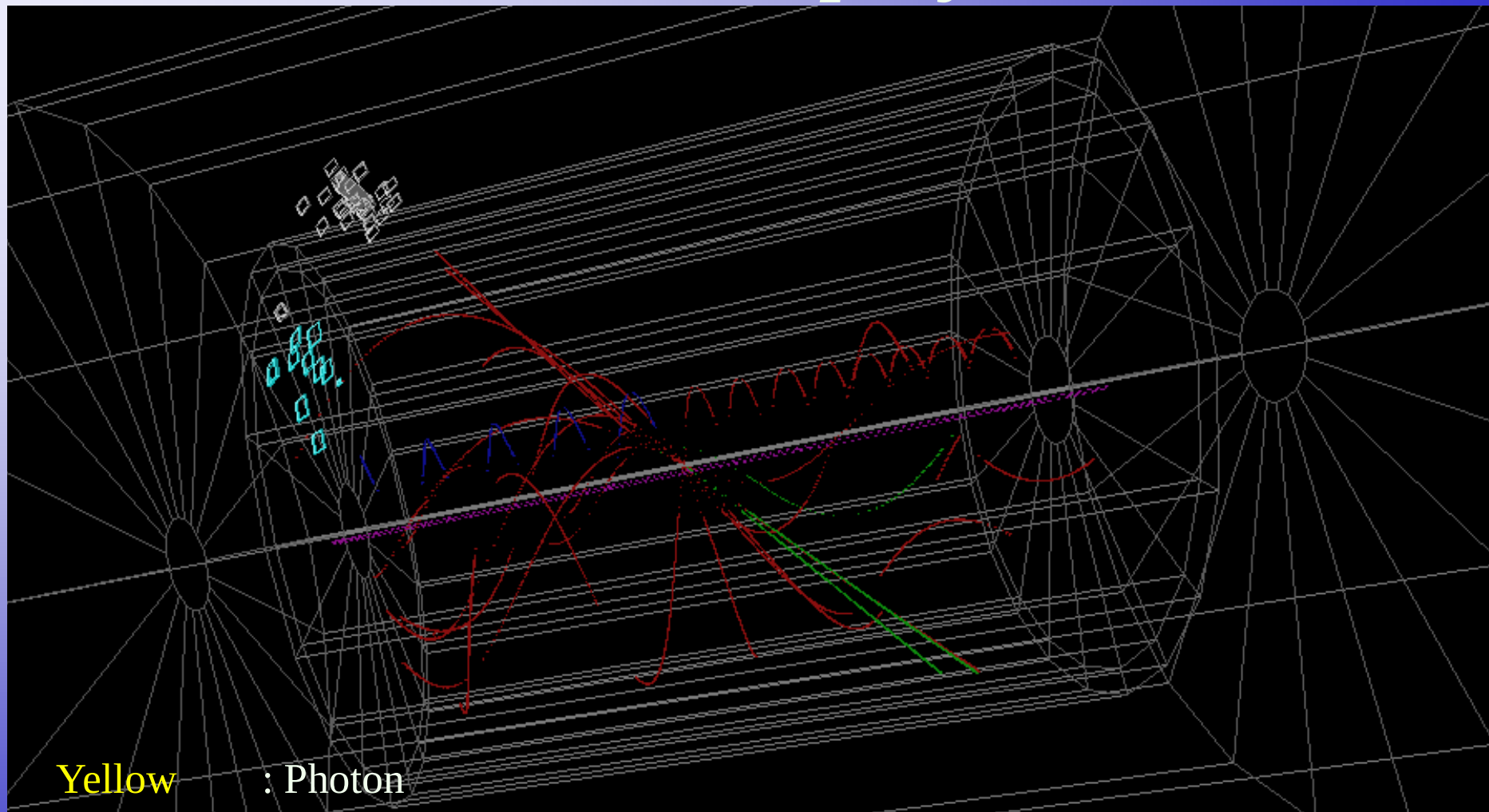
Black Blue : Neutral Hadron

Satellite Hits Finding

PFA

Event Display

T. Yoshioka



Yellow : Photon

Red Green : Charged Hadron

Black Blue : Neutral Hadron

Remaining : Neutral Hadron

ILC Detectors

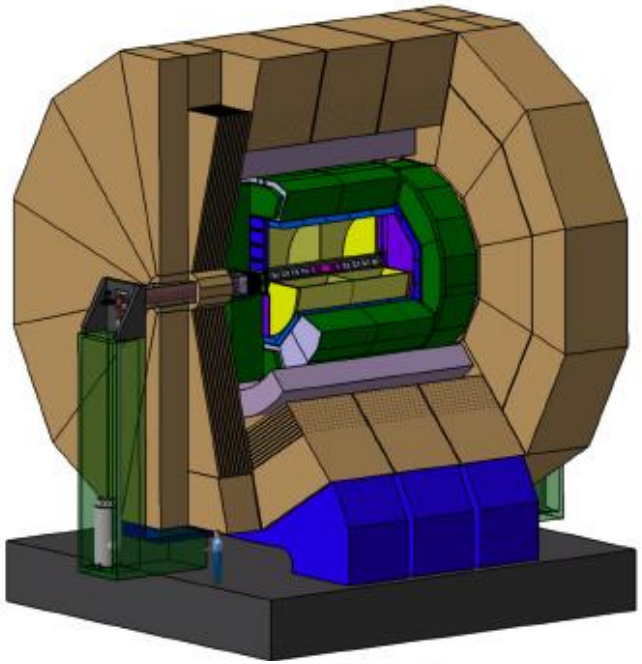
Sep. 2009：
2 detectors were ‘validated’

- ILD (695 signatories、32 countries)
  - Main tracker：TPC
  - Solenoid: 3.5 Tesla
- SiD (240 signatories、17 countries)
  - Main tracker：Si strip
  - Solenoid: 5 Tesla

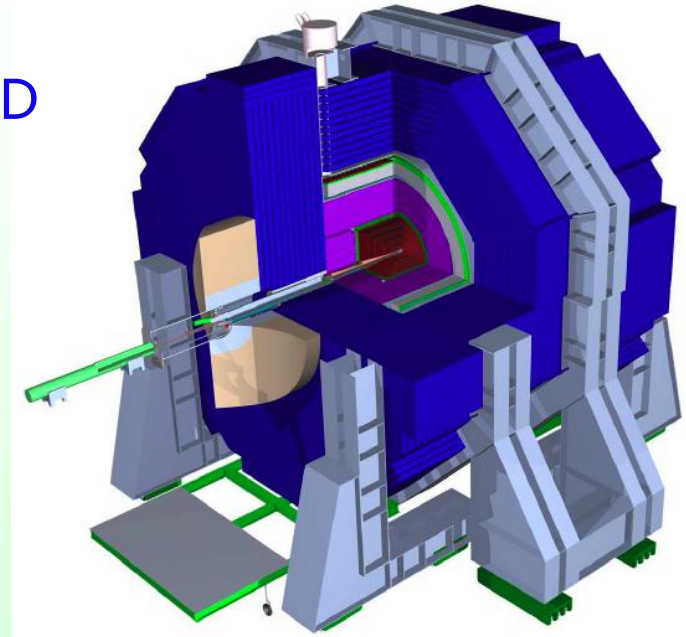
Common features：

Pixel vertex detector, Main tracker, EM and Hadron calorimeters:
All placed within the solenoid
(for good jet energy resolution)

ILD

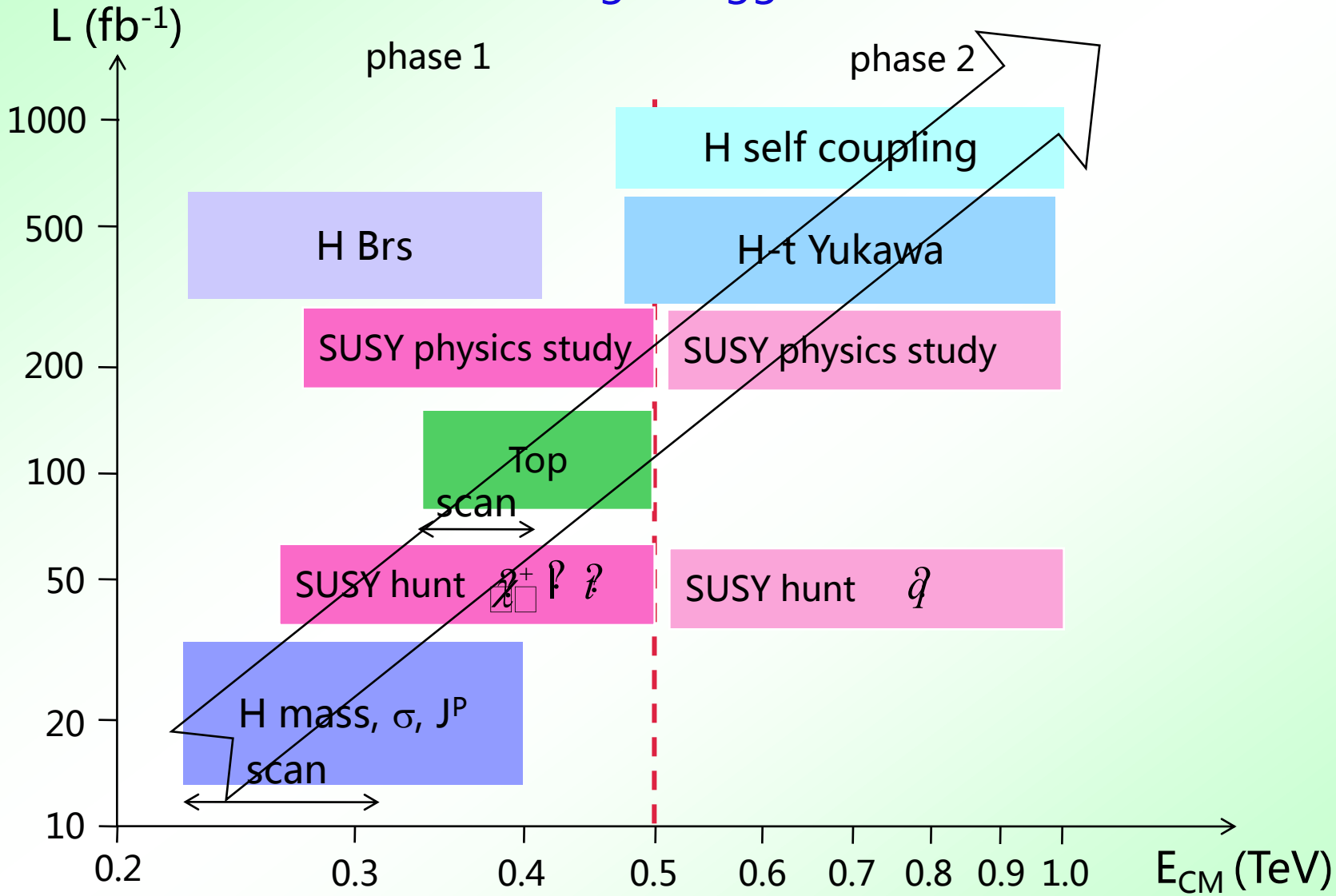


SiD



ILC Physics Scenario

Light Higgs and SUSY



ILC Features

- Simple and well-defined initial state
  - e+e– 4-momentum known → recoil mass analysis etc.
  - Beam polarization → select intermediate states、background rejection
- Energy scan
  - Threshold scan $e^+e^- \to ZH, t\bar{t}, \tilde{\chi}^+\tilde{\chi}^- \ldots$

    Mass measurements, determination of spin parity
- Relatively mild environment

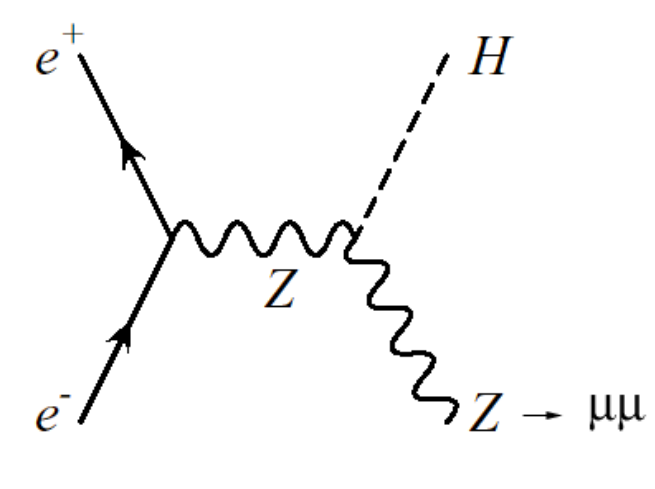
  → High resolution detectors

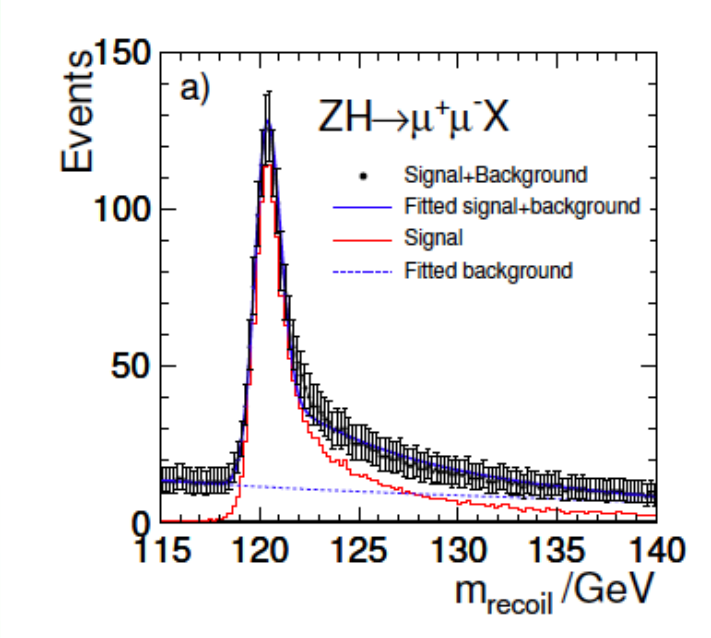
High resolution / high sensitivity → discoveries

Higgs Physics
(an example of recoil mass analysis)

'Higgs-strahlung'

$e^+e^- \rightarrow ZH,\ Z \rightarrow \mu\mu, ee$

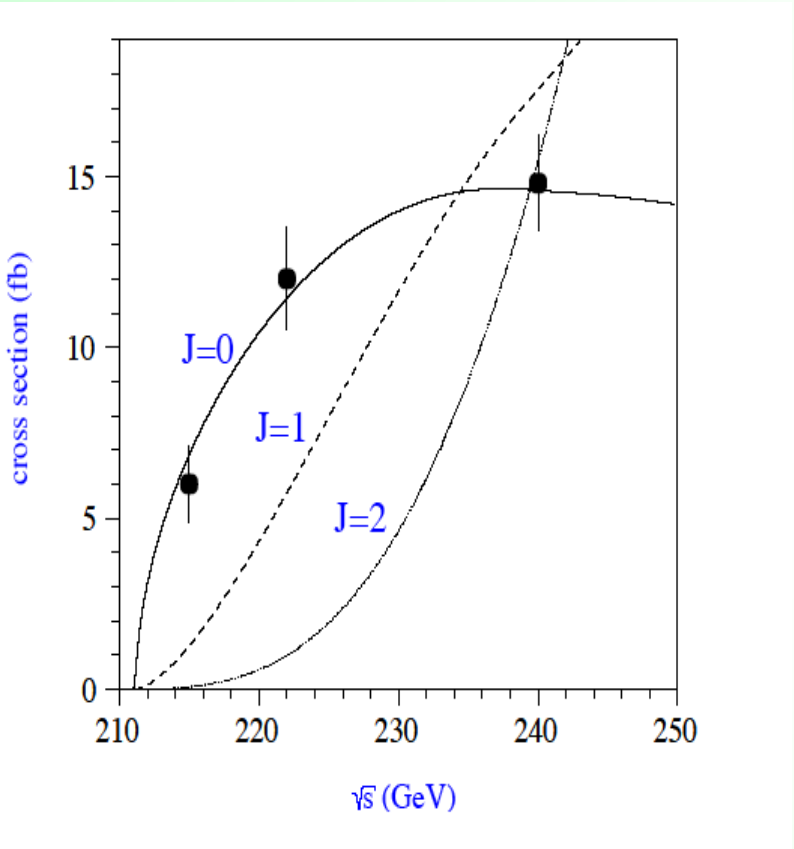




- Detect Z, look at the recoil mass $m^2_{\text{recoil}} = (P_{e+e-} - P_Z)^2$
- Determine Higgs mass and production rate without detecting Higgs decay
- Then detect Higgs decays → Absolute measurement of Higgs decay branching fractions
- **Higgs factory: 5σ signal in 1 day**

Threshold Scan

$$e^+e^- \to ZH,\ Z \to \mu\mu, ee$$



- Higgs mass

  $\sigma(m_h)$ = 40 MeV

- J^P of Higgs
  - Threshold curve
  - Higgs production angle dist.
  - Higgs decay angle dist.

  → $J^P = 0^+$

Measurement of Higgs couplings

- Yukawa coupling with c,b,τ

  $h \to q\bar{q}$

- Yukawa coupling with top

  $e^+e^- \to t\bar{t}h$

- Gauge boson couplings (WWh, ZZh)

  $e^+e^- \to \nu\bar{\nu}h, e^+e^-h$ and $e^+e^- \to Zh$

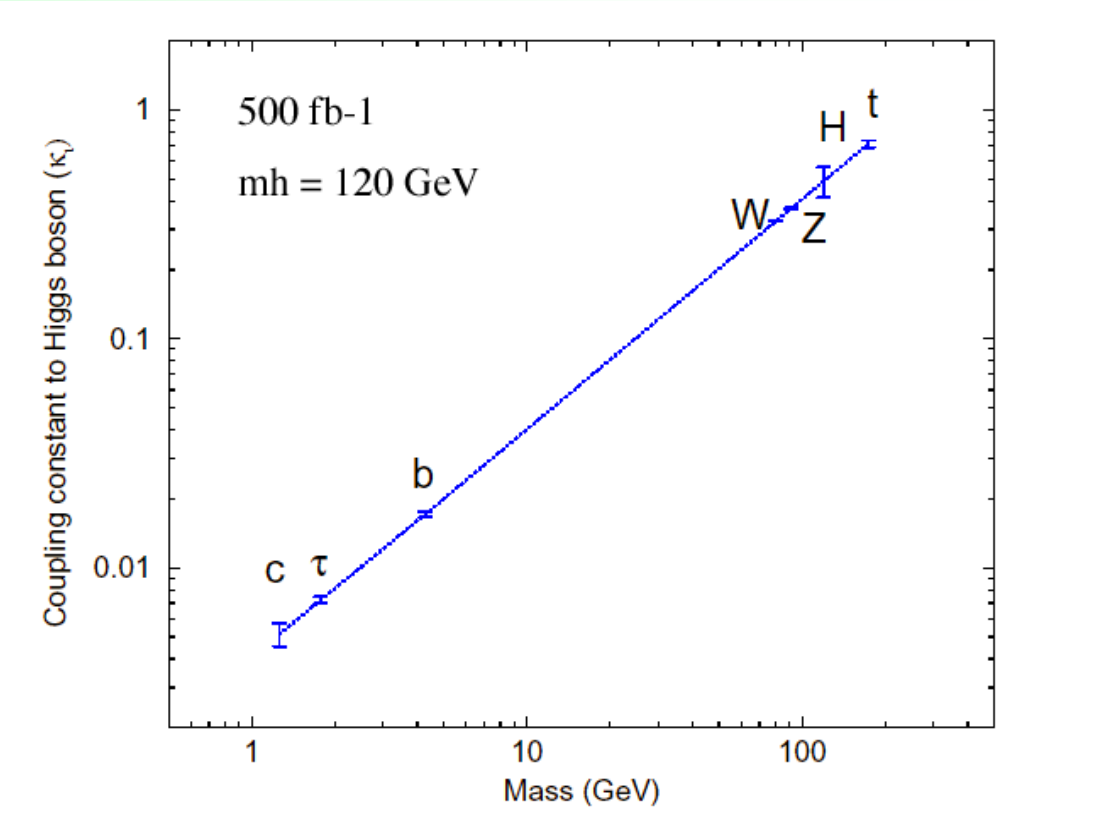
- Higgs self coupling (hhh)

  $e^+e^- \to \nu\bar{\nu}hh, e^+e^-hh$ and $e^+e^- \to Zhh$

- Higgs total width to 5%

  Γ(h$\to$WW*) and Br(h$\to$WW*)

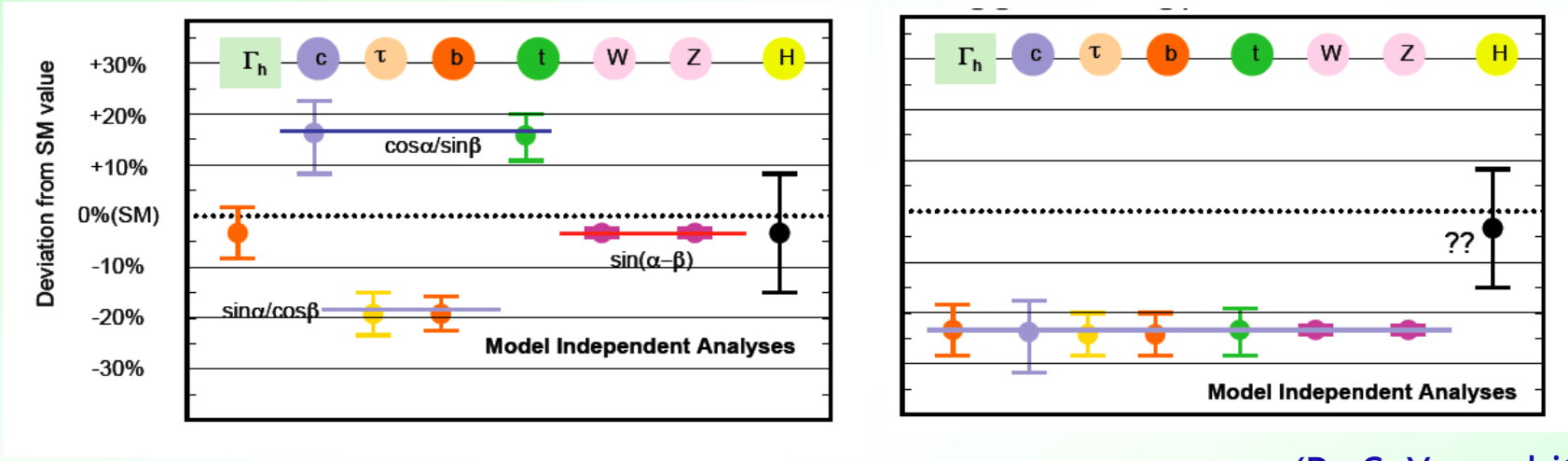
Higgs coupling measurements



SM Higgs : coupling ∝mass

Higgs couplings

pattern of deviation from SM → structure of New Physics



(By S. Yamashita)

SUSY
(2 Higgs Doulet Model)

Extra dimension
(Higgs-radion mixing)

SUSY Particles
(use of polarization)

- SUSY can be pair-created

$$e^+e^- \to \tilde{\mu}_R^+\tilde{\mu}_R^-,\ \tilde{\mu}_R \to \mu\tilde{\chi}_1^0$$

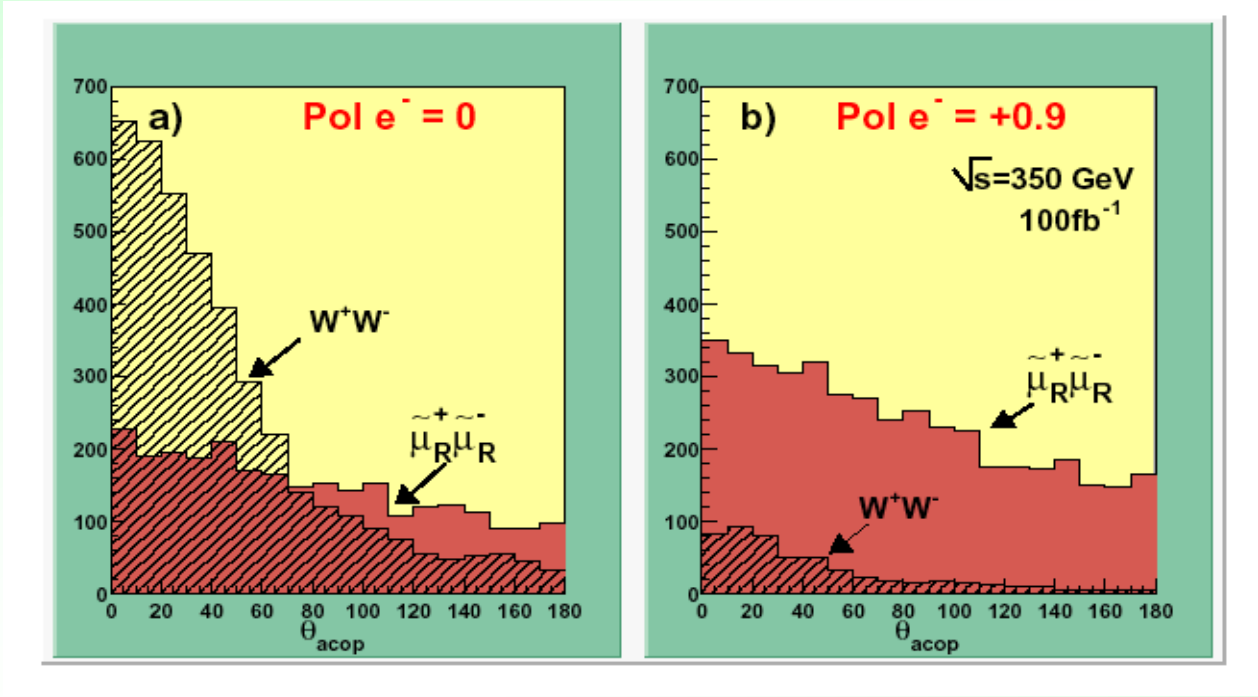
$$e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-,\ \tilde{\chi}_1^+ \to W^+\tilde{\chi}_1^0$$

etc.

- Clear signal: μ-pair, W-pair + missing energy
- Beam polarization
  - Control the intermediate state, remove backgrounds
- Measurements of mass, spin, hypercharge, and mixing

Example: Smuon Detection

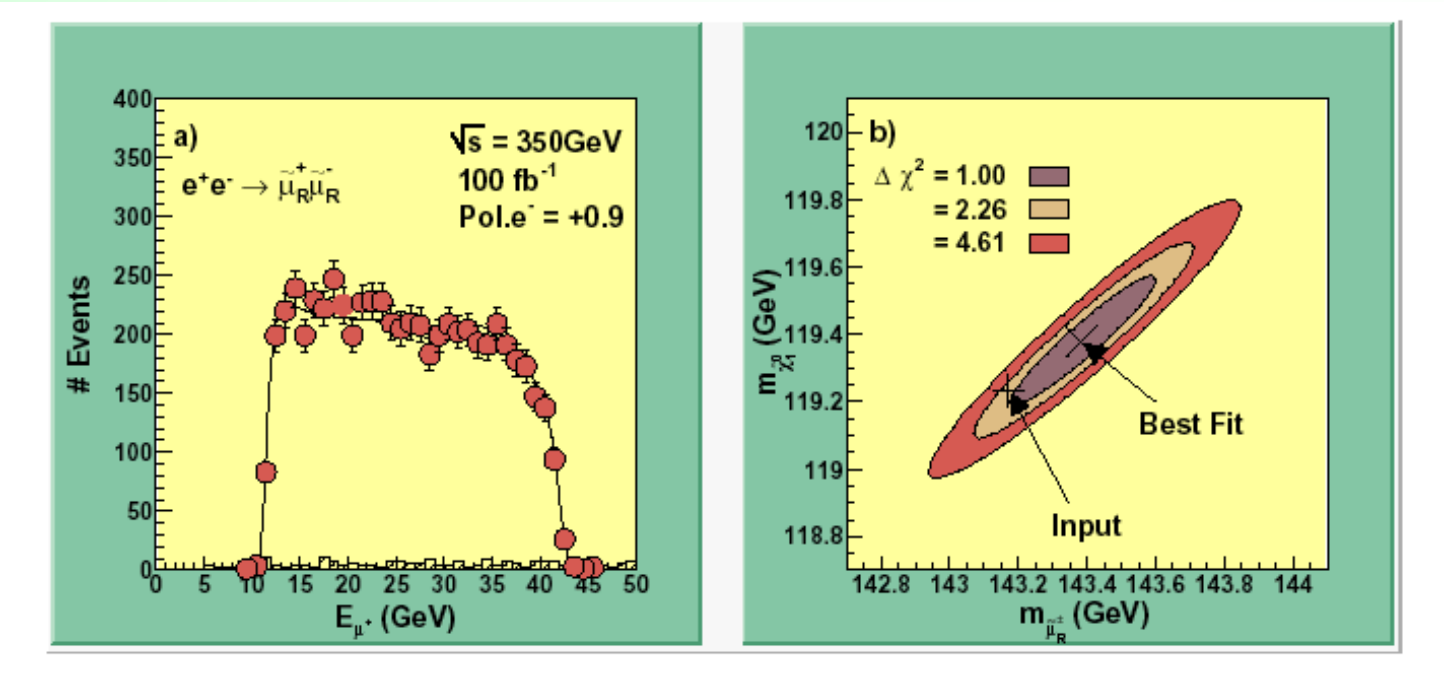
$$e^+e^- \to \tilde{\mu}_R^+\tilde{\mu}_R^-,\ \tilde{\mu}_R \to \mu\tilde{\chi}_1^0$$



- Singal : μ-pair
  - Look at $\mu^+\mu^-$ acoplanarity wrt the beam axis
- Poralization of e^- (R) → reject W^+ W^- background

Simultaneous mass measurement of Smuon and LSP

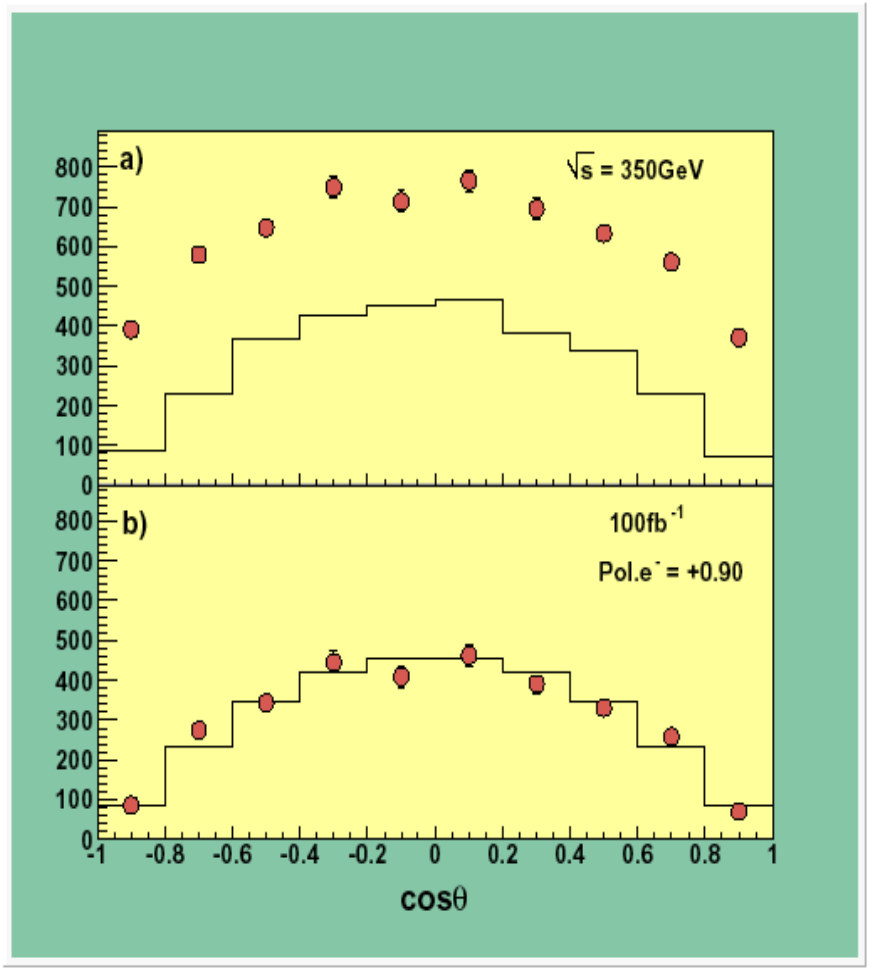
$$e^+e^- \to \tilde{\mu}_R^+\tilde{\mu}_R^-,\ \tilde{\mu}_R \to \mu\tilde{\chi}_1^0$$



- End points of $\mu^\pm$ energy distribution
  - → model-independent determination of $m(\tilde{\mu}_R)$ and $m(\tilde{\chi}_1^0)$

Smuon spin determination

$$e^+e^- \to \tilde{\mu}_R^+\tilde{\mu}_R^-,\ \tilde{\mu}_R \to \mu\tilde{\chi}_1^0$$



- Smuon production angle
  - Quadratic solutions
  - Wrong solution ~ flat
  - $\sin^2\theta \to$ spin0
- Similarly for $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-$

SUSY Parameter Determination

- Chargino: mixture of Wino and Higgsino

$$(\tilde{W}^+, \tilde{H}^+)\begin{pmatrix} M_2 & \sqrt{2}m_W\cos\beta \\ \sqrt{2}m_W\sin\beta & \mu \end{pmatrix}\begin{pmatrix} \tilde{W}^- \\ \tilde{H}^- \end{pmatrix}$$

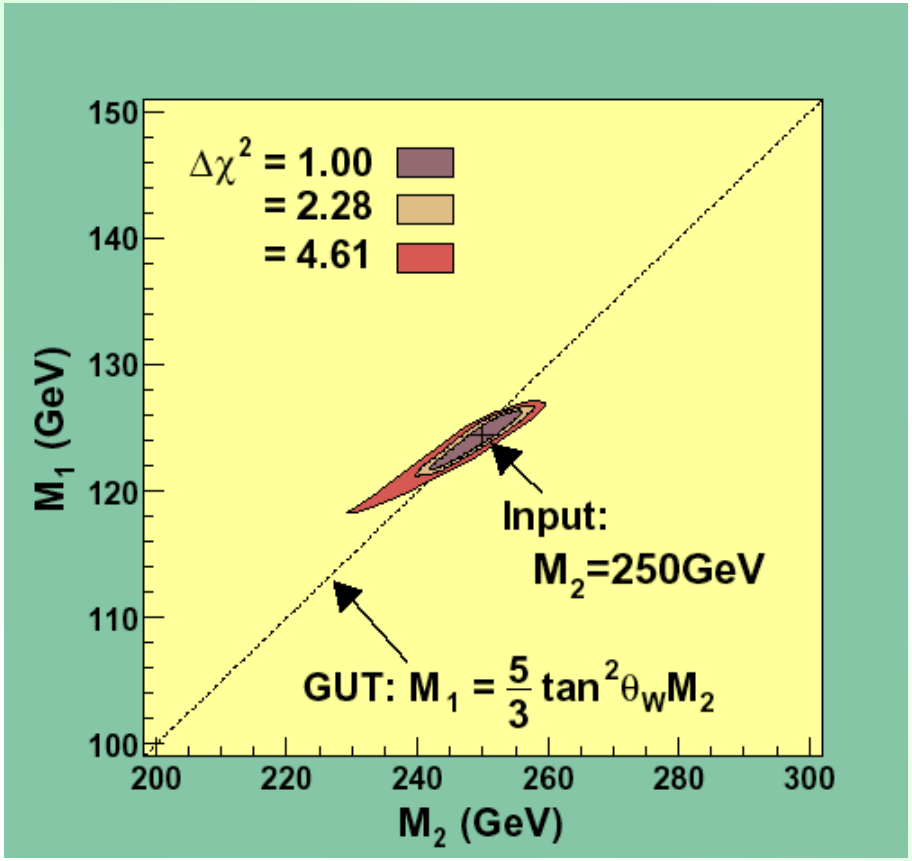
- Use polarized electron (e^-_R: iso-singlet)
  - Can turn off isospin interactions
  - Higgsino component contributes to Chargino pair creation
  - Right-handed selectron pair creation depends on Bino

- $(M_1, \tan\beta, M_2, \mu)$ can be extracted from

$$\sigma(e^+e^-_R \to \tilde{e}^+_R\tilde{e}^-_R) \qquad \sigma(e^+e^-_R \to \tilde{\chi}^+_1\tilde{\chi}^-_1)$$

$$m(\tilde{\chi}^+_1) \qquad m(\tilde{\chi}^0_1)$$

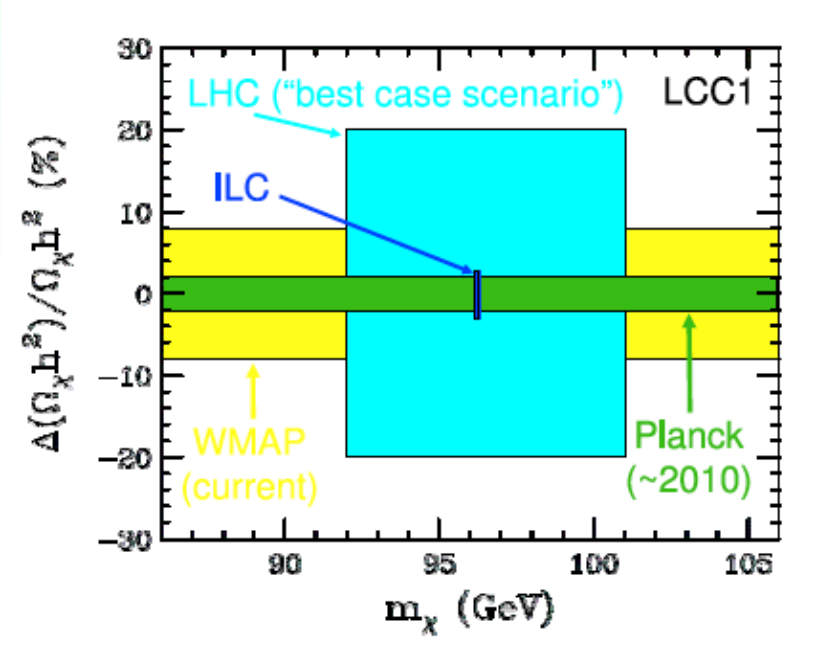
SUSY: probe underlying physics



- E_{cm} = 500 GeV, 50 fb^{-1}
- Probe GUT relation (or any other theoretical structures)

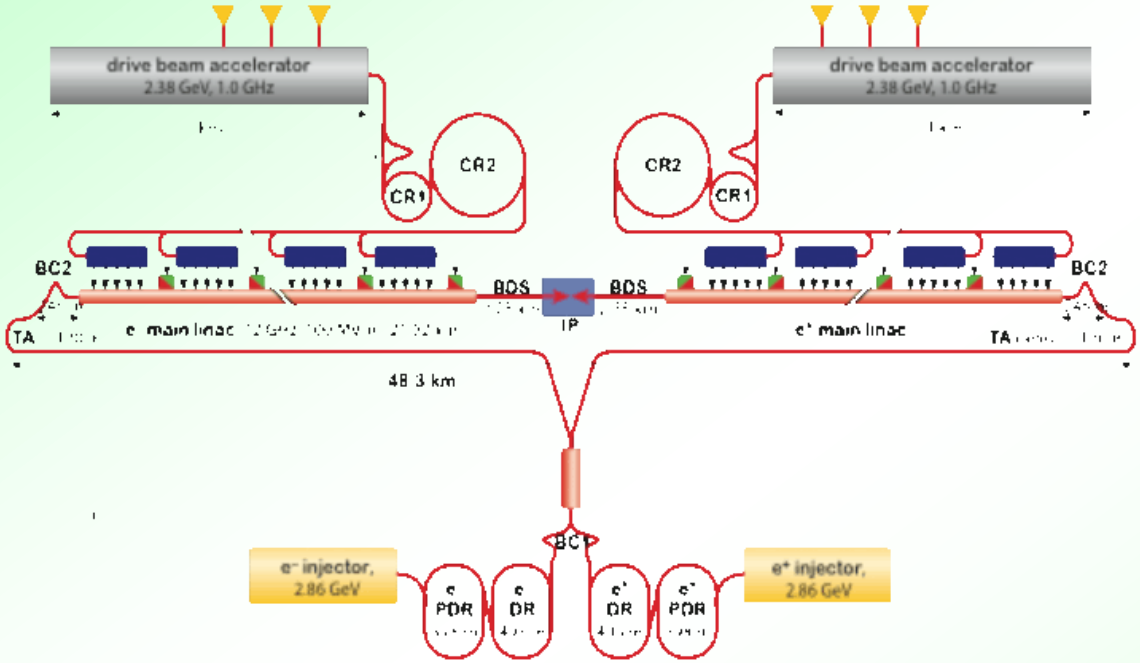
Dark Matter

- Lightest super particle (LSP) is the dark matter?
- Key: can the theory explain the relic density of ' 23%' ?
- Creation and annihilation → relic density
- Need to know all processes contributing to LSP annihilation



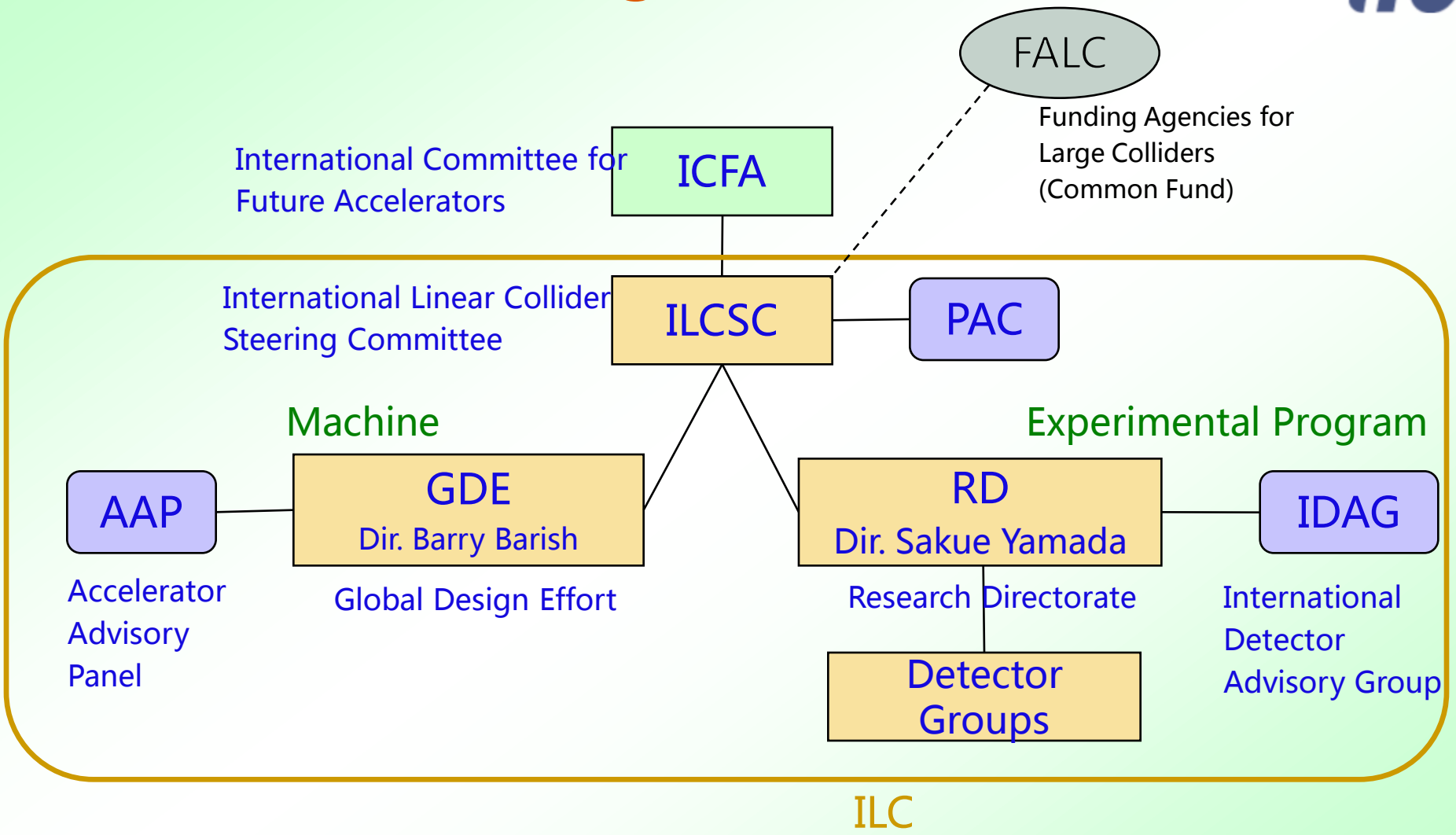
Relic density estimation by LHC and ILC (mSUGRA SPS1a)

CLIC (Compact LInear Collider)



- A CERN project. DG strongly supports ILC/CLIC
- Electric field generated by high-intensity low-energy beam accelerates high-energy beam
- E_{CM} : 500 GeV→ 3 TeV
- CDR to be produced in 2011
- Close collaboration with ILC （particularly in physics and detectors）

Global Organization of ILC



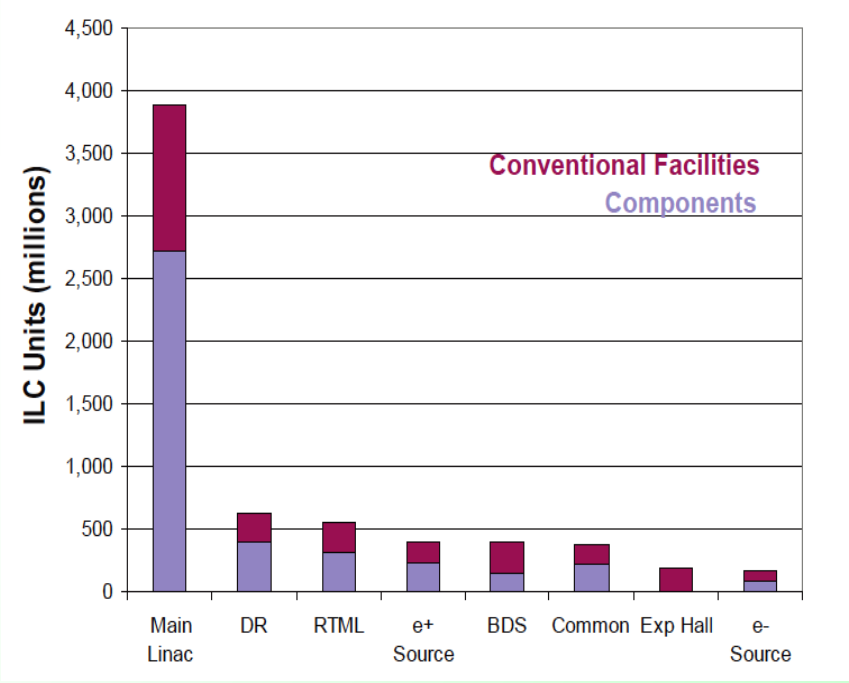
ILC Cost

- RDR(2007 Reference Design Report) cost evaluation
  - Site dependent 1.83 B ILCU
  - Shared 4.79 B ILCU
  - Total 6.62 B ILCU

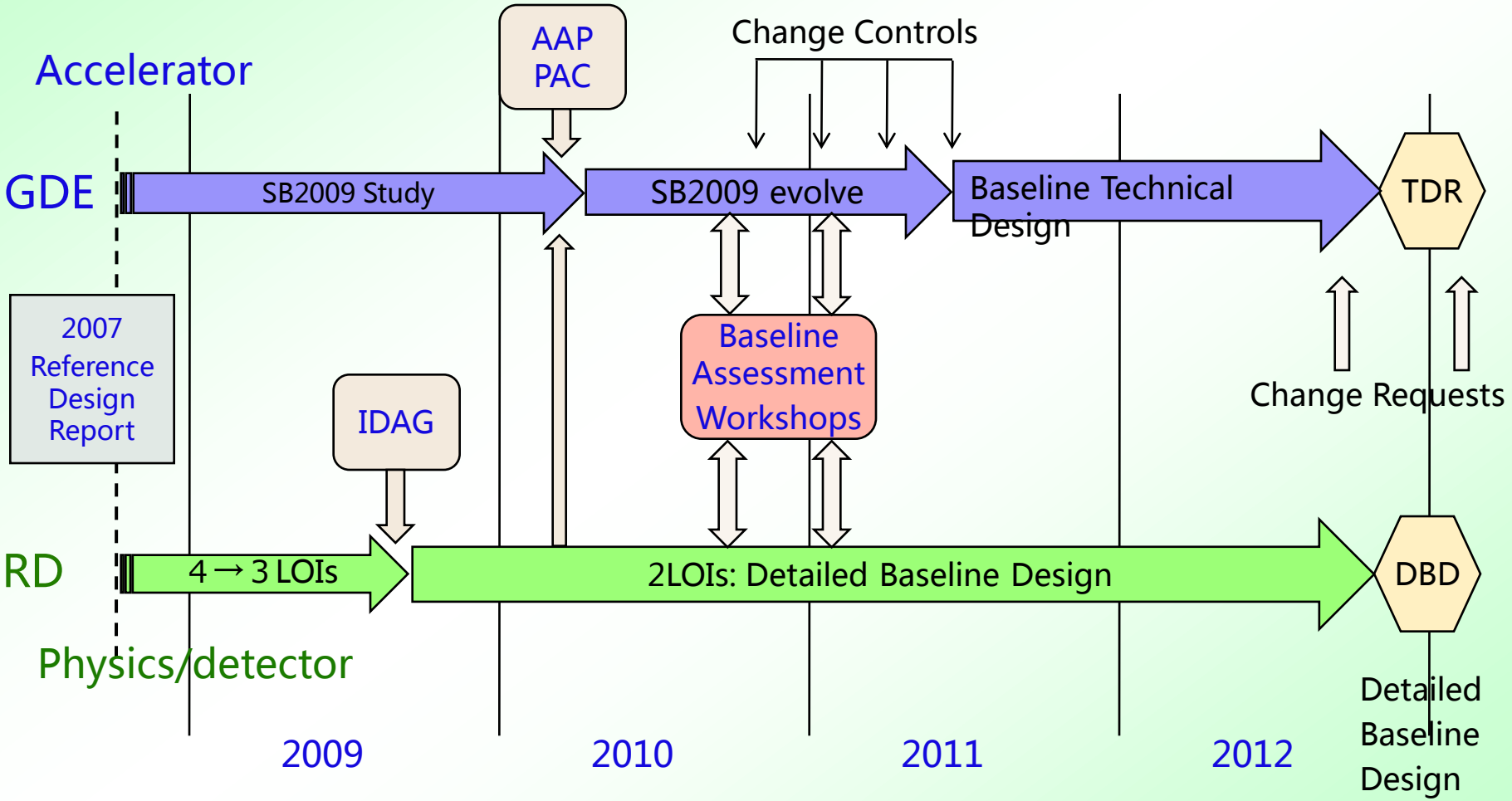
    (1 ILCU = 1 $ (2007))

    + labor
- Cost reduction

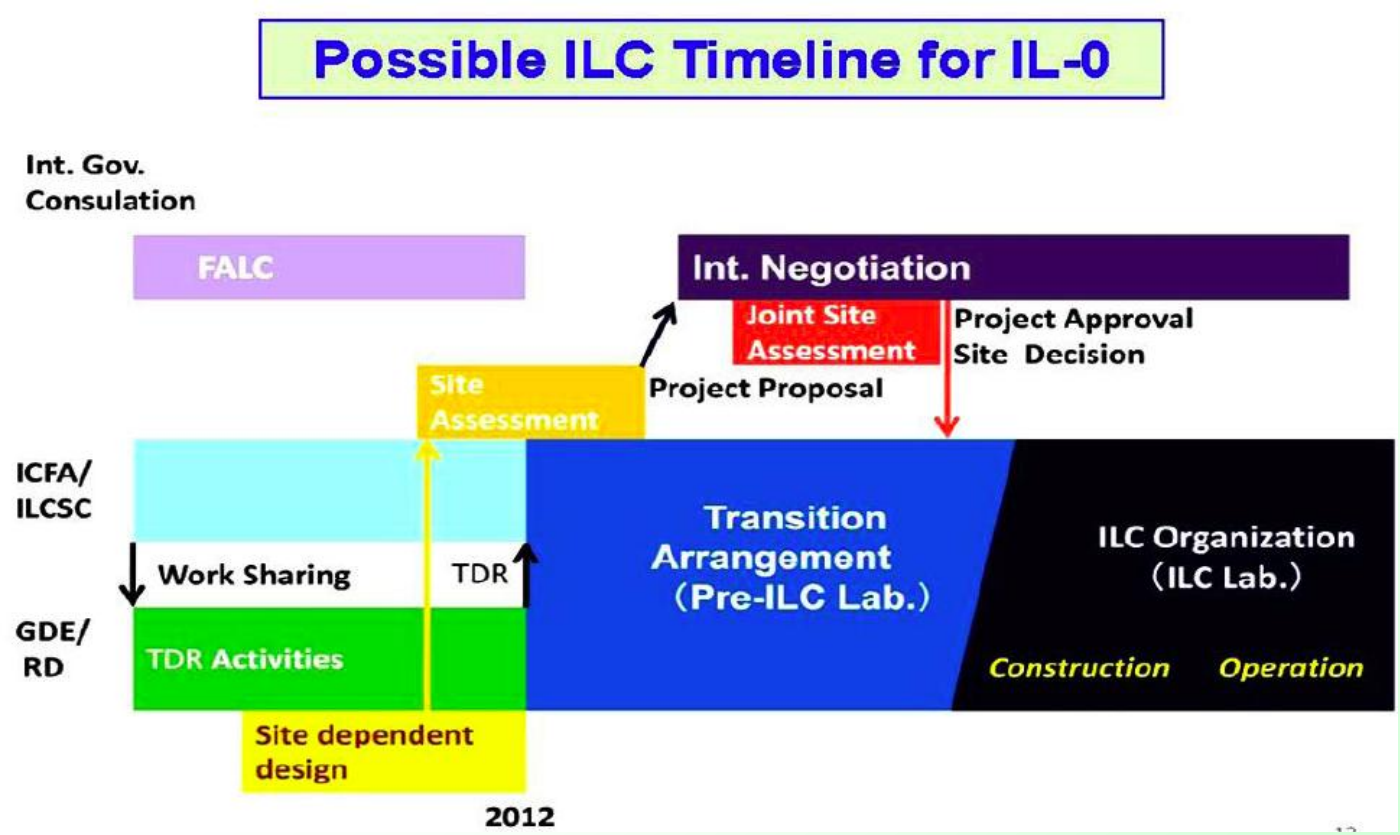
  - without sacrificing physics -
  - SB2009 (Strawman Baseline)
  - Process is under way



ILC Timeline

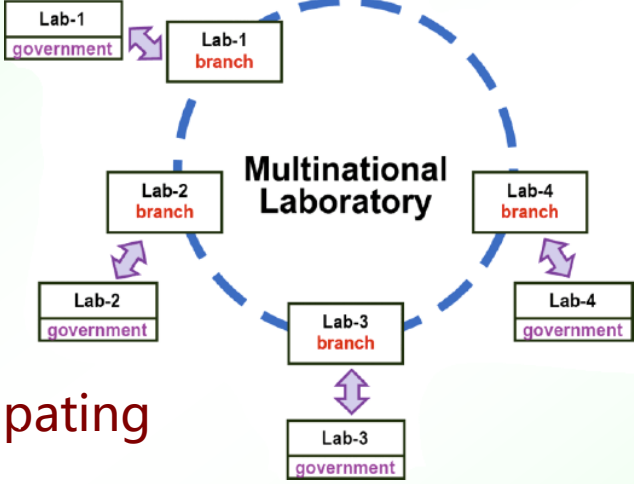


ILC Timeline beyond 2012
by ILCSC/ICFA



Pre ILC Laboratory

Approved by ILCSC



- Organization
  - Counseling body: representatives from participating labs
  - GD and directors
  - Operation: on the basis of preconstruction budgets from each participating labs and common fund
- Mission
  - To build and demonstrate operations of realistic prototype accelerator system
  - To coordinate the remaining technical and engineering efforts as left by GDE and RD
  - To complete the engineering design report (EDR)
  - To finalize the phase-1 site selection
  - To bring the ILC project to the top level table among relevant nations

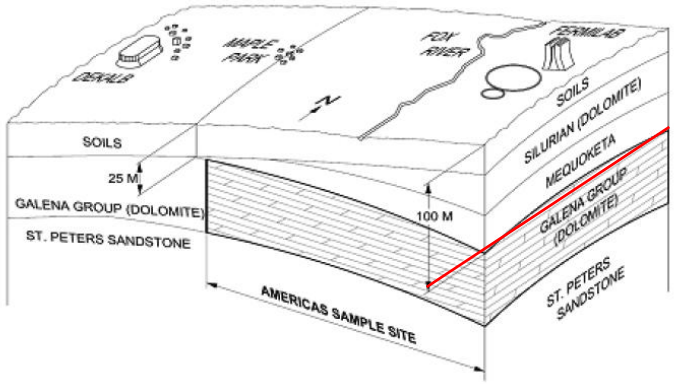
Requirements for ILC Sites

- Long straight tunnel
  - 31km → extendable to 50 km
- Stable ground
  - No active faults nearby, little ground vibration
- Electric power
  - ～250MW
- Transportation
  - For equipments, human access
- Research and living environments
  - Location of the lab., education, residential environment

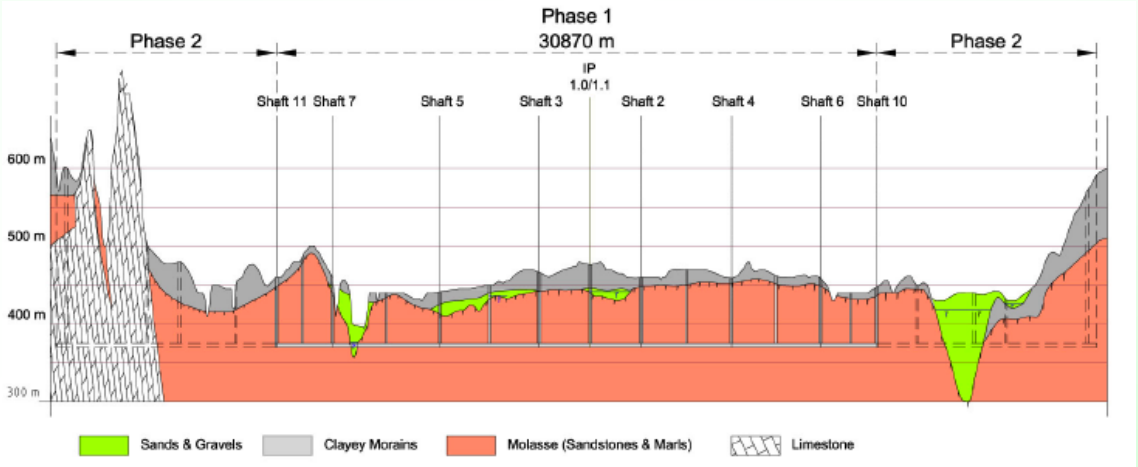
Official requirements will be decided by ILCSC

ILC Candidate Sites

- Americas site
  - Northern Illinois, near Fermilab

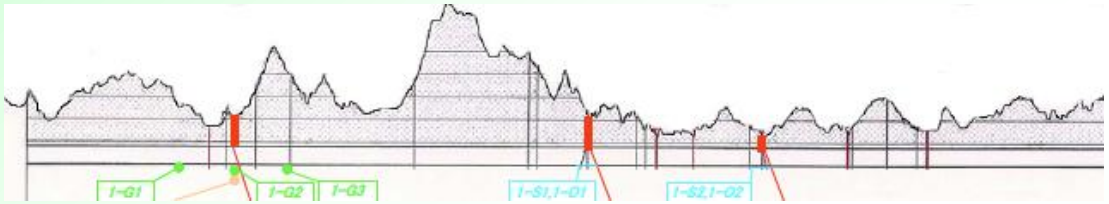


- European sites
  - Northwestern part of the Geneva region, near CERN



  - Also, near DESY, Germany, and near Dubna, Russia.

- Asian Sites
  - Kyushu, Seburi mountains
  - Tohoku, Kitakami mountains



ILC in Japan

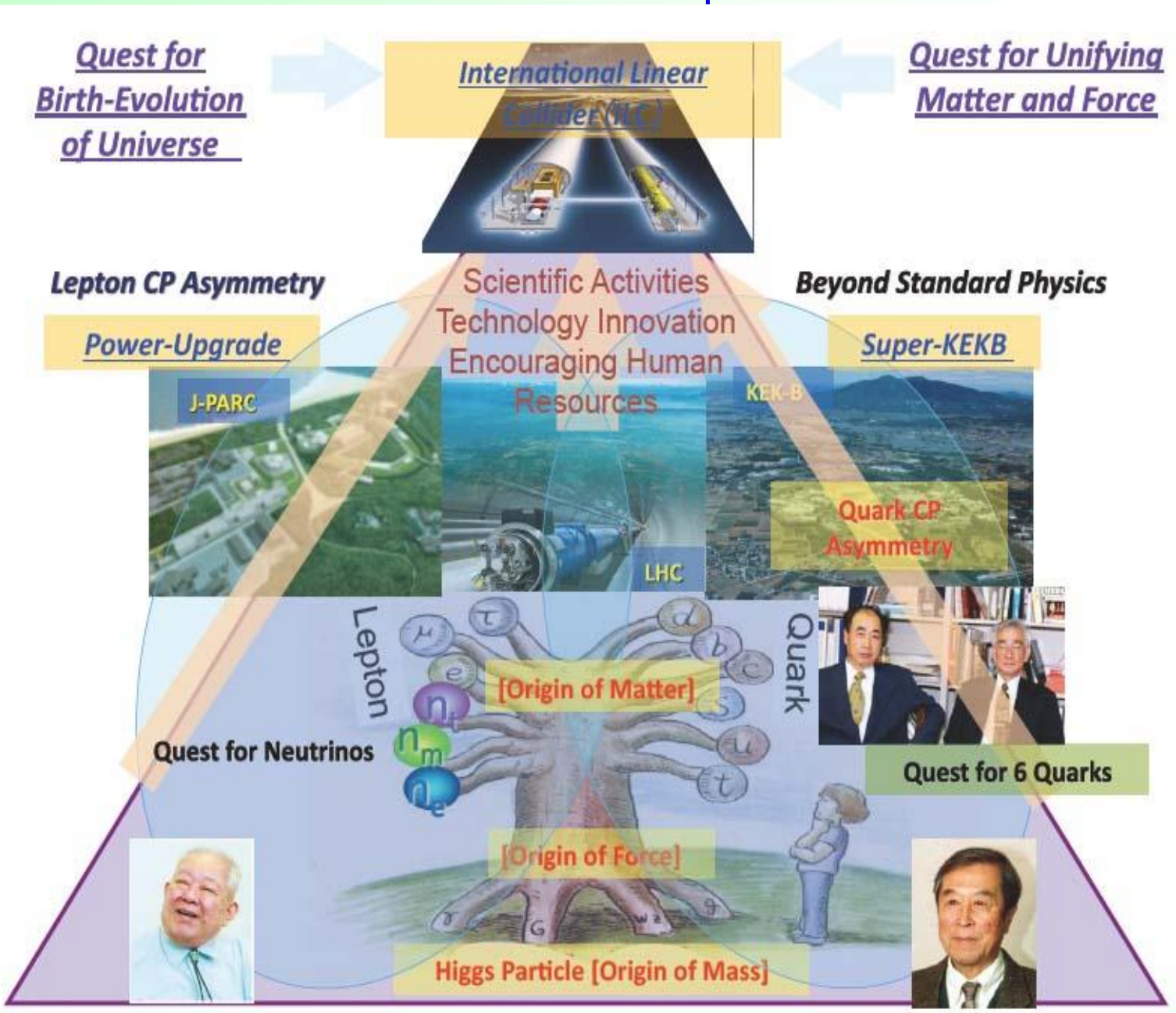
- Leadership by KEK
  - Linear collider project office
  - Linear collider project steering committee
- Active collaboration with industries
  - Association for advancement of basic science based on accelerators (AAA)

    67 companies（Mitsubishi, Toshiba, Hitachi, etc.）

    35 academic members （KEK, Tokyo U, Tohoku U, Kyoto U, etc.）
    - Technical sub. comm.
    - PR sub. comm.

    etc.

KEK Roadmap


Quest for Birth-Evolution of Universe
International Linear Collider(ILC)
Quest for Unifying Matter and Force
Lepton CP Asymmetry
Scientific Activities
Technology Innovation
Encouraging Human Resources
Beyond Standard Physics
Power-Upgrade
Super-KEKB
J-PARC
LHC
KEK-B
Quark CP Asymmetry
Lepton
Quark
[Origin of Matter]
Quest for Neutrinos
Quest for 6 Quarks
[Origin of Force]
Higgs Particle [Origin of Mass]

Backups

Physics at ILC

References

'Understanding matter, energy, and time: the case for the linear collider' ('consensus report')
(http://sbhep1.physics.sunysb.edu/~grannis/lc_consensus.html)

GLC project report (http://lcdev.kek.jp/Rmdraft)

LHC/LC study group report (hep-ph/0410364)

Tesla TDR (http://tesla.desy.de/new_pages/TDR_CD/start.html)

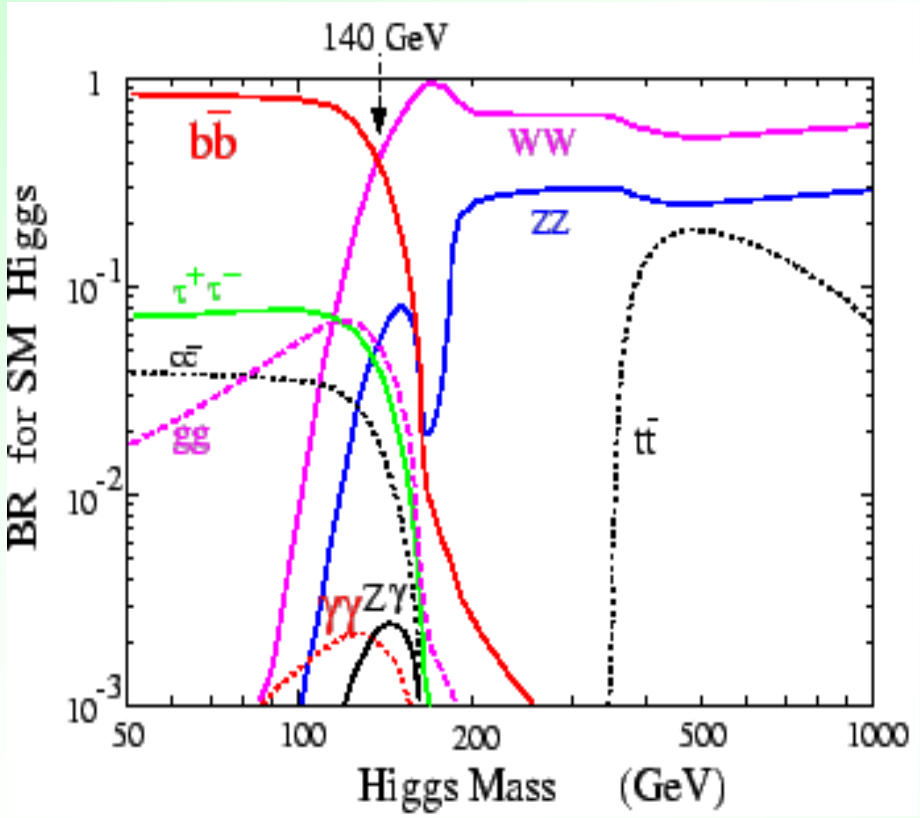
ACFA LC report (http://acfahep.kek.jp/acfareport)

Snowmass resource book
(http://www.slac.stanford.edu/grp/th/LCBook)

Cosmology and LC (web page)
(http://www.physics.syr.edu/~trodden/lc-cosmology)

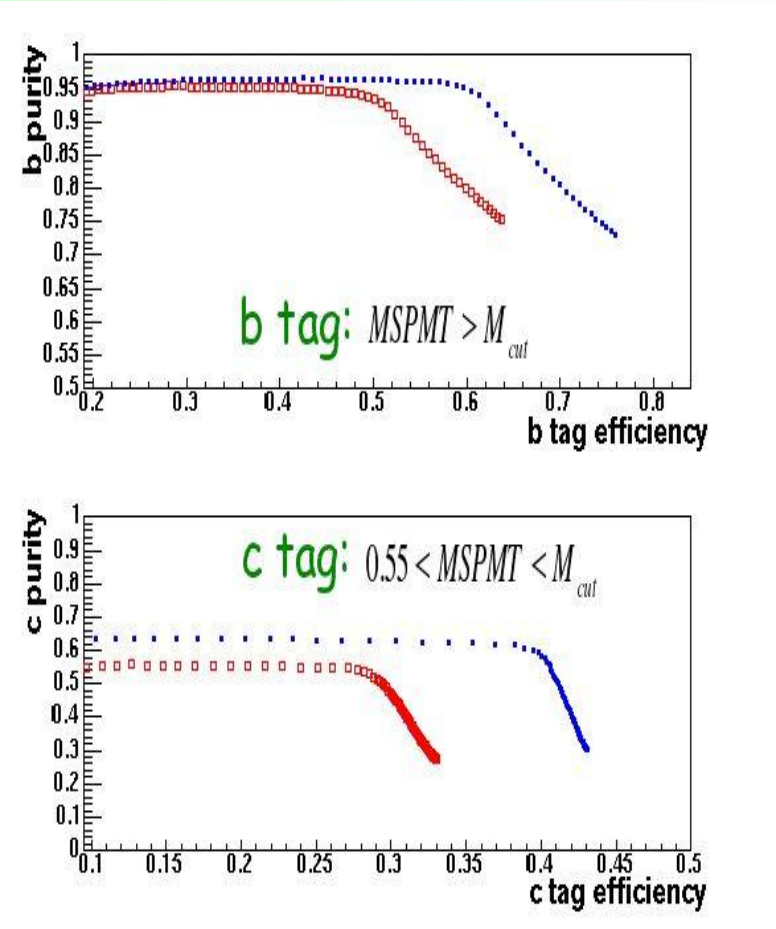
Physics section of DCR (2007.2)
(http://www.linearcollider.org/wiki/doku.php)

SM Higgs Branching Fractions



- Dominant decay:
  - b pair (m_h <140 GeV)
  - W pair (m_h >140 GeV)
- Tag b's by vertexing
- Combine with the recoil mass tag

b, c quarks can be tagged by vertexing



Pixel vertex detector

- 4-layer

  0.3 % X_0/ layer

  r_{bp} = 2 cm

  conservative design

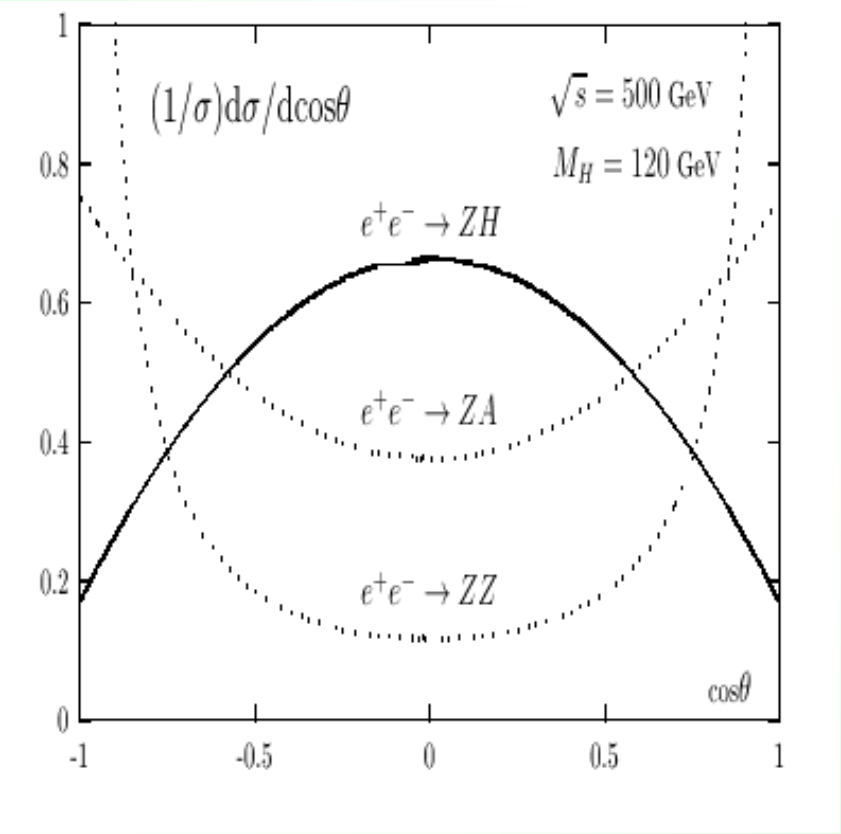
- 5-layer

  0.1 % X_0/ layer

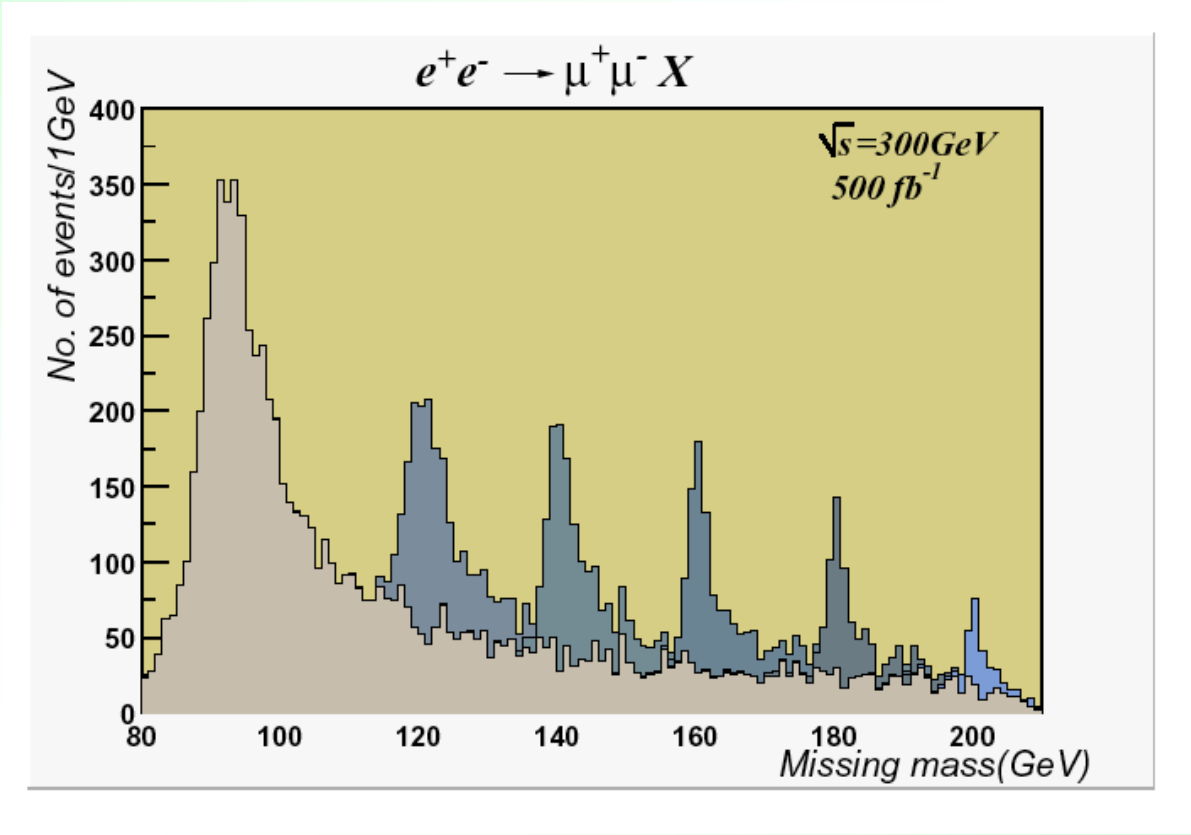
  r_{bp} = 1 cm

  agressive design

Higgs parity can also be determined



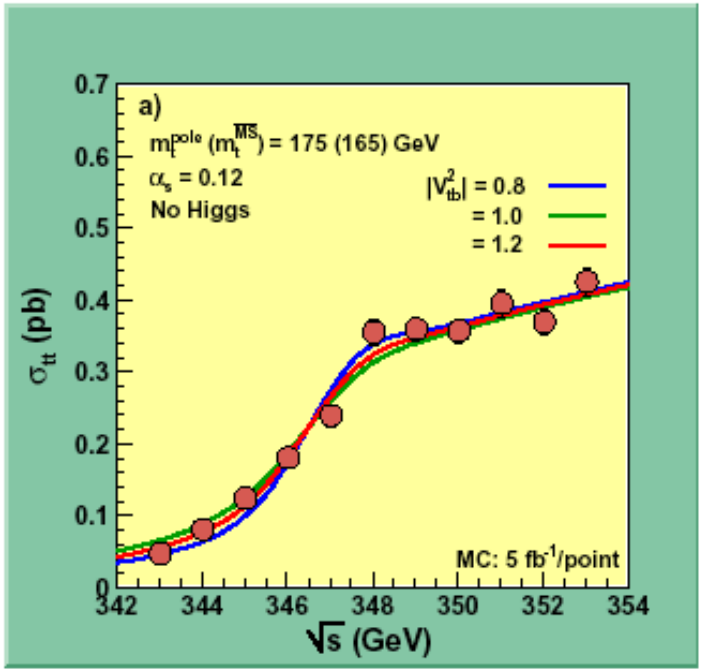
Recoil mass plot of Higgs-strahlung

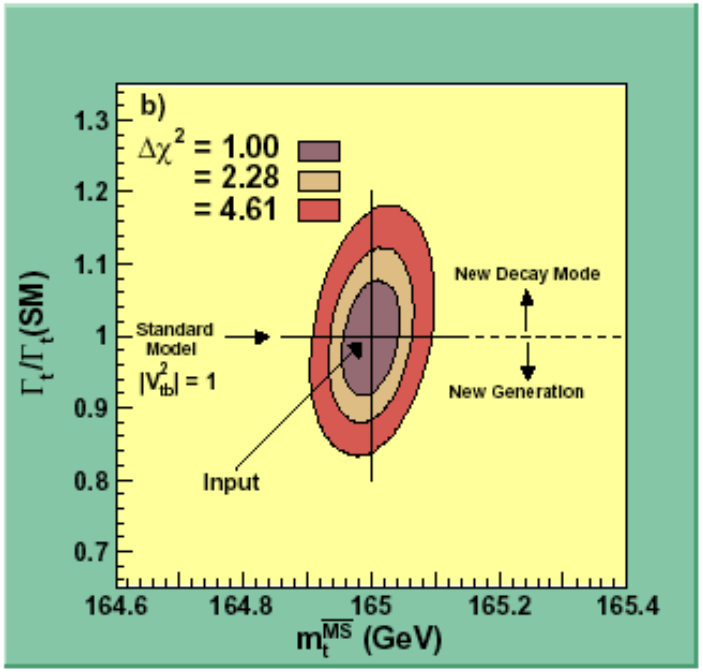


- Detectable for m_h up to ~ 2/3 beam energy

Top studies

$$e^+e^- \to t\bar{t}$$





- Threshold scan (5 fb^{-1} each point)
  - m(t) to 50 MeV : required to similar to $\sigma(m_h)$
  - Top decay width to a few % (with p_{top} dist. also)