# Issues for Vertex Detection at the ILC

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# ILC Detector Benchmark Report    M. Battaglia et al. hep-ph/0603010

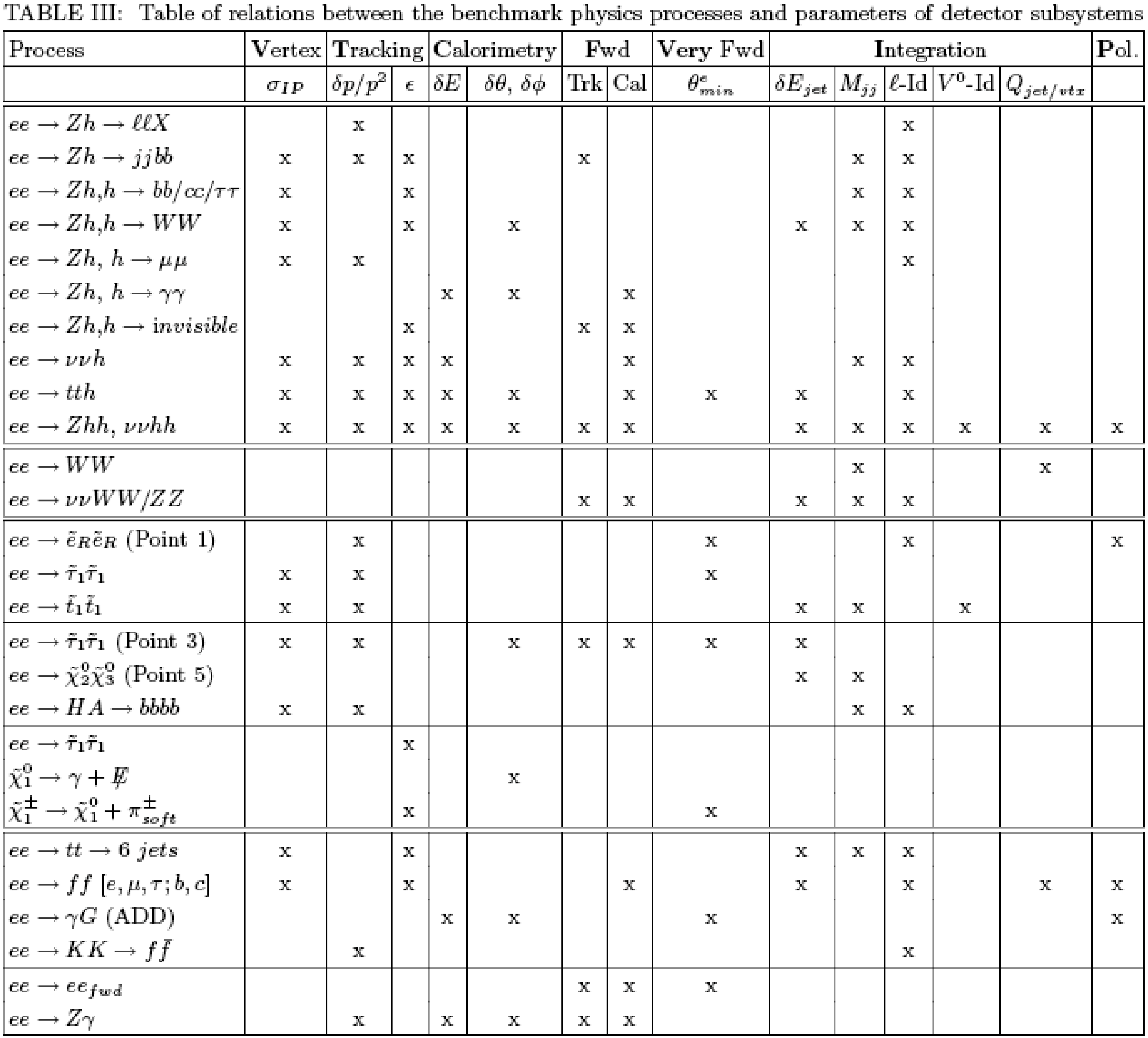


TABLE III: Table of relations between the benchmark physics processes and parameters of detector subsystems

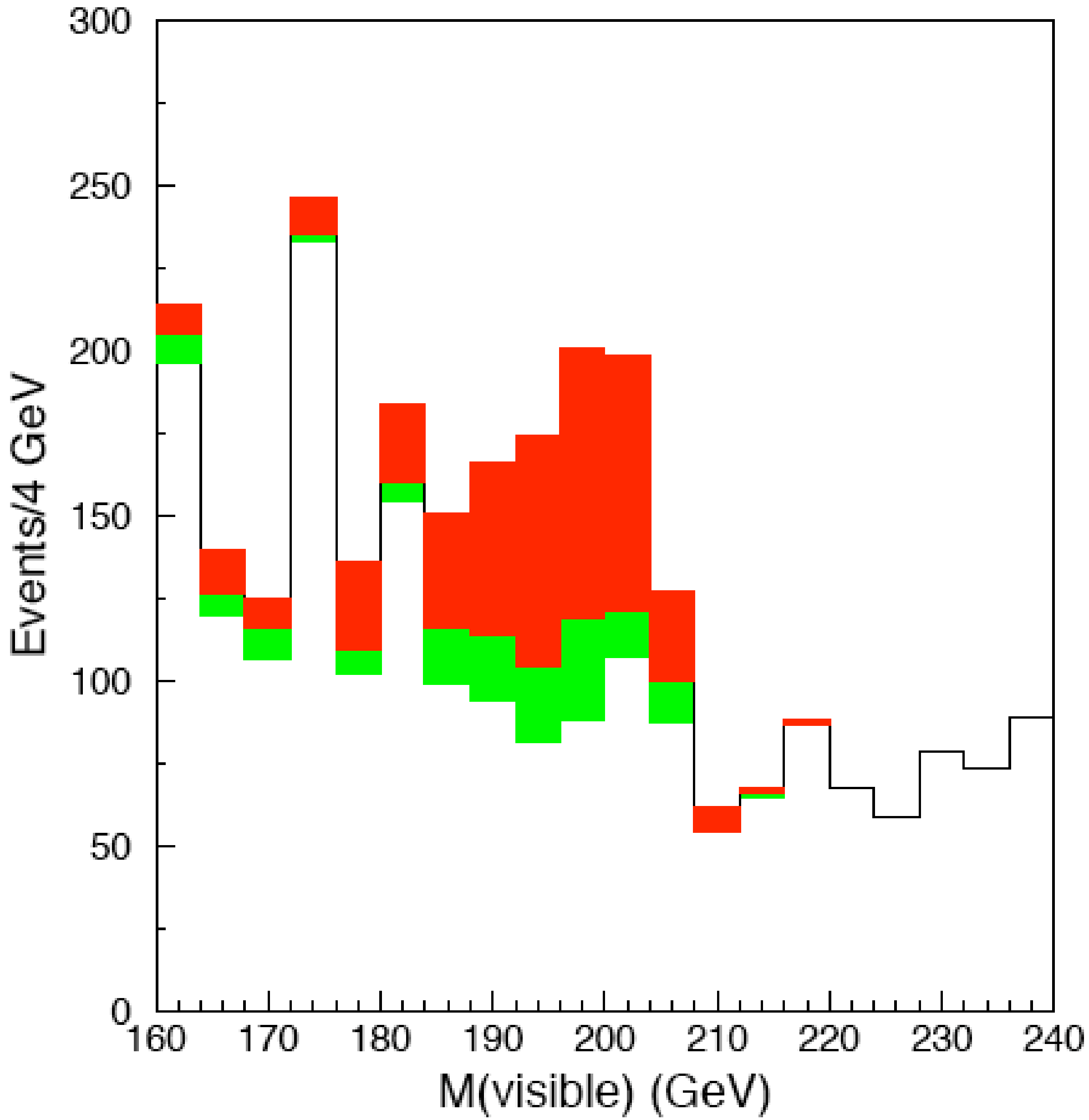
| Process | Vertex | Tracking | | Calorimetry | | Fwd | | Very Fwd | Integration | | | | | Pol. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\sigma_{IP}$ | $\delta p/p^2$ | $\epsilon$ | $\delta E$ | $\delta\theta$, $\delta\phi$ | Trk | Cal | $\theta^e_{min}$ | $\delta E_{jet}$ | $M_{jj}$ | $\ell$-Id | $V^0$-Id | $Q_{jet/vtx}$ | |
| $ee \to Zh \to \ell\ell X$ | | x | | | | | | | | | x | | | |
| $ee \to Zh \to jjbb$ | x | x | x | | | x | | | | x | x | | | |
| $ee \to Zh, h \to bb/cc/\tau\tau$ | x | | x | | | | | | | x | x | | | |
| $ee \to Zh, h \to WW$ | x | | x | | x | | | | x | x | x | | | |
| $ee \to Zh,\ h \to \mu\mu$ | x | x | | | | | | | | | x | | | |
| $ee \to Zh,\ h \to \gamma\gamma$ | | | | x | x | | x | | | | | | | |
| $ee \to Zh, h \to invisible$ | | | x | | | x | x | | | | | | | |
| $ee \to \nu\nu h$ | x | x | x | x | | | x | | | x | x | | | |
| $ee \to tth$ | x | x | x | x | x | | x | x | x | | x | | | |
| $ee \to Zhh,\ \nu\nu hh$ | x | x | x | x | x | x | x | | x | x | x | x | x | x |
| $ee \to WW$ | | | | | | | | | | x | | | x | |
| $ee \to \nu\nu WW/ZZ$ | | | | | | x | x | | x | x | x | | | |
| $ee \to \tilde{e}_R\tilde{e}_R$ (Point 1) | | x | | | | | | x | | | x | | | x |
| $ee \to \tilde{\tau}_1\tilde{\tau}_1$ | x | x | | | | | | x | | | | | | |
| $ee \to \tilde{t}_1\tilde{t}_1$ | x | x | | | | | | | x | x | | x | | |
| $ee \to \tilde{\tau}_1\tilde{\tau}_1$ (Point 3) | x | x | | | x | x | x | x | x | | | | | |
| $ee \to \tilde{\chi}^0_2\tilde{\chi}^0_3$ (Point 5) | | | | | | | | | x | x | | | | |
| $ee \to HA \to bbbb$ | x | x | | | | | | | | x | x | | | |
| $ee \to \tilde{\tau}_1\tilde{\tau}_1$ | | | x | | | | | | | | | | | |
| $\tilde{\chi}^0_1 \to \gamma + \not{E}$ | | | | | x | | | | | | | | | |
| $\tilde{\chi}^\pm_1 \to \tilde{\chi}^0_1 + \pi^\pm_{soft}$ | | | x | | | | | x | | | | | | |
| $ee \to tt \to 6\ jets$ | x | | x | | | | | | x | x | x | | | |
| $ee \to ff\ [e,\mu,\tau;b,c]$ | x | | x | | | | x | | x | | x | | x | x |
| $ee \to \gamma G$ (ADD) | | | | x | x | | | x | | | | | | x |
| $ee \to KK \to f\bar{f}$ | | x | | | | | | | | | x | | | |
| $ee \to ee_{fwd}$ | | | | | | x | x | x | | | | | | |
| $ee \to Z\gamma$ | | x | | x | x | x | x | | | | | | | |

Vertex Detection at the ILC is useful for:

1. identification of heavy flavor
2. discrimination of b and c
3. exclusion of b, c
4. signing of b, c
5. resolution of combinatorics
6. analysis of W polarization
7. exclusion of tau

Higgs physics gives examples of several of these goals.

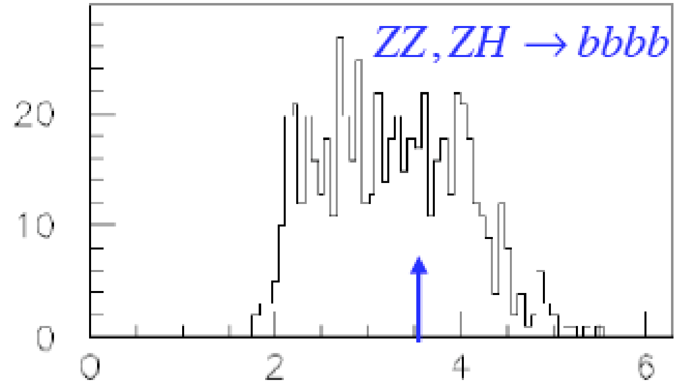
Begin with b identification:

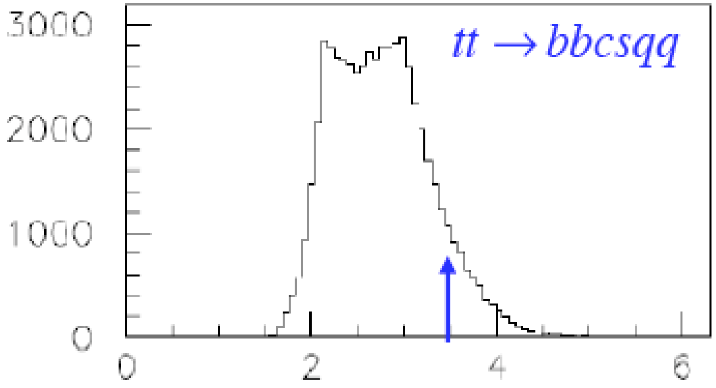


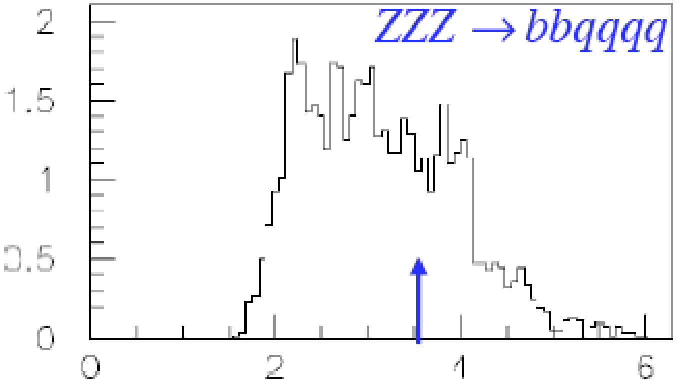
Barklow study of 200 GeV Higgs in 1 TeV e+e-

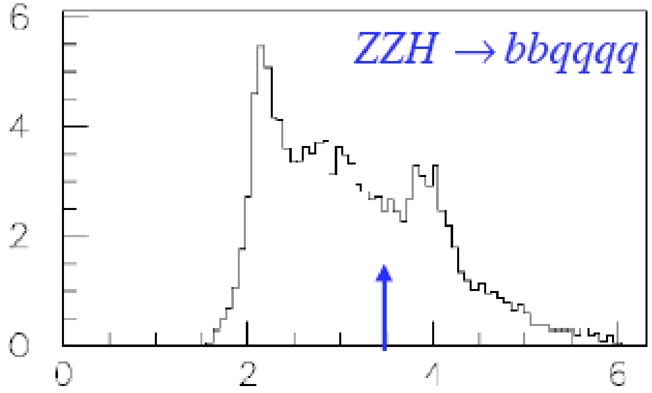
$\Gamma(h^0 \to b\bar{b}) = 2 \times 10^{-3}$ determine to 9%

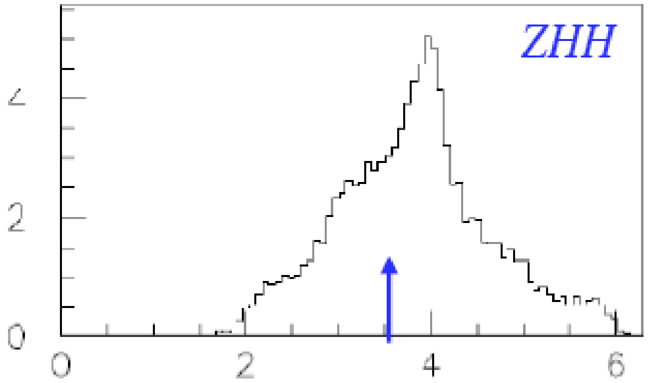
# $e^+e^- \to Zhh$











$$\sum_{1}^{6} NN(\text{jet } i) > 3.5$$

Barklow

Next, look at the example of the Higgs branching ratios, observed in

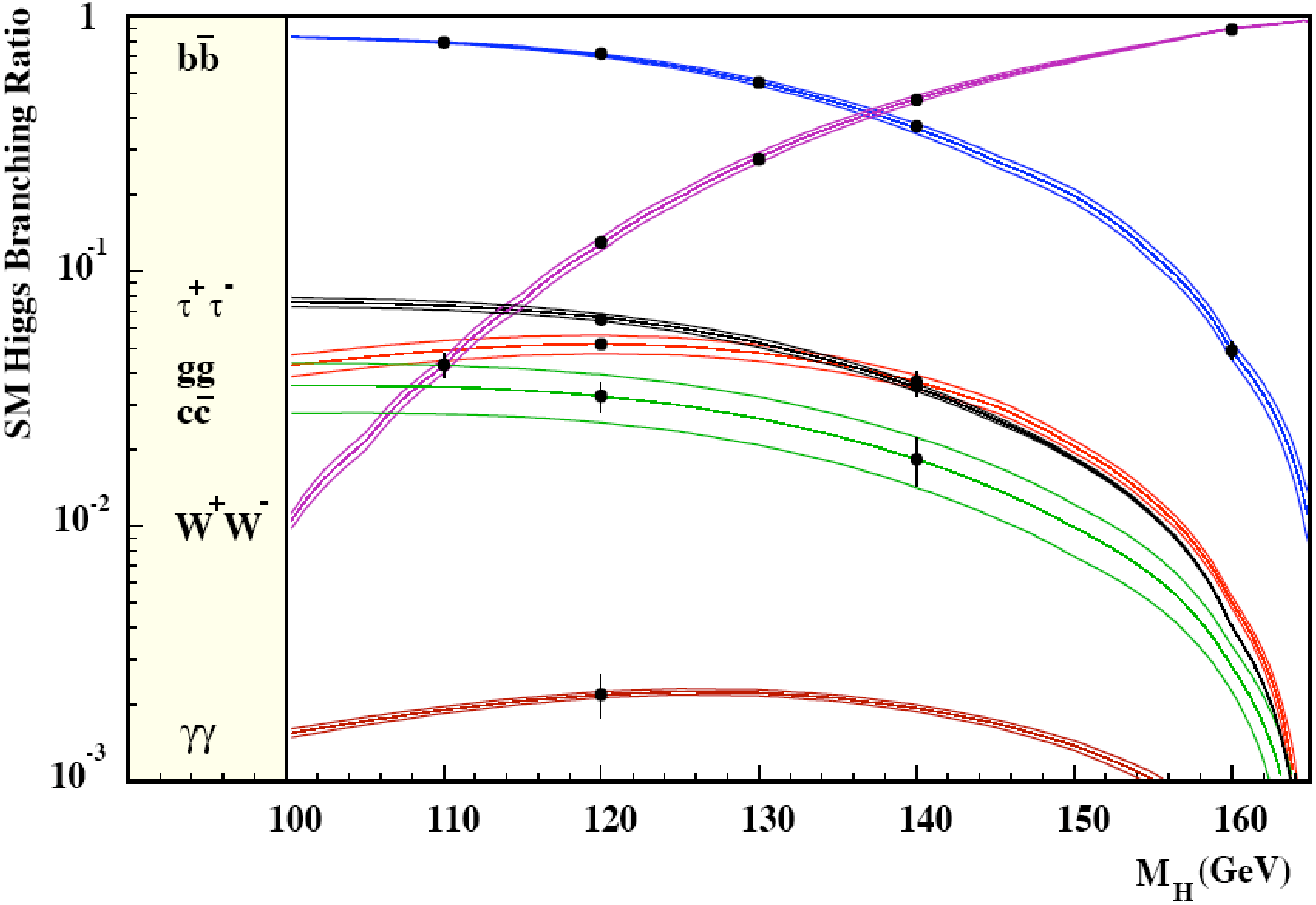
$$e^+e^- \to Zh$$

The goal of the study is to find out whether the Higgs couples to all species precisely proportional to mass.

To do this, we would like to obtain the normalized partial widths of the Higgs to a representative of each particle type:

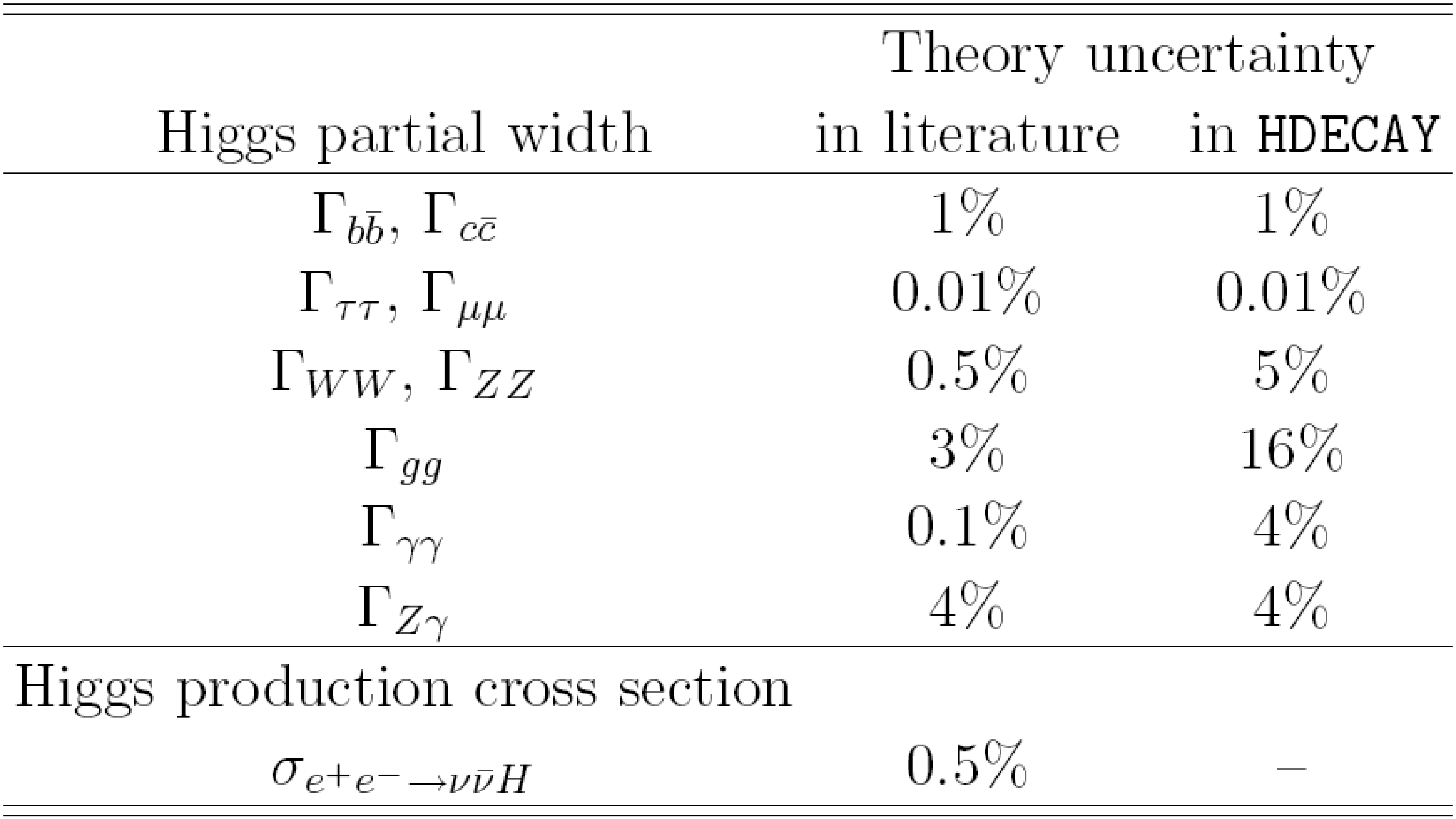
up quark, down quark, lepton, boson.

The 1-loop decays $h \to \gamma\gamma,\ gg$ have special interest, since these may show order-1 effects from new particles in loops and from Higgs/singlet (moduli, radion) mixing.



m(h) = 120 GeV:

| | | | |
|---|---|---|---|
| $b\bar{b}$ | 70% | $gg$ | 5% |
| $WW^*$ | 15% | $c\bar{c}$ | 3% |
| $\tau^+\tau^-$ | 7% | $\gamma\gamma$ | 0.2% |



|  | Theory uncertainty |  |
|---|---|---|
| Higgs partial width | in literature | in `HDECAY` |
| $\Gamma_{b\bar{b}}$, $\Gamma_{c\bar{c}}$ | 1% | 1% |
| $\Gamma_{\tau\tau}$, $\Gamma_{\mu\mu}$ | 0.01% | 0.01% |
| $\Gamma_{WW}$, $\Gamma_{ZZ}$ | 0.5% | 5% |
| $\Gamma_{gg}$ | 3% | 16% |
| $\Gamma_{\gamma\gamma}$ | 0.1% | 4% |
| $\Gamma_{Z\gamma}$ | 4% | 4% |
| Higgs production cross section |  |  |
| $\sigma_{e^+e^-\to\nu\bar{\nu}H}$ | 0.5% | – |

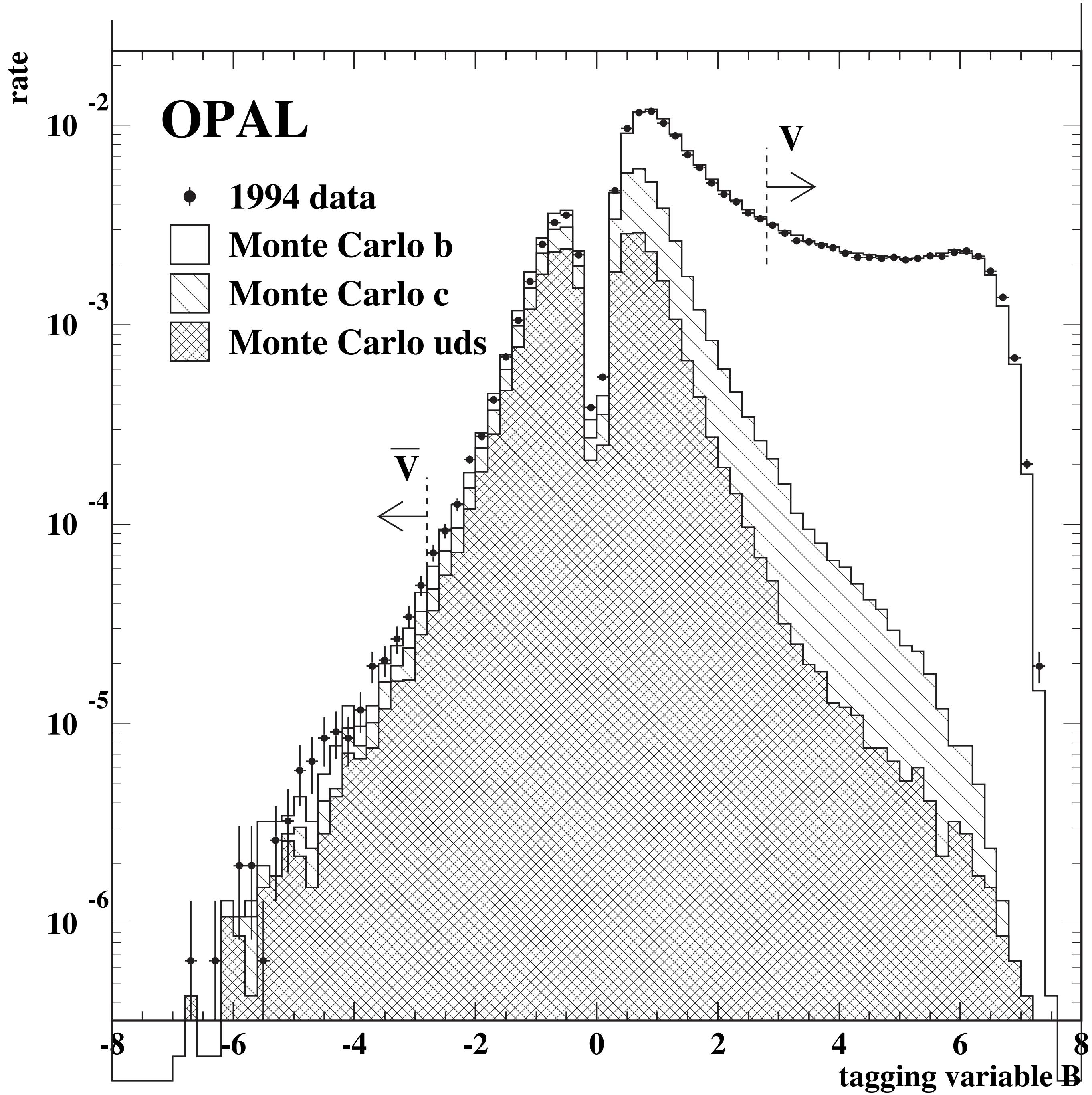
Droll and Logan, hep-ph/0612317 m(h) = 115 - 140

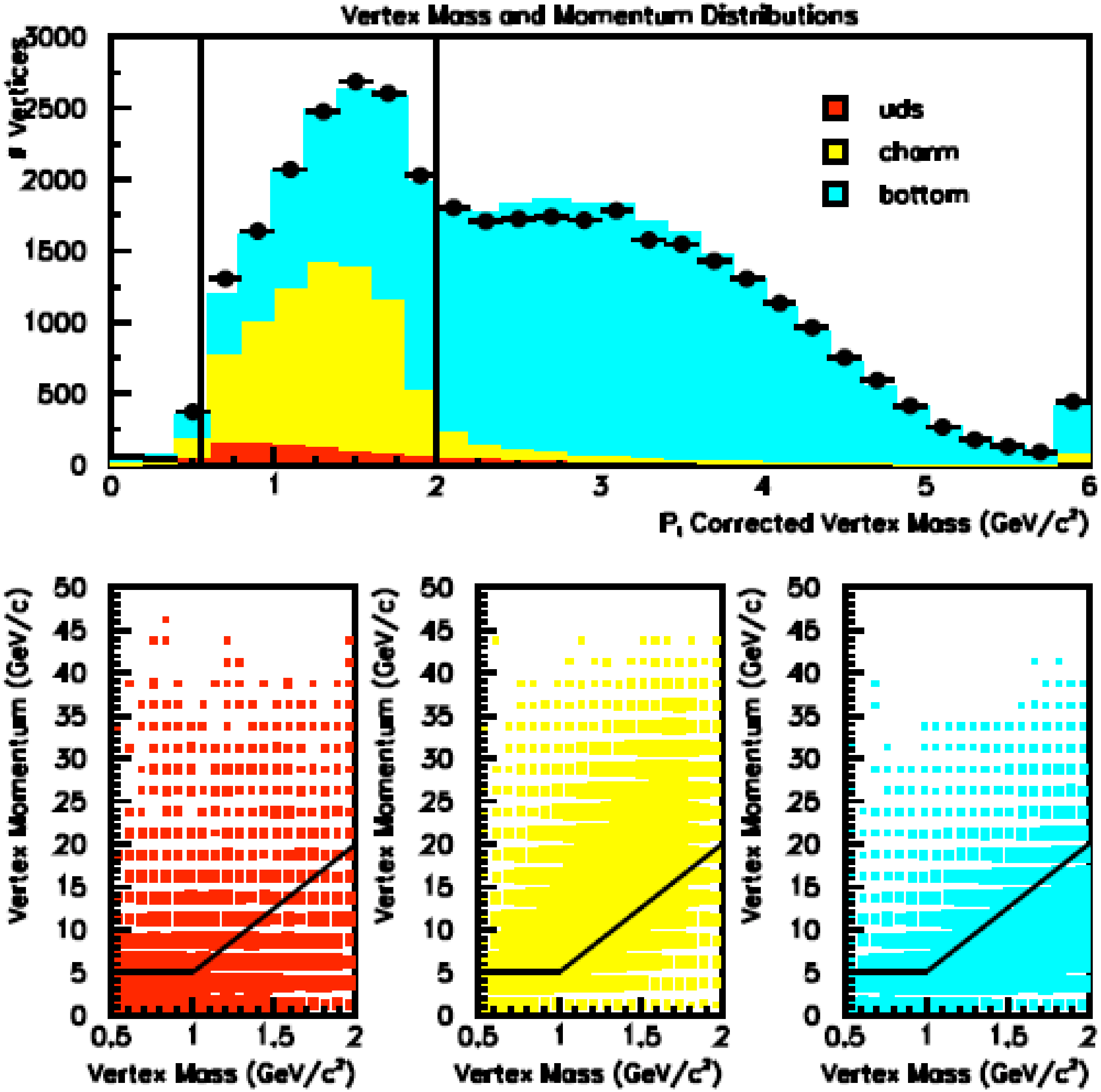
$$\overline{m}_c = 1.224 \pm 0.057 \qquad \overline{m}_b = 4.20 \pm 0.4$$

The biggest challenges are the measurements of the branching ratios for

$$h \rightarrow c\bar{c},\ h \rightarrow gg$$

These are, to a great extent, antitagging experiments that seek to eliminate the dominant $h \rightarrow b\bar{b}$ decay. Vertex mass can help. However, we need to have high efficiency for c vertices to anti-tag against c.


OPAL
1994 data
Monte Carlo b
Monte Carlo c
Monte Carlo uds
rate
$10^{-2}$
$10^{-3}$
$10^{-4}$
$10^{-5}$
$10^{-6}$
V
$\overline{V}$
-8
-6
-4
-2
0
2
4
6
8
tagging variable B


Vertex Mass and Momentum Distributions
# Vertices
0
500
1000
1500
2000
2500
3000
0
1
2
3
4
5
6
P, Corrected Vertex Mass (GeV/c²)
🟥 uds
🟨 charm
🟦 bottom
Vertex Momentum (GeV/c)
0
5
10
15
20
25
30
35
40
45
50
0.5
1
1.5
2
Vertex Mass (GeV/c²)

SLD

b quark identification can be important in resolving combinatoric ambiguities for multijet reactions

$$e^+e^- \rightarrow t\bar{t} \rightarrow bq\bar{q}\ , \bar{b}q\bar{q}$$

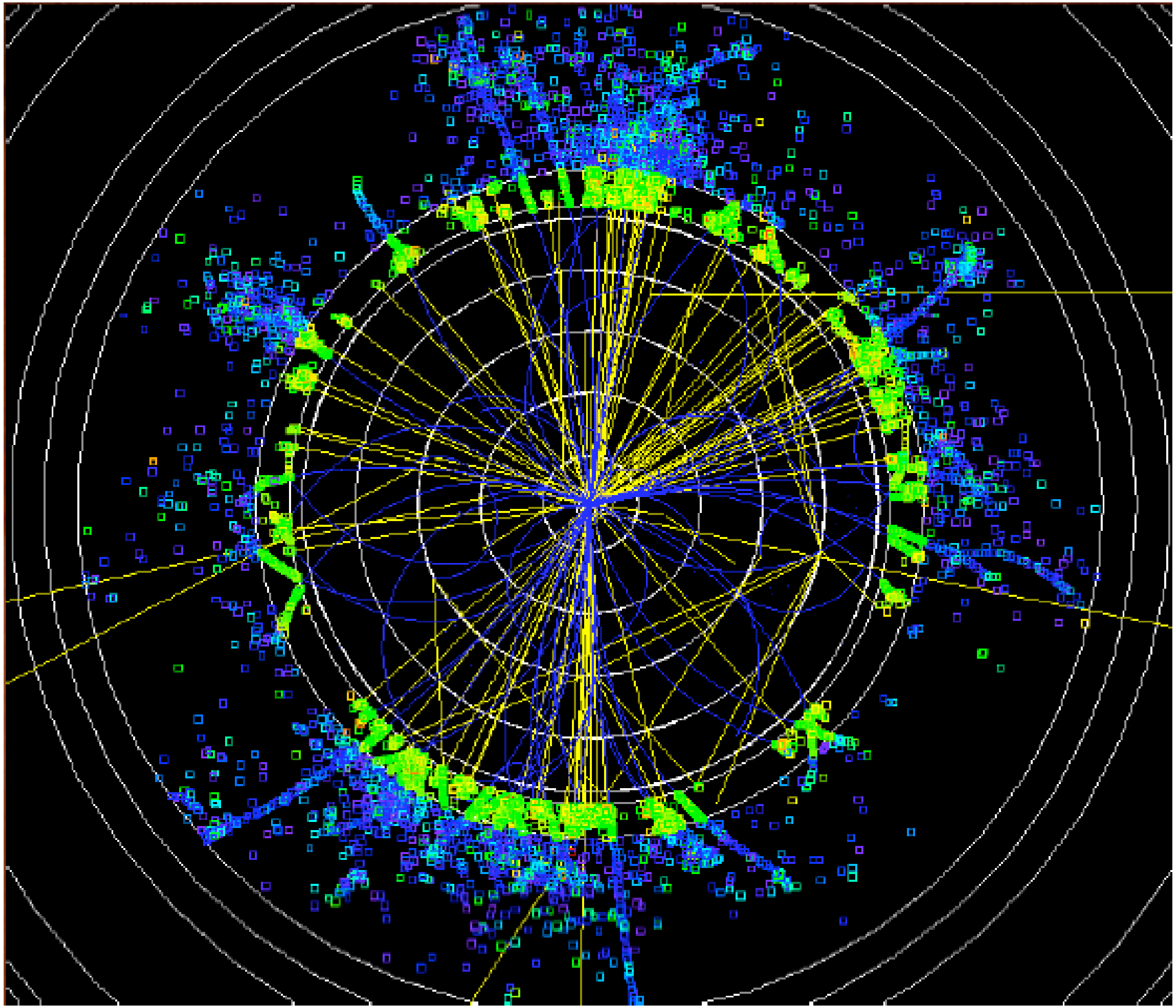
will be a bread-and-butter process at the ILC.

Some harder examples are:

$$e^+e^- \rightarrow \widetilde{b}\widetilde{\bar{b}} \rightarrow bN_2\bar{b}N_2 \rightarrow b\,q\bar{q}N_1\bar{b}q\bar{q}N_1$$

$$e^+e^- \rightarrow t\bar{t}h \rightarrow bq\bar{q}\,\bar{b}q\bar{q}\,b\bar{b}$$

$e^+e^- \to t\bar{t} \qquad E_{CM} = 500\ \text{GeV}$

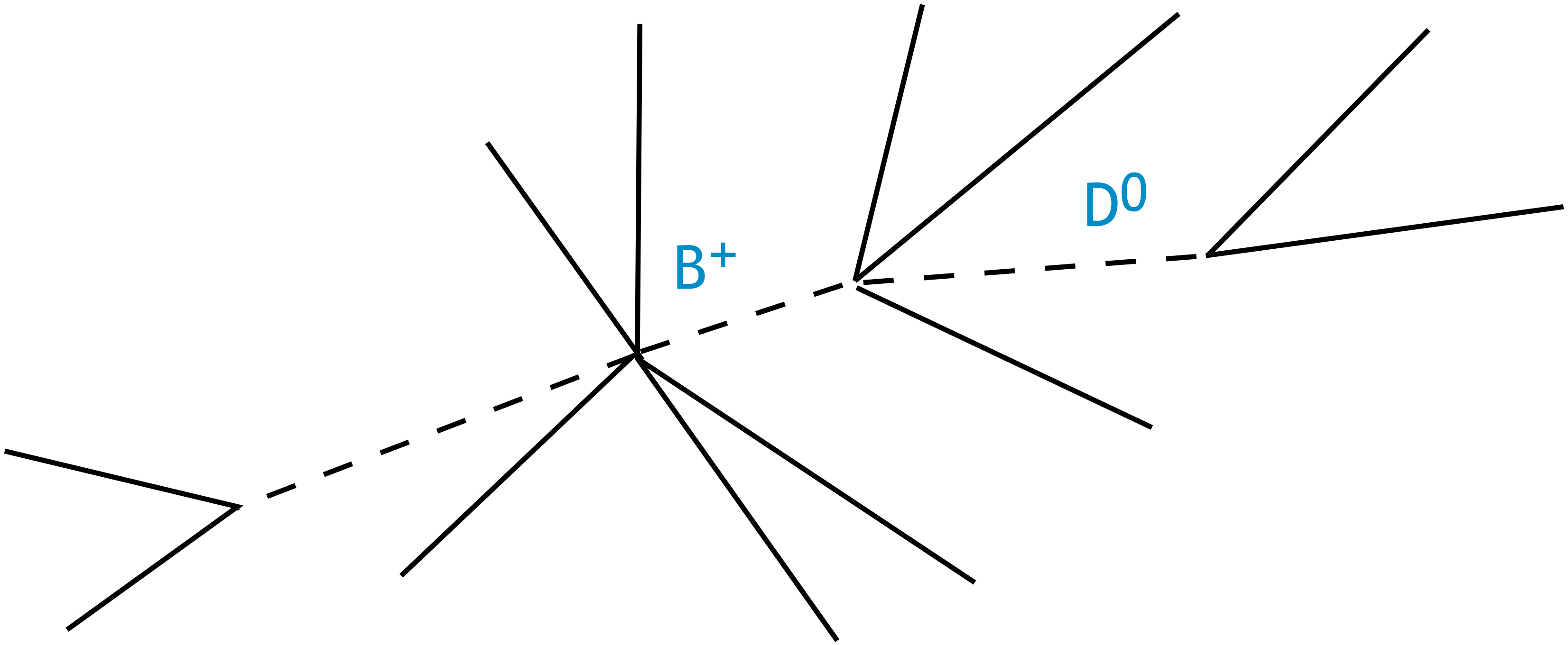


Magill

This example also points to the importance of distinguishing b quarks and antiquarks.

This can be done with leptonic decays (with 20% efficiency/b).

A better method, in a high-precision vertexing environment, uses the vertex charge and the charge dipole.



The abilities to identify b, c and to distinguish quarks from antiquarks are both needed in the study of s-channel resonances.

The general theory of $e^+e^- \to f\overline{f}$ (with spin 1 exchanges) is quite simple

$$\frac{d\sigma}{d\cos\theta}(e^-_L e^+_R) = \frac{\pi\alpha^2}{2s}\left[(1+\cos\theta)^2 f_{LL}(s) + (1-\cos\theta)^2 f_{LR}(s)\right]$$

where

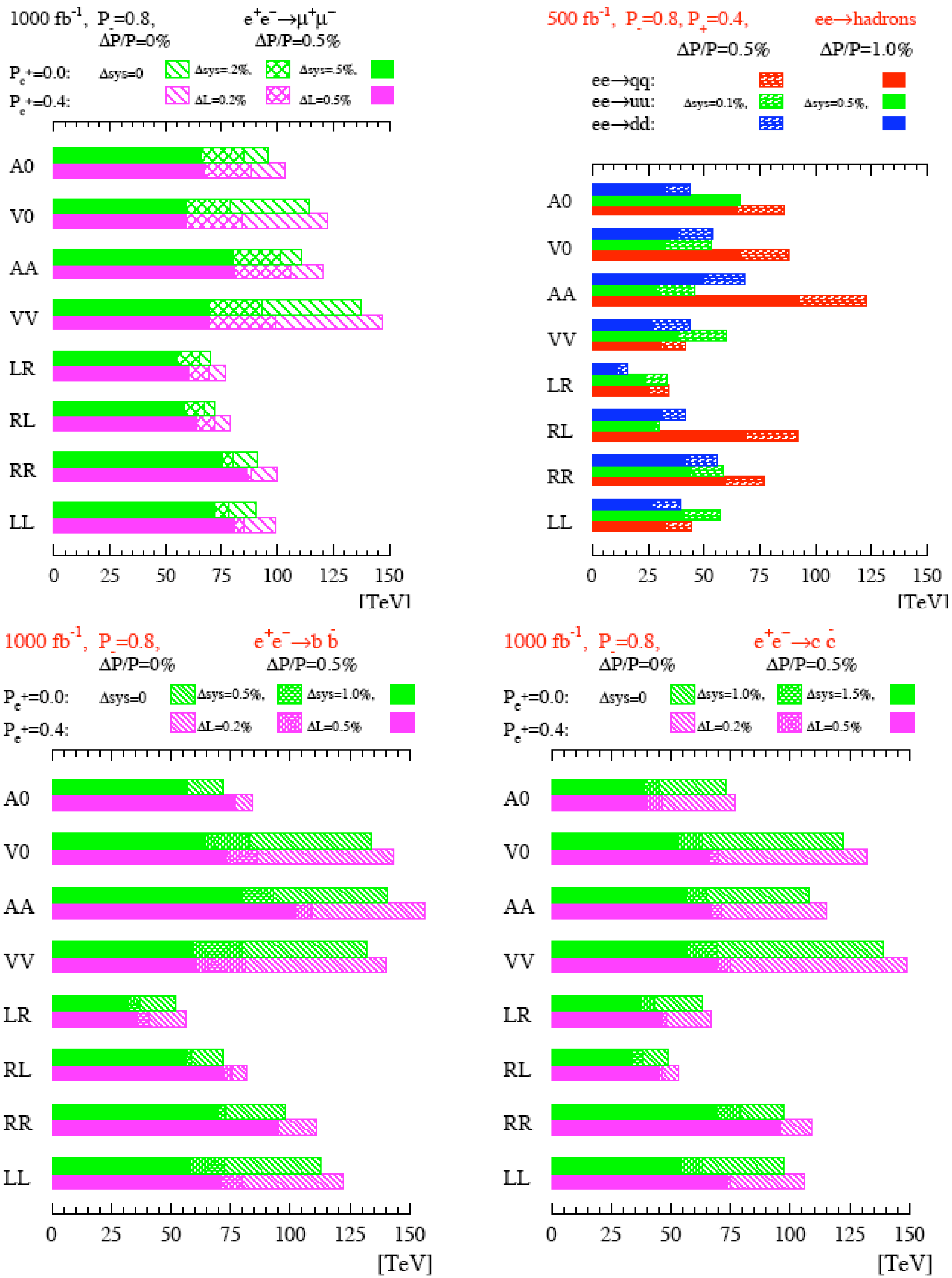
$$f_{LL}(s) = s^2\left|\frac{-Q}{s} + \frac{g_{ZeL}g_{ZfL}}{s-m_Z^2} + \frac{g_{XeL}g_{XfL}}{s-m_X^2} + \cdots\right|^2$$

and similarly for R <-> L for both e and f. In all, there are four functions of s to be determined, and these can be obtained from cross sections and FB asymmetries for 2 initial-state polarizations.

We have these four observables for each species of quark and lepton that we can identify.

For the related issue of contact interactions, here is a summary by Riemann of the comparative power of leptons, integrated quarks, b, c in individual helicity channels.

LL, RR have the largest Standard Model amplitudes, so these also show the greatest sensitivity to new interfering terms.



For many purposes, it is important to do t or W polarization analysis. In hadronic W decays, this requires distinguishing the quark from the antiquark in W decays.

For top decay to leptons: $\frac{d\Gamma}{d\cos\chi} \sim (1+\cos\chi)$

where $\chi$ is the angle between the top spin orientation and the final lepton.

In hadronic decays $t \to b\, c\bar{s}$ , the s quark is a surrogate for the lepton.

With charm-finding efficiency of 60%, this becomes a method of t polarization analysis equally powerful to measurement of the leptonic decays.

This has been studied for $e^+e^- \to t\bar{t}\,\nu\bar{\nu}$ (Ruiz-Morales and MEP, hep-ph/9909383). The method should be relevant for SUSY and other new particle decays with real W's.

Finally, I will give an example of the utility of tau anti-tagging.

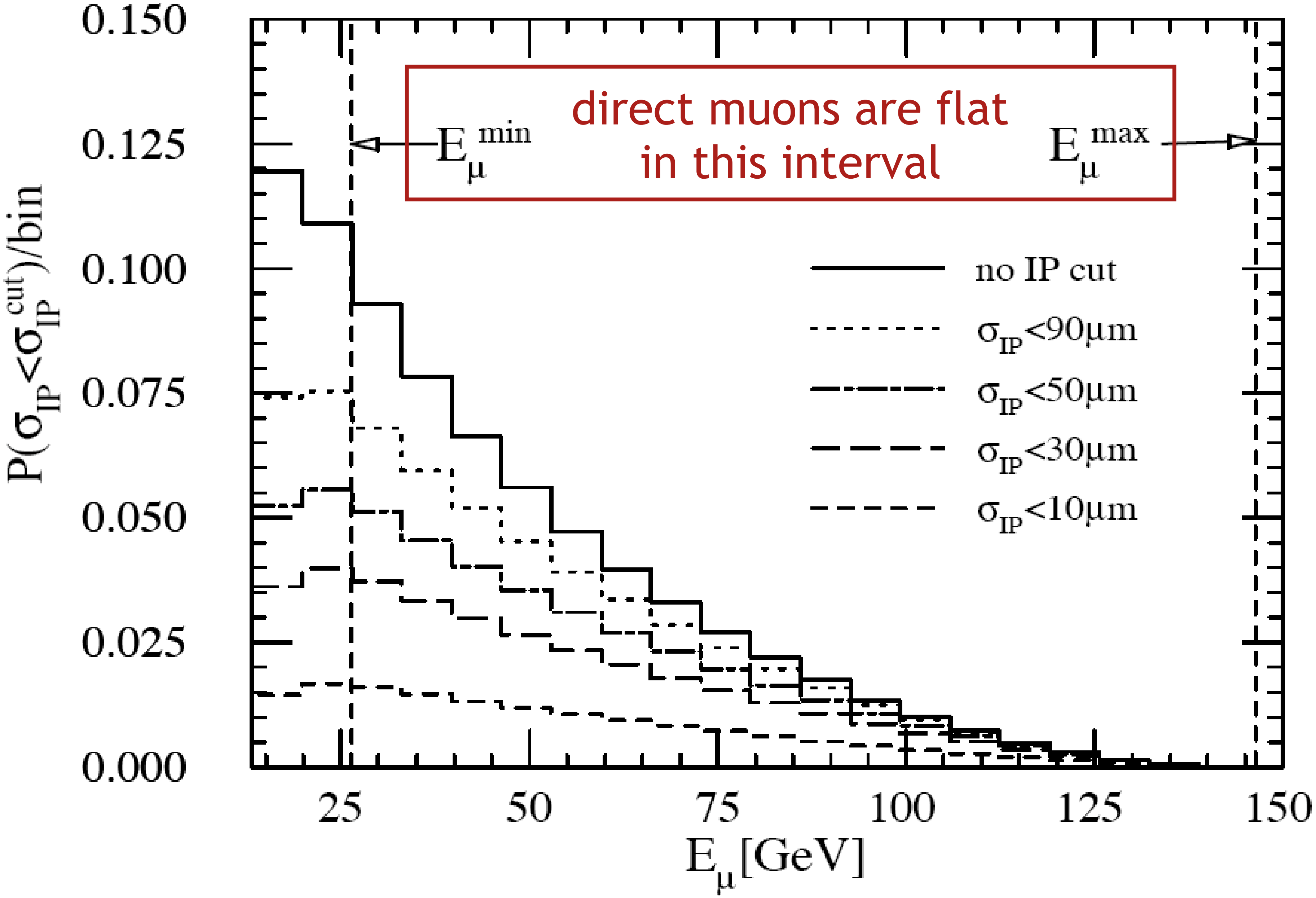
If we have lepton flavor violation and supersymmetry, we expect slepton flavor mixing. Neutrino physics suggests that the largest effects will be seen in mu-tau sneutrino mixing.

Hisano, Nojiri, Shimizu, and Tanaka studied

$$e^+e^- \to \widetilde{\nu}\overline{\widetilde{\nu}} \to \tau\mu\, C^+C^-$$

Very likely, the mixing is small and this process is a small signal under

$$e^+e^- \to \widetilde{\nu}\overline{\widetilde{\nu}} \to \tau\tau\, C^+C^- \quad \tau \to \mu\nu\overline{\nu}$$



direct muons are flat
in this interval

Hisano, Nojiri, Shimizu, Tanaka

In this talk, I have given examples of seven distinct uses of high-precision or high-efficiency vertex detection in ILC physics.

1. identification of heavy flavor
2. discrimination of b and c
3. exclusion of b, c
4. signing of b, c
5. resolution of combinatorics
6. analysis of W polarization
7. exclusion of tau

I am sure that this list is not exhaustive. Please add to it.