GLC Physics and Detector

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JPS, Miyazaki, September 10, 2003

Physics of GLC

GLC program studies :
EW symmetry breaking (Higgs) and
possible new physics in TeV scale.

GLC is to start 2012∼2015,
i.e. 5-8 years later than LHC.

However, GLC can exploit

- cleaner and simpler physics events, with
- well-controlled initial states
  (incl. beam polarizations).
- larger fraction of physics/event.
  (→ less backgrounds)
- lower rates and radiation dose.
  (→ push for better detector performances)

GLC parameters

- Max c.m. energy : 500 GeV, upgradable to ~1 TeV.
- Luminosity : $1 \sim 3 \times 10^{34}$/cm^{2}s → 500 fb^{-1} over 2-4 years.

	warm	cold
CM energy	500 GeV	
#bunch/train	192	2820
#train/s	150 Hz	5 Hz
bunch sp.	1.4 ns	337 ns
train length	269 ns	950 μs
gap/train	6.6 ms	199 ms

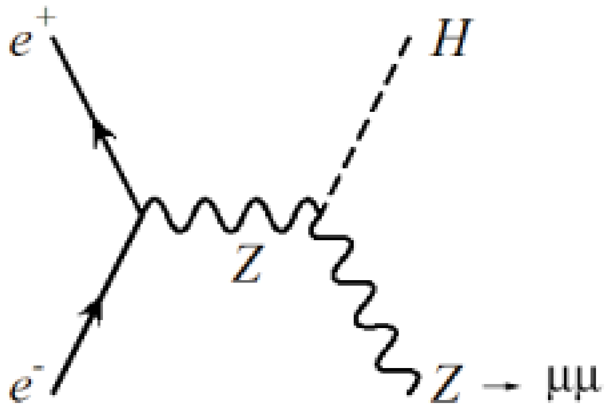
Readout/DAQ tougher for cold.

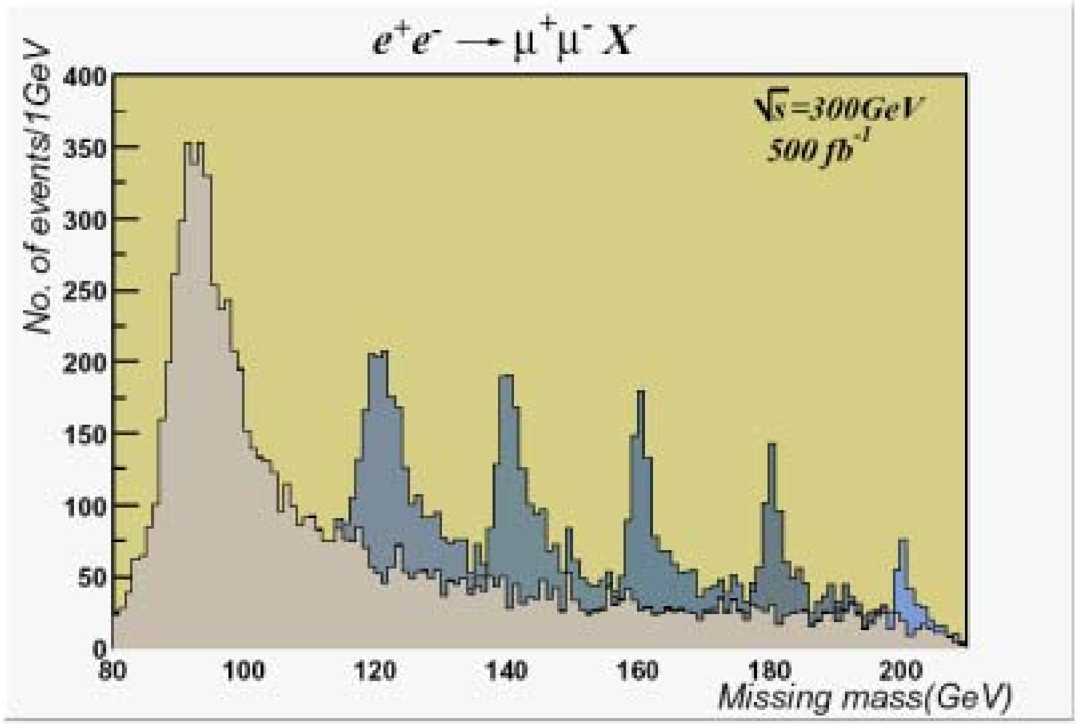
Higgs Studies

'Gold-plated' mode

$e^+e^- \longrightarrow ZH$

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





Plot $\ell\ell$ recoil mass (Higgs not directly measured).

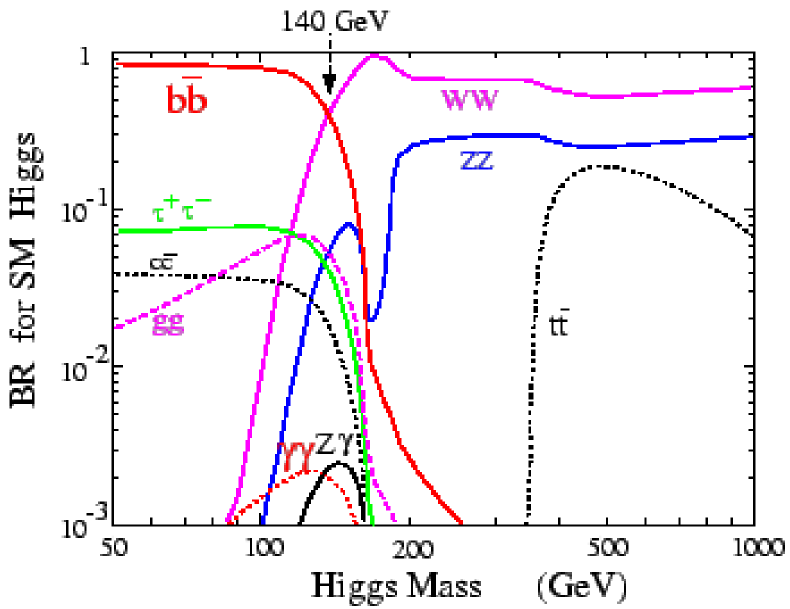
Decay-independent measurements of Higgs mass, production rate.

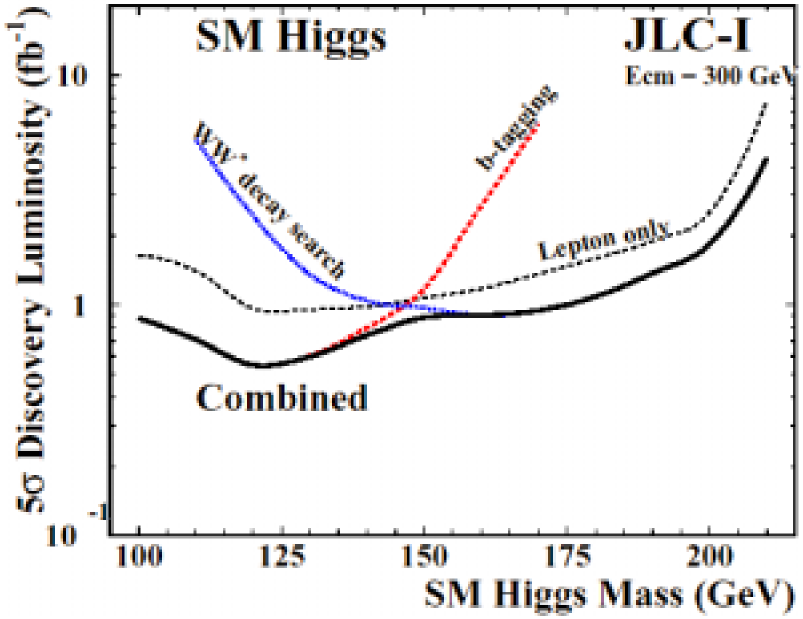
Detecting Higgs decays $\longrightarrow$

absolute Brs, background reduction($ee \rightarrow ZZ$).

SM Higgs Sensitivity

SM HIggs branching fractions





Dominant decay :

$b\bar{b}$ $(m_h < 140$ GeV)

WW $(m_h > 140$ GeV)

b-tag by vertexing.

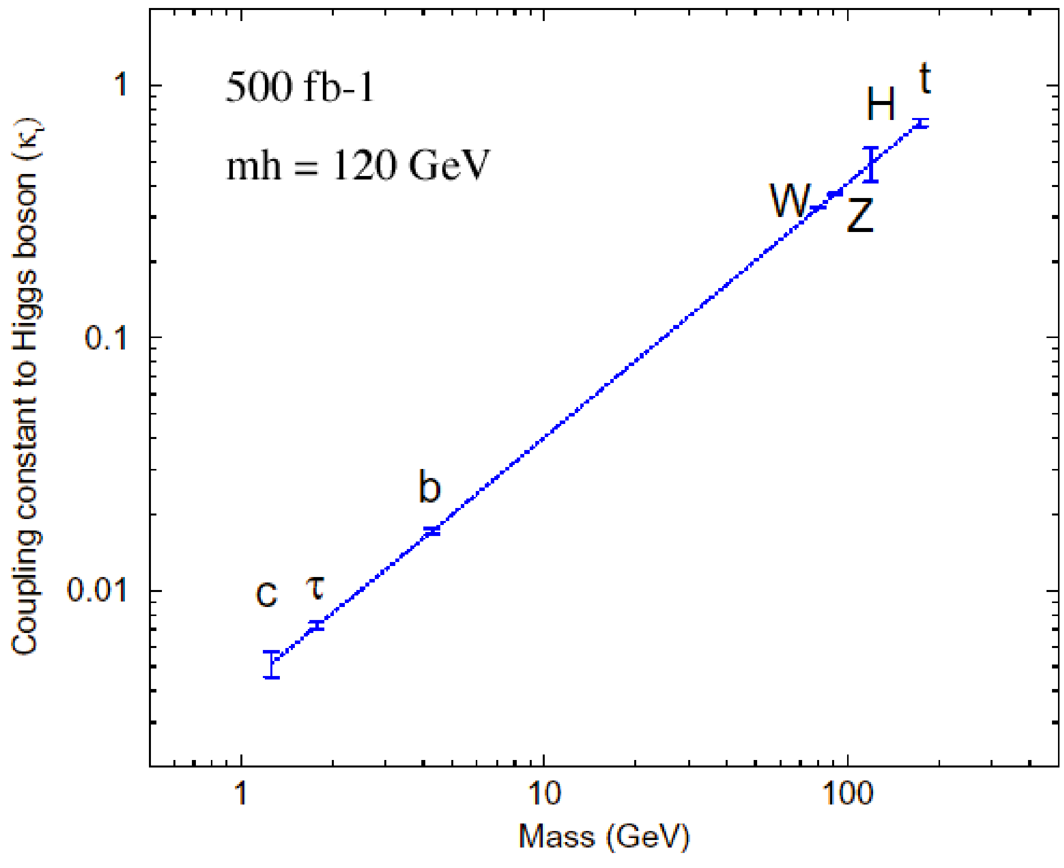
- 5σ discovery in ~ 1 day.
- LHC : 5σ in ~ 1 year.
  GLC starts 5-8 years later $\rightarrow$
  'discovery machine' after one week.
- 500 fb^{-1} $\rightarrow$ 10^5 Higgs detected in clean environments.

Determination of Higgs Parameters

For $m_h = 120$ GeV with 500 fb^{-1} :

- $\sigma_{m_h} = 40$ MeV (model-independent).
- Spin, CP by angular distributions of Higgs productions and decays as well as energy scan.
- ZZH, WWH couplngs to a few % by $ee \to ZH$ and $ee \to \nu\bar{\nu}H$.
- Higgs total width to 5% by $Br(H \to WW)$ and $\Gamma(H \to WW)$.
- Couplings to b, c, τ by $Br(H \to f\bar{f})$.
  (b, c-tagging by vertexing essential)
- Coupling to t by $ee \to t\bar{t}H$.
- Higgs self coupling by $ee \to ZHH$ and $\nu\bar{\nu}HH$.

Higgs Coupling Sensitivities



$\sqrt{s} = 300$ **GeV** (b, c, τ, W, Z), **500 GeV** (H), **700 GeV** (t).

SM Higgs : coupling $\propto$ particle mass.

Supersymmetric Particles

- GLC can pair-create many sparticles in variety of models.
- Precision measurements of masses and mixings.
- Determine qunatum numbers: spin, hypercharge etc.
- Beam polarization can be useful above and often reduce backgrounds.

For example,

$$e^+e^- \longrightarrow \tilde{\mu}_R^+ \tilde{\mu}_R^- , \quad \tilde{\mu}_R^\pm \rightarrow \mu^\pm \tilde{\chi}_1^0$$

or

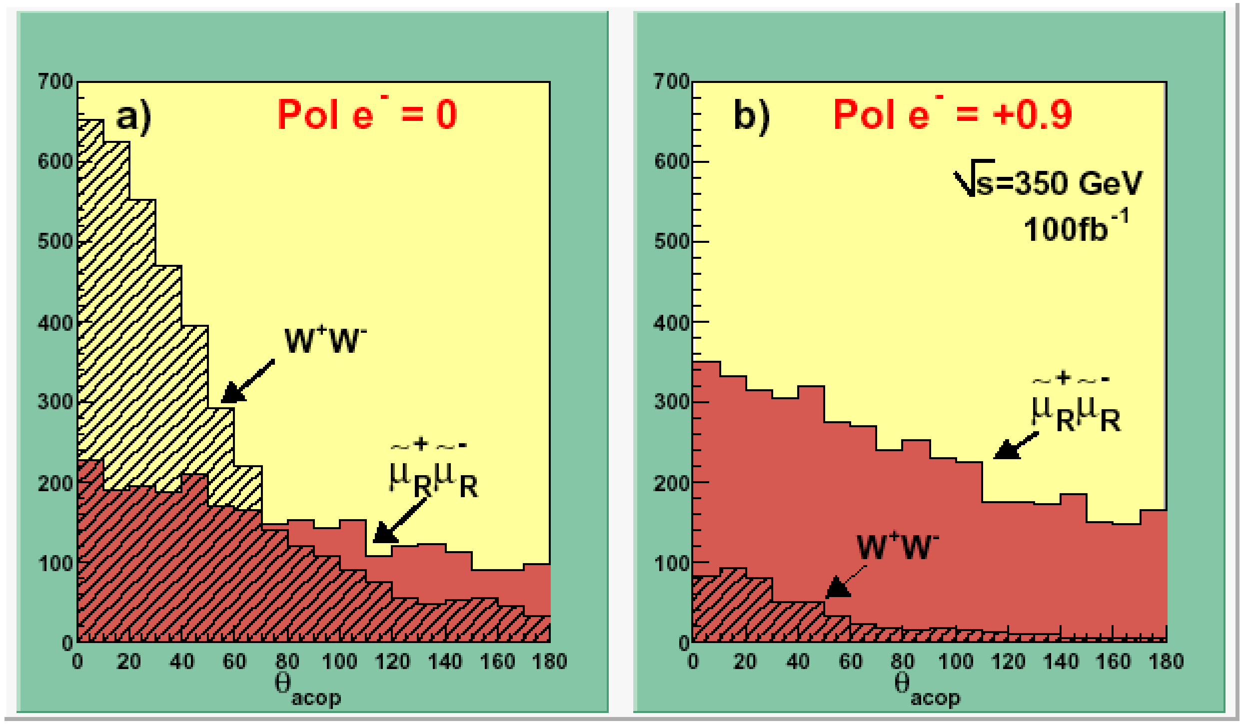
$$e^+e^- \longrightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^- , \quad \tilde{\chi}_1^\pm \rightarrow W^\pm \tilde{\chi}_1^0$$

etc.

Detection of Smuon

$$e^+e^- \longrightarrow \tilde{\mu}_R^+ \tilde{\mu}_R^-, \quad \tilde{\mu}_R^\pm \longrightarrow \mu^\pm \tilde{\chi}_1^0$$

Signal: $\mu^+\mu^-$ + nothing ($\tilde{\chi}^0$'s)
Plot the acolinearity of $\mu^+\mu^-$.

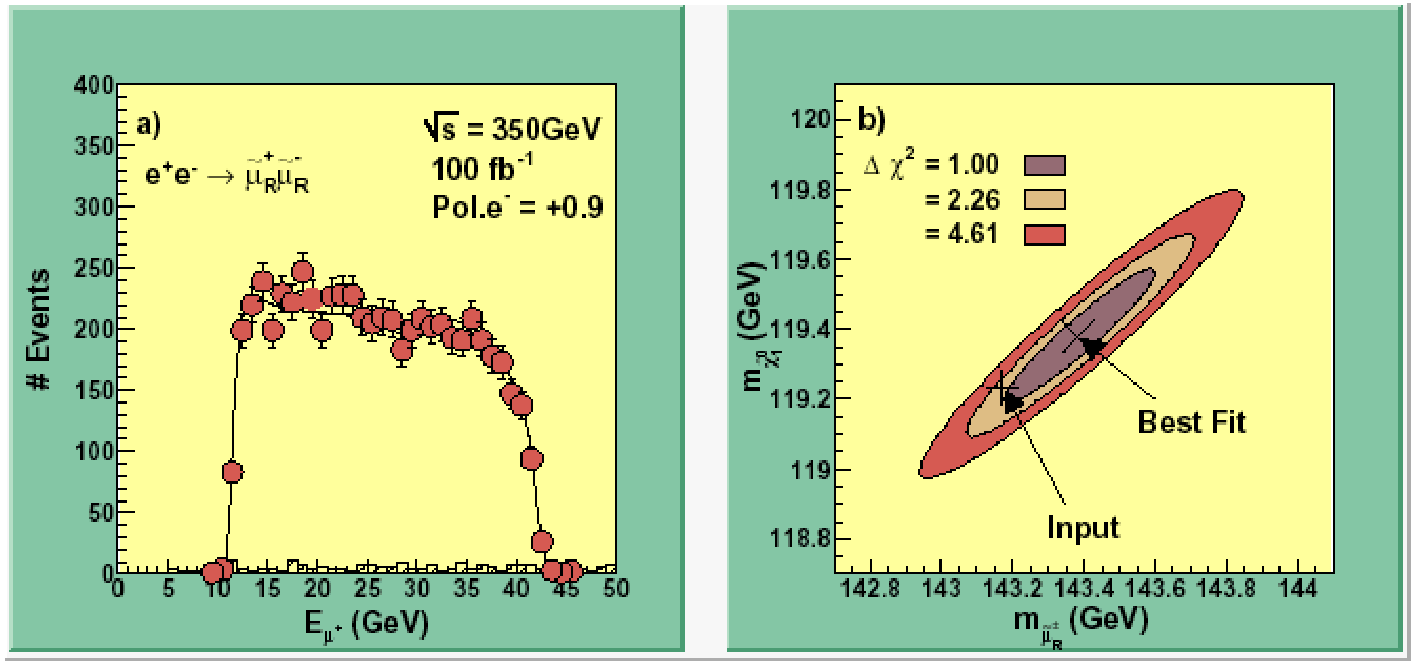


Right-handed e^- beam reduces the W^+W^- background.

Smuon Pair Production

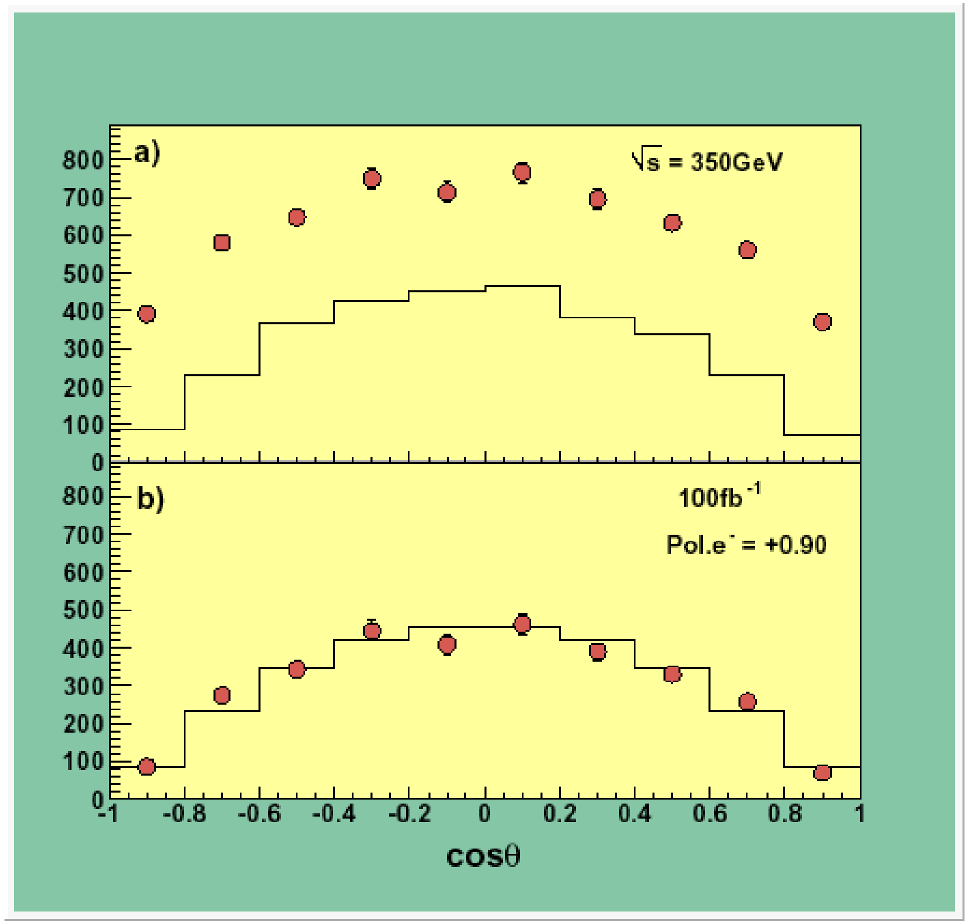
Determination of masses of $\tilde{\mu}_R$ and χ^0

From the (end point of) $\mu^\pm$ spectrum.



Smuon Pair Production

Determination of $\tilde{\mu}_R$ spin



Angular distribution of $\tilde{\mu}_R$ w.r.t. beam axis.
a) With double solutions.
b) Wrong solution removed (found to be flat).

$\sin^2\theta \quad \longrightarrow \quad \tilde{\mu}_R$ **spin = 0.**

Similar analyses for
$e^+e^- \longrightarrow \tilde{\mu}_R^+ \tilde{\mu}_R^-$ and $\tilde{\chi}_1^+ \tilde{\chi}_1^-$

Determination of SUSY Parameters

Example:

Charginos $\tilde{\chi}^+_{1,2}$ are mixture of Wino and Higgino:

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

With e^-_R beam:

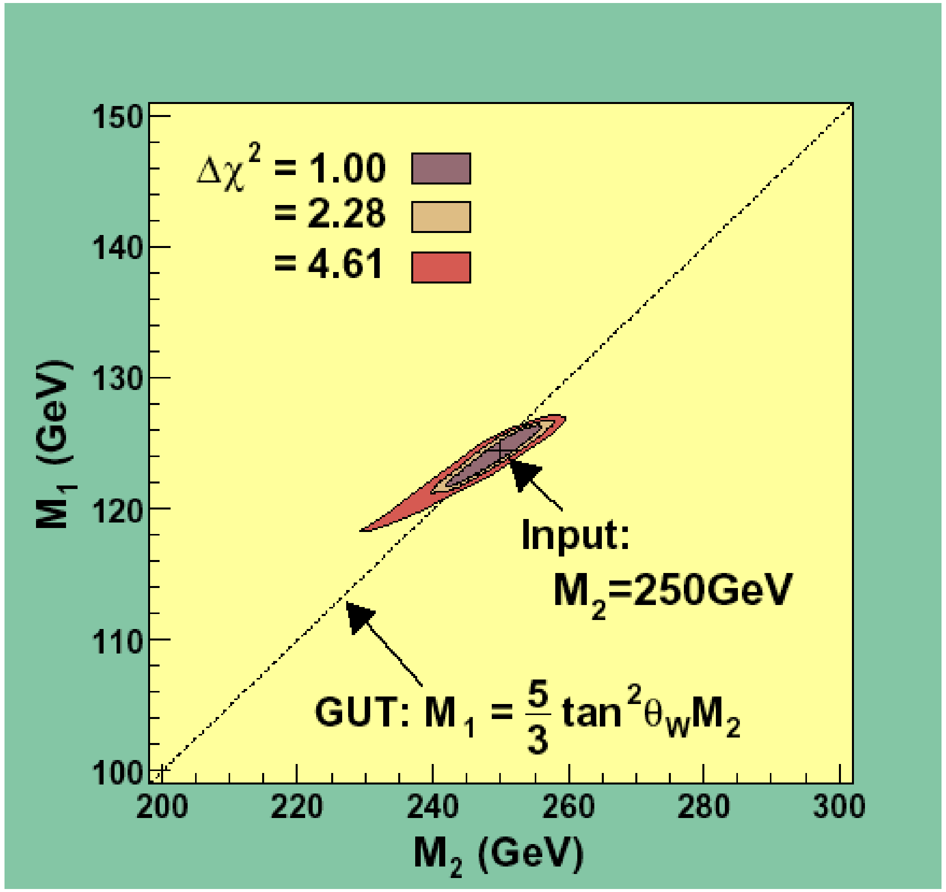
- **only $\tilde{H}^\pm$ component of $\tilde{\chi}^+_1$ contribute to $\tilde{\chi}^+_1 \tilde{\chi}^-_1$ creation.**
- **depends on $\tilde{B}$ in $\tilde{e}^+_R \tilde{e}^-_R$ creation.**

Perform global fit $(M_1, M_2, \tan\beta, \mu)$ to

$$\sigma(e^+ e^-_R \to \tilde{e}^+_R \tilde{e}^-_R)\,, \quad \sigma(e^+ e^-_R \to \tilde{\chi}^+_1 \tilde{\chi}^-_1)\,, \quad m_{\tilde{\chi}^0_1}\,, \quad m_{\tilde{\chi}^+_1}\,.$$

Determination of SUSY Parameters (cont'd)

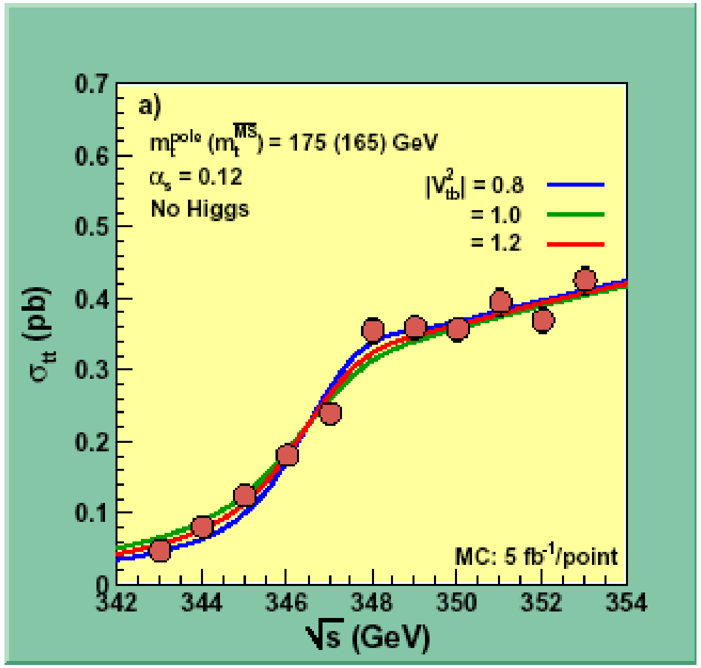
$\sqrt{s} = 500 GeV$, 50 fb^{-1}

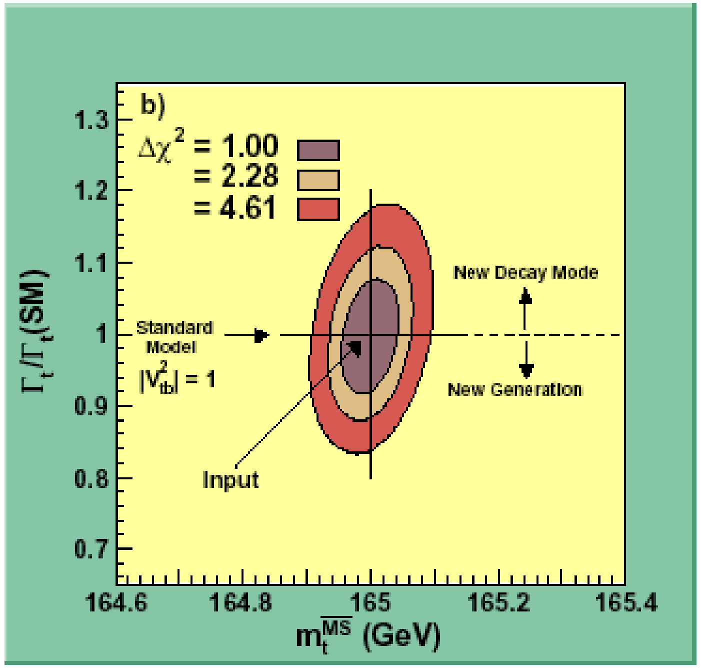


Serves as a test of GUT relation (or other mechanisms).

Top Studies

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

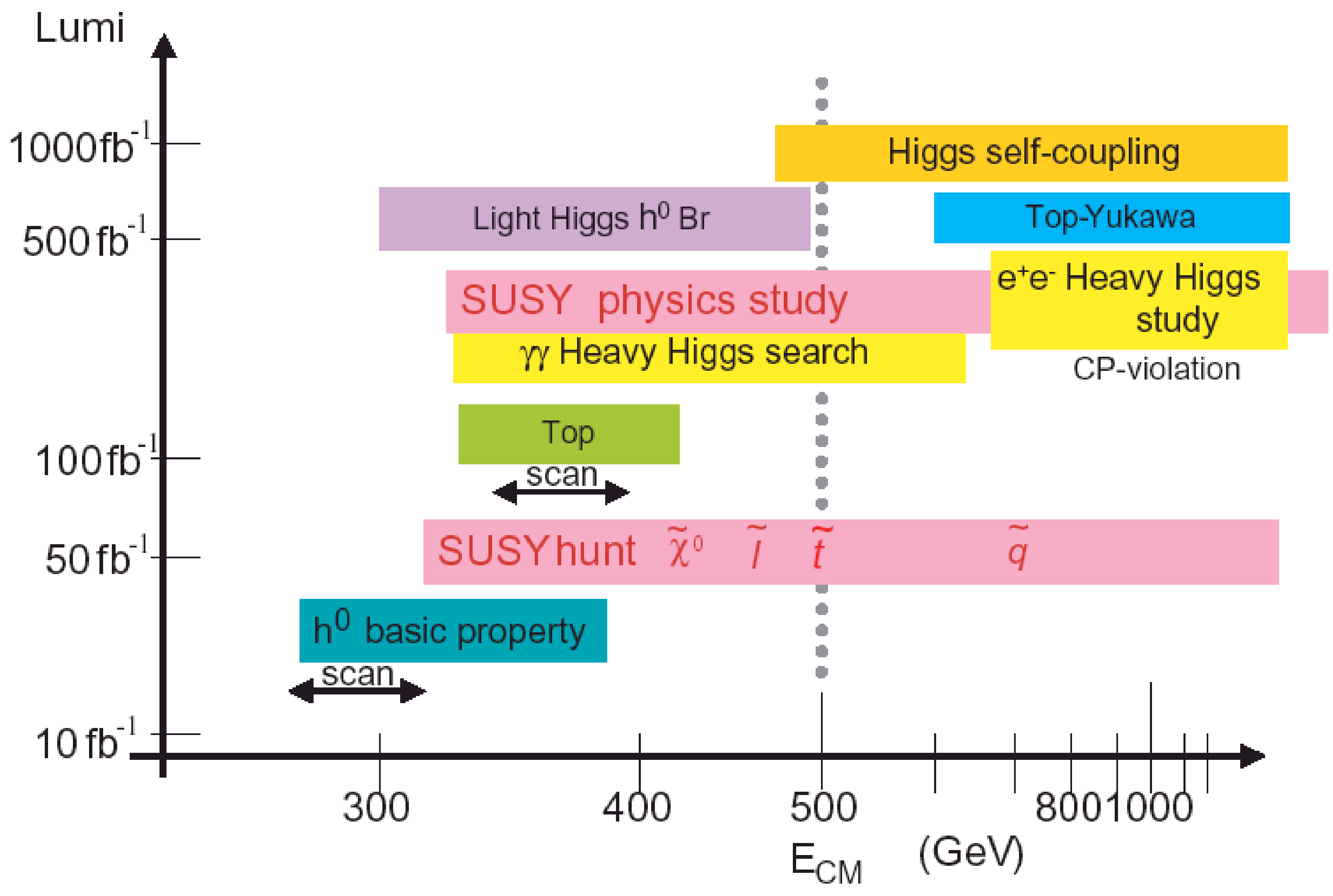




5 fb^{-1}/point $\rightarrow$ $\sigma_{m_t} \sim 50$ MeV (LHC: $1 \sim 2$ GeV)

Detailed study of top production/decays.

(New generation, new decay modes, CP violations)



No time to cover many other physics.

GLC Detector

GLC detector should take advantage of the clean environment
of linear collider to achieve best possible performances.

GLC detector will be designed/constructed
in an entirely international environment.

'Best possible' is defined by expertise available worldwide.

The machine may be warm or cold.
(to be determined in about a year by
the 'wise-person's committee' or otherwise)

Detector performance goals
(compiled by the int'l R&D review)

- vertexing: $\sigma_{r\phi,z}(ip) \leq 5\,\mu\mathrm{m} \oplus \frac{10\,\mu\mathrm{m\,GeV/c}}{p\sin^{3/2}\theta}$,
  ($1/5$ r_{beampipe}, 1/30 pixel size, 1/30 thin w.r.t LHC)

  (Example)
  b, c tagging. ($H \longrightarrow b\bar{b}$ vs $c\bar{c}$)
  $t \longrightarrow$ 3jets reconstruction.

- central tracking: $\sigma(\frac{1}{p_t}) \leq 5 \times 10^{-5}(\mathrm{GeV/c})^{-1}$
  ($\sim 1/10$ LHC. 1/6 material in tracking volume.)

  (Example)
  M_H by $e^+e^- \longrightarrow ZH \longrightarrow \ell^+\ell^- X$
  $M_{\tilde{\ell}}$ by $e^+e^- \longrightarrow \tilde{\ell}\tilde{\ell} \longrightarrow \ell^+\ell^-\chi^0\chi^0$

Detector performance goals (cont'd)

- forward tracking: $\sigma(\frac{1}{p_t}) \leq 3 \times 10^{-4}(\mathrm{GeV/c})^{-1}$,
  $\sigma(\delta\theta) \leq 2\mu$rad to $|\cos\theta| \sim 0.99$.

  (Examples)
  SUSY t-channel production.
  $d\mathcal{L}/dE$ by forward Bhabha.

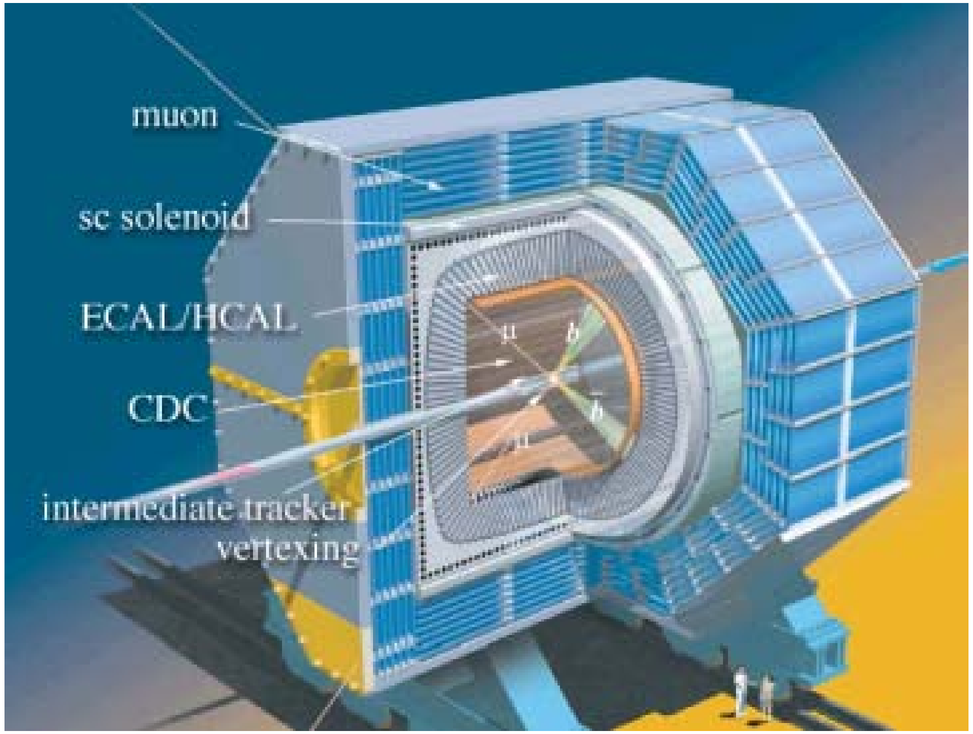
- Jet 'particle-flow': $\frac{\sigma_E}{E} \simeq 0.30 \frac{1}{\sqrt{E(\mathrm{GeV})}}$
  (1/200 calorimeter granularity w.r.t. LHC)

  jet 4-momentum measurement.
  (e.g. $Z, W, H \to 2$jets, $t \to 3$jets)

- hermeticity
  (only ~ 10mrad hole along beamline)

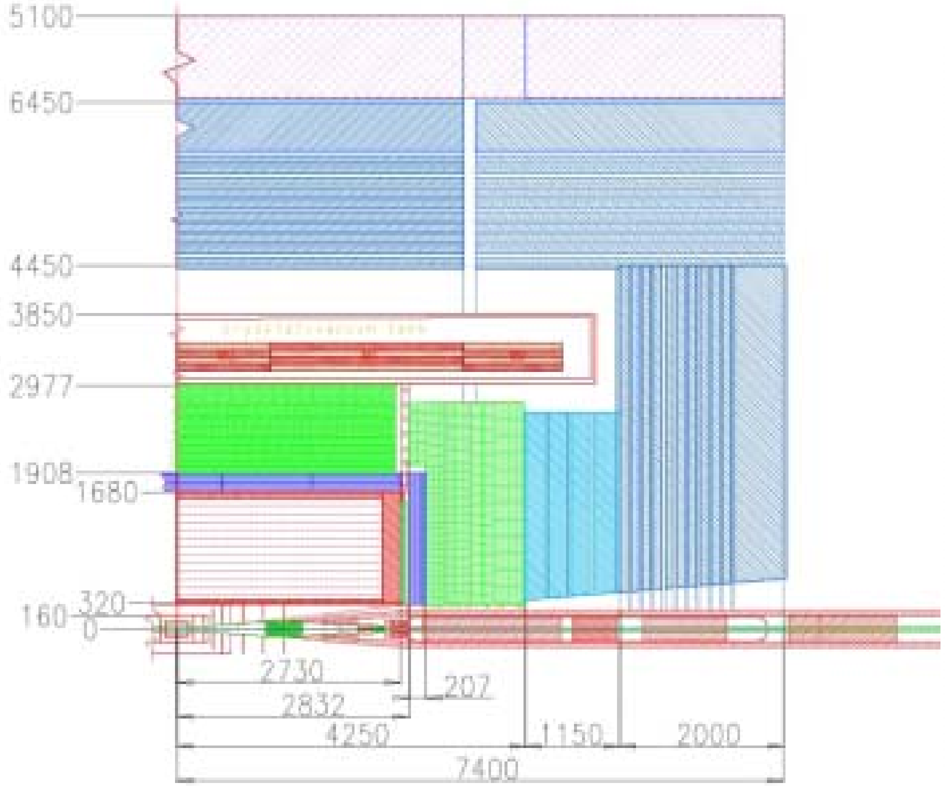
  Missing energy measurement (LSP etc.).

Generic LC detector (GLC)

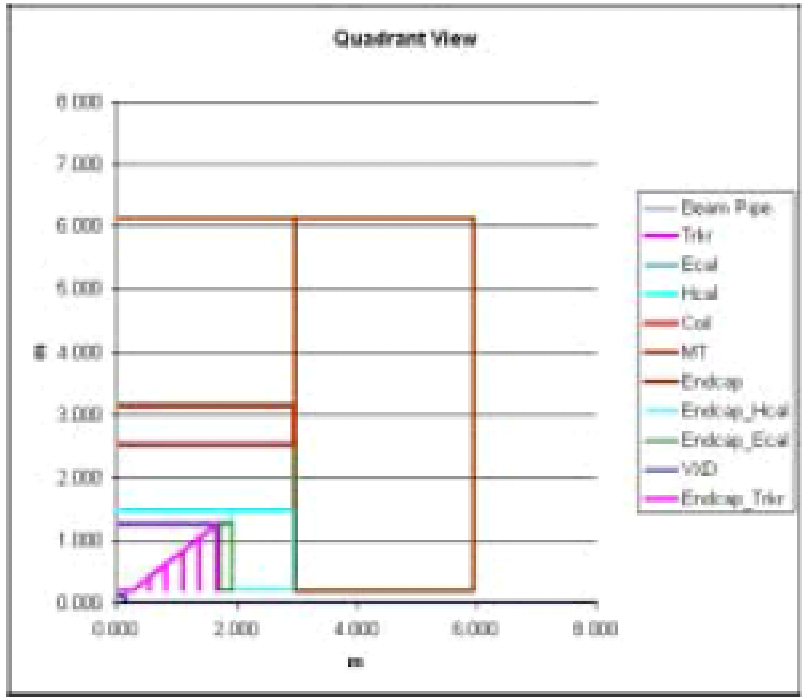


- Pixel-based vertex detector.
- High B-field ($\geq 3T$)
  (For p-resolution.
  Also, squeeze pair background)
- ECAL&HCAL within B-field.
- Flux-return as muon detector.
  (catches hadronic shower tail)

‘Large’ design (Tesla)
(gas-based central tracker)



‘Small’ design (NLC Small Version)
(Silicon-based central tracker)



Vertex Detector

GLC Default: Charge-Coupled Devices (CCD's)

Pros: proven performance at SLD
Small pixel size $\sim(20\mu m)^2$
Relatively easy to thin

Cons: slow readout ($\rightarrow$ parallel readout)
modest radhardness (probably OK)
Needs to be cooled(?)

Solution exists for warm machine.
Cold machine may have a readout difficulty.

- LCFIcollaboration (UK institutions)
- US collaboration (Oregon, Yale)
- Japanese collaboration (KEK, Niigata, Tohoku, Saga)

Vertexing Option: Active Pixel Sensors (APS)

- Hybrid pixel sensors (i.e. bump-bonded readout/sensor) (CERN, Helsinki, INFN, Krakow, Warsow)
  - material is thick.
  - pixel size typ. 50x400 μm^2 too big.
  - capacitively-coupled readout to reduce #channel.
- Monolithic active pixel sensors (MAPS). CMOS image sensor technology. Pixel size ~CCD Commercial fab process. Readout/sensor on one chip.
  - large-area sensor (3.5 cm^2) tested OK.
  - fast readout (50 MHz possible) works.
  - thinned to 120 μm, tested OK.
  - Seems to work at least for warm machine.

MAPS Collaboration newly formed

The roadmap of MAPS collaboration
(IRES&LEPSI, DESY, NIKHEF, University of Geneve)

Chip design and
chip interconnection - stitching
IRES&LEPSI
DESY (simulations,radhard,tests)

DAQ – hybrid design
University of Geneve
DESY ?

Thinning
Industry – can do up to 80 μm -> further labs

Mechanical support
DESY (pulse powering)
DESY&NIKHEF(design)

Power consumption and cooling
IRES-LEPSI (chip based)
DESY (cooling system, FEA)
NIKHEF(FEA)

Physics simulation aiming to optimize MAPS vertex detector design (pixel size, ladder position)
DESY

Goal: to have a full ladder 6 chips done by 2005 – not the final design

Central Tracker

Two basic types:

- Gaseous
  large, many samplings/trk
  dE/dx π/K separation promissing.
  - Jet chamber
    (GLC default - more or less OK)
  - TPC

- Silicon
  small, $\sim$5 samplings/trk
  No dE/dx π/K separation.

  Main goal : reduce volume of ECAL (SiW).

Tracking Option: TPC

Europe (Aachen, DESY/Hamburg, Karlsruhe, Krakow, MPI-Munich,
NIKHEF, Novosibirsk, Orsay/Sacley, Rostok)
N. America (Carleton,/Montreal, LBNL, MIT)
KEK (new)

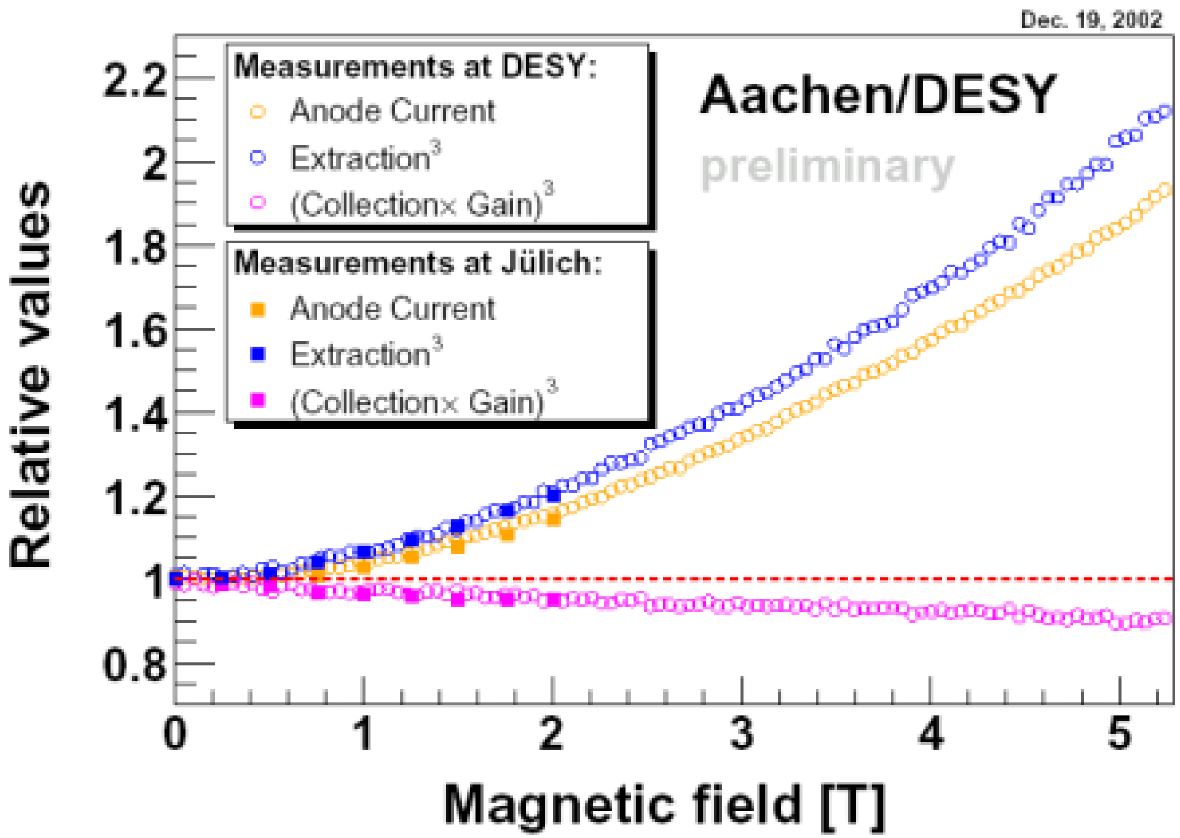
Pros:
Works at high B field ($>$3 T)
Good 2-trk resolution, dE/dx.
No thick endplates, no wires in tracking volume.

Cons (?):
probably needs new charge readout system.

- Novel readouts: GEM, MicroMEGAS, or silicon-based.
  Avoid high-tension wires (reduce material of endplate).
  Reduce dead regions.

  Prototypes are working well.

GEM-TPC Tested In 5Tesla (LC-TPC group)



Works fine at 5T.

Calorimeters

ECAL (EM Calorimeter)

- GLC default: Tile-fibre calorimeter
  Modest granurarity (4×4cm^2)
  (KEK, Niigata, Tsukuba)

  More or less achieves goal.

- Option: Si-W calorimeter
  High granurarity ($\sim$1cm^2), but expensive:
  $100M/Si now. How far does it do down?
  (CALICE collaboration, Oregon/SLAC)

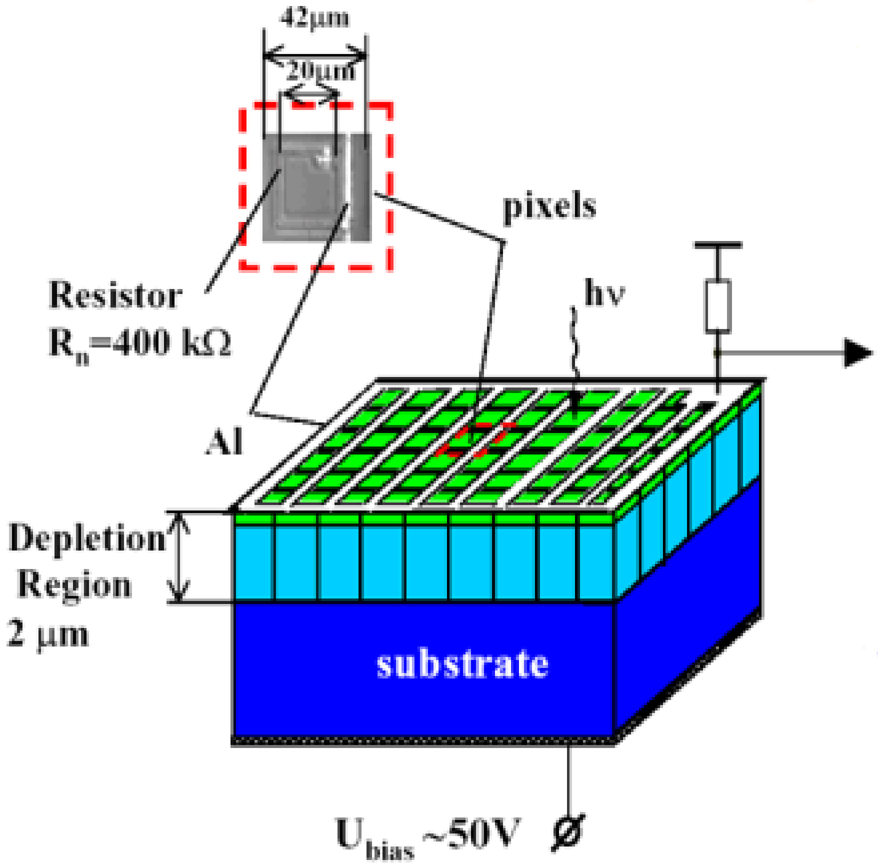
- Option: Strip-fiber calorimeter
  Use scint.strip/fiber instead of tile/fiber.
  (Tsukuba U.)

HCAL (Hadron Calorimeter)

- **GLC default: Tile-fibre calorimeter**
  Larger granurarity than the ECAL version.
  Fe: good for effective Moliere radius.
  Pb: hardware compensation at 4mm/1mm sampling.
  (CALICE, KEK, Kobe/Konan)

  R&D items:
  - Photon detectors in high B field:
    APD, SiPM, HPD, HAPD, EBCCD.

SiPM (Silicon Photomultiplier)



- $(42\mu\mathrm{m})^2$ cell, limitted Geiger $(1\mathrm{mm})^2$ total/SiPM now.
- $V_{\mathrm{bias}} \sim$ 50 V.
- Works in a high B-field
- Quantum eff.$\sim$ 0.3.
- Fast ($\sigma_{1\gamma} = 50$ ps).
- Quite cheap.

Still in R&D stage, but quite promising.

HCAL (cont'd)

- Option: Digital calorimeter

  Very-high granurarity (~ 1cm^2) with 1-bit readout.
  Use granurarity also for compensation.
  ('software compensation'+finer trk matching)
  (CALICE collaboration, U. Texas)

  Principle still to be demonstarated (MC).

  Read out: RPC or wires as default.
  R&D: GEM, VLPC.

LHC and GLC

- LHC has wider ranges of particle searches.
- GLC has more precise measurements.
- History shows the complementality of hadron and lepton machines:
  - Charm(J/Ψ) discovered by hadron and lepton machines, followed immediately by detailed studies by leptonic machines.
  - Bottom discovered by a hadron machine and then studied in detail by lepton machines (e.g. LEP, B-factories).
- Sign of a new particle by GLC $\to$ LHC and vice versa real-time. (with necessary refinements in software/hardware)
- Simultaneous running of LHC and GLC is essential in achieving such cross fertilizations.